INDEX

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

RADIATION LABORATORY SERIES

---

1. RADAR SYSTEM ENGINEERING—*Ridenour*
2. RADAR AIDS TO NAVIGATION—*Hall*
3. RADAR BEACONS—*Roberts*
4. LORAN—*Pierce, McKenzie, and Woodward*
5. PULSE GENERATORS—*Glasoe and Lebacqz*
6. MICROWAVE MAGNETRONS—*Collins*
7. KLYSTRONS AND MICROWAVE TRIODES—*Hamilton, Knipp, and Kuper*
8. PRINCIPLES OF MICROWAVE CIRCUITS—*Montgomery, Dicke, and Purcell*
9. MICROWAVE TRANSMISSION CIRCUITS—*Ragan*
10. WAVEGUIDE HANDBOOK—*Marcuvitz*
11. TECHNIQUE OF MICROWAVE MEASUREMENTS—*Montgomery*
12. MICROWAVE ANTENNA THEORY AND DESIGN—*Silver*
13. PROPAGATION OF SHORT RADIO WAVES—*Kerr*
14. MICROWAVE DUPLEXERS—*Smullin and Montgomery*
15. CRYSTAL RECTIFIERS—*Torrey and Whitmer*
16. MICROWAVE MIXERS—*Pound*
17. COMPONENTS HANDBOOK—*Blackburn*
18. VACUUM TUBE AMPLIFIERS—*Valley and Wallman*
19. WAVEFORMS—*Chance, Hughes, MacNichol, Sayre, and Williams*
20. ELECTRONIC TIME MEASUREMENTS—*Chance, Hulsizer, MacNichol, and Williams*
21. ELECTRONIC INSTRUMENTS—*Greenwood, Holdam, and MacRae*
22. CATHODE RAY TUBE DISPLAYS—*Soller, Starr, and Valley*
23. MICROWAVE RECEIVERS—*Van Voorhis*
24. THRESHOLD SIGNALS—*Lawson and Uhlenbeck*
25. THEORY OF SERVOMECHANISMS—*James, Nichols, and Phillips*
26. RADAR SCANNERS AND RADOMES—*Cady, Karelitz, and Turner*
27. COMPUTING MECHANISMS AND LINKAGES—*Svoboda*
28. INDEX—*Henney*

INDEX

Edited by

KEITH HENNEY

EDITORIAL DIRECTOR, ELECTRONICS, NUCLEONICS

Foreword by

VANNEVAR BUSH

PRESIDENT, CARNEGIE INSTITUTION OF WASHINGTON

Introductory Notes by

KARL T. COMPTON

LEE A. DuBRIDGE

LOUIS N. RIDENOUR

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

NATIONAL DEFENSE RESEARCH COMMITTEE

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INDEX

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Foreword

Linked to man's age-old propensity for waging war has been his tendency to boast of his warlike accomplishments. In the ancient sculptures of the Euphrates Valley and the colorful friezes of Egyptian tombs we can see the warriors of prehistory marching to battle and can surmise something of their weapons, their tactics, and their equipment. Herodotus, the father of history, earned his title for his story of the Greco-Persian wars; and the epic verse of Homer has preserved forever the legendary battles of Troy, preceding in time the century-long struggles of the Peloponnesian wars. Later, Julius Caesar recorded for us not modestly, but with revealing detail, the story of his Gallic conquests. The men of the North first recorded the sturdy heritage of the Anglo-Saxon in the epic story of Beowulf. The wars which ravaged Europe during the dark ages were preserved in history in the cloisters, last refuge of the written word. In modern times, the chronicles of war have lost the epic touch and become the handbooks for future warriors. Every general has read his Clausewitz, and every admiral his Mahan.

World War II brought with it the responsibility for a new kind of documentation. Technological progress in weapons and devices of warfare was of such transcendent importance that it influenced the turn of events at almost every point. Science was organized for war in a way that it had never been organized before. It therefore became a matter of major importance to record processes and achievements of technology in such a way that future generations might benefit to the fullest by the trials, errors, and successes of the experimenters.

The late President Roosevelt, with an appreciation of the historical significance of current happenings, directed that each agency of the Federal government should write the history of its wartime accomplishments. In the case of the Office of Scientific Research and Development, the mere chronology of its undertakings and accomplishments would not have sufficed to aid the researchers of the future in dealing with related problems. The Office of Scientific Research and Development, therefore, has left behind it full documentation in the form of summary technical reports covering the programs of the technical divisions of the National Defense Research Committee; a technical monograph series dealing with special aspects of its program—of which this Radiation Laboratory Series is a part; and a detailed history by field of endeavor, including that of the Committee on Medical Research, expanding the popular history by James Phinney Baxter, III, *Scientists against Time,* which won the Pulitzer prize for history for 1946. It is hoped that this attempt at full documentation, made though it was by busy scientists amid all the pressures of war and postwar adjustments, will contribute substantially to the soundness of our present program of military research and development and will prevent the retracing of old ground and the exploration of unfruitful paths, already explored to no avail. For one of the principal functions of the scientist's notebook is to record his failures as well as his successes in order that others may not duplicate his efforts in vain.

I am particularly happy to contribute these few words to this, the concluding volume in the series of 28 volumes which comprise the technical details of radar. It is gratifying to observe that not all the efforts of scientific warfare were directed to the creation of lethal devices whose sole objective is destruction. Radar, which is the ear-catching word coined to describe the processes of radio detection and ranging, was one of the greatest tools of the recent war, but it also has vast usefulness in the postwar world and its powers are happily extensible to many problems of modern navigation.

Early warning radar can look into 300,000 cubic miles of space. It is as efficient on a moonless night as on the brightest day, and the obscuring effects of storms and fogs, which have beset navigators from earliest times, hold no problems for it. It not only revealed the hiding places of the enemy's ships and planes, but it identified our own planes in darkness and in battle and guided many a flyer back to the safety of his own base. Now an instrument which can accomplish such wonders is necessarily a complex mechanism. Although its development spreads over the two decades of the twenties and thirties, the period of greatest progress occurred during the war under the impetus of strategic and tactical needs. It is the technological achievements of these years which the present series records.

Back of the efforts of the Radiation Laboratory lie the perceptive observations of A. Hoyt Taylor and Leo C. Young of the United States Navy Department, who in 1922 were quick to grasp the implications of interference in the signals caused by a steamer passing on the Potomac.

Three years later, Gregory Breit and Merle A. Tuve of the Carnegie Institution developed a short-pulse technique for measuring the height of the reflecting layers in the ionosphere. This was the first true radar, for radar is in essence the method of locating objects in space by propagating a beam of short pulses of electromagnetic energy and measuring the time between the pulse and its echo at the sending station. In the decade of the thirties, the British advanced the art to the point where they were able to throw up around their island a lifeline of radar surveillance stations and so made possible the defense of Britain against the superior numbers of the Luftwaffe.

To tell the full story of the United States radar program would necessarily be to tell, also, the story of the Office of Scientific Research and Development under whose cognizance the work of the Radiation Laboratory of the Massachusetts Institute of Technology was done. For large though it was, both in dollar volume and in achievement, the Radiation Laboratory contract was but one of the many research and development contracts through which the OSRD made its contributions to the winning of the war. One would find, too, that applications of radar extended in an important way to other phases of the OSRD program such as fire control, submarine detection, and wave propagation. To tell such a story fully would be in effect to recapitulate tasks which have already been adequately done. It is suggested, therefore, that the reader who finds the present series of interest and who cares to explore the background against which the radar story developed, may do so through the medium of the historical series which has been made available to the public at large and through the summary reports which are available through official channels to authorized persons.

The individual authors of the volumes of the Radiation Laboratory Series and the over-all editor, Dr. Louis Ridenour, are to be commended for the immense amount of additional work and research they have performed above and beyond their technical accomplishments in thus recording in such detail the achievements in the Laboratory.

VANNEVAR BUSH

WASHINGTON, D.C.
February, 1953

Establishment of the Radiation Laboratory

By Karl T. Compton

One of the first steps taken by the members of the National Defense Research Committee after its appointment in June, 1940, was a preliminary breakdown of the fields of activity into four main categories dealing respectively with ordnance, chemistry, communications, and physics. Drs. Tolman, Conant, Jewett, and Compton were respectively given the initial cognizance over these areas.

Through the Army and Navy members of NDRC there were next received lists of all of the research and development projects currently being carried on by the Services, each with a brief description and an estimate of priority. This list was distributed among the four divisions of the National Defense Research Committee and provided the starting point for its thinking and its activities.

To Section 1 of Division D was assigned the problem of detection devices. Since it was clear that the art of electronics would play a very important part in practically all detection devices, it was to someone versed in that art, and who at the same time had demonstrated a high degree of imagination and administrative skill, that we turned to head this division. This person was Dr. Alfred L. Loomis of Tuxedo Park, New York.

Early in the 1920's Dr. Loomis had established his own private research laboratory in Tuxedo Park, to which he had invited visiting scientists to cooperate with him or to carry on their own independent research work. In this laboratory, shortly before the war, there had been completed important exploratory investigations on the subject of brain waves, and Dr. Loomis had decided that the time had come to pass on his equipment and techniques to medical schools and hospitals where the applications and further scientific investigations could more effectively be carried on. For over a year he had been studying various scientific fields with a view to deciding what general line he should select next for the major activity of his laboratory. After consultation and visits to university and industrial laboratories he had decided on the field of microwaves and had begun to assemble equipment and a small staff of collaborators. Thus Dr.

Loomis' selection was a "natural" to head this original detection section of NDRC.

A second fortunate coincidence bearing on the ultimate selection of Massachusetts Institute of Technology as the place for the Radiation Laboratory was the fact that its Electrical Engineering Department had for a couple of years been carrying on a microwave development for the blind landing of airplanes, under the sponsorship of the Sperry Gyroscope Company in the interests of the Air Force of the Army. This development, using a 40-cm wavelength and an oscillating tube of the newly developed klystron type, had reached the stage of successful flight tests at Wright Field by the time NDRC was established. Thus there was at M.I.T. a small group actively working in the microwave field.

The other principal centers of microwave interest in the United States at that time were the Bell, General Electric, Westinghouse, and RCA Laboratories, and Stanford University, in all of which the interest had been principally centered on the development of oscillating tubes capable of producing appreciable power in the wavelength range of roughly 50 cm or less.

One of our first moves was for Dr. Loomis and me to visit research and development establishments of the Army and Navy where work in the detection field was in progress. Our first visit was to the Naval Research Laboratory where for the first time we saw radar in the laboratory and in operation. Rear Admiral Harold G. Bowen as Chief of the Naval Research Laboratory gave us every opportunity to see what that laboratory had done and to learn its future plans, and gave us every encouragement to enter this field to supplement the NRL activities. On this visit we also examined the status of the submarine-detection techniques which were principally "Asdic," an engineered improvement over the underwater supersonic detector which had been developed by Professor Langevin in France during World War I.

Our next visit was to the Signal Corps laboratories at Fort Monmouth, New Jersey, where we saw two Army versions of radar, one for detection and the other for fire control. Here the Commanding Officer was Colonel (later Major General) Roger B. Colton, the warmth of whose welcome rose many degrees when he learned that our organization might have a considerable amount of money to devote to further research and development in this field. We learned from him of the great struggle against economy through which the Signal Corps had finally succeeded in carrying the radar development to its then operating stage.

Finally, Dr. Loomis and I visited the Army maneuvers in the fall of 1940 in the northern New York State region of Ogdensburg where for the first time the Army version of radar was tested as a part of an early-warning network against "enemy" aircraft. Here we first saw the early-warning reporting center with its complicated array of charts, plotting boards, and communication networks. Radar was so secret at that time that even generals of the Army were not permitted to approach the radar equipment unless they were directly concerned with its operation.

As a result of these visits Dr. Loomis decided that the work of his Committee on Detection Devices should concentrate initially on the field of microwave radar. Since the Army and Navy were working at the longer wavelengths, this decision avoided a duplication of effort. Since the airplane and the submarine appeared to be the two most important things to be detected in the type of mobile warfare which might be expected, and since detection of submerged submarines by supersonic devices was already an established art in the Navy, this decision to start out by concentrating on applications of microwaves for detection was a happy one. As the work developed, it soon became evident that the opportunities for the application of microwaves were so numerous and so important that this committee actually never expanded its field of activity outside of the microwave range, except for the development of the long-range navigation system, Loran, which involved something of the same techniques and principles. Consequently this initial section, D-1, on detection devices soon became the Microwave Division of NDRC.

An enormous lift to the developments in this field was provided through a visit of the British Scientific Mission headed by Sir Henry Tizard in the fall of 1940. Accompanied by Dr. Cockcroft and other British scientists, this Tizard mission brought to the United States the full story of research and development for military applications which had been carried on by the British up to that time. Among the material brought to America by the Tizard mission was a "cavity magnetron" of a type which had been invented in England by Dr. Oliphant and which was capable of delivering power at microwave frequencies far in excess of any of the tubes which had thus far been developed in America. This cavity magnetron, as further improved, became the heart of microwave radar. Small as it was in size, it has been called "the most important piece of cargo ever to cross the Atlantic Ocean."

Another valuable gift from Great Britain was Dr. E. G. Bowen, a British physicist and communications engineer who had worked with Sir Robert Watson-Watt in the development of Britain's first version of radar, and who also had had flying experience and was keenly interested in the problems of detection of enemy aircraft—especially the development of radar, which could be mounted in a pursuit plane and used to detect and home on the enemy bombers. Dr. Bowen also had the vision of microwave radar, with its enormous advantages over the longer wave radar, provided sufficient output power could be secured. Dr. Bowen was immediately attached to the Microwave Committee and it was as a result of a series of discussions between Dr. Bowen and Dr. Loomis that the decision was reached to make the first radar-system objective of NDRC the development of a 10-cm AI (Air Interceptor) radar equipment. The initial tentative specifications were drawn up and the next move was to organize a laboratory, under some contractor, to carry out the work.

The selection of the site and the contractor for the Radiation Laboratory came about in this way. It was immediately realized that a laboratory for the development of radar must be close to an important air field in order that experiments with and on aircraft could be carried out, and should also be near the seashore in order that similar experiments could be carried out on the detection of ships. The first idea was to locate the laboratory at the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. When this laboratory was visited, however, it was found that another NDRC project had already become established there, and it was felt that the remaining space available in the laboratories of this organization was inadequate for the future expansion of that other project, together with the new microwave work.

Negotiations were then undertaken with the Army to use one of its hangars on Bolling Field as a radar laboratory. Since this solution seemed feasible, a contract was prepared for submission to the NDRC, providing for the operation of this contract through the Carnegie Institution of Washington as contractor, with the work to be carried on at Bolling Field.

When I arrived in Washington to attend the meeting at which this proposal was to be submitted, I found, through Drs. Bush and Loomis, that the hopes for this solution had been completely dashed by a decision just transmitted from the Army to the effect that further plans for the use of Bolling Field made its use by NDRC impracticable. Another solution had to be found in a hurry. Bush and Loomis had one to propose. They asked me to find out whether the Massachusetts Institute of Technology could immediately make available 11,000 sq ft of floor space and could secure the use of the National Guard Hangar at the East Boston Airport, adjacent to the Boston Harbor. The idea was that the research and development could be done in the laboratories of M.I.T. and the experiments on aircraft or naval ships could be carried out with installations in this National Guard Hangar. I immediately called up M.I.T.'s Vice-President, Dr. J. Rhyne Killian, Jr., and asked him to explore the situation and report back immediately. Within a few hours he reported that the desired arrangements could be made, and thus this proposal went before NDRC and resulted in the initial contract with M.I.T., establishing what soon came to be called the "Radiation Laboratory." The failure of the first two plans was a blessing in disguise, for neither of those locations in Washington would have permitted the unexpectedly large and rapid growth of the radar project.

Because of the background of microwave work carried out by the M.I.T. Electrical Engineering Department in its cooperation with the Sperry Gyroscope Company and the Army, this contract, which was made through the Division of Industrial Cooperation of M.I.T., was originally under the general supervision of M.I.T.'s Electrical Engineering Department. This was a convenient arrangement also because Dr. Edward L. Bowles, who was secretary of the NDRC Microwave Committee, had been in charge of the electrical engineering group working on the microwave blind-landing problem. However, it was agreed from the beginning that the prosecution of the radar program would require the importation of a great deal of outside talent—physicists, electrical engineers, and many others—and that as soon as possible this laboratory should be set up in as autonomous a manner as possible, with a maximum degree of freedom and responsibility for initiating and carrying out its program. It had of course to be responsible to M.I.T., since M.I.T. had the contract responsibility, and it had to be responsible to NDRC. But within these limits of financial responsibility and over-all direction it is certainly true that the great success of this laboratory was in no small measure due to the opportunity afforded its staff to accept responsibility and to take initiative.

The next most important problem facing the laboratory was its selection of personnel, and to aid in this selection Professor Ernest O. Lawrence of the University of California, who at about that same time was made a member of the Microwave Committee of NDRC,[1] was called in to assist the Microwave Committee and M.I.T. in the initial selection of personnel. This was a most fortunate choice and Professor Lawrence naturally turned to his many associates and disciples in the cyclotron field, because the circuits of a cyclotron, like those of radar, involve the pulsing of large amounts of high-frequency electric power. Thus the initial members of the high-powered team were selected, with the really inspired choice of the two top executives of the laboratory, Dr. Lee A. DuBridge as Director and Dr. F. Wheeler Loomis as Associate Director.

The operations and accomplishments of this Radiation Laboratory have been well and adequately described elsewhere and I shall not attempt to duplicate these statements. However, I should like to say something

[1] The first membership of the Microwave Committee consisted of Alfred L. Loomis, Chairman, Edward L. Bowles, Secretary, Ralph Bown, Hugh Willis. In July, 1945, it consisted of A. L. Loomis, Chief, J. R. Loofbourow, Secretary, W. R. G. Baker, Ralph Bown, L. A. DuBridge, Melville Eastham, J. A. Hutcheson, L. F. Jones, M. J. Kelly, E. O. Lawrence, I. I. Rabi, C. G. Suits, F. E. Terman, A. T. Waterman, Warren Weaver, H. H. Willis.

about the relationship of the Massachusetts Institute of Technology to this radar project.

Until the Radiation Laboratory was so strongly established that it could do its own recruiting, M.I.T. had the responsibility of selecting the first staff, as described above. Then it had the responsibility of making the arrangements with scientists and engineers from other institutions, and particularly it had the job of negotiating with their home institutions the leaves of absence for these scientists. At that time the United States was not yet at war. The duration of this preparedness effort was uncertain. Consequently the leaves of absence were negotiated for a period of one year.

M.I.T. had to take the financial responsibility for the members of the staff thus recruited, as well as for the purchases and subcontracts. This financial responsibility involved two difficult factors, one of delay and the other of risk. The delay was incurred because of the time required to assemble vouchers and have them cleared through the Government Accounting Office, and for this reason M.I.T. was continuously out of pocket by amounts which ultimately ran into several million dollars. The payments of course came through eventually, but in the meantime M.I.T.'s endowment fund had been reduced by a sizable portion.

The risk involved was of two types. The regulations of government purchasing were such as frequently to require considerable time for competitive bids or other established procedures. The exigencies of the situation, however, required speed. M.I.T. from the beginning adopted the policy that it would permit no consideration of convenience or financial safety or any other consideration to stand in the way of doing what had to be done as promptly as possible for the winning of the war. Consequently, there were some purchases made for which reimbursement was not allowed, but the largest item of financial risk was in the reappointment of the scientists on leave of absence for their second year of duty, which came about in the following manner.

It was the end of June, 1941, before Congress voted the appropriation to continue the work of OSRD in the following fiscal year. However, M.I.T. could not wait this long to re-engage the staff of the Radiation Laboratory for the following year, because the personal financial risk to the individuals would have been too great, and also because the institutions which had loaned them to M.I.T. were demanding, as early as March or April, definite information as to whether the leave of absence of their scientists should be continued in the following academic year. In order to meet this situation the Executive Committee of M.I.T. agreed to underwrite the staff appointments for the following year to the extent of a half million dollars. This, however, was only about half enough to handle the situation, and I secured permission from Dr. Bush to describe the problem to John D. Rockefeller, Jr., who immediately agreed to underwrite another half million dollars, and thus the staff of the Radiation Laboratory was saved from disintegration at this critical period between the first and second years of its operation.

I have mentioned M.I.T.'s responsibility in the radar program by acting as contractor and banker and by following the basic principle that nothing within its power should be allowed to interfere with doing what needed to be done to help win the war. There were other contributions, however, which were also significant for the work of NDRC and of its other contractors. Because M.I.T. was the first large contractor of NDRC, and probably also because it had previously, over a number of years, given a good deal of thought to the appropriate conditions under which research and development work should be carried on for outside agencies in an educational institution, M.I.T. became the "guinea pig" for working out a wide variety of contractual policies having to do with the repayment of overhead expenses, the establishment of salary and wage scales, the handling of patentable inventions, the advancement of funds to meet contractual obligations, and many other factors. Notably helpful in such negotations and agreements were Vice-President J. Rhyne Killian, Jr., Director Nathaniel M. Sage of the Division of Industrial Cooperation, and Phillips Ketchum, legal counsel of M.I.T. Their services on such matters were not only of great advantage to the Office of Scientific Research and Development and its other contractors, but they also relieved the research and development staff of the Radiation Laboratory from as much troublesome business detail work as possible.

In conclusion I should say a word with reference to the relations between the Radiation Laboratory and our allies of the United Kingdom. I have already mentioned the Tizard mission and the valuable services of Dr. E. G. Bowen. I should also mention Dr. Denis M. Robinson, who arrived shortly after Dr. Bowen and teamed up with him in contributing to the work of the Laboratory, at the same time taking general oversight of the design and production of certain types of radar equipment in which the United Kingdom was particularly interested. There was also a continual stream of research workers from Canada, Australia, and New Zealand, together with additional scientists from England, who stayed in the Laboratory for longer or shorter periods and contributed both to the productivity of the Laboratory and to the coordination of its work with the efforts of our allies.

Particularly important in our cooperation with the United Kingdom was the work of two parallel committees, one the United States Joint Chiefs of Staff's Committee on Radar, and the other a parallel committee of the British Radar Board which, under Professor G. P. Thomson and Sir Robert Watson-Watt, was charged with the development of the

United Kingdom's program in radar. I served with Dr. Lee DuBridge and Dr. Alfred Loomis as civilian members of this United States committee, and Dr. I. I. Rabi served as the committee's chief analyst. I believe that one of the "claims to fame" of this committee is the fact that in early 1943 it selected, as a means for focussing its thought on practical issues, the conception of a landing operation carried across the Atlantic Ocean from the United States to the north coast of Africa, making a landing and establishing a beach-head, and later a base, in Africa, then moving armies across North Africa with parallel fleet movements in the Mediterranean, and finally crossing the Mediterranean to Italy and working up through Italy into the backdoor of Germany. At every stage in this hypothetical process, of whose actual conception as a military plan we had no information, our committee attempted to analyze each movement and hazard, to see whether radar could advantageously be used and whether it was better than any other method of handling the situation. Then, if radar appeared to be indicated for any purpose in this whole series of operations, we asked the question: Is the radar already available for this use, or does a new type of radar have to be developed and, if so, what are its specifications and what is the priority?

In this way the American Program of Research and Development in Radar came to be established and actually went into operation in the various civilian and military radar agencies of the country while the discussions were going on, because of the presence of representatives of these important agencies at our committee meetings.

Organization of the Radiation Laboratory

By Lee A. DuBridge

The story of the growth, the activities, and the accomplishments of the Radiation Laboratory of the Massachusetts Institute of Technology cannot easily be condensed into a few short pages. Its operations were so complex and far reaching that an entire book would be required to describe them. Such a book has, indeed, been written by Dr. Henry Guerlac, who was brought to the Radiation Laboratory for the purpose of compiling its history. Unfortunately, no mechanism for the publication of this extensive and important document is now available. Various brief accounts of the Laboratory have appeared, however, the most complete being that which constitutes Chap. 9 of *Scientists against Time* by James Phinney Baxter, III (Little, Brown, and Company, 1946). The material covered therein, relating particularly to the role played by microwave radar in the war effort, need not be repeated here.

The technical work of the Radiation Laboratory is a still longer story. This 28-volume Radiation Laboratory Series is an attempt to tell the essential features of this work, and, in addition, to compile from the work of all the radar laboratories in the allied countries a reasonably complete account of the status of technical developments related to radar as they stood at the end of World War II.

This present summary is intended primarily as a background for those who are interested in the kind of organization which produced this technical series. It will concentrate on the functioning of the Laboratory itself rather than on its accomplishments in providing new military weapons.

History

The Radiation Laboratory as an organization dates from Nov. 10, 1940. On this date a group of about 15 physicists assembled at the Massachusetts Institute of Technology in Cambridge, following weeks of preliminary planning and recruiting by the NDRC Microwave Committee, as described in Dr. Compton's article in this volume. Drs. Karl T. Compton, Alfred L. Loomis, and Edward L. Bowles, respresenting the Microwave Committee, presented to this group the NDRC plans for the establishment of a laboratory to be devoted to the development of microwave-radio-detection techniques and their application to the problems of warfare. The initial project which the Microwave Committee had agreed to undertake at the request of the British, namely, the development of microwave-detection equipment for use in night fighters, was outlined in broad terms by Dr. Loomis and a week later in more detail by Dr. E. G. Bowen, the representative of the British effort in this field. A preliminary laboratory organization designed to undertake this project was agreed upon at the Nov. 10 meeting and the embryonic laboratory group proceeded to prepare the quarters which had been assigned to it in Building 4 of M.I.T., to become familiar with the technical problems involved, and to recruit additional members for the staff.

The Microwave Committee had agreed that the new laboratory should be recruited largely from the ranks of the physicists of the country. This was partly because British experience in this direction had already proved highly successful; partly because the electrical and radio engineers were already being drawn into industrial laboratories to man their expanding war programs, while the physicists as a group had not yet been drawn into war work. Also the field of microwaves was at that time an almost unexplored area in which few engineers had been trained. Since it depended on the basic principles of physics, it seemed that physicists would be well equipped by previous training and experience to undertake its development.

The three laboratory rooms initially assigned to this new group almost at once became a beehive of activity. Equipment was ordered and assembled, components previously ordered by the Microwave Committee soon began to arrive, and new recruits to the staff came in at an average rate of about one per day. By Jan. 1, 1941, most of the men who were to be the key leaders of the Laboratory throughout its five years of activity had been assembled.

By mid-January a crude laboratory model of a microwave radar set was in actual operation in a shack on the roof of Building 6. By March a set was being successfully flown in a B-18 aircraft provided by the Army. A few weeks later, in May, a model for an airborne AI set was turned over to the Bell Telephone Laboratories which had received an Army order for its further development and production. The SCR-520, and later the vastly improved and widely used SCR-720, resulted from this project.

Following this initial "blitz" effort the Laboratory group really settled down to work. It was now evident that microwave radar was feasible and had many potentially important applications. It was also clear that the microwave art was in the very early stage of development and a large effort was still ahead.

Two other projects initially decided upon by the Microwave Committee were also under way. One was the design of a precision antiaircraft fire-control radar and the other a long-range radio navigational system, later called Loran, which was the only major nonmicrowave project the Laboratory ever undertook.

The initial AI project itself turned out to be less important in the war than a whole host of other projects which grew directly out of it. These included radar equipment for detecting surface vessels and submarines, for firing of guns and rockets, for blind bombing, for harbor surveillance, and for general navigation of both ships and aircraft. A variety of sets serving each of these functions were developed in sequence as improved techniques came along and as it became necessary to meet the special demands of different types of Army and Navy aircraft.

The fire-control project, also off to an early start, eventually led to one of the most successful of all Radiation Laboratory equipments, the SCR-584, which proved adaptable to many uses and which gave rise to many other radar sets for ground and ship applications.

The Loran equipment developed by the Laboratory eventually provided a radio navigational system which covered a large proportion of the air and sea traffic lanes of the world.

At the time of Pearl Harbor, Dec. 7, 1941, the Laboratory had grown to a staff of over 400 and was just moving from its outgrown quarters in the main M.I.T. building into a new permanent building. It was at work on many of these projects and had made important improvements in all microwave components and techniques.

The entrance of the United States into the war enormously accelerated the Laboratory's activity and its rate of recruiting. It expanded into additional buildings, of which some were rented in nearby Cambridge, and others were temporary structures built on the M.I.T. campus. By the end of the war the Laboratory had a staff numbering just under 4,000 individuals, it occupied a half million square feet of space in buildings on or near the M.I.T. campus, and had groups spread in a dozen field stations throughout the world, including a branch laboratory in Malvern, England, and another in Paris, France. By this time it had undertaken and had fully or partially completed work on some 100 different models of radar equipment for use on land, on sea, and in the air. Over a billion and a half dollars' worth of equipment, which had its inception at the Radiation Laboratory, had been produced, and another billion dollars' worth was on order when the war ended. This equipment saw service in every fighting area and was supplemented by a substantial amount of equipment manufactured directly in the Laboratory and in the Research Construction Company model shop that reached the field before production lines were delivering it in quantity.

As the end of the war approached, the desirability of writing a systematic account of the technical developments in the field of radar became apparent and the Office of Publications, under the direction of Dr. L. N. Ridenour, was established in the Laboratory. At the end of the war, as projects were terminated, the Office of Publications acquired a large staff which remained at work for an additional six to nine months, during which period the bulk of the manuscript for the Radiation Laboratory Series was completed.

The Functions of the Radiation Laboratory

The Radiation Laboratory has often been referred to as a research laboratory. As a matter of fact, research, in the true sense, was only a small, though vital, part of its activities. A complete list of its functions would go something like this:

1. Research on microwave equipment and techniques
2. Component development and engineering
3. System design, engineering, and test
4. Collaboration with the manufacturers on design of production equipment
5. Coordination of military tactics with equipment design
6. Field trials of pilot-model equipment
7. Operational trials, often under actual battle conditions
8. Assisting military services in introducing new equipment into operational use, modifying it to meet new operational requirements, and assisting in the training of operation and maintenance personnel
9. Reporting field experience and problems back to the Laboratory for guidance in future design
10. Manufacture of small quantities of new equipment for immediate use in the field
11. Collaboration with all other research and development agencies in this country and abroad, seeking and rendering assistance in all of the foregoing areas

During the early days of the Laboratory the first three functions naturally occupied the major portion of the attention. As time went on, and equipment got into the field, the other items on this list occupied a larger and larger fraction of the Laboratory's effort.

This article would be entirely too long if we attempted to give a complete account of all the above functions. It would, however, be desirable to say a few words about several of the more important items.

Research Activities

All the important activities of the Laboratory, other than the early ones in which the experience of the British and of other United States laboratories was copied, depended upon two things: (*a*) research which uncovered basically new microwave and electronic techniques, and (*b*) imaginative thinking on the adaptation of these techniques to tactical problems.

The research activities of the Laboratory did not get under way during the early rather hectic days of investigating whether a microwave radar could be made to work at all. Indeed, it was always a struggle to give proper emphasis to long-range research problems in the face of pressure to get equipment completed for immediate operational use. Nevertheless, some research got under way at quite an early stage, and the efforts grew steadily in magnitude, proving in the end extremely productive.

Shortly after the first 10-cm magnetrons, copied from British designs, were delivered by the Bell Telephone Laboratories, research was undertaken to develop a magnetron which would operate at a wavelength of 3 cm. As early as the spring of 1941 such a magnetron was actually operating as a result of the combined efforts of the Radiation Laboratory magnetron group and the model shop of the Raytheon Manufacturing Company. This success initiated a considerable effort aimed toward the development of other 3-cm equipment, and eventually some of the best and most important sets developed by the Laboratory operated at this wavelength.

Later the extension of magnetron and radio-frequency techniques to wavelengths in the range of 1 cm was undertaken. This endeavor encountered very serious and difficult problems, most of which were eventually solved, and equipment operating at 1 cm actually was getting into production at the end of the war. In this program the Columbia Radiation Laboratory played a most important role, partly because it was purposely isolated from the press of equipment-development problems at the M.I.T. Radiation Laboratory itself. The research groups of both laboratories operated under the inspiring leadership of Dr. I. I. Rabi.

The problems involved in extending radio techniques into ever higher frequency ranges led to research in many areas aimed at a better understanding of high-frequency phenomena. As a result, the radar equipment designed toward the end of the war incorporated apparatus and techniques which made the early sets look very crude and inefficient, as indeed they were. Research on the theory of propagation of electromagnetic waves in waveguides and in free space, on the "optics" of microwave-antenna design, on the basic theory of component and system operation and performance, and indeed, on every subject discussed in this 28-volume Radiation Laboratory Series eventually paid large dividends in better understanding of radio and microwave technology and in marked improvements in the performance and adaptability of microwave radar sets. Possibly never before in history has a new technology advanced so rapidly on so wide a front as in this area.

Component Development

The activities of the research division, aimed at discovering new phenomena or at a better understanding of old ones, merged imperceptibly into activities aimed at the development of new components. The two largest divisions of the Laboratory were devoted to this work. Magnetrons, pulsers, antennas, indicators, receivers, together with all the vacuum tubes, condensers, waveguide elements, transformers, and the dozens of other parts all had to be developed, improved, tested, adapted to new types of sets, and engineered for mass production. The work of the many component development groups not only continually improved the performance and the reliability of radar equipment but also, through new ideas originating there, opened up new possibilities in the design of sets for new tactical purposes.

The separation in the Laboratory organization of equipment development from component development made possible more concentrated attention on the latter as well as a degree of standardization which was essential for economy of effort and production.

It must be remembered that parts, tubes, and equipment for radar, especially microwave radar, simply did not exist in 1940. Though many standard radio parts could readily be adapted to radar, many others had to be developed and put into manufacture. These covered an amazing variety of devices, from shock mounts to huge antenna structures, from detector crystals to hydrogen-filled thyratrons, from i-f amplifiers to microsecond timing circuits, and literally hundreds of additional items.

It is the work which was involved in component development which occupies the bulk of these volumes, and even much of this work is omitted for lack of space.

System Development

It was the task of the several system divisions to keep in touch with tactical problems on the one hand, and the status of technical developments of components on the other, and then to design and build the best possible radar systems to meet operational needs. Sometimes these operational needs could be stated in precise terms by military agencies; frequently, however, equipment was evolved to meet possible operational requirements before the need for such equipment or the possibility of obtaining it was realized by the Army or Navy. It was not the practice of the Laboratory to wait for official requests for new equipment but rather, by studying the progress of the war, to attempt to visualize such needs in advance. In fact, strenuous "selling" was often required to convince some military agencies of the need, or the feasibility, or the possibilities of new radar sets.

If the research and component development divisions made radar possible and practical, the system development divisions made it usable, valuable, and adaptable to new needs. Since all groups in the Laboratory kept in close contact with each other, with other laboratories and agencies, and with the problems of war, a cooperative effort was possible which multiplied the effectiveness of the whole Laboratory manyfold. It is this spirit of friendly cooperation which now stands forth in my own mind as the most essential feature of the Laboratory's operations.

Relation to Other Agencies

Although the Radiation Laboratory grew to be probably the largest single radar laboratory either in this country or in England, it would be a mistake to assume that it was the predominant source of radar and electronic research and development. The radar effort of the Allies went forward on a very large scale at a host of research, development, and manufacturing centers, and it was characterized by extensive collaboration, on both a national and an international scale.

The Radiation Laboratory itself was founded on the basis of information brought to this country by the British, and it depended heavily, particularly during its early years, upon British experience, both operational and technical. The AI project, which occupied such a large share of the Laboratory's attention in the first months of its existence, was itself visualized as an effort to help the Royal Air Force in its night-fighter problem. The British magnetron developments and the British concepts of airborne microwave radar were brought to the Laboratory by Drs. E. G. Bowen and D. M. Robinson, and by a large volume of correspondence and reports exchanged between the two countries. The British ideas were the guiding influence of the initial group of physicists who had, for the most part, never before heard of microwaves or of the detection of aircraft by radio.

Throughout the history of the Radiation Laboratory the contact with the British laboratories and the British services was extremely close and cordial. Many representatives from British laboratories visited the Radiation Laboratory and other laboratories of this country repeatedly, and often for extended periods. As early as 1941 a Radiation Laboratory representative, Dr. K. T. Bainbridge, made an extended visit to England to secure a better view of British developments and problems. He served as the vanguard of a host of Laboratory travelers who went to England, and later to the continent, and who sent or brought back a most complete story of technical developments and operational problems. The British Branch of the Radiation Laboratory (BBRL) was established on the grounds of the largest British radar laboratory, the Telecommunications Research Establishment, in Malvern, England, in 1943. Though much of the effort of this laboratory was devoted to rendering help to the United States forces in Europe, a major result of its activity was the still closer liaison between British and American radar scientists and engineers.

The importance of the contacts between the two countries was dramatically illustrated as early as June, 1941, when an early model of the Radiation Laboratory's AI equipment was installed in an airplane supplied by the Royal Canadian Air Force and sent to England, accompanied by Dr. D. R. Corson, for technical and operational trials.

These trials showed the American equipment to be inferior in performance to the British equipment as far as the receiver techniques were concerned, but also showed that the American transmitter equipment was more powerful than the British. By combining the best features of British and American sets, a set which outperformed either was put together.

It would require many pages even to list the other examples of a fruitful outcome of British and American collaboration. The British laboratories were a continual source of new ideas and new techniques which were generously shared with the Americans and which were promptly incorporated into American practice. The Radiation Laboratory only hoped that by the time the war was ended its own contributions, particularly in the field of radar engineering, had eventually made the exchange an even one.

The Radiation Laboratory also owed much to, and collaborated extensively with, other American agencies. Before the Radiation Laboratory was started, the U.S. Naval Research Laboratory and the U.S. Signal Corps Laboratories already had practical radar equipment in production. Though these and other military laboratories concentrated largely on longer wavelength radar equipment, while the Radiation Laboratory devoted most of its attention to microwaves, the collaboration with these laboratories became very extensive and mutually valuable.

The design and engineering of radar components and sets eventually involved literally hundreds of manufacturing companies, many of which either had or acquired important research and engineering activities. With all these the Radiation Laboratory kept in closest contact and each of them contributed in many important ways to the development of the art.

Special mention should be made of the large and very important contributions of the Bell Telephone Laboratories and the Western Electric Company in research, development, design, engineering, and production. The contribution of the Bell Laboratories in magnetron development, vacuum-tube development, development of receiver and antenna techniques, and many other fields was particularly important to the whole United States effort. The Radiation Laboratory borrowed generously from the work of these laboratories as well as from the work of the research laboratories of the General Electric Company, the Westinghouse Electric and Manufacturing Company, and a host of others. The above companies, together with the Philco Radio Company and the Raytheon Manufacturing Company, were the chief producers of microwave radar, and close collaboration with them on development and engineering problems often greatly expedited production schedules.

Finally, it must never be forgotten that the Radiation Laboratory was an integral part of the program of the National Defense Research Committee and the Office of Scientific Research and Development, and it was at the same time a part of the Massachusetts Institute of Technology. It was the NDRC-OSRD organization which set the basic policies and provided the framework of organization and funds within which all its separate units operated. The Radar Committee (initially dubbed the Microwave Committee) was an agent of NDRC in administering these policies and programs in the radar field. This Committee served in a sense as the Board of Trustees of the Laboratory. To this Committee, and especially to its genial and far-sighted chairman, A. L. Loomis, the Radiation Laboratory owed as much as a child owes to its parents for wise guidance and control combined with wisdom and confidence in allowing necessary freedom of action.

To M.I.T. the Radiation Laboratory owed all its physical facilities and its framework of operation. The Laboratory was a part of the M.I.T. organization, though a large and somewhat separated part to be sure. But the Laboratory could not have existed except as a part of some such organization and it was fortunate indeed to be a part of M.I.T. The flexibility of its administrative organization, the kindly and wise leadership of President Compton and Vice-President (now President) Killian were vital factors in the Laboratory's operation and success.

In conclusion, I wish to pay a personal tribute to the men and women of the Laboratory itself. They constituted a superb group, certainly one of the finest ever assembled. Only in a time of national crisis would it have been possible to assemble such a magnificent array of talent. The task of the Director was made a simple one by the loyalty, intelligence, and cooperative spirit of this splendid group of people.

Preparation of the Radiation Laboratory Series

By Louis N. Ridenour

With the publication of this Series Index, the Radiation Laboratory Series is complete. It has seemed appropriate to include in this volume some short historical accounts of the work which gave rise to the Series. Dr. Vannevar Bush, wartime Director of the Office of Scientific Research and Development, the parent organization of the Radiation Laboratory, has contributed a Foreword for this volume which replaces the Foreword by Dr. L. A. DuBridge that appears in the other volumes of the Series.

Dr. Karl T. Compton, who led the Division of the National Defense Research Committee that established the Radiation Laboratory, has given an account of the Laboratory's founding. Dr. DuBridge, Director of the Radiation Laboratory during its 62 months of existence, has written a very brief account of its organization, its growth, and its work. Here follows a short sketch of how the Series was prepared for publication.

Dr. I. I. Rabi, then Associate Director of the Radiation Laboratory, proposed the original idea for the Series in the fall of 1944, when it began to appear that the war in Europe was nearing its end. Preliminary outlines for the work were made at that time, contemplating only the preparation of books dealing with the basic microwave theory and techniques which had been developed during the wartime work on radar. Work on the planning of the Series was laid aside when the bitter fighting of the winter of 1944–1945 in Europe made it clear that the war was not yet over.

Work was resumed in the late spring of 1945. The Editor-in-Chief of the Radiation Laboratory Office of Publications was appointed in May of that year, and actual work began about June 1, 1945. Progress was slow at first, since most of the Laboratory's staff members were understandably more concerned with the further prosecution of their technical work than with the preparation of reports on work already done. During the early days of the Office of Publications, invaluable help and encouragement were offered by Dr. George B. Collins, who became Deputy Editor-in-Chief; by Charles Newton, who, as Production Manager, handled all the technical matters concerned with typing, drafting, photography, and the processing of manuscript and illustrations; and by Dr. George E. Valley, who was the first Radiation Laboratory staff member to join the Office of Publications.

At the outset of the work of preparing the Series, it was necessary to proceed in two general directions. Outlines for the various volumes had to be worked out, authors and editors chosen and induced to undertake the work, drafting and typing facilities set up, and the actual task of writing begun. This, although difficult, was a relatively straightforward job. The second part of the work—that of making the formal arrangements for the publication of the Series—was far more troublesome, mainly because no pattern existed for what was being attempted.

Since the Radiation Laboratory had been maintained by contract with the OSRD, an agency of the Federal government, it was necessary to obtain the approval of the Government Printing Office for the arrangements made to publish the Series. With the help of Dr. John E. Burchard, then Chairman of the OSRD Committee on Publications, and of Dr. Carroll L. Wilson, then assistant to Dr. Bush, discussions with the Government Printing Office were undertaken. It was determined by the GPO that publication of the Series would be accomplished most expeditiously if the job were handled by a commercial publisher.

The leading technical publishers of the country were then approached to learn their interest in publishing the Series. The McGraw-Hill Book Company, represented in these initial negotiations by James S. Thompson, then President of the company, showed a keen interest in the project from the very beginning. Proposals were ultimately submitted by three publishers, and that of the McGraw-Hill Book Company proved to be the one most favorable to the government.

Contractual arrangements for the publication of the Series had to include the Massachusetts Institute of Technology as "author" of the manuscripts, since the Institute was the contractor maintaining the Radiation Laboratory. This presented new problems, for the actual authors of the manuscripts for which the Institute was asked to become contractually responsible were in fact hundreds of individuals, each with his own postwar problems of relocation and readjustment. Nothing beyond the good faith of the author could be relied on as a guarantee of satisfactory completion of the work.

Negotiations for publishing the Series could readily have collapsed completely at this point, but the energetic efforts of Dr. James R. Killian, Jr., then Vice-President (now President) of the Massachusetts Institute of Technology, and of Curtis G. Benjamin, then Vice-President (now President) of the McGraw-Hill Book Company, surmounted every obstacle. A contract for the publication of the Series was finally signed on Nov. 14, 1945, largely as a result of the vigor, good faith, and generous cooperation of Benjamin and Killian.

Until the end of 1945, the work of the Office of Publications was budgeted as a part of the operation of the Radiation Laboratory, but that laboratory formally ended its existence at the close of the year. Estimates of the additional cost of preparing the manuscripts and illustrations for the Series came to $500,000, and this sum was set aside by OSRD to provide for the independent existence of the Office of Publications during the first six months of 1946, in which time it was estimated that the work could be finished. In recognition of the fact that the costs of preparing the Series had been met from the Federal treasury, the contract with McGraw-Hill for the publication of the Series provided that the usual authors' royalties be returned to the treasury of the United States. Up to January, 1953, the sum of $132,367 had already been returned to the government in the form of royalties on the Series. There appears to be a possibility that the entire direct costs of preparing the manuscripts and illustrations of the Series will eventually be returned to the government in the form of royalties. The publisher assumed all the substantial costs of composing, printing, and binding the volumes. In the public interest, the contract with the publisher also provides that McGraw-Hill will hold its copyright on each volume of the Series for only ten years following the date of publication.

The mechanical task of preparing in six months the manuscripts and illustrations for 27 technical volumes was as formidable as the literary task of writing and editing them. Preliminary estimates, which turned out to be surprisingly accurate, indicated that about a ton and a half of copy paper would be used, that about 75 typists would be needed, at the peak of activity, to prepare the various drafts of the manuscripts, and that about 100 draftsmen would be required to prepare the line drawings illustrating the Series. Substantial photographic facilities were needed to prepare the prints used for half-tone illustrations. Charles Newton managed all these arrangements, and supervised the photographic service which he had previously operated for the Radiation Laboratory. Mary Dolbeare was in charge of the typing center, Vernon Josephson of the drafting room.

By the end of 1945, the preparation of outlines for the work as a whole had been substantially completed, and actual writing was well under way. To the volumes on basic techniques that had been planned earlier there were added several books on systems problems, such as Vols. 1, 2, 3, and 4; and books on specialized techniques, such as Vol. 27. Every effort was made to achieve a maximum of technical and stylistic uniformity, with a minimum of confusing shifts in notation, abbreviations, and the like. Dr. Leon Linford headed the group that was responsible for setting the technical standards of style; he was greatly assisted by Monica Stevens, who was assigned by the McGraw-Hill Book Company to the Office of Publications as an expert on style. Whatever uniformity is observable in the books of the Series was very largely conferred upon them by the efforts of Elizabeth Gile, now Editor-in-Chief of the McGraw-Hill Book Company, Miss Stevens, and Dr. Linford and his group, who went so far as to prepare a Style Manual for the use of authors and editors, there being no suitable technical manual in existence.

By no means all the technical information reported in the Series originated in the work of the Radiation Laboratory. As the brief histories in this Index volume attest, the very notion of establishing the Radiation Laboratory was a result of the British invention of the multicavity magnetron and the disclosure of this capital device to representatives of the United States. For early leadership in the field and for many important advances in radar, the free world is deeply indebted to the Telecommunications Research Establishment and the other British radar laboratories. The recent Royal Commission award to Sir Robert Watson-Watt, the acknowledged father of radar, has come as welcome news to those of us who took part in the wartime radar development program. In order to make sure that British work would be adequately reported in the Series, the Office of Publications secured the assignment to the editorial staff of Dr. B. V. Bowden, then of the British Air Commission in Washington. Dr. Bowden was of great help in securing British documents, in making sure that important British work was not overlooked, and in taking part in the actual writing.

Apart from the Radiation Laboratory, the main centers of radar development in this country were the technical laboratories of the Army and the Navy, and the development laboratories of the principal electrical manufacturers, the most important by far being Bell Telephone Laboratories. Liaison offices were maintained at the Radiation Laboratory by the Army, the Navy, and the Army Air Forces; there were also groups of engineers from most of the important manufacturers. This made it possible to include in the Series the principal results obtained elsewhere in the country. In addition, Dr. M. J. Kelly, then Executive Vice-President (now President) of Bell Telephone Laboratories, was kind enough to arrange for members of Bell Laboratories to review and comment on manuscripts of the Series prior to publication; this was very helpful in correcting errors both of omission and of commission.

Before the publication of any volume of the Series, two sorts of clearance of the manuscript and illustrations had to be secured. Despite the extensive declassification of technical material at the end of 1945, formal security clearance had to be obtained. This was managed in two steps. At the time the outlines for the volumes were being settled, they were discussed with a joint Army-Navy-AAF security committee especially appointed for this purpose, and all outline entries of dubious clearance status were either eliminated or else determined to cover unclassified material. When the manuscripts were in hand, this same committee studied them to determine compliance with the original judgments on security. Thanks largely to the effective work of this Service group, the usually troublesome task of security clearance was accomplished with a minimum of difficulty. Members of the special security panel were Commanders J. E. Boyd, W. C. Hilgedick, and C. A. Smith, Lieutenant Commander J. Weber, Major Max Hall, Captain Hugh Winter (Army), Lieutenant J. A. Rexroth (Navy), and W. J. Brown, of the Signal Corps.

The other clearance required before publication involved a review of the manuscripts to ensure that they did not jeopardize the integrity of government-held patents, for example, by making inaccurate statements about dates or sources of invention. Captain R. A. Lavender, the principal patent advisor to the OSRD, was helpful in setting up the mechanism for reviewing the manuscripts from the patent standpoint. Most of the actual work of review was accomplished by John C. Batchelor, who was uniformly patient and helpful.

Much of the work of securing the formal clearance of the completed Series manuscripts came after the dissolution of the Office of Publications, and consequently fell on the late Dr. J. R. Loofbourow and J. L. Danforth, of the OSRD liaison office at M.I.T., and on Dr. Eugene W. Scott, J. H. Sole, and the late Cleveland Norcross, of the Washington staff of OSRD. Their effective help in this undertaking is gratefully acknowledged.

For those Radiation Laboratory staff members who remained with the Office of Publications after the termination of the Radiation Laboratory, doing so often represented a substantial sacrifice in terms of postponing or foregoing academic fellowships, professorial appointments, or industrial jobs. After the close of the Office of Publications, there was still much work to be done in "spare" time, without any additional compensation except the reward inherent in a job well done. At best, there were proofs to be corrected; in many instances, there were substantial tasks of writing and editing still to do. All this work was ultimately done, and the Series is complete.

During the active life of the Radiation Laboratory's Office of Publications, it was planned that Dr. Leon Linford should prepare the general index volume for the Series. Unavoidable delays in the completion of the last few manuscripts, however, delayed the appearance of the Index very considerably. Meanwhile, Dr. Linford became so busy with his professional duties that he was unable to invest the substantial amount of time necessary to prepare an adequate index. Fortunately for the Series, Keith Henney, of the McGraw-Hill Publishing Company, very generously agreed to undertake the difficult task of preparing a unified Index for the entire Radiation Laboratory Series. He has carried out this job with vigor, skill, and success, and all users of the Series are permanently in his debt.

Those of us who helped prepare the Series sincerely hope that it is worthy of the dedication Dr. DuBridge has given it—"to the unnamed hundreds and thousands of . . . scientists, engineers, and others who actually carried on the research, development, and engineering work the results of which are herein described."

Editor's Introduction

The best person to make a book index is the author. He knows what is in his book, why it is there, and where a reader is likely to look for it. But it would be impossible to get the 53 authors whose names appear on the jackets of the 27 volumes of the Radiation Laboratory Series to compile the final volume—the master index—even if they could agree upon an index style!

This editor, therefore, assumed a job which at first sight seemed quite simple. But closer look made it apparent that an index of the individual indexes would not be very useful; and still closer scrutiny indicated that the final index could not be made by merely shuffling the entries in the 27 volume indexes. These individual indexes are not uniform in magnitude, style, or in any other parameter. Some have author's names and others do not. Some indexes are sparse; others are voluminous. And in the individual index an entry without qualification, "amplifier," for example, might be all that was necessary, but when included in the master index such an entry would be virtually worthless.

The editor took a bold step. He eliminated all authors' names. He eliminated all company and laboratory names unless the item referred to has real meaning at this date. Many entries were eliminated because time has negated their importance. Other entries which contribute little or no information have been dropped—the mere mention of a 6SA7 tube, for example.

Qualifying adjectives have been added to many thousands of entries which now appear in the individual volume indexes without qualification. In this way the reader has a better and quicker chance to find what he wants. Every attempt has been made to bring together matters which naturally belong together—beacons, for example, are collected and not scattered; antennas, for whatever purpose, are found under "antenna."

Some of the larger individual indexes have been streamlined; and in many cases the slender indexes have been built up when the editor found material which a present-day reader would want.

The editor cannot end this preface without saying something about the 15,476 pages of the 27 volumes themselves. Throughout the job of making this index it was a constant temptation to read paragraphs, chapters, or whole books to learn more about matters which are still so current and so important that the books might have been written yesterday instead of from three to eight years ago. There is an amazing amount of information in this library, much of which is currently being applied to many scientific and engineering jobs which have no relation whatever to radar.

May the reader find this index useful in locating what he wants when he wants it; and may he remember that the Radiation Laboratory Series exists only because of the vision of men like Bush, DuBridge, and Ridenour and because of their unconquerable determination in forcing the contents of these 27 volumes out into the open where all can read and learn.

KEITH HENNEY

NEW YORK, N.Y.
February, 1953

Radiation Laboratory Series
Index

Volume numbers appear in **boldface** type preceding page-number references.
For names of persons, companies, and laboratories, please refer to the indexes in the individual volumes.

A

Absorbing material for radiation, **1,** 69; **12,** 560
  bandwidth of, **1,** 71
Absorbing mediums, theory of, **26,** 343–346
Absorption, atmospheric (*see* radio-wave, below)
  coefficient (*see also* Attenuation constant), **13,** 24, 647, 650
    for oxygen, **13,** 647, 651–656, 663
      measurements, **13,** 654–656, 665
      theory, **13,** 648–656
    radiation, **26,** 266, 345
    for water vapor, measurements, **13,** 659, 666–671
      theory, **13,** 656–664
  dielectric, **13,** 24, 676–678
  radio-wave (*see also* Attenuation), **1,** 112; **2,** 22; **3,** 53-56; **4,** 131, 146; **13,** 641–692
    by condensed water, **13,** 671–692
    by fog or cloud, **1,** 60, 62
    by hailstone, **13,** 25, 687
    measurements, **13,** 658, 661, 664–671, 688–692
    by nitrogen, **2,** 22
    by oxygen, **1,** 59; **2,** 22; **13,** 26, 646–656, 663
    by particles, **13,** 23, 676–678
    by precipitation, **2,** 22; **13,** 672, 673, 676–680, 682–688, 691
Absorption, radio-wave, by precipitation, measurements, **13,** 688–692
    by rain, **1,** 61; **13,** 615, 673, 678–685, 691, 692
      measurements, **13,** 688–692
      nonresonant, **13,** 643, 652–653
    relation to index of refraction, **13,** 641–646
    resonant, **13,** 644, 646, 653
    by trees, **3,** 438
    by uncondensed gases, **13,** 646–664
    by water droplets, **1,** 60
    by water vapor, **1,** 159; **2,** 25; **13,** 26, 312, 363, 646, 647, 656–664
A-c charging, diode, **5,** 414–416
  general analysis, **5,** 380–386
  line-type pulser, **5,** 386–416
  nonresonant, **5,** 381, 385, 393–400
    wave shape for, **5,** 399
  resonant, **5,** 381, 385, 386–393
  transformers, **5,** 400–407
  voltage wave shape, **5,** 408
A-c discharge, similarity principle, **9,** 239
A-c resistance, space charge, **7,** 130, 141
A-c resonance charging, pulse network, **3,** 245
Acceleration, measurement, **21,** 371
  servo, **21,** 356, 398
Accelerometers, **21,** 77
Achromatic doublets, **12,** 410
Acoustical media, properties, **19,** 755–757
Acoustical waves, propagation, **19,** 757–759

Acrylic plastic, **26,** 370
Action function, **6,** 226
Actuators, rotary, **17,** 495–497
Adapters, for coaxial connectors, **9,** 273
  type N, **9,** 259, 261
Adder (computer), bar-linkage, **27,** 36
  star-linkage, **27,** 256
Addition, agents, semiconductor, **15,** 67, 306–308, 364
  as circuit operation, **21,** 32, 35
  with mechanical devices, **21,** 39
  potential, **19,** 18
  of pulse counts, **21,** 40
  with series sources, **21,** 35
  with synchros, **21,** 36
  using parallel impedance networks, **21,** 32
  by vacuum-tube circuits, **21,** 41
  voltage and current, **19,** 629
Additive (computer) cells, **27,** 6–12
  differential, belt, **27,** 10
    bevel-gear, **27,** 6–7
    cylindrical-gear, **27,** 7
    loop-belt, **27,** 10–11
    screw, **27,** 9–10
    with spiral gear, **27,** 9
    spur-gear, **27,** 7–9
  differential worm gearing, **27,** 9, 11
ADF, **2,** 46, 53
Adhesive in radomes, **26,** 282, 318
Adiabatic lapse rate, **13,** 194
Adiabatic process, **13,** 186, 193
Adiabatic theory, magnetron starting, **6,** 357
Admittance, cavity gap, **7,** 50, 68, 144
  characteristic, magnetron system, **6,** 113, 461
  chart, rectangular, **9,** 72
    Smith, **6,** 318, 707; **8,** 73, 226; **9,** 60–67; **10,** 10; **12,** 29
    use of, **9,** 94
  circuit, **8,** 84
    lumped-constant, **7,** 81
    resonator, **7,** 319
  combinations, **8,** 70
  computation, **6,** 77
  density-modulation, **7,** 50, 58, 68, 99
  electron stream, **6,** 214
  interaction space, magnetron, **6,** 63, 84
  intrinsic, *TEM*, **8,** 19
  matrix, **8,** 89, 140; **10,** 106; **15,** 114–124
Admittance, matrix, in terms of measurable parameters, **15,** 119–124
  measurements, **11,** 476; **16,** 352
    mixer-loss, **16,** 367–372
  modulation, density, and velocity, **7,** 114
  resonator, annular-sector, **6,** 62
    cylindrical side, **6,** 59
    rectangular-slot side, **6,** 57
  scatter, **16,** 134–136, 168
  short-circuit, **9,** 542
  side resonator, **6,** 56
  single-velocity, **7,** 103
  source, optimum, **18,** 639–641
  terminal, of waveguide, **12,** 366
  transformation ratio, **14,** 27
  transmission-line (*see* Line)
  velocity-modulation, **7,** 50, 56, 69, 99
Advection fog, **13,** 230
Aerometeorographs, **13,** 347
Aeropsychograph, **13,** 272, 297, 298
  housing, **13,** 274, 275
  on PBY aircraft, **13,** 276
  speed correction, **13,** 276–280
AFC, **16,** 190–202, 290–351, 360; **20,** 96, 267; **23,** 10, 27–78
  absolute frequency systems, **16,** 294; **23,** 27, 74–78
  amplifiers, **3,** 274–276
  attenuator, **16,** 196–199, 372
  beacon, **1,** 456; **16,** 190–202, 227–231, 234, 244, 287, 341; **23,** 75
    receiver, **3,** 170–172, 270–278
    reflector modulation scheme, **16,** 342–347
    for thermally tuned tubes, **16,** 347–351
  control circuits, gas-tube, **23,** 56
    hard-tube, **16,** 326; **23,** 64
    reflex oscillator, **23,** 34
    thermally tuned oscillators, **23,** 69
  control range, **23,** 51
  control voltage, **16,** 296
  d-c amplifier-type, **16,** 313; **23,** 54
  difference-frequency systems, **16,** 295–341
  diode-transitron, **16,** 326–331
  discriminator, **3,** 271–274
    modulated-cavity single-crystal, **3,** 271
    two-crystal standing-wave, **3,** 272

AFC, double-balanced mixer, **16**, 283–287
double-mixer, **16**, 193–202, 300; **23**, 17
down-pull rate, **16**, 318, 322, 325
drift-in system, **16**, 314–331
effect on radome design, **12**, 527, 538
error voltage, **16**, 295
feedback loop, **16**, 295
following rate, **16**, 317, 318
gas-discharge-tube, **16**, 315, 317–326, 345
hold-in, **16**, 295; **23**, 32
hum problems, **16**, 349
hunting, **16**, 295, 331
absolute-frequency, **16**, 341–351
locking, **16**, 246, 292, 302
magnetron, **6**, 623
microwave, **7**, 18, 27, 384
oscillator, **11**, 58
mixer tests, **16**, 372–374
Nibbe-Durand, **16**, 333, 337
nonhunting systems, **16**, 295, 312–314
on-off control, **23**, 70
on-off principle, **16**, 294, 331
overshoot, **16**, 335
pull-in range, **16**, 295; **23**, 32
pulling, **16**, 290, 317
radar receiver, **1**, 453–457; **2**, 143
requirements, **23**, 39
resistance-voltage graph, **23**, 347
search stopper, **16**, 314, 317, 326
separate-channel, **16**, 300
separate-mixer, **16**, 193–202
servomechanisms, **3**, 276–278
sideband, wrong, **16**, 294, 314, 331, 332
systems, classification, **16**, 294
difference-frequency, **23**, 28–74
thermal hunting, **16**, 331–341
Whitford, **16**, 332, 333, 337, 339
wide-range tunable, **16**, 331–341
transmitter sample, **16**, 196–199, 296–299, 301
tuning coefficient, **23**, 24, 31
up-pull rate, **16**, 319, 322, 325
AGC, **20**, 41, 279; **23**, 241–248, 402–409
gated, **20**, 373
gating circuit, effect on stability, **23**, 243
Loran, **4**, 394
Agitation, thermal, **16**, 10
AI, **1**, 200; **26**, 165
AI, Mark IV, **1**, 201
Mark VI, **20**, 334, 370
automatic target-selection system, **20**, 332
time discriminator and target selector, **20**, 334
Mark VI A, **20**, 341
AIA, **1**, 203
Aided tracking, **20**, 200, 203, 206; **25**, 361
with intermittent data, **20**, 247–251
mechanical, **19**, 541
rms-error criterion in determining, **25**, 363–368
time constant, definition, **25**, 362
unit, **25**, 361–363
velocity servo for, **20**, 250
Air, control, high-performance radar for, **1**, 592–611
dry, density, **13**, 292
equilibrium, neutral, **13**, 195, 213, 223, 226, 238
stable, **13**, 196, 220, 228, 234, 238
fluctuations in, **13**, 270–271
shear in, **13**, 234–237
unstable, **13**, 196, 220, 225, 235, 268
fluctuations, **13**, 268
homogeneous, **13**, 193, 207
layer, **13**, 221, 222, 226
horizon ray, **13**, 17
mass boundary, **13**, 339
-mileage unit, Bendix, **20**, 251
molecular weight, **13**, 292
-position indicator, **20**, 251
specific heat, **13**, 188, 293
surveillance, high-performance radar for, **1**, 592–611
-to-air rendezvous, **3**, 13
-to-surface search, **12**, 466
Transportable Loran, **4**, 35, 44, 93, 413
unstable, modification rate, **13**, 226
warm, over cold water, **13**, 237–250
Aircraft, antennas, **12**, 512
control by Loran, **4**, 115–116
echoes, aximuth variation, **13**, 543
propeller modulation, **13**, 539–541
slow-fading, **13**, 543
electrical systems, **1**, 555
gun sight, AN/APG-15, **26**, 171
installations, interference effects in, **12**, 515–519
interception (*see* AI)

Aircraft, psychrometer, **13**, 287, 288
Airfoil section, **26**, 423
Airplane detection over water, **2**, 115
Airy integral, **13**, 95, 149, 150
asymptotic expansion, **13**, 150
Alarms, circuit-trouble, beacon receivers, **3**, 322
Alloys, resistance properties, **17**, 70–72
Alnico V, **6**, 542, 547, 548
Alternator, airborne, direct-driven (*see also* Dynamometer; Generator), **1**, 557–561
wave shape, **1**, 557
aircraft, **1**, 561–563
alternatives to direct-driven, **1**, 560
speed regulators, **1**, 571–578
engine-driven, **3**, 314–316
inductor, performance, **1**, 557
starting current, **1**, 561–563
voltage regulators for (*see* Voltage regulators)
Altimeter, AN/APN-1, **2**, 136–141
barometric, **20**, 163, 164
frequency-modulated, 136–141
pulsed and f-m, comparison, **2**, 141
radio, **1**, 143–147; **2**, 131–142
pulsed, SCR-718C, **2**, 132–136
SCR-718, **20**, 163, 219
Altitude, circle, **12**, 514
determination, **2**, 131–142
Aluminum, as addition agent, semiconductor, **15**, 67
cathode gap (*see* Spark gap, fixed)
Ambipolar diffusion, **14**, 184
A.M.E.S. height finder, Type 7, **1**, 186
Type 13, **1**, 190
Amperite, characteristics, **21**, 501
Amplidyne, **2**, 28; **21**, 401; **22**, 189; **25**, 106; **26**, 221, 233, 238
generators, **21**, 437
Amplification bridge (voltage regulator), **21**, 532
Amplified back-bias (AGC), **1**, 459
Amplifiers, **21**, 375–386, 484
a-c, **21**, velocity servo with, 487
AFC, **3**, 274–276
d-c, **23**, 54
for antenna measurement, **12**, 604–609
asymptotic characteristic, **18**, 340
audio, **12**, 605
Amplifiers, bandpass, alignment, **18**, 318–323
gain control, **18**, 290
gain variability, **18**, 291
input connections, **18**, 319
measurements, **18**, 318–323
overload, recovery from, **18**, 290
pulse response, **18**, 274–300
regeneration in, **18**, 323
response to pulse of detuned carrier frequency, **18**, 329
synchronous and staggered single-tuned high-frequency, **18**, 166–200
undesired feedback effects, **18**, 323–327
bandwidth, **18**, 169, 322
input circuit, methods of increasing, **18**, 690
maximum possible at given over-all gain, **18**, 173
noise, **18**, 169
over-all, obtainable with various circuits, **18**, 289
basic pentode, **18**, 72
bias, **18**, 353
blackout effects, **18**, 329, 330; **23**, 187
cancellation, **20**, 498–511
capacity, effect of, between input and output, **23**, 96
variation effect, **18**, 292–295
cascade, 2K35, **7**, 22
output admittance, **23**, 83
synchronous single-tuned, **18**, 172–174
voltage, **7**, 249, 271–278
cascode, **18**, 440
cathode-compensated, **19**, 771–774
choke-coupled, **18**, 126; **23**, 527
circuits for minimal noise, **18**, 615–694
class C, **19**, 547
comparator, **19**, 335–338
compensation, **23**, 219–220, 399
components, aging of, **18**, 390, 411
temperature coefficients, **18**, 390
tolerances, **18**, 400
variability, **18**, 390
computer, simple designs, **18**, 347–351
current waveform, **22**, 362–370
d-c, **16**, 300, 312, 327; **21**, 649
reflex, **16**, 314
design, **16**, 1

Amplifiers, differential, 4, 231, 246; **18,** 441–451
direct-coupled, **18,** 409–495; **21,** 512; **22,** 370–374
design, **18,** 424–479
floating-grid potential, **18,** 420
gain, maximum, **18,** 418
integration by, **18,** 411
plate potential, minimum allowable, **18,** 420
special aspects and effects of vacuum-tube properties, **18,** 412–424
special-purpose, **18,** 479–495
temperature variation effects, **18,** 411
voltage gain, maximum, **18,** 417
voltage-supply variation, **18,** 411
zero adjustment, **18,** 411
double-tuned (*see also* Double-tuned circuits), **18,** 201–231, 322
feedback, **21,** 210; **22,** 363
design, practical considerations, **18,** 261–266
flat quadruple, **18,** 270
four-terminal coupling networks, **18,** 266
high-frequency, **18,** 232–273
low-frequency, **18,** 384–408
amplitude characteristics, **18,** 394
negative, **20,** 117
figure of merit, **18,** 73, 171
filter, **18,** 179
folded, **18,** 194
gain, attainable at increasing frequency, **23,** 132
bandwidth factor, **18,** 172, 205, 287–290
control, **22,** 157
maximization, **7,** 255–256
measurement, **18,** 330
over-all, **18,** 336, 361
production-line test, **18,** 331
gated, **1,** 508–510
grid-separation (grounded-grid), **7,** 146
grounded-cathode, **18,** 655; **23,** 126
grounded-grid, **18,** 661
grounded-grid, **7,** 146; **18,** 634, 648, 653; **23,** 83, 92, 117, 136
grounded-plate, **18,** 655
high-efficiency, space-charge tube, **7,** 148, 162
Amplifiers, high-frequency compensation, 23, 399
i-f (*see also* I-f), **16,** 24; **23,** 155–187
bandpass shape, **23,** 305
bandwidth requirements, **16, 302**
beacon receiver, **3,** 157–158
conductance, **16,** 111, 249, 360
design, **1,** 442–449
double-tuned, **1,** 446
flat-staggered pairs, **18,** 187–189; **23,** 166
of small fractional bandwidth, **23,** 168
flat-staggered triples, **18,** 189–191; **23,** 168
gain, **23,** 166
incremental, **23,** 184
stability, **23,** 182
input circuits, **23,** 79–121
autotransformer, **23,** 103
double-tuned, **23,** 105–109
impedance change due to feedback, **23,** 90
single-tuned, 103
logarithmic, **24,** 306–308
output admittance, **16,** 90, 178–185
output lead, **16,** 128–131
overload characteristics, **23,** 305
pulse response, **23,** 305
radar receiver, **1,** 8, 442
resistance, **16,** 115
single-tuned, **1,** 445
test equipment, **23,** 305–335
transfer impedance, **23,** 108
transient response, **23,** 181
tube capacitance, criticalness with regard to, **23,** 180
and video, **23,** 429–439
W-5, **11,** 555
infinite gain, **21,** 81
input, capacitance, **18,** 339
coupling networks, **18,** 682–692
impedance, **18,** 338, 339, 348, 363
loading, **23,** 128
inverse-feedback, **18,** 323
klystron, **7,** 20–23, 240, 243, 244, 248–284
law, **18,** 332
lightweight selective, **18,** 403
limiting, **18,** 98; **19,** 160
lin-log, buffering, **23,** 587

Amplifiers, linear, negative feedback, **19,** 24–27
linear shaping, **19,** 31–37
load, in cathode, **18,** 87
impedance, **18,** 353
line, **18,** 356, 426
resistive, **18,** 354
logarithmic, **9,** 713
low-frequency, compensation, **23,** 216
response, **23,** 214
with stabilized gain, **18,** 333–383
magnetic, **19,** 666; **21,** 72
measurements, **18,** 301–332
microwave, **7,** 18–23
motor and power, **25,** 103
multiple-overshoot, **18,** 142
negative-capacity, **19,** 767–770
negative feedback, **1,** 492
Neher tube, **7,** 344
noise, **7,** 19–21
nonlinear effects, **18,** 121
output, impedance, **18,** 336
power, **18,** 708
measurement, **18,** 708–717
stages, **18,** 103, 352–357
overdriven, **22,** 120
overload effects, **18,** 329, 330; **23,** 184–187
overshoot, **18,** 280
overstaggered, **18,** 284–287
P4E, **21,** 600
paraphase, **4,** 229
phase response, **18,** 341, 343
phase shift, **18,** 353
phase-splitting, **1,** 495; **19,** 154–156
power, **18,** 430
available, **18,** 621, 697–699
gain, **18,** 621–635
available, **18,** 596–604, 651; **23,** 2, 81, 85
klystron, **7,** 249, 280–284
Loran, **4,** 298
microwave, **7,** 21–23, 249
pulse, **11,** 550; **18,** 72
cutoff, low-frequency, and step-function response, **18,** 86
for deflection-modulated cathode-ray tube, **18,** 109
electronic switching, **18,** 102
flat-top compensation, **18,** 89
-forming, **20,** 72
Amplifiers, pulse, gain control, **18,** 93–96
gain/rise time ratio, **18,** 73
grid circuit, **18,** 84
high-fidelity, **18,** 71–112
for intensity-modulated cathode-ray tube, **18,** 111
large dynamic range, **18,** 113–165
output circuits, **18,** 142
overshoot, **18,** 71–84, 114–123
limiting, **18,** 122
rise time, **18,** 71–84
steady-state and transient responses, relations between, **18,** 80
step-function response, and low-frequency cutoff, **18,** 86
pulse response, **18,** 327
push-pull, **18,** 104
r-f, **16,** 2, 23, 43
beacon receiver, **3,** 157
microwave, **7,** 18–21, 257–259
pentode, **17,** 570–585
cutoff characteristics of, **17,** 570–571
figures of merit, **17,** 571–572
RC-coupled, *n*-stage, **18,** 64
regeneration problems, **18,** 323
for resistive load, three-stage, **18,** 366–383
rotary magnetic, **25,** 106
schemes, different, pros and cons, **23,** 178–182
screen bias, design, **18,** 359
screen-biasing circuit, **18,** 362
sensitivity of, **18,** 496–614
series-fed circuit, **18,** 151
shunt peaking, **18,** 73; **23,** 219
signal, **21,** 600
microwave, **7,** 18–21
sine-wave comparison, **19,** 355
single-overshoot, **18,** 140
single-tuned, **18,** 168–176
synchronous, **18,** 322; **23,** 160
gain-bandwidth factor, **18,** 172
space-charge devices as microwave, **7,** 146–169
squaring, **20,** 70, 72, 110
stability, **18,** 339–348, 411, **23,** 126, 135
against oscillation, **18,** 363-366
stabilization factor, **18,** 358
stagger-tuned, **18,** 322; **23,** 162–169

Amplifiers, stagger-tuned, gain control, **18,** 191
negative input resistance at high frequencies, **18,** 197
staggered, **18,** 176–186
for standing-wave measurements, **11,** 496–503
step-up, **21,** 181
sweep for reactive loads, **22,** 356–383
temperature effects, **18,** 390
testing, **18,** 301–332
proper making of connections, **18,** 319
self-rectification, **18,** 321
with swept-frequency generator, **18,** 302
vacuum-tube voltmeter use, **18,** 320
torque, **21,** 443
transmission-line, **18,** 83
traveling-wave, **7,** 18
triode, with cathode resistor, **18,** 426
characteristic, **18,** 426
linearity, **18,** 426, 431
single-ended, **18,** 424–432
twin-T, **11,** 501
two-channel, for MTI, **1,** 672–675
types, comparison, **18,** 297–300
variable-gain, **21,** 53
VHF, mixers and oscillators, **23,** 126–138
video, **1,** 8, 450–453; **21,** 584, 604, 610, 620, 626, 628, 637, 642, 652; **22,** 145–159, 436, 444, 731–735; **23,** 213–237, 515–544
bandwidth, **22,** 30, 147
beacon receiver, **3,** 177–179
brute-force circuit, **23,** 523
cutoff frequency, **1,** 451
high-frequency response, **22,** 151; **23,** 218
low-frequency response, **22,** 150
output, **22,** 154
overshoot, **22,** 149
recovery, **23,** 516
rise time, **1,** 450; **21,** 584; **22,** 149
voltage, microwave, **7,** 18–21, 249–260
waveform, **22,** 359–362
Whippany effect, **23,** 187
wideband, **22,** 268
single-sideband, **23,** 456
switched-LO, **23,** 456
Amplitude, -balance control, Loran, **4,** 387
coefficients of reflection and refraction, **26,** 349
comparison, **19,** 12, 45, 166, 325–363, 701; **20,** 71, 75, 76, 107, 109, 110, 142–175
comparator, **20,** 144
diode, **20,** 71, 73, 108, 125–131, 151, 173
regenerative, **20,** 73–75
sinusoid, **20,** *145*
demodulation, **19,** 53, 501–544
discrimination, **19,** 12, 57, 325–363, 697
factor, alternator waveshape, **1,** 557
measurements, direct, **19,** 695
substitution in, **19,** 695
subtraction in, **19,** 696
waveform, **19,** 695–697
modulation (*see* Modulation, amplitude)
pulse jitter, **5,** 290, 331
pulsing, **24,** 18
-reflection coefficient, **26,** 261, 262, 267, 288, 290
chart, **26,** 275
selection, **19,** 11, 44, 325–363, 696
electrical, **20,** 221
selector, **19,** 331, 365–370, 390, 503–511
cathode-ray tube, **20,** 220
double diode self-stabilizing, **19,** 480
half-wave circuits, **19,** 390–391
stability, oscillator, **19,** 103
stabilization, oscillator, **19,** 126–128
transmission measurement, in waveguide, **11,** 577–584
Analogue computers, **21,** 3-212
"Angels," **13,** 593–595
Anger pulser circuit, **5,** 468–471
Angle, arrival, affecting radar echoes, **13,** 532
measurements, **13,** 385–395
ray theory, **13,** 391
attack, effect on radome, **26,** 164
coaxial-line, **9,** 170–182
incidence, radome, range of, **26,** 286
indices, phototube, **22,** 230
fixed electronic, **1,** 514
movable electronic, **1,** 516
radar, **1,** 514–518
markers, electronic, **22,** 398

Angle, navigation systems, **4**, 17
penetration, **13**, 17
-positioning, automatic, with grouped data, **20**, 389
resolvers, **18**, 347
-tracking circuits, AN/APG-1, **20**, 376, 377
SCR-615, **20**, 374
Angular position of target, shift of, **26**, 249
AN/MPN-1 (*see* GCA)
Anode block (*see* Magnetron)
Anode buildup, spark gap, **5**, 320
Antenna (*see also* Radiator), 3-cm, **3**, 131
10-cm, **3**, 130
180-kc/sec, **4**, 329
2-Mc/sec, **4**, 323
airborne, **2**, 155; **26**, 155
fixed, Loran, **4**, 343
stabilization, **26**, 13, 195–210
aircraft, **12**, 512
arrays (*see* Array)
assembly of shipborne navigational radar, **2**, 364
backlash in driving mechanism, **26**, 138
bandwidth, **4**, 307, 317
barrel-reflector, cross polarization, **12**, 503
beacon, **3**, 125–135; **12**, 327
on aircraft, **12**, 521
beamwidth, **3**, 374
design, **3**, 129–135
duplexer, **3**, 138–144
housing, **26**, 460
pattern measurements, **12**, 573
requirements, **3**, 133
beam (*see* Beam)
beamwidth, **1**, 20, 271; **2**, 12; **3**, 274; **14**, 3; **26**, 11
antenna size and wavelength, relation between, **2**, 14
and azimuth resolution, **2**, 14
resolution with different, photographs showing, **2**, 365
beavertail, **2**, 210, 215–223; **12**, 453, 477; **26**, 85
Beverage, **4**, 87, 267, 328
tilt angle, **4**, 328
center of feed, determination, **12**, 564–570
cheese, **12**, 459
Antenna, conically scanning, **12**, 347
-control servo, AN/APA-46 radar, **21**, 434
cosecant-squared, **1**, 23–27, 274–277; **13**, 38: **26**, 156, 176, 252
low-altitude, **12**, 484–486
coupling networks, **4**, 303, 306, 310, 324, 341–343
cross section (*see* Cross section)
cut paraboloid, **1**, 272
feedtilt effects, **12**, 488, 489
offset feeding, **12**, 454
for shaped beams, **12**, 477–483, 487–491
for simple fanned beams, **12**, 451–457
cylindrical, **4**, 315
design, radar, **3**, 374–377
diffraction, **12**, 162–168
dipole, **12**, 239–256
center of feed, **12**, 239, 343, 562
electric, **12**, 92–95
feeds, directive, **12**, 250
-disk, **12**, 251–253
gain, **2**, 16
half-wave, **12**, 98
gain, **12**, 99
magnetic, **12**, 95
skirt-, **12**, 240–242
slot-fed, **12**, 245–248
as array element, **12**, 284–286
spheroidal, impedance, **12**, 249
driving mechanisms, **26**, 135–137
dummy, **4**, 314
design, **4**, 321
duplexing, **23**, 421
effective height, **1**, 52
electrical length, **4**, 315
elevation order, **26**, 109, 110, 463
elevation patterns, **26**, 450
end-fire, **1**, 277
fanned-beam, **12**, 450–464
feed (*see also* Feed), **12**, 250–253; **26**, 5, 15, 156–158, 161, 184
definition, **12**, 12
mechanically oscillated, **26**, 67
offset, **26**, 64
pillbox, **26**, 161, 176, 206
radar, **1**, 272–274
trapezoidal, **26**, 45
vertex, **26**, 158
gain (*see* Gain, antenna)

Antenna, ground, **12**, 510; **26**, 15
guy insulators, **4**, 340
guy wires, **4**, 339
H-plane pattern, **12**, 103
half-beacon, **12**, 460
half-power width, **12**, 94, 104
horn (*see* Horn)
impedance, characteristic, **4**, 315
input, **4**, 307, 324, 327, 331
level, **4**, 322
measurements, **12**, 544–557
input, reactance, **4**, 318
resistance, **4**, 317
installation, **3**, 443–445
deicing, **3**, 443
mast, **3**, 443
pressurizing, **3**, 443
problems, **12**, 510–542
interaction between, **12**, 587–592
inverted-L, **4**, 323
isotropic, definition, **13**, 28
lens (*see* Lens)
line-of-sight (tilt), stabilization, **26**, 195–199, 207
two-axis, **26**, 144
lobe, region, **2**, 356
side, **2**, 13
-switching, **3**, 375
Loran, **4**, 87, 97, 301–344
2-Mc/sec, **4**, 323
airborne trailing, **4**, 343
bandwidth, **4**, 307, 317
characteristics, **4**, 314
ground-station, **4**, 301
receiver-indicator, **4**, 342
receiving, **4**, 302, 340
vertical, **4**, 328
umbrella-type, **4**, 97, 333
mattress, **1**, 274
measurements, equipment, **12**, 593–613
feed pattern, **12**, 557–573
techniques, **12**, 543–592
metal-lens, **13**, 386
bandwidth, **12**, 408–410
microwave, **3**, 130–133; **14**, 3
circuit relations, reciprocity theorems, **12**, 16–60
radiation from current distributions, **12**, 61–106
minimum-scattering, **8**, 329–333
Antenna, mismatch, dependence of absorption cross section on, **12**, 51–53
mount, 10-cm, fully stabilized, **26**, 149
airborne, **26**, 162–170
AN/TPS-1, **26**, 79
AN/TPS-10, **1**, 286; **2**, 215; **26**, 12, 97
bearing, **26**, 170
corrosion, **26**, 141
CXBL, **26**, 232
function and design, **26**, 10–14
gear boxes, **26**, 139
gear case, **26**, 78
gearing, worm, **26**, 138
gears for power drives, **26**, 138
ground, **26**, 70–103
height-finding, **26**, 85–103
ice loading, **26**, 131
line-of-sight stabilized, **26**, 133
loads, inertial, **26**, 129
radar, **1**, 271
three-axis, **1**, 309
r-f head, **26**, 73
r-f package, **26**, 73
ship, **26**, 129–154
driving mechanism, **26**, 135–142
shock, **26**, 130
shock loading, **26**, 129
simple search, **26**, 70–84
SP-1M, **26**, 86
stable-base, **26**, 134, 147
vibration, **26**, 163
noise, **24**, 103–108
nonscanning, **1**, 277–279
nutating, **23**, 380
for overhead coverage, **3**, 133
parabolic cylindrical, gain, **12**, 458
paraboloid, 1, 272–274; **2**, 14
focal length, **26**, 26
patterns, **3**, 126
and aperture illumination, **12**, 169–199
apparent, radome effect on, **12**, 526
conical scanning, SCR-584, **20**, 367
distortion by radome, **12**, 524–526
function, **13**, 27–31, 116, 437–440, 482, 589, 629
gain determination by integration, **11**, 914
H-plane, **12**, 103
measurements, **11**, 898–915
intensity, **11**, 900–907

Antenna, patterns, parameters, **11**, 898
phase, center of, **11**, 900
primary, **12**, 12
intensity measurements, **12**, 561–564
line-source, **12**, 570–572
for point-source feeds, **12**, 557–570
siting apparatus, **12**, 560
recorder, automatic, **12**, 609–613
secondary, **12**, 12, 169, 175–180
phase-error effects, **12**, 186–191
symmetrical, **13**, 38
symmetry in pattern-propagation factor, **13**, 38
synthesis by linear array, **12**, 279–284
testing apparatus, **26**, 445
pedestal, **1**, 271; **4**, 65; **26**, 8, 115
pencil-beam, **12**, 413–450
cross polarization, **12**, 419, 423
gain, **12**, 423–432
H-plane patterns, **12**, 422–423, 433–437
impedance correction, **12**, 443–448
pillbox, **12**, 459–464
impedance correction, **12**, 463
polyrod, **1**, 278
pyramidal horn, gain, **12**, 587
Q, **4**, 301, 308, 320
radar, **1**, 271–280; **2**, 155–160, 194
equation, **1**, 271–272
mechanical construction, **1**, 279–280
search and height-finding, on single mount, **2**, 221
for radar relay, **1**, 713–719
filter for, **1**, 720
radiation by, **8**, 317–333
reactance networks, **4**, 304
reactance slope, **4**, 318
receiving, equivalent circuit, **12**, 40–45
pattern, **12**, 4
resonant frequency, **4**, 317, 322
scanning, **12**, 513–521
rolled parallel-plate, **1**, 304
scattering by, **8**, 317–333; **11**, 899
Schwarzschild, **1**, 295–298; **26**, 55–61
SCI height finder, **1**, 298–302
secondary pattern measurements, **12**, 574–592
shaped-beam, **12**, 465–509
Antenna, shaped-beam, line sources for, **12**, 495–497
secondary-pattern measurement, **12**, 579
shipborne, **26**, 15–69
beamwidth, vertical, **26**, 132
installation problems, **12**, 511
Loran, **4**, 342
stabilization, **26**, 463–472
for surface search, **12**, 467
sideband energy, **4**, 310
size, beamwidth, and wavelength, relation between, **2**, 14
stabilization (*see* Stabilization, antenna)
strip reflector, **12**, 484
submarine, **26**, 132
surface, for air search, **12**, 465
T-network, **4**, 305, 306
temperature of, **1**, 32; **16**, 12; **24**, 105
top loading, **4**, 334
transmitting, balloon-supported, **4**, 329–336
equivalent-circuit, **12**, 37–40
low-frequency, Loran, **4**, 330, 338
steel mast, **4**, 325
tower, **4**, 332
tripole, **3**, 130
variable beam shape, **12**, 508–509
wave, **4**, 301
wind resistance, **12**, 450, 453
Yagi, **1**, 277
Anticlutter circuits, **1**, 460; **2**, 197
Anticollision radar devices, **2**, 128–131
Anticyclone, Pacific, **13**, 262
subtropical, **13**, 261
Anticyclonic conditions, **13**, 347
Anti-icing, **26**, 425
fluid, **26**, 131
Antijamming, **1**, 457–460
Loran, **4**, 234
Antimony as addition agent, semiconductor, **15**, 67
Antirattle clip, **23**, 255
Anti-Stokes lines, **13**, 73
Eckersley modes, **13**, 84
Anti-TR (*see* ATR)
Aperture, angular, **12**, 416
blocking, effects of, **12**, 190–192
cavity, **7**, 500
circular, **12**, 192–195

Aperture, circular, rectangular guide, **10,** 194
  coupling, **16,** 160
    concentric coaxial guides, **10,** 377–378
    contiguous rectangular guides, *E*-plane, **10,** 375–376
      H-plane, **10,** 379–380
  efficiency, **12,** 178
  equivalent circuit, two, **8,** 174
  far-zone region, **12,** 172
  -field distributions, moments of, **12,** 184
    separable, **12,** 182
  -field method for reflectors, **12,** 158–160
  gain, maximum, **12,** 177, 178
  gain function, **12,** 162
  near-zone region, **12,** 170
  rectangular, in rectangular guide, **10,** 193
    uniformly illuminated, **12,** 180–182
  relations, optimum angular, **12,** 424
  treatment of radiation, from horns, **12,** 357
    from waveguides, **12,** 334–336
Apollonia, **4,** 32
Apparatus design, check list, **21,** 688–689
  heat-dissipation problems, **21,** 674
  minimum weight, **21,** 680
  specifications, **21,** 668
  subassembly, **21,** 701–704
Applegate diagram, **7,** 204, 272–273, 395
Approach, final, control in, **2,** 306–310
  instrument, standard, **2,** 291
  system, **2,** 227–232
    beacon (*see* BABS)
    GCA (*see* GCA)
A-and-R-scope (*see* A/R-scope)
A/R scope, **1,** 166; **20,** 76, 89, 231–238; **21,** 617–626; **22,** 17, 275–288
Arc power (*see* TR tube)
Arc-sine sums, **10,** 415–420
Arc-suppressing circuits for relays, **17,** 489
Arc-width control, beacon, **3,** 71
Arithmetic (circuit) operations, **21,** 32–63
Arma resolver, **20,** 418, 438
Armor for r-f cable, **17,** 23
ARO (automatic range only) radar, **20,** 275, 317, 342–348
  electrical system, **20,** 342–348
  Mark I, **20,** 342
ARO (automatic range only) radar, Mark II, **20,** 342, 345
  Midget, **20,** 342
  range system, **20,** 342
ARP (autofocus radar projector), **2,** 340
Array, binomial, **12,** 269
  broadband-normal-firing, **12,** 331–333
  broadside, **12,** 318–333; **26,** 186
    beacon, **26,** 162
    binomial illumination, **12,** 269
    gabled illumination, **12,** 269
    gain, **12,** 271–274
    maximum gain conditions, **12,** 270, 271
    resonant, **12,** 321–327
  corrugated coaxial line, **1,** 303
  designs, nonresonant, **12,** 328–333
  dipole, **26,** 186
  element, longitudinally polarized, **12,** 302, 309, 312
    slot-fed dipole as, **12,** 284–286
    slots as, **12,** 291–301
    streamlined, longitudinally polarized, **12,** 312
      transversely polarized, **12,** 310, 311
    tridipole radiator as, **12,** 304, 305
    waveguide radiators as, **12,** 301–303, 329
  end fire, **26,** 161
    design, **12,** 316–318
    gain, **12,** 277–278
  factor, **12,** 260
  free space, capacitive posts, **10,** 285–286
    capacitive strips, **10,** 280–284
    inductive posts, **10,** 286–289
    inductive strips, **10,** 284–285
  horn, **12,** 319
  linear, **3,** 130; **12,** 312–318; **26,** 83, 161
    pattern synthesis by, **12,** 279–284
  phase-reversal techniques, **12,** 321
  polynomial associated with, **12,** 261–264
  polyrod radiator, **1,** 303
  semi-infinite plane, *E*-plane, **10,** 289–292
    H-plane, **10,** 195, 292–295
  Tchebyscheff, **12,** 282–284
  uniform, **12,** 264–267
  uniformly illuminated, **12,** 267–269
ASB, homing radar, **1,** 197

A-scope, **1,** 164; **2,** 30; **14,** 417; **20,** 215; **22,** 17
design, **1,** 524–528
display, **22,** 26
focus, **24,** 211–222
presentation, **2,** 31
in British CMH system, **20,** 238–243
Aspect function, target, **1,** 88
Assembly of random scatterers, **13,** 551, 554
average echo, **13,** 589–591, 699–700
coherence of scattering, **13,** 601, 699–706
frequency sensitivity of echo, **13,** 529
theory of fluctuation, **13,** 553
Astable circuit as waveform generator, **19,** 162
Astable multivibrator (*see* Multivibrator)
ASV Mark II, **1,** 196
A-sweep, **22,** 17
Asymptotic expansion of Airy integral, **13,** 150
Asymptotic representations of solution of wave equation, **13,** 70, 75–77, 92–95, 98, 101, 105, 110
A timer, Loran, **4,** 199
Atmosphere, pressure, and temperature vs. altitude, table, **26,** 163
Atmospheric absorption (*see* Absorption, radio-wave)
Atmospheric inhomogeneities, caused by echo fluctuations, **13,** 531–535
meteorological evidence, **13,** 267–271, 533, 595, 603
producing radar echo, **13,** 594, 600–604, 700, 703
wavelength dependence of resulting transmission instability, **13,** 534
Atmospheric waves, **13,** 346
Atomic nucleus, **22,** 612
ATR, cavity, loaded-Q, **14,** 118
susceptance, **14,** 118
circuits, fixed-tuned, branching loss, **14,** 292
multiple, duplexers with, **14,** 308
wideband, double tuning, **14,** 317
switch, **1,** 7, 407–411; **16,** 10
3-cm wide-range, **14,** 132
coaxial, **14,** 132
duplexing loss, **14,** 279
equivalent circuits, **14,** 115
ATR, switch, at low power levels, **14,** 115–138
low-Q, **14,** 127–128
series mount, **14,** 117
shunt mount, **14,** 119
and TR, distance between, **14,** 288
tuning, **14,** 284
tube, **1,** 407; **23,** 7
1B35, **14,** 134, 135, 138, 240, 244, 248, 249
1B36, **14,** 134, 135, 137, 248, 249
1B37, **14,** 134, 135, 138, 248, 249
1B44, **14,** 134, 136, 248
1B52, **14,** 116, 134, 136, 248
1B53, **14,** 134, 248
1B56, **14,** 134, 248
1B57, **14,** 134, 248
branching loss, **14,** 277, 292, 322, 427
fixed-tuned, **14,** 134
impedance measurements, **14,** 397
life, **14,** 142
low-Q, equivalent circuits, **14,** 398
high-power characteristics, **14,** 248
production testing, **14,** 402
reversible mount, **14,** 402
recovery-time measurements, **14,** 423
Attention interval, operator, **24,** 233
Attenuation, atmospheric (*see* Absorption, radio-wave)
by atmospheric gases (*see* Absorption, radio-wave)
band, microwave filter, **9,** 557
Tchebyscheff behavior in, **9,** 593–597
cable, table, **11,** 701
calibration with absolute power measurement, **11,** 838–841
coaxial line, **9,** 25
constant (*see also* Absorption, coefficient, radio-wave) **8,** 18; **11,** 3, 682, 686
circular waveguides, E-modes, **10,** 67
clouds or fog, **13,** 24, 672–673, 677, 682
coaxial waveguides, **10,** 73–79
conical waveguides, dominant E-mode, **10,** 99
due to losses in metallic guide walls, **10,** 24
E-mode in arbitrary uniform guide with dissipative metallic walls, **10,** 24

Attenuation, constant, for ice and snow, **13**, 687–688
measurement, **11**, 822
parallel plate guide, **10**, 64
plane waves in free space, **10**, 87
rain, anomalous values, at 1.25 cm, **13**, 691–692
raindrops, **13**, 678–685
waveguide, **10**, 18
rectangular, **10**, 57, 60, 61
cross-, **16**, 194–195, 284
definitions, **11**, 679–682
dielectric, **9**, 27, 50
direct-coupling, through 721A TR cavities, **14**, 57
TR tube, **14**, 13, 24, 55
dissipative, **11**, 681
flexible cables, **9**, 245–247
frequency sensitivity, **11**, 683
function, **9**, 555; **13**, 122, 126, 161, 168–174
as function of wavelength in coaxial-line attenuators, **11**, 764, 766
at harmonic frequencies, TR switch, **14**, 412
in line, change in standing-wave voltage ratio resulting from, **11**, 702
low-level signal caused by keep-alive discharge, **14**, 209
measurement, **11**, 804–853
with Ballantine voltmeter, **11**, 806
with i-f standard attenuator, **11**, 812
sources of error, **11**, 824–832
by standing waves, **11**, 816–821
substitution method, **11**, 808–816
with thermistor bridge, **11**, 813
with two-slotted sections, **11**, 805
metals and alloys, **9**, 120
within meteorological echoes, **13**, 613–615
microwave cable, **11**, 744
of microwaves by atmosphere (*see also* Absorption, radio-wave), **1**, 58
-phase analysis, servo, **25**, 163
and phase diagrams, construction and interpretation, **25**, 171
phase relationships, servo, **25**, 169–196
phase shifter, **19**, 496
plated conductors, **9**, 128
reflective, **11**, 681
in sheets, **26**, 291
Attenuation, standard cables, **9**, 268
standards, calibration, **11**, 832–838
secondary, calibration, **11**, 841–848
very small, measurement of, **11**, 821–824
and voltage standing-wave-ratio chart, **11**, 820
waveguide, **1**, 405
measurement, **11**, 804–853
Attenuator, **4**, 68, 207, 212, 213, 229, 258, 259, 265, 269, 271, 272; **18**, 93, 314; **23**, 324, 325, 329
1-cm, 3-cm, 10-cm band, **11**, 925
24,000 Mc/sec, **11**, 716–718
calibration by noise generator, **18**, 713
coaxial, cable as, **11**, 743–745, 762
carbon-coated, **11**, 745–747
variable metalized-glass, **11**, 769–774
cutoff, **11**, 685–719; **16**, 196, 374
3-cm-band TE_{11}-mode, **11**, 715
equivalent circuit, **11**, 700
input impedance, **11**, 696–700
mode purity, **11**, 687–689
principles, **11**, 685–687
with TM_{01}-mode, **11**, 719
design considerations, **11**, 682–685
dissipative, **11**, 720
double-vane, **11**, 785
fixed, adjustment, **11**, 850
TMX-81 PB, **11**, 782
flap, **11**, 748
helical-spring r-f contacts, **11**, 714
impedance matching in, **11**, 700–707
inserts, evaporation chamber, **11**, 760
loop-coupled TE_{11}-mode, **11**, 689
metalized-glass, precision, **11**, 751–799
micrometer, **15**, 275
microwave, **11**, 679–803
Model O, **11**, 709
Model S, **11**, 710
Model T, **11**, 709
pads (*see* Pads)
power dividers, **11**, 799–803
production calibration, **11**, 848–853
pulsed, as computer, **21**, 50
for reflection reduction, **11**, 573
resistive, **11**, 720–799
general laboratory, **11**, 743–751
separation of undesirable modes, **11**, 689–693
sliding-vane, **14**, 383

Attenuator, standard, coaxial, **11**, 763
    waveguide metalized glass, **11**, 836
  step, **22**, 157
    compensated, **18**, 94
  switch, **14**, 349
  TMX-81 PB, **11**, 782
  TPK 35/PB/40, **11**, 786
  TPS-15, **11**, 707
  vane, **11**, 749; **15**, 285
  variable, ⅝-in.-line, **11**, 770
    ⅞-in.-line, **11**, 771
    1-cm-band, **11**, 786
    calibration, for signal generators, **11**, 851
    cam drive, **11**, 784
    coaxial-line, matching, **11**, 772
  waveguide, **23**, 282
    3000 Mc/sec, **11**, 707–715
    9000 Mc/sec, **11**, 715
    fixed, **11**, 747
    variable, **11**, 748–751
      construction, **11**, 784–790
      performance, **11**, 790–799
Audio-frequency spectrometers, **13**, 562, 576
Aural detection (*see* Detection, aural)
Aural methods of interpretation, **3**, 226
Aural null, DF, **4**, 3
Aural perception, **24**, 23
Auroral zone propagation, **4**, 146
Austin-Cohen formula, **13**, 2, 3
Autocorrelation function, **25**, 273
Automatic flight control, C-1, **21**, 397
Automatic frequency control (*see* AFC)
Automatic gain stabilization (AGS) circuits, **23**, 565–567
Automatic plotting boards, Loran, **4**, 105
Automatic shutoff circuits, **22**, 139–144, 440, 450, 462
Automatic synchronizer, Loran, **4**, 67
Automatic target selection, **20**, 325–337
Automatic volume control, Loran, **4**, 217, 240
Autosyn, **1**, 487; **20**, 394; **21**, 365; **22**, 185; **26**, 9, 167, 234
Autotransformer, **21**, 48
  circuits, **23**, 103
  variable, **21**, 521
Average-current meter, **5**, 701–706
Axis, pedestal, cross-elevation, **26**, 115
    cross-level, **26**, 111
Axis, pedestal, cross-traverse, **26**, 114
    level, **26**, 111
    train, **26**, 105
Ayrton-Perry winding inductance, **17**, 86
Azimuth, accuracy, **2**, 12
  chopping, **3**, 90
  discrimination, **3**, 466
  -elevation indication, **22**, 22
  mark circuit, **21**, 182, 189
  markers, **2**, 148
  -pulse removal, **1**, 695
  ratio, **12**, 304
  resolution, **2**, 12
    and beamwidth of antenna, **2**, 14
  stabilization, **2**, 149
    methods of, **2**, 159
    requirements, **2**, 158
    roll, **2**, 160
  sweep, reverse, **22**, 393
  torque tube, **26**, 76

B

Babinet's principle, **8**, 28–30, 256; **12**, 167
BABS (beacon approach system), **2**, 232–237
  airborne reception and indication, **2**, 234
  ground responder beacons, **2**, 233
  interrogation, **2**, 233
  L-scope localizer presentation, **2**, 234
  system, American 200-Mc, L-scope presentation, **2**, 235
    British, indicator, **2**, 235
Back-bias (AGC), **1**, 459; **23**, 249
Back-of-the-dish system, **1**, 419
Back-lobe interference, **12**, 428, 435
Back-resistance meter, **16**, 100, 113
Back-scattering, coefficient, **12**, 468
  cross section, **13**, 33
Backlash, antenna mechanism, **26**, 138
Backswing voltage pulser, **5**, 43, 45, 50, 79, 88, 146, 154, 261, 509, 551, 569
Bag-molding technique, radome, **26**, 372, 375
Bakelite, dielectric constants, **26**, 409
  loss tangents, **26**, 409
Ballistic computer, **20**, 142
  AN/APA-30, **20**, 247
Ballistic function in vacuum, mechanization, **27**, 286–299

Balsa wood for radomes, **26**, 379
Bandpass, filter, electronic, **18**, 384
  maximally flat, **18**, 279
  TR tubes (*see also* TR tubes), **14**, 67–114
Bandwidth, 3-db, amplifiers and receivers, **23**, 81
  antenna, **4**, 307, 317
  cascaded stages, **1**, 446–448
  considerations, **23**, 157
  dielectric lens, **12**, 398
    radar receiver, **1**, 444
  large fractional, double-tuned circuits, **23**, 172
  metal-plate lens, **12**, 408–410
  microwave circuit, **9**, 96–99
  noise, **23**, 81
  receiver (*see* Receiver bandwidth)
  requirements preceding limiter, **23**, 221
  small fractional, double-tuned circuits, **23**, 170
  space-charge tube, **7**, 151
  switching with inverse-feedback pairs, **18**, 258
  transitional coupling, **23**, 108
  video, **23**, 213
Bank angle, **26**, 164
Bar linkage (computer) (*see also* Linkage; Three-bar linkage), **27**, 5, 27–42
  adder, **27**, 37
    accuracy, **27**, 41
    error, **27**, 37, 41, 42
      structural, **27**, 41
  advantages, **27**, 32–33
  backlash, **27**, 21, 27, 33
  vs. camoids, **27**, 23
  characteristics, **27**, 32–33
  compared with cams, **27**, 33
  compared with integrators, **27**, 27
  complex, **27**, 40–42
  concepts, **27**, 43–57
  definition, **27**, 27
  design, **27**, 31–32
  dimensional constants, **27**, 31–32
  disadvantages, **27**, 33
  divider, **27**, 40
  efficiency, **27**, 28
  error, **27**, 27, 28, 31–33, 37, 41, **42**
  frictional losses, **27**, 28, 32
  history, **27**, 28–31
  inertia, **27**, 33
Bar linkage (computer), mechanical features, **27**, 28
  multipliers, **27**, 37–40, 250–283
    accuracy, **27**, 39
    error, **27**, 37–40
  with one degree of freedom, **27**, 34–36
  residual error, **27**, 32
  straight-line motion by, **27**, 29
  with two degrees of freedom, **27**, 37–40, 223–249
    as substitute for three-dimensional cam, **27**, 37
Barrel field, CRT, **22**, 313
Barrel stave, reflector, **26**, 157
Barretter, **11**, 81–83, 156–171
  -amplifier combinations, **11**, 171–175
  demodulation, **11**, 166
  direct-reading bridges for, **11**, 169–171
  mount, **11**, 175–179
  theory of operation, **11**, 161–169
Barrier, atmospheric, **13**, 76
    nonstandard layer as, **13**, 168
  layer, semiconductor, capacitance, (*see also* Semiconductor), **15**, 75–77
    formation and structure, **15**, 70–77
Bartlett's bisection network theorem, **9**, 556
Baseline, Loran, **13**, 53, 56, 59, 62, 70, 71, 86, 96, 99, 102
Batteries, **17**, 399–401
  life, dry, vs. current, **17**, 400
  as regulator reference element, **21**, 494
Beacon, **1**, 27, 243–270; **2**, 36–43, 257; **3**, 1–7; **4**, 7; **16**, 23, 190, 223, 231, 287, 295; **20**, 33
  3-cm, **3**, 12, 24
  10-cm, **3**, 12
  AFC (*see* AFC, beacon)
  air-to-air systems, **3**, 22
  air-to-surface systems, **3**, 20
  airborne, **1**, 246; **2**, 256–258; **3**, 12–14, 408–419
    frequency choice, **3**, 70
    installation, **3**, 455–458
    maintenance, **3**, 456–458
    maximum and minimum range, **2**, 257
    operation, **3**, 456–458
  AN/APN-3, **3**, 426
  AN/APN-19, **3**, 77, 359, 408–419
    power supply, **3**, 330

Beacon, AN/APS-10, **3**, 398–400
beacon-radar presentation, **3**, 381
AN/CPN-2, **3**, 426
AN/CPN-6, **3**, 400
power supply, **3**, 324–327
AN/CPN-8, monitor, **3**, 332
antenna (*see* Antenna, beacon)
AN/UPN-1, **3**, 358
AN/UPN-2, power supply, **3**, 327
AN/UPN-3, **3**, 405
AN/UPN-4, **3**, 405
power supply, **3**, 328
application, **2**, 37
approach system (*see* BABS)
arc-width control, **3**, 71
art, first principles, **3**, 28
azimuth width of reply, **1**, 256
block diagram, **3**, 6-7
CCB, **3**, 77
characteristics, **3**, 26, 29
code distinguishability, **3**, 91
coding, **1**, 263–265; **3**, 83–103
interrogation, **1**, 263–264
range, **2**, 37; **3**, 91–93
reply, **3**, 89–97, 204–220
reply-frequency, **3**, 74
response, **3**, 204–220
comparison with other navigational aids, **3**, 24–26
coverage, mapping, **3**, 439
decoder, **3**, 6
delay, **3**, 101, 152, 344, 379
density, **3**, 105
design, **3**, 123–361
distinguishable, number of, **3**, 92
drift station, **3**, 429
duplexer, **3**, 139–144
elements, **12**, 303–309
equipment, **2**, 39
filament supplies, **3**, 321
fixed-channel operation, **3**, 76–79
fixed ground, **1**, 248
frequency assignments, **3**, 73–82
frequency choice, **1**, 260; **3**, 29, 63–73
functions, **3**, 18–20
future developments, **2**, 40
ground, cost, **2**, 189
frequency choice, **3**, 69
heavy, **3**, 437–452
lightweight, **3**, 10–12
site, choice, **3**, 437–442
Beacon, ground-based, special applications, **2**, 121
ground-to-ground systems, **3**, 23
with ground radar, **1**, 609
housing, **3**, 442; **26**, 457, 460
how used, **3**, 17–24
identification, **3**, 19, 30
installation, **3**, 437–472
interaction of components, **3**, 343
interrogation, **1**, 252–264; **2**, 361
coding (*see also* Coding), **1**, 263; **3**, 83–89, 180–203
frequency, **1**, 263
multiple-pulse, **1**, 263; **3**, 367
pulse length, **1**, 263
slow, **3**, 89
two-frequency, **1**, 263; **3**, 367
side-lobe, **1**, 257
interrogator (*see also* Interrogator-responsor), **3**, 4, 6, 386
lightweight, **3**, 405–408
maintenance, **3**, 437–472
manual tuning aid, **16**, 342
marine radar, **2**, 322–324
mixers, **16**, 190
mobile, installation, maintenance, operation, **3**, 458–472
modulator, **3**, 237–255
monitors, **3**, 332, 339–341, 457
mutual triggering interference, **3**, 116
navigation, **2**, 117–121
omnidirectional, **2**, 51; **20**, 36
British, **20**, 400, 410–416
operation, **3**, 437–472
radar design for, **3**, 365–384
operational check, **3**, 445
overinterrogation, **1**, 265
control, **3**, 107
overload protection, **3**, 322
overwater systems, **3**, 63
packaging, **3**, 357–361
pressurized, **3**, 359
splash-proof, **3**, 359
waterproof, **3**, 359
performance, charts, **3**, 257–259
check, **3**, 446–452
testing, **3**, 332–341
personnel requirements, **3**, 456
phase shifter, **3**, 148
portable, **1**, 249; **3**, 458–472
power-control circuits, **3**, 322–332

Beacon, power-saving circuits, **3**, 324
protection against interference, **3**, 352–356
-radar presentation, simultaneous, PPI, **3**, 381
radome designs (*see also* Radome), **12**, 540
range, accuracy, **3**, 379
calculations, **3**, 59–62
coding, **3**, 91–93
considerations, **3**, 27–41
equation, **3**, 31–33, 38–41, 66
error, **3**, 472
-only systems, **3**, 63
performance, **1**, 254
requirements, **3**, 30–41
rate station, **3**, 429
receiver (*see* Receiver, beacon)
relay, **3**, 22
reply coding, **1**, 264
gap, range, and width coding, **1**, 264
resolving time, **3**, 86
responder, **3**, 6
response, for heavy traffic, **3**, 110
for light traffic, **3**, 109
link, **3**, 5
saturation, **3**, 106
loss, **3**, 35
omnidirectional, **3**, 64–66
probability of, **3**, 108–114
spurious, **3**, 118
r-f channeling, **3**, 160
sensitivity, **3**, 150, 174
separate-band, **2**, 42
ship-to-shore systems, **3**, 23
shipborne, **3**, 59
frequency choice, **3**, 69
installation and maintenance, **3**, 452–455
shore, **3**, 19
signals, distinguishability from radar signals, **3**, 93
unsynchronized, interference, **3**, 118
site choice, **3**, 437–442
Sonne, **4**, 4
special provisions for, in radar, **2**, 40
statistical considerations, **1**, 265–270
stealing, **3**, 105, 420
stretch-amplitude compensation, **3**, 194
suppression of unwanted triggering, **3**, 354–356
Beacon, swept-frequency, **1**, 262
synthesis, **3**, 342–361
systems, **2**, 42
airborne, used with ground radar, **3**, 408–419
crossband, choice of frequency, **3**, 70–73
ground, used with airborne radar for air navigation, **3**, 398–408
microwave bands for, **3**, 76
navigation, precision, Shoran, **3**, 426–433
shore, used with ship interrogator-responsor, **3**, 419–426
surface, **3**, 464–472
surface-to-surface, **3**, 23
sweeping-frequency, **3**, 73
types, **3**, 20–24
typical, **3**, 398–433
voice-modulation, **3**, 232–236
test equipment, **3**, 332–339, 447
traffic capacity, **1**, 265–268; **3**, 104, 221, 403
interrogation and response links, **3**, 104, 106
traffic considerations, **3**, 104–119
transmitter, **2**, 36; **3**, 256–312
dummy load, **3**, 148
frequency, **2**, 40
triode (*see* Oscillator, transmitting triode)
triggering by noise, **3**, 348, 352–354
tuner, **16**, 225, 234
unsynchronized replies, **1**, 268
uses, **3**, 1–26
for communication, **1**, 244, 264–265
vibration, **3**, 360
Bead, dielectric, **11**, 11
Teflon, **9**, 257
half-wavelength, **9**, 162
supports, **9**, 155–170
thin, **9**, 158
three-section, **9**, 165
undercut, **9**, 163
Beam, angular distortion, **26**, 252
beavertail, **12**, 377, 478
broadside, **12**, 267–274
deviation factor, **12**, 488
end-fire, **12**, 274–278
fan, **1**, 22, 274–277; **26**, 30

Beam, fanned, **12**, 7
applications, **12**, 450
flexure of, **26**, 383
gap, klystron (*see* Klystron)
low-altitude, **12**, 484
omnidirectional, **12**, 6
pencil, **12**, 7
sector-shaped, **12**, 475
shape, choice for radar, **1**, 600–604
variable, **12**, 508–509
shaped, applications, **12**, 465–468
cut paraboloid for, **12**, 477–483, 487–491
cylindrical reflectors for, **12**, 494–497
requirements, **12**, 465–468
shaping by obstacles in horn and waveguide apertures, **12**, 380–383
toroidal, **12**, 6
Beamwidth, affecting sea echo, **13**, 483–485, 491
vs. aperture illumination, **12**, 179, 183–187, 195
Bearing measurement, **2**, 9
Bearing transmission circuit for ship navigation radar, **2**, 34
Bearings, generator and motor, **17**, 367–370, 412
Bellows, flexible, **9**, 288–291
Belt cam, **27**, 20–21
Belt differential, **27**, 10
Beryllium as addition agent, semiconductor, **15**, 67
Beryllium copper, sliding contacts, **9**, 119
Bessel functions, **10**, 32
half-order, **10**, 52
*m*th-order, **10**, 66
roots, **8**, 41; **11**, 299
table, **8**, 247
Bethe-hole coupler, **8**, 313; **11**, 858–866
Betting curve, **24**, 150, 182
calculation, **24**, 171
width, **24**, 173
Bevel-gear differential, **27**, 6–7
B-H loop, d-c, **5**, 612
idealized, **5**, 633
and actual pulse, **5**, 627
pulse, **5**, 612, 641, 643
B-H oscillograms, for a-c charging transformers, **5**, 403, 405, 406
for d-c charging reactor, **5**, 369, 370
Bias, cathode, amplifier, **18**, 353
cutoff, 304TH, **5**, 100
5D21, **5**, 100
fixed, **18**, 358
screen, **18**, 359
voltage, and transconductance, correlation between, **18**, 290
Biased diode, **5**, 32, 231, 527
Biconical horn, **12**, 9
Bifurcation, coaxial-line, **10**, 369–372
E-plane, **10**, 112, 160
rectangular guides, *E*-plane, **10**, 353–355, 380–383
H-plane, **10**, 172, 302–307, 362, 383–386
Bilinear modified-index profile, **13**, 140–174
Bilinear *N*-profiles, examples, **13**, 143
Bipolar charts, **12**, 33–36
Birds, echoes from, **13**, 595
Bisection theorem, **8**, 110; **10**, 128
Bistable, as waveform generator, **19**, 162
Bistable multivibrator (*see* Multivibrator)
Black-body radiation by clouds and earth, **13**, 254
Blackout effects, amplifier, **18**, 329, 330; **23**, 187
Blanking gate, pulse coder, **3**, 206
Blind-landing system, bolometer, **2**, 228
Blind speed, **24**, 334
MTI, **1**, 650–654
Blink, blinker, blinking (*see* Loran)
Blister, **12**, 512
Block-diagram design, computer, **21**, 12, 177
Blocking condenser, lighthouse-tube, **7**, 164
Blocking oscillator (*see also* Oscillator), driver, **5**, 124–132
transformer, design, **5**, 543–547
Blooming, CRT, **22**, 35
Blow-in, waveguide window, **6**, 489
Blower engineering, **21**, 677
Blumlein pulser circuit, **5**, 465–468
Bolometer, **2**, 228; **11**, 81–83; **12**, 549, 555, 601, 604; **16**, 19; **18**, 715–717; **23**, 334
a-f response, **11**, 100–103
bridges, temperature compensation, **11**, 103–105

Bolometer, metalized-glass, **11**, 184–187
Boltzmann's constant, **18**, 503, 517, 620, 695
Bombardment, corpuscular, propagation, **4**, 144
meteoric, propagation, **4**, 133
Bombing systems, **3**, 14–20
Bootstrap, cathode-follower linear-sweep generator, **19**, 258
circuit, **19**, 35
double integrator, **20**, 386
driver (*see also* Driver, bootstrap), **5**, 120–124, 138
integrators, **19**, 662; **20**, 302, 303
linear-sawtooth generator, **20**, 151, 358
self-gating, **20**, 347
linear-sweep generator, **19**, 267–278
modulator, **4**, 281
self-gating linear-sawtooth generator, **20**, 347
time-modulation circuit, **20**, 128
triangle generator, **20**, 125–131
Boron as addition agent, semiconductor, **15**, 67
for use as crystal rectifiers, **15**, 7
Boundaries, land-water, **2**, 90
Boundary conditions, cathode, magnetron, **6**, 257
at earth's surface, **13**, 58, 62–64, 111–112
for meteorological quantities, **13**, 201, 255
simplified, **13**, 140
general formulation, radiation theory, **12**, 66–68
at infinity, **12**, 84–86; **13**, 71, 76
at media boundary, **8**, 12
for scattering problems, **12**, 130–132
statistical nature, **13**, 430, 527
for targets, **13**, 445, 448, 454, 456, 458, 462, 476
for trapped modes, **13**, 78
Boundary error in correlation function, **13**, 570–572
Boundary friction, **13**, 221
Boundary-value problem, electromagnetic-, **10**, 101
Box horns, **12**, 377–380
Boxcars, **24**, 257
average value, **24**, 258
generator, **24**, 28
Boxcars, peak value, **24**, 258
spectrum, theoretical derivation, **24**, 273–278
Brakes, magnetic, on motors, **17**, 390–391
Branch, in coaxial lines, **8**, 193–195
cuts, **13**, 66, 109
network, **8**, 85
points, **8**, 85; **13**, 66, 109
servo, **25**, 135
Branching loss (ATR), **14**, 322, 427
with available ATR tubes, **14**, 322
factor, **14**, 277
for fixed-tuned ATR circuits, **14**, 292
for general T-junction, **14**, 323
Brazing, alloys, **6**, 664–667
magnetron, **6**, 662–670
precision, **6**, 670
problems, **6**, 670
Breakdown, field strength and pressure, relation between, **9**, 237
power, dependence, on pulse width, **9**, 235
on repetition rate, **9**, 236
effect of radioactive cobalt, **9**, 232
of TM_{01}-transitions, **9**, 405
voltage (*see* Voltage breakdown)
Brewster angle, **12**, 402; **13**, 399; **26**, 289, 296
Bridge (*see also* specific types of bridges), admittance, **16**, 80, 367–372
amplification (voltage regulator), **21**, 532
bolometer, **11**, 103–105
circuit, **11**, 84–89; **21**, 25, 35, 124
microwave, **10**, 128
operation of thermistor in, **11**, 84, 97–100, 169–171: **14**, 405
crystal oscillator, **4**, 239
direct-reading, **11**, 84, 169–171
impedance (*see* Impedance, bridge)
log, **21**, 124
methods for arithmetic operations, **21**, 56
oscillators, **19**, 115–123
sensitivity, **11**, 86
speed-feedback, servo, **25**, 214
T, symmetrical, **25**, 123
TBX-1BR, **11**, 446, 552
thermistor, **11**, 84, 97–100, 169–171; **14**, 405
self-balancing, **11**, 127–130

Bridge, transconductance, **21**, 532, 570
W-, **11**, 118–123
Wien, **18**, 384, 386; **19**, 116; **20**, 70, 139
X-, **11**, 123–127
Bridged-T networks, **18**, 384, 385; **19**, 116
Bright band from snow echoes, **13**, 620
Brillouin steady state, **6**, 245
British cavity magnetron, **6**, 8
Broadband matching, with coaxial stubs, **9**, 332–335
with waveguide iris, **9**, 322–331
Broadband stub support, **8**, 194
Broadband T-stub, **14**, 266
Broadbanding, microwave apparatus, **8**, 203–206
Broken-line characteristic, nonlinear element, **19**, 41
Brownian movement, **18**, 497
Brushes, **17**, 365–367, 414, 424–425
antenna mount, **26**, 78
high-altitude, for rotating machines, **1**, 561
Brute-force circuit, video amplifier, **23**, 523
B-scan, **22**, 384
distortion, **22**, 385
B-scope, **1**, 171; **2**, 35; **3**, 37; **22**, 227
design, **1**, 528–532
display, **22**, 26
electrostatic, **1**, 528
magnetic, **1**, 528
systems using J-scope with, **20**, 243–246
typical, **22**, 386
B timer, Loran, **4**, 199, 201
Buffer, Loran transmitter, **4**, 296
Buffering, lin-log amplifier, **23**, 587
Buildup, magnetron starting, **6**, 357, 372
Q for, **6**, 365, 374
time τ_b, filter, **25**, 142
Bullet, coaxial-line, **9**, 151
Bunching, **7**, 11, 35, 201–247, 449–452; **11**, 24, 25
angle, **7**, 221
effective, **7**, 317
cascade, **7**, 229, 240–245, 393
harmonic, **7**, 281
influence of reflector field, **7**, 373–383
optimum, **7**, 240, 261–263, 270, 287–289, 290–291, 294
Bunching, parameter, **7**, 205, 215–224, 228, 243, 292, 313, 314, 320
equivalent, **7**, 277
X, **7**, 241, 304
X', equivalent, **7**, 273
and space charge, **7**, 380–382
time, equivalent, **7**, 374, 375–382
Burnout, crystal (*see* Crystal burnout)
Bushings (*see* Transformers, bushings)
Butadiene-acrylonitrile copolymer, **26**, 379
Butterfly circuit, **7**, 174
Buttons and dents, capacitive, waveguide, **9**, 215–217

C

Cable, attenuation, table, **11**, 701
beaded, **9**, 243
coaxial (*see* Coaxial cable; Line)
flexible, attenuation, **9**, 245–247
high-impedance, **19**, 748
high-power, **9**, 252
impedance, characteristic, **5**, 670
matching, **5**, 164, 671, 677
jacketing materials, **9**, 247
and leads, introduction into receivers, **23**, 256
lossy, **14**, 378
low-power, **9**, 248–252
connectors, **9**, 256–259
microwave, **11**, 9
properties and delay lines, **5**, 689
r-f, **17**, 15–32
air-spaced dielectric in, **17**, 22
armor for, **17**, 23
metal-braid, **17**, 22
Army-Navy standard, list, **9**, 269
attenuation, **17**, 17–19, 25–27
capacitance, **17**, 17–20, 24
center conductor, **17**, 16–21
connectors, **9**, 270
high-attenuation, **17**, 21, 26
high-impedance, **17**, 27–32
delay in, **17**, 27–32
design methods, **17**, 27–31
RG-65/U, **17**, 31–32
impedance, **17**, 17–19, 24–25, 28–31
jacket, **17**, 23
primary insulation, **17**, 21–22

Cable, r-f, resistance, to extreme temperatures, **17,** 23–24
to moisture and solvents, **17,** 24
standard, characteristics, **17,** 17–19, 24–27
voltage rating, **17,** 17–19, 27
solid dielectric, **9,** 243
standard, attenuation, **9,** 268
Cabling to eliminate noise, **3,** 351
Calculus, as circuit operation, **21,** 64–89
Heaviside, **21,** 229
Calibration markers, Loran, **4,** 205
Calibrator, Model III, **20,** 87–89
range (*see* Range calibrator)
range circuit, **21,** 617
Calorimeter for measuring loss, **11,** 582
Camoids, accuracy, **27,** 23
vs. bar linkages, **27,** 23
friction, **27,** 23
precision, **27,** 23
Campbell's loaded-line formulas, **12,** 313–316
Cams, **21,** 55, 59; **27,** 2, 4, 19–23
belt, **27,** 20–21
compensated, **27,** 21–23
compared with bar linkages, **27,** 33, 37
cylindrical, **27,** 20
definition, **27,** 19
linkage, **27,** 34
plane, **27,** 19
backlash, **27,** 19
self-locking, **27,** 19
space, **21,** 59
squaring, **27,** 21–23
three-dimensional, **27,** 23, 37
Capacitance (*see also* Capacitor; Capacity; Condensers), of barrier, **15,** 75–77
crystal, **16,** 53, 92
distributed, transformer winding, **5,** 507, 516–522, 537; **17,** 124, 141–145
fringing, **6,** 464
i-f, **16,** 129
interwinding, in transformers, **17,** 124–125, 144
network, **8,** 84
strip, effect of, in electromagnetic delay lines, **17,** 198–203
variable, as transducers, **19,** 428
voltage divider, **5,** 673–675
X-cut crystal, **17,** 220
Capacitive gap, coaxial line termination, **10,** 178
Capacitive tuning slug, **14,** 43
Capacitor (*see also* Condensers), phase-shift, Loran, **4,** 199, 203, 207, 219
synchro, **17,** 314, 325–328
Capacity, coupling, transmission-line, **9,** 100–114
equivalent, magnetron anode, **6,** 108
variability, effect on amplifiers, **18,** 292–295
Carbon-pile, centrifugal governor, **17,** 430
inverter regulator, **21,** 545
voltage regulator, **1,** 566–570; **3,** 320; **17,** 430, 446–451; **21,** 522, 545
Carbon resistors (*see* Resistors, composition)
Carrier, content, constant-output circuit, **19,** 510
switch demodulator, **19,** 520
demodulation, **22,** 128
frequency-modulated, **19,** 716
high-frequency, **19,** 461
sinusoidal, use of synchros with, **19,** 444
spectrum, **24,** 5, 14
Cartridge, crystal, **15,** 15–20
assembly and adjustment, **15,** 323–328
ceramic, **15,** 16, 17, 323–326
coaxial, **15,** 17, 326–328
germanium rectifier, **15,** 369–372
parts, **15,** 322
pigtail, **15,** 18
resistor, **15,** 287
standard-impedance, **15,** 270
Cascode amplifier, **18,** 440
Casting, centrifugal, **9,** 122
die, **9,** 122
lost-wax method, **9,** 122
precision, **9,** 122
Cat-mouse courses, **3,** 15
Cat station, **3,** 15
Catalyst wash, **26,** 382
Cathode, -anode short circuit, magnetron, test for, **6,** 736
bias, **18,** 353
cathode-ray tube, **22,** 44, 58
degeneration, **18,** 401
drift, compensation, **19,** 333
emission, pulsed-tube, **7,** 191
emitting area, **22,** 51

Cathode, feedback, **18**, 336, 351
flicker effect, **18**, 588
follower (*see* Cathode follower)
-grid region, space-charge tube, **7**, 104
as input terminal, **18**, 441
interception of electrons, klystron, **7**, 396
-lens system, **22**, 44
loading, **22**, 51
magnetron, **6**, 11, 23, 378, 411, 503–539
back bombardment, **6**, 285
boundary conditions, **6**, 257
breakdown temperature, **6**, 529
construction, **6**, 685–687
-current density, **6**, 440
diameter, ratio to anode diameter, **6**, 105
emission phenomena, **6**, 503–519
end-mounted, **6**, 411, 530
end shields, **6**, 537
heat balance, **6**, 412, 519–537
helical-shape, **6**, 796
-lead loss, **6**, 728, 729
localized deterioration, **6**, 762
ohmic loss in, **6**, 524
overheated, **6**, 738
pulsed, thermal behavior, **6**, 520
radial-mounted, **6**, 411, 529
radiator, **6**, 781
radius, **6**, 440
secondary-emission, **6**, 411
size, **6**, 23
sparking, **6**, 413
steps, **6**, 758
temperature, characteristics for 2J42, **6**, 528
range, **6**, 412
thorium oxide, **6**, 534, 692
peaking, **18**, 90
pulsing, **3**, 289
-ray tubes (*see* Cathode-ray tubes)
resistor, **18**, 90
temperature, **18**, 419–421
unipotential, **18**, 421
virtual, **7**, 157
Cathode follower, **18**, 107, 348; **20**, 130; **21**, 531; **22**, 114–118, 359
d-c, **18**, 430
differential, **18**, 454
-diode switch, **22**, 365
driver, **5**, 121, 125
Cathode follower, as feedback amplifier, **23**, 91
input admittance, **25**, 83
input capacity, **22**, 116
input resistance, **22**, 116
operating conditions, **22**, 118
output voltage, **18**, 431
overshoot, **22**, 359
pentode, **18**, 436
probe, **21**, 586
radar receiver, **1**, 494
Cathode-ray tubes, **2**, 26; **18**, 410; **22**, 2–6, 39–92
acceleration, postdeflection, **22**, 65
accelerator electron gun, **22**, 60
as amplitude selector, **20**, 220
barrel field, **22**, 313
basing table, **22**, 727
beam, convergence, **22**, 53
current, grid-bias relations, **22**, 48
divergence, **22**, 52, 83
bias, cutoff, **22**, 82
grid, **22**, 48
blanking, **22**, 82, 159
blooming, **22**, 35
cathode loading, **22**, 51
central-electrode, radial-deflection type, 3DP1, **22**, 70
characteristics, table, **22**, 722–730
circuit techniques, **22**, 111–183
circular sweep, **21**, 579
contrast, filter, **22**, 561
gradient, **22**, 35, 648
liminal, **22**, 647
crossover, **22**, 46
current density, **22**, 53, 55
cutoff voltage, **22**, 722
dark-trace, **1**, 220
projection of, **22**, 578
deflection (*see also* Deflecting coils; Deflecting fields), characteristics, **22**, 66
defocusing, **22**, 54, 102, 312
efficiency, **22**, 306–308
electrostatic, **1**, 476; **22**, 3, 62–65
factor, **22**, 64, 309, 723
magnetic, **1**, 477; **22**, 3
-modulated, pulse amplifier for, **18**, 109
push-pull, **22**, 76
sensitivity, **22**, 64, 308, 723

Cathode-ray tubes, deflection, systems, **21,** 578
theory, **22,** 303–306
delay circuits, **22,** 262, 272, 279–282
development of, **21,** 577
dispersion, **22,** 35
displays, **19,** 387
demodulation by, **19,** 539–543
intensity-modulated, **24,** 238–252
projection, **1,** 219
electrostatic, **22,** 4, 57–77
focusing, **1,** 476; **22,** 44
tube mounts, **22,** 540
filters, **21,** 578; **22,** 560–564
flat-faced, pattern distortions, **22,** 338–342
focus coils (*see* Focus coils)
focus magnet (*see* Focus magnet)
grid, control or modulating, **22,** 59
drive, **22,** 49
skirt, **22,** 59
guns (*see* Electron gun)
high-intensity, **22,** 72
intensifier, **22,** 65
intensity-modulated, pulse amplifier for, **18,** 111; **19,** 717; **22,** 6, 246, 384; **24,** 238–252
ion spot, **22,** 44, 94
jump, **22,** 345–347
light output, **22,** 723
liminal contrast, **22,** 647
limiting apertures, **22,** 86
line-width, characteristic, **22,** 69
measurement, **22,** 723
splitting, **22,** 347–351
luminance, **22,** 659
characteristics, P7 components, **22,** 646
level, **22,** 609
luminescence, **22,** 609, 617
short-time, **22,** 648
magnetic, **22,** 77–92
fixed-coil mounts, **22,** 541–545
focusing, **1,** 476
operating conditions, **22,** 91
pattern distortion, **22,** 338–355
mean potential adjustment, **22,** 75
measurements, manual, **20,** 176–274
modulation characteristic, **22,** 723
mounts, **22,** 539, 540
multigun, **21,** 588; **22,** 71
Cathode-ray tubes, off-centering, **22,** 103, 429, 466, 483
coil, **22,** 429–431, 484
control, **22,** 444
mount for, **22,** 552
permanent-magnet, **22,** 412–419
optimum resolution, **22,** 606
overlays, **22,** 558–560
parameters, spot size affected by, **22,** 601–606
pattern rotation, **22,** 94, 344, 345
persistence, intermediate, **22,** 609, 653
phosphors, **22,** 609
photography, **21,** 578
-pip generator, **3,** 217
projection, **22,** 89, 576–589
indicator, **22,** 579–584
of televised display, **22,** 577
as radar indicator, **1,** 475–486
radial-deflection, **22,** 70
resolution, **22,** 34
screens, **1,** 479–483; **21,** 578; **22,** 4, 609
absorptance, **22,** 620
buildup, **22,** 6, 32
supernormal, **1,** 482; **22,** 34
cascade, **1,** 480; **22,** 5
characteristics, table, **22,** 728
dark-trace, **1,** 483; **22,** 6, 664–699
deexcitation, **22,** 638
long-persistence, **1,** 480; **22,** 609, 626
materials, **22,** 610; **24,** 230–232
multiple-layer, **22,** 610
P7, components, luminance characteristics, **22,** 646
filters, **22,** 562
persistent, **22,** 626, 653
short-persistence, **22,** 643, 609
single-layer, comparison to cascade, **22,** 655
special, properties, **22,** 658–664
sulfide, double-layer, **22,** 645–658
superproportionality, **22,** 625, 651
transmittance, **22,** 620–623
triple-component, **22,** 658
two-color, **22,** 661
wavelength, dominant, **22,** 659
spot, equivalent rise time, **18,** 79
size, **22,** 34, 55, 97, 590–608
affected by various parameters, **22,** 601–606

Cathode-ray tubes, spot, size, measurement methods, **22**, 723
double-pulse, **22**, 592
microscope, **22**, 591
miscellaneous, **22**, 599
polka-dot-raster, **22**, 597
shrinking-raster, **22**, 594
sweeps, delayed, **1**, 522
"tails," **22**, 108
test pattern, **22**, 723
transfer characteristic, **22**, 67, 80
types, **1**, 483
ultrahigh-frequency, **22**, 73
voltage, blanking, **22**, 92
cutoff, **22**, 722
focus, **22**, 723
Catwhisker, **15**, 316–323; **23**, 11
fabrication, **15**, 318–322
for low-level detectors, **15**, 359
materials, **15**, 316
mounting, **15**, 321
point forming, **15**, 318–320
shape, **15**, 320
thermal resistance, **15**, 243, 245
Cauer's extension of Foster's theorem, **5**, 194
Cavity, for 1B23 tube, **14**, 41
bandwidth, **8**, 239; **11**, 291
beacon-reference, **11**, 377
breakdown, **6**, 641
capacitively loaded, **8**, 274; **9**, 687
with change in height, **8**, 275–277
characteristics, distortion, approximate correction, **9**, 672
as circuit element, **11**, 286–293
circuits, **16**, 34
circulating current, **7**, 32
coaxial-line, **7**, 72; **8**, 273; **14**, 45
comparator, **11**, 403–407, 446
TFU-1RL, **11**, 406
containing dielectric materials, **11**, 307
coupling, **11**, 286, 330–342; **14**, 31, 33, 49, 385
to coaxial line, **14**, 50
equivalent circuit, **8**, 208; **11**, 286, 289
with two emergent transmission lines, **8**, 234–239
two-line, transmission through, **11**, 289
cylindrical, **8**, 48
Cavity, design, typical, **7**, 188
with dielectrics, **8**, 390–393
direct-coupled, **9**, 661–666
filters using, **9**, 666–673
dissipation in, **9**, 672
equivalent circuit, **6**, 289, 293, 297–299, 311, 330; **14**, 29, 386, 388
excitation, **7**, 90
excited in more than one mode, **9**, 673–677
filter, **11**, 377
formed by shunt reactances, **8**, 182–186
H-plane mounted, **14**, 119
iris-coupled, coaxial duplexer with, **14**, 337
$\lambda_g/4$-coupled, **9**, 683–688
length measurements, absorption method, **6**, 704
loaded-*Q*, **14**, 388
loop-coupled, equivalent circuit, **8**, 218–225
losses, **14**, 16
lossless, impedance, **7**, 406
measurement conditions, standard, **11**, 393
microwave, **3**, 301
normal mode fields, **11**, 293–308
oscillator, 707B, **11**, 250
padding, **16**, 219–223
parameters, determination, **7**, 410
partial-coaxial, **11**, 377–379
phase of standing wave from, **14**, 387
precision reference, **16**, 342
Q, **14**, 30, 388
Q-meter, **11**, 396–403, 447
radial-line, **7**, 72
reaction, **16**, 218
rectangular, behaving as double-tuned filter, **9**, 675
reentrant, **3**, 301, 304–311; **7**, 71
cathode-tuned, **3**, 311
chokes, **3**, 304
cylindrical, **9**, 683
plate-tuned, **3**, 304
reference, **3**, 337; **7**, 24; **16**, 228, 261–264
resonant, **1**, 405–407; **6**, 773; **8**, 207–239; **10**, 89; **11**, 390–392
frequency, **7**, 86
optimum coupling, **14**, 31
voltage transformation ratio, **14**, 21

Cavity, resonators (*see also* Resonators), **6**, 290; **7**, 7, 70
as circuit elements, **9**, 646–653
design, **9**, 653–661
direct-coupled, filters using, **9**, 645–677
equivalent circuits, **9**, 647
insertion loss, **9**, 654
rectangular, **9**, 656
reentrant cylindrical, **9**, 660
shunt conductance, **7**, 76, 88, 280
shunt-mounted, **14**, 120
shunt resistance, equivalent, **14**, 17
side, magnetron, **6**, 49
spherical, **10**, 96
stabilization, **6**, 747, 758, 769, 773, 790
standard, 24,000 Mc/sec, **11**, 383
external temperature compensation, **11**, 386–390
humidity effects, **11**, 384, 390–392
temperature, **11**, 384–390
temperature-compensated, **11**, 384
TE_{011}-mode, **11**, 325, 379–382
hybrid, **11**, 382–384
TFS-10, **11**, 377
TR (*see* TR cavity)
transmission, **16**, 215, 220
tuning, **6**, 583, 758, 773
with two loop-coupled lines, representation of, **8**, 237
with two pairs of terminals, equivalent circuit of, **9**, 650
use to reduce local-oscillator noise, **16**, 245–249
very high-Q, **11**, 340
very low-Q, **11**, 339
wavelength measurements, transmission method, **6**, 702
Cayley-Hamilton's matrix theorem, **8**, 410
Celcure, impregnant, **26**, 61
Cells, computer, **27**, 3, 6, 40
additive (*see* Additive cells)
bar-linkage, **27**, 41
cams (*see* Cams)
integrators (*see* Integrators)
linear, **27**, 6
linkage, **27**, 40
multipliers (*see* Multipliers)
resolvers, **27**, 15–19
Weston, **21**, 495
Cellulose acetate, for radomes, **26**, 379
Cement resorcinol-formaldehyde, **26**, 284, 383
rubber-base, **26**, 284
Centering, display, **22**, 411, 477
Centibel (radiance unit), **22**, 623
Central-limit theorem, **24**, 46
CH (*see* Home chain)
Chaff (*see also* Clutter; Echoes), **1**, 82; **13**, 550; **24**, 124, 137
echo fluctuations, **13**, 551, 572–575
first probability distribution, **24**, 137
frequency spectrum, **13**, 572–575; **24**, 138
mean spread in velocity, **13**, 574
voltage correlation function, **13**, 567
Chain, Loran, **4**, 55
star, Gee, **4**, 80
Channel, Loran, **4**, 70, 347
signal radar receiver, **1**, 434
switching, **3**, 161
width and data-handling capacity, Hartley law, **3**, 97–99
Chapman distribution, free electrons, **4**, 127
Characteristic diagram, vapor pressure-temperature, **13**, 184, 189, 191, 200–203, 236, 300
Characteristic impedance, line (*see* Line)
mode, **10**, 8
Characteristic values, for bilinear N-profile, **13**, 146, 162
for first mode, **13**, 161
for large values of g and $s = +\sqrt{\frac{1}{3}}$, **13**, 171
methods for calculating, **13**, 146
for s nearly unity, **13**, 163
trapped modes, **13**, 75
Charge, conservation of, **7**, 205–207, 215
Charge density, **7**, 123
Charging, storage condenser (*see also* A-c charging; D-c charging; Full-cycle charging; Half-cycle charging; Inductance charging; Resonant charging), **5**, 51–69
Charging circuits, pulser, miscellaneous, **5**, 414–416
Charging cycle, pulse transformer, **5**, 358
Charging inductance, pulser, **5**, 355, 361, 455, 467, 483, 526–530
Charging period, pulser, **5**, 384

Charging reactor, **5**, 356–380
core, saturation, **5**, 364, 370
design, **5**, 372–380
coil, **5**, 372
linearity, **5**, 366
Charging voltage, forward, pulser measurement, **5**, 690, 692
Chart, Loran, **2**, *73*; **4**, *31*, *40*, *55*, 97, 102, 104, 109, 154, 170–194, 406
matching (*see also* Navigation, ship, superposition), **2**, 333
accuracy obtainable, **2**, 344
equipment, **2**, 335
indicator requirements for, **2**, 350
suggested improvements, **2**, 351
projector, radar, **1**, 215
Check, preflight, beacon, **3**, 457
Chemical processes used in magnetron construction, **6**, 674–676
Chemical reservoirs, TR tube, **14**, 219
Choke, *coupling, transmission-line*, **9**, 100–114
waveguide, design details, **9**, 202
flush, **14**, 333
dipole, **12**, 242, 243, 245
filter, inductance vs. weight, **17**, 129
optimum air-gap ratio, **17**, 128
-flange couplings, circular-groove, **9**, 193–199
junctions, waveguide, open, **9**, 291–294
harmonic, **16**, 174–178
iron-core, design, **17**, 126–130
joints, coaxial-line, **8**, *196*
magnetron, **6**, 483
on waveguide, **8**, 197
quarter-wave sections as, **1**, 397
reentrant cavity, **3**, 304
resonant-charging, **17**, 129
snuffing, Loran, **4**, 283
split, waveguide, **14**, 333, 334
swinging, **21**, 521
waveguide, **26**, 166, 188
Chromium copper, sliding contact, **9**, 119
Circle diagram, line (*see also* Smith impedance chart), **10**, 11
Circuit, efficiency, η_c, **6**, 407
magnetron, **6**, 36, 181, 185, 421, 626, 717
element, electron stream as, **6**, 291–297
linear, **19**, 8, 40
Circuit, element, multivariable, **19**, 40
nonlinear, **19**, 10
halo-loop, magnetron output, **6**, 191
merit, propagation, **4**, 124
general, filter, **9**, 543
phenomena at high frequencies, basic, **7**, 70–94
scale-of-two (*see* Scale-of-two circuit)
Circular waveguide (*see* Waveguide)
Cities, radar features, **2**, 91–96
radar signals from, **1**, 101
Clamp, *circuits*, **22**, 128–132; **23**, 414
diode, **11**, 238
electronic switch, **1**, 503–508
filter, **25**, 245–246
four-diode, **22**, 476
one-way, **22**, 128
resistance, **22**, 129
triode, **22**, 129
two-diode, **22**, 131
two-triode, **22**, 131
two-way, **22**, 131, 475
two-way four-diode, **22**, 131
Clapeyron's equation, **13**, 183, 279
Clipper, *diode*, **18**, *129*
Clipping factor, **24**, 356
Close control by FDP (forward director post), **1**, 232–240
Clutch, magnetic, **21**, 393, 404
acceleration considerations, **21**, 395
motor, **17**, 390–392
Clutter (*see also* Chaff; Echoes), **1**, 124–126; **24**, 297–298
echoes, definition, **13**, 550
fluctuations, **13**, 550–587
Gaussian distribution, **13**, 555
measuring techniques, **13**, 562–571
experimental techniques, **24**, 132–137
fluctuations, **23**, 582
internal, **1**, 642–644
measured values, **1**, 643
when radar is moving, **1**, 657–658
foliage, **13**, 584
frequency spectrum, **13**, 558
ground, **13**, 551; **16**, 300; **24**, 142; **26**, 94, 250
first-probability distributions, **13**, 582–583
fluctuations, **13**, 551–553, 582–587
frequency spectra, **13**, 582–587

Clutter, ground, moving and stationary targets, **13**, 552, 582
-noise, **1**, 651
origin and description, **24**, 124–125
PPI, **3**, 91–93
rain, **1**, 81
saturation, reducing, **24**, 303–323
sea, removal by sensitivity time control, **2**, 372

CMH, height finder, **1**, 188
A-scope presentation in, **20**, 238–243

Coatings for power-type wire-wound resistors, **17**, 74–76

Coaxial, cable, **1**, 393–398; **7**, 7; **11**, 11–13; **12**, 217–226; **26**, 6, 166
50-ohm, **9**, 149
attenuation, **9**, 25
bifurcation, **10**, 369–372
E-plane, **10**, 112, 160
bullet, **9**, 151
cascade transformers in, **12**, 221–223
characteristics, **9**, 23–29, 150
choke, **6**, 11
choke joints, **8**, 196
connector, **11**, 13
adapters for, **9**, 259, 261, 273
contacts, sliding, **9**, 119
coupling for, **1**, 396; **9**, 150–155
coupling to circular guide, **10**, 174
discontinuities, **9**, 184–188
durability, **9**, 254–256
factors in choice of dimensions, **9**, 144–150
flexible, **9**, 243–273
impedance, **9**, 183
infinite center conductor, **10**, 208
motional joints, **9**, 407–416, 446–455
parallel stubs, **12**, 223–225
radiating into half space, **10**, 213
resonances, **9**, 253
rigid, **11**, 923
rotary joint for, **1**, 396
series reactance transformer, **12**, 225
switches, **9**, 528–533
tapers, **9**, 305–311
TEM-mode, **12**, 217–219
termination by capacitive gap, **10**, 178
transformer sections between, **9**, 311–314

Coaxial, cable, transition, one line to another, **9**, 305–314
matching techniques, **9**, 317–336
to waveguide, **1**, 403; **6**, 485; **9**, 314–361
tubing for, **9**, 115–119
tuners, **9**, 460–481
tuning, **6**, 746
cavity, **14**, 45
connectors (*see* Connectors)
coupling section, magnetron output, **6**, 483
junctions, **14**, 265
line (*see* cable, above)
output circuit, magnetron, **6**, 169, 191, 482
power-carrying capacity, maximum, **9**, 145, 147
power divider, **14**, 414
resonator, **11**, 303
T-junction with broadband transformer, **14**, 268
T's, **11**, 527
-type mixer, **1**, 417
universal joint, **9**, 414
waveguide (*see* Waveguide)
wavemeter, **11**, 320–322

Code, color, for composition resistors, **17**, 37–38
distinguishability, beacon, **3**, 91
group, multiple-pulse, **20**, 400
legibility, **3**, 92, 377
reply, number of, **3**, 94–97

Coded operation, magnetron, in beacon, **3**, 262

Coder, **3**, 6
combined pulse-width and pulse-spacing, **3**, 219
for equally spaced pulses, **3**, 208–210
low-power, **3**, 217
pulse, **3**, 206–217
blanking-gate, **3**, 206
multiple-response, **3**, 206–210
pulse-spacing, **3**, 210–217
pulse-width, **3**, 206
-pulser combinations, **3**, 218
radar, **20**, 451
response, **3**, 204–220
single-pulse, **3**, 206
triple-pulse, **1**, 686

Coding (*see also* Beacon, interrogation coding), **3**, 6, 83–103
by amplitude modulation, **3**, 94
combined pulse-width and pulse-spacing, **3**, 96
and data transmission, **3**, 100
delay, Loran, **4**, 57, 102, 204
effectiveness of, **1**, 688
frequency, **2**, 41
interrogation, **1**, 263; **3**, 83–89, 180–203
multiple-pulse, **3**, 367
slow, **3**, 89
parameters, **3**, 85–89
reply, **3**, 89
pip, **3**, 96
pulse, **1**, 686; **5**, 131, 486
pulse-width, **2**, 41; **3**, 88
radar, **2**, 40
range, beacon, **2**, 37; **3**, 91–93
reply, beacon, **3**, 89–97, 204–220
frequency, **3**, 74
response, beacon, **3**, 89–97, 204–220
space, **2**, 41
Coherence, ways of producing, between echo signals and reference signal, **1**, 635–638
Coherent scattering, from assemblies of random scatterers, **13**, 601–607, 699–706
magnitude, from drops, **13**, 600, 605–607
Coherent systems, **24**, 329
Coho (coherent oscillator), **1**, 632; **20**, 11; **23**, 579
amplitude, **23**, 588
locking, **23**, 606
moving, **23**, 610
output, **23**, 609
signal, addition of, **23**, 588, 597
stability, **23**, 609
Coil, bifilar, **18**, 196
deflection (*see* Deflection coils)
duolaterally wound, **5**, 554
Helmholtz, **20**, 137
loss, contribution to amplifier noise, **18**, 649
material, pulse transformers, **5**, 648–660
pretuned, **18**, 295–297
vs. tunable, **18**, 295
relay, **17**, 474–479
Coil, tunable, **18**, 295
unity-coupled, **18**, 196
Coincidence, circuit, **4**, 210; **19**, 364
detection, **16**, 344
tube, **16**, 342, 345, 347
Cold fronts, **13**, 263
echoes from, **13**, 23, 630–632
from radar echoes, **2**, 320
Color code for composition resistors, **17**, 37–38
Column vectors, matrix, **8**, 87
Coma lobes, **12**, 488
Combined plan and height systems, **1**, 192
Common-mode signal, **19**, 58, 340, 359
Communication, beacon, **3**, 221–236
properties, **3**, 97–100
by blinking, Loran, **4**, 252, 256
pulse, **3**, 221–236
Commutated signal in automatic tracking, **25**, 293
Comparators, amplifiers for, **19**, 335–338
amplitude (*see* Amplitude comparator)
blocking-oscillator, **19**, 342
double-triode, **20**, 116, 118
cathode-coupled, **20**, 116–118
multiar, **20**, 114–116, 124, 356
multivibrator, **19**, 341
regenerative amplitude, **20**, 356
SCR-268, **20**, 135–137
sine-wave, **19**, 348–350
two-way, **19**, 348
Comparison, circuit, balanced, **21**, 549
voltage regulator, **21**, 511–519
as circuit operation, **19**, 42
Compass, Gyro Fluxgate, **21**, 365
radio, **2**, 46, 53; **3**, 25
Compensated belt cam, **27**, 21–23
Compensating differential, **27**, 16
Compensation theorem, network, **8**, 92
Complementary identification of parameter and variable, **27**, 49
Complex radar targets, **1**, 73, 75–81
Component, characteristics, for waveform generators, **20**, 50–62
for computer, **27**, 4
solver, **27**, 2, 26
tolerances, amplifier, **18**, 400
variability of, **18**, 390

Composite waveguide structures, **10,** 387–413
Composition resistors (*see* Resistors, composition)
Compound targets, **1,** 73, 81
Compression, dynamic-range, **20,** 496
Computation, Loran, methods, **4,** 177–180
  speed, **21,** 9, 130
Computational errors, **27,** 201
Computer, accuracy, **21,** 22; **27,** 1, 4, 166
  airborne navigation, **21,** 172
  analog, **21,** 3–214
  analytic, **26,** 117
  bail, **26,** 117
  ballistic, **20,** 142
    AN/APA-30, **20,** 247
    constraint linkage in, **27,** 297–299
  bar-linkage multipliers, **27,** 250–283
  cells (*see* Cells, computer)
  component solver, **27,** 26
  components for, **27,** 4
  constraint, **26,** 117
  constructive, **26,** 118
  continuously acting, **27,** 1
  crank, **27,** 27
  dead-reckoning, **1,** 215
  design, **21,** 11–31, 172–212; **27,** 2–5
    analytical method, **27,** 3
    block-diagram, **21,** 12, 177
    constructive method, **27,** 2
    error, **27,** 2, 4, 223
    function generators with two degrees of freedom, **27,** 284–300
    linkage, combinations, **27,** 166–222
      harmonic-transformer, **27,** 58–106
      three-bar (*see also* Three-bar linkages), **27,** 107–165
      with two degrees of freedom, **27,** 223–249
  differential-equation solvers, **27,** 1–2
    component solvers, **27,** 2, 26
    integrators, **27,** 2
    planimeter, **27,** 2
    speedometers, **27,** 2
  digital vs. analogue, **21,** 6
  dimensional constants, **27,** 32
    variations of, **27,** 201, 205
  driver, **21,** 180
  EDVAC, **21,** 40
  elementary (*see* Cells)
Computer, elements, **21,** 5–8
  ENIAC, **21,** 40
  equalizing network, **26,** 221, 223
  equations, rearrangement, **21,** 14
  errors, **21,** 21–23, 186; **27,** 2, 4
    cancellation, **21,** 24
  explicit analogue, **21,** 15
  general comments, **21,** 3–5
  geometric, **26,** 117
  ideal functional, **27,** 43
  input parameters, **27,** 10, 19, 44, 45
  linkages (*see* Linkage)
  loading, **21,** 130
  mechanical constraint, **26,** 118
  as mechanization of equation, **27,** 3
  navigational, **21,** 173–190
  operation speed, **21,** 25
  output parameters, **27,** 11, 19, 44, 45
  performance analysis, **21,** 185
  power-dissipation reduction, **21,** 26, 27
  power supply, **21,** 24, 25
  precision, **21,** 22
  pulse digital, **21,** 40
  radar, stabilization, **26,** 117–128, 217
    trainer, **21,** 172
  Radiation Laboratory, **26,** 128
  reference voltages, **21,** 24, 25
  regular mechanism, **27,** 45
  restricted parameters, **27,** 280, 282
  scale factors, **21,** 130, 184; **27,** 61
    input, **27,** 51
    output, **27,** 51
  screw differential, **27,** 11
  stability, **21,** 25
  structural error reduction, **27,** 199, 207
  terminals, **27,** 43–44
    crank, **27,** 44
    input, **27,** 11, 43
    linear, **27,** 46
    output, **27,** 11, 43–44
    slide, **27,** 44
    travel, **27,** 45
  tolerances, **21,** 21–23
  types, **21,** 5–8; **27,** 1–2
  use of servomechanisms, **21,** 23
  weight reduction, **21,** 26, 27
  working model, **27,** 5
Condensers (*see also* Capacitor), **21, 55,** 105, 369
  3-phase, 4-phase, **19,** 494
  absorption, **21,** 68

Condensers, bypass, cathode, **18**, 368
series-resonant, **18**, 273
calculation of load-tuning, **18**, 728–729
charging (*see also* Charging; Storage condenser), **5**, 51–69
coupling, **22**, 112
CV-11 sweep, **22**, 216
D-150734 4-phase, **19**, 494
discharging, **5**, 25–51
electrolytic, **18**, 348
as energy reservoir, **5**, 21–23
leakage, **21**, 82
linear-sweep, commercial, **17**, 305–309
method of data transmission, **22**, 398
modulator, **21**, 516
use of, **19**, 457
phase-shifting, **17**, 288–298; **19**, 492–496; **21**, 105, 370
accuracy of phase shift, **17**, 296
construction, **19**, 494
mechanical design, **17**, 296–298
resolved-time-base, applications, **22**, 217
PPI, **22**, 218
sine-cosine, **22**, 452
sinusoidal, **22**, 218, 472
sweep, **17**, 308–309
soaking, **21**, 68
stability, **19**, 475
sweep-scanning, **17**, 298–309
tachometers, **21**, 370
timing, **19**, 167
variable, **17**, 288–309; **19**, 455, 456
as electromechanical modulators, **22**, 212
as position-data-transmission device, **22**, 213
as transducer, **19**, 428
voltage equilibrium, **5**, 53, 55
Conductance, network, **8**, 84; **18**, 4
shunt, cavity, **7**, 76, 88, 280
Conduction (thermal), **13**, 213, 219
Conductivity (thermal), **13**, 208, 209, 293
Conductor, attenuation, **9**, 50
center, for r-f cable, **17**, 16–21
loss, **9**, 21, 26
minimum, **9**, 146, 147
metallic, at microwave frequencies, skin depth in, **9**, 127
plated, attenuation in, **9**, 128
stranded, for hook-up wire, **17**, 3–4
Cone of silence, **3**, 41, 58
Cone-cylinder combination as multiplying device, **21**, 55, 120
Conformal mapping, **10**, 154
Conical regions, waveguide, **10**, 53
Conical scan, **1**, 188, 205; **3**, 56; **20**, 367, 368
antenna pattern, SCR-584, **20**, 367
Conical waveguide (*see* Waveguide)
Connector, coaxial, **11**, 13
adapters for, **9**, 273
assembly, convention to be followed in, **9**, 153
for cables for low power, **9**, 256–259
high-power, to rigid lines, **9**, 260–267
HN, **9**, 260
polarized, **9**, 151
Polyglas, **9**, 267
pulse-transformer, **5**, 654
r-f cable, **9**, 270
Teflon, **9**, 259
type N, **1**, 397; **9**, 256–259; **11**, 9
UHF, **11**, 10
unpolarized, **9**, 153
Constant-current circuits, **18**, 431, 432, 437
Constant-current elements, voltage regulator, **21**, 501
Construction techniques, microwave components, **9**, 121–124
Contact, bounce, **17**, 471, 512, 514
losses, transmission-line, **9**, 108
potential, **15**, 51–53
distributed, **15**, 183
uniform, **15**, 182
potentiometer, **17**, 255–261
pressure, **17**, 261
rectifiers, **19**, 68–72, 671
relay, **17**, 467–472
materials, **17**, 470
pressures, **17**, 471
protection, **21**, 436
ratings, **17**, 468–470
shapes, **17**, 471
special forms, **17**, 472, 490–491
sliding, coaxial-line, **9**, 119
Contactors, motor, d-c, **17**, 504–507
Continuous-wave navigation systems, **4**, 18
Continuous-wave signals (*see* C-w signals)

Contour, of constant field strength, **13,** 130
 diagram, free-space, **13,** 30
  propagation, **13,** 32
 field strength in surface duct, **13,** 178, 179
 radome, constant-reflection, **26,** 309
  first-order, **26,** 295
  reflection, **26,** 294, 323
  second-order, **26,** 295
  zero-order, **26,** 295
Contrast, CRT, **22,** 35
Control, automatic, for engine-driven generator sets, **17,** 408
 -motors, synchro, **17,** 321–323
 transformer (servo), **17,** 314, 319–321, 325–326; **22,** 187; **26,** 224
Controllers, photoelectric, **19,** 541
 scanner, **26,** 211–213, 216, 218, 220
 servo (*see* Servo)
Convection, air, **13,** 193, 220, 268, 283
Convective mixing, **13,** 225, 253, 258
Conversion (frequency) (*see also* Detection), **15,** 4, 111–178; **16,** 26; **24,** 10
 amplification, crystal, **15,** 398
  theory, **15,** 406–415
 efficiency, **16,** 58; **24,** 9
 gain, **16,** 90
 loss (*see also* Crystal conversion loss), **15,** 25; **16,** 100, 249, 359, 365
  dependence on image-frequency termination, **16,** 75–83
  measurement methods, **16,** 101–105
   amplitude-modulation, **15,** 215–218
   heterodyne, **15,** 200–202
   impedance, **15,** 202–213
   incremental, **15,** 213–215
   Llewelyn, **15,** 207
   mechanical-modulation, **15,** 218
   Pound, **15,** 208–212
  and mixer admittances, **15,** 128–152
  special definitions, **15,** 128
  test set, 1-cm, output circuit, **15,** 278
 phenomenological theory, **15,** 119–152
 physical theory, **15,** 152–170
 reciprocity in, **15,** 117–118, 124–128, 203, 216
 with subharmonic local oscillator, **15,** 114, 170–173
Converters, **16,** 3, 24, 26–28, 44, 56, 119; **17,** 417–445, 599–610; **24,** 9
 Brown (modulator), **19,** 402; **20,** 361, 447
 crystal, **16,** 56–66
  linear-network representation, **16,** 59–61
  three-terminal-pair-network representation, **16,** 61–66
 Loran, **4,** 97, 367
 noise, **24,** 108–112
 pentagrid, **17,** 600–604, 606
 regenerative, **16,** 90, 93
 rotating, **17,** 417–431
 superregenerative, **16,** 93
 triode-heptode, **17,** 606–607
 triode-hexode, **17,** 605–606
 tubes, **16,** 28; **17,** 599–610
 vibrator (*see* Power supply, vibrator)
Convolution theorem, **18,** 3, 39
Cook bellows, **9,** 290
Cooling, from below, **13,** 220, 228–234, 251, 254, 300
 initially stratified air over water, **13,** 251
 microwave-tube, **7,** 177
 by radiation, magnetron, **6,** 524
Cooling system, constant-temperature, **17,** 406–407
 nocturnal, **13,** 221, 253–257
Coordinate, bipolar, **21,** 167
 fixing by beacons, **3,** 18
 integration, spherical, computer design, **21,** 190–212
 nonrectangular, **21,** 157
 oblique, **21,** 165
 polar, **21,** 157
 rectangular, **21,** 157
  rotation of, **21,** 159
 transformation as circuit operation, **21,** 157–171, 226, 477
Copper, oxygen-free high-conductivity (OFHC), **6,** 650, 694, 695
Coradi harmonic analyzer, **25,** 283
Cores, design, d-c charging reactor (*see also* Transformer cores), **5,** 372
 energy dissipation, **5,** 626–630, 660
 equivalent circuit for pulse-transformer, **5,** 626–633
 Hipersil pulse-transformer, **5,** 610
 loss, **17,** 149

Cores, performance, techniques for measuring, **5**, 639–648
Corner reflector, **1**, 67; **2**, 324; **26**, 21
4-ft, **2**, 330
clusters, **2**, 326, 328
dropped from airplane, **2**, 112
mounted on life raft, **2**, 329
square, **2**, 325
triangular, **2**, 325
Correlations, between angle of arrival and *M*-profile, **13**, 388
function, **24**, 37; **25**, 273–277; 283–288
in amplitude, **13**, 557, 567–569
connection, with frequency spectrum, **13**, 559
definition, **13**, 556
effect of steady signal, **13**, 562
finite sample, **13**, 566, 568
ln *R*, **13**, 558
measurement, **13**, 566
errors in, **13**, 569
nonstationary signals, **13**, 567–569
normalized, **24**, 38
power, **13**, 568
presence of noise, **13**, 559, 566
and spectral density, relation between, **25**, 283–288
statistical fluctuations, **13**, 568, 569
and velocity distribution of scatterers, **13**, 556
matrix, definition, **25**, 277
between one-way transmission and refraction, Massachusetts Bay, **13**, 301–328, 336–353
between radar echoes, and *M*-profiles, **13**, 355–361, 365–368
and one-way transmission, **13**, 10, 361, 367
and precipitation, **13**, 591–592
and superrefraction, **13**, 363, 367–373
Corrosion tests, microwave components, **9**, 130–132
Cosecant-squared coverage, **2**, 15
Coulomb friction, **21**, 357
d-c motor, **26**, 220, 226
Coulomb's law, **7**, 354
Counters, **20**, 102
blocking-oscillator, **19**, 621
cascaded, feedback in, **19**, 626
cascading, **19**, 624
combinations of, **19**, 624–628
Counters, dividers, **20**, 102
energy storage, **19**, 602, 614–628
methods of introducing feedback into, **19**, 618
parallel, **19**, 625
phantastron, **19**, 624
ring, **19**, 603, 612–614
scale-of-two, **20**, 154
sequence, feedback in, **19**, 628
sequence-operated, **19**, 602
step, gas-filled tube, **20**, 100
thyratron, **19**, 619
Counting as circuit function, **19**, 602–628
Coupler, Bethe-hole, **8**, 313; **11**, 858–866
branched-guide, **11**, 866–873
equivalent circuit, **11**, 868
coaxial, inside-out, **11**, 874
directional (*see also* Coupling), **3**, 147; **8**, 299–301, 437; **9**, 229; **11**, 522, 800, 854–897, 925; **16**, 146–150, 201, 301; **23**, 298
biplanar, **8**, 445–447
branched-guide, modified, **11**, 873
equivalent circuit, **11**, 855–858
properties, measurements, **11**, 894
reverse-coupling, **11**, 883
scattering matrix, **8**, 301–303
Schwinger, **11**, 885
reverse-coupling, **8**, 312
single-hole, **8**, 437–445
slotted-block, for coaxial line, **11**, 878
theoretical considerations, **11**, 891–894
two-hole, **8**, 312; **11**, 873–879
with two slots, **11**, 876
types, **11**, 850
long-slot, **11**, 885–890
multiple-path, **11**, 879–883
resistive-loop, **11**, 891
two-hole, **11**, 873–879
Coupling (*see also* Line, coaxial; Waveguide), capacity, transmission-line, **9**, 100–114
cavity, **11**, 286, 330–342; **14**, 31, 33, 49, 385
channel, equivalent network, **16**, 155–163
choke (*see* Choke coupling)
choke-flange, circular-groove, **9**, 193–199
coaxial-line, **9**, 150–155

Coupling, coefficient, **11**, 487
cavity-to-line, **8**, 228–230
maximum, T and π network, **23**, 112
conductive, d-c amplifier, **18**, 411
contact, waveguide, **9**, 193
critical, amplifier, **23**, 107, 170
devices, low-Q, **6**, 578
microwave, **9**, 654, 659
filter, high-pass, **23**, 467
flexible, **21**, 461
i-f, **16**, 271
iris, **9**, 659
resonator, **7**, 507
load, microwave-tube, **7**, 197
loop, **6**, 11, 169; **9**, 659
resistive-stripe, for cutoff attenuator, **11**, 703
for TE_{11}-mode cutoff attenuator, **11**, 703
magnetic, **9**, 354
measurement, **11**, 895
parameters, **11**, 288
probe, **9**, 659
quarter-wavelength, **9**, 677–683
filters using, **9**, 677–706
resonant-slot, **9**, 354
sealing, **9**, 140
sections, frequency sensitivity, **9**, 691
segment-fed, **6**, 170, 194
strap-fed, **6**, 170, 193
from TE_{10}-mode to TE_{20}-mode, **8**, 337
transitional, amplifier, **23**, 107, 170
bandwidth at, **23**, 108
between transmitter and receiver, **12**, 45–48
waveguide, **9**, 193–202, 288–303; **11**, 15, 859
Course indication, **2**, 117
Course-indicator method of navigation, **2**, 119
Course lines, para-, **2**, 119
Coverage, antenna, **2**, 14
beacon, **3**, 42, 57, 126–129
considerations, **3**, 57–62
cosecant-squared, **2**, 15
diagram, GCA antennas, **2**, 242
long-range microwave radar system, **2**, 202
distortion by refraction, **13**, 9–11, 366, 369, 370, 374–385, 427, 473
frequency, **3**, 151, 162, 172
Coverage, overhead, **3**, 128
pattern, antenna, **12**, 4, 5
and specular reflection from earth, **13**, 406
statistical properties, **13**, 430
target, **1**, 50–54
wavelength dependence, **13**, 409
Crest factor, alternator waveshape, **1**, 557
Critical field, magnetron, **6**, 437–439
Cross attenuation, mixer, **16**, 194, 195, 284
Cross-correlation function, definition, **25**, 277
Cross modulation, **24**, 8
Cross polarization, **12**, 423, 579
of antennas, barrel-reflector, **12**, 503
fanned-beam, **12**, 457
pencil-beam, **12**, 419, 423
measurement, **12**, 579–580
Cross section, aircraft, **1**, 76–78; **13**, 470–472
antenna, **11**, 899; **12**, 3, 42
average, for matched system, **12**, 50, 51
dependence on antenna mismatch, **12**, 51–53
receiving, **12**, 3
corner reflector, **1**, 67
cylinder, **1**, 66; **13**, 458–462
effective receiving, **1**, 20
flat sheet, **1**, 65
interception, **12**, 468
per unit area for sea echo, **13**, 483
per unit volume, for echoes from ions, **13**, 590, 599, 618–621
for precipitation echoes, **13**, 590, 596
propeller modulation, **1**, 76
radar (*see* Radar, cross section)
raindrops, **13**, 608–612
scattering (*see* Scattering, cross section)
segment of sphere, **1**, 66; **13**, 450, 452–453
ships, **1**, 80; **13**, 472
target, **2**, 16
waveguide, resonant change in, **8**, 189
Cross-spectral density, definition, **25**, 279
Crossbar transitions, coaxial line to waveguide, **9**, 346–349
Crossing angle, lines of position, **4**, 80, 83
Crossover, CRT, **22**, 46
statistical analysis, **25**, 304

Crystal (*see also* Semiconductors), acceptance testing, **1**, 128
back resistance, **1**, 413; **16**, 54, 113, 297
back-to-front ratio, **15**, 297
barrier, equivalent circuit, **11**, 279
bias, d-c (*see* d-c bias, below)
voltage, **16**, 95, 249, 251
boundary layer, **11**, 279
British red-dot, **15**, 8, 91, 99
burnout, **3**, 176; **14**, 151; **15**, 236–263; **16**, 96–100, 118, 172–174
affected by design, **15**, 329
causes, **15**, 236
continuous d-c power, **15**, 256–258
harmonic leakage, **15**, 238
long pulses, **15**, 241–248
short d-c pulses, **15**, 258–260
short pulses, **15**, 248–256
definition, **15**, 236
edge, **15**, 253
electrostatic discharge, **15**, 100
experiments, **15**, 256–263
flat and spike, importance of, **15**, 260
limitations of standard crystal units, **15**, 260
temperature at, **15**, 257
testing, **15**, 239, 293–300; **16**, 111–113
field, **15**, 297–300
with microsecond d-c pulses, **15**, 295
simulated spike, **14**, 152
spike, **15**, 293–295
using circuit for coaxial line, **15**, 293
theory, **15**, 239–256
voltage-breakdown hypothesis, **15**, 240
calibration, **14**, 380
capacitance, **16**, 53, 92
cartridge (*see* Cartridge)
cat whisker (*see* Catwhisker)
checker, **16**, 113; **23**, 294
d-c, **15**, 297
limitations, **15**, 298
reliability, **15**, 300
conductance, negative, **16**, 90, 92
contact, capacitance with voltage, variability of, **15**, 398
as function of time, **15**, 248–254
Crystal, contact, geometry, ideal, from point of view of burnout by short pulses, **15**, 254
long thin, **15**, 247
conversion amplification, **15**, 398, 406–415
conversion loss $\mathfrak{L}$ (*see also* Conversion, loss), **23**, 18
affected by design, **15**, 329
in broadband case, **15**, 130–135
effect of parasitic impedances, **15**, 157–163
as function, of image impedance, **15**, 202
of image tuning, **15**, 212
of r-f tuning, **15**, 232–235
general expression, **15**, 136–140
image termination effect, **15**, 140–148
L_0, mixer matched to local oscillator, **15**, 133
measurements, **15**, 198–218, 227–235
welded-contact rectifier, **15**, 403–406
production testing methods, **15**, 213–218
range of, in production units, **15**, 32
test set, 1-cm band, **15**, 276–280
3-cm band, **15**, 265–272
10-cm band, **15**, 272–276
standard, **15**, 264–283
converter-type, specifications, **1**, 414
and crystal holder, **23**, 508–515
current, **16**, 95, 256
sensitivity, **15**, 335–340, 342
measurement, **15**, 349–357
damage, **3**, 444
d-c bias, **16**, 88
effect, on figure of merit, **15**, 347
on low-level properties, **15**, 340–342
on mixer crystal, **16**, 249–256
on noise temperature of germanium rectifiers, **15**, 35
on silicon crystal-mixer performance, **15**, 34
d-c characteristic, **16**, 50, 90
d-c impedance, **15**, 333
d-c resistance, comparison with i-f resistance, **15**, 41

Crystal, d-c resistance, measurement, **15,** 40
d-c return, **16,** 126
delay-line, **17,** 221–229
absorbing backing, **17,** 224–225, 227
active area, **17,** 222
bandwidth, **17,** 220
beam-spread formula, **17,** 220
capacitance measurement, **17,** 237
mounting technique, **17,** 222–229
thickness, **17,** 221–222
detection, **3,** 172–177; **12,** 549, 554, 555, 601, 604; **16,** 19; **23,** 197
deterioration, **16,** 99, 114
dummy, **18,** 317; **23,** 326
electrical performance, design considerations, **15,** 328–330
electrolytic pointing, **15,** 319
electrolytic polishing process, **15,** 318
etching, **15,** 314–316, 369
figure of merit, **15,** 239
measurement equipment, **15,** 355–357
video, **15,** 344–347
forward conductance as function of frequency, **15,** 378–380
forward resistance, **16,** 297
frequency standards, **17,** 175–180; **21,** 587
accuracy requirements for radar, **17,** 176
effect of oscillator circuit on frequency, **17,** 177
mountings, **17,** 178–180
resistance, to humidity, **17,** 177
to shock and vibration, **17,** 177
special quartz cuts, **17,** 177–178
table, **17,** 179
temperature coefficient, **17,** 176
use in radar, **17,** 176–177
gate, **14,** 406
germanium (*see* Germanium)
harmonic response, **16,** 298
heat treatment, **15,** 91, 314–316, 365
high-burnout, **15,** 8
high-frequency properties, **15,** 378–389
holders, **3,** 172; **11,** 925; **15,** 267
for video-crystal testing, fixed-tuned, **15,** 351
tunable, **15,** 351
Crystal, holders, for video-crystal testing, variable-tune, in 3-cm band, **15,** 353
waveguide, **15,** 278
i-f conductance, negative, **15,** 398, 401
theory of, **15,** 406–415
i-f impedance, **15,** 40–44
effect, of image termination, **15,** 148–152
on *Y*-factor, **15,** 220
measurement, **15,** 40
i-f resistance, comparison with d-c resistance, **15,** 41
dependence on r-f matching conditions, **15,** 43
as function of rectified current, **15,** 42
measurement, **15,** 230
spread, **15,** 42
image impedance, effect on conversion loss, **15,** 202
image termination, effect, on conversion loss, **15,** 140–148
on i-f impedance, **15,** 148–153
image tuning, effect on conversion loss, **15,** 212
impedance, conversion loss, **15,** 208
loss, **15,** 203
r-f (*see* r-f impedance, below)
tester, **15,** 383
variation with frequency, **15,** 39
law, calibration, **12,** 552–556
local-oscillator level, optimum, **15,** 33
loss and noise measurements, **15,** 198–235
low-frequency, **19,** 109
properties, **15,** 372–378
low-level properties, dependence on bias, **15,** 340–342
variation with temperature, **15,** 342–344
manufacturing techniques, **15,** 301–330
special, for low-level detectors, **15,** 357–360
in measurements (*see also* tests, below), **12,** 555, 559, 601, 604
circuit details, **15,** 285
mechanical shock, **16,** 96, 100
as microwave noise generator, **15,** 195–197, 229

Crystal, mixer (*see* Mixer)
modulators, **15**, 174–178
mounts, **16**, 101, 122–126, 171–172, 279–283
3-cm and 10-cm bands, **16**, 124–128
balanced mixer, **16**, 279–283
broadband, **16**, 281
crossbar, **16**, 171, 172
inverted, **16**, 280
tunable, **16**, 131–134
fixed, **16**, 123, 134–136
tuning screws, **16**, 132
negative-resistance, characteristics, **15**, 391
region in back direction, **15**, 362
noise, dependence on temperature, **15**, 194
figure, **15**, 25–30
generators, **23**, 323
i-f, **15**, 187–195
dependence on excitation frequency, **15**, 188
and loss measurements, **15**, 198–235
ratio, **15**, 30
sources, **15**, 186
temperature (*see* Noise temperature)
video, **15**, 187–195
spectrum, **15**, 189–194
oscillation, **16**, 90
oscillator (*see* Oscillator, crystal)
output, circuit, **15**, 269
-meter circuit, **15**, 287
resistance, dynamic, **15**, 333
performance figures, **14**, 152
photopeak, **15**, 395
polishing, **15**, 314–316
precautions, handling, **15**, 18–20
production units, range of conversion loss and noise temperature, **15**, 32
properties, effect of phase of reflected wave at image frequency, **15**, 233
protection, **3**, 357
gate for, **14**, 424
quartz, **19**, 752–755
for supersonic crystal transducer, **17**, 181–182
frequency standards, **17**, 175–180
receiving, **20**, 135
rectification (*see* Rectification)
representative, **16**, 134, 354
r-f impedance, **11**, 498; **15**, 35–40
Crystal, r-f impedance, affected by design, **15**, 328
effect of varying r-f power level on, **15**, 39
r-f matching, dependence of i-f resistance on, **15**, 43
r-f power, **15**, 206
second detector, rectification efficiency, **15**, 388
silicon (*see* Silicon)
special types, development of, **15**, 9–11
specifications, **16**, 100, 114–118
JAN, **15**, 264
comments on, **15**, 429
spreading resistance, **1**, 413; **15**, 24, 83; **16**, 51, 92
of elliptical contact, **15**, 427
local, **15**, 88
stability, **15**, 18–20
standard, **15**, 201
calibration, **15**, 272
techniques, Loran, **4**, 216, 237
temperature, **7**, 473
equivalent, **18**, 618
ratio t_c, **23**, 18
tests, **16**, 100–114
coupling-circuit, **15**, 286
narrow-band, **15**, 222, 225
Roberts, **15**, 223–225
equipment, **15**, 264–300
modulation-circuit, **15**, 268
preamplifier-circuit, **15**, 287
production methods, loss measurement, **15**, 213–218
r-f components, **15**, 277, 285, 290
adjustment, **15**, 269, 276, 279
r-f filter, **15**, 285
r-f oscillator, **15**, 273
tuning, standard fixed, **15**, 270
Type B test set for measuring over-all performance of crystal second detectors, **15**, 386
Type C test set for measuring rectification efficiency of crystal second detectors, **15**, 388
tolerances, **16**, 114
transmitting, **20**, 135
types, **23**, 512
units, cartridge, properties, **11**, 7
video, **3**, 172–177; **16**, 56; **23**, 508
characteristics, **3**, 176

Crystal, video, equipment for production testing, **15**, 352
figure of merit, **3**, 175; **15**, 344–347
holder, with single tuning adjustment for 1N30 rectifiers, **15**, 354
low-temperature performance, **3**, 177
-video receiver (*see* Receiver, crystal-video)
welded contacts, **15**, 99, 254
X-cut, capacitance, **17**, 220
resonant frequency, **17**, 219
Y-factor, **15**, 31
as function of i-f impedance, **15**, 220
$\csc^2 \theta$ pattern, **12**, 466, 470, 507
C-scan, **22**, 384, 401
C-scope, **1**, 173; **22**, 401–406
cst (x,y), function, **8**, 268
ct (x,y), function, **8**, 259
Ct (x,y), function, **8**, 259
Current, addition, **19**, 18, 629–648
-balance tube, **22**, 438
discriminator, **21**, 44
saturable-core, **21**, 45
distribution, radiation theory, discontinuous, **12**, 146–149
far-zone fields, **12**, 87–91
over reflector, **12**, 144–149
space-charge tube, **7**, 100, 122
due to moving charge, **7**, 36, 37
electron, **7**, 48
exciting, tube, **7**, 50, 58, 68, 99, 106
-fed network (*see* Network)
feedback, **22**, 363, 436–440
generator, **18**, 4
longitudinal, waveguide, **9**, 51
modes in pulse transformer, **5**, 528
noise-exciting, **7**, 106, 112
pulse, **5**, 175, 176, 666
amplitude, **5**, 69
droop (*see* Pulse droop)
rectangular, **19**, 215
in copper, **5**, 655–658
shapes (*see* Pulse shape)
-viewing resistors, **5**, 676
regulation (*see* Voltage regulation)
subtraction, **19**, 18, 629–648
transformer, **20**, 316
pulser, **5**, 574
-viewing resistors, **5**, 666
waveforms, **19**, 317–324
amplifiers for, **22**, 362–370
Current, waveforms, in inductance, **22**, 358
level-setting, **19**, 321–324
Cursors, **20**, 178
Curve, approximation of, by segments, **19**, 315
fitting, **21**, 90–104
with linear potentiometers, **21**, 95
for triangle solution, **21**, 143
Cutoff, attenuator (*see* Attenuator, cutoff)
frequency, low-pass filter, **8**, 116
waveguide (*see* Waveguide)
magnetron, **6**, 3, 238, 340, 342, 369
parameter, **11**, 686
plate current, in grid-controlled tubes, **19**, 73–77
wave number, waveguide, **10**, 8
wavelength, **11**, 685; **12**, 205
circular waveguides, E-modes, **10**, 67
H-modes, **10**, 70
coaxial waveguides, H-modes, **10**, 77
higher E-modes, **10**, 74
conical waveguides, dominant E-mode, **10**, 99
E_i and H_i-modes, **10**, 88
elliptical waveguides, ${}_eH_{mn}$-mode, **10**, 83
parallel-plate waveguide, E-modes, **10**, 64
H-modes, **10**, 65
radial waveguides, E-type modes, **10**, 91, 94
H-type modes, **10**, 92, 95
rectangular waveguide, **8**, 35
E-modes, **10**, 57
H-modes, **10**, 60
for TE_{10}-mode between coaxial cylinders, **8**, 42
C-w modulation (*see* Modulation, continuous-wave)
C-w signals, **24**, 3–17
Fourier analysis, **24**, 152
frequency-modulated, **24**, 13–17
minimum detectable, **24**, 150
phase-modulated, **24**, 17
C-w systems, frequency-modulated, **20**, 398
CXAM, radar, **1**, 180
Cycle matching, **20**, 11
Loran, **4**, 99, 117, 252, 400

Cyclized rubber for radomes, **26**, 371
Cyclotron frequency, **6**, 599
  oscillations, **6**, 3
Cylinder, multiple moments, **13**, 461
  parabolic, **12**, 457–459
  scattering coefficients, **13**, 459
Cylindrical cam, **27**, 19
Cylindrical-gear differential, **27**, 7
  backlash, **27**, 7
  friction, **27**, 7
Cylindrical rack, **27**, 10
Cylindrical reflector, **1**, 276

D

δ-function, **18**, 23
Dampers, oscillation, **21**, 332–341
Damping resistors, synchro, **22**, 382
Dark-trace screens, **1**, 483; **22**, 6, 664–699
Dark-trace tube, **1**, 220
Darlington pulser circuit, **5**, 464
Data, grouped, or periodically interrupted, tracking on, **20**, 378
  -handling capacity and channel width, **3**, 97–99
  high-precision, methods for using, **3**, 102
  input devices, **21**, 362–374
    measurement, **21**, 461
    time-derivative, **21**, 370
  intermittent, **20**, 28, 29
    aided tracking with, **20**, 247–251
  multiscale, **21**, 27
  output devices, **21**, 362–374
    measurement, **21**, 461
    time-derivative, **21**, 370
  precise, **3**, 100–103
  representation, **21**, 28, 29, 60
    discrimination with other types, **21**, 48
  single-scale, **21**, 27
  smoothing, **21**, 25
    in servo loop, **21**, 347
  stabilization, **1**, 311–312
  transmission, **1**, 283; **3**, 97–103; **21**, 372; **26**, 167, 212, 223–225
    beacon, systems, **3**, 99
    and coding, **3**, 100
    condenser method, **22**, 398
    phase for, **20**, 393
    photoelectric-mechanical, **22**, 221
Data, transmission, position-, **22**, 184–226
    potentiometers, **1**, 487
    radio, **20**, 398–416
    short-distance wire, **20**, 391–398
    systems, special, **20**, 391–416
      various, characteristics, **20**, 399
    variable condensers, **1**, 489
    variable transformers, **1**, 487
  transmitter, angle, **1**, 486–492
D-c charging, current from nonlinear charging reactor, **5**, 365
  general analysis, **5**, 356–363
  line-type pulser, **5**, 356–380
  reactor design, **5**, 372–380
    practical, **5**, 364–372
  voltage for, **5**, 362, 365
D-c hysteresis loop (*see also B-H* loop), **5**, 600, 605
D-c resolvers, **21**, 110
  supplies (*see* Power supply)
D-c resonance charging, pulse network, **3**, 243
D-c restoration, **18**, 96–98; **19**, 11, 55; **22**, 112, 113
D-c restorer (*see also* Level setting), **1**, 503; **23**, 227, 230–232
  heater-to-cathode hum, **18**, 96
D-c servo motors, **25**, 103
Debunching (*see* Klystron)
Debye formula for dielectric constant, **13**, 609, 643, 652, 675
Decay, phosphorescent, **22**, 632
Decay laws, **22**, 632
Decca, **2**, 76; **4**, 13; **20**, 34
Decibel-log frequency diagrams, **21**, 271, 304
Decibel phase-margin diagram, **21**, 310
Deck-tilt correction, antenna, **26**, 108, 463–468
Decoder, **19**, 366; **20**, 426, 454
  beacon, **3**, 6
  double-pulse, **3**, 195–199
  multiple-pulse, **3**, 199–201
  pulse, **3**, 84
  storage, **3**, 84
  trigger, **3**, 84
  triple-pulse, **1**, 687
Decoding circuits, synchronizing-pulse, **20**, 426–429
Decrement measurements, **11**, 340–342

Deflecting fields, magnetic, defects in, **22,** 312–314
methods of producing, **22,** 314–316
square iron-core coil, **22,** 316
Deflection characteristic, CRT, **22,** 66
Deflection coils, **1,** 477; **22,** 3, 303–337, 356–359
air-core, **22,** 330, 712–718
with distributed windings, **22,** 333
with iron return path, **22,** 334
with lumped windings, **22,** 330
two-axis, **22,** 334
balanced winding, **22,** 320
bearings, **22,** 546
characteristics, **22,** 713
circuit constants, measurement, **22,** 325–329
construction, **22,** 712
core materials, **22,** 317
damping resistance, **22,** 356
distributed capacity, **22,** 358
eddy currents, **22,** 317
energy storage, **22,** 307
fixed, mounts, **22,** 541–545
impregnation, **22,** 719–721
inductance, **22,** 310
iron-core, distortion due to, **22,** 351–354
equivalent circuit, **22,** 324, 356
inductance, **22,** 323
square, deflecting field, **22,** 316
toroidal, **22,** 329
maximum length, **22,** 306
motor stator, **22,** 336
mount, off-centering, **22,** 552
rotating-coil, **22,** 545–555
servomechanism-driven, **22,** 550
synchro-driven, **22,** 547
pie windings, **22,** 320
power loss, **22,** 310
push-pull-operation, **22,** 319
recovery time, **22,** 311
resistance, **22,** 309
rotating, **22,** 426–445, 484, 492
selenium rectifiers with, **22,** 466
shields, **22,** 321–324
single-ended-operation, **22,** 319
and synchro, equivalent circuit, **22,** 382
synchro driving, **22,** 381
voltage drive for, **22,** 310
windings, **22,** 318–320
Degeneration, cathode, **23,** 465
d-c, **23,** 100
Deicing, **26,** 425
Delay, absolute, Loran, **4,** 52, 56, 96
beacon, **3,** 101, 152, 344
correction for, **3,** 379
and cancellation of recurrent wave trains, **20,** 471–525
circuits, CRT, **22,** 262, 272, 279–282
coding, **4,** 57, 102, 204
device, supersonic, **19,** 751–765
intentional, **3,** 347
interrogator, **3,** 102
line, **5,** 133, 158; **20,** 475–487
attenuation, **1,** 670
and cable properties, **5,** 689
characteristic impedance, **1,** 671
circuits, **1,** 634
terminated in too-high (low) impedance, **18,** 133
crystals (*see* Crystal, delay-line)
driving circuits, **1,** 672
duplication of pulses by, **19,** 247–253
electrical, **19,** 730–750
correction methods, **19,** 746
measurement of properties, **19,** 749–750
types, **19,** 742–747
uses, **19,** 747–749
electromagnetic, **17,** 191–217
balanced, **17,** 198–199
continuous, **17,** 197–202
distributed-parameter, **17,** 192–209
effect of natural coil capacitance, **17,** 202
effective inductance, **17,** 192–193
equalized, typical, **17,** 203–209
high-dielectric constant, **17,** 206
lumped-parameter, **17,** 209–217
mismatch effects, **17,** 194–196
simple, **17,** 194
with subdivided winding, **17,** 203, 206–209
end cells, **1,** 669
examples, **19,** 752–764
fused-quartz, **1,** 669
grid-circuit, **18,** 131, 145
laboratory-type, **1,** 633
liquid, **1,** 667–669

Delay, line, mercury, design constants, **1**, 670
folded, **1**, 668
supersonic, **20**, 481
signal circuits, **1**, 672–675
stabilization, frequency dividers, **19**, 599
supersonic, **1**, 667–672; **17**, 218–242; **19**, 708
assembly, **17**, 236–239
crystals (*see* Crystal, delay-line)
faithful reproduction, **19**, 763
folded, **17**, 226, 231–233, 242
formulas, **17**, 218–221
insertion loss, **17**, 220–221, 235–236
line-design problems, **17**, 229–235
maintenance, **17**, 239
mechanical tolerances, **17**, 232
mercury, **20**, 481
multiple echoes, **17**, 223
reflectors, **17**, 226, 230–232, 235
solid, **20**, 484–487
specifications, **17**, 239–241
stability, **17**, 229–230
table, **17**, 240–241
variable, **17**, 226, 227, 230, 232–235, 242
water, **20**, 482–484
temperature coefficient, **19**, 474
to terminate, regenerative action, **19**, 245
step function, **19**, 238–242
trigger circuits, **1**, 675–677
variable, **20**, 132
linear, **20**, 429–433
linear-sweep, **3**, 217
multivibrators, **4**, 199, 204, 206, 210, 211, 226
over-all control of, **3**, 344–348
patterns, propagation, correlation between, **4**, 141
stages, blocking-oscillator, **3**, 215–217
delay-line, **3**, 210
multivibrator, **3**, 211–213
overshoot, **3**, 213–215
trigger, **3**, 206
tank, liquid, **1**, 669
supersonic, **20**, 132–135, 140
time-modulation system, **20**, 132
Delta function, **10**, 162; **25**, 30
Demagnetization curve, Alnico, **6**, 542
Demodulation, amplitude and time, **19**, 53, 501–544
by cathode-ray-tube display, **19**, 539–543
mechanical, **19**, 543
time, **20**, 5–7, 62–64
and amplitude, **19**, 53, 501–544
Demodulators, **20**, 391, 400
balanced triode, **19**, 512, 513
four-diode bidirectional-switch, **19**, 519
full-wave bidirectional-switch, **19**, 522
phase-sensitive, carrier-balanced, **19**, 512
switch, **19**, 513–524
Density modulation, **7**, 33, 40, 57, 59, 132, 143
Depolarization, **13**, 389, 457, 468
by rough surfaces, **13**, 539
by scattering cylinder, **13**, 462
Derivative feedback, **21**, 329–332
Despiking circuit, **5**, 453
Despiking *RC*-network, **5**, 436
Detectability criteria, **24**, 161–165
deflection criteria, **24**, 161
power criterion, **24**, 163
Detection (*see also* Conversion), **15**, 2–4; **16**, 20; **23**, 564
aural for c-w radar, **1**, 134
methods, **24**, 252–256
average, **19**, 502
coincidence, **16**, 344
crystal, **3**, 172–177; **12**, 549, 554, 555, 601, 604; **16**, 19; **23**, 197
double-time-constant, **19**, 509
heterodyne, **24**, 10
linear, **15**, 2
low-level, **15**, 333–360
theory, **15**, 344–349
meter, **24**, 23
methods, **24**, 252–256
peak, short-time-constant, **19**, 502
square-law, **15**, 3
superheterodyne, **12**, 559, 578, 607–609
system calibration, **12**, 552–556
Detector, **24**, 6
-balance-bias (DBB), **23**, 251, 371
balanced, **23**, 597
for MTI, **1**, 666
bolometer, **12**, 555, 601–604
boxcar, **22**, 198

Detector, cathode-follower, **19**, 507
coherent-signal, **11**, 546
crystal, **3**, 172–177; **12**, 549, 554, 555, 601, 604; **16**, 19; **23**, 197
difference (*see also* Difference detectors), **19**, 528–530
diode, **17**, 533–539
double-time-constant, with recycling, **19**, 510
efficiency, **23**, 191
envelope, **21**, 600
first, **16**, 3
gain, **16**, 20
grid, **23**, 204
and i-f stage, interaction between, **23**, 194
infinite-impedance, **23**, 204
keyed, **22**, 197
law, **18**, 332
Littelfuse, **16**, 18
low-level, **16**, 17–19, 47, 54, 111, 115, 124, 133
measurements, **15**, 349–357
special manufacturing techniques, **15**, 357–360
multielectrode, **23**, 204
nonlinearity effects, **11**, 635
peak, **22**, 196, 231
half-wave diode, **19**, 503
precision, **19**, 506
synchro modulator using, **19**, 446
pentode-switch, **19**, 516
phase-sensitive, **19**, 503, 515; **22**, 196; **25**, 111
synchro modulator and, **19**, 446
plate, **23**, 204
position error, **20**, 367
push-pull, **23**, 196, 197
recycling, **19**, 508, 509, 532
regenerative, **16**, 45
response, **12**, 601–603
r-f, **22**, 259
second, **23**, 188–212
germanium crystal as, **15**, 384–388
radar receiver, **1**, 449
testing, **23**, 208–210
square-law, **16**, 19–21; **24**, 8
for standing-wave measurements, **11**, 496–503
traveling, **23**, 328
Detector, video, **16**, 115
peaking, **23**, 201–204
Wollaston wire, **16**, 18–19
Dew point, **13**, 182, 186, 198, 200, 207
hygrometer, **13**, 182, 186
DFF circuit (double flip-flop), **23**, 71, 73
Diamond (diode modulator), **19**, 397, 398, 521
Diaphragms, capacitive, **8**, 166
interaction between, **8**, 173
as shunt reactances, wave-guide, **8**, 163–179
Diaplex (mica substitute), **5**, 215
Dicke method of loss measurement, **15**, 203–207
Dicke reciprocity theorem, **15**, 417–420
Diehl motor, **21**, 391, 437, 474
Diehlsyn (servo), **26**, 167
Dielectric, air-spaced, in r-f cables, **17**, 22
attenuation, **9**, 27, 50
constant, **9**, 59
cavity with, **8**, 390–393
constant (*see also* Index, of refraction), air, **4**, 129
experimental information, **13**, 190
Bakelite, **26**, 409
complex, **9**, 28, 133; **10**, 18; **11**, 561; **13**, 397, 448, 641; **26**, 266, 344
earth, **13**, 111, 398
effective, **26**, 287, 288
Fiber-A laminates, **26**, 413
foam, **26**, 409–413
GR-N, **26**, 411
general properties, **13**, 641–646
glasses, **14**, 39
high, reflection of sandwiches with cores, **26**, 327
low-frequency, **7**, 66
measurement, **11**, 561–676
bibliography, **11**, 673–676
choice of method, **11**, 568–570
comparison with optical methods, **11**, 604
consistency of results, **11**, 666
corrections for clearance, **11**, 576
details of computation, **11**, 584
by phase shift in guide, **11**, 571
by reflection, **11**, 606–625
by resonant-cavity methods, **11**, 657–665

Dielectric, constant, measurement, by short-circuited-line *method*, **11**, 621, 625–656
summary of methods, **11**, 666–672
by transmission in free space, **11**, 591–606
by transmission in guide, **11**, 570–591
mixtures, **26**, 410, 412
phase angle, **8**, 365
and power factor, *definition*, **5**, 652
radome materials, tables, **26**, 409, 411
reflection from change in, **8**, 369–374
relation to absorption, **13**, 641–646
relations for analysis of data, **11**, 562–568
relative, **11**, 561
resonant and nonresonant, **13**, 643
sandwich core, tolerances, **26**, 320
sandwich skin, tolerances, **26**, 321
soil, table, **13**, 398
specific, **26**, 266, 343
effective, theory, **26**, 352
table, **8**, 382
water, **13**, 111, 398, 609–613, 674–675
dissipation factor, **5**, 216
electrical properties, **9**, 134, 135
electrical thickness, **26**, 261
at oblique incidence, **26**, 291
loss, **9**, 21
loss tangents, **26**, 266, 409
materials, **9**, 132–143
properties, **10**, 19
reflection and transmission of electromagnetic waves by, **26**, 341–368
mechanical properties, **9**, 134, 135
and metal-plate lenses, **12**, 388–412
parts, construction, **9**, 137–140
plates in waveguide, **8**, 374–376
plugs, half-wavelength, **9**, 222
in pulse network, **5**, 215
sheet, half-wavelength thickness, **26**, 263
modified, at perpendicular polarization, **26**, 302
tolerances, **26**, 264
quarter wavelength, **26**, 273
waveguide, **8**, 365–400
partially filled with, **8**, 385–389
Difference detectors, **19**, 528–530
with constant output, **19**, 524–531
time selectors and, **19**, 534
Difference frequency AFC systems, **16**, 294; **23**, 27
Differential, amplifier, Loran synchronizer, **4**, 231, 246
analyzer, **21**, 89, 369; **27**, 4
belt (computer), **27**, 10
bevel-gear, **27**, 6–7
compensating, **27**, 16
cylindrical-gear, **27**, 7
loop-belt, **27**, 10–11
in mechanization of functions, **27**, 233–238
screw, **27**, 9–10
spiral-gear, **27**, 9
spur-gear, **27**, 7–9
worm gearing, **27**, 9, 11
equation solvers (*see* Computer)
gear, **21**, 39
input, amplifier, **18**, 443
output, amplifier, **18**, 447
Differentiation, **19**, 648–662, 700
based on inductance, **21**, 72
as circuit operation, **21**, 64–78
with current amplifiers, **21**, 72
in d-c amplifier, **18**, 411
Differentiator, ball-and-disk, **21**, 77
drag-type, **21**, 76
mechanical, **21**, 76
RC-, **21**, 64, 65, 70
cross section, target, **1**, 69
Diffraction, by earth's surface, **13**, 6, 34
Fraunhofer, **11**, 898
phenomena at medium wavelength, **1**, 715
of radiation, **3**, 52
region, **13**, 5, 6, 109
Diffusion, **13**, 213, 248, 252
equations, **5**, 617–626, 656
theory, **13**, 175, 238
of rectification, **15**, 77–81
Diffusivity, **13**, 209, 293
Diode, **17**, 533–548; **22**, 113, 128
amplitude comparator, **20**, 71, 73, 108, 125–131, 151, 153, 173
biased, **5**, 32, 231, 527
bridge circuits, **19**, 409
characteristics, **19**, 59

Diode, charging (*see also* hold-off, below), **5**, 138, 361, 414
pulser, **1**, 383
clippers, **16**, 129
cold-cathode gas, voltage regulators, **17**, 609–610
comparator, simple, **19**, 338
detectors, **17**, 533–539
carrier-balanced full-wave, **19**, 513
drift, **19**, 64
dynamic resistance, **5**, 231
filamentary, **19**, 65
GL-559, **11**, 193
GL-582, **11**, 193
half-wave, for detection, **17**, 536
heater voltage effect, **19**, 63
hold-off (*see also* charging, above), **5**, 163, 381, 414, 416, 456
impedance, a-c, **7**, 64
limiters, **1**, 504
logarithmic characteristics, **19**, 62
microwave, **7**, 17
mixer, **23**, 141
microwave, **7**, 17
multiple, for detection, **17**, 537, 538
noise, generators, **23**, 321
temperature-limited, **7**, 158
as nonlinear circuit element, **19**, 58–68
-phantastron control circuit, **23**, 64
plate-supply, **17**, 539–547
R6271, **11**, 464
rectifiers, **11**, 193; **23**, 334
high-voltage, **17**, 545–547
resistance, a-c, **7**, 113
selectors, **19**, 328–331
shunt, 8020, **5**, 154
in pulser, **5**, 44, 146, 154, 348, 426–429, 433, 443, 455
space-charge-limited, **7**, 113
strobed, **19**, 516
-switch, for bipolar signals, **19**, 371
modulator, **19**, 401
for unipolar signals, **19**, 370
temperature-limited, **16**, 109, 365
theory of rectification, **15**, 78, 81–82
transitron, **16**, 345
tube, single, **23**, 188
tuning, magnetron, **6**, 615–621
variation from tube to tube, **19**, **65**
Diplane, reflector, **13**, 11
Dipole, **26**, 159, 161, 186, 190
Dipole, moment, **13**, 13, 190, 451, 461, 599, 609, 646, 649, 650, 652, 658, 675, 677
Dirac delta function, **7**, 101; **25**, 279
Direct identification of parameter and variable, computer, **27**, 48
Direct ray, **13**, 5, 36–38, 99, 100, 104, 107, 116
Direct-reading bridge, **11**, 84
for barretter, **11**, 169–171
Direction finders, airborne, **2**, 51–54
automatic (*see* ADF)
ground, **2**, 54
shipborne, **2**, 51–54
Direction finding, **4**, 3, 17, 110
Directional coupler (*see* Coupler, directional)
Directivity, measurement, **11**, 895
waveguide, definition, **11**, 859
Discharge, r-f, spectrograms, **14**, 148
TR-tube, decay of light intensity from, **14**, 196
Discharging, storage condenser, **5**, 25–51
Discharging circuit, effect on pulse shape, **5**, 255–261
efficiency, **5**, 449
general properties, **5**, 225–233
line-type pulser, **5**, 225–272
Discharging (pulse) interval, **5**, 54
Disconnector, **20**, 304
neon tube, **20**, 386
Discontinuities, waveguide, equivalent circuits, **10**, 108–117
representation, **10**, 101–108
Discrimination, as circuit operation, **19**, 42; **21**, 32, 42–48, 511
with other types of data representation, **21**, 48
pulse-shape, **24**, 363
beacon, **3**, 152
pulse-width, general characteristics, **3**, 193–195
time, **19**, 12, 56, 364; **20**, 62–64, 276
time-interval, **21**, 47
Discriminator, **16**, 295, 302–312; **21**, 378; **23**, 28
AFC (*see also* AFC discriminator), **3**, 271–274
beacon (decoder), **3**, 6
circuits, **23**, 35–38

Discriminator, crossover frequency, **16**, 296, 302, 304, 307, 310, 314, 328
current, **21**, 44
delay-line and integrator, comparison of, **3**, 187–189
direct-coupled, **19**, 358–362
efficiency, **16**, 305
Foster-Seeley, **16**, 304
gain, **16**, 305
hum in, **16**, 306, 311
integrator, **3**, 180–184
Loran, **4**, 260, 261, 265, 269
microwave, **11**, 63–67; **16**, 342; **23**, 77
two magic T's, **11**, 66
modulated-carrier-amplitude, **19**, 362
peak-reading, **23**, 36
peak-to-peak separation, **16**, 304, 310
phase, **3**, 170
pulse, constant-delay, **3**, 191
delay-line, **3**, 184–187
repetition-frequency, **3**, 201–203
-width, **3**, 180–195
to reject, long and short pulses, **3**, 186
short pulses, **3**, 181–186
short and long pulses, **3**, 183
theory, **16**, 308–312
time (*see* Time discriminator)
Travis, **16**, 304
with triode detectors, **16**, 307
Weiss, **16**, 305, 308–312
video, **23**, 75
balance needed by, **16**, 306
voltage, **21**, 43
Disdrometer, **13**, 617
Dish, **26**, 16
Dispersion (beam direction), **3**, 375–377
CRT, **22**, 35
Display (*see also* Indication; Presentation), A-scope, **22**, 26
B-scope, **22**, 26
centering, **22**, 411, 477
CRT, **20**, 64
demodulation by, **19**, 387, 539–543
deflection-modulated, **22**, 6, 17, 251–302
double-dot, **1**, 174; **22**, 22
expanded, **22**, 429–432, 516
intensity-modulated, **24**, 238–252
jitter, **22**, 429
loss, CRT, **3**, 34–38
micro-B, **22**, 21
Display, one-dimensional, **1**, 164–167
pip-matching, **1**, 167
polar, **22**, 426
rotating-coil method, **22**, 426–445, 484
radial-time-base, **22**, 425–481
off-centering, **22**, 419–424, 440–445
zero reference level, **22**, 445
rectangular-coordinate, **22**, 384–410
sector, **1**, 168; **22**, 19, 482–515
coil, fixed, **22**, 484–486
position error, **22**, 488, 493, 502, 504
television, **22**, 406
projection of, **22**, 577
three-dimensional, **1**, 174–175
three-tone, **22**, 38
two-dimensional, **1**, 167–174
type A, **22**, 14
type B, **22**, 15, 21
type C, **22**, 15
type E, **22**, 15, 21
type F, **22**, 15
type J, **20**, 180, 220; **22**, 14
type K, **22**, 15
type L, **22**, 15
type M, **20**, 180
V-beam, **22**, 15
vertically expanded, **22**, 517
Dissipation, in cavities, **9**, 672
effect, on pass-band characteristics, **9**, 603
on rejection-band characteristics, **9**, 604–607
electric-type, **10**, 18
factor, dielectric, **5**, 216
tuned-circuit, **18**, 168
incidental, **9**, 601–609
magnetic-type, **10**, 23
uniform, correction for, **9**, 607–609
waveguides, **10**, 17
Dissipative line, perturbation method of calculation, **10**, 26
standing waves, **10**, 26
Dissipative waveguide, scattering description in, **10**, 27
Distance finder, c-w system, **20**, 7
Distance measurements, **20**, 4–16
accuracy, **20**, 32
Distortion, associated with resolving power, **2**, 91

Distortion, due, to asymmetries in iron-core deflection coils, **22,** 351–354
to finite beamwidth and pulse length, **2,** 153
geometrical, CRT, **22,** 429
range, on PPI, **2,** 151
in start of sweep, **22,** 354
Diurnal cycle, **13,** 253–260
Diurnal effects, **13,** 321, 324, 331, 337–339, 343, 351, 368
Divergence factor, **12,** 143; **13,** 40, 99, 113–115, 137, 138, 401, 404
Divergence theorem, **7,** 83
Diversity effects, and average signal level, **13,** 306
frequency, **13,** 304, 306
spatial, **13,** 304, 306, 345, 420, 432
Diversity reception, **13,** 136
Divider (*see also* specific types of dividers), astable multivibrator, **19,** 575–577
blocking oscillator, **19,** 582–591; **20,** 83, 110, 165
single-stage, synchronization, **19,** 586
variations associated with circuit configuration, **19,** 586
chains, with feedback, **19,** 599
phantastron triggering, **19,** 581
computer, bar-linkage, **27,** 40
counter, **20,** 102
frequency, **11,** 354–357; **20,** 88, 102, 267; **22,** 122
amplitude-comparison multivibrator, **20,** 147
delay-line stabilization, **19,** 599
fundamental circuits as continuous, **19,** 572–592
with injection feedback, **20,** 100
jitter, **19,** 508
monostable oscillators, **19,** 569
neutralization, **19,** 590
pulse, **20,** 83
regenerative-modulator, **11,** 356
sinusoidal, **19,** 545–566; **20,** 160
stability, **19,** 580
triggering, **19,** 580
frequency-tracking, **19,** 570
gas-tube, **19,** 591
monostable multivibrator, **19,** 572–575
phantastron, **19,** 577–582; **20,** 104
Divider, phase delay, **19,** 508
phase jitter, **19,** 508
PRF, **19,** 567–601
pulse, **4,** 199, 203, 209, 219, 222, 236
pulse-frequency, multivibrators as, **20,** 154
with regeneration and modulation, **19,** 562–566
regenerative, **19,** 558, 560–562
schemes and intermittent-frequency division, **19,** 592–601
sinusoidal, **20,** 158
stability, **19,** 580
ten-to-one AN/APS-15, **20,** 166
twenty-five-to-one AN/APS-15, **20,** 166
using time base, **19,** 558–560
voltage (*see* Voltage dividers)
Division, based on Ohm's law, **21,** 58
as circuit operation, **19,** 668–678; **21,** 32, 48–60
frequency (*see* Frequency division)
intermittent-frequency and divider schemes, **19,** 592–601
by multipliers, **27,** 40
potential, **19,** 18
D-layer, ionosphere, **4,** 88, 128
Domain (computer), of parameters, **27,** 44
of variable, **27,** 44
Dominant mode, waveguide, **10,** 2
Doorknob transitions, **6,** 485; **9,** 349–353
high-power rotary joints with, **9,** 451–455
Doping materials (*see* Addition agent)
Doppler, c-w radar, **1,** 125–159
frequency, **20,** 17
shift, **2,** 107
MTI, **1,** 626–677
pulsed, **20,** 20
radar system, bandwidth, **1,** 135
range-measuring, **1,** 139–143
simple, **1,** 132–139
Double-ball integrators, **27,** 24–26
accuracy, **27,** 26
error, **27,** 26
Double-dipole system, on coaxial line, **12,** 253–254
theory, **12,** 101–104
waveguide, **12,** 255–256
Double-mixer system, **23,** 44

Double-probe coupling, **11**, 213
Double-scale systems, phase modulation, **19**, 490
  time modulation, **20**, 49
Double-tuned circuits, **18**, 201–231; **23**, 169
  admittance, input driving point, **18**, 214
  alternate primary and secondary loading, **18**, 230
  capacity-coupled, **18**, 210
  coupling, coefficient, **18**, 202
    critical, **18**, 204, 214
    transitional, **18**, 204, 213
  equal-Q, critical coupling for, **18**, 279
  high-Q, **18**, 202, 210
  input network, **18**, 686
  large fractional bandwidth, **23**, 172
  low-Q, transitionally coupled, **18**, 216
  mistuning, effects of, **18**, 215
  radar receiver, **1**, 446
  small fractional bandwidth, **23**, 170
  stagger-damped, **18**, 221–226
  transitionally coupled, **23**, 171
    exact, equal-Q, **18**, 218
      with one-side loading, **18**, 220
Doublet lens, **12**, 410
Drag-cup a-c motors, **17**, 383–385
Drift, action, bunching by, **7**, 35
  determination, doppler, **2**, 107
  measurement, **2**, 105–110
  over water, determination, **2**, 110
  station, beacon, **3**, 429
Drive, mechanical, data transmission, **22**, 184
Driver, 50-kc/sec, Loran, **4**, 253
  attenuator, Loran, **4**, 229
    -bias, Loran, **4**, 212
  blocking-oscillator, **5**, 124–132
  bootstrap, **5**, 120–124, 138
  circuits, **5**, 119–139, 157, 168
  computer, **21**, 180
  exciter, Loran, **4**, 211
  Loran, **4**, 298
  multivibrator, **5**, 132–139
  pulse-forming-network, **5**, 132–139
  pulse-power output, **5**, 119, 229
  regenerative, **5**, 124–134, 150
  resolver, **21**, 188
  step-up, **21**, 188
Driving line, circuit considerations in, **20**, 487–498
Driving mechanisms, antenna, **26**, 135–137
Droop, **22**, 149
  percentage, **23**, 215
Drooping, pulse oscillator, **7**, 185
Drop-size distribution, **13**, 672, 680–681
  method of measuring, **13**, 615–618
Droplet theory of sea echo, **13**, 494, 497, 519, 522–527
Drops, attenuation, **13**, 615, 678–685
  cross sections, **13**, 608–613
Dry-adiabatic lapse rate, **13**, 194, 280
Duality principle, **8**, 85; **10**, 10
Duct (*see also* M-inversion), **1**, 56–58; **3**, 50; **13**, 9, 14, 17–22, 143
  associated with M-inversions, **13**, 15
  conditions for, over water, **13**, 9, 223–226, 228–234, 254–260
  elevated, **13**, 14, 18
  height, **13**, 21, 225, 238, 243
    and height of temperature inversion, **13**, 244
    definition, **13**, 224
    ratio of, to M-deficit, **13**, 225, 241, 243
  surface, **13**, 14, 18, 75, 176, 304, 335, 364
    deep, **13**, 302, 306, 308, 378
    formation, over land, **13**, 352
    shallow, **13**, 302, 306, 308, 374
  trapping in, **13**, 21
Dueppel (German chaff), **1**, 82
Dummy input circuits, **23**, 326
Dummy load, beacon transmitter, **3**, 148
Dummy mixer, **18**, 317
  double, **18**, 318
Duplexer, **16**, 6, 96, 199; **23**, 7; **26**, 72
  1.25-cm, **14**, 346
    using circular polarization, **14**, 372
  3-cm, **14**, 343, 344
    wideband for, **14**, 345
  8.5 cm, **14**, 342
  10.7 cm, **14**, 342
    reception loss for, **14**, 343
  1050 Mc/sec, **14**, 339
  balanced, **14**, 350–375
  basic circuits, **14**, 279
  beacon, **3**, 138–144
  branched, **14**, 262–328, 329–350

Duplexer, circular-polarization, **14,** 369
coaxial, with iris-coupled cavities, **14,** 337
double-tuned, **14,** 339
electrical design, **14,** 329
without gas-filled tubes, **3,** 141
high-power operation, **14,** 429
impedance, cold, **14,** 336
insertion loss, **14,** 427
measurement, **14,** 382
junction, **14,** 262
leakage, r-f, **14,** 335
linear balanced, **14,** 352
loop-coupled coaxial, **14,** 336
mechanical design, **14,** 333
microwave mixers, and local oscillators, **23,** 7–26
with multiple ATR circuits, **14,** 308
nonlinear balanced, **14,** 355
pressurized coaxial, **14,** 335
pressurizing, **14,** 334
radar, **3,** 139–141
recovery time, **14,** 430
with r-f filter protection, **3,** 143
ring-circuit, **14,** 357
turnstile, **14,** 372
frequency sensitivity, **14,** 375
two-channel, **14,** 347
ultrahigh-frequency, **3,** 142
waveguide, **14,** 341
Duplexing, i-f, **23,** 428
loss, with ATR switch, **14,** 279
without ATR tube, **14,** 274
r-f, **23,** 423
switch, requirements, **14,** 4
and TR switches, **1,** 407–411
Duration (*see* Pulse duration)
Duty, **5,** 4
cycle, **5,** 4
ratio, **5,** 4; **22,** 113
limitation, **3,** 111
magnetron, **6,** 8
Dynamic resistance of pulser load, **5,** 3, 33, 78, 110
Dynamometers (*see also* Alternators; Generators), **1,** 579–581; **17,** 417–420
booster armature voltage regulation, **1,** 580
dual-output, **1,** 579
triple-output, **1,** 579
Dynamometers, voltage regulation, **17,** 418–420
Dynatrol (motor), **21,** 450

E

Earth, curvature, **13,** 40, 48, 50
correction, **22,** 533
effective radius, **13,** 6, 53, 115, 339, 392, 406
Earth-flattening method, Maxwell's equation, **13,** 51
Ebonol corrosion protection, **9,** 125; **26,** 142
Eccles-Jordan circuit, **1,** 497; **4,** 209, 223; **16,** 333
Echo (*see also* Chaff; Clutter), box, **2,** 381; **11,** 192, 303, 325; **23,** 294
nonresonant, **13,** 669–671
OBU-3, **11,** 327
TS-218A, **11,** 447
clutter (*see* Chaff; Clutter)
fluctuations, distribution, first probability, **13,** 514, 515, 518, 554, 560, 571, 575, 582
ground-reflection effects, **13,** 539
interference effects as source, **13,** 535–538, 543–545, 547–550
origins, **13,** 527–550
from insects, **13,** 595
from ions, **13,** 598
meteorological, **13,** 588–640
average echo, **13,** 589–591
from causes other than precipitation, **13,** 593–595
and coherent scattering, **13,** 605–607
correlation, with precipitation, **13,** 591–592
cross section, per unit volume, **13,** 590, 596–598
dependence, on antenna area, **13,** 591
on beam width, **13,** 590
on drop size, **13,** 596
on pulse length, **13,** 590
intensity, **13,** 607–621
magnitude, from atmospheric inhomogeneities, **13,** 600–604
nondrop theories, **13,** 598
origin, **13,** 588–607
from solid precipitation, **13,** 618

Echo, meteorological, validity of Rayleigh scattering law, **13**, 598
variants of drop theories, **13**, 604–608
multiple, in supersonic delay lines, **17**, 223
paired, method of phase-distortion analysis, **19**, 736
precipitation, **13**, 22, 621; **24**, 140
band structure, **13**, 632, 637
confusion and masking, **13**, 625–626
first probability distribution, **13**, 575; **24**, 140–141
fluctuation, **13**, 551, 575–578, 588
frequency spectra, **13**, 575–578; **24**, 140–141
from hurricanes and typhoons, **13**, 636–640
identification, **13**, 621–625
from layers, **13**, 634–636
magnitude, **13**, 596–598
meteorological structure, **13**, 626
probability distribution for ratio of successive amplitudes, **13**, 578
properties, **13**, 621–640
rain, **13**, 591–592
magnitude, **13**, 596–598
self-absorption, **13**, 613
variability in frequency spectra, **13**, 575, 576
from widespread rain, **13**, 633
radar, from cold front, **2**, 320
long-range, **13**, 9, 358, 367–373
steady, examples, **13**, 547
from rain and storm, **13**, 81–84
reducer (enabling circuit), **16**, 300, 314
sea, **13**, 481–527; **24**, 142
appearance, on airborne radar, **13**, 481
on A-scope, **13**, 492
with high resolution, **13**, 491–492
azimuth variation, **13**, 514
beam width affecting, **13**, 483–485, 491
dependence, on beam width and pulse length, **13**, 491
on range, **13**, 490
difficulties in measurement, **13**, 496, 500, 503
errors in measurement, **13**, 496
experiments with, table, **13**, 501
Echo, sea, first probability distribution, **13**, 514–516, 579
fluctuation, **13**, 486, 514–518, 551, 579–581
frequency dependence, **13**, 494–499, 511, 524
frequency spectrum, **24**, 142
σ^0 vs. Θ, **13**, 503–510, 521, 524, 525
average signal, **13**, 482–486, 495, 500
dependence, on wavelength, **13**, 517, 580
fluctuations, **13**, 514–518, 578
frequency spectra, **13**, 516–518, 579–581
at large depression angles, **13**, 485, 490, 503–510, 518–519
maximum range, vs. height, **13**, 500–503
methods of measuring, **13**, 495, 500
polarization affecting, **13**, 498, 522, 527
probability distribution for ratio of successive amplitudes, **13**, 580
radar cross section, **13**, 483
per unit area, **13**, 490–499, 506, 512–514, 522, 526
radar transmission equation for, **13**, 484
range dependence, **13**, 490
saturation of, in rough seas, **13**, 513
scattering from surface waves, **13**, 519–522
shadow effect, **13**, 493, 522
slow variation, **13**, 517–518, 578–579
theories, **13**, 494, 518–527
velocity distribution of scatterers, **13**, 517
studies, future progress, **13**, 526
second time around, **1**, 117
ship, first probability distributions, **13**, 545–546
fluctuations, **13**, 543–546
frequency of fluctuation, **13**, 543–544
range of, **13**, 474
smoke, **13**, 593, 621
snow, **13**, 620
storm, **1**, 81

Echo, stretching, **3**, 195, 441
suppression, **3**, 161; **23**, 469
techniques in measurement, **13**, 562–570
Eckersley modes, **13**, 71, 84
generalized discussion, **13**, 85–87
phase-integral method, **13**, 87, 151
Eddy, current, **5**, 620, 624, 636
energy dissipated by, **5**, 626
loss, **5**, 629
diffusion, **13**, 208–219, 232, 238, 245
diffusivity, **13**, 208, 211, 213, 218, 238
height distribution, **13**, 219, 239
ratio to eddy viscosity, **13**, 211–212
stress, **13**, 210, 216, 218
transfer of heat and water vapor, **13**, 211, 212
viscosity, **13**, 208, 210, 213, 214, 217, 218
dynamic, **13**, 210
ratio to eddy diffusivity, **13**, 211–212
Rossby's distribution, **13**, 215
Edge effects in scattering, **13**, 457, 462, 464, 465
Edgewise compression test, **26**, 402
EDVAC computers, **21**, 40
Effective height, ship target, **1**, 80
Efficiency, contours, **6**, 443, 452
adjusted, **6**, 445
lines, **6**, 447
magnetron, **6**, 35, 36, 333, 401, 409, 450
microwave tube, **7**, 27, 28, 269, 305, 310, 349, 378–383
pulser, **5**, 13, 16, 244, 249–255, 462, 470
Eigenvalue equations, matrix algebra, **8**, 405
Eight-terminal waveguide structures, **10**, 373–386
Eighth-power region, **1**, 51
Eikonal equation, **13**, 41
Ekman spiral, **13**, 213, 214
E-layer, ionosphere, **4**, 60, 95, 128, 135, 136
transmission, **4**, 133
one-hop, **4**, 62
Electrical length, determination, **12**, 550–552
line, **10**, 12
Electrical quantities, dimensions and units, **8**, 12
Electrodynamometer multiplier, **21**, 57
Electroforming, **9**, 121; **11**, 524; **26**, 55
Electromagnetic energy storage, **1**, 356
Electromagnetic field and electron reaction, **6**, 207–287
Electromagnetic waves, **8**, 10–59
longitudinal, **8**, 30–59
reflection and transmission by dielectric materials, **26**, 341–368
Electromagnets, magnetron, **6**, 540
Electromechanical systems, time measurement, **20**, 357–366
Electrometer, condenser, dynamic, **19**, 418
tubes, **18**, 409, 419
Electron, attachment, **14**, 187
beam (*see also* Beam; Gap), **7**, 31
precentering, **22**, 342–344
-beam tuning, magnetrons, **6**, 592–615
capture, mechanism, **14**, 188
cathode interception of, klystron, **7**, 396
and electromagnetic field interaction, **6**, 207–287
excitation impedance, **7**, 127, 133
free, vertical distribution, **4**, 128
-gas dispersion formula, **6**, 598
gun, **22**, 2, 46–56, 57–62, 78–89
accelerator, **22**, 60
electrostatic focus, **22**, 86
ion-trap, **22**, 87
tetrode, **22**, 79–85
modified, **22**, 85
triode, **22**, 59, 78
zero-first-anode-current, **22**, 61
leakage, magnetron cathode, **6**, 537
lens (*see also* Focusing lens), **22**, 2, 40, 93
multiple-transit, klystron, **7**, 393–403
optics, **22**, 39–43
d-c, **7**, 352–357
secondary, beam-loading loss, **7**, 254
-stream admittance, **6**, 214
as circuit element, **6**, 291–297
thermal velocities, **6**, 211
trapping, **22**, 694
Electronic admittance, **6**, 293, 312
Electronic angle markers, **22**, 230, 398
Electronic apparatus, design and construction, **21**, 667–708
mechanical assemblies, **21**, 698–700

Electronic computing devices, **18**, 333
Electronic conductance, **6**, 391
Electronic efficiency, klystron, **7**, 304
 magnetron, **1**, 345
Electronic markers, **22**, 16
 and indices, **22**, 227–250
 movable, **20**, 222–225
Electronic phenomena, basic at high frequencies, **7**, 31–69
Electronic susceptance, **6**, 410
Electronic switches, **1**, 503–510; **22**, 128
Electronic transadmittance (*see* Transadmittance, electronic)
Electronic tuning, coefficient, **23**, 24
 hysteresis, klystron, **11**, 30
 magnetron, **6**, 592–621
Electroplating, **9**, 124–132
Electrostatic energy storage, **1**, 356
Elevation angle, true, **26**, 463
Ellipse, probable, Loran geometry, **4**, 85, 427
Emagram, **13**, 188
Emission, magnetron cathode, **6**, 352, 379
 primary, **6**, 413
Emitters, electron, **6**, 411
 metallic, high-temperature, **6**, 413
Enabling circuit (echo reducer), **16**, 300, 314
E modes (*see* Modes)
Energy, conservation of, **7**, 354
 density in waveguide, **8**, 50–54
 and impedance relations, field, **8**, 135–137
 integral, **7**, 52
 loss, pulse transformer, **5**, 626–633
 product, magnetic, **6**, 541
 reservoir, comparison of a condenser and an inductance, **5**, 23–25
 -storage units, **21**, 255
 transfer, maximum, pulse transformer, **5**, 533
Engine, cooling system, constant-temperature, **17**, 406–407
 fuel, **17**, 405
 ignition, **17**, 407
 power-supply, **17**, 401–403
 two-cycle vs. four-cycle, **17**, 405–406
ENIAC computers, **21**, 40
Ensemble average, **18**, 504, 519; **24**, 35; **25**, 266, 271–273
Entropy, **18**, 516
Envelope, Loran signal, **4**, 151, 153
Envelope-viewer, CRO, **3**, 334; **16**, 97, 373
E-plane, bifurcation of waveguide, **8**, 293
 junction, **14**, 269
  equivalent circuit, **14**, 121
 mounting, **14**, 117
 patterns, principal, of pencil-beam antennas, **12**, 422–423, 433–437
 principal, **12**, 103
 sectoral horns (*see* Horns)
 T, wavemeter on, **11**, 314–316
 T-junction (*see* Junction)
Equation, simultaneous, solution, electronic, **21**, 135
 solver (*see also* Computer), illustrative design, **21**, 133
 third-degree, fourth-degree, roots of, **21**, 263
Equisignal, Sonne, **4**, 4
Equivalence relations for free space and waveguide, **11**, 565
Ergodic hypothesis, **25**, 271–273
Ergodic system, **18**, 519
Error, curve, microwave network measurements, **10**, 136
 cyclic, **20**, 141
 deck-tilt, **1**, 309; **2**, 364
  in aircraft, **1**, 311
 gimbal inertia, **26**, 208
 gross, **20**, 156
 independent linearity, **21**, 363
 indicators, **22**, 23
 limiting, **20**, 113
 Loran, **4**, 33, 144, 157, 167, 193, 432
 measuring element, servo, **25**, 134
  systems, **25**, 77
   potentiometer, **25**, 95
 probable, in measurements, **20**, 113
 range, beacon, **3**, 472
 reset, **20**, 192
 servo, **26**, 212, 213, 215, 216, 222, 228
 signal distortion, **23**, 41
 slope, **20**, 114
 synchro, **17**, 330–331
 voltage, AFC, **16**, 295
 zero, **20**, 114
E-scope, **1**, 173; **22**, 250, 518
 hybrid RHI, **22**, 534–538
E-transformer (servo), **25**, 102

Euler's equation, **13**, 45
Eureka, **3**, 10
Evaporation coefficient, **13**, 219, 224
Evaporation duct, **13**, 329, 336, 364, 374
E-waves, **8**, 17
Excitation, space-charge tube, **7**, 99, 100–102
Excitation transform, **18**, 30
Exciter driver, Loran, **4**, 211
Exciter units, Loran, **4**, 211, 278
Expanded elevation indicator, **13**, 627
Exponential, function generator, **21**, 122
  waveform, **19**, 297–301
Extra-optical path, **13**, 6

F

Fading, **4**, 88, 90, 95; **13**, 302, 324, 335, 339, 340
  on 1.25 cm, **13**, 312
  amplitude, **13**, 307, 336, 343, 346, 348, 350
  early studies, over land, **13**, 337
  effect of path geometry, **13**, 343
  on Mt. Snowdon, **13**, 328
  period of, **13**, 304, 350
  proposed mechanisms for, over land, **13**, 339
  radar, **25**, 265
    echoes, **13**, 354, 363, 367
  as random process, **13**, 313–315, 328
  roller, **13**, 302, 304, 306, 324, 328, 335, 337–343
  ship echoes, **13**, 543
  synchronism of, **13**, 307, 328, 336, 345, 346
  wavelength dependence, **13**, 307, 324, 343, 348
Falcon radar, AN/APG-13A, **20**, 223, 225–231
Fall time, video amplifier, **23**, 215
Faltung theorem (*see also* Convolution theorem), **18**, 39
Families, of hyperbolas, **4**, 113
  Loran, **4**, 55, 99, 180
Fan beam, **1**, 22, 274–277; **26**, 30
Far-zone fields, of current distributions, **12**, 87–91
  of line-current distributions, **12**, 96–98
Far-zone region of apertures, **12**, 172
Fast-time-constant circuit, **1**, 458; **23**, 223, 374
Fast-trace pattern, Loran indicator, **4**, 65
Feed (*see also* Antenna feed), center of, **12**, 239, 343, 562
  coefficients, **12**, 259
  dipole-disk, **12**, 251–253
  double-dipole, **12**, 253–256, 434
  double-slot, **12**, 348–349
  extended, **12**, 473, 474, 477, 487–494
    dipole-array, **12**, 491–493
    horn-array, **12**, 493–494
  four-dipole, **12**, 256
  point-source, primary pattern for, **12**, 557–570
    and reflectors, **12**, 149–151
  primary, **12**, 12
    requirements, **12**, 239–240
  systems, front, **12**, 448
    rear, **12**, 347, 434, 448
  -tilt, effects, in cut paraboloids, **12**, 488, 489
      in paraboloidal reflectors, **12**, 487, 488
    impedance changes with, **12**, 488
Feedback, **21**, 16, 24, 54, 63, 129
  amplifier, **21**, 210
    integrator using inductance, **21**, 83
    RC-differentiator, **21**, 65
    RC-integrator, **21**, 79
  arrangements, microwave oscillators, **7**, 179
  cascaded counter, **19**, 626
  cathode, **18**, 336, 351
    -to-grid, **19**, 231
    -lead inductance, **18**, 675; **23**, 93
  chain, **18**, 235
    with four-terminal shunt impedances, **18**, 233
    gain, **18**, 236
    gain-bandwidth product, **18**, 238
    radar receiver, **1**, 449
    reduction of, to feedback pairs, **18**, 249
    synthesis, **18**, 249–253
    uniform, **18**, 252, 266
  change of impedance due to, **23**, 90
  circuit, *RC*-, **19**, 150–154
  cutoff frequency, **25**, 160
  derivative, **21**, 329–332
  divider chains, **19**, 599

Feedback, effect, on noise figure, **18**, 666–672; **23**, 91
undesired, in bandpass amplifiers, **18**, 323–327
energy-storage counter, **19**, 626
function, servo, **25**, 134
without high gain, **21**, 18
and implicit functions, **21**, 131
with integration, **21**, 18
inverse (*see* Inverse feedback)
loop, **18**, 384, 392
AFC, **16**, 290
methods of introducing into counters, **19**, 618
in microwave amplifiers, **7**, 152, 294–295, 301
Miller, **20**, 131; **21**, 80
time modulator, **20**, 114
negative, **18**, 428, 459; **22**, 535
networks, **19**, 242–245
one-stage, **23**, 183
pairs (*see also* Inverse feedback pairs), **18**, 134, 234
radar receiver, **1**, 449
reduction of feedback chain to, **18**, 249
resistor in, effect of capacity across, **18**, 265
synthesis, **18**, 244
phase shifting by, **21**, 150
plate-to-cathode-to-grid, **19**, 232
plate-to-grid, **19**, 226
practical considerations, **23**, 182
RC, velocity servo with, **21**, 487
resistor, between input and output, **23**, 92
tapped on coil, **18**, 266
sequence counter, **19**, 628
signal, compensation for screen current, **22**, 368
single-stage, gain, **18**, 235
system analysis, **25**, 62–75
tachometer, **21**, 329–332
T-network, **18**, 266
transfer function, **21**, 230, 266
transfer locus, **25**, 66–68
with transit angle, vector diagram for, **18**, 264
triples, **18**, 234, 250
variable negative, **18**, 95
voltage, **18**, 353
Fermat's principle, **12**, 122–125; **13**, 6, 45, 99
Fernico, **9**, 119
Ferromagnetism at microwave frequencies, **8**, 382–385
Fetch (wind), **13**, 488
Fiber-A, **26**, 379
laminates, dielectric constants, **26**, 413
stiffness rating, **26**, 416
strength rating, **26**, 416
Fiber mat, cellulosic, **26**, 379
Fiberglas, **26**, 375, 377
fabric, **26**, 377
heat-cleaned, **26**, 375
heat-treated, **26**, 375
laminates, dielectric properties, **26**, 413
flexure, **26**, 389
stiffness rating, **26**, 416
strength rating, **26**, 416
resin-impregnated, **26**, 52
Field, attenuation, **13**, 30, 31
current control of generator voltage, **21**, 57
distribution, circular waveguides, *E*-modes, **10**, 66
H-modes, **10**, 69
coaxial waveguides, higher *E*-modes, **10**, 75
H-modes, **10**, 78
lowest *E*-mode, **10**, 72
elliptical waveguides, ${}_eE_{mn}$-mode, **10**, 81
${}_eH_{mn}$-mode, **10**, 82
parallel plate guide, *H*-modes, **10**, 65
radial waveguides, *E*-type modes, **10**, 90, 93
H-type modes, **10**, 92, 94
rectangular waveguides, *E*-modes, **10**, 57
H-modes, **10**, 60
H_{10}-mode, **10**, 61
spherical waveguides, E_{mn}-mode, **10**, 97
H_{mn}-mode, **10**, 97
dominant-mode, of sectoral horns, **12**, 352, 355
equations, for cylindrical waveguide, **12**, 201–203
invariant transverse vector formulation, **10**, 3
magnetron, **6**, 217–222

Field, equations, radial waveguides, **10,** 29
fluctuations, magnetron, **6,** 222–228
intensity, sky-wave, **4,** 121
longitudinal, **10,** 5
magnetic, **10,** 5
transverse electric, **10,** 5
pattern measurements, magnetron, **6,** 710–713
representation by characteristic modes, **8,** 252–256
strength, **4,** 121
calculation, in interference region, **13,** 117–122
bilinear profile, **13,** 168
standard refraction, **13,** 112–140
at total horizon range, **13,** 125
contours, constant, **13,** 130
in surface duct, **13,** 178, 179
coverage diagram, **13,** 32
coarse, **13,** 130, 138–140
free-space, **13,** 32
generalized equation, **13,** 36
for plane earth, **13,** 39
radar, free-space, **13,** 34
depth-loss effect, **13,** 168–170
dipole, **13,** 21, 58, 65
integral for, **13,** 95, 101
free-space, **13,** 29
intermediate region, **13,** 125, 409
from $\lambda/2$ doublet, **13,** 30
level surfaces, **13,** 42
natural units, advantages, in computation, **13,** 136
space variations in, **13,** 373–385
standard, definition, **13,** 14
with standard refraction, **13,** 112
superposition of, **12,** 99–101
theory, magnetron spectrum by, **6,** 66
time-periodic, Maxwell's equations, **12,** 68
Fighter control system, IX TAC, **1,** 229
Figure of merit, amplifier, **7,** 19–22, 152
FM, **23,** 509
Filter (*see also* Network), **25,** 24–30
absorption, **9,** 707
amplifiers, **18,** 179
bandpass, electronic, **18,** 384
antihunt, use of, **25,** 215
arbitrary input, response to, **25,** 48
Filter, attenuation, average, in pass band, **9,** 603
band-rejection, **9,** 704
bandpass, electronic, **18,** 384
broadband, **9,** 709, 710
test procedures, **9,** 709–714
build-time, **25,** 142
cavity, **16,** 235
characteristics, degree of dissipation, **9,** 696
effect, of incidental dissipation, **9,** 601–609
of mismatched terminations, **9,** 609–612
clamped, stability, **25,** 251
with clamping, **25,** 245–254
constant-*k*, **9,** 569–572
CRT, **22,** 560–564
contrast, **22,** 561
dark adaptation, **22,** 564
P7 screens, **22,** 562
delay time, **25,** 142
design, assembly and test procedures, **9,** 709–715
normalization, **9,** 560–566
double-tuned, equivalent forms, **9,** 674
rectangular cavity behaving as, **9,** 675
employing transmission lines, **9,** 614–645
equations, **8,** 115–119
feedback, **25,** 124
fin TE_{11}-mode, **9,** 397
frequency-response function, **25,** 40–51
frequency-selecting, **19,** 548–551
high-pass, for d-c feedback, **25,** 126
waveguides as, **9,** 644
idealized low-pass, **18,** 722
image parameters, **9,** 554–560
linear, **25,** 28–35
response to sinusoidal input, **25,** 40–42
low-pass, cutoff frequency, **8,** 116
between detector and video amplifier, **23,** 199
ideal, **25,** 141
lumped-constant, **25,** 24–28
frequency-response function, **25,** 42–43
normal modes, **25,** 26–28
transfer function, **25,** 59–61

Filter, *m*-derived, **9**, 572–576, 702
derivation of delay line from, **17**, 210–211
microwave, design, **9**, 613–716
miscellaneous, **9**, 706–709
mode, **8**, 347–349; **9**, 707
with *n* identical sections in cascade, **9**, 577
narrow-band, **9**, 710–714
normal modes, **25**, 27
response, **25**, 26
normalized, definition, **25**, 236
notch interval, **25**, 121
parameters, **9**, 543
pass band, **9**, 557
power-loss ratio, **9**, 550, 558
selection of, **9**, 589–597
power-transmission ratio, **9**, 550
pulsed, definition, **25**, 232
repetition frequency, **25**, 232
stability, **25**, 233–236, 242–244
transfer function, **25**, 240–242
with pulsed data, **25**, 232–245
RC, two-section high-pass, graph for designing, **25**, 127
realizability of, **18**, 721–727
rejection, **24**, 346
resonant, to reduce local-oscillator noise, **16**, 243–245
response to sinusoidal input, **25**, 238–240
r-f, **3**, 144–146
band-rejection, **3**, 146
bandpass, **3**, 144
double-tuned, **3**, 145
coupled-mode, **3**, 145
high-pass, **3**, 145
single-tuned, **3**, 144
-ring transitions, **9**, 393
and servo systems with pulsed data, **25**, 231–261
slope, **24**, 16
stable, **25**, 38–40
response to arbitrary input, **25**, 48
with switches, **25**, 253–254
TE_{11}-mode, **9**, 388–400
theory, **9**, 540–612
tone, **18**, 407
transfer function, **25**, 241
transient response, **25**, 27
with transmission lines, **9**, 614–645
Filter, unstable, **25**, 38–40
using direct-coupled cavity resonators, **9**, 645–677
using lines, as four-terminal elements, **9**, 634–643
as two-terminal elements, **9**, 625–634
using quarter-wavelength couplings, **9**, 677–706, 714, 715
waveguide, **9**, 643–645
Filtering, noise, **3**, 351
in servo loop, **21**, 347
Fin TE_{11}-mode filter, **9**, 397
Finishes, microwave-component, **9**, 124–132
nonmetallic, **9**, 124, 125
Fire control, servo systems, **26**, 237
First-hop length of ray, **13**, 83
Fittings, type-N (*see* Connectors, type N)
Fix, errors, **4**, 169
navigational, **4**, 53
precision, **4**, 83
probable error, **4**, 429
relayed, **4**, 115
taking-process, **2**, 117
Fixed-channel operation, beacon, **3**, 76–79
Fixed-coil mounts for magnetic cathode-ray tubes, **22**, 541–545
Fixing, instantaneous, Loran, **4**, 366
simultaneous, Loran, **4**, 249
Flat-earth formulas, region of validity, **13**, 121–122
Flat-staggered pairs, **18**, 187–189; **23**, 166
bandwidth, small fractional, **23**, 168
exact, **18**, 188
m-cascaded, shrinking of over-all bandwidth, **18**, 187
quintuples, **18**, 193
triples, **18**, 189–191
bandwidth, small fractional, **23**, 168
F-layer, ionosphere, **4**, 128, 135
Flexible-shaft coupling, **22**, 184
Flicker effect, **24**, 95
Flight checks, quantitative beacon, **3**, 451
Flight rules, contact, CFR, **2**, 288
instrument, IFR, **2**, 288
Flights over water, information available, **2**, 112–115
Flip-flop, **1**, 497; **19**, 162; **22**, 125, 127, 128, 142, 239, 243
double (DFF), **23**, 71, **73**

Flip-flop, single (SFF), 23, 71–74
Floating-paraphase circuit, 22, 139
Flopover circuit, **1**, 497, 498–499; **22**, 126, 234, 249
Fluctuation, **24**, 36
compression, **23**, 604
strong signal, **23**, 582
clutter, **23**, 582
frequency spectrum, as Doppler beats, **13**, 516, 575
for sea echo, **13**, 516–518, 579-581
in *M*, **13**, 268–271
noise, **18**, 497
radar echoes, from aircraft, **13**, 539–543
from chaff, **13**, 551, 572–575
from complex targets, **13**, 547–550
due to, atmospheric variations, **13**, 531–535
varying ground reflection, **13**, 539
varying water reflection, **13**, 535–538
experimental techniques, **13**, 562–571
origin, **13**, 527
from precipitation, **13**, 551
from ships, **13**, 543–547
from two interfering simple targets, **13**, 549
sea echo, **13**, 486, 514–518, 551
signal, **24**, 249–252
in stable equilibrium, **13**, 270–271
statistical, **18**, 496
in unstable air, **13**, 269, 270, 375
in unstable equilibrium, **13**, 268
Fluorescence, **22**, 616, 617
Flux density, distribution, pulse transformer, **5**, 623
incremental, **5**, 537
Flux plot for typical pulse-transforming winding, **5**, 659
Flux-plotting methods, **61**, 72
Fluxes, soldering, **6**, 664–667
Flyback, **22**, 133
Flywheel, synchro motor-damping, **17**, 316, 318
FM (*see also* Modulation, frequency), figure of merit, **23**, 509
–LO method (wideband receiver), **23**, 456
range-measuring system, **1**, 143–147
FM, signal, pulsed, spectral distribution, **23**, 442
Foam, dielectric constants, **26**, 409–413
GR-N, dielectric constants, **26**, 411
hard-rubber, **26**, 379
phenolic. **26**, 379
polyester-styrene, **26**, 379
polystyrene, **26**, 379
Foaming in place, radome fabrication, **26**, 379
Focal length, paraboloid antenna, **26**, 26
Focus, coils, **22**, 93–105
construction, **22**, 707
current control, **22**, 98–102
impregnation, **22**, 719–721
mechanical adjustment, **22**, 103–105
performance, **22**, 96–98
types, **22**, 95
compensation, **22**, 102, 440
magnets, **22**, 105–110
construction, **22**, 708
magnetization, **22**, 710
operation, **22**, 105
shunt, **22**, 708
modulation, **19**, 716
voltage, **22**, 723
characteristic, **22**, 68
Focusing lens, **22**, 48
magnetic, **22**, 43
magnetostatic, **22**, 43
systems, **22**, 43–46
Fog, advection, **13**, 230
and fading, **13**, 346
vs. poor visibility and substandard transmission, **13**, 324
Follow rate, **23**, 50
Follow-up systems, **20**, 395–397; **25**, 1
Follower (of three-dimensional cam), **27**, 23
Form factor, alternator waveshape, **1**, 557
Formvar, **17**, 150–151
Forward Director Posts, **1**, 229–240
Fosterite varnish, **5**, 557, 649, 650
Foster's theorem, **5**, 193, 194; **8**, 97, 156–158
Four-junctions, degenerate, **8**, 313–315
equivalent circuit, **8**, 298
with small holes, **8**, 311–313
Four-terminal waveguide structures, **10**, 217–335

Fourier analysis, **6**, 340
Fourier integral, **18**, 2; **25**, 43–48
  representation of Fraunhofer region, **12**, 174–175
Fourier series, **5**, 187; **18**, 2; **25**, 43
Fourier transform, **10**, 164; **18**, 1, 59–63; **21**, 231; **25**, 45
Fractional modulation, **24**, 4
Fraunhofer region, **12**, 160–162, 172
  criteria for, **12**, 198, 199, 561, 574
  Fourier integral representation, **12**, 174–175
Free-running circuit, **19**, 162
  gratings in, **10**, 88
Free space, plane waves in, attenuation constant, **10**, 87
  propagation range, **13**, 31–33
  system, frequency consideration, **3**, 63
  transmission, **13**, 27–34
  as uniform waveguide, fields in, **10**, 84–88
Frequency, channels for single-band microwave systems, **3**, 75
  choice, beacon, **1**, 260; **3**, 29, 63–73
  complex, **6**, 300, 306, 357
  conversion (*see* Conversion)
  dependence, of lossless junctions **8**, 151,
    of symmetrical junctions, **8**, 476–479
  determination, CRT circular sweep, **19**, 704
  diagrams, decibel vs. log, **21**, 271, 304
  -difference measurements, **11**, 453; **14**, 391
  discrimination, **21**, 46; **24**, 362
  divider (*see* Divider, frequency)
  division, **19**, 225; **20**, 81–89
    pulse-recurrence (*see* Division, PRF)
    use of time selectors in, **19**, 569
    using resonant stabilization, **19**, 595–599
  doubler, **4**, 207, 219
  -doubling, klystron, **7**, 400
  jitter, in PRF dividers, **19**, 568
  marker, active, **18**, 305
    blanking, **18**, 306
    passive, **18**, 305
  measurements, **11**, 343–407, 453
    equipment and techniques, **11**, 392–407
    oscilloscopic, **19**, 702–706
Frequency, measurements, spectrum, **11**, 393–395, 408–469
  multiplication, **11**, 33
    chain, klystron, **7**, 286
    in detector crystals, **7**, 24
  multiplier, klystron (*see also* Klystron, frequency multiplier), **7**, 22, 285–294
    microwave, **7**, 23–25, 232
    push-pull, **11**, 368
    push-push, **11**, 368
    sinusoidal, **19**, 545
    vacuum-tube, **11**, 365–373
    velocity-modulated, **11**, 373
  plots, decibel-log, **21**, 328
  pulling, **12**, 538
    by reactive load, **11**, 291–293
  pulsing, **24**, 18
  -response function, filter, **25**, 40–51
    lumped-constant filter, **25**, 42–43
    and weighting function, relation between, **25**, 48–50
  sensitivity, magnetron output, **6**, 189, 482, 582
  -shifting, spontaneous, **3**, 237
  sink, Rieke diagram, **6**, 328
  spectrum, **24**, 138, 140, 141
    for precipitation echo, **24**, 140–141
    for sea echo, **24**, 142
  stability, klystron, **7**, 179, 191, 328
    magnetron, **6**, 35, 408, 409
    oscillator, **3**, 256, 259–261, 303, 310, 366; **9**, 83; **16**, 212; **19**, 103, 128
  stabilization, magnetron, **6**, 402, 622–645
    microwave, **11**, 67
    oscillator, **19**, 128
  standard, broadcasts, **11**, 353
    crystal (*see* Crystal frequency standards)
    microwave, **11**, 344
      design considerations, **11**, 345–347
      Radiation Laboratory, **11**, 347–375
    primary, **11**, 343–347
    secondary, **11**, 375–384
  synchronizer, reactance-tube-controlled, **19**, 554
  tracking, electronic, **20**, 522
  -tripling, klystron, **7**, 400
Fresnel diffraction, **13**, 412

Fresnel equations for specular reflection, **13**, 396
Fresnel integrals, **13**, 477
Fresnel region, circular aperture, **12**, 196–199
general characteristics, **12**, 171–172
Fresnel zones, **12**, 196; **13**, 417
on targets, **13**, 464, 468
Friction, Coulomb, **21**, 357; **26**, 220, 226
dynamic, **21**, 357
lumpy, **21**, 357
measurement, **21**, 460
static, **21**, 357
viscous, **21**, 357, 452; **26**, 212, 216, 218, 221, 226
-wheel integrators, **27**, 24
Frictional influence, layer of, **13**, 213, 231
Front-feed systems, **12**, 448
Frontal inversion, **13**, 263
Frontal passage, **13**, 264
Frontal surface, **13**, 263
Fronts, effect on propagation, **13**, 263, 319, 325, 331, 347
Fruit, CRO, **3**, 75, 222
𝔉-transform, **18**, 59
Full-cycle charging, line-type pulser, **5**, 394–397, 449
Function, factorization, **27**, 168–174
generated by three-bar linkage, **27**, 122–127
generation (*see also* Addition; Multiplication; Roots), **21**, 90–128
generators, **21**, 90–128; **27**, 1
bar-linkage computers, **27**, 27–42
compared with integrators, **27**, 23
grid structure, **27**, 228–233
ideal, **27**, 233
immittance, **21**, 230
implicit, and feedback, **21**, 131
mechanization (computer) (*see* Mechanization of function)
miscellaneous, **21**, 120–128
with two degrees of freedom, **27**, 284–299
of two independent parameters, **27**, 224
of two independent variables, **27**, 23, 223
unit, automatic time measurement, **20**, 277, 279, 280, 305–308
Fungus growth, protection against, **9**, 125

G

$\tilde{G}$, G (*see also* Spectral density), **25**, 313, 317–321
Gain, antenna, **1**, 19; **2**, 16; **3**, 125; **11**, 899; **12**, 3, 90, 99, 177; **13**, 28–29, 31; **26**, 10
absolute, **12**, 90
comparison, **12**, 581
dependence on aperture illumination, **12**, 177–178
determination, by mirror method, **11**, 911–914
by pattern integration, **11**, 914
by reflection method, **12**, 585–586
directive, **12**, 580–581
effective, **12**, 583
factor, **11**, 899; **12**, 178, 425
vs. aperture illumination, **12**, 187, 195
function, **2**, 90, 94
for aperture, **12**, 162
scattering, **12**, 590
measurements, **11**, 907–912; **12**, 580–586
parabolic cylindrical, **12**, 457–458
pencil-beam, **12**, 423–432
scattering pattern, **12**, 468
sectoral horns, **12**, 587
standard determination, **12**, 582–585
standards, secondary, **12**, 586
balance, Loran, **4**, 389, 393
-bandwidth, factor, amplifier, **18**, 172, 205, 287–290
feedback chain, **18**, 268
flat-staggered *n*-uple, **18**, 176
increase due to overstaggering, **18**, 287
synchronous single-tuned amplifiers, **18**, 172
transitionally coupled double-tuned circuit as function of Q-ratio, **18**, 206
various interstage coupling schemes, **18**, 288
product, **7**, 19–21; **18**, 171, 172; 297, 298; **23**, 177
double-tuned stage, **1**, 447
feedback chain, **18**, 238
maximum, **18**, 82
single-tuned stage, **1**, 446

Gain, control, amplifier, **18**, 93–96, 290; **23**, 168, 182, 238–252
automatic (*see* AGC)
effect on noise figure, **18**, 717
instantaneous automatic (*see* IAGC)
manual, **23**, 238
stagger-tuned amplifiers, **18**, 191
time-varied, **24**, 303, 311–313
limited receiver, **23**, 277
storage, **1**, 44
voltage-amplifier, **7**, 252–257
Galvanometer-amplifier, **11**, 499
Roberts, **21**, 517, 518
Gamow mode, **13**, 83, 309
Gamow phase-integral method, **13**, 151, 167
Gap (*see also* Klystron; Magnetron), admittance, **7**, 50, 68, 144
beam current, **7**, 32
conduction current, **7**, 36
current density, total, **7**, 37, 84
d-c gap field, **7**, 46
high-velocity, **7**, 54
low-velocity, **7**, 60
d-c conditions, **7**, 62, 129, 140
pulser (*see* Spark gap)
resonator, driving current, **7**, 32, 42, 43, 49, 58, 98, 338, 340, 345
displacement current, **7**, 36
rotary (*see* Spark gap, rotary)
transit angle (*see* Transit angle, gap)
voltage, **7**, 49, 133, 232–240
characteristics, finite, **7**, 218–224
momentary, **7**, 446
spectrum, **7**, 480
Garlock Klozure (oil seal), **26**, 140
Gas, discharges, microwave, **14**, 139–225
focusing, klystron, **7**, 212
tubes, **17**, 610–613
cold-cathode, **19**, 592
control circuits, **23**, 56–64
Gate, **24**, 26, 343
for crystal protection, **14**, 424
feedthrough, **22**, 476
generator multivibrator, **20**, 117
pulse-selecting, 6-μ sec, **20**, 152
Loran timing, **4**, 210, 231, 246
-pulse mixer, **4**, 199, 227
selecting, **20**, 151
Gating, **22**, 223; **24**, 253
circuits, **19**, 364
Gating, signal, **22**, 123
system, automatic tracking, **2**, 205
Gaussian distribution, **24**, 46–50
n-dimensional, **24**, 47
one-dimensional, **24**, 46
two-dimensional, **24**, 49
Gaussian error curve, **18**, 80, 81, 721, 723
GCA (ground control of approach), **2**, 227, 237–251; **13**, 432; **26**, 86, 188
advantages and limitations, **2**, 248–251
AN/MPN-1, **1**, 211
antenna beam coverages, **2**, 242
azimuth and elevation assemblies, **2**, 244
presentation, **2**, 241, 245–247, 249
GCI (ground control of interception), **3**, 8; **26**, 12, 231
Gears, **21**, 55, 59
boxes, aircraft, dual-outlet, **1**, 560
differential, **21**, 39
motor, **17**, 389–390
ratios, **21**, 355
trains, **25**, 130–133
lubrication, **26**, 169
Gee, **2**, 60–64; **3**, 17, 26; **4**, 9, 11, 17, 22, 80, 100; **20**, 30, 34, 261
lattice, **4**, 11
Generation, of functions (*see also* Addition; Multiplication; Roots), **21**, 90–128
harmonic, **19**, 546–548
Generators, **17**, 408–417
400-cps, permanent-magnet-field, **1**, 585
a-c, type of excitation, **17**, 411
aircraft, voltage waveshape, **17**, 422–423
aircraft (*see also* Alternators; Dynamotors), **17**, 413–417
dual-purpose, **1**, 560
amplidyne, **21**, 437
angle information, **20**, 458
angle-sweep, SCR-598, **19**, 460
azimuth-marker, **19**, 345
bearings and lubrication, **17**, 367–370, 412
boxcar, **24**, 28
brush wear, **17**, 424–425
compound-wound, **17**, 409–410
controlled, **21**, 401, 436

Generators, crystal-controlled range mark, TS-102/AP, **21,** 662
d-c, type of excitation, **17,** 410–411
delay-line pulse, and blocking oscillators, **19,** 205–253
delayed-pulse, **21,** 591
delayed-trigger, **22,** 281
Diehl, **20,** 424
differential, **26,** 225
drag cup, **21,** 75
dual-voltage, **17,** 415–416
electromagnetic, **21,** 74
enclosures, **17,** 412
engine-driven automatic controls, **17,** 408
heavy-duty, **17,** 401–402
maintenance, **17,** 408
portable, **17,** 402
power required, **17,** 405
speed of operation, **17,** 407–408
type of duty, **17,** 404–405
ultraportable, **17,** 402–403
function (*see also* Addition; Multiplication; Roots), **21,** 90–128
grouped-marker, **20,** 106–110
grouped pulse, **20,** 400
i-f pulse, **23,** 311
induction, **21,** 75, 86
linear-sawtooth, bootstrap, **20,** 151, 347, 358
positive-feedback, **20,** 225
linear sweep, **20,** 153
Loran, 90-kc/sec, **4,** 291
fast-sweep, **4,** 199, 205, 212, 227, 228, 255
pulse-signal, **4,** 395
r-f, **4,** 293
marker, **22,** 283
20-mile, **20,** 85
multiple-frequency, **20,** 81
and trigger, **20,** 81–106
single-frequency, **20,** 69–81
noise (*see* Noise generators)
permanent-magnet, **17,** 372, 374–376
phantastron-gate, **20,** 104
pulse (*see* Pulse generators)
range-mark, **20,** 69
ratings, **17,** 409
rectangle, **20,** 222
rectangular-wave, **22,** 123–128, 140, 432, 526
Generators, sawtooth, **1,** 510–514; **22,** 132–139
bootstrap, **22,** 135–138
linear, **20,** 151, 347, 358
SCR-598, **19,** 460
series-wound, **17,** 409
shunt-wound, **17,** 409
signal (*see* Signal generator)
single-stroke, **1,** 496
sinusoidal waveform, **19,** 101–158
slow-sweep, **4,** 209, 212, 229; **16,** 314, 316, 326
specifications, **17,** 408–413
square-wave, **4,** 203, 209, 223
sweep, **4,** 212; **21,** 595, 603, 611, 614, 618, 626, 642, 647; **22,** 266, 274, 360, 435
bootstrap, **22,** 367
exponential, **20,** 144
Loran, **4,** 212
shutoff, automatic, **22,** 508
synchro, **22,** 185; **17,** 313, 316–317; **26,** 224
differential, **17,** 314
tachometer, **22,** 219
time-base, **22,** 258
time-mark, **19,** 727
time-marker, **20,** 108
triangle, bootstrap, **20,** 125–131
accuracy tests, **20,** 129
trigger, **22,** 118–123, 255, 262, 272
multiple-frequency, **20,** 81
tube-oscillator high-voltage, **22,** 173
video pulse, **21,** 593
voltage control (*see also* Governor; Voltage regulation), **17,** 411–412, 418–420, 445–454
carbon-pile, **17,** 446–451
by field current, **21,** 57
Ward Leonard, **21,** 401
Geodetic reference points, **4,** 193
Geometrical optics, **13,** 4, 6, 41–58
back scattering, **13,** 461, 465–468
Geometrical precision, hyperbolic family, **4,** 72, 102, 425
Germanium (*see also* Crystal; Detector; Rectifier; Semiconductor), **15,** 10, 21, 398–416; **19,** 69, 331, 408, 608; **20,** 91; **23,** 11
addition agents for, **15,** 308
back current, **15,** 374

Germanium, cartridge, **15**, 328
characteristic constants, **15**, 61
etching, **15**, 316, 369
forward conductance, **15**, 373
heat treatment, **15**, 316
i-f impedance, **15**, 382–384
ingot, preparation, **15**, 308–313, 364–369
life tests, **15**, 377
photoelectric effects, **15**, 393–397
polishing, **15**, 316
purification, **15**, 304–306
rectifier, **15**, 10
noise temperature, **15**, 35
welded-contact, **15**, 21, 398–416; **16**, 87–93, 104, 365, 367
surface treatment, **15**, 369
Ghost, **22**, 59
Loran, **4**, 101, 250
Gibbs phenomenon, **5**, 187
Gimbal inertia error, **26**, 208
Glass, dielectric constant, **14**, 39; **26**, 409
laboratory, **6**, 679, 680
layer, **22**, 645
loss tangents, **26**, 409
low-Q, window, leakage, **14**, 233
for magnetrons, **6**, 483, 487
seal, Kovar-to-, **6**, 483
magnetron output, **6**, 482
secondary-emission coefficients, **19**, 709
windows, resonant, **14**, 102
Glide-path, facilities, POPI, **4**, 13
system, **2**, 227
Glow tubes, drift, **21**, 500
modes, **21**, 499
regulator, **21**, 530
temperature effects, **21**, 499
Goniometer, **20**, 240; **21**, 105
inductance, **20**, 158, 161
phase-modulating, **20**, 154
Governor, centrifugal carbon-pile, **17**, 430
Lee centrifugal, **17**, 392–395
motor-speed, **17**, 392–395
GPI (ground position indicator), **1**, 216; **2**, 122–128; **20**, 251; **21**, 173
Gradient operator, **10**, 4
Gradients, meteorological, **13**, 192, 193, 198, 267
Grating, and arrays in free space, **10**, 280–295
in free space, **10**, 88
Grating, quarter-wave, **12**, 447
reflectors, **12**, 449–450
Gravitational waves, **13**, 346
Grazing angle, **13**, 108, 114, 115
Grazing path, **13**, 6
Green's function, **10**, 162
Green's theorem, **8**, 44, 51
scalar, **12**, 108
vector, **12**, 80
Grid, bias, microwave-tube, **7**, 176, 193
characteristics, pulsed, **19**, 81
circuit, delay-line, **18**, 131, 145
current, **18**, 349, 418–421
klystron, **7**, 107
negative, **18**, 418
nonlinearities, 6SN7, **19**, 80
photoelectric, **18**, 419
positive, **18**, 419
emission, **18**, 419
generator, computer, definition, **27**, 225
gauging error, **27**, 281–283
for given function, **27**, 225
mechanization of function by, **27**, 238
nonideal, **27**, 238–242
star, with almost ideal grid structure, **27**, 250–284
structural error, **27**, 226
grounded (*see* Grounded grid)
klystron, **7**, 500
-leak bias, microwave-tube, **7**, 175
noise, current, **7**, 107–109, 117, 120
induced, and shot noise, correlation between, **18**, 677–682
partition current, **7**, 108
-plate capacitance, **7**, 184
pulsing, **3**, 288; **7**, 187
-screen regions, microwave-tube, **7**, 115
-separation amplifier (grounded grid), **7**, 146
structure (computer), function, **27**, 228–233
generalized, **27**, 243
ideal, **27**, 229–230, 233–238, 240
star-grid generators with, **27**, 250–284
nonideal, **27**, 230–233, 241, 284–299
regularized, **27**, 239–242
transformation of, topological, **27**, 232–233, 239, 244, 246, 249, 251
use of, in linkage design, **27**, 243–249

Grid, transadmittance, microwave-tube, **7**, 107–109
GR-N foam, dielectric constants, **26**, 411
Ground, circuits for i-f stages, **23**, 266
  clutter (*see* Clutter)
  control-of-interception (GCI), **3**, 8; **26**, 12, 231
  currents, **23**, 261
  -position indicator (GPI), **1**, 216; **2**, 122–128; **20**, 251; **21**, 173
  return, **1**, 92, 154
  speed measurement, **2**, 105
    Doppler method, **2**, 110
    over water, **2**, 110
  target area, effective, **12**, 469
  track, **20**, 23
  virtual, **20**, 294, 295
  wave propagation, **4**, 60
Grounded cathode, **18**, 634, 652; **23**, 83, 126
  grounded-grid, **18**, 616, 645, 657, 660, 661; **23**, 117
  input circuit, **18**, 646
  pentode, **18**, 644
  triode, **18**, 645
Grounded grid, **18**, 634, 648, 652; **23**, 83, 135
  amplifier as feedback amplifier, **23**, 92
  triode, **18**, 645
Grounded plate, **18**, 648, 652; **23**, 83
  -grounded-grid triode, **18**, 645, 664
Group velocity, propagation, **4**, 129
GR-S cyclized rubber, **26**, 371
Guide (*see also* Waveguide), chamfered, waveguide window, **6**, 488
Guided-wave concept, **9**, 36–40
Guillemin networks (*see* Network)
Guillemin's theory, **5**, 189–207
Guillotine attenuator, **11**, 787
Gyroscope, **21**, 77, 88; **26**, 194, 196, 197, 202, 206
  erection mechanism, **26**, 202

H

Habann-type oscillations, **6**, 4
Hailstones, attenuation by, **13**, 25, 687
  echoes, **13**, 619
Hair hygrometer, **13**, 182
Half-cycle charging, **5**, 397–400
Half-period zones, **13**, 413
Half-power points, **14**, 389
Half-wave amplitude-selector circuits, carrier-balanced, **19**, 391
  unbalanced, **19**, 390
Half-wave charging, single-phase, **5**, 476–478
Hall coefficient, **15**, 53–61
Hall effect, **15**, 54
Hankel function, **10**, 43
  amplitude, **10**, 44
    and phase, **8**, 246
  modified, of order one-third, **13**, 94
  phase, **10**, 44
    spherical, **10**, 54
Harmonic, analysis for stationary random processes, **25**, 270–291
  analyzer, Coradi, **25**, 283
  bunching, **7**, 281
  chokes, **16**, 174–178
  content, klystron-tube, **7**, 207, 209, 217, 239, 240, 245
  generator, **16**, 3–4
    crystal rectifier, **11**, 373; **15**, 173
    frequency range covered, **11**, 374
    welded-contact rectifier, **15**, 398, 415
  "hash," **16**, 298
  i-f, **23**, 41
  mixer, **16**, 61, 82, 285, 301, 372, 374; **23**, 19
  ratio, **23**, 46
  reinforcement in frequency conversion, **15**, 114, 167–170
  shutters, **16**, 174–178
  transformer (computer), **27**, 27, 34, 36, 58–106
    double, **27**, 36, 77–106
    functions, tables, **27**, 63–67, 301–332
    ideal, **27**, 58–67
      double, **27**, 77–95
      in homogeneous parameters, **27**, 62–63
      monotonic functions mechanized by, **27**, 78, 82–88
    mechanization of function by, **27**, 61–63
    monotonic functions, **27**, 78, 82–88
    nonideal, **27**, 58–60, 67–77, 249
      structural error, **27**, 59, 64, 67–75
    nonideal double, **27**, 95–102
    nonmonotonic function, **27**, 89–91
    parameters, **27**, 61

Harmonic, transformer, in series, **27,** 77–106
two, with three-bar linkage, **27,** 166–195
usage, **27,** 61–62
Hart inversor, **27,** 30
Hartree diagram, **6,** 30, 341
Hartree's condition, **6,** 340
Hash, **3,** 75
Haze layers and signal fluctuations, **13,** 346
H + *B* triangle solutions, **21,** 40
Heading marker (data take-off), **26,** 168
Heat, capacity of air, **13,** 293
convection, **21,** 675
dissipation in beacon packaging, **3,** 359
latent, **13,** 183
radiation, **21,** 674
vaporization of water, **13,** 188, 293
Heater, construction, cathode, **6,** 687–693
open, magnetron cathode, **6,** 736
power, magnetron, **6,** 402, 411
rated, magnetron, **6,** 528
-voltage variation, effect on amplifier, **18,** 353, 421–424
Heating from below, **13,** 193, 220–223, 227, 228, 300, 364
Heaviside calculus, **21,** 229
Heaviside unit function, **21,** 235
Height as function of wavelength, **13,** 123
natural unit, **13,** 96
Height finders, **2,** 207–227
AN/TPS-10, **1,** 191
beavertail, 10-cm, mount, **2,** 218
CMH, **1,** 188
Height-finding, **1,** 184–196; **12,** 467; **26,** 85
accuracy, absolute and relative, **2,** 212
effect of elevation beamwidth, **2,** 213
by elevation scanning, **1,** 189
methods, **2,** 207
long-wave, **2,** 208
pencil-beam with conical scan, **2,** 210
V-beam, **2,** 211; **26,** 85, 89
vertically scanned beams, **2,** 210
by null readings, **1,** 184
by searchlighting, **1,** 187
by signal comparison, **1,** 185
system, combined with plan system, **1,** 192
Height-gain effect, **13,** 10, 304, 307, 350, 375, 378
Height-gain function, **13,** 22, 65, 78, 86, 112, 122, 128, 141–142, 145, 164–168
Height-indicator, scale, **22,** 565
V-beam, **1,** 547; **2,** 211; **26,** 85, 89
Height indices, **1,** 518–524
Height-loss effect, **13,** 10
Height markers, **22,** 521
movable, **1,** 520
Height measurement, **22,** 517
by radar, errors, from refractive effects, **13,** 385, 436
Heil tube, **7,** 29
S22A, **7,** 30
Helical-spring r-f contact for attenuators, **11,** 714
Helipot, **21,** 368
Helmholtz coil assembly, **20,** 137
Hertz vector, **8,** 21; **13,** 58–60
Hertzian dipoles, free-space transmission equation, **13,** 32
Heterodyne detection, **24,** 10
High-frequency a-c motors, **17,** 379–381
High output-voltage circuit, **18,** 144
Hinge joints, waveguide, **9,** 438–442
Hipersil, **17,** 145–149
H modes (*see* Modes)
HN connectors, **9,** 260
Home Chain, British (CH), **1,** 175–180, 226
Homing, on aircraft, **1,** 200
ASD, **1,** 199–203
with gee, **2,** 63
radar, ASE, **1,** 196
ASG, **1,** 199
ASH, **1,** 199
on surface target, **1,** 196
techniques, **4,** 16
Homogeneous parameters, **27,** 43, 47–49, 62–63, 68–71
ideal harmonic transformer expressed in, **27,** 62–63
Homogeneous variables, **27,** 43, 47–49, 62, 64–67, 78, 79, 87, 89, 171
Horn, **2,** 15, 16; **26,** 158, 174
arrays, **12,** 319
biconical, **12,** 9
box, **12,** 377–380
compound, **12,** 350, 376
E-plane, **11,** 906

Horn, *E*-plane, phase center, **11,** 906
phase front, **11,** 906
power pattern, **11,** 906
radiation pattern, **11,** 906
as extended feeds, **12,** 493–494
feeds, **12,** 334–387
pyramidal, **12,** 587
sectoral, *E*-plane, admittance characteristics, **12,** 369–374
modes in, **12,** 350–354
mouth admittance, **12,** 369
radiation from, **12,** 357–365
tenth-power widths, **12,** 364, 365
throat transition, **12,** 369–371
transmission-line equations, **12,** 366–369
H-plane, admittance characteristics, **12,** 374–376
modes in, **12,** 355–357
mouth admittances, **12,** 375
radiation from, **12,** 358–365
tenth-power widths, **12,** 365
throat transition, **12,** 375
HR radar system, **20,** 163
H-systems of navigation, **3,** 15–17, 426; **4,** 9
Hue, **22,** 659
Hulsmeyer patent, **1,** 13
Hum, AFC, **16,** 349
reduction, multivibrator, **19,** 194
synchroscope, **22,** 266
Humidiometer, Gregory, **13,** 289
Humidity, **13,** 182, 206
absolute, **13,** 182
deficit, **13,** 222, 224, 229
10-per cent rule, **13,** *227, 228, 300*
-effect nomograph for cavities, **11,** 391
and refractive index, **13,** 181–193
relative, **13,** 182, 184, 206
specific, **13,** 185, 187, 188, 206, 218
and temperature in lower atmosphere, instruments to measure, **13,** 272–293
Hunting, AFC, **16,** 295, 331
Hurricane study by radar, **13,** 23, 636–640
Huygens' principle, **13,** 412, 454
Huygens-Fresnel principle, **12,** 108
H_2X, **20,** 119
range phantastron, **20,** 122
range unit, **20,** 120, 123
H_2X, time modulator, **20,** 121
H_3X, **20,** 386–388
H-waves, **8,** 17
Hybrid coil, **8,** 307; **10,** 128; **11,** 546; **16,** 267
Hybrid junction, **10,** 386
Hybrid time and phase discriminator, **20,** 97
Hydraulic devices, **21,** 397
Hydraulic servos, **21,** 398
Hydrogen bottle for brazing, **6,** 669
Hydrogen thyratron (*see* Thyratron, hydrogen)
Hydrostatic equilibrium, **13,** 220
Hygraph, Loran, **4,** 186
Hygrometer, dew-point, **13,** 182, 186
electrolytic, **13,** 182, 284, 286
Hyperbolas, **4,** 11, 70
families of, **4,** 113
spherical, **4,** 72, 175
waveform generation, **19,** 301–305
Hyperbolic, course, **3,** 16
line of position, **4,** 10
navigation, **2,** 56–60; **3,** 17; **4,** 17, 19; **20,** 261
accuracy, **2,** 77
positional, **2,** 59
automatic piloting, **2,** 82–85
Gee, **3,** 17
range, **2,** 77
surveying, **4,** 117
track, **4,** 16
Hysteresis, d-c motor, **21,** 360
electronic-tuning, **11,** 30
loop (*see* B-H loop)
loss, **5,** *627*
nonlinear characteristic, **19,** 41, 85, 165
in reflex klystrons, **7,** 384–403
tachometer, **21,** 75

I

IAGC (instantaneous automatic gain control), **1,** 459; **23,** 248, 369–371; **24,** 302, 345
receiver, **23,** 601
Ice, crystals, attenuation by, **13,** 687–688
echoes from, **13,** 618
index of refraction, **13,** 686
point, **13,** 292
Iconoscope, **19,** 707

Ideal observer, criterion, **24**, 168
theory, **24**, 167–173
Ideal transformer, three-winding, **10**, 127
Identification, beacon, **3**, 19, 30
blinker, Loran, **4**, 256
complementary (computer), **27**, 49
direct, **27**, 48–49
Identity operations, **21**, 32, 60–63
change, impedance, **21**, 61
of representation, **21**, 62
scale, **21**, 61
voltage-level, **21**, 60
I-f, admittance, **16**, 71–75, 79, 105, 253, 277, 359
output, **16**, 90, 178–185
amplifiers (*see* Amplifiers)
bandwidth, **24**, 199–210, 239
capacitance, **16**, 129
choice of, **1**, 444; **23**, 158–160
conductance, **16**, 111, 249, 360
coupling circuit, **16**, 271
impedance, **16**, 256
output lead, **16**, 128–131
overloading, **24**, 343–347
rejection ratio, Loran receiver, **4**, 389
resistance, **16**, 115
spectrum, **16**, 302
strip, bent, **23**, 264
IFF, **1**, 251; **2**, 42; **3**, 8, 19
Illumination, aperture, beamwidths vs., **12**, 179, 183–187, 195
dependence of gain on, **12**, 177–178
gain factor vs., **12**, 187, 195
side lobes vs., **12**, 179, 187, 195
binomial, of broadside arrays, **12**, 269
gabled, of broadside arrays, **12**, 269
Image, current density, CRT, **22**, 53
of dipole radiators, **12**, 135–137
frequency, **16**, 27, 60, 256, 276, 358, 362, 364, 365; **23**, 17
termination and conversion loss, **16**, 75–83
higher-order, frequency spectrum, **11**, 416
principle of, **12**, 132–137
for dipole sources, **12**, 135–137
reflection, **16**, 367
-rejection ratio, Loran receiver, **4**, 388
response, **16**, 26
termination, **16**, 62
Immersion-lens system, **22**, 44
Impedance, a-c, line (*see* Line, impedance)
bridge, **11**, 446, 515–560; **14**, 395
basic measuring techniques, **11**, 530–537
built-in calibrator, **11**, 558
calibration, **11**, 556–559
elements, **11**, 516–530
line-component, **11**, 540–545, 549, 554
magic-T, **14**, 395
for measuring phase shift, **14**, 403
with modulation frequency discrimination, **11**, 543–548
multifrequency, **11**, 537–543
with panoramic receiver, **11**, 539
with panoramic receiver, **11**, 552–556
pulse-modulated, **11**, 538, 548–552
single-frequency, **11**, 530
sources of error, **11**, 559
typical, error, **11**, 560
changer, **18**, 430; **22**, 114–116
changes, with feed tilt, **12**, 488
chart, rectangular, **8**, 74; **9**, 72
Smith, **8**, 73, 226; **9**, 60–67
use of, **9**, 457–460
-circle diagrams, **11**, 697
delay lines, **1**, 671
discontinuity in klystron output line, **7**, 427
and energy relations, field, **8**, 135–137
free space, **9**, 58
gap, and admittance, **7**, 110
i-f, **16**, 256
image, microwave filter, **9**, 554–557
network, **8**, 114
input network, determination, **9**, 583–586
prescribed, **9**, 586–589
internal, pulser, **1**, 366
VR tube, **21**, 530
intrinsic, *TEM* wave, **8**, 19
iterative network, **8**, 113
loss, **16**, 66, 68, 80, 89
low-pass filter, **8**, 66, 115, 116
-matching, **5**, 4, 9, 13, 16, 227; **8**, 179–187; **9**, 4, 59–100, 209–218
beacon oscillator, **3**, 285
cable, **5**, 671, 677
hard-tube pulser to load, **5**, 70–76
methods of achieving, **9**, 86

Impedance, -matching, transformers, **9,** 90–95
transmission-cable use in measurements, **5,** 669–673
matrix, **8,** 87, 140; **10,** 103
measurement, **9,** 18; **19,** 706
apparatus, **12,** 547
of ATR tubes, **14,** 397
input-output, network, **10,** 131
microwave, **6,** 705
probe errors in, **12,** 548, 556
mismatch with long cable, reflection effects of, **5,** 84–89
mutual, mesh, **8,** 86
network, **8,** 84; **18,** 4, 5
reciprocal, **9,** 544
nonlinear, **21,** 503
normalization, **9,** 561
open-circuit, network, **9,** 542, 555
oscillator, magnetron, **6,** 36
polyiron, in coaxial line, **11,** 724
in waveguide, **11,** 727
pulser load, **7,** 187
short-circuit, network, **9,** 555
source of low, **18,** 366
spheroidal dipole, **12,** 249
static input, magnetron, **6,** 401
transformation, ratio, of transformer, **5,** 10
by transmission line, **8,** 67–69
transformers, variable, **9,** 456–516
transmission line (*see* Line, transmission)
transverse wave, **12,** 209
wave, **8,** 18; **9,** 37, 41, 53, 647
TEM, **8,** 18
Implicit-function, loops, stability, **21,** 21
techniques, **21,** 15
Impregnation compound, **22,** 719
Impulse function, **22,** 357
Incidence, angle of, measurement, **11,** 602
arbitrary, measurements at, **11,** 599–604
far from normal, **11,** 613
normal, measurements at, **11,** 593–599
Incoherent scatterers, **13,** 588–591, 699–706
Index of refraction (*see also* Dielectric constant), additivity rule, **13,** 190
air, **4,** 129; **13,** 6, 189
Index of refraction, atmospheric, constancy, in microwave region, **13,** 641, 643
complex, **13,** 448
dependence on meteorological parameters, **13,** 13, 191
dielectric, **8,** 366
effective, **26,** 352
and humidity, **13,** 181–193
ice, **13,** 686
modified, **13,** 12, 50, 53, 191, 192
gradient, **13,** 192
inadequacy, over land, **13,** 352
profile, bilinear, analytical statement, **13,** 142
idealizations and definitions of types, **13,** 14
nonlinear, **13,** 174
radome materials, **26,** 266, 343, 345
variable gradients, **13,** 9. 192
water, **13,** 609–613, 674–676
Indication, azimuth-elevation, **22,** 22
moving-target (*see* MTI)
on-target, **20,** 328
true-bearing, **1,** 311
type C, **22,** 22
Indicator, **24,** 2
Air-Position, Bendix, **20,** 251
angular resolution, **22,** 35
classification of, **1,** 164
design considerations, **2,** 148–153
Gee, **4,** 11
ground position (*see* GPI)
Loran, **4,** 100
direct-reading, **4,** 104
plan-position (*see* PPI)
position error, **20,** 367
presenting search and height data, **2,** 223
projection, **22,** 579–584
radar, **1,** 161–175; **2,** 7, 26–36; **3,** 377–384; **20,** 108
radial time base, **1,** 174
range-height (*see also* RHI), **24,** 22
remote, **22,** 191
response of, in line measurements, **12,** 549
right-left, **4,** 110
self-synchronous, **22,** 25
for shipborne navigational radar, **2,** 373–377

Indicator, spot error, **1,** 175
-Tracker Unit BC-1365, **20,** 255
two-trace, **4,** 21, 22
type B precision, **20,** 255
type C, **24,** 22
type M, **20,** 223
types, **2,** 30–36
Indices (scale markers), **1,** 163; **20,** 180–184; **22,** 15
angle generator, photoelectric, **22,** 230
derived, **22,** 249
fixed, **20,** 181
flashing, **22,** 229
generation of, **20,** 69–110
for manual time measurement, **20,** 215
movable, generation, **20,** 111–175, 182
range and angle, **1,** 513–524
single-scale circuits, **20,** 111–114
slow-scan, **22,** 229–238
substitution, **22,** 229, 236
timing, **22,** 238–247
tracking, **20,** 183
Inductance, Ayrton-Perry windings, **17,** 86
charging, **1,** 382; **5,** 355, 361, 455, 467, 483
from a-c source (*see also* A-c charging), **5,** 380–386
from d-c power supply, **5,** 356–380
efficiency, **5,** 363
as energy reservoir, **5,** 23
equivalent, resonator, **6,** 114
leakage calculation, **5,** 512
measurement, **5,** 366–372, 515
mutual, in nodal analysis, **18,** 16
network, **8,** 84
nonlinear, as switch, **1,** 381
self-, of iron-core coil, **17,** 118–124
transformer, **5,** 400
-tuned system, multicavity, mode spectrum, **6,** 165
Inductive, capacity, specific, **11,** 561
kicker pulse circuit, **5,** 305–307
slit, waveguide, **8,** 164–166
tuning screws, **14,** 43
wire, thin, in waveguide, **8,** 167
Inductors, iron-core, **17,** 115–174
construction, **17,** 145–174
design, **17,** 115–145
pie windings, **22,** 320
Inductors, rotary (*see also* Magnesyn; Resolver; Selsyn, d-c; Synchro; Telegon), **17,** 310–355
Inhomogeneity of rain, **13,** 24, 672, 684, 689
Injection, in cycle matching, controlled, **4,** 401
pulsed, **4,** 398
Input circuits, bandwidth, methods of increasing, **18,** 690
double-triode, **18,** 656–666
double-tuned, noise figure of first stage, **18,** 690
dummy, **18,** 316; **23,** 326
noise, **7,** 157
loading, microwave-tube, **7,** 155
noise, microwave-tube, **7,** 112
spectral-density matrix, **25,** 313
scale (computer), **27,** 46, 51
signals, multiple, mixing of, **18,** 99–102
variable (computer), **27,** 45
Inquisitor, beacon, **3,** 6
Insertion loss, of cavity resonators, **9,** 654; **14,** 29
definition, **11,** 680
functions, physical realizability, **9,** 580–583
network, **9,** 550
specified, reactive networks with, **9,** 580–589
supersonic delay lines, **17,** 220–221, 235–236
Instability, magnetron, **6,** 345, 349, 355
Instrument motors, **17,** 356–395
Instrument vibrators, **17,** 497–498
Insulation, interlaminar, **5,** 638
material measurements, **5,** 653
primary, for r-f cables, **17,** 21–22
for pulse transformers, **5,** 648–655
relay, **17,** 488
resistance of hook-up wire, **17,** 14–15
Integral, controllers (*see* Servo controllers)
equation, homogeneous, **10,** 163
r-f field, **7,** 127, 128, 130, 141
Wiener-Hopf, **10,** 164
superposition, **19,** 653
Integrals table, **25,** 369
evaluation of, **25,** 333–339
Integrated-square error, **25,** 314
Integration, **19,** 648–668

Integration, based on inductance, **21,** 82
  as circuit operation, **21,** 78–89
  multiplication by, **21,** 56
  of radar information, **1,** 38–47
  with respect to dimension other than time, **21,** 86
  time, **24,** 150
  of voltage with respect to time, **21,** 83
Integrator, ball-and-disk, **21,** 88, 199
  bootstrap, **19,** 662; **20,** 302, 303
  coast, **20,** 304
  computer, **27,** 2, 4, 23–26
    compared with function generators, **27,** 23
    component solver, **27,** 26
    double-ball, **27,** 24–26
    friction-wheel, **27,** 24
  difference, **20,** 302, 303
  double, bootstrap, **20,** 386
  electrical, **20,** 291–303
    Oboe, **20,** 354
  electrolytic, **21,** 89
  electromechanical, **20,** 252
  electronic, **20,** 347, 357
  feedback amplifier, **20,** 302, 303
    using inductance, **21,** 83
  mechanical, **20,** 305; **21,** 88
  Miller, **19,** 37, 323, 664; **20,** 114–117
    high-gain, **20,** 140
    linear-sweep generator, **19,** 278–285
    multistage, **20,** 116–118
    parabola generator, **19,** 310
    self-gating, **20,** 118–124
  RC-, **21,** 78
    feedback amplifier, **21,** 79
  with regeneration, **21,** 82
  system operation, **21,** 194
  using tachometers, **21,** 83
  velocity servo, **21,** 84
  watt-hour meters as, **21,** 87
Integro-differential-function generation, **21,** 126
Interaction field, resonator, **6,** 74, 92–98
Interaction space, **6,** 11, 84, 403
  admittance, **6,** 63, 84
  equivalent network, **6,** 52
  trial design, **6,** 403
Interface reflection, dielectrics, **11,** 600
Interference, -absorbing materials, **1,** 69
  within beacon system, **3,** 116
Interference, classification, **24,** 143–144
  coherent, propagation, **3,** 42–45, 466
  complex types, **24,** 145–148
  c-w, **24,** 144, 335–340
    amplitude-modulated by noise, **24,** 146
    frequency-modulated by noise, **24,** 147
    noise-modulated, **24,** 353–358
  effects on microwaves, **3,** 45–49
  electronic, **24,** 335–366
  elimination, beacon, **3,** 454
  lobes, **1,** 50; **3,** 45
  low-frequency, **23,** 519
  nulls, **3,** 437
  pattern, **13,** 5, 38–40, 113–122, 407–410, 421–444
    fluctuations, **13,** 535
  pulsed, **24,** 145, 358–366
  radar, **3,** 442
  railing, **24,** 358–365
  region, **13,** 5, 6, 113–122, 408
  rejection, **20,** 400
  suppressor, **24,** 361
Interfering signals in beacon systems, **3,** 114–119
Intermediate-frequency (*see* I-f)
  amplifier (*see* Amplifier, i-f)
  choice of, **1,** 444; **23,** 158–160
Internally gated circuits, **19,** 486–490
Interpulse interval, **5,** 16, 54, 119
Interrogation, channel, **3,** 418
  coding (*see* Coding, interrogation)
  directional, **3,** 64–66
  link saturation, **3,** 104
  random, **3,** 85–89
Interrogator, beacon, **3,** 4, 6, 386
  as radar set, **3,** 66–69
  -responsor, **1,** 253; **2,** 42; **3,** 6, 385
    -beacon, combined, **3,** 389
    design, **3,** 385–397
    ship, with shore-beacon system, **3,** 419–426
    used alone, for range and azimuth information, **3,** 389–394
      for range-only information, **3,** 385–389
    used with radars, for range and azimuth information, **3,** 396
      for range-only information, **3,** 394–396

Interrogator, shipborne, **3**, 19
Interruption frequency, **24**, 12
Intersection nomograms, **27**, 40, 251
Interval-selector circuits, **19**, 364
Inverse feedback, **18**, 90–93, 333, 384, 422; **23**, 175
afc, **16**, 324
chain, gain stability, **18**, 253
and output voltage capability, **18**, 104
pairs (*see also* Feedback pairs), **18**, 134, 241–249; **23**, 524
bandwidth switching, **18**, 258
direct-coupled, **18**, 136
flat, **23**, 177
gain stability, **18**, 253
overloading, **18**, 255
series-fed direct-coupled, **18**, 151
Inversion, temperature, **3**, 50
Inversor (computer), Hart, **27**, 30
Peaucellier, **27**, 29, 30
Inverted function, **27**, 184
mechanization, **27**, 138–139, 143–145, 155, 177
Inverter, **17**, 420–431
Leland aircraft, **21**, 544
output waveform, **17**, 422–423
regulator, carbon-pile, **21**, 545
speed regulation, **17**, 425–431
speed variations, **17**, 426
starting current, **17**, 422, 424
trigger, **22**, 432
Ionization, clouds, **4**, 136
maximum, height of, **4**, 130
sporadic *E*-region, **4**, 144
Ionized gases, propagation in, **8**, 393–396
Ionosphere, **4**, 59, 88, 94, 126
reflections from, **2**, 71
Ions, focusing, **22**, 44
noise, magnetron, **6**, 395
Iris, coupling, adjustable, **16**, 164, 165
in attenuators, **11**, 709
magnetron output, **6**, 194
resonator, **7**, 507
dielectric-filled, **8**, 392
inductive, in waveguides, **9**, 78
output, stabilized, **6**, 498, 499
rejection, **9**, 706
resonant, **8**, 169–171; **9**, 660, 688–690
thick, **8**, 417–420
transformer, **6**, 494
trial, **12**, 552
Iris, waveguide, **8**, 162
broadband matching with, **9**, 322–331
windows, **6**, 203
Iron-sponge mercury-cathode gap (*see* Spark gap)
Isobaric cooling, **13**, 186
Isolating element pulser (*see* Pulser)
Isotropic spherical waves, **12**, 78

J

Jamming, **16**, 193, 300, 331
Jig, bending, panel tests, **26**, 386
test, sandwich, **26**, 400
Jitter, frequency, in PRF division, **19**, 568
multivibrator, **19**, 194
phase, in PRF division, **19**, 568
time, **5**, 15, 16, 120, 129, 278, 284, 295, 299, 326, 330, 334, 351, 471
Johnson noise, **7**, 257; **16**, 11
Johnson wattmeter, **11**, 216
Joints, motional, in coaxial line, **9**, 407–416
combining coaxial line and waveguide, **9**, 446–455
waveguide, **9**, 433–445
with polarization rotator, **9**, 430–432
rotary, **1**, 403; **9**, 100–109, 407, 416–433; **16**, 291; **26**, 6, 74, 165, 184
circular-polarization, **9**, 428
resonance in, **9**, 429
coaxial, **9**, 407–413
chokes in, **9**, 408
with combinations of transitions, **9**, 448–451
with cross-transition from coaxial line to waveguide, **9**, 446
filter-ring, TE_{11}-mode for, resonances in, **9**, 423
high-power, with doorknob transitions, **9**, 451–455
resonances in, **9**, 422
pressure seals, **9**, 141–143
with probe transitions, **9**, 447
pulse, **26**, 73
resonances in, **9**, 416–420
r-f, **26**, 73, 141
with TE_{11}-mode filter-ring transitions with TE_{11}-absorbers, **9**, 425

Joints, rotary, waveguide, **1**, 403; **9**, 416–433
swivel, **9**, 433–438
universal, **9**, 442–445
Jordan's lemma, **13**, 110
J-scope, **1**, 166; **20**, 216–219; **22**, 10, 17, 70, 296–301
with B-scope, **20**, 243–246
with PPI, **20**, 243–246
Junction, choke-flange, open, **9**, 291–294
circuit, three-way, **14**, 262
coaxial, **14**, 265
coaxial T-, **10**, 114
to waveguide, **10**, 116
connected in cascade, **8**, 150
cross, H-plane, **8**, 315
two coaxial guides, **10**, 116
effect, in transmission lines, **8**, 187
in waveguides **12**, 214, 215
E-plane, symmetry, **10**, 114; **14**, 269
T-junction, **16**, 260
equivalent circuits, **8**, 289, 292, 294
at high frequencies, **8**, 291–294
at long wavelengths **8**, 288–291
with three-winding transformer, **8**, 294
equivalent circuit, choice of, **8**, 286–288
four-, degenerate, **8**, 313–315
H-plane, **14**, 269
equivalent circuit, **14**, 121
symmetry, **10**, 116
T-junction, **8**, 294; **16**, 260
equivalent circuit, **8**, 295
lossless, frequency dependence, **8**, 151
Magic-T, **10**, 116
N waveguides, **10**, 102
probe-coupled, **10**, 114
Purcell, **8**, 466–476
symmetrical, frequency dependence, **8**, 476–479
T-junction, **8**, 283–297; **16**, 155, 260
120°, **8**, 292
coaxial, **10**, 114
in coaxial guide, aperture-coupled, **10**, 368
coaxial-line, **8**, 295; **14**, 268
equivalent circuit, **11**, 867
general, branching loss, **14**, 323
general theorems, **8**, 283–286
Junction, T-junction, monitoring, **11**, 257
in rectangular guide, aperture-coupled, circular stub, **10**, 364, 367
E-plane, **10**, 363–366
H-plane, **10**, 366
rectangular stub, **10**, 363, 366
open, E-plane, **10**, 337–339
H-plane, **10**, 355–360
slit-coupled, E-plane, **10**, 339–352, 412–413
H-plane, **10**, 360–362
with small hole, **8**, 296
standing-wave-ratio curves, **14**, 272
symmetrical, **8**, 430
transformer representation, **8**, 122
waveguide, circuit elements, **14**, 122
turnstile, **8**, 459–466
waveguide (*see* Waveguide junction)
wideband symmetrical, **8**, 479
Y-junction, **10**, 112
H-plane, **10**, 113
symmetrical, **8**, 420–427
Juxtaposition in manual CRT measurements, **20**, *186*, 188, 190–196

K

Keep-alive, characteristics, TR tube, **14**, 208
circuits, **14**, 211
prepulsed, **14**, 212
discharge, **14**, 143
low-level signal attenuation, **14**, 209
structure, **14**, 206
volt-ampere characteristics, **14**, 205
electrodes, **14**, 245; **23**, 10
coaxial, **14**, 200, 245
within cones of 1B24 and 1B27 tubes, **14**, 205
properties, **14**, 426
side-arm, **14**, 206, 245
TR tube, **1**, 410
pressure-voltage characteristic, 1B24 TR tube, **14**, 209
Kelvin line, **18**, 95
Kicker, inductive, **5**, 305–307
Kinematic viscosity, **13**, 208, 214, 293
Kirchhoff's laws, **8**, 85; **18**, 1, 10
Kite ascents, **13**, 262

Klystron, **7,** 11; **14,** 377; **16,** 36
2K25 (723A/B), **7,** 27, 512; **11,** 31, 35–37; **23,** 22
mount, **11,** 39
2K28, **11,** 35–41; **23,** 22
2K33, **7,** 392–403, 516; **11,** 36, 47
2K45, **7,** 513; **11,** 45; **23,** 25
2K50, **7,** 518; **11,** 47; **23,** 25
2K57, **7,** 517
410R, **7,** 21, 26, 27, 296, 300, 310; **12,** 596
operating characteristics, **7,** 268–270
417A, **7,** 378, 510; **11,** 43
as noise generator, **15,** 229
419B, **12,** 595
707A, **23,** 22
707B, **7,** 508; **11,** 35; **23,** 22
723A/B, **7,** 27, 512; **11,** 31, 35–37; **23,** 22
726, **7,** 403; **23,** 22
amplifiers, **7,** 20–23, 240, 243, 244, 248–284
overdrive, **7,** 261
Applegate diagram, **7,** 204, 272, 395
asymmetry, **7,** 384–403
beam, conductance, **7,** 44, 64, 252, 318
coupling, **7,** 41
coupling coefficient, **7,** 33–35, 42, 203, 225, 231, 241, 269, 332, 499
current, effective, **7,** 335
modulation, **7,** 452–454, 465–469
loading, **7,** 44, 225, 231, 254–256, 260, 267, 269, 289, 332, 380
admittance, **7,** 45, 49, 58, 68, 99, 319, 347
coefficient, **7,** 43
conductance, **7,** 45
impedance, **7,** 51, 67, 110
susceptance, **7,** 45
potential, **7,** 44
bunching (*see* Bunching)
cascade amplifier, **7,** 22
circuit efficiency, **7,** 251, 267, 304, 306
cold tests, **7,** 404, 409
conductance, critical, **7,** 265, 269
load, **7,** 319, 328
parameter, **7,** 319, 320, 322
current, bunched, waveform, **7,** 205–207, 218
density, reflector, **7,** 354–357
driving, with noise, **7,** 491
Klystron, current, integrated, **7,** 123
peaks, infinite, **7,** 206, 233–236
starting, **7,** 320, 333
total, **7,** 32, 36, 39, 48
debunching, **7,** 66, 209–217, 219, 252, 253, 262–263, 268, 278, 286–294
longitudinal, **7,** 214–217
transverse, **7,** 212–213
wave number, **7,** 211
detuning, **7,** 298, 299, 305, 307, 310
double-cavity, **11,** 374; **12,** 596–599
electronic efficiency, **7,** 304
electronic tuning, **7,** 315, 323, 350, 420; **11,** 23, 29, 30; **16,** 38
frequency doubling, **7,** 400
frequency multiplier, **7,** 22, 285–294, 298
2K37, **7,** 285
applications, **7,** 286
efficiency, **7,** 293
operation at high input-gap voltage, **7,** 293
stability, **7,** 179, 191, 328
frequency tripling, **7,** 400
gain, gap-voltage, **7,** 250
gap, input, **7,** 202, 225
output, **7,** 225, 231
gas focussing, **7,** 212
grid-absorption losses, **7,** 269
harmonic content, **7,** 207, 209, 217, 239, 240, 245
hysteresis, **7,** 221, 330, 384–403, 431; **11,** 30
multiple-transit, **7,** 397–403
load conductance, **7,** 319, 328
effects, **7,** 404
high-*Q*, **7,** 435
optimum, **7,** 251, 267
long-line effects, **7,** 429
mixers, **7,** 18
modes (*see* Mode)
modulation (*see* Modulation)
multiple-transit electrons, **7,** 395–403
multiresonator, **7,** 248
oscillation, condition, **7,** 299, 302, 303, 348
frequency, **7,** 306
modes, **7,** 301, 307
phase relations, **7,** 329
steady, **7,** 314

Klystron, oscillator (*see also* Oscillator, klystron), 2K34, **7,** 29, 296
-buffer, **7,** 28, 295–296
output coupling, **7,** 422, 507
efficiency, **7,** 304
overbunching, **7,** 222, 253, 261–263
phase aberrations, **7,** 380
modulation with, **6,** 597
optimum, **7,** 312
and reflector nonlinearities, comparison of, **7,** 382–383
factors, **7,** 221–230
shift, **7,** 221–230
hysteresis, **7,** 387–393, 401–403
stationary, points of, **7,** 233, 236, 240
power-amplifier, **7,** 260–271
power supplies, **11,** 924
pulling, **7,** 197, 416, 437
reflection transit time, **7,** 465–469
reflector, deep, **7,** 366
field, influence on bunching, **7,** 373–383
with phase aberrations, **7,** 383
hemispherical, **7,** 367
mode patterns, **7,** 357–374
nonideal, **7,** 352–383
plane-parallel space-charge free, **7,** 359
space-charge effects, **7,** 373
space-charge-free recessed, **7,** 364–367
supply impedance, **7,** 525
reflex, **1,** 414; **7,** 27, 211, 218–219, 222, 223, 226, 230, 238, 240, 311–526; **11,** 21, 31–51; **12,** 594–596; **16,** 37–43, 206, 236, 361; **23,** 21–25
1-cm, **11,** 47–51
characteristics table, **11,** 35–36
hysteresis in, **7,** 384–403
load effects, **7,** 404–440
losses, **7,** 407, 416, 423
modulation, **7,** 441–469
noise in, **6,** 7, 470
oscillator, **11,** 23–33
output, coupling effect, **7,** 422, 507
conversion efficiency, **7,** 327
power and efficiency, **7,** 320
supplies, **11,** 51–58
practical tubes, **7,** 495–526
principle, **16,** 36
static characteristics, **7,** 442–444
Klystron, reflex, voltage generator, equivalent, **7,** 456, 463
resonator (*see* Resonator)
Rieke diagram, **1,** 339; **3,** 257–259; **6,** 40, 178–187, 317, 327, 733; **7,** 405, 414–416, 417; **9,** 83; **11,** 31; **16,** 203, 211
experimental, **7,** 432
practical, **7,** 421
scaling, **7,** 354–357, 373
SD-835 external resonator tube, **7,** 379
space, **7,** 203, 212, 218–219, 231, 248
characteristics, **7,** 218–224
charge, **7,** 209–217, 354–357, 372
coefficients, **7,** 219–224, 241, 271, 374, 377, 387
distance, **7,** 252–253
field-free, **7,** 212, 222–224, 230
length, **7,** 286
spectra, primary, **7,** 490
stabilization, **7,** 435, 439
thermal effects, **7,** 413
thermal tuning, **7,** 503–504
transadmittance (*see* Transadmittance)
transconductance (*see* Transconductance)
transient phenomena, **7,** 458–462
turn-around point, **7,** 367, 368, 377, 381
wavelength limit, long, **7,** 373
short, for klystron operation, **7,** 373
wavelength range, **7,** 373
Kovar, **6,** 677, 678, 695; **9,** 119
-to-glass seal, **6,** 483, 677
Kraft paper, **5,** 551
K-scope, **1,** 167
KXS trials, **13,** 327, 363

L

Laboratory glasses, **6,** 679, 680
Ladder networks, **9,** 597–601
Lag coefficient, **13,** 280
ML-313, **13,** 287
psychograph, **13,** 280–281
Laguerre functions, **25,** 319
Laguerre polynomials, **18,** 86
Lambert correction, Loran, **4,** 176
Lambert projection, **4,** 181
Lambert's law, **21,** 122
Laminar sublayer, **13,** 209, 213, 219

Laminates, electrical properties, **26,** 413, 414
  loss tangents, **26,** 414
  reduced-density, **26,** 377
Lamp, load, L4PD, **11,** 180
Land, reflection coefficient, **13,** 430–436
Landing, final control, **2,** 306–310
  radar aids, **2,** 227–251
Landing aids (*see* Approach system)
Langmuir-Childs law, **7,** 356
Laplace integral, **13,** 88
Laplace transform, **5,** 27, 175; **18,** 1, 21–42; **19,** 651; **21,** 226; **25,** 51–57
  convergence, absolute, abscissa, **25,** 51
  convolution, definition, **25,** 54
    of two functions, **25,** 54
  $e^{-at}g(t)$, **25,** 54
  integral, **25,** 54
  inverse, **18,** 3, 31
  limiting values, **25,** 55
  pairs, **21,** 228
    list, **18,** 70
  steady-state, **18,** 55
  use in solution of linear differential equations, **25,** 56–58
Lapse rate, **13,** 193, 194, 196, 197, 260, 279, 280, 297
Latent heat, **13,** 183
  vaporization of water, **13,** 188, 293
Lattice, factor, **12,** 105
  network, **8,** 110; **9,** 706
  symmetrical, **9,** 566
Lawson method, Q measurement, **6,** 713
Lawson regulator, **21,** 562
Layer, elevated, **13,** 14, 18
  frictional influence, **13,** 213, 214
  homogeneous, **13,** 193, 199, 231, 235
  nonstandard, as barrier, **13,** 75, 76, 83, 168
  saturated, **13,** 207
  standard, **13,** 14, 235
  substandard (*see also* surface, below), **13,** 14, 143, 168, 301, 302, 315
    analytical complications, **13,** 172
  superstandard, **13,** 15, 237, 304
  surface, **13,** 14, 220–226, 228–234, 238–260, 348
    standard, **13,** 230, 258
    substandard, **13,** 14, 230, 258, 303, 306, 316
      and scintillations, **13,** 305
Layer, surface, superadiabatic, **13,** 221, 222
    superstandard, **13,** 14, 229, 258
"Lazy man" reversing switch, **16,** 333
Lead (derivative control, servo), **25,** 197
Leading edge of pulse (*see* Pulse)
Leakage, core, pulse transformer, **5,** 400, 409
  diode heater-cathode, **19,** 67
  energy, spike (*see* Spike leakage energy)
  inductance, calculation, **5,** 512
    measurement, **5,** 515
    transformer, **5,** 400
  -reactance-core gap, **5,** 411
  of signal, transmitter, **16,** 198, 199, 299
Leaking modes, **13,** 22, 71, 84, 333, 378, 382
Least-square method in leakage problems, **27,** 206–207
Lee centrifugal governor, **17,** 392–395
Lee speed regulator, **1,** 574
Legendre function, associated, **10,** 96
Length, natural unit, as function of wavelength, **13,** 124
Lens, dielectric, **12,** 389–402
    attenuation, **12,** 399–400
    bandwidth, **12,** 398
    frequency sensitivity, **12,** 398
    one-surface, with elliptical contour, **12,** 392–393
      with hyperbolic contour, **12,** 390–392
    reflections from surfaces, **12,** 401
    tolerances, **12,** 400
    two-surface, **12,** 390, 394
    zoned, **12,** 395–398
  doublet, **12,** 410
  focusing CRT (*see* Focusing lens)
  metal-plate, **12,** 402–412
    achromatic doublets, **12,** 410
    bandwidth, **12,** 408–410
    one-surface, with elliptical contour, **12,** 403–405
    parallel plates, **12,** 402–405
    parallel wires, **12,** 406
    polystyrene-foam bonded, **12,** 406
    reflection from surfaces, **12,** 410–412
    tolerances, **12,** 407–408
  spherical, **12,** 390

Level setting (*see also* D-c restorer), **19**, 11, 54
of current waveforms, **19**, 321–324
d-c, in synchro systems, **19**, 454
level stabilization (d-c restoration), **22**, 113
by waveform distortion, **19**, 454
Levers, **21**, 39, 55; **27**, 27
LHTR, **14**, 339
power supply, **1**, 208
Light intensity, decay of, from discharge, **14**, 196
Light-microsecond, **4**, 52
Lighthouse tube, **1**, 207; **7**, 9, 286; **14**, 377; **16**, 18, 29, 33, 35, 45, 290; **23**, 20
2B22, **11**, 193, 461
2C40, **7**, 25; **23**, 20
2C43, **7**, 25
cavity, **11**, 256
inverted, **7**, 163
Lightweight apparatus, design, **21**, 679
Lightweight construction, **21**, 700–708
Limit switches, **21**, 403
Limiter, **24**, 16
bandwidth requirements preceding, **23**, 221
cascade, **23**, 445
design, **23**, 443
diode, biased, **1**, 504
single-stage, **23**, 443
special, **23**, 228
time constants, **23**, 444
Limiting, **24**, 30, 195, 246–248, 301
i-f, **23**, 585
link, beacon, **3**, 40
plate-circuit, **23**, 444
receiver, **23**, 596
of video output signal level, **1**, 452
Lin-log (linear-logarithmic) receiver, **23**, 583
range, **23**, 591
Line (transmission), **3**, 136–138; **5**, 177; **10**, 1-54; **26**, 73, 157, 165, 184
admittance, **10**, 10–12; **12**, 26, 213
functions, **5**, 185
attenuation, **26**, 6
bifurcated, **11**, 801
branched, **8**, 193–198
-breadth constant, **13**, 650, 654
breakdown, **9**, 84, 106
broadening, **13**, 645, 650
Line (transmission), capacitance, **5**, 228
charts, **8**, 71–75; **9**, 59–82
choice of, **9**, 75–82
and impedance-matching, **9**, 59–82
coaxial (*see* Coaxial cable)
components, **9**, 5
contact losses, **9**, 108
corrugated, **12**, 319
coupling capacity, **9**, 100–114
coupling units and lines, flexible, **9**, 243–304
waveguide units, **9**, 273–304
-current distributions, far-zone fields, **12**, 96–98
current parameters, **12**, 210
dielectric materials, **9**, 132–139
dissipative, perturbation method of calculation, **10**, 26
distributed-constant, **19**, 745
elementary theory, **9**, 9–114
equations, **8**, 65, 79–82; **9**, 32; **10**, 6
for E-plane sectoral horns, **12**, 366–369
equivalent, for E-modes, **8**, 119
filters with, **9**, 614–645
finishes and electroplating, **9**, 124–132
frequency behavior, **9**, 614–623
as guides for electromagnetic waves, **9**, 36–59
half-wave, **1**, 392
homogeneous, **12**, 23–26, 544–546
ideal (lossless), **9**, 19, 23
impedance, **1**, 391; **5**, 177; **8**, 66; **9**, 13–23, 41, 51; **10**, 6; **11**, 476; **12**, 23, 213, 216
changes in, **8**, 187–193
coaxial, **9**, 183
eccentric, **9**, 148
effective, **9**, 52
function, **5**, 181
-matching and design procedure, **9**, 82–114
transformation, **14**, 14
loaded, constants, **12**, 313–316
long, effect of, **1**, 393
loss length, **9**, 146
lossless, **5**, 176, 226; **12**, 26–29
lumped-constant, **19**, 743–745
matched, **1**, 393
materials, and construction techniques, **9**, 115–143

Line (transmission), materials, metallic, **9,** 115–124
microwave, **12,** 200–238
mismatched, **6,** 309
as resonant load, **6,** 320–329
modes, **10,** 55–100
motional joints, **9,** 406–455
combining coaxial line and waveguide, **9,** 446–455
nonuniform, **8,** 242
open-circuited lossless, **5,** 176
π-network equivalent, **10,** 12
power, dividers, **9,** 516–528
effect of, on leakage characteristics, **14,** 243
-loss ratios, selection of, **9,** 589–597
pressurization, **9,** 139–143; **26,** 163, 167
quarter-wave, **1,** 393
radial, **8,** 240–282
dominant *E*-type mode, scattering description, **10,** 43
dominant *H*-type mode, **10,** 46
equivalent circuit, **8,** 267–271
E-type, circuit representation, **10,** 42
frequency sensitivity, **10,** 43, 46
H-type, *T*-circuit representation, **10,** 42
voltage reflection coefficient, **10,** 44
impedance description, **8,** 256–265
voltage and current nodes, **9,** 196, 197
radiating into space, **10,** 179–216
reflection coefficients, **10,** 13, 15, 44
relations in, **9,** 29–36
r-f, **26,** 73
breakdown, **6,** 738
rigid, **9,** 144–242
coaxial, **9,** 144–188
waveguides, **9,** 188–242
sealing, **9,** 140
short-circuited, **5,** 209
-simulating network, **5,** 124, 180
single, termination of, **8,** 132–138
with small losses, **9,** 20, 34
source feed, primary pattern, **12,** 570–572
and reflectors, **12,** 151–154
sources for shaped-beam antennas, **12,** 495–497
spherical, scattering description, **10,** 53
Line (transmission), standing-wave ratio, **14,** 30
stretcher, type N, **9,** 481
stub-supported, **1,** 393
switches, **9,** 528–539
tapered, **8,** 191
terminating in guides beyond cutoff, **10,** 168–178
termination, **8,** 154–156
theory, conventional, **9,** 9–36
three-wire, **12,** 247
T-network equivalent, **10,** 12
transformation charts, **12,** 29–36
transition units, **9,** 305–405
tuners, **9,** 456–516
two-wire, **12,** 21–37
uniform, **10,** 7–29
complex parameter, **10,** 17–29
impedance descriptions, **8,** 248–252; **10,** 9
scattering descriptions, **10,** 13–16
voltage reflection coefficient, **10,** 13
use, in impedance matching, **5,** 669–673
limitations on, **9,** 623–625
voltage, attenuation constant, **12,** 23
parameters, **12,** 210
vs. pulse-power output, **5,** 229
reflection coefficient, **12,** 25
variation, effect on switch-tube, **5,** 117
waveguides as, **8,** 60–82
Linear cells (*see* Additive cells)
Linear-exponential, *M*-profile, field-strength contours, **13,** 178–180
profile, **13,** 169, 174
Linear, mechanization, **27,** 46–48
modified-index profile, **13,** 14–16, 87–112
shaping (waveshape), **19,** 9
-sweep delay, **21,** 591
terminal computer, **27,** 46
Linearity, circuit, in time measurements, **20,** 114
Link computer, **27,** 27
Linkage, bar (*see* Bar linkage (computer))
cams, **27,** 34
computers, definition, **27,** 44
constants, final adjustment of, eccentric linkage, **27,** 217–222
gauging parameters, **27,** 200–217

Linkage, design, graphical vs. numerical methods, **27**, 199–200
numerical methods, **27**, 167–198
structural error, **27**, 199
three-bar, geometric method, **27**, 145–165
use of grid structure, **27**, 243–249
double three-bar, **27**, 36
in series, **27**, 195–198
successive approximations in design, **27**, 196
eccentric, **27**, 35
as corrective device, **27**, 217
in function generation, **21**, 104
gauge of precision, **27**, 201
gauging constant, **27**, 202
gauging error, **27**, 201, 205, 211–215
gauging parameters, **27**, 200–217
eccentric, **27**, 218
three-bar linkage design, **27**, 207–217
inversors, **27**, 34
logarithmic, **27**, 238
check of, **27**, 209–217
improvement, by eccentric linkage, **27**, 219–222
by gauging-parameter method, **27**, 209–217
structural error, **27**, 216, 219, 222, 223
multiplier, **27**, 4, 28–29, 223–283
adjustment, **27**, 277–281
error, **27**, 4
with one degree of freedom, **27**, 58–198
precision, gauge of, **27**, 201
star, **27**, 238
three-bar (*see* Three-bar linkages)
transformer (*see* Transformer, linkage)
with two degrees of freedom, **27**, 37, 40, 223–250
structural error, **27**, 223
$\mathfrak{L}$-integral, **18**, 25
Liouville's theorem, **7**, 123
Liquids, velocity of propagation of sound in, **17**, 218–219
Lissajous figure, **21**, 579
Littelfuse detector, **16**, 18
mount, tunable, **11**, 176
Llewelyn approximation, **7**, 101, 129, 135
Llewelyn's equation, **7**, 61, 66
Lloyd's mirror, **13**, 4
propagation effect, **3**, 42
L-network, antenna, **4**, 306
LO (*see* Oscillator, local)
Load, characteristics, effect on pulser regulation, **5**, 108–118
circuits, containing transmission cavity, **16**, 215–218
high-Q, **16**, 209–215
coaxial-line, high-power, **11**, 732–735
coupling, lighthouse tube, **7**, 197
current, change in, during a pulse, **5**, 58, 166
variation, pulser, **5**, 117
effect, on mode spectrum, **6**, 141–147
on pulser operation, **5**, 418–423
g, reduced, **6**, 443
gas, for power measurement, **11**, 214
high-power, **11**, 721
1.25-cm-band, **11**, 742
3-cm-band, **11**, 738
dissipative-wall, **11**, 739
hot transmission-line, **11**, 271
IRC resistance, for rectangular waveguide, **11**, 729
lamps, **11**, 180–183
line, **5**, 238–244
low-power, **11**, 721
matched, **11**, 503–505; **16**, 200, 206
water, **11**, 194–213
1-cm-band, **11**, 203
3-cm-band, **11**, 202
coaxial line, **11**, 195–199
flow systems, **11**, 204–211
r-f, **9**, 229
thermopiles for, **11**, 211
waveguide, **11**, 199–204
high-power, **11**, 735–743
Loalin, **26**, 372
Lobe-switching, **1**, 203; **3**, 390; **13**, 436; **20**, 367
system, airborne, **3**, 390
Lobes, **13**, 39, 40, 407–410
side, **1**, 272; **12**, 176; **26**, 250
vs. illumination, **12**, 179, 187, 195
Local-oscillator, injection, **23**, 147
klystron, **1**, 414–416
MTI, design, **1**, 659–662
stability, **1**, 638–640
stabilities, typical, **1**, 661
Localizer system, **2**, 227
Loci of $A_{\{m\}}^{(\infty)}(s)$ and $A_{\{m\}}^{\{\infty\}}(s)$ in complex plane, **13**, 158

Lockover (scaling) circuits, **1**, 497; **19**, 164
Locus of maxima, **13**, 137
Log bridges, **21**, 124
Log frequency-decibel diagrams, **21**, 271, 304
Logarithmic devices, **19**, 670–674
Logarithmic distribution, **13**, 223
  specific humidity, **13**, 218
    turbulent boundary layer, **13**, 215
    velocity, **13**, 217
    water vapor, **13**, 223
Logarithmic function, **27**, 36
  with diodes, **21**, 125
Logarithms as circuit operation, **21**, 55, 122
Long-line effect (*see also* Klystron; Magnetron; Oscillator), **3**, 265–267
Long-wave transmission, proposed mechanisms, **13**, 1
Loop-belt differential, **27**, 10–11
Loop gain, **18**, 336, 340, 352, 363; **22**, 124, 367
  servo, **21**, 345, 375
£-operator, **18**, 25
Loran, **2**, 64–70; **3**, 26; **20**, 11, 34, 173, *181*, *261*
  accuracy, **4**, 107
  Air Transportable, **4**, 35, 44, 93, 413
  angle, crossing, **4**, 80, 83
    tilt, **4**, 328
  A timer, **4**, 199
  automatic data analysis, **2**, 79–82
  automatic-frequency-tracking circuit, lightweight, **20**, 97
  automatic plotting boards, **4**, 105
  automatic synchronizer, **4**, 67
  AVC, **4**, 217, 240
  average errors of fix, **2**, 66
  baseline, **4**, 13, 53, 56, 59, 62, 70, 71, 86, 96, 99, 102
  bibliography, **4**, 457–461
  blink, **4**, 68
    warning, **4**, 229
  blinker communication, **4**, 252, 256
    identification, **4**, 256
  blinking, **4**, 197
  B timer, **4**, 199, 201
  buffer, **4**, 296
  calibration markers, **4**, 205
  charts, **2**, 73; **4**, 31, 41, 55, 97, 102, 104, 109, 154, 170–194, 406
Loran, choke, snuffing, **4**, 283
  coding delay, **4**, 57, 102, 204
  computations, **4**, 170
    methods, **4**, 177–180
  converter, **4**, 97, 367
  coordinates, **4**, 55, 109
    chart, **4**, 110
  cycle matching, **4**, 99, 117, 252, 400
  delay, absolute, **4**, 4, 52, 56, 96
    control, **4**, 65
    curve, **4**, 134
    differential, **4**, 391
    sky-wave, **4**, *134*, *139*, *147*
  delayed synchronism, **4**, 67
  disadvantages, **2**, 70
  distance, computing, **4**, 171
  double pulsing, **4**, 70
  driver, **4**, 298
    50-kc/sec, **4**, 253
      attenuator, **4**, 229
        -bias, **4**, 212
  ellipse, probable, **4**, 85, 427
  envelope, signal, **4**, 151, 153
  errors, **4**, 33, 144, 157, 167, 193, 432
  exciter, **4**, 211, 278
  families, **4**, *55*, 99, 180
  fast-trace pattern, **4**, 65
  feedback PRF divider, direct-reading, lightweight, **20**, 101
  field equipment, **4**, 397
  fix (*see* Fix; Fixing)
  frequency, **4**, 135
  future trends, **4**, 107–120
  gain balance, **4**, 389, 393
  gain control, automatic, **4**, 394
    differential, **4**, 23, 390
  gate, timing, **4**, 210, 231, 246
  generators (*see* Generator, Loran)
  geometrical error, **4**, 144
  geometry, parametric latitude, **4**, 173
  ghost, **4**, 101, 250
  graphical solution, **4**, 434
  grid, **4**, 11
  ground stations, **4**, 31, 419–424
    system, **4**, 87, 301, 324, 340, 341
    -wave range, 1.95 Mc/sec, **4**, 23
  history, **4**, 19–51, 403–405
  hygraph, **4**, 186
  indicated time difference, **4**, 59
  indicators, **2**, 65, 67; **4**, 100
    circuit details, **20**, 267–274

Loran, indicators, lightweight, direct-reading, **20,** 169–174
internal memoranda on, **4,** 457, 465–468
Lambert correction, **4,** 176
Lambert projection, **4,** 181
latitude effect, **4,** 139
LF, **2,** 72–76; **4,** 60, 97
average position-line error, **2,** 74
indication, **2,** 75
lines, **4,** 173, 425–431
marker-mixer, **4,** 212, 226
markers, **4,** 12, 66, 104
master station, **4,** 59, 68; **20,** 261
measurements, **4,** 386–404
precision of, **4,** 107
median errors, **4,** 167
modulator, **4,** 278
monitor station, **4,** 68
monitor timer, **4,** 250
multiple-hop transmission, **4,** 136
network, **4,** 56
oscillator (*see also* Oscillator, Loran), crystal, **4,** 201, 207, 253
oscilloscope (*see* Oscilloscope, Loran)
and other navigational nets, **2,** 56–85
pair designation, **4,** 70
pairs of stations, **4,** 11, 76, 80
parallelogram, probable, **4,** 84
phase, control, UE-1, **4,** 240
corrector, **4,** 231
inverter, **4,** 218
shift, coarse, **4,** 204
plotting board, **4,** 104, 110; **21,** 165
with Loran projection, **2,** 81
position-determining set, **4,** 108
positional error, **4,** 33
power, amplifier, **4,** 298
plant, **4,** 87
preamplifier, **4,** 278
PRF generator, direct-reading, lightweight, **20,** 100–103
principles, **4,** 52–106
probable error, **4,** 72, 84, 91, 95, 98, 140, 193
in distance, **4,** 85
of fix, **4,** 429
propagation, **4,** 121–169
pulse, -matching accuracy, **4,** 98
mixer, **4,** 210
overlapping, **4,** 137
Loran, pulse, recurrence rate, **4,** 57, 348
remote, **4,** 67
shapes, low-frequency, **4,** 149
time sequence, **4,** 57
pulsed doubler, **4,** 294
pulsed injection, **4,** 398
Q-procedure, computation, **4,** 187
quadrilateral, **4,** 55, 79, 94
SS, **4,** 72
radio frequencies, **4,** 55
range, **4,** 62, 98, 107, 122, 130
rate, basic, **4,** 69
specific, **4,** 69
receiver-indicator (*see* Receiver-indicator, Loran)
recurrence, period, **4,** 57
rates, **4,** 12, 23, 57, 204, 348
remote signal, **4,** 259
repetition frequencies, **20,** 264
selector circuits, **4,** 199, 206
selectors, **4,** 210, 226, 236
service area, **4,** 49, 74, 92, 99
signal, required, **4,** 122, 124
single-hop, **4,** 130
sky-wave, accuracy patterns, **4,** 142
corrections, **4,** 31, 61, 62, 138, 157, 180
delay, **4,** 134, 137, 139, 147, 152
pulse, **4,** 88
ranges, **4,** 23
results, **4,** 22
synchronized (*see* SS, below)
synchronized pairs, **4,** 36
train of, **4,** 60
transmission, **4,** 59, 159
at 2 Mc/sec, **4,** 126–139
delay, **4,** 60, 62
errors, **4,** 139–148
time, **4,** 133
slave station, **4,** 59, 68; **20,** 261
slow-trace pattern, **4,** 63
special techniques and measurements, **4,** 386–402
spectrum-control filter, **4,** 310
spectrum measurements, **4,** 397
splitting, pulse, **4,** 88, 90
spurious response, **4,** 389
SS, **2,** 70–73; **4,** 12, 30, 94, 144
charts for, **4,** 97
European system, **4,** 420
navigation, **4,** 33

Loran, SS, tests, **4**, 31
Standard, **4**, 12, 56, 85
station equipment, **4**, 87
station, error, **4**, 193
positions, **4**, 432
selection, **4**, 69
stations, Air Transportable, **4**, 413–414
switching equipment, **4**, 258–274
synchronism, **4**, 101
average deviation of, **4**, 158
delayed, **4**, 67
synchronizer, **4**, 67, 199, 213, 229, 234, 245
tables, **4**, 102, 180
and charts, methods of computing, **4**, 170–194
test and training equipment, **4**, 381–385
time difference, **4**, 12, 52, 59, 63, 67, 101, 432
measurement, **4**, 345
time discriminator, lightweight, automatic-frequency-control circuit, **20**, 98
timing diagram, **20**, 99
time modulator, direct-reading, lightweight, **20**, 169
timers (*see* Timers, Loran)
timing errors, **4**, 144
timing sequence, **4**, 57; **20**, 264–267
top-locking synchronizer, **4**, 366
trace separation, **4**, 207, 212, 223
traces, nonlinear, **4**, 374
transmission, at 180 kc/sec, **4**, 148–169
delay, **4**, 98
sky-wave, **4**, 60, 62
line, **4**, 304
time, **4**, 123
sky-wave, **4**, 133
transmitters, **4**, 87, 275–300, 577
low-frequency, **4**, 288–300
pairs of, **4**, 52
Standard Loran, **4**, 277
TDP, TDP-1, **4**, 278
timer, **4**, 63
transmitting stations, determining errors in position of, **4**, 432–455
trap circuits, antenna, **4**, 388
trials, **4**, 23
triplet, **4**, 34–36, 38, 55, 70, 92, 97, 102
Lorentz reciprocity theorem, **8**, 90; **13**, 97, 114, 468, 693–698; **16**, 63
Lorhumb, **2**, 84, 85; **4**, 106, 112
Loss, conductor, **9**, 21, 26, 146, 147
conversion (*see* Conversion loss)
in CRT displays, **3**, 34–36
dielectric, **9**, 21
general definition, **15**, 128
pulser, **5**, 237–238
reflex klystron, **7**, 407, 416, 423
relative, of various metals, table, **8**, 47
tangent, **9**, 29
calculation, **11**, 629
dielectric constant, **11**, 561
water, **11**, 587
distilled, **11**, 195
Lossy cables, **14**, 378
Lowpass-bandpass analogy, **18**, 276
L-scope, **1**, 167
localizer presentation, **2**, 234
presentation, **3**, 11
American 200-Mc BABS system, **2**, 235
LST, radome, **26**, 440
$\mathfrak{L}$-transform, **18**, 25
Lubricants, **26**, 140
Lubrication, **17**, 367–370, 412
Lucero, **3**, 6
Lucite, **26**, 370
Lumped guides, magnetron output, **6**, 198
Lustron, **26**, 372

M

Mach number, **26**, 423
Magic T, **8**, 306–308, 447; **9**, 706; **11**, 63, 237, 331, 517, 525, 546; **12**, 572, **14**, 350; **15**, 196; **16**, 7, 259–262, 363–365; **23**, 16
alignment, **11**, 535
coupling-hole, **8**, 451
equivalent circuit, **8**, 308; **16**, 264
impedance bridge, **14**, 395
junctions, **10**, 116, 386
modified, **14**, 365
frequency sensitivity, **14**, 365
practical, **14**, 361
ring-circuit, **14**, 357
coaxial, **14**, 368
right-angle, **14**, 367
with single symmetry plane, **8**, 452–454
standing-wave ratio, **14**, 359
using round waveguide, **14**, 369
voltages and currents, **16**, 264–269

Magnesyns, **17,** 345–351; **19,** 454; **20,** 394; **21,** 364
Autosyn servo system, **17,** 350–351
construction, **17,** 346
electrical characteristics, **17,** 346
linear, **17,** 350
theory of operation, **17,** 347–349
Magnet, charging, **6,** 548
design, magnetron, **6,** 540
weight, **6,** 414
wire, **17,** 150–151
Magnetic, activity, **4,** 145
circuit, magnetron, **6,** 414, 540–557
nonlinear, **19,** 421
deflecting fields, defects in, **22,** 312–314
field, magnetron, **6,** 416, 436
material, **6,** 414; **22,** 556
measurements, **6,** 553
-path length, mean, pulse transformer, **5,** 599
saturation, **18,** 350
shunt, pulse transformer, **5,** 400
stabilization, **6,** 550
wall, **8,** 13
Magnetizing current, pulse transformer, **5,** 522
Magnetron, **1,** 7, 320–355; **3,** 256–278; **12,** 599–601; **14,** 2; **16,** 290; **19,** 691; **22,** 11; **26,** 72
2J22, **6,** 751–756
2J32, **6,** 426
2J34, **6,** 751–756
2J38, **6,** 747–751
2J39, **6,** 426, 747–751
2J41 stabilized, **6,** 766–769
2J42, **6,** 770–774
cathode-temperature characteristics, **6,** 528
2J53, **6,** 777
3J21, **6,** 789
3J31, **6,** 429, 786–790
4J31, **6,** 760
4J33, **6,** 423, 427
4J35, **6,** 760
4J36, **6,** 760
4J39, **6,** 426
4J41, **6,** 760
4J50, **6,** 428, 780–784
4J52, **6,** 783
4J70 tunable, **6,** 756–760
4J77 tunable, **6,** 756–760
Magnetron, 4J78, **6,** 783
725A, **6,** 428, 774–777
730A, **6,** 777
admittance (*see* Admittance; Resonator)
AFC, **6,** 623
anode, block, **6,** 11, 49, 406
closed-end, **6,** 69
diameter ratio to π-mode wavelength, **6,** 104
fabrication, **6,** 649–662
height, **6,** 473
hole-and-slot, **6,** 14
rising-sun, **6,** 437
diameter, **6,** 472
ratio to cathode diameter, **6,** 105
double-ring-strapped, **6,** 460
height, **6,** 439
segment-width ratio to gap width, **6,** 107
strapped, circuit constants, **6,** 465
arcing, **6,** 737
asymmetrical systems, **6,** 140–166
AX9, **6,** 429, 784–786
back-bombardment power, **6,** 411, 437, 520, 525, 527, 529
beacon, requirements, **3,** 262–270
BM50, **6,** 429, 764–766
British cavity, **6,** 8
buildup, starting, **6,** 357, 372; **14,** 154
capacitive and inductive tuning, **6,** 564–575
cathode (*see also* Cathode), **6,** 503–539
back bombardment, **1,** 344
ohmic loss, **6,** 524
choke joints, **6,** 483
circuit efficiency, **1,** 345
component weights, **1,** 351
conductance, G_L, at slots, **6,** 422
map, **6,** 338, 358, 361
construction, **1,** 321–325; **6,** 649–697
chemical processes used in, **6,** 674–676
contours, efficiency, **6,** 443
cooling by radiation, **6,** 524
coupled-circuit tuning, **6,** 576–591
critical field, **6,** 437–439
current, average, **5,** 146, 155, 253
cutoff, **6,** 3, 238, 340, 342, 369
density, reduced linear, **6,** 235
-voltage characteristic, **5,** 32, 702

Magnetron, c-w, CM16B, **6,** 744–747
LCW, **6,** 740–744
XCR, **6,** 795, 796
design, **6,** 401–459
parameters, **6,** 401, 405, 435, 455
diode tuning, **6,** 615
double-moding, **3,** 237
double-ring-strapped system, **6,** 119
early types, **6,** 1–8
efficiency, **1,** 345; **6,** 35, 36, 333, 401, 409, 437, 450
limiting, **6,** 240
electron-beam tuning, **6,** 592–621
electron orbits, **1,** 330
electron stream admittance, **6,** 214
end plates, insulated, **6,** 538
end shield, **6,** 12, 530
cathode, **6,** 537
Permendur, **6,** 781
end space, **6,** 11, 91, 498
effects, **6,** 69, 418
resonance, **6,** 74
energy-loss function, **6,** 241
ET10 reactance tube, **6,** 747
family, **6,** 416
field, pattern measurements, **6,** 710–713
uniformity, **6,** 552
fields, boundary conditions for, **6,** 234
fixed-tuned, **3,** 263–265
flux leakage, **6,** 545
frequency, pulling, **1,** 349
stability, **6,** 35, 408, 409
stabilization, **1,** 351; **3,** 267–270; **6,** 402, 622–645
gap width (*see also* Gap), ratio to anode-segment width, **6,** 107
gassy tube, **6,** 736
GK13-1, **6,** 430
heater, open, **6,** 736
power, **6,** 402, 411
rated, **6,** 528
HP10V, **6,** 426, 760–764
impedance (*see* Impedance)
index, **6,** 742
inductive tuning, **1,** 347; **6,** 564–575
input, characteristics, **5,** 435
impedance, **1,** 346
requirements, **3,** 261
instabilities, **1,** 353
mode-changing, **1,** 353
sparking, **1,** 353
Magnetron, instability, **6,** 3–5, 349, 355
interaction between modes, **6,** 380
interaction space, **6,** 63, 84
lamination, anode, **6,** 650
large-signal conditions, modulation, **6,** 619
L/C ratio, oscillator, **6,** 726
LCW, **6,** 428, 740–744
leakage-flux reduction, **6,** 545
linear, **6,** 233
LL3, **6,** 352, 367
load, **5,** 527
curves, **6,** 444
instability, **6,** 42
optimum, **6,** 563
pulser performance with, **5,** 435–447, 707
long-line effect, **6,** 322; **26,** 5
low-voltage, **6,** 440
magnetic circuit, **6,** 414, 540–557
field, **6,** 416, 436
stabilization, **6,** 550
measurements, operating, **6,** 730–738
resonant-system, **6,** 698–730
mechanical tuning, **6,** 561–591
mica windows, **6,** 489, 684
misfiring, **6,** 43, 346, 350, 354
mode changes, **3,** 260; **5,** 206, 417, 438–441
mode skipping, **5,** 439
model, **6,** 729
modes (*see also* Modes), of operation, **1,** 326–328
modulation (*see* Modulation)
MTI, stability, **1,** 640
noise (*see also* Noise, magnetron), **6,** 388–398
nonoscillating states, **6,** 342, 362, 367
normal operation, **5,** 435–438
operating, characteristics, **6,** 613, 614
constants, **6,** 405
curve, **6,** 296, 297, 307, 315, 332, 338
data, reduced, **6,** 419
point, relative, **6,** 403, 435, 455
operation, efficiency, **6,** 409
parameters, **6,** 37
oscillation, buildup, **6,** 43; **20,** 38; **23,** 547
oscillator, *L/C* ratio, **6,** 726
output, **6,** 481–502
circuits, **6,** 11, 167–203

Magnetron, output, circuits, center-loop, 6, 191
coaxial, 6, 169, 191, 482
frequency sensitivity, 6, 18
functions, 6, 187
high-impedance, 6, 190
low-impedance, 6, 190
coupling, 1, 329; 3, 251
loop-coupling, halo, 6, 169
packaged, 6, 13
performance, 6, 316
performance chart, 1, 336; 6, 38, 317, 334, 732
reduced, 6, 436, 441
universal, 6, 448, 450
variation with load, 6, 441
phase coherence, 6, 388
π-mode radiation, 6, 501
power, characteristic, 6, 416
output, 6, 401
pseudo scaling, 6, 450
pulling, 26, 246–248
pulling figure, 1, 349; 3, 259; 6, 182, 186, 188, 326, 734
pulse-length limitations, 1, 346
pulse power, 1, 341
pulsed, 6, 42, 45
sparking, 6, 24
pushing figure, 3, 239, 259; 5, 118; 16, 291
QK61, 6, 428
radial cathode supports, 6, 13
RD11-2, 6, 430
resistance, internal, 6, 343, 356, 363, 371
resonance, end-space, 6, 74
resonant, circuit, internal, 6, 7
systems, 1, 325; 6, 11, 13–23, 297–304, 406, 460–502
strapped, 6, 461
unstrapped, 6, 49
various, 6, 22
resonator (*see also* Resonator), depths, ratio of, 6, 102, 478
shape, 6, 108
Rieke diagram (*see* Rieke diagram)
rising-sun, 1, 330; 6, 21, 283, 528
22-cavity, 6, 790, 791
38-cavity, 6, 791–794
system, 6, 83–117, 470–481
closed-end, 6, 110–113
Magnetron, rising-sun, system, partially closed-end, 6, 113
scaling, 6, 236, 414, 417, 450, 610
pseudo-, 6, 450
SCWC, 6, 430
segment-tuned system, multicavity, mode spectrum, 6, 161
shape factors, 6, 403, 435, 455
single LCW, 6, 428
single-ring-strapped systems, 6, 119
single-stream states, conditions for, 6, 251
sink, 16, 204, 206, 208
sintering, 6, 662
small-amplitude theory, 6, 253–265
small-signal theory, tuning, 6, 616
space-charge distribution, 1, 335
sparking, 5, 417, 425, 441–447, 707
split-anode, 6, 4
sprocket tuning, 6, 565
spurious oscillation, 6, 418
stability, 6, 305, 313, 328, 362
stabilization, 6, 408, 576, 586, 622–645
factor, 6, 625, 723–726
frequency, 6, 622–645
stabilized, 2J41, 6, 766–769
start, false, 6, 372
starting, 6, 357, 367, 376
speed, 6, 365, 388, 632
strap, 6, 11, 19, 118
breaks, 6, 147–157, 470
effect on mode spectrum, 6, 147–154
strap-tuned system, multicavity, mode spectrum, 6, 159
strapped, 1, 330; 6, 118–166, 461–470
double-ring, 6, 119
mode spectrum, 6, 133–138
single-cavity-tuned, mode spectrum, 6, 157
single-ring, 6, 119
mode spectrum, 6, 138
strapping, 6, 118, 384
by staggering of vanes, 6, 766
symmetrical states, 6, 243–253
testing, 6, 553
thermal expansion, 6, 407
transient behavior, 6, 315, 339–387
tube, construction, 6, 649–697
evacuation, 6, 693, 694
tunable, 6, 320

Magnetron, tunable, 2J51, **6**, 778–780
4J70, **6**, 756–760
4J77, **6**, 756–760
C-ring, **1**, 347
tuning, **1**, 347; **3**, 262
capacitive, **6**, 570
coaxial, **6**, 588, 746
cookie-cutter, **6**, 570
coupled-circuit, **6**, 576
diode, **6**, 615
double-output, **6**, 576
electron-beam, **6**, 592
electronic, **6**, 592–621
inductive, **6**, 565
iris-coupled, **6**, 583
mechanical, **6**, 561–591
by perforated plate, **6**, 769
by pins in oscillators, **6**, 778
ring, **6**, 572
short-line effects, **6**, 322
single-stub, **6**, 589
sprocket, **6**, 565
typical, **6**, 739–796
unstrapped resonant system, **6**, 49–82
(V,I)-characteristics, **6**, 341, 343, 346, 347, 450
(V,I)-trace, **6**, 347, 348, 358, 368, 372
voltage, instability, **6**, 264
range, **6**, 401
wavelength, calculations, **6**, 479
resonant system, **6**, 461
scaling, **1**, 341
Magslip, **20**, 394
Malus, theorem of, **12**, 126
Map, radar, **2**, 346–350
as aid to pilotage, **2**, 115
Map superposition and plotting, **22**, 566
Mapping, radar, aids, **2**, 278–284
features revealed by, **2**, 89–96
highway and runway details, **2**, 102
mountain relief in, **2**, 103
Mapping theorem, servo stability, **25**, 68–70
Marauders, **3**, 14
Marbon B and Marbon S, **26**, 371, 411
Marker, absorption, **23**, 310
active, **23**, 310
blanking, **23**, 310
calibration, **4**, 205
generator, **22**, 283
height, **22**, 249
Marker, Loran, **4**, 12, 66, 104
mixer, **4**, 212, 226
multiple, **22**, 246
range, **22**, 25, 238
Markers (*see* Angle; Azimuth; Height; Range; Timing)
Marx voltage-multiplier circuit, **5**, 494
Massachusetts Bay, meteorological measurements and analysis, **13**, 297
radio measurements, **13**, 296
Master station, Loran, **4**, 59, 68; **20**, 261
Match, sliding, bridge, **11**, 534
Matching, diaphragms, capacitive, **9**, 214
inductive, **9**, 211–214
narrow-band, coaxial-line to waveguide, **9**, 318–322
techniques for T's, **11**, 525
waveguide and horn feeds, **12**, 383–387
Materials, stiffness, **26**, 383, 415, 416
strength, **26**, 383, 415, 416
Mathematical operations on waveforms, **19**, 629–693
Mathieu function, **10**, 81
Matrix, **9**, 544–547
admittance, **8**, 89, 140; **10**, 106; **15**, 114–124
algebra, **8**, 405–411
Eigenvalue equations, **8**, 405
calculations, **14**, 85
commuting, **8**, 410
correlation, definition, **25**, 277
excitation, **7**, 112
functions, rational, **8**, 409
impedance, **8**, 87, 140; **10**, 103
modulation, **7**, 99, 102, 115
nonlinear resistance, **15**, 153–157
physical realizability, **8**, 142
row vector, **8**, 89
scattering, **8**, 146–149; **10**, 107; **11**, 517, 892
directional coupler, **8**, 301–303
free space, **8**, 324
simple electric dipole, **8**, 325
transformation of, **8**, 149
symmetrical, **8**, 407–409
unit, **8**, 88
unitary, **11**, 518
vector column, **8**, 87
vector row, **8**, 89
wave, **9**, 551–554
zero, **8**, 88

Matter, conservation of, **7**, 354
Mattress antennas, **1**, 274
Maximum-power theorem, **12**, 20, 21
Maxwell's equations, **5**, 618; **7**, 83; **8**, 10–14; **9**, 3, 37; **26**, 341
differential form, **12**, 64
in earth-flattening method, **13**, 51
integral form, **12**, 64
symmetries of, **8**, 411–417
for time-periodic fields, **12**, 68
Maxwell-Boltzmann velocity distribution, **7**, 124
Mazda lamps as regulator element, **21**, 502
M-deficit, **13**, 222, 229, 230, 234, 237-239, 244, 245
Meacham range unit, **20**, 142–147
Mean free path, electron, **4**, 131; **15**, 63
Mean-square, definition, random process, **25**, 273
error, minimizing, **25**, 325–328
Measurement (*see* quantity to be measured)
Measurement problems, laboratory, **21**, 574
Measuring techniques, pulse generator, **5**, 661–709
Mechanical assemblies in electronic apparatus, **21**, 698–700
Mechanical devices, addition with, **21**, 39
subtraction with, **21**, 39
Mechanical integration by differential analyzers, **13**, 177
Mechanical mixing, **13**, 238, 252
and temperature excess, **13**, 231
and wind speed, **13**, 231
Mechanism, regular (computer), **27**, 45, 223
Mechanization, alignment nomogram with three parallel straight lines, **27**, 37
function, **27**, 46–47
ballistic, in vacuum, **27**, 286–299
by combination of three-bar linkage and two ideal harmonic transformers, **27**, 171, 186
with a discontinuity in derivative, **27**, 114–117
by harmonic transformer, **27**, 61–63, 166
Mechanization, function, by homogeneous parameters and variables, **27**, 62–67
by ideal double harmonic transformer, **27**, 78–95
with ideal grid structure, **27**, 250, 272
by linkage combinations, **27**, 166
by method of least squares, **27**, 62
by nonideal double harmonic transformer, **27**, 95–101
by three-bar linkage, **27**, 166, 184
inverted function by nomographic method, **27**, 138–139, 143–145, 155
logarithmic function, by double three-bar linkage, **27**, 36
by geometric method, **27**, 156–166
monotonic functions, **27**, 78, 82–88
relation between variables, **27**, 2
tangent function, **27**, 171, 175, 177, 178, 180, 182, 183, 186
by ideal harmonic transformer, **27**, 165
Memory, circuits, **19**, 503, 519
time, human, **24**, 231
time measurements, **20**, 304
position, **20**, 282, 380
velocity, **20**, 278, 284, 380
servomechanism with, **20**, 449
Mercator projection, **4**, 174
Mercury relay, **19**, 403
Mesh, analysis, **18**, 11
and nodal analysis, comparison, **18**, 19, 20
equations, for active network, **18**, 14
for passive network, **18**, 13
network, **8**, 85
Metal-hose, wound, **9**, 274–279
Metal-to-glass seals, **14**, 255
Metalized glass, coaxial-line termination of, **11**, 724
plates, matching of, **11**, 778
metalization of, **11**, 775
use with low-power terminations, **11**, 731
Metallic materials, microwave-component, **9**, 115–124
Metals and alloys, attenuation, **9**, 120
conductivity, **9**, 120
Meteoric bombardment, **4**, 133
Meteorograph, **13**, 337

Meteorological conditions, nonuniform, **13**, 315, 318–319, 368
Meteorological constants, table, **13**, 292
Meteorological echoes (*see* Echoes)
Meterological mixing, **13**, 200
  convective, **13**, 225
  mechanical, **13**, 238, 252
  ratio, **13**, 185, 187, 188, 200, 206
M fluctuations, **13**, 268–271
M-gradient, standard, definition, **13**, 14
Mica windows, magnetron, **6**, 489, 684
Mickey, **3**, 17
Micro-*B*, **1**, 171
  display, **1**, 531
  scope with range normalization, **22**, 487–492
Micro-*H*, **3**, 17; **4**, 9, 16; **20**, 30
Microphonics, **16**, 349; **18**, 144, 594; **23**, 519
  multivibrator, **19**, 194
  rejection circuits, **18**, 145
Micropot, **19**, 432; **21**, 368
  Gibbs, **19**, 476
Microsyns, **20**, 394; **21**, 365
Microtorque, **21**, 368
Microwave, attenuator (*see* Attenuator, microwave)
  circuit theorems, **8**, 130–161
  component design factors, **9**, 95–100
  construction techniques, **9**, 121–124
  current, heating effects, **11**, 166
  detection, **11**, 4–8
  filter, assembly procedures, **9**, 709–714
  frequencies, crystal-controlled, **7**, 286
    ferromagnetism at, **8**, 382–385
  networks, **10**, 101–167
  oscilloscopes (*see also* Oscilloscope), **11**, 468
  power amplifier, **7**, 21–23, 249
  propagation (*see also* Propagation), **1**, 11, 47–62
  realizations of resonant branches, **9**, 703
  receivers, **7**, 5
  reflectors, **26**, 15
  region, **8**, 1; **11**, 1
  transmission circuits, **9**, 5
  triode oscillators, **7**, 170–186
  use of, **1**, 10
  useful properties, **9**, 2
Microwave, wavemeters, **11**, 319–330
Migratory highs, **13**, 261
Mile, 2000-yd, **20**, 103
  nautical, **20**, 103
  statute, **20**, 103
Military beacon, uses, **3**, 8
Miller, feedback, **20**, 131; **21**, 80
  integrator (*see* Integrator, Miller)
  negative-going sweeps, **19**, 483
  sweep generation, **19**, 195–197
  transitron, **19**, 197
Millimeter waves, absorption, by water vapor, **13**, 664
  raindrop radar cross sections, **13**, 612
Millivoltmeter, recording, **19**, 406
Minnie, **3**, 17
M-inversion, **13**, 14, 15
  elevated, **13**, 18, 223, 231, 249, 261–266, 302–304, 329–335, 339, 359, 361, 362, 364, 366, 372, 373, 382
    and 256 Mc/s transmission, **13**, 315
    overhanging, **13**, 304, 332
  Meteor expedition, **13**, 262
  shallow, **13**, 224
  with subsidence, **13**, 261
Mismatch, accumulative, **9**, 551–554, 611
  adjustable reference, **11**, 557
  introduced by reflector, **12**, 155–158, 439–443, 454
  measurement, **9**, 85
  terminations, **9**, 609–612
Mixer and mixing (*see also* Conversion; Converter), **3**, 168–170; **15**, 111–114; **16**, 3, 119; **17**, 599–610; **23**, 138–148; **24**, 9; **26**, 72
  for 10-cm conversion-loss test set, **15**, 275
  admittances and conversion loss, **15**, 128–152
  AFC, double-balanced, **16**, 283–287
  balanced, **4**, 246; **16**, 257–289, 301; **23**, 16
    to reduce noise, **7**, 471
  basic, **16**, 120–122
  broadband two-channel, **16**, 231
  coaxial-line, with loop coupling, **16**, 180
  coincidence, **4**, 231
  complete, drawings, **16**, 180–189
  conversion transconductance, **23**, 138
  cross attentuation, **16**, 194, 195, 284

Mixer and mixing, crystal, **1**, 412–414; **3**, 168; **15**, 7–9, 25–44; **16**, 34, 56, 119–189; **23**, 11–16; **24**, 109
as modulator, **15**, 148
properties, measurement **15**, 230–232
self-protection, **16**, 172–174
diode, **4**, 281; **16**, 32–34; **23**, 141–143
double, **16**, 194; **23**, 44
double-balanced, **16**, 286
driving power, **16**, 34
dummy, **18**, 317; **23**, 326
four-crystal, **16**, 283, 301
gate-pulse, **4**, 199, 227
harmonic effects, **16**, 61, 82–87, 285, 301, 372, 374
high-loss, **16**, 122
i-f, **15**, 112
image frequency, **15**, 112
input admittance, **16**, 66–71, 122
interference, **16**, 276
iris-coupled, **16**, 183
loss, **16**, 58, 115, 169, 353
impedance, **16**, 66, 68, 80, 89
measurement, **16**, 367–372
low-Q, **15**, 115, 119
Magic-T, **16**, 269–279; **24**, 115
measurement techniques, **16**, 352–374
microwave, **1**, 416–418; **7**, 17–18
mixing ratio, **24**, 237
multiple-function, **16**, 190–234
nonadditive, **18**, 100; **22**, 533
pentagrid, **17**, 606, 608
pentode, **18**, 99; **23**, 144
production tests, **16**, 352–354
pulling figure, **16**, 203–206, 213, 291
pulse, **4**, 210
reciprocity, **16**, 64, 66, 74, 87, 371
resistive, **18**, 334, 335
resonant, **16**, 122
for 10-cm band, **16**, 188
signal-input circuit, **16**, 166–171
single, **16**, 299; **23**, 42–44
thermionic, **23**, 19
transmission loss, **16**, 169
triode, **23**, 144
tubes, **3**, 169; **16**, 28; **17**, 599–610; **18**, 99
tuning, **16**, 70, 123, 293
two-channel, **16**, 199–201
video, **1**, 45; **20**, 451; **24**, 230–237, 248
mixing ratio, **24**, 237
Mixer and mixing, waveguide, **16**, 188
for 10-cm band, **16**, 171–172
local-oscillator coupling in, **16**, 144–146
Mks system of units, **8**, 11; **9**, 8
Mode, **23**, 24
absorbers, **8**, 347–349
asymmetry, reflex klystron, **7**, 384–403
cavity, **6**, 339
changes, magnetron, **6**, 343, 345, 376
changing, **6**, 43
characteristic impedance, **10**, 8
characteristics, **10**, 55–56
field representation by, **8**, 252–256
chart, **11**, 298
coaxial cylinder, **11**, 304
right circular cylinder, **11**, 298
for TFX-30 wavemeter, **11**, 324
in circular waveguide, **11**, 690
in coaxial cylinders, **8**, 41
competition, **6**, 100, 474
component, **6**, 32
damping, **6**, 769
degenerate, **6**, 17, 75
discontinuities, **7**, 401
distortion, **7**, 330
dominant, **8**, 35; **10**, 2
elementary, **13**, 18
E- (*see also* Waveguide, E-mode), **8**, 253
circular waveguide, **10**, 66
coaxial waveguide, **10**, 73–77
equivalent transmission lines for, **8**, 119
functions, **10**, 4
parallel-plate waveguide, **10**, 62
radial waveguide, **10**, 31, 90
rectangular waveguide, **10**, 56
spherical waveguide, **10**, 49
${}_{e}E_{mn}$- (*see* Waveguide, elliptical)
E_{01}-, circular waveguide, **10**, 196
round waveguide, **8**, 57
E_{11}-, rectangular waveguide, **8**, 56
round waveguide, **8**, 59
field distribution, **6**, 17
filtering, **11**, 693–696
filters, **8**, 347–349
frequencies, **6**, 19
fundamental, **7**, 71
glow-tube, **21**, 499

Mode, *H*-, **8**, 253
circular waveguide, **10**, 69
coaxial waveguide, **10**, 77
functions, **10**, 4
parallel-plate waveguide, **10**, 65
radial waveguide, **10**, 92
rectangular waveguide, **10**, 58
spherical waveguide, **10**, 49
H_{01}-, circular waveguide, **10**, 201
round waveguide, **8**, 58
H_{10}-, rectangular waveguide, **8**, 54; **10**, 61
H_{11}-, circular guide, **10**, 206
round waveguide, **8**, 56
H_{20}-, rectangular waveguide, **8**, 55
H_{21}-, round waveguide, **8**, 57
identification, **6**, 726, 727
instability, **6**, 737
jumps, **6**, 355
loci, **7**, 357, 359, 360
locus, normalized, **7**, 360
magnetron, **3**, 237; **6**, 16
normal, of cavity, **11**, 285, 293
in coaxial resonator, **11**, 303–307
in rectangular parallelopiped cavity, **11**, 294–296
in rectangular pipes, **8**, 33–38
of right-circular cylinder, **11**, 297–303
in round pipes, **8**, 38–40
in slotted guides, **11**, 889
number, **6**, 29
assignment of, **7**, 358
n, **6**, 33
oscillation, **6**, 627
patterns, **10**, 56
reflector, **11**, 26
Π, **6**, 461, 467, 470, 472, 474, 479
field distortion, **6**, 97
operation, **6**, 98
oscillations, **6**, 16
radiation leakage, **6**, 501
wavelength, ratio to anode-block diameter, **6**, 104
principal, **7**, 71
purity, **9**, 99
results, summary, **8**, 54–59
selection, **6**, 339, 348, 575, 586
separation, **6**, 468
shapes, **7**, 308–310, 330
universal, **11**, 28
Mode, shift, **6**, 345, 351, 562
single, in duct, **13**, 19
skip, **6**, 345, 348, 350
spectrum, **6**, 474
double-ring-strapped systems, **6**, 133–138
effect of loading on, **6**, 141–157
multicavity inductance-tuned system, **6**, 165
multicavity segment-tuned system, **6**, 161
multicavity strap-tuned system, **6**, 159
single-cavity-tuned strapped system, **6**, 157
single-ring-strapped systems, **6**, 138
stability, **6**, 538
superregenerator (*see* Receiver, superregenerator)
TE-, **9**, 39
circular guide, **12**, 233
coaxial line, **12**, 220
cylindrical guide, **12**, 204–206
E-plane sectoral guide, **12**, 352–353
H-plane sectoral guide, **12**, 353–356
parallel-plate guide, **12**, 237
rectangular waveguide, **12**, 226–229
TE_{01}- round waveguide, **8**, 57
TE_{10}-, between coaxial cylinders, cutoff wavelength, **8**, 42
coupling to TE_{20}-mode, **8**, 337
rectangular guide, **8**, 54; **9**, 46–54
to TM_{01}-mode converter, **12**, 308
transition to TE_{20}-mode, **8**, 339
TE_{11}-, circular guide, **11**, 690
circular polarization, **9**, 369–378
cylindrical guide, determining percentage of, **9**, 381–388
for filter-ring rotary joint, resonances in, **9**, 423
filters, **9**, 388–400
fin, **9**, 397
rectangular waveguide, **8**, 56
round guide, **8**, 56, 349–351
TE_{20}-, excited from coaxial line, **8**, 336
rectangular guide, **8**, 55
TE_{21}-, round guide, **8**, 57
TEM-, **9**, 39
coaxial, **8**, 54; **12**, 217–219
cylindrical guide, **12**, 203
parallel-plate guide, **12**, 235

Mode, *TEM*-, voltage, **12**, 216
TM-, **9**, 39
circular guide, **12**, 233
coaxial line, **2**, 220
cylindrical guide, **12**, 206
parallel-plate guide, **12**, 236
rectangular guide, **12**, 226–229
TM_{01}-, circular guide, **11**, 690
round guide, **8**, 57
transitions to, **9**, 379–381
breakdown of, **9**, 405
Preston, **9**, 389
straight-on, **9**, 400–403
TM_{11}-, round guide, **8**, 59
transducers, **8**, 335–340
properties, measurement, **8**, 343-347
with taper, **8**, 339
transformations, **8**, 334–364
trapped, **13**, 22, 71, 75, 82, 149
boundary conditions, **13**, 78
characteristic values, **13**, 75
waveguide, **1**, 400; **10**, 1
orthogonality, **12**, 207–209
transitions with change in, **9**, 379–405
two-wire representation, **12**, 209–216
width, **23**, 24
zero, **6**, 472
Modification, of air over water, for long trajectories, **13**, 248–250
cross section, **13**, 239–241
height, **13**, 238, 241, 242
Modulating function, **24**, 3
Modulation, admittance, density and velocity, **7**, 114
amplitude, **1**, 129, 139; **19**, 49; **24**, 5–13
electrical, **19**, 389–426
klystron, **7**, 257, 447, 464–469; **11**, 24
magnetron, **6**, 592
mechanical, **19**, 427
minimum detectable, **24**, 368–369
nonlinear transformer for, **19**, 422
of pulses, **3**, 473
approximation, small-signal, **7**, 447
of beam current, klystron, **7**, 452–454, 465–469
coefficient, klystron, **7**, 35
complex-current-waveform, **19**, 450–455
complex-voltage-waveform, **19**, 447–450
Modulation, complex-waveform, **19**, 461–463
continuous-wave, **3**, 98
cross, **24**, 8
crystal, **15**, 174–178
deflection, **19**, 713
density, **7**, 33, 40, 57, 59, 132, 143
double-pulse, **3**, 232
focus, **19**, 716
fractional, **24**, 4
frequency (*see also* F-m), **1**, 130; **20**, 5, 393; **24**, 31
beacon transmitter, **3**, 265
and demodulation, **20**, 13–15
klystron, **11**, 24
magnetron, **6**, 592
microwave, **7**, 27, 441, 447, 465–469
minimum detectable, **24**, 380–383
functions, density and velocity, **7**, 127
index, **24**, 14
intensity, storage-action, **19**, 708–713
klystron, **7**, 22
matrix, **7**, 99, 102, 115
parameter, **7**, 449, 452–455
percentage, **24**, 4
phase, **19**, 53; **20**, 142–175; **24**, 31
and amplitude comparison, **20**, 142–164
and demodulation, **20**, 7–13
klystron, **7**, 257, 447, 464–469
magnetron, **6**, 597
network, **20**, 158
range unit, two-scale, **20**, 143
system, three-scale, **20**, 157–161
of timing, **20**, 57
PRF, **3**, 222; **24**, 31
propeller, **13**, 539–543; **24**, 288–292, 334
pulse, **1**, 130; **3**, 98
pulse-length, **24**, 30
of pulse-repetition frequency, **3**, 222; **24**, 31
pulse-width, **3**, 226; **24**, 30, 292–296
reflection-time, klystron, **7**, 454–455
reflex-klystron, **7**, 441–469
from scanning, **1**, 136
signal-plate, **19**, 714
space, **3**, 223–226
square-wave amplitude, klystron, **7**, 441
theory, quasistatic approximation in, **7**, 444–446

Modulation, threshold for a-m, f-m, and c-w systems, **24**, 367–383
of time of passage, **7**, 56, 59
time, **19**, *12, 52*, 300, 466–500; **20**, 4, 47–62
bootstrap circuit, **20**, 128
delay-tank, **20**, 132
and demodulation, **20**, 5–7
double-scale, **20**, 49, 58–61
electrical control, **20**, 168
errors in, **19**, 472–476
general accuracy considerations, **19**, 472–476
multiple-scale, **20**, 48–50
nonlinear, circuit, **20**, 112
phase-modulation method, **19**, 476, 490–499
propagation-velocity method, **19**, 473
single-scale, **20**, 47, 55–58
step-interpolation, **20**, 164–175
storage-tube method, **19**, 499–500
three-scale, **20**, 169
transfer function, **19**, 466
voltage-sawtooth method, **19**, 477–490
types, **3**, 230
velocity (*see* Velocity modulation)
weak, **7**, 313
Modulator (*see also* Pulser), 1, 7; **21**, 53, 375–386; **26**, 72
3-phase, condenser, **20**, 172
balanced-triode, **19**, 413, 414
beacon, **3**, 237–255
bootstrap, **4**, 281
Brown converter, **19**, 402
carrier-balanced, **19**, 415
condenser, **21**, 44, 57, 516
copper-oxide, **19**, 409
crystal, **15**, 174–178
diode, Diamod, **19**, 397, 398, 521
switch, **19**, 401
double-balanced, **19**, 409
electromechanical, **19**, 427–465; **20**, 391
variable-condenser, **22**, 212
equating circuits, **21**, 514
full-wave, **19**, 408
balanced-triode, **19**, 416
diode-switch, **19**, 407
switch, **19**, 402
half-wave-switch, **19**, 397
Modulator, hard-tube, **3**, 248–250
line-type, **3**, 246–248
and hard-tube, comparison, **3**, 255
Loran, **4**, 278
mechanical, for crystal test, **15**, 218, 280–283
-switch, **19**, 362
MTI requirements, **1**, 641
negative-feedback, **19**, 420
operation, **4**, 282
phase, **19**, 53; **20**, 135–137, 145
condenser, **20**, 142, 144, 150, 151, 170
Loran, **20**, 170
mechanical, **20**, 168
photomechanical, **19**, 463–465
potentiometer, with feedback amplifier, **19**, 433
pulse formation in, **3**, 245–255
radar, **3**, 237; **5**, 1
ring circuit, **19**, 409
signal- and carrier-balanced, **19**, 416
single-sideband, **11**, 331
switch-type, **21**, 43, 379
tetrode, for electrometer application, **19**, 414
time, **20**, 146, 171, 400
AN/APS-15, **20**, 167
-base, frequency-modulation system, **19**, 463
circular-sweep, SCR-584, **20**, 161
H_2X, **20**, 121
linear-sweep, **20**, 152
Miller feedback, **20**, 114
multiple-scale, **20**, 174
and pulse selector, **20**, 146
two-scale, **20**, 71, 170
trigger, **20**, 91
zero-range, **20**, 95
variable-capacitance, **19**, 418, 419
vibrator, **25**, 108
Modulus, deficit, **13**, 222, 224
of rupture, **26**, 384
Young's, **26**, 385
Molding, compression, **9**, 138
extrusion, **9**, 138
transfer, **9**, 138
Moments, aperture-field distributions, **12**, 184
random process, **25**, 273
Momentum integral, **7**, 53
Monitors, beacon, **3**, 332, 339–341

Monitors, beacon, audio, **3**, 340
remote, **3**, 449, 457
station, Loran, **4**, 68
timer, Loran, **4**, 250
TRE general-purpose, **21**, 652–657
Monostable circuit, **19**, 162
for very short pulses, **19**, 179–182
Monostable multivibrator dividers, **19**, 572–575
Monotron, **7**, 30
Monsoons, **13**, 371, 372
Mosquitoes, **3**, 14
Motion, equations of, electron, **6**, 222–228
nonrelativistic, **6**, 231–243
Motorboating, **18**, 327
Motors, **21**, 386–400
a-c, **17**, 377–384
brush-shifting commutator-type, **17**, 379
capacitor, **17**, 377–378
control (*see also* Speed control), Ward Leonard system, **21**, 437
drag-cup, **17**, 383–385
high-frequency, **17**, 379–381
low-inertia, **17**, 381–385
relay control, **21**, 445
repulsion-start, **17**, 379
saturable reactor control (*see also* Speed control), **21**, 440
shaded-pole, **17**, 378–379
single-phase, **21**, 393
split-phase, **17**, 377
vacuum-tube control, **21**, 437
variable-frequency capacitor-run, **17**, 380
attachments and auxiliaries, **17**, 370, 387–395
bearings and lubrication, **17**, 367–370
brakes, magnetic, **17**, 390–391
brush-shifting, **17**, 379
brushes, **17**, 365–367, 414, 424–425
capacitor, **17**, 377–378
characteristics, **17**, 358–363
check list, **17**, 357–358
CK-1, relay servo for, **21**, 449
CK-5, **21**, 392, 479
clutches and brakes, **17**, 390–392
compound, **17**, 372
contactors, d-c, **17**, 504, 507
control (*see also* Speed control), mode of, **17**, 360
Motors, control, synchro, **17**, 321–323
d-c, **17**, 371–377
compound, **17**, 372–373
hysteresis, **21**, 360
permanent-magnet, **17**, 372, 374–376
relay control, **21**, 400, 427
series, **17**, 371
servo, **25**, 103–108
shunt, **17**, 371–372
two-speed, **17**, 387–388
split-field, **17**, 377
thyratron control, **21**, 400–417
vacuum-tube control, **21**, 417–427
Diehl, **21**, 391
drag-cup, **17**, 383–385
Dynatrol, **21**, 450
enclosures, **17**, 363–364
field control, **21**, 389, 423, 425
frames, **17**, 363–364
gear, **17**, 389–390
high-frequency, **17**, 379–381
horsepower rating, **17**, 361–362
hydraulic, **26**, 219, 222
impulse, **21**, 449
inertia measurement, **21**, 455
instrument, **17**, 356–395
types, **17**, 370–395
integral variable-speed transmissions, **17**, 390
low-inertia, **17**, 381–384
magnetic brakes, **17**, 390–391
materials, **17**, 364–365
measurement, **21**, 452
noise, electrical, **17**, 360
permanent-magnet, **17**, 372, 374–376; **21**, 389
polyphase, **26**, 220, 221
power source, **17**, 358–360
RBD-0808 motor, **21**, 390, 423, 424
repulsion, **21**, 393
repulsion-start induction-run, **17**, 379
scanner, **26**, 169
series, **21**, 388
servo, **26**, 212, 213, 218–220
shaded-pole, **17**, 378–379; **21**, 393
shunt, **17**, 371–372; **21**, 389
speed, **17**, 363
control (*see* Speed control)
measurement, **21**, 458
split-field, **17**, 377
split-phase, **17**, 377; **21**, 393

Motors, split-series, **21**, 388
control, **21**, 418
step, **21**, 449
synchro, **17**, 314, 316, 318
damping, **17**, 316, 318
differential, **17**, 314
synchronous, **21**, 392
temperature, measurement, **21**, 460
rise, **17**, 361–363
time constant, **21**, 461
two-phase induction, **21**, 390
two-speed, **17**, 387–388
types, **17**, 370–395
universal, **21**, 393
vibration, **17**, 360–361
Mountain-relief indication, **1**, 96
Mouse station, **3**, 15
Moving-target indication (*see* MTI)
M-profile, bilinear, and angle of arrival, **13**, 307–313, 393
characteristic values, **13**, 146–163
definition, **13**, 14
linear-exponential, **13**, 312
other atmospheric processes and their effect on, **13**, 260–271
power-law, **13**, 312
standard, definition, **13**, 14
M-scope, **20**, 225
MTI (moving target indicator), **1**, 626–679; **2**, 252–256; **3**, 107; **23**, 579–611; **24**, 324–334
airborne, **2**, 255
basic principles, **1**, 626–632
blind speeds, **1**, 650–654
cancellation equipment, stability requirements, **1**, 641
component design, **1**, 658–679
component requirements, **1**, 642
delay line, **2**, 253
local oscillator stability, **1**, 638–640
locking-pulse requirements, **1**, 662
locking test, receiver, **23**, 608
magnetron for, stability, **1**, 640
on moving system, **1**, 655–658
noncoherent method, **1**, 656
operating tests, **1**, 677
oscillator stability, testing, **1**, 677
performance, **2**, 253
criteria and choice of system constants, **1**, 638–655
phase-shift unit, **1**, 655
MTI (moving target indicator), phase-shift unit, design, **1**, 663
receivers (*see* Receivers, MTI)
requirements on modulator, **1**, 641
shipborne, **2**, 255
system, constants, choice of, **1**, 638–655
practical, **1**, 632–635
target visibility, **1**, 649–653
in clutter, **1**, 651–653
test equipment, special, **1**, 677–679
transmitter, **1**, 658
trigger generator, **1**, 634
Multiar, amplitude-comparison circuit, **19**, 343
comparator, **20**, 114–116, 124, 356
Multiple-coincidence circuits, **19**, 381–384
Multiple-element network circuits, **14**, 91
Multiple-hop transmission, Loran, **4**, 136
Multiple-ray paths, **13**, 388, 390, 395
Multiple-scale circuit, **19**, 468
Multiple-scale systems, time measurements, **20**, 61, 219
Multiple-switch, circuit for voltage multiplication, **5**, 494–496
multiple-network circuit, **5**, 485–488
Multiplexers, **9**, 708
Multiplication, based on Ohm's law, **21**, 58
as circuit operation, **19**, 668; **21**, 32, 48–60
by cone-cylinder combination, **21**, 55, 120
by integration, **21**, 56
mechanical methods, **21**, 59
nonlinear methods, **21**, 55
Multiplier, computer, **21**, 48; **27**, 12–15
bar-linkage, **27**, 37–40, 250–283
electrodynamometer, **21**, 57
full-range, **27**, 40
half-range, **27**, 40
linkage, **21**, 59, 60; **27**, 4
nomographic, **27**, 14–15
quarter-range, **27**, 40
resolver, **27**, 15–19
self-locking, **27**, 12
slide, **27**, 4, 12–14
star linkage in designing, **27**, 256–283
transformation of grid structure, **27**, 258–264
with uniform scales, **27**, 272

Multiplier, frequency (*see* Frequency multiplier)
probability, **21**, 59
sector, **21**, 59
time-coincidence, **21**, 59
Multipoles on raindrops, **13**, 676
Multivariable circuit element, **19**, 40
Multivibrator, **3**, 239; **19**, 163–195; **20**, 80; **22**, 122, 125
100-μ sec, **20**, 97
astable, **19**, 171–173
dividers, **19**, 575–577
free-running, **19**, 171
plate-to-grid-coupled, **19**, 171
self-running, **19**, 171
biased, **5**, 132
bistable, **19**, 164–166
cathode-coupled, **19**, 165
plate-to-grid-coupled, **19**, 164
cathode-coupled, **1**, 499
comparators, **19**, 341
delay, **4**, 199, 204, 206, 210, 211, 226; **20**, 131, 140, 342, 347; **21**, 591
coarse-scale, **20**, 162
driver, **5**, 132–139
figure of merit, tube, **19**, 177
flip-flop, **1**, 498; **19**, 167
gate generator, **20**, 117
gating, **19**, 167
hum reduction, **19**, 194
jitter, **19**, 194
microphonics, **19**, 194
monostable, **19**, 166–171; **20**, 144
cathode-coupled, **19**, 168
plate-to-grid-coupled, **19**, 167
one-shot, **19**, 167
output circuit, **18**, 144
output coupling, **22**, 123
overshoots, **19**, 168
pulse, **11**, 239
as pulse-frequency divider, **20**, 154
quasi-stable state, **19**, 160
radar receiver, **1**, 497–500
scale-of-two, **20**, 84
single-stroke, **1**, 498
stabilization, **19**, 190–194
symmetrical, **20**, 80
as PRF generator, **20**, 80
transition in, **19**, 174–177
tubes, figure of merit, **19**, 177
unsymmetrical monostable, **20**, 94
Mutual triggering, beacon interference, **3**, 116

N

Nacelle, **12**, 512, 513
Navigation, aids, air-traffic control, **2**, 122–131, 285–313
airborne-radar–ground-beacon system, **3**, 398–408
in approach zones, **2**, 304
beacon, comparison with other methods, **3**, 24–26
by ground radar, advantages and limitations of, **2**, 310
present system, **2**, 287–291
radar aids for, **2**, 293, 311–313
special equipment, **2**, 302
using airborne radar aids, **2**, 293–299
using ground-based radar aids, **2**, 299–310
radio-range, **3**, 25
ultra-high-frequency, **2**, 50
celestial, **3**, 55
chart-matching techniques, **2**, 333
by fixing position, **4**, 3–15
methods, nonradar, **2**, 44–85
microfilm projector, **2**, 338
nets, **2**, 56–85
radar, beacon, **2**, 117–121
ship, bearing transmission circuit for, **2**, 34
range (*see* Radio range)
ship, and pilotage, **2**, 317–353
superposition, **2**, 331
bibliography, **2**, 353
principle of, **2**, 331–335
systems, *H*-, **3**, 15–17; **4**, 9
hyperbolic (*see also* Hyperbolic navigation), **2**, 56–60; **4**, 19; **20**, 261
precision-beacon, Shoran, **3**, 426–433
by tracking and homing, **4**, 15–18
Near-zone region of apertures, **12**, 170
Negative-capacity circuit, **18**, 83
Negative heights, **13**, 444
Neher amplifier tubes, **7**, 153
Neon tubes as power indicators, **11**, 218
Networks (*see also* Filter), a-c error signal, **25**, 117
active-element representation, **1**, 5

Networks, adding, **25**, 96
admittances, **2**, 4, 5
antenna coupling, **4**, 303, 306, 310, 324, 341–343
Bartlett's bisection theorem, **9**, 556
branch, **18**, 8
bridge, **18**, 384
bridged-T, **18**, 384, 385; **19**, 116; **25**, 123
capacitance, **8**, 84
in cascade, **8**, 112; **9**, 546
cathode-circuit, **23**, 465
characteristic determinant, **18**, 385
charging circuit, **5**, 12
nonlinear circuits, **5**, 429–431
circulating currents, **8**, 86
cofactors, **18**, 385
compensation theorem, **8**, 92
condenser, push-pull, **19**, 457
conductance, **8**, 84; **18**, 4
coupling, **18**, 398; **23**, 122–125
derivative-pulse-proportional, **25**, 114
double-tuned-type, alignment, **23**, 113
elastance, **18**, 4
equalizing, **25**, 114; **26**, 221, 223
equivalent, four-terminal, of section of transmission line, **12**, 36
for magnetron, interaction space, **6**, 52
for side resonators, **6**, 52
spectrum by, **6**, 54
four-terminal, **12**, 17–19; **18**, 385
coupling, **18**, 75
gain, **15**, 26
Guillemin (*see* pulse-forming, below)
image parameters, limitations on use of, **9**, 576–581
impedance (*see* Impedance)
inductance, **18**, 4
mutual, **18**, 7
input coupling, **18**, 622
integral-plus-proportional, **25**, 115
integro-differential equations, **18**, 4, 10–21
L-, antenna, **4**, 306
ladder, **9**, 597–601
lattice, **8**, 110; **9**, 706
line-simulating, **5**, 124, 180
linear, **18**, 3–10
charging, **5**, 12, 361
-circuit analysis, **18**, 1–70
Networks, linear, passive, **19**, 632–640
-phase, **18**, 67, 75; **23**, 220
Loran, **4**, 56
loss, **15**, 26
low-frequency rejection, **23**, 465
matching, **8**, 95
mesh, **18**, 4, 9
n-pole, **18**, 282–284
microwave, **10**, 101–167
discontinuities, **10**, 101–108
distance invariant, **10**, 137
equivalent circuits, **10**, 117–130
parameter, determination, **10**, 138–167
measurements, **10**, 118–124
two-terminal pair, **10**, 118–124
multiple-element, **14**, 91
node, **18**, 4, 8
n-pole, **18**, 284
one-pole, **18**, 277
with one terminal pair, **8**, 95–99
in parallel, **9**, 545
parallel connection, **8**, 119, 120
parallel impedance, addition using, **21**, 32
parallel-T, **18**, 384
with equal condensers, **25**, 121
notch interval, table, **25**, 121
parameters, four-terminal, **12**, 17
of lines, **8**, 78
pass-band, average attenuation in, **9**, 603
behavior, Tchebyscheff, **9**, 590–593
characteristics, effect of dissipation on, **9**, 603
normalization, **9**, 562–566
passive-element representation, **18**, 4
phase-advance, **18**, 343
phase characteristics, **18**, 394
phase function, **9**, 555
phase-lag, **25**, 227
frequency response, **25**, 227
phase-shift, minimum, **18**, 277, 301
physical realization of specified reactive, **9**, 597–601
Π-, **8**, 100; **12**, 19
capacity-coupled, **23**, 112
maximum coupling coefficient, **23**, 112
power available, **23**, 2, 80, 81; **24**, 99

Networks, with prescribed input impedance, **9**, 586–589
pulse-forming (*see also* Pulse-forming circuits), **1**, 375; **3**, 239, 242; **5**, 8, 175–224, 225, 234, 356
attenuation, **5**, 222
average power supplied by, **5**, 253
cable as, **5**, 164
capacitance, **5**, 454
characteristic impedance, **5**, 9, 129
coils, **5**, 213–215
construction, **5**, 221
condensers, **5**, 215–221
current-fed, **5**, 8, 25, 135, 175, 207–213
derived from transmission line, **5**, 179–189
discharging efficiency, **5**, 466, 483
driver, **5**, 132–139
equal capacitance per section, **5**, 196–200, 203–207
Guillemin, **5**, 200–203, 211–213
current-fed, **5**, 211–213
types A, B, C, D, E, **5**, 201, 205, 212, 213, 219
voltage-fed, **5**, 201
impedance, **5**, 9, 129, 176, 181
measurement, **5**, 221
initial charge on, **5**, 176
inverse voltage, **5**, 427
mutual inductance, **5**, 199
phase shift, **5**, 222
power, average, **5**, 466, 483
reflections, **5**, 178
steady-state theory, **5**, 183–185
storage capacitance, **5**, 176
voltage, **5**, 358, 388, 395, 398, 424, 454, 455
voltage-fed, **5**, 8, 175, 189–207
push-pull condenser, **22**, 214
RC, phase-retard, **18**, 379
reactance, **4**, 304
reactive, image parameters of, **9**, 557–561
specified, **9**, 566–580
with specified insertion loss, **9**, 580–589
reciprocal image impedance, **9**, 559
reciprocal impedance, **9**, 544
rejection band, **18**, 390
rejection frequency, **18**, 386
Networks, resonant frequency, **18**, 386, 394
rings, **6**, 123–130; **11**, 527
in series, **9**, 546
series connection, **8**, 119, 120
symmetrical, **9**, 544, 558
T-, **4**, 305, 306; **8**, 99; **12**, 18; **23**, 111
equivalent, of length of waveguide, **8**, 77
feedback, **18**, 266
maximum coupling coefficient, **23**, 112
theory, elements of, **8**, 83–129
three-pole, **18**, 282
three-terminal, **18**, 384
three-terminal-pair, **8**, 121–124
transfer coefficients, **12**, 18
transform, **18**, 3, 50–53
transient response, **18**, 1–70
and steady-state response, relation between, **18**, 80
twin-T, **18**, 384, 387; **19**, 116
two-pole, **18**, 278–282
two-terminal-pair, **8**, 99–112; **9**, 541–554; **12**, 17
uniformly dissipative, **9**, 601–603
Wien-bridge, **18**, 386; **19**, 116
Neutralization, of frequency dividers, **19**, 590
microwave triode, **7**, 169
Neutrode, ZP676 magnetron, **6**, 423
Newton voltage regulator, **1**, 566–570
Newton's law of motion, **7**, 214, 354
Newton-Raphson method for obtaining characteristic values, **13**, 146
Nibbe-Dur and AFC, **16**, 333, 337
N-inversion, definition, **13**, 15
NMP (navigation microfilm projector), **2**, 338
Nocturnal cooling, **13**, 221, 253–257
Nocturnal inversion, **13**, 346, 348
Nocturnal radiation, **13**, 220, 232, 234, 254, 359
and elevated *M*-inversions, **13**, 316
Nocturnal surface inversions, **13**, 339, 348
Nodal analysis, **18**, 15, 385
and mesh analysis comparison, **18**, 19
mutual inductance in, **18**, 16
Nodes, mesh, **8**, 85
Noise, **18**, 497; **23**, 556; **24**, 19, 56
amplified r-f, **24**, 145

Noise, antenna, **24,** 103–108
atmospheric, **4,** 125; **18,** 616
available power of, **1,** 30
average values (*see also* Ensemble average; Time average), **24,** 35–39
conditional, **24,** 39
bandwidth, **18,** 169; **23,** 81; **24,** 176
cancellation, **24,** 122–123
characteristic function, **24,** 36
circuit equations, **7,** 493
circuits, minimal, **18,** 615–694
converter, **24,** 108–112
correlation function, **18,** 500
cosmic, **24,** 103
current, **18,** 497; **24,** 95–97
coherence of, **7,** 482
tetrode, output, **7,** 108
deflection, average, **24,** 197–199
dependence on load, **7,** 477
detectability of signals in presence of, **24,** 149–175
detection of radar echoes in, **14,** 471
diode, **16,** 109, 254, 359, 367
crystal, **15,** 286
temperature-limited, **16,** 101
use in noise-temperature measurements, **15,** 226
due to discreteness of electronic charge (*see* shot, below)
effect, on first and second probability distributions, **13,** 559
of input circuit loss, **18,** 637
on receiver output calibration, **13,** 565
on signal, **23,** 210
effective, bandwidth, **16,** 14, 22, 27
electrical, **18,** 497
external, **24,** 124–128
factor, **4,** 121, 389; **23,** 2
feedback effects, **23,** 91
figure, **7,** 6, 107, 116, 120, 121; **18,** 596–604, 621–635, 645; **23,** 1, 2, 127, 137, 306; **24,** 100
amplifier with push-pull input, **18,** 719
comparison of alternative tube configurations, **18,** 643–651
considerations, **18,** 618–621
correction for temperature, **18,** 417
crystal, **15,** 25–30
effect, of feedback, **18,** 666–672
Noise, figure, effect, of gain control, **18,** 717
first stage, **18,** 632, 638
with double-tuned input circuit, **18,** 690
i-f amplifiers, measurement, **15,** 227
with increasing frequency, **23,** 130
integrated, **24,** 101
measurement, **11,** 224; **16,** 15; **18,** 695–720
with microwave noise source, **11,** 225
by unmodulated signal generator, **18,** 699
over-all, **16,** 15, 249
effect of local-oscillator noise, **16,** 239–241
effective, **16,** 15, 17, 43, 58, 100, 235, 250, 253
measurements, **16,** 356–361
receiver, **1,** 32, 441
receiver, **11,** 222–226; **16,** 10–17
measurement, **15,** 227–235
single-frequency, **18,** 696
single-stage, **23,** 85
single-triode input circuits, **18,** 651–656
two networks in cascade, **15,** 28–30
variation with source conductance and frequency, **18,** 641–643
welded-contact rectifier, **15,** 403–406
fluctuations, **1,** 35–40; **6,** 418
cathode and partition, **7,** 106
Fourier analysis, **24,** 152
generation, in frequency conversion, **15,** 179–197
theory, **15,** 179–187
generators, **11,** 222; **16,** 236; **18,** 700–708; **23,** 293, 318
attenuator calibration by means of, **18,** 713
crystal, **16,** 363; **18,** 708; **23,** 323
diode, **18,** 704–708; **23,** 321
matched-line, **18,** 702
high-impedance, **18,** 701; **23,** 318
matched-line, **23,** 319
microwave, crystal as, **15,** 195–197
r-f, **16,** 361–364
crystal as, **15,** 229
with temperature-limited diodes, **18,** 701–704

Noise, generators, using 417A klystron, **15**, 229
i-f, **24**, 115–122
impulse, **23**, 444
induced grid, **18**, 625; **24**, 93–95, 122
input-circuit, **18**, 595
internal, basic origins, **24**, 64–67
pulse trains in, **24**, 176–256
Johnson, **7**, 257; **16**, 11
klystron, **7**, 257–259; **11**, 274
level, input, klystron, **7**, 461
-limited receiver, **23**, 277
local-oscillator, **16**, 235–256; **18**, 618; **24**, 112–115
reduction, by cavity, **16**, 245–249
by resonant filters, **16**, 243–245
by TR cavity, **16**, 241–243
suppression, **16**, 257
long-distance, **4**, 125
and loss measurements, crystal, **15**, 198–235
low-frequency, reflex klystron, **7**, 482
magnetron, **6**, 365, 367, 388–398
mathematical description, **24**, 33–35
measurement, **7**, 471; **18**, 600
measuring set, 3-cm band, **15**, 283–289
10-cm band, **15**, 289–292
-modulated c-w interference, **24**, 353–358
network not in thermal equilibrium, **18**, 541
origins of, **6**, 395–398; **23**, 80
output, **23**, 141
partition, **18**, 579; **23**, 97; **24**, 91–93
peak carrier-to-noise ratio, **23**, 440
pentode, **18**, 624
positive-ion, **18**, 589
power, available, **18**, 619; **23**, 2, 80
background, of receiving system, **2**, 19
spectrum, **7**, 485
primary, **24**, 56
produced by beacons, elimination, **3**, 349–352
radar, **2**, 16
radiation, **3**, 348
radio, prevention, **3**, 348–356
random, **16**, 10; **18**, 497
ratio, microwave amplifier input, **7**, 159
receiver, **1**, 28–47; **24**, 98–123
Noise, reduction, space-charge, **18**, 625
by space-charge smoothing, **7**, 160
reflex klystrons, **7**, 470
representation, **18**, 620, 623, 624
resistance, equivalent, **18**, 635; **23**, 98, 99
separate-sideband, klystron, **7**, 475
shot, crystal rectifier, **15**, 179–186
diode, **18**, 546
and induced grid noise, correlation between, **18**, 677–682
negative-grid triodes, **18**, 560
parallel resonant circuit, **18**, 546
pentodes, **18**, 575
sources, **11**, 273–278
space charge, depression, **24**, 83–89
reduction, **18**, 556
temperature-limited, **18**, 549
and thermal noise, distinction between, **18**, 584–587
shot effect, **6**, 396; **7**, 258; **11**, 270; **15**, 180; **18**, 544–584; **24**, 79–95
source, **6**, 395–398; **23**, 80
crystal, **11**, 278–281
klystron, **11**, 277
microwave, **11**, 270–281
thermal, **11**, 271–273
spectrum (*see* Spectrum, noise)
suppression, **16**, 247, 270, 273, 275
of signal, **23**, 211
temperature, **11**, 225; **16**, 16, 235, 359; **18**, 596–604
crystal, **1**, 413; **15**, 30, 179; **16**, 58, 93–96, 100, 115
measurement, **16**, 105–111
range in production units, **15**, 32
r-f tuning, effect of, **15**, 232–235
dependence on frequency, **15**, 188–195
equivalent, **23**, 3
as function, of r-f tuning, **15**, 232–235
of signal and image reflection, **15**, 234
klystron, 417-A, **11**, 276
measurement, **15**, 218–235
1-cm rectifiers, **15**, 292
using noise diode, **15**, 226
test sets, standard, crystal, **15**, 283–293

Noise, thermal, **18**, 497–544, 620; **24**, 64–79
in crystal rectifiers, **15**, 179–186
energy, electromagnetic, **18**, 512
seat of, **18**, 513
sink of, **18**, 513
source, **18**, 514
formula, **18**, 505
harmonic analysis, **18**, 507
localization, **18**, 505
quantum statistics, **18**, 525
and shot noise, distinction between, **18**, 584–587
spectrum, **18**, 519
statistical mechanics, **18**, 515
theorem, **18**, 532
voltage, **18**, 498
theory of, **7**, 489
triggering, beacon, **3**, 348, 352–354
tube, suppression, **18**, 604–614
voltage, mixing of, klystron, **7**, 484
Nomogram (computer), **27**, 13, 14, 15, 37, 176, 184
three-bar-linkage, **27**, 120–145, 333–352
calculations, **27**, 120–122
functions represented by, **27**, 120–127
for transformer linkage, **27**, 275
Nomographic method (computer), **27**, 178, 181, 183
three-bar linkage, **27**, 174
design, **27**, 118–145
Nomographic multipliers, **27**, 14–15, 40
Nonhunting, AFC, **16**, 295
Nonlinear, circuit characteristics, **19**, 41
elements, **19**, 40; **21**, 55
construction, **21**, 91
as rectifier, **15**, 1
functions with simple elements, **21**, 93
-inductance circuit, **5**, 471–476
mechanization (computer), **27**, 47
methods of multiplication, **21**, 55
modified-index profile, **13**, 174–180
positioning, **21**, 372
receiver characteristics, effects on pulse-measurement accuracy, **13**, 564–571
resistance matrix, **15**, 153–157
Nonlinearity, space charge, **6**, 313, 381
Nonmonotonic function, **27**, 89–91, 169, 170, 172
Nonoscillating states, magnetron, **6**, 342, 362, 367
Nonscanning antennas, **1**, 277–279
Normal incidence, radiation, **11**, 612
Normalization of height-gain function, **13**, 141–142
Norton's theorem, **18**, 697
Nosmo, AN/APS-15, **26**, 236
N-profile, **13**, 14
bilinear, characteristic values, **13**, 162
examples, **13**, 143
N-terminal pairs, circuits with, **8**, 124
Null devices, servo, **25**, 101
Numerical integration of Riccati equation, **13**, 177
Nutating antenna, **23**, 380
n-uples, staggered, **18**, 176–186
Nyquist criterion (servo theory), **25**, 70–72, 134, 136, 138
modified form, **25**, 256
Nyquist diagram, **18**, 397; **21**, 270
servo, **25**, 66, 158
with tachometer-feedback loop, **25**, 359
Nyquist theorem, **16**, 296

O

Oboe, **3**, 14, 225; **4**, 10; **20**, 168, 277, 311, 315, 337, 348–357
5-mile pip selector, **20**, 352
active-region, delay phantastron, **20**, 353
timing diagram, **20**, 351
blind bombing, geometry, **20**, 348
electrical integrators, **20**, 354
electrical system, **20**, 348–357
ground station, **20**, 103, 311
Mark II, **3**, 77
Mark IIM, **20**, 348
Mark III, **3**, 98
mouse station, **20**, 337
PRF divider, **20**, 103–107
range-tracking system, **20**, 349
time discriminator, **20**, 311, 312
Obscuration of target signal, **12**, 520
Observation time, **24**, 150
Observer, considerations, beacon, **3**, 35
human, **24**, 2
Occlusions, **13**, 347

Ocean reflection coefficient, **13**, 418–430, 537
Odographs, **1**, 216
Offset feeding technique, **12**, 453–457
Ohmic loss in cathode, magnetron, **6**, 524
Ohmmeters, **18**, 410
Ohm's law, division based on, **21**, 58
  multiplication based on, **21**, 58
Oil seal, Garlock Klozure, **26**, 146
Oilcan tube, **16**, 18
Omnidirectional beacons, **2**, 51; **3**, 63
Omnidirectional radio range, **4**, 5
On-target indication, **20**, 328
Open circuits, in pulser, **5**, 417, 431–435
Operational analysis, **19**, 37–39
Operations, grouped, function generation, **21**, 129–171
Operator (computer), **27**, 49–57
  for double-harmonic transformer, **27**, 79, 81, 86, 93, 95, 96
  equation, **27**, 50, 51, 53
  formalism, **27**, 49–51
  graphical representation, **27**, 51–54
  inverse, **27**, 50–51
  notation, **27**, 49–57
  product, **27**, 51–53
  square, **27**, 54
  square-root, **27**, 54–57
  symbolism, **27**, 195
Operator training, radar, **2**, 105
Optical-Fresnel field, **12**, 171
Optical path, **13**, 6
  length, **12**, 122; **13**, 47, 50, 99, 104, 107
Optical-superposition, devices, **22**, 564–567
  indicator scales, **1**, 218
Optical system, reflective, **22**, 579–583
Optics, geometrical, **13**, 4, 6, 41–58, 461, 465–468
  physical, **13**, 4, 58–87
Orthicon, **19**, 707
Orthogonality properties, waveguide, **10**, 5; **12**, 207–209
Oscillating beavertail scans, **26**, 97
Oscillation, cyclotron frequency, **6**, 3
  damped, cavity, **7**, 89
  dampers, **21**, 332–341
  frequency, klystron, **7**, 306
  Habann-type, **6**, 4
  modes, **23**, 547
    klystron, **7**, 301, 307
Oscillation, modes, magnetron, **6**, 309
    π, **6**, 16
  negative-resistance, **6**, 4
  parasitic, **18**, 383; **23**, 183
    microwave triode, **7**, 176
  phase relations, reflex klystron, **7**, 329
  pulsed, **19**, 140–148
    for use with synchros, **19**, 156–158
  relations, general, with sinusoidal modulation, **7**, 462–465
  stability against, **18**, 363–366
  on top of current pulse, **5**, 265
  traveling-wave, **6**, 5
Oscillators, **20**, 107; **21**, 188, 596
  1-Mc/sec, **22**, 398
  20 kc/sec, **22**, 208
  alignment, wideband frequency-modulated, **18**, 303
  amplitude, control, **16**, 317
    stability, **19**, 103
    stabilization, **19**, 126–128
  audio interpolation, **11**, 359–361
  beat-frequency, **19**, 124
  beating, **16**, 3
  blocking, **4**, 209, 221, 222; **19**, 205–211; **20**, 75, 76, 78–80, 151, 167, 317; **22**, 120, 465
    500-yd (328-kc/sec), **20**, 110
    as amplitude comparator, **19**, 235
    applications, **19**, 233–238
    astable, **19**, 208
    beacon, **3**, 240
    cascaded, **19**, 235
    comparator, **19**, 342
    counter circuits, **19**, 621
    and delay-line pulse generators, **19**, 205–253
    dividers, **20**, 83, 110, 165
      chains, **19**, 588–591
    driver, **3**, 253
    frequency stability, **22**, 121
    LC-stabilization, **20**, 83
    line-controlled, **3**, 239, 240
    low-impedance, **20**, 91
    monostable, **19**, 208
    power limitation, **19**, 214
    PRF generator, **20**, 78
    pulse, **22**, 121
    pulse generator, **20**, 70, 84
    radar receiver, **1**, 502

Oscillators, blocking, recovery time, **3**, 241; **19**, 223–226
transformer for, **5**, 543–547
trigger effect on waveform, **19**, 222
use in actuating bidirectional switches, **19**, 233
to produce variable-width rectangle, **19**, 235
voltage pulses, **20**, 78
bridge, **19**, 115–123
constant-voltage, **21**, 546
cavity coupled to rectangular waveguide, **8**, 277–282
circuits, microwave, **7**, 171
coherent (*see also* Coho), **1**, 632; **20**, 11; **23**, 579
effect of detuning, **1**, 640
for MTI, **1**, 662–665
Colpitts, **23**, 150
continuous, **19**, 702
crystal, **4**, 201, 207, 253; **19**, 106–110; **20**, 71, 83, 141, 153
80.86-kc/sec, **20**, 93, 164
-bridge, **19**, 122
Class C, **20**, 75
for frequency standard, **11**, 352
with harmonic-tuned plate circuit, **19**, 553
pulsed, **19**, 145–150; **20**, 238
tri-tet, **20**, 88
triode, **20**, 83
drift, electronic-tuning factors, **16**, 291
dynatron, **19**, 123
feedback, constant-frequency, **21**, 547
floating-drift-tube, **7**, 29, 295
1280 CT, **7**, 29
frequency-marker, **11**, 437
frequency stability, **3**, 256, 259–261, 303, 310, 366; **9**, 83; **16**, 212; **19**, 103, 128
gated, **20**, 110
grid-separation (grounded-grid), **7**, 172, 177
Hartley, **19**, 105, 106, 130
pulsed, **19**, 142–145
heater voltage, effect on, **16**, 294
idealized, **7**, 337
klystron, **7**, 27–28, 311–351, 495
electronic tuning, **16**, 38
floating-drift-tube, **7**, 29, 295
instability, **20**, 77
Oscillators, klystron, operation modes, **7**, 312
overcoupling, **7**, 307
reflex, **7**, 27–28, 311–351
two-cavity, **7**, 26–27
two-resonator, **7**, 294–310
equivalent, **7**, 296
LC-, **20**, 107, 135–137
20-kc/sec, **20**, 96
328-kc/sec, **20**, 110
pulsed, **20**, 108
local, **16**, 3, 35–37, 172; **23**, 21, 148–154; **24**, 9
controlled reflector, **16**, 324
coupling, **16**, 172, 354–356
capacitive probe, **16**, 140–144
channel, **16**, 150–160, 232
coaxial, line mixers, **16**, 142–144
iris for, **16**, 160–166
mechanisms, **16**, 136–140
in waveguide mixers, **16**, 144–146
drive, **16**, 58, 252
frequency control (*see also* AFC), **16**, 290–351
frequency ripple, **16**, 318
inverse-feedback stabilization, **16**, 325
noise, **16**, 235–256
power, **16**, 57, 115, 275; **23**, 18
sine-wave frequency-modulated, **3**, 166–168
square-wave-modulated, **3**, 164–166
tubes, **16**, 35, 40
long-line effect on, **23**, 25
Loran, C-1, **4**, 215
power, operation, **4**, 282
self-excited, **4**, 278
UE-1, **4**, 237
microwave, **7**, 25–31, 170–186; **11**, 21–58
monostable, as frequency dividers, **19**, 569
negative-resistance, **19**, 123
overload, **16**, 206, 207
phase locking of, **1**, 632
phase-shift, **16**, 344; **19**, 110–115
Pierce, **19**, 107
PRF, **20**, 400
pulsed, **19**, 703; **20**, 107, 109, 142, 144, 145, 148, 229
quenching, **19**, 205, 235; **20**, 79

Oscillators, quenching, with air-core transformer, **20,** 79
random, precise synchronization, **20,** 99
range circuits, sinusoidal, **20,** 135–141
RC, **19,** 561; **20,** 70, 80
reentrant, **7,** 179
-cavity, **23,** 25
tuning of, **7,** 180
reflex, **16,** 292
control circuits for, **23,** 34
klystron, **7,** 27–28, 311–351, 495
secondary-emission, **7,** 28
volume control, **9,** 711
regulated a-c, **21,** 546
relaxation, **19,** 47, 558; **20,** 107; **21,** 355
astable, **19,** 569
free-running, **1,** 496
gas-tetrode, **20,** 76, 77
resonant-circuit, **19,** 104–106
SCR-268, **20,** 137
sine wave, **21,** 180
crystal-controlled, 81.94-kc/sec, **20,** 76
163.88-kc/sec, **20,** 72
squegging, **3,** 392; **20,** 79
stability, capacitance, **19,** 475
frequency, **19,** 103
stabilization of, **11,** 58–78; **19,** 103, 126–131
stabilized, **11,** 331
temperature compensation, **19,** 129
thermally tuned, **23,** 69
thermistor use, **21,** 547
timing, **21,** 588
transitron, **19,** 124
capacitance amplification, **16,** 327
Miller, **19,** 197
transmitting triode, **3,** 279–312
cavity, **3,** 281–284, 297–301
coaxial-line, **3,** 281, 284, 293–297
frequency range, **3,** 283
limitations, **3,** 283
lumped-constant, **3,** 283, 291
microwave, **3,** 301–312
microwave cavity, **3,** 301
parallel-line, **3,** 280, 284, 291
types of modulation, **3,** 286
UHF, **3,** 291
VHF, **3,** 291
triode, **7,** 25–26
microwave, **7,** 170–186
Oscillators, triode, modulation of, **7,** 185
Tritet, **19,** 108
tunable, laboratory, **11,** 357–359
tuned-plate–tuned-grid, **23,** 150
two independent, precise system of synchronization for, **20,** 99
variable-frequency, **20,** 137–140
wave shape, **19,** 103
Wien-bridge, **20,** 70, 139
Oscillograph, mirror, **18,** 410
Oscilloscope, 256 A/R, **1,** 166; **20,** 76, 89, 231–238; **21,** 617–626; **22,** 17, 275–288
amplitude standards, **21,** 602, 605
auxiliary circuits, **21,** 587
comparison, **11,** 361–365
general-purpose, **21,** 657
high-speed, **5,** 664; **22,** 288–296
K1017, **11,** 469
linear time-base, **24,** 20
Loran, **4,** 199, 205
fast-sweep, **4,** 212
slow-sweep, **4,** 212
test, **4,** 213, 237, 285, 291
for potentiometer testing, **21,** 647–652
in pulser measurements, **5,** 662–692
Q, **21,** 657, 664
r-f, **11,** 408, 455, 467–469
self-synchronous arrangement, **5,** 663
signal channels, **21,** 583
sweep calibrator, **5,** 665
sweep speeds, **5,** 663
techniques, **19,** 694–706
TS-34/AP, **21,** 611–617, 664
TS100/AP, **20,** 218; **21,** 626–635
TS-126/AP, **21,** 641–647
TS262A/TPS-10, **21,** 663
type A, **24,** 20
type B, **24,** 21
type E, **21,** 664
Output-circuit noise, microwave amplifier, **7,** 159
Output regions, multigrid tube, **7,** 115
Output scale, computer, **27,** 46, 51
Output transformers, quarter-wavelength, magnetron, **6,** 195
Output tubes, figures of merit, **17,** 594
Output variable, computer, **27,** 45
Output waveguide, **6,** 486
Oven, constant-temperature, **4,** 207

Oven, crystal, **4**, 216
temperature, **4**, 217
Overbunching, **7**, 222, 253, 261–263
Overlay, for cathode-ray tubes, **22**, 558–560
computer, *construction*, **27**, 133–137, 143, 176
use, **27**, 135–136, 141–142, 150–154
Overload relay, pulser, **5**, 433
Overshoot, oscillation, **18**, 72
pulse, **5**, 179, 187
RC, multiple-, **23**, 527
secondary, **18**, 125
shunt-capacity effect, **23**, 518
single, double short-time-constant circuit, **23**, 526
staggered pair, **18**, 279
video amplifier, **23**, 516
Oxygen, absorption, **13**, 26, 646–656, 663
measurements, **13**, 655, 656, 665–666
line-breadth constant, **13**, 654–656
magnetic-dipole transitions, **13**, 649
rotational spectrum, **13**, 649, 653–654
selection rules for, **13**, 649–650

P

Pads, coaxial, fixed, **11**, 745–747
construction, **11**, 757–763
performance characteristics, **11**, 763–769
inserts, electrical design, **11**, 752–757
waveguide, fixed, **11**, 781–784
polyiron, **11**, 747
Pairs, cascaded, **18**, 187
flat-staggered, **18**, 187–189
overstaggered, **18**, 284
overshoot, **18**, 280
stagger-damped, **18**, 224, 230
staggered, overshoot, **18**, 279
step-function response, **18**, 280
Paley-Wiener criterion, **18**, 721–723, 726, 727
Palmer scan, **1**, 282; **26**, 8, 66
Panels, half-wavelength, modified, **26**, 305
at perpendicular polarization, **26**, 297
tolerances, **26**, 264, 298
transmission, **26**, 305
Panels, half-wavelength, *N*-, power-transmission coefficient, **26**, 270
honeycomb core, experimental results on transmission, **26**, 334
lossless, at parallel polarization, **26**, 300
lossy, at arbitrary incidence, **26**, 303
low dielectric constant, **26**, 265, 299, 303
thin, reflection of, **26**, 300, 303
Paper, oil-impregnated, **5**, 215, 651
Parabola waveform generation, **19**, 305–312
Parabolic cylinder, reflector, **26**, 29
Parabolic fall of pulse, **5**, 191
Parabolic reflector, **26**, 5
Parabolic rise of pulse, **5**, 191
Parabolic-waveform method, triangle solution, **21**, 144
Parallel-pin rotary gap, **5**, 287
Parallel resonant circuit as frequency-selecting filter, **19**, 549
Parallelogram linkage computer, **27**, 28, 29, 34, 113, 115, 127
Parameters, affecting signal visibility, **24**, 193–196
constitutive, radiation theory, **12**, 65
grid-screen smoothing, **7**, 122
modulation, **7**, 449, 452–455
Parasitic impedances, effect on conversion loss, **15**, 157–163
Parasitics in frequency conversion, **15**, 112
Paratroop pathfinders, **3**, 11, 13
Parseval theorem, **25**, 61
Path length, optical, **12**, 122; **13**, 47, 50, 99, 104, 107
Path-length difference, **13**, 37, 108, 114, 115
Paths of integration, in κ-plane, **13**, 68
in normalization, **13**, 141, 177
in *t*-plane, **13**, 89
Pattern distortion, due to flat-faced cathode-ray tubes, **22**, 338–342
in magnetron system, **6**, 141, 144, 151, 189, 576
Pattern propagation factor, **3**, 43; **13**, 34, 35, 117
in diffraction region, **13**, 109, 122, 124, 141
in interference region, **13**, 38, 99, 115–117

Pattern propagation factor, in natural coordinates, 13, 98
sample calculation, extending through intermediate region, 13, 133–135
simple properties, 13, 36–41
Peak detector, **22,** 196, 231
half-wave diode, **19,** 503
precision, **19,** 506
synchro modulator using, **19,** 446
Peak-to-peak separation, **23,** 36
Peak signal-to-noise ratio, **23,** 440
Peaking, low-frequency, **22,** 450
series, **1,** 452
shunt, **1,** 451; **18,** 73
in sinewave comparator, **19,** 348
Peaucellier inversor, **27,** 29, 30, 95
Pedestal, antenna, **1,** 271; **26,** 8
Loran, **4,** 65
stable-base, **26,** 115
Penacolite, **26,** 383
dielectric constants, **26,** 409
loss tangents, **26,** 409
Pencil-beam requirements, **12,** 413, 414
Pentagrid converters, **17,** 600–604, 606
Pentagrid mixers, **17,** 606, 608
Pentodes, **17,** 570–599
6AG7, **19,** 78
amplitude selector, **19,** 331
British, VR-116, **19,** 88
choice of, **17,** 595, 599
constant-current, **19,** 264
cutoff characteristics, **17,** 570–571
suppressor-grid, **17,** 578–579
differential amplifiers, **18,** 450
at moderately high frequencies, **18,** 581, 583
noise representation, **18,** 624
output, **17,** 581, 586–594
remote-cutoff, **17,** 580, 582–585
semiremote-cutoff, **17,** 580, 582, 585
sharp-cutoff, **17,** 574–577
shot noise, **18,** 575
transmitting, small, **17,** 594–599
triode-connected, **17,** 550, 558, 567
twin output, **17,** 591
twin transmitting, small, **17,** 594–599
Periodicities, hidden, random process, **25,** 279
Permafil, **5,** 557, 649, 650
Permanent-magnet motors and generators, **17,** 372, 374–376
Permeability, complex, **11,** 561
d-c incremental, **5,** 601, 632, 634
effective, **17,** 123
pulser core, **5,** 537
incremental, **17,** 123
Permendur end shields, **6,** 781
Perspex (polymethyl methacrylate), **26,** 370
Perturbation calculations, **13,** 177
Perveance, **7,** 371
PFN (*see* Network, pulse-forming)
PGP (pulsed glide path), **2,** 228–232
Phantastron, **1,** 500; **19,** 195–204; **20,** 95, 106, 118, 120, 164, 167, 168, 171, 349, 350, 352, 355–357; **21,** 591, 652; **23,** 64
accuracy, **20,** 122
astable, **19,** 199
cathode-coupled, **19,** 203
cathode waveform, **20,** 105
control circuit, diode, **23,** 64
counter circuit, **19,** 624
delay, component-variation effects, **20,** 123
Oboe active-region, **20,** 353
dividers, **19,** 577–582; **20,** 104
maximum PRF, **19,** 579
-gate generator, **20,** 104
microphonic effects, **20,** 123
operation, **20,** 121
pulse-selecting, **20,** 94, 171, 173
screen-coupled, **19,** 197
temperature compensation, **20,** 123
Phase, apparatus, for line sources, **11,** 918
for point sources, **11,** 916
comparison circuit, AGL(T), **20,** 372
constant, **12,** 23, 205
of first mode, **13,** 162
TEM, **8,** 18
waveguide, **9,** 49
-control circuit, **14,** 418
delay, PRF divider, **19,** 568
demodulation, **20,** 5
detectors, **21,** 375–386
determinations on point-source feeds, **12,** 564–570
difference, propagation, **3,** 43
discrimination, **21,** 47
discriminator, **20,** 155
hybrid time and, **20,** 97
distortion, in broadband T-stub, **9,** 176

Phase, errors, defocusing, **12**, 432
effects, on pencil-beam gain, **12**, 430
on secondary patterns, **12**, 186–192
frequency sensitivity in measurements, **11**, 917
front measurements, **13**, 389
-integral methods, **13**, 70, 177
for Eckersley modes, validity, **13**, 87
relation to ray tracing, **13**, 82
inverters, **4**, 218; **18**, 106
jitter, PRF divider, **19**, 568
measurement, in free space, **11**, 592
line-length effect, **12**, 569
by phase-modulation method, **11**, 919–922
of Q, **11**, 336–340
modulation (*see* Modulation)
modulator (*see* Modulator)
shift, accuracy with phase-shifting condenser, **17**, 296
capacitor, **4**, 199, 203, 207, 219
in dielectric radome panel, **26**, 338
impedance, minimum, **18**, 178
impedance bridge for measuring, **14**, 403
klystron, **7**, 221–222, 230–231
measurement, **11**, 570–577
near resonance, use in measuring Q, **14**, 399
theory, **26**, 366
shifter, **20**, 238
attenuation, **19**, 496
condenser, **20**, 358
dielectric, **9**, 514
magnetic, **20**, 137
RC-feedback circuit, **19**, 150–154
resistance-reactance, **19**, 136–141
rotary, waveguide, **8**, 355–358
slotted-waveguide, **9**, 513
system, **20**, 443–449
transmission-line, **9**, 478–481, 513–517
voltage system, four-phase, **19**, 138
three-phase, **19**, 138
-shifting condensers, **21**, 370
by feedback, **21**, 150
velocity, **4**, 129; **9**, 12, 20, 42, 50
Phosphor bronze, for microwave components, **9**, 119
Phosphorescence, **22**, 609, 616
short-time, **22**, 649
Phosphorescent decay, **22**, 632, 653
Phosphorescent light, **22**, 609
Phosphorus as addition agent, **15**, 67
Photocell, **19**, 72; **20**, 276
919, high-vacuum, **19**, 73
Photodiode, **15**, 394
Photoelectric, angle index generator, **22**, 230
devices, as transducers, **19**, 428
effects, in germanium, **15**, 393–397
in silicon, **15**, 392
-mechanical data transmission, **22**, 221
switch, **22**, 398
Photographic projection, **22**, 584–589
Photography of A-scope for study of echo fluctuations, **13**, 562
Photopic vision, **22**, 659
Physical optics, **13**, 4, 58
Pickoffs, regenerative, **19**, 485
Pickup probe, **14**, 378
Pierce method for design of choke grooves, **9**, 198
Piezoelectric devices, **17**, 175–190
Pillbox feed, **26**, 161, 176, 206
design problems, **12**, 460–464
waveguide, **1**, 276
Pilot-balloon observations, **13**, 298
Pilotage, radar, **3**, 25
Piloting, automatic, by hyperbolic systems, **2**, 82–85
Pin gearing, **27**, 19
Pincushion field, **22**, 313
Pip, **24**, 20
-matching, **1**, 203; **13**, 436
Pipes (*see* Waveguide)
Pistons, hydraulic, **26**, 136
Pitot marine-log system, **21**, 488
Planck's constant, **18**, 529
Plane electromagnetic waves, theory, **26**, 341–343
Plane lossless sheets, at arbitrary incidence, **26**, 292–296
at normal incidence, **26**, 260–265
power-reflection coefficient, **26**, 260
Plane lossy sheets, at normal incidence, **26**, 265–272
power-reflection coefficient, **26**, 267
power-transmission coefficient, **26**, 268

Plane sheets, homogeneous, at perpendicular polarization, **26**, 298
Plane waves, in free space, **9**, 36
  hybrid, theory, **26**, 346
  nonuniform, **8**, 19–21
  uniform, **8**, 17–19
Planimeter, **27**, 2
Plaskon, dielectric constants, **26**, 409
  loss tangents, **26**, 409
Plate, current, and transconductance, correlation between, **18**, 290
  grounded, **18**, 634
  load, line, **18**, 358
    resistance, d-c, **18**, 354
  parallel, *TEM*-waves between, **8**, 22
  -plunger position, reentrant oscillator, **7**, 192
  pulsing, **3**, 286
  quarter-wave, **9**, 371
Plating, silver, **6**, 676
Plexiglas, **26**, 370
Plotting, CRO, **22**, 567–570, 579
  and map superposition, **22**, 566
Plotting board, 180°, **1**, 238
  automatic, **4**, 105
  Loran, **4**, 104, 110; **21**, 165
  vertical, **1**, 235
  X-Y, **1**, 240
Plotting screen, CRO, **22**, 588
Plugs, dielectric, half-wavelength, **9**, 222
  T-shaped, three-quarters wavelength long, **9**, 223
Plungers, for rectangular waveguide, **8**, 198
  short-circuiting, **9**, 460–463, 481–483; **11**, 504
    capacity-coupled, **9**, 462
    quarter-wavelength-finger, **9**, 461
Plywood in Schwarzschild horn, **26**, 60
Pneumatic devices, **21**, 397
Point of reflection, **13**, 113
Point-source, cone, **12**, 240
Poisson distribution, definition, **25**, 302
Poisson's equation, **7**, 214, 367
Polar diagram, **12**, 3, 90
Polar display, **22**, 426
Polarization, **3**, 56, 374 ,472; **13**, 140
  affecting sea echo, **13**, 498, 522, 527
  affecting σ, **13**, 33, 461, 462, 468, 471, 475, 696–699
  antenna, **4**, 301
Polarization, basic, TE_{11}, **8**, 350
    transformation by rotation, **8**, 351
  and boundary conditions at earth's surface, **13**, 58, 63, 111, 112, 124, 140
  circular, **12**, 92; **13**, 697–699
    rotary-joint, **9**, 428
    scattering from smooth targets, **13**, 468
    in square waveguide, **9**, 378
    TE_{11}-mode, **9**, 369–378
  cross (*see* Cross polarization)
  effect, in refraction studies, **13**, 297, 337, 343, 351, 389
    on reflection coefficient, **13**, 40, 98, 397–401, 408, 423–424, 427–429, 434
  elliptical, **9**, 54; **12**, 91; **13**, 696–697; **26**, 338–340, 366–368
  general, **26**, 291
  horizontal, **3**, 46
  parallel, effect of core thickness on reflection at, **26**, 314
    lossless panels at, **26**, 300
  perpendicular, effect of core thickness on reflection at, **26**, 312
    homogeneous plane sheets at, **26**, 298
    lossless panels at, **26**, 296–300
    modified half-wavelength panel at, **26**, 297
    modified half-wavelength thickness at, **26**, 302
  purity in, relation to reflection coefficient, **13**, 426
  radiated wave, **13**, 29
  rotator, joints with, **9**, 430–432
  and sea return, **2**, 113
  vertical, **3**, 46
Polka-dot raster, **22**, 597
Polybutylmethacrylate, **13**, 273, 281
Poly 2,5-dichlorostyrene, **26**, 374, 376
  dielectric constants, **26**, 409
  loss tangents, **26**, 409
Polyester-styrene foam, **26**, 379
Polyfibre, **26**, 372
  dielectric constants, **26**, 409–413
  flexure, **26**, 389
  stiffness, **26**, 388
  stiffness rating, **26**, 416
  strength, **26**, 388

Polyfibre, strength rating, **26**, 416
Polyflex, **26**, 372, 373
  flexure, **26**, 387
  stiffness rating, **26**, 416
  strength rating, **26**, 416
Polyglas, **9**, 132
  connectors, **9**, 267
Polyiron, **16**, 198, 199, 285, 301; **26**, 48
  impedance, in coaxial line, **11**, 724
    in waveguide, **11**, 727
  low-power waveguide termination with, **11**, 726–728
  in microwave circuits, **11**, 133, 463
Polymethyl methacrylate, **26**, 369
  dielectric constants, **26**, 409
  flexure, **26**, 387
  loss tangents, **26**, 409
  stiffness rating, **26**, 416
  strength rating, **26**, 416
Polynomial associated with array, **12**, 261–264
Polyphase sinusoids, **19**, 131
  pulsed, **19**, 148
Polystyrene, **26**, 370, 372
  dielectric constants, **26**, 409
  fiber, flexure, **26**, 389
    stiffness rating, **26**, 416
    strength rating, **26**, 416
  flexure, **26**, 387
  foam, **26**, 379
  loss tangents, **26**, 409
Polyvinyl carbazole, **26**, 374
POPI, **4**, 13
Position, finding, **20**, 29–36
  identification, by group of signals, **2**, 93
    by shape of built-up areas, **2**, 94
  learning time, **20**, 380
  lines of, **4**, 3, 10, 52, 102, 107
  memory, **20**, 282, 380
Position-data transmission, **22**, 184–226
Position-error detectors and indicators, **20**, 367–378
Positive-ion current, **18**, 418
Positive real function (*p.r.*), **9**, 581
Post, thick, in waveguide, **8**, 199
Post-pulse voltage measurements, **5**, 691
Postamplifier, **23**, 329
Postforming, thermosetting resin, **26**, 378
Potential modulus, **13**, 198–200, 207
Potential temperature, **13**, 194, 195, 200, 202
Potentiometers, **17**, 243–287; **19**, 428–465; **21**, 48, 55, 91, 183, 367–369, 461
  360°, **20**, 396
  cascaded, **21**, 93
  characteristics, **17**, 266–287
  commercial, **17**, 276–287
  contacts, **17**, 255–261
    materials, **17**, 255, 259–260
    pressure, **17**, 261
    shape, **17**, 256–257, 259–260, 284
  cosine, **21**, 111
  data transmission, **26**, 168, 205, 225
  error-measuring systems, **25**, 95
  exponentially tapered, **20**, 142, 146, 153
  gauged, **21**, 93
  Helipot, **19**, 432, 476
  inherently linear, nonlinear output signals obtained by use of, **19**, 436
  leads, **17**, 254–255
  linear, **22**, 200–202; **19**, 428, 431–434
    curve fitting with, **21**, 95
  linear range, **20**, 151
  linearity, **17**, 256–258, 266–268, 271–276
    definitions, **17**, 266–267
    testing, **17**, 271–276
      continuous-comparison method, **17**, 272–276
      point-measurement method, **17**, 271–272, 274
  loaded, **21**, 94
  low-torque, **19**, 439
  manufacturers, **17**, 286
  Micropot, **19**, 476
  Microtorque, **19**, 439
  modulator, with feedback amplifier, **19**, 433
  mountings, **17**, 252–254
  noise, **17**, 268; **25**, 305–307
  nonlinear, **17**, 261–266, 282–286; **19**, 430, 436–439; **22**, 204–207
  partially compensated, **18**, 94
  phase-modulating, **19**, 491
  resistance elements, **17**, 243–252
    finishing, **17**, 249
    mandrels, **17**, 243–245
    winding, **17**, 248–249
      machines for, **17**, 248–251
  resistance wire for, **17**, 246–248
  resolution, **25**, 98
  ring, **17**, 280–283

Potentiometers, ring, table, **17**, 283
secant, **19**, 437
sine, **21**, 55, 111, 162, 465
sine-cosine, **17**, 264–265, 284–286; **20**, 252; **22**, 450
sinusoidal, **19**, 430, 434–436; **22**, 202–204, 472
square law, **19**, 437
standard linear, **17**, 278–279
testing, **17**, 271–276
oscilloscopic, **21**, 647–652
torque requirements, **17**, 271
total resistance, **17**, 269–270
wear of contacts and windings, **17**, 257–260
Powder metallurgy, **9**, 123
Power, absorber, in Robinson feed, **26**, 47
aircraft, for radar, **1**, 555–583
amplifier (*see* Amplifier)
arc, **14**, 140
available, from network, **24**, 99
from signal generator, **24**, 99
average, **11**, 80
back-bombardment (*see* Magnetron)
beacon, conservation of, **3**, 322
-control circuits, **3**, 322–332
restoration of, following overload, **3**, 322
-control circuits, full-wave and half-wave, **21**, 401
-control devices, **21**, 386–400
-control elements, **21**, 519–522
criterion, **24**, 163
divider, adjustable, **11**, 214
as attenuator, **11**, 799–803
coaxial, **9**, 516–522; **14**, 414
fixed, **9**, 516–519
fixed, **9**, 522–525
for high-power measurements, **11**, 213–215
variable, **9**, 519–522, 525–528
waveguide, **9**, 522–528
factor, **9**, 28
and dielectric constant, **6**, 652
flow in waveguide, **8**, 50–54; **10**, 5
frequencies, aircraft, standard, **1**, 556
gain, microwave tube, **7**, 106
network, **24**, 99
small-signal, amplifier klystron, **7**, 270
Power, -handling capabilities, transmission-line, **9**, 95
-law *M*-profile, **13**, 312
profile, **13**, 174
measurement, at high level, **11**, 194–220
at low and medium levels, **11**, 84–194
microwave, **11**, 79–220
meters, **23**, 296
for mobile radar, **1**, 585
modes, **12**, 595
output, microwave tube, **7**, 264–267, 304, 331
output control of radar transmitter, **3**, 365–367
product theorem, **3**, 40, 119
pulse, definition, **11**, 80
of transmitter, **2**, 15
radar, at fixed locations, **1**, 583
primary, frequency of, **1**, 555
ratio, measurement, **11**, 805–808
reflection of, transmission-line, **9**, 29
-reflection coefficient, at oblique incidence, **26**, 290
plane lossless sheet, **26**, 260
plane lossy sheet, **26**, 267
radome, **26**, 256, 261, 262
sheet, theory, **26**, 358
for shipborne radar, **1**, 586
sources, **11**, 21–78
for motors, **17**, 358–360
primary, **3**, 313–316
splitter, **23**, 356
supply (*see also* Alternators; Dynamotors), **17**, 396–466; **21**, 602, 610, 617, 626, 651
a-f oscillator, **17**, 138–141
beacon, **3**, 313–332, 442
choice, **17**, 396–399
CRT, **22**, 161–163
d-c, laboratory, regulated, **21**, 555–567
precision, **21**, 548–555
high-voltage, **22**, 163–183
klystron, **7**, 521; **11**, 55
LHTR, **1**, 208
prime, **17**, 399–408
radar, 3-phase a-c, **1**, 559
aircraft systems, **1**, 555–583
ground and shipboard systems, **1**, 583–587
prime, **1**, 555–587

Power, supply, radar, shipborne navigational, **2,** 377
TVN-7BL, **11,** 52
ultraportable equipment, **1,** 585
vibrator (*see also* Vibrator), **1,** 581–582; **3,** 313–320; **17,** 431–445
power output, **17,** 432
rectifier tubes, **17,** 444
r-f interference suppression, **17,** 445
transfer, maximum, generator-to-load, **8,** 94
transformers, design, **17,** 130–141
transmission, **9,** 29
average, coaxial-line, **6,** 484, 489
coefficient, lossy sandwich, **26,** 284
N-half-wavelength panels, **26,** 270
plane lossy sheet, **26,** 268
radome, **26,** 256
sandwich, **26,** 361
sheet, **26,** 358
transmitter, **2,** 20
Powers and roots, function generation, **21,** 120
Poynting theorems, **8,** 14–16, 132–134; **9,** 41; **12,** 69–71
time-average, **12,** 70
PPI, **1,** 167; **2,** 5, 30–35; **3,** 3, 24; **4,** 6; **12,** 514; **22,** 15, 19, 26, 425; **24,** 22, 238; **26,** 71, 168, 200
clutter, **3,** 91–93
delayed, **1,** 169; **22,** 15, 20, 429
design, **1,** 532–545
displays, contrast, **1,** 548–554
resolution, **1,** 548–554
distortion, **26,** 200
electronic, **22,** 27
follow-up servo, **21,** 471–475
high-resolution shipborne radar, **2,** 318
index, **21,** 173
Magnetic-Electric (ME), **2,** 34; **20,** 458
Magnetic-Mechanical (MM), **2,** 34
Magnetic-Selsyn (MS), **2,** 34
mechanical scale, **20,** 219
off-center, **1,** 168; **2,** 199; **22,** 19
open-center, **1,** 169; **22,** 15, 19
pattern superimposed on map, **2,** 337
pre-time-base resolution, **1,** 544
pulsed range-mark circuit designed for, **20,** 107
PPI, with range and azimuth markers, **21,** 175
range distortion, **2,** 151
range-marker circuit, **20,** 108
resolved-current, **1,** 538–545; **2,** 34
resolved time base, **1,** 534–538
with sweep through synchro, **22,** 447–450
using condenser, **22,** 218, 452–454
resolved-voltage type, **2,** 34
rotating coil, **1,** 534; **2,** 34; **22,** 26, 426–445
simulations, **2,** 351
stretched, **1,** 170; **22,** 15, 20
systems using J-scope, **20,** 243-246
three-tone, **1,** 553; **22,** 38
using automatic transmitter triggering, **1,** 540
Precession, gyro, **26,** 203, 204
Precipitation, attenuation by, **2,** 22; **13,** 671–692
causing meteorological echoes, **13,** 581–598, 604–615, 618–621
echoes (*see* Echo)
effects on transmission, **13,** 339
onset, **13,** 339
rate and attenuation by, **13,** 673, 683, 691
static, **4,** 328, 344
Precision range indicator, **20,** 108, 148
Preferred-number system, **17,** 38–39, 78
Pre-plumbing, **1,** 408
Preselection, **16,** 2, 5, 8, 23, 27, 43, 123
r-f, **24,** 19
Presentation (*see also* Display), dual, beacon-radar, **3,** 381
split azimuth, **3,** 380–384
two-color, **3,** 93
two-tone, **3,** 93, 383
type G, **20,** 368
Pressure, versus altitude-temperature, table, **26,** 162, 163
gauge, r-f, **14,** 415
gradient, **13,** 193
recorders, **13,** 490
Pressurized coaxial duplexer, **14,** 335
Pressurizing, **12,** 383–387
device, **12,** 376
transmission lines, **1,** 283, 420; **9,** 139–143
Preston TM_{01}-transition, **9,** 389

Pre-TR switch, **16,** 175
Pre-TR tubes, leakage power, **14,** 407
Pretrigger, **22,** 26
PRF, **3,** 367; **5,** 3, 123; **24,** 18, 244
  choice, **1,** 598
  dividers, **20,** 85
    Oboe, **20,** 103
    phantastron, waveform, **20,** 105
    pulse-selection, **19,** 592–594
  division, **19,** 567–601
    frequency jitter, **19,** 568
    intermittent, **19,** 600
    phase jitter, **19,** 568
  effect of, **2,** 214
  generators, **20,** 69, 78
    blocking-oscillator, **20,** 78
    Loran (*see* Loran PRF generator)
    multivibrator, **20,** 80
    synchronization by, **20,** 45
  maximum, of phantastron dividers, **19,** 579
  modulation, **24,** 31
  oscillators, **20,** 400
  random variations, **19,** 225
Prime movers, small, **1,** 586
Principle of similarity, **13,** 201, 232, 233, 238, 240, 243, 268
Probable error in measurements, **20,** 113
Probability, central-limit theorem, **18,** 77, 80
  distribution, **24,** 151–161
    conditional, **24,** 38
    first, **24,** 34, 137, 140, 141
    functions, **25,** 268–270
    for ratio of amplitude, **13,** 558, 577–578
    second, **24,** 34
    after second detector, **24,** 154
  functions, **7,** 438
    of multiplier, **21,** 59
Probe, 10-cm, **11,** 495
  calibrated pickup, **11,** 799
  capacitive, as local-oscillator coupling, **16,** 140–144
  cathode-follower, **21,** 586
  coupling, adjustable, to coaxial line, **14,** 409
  design, **11,** 488–496
  distortion of standing-wave pattern by, **11,** 485
  electric, **11,** 479
Probe, electronic, **21,** 662
  errors in impedance measurements, **12,** 556
  magnetic, **11,** 479
  response, **12,** 549
  shielded, **11,** 489
  transition, coaxial-line, **6,** 486
  traveling, **11,** 478–480, 483–488
  voltage-divider, **21,** 586
Projector chart, **1,** 215
Propagation (*see also* Transmission), **2,** 21–26
  anomalous, **2,** 220; **3,** 49–51
  constant, iterative, network, **8,** 113
    line, **12,** 205
    TEM, **8,** 18
    uniform waveguide, **10,** 6
  effect of "fronts," **13,** 263, 319, 325, 331, 347
  effects, **3,** 42–57
  factor, **9,** 13, 19–23
  forecasting, **13,** 368
  free-space, **1,** 18
  function, network, **9,** 554–557
  in horizontally stratified atmosphere, **13,** 27–180
    fundamental concepts, **13,** 27–41
  in interference region, geometrical parameters, **13,** 116
  long-wave, proposed mechanism, **13,** 1
  microwave, **1,** 11, 47–62
  nonstandard, **2,** 360–363
    geographical distribution, **13,** 369
  radar waves, over reflecting surface, **1,** 47–53
    over water, **2,** 354–363
  short-wave, **13,** 1–26
  of sound, velocity in liquids, **17,** 218–219
  -time circuits, **20,** 141
  velocity, **4,** 122, 166
Propeller modulation, **13,** 539–543
Proximity effect, transformer, **5,** 547, 658–660
Pseudoadiabatic chart, **13,** 188
Pseudo-flat, arc-discharge, **14,** 163
PSWR (*see* Standing-wave ratio)
Psychrograph, **13,** 272
  circuit diagram, **13,** 277
  housing for ground-based soundings, **13,** 283

Psychrograph, lag coefficient, **13**, 280–281
Psychrometer, **13**, 182
  aircraft, **13**, 287, 288, 289
  ML-313, **13**, 287
Psychrometric formula, **13**, 187
Pulling, klystron, **7**, 197, 416, 437
Pulling figure, oscillator, **9**, 84, 472
Pulse, ambiguity in identifying, Loran, **4**, 57
  amplifiers (*see* Amplifier, pulse)
  amplitude, **5**, 710–722
    average, **5**, 69
    definition, **5**, 710
    jitter (fluctuation), **5**, 290, 331, 468
    modulation, **3**, 473
  backswing on tail, **5**, 569–571
  bandwidth measurements, **4**, 396
  buildup, klystron, **7**, 458–462
  cable, **1**, 386; **5**, 231, 255
    between pulser and load, effect of, **5**, 271
  change in load current during, **5**, 58
  characteristics, **5**, 98
    receiver-type, **5**, 102
  coder, blanking gate, **3**, 206
  coding, **5**, 131, 486
  composite, Loran, **4**, 60
  count, addition, **21**, 40
    subtraction, **21**, 40
  current (*see also* Current pulse), **5**, 3, 320, 447
    change in, **5**, 165
  delay characteristics, triode oscillator, **3**, 284
  digital computers, **21**, 40
  divider, ten-to-one, **20**, 165
  droop, **5**, 80, 88, 169, 509, 568, 569, 674, 702
  dunking, in recycling detector, **19**, 509
  duplication by delay lines, **19**, 247–253
  duration, **5**, 2, 15, 119, 123, 136, 226, 236, 320, 447, 456, 534, 544, 710–722
    from 0.1–0.5 μsec, **5**, 160
    from 0.3 μsec to 0.15 μsec, **5**, 160
    change of, **5**, 16
    continuously variable, from 0.5 μsec to 5 μsec, **5**, 158
    definition, **5**, 710
    equivalent, **5**, 251, 710–722
    maximum, **5**, 587, 634
Pulse, duration, range, **5**, 127
  energy, **5**, 184
  equivalent rectangular, by conservation of energy, **5**, 711–716
    by minimum departure areas, **5**, 716–720
  flat, **15**, 237
  flat top, **18**, 84–90
  formation, **5**, 175–179
    in modulators, **3**, 245–255
  -forming circuits (*see also* Network, pulse-forming), **3**, 239–245; **11**, 237
    a-c resonance charging, **3**, 245
    d-c resonance charging, **3**, 243
    line-type, **3**, 242–245
    resistance charging, **3**, 242
    straight-line charging, **3**, 244
  generators, **18**, 308; **21**, 641
    AN/APS-15, **20**, 165
    basic circuit, **5**, 5
    blocking-oscillator, **20**, 70, 84
    carrier-frequency, **18**, 306–313
    delay-line, **19**, 238; **20**, 107
    direct, **18**, 306–313
    line-type, with magnetron load, **5**, 573
    materials and their uses in design, **5**, 599–660
    measuring techniques, **5**, 661–709
      metering, **5**, 692–709
      oscilloscopic, **5**, 662–692
    output transformer, **5**, 500
    regenerative basic circuit, **5**, 124
    r-f, synchronization by, **20**, 43
    video, **21**, 593
  ghost, **4**, 250
  grouped, generator of, **20**, 400
  hysteresis loop, **5**, 641–648
    theoretical construction (*see* *B-H* loop)
  integrator, **13**, 496
  leading edge (*see also* rise, below), **5**, 2, 255–257; **18**, 72
  length, **2**, 19
    affecting sea echo, **13**, 491
    choice of, **1**, 596–598
    Loran, **4**, 98
    measurement, **14**, 408
  local, Loran, **4**, 67
  locking, **23**, 606
  magnetization, **5**, 613–626, 633–638

Pulse, measurements, **5**, 667–687
metering techniques, **5**, 692–709
V-I plots, **5**, 675–680
-modulated doppler system, **1**, 150
modulation, oscillator, **11**, 237–240
network, a-c resonance charging, **3**, 245
operation of microwave triodes, **7**, 187–198
packet, **1**, 122
parabolic fall and rise, **5**, 191
phase-shifted, **1**, 697
power, pulser, **5**, 3, 69, 238–244
radiated, Loran, **4**, 56
-to-pulse cancellation, amplitude, of radar-video signals, **19**, 708
in MTI, **1**, 631
radar, **16**, 4
rectangular, **5**, 177, 711–720; **18**, 72
spectrum of, **14**, 408
recurrence frequency (*see* PRF)
remote-control system, **20**, 400–408
repetition frequency (*see* PRF)
repetition rate, **26**, 85
response, and absolute-value curve alone, **18**, 277
amplifiers, **18**, 274, 327
bandpass, **18**, 274
receiver, **11**, 227
rise (*see also* leading edge of, above), **5**, 2
on magnetron load, **5**, 565–568
on resistance load, **5**, 563–565
time, **23**, 215
in measuring apparatus, **18**, 79
selection, **20**, 87–89, 160
circuits, AN/APN-3, Shoran, **20**, 159
selector, **20**, 89–95, 146, 153, 171
AN/APS-15, **20**, 167
and time modulator, **20**, 146
shape, **5**, 2, 13, 16, 179, 186, 188, 190, 207, 220, 534, 687
and adjacent-channel selectivity, **3**, 79–82
computed and actual, **5**, 261–272
discrimination, **24**, 363
effect of discharging circuit, **5**, 255–261
from hard-tube pulser, with biased-diode load, **5**, 33–51
effect, of measuring circuit, **5**, 678
Pulse, shape, from hard-tube pulser, effect, of pulse transformer and cable, **5**, 81–84, 88
of shunt capacitance and load resistance, **5**, 31
examples of, magnetron (biased-diode) load, **5**, 38, 46–49
with resistance load, **5**, 26–32
sloping top or droop, **5**, 51, 56–58
from line-type pulser, effect, of cable, **5**, 271, 272
of circuit parameters, **5**, 262, 266–268, 440
of magnetron sparking, **5**, 442
magnetron load, **5**, 271, 272, 715, 719
multiple pulses, **5**, 491, 493
with nonlinear inductance switch, **5**, 472
with various types of PFN, **5**, 183, 188, 189, 203–207, 220, 715
Loran, **4**, 149, 155
and magnitude of coherent scattering, **13**, *605–607, 704–706*
measurement, **11**, 408–469
optimum, **5**, 552
from regenerative driver, **5**, 126, 128, 130
very-short-pulse duration, **5**, 165
from regenerative pulse generator, **5**, 590
resistance load, **5**, 573
in sea echo, **13**, 484
shaping, **4**, 396; **5**, 177, 473; **19**, 313
sharp, generation of, **1**, 501–503
-sharpening circuits, **19**, 699
-signal generator, **4**, 395
signals in clutter, threshold, **24**, 297–334
sinusoidal power, **5**, 714
sinusoidal spectrum distribution, **5**, 718
spacing, beacon, **3**, 87
spike (*see* Spike)
stretching, **16**, 306, 312; **18**, 146; **23**, 193, 520
synchronization, **11**, 239
system, phase-modulated, **20**, 442
time-modulated, **20**, 398
tail, **5**, 2, 183, 189, 258–261, 569, 571–573
test equipment, **21**, 573–664

Pulse, test equipment, development and design, **21,** 573–593
practical designs, **21,** 594–664
time-measurements techniques, **20,** 37–68
time-modulated, **20,** 400
time sequence, Loran, **4,** 57
top, **5,** 2, 257
magnetron load, **5,** 569
resistance load, **5,** 568
trailing edge, **5,** 2, 183, 189, 258–261, 569, 571–573
trains, modulated, **24,** 257–296
receiving system, **24,** 257–264
experimental results, **24,** 264–273
indicator for, **24,** 263
transformer (*see* Transformer, pulse)
triangular power, **5,** 713
triangular spectrum distribution, **5,** 718
trigger, **22,** 9, 120
very long, **19,** 237
voltage, **5,** 3, 69, 537
change, **5,** 165
rise rate, **5,** 77
and time derivatives, **5,** 681
short, oscilloscope traces of, **5,** 685
voltmeters, **5,** 692–701
intrinsic error, **5,** 694–698
width, dependence of breakdown power on, **9,** 235
loss, CRT, **3,** 35
modulation, **24,** 30, 292–296
selector, **19,** 368
Pulsed bridge circuit, **5,** 222
Pulsed filter (*see* Filter, pulsed)
Pulsed glide path (PGP), **2,** 228–232
Pulsed navigation systems, **4,** 18
Pulsed signals, **24,** 18–32
amplitude pulsing, **24,** 18
frequency pulsing, **24,** 18
phase pulsing, **24,** 18
Pulser, **1,** 355–390
a-c charging (*see* A-c charging)
charging (*see* Charging)
-circuit efficiency, **5,** 470
circuits, Anger, **5,** 468–471
basic, **1,** 356–360
Blumlein, **5,** 464
Darlington, **5,** 464
direct-connection, **5,** 70
Pulser, circuits, double-switch single-network, **5,** 488–492
driver, **1,** 371
coded, **5,** 486
comparison of hard-tube and line-type, **5,** 13–17
design, switch-tube characteristics, **5,** 93–98
efficiency, **5,** 13, 16, 244, 249–255, 462, 470
energy sources, **1,** 387
gaps (*see* Spark gap)
hard-tube, **1,** 367–373; **5,** 5–8, 19–172; **6,** 343
1-Mw, **5,** 152–160
application of pulse-shaping networks, **5,** 165–172
comparison with line-type pulser, **1,** 360–363; **5,** 13–17
high-power short-pulse, **5,** 160–165
lightweight medium power, **5,** 140–152
load, coupling to, **5,** 70–76
output circuit, **5,** 21–89, 141, 153, 160
biased-diode load, **5,** 32–51
high resistance as isolating element, **5,** 52–61
inductance or inductive resistor as isolating element, **5,** 61–69
resistance load, **5,** 26–31
output-power regulation, **5,** 77
particular applications, **5,** 140–172
peak power, **5,** 69
power-supply voltage, **5,** 73, 77
power transfer to load, **5,** 69–89
regulation, **5,** 16, 77
switch characteristics required, **5,** 90–98
two arrangements of pulse transformer with, **5,** 74
high-power airborne, **5,** 454–463
performance, **5,** 461–463
power supply, **5,** 14, 455
high-power rotary-gap, **5,** 448–454
performance, **5,** 451
impedance, internal, **5,** 4
isolating element, **5,** 6, 12, 52
average power dissipated, **5,** 59
effect of inductance on charging of storage condenser, **5,** 67

Pulser, isolating element, high resistance as, **5**, 52–61
inductance, **5**, 61–69, 145
principal advantages of, **5**, 68
inductive resistor as, **5**, 61–69
resistance, **5**, 153
lightweight medium-power, for airborne radar systems, **5**, 140–152
heat dissipation, **5**, 151, 459
line-type, **1**, 358, 374–383; **5**, 5, 8–12, 173–496; **6**, 344
a-c charging, **1**, 383
characteristics, **5**, 233–244
charging circuit, **5**, 355–416
efficiency, **5**, 392, 421
losses, **5**, 429
measurement, **5**, 690
comparison with hard-tube pulser, **1**, 360–363; **5**, 13–17
discharging circuit, **5**, 225–272
efficiency, **5**, 13, 16, 249
equivalent circuit, **5**, 236–238
impedance, mismatch, **5**, 417
performance, **5**, 417–447
power transfer, **5**, 227, 232, 238–244
recharging circuit, **1**, 382
recurrence period, **5**, 358
short circuit in load, **5**, 248, 417, 423–431, 457
shunt-inductance effect, **5**, 251
switches, **1**, 377–381; **5**, 234, 273–354
voltage-stepup ratios, **5**, 396, 398, 420
load, duration of pulse at, **5**, 226
dynamic resistance, **5**, 3, 33, 78, 110
energy dissipated in, **5**, 226
line, **5**, 243
linear, **5**, 3
nonlinear, **5**, 3
open circuit in, **5**, 417, 431–435
pulse power in, **5**, 226
resistance, **5**, 177
static, **5**, 3, 110
transformer-coupled, **5**, 73
magnetron, **6**, 343, 380
Model 9, **5**, 152–160
multiple-load, **5**, 480–483
multiple-network, **5**, 463–468
multiple-pulse-line-type, **5**, 484–494
output, effect of stray capacitance, **5**, 76
overload protection, **1**, 364
Pulser, particular applications, **5**, 448–496
performance with magnetron load, **5**, 435–447
power input, average, **5**, 151
power output, average, **5**, 3
power supply, **5**, 16
average current, **5**, 149
voltage-doubler, **5**, 148
protection of circuit elements, **5**, 433–435, 457
protective measures, **5**, 151, 160, 431
regenerative, **3**, 240
regulation, **3**, 244–249
effect of switch-tube and load characteristics, **5**, 108–118
transient, **5**, 244
against variations, in load characteristics, **5**, 247–249
in network voltage, **5**, 245–247
shunt-capacitance effect, **5**, 26, 30, 161, 251
thyratron bridge, operating data, **5**, 480
vest-pocket, **5**, 140
Pulsing, amplitude, **24**, 18
double, Loran, **4**, 70
frequency, **24**, 18
phase, **24**, 18
Purcell's junction, waveguide, **8**, 466–476

Q

Q, for build-up, magnetron, **6**, 365, 374
cavity, **1**, 406; **8**, 48; **14**, 30
measurement, **14**, 385–393
charging circuit, **5**, 359
-circle, magnetron output, **6**, 178–187
complex circuit, **8**, 230
definition, **6**, 301; **14**, 11
external, magnetron output, **6**, 181
reflex klystron, **7**, 408
-factors, **11**, 288, 293; **18**, 393
loaded, **11**, 289
ATR cavity, **14**, 118
cavity, **8**, 228; **14**, 388
klystron oscillator, **7**, 319
magnetron output, **6**, 188
phase measurements, **11**, 336–340
resonator, **1**, 406; **9**, 652
measurement **6**, 180, 713–723
Lawson method, **6**, 713

Q, measurement, by power drop in load, **14**, 401
-meter, cavity, **11**, 396–403, 447
radiation, **11**, 289
resonant antenna, **4**, 308
resonant circuit, **8**, 127
unloaded, **9**, 653; **11**, 289
cavity, **8**, 228
magnetron system, **6**, 108, 113, 184, 466, 467, 561, 575
resonator, **1**, 406; **7**, 76, 87; **9**, 653
Q_0, cylindrical cavity, **8**, 48
Q_L, low-Q ATR switch, **14**, 128
Quarter-wave line, **1**, 393
Quarter-wave plate, **1**, 84; **14**, 370
Quartz crystals (*see* Crystals)
Quasi-bistable circuit, **19**, 163
Quasi-monostable circuit, **19**, 162
Quasi selector in amplitude comparison, **19**, 325, 334, 369
Quasi time selectors, **19**, 366

R

Racons, **1**, 246; **3**, 6
Radar, **1**, 12, 419; **4**, 17
1-cm, experimental, radome for, **26**, 437
AGL-(T), **20**, 278, 310, 322, 330, 341, 372, 373
AI (*see* AI)
aids, air-navigation and traffic-control (*see also* Navigation; Traffic control), **2**, 285–313
landing, **2**, 227–251
mapping, **2**, 278–284
ship-navigation (*see* Navigation, ship)
special, **2**, 252–284
traffic-control (*see* Navigation, aids; Traffic control)
air-surveillance, **3**, 14
airborne, characteristics, **2**, 89–121
design considerations, **2**, 143–171
economic aspects, **2**, 187
electrical noise interference and its elimination, **2**, 169
with ground-beacon system for air navigation, **3**, 398–408
ground pointing by, **1**, 88–115
lightweight, for navigation, **1**, 611–625
Radar, airborne, performance, **2**, 171–185
primary electrical power, **2**, 169
radome problems, **2**, 161–165
scanner installation, **2**, 161–165
special aids and devices, **2**, 122–142
test equipment, **2**, 170
airway and airport control, specifications, **2**, 301
AN/APA-15, **26**, 176, 207, 236
AN/APG scanner, **26**, 237, 238
AN/APG-13A, Falcon, **20**, 223
radome, **26**, 456
AN/APG-15, **20**, 316, 327, 331, 342, 368, 371, 373
AN/APQ-3, radome, **26**, 420
AN/APQ-7, **26**, 162, 185–193, 244, 421, 426, 434
AN/APQ-13, **26**, 175–177, 207, 252–254, 331
radome, **26**, 431, 432, 452, 457
AN/APS-2, **26**, 207, 236, 245–247, 426
AN/APS-4 radome, **26**, 349, 427
AN/APS-6, radome, **26**, 349, 427
scanner, **26**, 183–185
AN/APS-10, **2**, 171–185
design, detailed, **1**, 616–625
general, **1**, 614
performance, 1, 622
AN/APS-15 stabilizer, **26**, 207, 236
AN/TPG-1, fire-control, **1**, 211
AN/TPS-10, **2**, 219–227
presentation, **2**, 217
range-height indicator, **2**, 216
ARO, **20**, 275, 317, 342–348
ASG radome, **26**, 246, 426, 430
Automatic, General Electric, **20**, 337
automatic tracking, **2**, 202–207; **25**, 291–298, 328–333
traverse, **25**, 291
azimuthal errors, **2**, 367
beacon (*see* Beacons)
British, time discriminator, **20**, 315
camouflage, **8**, 396
chart projector, **2**, 341
comparison with eye, **1**, 1
components, **1**, 6–8
converage, effects of surface reflection, **1**, 603
cross section (*see also* Cross section), **1**, 63; **12**, 468; **13**, 33, 445

Radar, cross section, aircraft, **1**, 76–78; **13**, 470–472
method of measurement, **13**, 470
polarization dependence, **13**, 471–472
table, **13**, 472
wavelength dependence, **13**, 471–472
circular-disk, **13**, 458
complex targets, **13**, 469
cylinders, **1**, 66; **13**, 458–462
dependence on polarization, **13**, 698
differential, **13**, 466
flat-plate, **13**, 457, 476–479
general formula, **13**, 455
isolated targets, **13**, 445–469
raindrops, **13**, 608–613
scattering (*see* Scattering cross section)
sea echo, **13**, 483, 497–499, 506, 512, 514, 522, 526
ships, **1**, 80; **13**, 472
aspect dependence, **13**, 479
far-zone, **13**, 478
incoherent scattering, **13**, 479–481
near-zone, **13**, 478
polarization dependence, **13**, 475
table, **13**, 475
wavelength dependence, **13**, 475, 479
simplified formula, **13**, 462
small objects, **13**, 465
smooth target, **13**, 697
sphere, **1**, 66; **13**, 450, 452–453
statistical nature, **13**, 470
c-w, **1**, 123–124, 127–159
comparison with pulse radar, **1**, 123
CXAM, **1**, 180
data, employment of, **1**, 213–242
gathering and presenting, **1**, 160–212
design for air surveillance and control, **1**, 592–611
for beacon operation, **3**, 365–384
examples, **1**, 588–625
for use with marine beacons, **2**, 323
detection near surface, range dependence, **13**, 474
wavelength dependence, **13**, 409, 474
detection ranges and duct height, **13**, 358
diffraction effects, **26**, 253
Radar, displays (*see also* Displays; Indication), **22**, 11–16
earth, **2**, 22
echoes (*see* Echo)
equation, **1**, 18, 21–27, 595; **2**, 15–18; **13**, 31–35; **14**, 1; **26**, 11
for free-space propagation, **1**, 18–28
microwave propagation, **1**, 47–62
minimum detectable signal, **1**, 28–47
for ships, **13**, 473
examples of major operational requirements, **1**, 175–212
external aids, **1**, 214–225
frequency band, **3**, 76
ground, with airborne-beacon system, **3**, 408–419
use of beacons with, **1**, 609
ground-based, **2**, 193–227
height finders, **2**, 207–227
scanning systems, **2**, 237–251
types and special equipment, **2**, 193–284
hand, **20**, 216, 243
Handy, **2**, 280
height-measurement errors, **13**, 436–444
high-performance, for air surveillance and control, **1**, 592–611
history, **1**, 13
horizon, **1**, 53
HR, **20**, 163
indicators, **1**, 161–175; **2**, 26–36; **20**, 108
landmarks, **1**, 113
limitations, **1**, 116–126
maps, **2**, 346–350
mapping (*see* Mapping, radar)
Mark 36, angle-tracking circuits, **20**, 375
measurements, short-range, **2**, 279
Mickey, AN/APS-15, **3**, 17
microwave, long-range, **2**, 193–202
modulator, **3**, 237
MTI (*see* MTI)
navigation, **1**, 108; **4**, 15
lightweight airborne-radar system, **1**, 611–625
and pilotage, **2**, 317–353
organizations, examples, **1**, 226–242
performance figure, **1**, 590
performance surveys, **1**, 592
-pilotage maps, **2**, 115

Radar, principles, **1,** 3–6
projector, autofocus, **2,** 340
propagation, **2,** 21–26
pulse, **1,** 3; **2,** 4; **16,** 4
pulse-echo systems, **20,** 31
range, **2,** 196
circuit, Model SJ, **20,** 134
free-space, **13,** 33
performance, **1,** 8–10
receivers (*see* Receivers, radar)
receiving systems, basic electrical circuits, **1,** 492–513
display synthesis, **1,** 524–548
indicators, **1,** 475–554
indices, **1,** 513–524
signal discrimination, resolution, contrast, **1,** 548–554
relay, **1,** 225, 680–735; **2,** 258–267; **20,** 400, 417–470
100 Mc/sec, **1,** 721–723
300 Mc/sec, **1,** 719–721
airborne, **1,** 732–735
AM versus FM for, **1,** 717–719
amplitude, **2,** 264
analyzer, **1,** 682
antenna, **1,** 713–719
filter, **1,** 720
comparative photographs, **2,** 266
for constant-speed rotation, **20,** 450–458
c-w system, AN/ARR-17, AN/ARR-18, **20,** 458–470
f-m, **2,** 264
frequencies used, **1,** 716
frequency, choice, **2,** 261–263
general design problem, **2,** 260
ground-to-ground, **1,** 726–732
interference, combating, **1,** 685
intermediate stations, **2,** 264
maximum range, **1,** 724
microwave, **1,** 723–726
minimum usable signal, **2,** 260
mixer unit, **20,** 451, 461
multichannel transmission, **2,** 264
performance, **20,** 439
phase-modulated pulse, **20,** 442–449
receiver, **1,** 717; **20,** 426, 466
r-f equipment, **1,** 682, 713–719
scan converter, **1,** 682
separator unit, **20,** 466
simple, **1,** 681
Radar, relay, summary, **2,** 265
synchronization, **2,** 265
synchronizer, **1,** 681
terminal equipment, **1,** 682
time-modulated sine-cosine, **20,** 417–442
transmitter, **20,** 463
design, **1,** 717
type-A link, **2,** 258
type-B link, **2,** 259
uses, **1,** 680
scan frequency, f_s, **25,** 291
scanners (*see also* Scanners), electrical, **1,** 291–304
mechanical, **1,** 282–291
scanning patterns, **1,** 280–282
SCR-268, **1,** 203
SCR-270, **1,** 181
SCR-271, **1,** 181
SCR-521, **1,** 196
SCR-527, **1,** 186
SCR-584, **1,** 207–210; **3,** 9, 14, 77, 418, 455; **13,** 444; **19,** 575; **20,** 89, 161, 163, 337, 368–370, 406
automatic-tracking loop, **25,** 212
close control with, **1,** 238
scanner, **1,** 284–286
servo data, **26,** 233
velocity, angular, and acceleration of target on straight-line course, **25,** 229
SCR-615, servo data, **26,** 231
SCR-717, **1,** 199
SCR-720, **1,** 201
search and automatic-tracking, **2,** 193–207
shadows, **3,** 55; **12,** 515
shipborne navigational, **2,** 354–382
antenna assembly, **2,** 364–371
general specifications, **2,** 363
indicator, **2,** 373–377
physical characteristics of components, **2,** 379
specifications, **2,** 363–382
test equipment, **2,** 379–383
transmitter-receiver package, **2,** 371–373
signals, distinguishability from beacon signals, **3,** 93
SM, **1,** 188
speed, blind, **20,** 19

Radar, speed, ground, **20,** 21, 24
stability, as affecting echo fluctuations, **13,** 527–529
importance in measurements, **13,** 527–529
limits, **13,** 528
stabilization, **1,** 304–319
computers for, **26,** 117, 217
synchronizer, **20,** 71
systems, frequency stability, **13,** 528
testing, need for, **1,** 590
versatility, **1,** 588
T-14, experimental, **13,** 495
targets, complicated, **1,** 73–88
complex, **13,** 469–481
and echoes, **13,** 445–587
frequency sensitivity, **13,** 529–531
properties, **1,** 63–115
simple, **1,** 63–73
test-equipment characteristics, **21,** 576–593
test oscilloscope (*see also* Oscilloscope), designs, practical, **21,** 594–664
trainer, type SP, **21,** 190
transmission, **13,** 353–373
equation (*see also* equation, above), elliptical-polarization and smooth-target, **13,** 697
flat-plate ship model, **13,** 479
free-space, **13,** 33
sea-echo, **13,** 484
transmitter, impedance, **14,** 275, 428
video signals, pulse-to-pulse amplitude cancellation, **19,** 708
wavelength choice, **1,** 604; **2,** 20, 195–198, 371
XT-2, experimental, **13,** 354, 495
XT-3, experimental, **13,** 10, 354, 495
Radial functions, cotangent, **10,** 33
tangent, **10,** 33
Radial time base (RTB) (*see also* PPI), **22,** 23, 425
expanded, **22,** 483
indicator, **1,** 174
Radial transmission line (*see* Line)
Radial waveguide structures, frequency sensitivity, **10,** 43
Radiation, absorption (*see* Absorption, radio-wave)
by antennas, **8,** 317–333
Radiation, into bounded half space, rectangular guide, E-plane, **10,** 184
into bounded space, rectangular guide, E-plane, **10,** 183
from circular guide, E_{01}-mode, **10,** 196
H_{01}-mode, **10,** 201
H_{11}-mode, **10,** 206
cooling, **13,** 343
magnetron, **6,** 524
from E-plane sectoral horns, **12,** 357
from H-plane sectoral horns, **12,** 358
into half space, coaxial line, **10,** 213
parallel-plate guide, E-plane, **10,** 183
H-plane, **10,** 187
line-of-sight, **13,** 5
losses, line-junction, **9,** 108
low-angle, **4,** 301
meteorological, **13,** 232, 234, 248
nocturnal (*see* Nocturnal radiation)
resistance, antenna, **4,** 316, 324; **12,** 39, 95
into space, parallel-plate guide, E-plane, **10,** 179
H-plane, **10,** 186
temperature of space used in water-vapor-absorption measurements, **13,** 669
from thick holes, **8,** 201
from waveguide, aperture treatment, **12,** 334
Radiator (*see also* Antenna) axially symmetrical, **12,** 303–309
dipole, **12,** 92–96
images of, **12,** 135–137
isotropic, **2,** 17
streamlined, **12,** 310–313
waveguide, **12,** 301–303, 329
Radio altimeters (*see* Altimeters, radio)
Radio compass, **3,** 25
Radio-frequency cables (*see* Cables, r-f)
Radio meteorological forecasting, **13,** 175
Radio-optical path, definition, **13,** 6
Radio range, **2,** 44–47; **4,** 15
German, **2,** 47–50
navigation, aids to, **2,** 46
omnidirectional, **4,** 5
single, navigation by, **2,** 45
Radio speed and distance measurements, **20,** 24–29
Radioactive cobalt, effect on breakdown power, **9,** 232

Radioactive cobalt chloride, **14**, 216
Radioactive priming, **14**, 216
Radiometer, microwave, **13**, 668–669; **15**, 197
  noise-figure measurement, **18**, 718
Radiosonde (*see also* Sounding), **13**, 185, 207, 255, 272, 298, 347, 348; **20**, 408
  ascents, **13**, 261, 348
Radome (*see also* Radar), **1**, 314–315; **16**, 291; **26**, 200
  abrasion, **26**, 255
  absorption of water, **26**, 255
  adhesive, **26**, 282, 318
  aerodynamic considerations, **26**, 419–425
  airborne, drag of, **1**, 315
  AN/APG-13, **26**, 456
  AN/APS-4, **26**, 427
  AN/APS-6, **26**, 427
  AN/APQ-13 (60-in.), **26**, 431, 432, 452, 457, 459
  bag-molding technique, **26**, 372, 375
  balsa wood for, **26**, 379
  bending, simple, theory, **26**, 384
  bending jig, **26**, 386
  cementing, **26**, 383
  cold resistance, **26**, 255
  compressible flow, **26**, 424
  compression test, edgewise, **26**, 402
  condensation prevention, **26**, 142
  contours (*see* Contour)
  cyclized rubber for, **26**, 371
  design problems and procedures, **12**, 522–542
  double-wall, **26**, 246, 272–276
    normal-incidence, electrical design, **26**, 276
  drag, **26**, 419
    coefficient, **26**, 420
  dynamic pressure on, **26**, 420
  electrical, and mechanical tests, **26**, 441–459
    design, normal-incidence, **26**, 259–285
      streamlined, **26**, 286–306
    requirements, **26**, 244
    transmission of, **1**, 316
  examples of, **1**, 317–319
  for experimental 1-cm radar, **26**, 437
  fabrication, **26**, 369–418
    foaming in place, **26**, 379
Radome, GEI scanner, **26**, 435
  general structural design, **26**, 424
  general survey, **26**, 241–258
  glass mat, **26**, 379
  glue line, effect of, **26**, 282, 284
  gun-blast resistance, **26**, 439
  heat resistance, **26**, 255
  installation and testing, **26**, 419–462
  laminated, **26**, 376
  large, design, **26**, 429
  LST, **26**, 440
  materials, electrical properties, **26**, 408–418
    evaluation at normal incidence, **26**, 415–418
    mechanical properties, **26**, 383–408
    mechanical requirements, **26**, 254–256
    methods of fabrication, **26**, 369–418
  mockup for testing, **26**, 446
  nonprotuding, for AN/APQ-13 (60-in.) radar, **26**, 432
  normal incidence, **12**, 537–539; **26**, 256
    design considerations, **12**, 538
    electrical design, **26**, 259–285
    impedance effects, **12**, 537
    pattern effects, **12**, 537
  panels (*see* Panels)
  pattern distortions, **12**, 524–526
  pressure, dynamic, **26**, 420
  problems, **2**, 161–165
  reflection-test apparatus, **26**, 444
  sandwich (*see* Sandwich)
  shipborne, **26**, 438–441
  skin (*see* Skin)
  span/depth ratio, **26**, 385
  stiffness, **26**, 254
  streamlined, **12**, 524, 535, 540–542; **26**, 257, 430–438
    electrical design, **26**, 286–340
  strength, **26**, 254
  structural design, **1**, 316
  test, **26**, 419–462
    equipment, **26**, 454
    methods, structural, **26**, 454–456
    mockup for, **26**, 446
  thin, **26**, 264, 272
  transmission-test apparatus, **26**, 443
  turbulence effect, **26**, 420
  types of installation, **26**, 242–244

Radome, walls, reflection coefficients, **12,** 529–537
sandwich, **12,** 532
single, **12,** 531
transmission coefficients, **12,** 529–537
Railing interference, **24,** 358–365
Rain, nonuniform spatial distribution, **13,** 672, 684, 689
Rain echoes (*see* Echo)
Rain gauges, **13,** 689
Raindrops, horizontal velocities, **13,** 577
multipole moments, **13,** 608–610, 676
size distributions, **13,** 615–618, 681
terminal velocity, **13,** 616, 679
Random process, **13,** 553; **24,** 33; **25,** 266–270
Gaussian, **24,** 53–56
mean-square, **25,** 273
error, minimizing, **25,** 325–328
moments, **25,** 273
periodicities, hidden, **25,** 279
purely, **24,** 42; **25,** 298–300
repetition period, **25,** 232, 281
rms, definition, **25,** 273
stationary, **25,** 270–273
harmonic analysis, **25,** 270–291
time averages, **25,** 271–273
Random scatterers, **13,** 551, 553
assembly (*see* Assembly of random scatterers)
plus steady signal, first and second probability distributions, **13,** 560–562
Random series, **25,** 267
Random-walk problem, **13,** 553; **24,** 50–53
discrete, **25,** 267, 269
two-dimensional, **24,** 126
Range, calibrator, AN/APG-5, **20,** 108, 275, 317, 331, 337, 342
Model III, **21,** 635–641
-height, displays, **22,** 516–538
indicator (*see* RHI)
horizon, **3,** 51–53
indicator, precision, **20,** 108, 148
indices, **1,** 518–524
Loran, **4,** 62, 98, 107, 122, 130
marker, **2,** 148; **22,** 25, 238
circuit, pulsed, *LC*, **20,** 108
precise, from precision-ranging indicator, **20,** 108
Range, marker, generation, **20,** 78
movable, **1,** 518
marks, **24,** 21
circuit, pulsed, for PPI, **20,** 107
fixed, **20,** 229
generators, **20,** 69
TS-103/AP, **21,** 662
mixer, **20,** 83
minimum, **3,** 40
natural unit, **13,** 97
normalization, **22,** 389, 487, 490
propagation, free-space, **3,** 60
reduction, **12,** 524
reliable, beacon, **3,** 30
experimental verification, **3,** 38–40
resolution, **2,** 10, 14, 150; **22,** 11, 35
scopes (*see also* Oscilloscope), **1,** 165–167; **22,** 17
-set control, **23,** 62
slant, **2,** 151
sweep, **1,** 162; **22,** 8, 14, 29
linear, **22,** 9
tracking, automatic, **20,** 168
on grouped data, **20,** 386–388
servoamplifier circuit, **20,** 362
tester, dynamic, **20,** 357, 361, 363
two-scale, **20,** 238
uhf, **2,** 50
unit, AN/APN-3, **19,** 565
AN/APS-15, **20,** 164–169, 277
waveforms, **20,** 165
calibration of, universal instrument for, **20,** 102
Meacham, **20,** 142–147
phase-modulation, two-scale, **20,** 143
two-scale, **20,** 143
Wurzburg, **20,** 163
visual two-course, **2,** 50
Ranging indicator, precision, **20,** 147–153
Rapid photographic projection, **1,** 221
Rapid-scan system, **2,** 187
Raster, excitation, **22,** 651
polka-dot, **22,** 597
shrinking, **22,** 69, 594
Rational-fraction expansions, **5,** 185
Ray, **13,** 4, 6, 12, 54
characteristic, **13,** 15, 49
curvature, **12,** 111, 112
in relation to index gradient, **13,** 44
relative, **13,** 12
to earth, **13,** 50

Ray, differential equation, **13**, 42–50
  direct, **13**, 5, 36–39, 99, 100, 104, 107, 116
  family, **13**, 15, 47
    linear *N*-profile, **13**, 16
    simple surface duct, **13**, **17**
  in surface duct, **13**, 19
  tangent, **13**, 5, 6, 116
  theory, **13**, 332, 391
  tracing, **13**, 17, 18
    conditions as criterion of validity of ray methods, **13**, 57
    errors, **13**, 7, 18
    formulas, **13**, 41–50
    methods, limitations, **13**, 53–58
    relation, to phase-integral methods, **13**, 82
  turning point (*see* Turning point)
  velocity, **12**, 110
  in waveguide, penetration of ducts, **13**, 18
Rayleigh, distribution, **24**, 53
  principle, **5**, 179–183
  reciprocity theorem, **12**, 19
  -Ritz procedure, **10**, 145
  roughness criterion, **13**, 411, 430, 431, 434, 539
  scattering, **1**, 63
    law, **13**, 23, 465
      cylinder, **13**, 461
      deviations from, **13**, 598, 612
      flat-plate, **13**, 8, 465
      meteorological echoes, **13**, 597–598, 610, 618
      sea-echo, **13**, 494
      sphere, **13**, 7, 452
      suspended matter, **13**, 621
RC-differentiator, calibration, **5**, 685
RC divider, parallel, **5**, 667
  series, **5**, 675
RC-feedback phase-shift circuit, **19**, 150–154
RCP (Radar chart projector), **2**, 341
Re(*a*), **25**, 47
Reactance tube, **16**, 292; **20**, 96, 97; **23**, 30
  vhf, **23**, 34
Reactors (*see also* Chokes; Transformers)
  charging (*see* Charging reactor)
    d-c, design, **5**, 372–380
Reactors, core saturation, **5**, 364, 370
  saturable, **21**, 521
    a-c control with, **21**, 440
    control circuit, emission-tube, **17**, 461
Rear-feed systems, **12**, 448
Rebecca, **3**, 10
  -Eureka, **3**, 10, 77; **4**, 7
    talking, **3**, 231
Rebecca-*H*, **3**, 17; **4**, 9
Received power, minimum useful, **13**, 32
  for pulses, **13**, 483
Receivers, **24**, 1
  airborne, incorporating anticlutter circuits, **23**, 349–379
  a-m versus f-m, **23**, 440
  bandwidth, **3**, 367
    effect on pulse, **4**, 155, 198
    requirements, Loran, **4**, 388
  beacon, circuit-trouble alarm, **3**, 149–179, 322
    components, **3**, 370
    delay in, **3**, 152
    fidelity, **3**, 152
    frequency-coverage, **3**, *151*, *162*, 172
    narrow-coverage, **3**, 151
    superheterodyne, **23**, 455–503
    types, **3**, 149
    wide-coverage, **3**, 152
  box, construction, **23**, 253
  calibrations, **13**, 564
  channel, separate, **3**, 369
    single, **3**, 368
  channeling, **3**, 368–371
  comparison, for frequency measurements, **11**, 353
  coupling into and out of, **23**, 324–329
  coupling r-f equipment to, **23**, 296–300
  crystal-video, **3**, 172–179; **15**, 9; **18**, 113; **23**, *1*, 5, 504–544
    figures of merit, **16**, 54–56
    output circuits, **23**, 528
    with r-f filter, **3**, *158*
    sensitivity, **3**, 176
  design, MTI, **1**, 665
  design considerations to facilitate testing and alignment, **23**, 300
  figure of merit, **16**, 10–17
  f-m versus a-m, **23**, 440
  gain control, **3**, 371–374
  gain-limited, **23**, 277

Receivers, gate, SCR-584, **20**, 163
holes for ventilation and adjustment, **23**, 258
i-f, wideband, **3**, 162–164
limiting, **23**, 596
for MTI, **1**, 647, 665
lin-log, **1**, 647, 665; **23**, 583
logarithmic, **1**, 553
Loran, **4**, 212
cycle-matching, **4**, 398
design, **4**, 386
i-f rejection ratio, **4**, 389
image rejection ratio, **4**, 388
-indicators, **4**, 56, 63, 99, 345–385
airborne, **4**, 363–381
AN/APN-4, **4**, 25, 31, 363, 367
AN/APN-9, **4**, 365, 374
DAS, **4**, 349–358
DBE, **4**, 349, 358
direct-reading, **4**, 358
LRN, **4**, 349
SCR-722, **4**, 363
shipboard, **4**, 345
UE-1, **4**, 243
sensitivity, **4**, 389
mechanical construction, **23**, 253–276
microwave, **3**, 157
classification and description of types, **16**, 17–46
MTI, **23**, 579–611
adjustment of limit level, **1**, 649
characteristics, **1**, 648–649
comparison of types, **1**, 648
dynamic range, **23**, 605
limiting, **1**, 647, 665
output signals, video frequency, **23**, 605
sensitivity to weak signals, **23**, 604
narrow-coverage, **3**, 153–161
noise, **24**, 98–123
noise-limited, **23**, 277
output, measuring, **23**, 329–335
output signals, dynamic range, **23**, 605
pulse, measurements, **11**, 226–234
response to frequency-modulated signals, **11**, 230
radar (*see also* Radar receiving systems), **1**, 433–474; **3**, 367–374
automatic-tracking, **23**, 380–418
bandwidth, **1**, 33, 444; **20**, 39
construction materials, **23**, 260
Receivers, radar, coordination with scanner, **1**, 486–492
definition, **1**, 435
delay time, **20**, 40
design consideration, **2**, 143–148
general-purpose, **1**, 462–464
input circuits, **1**, 442
lightweight airborne, **1**, 464–470
over-all noise figure, **1**, 32, 441
pass-band, **2**, 10
selectivity, **23**, 180, 554
sensitivity, **16**, 10, 21
effective, **3**, 33
simple, **23**, 336–348
typical, **1**, 435–441, 460–474
wideband, **1**, 470–474; **23**, 455–461
single-detection, **24**, 6
single-sideband, **23**, 472–478
superheterodyne, **3**, 157, 161–172; **16**, 3, 24–26, 235; **23**, 1; **24**, 8
two-band 200-Mc/Sec, **23**, 419–439
superregenerative, **3**, 153–157; **16**, 45; **23**, 545–578; **24**, 11
gain, linear mode, **23**, 560
logarithmic mode, **23**, 548
maximum, **23**, 552
high-frequency, velocity-modulated tubes for, **23**, 578
linear, **23**, 547
output characteristics, **23**, 562
logarithmic, **23**, 547
output characteristics, **23**, 550
quench frequency, **23**, 562; **24**, 12
maximum usable, determination, **23**, 551
quench oscillator *QFO*, **23**, 546
quench voltages, sinusoidal, **23**, 552
quenching, single-cycle, **3**, 156, 157; **23**, 567
self-quenching circuits, **23**, 559
theory of operation, **23**, 546
synchro, **26**, 224
test equipment, built-in, **23**, 301
test points, **23**, 301
testing, **11**, 222–234
TRF, **3**, 159; **4**, 398; **23**, 1, 5
types, comparison, **23**, 604
difficulty of maintaining proper operation, **23**, 605
use in MTI with no coho, **23**, 605
ultimate sensitivity, **11**, 222

Receivers, wideband f-m, **23**, 440–454
wide-coverage, **3**, 161–179; **23**, 472–503
Receiving area, effective, **24**, 104
Recharging path, pulser, **5**, 33–39, 144, 163
Reciprocity, experimental tests, **15**, 125–127
frequency conversion, **15**, 118, 124–128, 203, 216
full, **15**, 118, 124
weak, **15**, 118, 124, 139, 203, 216
general condition, **15**, 124
relations, microwave networks, **10**, 104
between transfer coefficients of network, **12**, 18
theorem, **8**, 90; **13**, 97, 114, 468, 693–698; **16**, 63
Dicke, **15**, 125, 417–420
between transmitting and receiving patterns, **12**, 48–50
Recognition of indicator patterns, **2**, 331
Recorder, Esterline-Angus, **20**, 387
Recovery time, of receiving system, **11**, 233
TR tube (*see* TR tube)
Recovery-time constant, **18**, 118
Rectangle generator, variable-width, to produce time-modulated tracking index, **20**, 222
Rectangular wave, **22**, 123
generation, **1**, 496–501; **22**, 123–128, 140, 432, 526
Rectification, barrier-layer (*see also* Semiconductors), **15**, 68–72
diffuse theory, **15**, 77–81
diode theory, **15**, 78, 81–82
crystal, efficiency, **15**, 3; **16**, 297
as function of applied voltage, **15**, 379
at high frequencies, **15**, 97–107
at low levels, **15**, 333–335
at metal-metal contact, **15**, 68–70
by metal-semiconductor barrier, **15**, 72
phenomena, **15**, 1–5
rectified current, as function of frequency, **15**, 379
i-f resistance as function of, **15**, 42
Rectifiers, for beacons, **3**, 318
contact, **19**, 68–72, 671; **21**, 55, 123
Rectifiers, crystal, **11**, 4, 924; **15**, 5–11; **16**, 47–118; **17**, 106–108; **18**, 715; **23**, 334
diode, **17**, 539–547
early use, **15**, 5
electrical properties, **15**, 20–25
equivalent circuit, **15**, 23–25
fundamental properties, **15**, 15–44
germanium (*see* Germanium)
d-c characteristic, temperature effect, **15**, 375
harmonic generation, **11**, 373
properties at low level, **15**, 333–344
recent developments, **15**, 6–11
r-f impedance, **15**, 35–40
shot and thermal noise, **15**, 179–186
silicon (*see* Silicon)
types and specifications, **15**, 429–433
diode, **18**, 715; **23**, 334
dry-disk, **17**, 106–109
high-inverse-voltage, **15**, 10, 64, 361–397
as low-frequency rectifier, **15**, 363
silicon, **15**, 389–391
high-quality, general processes for making, **15**, 301
high-voltage, **17**, 545–547
low-level, video resistance, **15**, 333
peak inverse voltage, **15**, 362, 375
dependence on frequency, **15**, 380–382
plate-supply, **17**, 539–547
for power indication, **11**, 191–194
selenium, **19**, 69; **22**, 166, 466–471
d-c characteristics, **19**, 69
with deflection coils, **22**, 466
resistance, **22**, 468
welded-contact, **15**, 11, 329
admittance-matrix elements, **15**, 407
applications, **15**, 415
construction, **15**, 398–400
general properties, **15**, 400
as generator of millimeter waves, **15**, 398
germanium crystals, **15**, 21, 398–416
as harmonic generators, **15**, 398, 415
noise measurement, **15**, 403–406
uniform contact potential difference, **15**, 400
Rectifying contact adjustment for low-level detection, **15**, 359

Rectifying rotary gap, **5**, 476
Recycling detector, **19**, 508, 509, 532
Reference plane, cavity measurements, **7**, 407
  waveguide, transformations, **10**, 120
Reflected ray, **13**, 5, 19, 36–38, 99–101, 108, 116
  variations, **13**, 424, 539
Reflecting surfaces, types, **26**, 17–25
Reflection, in beacon reception, **3**, 441, 453
  from change in dielectric constant, **8**, 369–374
  coefficient, **1**, 49; **3**, 43; **11**, 475
    amplitude, **26**, 349
    chart (*see also* Smith impedance charts), **9**, 60–67; **12**, 28–33
    complex, **11**, 565
    current, **8**, 67, 266; **12**, 32
    dependence on grazing angle, **13**, 401–403
    electric-field, **12**, 212
    land, **13**, 430–436
    measurements, interpretation, **13**, 429, 435
      over land, **13**, 430, 433
      over sea, **13**, 421, 427
      rapid variations in, **13**, 419, 538
    obstacle, **8**, 63
    ocean, **13**, 418–430, 537
    paraboloidal reflectors, **12**, 439–443
    in radial lines, **8**, 265–267
    radome walls, **12**, 529–537
    reflex klystron, **7**, 409
    and sea echo, **13**, 418
    smooth plane, **13**, 396
    smooth sea, **13**, 402–403
    and stored energy, **8**, 138
    surface roughness, **13**, 411
    termination, **8**, 137
    transmission line, **6**, 706; **9**, 13–19, 29, 63
    very smooth land, **13**, 432
    voltage, **8**, 67, 266; **12**, 25
  constant contours, **26**, 309
  contour, **26**, 294, 323
    sandwiches, **26**, 309
  from curved surfaces, **12**, 138–143
  from curved undersurface of fuselage, **12**, 517
  dielectric, **26**, 341–368
Reflection, dielectric, at boundary, **26**, 347–353
  diffuse, **1**, 89
  from earth's surface, **13**, 5, 34, 396–444
    and radar-height measurements, **13**, 436
  edge, **12**, 518
  effects, of core thickness, at parallel polarization, **26**, 314
      at perpendicular polarization, **26**, 312
    of impedance mismatch with long cable, **5**, 84–89
  from elevated *M*-inversion, **13**, 334
  geometry of, from plane earth, **13**, 36
  group, multiplication table, **8**, 414
    symmetry types under, **8**, 415
  interface, **11**, 565, 606–612
  ionospheric, **13**, 3
  large, measurement, **11**, 536
  laws of, **12**, 124, 134
  low-loss material, **26**, 353
  measurement in free space, **11**, 612–616
  method for gain determination, **12**, 585
  minimized maximum, **26**, 297
  multiple, **4**, 60; **26**, 354
  in plane, symmetry of, **8**, 412–414
  power, coefficients, **26**, 353
  probe, **11**, 607–609
  propagation, **4**, 88, 129
  radome, **26**, 244
    at oblique incidence, **26**, 290
  rough terrain, **13**, 340, 351, 471
  sandwiches, **26**, 306, 322–327, 360–365
  sheet, **26**, 354–360
  skin, **26**, 252
  specular, **1**, 89; **13**, 344, 391, 396–418
  stability of, **4**, 134
  test apparatus, **26**, 444
  thin panel, **26**, 300, 303
  time variation and rough surface, **13**, 418
  transit time, klystron, **7**, 465–469
Reflectometer, **11**, 896
Reflectors, arbitrary shape, **12**, 137–162
  barrel, **12**, 480, 503
  barrel-stave, **26**, 157
  contour cutting, **12**, 453–457
  corner (*see* Corner reflector)
  current distribution, **12**, 144–149
  cut paraboloidal, **12**, 451–457, 477

Reflectors, cut paraboloidal, symmetrical-type, **12**, 451–453
cylindrical, **1**, 276; **26**, 19
for shaped beams, **12**, 494–497
double-curvature, **12**, 502–508
drag, **26**, 33
forms and templates, **26**, 25–33
grating, **12**, 449–450; **26**, 21
hardware cloth, **26**, 20
illumination, **26**, 26
klystron (*see* Klystron)
line-source feed and, **12**, 151–155
mesh, **26**, 20
microwave, **26**, 15
mismatch introduced by, **12**, 155–158, 439–443, 454
modified, **12**, 474, 477, 479–495, 503
parabolic, **26**, 5
parabolic cylinder, **26**, 29
paraboloid, **26**, 18, 25–29, 156
astigmatic, **26**, 25, 28
template, **26**, 29
spun, **26**, 18
true, **26**, 25–28
paraboloidal, feed-tilt effects, **12**, 487, 488
structural design problems, **12**, 448–450
point-source feed and, **12**, 149–151
properties, **26**, 15–17
screen, **12**, 449
shaped cylindrical, **26**, 160
shovel, **12**, 481, 483
structural characteristics of specific, **26**, 38–45
supersonic crystal transducer, **17**, 189–190
supersonic delay line, **17**, 226, 230–232, 235
surfaces, special, **26**, 30
template, **26**, 26, 29
wind loads, **26**, 33–38
Reflex klystron (*see* Klystron)
Refraction, amplitude coefficients, **26**, 349
atmospheric, **2**, 21; **13**, 34
at boundary, **26**, 347–353
experimental studies, **13**, 294–394
index (*see* Index of refraction)
laws, **12**, 125
meteorology, **13**, 181–294
Refraction, propagation, **1**, 53; **4**, 130
standard, **2**, 22; **3**, 50; **13**, 14, 22, 53, 95
in diffraction region, **13**, 122
studies by radar, **13**, 353–373
tropospheric, **13**, 9–22
Refractive index (*see* Index of refraction)
Refractive modulus, **13**, 191, 192, 203, 207
approximate formula, **13**, 203
errors, **13**, 203
gradient, **13**, 192, 198
errors, **13**, 204
potential, **13**, 199, 201
approximate formula, **13**, 205
Regeneration in amplifiers, **18**, 323–326
Regenerative driver, **5**, 124–132, 150
Regenerative pulse generator (*see also* Transformer, pulse), **5**, 575–591
Regulator (*see* Speed; Voltage)
Rejection-band characteristics, effect of dissipation, **9**, 604–607
Rejection filters, **24**, 346
Relativistic effects, **6**, 228
electron motion, **6**, 211
Relaxation oscillator (*see* Oscillator)
Relaxation time, dielectric, **8**, 379
Relay (*see also* specific types of relay), a-c, general-purpose, **17**, 509
arc-suppressing circuits, **17**, 489
armature and contact structures, **17**, 511
coils, **17**, 474–479; **22**, 126
operating temperature, **17**, 474–476
contact protection, **21**, 436
current, **17**, 491
release, **17**, 478
D-168479, **21**, 432
d-c, general-purpose, **17**, 506
differential, **17**, 493
directional, **17**, 492
enclosures, **17**, 489
general-purpose, **17**, 510
indexing, **17**, 468
insulation, **17**, 488
keying, **17**, 493
lag, **17**, 480–483, 494–495, 505, 508
escapement-type, **17**, 480, 494
operate- and release-time curves, **17**, 481
slug-type, **17**, 480, 505, 508
thermal, **17**, 481–483, 494–495

Relay, latching, **17**, 492
life, **17**, 490
magnetic structures, **17**, 472–474
mercury, **17**, 498–500; **19**, 403; **21**, 432
multiple-unit, **17**, 495
operate current, **17**, 478
operate time, **17**, 479–483, 514
overload, **17**, 491–492
polarized, **17**, 492
potential, **17**, 491
power requirements, **17**, 476
radar (*see* Radar relay)
and related devices, **17**, 467–516
release current, **17**, 478
release time, **17**, 479–483, 514
replacement, **17**, 489
resistance to shock and vibration, **17**, 472, 483, 487–488, 504–505, 510–517
rotary, **17**, 483–488
sensitive, **17**, 504, 507
servicing, **17**, 489
servo, 400-cps, **22**, 193
shock tests, **17**, 504–505, 510–517
Silverstat, **21**, 428
sizes and weights, **17**, 490, 506–509
slow-acting (*see* lag, above)
special types, **17**, 490–495
telephone-type, **17**, 503
tests, **17**, 500–516
thermal time-delay, **17**, 481, 482
time-delay (*see* lag, above)
time-delay circuits, **17**, 482–483
tropicalization, **17**, 488–489
type 80, **21**, 432
undercurrent, **5**, 433
underload, **17**, 491
vibrating mercury, **22**, 193
vibration test, **17**, 504, 510–517
voltage and current requirements, **17**, 476–479
Relaying, scanner data, **1**, 683
sine and cosine data, **1**, 701–711
Remote control, **25**, 1
Repeater, electromechanical, **1**, 490–492
synchro-driven, **1**, 490
Repetition frequency, **24**, 222–230
Repetition rates, **2**, 16, 18; **22**, 121
control, **20**, 511–525
Reply coding (*see* Coding, reply)
Representation, change of, as circuit operation, **21**, 62, 129
Reproduction of canned data, **2**, 268
Reradiation, **23**, 557
Reservoirs, chemical, TR tube, **14**, 219
silica-gel, **14**, 220
Reset error in CRT measurements, **20**, 192
Reset interval in CRT measurements, **20**, 194
Residues, method, **25**, 46–48, 333
sum, of field integral, **13**, 110
Resins, thermosetting, **26**, 374–378
Resistance, card, attenuator, **16**, 197
load, **9**, 97
charging, **3**, 242; **5**, 487
coefficient, **13**, 216, 217
divider, **5**, 668
equivalent, resonant-circuit, **6**, 114
interlaminar, **5**, 636–638
stability, **19**, 475
thermometer, **13**, 289
video measurement, **15**, 349–357
wire, alloy properties, **17**, 70–72
in high-attenuation cables, **17**, 21
for potentiometers, **17**, 246–248
table, **17**, 247
Resistive disk, **11**, 705; **16**, 141, 149, 206, 356
Resistivity, d-c, of common metals and alloys, **11**, 296
Resistors, bobbin-type, high-frequency characteristics, **17**, 95–96
choice, **17**, 33–34
composition, **17**, 33–64, 96–99, 110–114
color code, **17**, 37–38
construction, **17**, 39–43
dimensions, **17**, 36
dissipation rating, **17**, 43–45
high-frequency properties, **17**, 51–60
methods of measurement, **17**, 54–56
JAN characteristics, **17**, 35, 37, 44
labeling, **17**, 37–38
noise, **17**, 49–51
pulsed operation, **17**, 45–46
resistance-temperature characteristics, **17**, 46–49
resistance values, **17**, 38–39
preferred-number system, **17**, 38–39

Resistors, composition, stability, **17,** 60–63
voltage rating, **17,** 45–46
disk, **11,** 705; **16,** 141, 149, 206, 356
high-frequency, **17,** 110–112
high-stability composition, **17,** 97–99
high-voltage, **17,** 95–97
metal-film, **17,** 99–101
meter, **17,** 88, 89
nonlinear, **21,** 55
pulse-current-viewing, **17,** 113–114
single-layer, inductance of, **17,** 86
strip, **16,** 231, 301
ultrahigh-frequency, **17,** 112–114
wire-wound, accurate, **17,** 87–95
a-c characteristics, **17,** 94–95
construction, **17,** 90–91
dimensions, **17,** 88–89
insulation, **17,** 93
resistance tolerance, **17,** 92–93
resistance values, **17,** 91–92
stability, **17,** 93–94
table, **17,** 88
temperature coefficient, **17,** 93–94
voltage rating, **17,** 93
fixed, **17,** 65–96, 109–110
low-power, **17,** 65
power-type, **17,** 65–87
a-c characteristics, **17,** 82–87
coatings, **17,** 74–76
construction, **17,** 71–77
dissipation rating, **17,** 67, 80–81
JAN characteristics, **17,** 68–69
JAN-type designations, **17,** 66
maximum available resistance, **17,** 74, 77–78
mountings, **17,** 66, 76–77
reactance, **17,** 87
resistance values, **17,** 77–80
table, **17,** 67
temperature coefficient, **17,** 79–80
voltage ratings, **17,** 82
windings, **17,** 72–74
r-f, **17,** 109–110
Resolution, range, importance, **2,** 150
before time-base generation, **22,** 471–481
Resolved-time-base applications using condensers, **22,** 217
Resolved-time-base method, **22,** 445–471
Resolvers, **21,** 55, 105, 162, 183, 203
a-c, **21,** 106
driving circuits, **21,** 108
Arma, **20,** 418, 438; **21,** 475
computer, **27,** 15–19
d-c, **20,** 440; **21,** 110
definition, **17,** 340–341
drivers, **21,** 188
electrical characteristics, **17,** 343
loaded-potentiometer, **21,** 164
servo, **21,** 188, 345, 475–480
sine-cosine, **22,** 27
single-frequency operation, **17,** 341–343
synchro system, **17,** 340–344
two-phase, **26,** 123, 209
use of, as vector adders, **17,** 342
variable transformer, **1,** 487
Resolving device, servo, **22,** 185, 186
Resolving power, distortion association, **2,** 91
Resonance, in closed circular waveguide, **8,** 361–364
curves, universal, **18,** 213
indicator, cavity, **6,** 704
phase shift near, **14,** 399
in rotary joints, **9,** 416–422
tuner, magnetron, **6,** 575
waveguide transition, **9,** 99
Resonant aperture, **9,** 221
Resonant charging, **1,** 382; **5,** 12, 360, 381, 386–393, 418
Resonant circuits, **8,** 127–129
driving by slowly changing r-f current, **7,** 455
terminal location, **6,** 720
Resonant elements, waveguide, **14,** 70–80, 97
Resonant gap, equivalent circuit, **14,** 74
Resonant load, mismatched transmission line as, **6,** 320–329
Resonant ring, **9,** 391
Resonant stub, **16,** 176
Resonant system, components, **6,** 406
Resonant transformers, **14,** 9
Resonator, admittance (*see also* Magnetron), **7,** 319
annular-sector, **6,** 62
cylindrical side, **6,** 59
rectangular-slot side, **6,** 57
annular-sector, **6,** 62
cavity (*see* Cavity resonators)

Resonator, closed-end, **6**, 471, 477
design, **7**, 498
hole-and-slot, circuit parameters, **6**, 463
magnetron, **6**, 11
number of, **6**, 107, 472
open, **6**, 471, 477
side, **6**, 49
admittance, **6**, 56
composite shape, **6**, 62
cylindrical, **6**, 59
equivalent network, **6**, 52
rectangular-slot, **6**, 57
single, equivalent circuit, **6**, 461, 466
tube, external, SD-835, **7**, 379
vane-type, circuit parameters, **6**, 462
Responder, **12**, 327
beacons (*see also* Beacon), **1**, 246; **3**, 6
Response transform, **18**, 30
Responsor, **3**, 387
Retarding field, space-charge tube, **7**, 138
Reverse magnetic field, core analysis, **5**, 605–607, 644
Reynolds number, **26**, 420
R-f bandwidth, radar, **3**, 368
R-f components, **1**, 391–432
beacon, **3**, 125–148
radar, **1**, 391–432; **9**, 6
R-f detector, **22**, 259
R-f discharges, similarity principle, **14**, 181
spectrograms, **14**, 148
R-f envelope, indicator, **21**, 663
viewer, **5**, 706; **11**, 193, 408, 455–468; **16**, 97, 373
crystal, **11**, 458
detector for, **11**, 459–461
R-f filter (*see* Filter, r-f)
R-f head, **1**, 419–432; **23**, 421–429; **26**, 73
heat removal from, **1**, 421
test points in, **1**, 424
R-f line, breakdown in, **6**, 738
R-f oscilloscope, **11**, 408, 455, 467–469
R-f output, detection of, magnetron, **6**, 732
R-f package, antenna mount, **26**, 73
R-f parts, mounting, **1**, 419–432
R-f patterns, π-mode, **6**, 470
R-f phase measurements, **11**, 898–900, 915–922
R-f power measurement, **3**, 338
R-f preselection, **24**, 10
R-f rotary joint, **26**, 73, 141
mode-absorber waveguide, **26**, 141
R-f source, modulation of, **11**, 500
R-f switch, **1**, 295; **3**, 148; **16**, 369; **26**, 53, 58, 191
R-f test equipment, **23**, 277–304
coupling to receiver, **23**, 296–300
R-f wobble joint, **26**, 69
R-gate, **20**, 233
RHI (range-height indicator), **1**, 172, 545–547; **2**, 36, 210; **13**, 630, 635–636; **22**, 15, 20, 26, 518
for AN/TPS-10, **2**, 216
-E-scope, hybrid, **22**, 534–538
precise, **22**, 527
presentation, **2**, 217
10-cm height finder, **2**, 219
Rhumb line, **4**, 3
Riccati equation, **13**, 147
numerical integration, **13**, 177
Rieke diagram, **1**, 339; **3**, 257–259; **6**, 40, 178–187, 317, 327, 733; **7**, 405, 414–417; **9**, 83; **11**, 31; **16**, 203, 211
experimental, **7**, 432
practical, **7**, 421
Right-triangle solution, squaring method, **21**, 138
Ring-around, **3**, 78, 116
Ring circuit, **19**, 141
3.33 cm, dimensions, **14**, 359
duplexer, **14**, 357
modulator, **19**, 409
waveguide junction, **8**, 308–311
Ring counters, **19**, 603
thyratron, **19**, 612–614
Ring source, **12**, 348
Ripple, peak-to-peak, **16**, 321
Ripple theory of sea echo, **13**, 494
Ripples, **13**, 487
Roberts crystal coupling circuit, **15**, 223–225
Robinson scanner, **2**, 222
Robinson scanning feed, **26**, 45–55
power absorber for, **26**, 47
Roots, as circuit operation, **21**, 120, 121
pairs of, product of all sums, **25**, 335–336
Rosebud, AN/APN-19, **3**, 408–419
Rossby distribution of eddy viscosity, **13**, 215

Rossby equivalent-potential-temperature diagram, **13**, 188, 200, 201
Rotary actuators, **17**, 495–497
Rotary inductors (*see* D-c Selsyn; Magnesyn; Resolver; Synchro; Telegon)
Rotary joint (*see* Joint)
Rotary probe, **6**, 710
Rotary relays, **17**, 483–488
Rotary spark gap (*see* Spark gap)
Rotating-wave hypothesis, **6**, 219, 282–287
Rough surfaces, and reflection coefficient (*see also* Reflection coefficient), **13**, 411, 423–425, 434
  and time variation of reflecting properties, **13**, 434
Roughness length, **13**, 217
R-scope, **1**, 165
R-sweep, **20**, 233; **22**, 17
RT switch (anti-TR), **16**, 10
Rubber, cyclized, **26**, 371
Rupture modulus, **26**, 384

S

Saddle points, **13**, 90, 92
Salt-spray corrosion test, **9**, 130
Sampling circuits, **21**, 507–511
Sanaphant (waveform generator), **19**, 200–202
Sanatron (waveform generator), **19**, 200–202, 285; **21**, 653
  errors, **20**, 124
  precision, **20**, 124
  simple, **20**, 124
Sandstorms, echoes, **13**, 621
Sandwich (*see also* Radome), asymmetrical, experimental results, **26**, 333
  beam flexure, **26**, 397
  bending, **26**, 395
    simple, **26**, 399
  construction, **1**, 316
    high dielectric constant, reflection of, **26**, 327
    honeycomb grid, **26**, 379
    material, **26**, 407
    thickness, effect on reflection, at parallel polarization, **26**, 314
      at perpendicular polarization, **26**, 312
      optimum, **26**, 279, 280, 315
Sandwich, construction, thickness, tolerances, **26**, 319
      dielectric-constant, **26**, 320
    wet lay-up, single-stage, **26**, 380
      two-stage, **26**, 382
  lossless, at arbitrary incidence, **26**, 308–312
    at normal incidence, **26**, 362
    symmetrical, **26**, 308
    thin skin, **26**, 312–322
  lossy, power-transmission coefficient, **26**, 284
    transmission of, **26**, 328
  mechanical properties, **26**, 395–406
  panel (*see* Panel)
  plane-lossy sheet, **26**, 283
  radomes, depth/span ratio, **26**, 398
    general, **26**, 272–276
    normal-incidence, electrical design, **26**, 277–283
      symmetrical, **26**, 279, 280
  reflection, **26**, 306, 322–327, 360–365
  reflection contour, **26**, 309
  representative, mechanical properties, **26**, 404
  shear, **26**, 395
  simple bending, **26**, 399
  skins (*see also* Skin), experimental results on transmission, cotton fabric, **26**, 337
      Fiber-A, **26**, 337
    thickness tolerances, **26**, 320
  spacers, **26**, 273
  symmetrical, **26**, 278
  tension test, normal, **26**, 404
  test jig, **26**, 400
  thin-skinned, experimental results, **26**, 330
    tolerances, **26**, 319
  transmission, **26**, 306–340, 360–365
    experimental methods, **26**, 329–338
    general considerations, **26**, 306
      losses, theory, **26**, 364
  unsymmetrical, **26**, 263, 275
Saturated vapor, **13**, 182, 183
Saturation, adiabatic lapse rate, **13**, 194, 279
  curves, **13**, 184
  magnetic, **18**, 350
  mixing ratio, **13**, 185, 188
  of reactor core, **5**, 364, 370

Saturation, specific humidity, **13**, 185, 188
and threshold signals, **24**, 302
vapor pressure, **13**, 183
Sawtooth, current, linear, **22**, 357
waveform, **22**, 362
generator (*see* Generator)
voltage, **20**, 114–135
Miller rundown, **22**, 135, 377
Scalar potential, diffraction region, **13**, 65
Scale, change, as circuit operation, **21**, 61
coordination by frequency division, **20**, 153–155
factors, characteristic, **6**, 416, 441
indicator, **1**, 162
magnetron, **6**, 448
markers, indicator, **1**, 163
Scale-of-ten circuit, **19**, 611
Scale-of-two circuit, **1**, 497, 499; **19**, 162, 164, 187, 603–612; **22**, 126
high-speed, **19**, 607
thyratron, **19**, 612
Scaling circuits, **9**, 87; **19**, 164
Scaling theorems, cavity, **11**, 308
Scan, B-, **22**, 384
C-, **22**, 384, 401
circular, **1**, 281
complex, **1**, 281; **26**, 8
conical, **1**, 188, 205, 281; **3**, 56; **13**, 440; **20**, 367, 368; **22**, 23, 220; **23**, 380; **26**, 7, 62, 66, 171, 184
helical, **1**, 281; **22**, 12; **26**, 8
horizon, **1**, 281; **26**, 7
oscillating beavertail, **26**, 97
Palmer, **1**, 282; **26**, 8, 66
sector, **1**, 199, 281; **26**, 7, 168, 174, 175, 177, 180, 183, 200, 208, 233
simple, **1**, 280, 281; **26**, 7
spiral, **1**, 281; **22**, 12; **26**, 8, 66, 183
system, rapid, **2**, 187
television, **22**, 384
types, **26**, 7
V-beam, **22**, 12
Scanner (*see also* Radar), **1**, 271; **26**, 3–14
airborne, **26**, 155–193, 205–210
installation, **1**, 312–313
AN/APQ-7, **1**, 291–295
AN/APS-10, **1**, 288
balance, **26**, 185
common elements, **26**, 5–10
control mechanisms, **26**, 211–238
Scanner, control mechanisms, accuracy, **26**, 228
data-transmission methods, **1**, 682–713
electrical, **1**, 291–304
elevation, mechanism, **26**, 181
GEI, radome, **26**, 435
gusts, effect on, **26**, 164
installation, **2**, 161–165
long-range ground-radar, **1**, 287
mechanical, **1**, 282–291
Robinson, **2**, 222
spiral, **1**, 290
stabilization of (*see* Stabilization; Stabilizer)
surface-based, installation, **1**, 313–314
weight, **1**, 283
worm gears, **26**, 227
Scanning, **24**, 20, 241–246
effect on beacon response, **3**, 113
factor, **24**, 239
feed, electrical, **26**, 45–61
mechanical, **26**, 61–69
nutating, **26**, 64
Robinson, **26**, 45–55
frequency, **24**, 244
loss, **1**, 43; **2**, 19, 214; **3**, 34, 73; **26**, 71
effect on σ, **13**, 471
modulation, **1**, 136
patterns, radar, **1**, 280–282
rate, **1**, 116–121; **2**, 214
azimuth, choice of, **1**, 599
types, **2**, 155
signal fluctuations due to, **1**, 644–646
techniques, **2**, 203
types, **2**, 155
Scatterband, beacon-transmitter, **3**, 366
Scatterers, fluctuation from finite number, **13**, 515, 554
Scattering, and absorption by particles, **13**, 23
by antennas, **8**, 317–333
approximate formula, **13**, 463
by atmospheric irregularities, **13**, 317, 600
and attenuation, atmospheric, **13**, 22–26
in backward direction, **13**, 455
coefficient, **10**, 107
cylinder, **13**, 459
sphere, **13**, 448
coherent (*see* Coherent scattering)

Scattering, cross section (*see also* Cross section; Radar cross section), **1**, 21, 64; **12**, 5, 42, 468
equivalent sphere, **12**, 5
description in dissipative guide, **10**, 27
and diffraction, **12**, 129–168
by earth's surface (*see* Reflection coefficient)
effects, **2**, 22
ellipsoid, **13**, 464
elliptic-paraboloid, **13**, 464
flat-plate, **13**, 8
functions for spherical particles, **13**, 611
gain function, **12**, 590
general formula, **13**, 454
geometrical optics in, **13**, 465–468
matrix (*see* Matrix, scattering)
multiple, **12**, 588
paraboloid, of revolution, **13**, 464
pattern, gain of, **12**, 468
propagation, **3**, 53
quadric surfaces, **13**, 463
sphere, **13**, 7, 445
treated by reciprocity theorem, **13**, 693–698
Schwartz inequality, **12**, 177; **25**, 61
Schwartz-Christoffel transformation, **10**, 155
Schwarzschild antenna, **1**, 295–298; **26**, 55–61
Schwinger reverse-coupling directional coupler, **8**, 312
Scintillation, **13**, 302, 305, 306, 324, 335, 339, 350, 389
Scotch yoke, **21**, 117
Scotopic, definition, **22**, 659
Screen, absorbing, **12**, 560
cathode-ray tube (*see* Cathode-ray tube)
circuit, effect of impedance in, **18**, 88
noise current, space-charge tube, **7**, 109, 121
reflectors, **12**, 449
resistor current stabilizing effect, **18**, 92
transadmittance, space-charge tube, **7**, 109
transmission coefficient, space-charge tube, **7**, 109
Screw tuners, **8**, 181
Screws, general-susceptance, **9**, 499–507
Sea, breeze, **13**, 264–266, 370
definition, **13**, 486
return, **1**, 92
alleviation, **2**, 112–115
polarization, **2**, 113
scales, **13**, 489
Sealing of rotating shafts, **26**, 140
Sealol rotary seal, **9**, 142
Seals, glass-to-Kovar, **6**, 677, 681
metal-to-glass, **6**, 676
Search, circuits, automatic, **20**, 278
and early-warning set, **26**, 81
lighting, **24**, 245
radars, high-resolution, in 1-cm band, **26**, 142
Seasonal effects, **13**, 338, 339, 343, 345, 351, 368, 370
in Irish Sea, **13**, 324
in Massachusetts Bay, **13**, 321
Secant, as circuit function, approximation, **21**, 102
inverse, **21**, 119
"Second-chance" feature, transitron trigger, **16**, 338
Second-probability distribution, **13**, 556
in power, **13**, 557
for random scatterers plus steady signal, **13**, 561
Sector, blanking, **12**, 517
display, **1**, 168
movable, B-scope, **22**, 390
scan (*see* Scan)
-selecting synchro, **22**, 209
true, **22**, 509–514
Secular variation, effect, on correlation function, **13**, 567
of ground clutter on, **13**, 587
of sea echo on, **13**, 517–518, 578–581
See-saw waveform generator, **19**, 28
Selection, as circuit operation, **19**, 42
time, **19**, 12, 47
Selectivity, adjacent-channel, **3**, 79, 160
and pulse shape, **3**, 79–82
curve, maximally flat, **18**, 176
Selectron, dielectric constants, **26**, 409
loss tangents, **26**, 409
Selenium rectifiers (*see* Rectifiers)
Self-absorption in precipitation echoes, **13**, 613
Self-consistent fields, magnetron analysis, **6**, 265–274, 279

Self-synchronous timer, **1,** 438
Selsyn (*see also* Servo; Synchro), **1,** 487; **19,** 441; **20,** 394; **22,** 185; **26,** 9, 167
  d-c, **17,** 353–355
Semiconductors (*see also* Crystal), **16,** 48
  acceptor, **15,** 47
  addition agents, **15,** 67, 306–308, 364
  artificial barrier, **15,** 75
  band theory, **15,** 45–48
  barrier, capacitance, *C*, **15,** 24
      variable, effect of, **15,** 163–167
      variation with bias, **15,** 77
    formation, **15,** 70–77
    natural, **15,** 75
    nonlinear resistance of, **15,** 24
    penetration, effect of, **15,** 85, 87
  bulk resistance, **83**
  bulk-resistivity measurement, **15,** 304
  characteristic, d-c, **15,** 82–90
    voltage-current, **15,** 20–23
  composite, **15,** 54, 55
  conductivity, electrical, **15,** 53–61
  depletion layers, **15,** 90–97
  donators, **15,** 47
  double-layer, **15,** 53
  electron distribution, **15,** 48–51
  energy level, **16,** 48
  exhaustion layer, **15,** 78
  extrinsic, **15,** 47
  fluctuation effects, **15,** 87–90
  forbidden region, width, **15,** 64
  holes, **15,** 48
  image force, effect of, **15,** 86
    lowering of barrier, **15,** 85
  impurity, activation energies, **15,** 61
    additions, effect of, **15,** 64–67
    atoms, with collisions, **15,** 58
    centers, **16,** 49
    diffusion, **15,** 93–97
    level, **15,** 47
  intrinsic, **15,** 47
  -metal contact, **15,** 68–107
  mobility, **15,** 54
    carrier, **15,** 62
  N-type, **15,** 49
  preparation, **15,** 301–316
  properties, **15,** 45–67
  P-type, **15,** 49
  purification, **15,** 301–306
  rectification, physical description, **16,** 48–52
Semiconductors, reserve layer, **15,** 78
  relaxation effects, **15,** 100–107
  spreading resistance, **16,** 51, 91
  structure of barrier layer, **15,** 70–77
  surface levels, **15,** 101–107
  thermal-relaxation time, **15,** 254
  thermal resistance, **15,** 243, 245
  tunnel effect, **15,** 85, 87
  work functions, **15,** 51–53
    fluctuations, **15,** 86
Sensitivity-time control (*see* STC)
Separator circuits, **19,** 364
Sequencing circuits, **1,** 710; **19,** 604–614; **20,** 429–433
Series branches, transmission-line, **9,** 100–114
Series-element discontinuities, wave-guide, **8,** 198–206
Series gap switch, **1,** 377
Series peaking, **1,** 452
Series reactances on coaxial lines, **12,** 223–226
Series-resonant bypass condensers, **18,** 273
Series sources, addition with, **21,** 35
  subtraction with, **21,** 35
Series spark gap (*see* Spark gap)
Servo (servomechanism) (*see also* Resolver; Selsyn; Synchro; Telegon), **1,** 491; **2,** 9, 28; **21,** 23, 181, 208, 215; **22,** 187–195; **26,** 9, 199, 211–238
  acceleration, **21,** 356, 398
    -error constant, **25,** 145
      definition, **25,** 66
  accessory disturbance, **21,** 251
  accuracy, **21,** 320, 355–361
  AFC, **3,** 276–278
  airborne radar antenna-control, AN/APA-46, **21,** 434
  amplifier, **18,** 410; **20,** 438
  amplitude function, **21,** 267
  AN/APG-5 range follow-up, **21,** 468–471
  antihunt gain, **25,** 217
  attenuation-phase analysis, **25,** 163
    relationships, **25,** 169–196
  applications, **25,** 212–230
  back-emf constant, **25,** 104
  backlash, **21,** 359
  block diagrams, **21,** 232–234

Servo (servomechanism), clamped, with proportional control, **25**, 259–261
in computers, **21**, 23
continuous-control, **25**, 7
controlled by filter with clamping, **25**, 257–259
controllers, **21**, 253
automatic, **21**, 218
basic, **21**, 327
compound lead, **21**, 327
derivative error, **21**, 254, 322
integral, **21**, 253, 342
coulomb friction in motor, **26**, 220, 226
cycle control, closed-, **21**, 219
open-, **21**, 219
cycle system, closed-, **21**, 252
decibel-phase-angle diagrams, **25**, 179
definite correction, **25**, 7
derivative, **26**, 216, 218, 220–223
control, **25**, 197
design, history, **25**, 15
principles, **25**, 134–230, 340–368
RMS error, **25**, 308–339
specifications, **26**, 227–230
techniques, **21**, 221–224; **25**, 151–169
differential equation, **21**, 236, 239–258; **25**, 134, 152
-driven mount, **22**, 550
elements, **25**, 76–133
equalizer, bridged-T, **25**, 227
frequency response, **25**, 227
proportional-derivative, **25**, 199
equalization, integral, **25**, 203
with subsidiary loops, **25**, 208
equation, characteristic, **21**, 240
graphical methods, **21**, 262
higher-degree, **21**, 262
error, **26**, 212, 213, 215, 216, 222, 228
coefficients, **25**, 147
measuring element, **25**, 77, 95, 134
steady-state, **21**, 259, 260, 341
transient, correction, **21**, 340
velocity, **21**, 259
velocity-lag, **21**, 342, 343
E-transformer, **25**, 102
experimental techniques and measurements, **21**, 451–467
feedback system, **25**, 62–75
figures of merit, **21**, 320
filter theory, **25**, 24–30
Servo (servomechanism), fire-control systems, **26**, 237
frequency analysis, **21**, 266–318
frequency response, **21**, 267, 376
characteristics, **25**, 179
graphical plots, **21**, 270–292
friction, **21**, 357
gain function, **21**, 267
with quadratic factor, **21**, 287–290
gain margin, **21**, 298
general principles, **21**, 215
hydraulic, **21**, 398
input, typical, **25**, 138, 300–304
input function, **21**, 234, 235
input member, **26**, 217
inspection tests, **21**, 462
instrument, **21**, 219
linear system, **21**, 236–239
linearity error, independent, **21**, 363
loop, **26**, 211, 212
data smoothing in, **21**, 347
equalization of, **25**, 196–212
filtering in, **21**, 347
gain, **21**, 345, 375
inertia, **26**, 212
output disturbance, **25**, 145
phase angle, maximum, **25**, 199
transfer function, **25**, 134, 228
zero-static-error, **25**, 140
Magnesyn-Autosyn system, **17**, 350–351
mathematical background, **25**, 23–75
mechanical-design factors, **26**, 225–227
-motor, **26**, 212, 218–220
d-c, **25**, 103
multiloop systems, **25**, 73–75, 186
nonlinear, **21**, 219
nonlinearity in systems, **21**, 350–355
null devices, **25**, 101
Nyquist criterion, **25**, 70–72, 134, 136, 138
diagram, **25**, 66, 158, 359
operational methods, **21**, 226
operators, **21**, 230
parameters, best control for finite amplifications, **25**, 352–360
nondimensional, **21**, 244
relational, **21**, 244
performance, evaluation and correction, **21**, 319–361
specifications, **25**, 17

Servo (servomechanism), phase, advance, **21,** 322
function, **21,** 267
margin, **21,** 298
diagram, **21,** 317
decibel, **21,** 310, 328
system, minimum, **21,** 293
power, **21,** 219
PPI follow-up, **21,** 471–475
principles, **26,** 211–225
proportional control, **25,** 342–348
decibel-log-frequency diagram, **25,** 346
pulsed, **25,** 254–261
stability, **25,** 255–257
with pulsed input, **25,** 254–261
radar antenna-control, AN/APA-46, **21,** 434
range follow-up, **20,** 331
AN/APG-5, **21,** 468–471
range-tracking calibrator, **21,** 421
regeneration theory, **21,** 295
relay, **22,** 193
relay-type, **25,** 7
resolution, **21,** 363
resolver, **21,** 188, 475–480
resolving device, **22,** 185, 186
response curves, nondimensional, **21,** 247
RMS error, mathematical formation, **25,** 312–315
stability, region of, **25,** 316
transpose, definition, **25,** 313
ship's log system, **21,** 488
special systems, **21,** 468–489
speed, **26,** 229
speed-voltage, constant, **25,** 104
stability, **21,** 295, 305, 320
systems, **25,** 1–22
1-speed, **22,** 191
1- and 36-speed 60-cps, **22,** 189
400-cps, **22,** 191
equation, **21,** 258–264
tests, **21,** 462–467
three-differential, **25,** 137
two-differential, **25,** 135
with pulsed data, filters and, **25,** 231–261
with tachometer-feedback loop, decibel-log-frequency diagram, **25,** 357
theory, **21,** 225–265
Servo (servomechanism), thyratron, **21,** 468
velocity, **21,** 485
time derivatives, **26,** 216, 218, 220–223
torque-current, **25,** 104
torque-error constant, **25,** 146
transfer functions, attenuation-phase relationships, **25,** 169–196
transient analysis, **21,** 225–265
with two-phase motor, **25,** 224
uses, **21,** 217
variable-gain, **21,** 475
velocity, **20,** 250, 252; **21,** 199, 205, 220, 480–489
with a-c amplifier, **21,** 487
error coefficient, **21,** 463
constant, **25,** 65, 145
lag, **21,** 463
with *RC* feedback, **21,** 487
with velocity memory, **20,** 449
voltage regulators, **21,** 218, 235
weighting function, **25,** 12, 30–40
and frequency-response function, **25,** 48–50
weighting sequence, **25,** 232–233
SFF control circuit (flip-flop), **23,** 71–74
Shadow effect in sea echo, **13,** 493, 522
Shadow region, **13,** 17
Shaft, rotating, sealing, **26,** 140
rotation, output voltage proportional to tangent, **22,** 212
resistance variation proportional to square, **22,** 204
voltage proportional, to reciprocal, **22,** 205
to secant, **22,** 205
Shafts, two, synchronizing rotation, **22,** 222
Shear, **13,** 232, 234, 248, 250, 271
in stable equilibrium, **13,** 234–237
Shearing stratification, **13,** 235, 248, 300
variables governing, **13,** 235
Sheet (*see also* Plane lossless sheets; Plane lossy sheet), attenuation in, **26,** 291
dielectric, quarter-wavelength, **26,** 273
reflection by, **26,** 354–360
thin, nonresonant, **9,** 218–220
reflections from, **9,** 220
in resonant mount, **9,** 220–222
transmission by, **26,** 354–360
Shielding, beacon, **3,** 350

Shielding, CRT, **22**, 77
magnetic, **22**, 555–558
by masts, **3**, 444
in measurements, **5**, 688
transformer, **17**, 144, 166–167
Shields in transformer coils, **17**, 144
Ship, detection by radar, **2**, 112
roll and pitch, **26**, 104
Shock mounting beacon, **3**, 360
Loran, **4**, 26
Shock tests, relay, **17**, 504–505, 510–517
Shoran, **2**, 281–284; **3**, 17, 426–433; **4**, 9; **20**, 30, 157, 159, 161
accuracy, **2**, 284
AN/APN-3, **3**, 426–433
equipment, airborne station, **2**, 282
ground station, **2**, 281–283
Short-line effects, magnetron tuning, **6**, 322
Short-time-constant circuit, double, for single overshoot, **23**, 526
Shot noise (*see* Noise)
Showers, in frontal systems, **13**, 633
in unstable air masses, **13**, 632
Shunt, element discontinuities, waveguide, **8**, 198–206
magnetic, **22**, 106
peaking (*see* Peaking, shunt)
reactances, cavity formed by, **8**, 182–186
diaphragms as, **8**, 163–179
waveguide, **8**, 163
susceptance elements, transmission-line, **9**, 93
Shutters, harmonic, **16**, 174–178
Side lobes, **1**, 272; **12**, 176; **26**, 250
versus illumination, **12**, 179, 187, 195
Side-outlet T, **11**, 516–522
Sideband, **24**, 5, 14
harmonic, frequency conversion, **15**, 112
wrong-sideband operation, **23**, 52, 53
Sign convention for angles, **13**, 38, 116
Signal, balanced circuits, **19**, 393
and carrier-balanced circuits, **19**, 394
continuous-wave, **24**, 3–17
devices for producing, **23**, 306–323
discernibility, **22**, 28–38
discrimination, **22**, 28–34
distortion, error, **23**, 41
effect of noise on, **23**, 210
Signal, effects during, **23**, 184
effects following, **23**, 187
fluctuations due to scanning, **1**, 644–646
generator, 3000-Mc/sec region, **11**, 247–253
24,000-Mc/sec region, **11**, 265–270
antenna measurement, **12**, 594
beacon, **3**, 333
calibration, **11**, 245
f-m, **23**, 286–290
with magic T, **11**, 236
microwave, **11**, 221–281
power available, **24**, 99
pulse-modulated, **23**, 283–286
pulsed, **11**, 228
pulsed-lighthouse-tube, **11**, 253–259
pulsed-off, **11**, 229
r-f leakage, **11**, 240–243
simple, **11**, 235
swept-frequency, **18**, 301–306; **23**, 306
test sets, **23**, 278
accuracy, **23**, 290
TGS-5BL, **11**, 247–253
TS-147, **11**, 259–264
TS-155, **11**, 253–259
and index, superposition of, **20**, 195–198
intensity, CRT indicator, **3**, 378
large, ability to handle, **23**, 605
level, average, **13**, 304
over desert, **13**, 350
versus duct height, **13**, 309–312
for Flathead Lake, **13**, 335
in Irish Sea, **13**, 323
over land, range of variation, **13**, 340, 343, 349
for nonoptical versus optical paths, **13**, 351
and substandard layers, **13**, 302, 303
and duct height, **13**, 306, 309–312
wavelength comparison, experimental, **13**, 310–312
maximum, **13**, 323, 352
midday, seasonal drifts in, **13**, 338
loss caused by MTI, **1**, 651
minimum, detectable, **1**, 28–47; **16**, 10, 21–24; **18**, 496; **22**, 30

Signal, minimum, discernible, **1**, 34; **2**, 16; **3**, 34; **23**, 292
observable, **2**, 20
mixing, **22**, 160
-modulation threshold, theoretical derivation, **24**, 278–288
-to-noise, discrimination, **22**, 14
ratio, **3**, 34; **6**, 388, 394; **7**, 257; **22**, 28
-plate modulation, **19**, 714
power, **24**, 176–179
presentation, **5**, 662–667
time, **24**, 230–232
and human memory time, **24**, 231
pulsed, **24**, 18–32
resolution, **22**, 28–38
source, **23**, 80
special, introduction of, **23**, 232
strong, fluctuation compression, **23**, 582
suppression by noise, **23**, 211
tangential, **23**, 292, 456
threshold, **24**, 33–63, 149–151
in electronic interference, **24**, 335–366
in noise-modulated c-w interference, **24**, 353–358
in pulsed interference, **24**, 356–366
in unmodulated c-w interference, **24**, 335–353
types, over land, **13**, 337, 342
over water, **13**, 301–307
weak, detectability, **18**, 615
sensitivity to, **23**, 604
Silica-gel reservoirs, **14**, 220
Silicon, **23**, 11
addition agents, **15**, 306–308
characteristic constants, **15**, 61
crystal, -mixer performance, effect of d-c bias, **15**, 34
rectifiers, **11**, 498; **15**, 8
etching, **15**, 314–316
heat treatment, **15**, 314–316
photoelectric effect, **15**, 392
polishing, **15**, 314–316
processing for low-level detectors, **15**, 358
purification, **15**, 301–304
Silver plating, **26**, 142
Silverstat (relay), **21**, 428
Similarity principle (*see* Principle of similarity)
Similitude principle, **9**, 87; **11**, 308
Sine, -cosine system, time-modulated, relay-radar, **20**, 417
inverse, as circuit function, **21**, 119
-wave carriers, **22**, 195, 207–210
-comparator amplifiers, **19**, 355
peak comparison, **19**, 350–352
zero comparison, **19**, 352–355
Single-scale index circuits, **20**, 111–141
Single-switch multiple-network circuit, **5**, 492
Single-tuned circuit, **1**, 445; **23**, 103
and transitionally coupled double-tuned circuit, comparison, **23**, 171
Sinusoidal, condensers, **22**, 218, 472
frequency dividers, **19**, 556–566
frequency multipliers, **19**, 545–556
potentiometers, **21**, 162; **22**, 202–204, 472
sequences, pulsed-data filters, **25**, 236–238
waveform generators, **19**, 101–158
electromechanical, **19**, 125
Sinusoids, phase-modulated, pulse representation, **20**, 442
polyphase, **19**, 131–140
pulsed, **19**, 148–158
pulsed, **19**, 703
Siting, impedance-measurement apparatus, **12**, 548
primary-pattern apparatus, **12**, 560
secondary-pattern apparatus, **12**, 574–578
Six-terminal waveguide structures, **10**, 336–372
Skiatron, **1**, 220, 483; **22**, 6
Skin, depth, **1**, 406; **5**, 659; **8**, 46; **9**, 26, 45; **11**, 296
in metallic conductors at microwave frequencies, **9**, 127
of various metals, **8**, 47
effect at metal-semiconductor contact, **15**, 421–426
modified half-wavelength, **26**, 322–327
reflection from, **26**, 252
resin, effect on transmission, **26**, 332
thickness, **26**, 315
effect of, **26**, 317
effective, **12**, 534; **26**, 281
tolerances, **26**, 320
in dielectric constant, **26**, 321

Skip distance, **4**, 130
Skip effect, **13**, 359, 360, 370–371
Sky waves, **4**, 60, 91, 95
components, propagation, **4**, 151
field intensity, **4**, 121
phenomena, **4**, 108
synchronized Loran (*see* SS Loran)
Skyline effect on beacon, **3**, 439
Slant range, **4**, 6; **22**, 13, 14
Slide, multiplier, computer, **27**, 4, 12–14
terminal, computer, **27**, 44, 166
Sliding-vane attenuator, **14**, 383
Slit, inductive, **8**, 164–166
thick capacitive, **8**, 200
Slot, array, axially symmetrical, **12**, 305
conductance G_L, magnetron anode, **6**, 407
dumbbell-shaped, **12**, 296
longitudinal, **12**, 291–297
nonradiating, **12**, 287
probe-fed, **12**, 299–301
radiators, impedance in waveguide, **12**, 287–299
resonant, **12**, 291–299
transverse, **12**, 291, 292
waves, **11**, 482
width, relative, magnetron design, **6**, 442
Slotted guide, wavelength in, **11**, 481
Slotted line, characteristic impedance, **11**, 480
Slotted section, **11**, 478–483, 925; **14**, 378
design, **11**, 488–496
Slow-sweep generator, **16**, 314, 316, 326
Smearer circuit, **18**, 128
Smith impedance chart, **6**, 318, 707; **8**, 73, 226; **9**, 60–67; **10**, 10; **12**, 29
loss contours, **14**, 283
Smoke, echoes from, **13**, 593, 621
Snell's law, **12**, 123–125; **13**, 6, 15, 19, 45, 46, 391
Snow, attenuation, **13**, 688
echoes from, **13**, 620
Solar heating, **13**, 193, 220–222, 232, 259
Solar radiation, **13**, 220, 254
Soldering, **6**, 662–670
hard, **9**, 123
silver, **9**, 123
soft, **9**, 123
technique, **9**, 123
Solenoids, **17**, 495–497
Sommerfield integral, **13**, 65
Sonde, wired (*see* Wired sonde)
Sonne, **2**, 47–50
beacon, **4**, 4
Sounding, instruments, future requirements, **13**, 292
methods, **13**, 282
problems in execution, **13**, 291
representation and description of, **13**, 202–208
synthetic, **13**, 298, 300, 309
Space arrays, regular, **12**, 104–106
Space cams, **21**, 59
Space charge, **6**, 24, 340, 391
as circuit element, **6**, 288–338
configuration, **6**, 27
CRT, **22**, 56
devices, **7**, 97
as microwave amplifiers, **7**, 146–169
theory of h-f, **7**, 97–145
klystron, **7**, 209–217, 372
density, **7**, 354–357
invariance of, **7**, 372
transit-time effects, **7**, 367–373
limitation, **6**, 211, 412, 418
nonlinearity, **6**, 313
properties, **6**, 316, 329–338
Space factors, **12**, 89
Space-interference-pattern changes as cause of echo fluctuations, **13**, 535–538
Spark gap, **5**, 175
1B22, 1B29, 1B31, 1B34, 1B41, 1B42, 1B45, 1B49, **5**, 321, 322, 324, 328
anode buildup, **5**, 320
cathode erosion, **5**, 317, 320
fixed, **5**, 294–335
aluminum-cathode, **5**, 318–327
breakdown voltage, **5**, 296
cathode and anode erosion, **5**, 319–321
design, general considerations, **5**, 316–318
dissipation, **5**, 324–326, 331
electrode, **5**, 319–321
electrode material, **5**, 317
Fe-I, **5**, 328
gap spacing, **5**, 320
gas, choice, **5**, 316
pressure, **5**, 320
geometry, determination, **5**, 318

Spark gap, fixed, ionization, residual, **5**, 297
mercury-cathode, **5**, 295, 303, 329
iron-sponge, **5**, 327–332
reverse-current effects, **5**, 331
static- and dynamic-breakdown voltages, **5**, 296
three-electrode, **5**, 332–335
hydrogen-filled, **5**, 335
two-gap operation, **5**, 302
voltage drop across three, **5**, 325
number versus voltage range, **5**, 300–302
prefire, **5**, 297
rotary, **1**, 381; **5**, 273–294
breakdown field, **5**, 291
breakdown time, **5**, 275
efficiency, **5**, 289
electrical considerations in design, **5**, 276–283
electrodes, fixed, **5**, 276
material, **5**, 280
moving, **5**, 276
number of, **5**, 282
gap restriking, **5**, 279
gas, **5**, 280
geometry, **5**, 276–280
holes in insulating disk, **5**, 287
mechanical design considerations, **5**, 283–289
motor and housing, **5**, 285
opposing-pin, **5**, 287
parallel-pin, **5**, 287
performance, resonant charging, **5**, 291
radial-pin, **5**, 287
rectifying, **5**, 476
rotor, size, **5**, 283
types, **5**, 286–289
series (*see also* fixed, above), **5**, 274
division of voltage across, **5**, 312–315
general operating characteristics, **5**, 296–304
two- and three-gap operation, **5**, 302–303
V_{max}, V_{min}, definition, **5**, 297
V_{start}, definition, **5**, 297
voltage range, versus number of gaps, **5**, 300–302
WX3226, **5**, 299, 320–322
WX3240, **5**, 320–322
Spatial pattern measurements, **12**, 563
Spectral density (random process), **25**, 278–288
and autocorrelation function of filtered signal, **25**, 288–291
calculation, **25**, 284–286
and correlation functions, **25**, 283–288
definition, **25**, 278
error integration, **25**, 323–325
reduction, **25**, 317–321
experimental data, **25**, 282–283
input and noise, **25**, 294–295
matrix, transpose of, **25**, 313
normalized, **25**, 280
random series, **25**, 281–282
stationary random process, **25**, 280–281
Spectral distribution of pulsed f-m signal, **23**, 442
Spectroscopy, microwave, **13**, 25
Spectrum, analyzer, **3**, 335; **5**, 706; **11**, 408, 925; **14**, 380; **16**, 347, 373; **23**, 294
beat-frequency indications, **11**, 395
design considerations, **11**, 416–423
for frequency measurement, **11**, 393–395
low-frequency, using microwave oscillators, **11**, 441–446
measurements with, **11**, 448–455
operation theory of, **11**, 411–416
principle, other instruments using, **11**, 446
principles and design, **11**, 409–423
representative, **11**, 423–448
RP-347, **11**, 443
RP-392-K, **11**, 443
sensitivity, **11**, 420
stability, **11**, 422
TS-148/UP, **11**, 409, 429–434
TSK-2SE, **11**, 435, 440
TSK-3RL, **11**, 411, 423–429
TSS-4SE, **11**, 434–439
TSS-4SF, **11**, 411
TSX-4SE, **11**, 416, 429, 435, 439
distribution of pulses, **5**, 718
frequency (*see* Frequency spectrum)
image, **11**, 415, 419
interpretation, **11**, 448
magnetron, **3**, 260
noise, **16**, 236; **18**, 500; **24**, 5, 39–42, 151–161

Spectrum, noise, determination, **24**, 157
for f-m receiver, **24**, 369–374
Gaussian, **24**, 59
after nonlinear device, **24**, 56–63
power, **24**, 40, 41
signal plus, for f-m receiver, **24**, 374–380
strongly clipped, **24**, 57
thermal, **24**, 64–66, 69–71
white, **24**, 42
power, **11**, 412
prediction, by equivalent network, **6**, 54
by field theory, **6**, 66
pulse, **6**, 83, 325, 345, 389, 735; **11**, 409, 449
Specular cross section, **1**, 69
Speech transmission on beacon systems, **3**, 228–236
Speed, control, motor, electronic, **1**, 578
motor-alternator sets, **1**, 574
tuned-circuit, **1**, 577
by voltage generator, **1**, 574
governors, **17**, 392–395
carbon-pile, **1**, 578
measurements, **20**, 16–24
accuracy, **20**, 32
coherence, external, **20**, 20
internal, **20**, 18
c-w system, **20**, 16–18
regulator, for aircraft motor-alternators, **1**, 571–578
motor-, Lee, **1**, 574
Spheres, scattering from, **13**, 445–453, 608–613
Spherical aberration, **22**, 44
Spherical functions, **10**, 53
Spherical Hankel functions, amplitude, **10**, 54
Spherical waves, isotropic, **12**, 78
in terms of cylindrical waves, **13**, 61
Spheroid, oblate, **4**, 170
Spike, **15**, 237; **16**, 8, 97, 98, 300; **23**, 8, 10
-blanking-circuit, **16**, 300, 314
energy, **14**, 143; **16**, 99, 111, 174, 373
cancellation circuit for measurement, **14**, 409
effect of gas-filling, **14**, 167
measurements, **14**, 409
and flat, relative importance in burnout, **15**, 237
Spike, and flat power, separation of, **14**, 411
leakage energy, **14**, 140, 235
direct-coupled, **14**, 237
effect on, of gap length, **14**, 170
of n_o, **14**, 166
of repetition rate, **14**, 167
for various gap spacings, **14**, 236
W_s for various gases, **14**, 168
linear theory, **14**, 156
microwave gas discharge, **14**, 153
nonlinear theory, **14**, 162
oscillogram, **14**, 164
-pressure characteristic for 1B26 TR tube, **14**, 169
TR tube, **23**, 42
Spiral gear, differential with, **27**, 9
Splash-proof beacon packaging, **3**, 359
Spur-gear differential, **27**, 7–8
Sputtering, keep-alive electrode, **14**, 210
Square-root as circuit function, **21**, 103
circuits, **19**, 678
-extracting circuits, **19**, 686–691
operator, **27**, 197–198
Squarer, multigrid, **19**, 682
Squares, as circuit function, **21**, 55
Squaring cam, **27**, 21–23
Squaring circuits, **19**, 166, 348, 678–686
Squeeze section, **11**, 507–510, 925
Squegging oscillator, **3**, 392
Squint, **12**, 245, 438
error, **3**, 375–377
Squinting, **2**, 204
Squirted flux, **5**, 530
Stabilization, antenna, **2**, 156–160; **3**, 374; **12**, 508; **26**, 178, 194–210
accuracy requirements, **26**, 201–205
airborne, **1**, 305–308; **26**, 13, 195–210
basic types, **26**, 105–116
deck-tilt correction, **26**, 108, 463–468
instrumentation, **26**, 116–117
level angle, **26**, 469
line-of-sight, **26**, 195–199, 207
pitch, **26**, 198
pitch angle, **26**, 463
roll, **26**, 110, 195, 199, 205, 234
roll angle, **26**, 463
shipborne, **1**, 308–312; **26**, 13, 104–128, 463–472
cross-level angle, **26**, 469
cross-level orders, **26**, 113

Stabilization, antenna, shipborne, train angle, **26,** 107
train axis, **26,** 105
stable-base, **26,** 195
stable element, **26,** 105, 113, 116, 196
stable vertical, **26,** 113, 116, 128, 196, 197, 206, 217, 234
tolerances in, **26,** 201
train order, **26,** 463
types, **26,** 195–210
azimuth, **2,** 149
cavity, **6,** 747, 758, 769, 773, 790
factor, frequency, **11,** 62
frequency system, i-f, **11,** 69–75
results and limitations, **11,** 75–78
magnet, **6,** 550
resonant, frequency division using, **19,** 595–599
sawtooth, **22,** 399
shipborne navigational radar, **2,** 367–371
Stabilizer, airborne, errors in, **1,** 308
AN/APA-15, **1,** 306
frequency, **11,** 67
electronic, **11,** 67
line-of-sight, **1,** 306–308
magnetron, **6,** 406, 494, 622
roll, **1,** 306
stable-base, **1,** 306
Stagger damping (widebanding), **1,** 449
Stagger-tuned amplifier (*see* Amplifier)
Stagger-tuned circuits, **1,** 448
Stagger tuning, **18,** 166, 407
Standard deviation of fluctuation from random scatterers, **13,** 555
Standard Loran (*see also* Loran), **4,** 12, 56, 85
Standard pressure, **13,** 195
Standing waves, **1,** 391; **9,** 13–19
detector, 1.25-cm, **11,** 490
3.2-cm, **11,** 492, 494
coaxial, **11,** 496
continuously indicating, **11,** 511
high-power, **11,** 510
equipment for measuring, **23,** 295
fundamental relations, **11,** 475–478
measurements, **6,** 705–710; **11,** 333–336, 473–514; **12,** 548–550
apparatus, **11,** 503
at high power, **11,** 510
on lossless devices, **11,** 512–514
Standing waves, minimum, position of, **10,** 132
shift in, **11,** 338
pattern, **11,** 475
phase of, from cavity, **14,** 387
ratio, **6,** 707; **9,** 17, 63; **10,** 15, 132; **12,** 28, 545
direct measurement, **11,** 634
high, measurement, **11,** 505–507
power, **1,** 392; **12,** 28
voltage, **1,** 392; **9,** 17; **11,** 476; **12,** 28
and attenuation, **11,** 820
cavity, **11,** 335
with line attenuation, change in, **11,** 702
measurement, **12,** 547–549
TFX-30EC cavity, **11,** 335
waveguide, **8,** 62; **9,** 118
in waveguide, **8,** 61
Star chain, Gee, **4,** 80
Star grid generator, **27,** 250–299
for ballistic function in vacuum, **27,** 264–271
improvement of, **27,** 264–271
as multiplier, **27,** 256, 264
structural error, **27,** 277–283
Star linkage (*see also* Star grid generator), **27,** 37, 238, 256
Stars, twinkling, **13,** 532–533
waveguide junction, **8,** 455–459
Starting voltage, magnetron pulser, **6,** 370
Static, precipitation, **4,** 328, 344
Stationary phase, **13,** 99, 103
principle of, **12,** 119–122, 157
Statistical distribution of signal strength, **13,** 320
Statistical equilibrium, **18,** 517
STC (sensitivity time control) (*see also* Time-varied gain), **2,** 11, 13, 146; **23,** 251, 252, 374–377
removal of sea clutter by, **2,** 372
Steady-to-random ratio for ground clutter, **13,** 582
Steepest descent, method, **13,** 90, 98, 105, 106
path, **13,** 92
Step attenuator, **22,** 157
Step displacement (unit function), **21,** 235

Step-interpolation time modulation, **20,** 164
Stereophotography of sea echo, **13,** 490, 527
Sticking potential, **22,** 577, 629, 630
Stiction (static friction), **21,** 357
Stiffness, general evaluation, **26,** 383
  rating, **26,** 415, 416
Stokes lines, **13,** 73, 77
Stokes phenomenon, **13,** 71, 72, 91
Stokes's theorem, **7,** 83
Storage action intensity modulation, theory of, **19,** 708–713
Storage circuits, **19,** 615–619
Storage gain, **1,** 44
Storage tube, **20,** 99, 107
  applications, **19,** 707
  as computing devices, **19,** 708
  definition, **19,** 707
  deflection modulation, **19,** 713, 722–727
  as delay device, **1,** 631
    tests, **19,** 722–727
  memory device in pulse-operated computers, **19,** 708
  sensitive time discriminator using, **19,** 728
  synchronizing devices, **19,** 727
  time demodulator, **19,** 728
  time modulation, **19,** 499–500
  use to record randomly occurring high-speed transients, **19,** 708
Storm detection, **2,** 104
Storm echo, **1,** 81
Storm structure, **13,** 23, 623, 625, 627–640
Straight-line motion (computer), **27,** 29
  bar-linkage adder, **27,** 37, 41
Straight-line network charging, **1,** 383; **3,** 244
S-transform, **18,** 55
Stream function, **10,** 156
Strength, radome, general evaluation, **26,** 383
  rating, **26,** 415, 416
Strobe circuits, **19,** 364
Strobing, **24,** 253
Stroboscopic disk, **21,** 459
Strobotac speed measurement, **21,** 458
Structure factor for microwave absorption, **13,** 650, 662
Structures, radar signals from, **1,** 99
Stub, coaxial, broadband matching with, **9,** 332–335
  guide, **10,** 111
  parallel, **12,** 223–226
    broadband, **1,** 395; **8,** 194; **11,** 13
  right-angle, **9,** 176–179
  supports, **9,** 170–182
  T-, broadband, **9,** 173–176; **14,** 266
    supports, simple, **9,** 170–173
  tuners, **3,** 264; **8,** 195; **9,** 472–478
    sliding series, **9,** 464–466
    waveguide, **9,** 483–485
  universal, **9,** 179
    dimensions, **9,** 180
Sturm differential equation, **13,** 69
Styron, **26,** 372
Subcarrier, phase-shifted, **1,** 695
Subcarrier data transmission, **1,** 684
Subclutter visibility, **24,** 328
Subdominant terms, **13,** 73
Subsidence, **13,** 260
Subsidence inversion, **13,** 260–262
Substandard layer (*see* Layer)
Subtraction, in amplitude measurements, **19,** 696
  as circuit operation, **21,** 32, 35
  with mechanical devices, **21,** 39
  of pulse counts, **21,** 40
  with series sources, **21,** 35
  with synchros, **21,** 36
  by vacuum-tube circuits, **21,** 41
  voltage and current, **19,** 629
Successive approximation (computer), **27,** 81, 91–95, 98
  in design of function generators, **27,** 286–292
  in double three-bar-linkage design, **27,** 196, 197
  in terminal-harmonic design, **27,** 187
  with three-bar-linkage components, **27,** 174, 177, 180, 184
  in three-bar-linkage design, **27,** 129, 137–140, 143–146, 154, 177
Sum frequency, frequency conversion, **15,** 112
Sun as noise source, **11,** 272
Superheating, water-load, **11,** 195
Superheterodyne receiver (*see* Receiver)
Superposition, optical, of indicator scales, **1,** 218
  theorem, **8,** 87; **12,** 66; **18,** 20

Superrefraction, **1,** 55; **3,** 50
Superregeneration, microwave amplifier, **7,** 176
Superregenerative receiver (*see* Receiver)
Supersonic delay lines (*see also* Delay lines), **17,** 218–242
Superstandard layer (*see* Layer)
Surface, -to-air beacon systems, **3,** 21
-to-air search, **12,** 465
current, **13,** 455, 460, 473, 476
layer (*see* Layer)
region, propagation, **2,** 357–360
sea, nature of, **13,** 486–490
wave, **13,** 2, 3, 40, 66, 103, 109
Susceptance shunting matched line, **9,** 31
Sutton tube, soft, **14,** 36, 68
Sweep, amplifiers, for reactive loads, **22,** 356–383
calibrators, **14,** 419
Model B-8127, **21,** 659
Model C, **21,** 661
circular, **19,** 132, 704; **20,** 81, 99, 142, 168, 184, 341; **22,** 299
display, **20,** 161
SCR-584, **19,** 136, 559
condenser, **22,** 216, 398
delayed, **22,** 487
direction, **24,** 197–199
expanded, **19,** 698
exponential, **20,** 215
field, rotation, **22,** 425
generator (*see* Generator)
length, **22,** 14
linear, **22,** 356
range, **1,** 162; **22,** 8, 9, 14, 29
speed, **24,** 209, 211–222, 240
radar indicator, **3,** 377
start, distortions in, **22,** 354
-stopping circuit, **22,** 234, 399
time-base, **22,** 8
transformer, circular, **21,** 634
Sweeping-frequency beacon systems, frequency choice, **3,** 73
Switch, ATR (*see* ATR switch)
attenuator, **14,** 349
bidirectional, **19,** 49
carrier-controlled, **19,** 396–413
characteristics for hard-tube pulsers, **5,** 90–98
circuits (*see also* Clamp circuits), **19,** 370–381; **22,** 365, 380
Switch, coaxial-line, **9,** 528–533
double-triode, **19,** 375
bidirectional, **19,** 376
duplexing, requirements of, **14,** 4
electronic, **1,** 503–510; **22,** 128
four-diode, **19,** 374
gaseous-discharge, **5,** 10, 14, 175
half-wave, **19,** 514
limit, **21,** 403
line-type pulsers, **1,** 377–382; **5,** 273–354
nonlinear inductance as, **1,** 381
operation, typical, **5,** 298–300
pentode, **19,** 379
phototube, **22,** 398
pulser, **1,** 357
bidirectional, **5,** 418, 424
resistance, effect of, **5,** 269
reversing, "lazy man," **16,** 333
r-f, **1,** 295; **3,** 148; **16,** 369; **26,** 53, 58, 191
in antenna mount, **26,** 53, 191
RT (anti-TR), **16,** 10
self-stabilizing double-diode, **19,** 479
stepping, **17,** 493, 494
TR (*see* TR switch)
tube, **5,** 225
average power dissipated, **5,** 22, 92
bias voltage, cutoff, **5,** 99
cathode fatigue, **5,** 97
characteristics, affecting pulser design, **5,** 93–98
effect on pulser regulation, **5,** 108–118
triodes and tetrodes, **5,** 98–108
current, **5,** 92
current-voltage characteristic of nonlinear load, **5,** 110
effective resistance, **5,** 23
enclosed-gap types, **5,** 321, 322, 328, 333
hard-tube types, **5,** 95, 96
high-vacuum, for pulsers, **1,** 368
hydrogen-thyratron types, **5,** 340, 341
I_p-V_p curve, **5,** 111–118
oxide-coated cathode, **5,** 93, 95
power dissipation, **5,** 73, 104
pulse network, **3,** 242
pulse-plate current, **5,** 95
resistance, **5,** 78

Switch, tube, sparking, **5**, 93, 95
thoriated-tungsten-cathode, **5**, 93, 95
type N, **9**, 529
unidirectional, **5**, 342, 418, 423; **19**, 49
vacuum tubes as, **5**, 6, 7, 90–118
voltage drop, **5**, 22
waveguide, **9**, 533–539
Switching, demodulators using, **19**, 513–524
equipment, C-1, **4**, 261
Loran, **4**, 258–274
low-frequency, **4**, 271
UM, **4**, 265
mechanical, **22**, 229
Swivel joints, **9**, 433–438
Symbols, list, pulse generators, **5**, 723–728
Symmetric functions, sum, **25**, 337–338
Symmetrical waveguide structures, **10**, 109
Symmetry, *E*-plane, **10**, 111
H-plane, **10**, 111
operators, **8**, 414
waveguide-junction, **8**, 401–478
Synchro (*see also* Resolver; Selsyn; Servo), **1**, 487; **2**, 28; **17**, 310–345; **19**, 439–444; **21**, 49, 55, 364, 461; **22**, 185, 472; **25**, 78; **26**, 9, 167, 205, 223
3-phase, 2-phase output, **22**, 208
accuracy, **17**, 330–331
addition with, **21**, 36
angular accuracy, **19**, 442; **22**, 210
autosyn, **19**, 441
Bendix AY 120D, **19**, 498
capacitors, **17**, 314, 325–328
circuits for driving, **22**, 377–381
construction, **17**, 314–324
control motors, **17**, 321–323
control transformers, **17**, 314, 319–321, 325–326; **25**, 82
conversion, 3-phase to 2-phase, **19**, 444
damping resistors, **22**, 382
d-c, **17**, 386–387
level-setting, **19**, 454
definitions, **17**, 313–314, 329
and deflection coil, equivalent circuit, **22**, 382
deflection coil driven by, **22**, 381–383
differential, **26**, 9
generator, **17**, 314, 318–320, 326; **22**, 187
Synchro, -driven mount, **22**, 547
dual-speed, synchronizing circuit for, **25**, 84
equivalent circuit, **22**, 374
errors, **17**, 330–331; **22**, 194
functional classification, **17**, 311
generator, **17**, 313, 316–317; **22**, 185; **26**, 224
effect, **19**, 443
load capacities, **17**, 330
matching transformers, **17**, 340
modulator, and phase-sensitive detector, **19**, 446
using peak detector, **19**, 446
motor, **17**, 314, 316, 318, 321–323; **22**, 185
damping flywheel, **17**, 316, 318
mountings, **17**, 331–333
nomenclature, **17**, 310–313
-null index, **22**, 231
phase rotation, **17**, 338–339
pulsed oscillations for use with, **19**, 156
receiver, **26**, 224
resolvers, **19**, 444
two-phase, **26**, 209
reversed, **17**, 323
rotors, **17**, 314–315
sector-selecting, **22**, 209
sizes and weights, **17**, 312
specifications, **17**, 336–339
stator leakage inductance, **22**, 376
subtraction with, **21**, 36
systems, **20**, 393
generator-control transformer, **17**, 325–326
generator-motor, **17**, 324–325
multiple-scale, **19**, 443
parallel, coercion in, **25**, 88
two-speed, **17**, 327
theory, **17**, 314–324
time-phase shifts, **17**, 339
torque, **17**, 328–329
versus accuracy, **17**, 329
gradient, **17**, 329
transient response, **22**, 374–377
transmitter and repeater data system, **25**, 79
units for 115-volt, 60-cycle operation, **25**, 80
use of, in cathode-ray-tube sweep circuits, **17**, 343–345

Synchro, use of, with nonsinusoidal voltages, **17**, 343–345
with sinusoidal carriers, **19**, 444
zeroing, **17**, 331–336
Synchronization, **19**, 189
by automatic frequency tracking, **20**, 95–100
beacon, **3**, 387
external, **19**, 469
incremental-angle method, **1**, 689–695
internal, **19**, 469
jittered-pulse system, **1**, 693
phase-shift method, **1**, 695–701
precise, of random oscillators, **20**, 99
by PRF generator, **20**, 45
radar receiver, **1**, 518–524
radar relay, **1**, 711–713
remote control of, **20**, 46
by r-f pulse generator, **20**, 43
rotation of two shafts, **22**, 222
single-stage blocking-oscillator dividers, **19**, 586
in time measurements, **20**, 42–47
Synchronizer, **20**, 81–83, 87, 90, 424–426
AN/APS-10, **20**, 91–94, 169, 172, 248
automatic-frequency-tracking, **20**, 96
Loran, **4**, 67, 199, 213, 229, 234, 245
Model G, **21**, 658, 664; **22**, 271–275
radar, **20**, 71
radar-relay, **1**, 681
Synchronizing, circuit, dual-speed synchro, **25**, 84
storage-tube method, **19**, 727
Synchroscope, **1**, 164; **3**, 334; **5**, 662–665; **18**, 314; **21**, 641, 657, 659; **22**, 9
envelope viewer, **11**, 457
hum pickup, **22**, 266
input impedance, **5**, 670
Model 5, **21**, 602–611; **22**, 261–270
P4, **21**, 595–602, 663; **22**, 252–261
TS-28/UPN, **21**, 657
Synthesis by factoring, **18**, 179
System transform, **18**, 30

T

T (*see* specific types of T)
Tables and charts, Loran, methods of computing, **4**, 170–194
Tachometers, **17**, 374–376, 384; **21**, 370, 483; **22**, 225; **25**, 101
Tachometers, a-c drag-cup, **17**, 384
commutated condenser, **21**, 76, 86
condenser, **21**, 370
d-c, **17**, 374–376
electrical, **21**, 74
feedback, **20**, 359; **21**, 329–332
control, **25**, 348–360
gain, infinite, ideal case, **25**, 349–352
generator as, **22**, 219
hysteresis effects, **21**, 75
induction, **21**, 370
integrators using, **21**, 83
ripple, **21**, 462
test card, **21**, 458
Type B-44, **20**, 361
Tail-biting circuit, **5**, 133
Take-off (data transmitter), **26**, 167, 169
Tangent, as circuit function, **21**, 101
inverse, **21**, 119
linkage, **27**, 193–195
plane, **13**, 116
ray, **13**, 5, 6, 116
relation, network analysis, **10**, 121
Tangential signal, **23**, 292, 456
signal generator, **11**, 228
Tape wheels, **21**, 59
Tapers in coaxial line, **9**, 305–311
Targets, angular-position shift, **26**, 249
complex, **1**, 73, 75–81
fluctuations in echoes, **13**, 547
compound, **1**, 73, 81
coverage, **1**, 50–54
cross section under nonstandard refraction, **13**, 354, 473
extended surface, **1**, 85
indication, **20**, 326
indicator, automatic, **20**, 278
movement, **24**, 249–252
moving, response to, in clutter of various phases, **23**, 604
sensitivity of receivers to, **23**, 581
properties by radar measurements, **13**, 369
response, directional, **12**, 468–471
selection, **20**, 277, 278, 325
automatic, **20**, 326, 330–337
manual, **20**, 329
ships, effective height, **1**, 80
signal, obscuration of, **12**, 520
standard, **13**, 479
T-asymmetry, **11**, 532

Tchebyscheff arrays, **12**, 282–284
Tchebyscheff behavior in attenuation band, **9**, 593–597
Tchebyscheff characteristics, filter with, **9**, 696–706
Tchebyscheff pass-band behavior, **9**, 590–593
Tchebyscheff polynomials, **9**, 590
TE waves, **8**, 17
Teflon, **5**. 650
  connectors, **9**, 259
  dielectric beads, **9**, 257
  seals, **9**, 143
Telegon (synchro), **17**, 350–353; **20**, 394; **21**, 366, 367
  construction, **17**, 351
  theory of operation, **17**, 351–352
Telegraphers' equation, **9**, 9–11
Telemetering, **20**, 391–393
Teleplotter, **21**, 369
Teleran, **1**, 240
Teletorque, **19**, 441; **20**, 394; **22**, 185
Television, display, **22**, 406
  scan, **22**, 384
TE-mode (*see* Mode)
TEM waves, **8**, 17–30
  between coaxial cylinders, **8**, 23–25
  between parallel plates, **8**, 22
  spherical, **8**, 25
Temperature, coefficients, in addition operations, **21**, 33
    amplifier components, **18**, 390
    delay lines, **19**, 474
    Hg, **19**, 473
    H_2O, **19**, 473
  compensation, bolometer bridges, **11**, 103–105
    oscillator, **19**, 129
    with two thermistor disks, **11**, 108–118
  deficit, 10-per cent rule, **13**, 227, 228, 300
  excess, **13**, 220–222, 229, 231, 236, 237, 245–247
  gradients, **13**, 192
  and humidity in lower atmosphere, instruments to measure, **13**, 272–293
  inversion, **13**, 192, 238
    elevated (*see M*-inversion, elevated)
    height of, **13**, 241–244
    and *M*-gradient, **13**, 13, 192, 259
Temperature, inversion, nocturnal, **13**, 258
    summer, **13**, 259
    winter, **13**, 259
  -limited diodes, **16**, 109
  logarithmic distribution, **13**, 223
  potential, **13**, 194, 195, 200, 202
  -rise analysis, **21**, 673–679
  wet-bulb, **13**, 182, 186, 187, 200, 206
    potential, **13**, 198, 200
Temporal gain control, **2**, 11
Tephigram, **13**, 188
Terminal-harmonic-transformer design, **27**, 186–192
Terminal planes, network analysis, **10**, 104
Terminals, transformer, **17**, 169–174
Termination, coaxial-line, low-power, **11**, 722–726
  metalized glass, **11**, 724
    polyiron, **11**, 723
  line, **11**, 720
    matched, **11**, 720–743
  low-power, with metalized glass, **11**, 731
    waveguide, **11**, 726–731
      polyiron, **11**, 726–728
Terrestrial radiation, **13**, 254
Test bench, magnetron, **6**, 731
Test scope, simple, **22**, 251
Tetrodes, **17**, 570–599
  3D21, **5**, 105, 115
  3E29, **5**, 135, 157
  5D21, **5**, 100, 104, 132, 472
  6D21, **5**, 100, 106, 163
  6Y6-G, **19**, 78
  715B, **5**, 104, 115, 126, 147
  829, **5**, 105, 123, 126, 132
  beam, **17**, 586–598
  characteristic curves, **5**, 98–108, 110
  choice, **17**, 595, 599
  gas, hot-cathode, **17**, 612–613
  microwave, **7**, 108, 119
  output, **17**, 581, 586–594
  in pulser, **5**, 92
  -switching, modulator, **3**, 250
  transmitting beam, **17**, 594–598
  VW-41, **19**, 414
Thermal agitation, **16**, 10
Thermal behavior of pulsed cathode, **6**, 520

Thermal compensation, klystron frequency, **7,** 505
Thermal conductivity, **13,** 209
 earth, **13,** 254–255
Thermal lag, **18,** 424
Thermal noise (*see* Noise)
Thermal relay, **5,** 434
Thermal stability, effect on shear, **13,** 234
Thermistors, **11,** 81–83; **13,** 272, 273; **16,** 18; **17,** 101–104; **21,** 504; **23,** 280
 applications, **17,** 102–104, 452, 481–482
 bead, **11,** 89, 924
  d-c characteristics, **11,** 96
 bridge, **9,** 229; **11,** 924; **14,** 405
  self-balancing, **11,** 128
  two-disk, **11,** 117
 disk, **11,** 90
 equivalent circuit, **11,** 149
 mount, **11,** 130–155, 925; **14,** 407
  1-cm-band, **11,** 151
  broadband coaxial-line, **11,** 136
  coaxial-line, **11,** 132
  double, **11,** 136
  fishtail, **11,** 150
  impedance variations, **11,** 147
  O-O, **11,** 140
  S-S, **11,** 140
  tri-tuner, **11,** 146
  waveguide, **11,** 139
 operation in bridge circuit, **11,** 97–100
 oscillator usage, **21,** 547
 parameters, **11,** 89–97
 power monitors, **11,** 155
 V-519, **11,** 90
Thermocouples, **13,** 290, 323
 dipole, **11,** 190
 meters, **18,** 717; **23,** 335
 power detectors, **11,** 187–191
 sensitivity, **11,** 187
Thermodynamic equilibrium, **18,** 516
Thermometer, ice-bulb, **13,** 283
 resistance, **13,** 289
Thermometric conductivity, **13,** 209, 293
Thévenin's theorem, **8,** 90; **12,** 20; **16,** 320; **18,** 378, 505, 697
Three-bar linkages (*see also* Bar linkages), **27,** 35, 36, 107–166
 classification, **27,** 108–112
 combined with two harmonic transformers, **27,** 166–195
 design, **27,** 174–195
Three-bar linkage, design, geometric method, **27,** 145–156
  nomographic method, **27,** 118–145
  problem of, **27,** 117–118, 127–128
 field of function, **27,** 118
 functions generated, **27,** 122–127
 nomogram, properties, **27,** 333–352
 in series, **27,** 195–198
 special cases, **27,** 112–117
Three-bar motion, **27,** 31
Three-dimensional cams, **27,** 23
Three-gap operation, pulser, **5,** 302, 303
Three-tone provisions, **2,** 144
Threshold (Hartree) voltage, **6,** 237
Threshold signal, **24,** 185, 192
Thunderstorms, **13,** 23, 627
Thyratrons, **17,** 610–613; **19,** 591; **21,** 521; **26,** 221
 3C45, **5,** 138, 341
 4C35, **5,** 138, 341, 479
 5C22, **5,** 138, 341, 455
 bridge, **5,** 478–480
 characteristics, **21,** 405, 410
 control of d-c motors, **21,** 405–417
 counter circuits, **19,** 619
 deionization time, **21,** 405
 delay time, **5,** 351
 hydrogen, **1,** 379; **5,** 335–354
  anode circuit, **5,** 344
  anode current, rate of rise, **5,** 348
  anode voltage, forward, **5,** 346
   inverse, **5,** 346–348
  characteristics, **5,** 339
   control-grid, **5,** 338
  deionization time, **5,** 336, 353
  gas cleanup, **5,** 336
  grid circuit, **5,** 349–354
  ionization time, **5,** 345
  life, **5,** 341
  operating characteristics, **5,** 336–344
  reignition voltage, **5,** 346
  voltage drop, **5,** 344–345
 mercury, **5,** 335
 in pulser, **5,** 175, 274
 ring counters, **19,** 612–614
 scale-of-two, **19,** 612
 servos, **21,** 468
  velocity, **21,** 485
Thyrite, **5,** 429; **17,** 104–106; **21,** 503, 548
Tidal effects, **13,** 321, 420
 cause of echo fluctuations, **13,** 535–539

Tidal effects, extended targets, **13**, 537–538
point targets, **13**, 535
Time, aperture, **20**, 277
average, noise, **24**, 35
average signal, from meteorological echoes, **13**, 589–591
from sea echo, **13**, 482–485
-base generation (*see also* Sweep generator), **22**, 508
resolution before, **22**, 471–481
coincidence multiplier, **21**, 59
comparison, **19**, 12, 14, 364
constant, amplified, **18**, 411
nonsinusoidal wave circuits, **22**, 112
delays, addition, **21**, 39
relays (*see* Relays, lag)
demodulation, **19**, 12, 55, 501–544; **20**, 62–64
by time comparison, **19**, 536
demodulator, negative-feedback, **19**, 537
storage-tube, **19**, 728
difference, Loran, **4**, 12, 52, 59, 63, 67, 101, 432
measurement, **4**, 345
discrimination, **19**, 12, 56, 364; **20**, 62–64, 276
discriminator, **19**, 533; **20**, 95, 97, 308, 309, 356
AN/APG-15, **20**, 316
British radar set, **20**, 315
Oboe, **20**, 311, 312
pulse-stretching, **20**, 318
SCR-784, **20**, 313–315, 337
sensitive, using storage tube, **19**, 728
with time selectors, pulse stretcher, and narrow-band pulse amplification, **20**, 317–321
indices, movable, **22**, 239
periodic, **22**, 243
-interval discrimination, **21**, 47
jitter, **5**, 15, 16, 120, 129, 278, 284, 295, 299, 326, 330, 334, 351, 471
lag, **5**, 275
markers, **20**, 81
Loran, **4**, 56
marks, electronic, **20**, 219
generator, crystal-controlled, externally synchronized, **19**, 727
delay-line, supersonic, **20**, 108
Time, measurement, **19**, 300, 697–699
automatic, **20**, 275–366
error, **20**, 40, 120
manual, **20**, 176–274
accuracy, **20**, 185–200
fixed indices for, **20**, 215–220
movable tracking marks for, **20**, 220–274
tracking, **20**, 200–214
medium-precision, **20**, 141
SCR-268 radar, **20**, 135
specially accurate systems, **20**, 261
tube-variation effects, **20**, 51
zero calibration, **20**, 45
zero correction, **20**, 46, 93, 94
modulation (*see* Modulation)
modulator (*see* Modulator)
and position measurement, automatic systems, **20**, 341–390
of ripple, **5**, 206
of rise, **5**, 206
selection, **19**, 12, 47, 364–388; **20**, 62–64, 321–325
selectors, **19**, 364; **20**, 400; **22**, 403
adjacent, **19**, 384, 385
and difference detector, **19**, 534
quasi, **19**, 366
sequence in receiving equipment, **20**, 400
use in frequency division, **19**, 569
-sharing method, data transmission, **1**, 684
-variable data, statistical properties, **25**, 262–307
-varied gain (TVG) (*see also* STC), **1**, 460; **2**, 11, 146; **3**, 41, 371–374
for voltage pulse, **5**, 80, 683
Timers, Loran, **4**, 67, 87, 197–257
A, **4**, 199
B, **4**, 199
B-1, **4**, 199–201
C, **4**, 205–232
low-frequency, **4**, 249–257
monitor, **4**, 250
UE-1, **4**, 232–249
UJ, **4**, 205
Timing, condenser, multivibrator, **19**, 167
errors, Loran, **4**, 144
markers, discrete, **1**, 520–522
resistor, multivibrator, **19**, 167

Timing, standard, **20**, 50; **21**, 596, 604, 613, 619, 625, 642
waveform, multivibrator, **19**, 167
Titanium dioxide, **26**, 412
Titeflex, waveguide, **9**, 116, 279–281
T-junction (*see* Junction)
T-m, circuits (*see* Modulation, time)
waves, **8**, 17
tn (x,y), function, **8**, 259
Tn (x,y), function, **8**, 259
Top of pulse (*see* Pulse)
Topological transformation of nomogram, **27**, 40
Torque, measurement, **21**, 456
tube, azimuth, **26**, 76
from wind loads, **26**, 36
Trace brightness, **24**, 197–199
Tracing paper, technique, transmission-line chart, **9**, 65
Tracking, aided (*see* Aided tracking)
automatic, **20**, 202; **26**, 225
angle, **1**, 207–210
conical scan, **3**, 56
frequency, synchronization by, **20**, 95–100
circuit, locking in, **1**, 710
step-gate, **20**, 433–435
direct, **20**, 200, 202, 220
on grouped or periodically interrupted data, **20**, 378–390
indices, **20**, 183
time-modulated, use of variable-width rectangle generator to produce, **20**, 222
with intermittent data, **20**, 247
linear-time-constant, **20**, 201
manual, **20**, 371–376; **25**, 360–368
AGL-(T), **20**, 373
AN/APG-15, **20**, 371
SCR-615, **20**, 373
marks, movable, for manual time measurement, **20**, 220
memory-point, **20**, 201, 207
methods, **20**, 200
regenerative, **20**, 201, 210, 256
pulses, **1**, 707
sine-wave, **20**, 155–157, 242
systems comparison, **20**, 340
tester, dynamic, **20**, 357, 361
two-coordinate, **20**, 251–261
velocity, **20**, 200, 203
Trade-wind inversion, **13**, 375
TR-aided tuning, **16**, 170, 173, 280
Trailing edge of pulse, **5**, 2, 183, 189, 258–261, 569, 571–573
Trammel linkage, **26**, 67, 68
Transadmittance, circuit, klystron oscillator, **7**, 297, 300, 302
diagrams, **7**, 302–304, 308–310
electronic, **7**, 52, 98, 106, 108, 116, 117, 120, 121, 250, 252, 278, 297, 300, 302, 313, 317, 318, 346
internal, **7**, 50, 58, 68
grid, **7**, 107–109
Transconductance, and bias voltage, correlation between, **18**, 290
bridge, **21**, 532, 570
effective, **7**, 146; **22**, 362
electronic, **7**, 280
small-signal, **7**, 252, 297, 299, 331
high-frequency, **7**, 149
maximum, **7**, 151
and plate current, correlation between, **18**, 290
Transducer, 4-terminal, **6**, 171–177
electromechanical, **1**, 667; **19**, 427
equivalent circuits, **19**, 759
mode (*see* Mode transducers)
rectangular-to-round, **8**, 358
TE_{10}-mode to TM_{01}-mode, **8**, 339
supersonic crystal, **17**, 180–190
bandwidth, **17**, 186–189
crystal cartridge, **17**, 182–189
electrical characteristics, **17**, 184
piezoelectric crystal for, **17**, 181
reflectors, **17**, 189–190
ringing, **17**, 183
Transfer constant, image, **8**, 115
network, **8**, 113
Transfer function, **18**, 385; **21**, 230–232, 266
definition, **25**, 58
feedback, **21**, 230, 266; **25**, 62, 255
as generating function, **25**, 244–245
lumped-constant servos, **25**, 64–66
filter, with clamping, **25**, 241, 246–251
lumped-constant filter, **25**, 59–61
nature of, **25**, 315–317
over-all, **25**, 62, 255
pulsed filter, **25**, 240–242
quadratic factor, **25**, 175, 176
servo, **25**, 58–62

Transfer function, simplified, for $|\alpha_k T_r| \gg |$, **25**, 251–253
stability criterion, **25**, 61
system definition, **25**, 62
t-m circuit, **19**, 466
Transfer locus, **21**, 270; **25**, 67, 158, 195, 256
Transferred region, computer overlays, **27**, 137
Transferred points, computer overlays, **27**, 137
Transform network, **18**, 3, 50–53
Transformations, bilinear, **6**, 174
bipolar to rectangular, **21**, 169
coordinate, **21**, 157–171, 226, 477
formulas, resonator-admittance, **6**, 62
Fourier, **21**, 231
Laplace, **21**, 226
mathematical expression of, **21**, 158
polar to rectangular, **21**, 160
rectangular to polar, **21**, 160
special coordinate, **21**, 165
Transformer, **17**, 115–174
3-phase, **17**, 134
a-c charging, **5**, 400–407
losses, **5**, 413
air-core, quenching oscillator with, **20**, 79
broadband, **17**, 141–145
coaxial T-junction with, **14**, 268
bushings, **17**, 169–174
assembly in cans, **17**, 173–174
high-altitude operation, **17**, 172
operating voltages, **17**, 172
butt joint in core, **5**, 601, 644
cascade, in coaxial lines, **12**, 221–223
circular sweep, **21**, 634
coaxial impedance, **9**, 182–184
coils, **17**, 150–165
design data, **17**, 125, 158–163
distributed capacitance, **5**, 507; **17**, 124, 141–145
finishing, **17**, 155–156
impregnating and sealing materials, **17**, 163–165
interlayer insulation, **17**, 151–152
magnet wire, **17**, 150–151
processing, **17**, 163–165
resistance, **17**, 125
self-inductance, **17**, 118–124
winding table, **17**, 160–161
Transformer, coils, winding types, **17**, 152–158
working-voltage gradient for insulation, **17**, 162–163
computer, **27**, 225
constant, principal, 4-terminal transducer, **6**, 177
constant-voltage, **17**, 455–460; **21**, 536
construction, **17**, 145–174
control, synchro, **17**, 314, 319–321, 325–326
cores, **17**, 145–150
material losses, **17**, 149
materials, magnetization curves, **17**, 148
current, **5**, 574; **20**, 316
design, **17**, 115–145
dissipation of energy in core, **5**, 508
double-tuned, **19**, 550
enclosures, **17**, 167–169
equivalent circuit, **5**, 503–508; **18**, 16
frequency response, oscilloscope presentation, **5**, 595
for hard-tube pulse generator, **5**, 566
high-reactance, design, **5**, 407–414
high-voltage, **17**, 137
H-section, **6**, 498
H-shaped cross section, **6**, 493
ideal, **8**, 103
impedance-matching, **9**, 90–95
impedance-transformation ratio, **5**, 10
interwinding capacitance, **17**, 124–125, 144
iris, **6**, 494
isolating, **4**, 259, 264; **5**, 512
jog, **1**, 295
leakage inductance, **17**, 117–118
for line-type pulse generator, **5**, 567
linkages (computer), **27**, 225
ballistic computer, **27**, 296–297
design, **27**, 271–277
geometric method, **27**, 276
graphical method, **27**, 276
for noncircular scales, **27**, 295–297
structural error, **27**, 277–283
logarithmic, **27**, 238
magnetron output, **6**, 489
mountings, **17**, 167–169
noninverting, **5**, 535
nonlinear, **19**, 424
for amplitude modulation, **19**, 422

Transformer, oil filling, **17**, 169
output, triangle solver with, **21**, 152
potting, **17**, 168
power, beacon, **3**, 318
design, **17**, 130–141
higher-frequency operation, **17**, 132–133, 138–141
life versus operating temperature, **17**, 132–133
proximity effect, **5**, 547, 658–660
pulse, **1**, 384–386; **5**, 9, 225, 235, 497–660; **19**, 18; **20**, 78; **22**, 120
advantages, **5**, 78
average current values, **5**, 396
bushings, **5**, 654
charging inductance, **5**, 526–530
coil material, **5**, 648–660
connectors, **5**, 654
core, d-c data, **5**, 614–615
d-c properties, **5**, 599–601
equivalent circuit, **5**, 626–633
gap length, **5**, 602–604
magnetization, **5**, 633
material for, **5**, 599–648
nickel-steel, **5**, 611
pulse data, **5**, 614–615
size, **5**, 538, 545
standard tests, **5**, 611
thickness, **5**, 599
coupling to load, **5**, 70–89
current, effective, **5**, 547–548
reverse, **5**, 511
current modes in, **5**, 528
design, **5**, 532–562
distributed capacitance, **5**, 516–522, 537
effect, on load input capacitance, **5**, 536
on pulse shapes, **5**, 563–575
elementary theory, **5**, 499–531
energy density, average, in coil and core, **5**, 541
stored in magnetic field, **5**, 627
equivalent circuit, **5**, 508–510
frequency response, **5**, 591–598
GE 68G627, **5**, 129, 150
impedance, instantaneous, **5**, 437
impedance characteristic, **5**, 522–526
inductance, leakage, **5**, 506, 511–516
primary, **5**, 510
insulation, **5**, 648–655
Transformer, pulse, iron-core, **5**, 124
materials, **5**, 599–660
operating data, **5**, 558
parameters, effect, on circuit, **5**, 563–598
on regenerative pulse generators, **5**, 575–591
power, loss, **5**, 660
output, **5**, 511
design, **5**, 547–554
transfer, efficiency, **5**, 71
maximum, **5**, 500–503
skin effect, **5**, 547
stray capacitance, **5**, 508
time delay, **5**, 85, 272
two arrangements for use with hard-tube pulse, **5**, 74
typical designs, **5**, 555–562
various types, **5**, 606
very-high-resistance load, **5**, 554
very-high-voltage, **5**, 555
winding schemes, **5**, 517, 518
wire, **5**, 655–660
quarter-wave, **6**, 482; **8**, 189–191; **9**, 90–92, 217
rectangular, **6**, 491
for regenerative pulse generator, **5**, 500, 511, 543–547
representation of T-junction, **8**, 122
resonant, **14**, 9
rms current, **5**, 483
rotary, **22**, 185
rotatable, **25**, 92
saturable, **21**, 440
shielding, **17**, 144, 166
small, copper allowance for, **17**, 158
stepdown, **5**, 510
stepup, **5**, 510
synchro, **17**, 321–323; **25**, 82
temperature rise, **17**, 125–126, 131–132
theory, general, **5**, 499–510
transmission delay, **5**, 525
two-harmonic (computer), design, of three-bar-linkage component, **27**, 168–186
factorization of function, **27**, 168–174
linkage combination assembly, **27**, 193–195
problem of, **27**, 166–168
properties, **27**, 166

Transformer, two-harmonic (computer), redesign of terminal, **27**, 186–193
variable impedance, **9**, 456–516
voltage, **5**, 483
formula for, **17**, 116
voltage-transformation ratio, **5**, 10
waveguide, **6**, 491
windings, distributed capacitance, **17**, 124, 141–145
with variable coupling between, **19**, 428
Transit angle, **7**, 33, 41
gap, **7**, 226–227, 231, 316
finite, **7**, 224–232
spread in, **7**, 150
Transit time, **7**, 33, 356
damping, **18**, 638
Transition, coaxial-to-waveguide, **1**, 403; **9**, 314–361; **16**, 172
crossbar, **9**, 346–349
doorknob, **9**, 349–353
rectangular-to-round, **8**, 339
TE_{10}-mode to TE_{20}-mode, **8**, 339
Transitional layers, **13**, 172
Transitron oscillator, **19**, 124
capacitance amplification in, **16**, 327
Miller, **19**, 197
Transits, multiple, elimination of, **7**, 403
Transmission, 360° rotation, **20**, 397
cable and impedance matching, **5**, 669–673
coefficient, complex, **11**, 565
radome walls, **12**, 529–537
of continuous rotation, **20**, 393–395
c-w, of sine and cosine, **1**, 703–711
data (*see* Data transmission)
delay, transformer, **5**, 525
devices, simple, with limited rotation, **20**, 392
E-layer (*see also* Propagation), **4**, 133
equation, free-space, one-way (*see also* Radar, equation), **13**, 31
one-way, generalized, **13**, 35
radar, generalized, **13**, 35
in free space, **13**, 27–34
ground, **4**, 59
ground-wave, **4**, 121
over land, general features, **13**, 340
one-way, **13**, 336–353
paths, **13**, 341
Transmission, line (*see also* Line, transmission), amplifiers, **18**, 83
coaxial (*see* Coaxial cable)
losses, waveguide, **8**, 45–48
measurement, in free space, **11**, 592
two-line cavity, **11**, 332
waveguide, **11**, 577
multiple-hop, **4**, 136
pulse, of sine and cosine, **1**, 704
and reception, pulse, **20**, 37–42
sky-wave, **4**, 59, 159
synchronized, of angular data, **22**, 222
time, Loran, **4**, 123, 133
pulse network, **5**, 177
variable-speed, for motors, **17**, 390
over water, one-way, **13**, 294–336
Transmit-receive unit, **1**, 420
Transmitters, beacon, **2**, 36; **3**, 256–312
Loran, **4**, 87, 275–300, 577
pulling, **12**, 517, 537
-receiver package, **2**, 371
receiver system, equivalent network, **12**, 53–60
triode, **3**, 279–312
Transmitting pattern, **12**, 3, 557
Transponder, **1**, 246; **2**, 36; **3**, 6; **12**, 327
Transverse-electric (*TE*) waves, **8**, 17
Transverse-electromagnetic waves (*see* *TEM* waves)
Transverse-magnetic (*TM*) waves, **8**, 17
Trapezoidal wave, **5**, 190
generation, **19**, 297
Trapped modes, **13**, **22**, 71, 75, 82, 149
boundary conditions, **13**, 78
characteristic values, **13**, 75
Trapping, criteria, **13**, 21, 84
elevated inversions, **13**, 332
propagation, **1**, 56–58; **3**, 50, 53
strong, **13**, 167
TR cavity (*see also* TR tube), **14**, 39; **16**, 28, 72, 139, 157, 162, 166, 174, 179, 224, 256, 276, 358, 364
1B27, **14**, 59
721, conductance, **14**, 54
dimensions, **14**, 54
direct-coupling, **14**, 57
coupling through, summary of formulas, **14**, 33
coupling to, **14**, 385
rectangular waveguide, **14**, 51
direct-coupling measurements, **14**, 412

TR cavity, leakage, **16**, 192, 201
leakage power, **16**, 173, 372
output loop, **16**, 168
reduction of local-oscillator noise by, **16**, 241–243
Travis discriminator circuit, **16**, 304
Tree-motion and radar-echo fluctuation, **13**, 547, 552, 584
Trial field, network-parameter determination, **10**, 143
Triangle, adders, **19**, 295
solution, curve-fitting methods, **21**, 143
$H + B$, **21**, 40
parabolic-waveform method, **21**, 144
phase-shift, **21**, 149
right triangle, **21**, 136–157
solvers, **21**, 189
algebraic, **21**, 137
parabolic-sweep, **21**, 139, 144
phase-shift, **21**, 182
with transformer output, **21**, 152
using resistance squaring and bridge, **21**, 139
solving using electronic multiplication, **21**, 140
waveform generation, **19**, 291
Tridipole transverse element, **12**, 304
Trigatron, **1**, 379; **5**, 295, 332
CV85, **5**, 332
CV125, **5**, 332–334
Trigger, circuits, **22**, 223–226
condenser-discharge, **5**, 307–311
Eccles-Jordan, **16**, 333
saturable-core transformer, **5**, 311
-coupling condensers, **5**, 297, 312, 314
delay, **20**, 78; **22**, 262, 272, 279–282
supersonic, **19**, 762
unit, variable, model PH, **21**, 659
effect on output waveforms, **19**, 222
generator, **5**, 304–312; **21**, 587, 596, 604, 619, 628, 637, 642; **22**, 118–123, 255, 262, 272
MTI, **1**, 634
multiple-frequency, **20**, 81
inverter, **22**, 432
pulses, **4**, 198; **5**, 119; **11**, 239; **22**, 9, 120
negative, **22**, 119
positive, transmission of, **22**, 119
rate of rise, **5**, 350
shaper, **16**, 349; **22**, 284
source, **22**, 122
Trigger, voltage, **5**, 302, 330, 334
waveforms, **22**, 118
Triggering, **19**, 187–190, 218–223; **22**, 223
frequency dividers, **19**, 580
methods, **19**, 218–223, 608
parallel, **5**, 124; **19**, 219
phantastron divider chain, **19**, 581
series, **5**, 124; **19**, 220
Trigonometric functions as circuit function, **21**, 55, 104–120
inverse, **21**, 118
Triode, **17**, 549–570
304th, **5**, 100, 104, 123
527, pulse characteristics, **5**, 106
6C21, **5**, 100, 106, 132, 157
6SN7, pulse characteristics, **5**, 106
baseless subminiature, **20**, 91
characteristic curves, **5**, 98–108
choice, **17**, 568–570
clamp, **22**, 129
coincidence tube, **20**, 95
-connected pentodes, **17**, 550, 558, 567
gas, hot-cathode, **17**, 610–611
high-mu, **7**, 108, 116; **17**, 557–570
input, **18**, 646
configurations, three, comparison, **18**, 647
grounded-cathode, **18**, 655; **23**, 126
grounded-grid, **7**, 146; **18**, 634, 648, 653; **23**, 83, 92, 117, 136
grounded-plate, **18**, 655
single, **18**, 651–656
low-mu, **17**, 548–551
medium-mu, **17**, 551–558
negative-grid, at moderately high frequencies, **18**, 571, 574
oscillators, microwave, **7**, 170–186
planar, **7**, 286
CV90, **7**, 23
pulse operation, microwave, **7**, 187–198
in pulser, **5**, 92
selector, **19**, 331
switching, modulator, **3**, 249
transmitter (*see* Oscillator, transmitting triode)
twin, high-mu, **17**, 559, 563–566
medium-mu, **17**, 555–557
Triple-coincidence circuit, **19**, 383
Triples, cascaded, **18**, 189
feedback, **18**, 234
flat-staggered, **18**, 189–191

Triples, flat-staggered, *n*-, step-function response, **18**, 281
overstaggered, **18**, 286
transient response, **18**, 287
stagger-damped, **18**, 224
Triplets of oxygen spectrum, **13**, 649, 653, 654
Tritet oscillator, **19**, 108
Troposphere, **13**, 9
TR switch, **1**, 7, 407–411, 420; **15**, 129; **16**, 9, 70, 78, 96, 97, 114, 172, 353
and ATR, distance between, **14**, 288
attenuation at harmonic frequencies, **14**, 412
high-*Q* pass-band measurement, **14**, 385
TR tube (*see also* TR cavity), **1**, 407; **9**, 688; **23**, 7
1B23, **14**, 36–42
1B24, **14**, 60, 62, 65, 66, 171, 179, 201, 209, 223, 227; **23**, 10
1B26, **14**, 61, 65, 66, 169, 201, 223, 227
1B27, **14**, 36, 37, 39, 44, 49, 168, 170, 171, 179, 180, 190–191, 222, 227, 256; **23**, 8
tuning screw, differential, **14**, 44
tuning-temperature curve, **14**, 49
1B38 pre-TR tube, **14**, 148, 154, 164, 223, 224, 249, 250
1B40, **14**, 36, 38
1B50, **14**, 61, 63, 65, 201, 227
1B54 pre-TR tube, **14**, 249, 250
1B55, **14**, 108, 239, 250
1B58, **14**, 108, 250
bandpass, **14**, 223
1B63, **14**, 111–112, 250
721A, **14**, 36, 48, 142, 197, 198, 222, 227
721B, **14**, 37, 39, 41, 42, 222
724A, **14**, 36, 167
724B, **14**, 37, 39, 41, 227
arc, leakage power, **14**, 140, 171
from 1B27 TR tube, **14**, 180
through 3-cm bandpass TR tube, **14**, 239
dependence on transmitting power, **14**, 175
with gap length, variation of, **14**, 174
loss, **14**, 240, 242
measurement, **14**, 413
power, **14**, 140
bandpass, **14**, 67–114
TR tube, bandpass, 3-cm, leakage-power envelope, **14**, 232
9.2-cm-band, **14**, 107
10-cm tubes, **14**, 109
experimental results, **14**, 91–114
future status, **14**, 252
high-level characteristics, **14**, 250
Marcus' calculation, **14**, 84
theoretical considerations, **14**, 70–90
tuning procedure, **14**, 396
broadband, pass band, **14**, 393
cell-type, **14**, 35
coatings, inert, **14**, 221
CV221, **14**, 64
firing power, minimum, **14**, 414
fixed-tuned, tuning check, **14**, 400
flat, **16**, 97, 300
gap design, **14**, 235
gap length, arc leakage power with variation of, **14**, 174
effect on spike leakage energy, **14**, 170
gas cleanup, **14**, 217
gas-filling, effect, on high-power characteristics, **14**, 239
on spike energy, **14**, 167
high-*Q*, high-power characteristics, **14**, 227
linear theory, **14**, 8–66
volumes of, **14**, 218
integral-cavity, **14**, 59
keep-alive electrode, **16**, 99, 174, 175
relaxation oscillations, **14**, 201
leakage characteristics, effect of line power on, **14**, 243
leakage power, direct-coupled, **14**, 13
envelope of 3-cm bandpass TR tube, **14**, 232
measurements, **14**, 405
of pre-TR tubes, **14**, 407
life, **14**, 142, 210
life tests, **14**, 423
measurement techniques, **14**, 376–430
mechanical tests, **14**, 425
prepulsing, **1**, 607
production testing, low-level, **14**, 400
PS3S, **14**, 108
recovery characteristic, **14**, 190, 192
recovery time, **14**, 141
measurements, **14**, 417

TR tube, recovery time, measurements, two-frequency method, **14**, 421–422
spike, **23**, 42
test bench, typical, **14**, 381
test equipment, low-level, basic, **14**, 376
tungsten water cycle, **14**, 211
tuning methods, **14**, 27
tuning-temperature compensation, **14**, 46
T-stub, broadband (*see also* Stub), **9**, 173–176; **14**, 266
Tubes (*see also* Converter; Diode; Gas tubes; Mixer; Pentodes; Tetrodes; Thyratrons; Triode), 1S5, logarithmic cutoff, **19**, 76
6AG5, logarithmic cutoff, **19**, 76
6AG7, low-plate-voltage region, **19**, 78
6AK5, logarithmic cutoff, **19**, 76
low-plate-voltage region, **19**, 79
6AL5, **19**, 58, 61, 63
6AS6, **19**, 81, 196
three-control-grid characteristic, **19**, 88
6H6, heater-cathode leakage, **19**, 67
6J6, diode-connected, **19**, 66
logarithmic cutoff, **19**, 75
6SA7, three-control-grid characteristic, **19**, 90
6SH7, diode-connected, **19**, 66
logarithmic cutoff, **19**, 76
6SL7, broken-line characteristic, **19**, 73
grid-current characteristic, **19**, 89
logarithmic cutoff, **19**, 75
6SN7, heater-cathode leakage, **19**, 68
logarithmic cutoff, **19**, 75
low-plate-voltage region, **19**, 79
baseless, **18**, 230
characteristics, at low currents, **18**, 414–418
direct, **19**, 100
drift under constant applied potentials, **18**, 730–733
mutual, **19**, 100
notation used in, **17**, 531–533
variation in, **17**, 563, 566, 590
choice of, general rules, **17**, 518–519
converter and mixer (*see also* Converter; Mixer), **17**, 599–610
Tubes, dissipation, pulser, **5**, 345
electrometer, **18**, 409, 419
gas-filled, **17**, 610–613; **19**, 82–85
gassy, magnetron, **6**, 736
glow, **21**, 495
index of types, **17**, 523–531
lighthouse (*see* Lighthouse tubes)
measurements, TR and ATR, **14**, 376–430
microwave, types and functions, **7**, 17–30
miniature, **17**, 522, 524
model, magnetron, **6**, 729
mount, **16**, 146
multigrid, **7**, 106; **19**, 415
noise suppression, **18**, 604–614
oilcan, **16**, 18
output, figures of merit, **17**, 594
parameter tolerances, **18**, 352
physical characteristics, **17**, 519–523
preferred types, **17**, 518
processing, **6**, 693, 694
reactance, **6**, 747; **23**, 30
receiving, **17**, 517–613
pulse characteristics, **5**, 102
reference filament-type, **21**, 502
replacement, **18**, 353
requirements, beacon, **3**, 303
reseasoning, **6**, 737
ruggedness, **17**, 521–523
size, **17**, 520–523
storage, **1**, 631; **19**, 499, 707–729; **20**, 99, 107
subminiature, **17**, 523–524; **18**, 156; **20**, 170
as switches, **5**, 90–118
thermally tuned, **23**, 25
TR and ATR (*see* ATR; TR)
use as series voltage regulator, **17**, 549, 551
vacuum **21**, 506
velocity-modulated, for high-frequency superregenerative receivers, **23**, 578
VR (*see* VR tube)
Tubing, for coaxial lines, **9**, 115–119
dimensional tolerances, **9**, 117
silver-lined, **9**, 117
for waveguides, **9**, 115–119
Tuned-circuit, symmetry, **18**, 169
Tuners, capacitive-screw, **9**, 498
cavity, **3**, 265

Tuners, coaxial line, **9**, 460–481
double-screw, waveguide, **9**, 507–513
double-slug, waveguide, **9**, 494–498
magnetron, stabilizing, **3**, 268
multicavity inductance, **6**, 165
segment, **6**, 161
strap, **6**, 159
resonances, **6**, 575
single-cavity, **6**, 157
single-screw, variable-position, **9**, 485–489
single-slug, **9**, 489–494
sliding-screw, **9**, 459
slug, **9**, 466–472
stub (*see* Stub tuners)
variable-impedance transformer, **9**, 456–516
waveguide, **9**, 481–516
Tuning, curve, **6**, 320, 324
microwave oscillator, **7**, 178
electronic, **16**, 38
hysteresis, **11**, 30
klystron, **7**, 315, 323, 350, 420; **11**, 23, 29; **16**, 38
linearity, **7**, 443
forks, **21**, 548
hysteresis, **6**, 562, **11**, 30
klystron, **7**, 502
magnetron (*see* Magnetron tuning)
parallel-resonant, **18**, 353
range, **6**, 402, 407, 408, 643
electronic, **7**, 27, 28, 331, 336, 378–384, 443
half-power, klystron oscillator, **7**, 327
rate, electronic, **7**, 443
resonant, **18**, 350
screw, capacitive, **8**, 168; **9**, 216
inductive, **14**, 43
slug, capacitive, **14**, 43
synchronous, **18**, 166
thermal, **11**, 46
TR-aided, **16**, 173
Turbulence, **13**, 23, 211, 250
constant, universal, **13**, 216
inversion, **13**, 231
mechanical, **13**, 221, 225, 268
and precipitation fluctuations, **13**, 577
thermal, **13**, 220, 221
Turbulent boundary layer, **13**, 214, 215, 217, 219
Turbulent, logarithmic distributions, **13**, 215
thickness, **13**, 218
Turning point, for mode of propagation in duct, **13**, 20
of ray, **13**, 16, 17, 19, 46, 83, 100
Turnstile duplexer, **14**, 372
frequency sensitivity, **14**, 375
Turnstile junction, **8**, 459–466
TVG (*see* Time-varied gain)
Twinkling of stars, **13**, 532
Two equal scatterers as radar target, **13**, 529, 548–550
Typhoons, **13**, 23, 636–640

U

Undercoupling, frequency-multiplier klystron, **7**, 308
Undercurrent relay, **5**, 433
Uniqueness theorem, **10**, 103
extension, **8**, 139
Unit pulse, definition, **25**, 233
Unit-ramp function, **25**, 53, 365
Unit-step function, definition, **25**, 37
Unit-step input, filter response to, **25**, 37
Unitary matrix, **11**, 518
Unitary relations, **10**, 108
Units, MKS, **13**, 28
Universal gas constant, **13**, 292
Universal joints, waveguide, **9**, 442–445
Universal turbulence constant, **13**, 216

V

Vacuum casting, magnetron anode, **6**, 661
Vacuum-tube switch (*see* Switch, tube)
Vacuum-tube voltmeter, **18**, 314, 409
average-reading, **19**, 502
high-impedance, **18**, 320
low-impedance, **18**, 320
Vacuum tubes, thermionic, as reference elements, **21**, 506
Vane equivalent, resonator, **6**, 108
Vane thickness, ratio of, to space between vanes, resonator, **6**, 473
Vapor pressure, **13**, 182, 187, 192, 206
curve, sea-water, **13**, 184
gradients, **13**, 192
lapse rate, **13**, 196
potential, **13**, 198, 200, 202

Vapor pressure, over sea water, **13,** 200
Vaporization, latent heat, **13,** 293
Variable (computer) complementary, **27,** 48
Variable elevation beam (VEB), **1,** 189
Variable-gear ratio, **21,** 59
Variables, definition, **27,** 45
  homogeneous (*see* Homogeneous variables)
  input, **27,** 45
  interchange of, as circuit operation, **21,** 20
  output, **27,** 45
  range, **27,** 46
Variacs, **19,** 463
Variance, random process, **25,** 273
Variational energy integral, **8,** 151–153
Variational methods, **13,** 177
  network parameter determination, **10,** 143, 150
Varigear, **21,** 59
Varistors, **17,** 100–109; **21,** 503, 548
  symmetrical, **17,** 104–106
  unsymmetrical, **17,** 106–108
V-beam, height indicator (*see* Height indicator, V-beam)
  mount, **2,** 224
  presentation, **2,** 225
  radar, **1,** 193–196
  scan, **22,** 12
V-bridge, **11,** 105–108
VEB (*see* Variable elevation beam)
Vector, adders, **17,** 342
  bombing, **4,** 34
  column, matrix, **8,** 87
  error, **22,** 489, 494, 502, 504
  Hertz, **8,** 21
  plane wave, expansion in spherical vector wave functions, **13,** 447
  potential, **8,** 21
    method for scattering calculations, **13,** 455
  row, matrix, **8,** 89
  two-dimensional, representation by circuits, **21,** 157–171
  wave equation, **13,** 455
Velocity, electron, average, **7,** 100, 123
    distribution, **7,** 100, 122
    fluctuation in, klystron, **7,** 483
    spread, **7,** 60, 137
  group, **9,** 12
Velocity, learning time, **20,** 380
  memory, *RC* network, **3,** 192
  modulation, **7,** 34, 40, 46, 55, 59, 133, 201–203, 218–219, 224–228, 233, 240, 245–246, 260; **16,** 36
    depth of, **7,** 203, 269
    klystron, **11,** 24
    second-harmonic, **7,** 228–230, 244
    tube, **16,** 290
  phase (*see also* Phase velocity), **4,** 129; **9,** 12, 20, 42, 50
  propagation of sound in liquids, **17,** 218–219
  signal, **9,** 12
  spectrograph, **7,** 269
Velodyne (motor), **21,** 424, 488
Vertex plate, matching technique, **12,** 443, 463
Vertical distributions, in neutral and unstable equilibrium, **13,** 219–228
  in stable equilibrium, **13,** 228–260
Vestigial 120° junction, **14,** 273, 334
Vibrator, buffer capacitors, **17,** 443–444
  circuits, **17,** 438–445
    design considerations, **17,** 440–445
    series, **17,** 440
    shunt, **17,** 439
  construction, **17,** 433–438
  converter, **21,** 487, 514, 515, 553
  driving circuits, **17,** 435–437
  instruments, **17,** 497–498
  Minneapolis-Honeywell, **19,** 403
  mountings, **17,** 437
  nonsynchronous, **17,** 437
  power supplies (*see* Power supply)
  synchronous, **17,** 437–438; **25,** 108
Video, amplifier (*see* Amplifier, video)
  bandwidth, **24,** 211–222, 240
  "hash," **16,** 298
  crystal (*see also* Crystal, video), **15,** 9
  integration, **3,** 106
  mapping, **1,** 223; **2,** 267–278; **22,** 570–576
    applications, **2,** 270, 272
    delineation of flight paths, **2,** 271
    equipment, **2,** 275
    general principles, **2,** 267
    precision, **2,** 273
    reproduction, by different methods, **2,** 276–277
      of live data, **2,** 274

Video, mixing, **1**, 45; **20**, 451; **24**, 230–237, 248
output limiting, **1**, 452
overloading, **24**, 341–343
pulse, **16**, 297
generators, **21**, 593
separator, **20**, 458
stretching, **3**, 37, 379
test equipment, **21**, 573
probe, **22**, 270
Viscosity, dynamic, **13**, 208
eddy (*see* Eddy viscosity)
kinematic, **13**, 208, 214, 293
Visibility, subclutter, **1**, 653
measurement, **1**, 679
target, in MTI, **1**, 649–653
Visual methods of interpretation, **3**, 226
Voice-modulation beacon systems, **3**, 232–236
Volt-ampere characteristics of keep-alive discharges, **14**, 205
Voltage, addition, **19**, 18, 629–648
amplification, **18**, 73
antistick-off, **25**, 85
breakdown, magnetron, **6**, 484, 488
microwave frequencies, **9**, 227–242
characteristic, magnetron, **6**, 416
circuit, high-output, **18**, 144
constant-, elements, **21**, 494
control (*see* Voltage regulation)
-current source transformation, **18**, 5
and currents, addition and subtraction of, **19**, 18, 629–648
differentiator, **5**, 680–687
and dimensions, scaling of, klystron, **7**, 354–357
distribution along windings of transformer, **5**, 519
dividers, **5**, 666
capacitance, **5**, 673–675; **17**, 299–302; **21**, 49
push-pull, **17**, 302
electronically controlled, **21**, 49
mechanically controlled, **21**, 48
probe, CAOR-62142, **21**, 664
resistors, **5**, 297, 312, 314
for series gaps, **5**, 312–315
-doubler power supply, **5**, 148
drive for deflection coils, **22**, 310
-fed network (*see* Network)
feedback, **22**, 360
Voltage, insertion ratio, **9**, 549
level, change, as circuit operation, **21**, 60, 61
linear steps of, **19**, 617
-multiplier, multiple-switch circuit, Marx, **5**, 494–496
output-gap, limitation on, amplifier klystron, **7**, 263–264
plate and heater, microwave triode, **7**, 195
position, minimum-, standing-wave, **6**, 707
proportional, to reciprocal of shaft displacement, **22**, 205
to secant of shaft rotation, **22**, 205
pulses, blocking-oscillator, **20**, 78
rectangular, **19**, 215
subtraction circuits, **19**, 629–648
supply (*see* Power supply)
transformation ratio of resonant cavity, **14**, 21
waveform drivers, **19**, 449
Voltage (and current) regulation, **18**, 410; **21**, 493–570; **22**, 116, 170–172, 180, 182, 438
a-c, commutator transmitter, **17**, 323–324
degenerative, **21**, 539
simple, **21**, 528
aircraft alternators, **1**, 563–566
amplification bridge, **21**, 532
booster armature, of dynamotors, **1**, 580
carbon pile, **1**, 566–570; **3**, 320; **17**, 430, 446–451
inverter, **21**, 545
cold-cathode gas diodes, **17**, 609–610
combination of, **21**, 527
comparison circuits, **21**, 511–519
compensating networks, **21**, 509
constant-current elements, **21**, 501
control, elements, **21**, 519–522
of motor speed, **1**, 574
current, **21**, 493–570
d-c, **21**, 529, 567
design, practical, **21**, 523–570
dynamotors, **17**, 418–420
electromechanical, **17**, 455; **21**, 541
electronic, **17**, 452–454, 460–466
degenerative, **21**, 531
design, **17**, 463–464

Voltage (and current) regulation, electronic, output waveform, **17**, 465
equating circuits, **21**, 511
finger-type, **1**, 570–571; **17**, 446
generators, **17**, 411–412, 418–420, 445–454
glow tube, **21**, 530
high-voltage, **21**, 568
klystron, necessity of, **7**, 522
Lawson, **21**, 562
line-voltage, **17**, 454–466
mechanical, **1**, 566–571; **17**, 445–450
degenerative, **21**, 534
reference elements, **21**, 494–507
thermionic tube, **21**, 506
regulator elements, **21**, 493–522
saturable-transformer, **17**, 455–460
series, tube for use as, **17**, 549, 551
servo-operated, **21**, 542
stability, **21**, 493, 533
static, **17**, 450–454
vibrating-contact, **17**, 446
VR-tube (*see also* VR tube), **21**, 567
Voltmeter, peak-reading, **19**, 166
vacuum-tube (*see* Vacuum-tube voltmeter)
VR tube, **21**, 495
characteristics table, **21**, 497
internal impedance, **21**, 530
VSWR (*see* Standing-wave voltage ratio)

W

Wall surfaces, corrugated, **9**, 116
scratched, **9**, 116
Warm front, **13**, 263
Water, index of refraction, **13**, 675
load (*see* Load, water)
molecular weight, **13**, 293
supercooled, **13**, 183
temperature, **13**, 300, 310
measurements, **13**, 299
variation, **13**, 250–254
vapor, **13**, 26
content of atmosphere, seasonal variation and effect, on M-profile, **13**, 259
equation of state, **13**, 182
lapse and M-gradient, **13**, 13, 192
line-breadth constant, **13**, 658–664
rotational spectrum, **13**, 656–658
Water, vapor, selection rules, **13**, 656–658
Wattmeter, coaxial, for field use, **11**, 215
Wave, circularly polarized, **8**, 350
continuous, **19**, 101–126
cylindrical, **12**, 75
elementary, **13**, 18
equation, **10**, 9; **12**, 71–73; **13**, 60
solution, diffraction region, **13**, 109
interference region, **13**, 99
vector form, **13**, 59, 445
impedance, **8**, 18; **9**, 37, 41, 53, 647
nonsymmetrical, **22**, 113
number, **8**, 18
plane, **12**, 73
principal, **12**, 203
rectangular, **22**, 123
sea, **13**, 486–493
scattering from, **13**, 492, 519–527
standing, **1**, 391; **9**, 13–19
trains, recurrent, cancellation, **20**, 471–527
delay, **20**, 471–527
uniform cylindrical, **8**, 26–28
velocity, **12**, 110
Waveforms, abrupt, **19**, 159
analysis, **21**, 574
area-balanced, **22**, 454–466
balancing, **22**, 446
bibliography, **19**, 764–765
bunched-beam-current, **7**, 233–235
current (*see* Current waveforms)
differentiation and integration, **19**, 648–666
distortion, **19**, 443
level setting by, **19**, 454
exponential, **19**, 297–301
function-generation methods, **21**, 104, 118
sine-wave, **19**, 101–158
stable states, **19**, 162
generator, fast, **19**, 159–204
hyperbolic, **19**, 301–305
parabola, **19**, 305–312
sanaphant, **19**, 200–202
sanatron, **19**, 200–202
sawtooth (*see* Generator)
see-saw, **19**, 28
trapezoid, **19**, 297
triangle, **19**, 254–288, 291

Waveforms, with linear circuit elements, operations on, **19**, 17–39
mathematical operations on, **19**, 629–693
measurements, **19**, 694–706
multiplication and division, **19**, 668–678
with nonlinear circuit elements, characteristics, **19**, 58–100
operations with, **19**, 40–58
pulse, **19**, 211–218
sawtooth, with amplitudes of several kilovolts, **19**, 482
shaping, by passive elements, **19**, 19–23
special, **19**, 289–324
squares and square roots, **19**, 678–693
staircase, **19**, 293
step-plus-sawtooth, **22**, 357
timing, **19**, 167
TM, general properties, **19**, 466–476
triangular, **19**, 254–288, 291
voltage amplifiers for, **22**, 359–362
Wavefront, **13**, 42
elementary wave, **13**, 63
and rays, **12**, 107–128
Waveguide, **1**, 398–405; **7**, 7; **26**, 5, 165, 174, 176, 186
attenuation, **1**, 405
measurement, **11**, 804–853
attenuation constant (*see* Attenuation constant)
bends, **1**, 402
and twists, **9**, 207–209
capacitively loaded, **8**, 192
choke coupling, **1**, 401
choke joints, **8**, 197
choke split, **14**, 333, 334
circuit, directly coupled, **6**, 195
efficiency, **6**, 36, 181, 185, 421, 626, 717
elements, **8**, 162–206
circular, annular obstacles in, of zero thickness, **10**, 249
annular window in, **10**, 247–249
aperture coupling of, **10**, 330
to rectangular guide, **10**, 332
circular obstacle in, **10**, 273–275
closed, resonance in, **8**, 361–364
coupling to coaxial guide, **10**, 323–324
cutoff wavelength, *E*-modes, **10**, 67
Waveguide, circular, cutoff wavelength, *H*-modes, **10**, 70
with dielectric cylinders, **10**, 393–396
elliptical and circular apertures in, **10**, 243–246
E-modes, attenuation constant, **10**, 67
cutoff wavelength, **10**, 67
field components, **10**, 66
total power, **10**, 67
gain, **12**, 340–341
H-modes, attenuation constant, **10**, 70
cutoff wavelength, **10**, 70
field components, **10**, 69
total power, **10**, 70
radiation from, E_{01}-mode, **10**, 196
H_{01}-mode, **10**, 201
H_{11}-mode, **10**, 206
and rectangular guide, junction of, **10**, 324–329
resonant ring in, **10**, 275–280
cleaning, **6**, 675
coaxial, **10**, 72
aperture coupling, **10**, 331
capacitive windows in, with disk, on inner conductor, **10**, 229–234
on outer conductor, **10**, 234–238
coupling to circular guide, **10**, 323–324
cutoff wavelength, *E*-modes, **10**, 74, 77
with dielectric cylinders, **10**, 396–397
higher *E*-modes, **10**, 73
attenuation constant, **10**, 75
cutoff wavelength, **10**, 74
field components, **10**, 75
H-modes, attenuation constant, **10**, 79
cutoff wavelength, **10**, 77
field components, **10**, 78
total power, **10**, 79
junction, **10**, 310–312
lowest *E*-mode, attenuation constant, **10**, 73
field components, **10**, 72
small elliptical and circular apertures, **10**, 246–247
common, characteristics, **9**, 54–59
conical, **10**, 53, 98

Waveguide, conical, dominant *E*-mode, attenuation constant, **10**, 99
components, **10**, 99
cutoff wavelength, **10**, 99
constants, **9**, 191
corners, **9**, 203–207
couplings, **9**, 193–202, 288–303; **11**, 15, 859
choke-flange, **11**, 14
beyond cutoff, **10**, 27
lines terminating in, **10**, 168–178
cutoff frequency, **1**, 400; **9**, 49
cylindrical, determining percentage of TE_{11}-mode, **9**, 381–388
field equations, **12**, 201–203
dielectric plates in, **8**, 374–376
dielectrics in, **8**, 365–400
different, joining of, **9**, 53
dimension choice, **9**, 188–193
with dissipation, **10**, 17
duplexers, **14**, 341
elliptical, **10**, 79
$_eE_{mn}$-mode, field components, **10**, 81
$_eH_{mn}$-mode, attenuation, **10**, 83
cutoff wavelengths, **10**, 83
degenerate modes, **10**, 83
field components, **10**, 82
power flow, **10**, 83
energy density, **8**, 50–54
E-plane bifurcation, **8**, 293; **10**, 353–355, 380–383
equivalent circuit, **10**, 12, 104
field distribution (*see* Field distribution)
fields in, **9**, 39
filters, **9**, 643–645
flexible, **11**, 244; **26**, 141
wire-screen, **9**, 287
halo-loop circuits, **6**, 191
height change, **8**, 188
as high-pass filters, **9**, 644
hinge joints, **9**, 438–442
and horn feeds, **12**, 334–387
H-section, **6**, 199
inductive iris, **9**, 78
inductive slit, **8**, 164–166
iris-coupled, short-circuited, **8**, 231–234
junction (*see also* Junction), **8**, 130–132; **14**, 269
effects in, **12**, 214, 215
with four arms, **8**, 298–317
Waveguide, junction, with several arms, **8**, 283–333
symmetry, **8**, 401–479
length, **1**, 400; **9**, 48
equivalent T-network of, **8**, 77
lossless, **9**, 40
lumped, **6**, 198
measurements, amplitude-transmission, **11**, 577–584
metal-hose, minimum bending radii, **9**, 276
modes (*see* Mode)
nonresonant flexible, **9**, 274–288
output, **6**, 170, 486, 497, 782
circuits, **6**, 194–203
parallel-plate, **9**, 40–46
E-modes, attenuation constant, **10**, 64
cutoff wavelength, **10**, 64
E-plane, gain pattern, **10**, 182
H-modes, attenuation constant, **10**, 65
cutoff wavelength, **10**, 65
field components, **10**, 65
radiating into half space, *E*-plane, **10**, 183
H-plane, **10**, 187
radiating into space, *E*-plane, **10**, 179
H-plane, **10**, 186
partially filled with dielectrics, **8**, 385–389
pipe, elliptical, **9**, 57
half-wave, **8**, 355
quarter-wave, **8**, 354
rectangular, normal modes, **8**, 33–38
round, normal modes, **8**, 38–40
plastic, **9**, 285–287
power dividers, **9**, 522–528
power flow, **8**, 50–54
power-handling ability, **1**, 404
propagation in composite, **10**, 387–404
radial, **10**, 89
cylindrical cross sections, **10**, 89
cylindrical sector cross sections, **10**, 93
E-type modes, cutoff wavelength, **10**, 91, 94
dominant, impedance description, **10**, 31
field components, **10**, 90, 93
total outward power, **10**, 91

Waveguide, radial, field representation, **10**, 29–47
H-type modes, cutoff wavelength, **10**, 92, 95
field components, **10**, 92, 94
radiation from, aperture treatment, **12**, 334
radiation patterns, circular, **12**, 336–341
rectangular, **12**, 341–347
radiators, as array elements, **12**, 301–303, 329
rectangular, **10**, 405
120° Y-junction, E-plane, **10**, 352
H-plane, **10**, 172, 302–307, 362, 383–386
aperture coupling, **10**, 329–333
to circular guide, **10**, 332
apertures, **10**, 193
bends and corners, **8**, 201–203
bifurcation of (*see* Bifurcation, rectangular guides)
capacitive obstacles in, of finite thickness, **10**, 249–255
of large thickness, **10**, 404–406
and windows in, of zero thickness, **10**, 218–221
capacitive post, **10**, 268–271
change, in cross section to circular guide, **10**, 176
in height, **10**, 307–310
circular aperture, **10**, 410
and elliptical apertures in, of zero thickness, **10**, 238–243
circular bends in, E-plane, **10**, 333–334
H-plane, **10**, 334–335
contiguous, slit coupling, E-plane, **10**, 373–375
H-plane, **10**, 378
cutoff frequency, **8**, 34
dielectric posts, **10**, 266–267
with dielectric slabs, parallel to E, **10**, 388–391
perpendicular to E, **10**, 391–393
of different sizes, transition between, **9**, 361–364
E-modes, **10**, 56
attenuation constant, **10**, 57
cutoff wavelength, **10**, 57
field distribution, **10**, 57
Waveguide, rectangular, E-modes, maximum electric-field intensity, **10**, 58
total power flow, **10**, 58
E-plane corners, arbitrary angle bends of, **10**, 316–318
right-angle bends, **10**, 312–316
equivalent circuit, **8**, 119
gain, **12**, 346
H-modes, attenuation constant, **10**, 60
cutoff wavelength, **10**, 60
field components, **10**, 60
maximum field intensity, **10**, 60
total power, **10**, 61
H_{10}-mode, attenuation constant, **10**, 61
field components, **10**, 61
wavelength, **10**, 62
H-plane corner, arbitrary angle, **10**, 319–322
right-angle bends, **10**, 318–319
inductive obstacles in, of finite thickness, **10**, 255–257
of large thickness, **10**, 407–408
and windows, of zero thickness, **10**, 221–229
junction, and circular guide, **10**, 324–329
H-plane, **10**, 168, 296–302
and radial guide, E-plane, **10**, 322–323
with "nonradiating" slit, **10**, 397–398
oscillator cavity coupled to, **8**, 277–282
plungers, **8**, 198
post of variable height, **10**, 271–273
radiating, into bounded half space, E-plane, **10**, 184
into bounded space, E-plane, **10**, 183
with rectangular ridge, **10**, 399–402
with resistive strip, **10**, 402–404
solid inductive post in, centered, **10**, 258–263
noncircular, **10**, 263–266
off-centered, **10**, 257–258
spherical dent in, **10**, 273
standard, **11**, 15
thick circular window, **10**, 408–412

Waveguide, rectangular, T-junction (*see* Junction, T-, in rectangular guide)
transition to cylindrical, **9**, 364–369
resonant elements, **14**, 70–80, 97
resonant flexible, **9**, 288–303
ridge, **9**, 358
rotary joint (*see* Joint, rotary)
round, principal axes, **8**, 360
screw, **9**, 458
seamless corrugated, **9**, 282–285
spherical, **10**, 96
cotangents, **10**, 53
E_{mn}-mode, cutoff wavelength, **10**, 98
field components, **10**, 97
total power, **10**, 97
equations for electric and magnetic fields transverse, **10**, 47
field representation, **10**, 47–54
H_{mn}-mode, field components, **10**, 97
longitudinal components, **10**, 47
tangents, **10**, 53
wave equations, **10**, 51
square, circular polarization, **9**, 378
structures, asymmetric, coupling of two guides, **10**, 296–335
composite, **10**, 387–413
thickness effect, **10**, 404–413
eight-terminal, **10**, 373–386
with finite thickness, **10**, 248–279
four-terminal, **10**, 217–335
six-terminal, **10**, 336–372
two-terminal, **10**, 168–216
with zero thickness, **10**, 218–248
stub tuners, **9**, 483–485
switches, **9**, 533–539
terminal admittance, **12**, 366
terminal currents, **8**, 144–146
uniqueness, **8**, 134, 135
terminal voltages, definition, **8**, 144–146
uniqueness, **8**, 134, 135
T-junctions, circuit elements, **14**, 122
transformers, **6**, 491
transitions, equivalent circuit (*see also* Transition), **11**, 513
lowest mode in, **9**, 361–379
as transmission lines, **8**, 60–82; **10**, 1–3
transmission lines, **11**, 13–16
motional joints, miscellaneous, **9**, 433–445
Waveguide, T's, manufacture, **11**, 524
tubing for, **9**, 115–119
two, VSWR introduced by junction between, **9**, 118
uniform, field representation, **10**, 3–7
variable-width, **1**, 291
vertebral flexible, **9**, 294–303
wall losses, **11**, 590
wavelength, **1**, 400
width change, **8**, 188
windows (*see* Windows, waveguide)
wobble joint, **26**, 69, 94, 167
Wavelength, critical, **9**, 48
cutoff (*see* Cutoff wavelength)
free-space, **7**, 70
intrinsic, **9**, 42
measurements, **6**, 702–705; **11**, 285–342
resonant, **7**, 73
Wavemeters, **3**, 337; **14**, 381
24,000-Mc/sec, **11**, 327
cavity, transmission, **11**, 309–311
circuits, practical, **11**, 308–319
on coaxial stub, **11**, 318
on E-plane T, **11**, 314–316
mode, TE_{011}, **11**, 322–325, 328–330
TE_{11m}, **11**, 327
reaction, **11**, 311–314
TFK-2, **11**, 327
TFS-5, coaxial, **11**, 320
TFX-30, **11**, 323
on top of waveguide, **11**, 316–318
W-bridge, **11**, 118–123
Weatherproofing beacons, **3**, 359
Weiss discriminator, **16**, 305, 308–312
Weston cell, **21**, 495
Wet-bulb depression, **13**, 187
coefficient, **13**, 188
Whisker (*see* Catwhisker)
White caps, sea echo in presence of, **13**, 512
Wideband symmetrical junctions, **8**, 479
Width, half-power, total, resonator, **7**, 323
Wiener-Hopf integral equation, **10**, 164
Wiener-Khintchine theorem, **13**, 558, 568
Wind, direction and strength of sea echo, **13**, 514
effect on ground-clutter fluctuation, **13**, 547, 551–553, 582–584
geostrophic, **13**, 213

Wind, loads on reflectors, **26**, 33–38
resistance effects, **12**, 450, 453; **26**, 156, 227, 232, 233
speed, and superrefraction, **13**, 375
variation, along trajectory, **13**, 251
Winding, Ayrton-Perry, inductance of, **17**, 86
pie, **22**, 320
table for paper-insulated layer windings, **17**, 160–161
Window (chaff), **1**, 81; **13**, 550; **24**, 124
Windows, waveguide, **6**, 487, 682
capacitative, **12**, 230
analysis, **10**, 146, 153
asymmetrical, **10**, 140
glass, low-*Q*, leakage energy characteristic, **14**, 233
inductive, **12**, 230
iris, **6**, 203
mica, **6**, 489, 684
pressurizing, **9**, 218–227
resonant, **12**, 231; **14**, 102, 128
Wire, Copperweld, **17**, 20
hook-up, **17**, 1–13
abrasion resistance, **17**, 10–11
conductor, **17**, 2–4
current-carrying capacity, **17**, 12–13
diameter, over-all, **17**, 8–9
flammability, **17**, 11
insulation, primary, **17**, 5–7
resistance, **17**, 14–15
JAN-type designation, **17**, 2
outer covering, **17**, 7–9
resistance, to abrasion, **17**, 10–11
to fungus, **17**, 11
to high temperatures, **17**, 9–10
to low temperatures, **17**, 10
to moisture, **17**, 11–12
Wire, hook-up, resistance, to solvents, **17**, 11
stranded conductor, **17**, 3–4
temperature rise, **17**, 12
voltage drop, **17**, 13
voltage rating, **17**, 13–14
magnet, **17**, 150–151
resistance (*see* Resistance wire)
stranded, **17**, 2–4
tinned copper, **17**, 2–4
Wollaston, **11**, 157; **12**, 559, 603; **16**, 18–19
Wired sonde, **13**, 269, 283, 284, 329, 348
ground unit, **13**, 286
housing, **13**, 285
WKB approximation, **13**, 72
Worm gearing, **27**, 9
differential, **27**, 9, 11
Wronskian, **13**, 58, 69, 79, 94
Wurzburg range unit, **20**, 163
WWV, radio station, **11**, 344, 353

X

X-bridge, **11**, 123–127
X-pandotite cement, **9**, 133

Y

Yaw stabilization, **1**, 311
Yehudi, **3**, 277
Y-junction (*see* Junction)

Z

$\zeta(x,y)$, function, **8**, 259
Zero position (computer), **27**, 6, 22
Zero-range trigger for modulator, **20**, 95
Zeroing of synchros, **17**, 331–336