Oscillator Phase Noise

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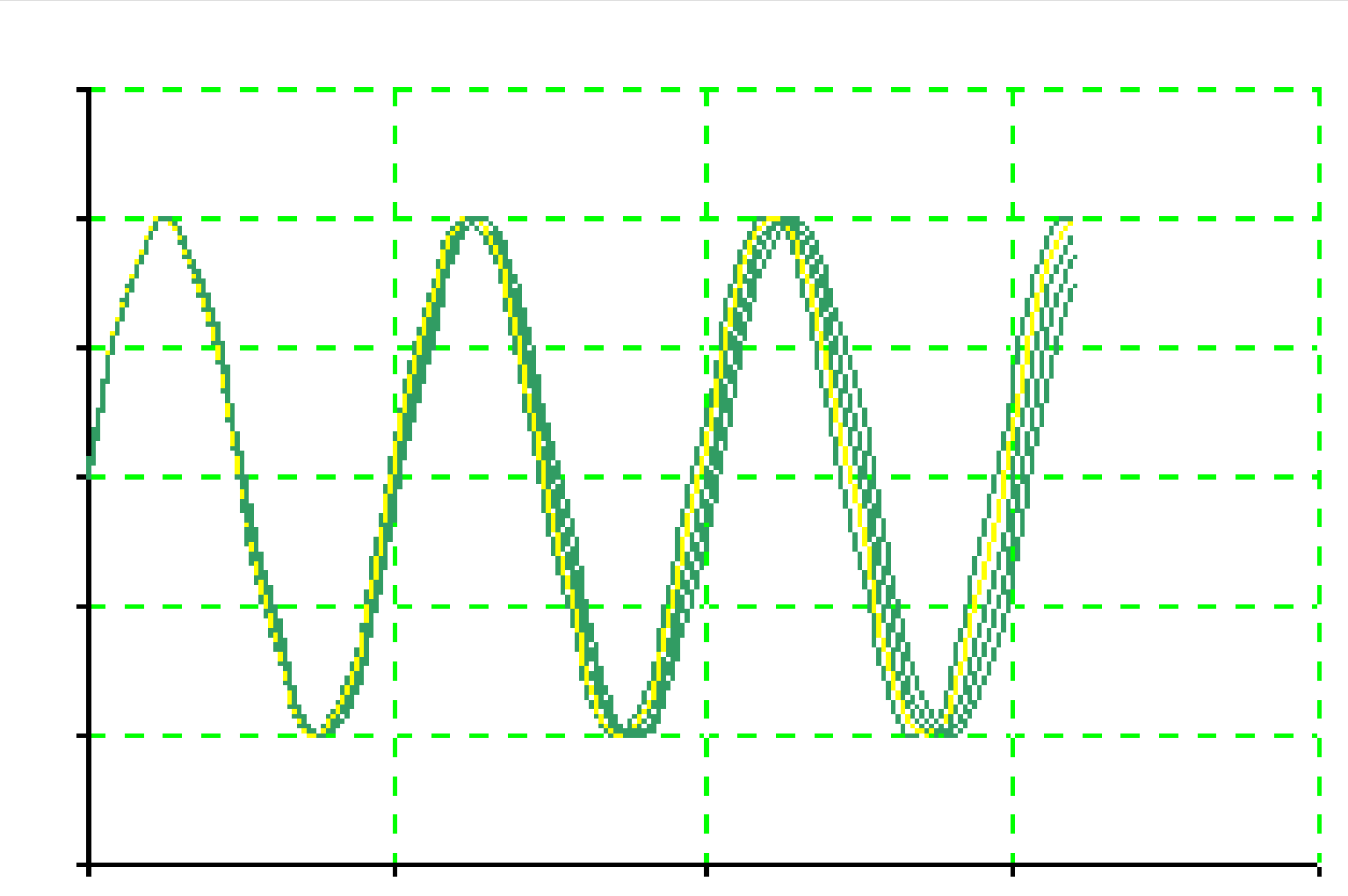
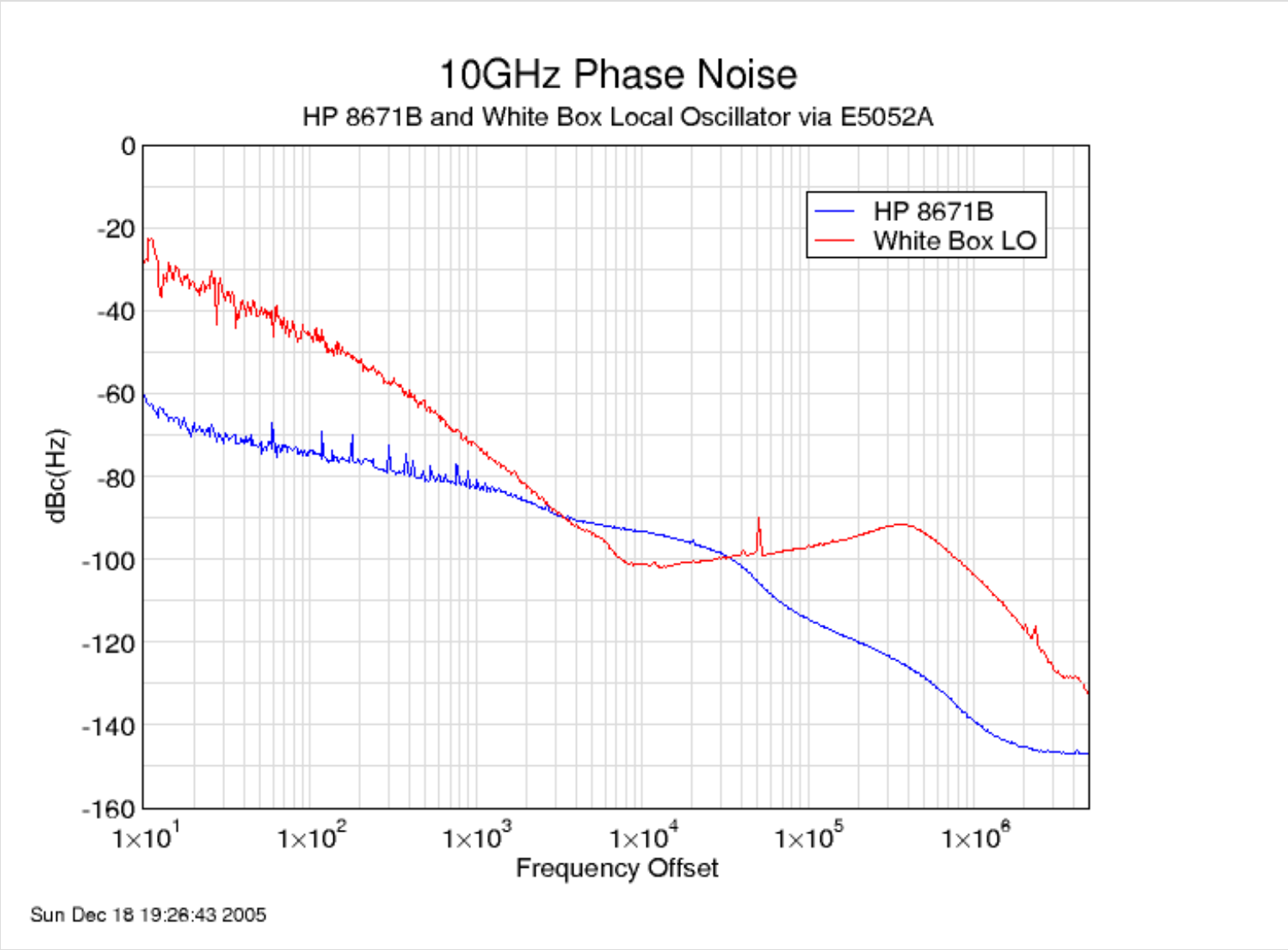
What is Phase Noise?

- All oscillators create noise in addition to the desired signal.
  - Noise is really just undesired modulation
- Amplitude noise is not usually a major design concern, but phase noise adversely affects performance
  - Higher noise floor – reduced SNR
  - Reciprocal mixing – distortion and interference
  - Fuzzy sounding signals – difficult copy

Phase Noise in the Time Domain



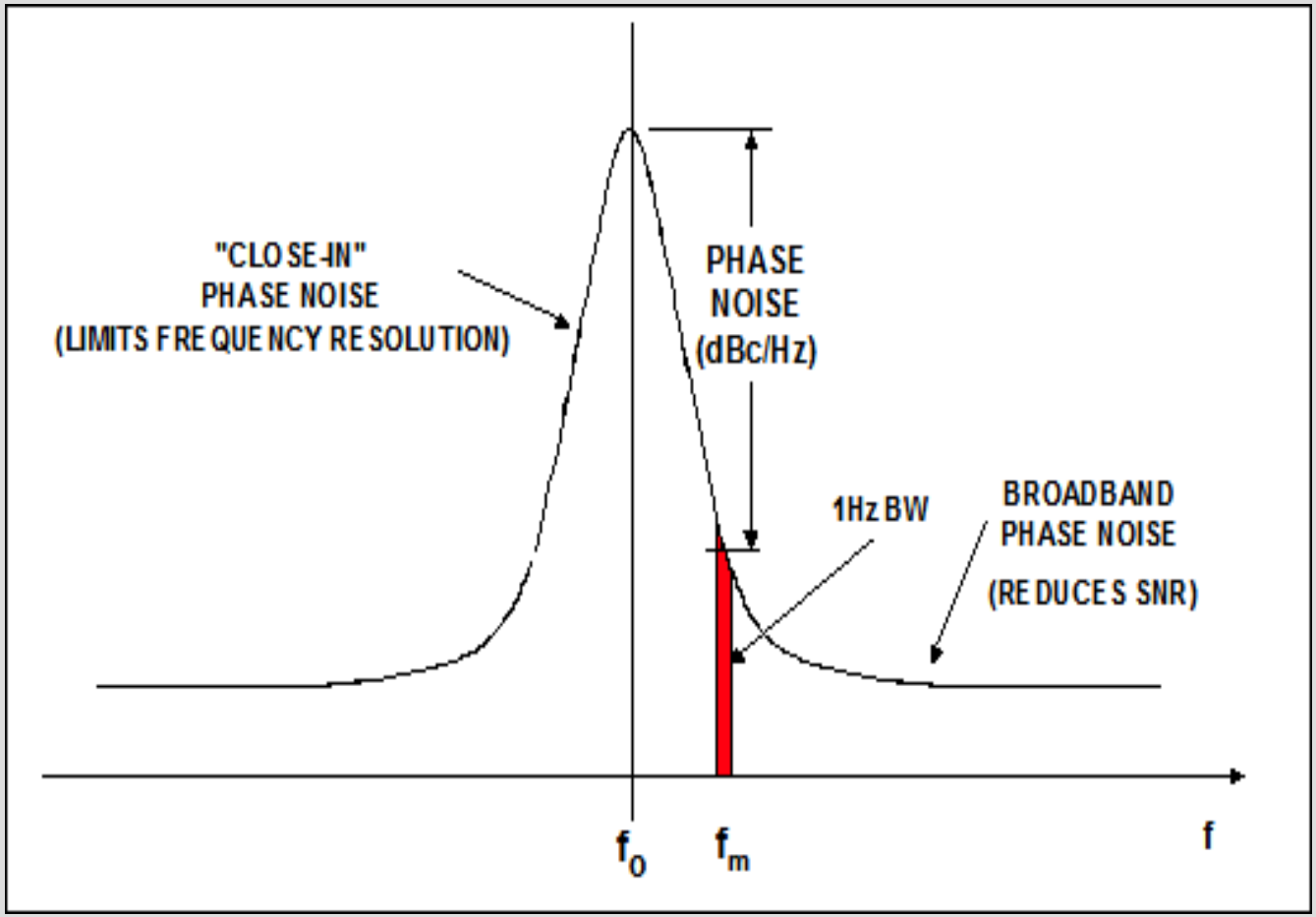
Phase Noise in the Frequency Domain



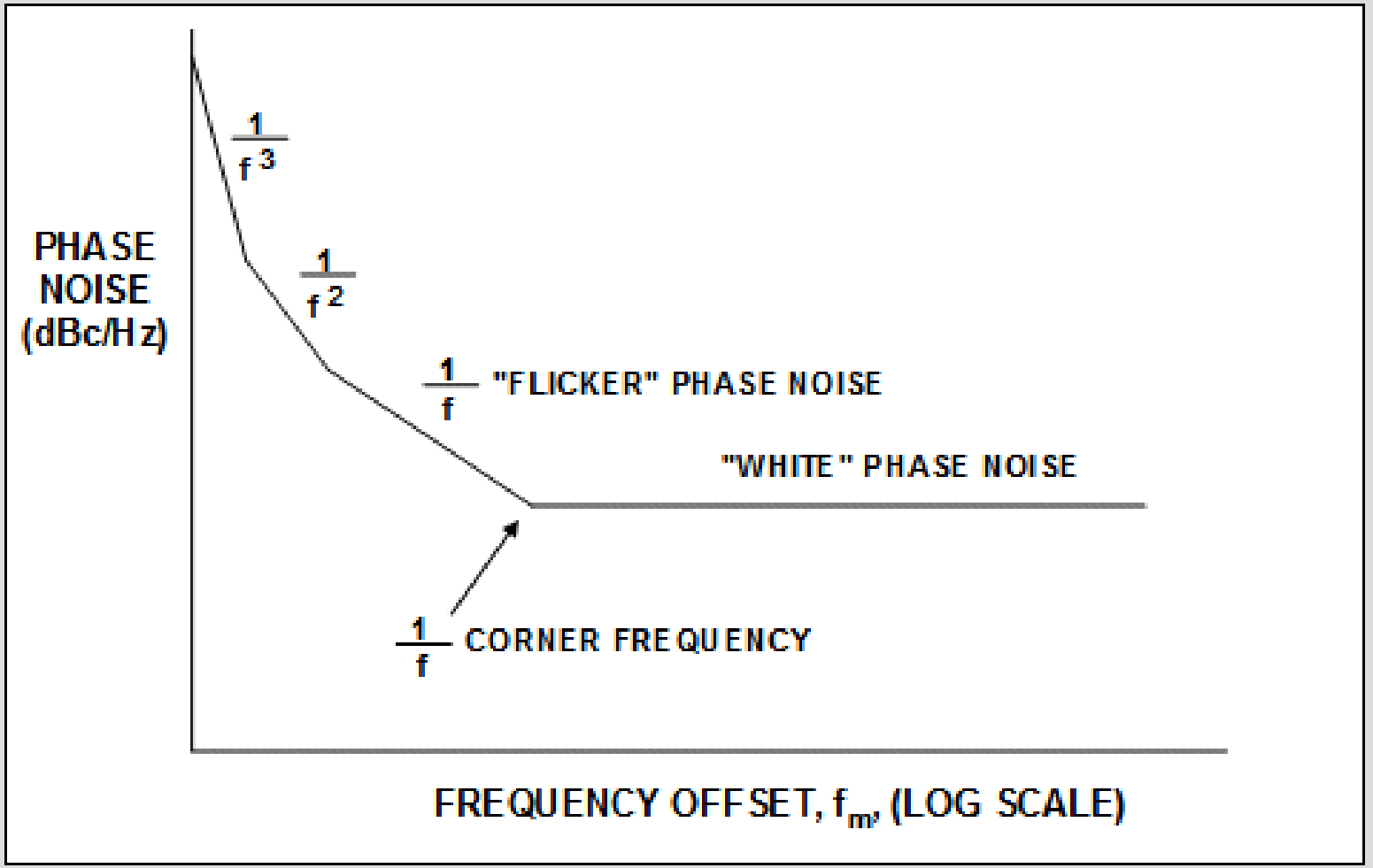
Phase Noise Terminology

- Usually measured as SSB noise normalized to 1 Hz BW at specified carrier offset
  - *e.g.*, “-125dBc/Hz at 100 Hz”
  - “dBc” = dB relative to carrier level
- Noise characteristics:
  - Close-in, decreases with offset; slope shows noise type
  - At some point, slope flattens and noise floor is reached
  - Spurs may occur at discrete frequencies (*e.g.*, 60 Hz or harmonics)

A Picture of Phase Noise



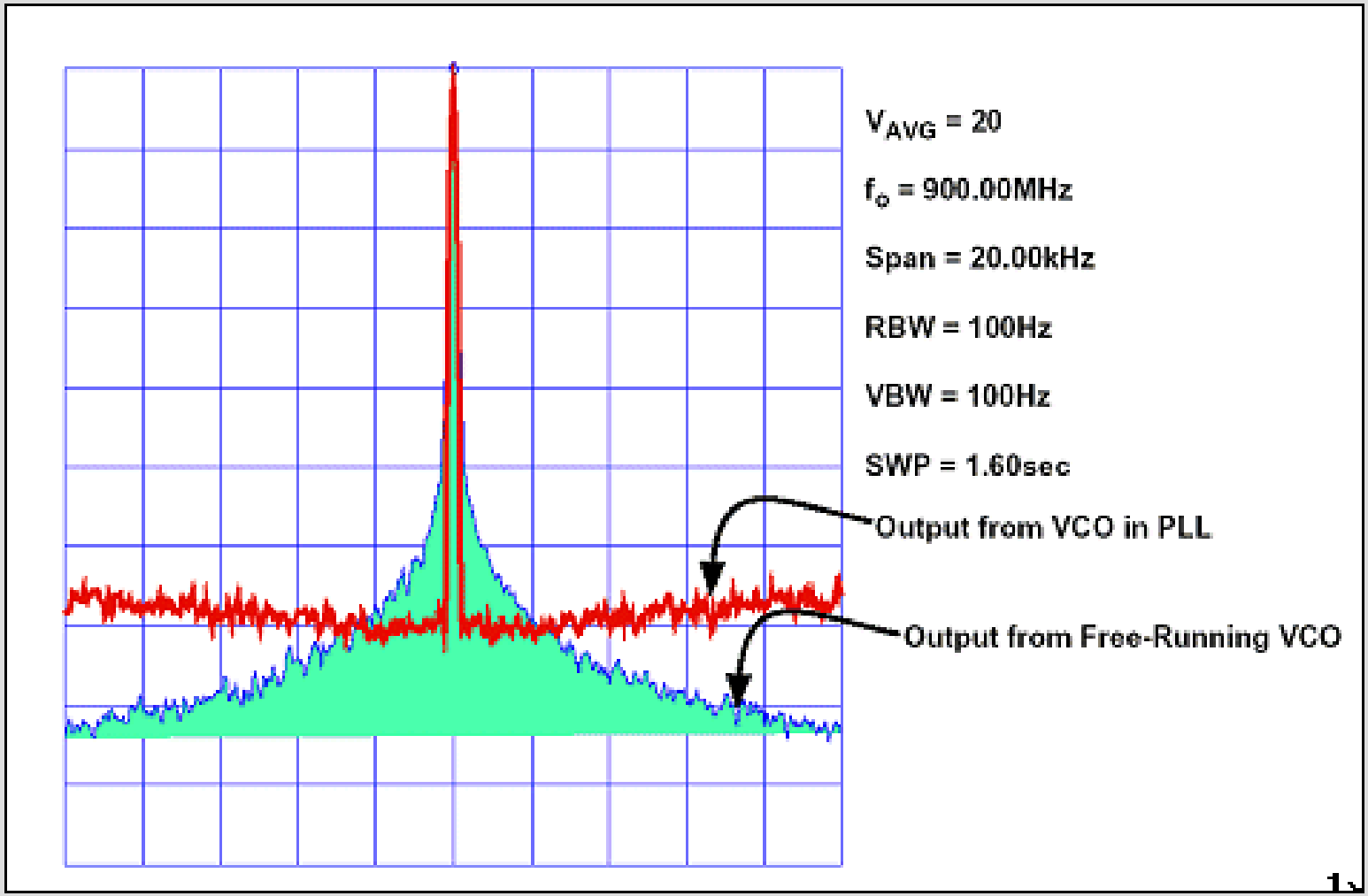
Types of Noise



The Laws of Physics

- Phase noise increases with frequency multiplication – 20 * log10(N) where N is the multiplication factor.
  - Doubler increases noise 6dB; 10X adds 20 dB
  - Formula is 20*log(N) where N is the multiplication factor
- Division similarly reduces noise
  - Limited by noise floor of divider
- A PLL can improve phase noise
  - Noise within loop BW is same as if multiplied
  - Noise outside BW is set by VCO

Effect of a PLL



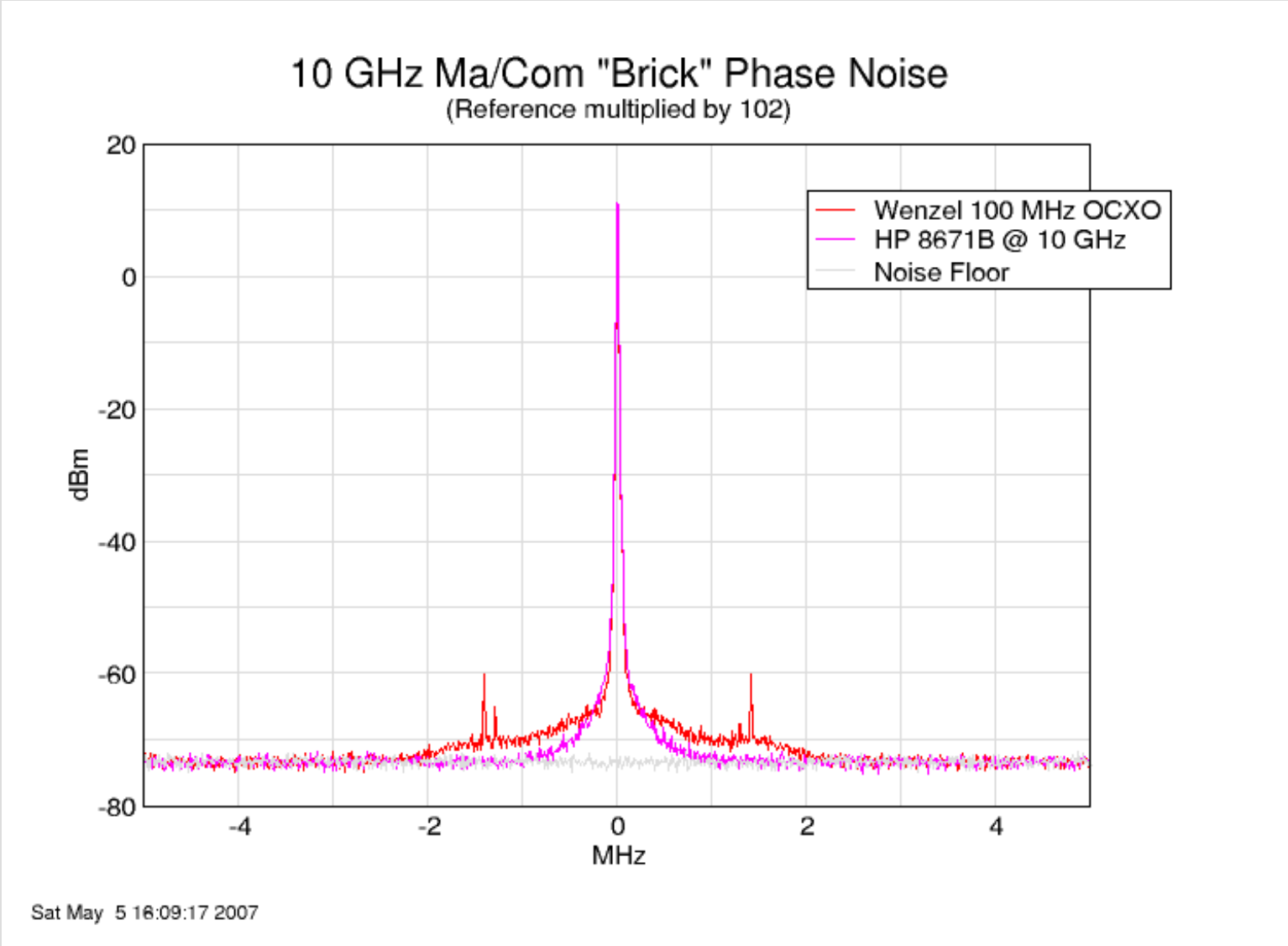
Measurement Techniques

- In theory, a spectrum analyzer can measure phase noise – simply measure noise power at given offset and normalize to 1 Hz BW
  - In practice, analyzer LO noise is limiting factor
  - Neat trick: multiply with a brick! (tnx KE5FX)
- Traditional system has reference locked in quadrature to DUT, with both fed to a mixer; low frequency output goes to analyzer
- Modern designs use DSP and correlation techniques to reduce the noise floor

The Real World

- OK, I'm building a 10 Ghz rig. What does this all mean to me?

10 MHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
HP 8671B @ 10 GHz
Noise Floor
dBm
20
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-20
-40
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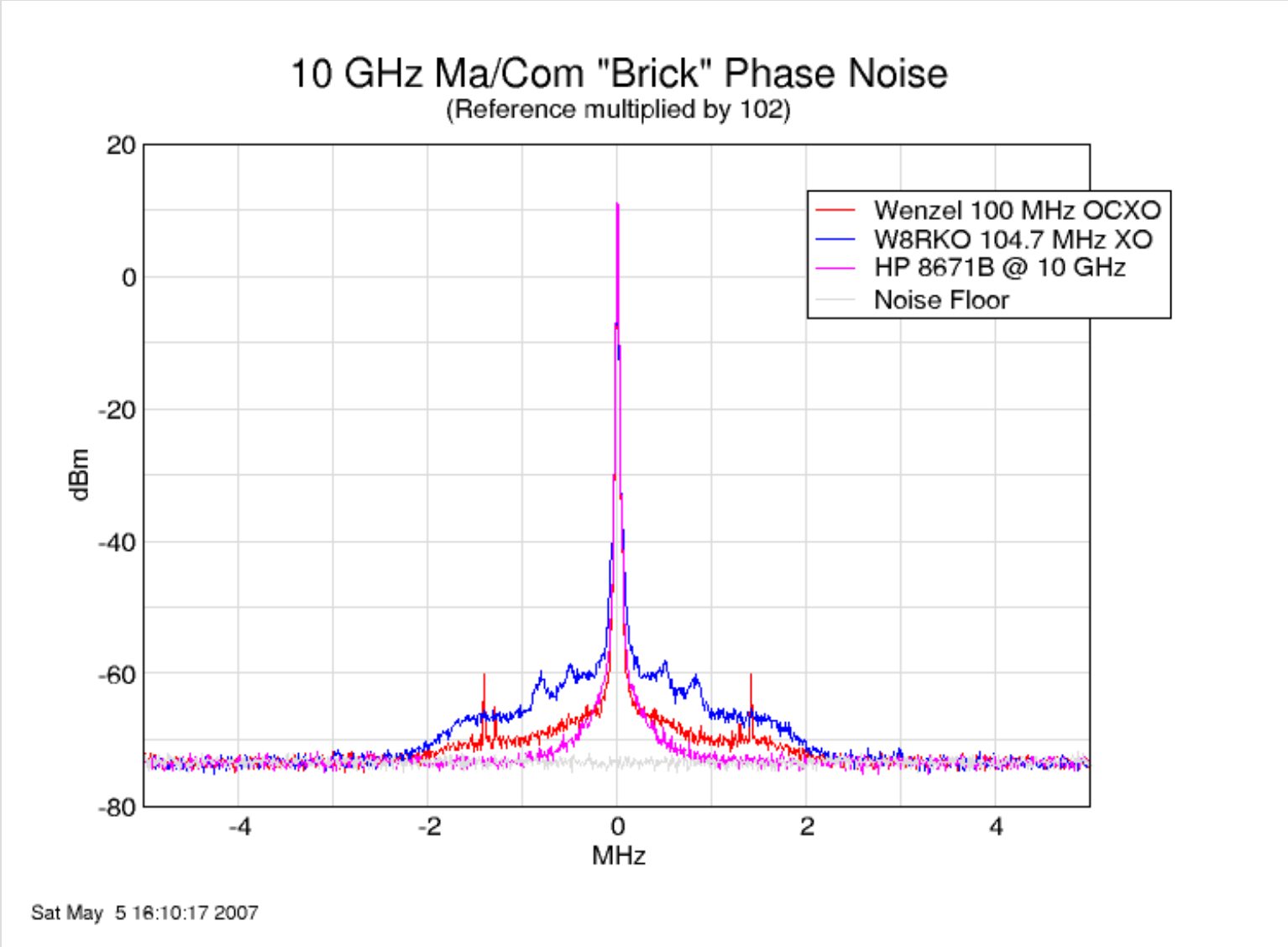
MHz
Sat May 5 16:09:17 2007

10 MHz Span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Noise Floor
dBm
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MHz
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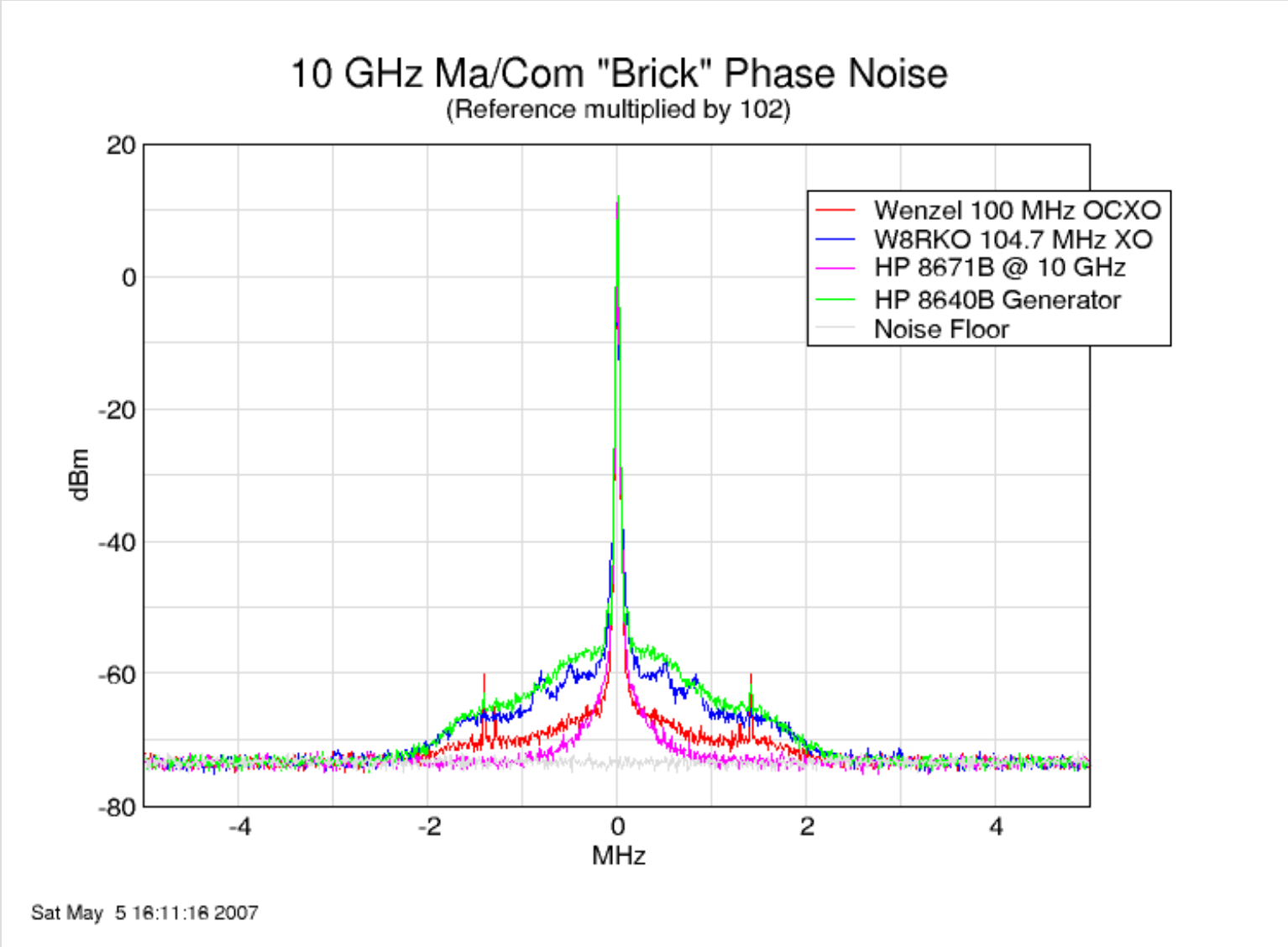
10 MHz Span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HP 8671B @ 10 GHz
HP 8640B Generator
Noise Floor
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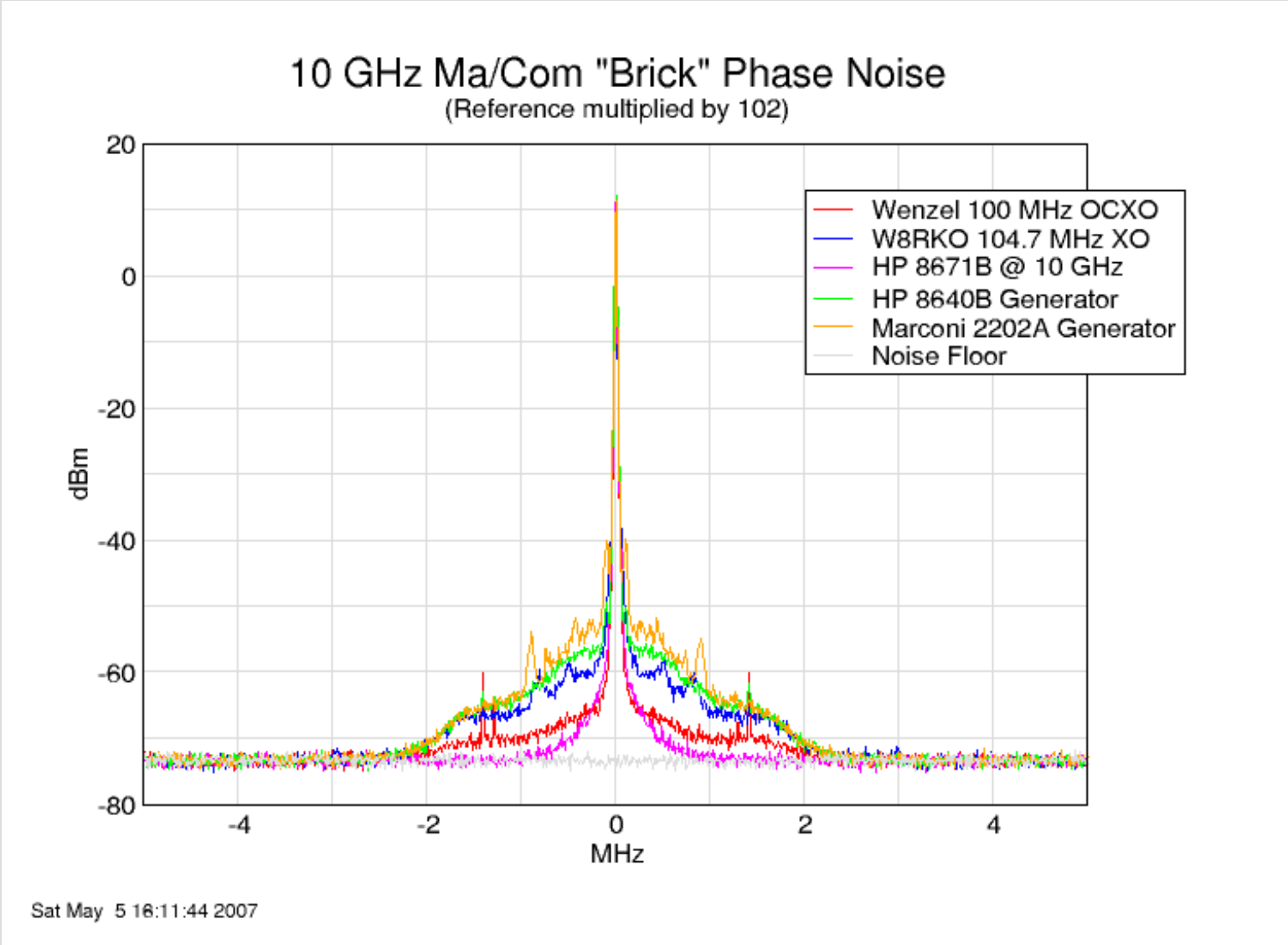
10 MHz Span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HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
Noise Floor
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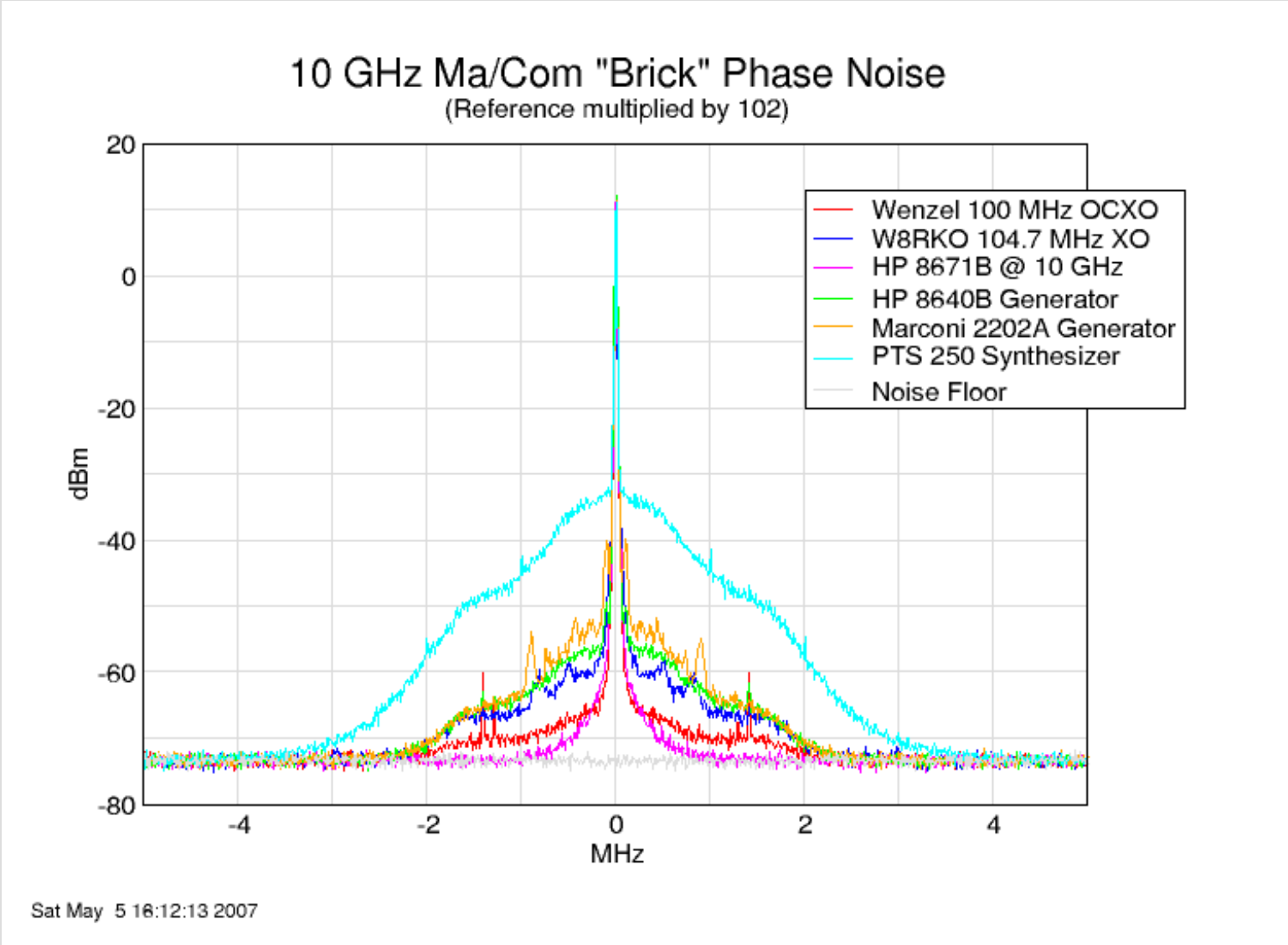
10 MHz Span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HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
PTS 250 Synthesizer
Noise Floor
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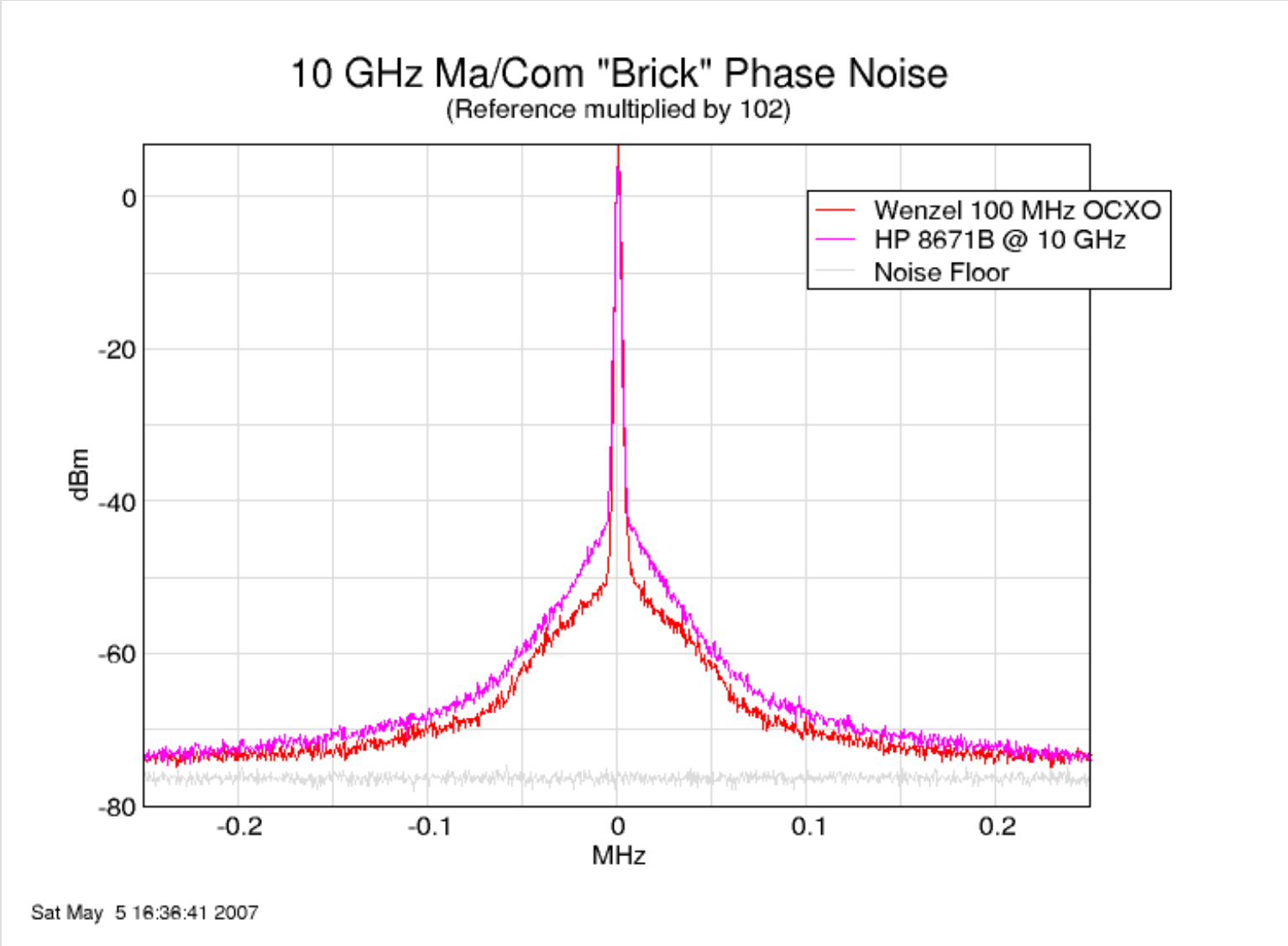
500 kHz Span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HP 8671B @ 10 GHz
Noise Floor
dBm
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MHz
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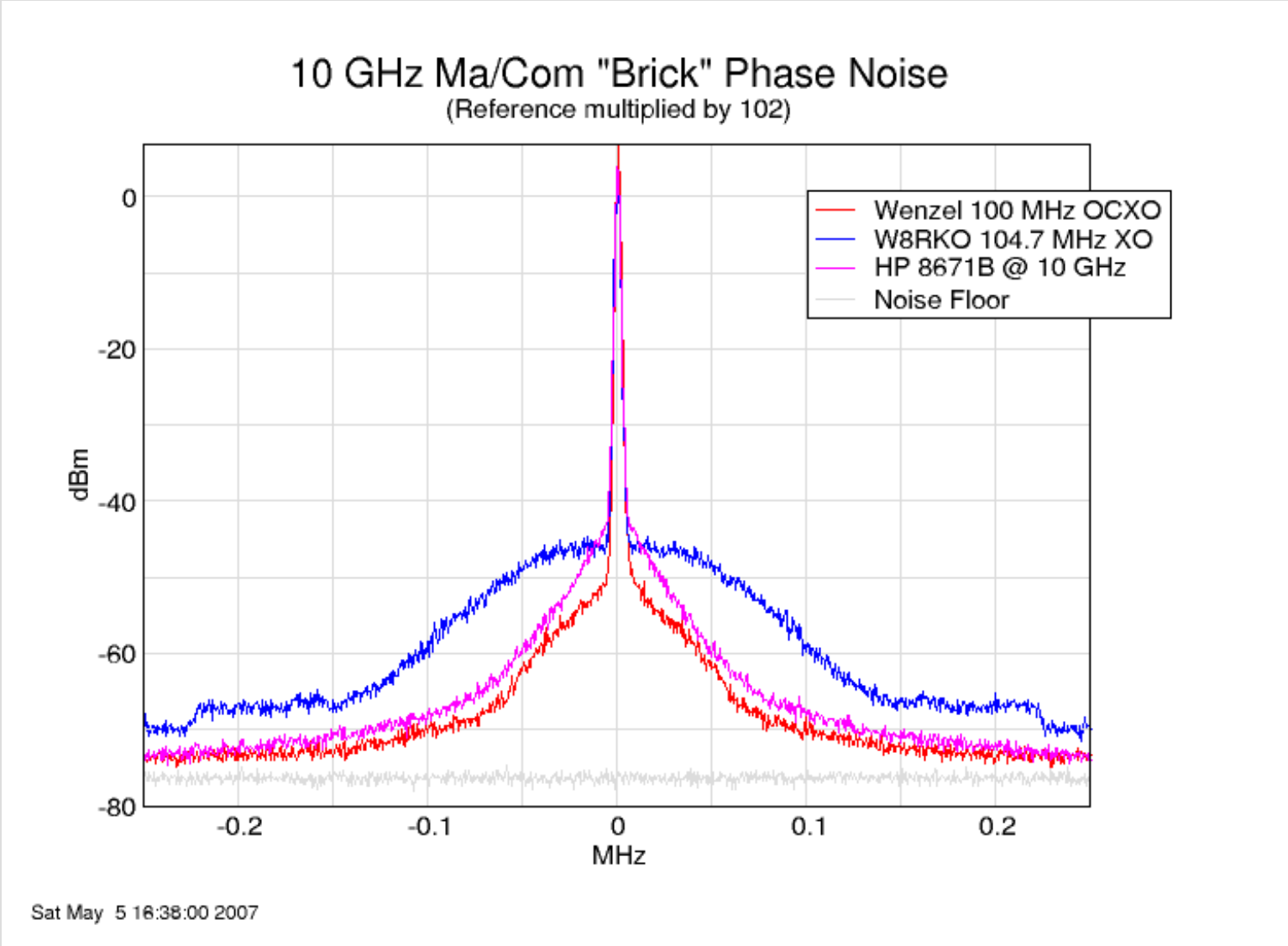
500 kHz Span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dBm
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MHz
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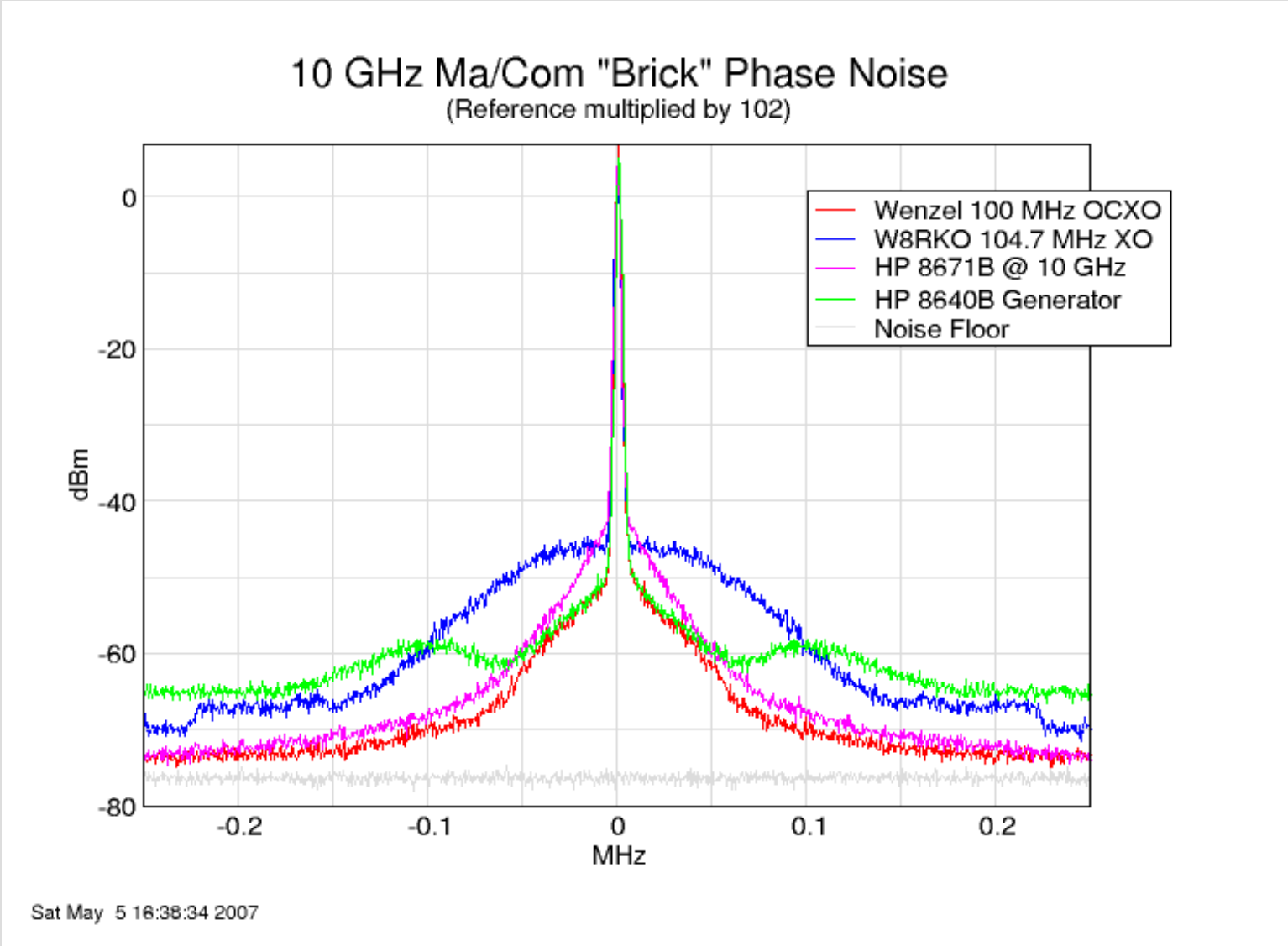
500 kHz Span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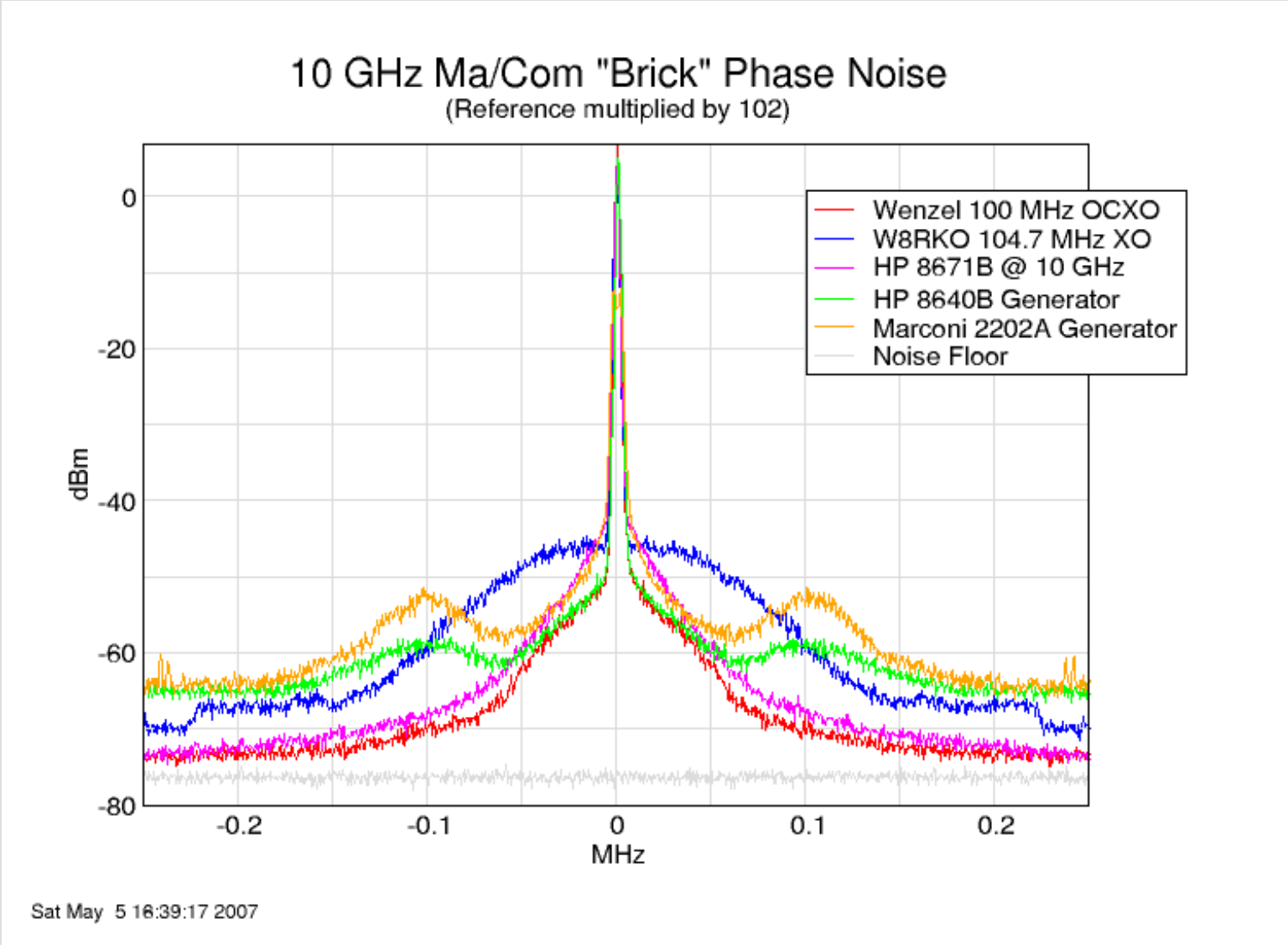
500 kHz Span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dBm
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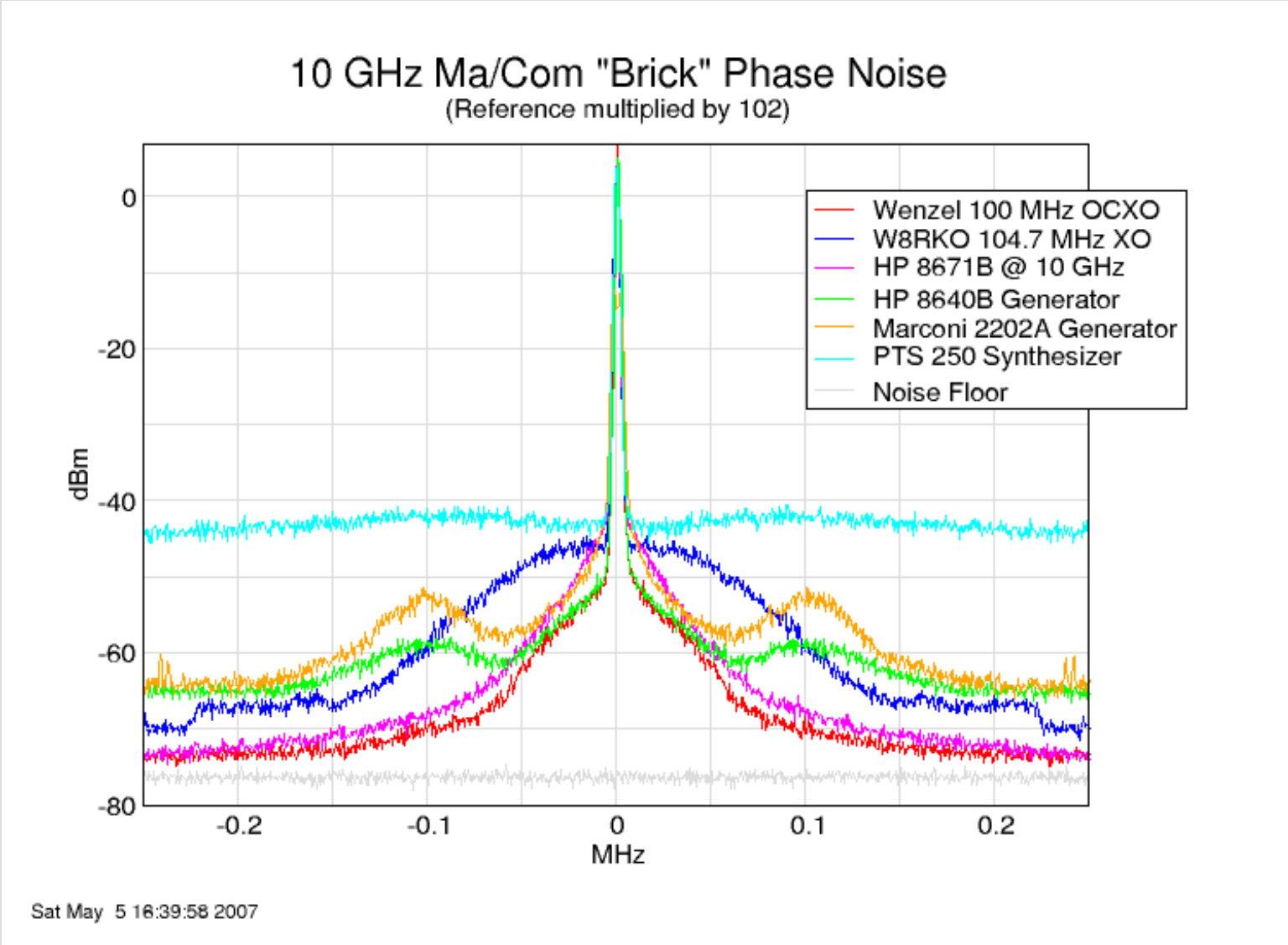
500 kHz Span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Noise Floor
dBm
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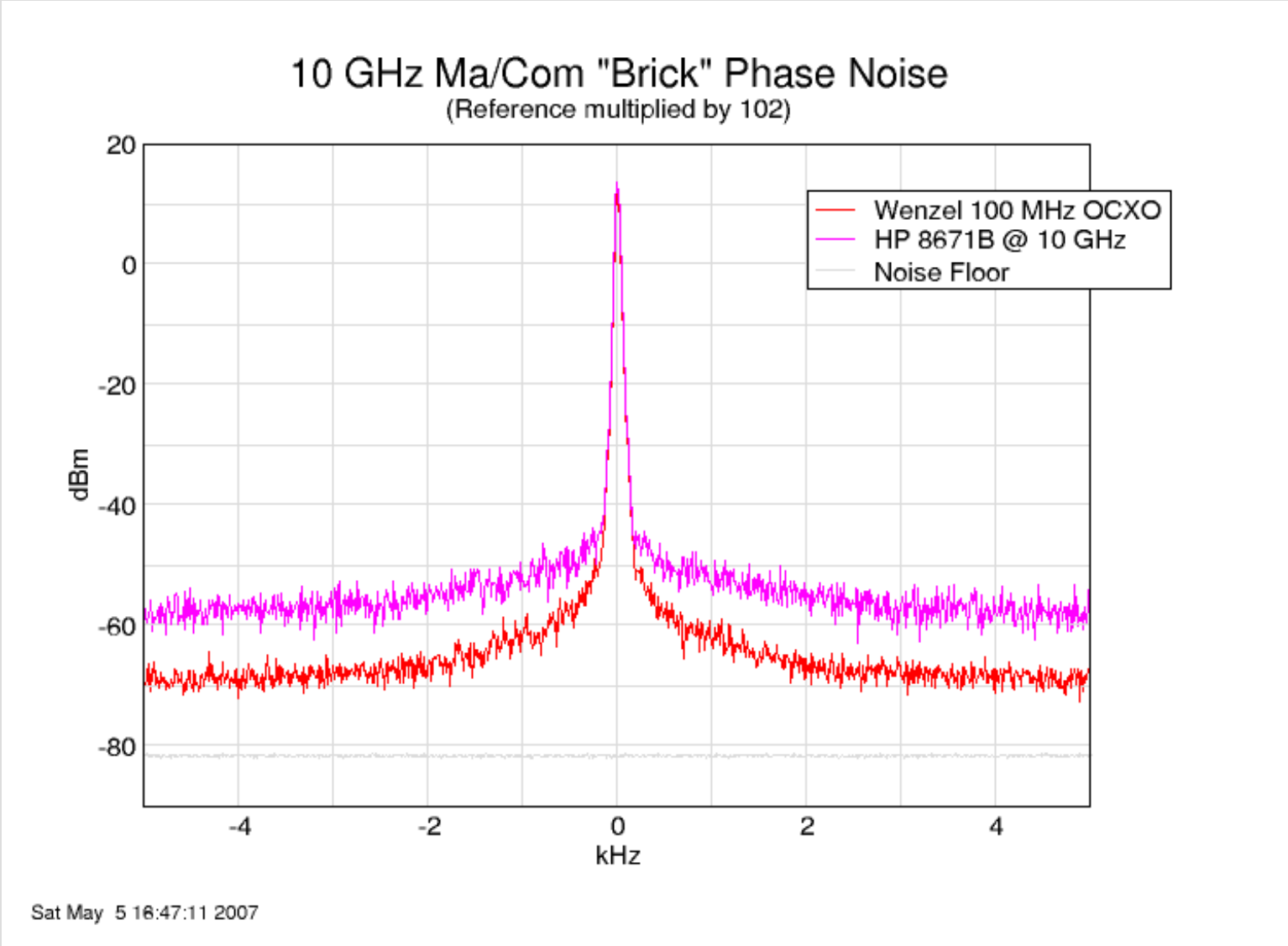
10 kHz Span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Noise Floor
dBm
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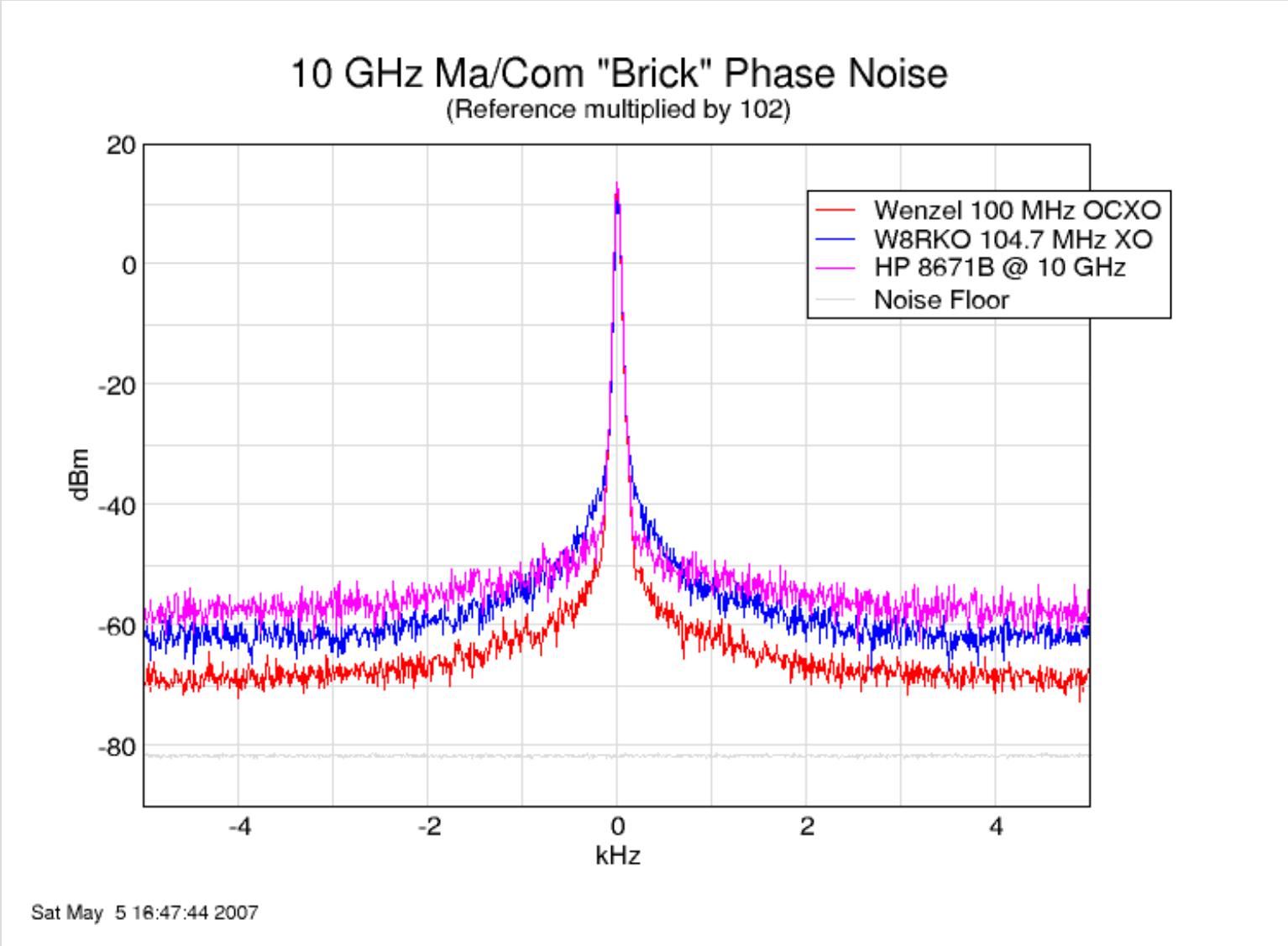
10 kHz Span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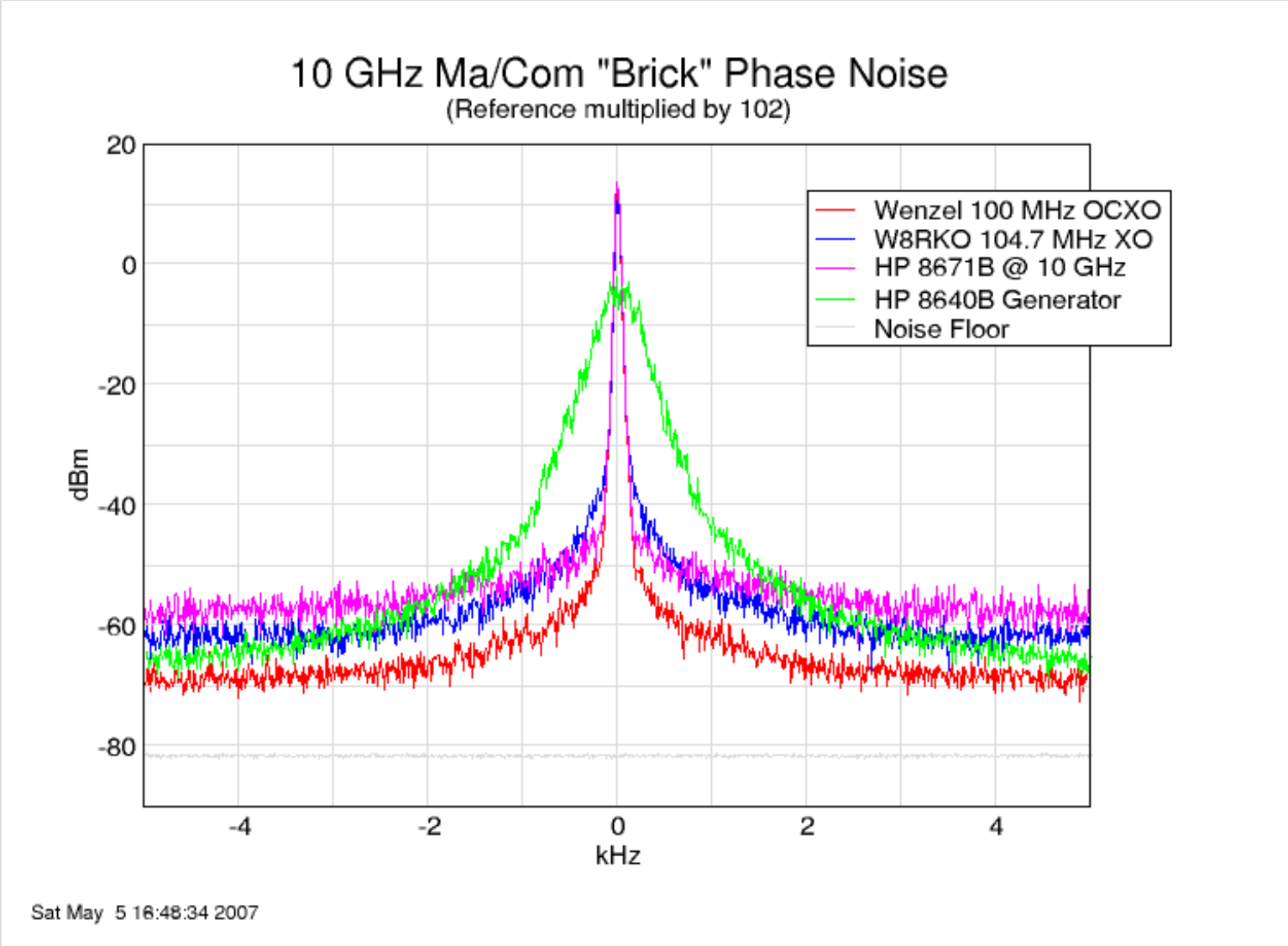
10 kHz Span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Wenzel 100 MHz OCXO
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HP 8671B @ 10 GHz
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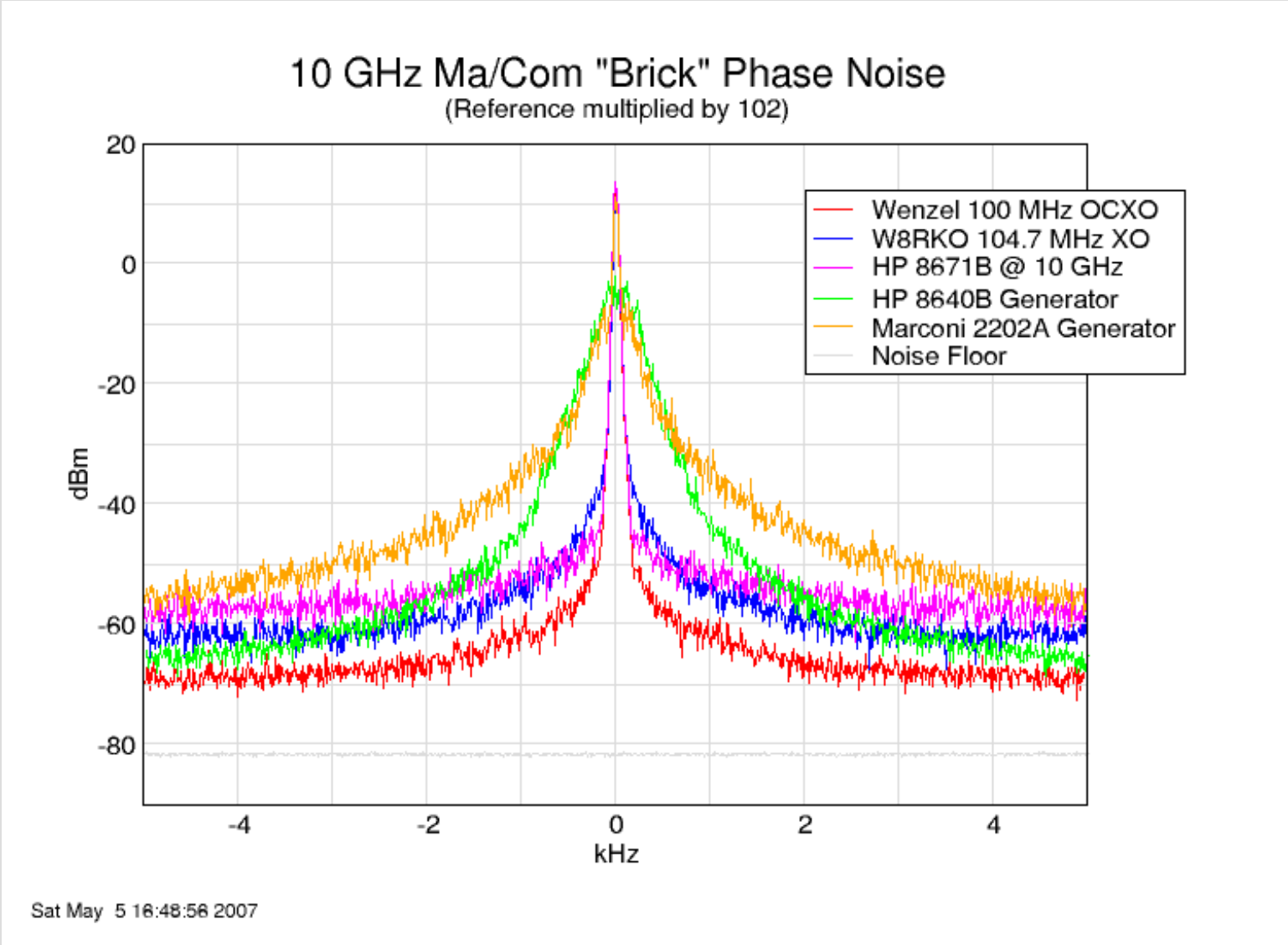
Sat May 5 16:48:34 2007

10 kHz Span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Wenzel 100 MHz OCXO
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HP 8671B @ 10 GHz
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Marconi 2202A Generator
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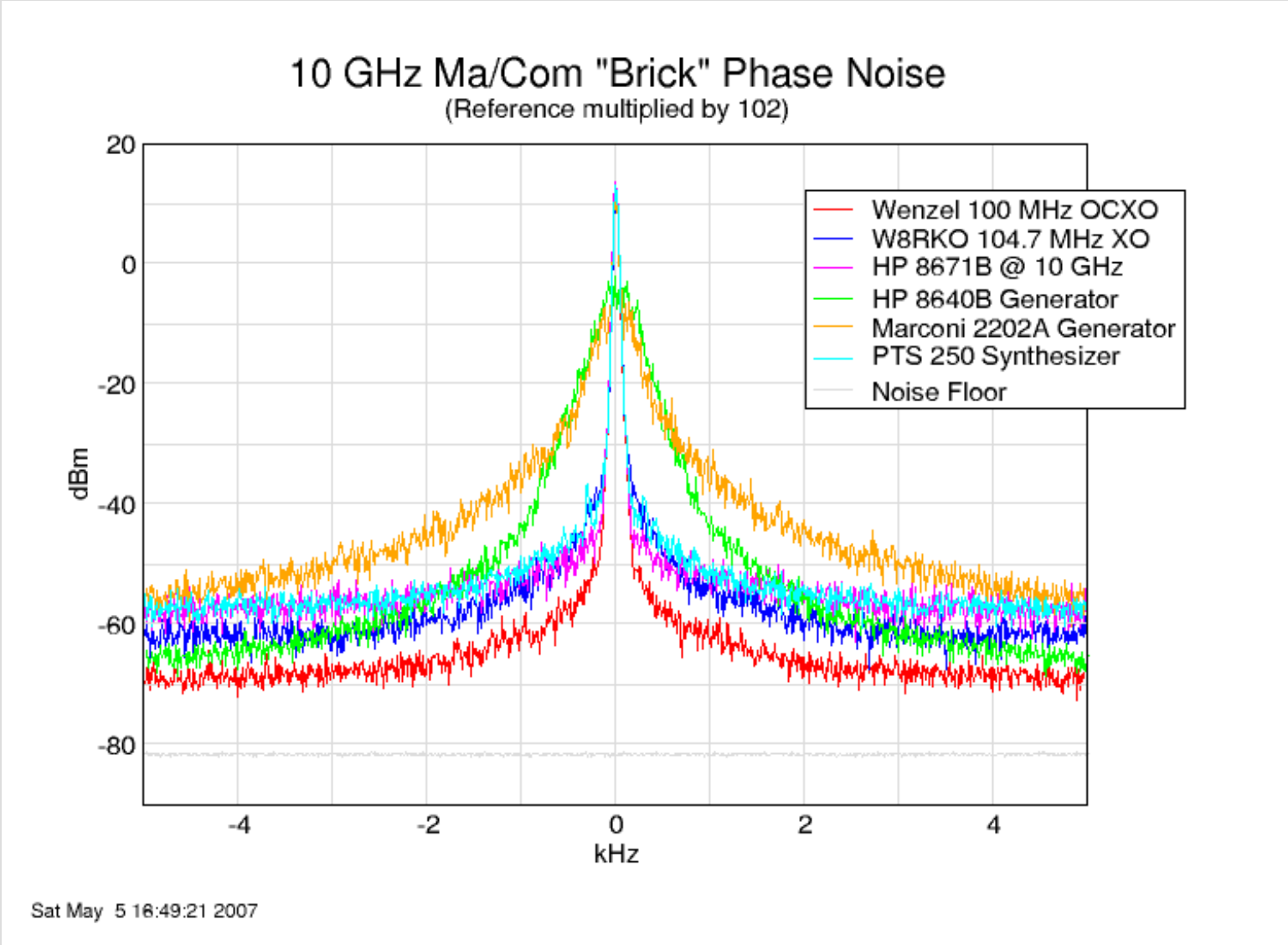
10 kHz Span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HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
PTS 250 Synthesizer
Noise Floor
Sat May 5 16:49:21 2007

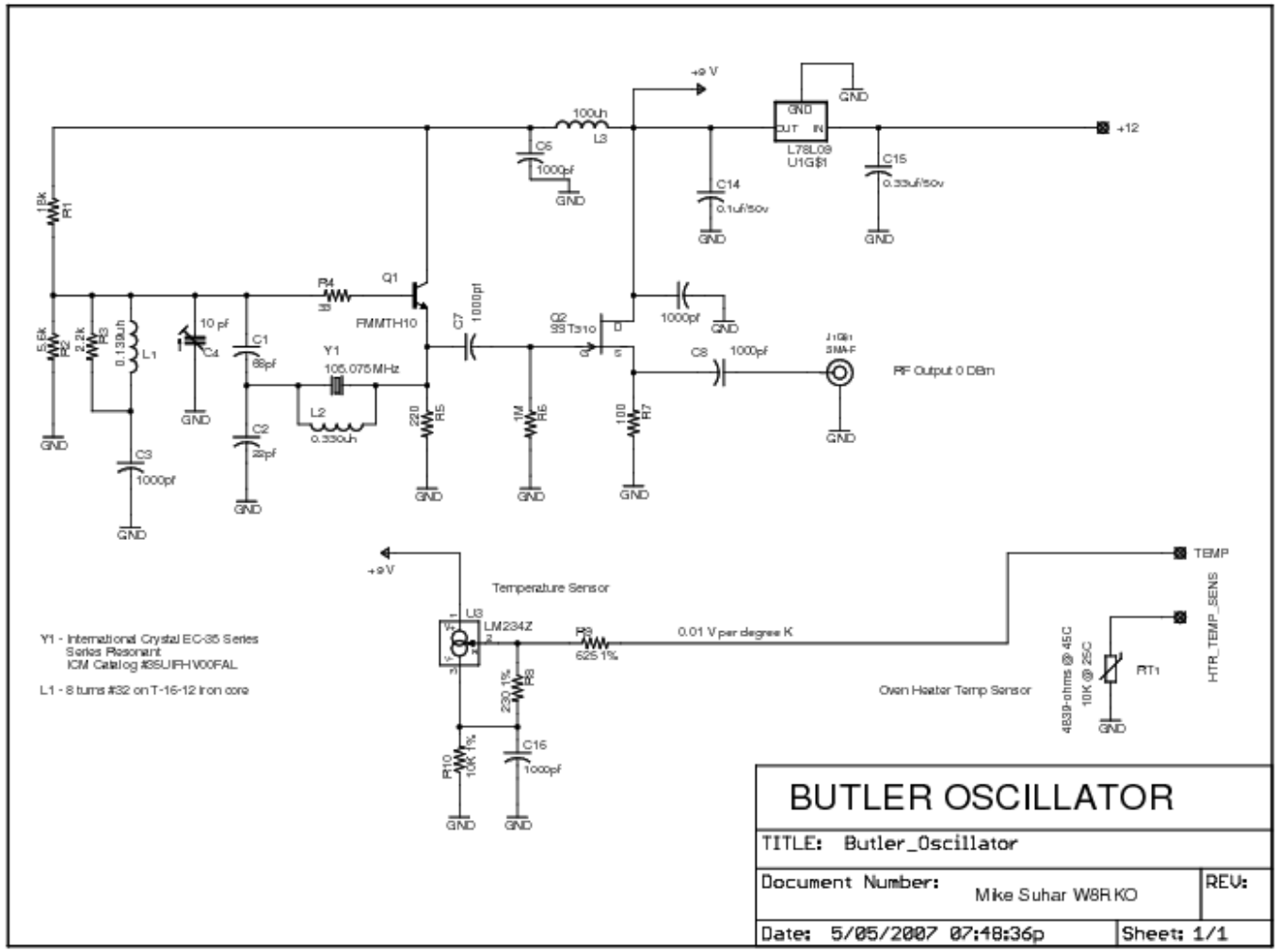
The Moral

- 10 GHz is a challenge – you're multiplying by 100 or more, so your phase noise will increase by 40+dB
  - And it gets worse when you go higher!
- No one number tells you whether a source is “good” or “bad”
  - Wideband performance may be very different from narrowband.
  - What's important to you?

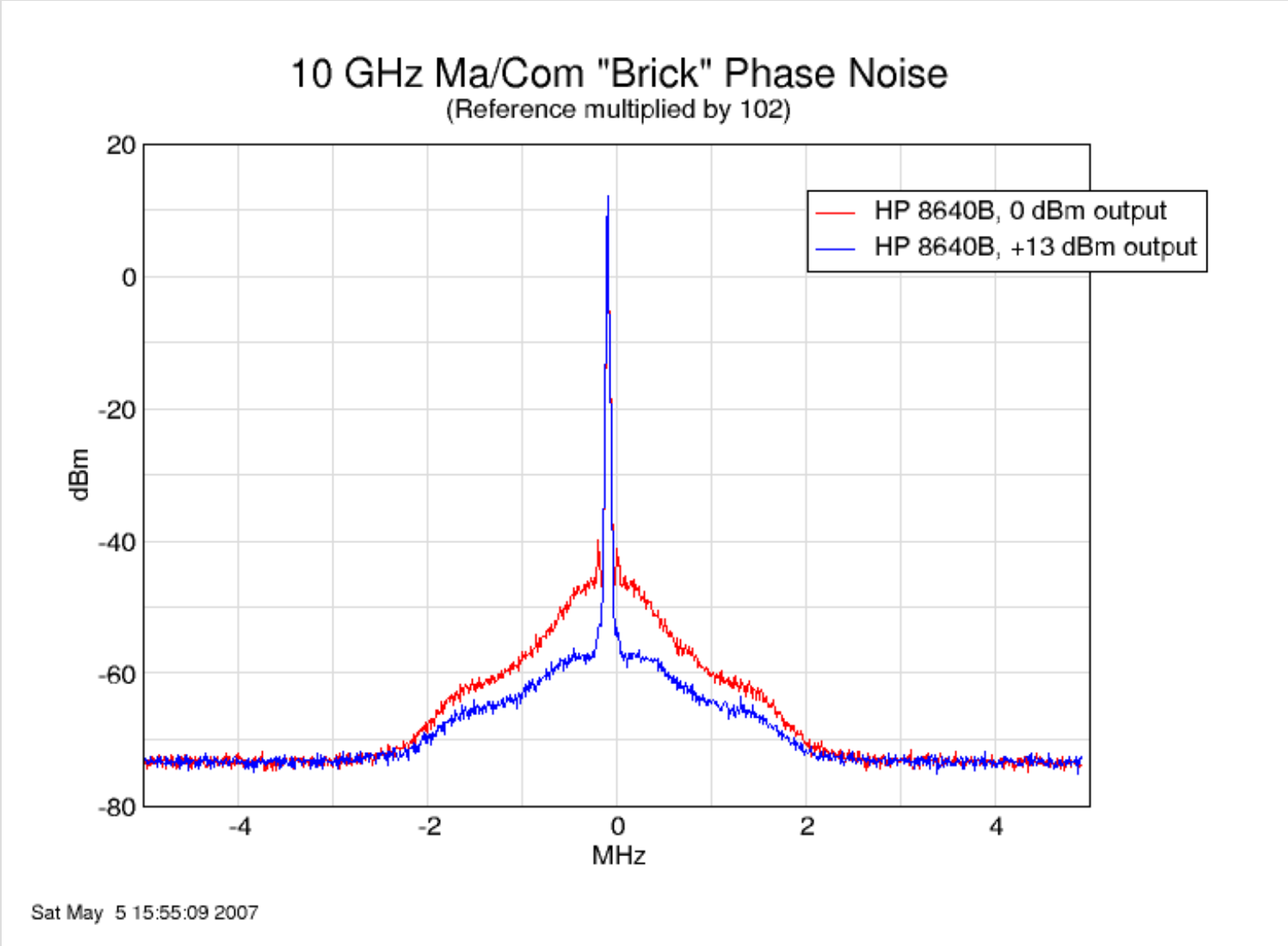
- Give a geek a “brick” and a spectrum analyzer, and you'll keep him in the basement for days!

Backup

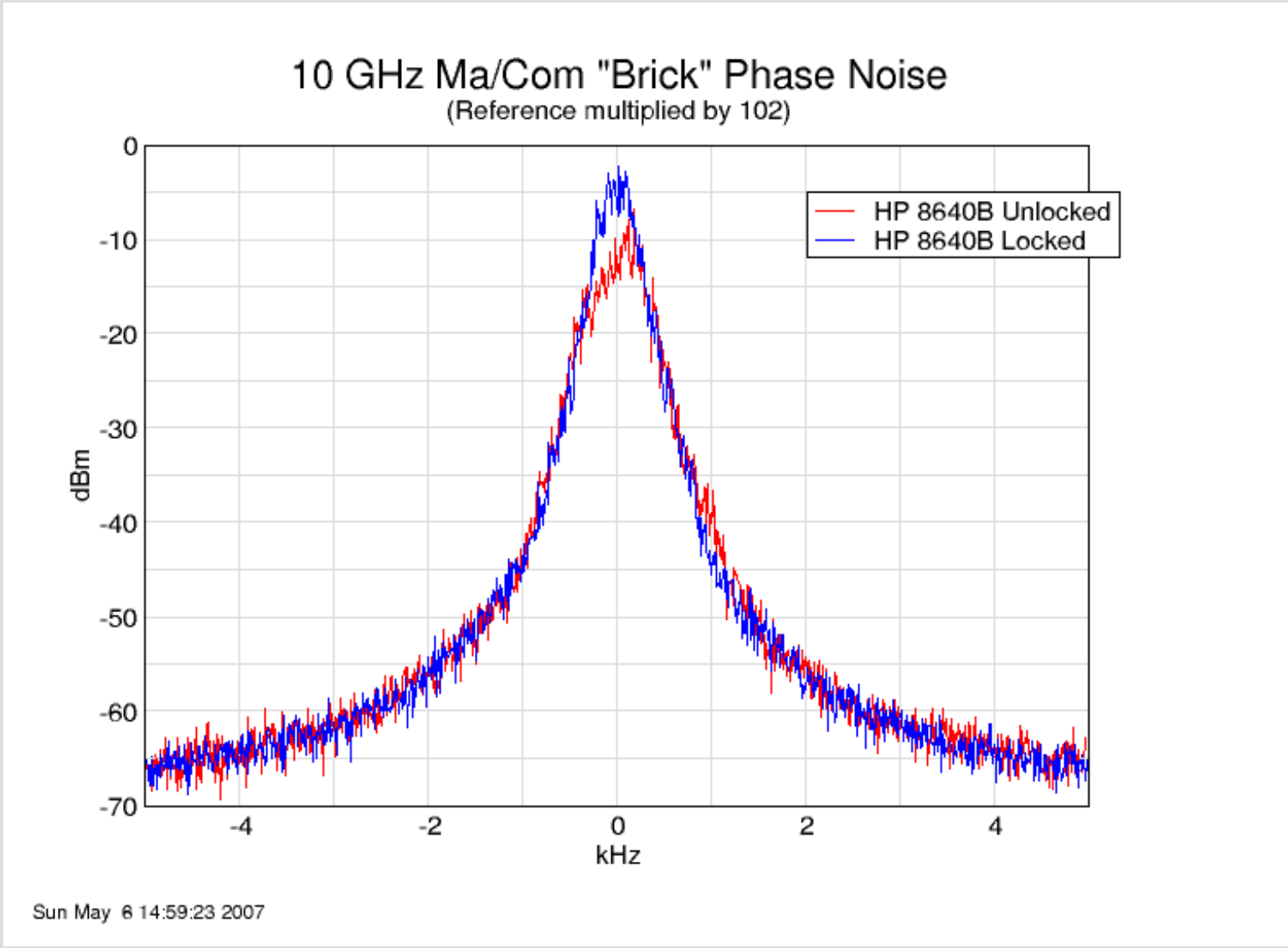
W8RKO Oscillator



Phase Noise vs. Reference Amplitude



HP 8640B
Locked vs. Unlocked Operation



Some References

- HP application notes (search at www.agilent.com)
  - AN 207 ("Understanding and measuring phase noise...")
  - AN 270-2 ("Automated noise sideband measurements...")
- Dieter Scherer (HP 8662A designer) course notes
  - "The Art of Phase Noise Measurement"
  - "Generation of Low Phase Noise Microwave Signals"
  - "Design Principles and Test Methods for Low PN Sources"
  - Available at http://www.ke5fx.com/scherer.zip
- HP Journal, February 1981
  - HP 8662A as an example of low-PN design goals/constraints
  - Available at http://www.hparchive.com/hp_journals.htm

Some References

- U. L. Rohde, "Microwave and Wireless Synthesizers: Theory and Design"
  - ISBN 0471520195
- Dean Banerjee, "PLL Performance, Simulation, and Design"
  - Free at http://www.national.com/appinfo/wireless/pll_designbook.html
  - Available at amazon.com (ISBN 1598581341)
- PN.EXE: Phase noise measurement for GPIB-controlled spectrum analyzers
  - Open-source software for Windows at http://www.ke5fx.com/gpib/pn.htm