Oscillator Phase Noise: Multiplication Matters!

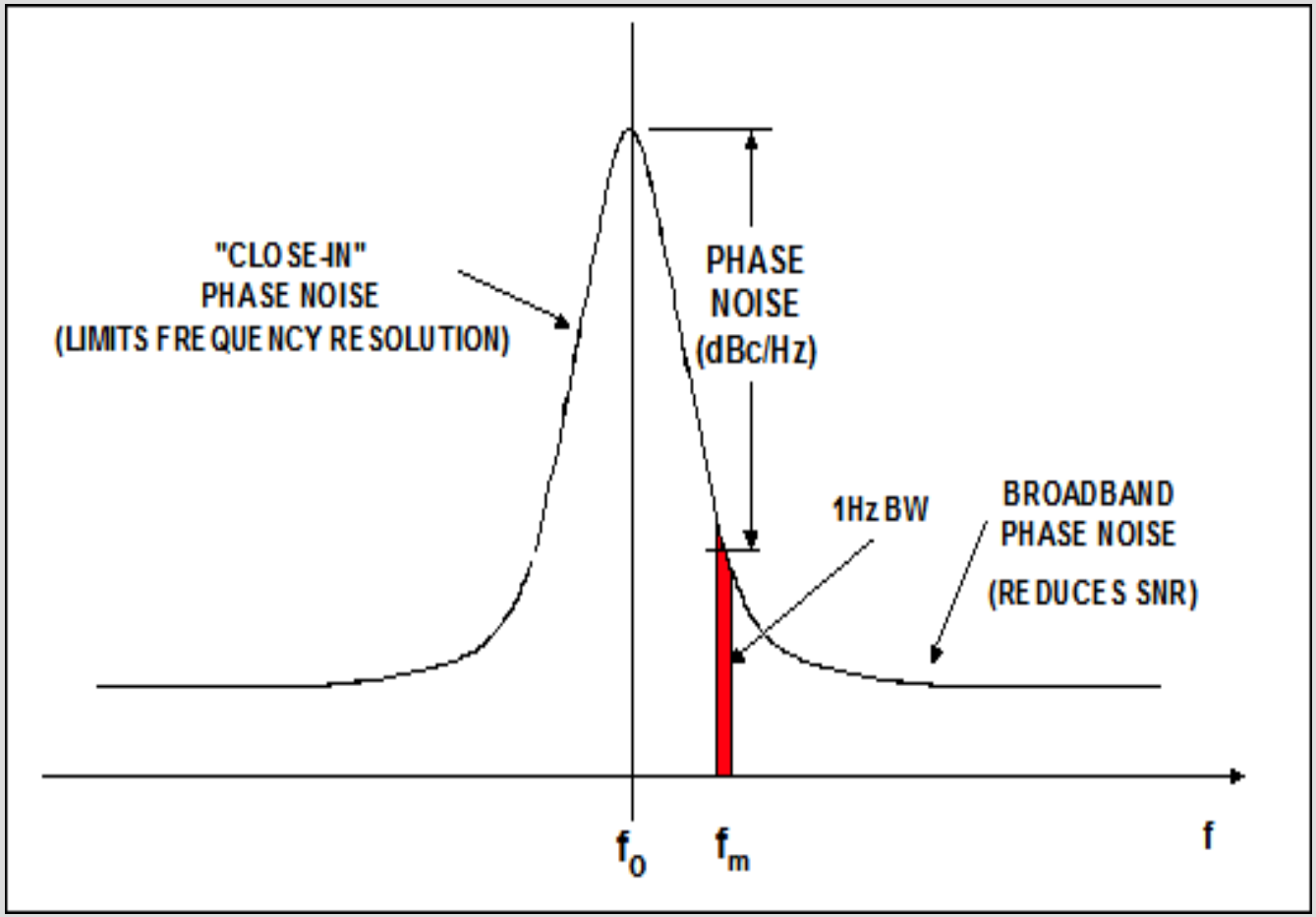
John Ackermann N8UR

SEVHFS 2010

What is Phase Noise?

- All oscillators create noise along with the desired signal
  - Noise in both amplitude and phase
  - Phase noise is harder to control, and has more impact on communications performance
- Impact of phase noise:
  - Higher noise floor – reduced SNR
  - Reciprocal mixing – distortion and interference
  - Fuzzy sounding signals – difficult copy

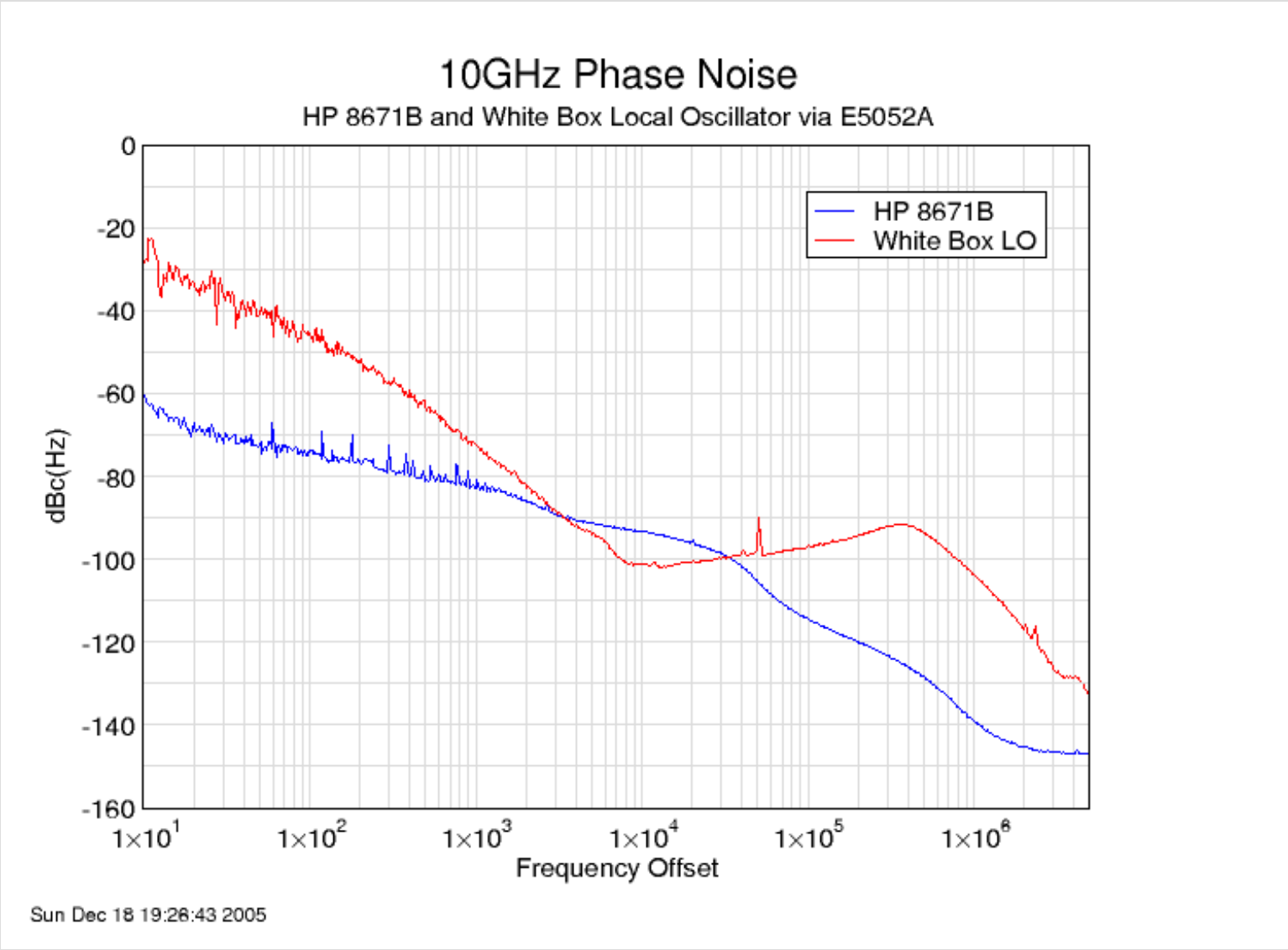
A Picture of Phase Noise



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
- 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

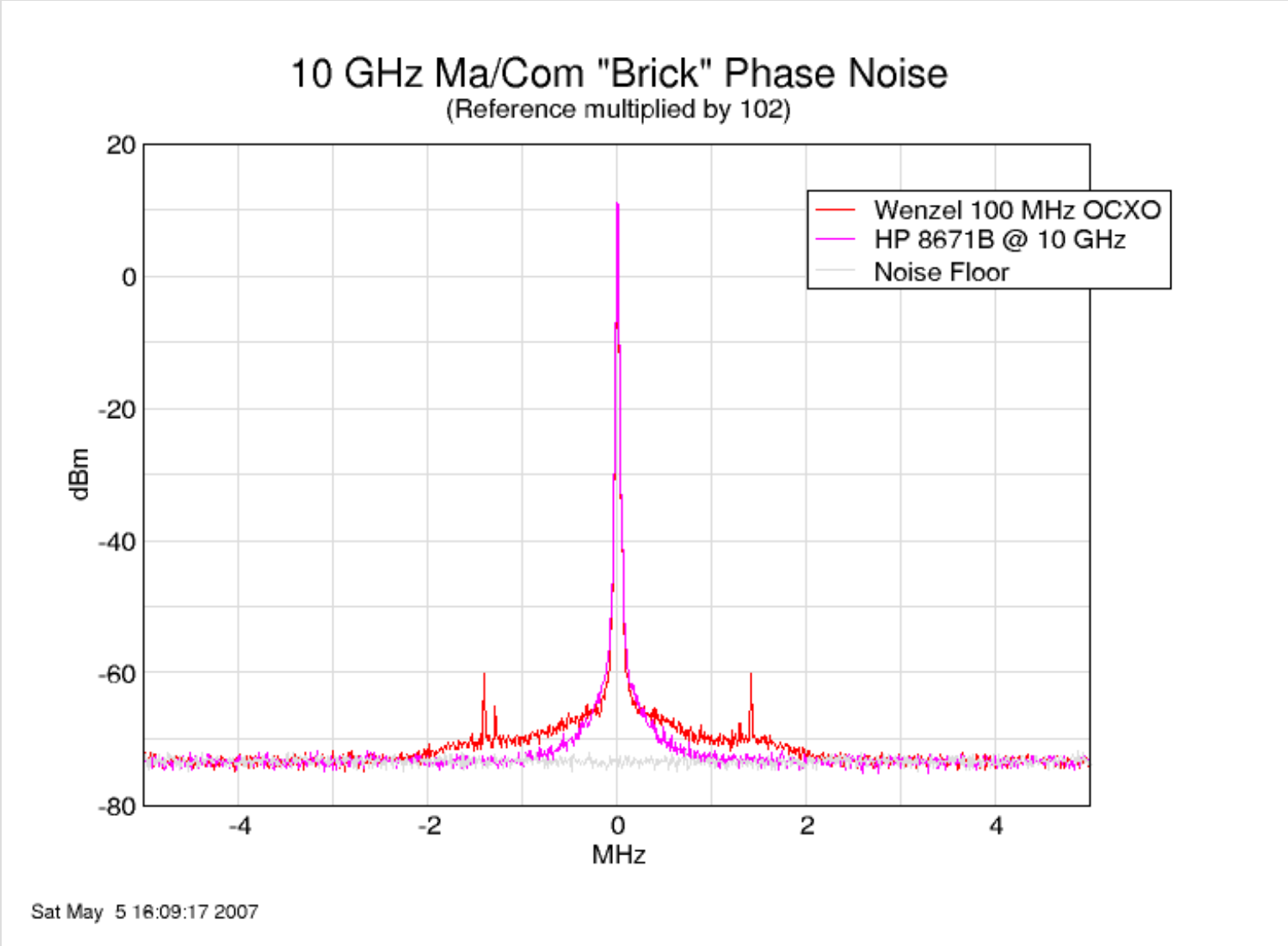
Phase Noise in the Frequency Domain



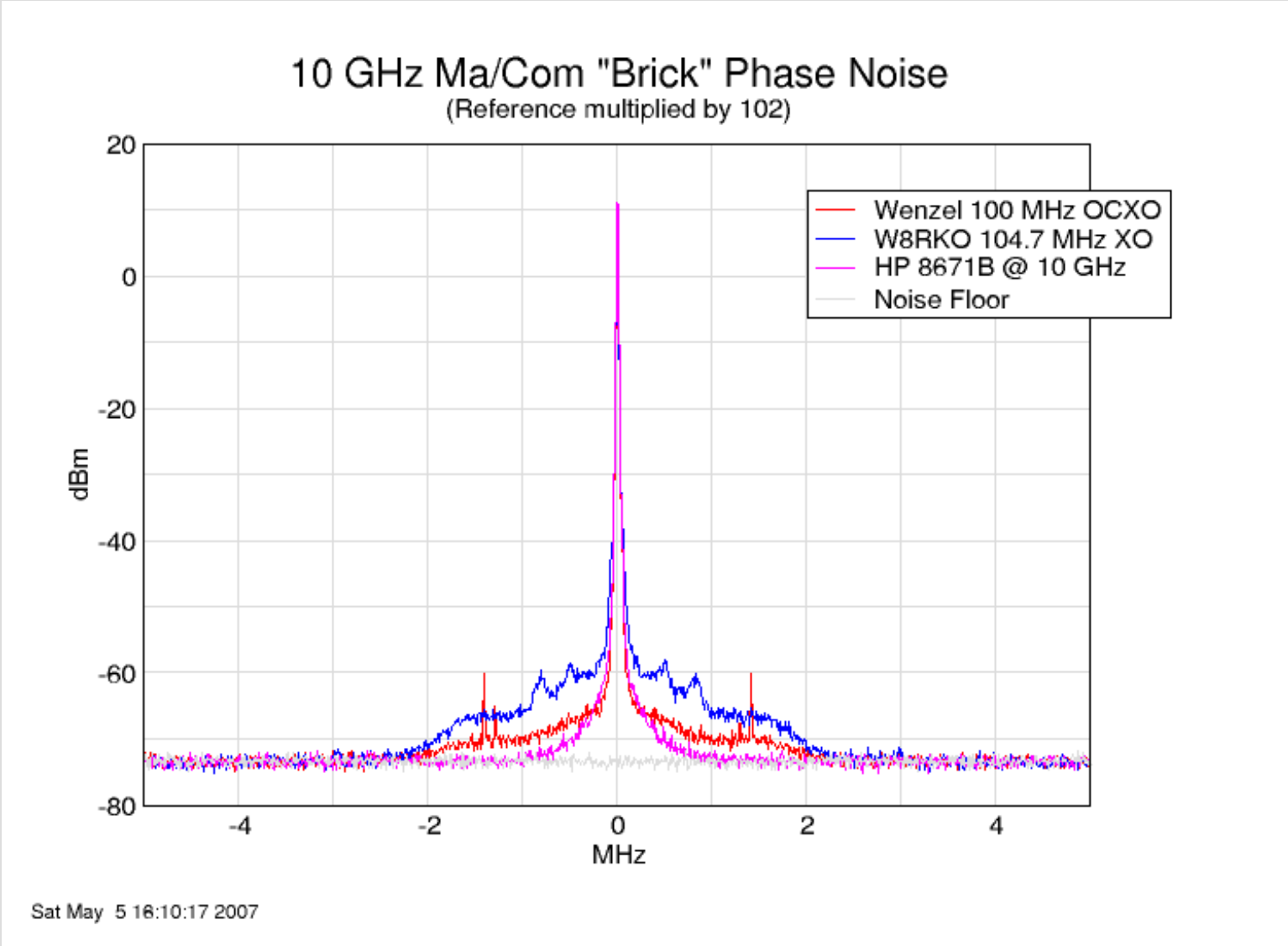
The Real World

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

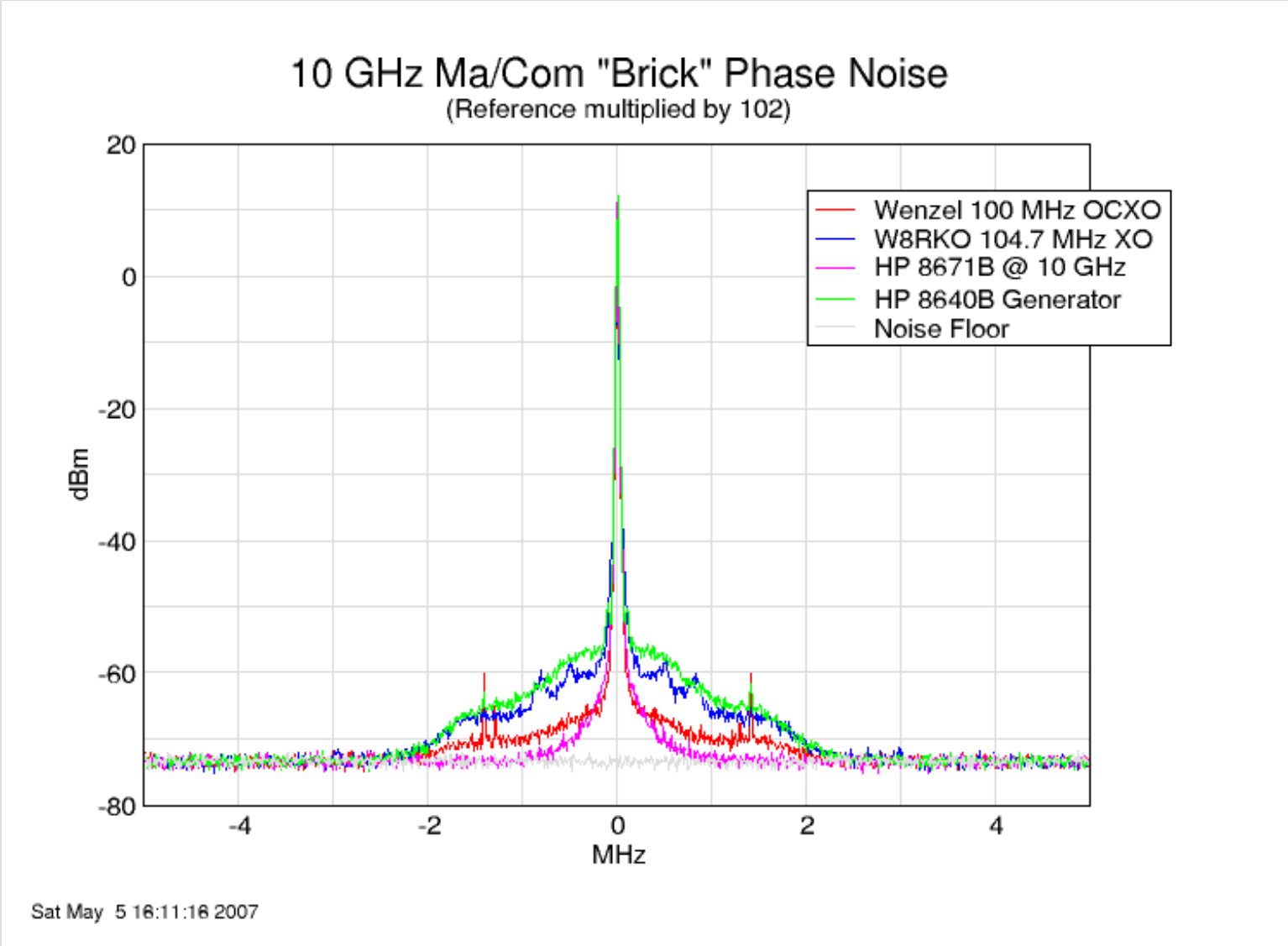
10 MHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
HP 8671B @ 10 GHz
Noise Floor
dBm
20
0
-20
-40
-60
-80
-4
-2
0
2
4
MHz
Sat May 5 16:09:17 2007

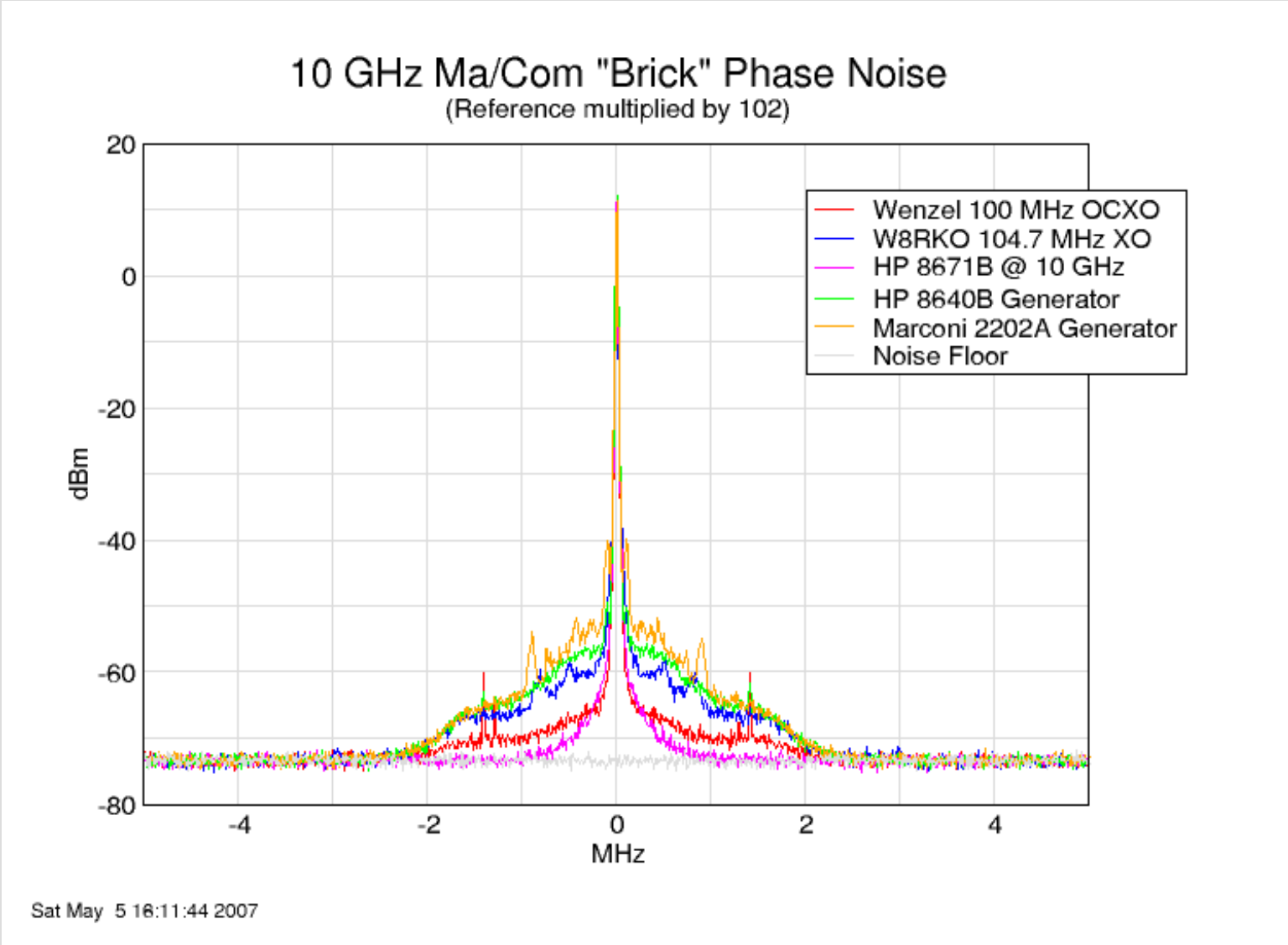
10 MHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
Noise Floor
dBm
20
0
-20
-40
-60
-80
-4
-2
0
2
4
MHz
Sat May 5 16:10:17 2007

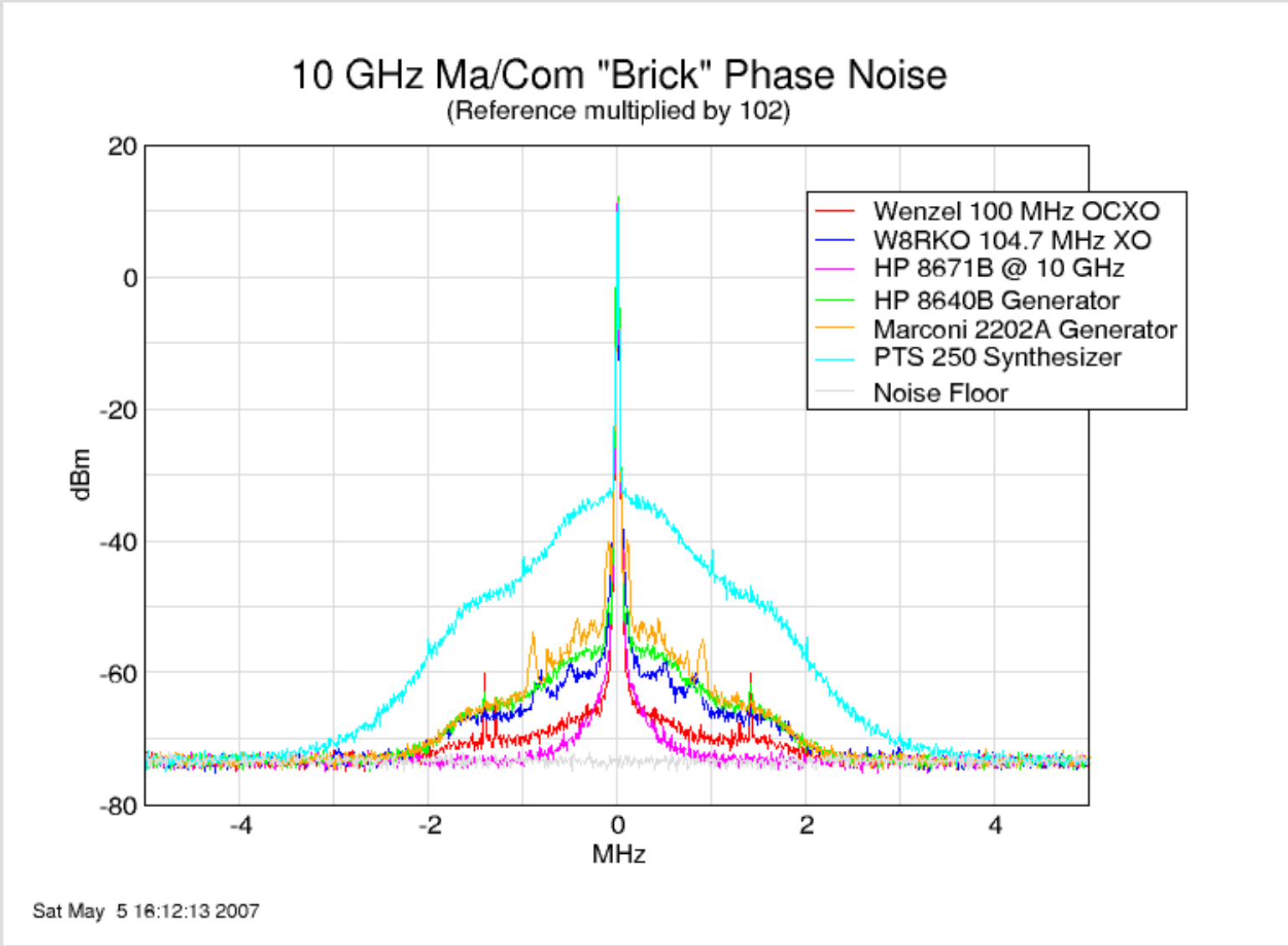
10 MHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
MHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Noise Floor
Sat May 5 16:11:16 2007

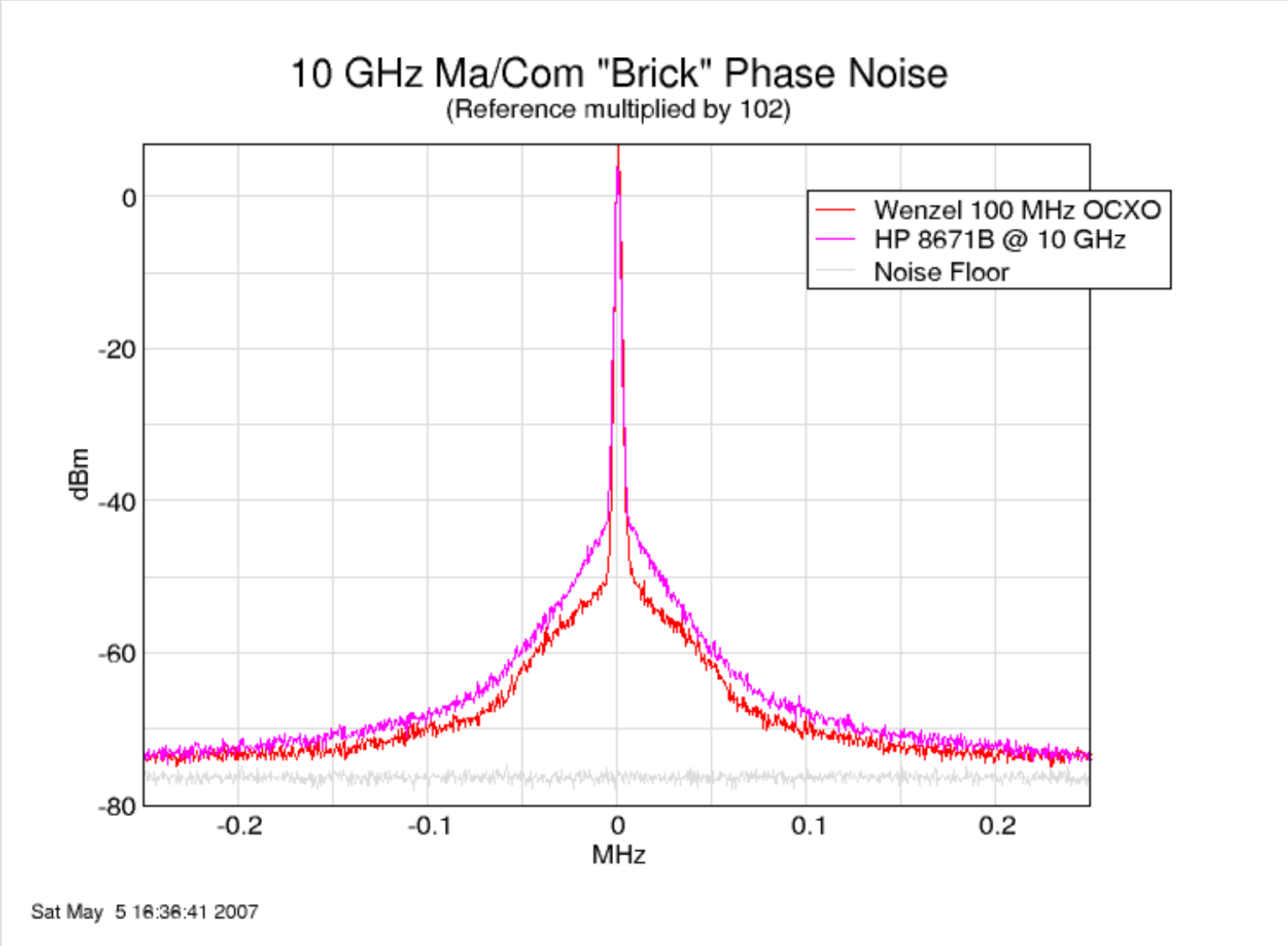
10 MHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
MHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
Noise Floor
Sat May 5 16:11:44 2007

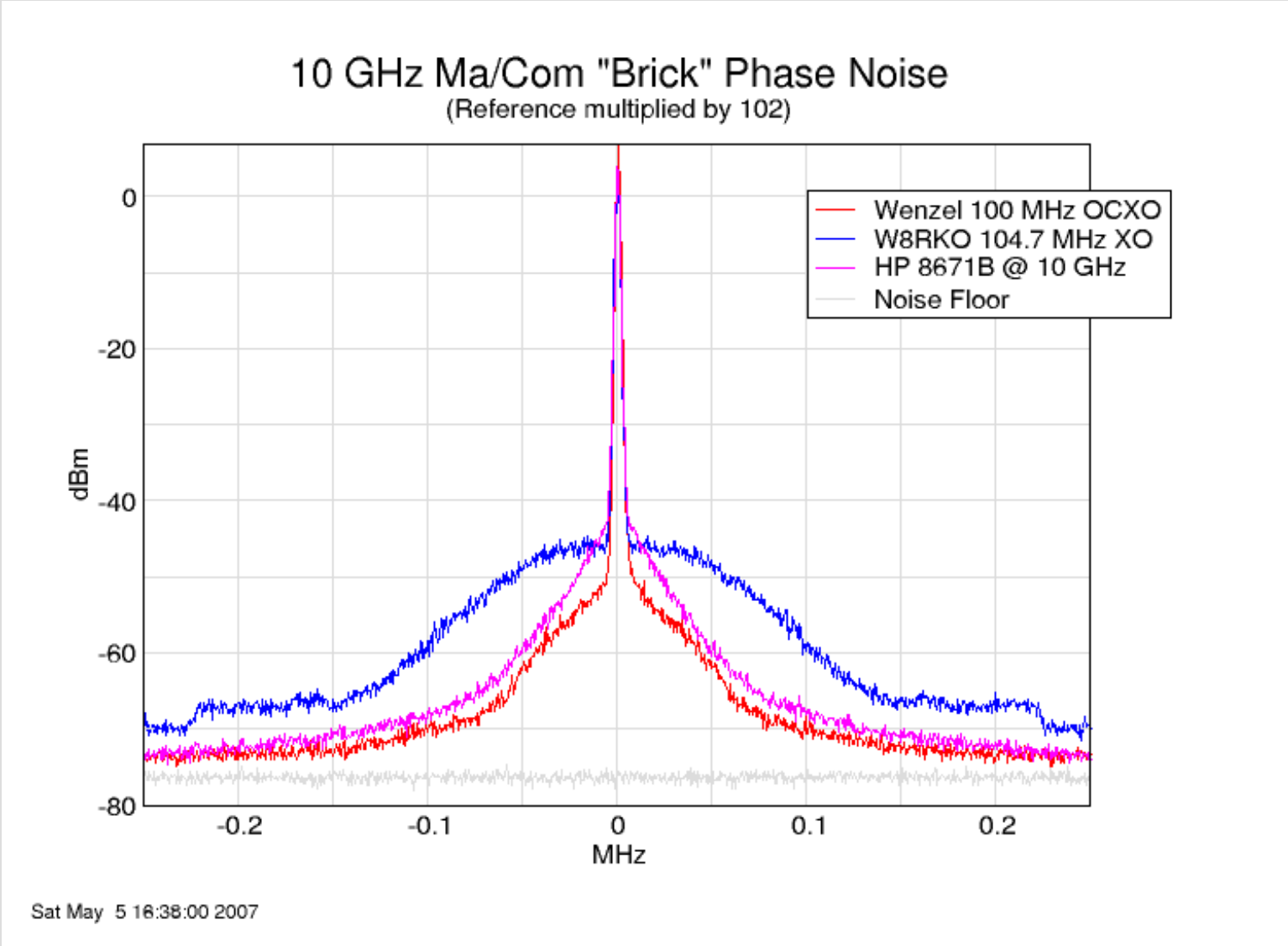
10 MHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
MHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
PTS 250 Synthesizer
Noise Floor
Sat May 5 16:12:13 2007

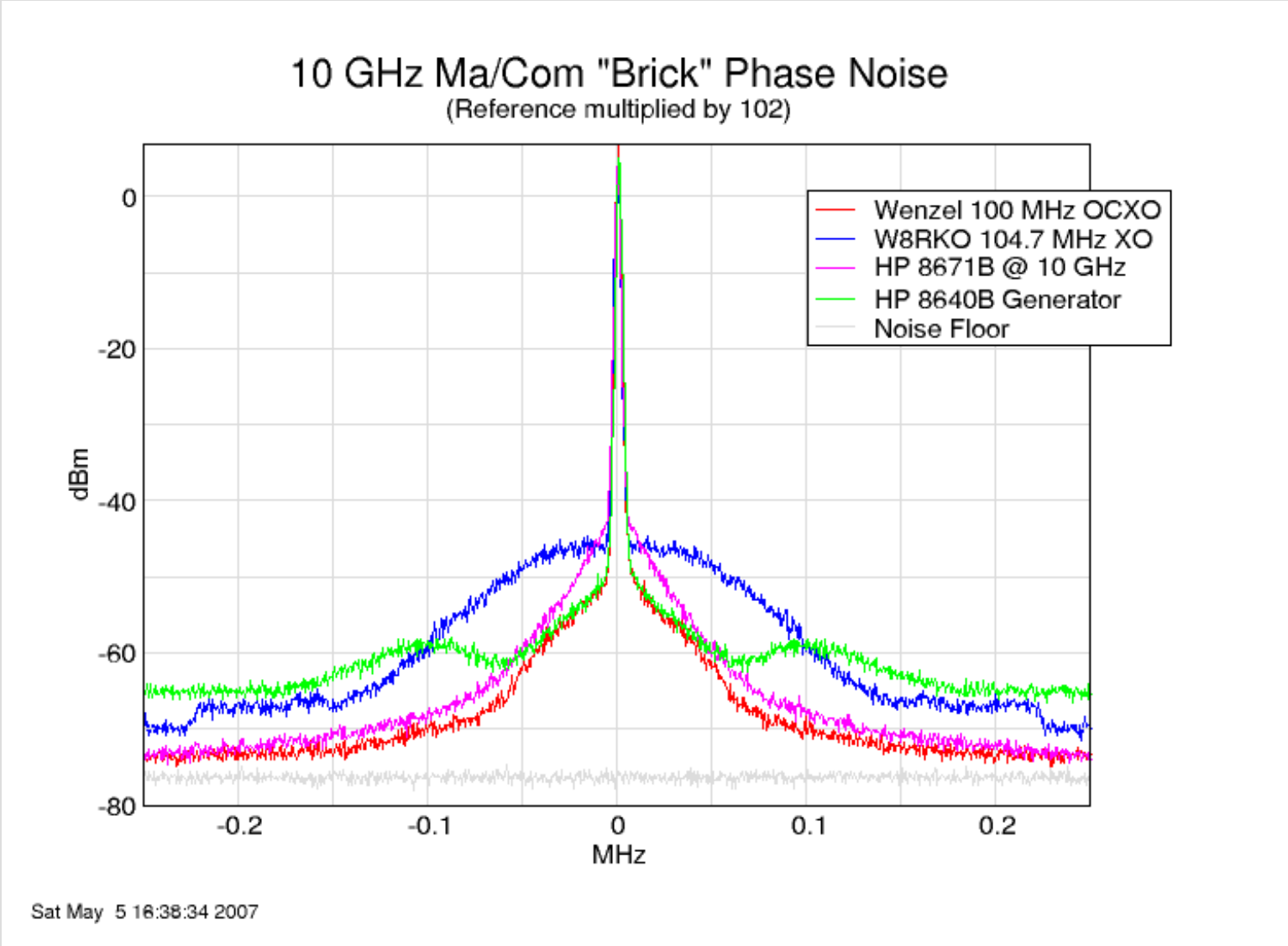
500 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
HP 8671B @ 10 GHz
Noise Floor
dBm
0
-20
-40
-60
-80
-0.2
-0.1
0
0.1
0.2
MHz
Sat May 5 16:36:41 2007

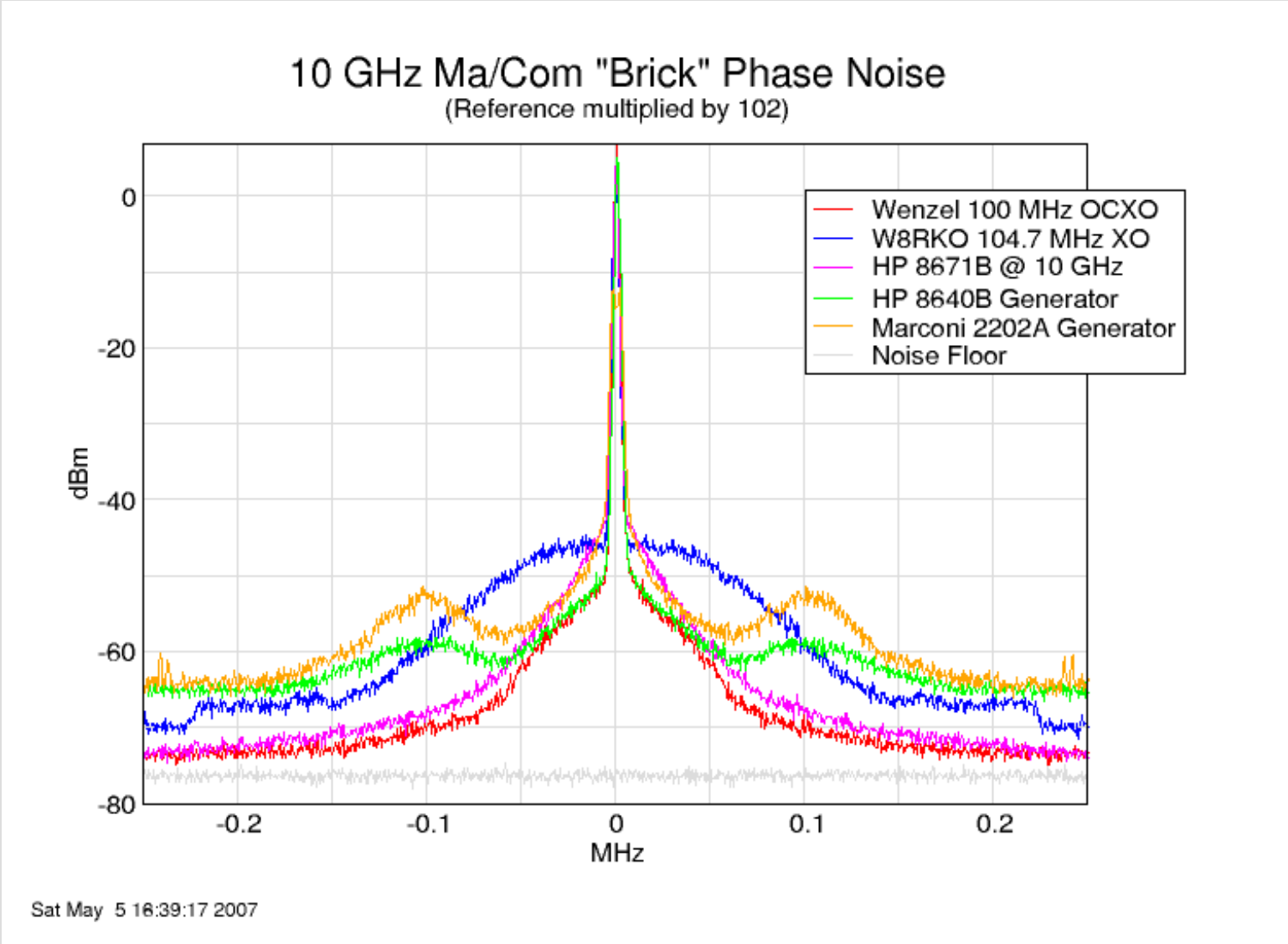
500 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
Noise Floor
dBm
0
-20
-40
-60
-80
-0.2
-0.1
0
0.1
0.2
MHz
Sat May 5 16:38:00 2007

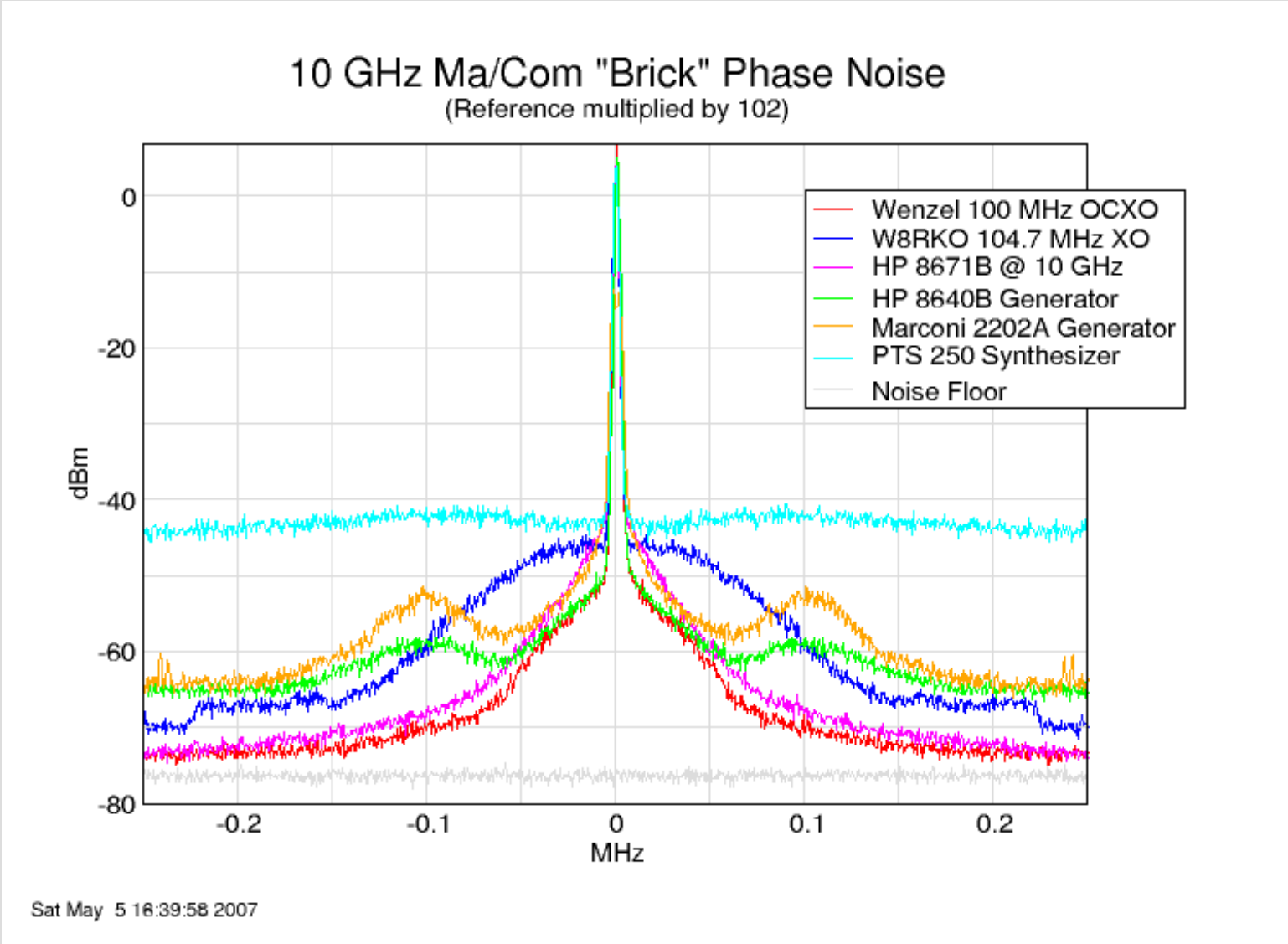
500 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Noise Floor
dBm
0
-20
-40
-60
-80
-0.2
-0.1
0
0.1
0.2
MHz
Sat May 5 16:38:34 2007

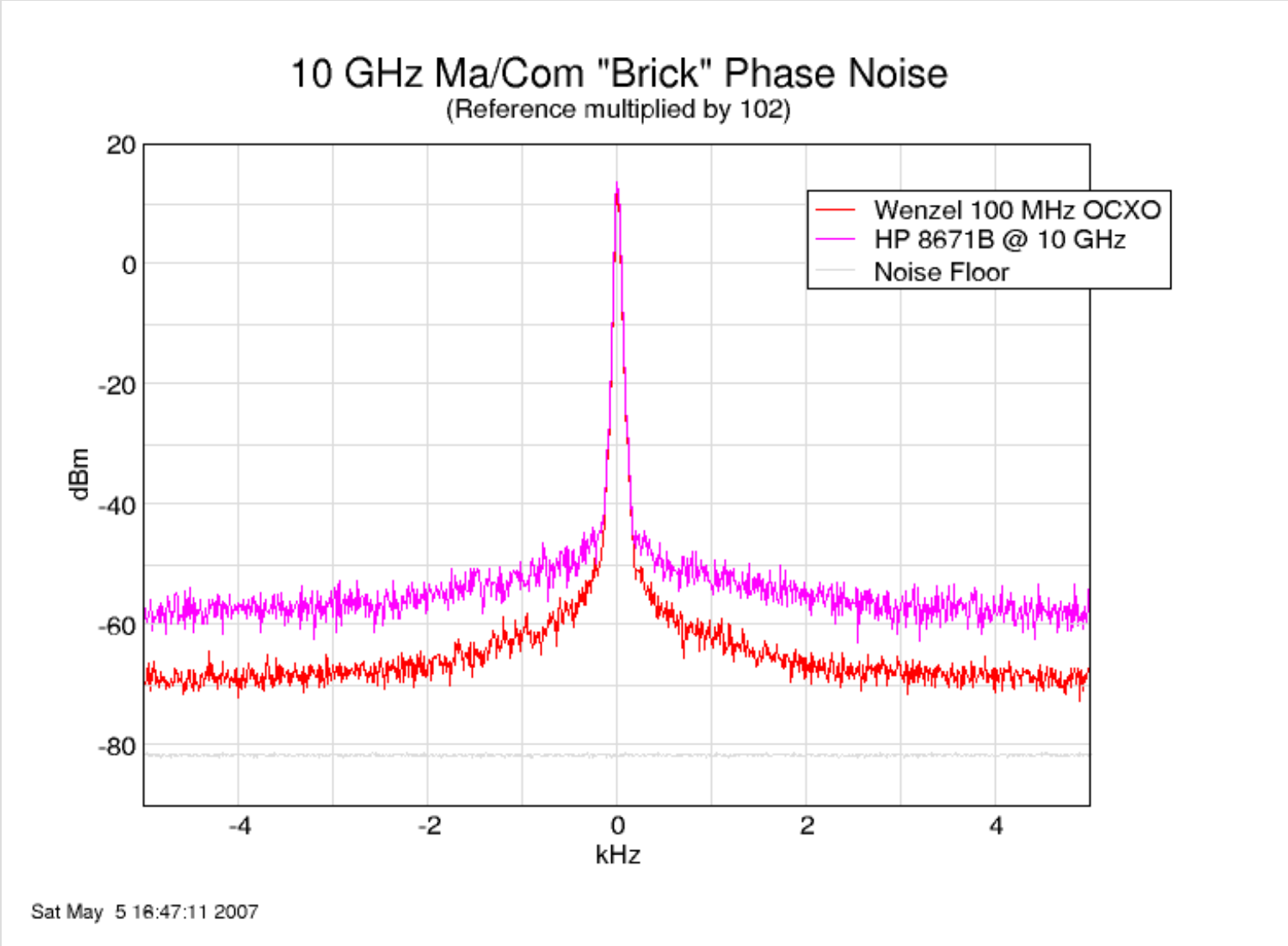
500 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
Noise Floor
dBm
0
-20
-40
-60
-80
-0.2
-0.1
0
0.1
0.2
MHz
Sat May 5 16:39:17 2007

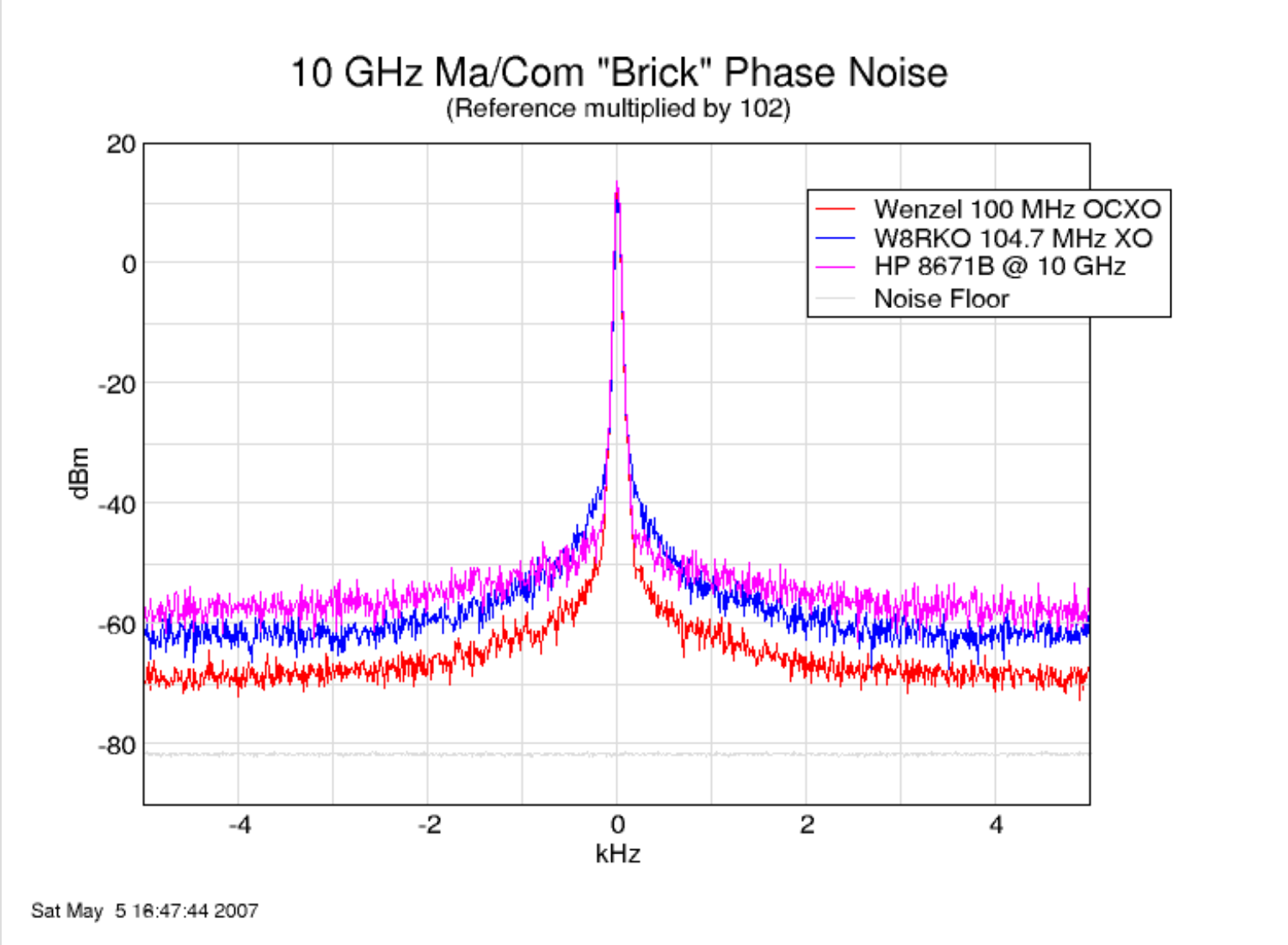
500 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
PTS 250 Synthesizer
Noise Floor
dBm
0
-20
-40
-60
-80
-0.2
-0.1
0
0.1
0.2
MHz
Sat May 5 16:39:58 2007

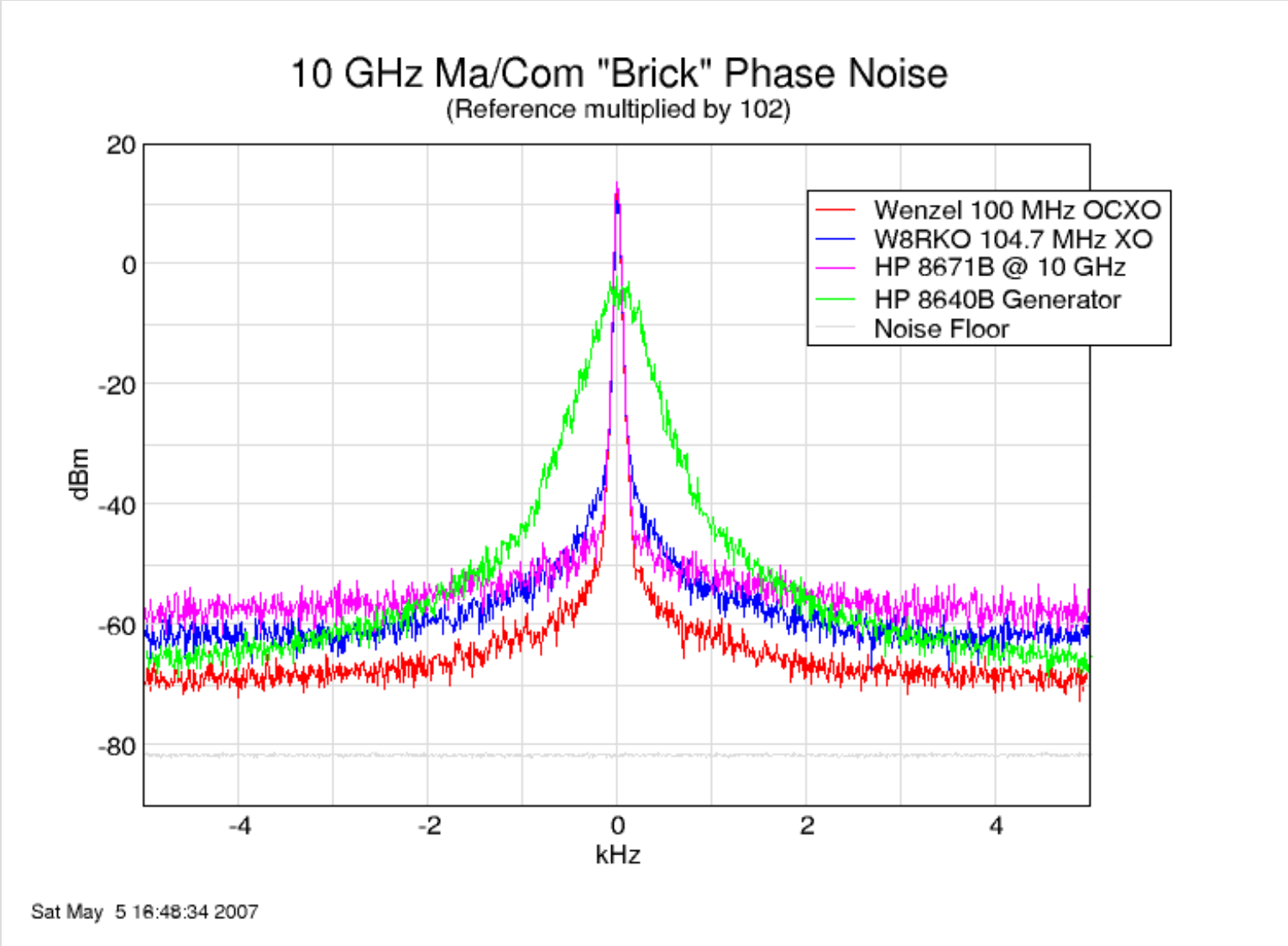
10 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
kHz
Wenzel 100 MHz OCXO
HP 8671B @ 10 GHz
Noise Floor
Sat May 5 16:47:11 2007

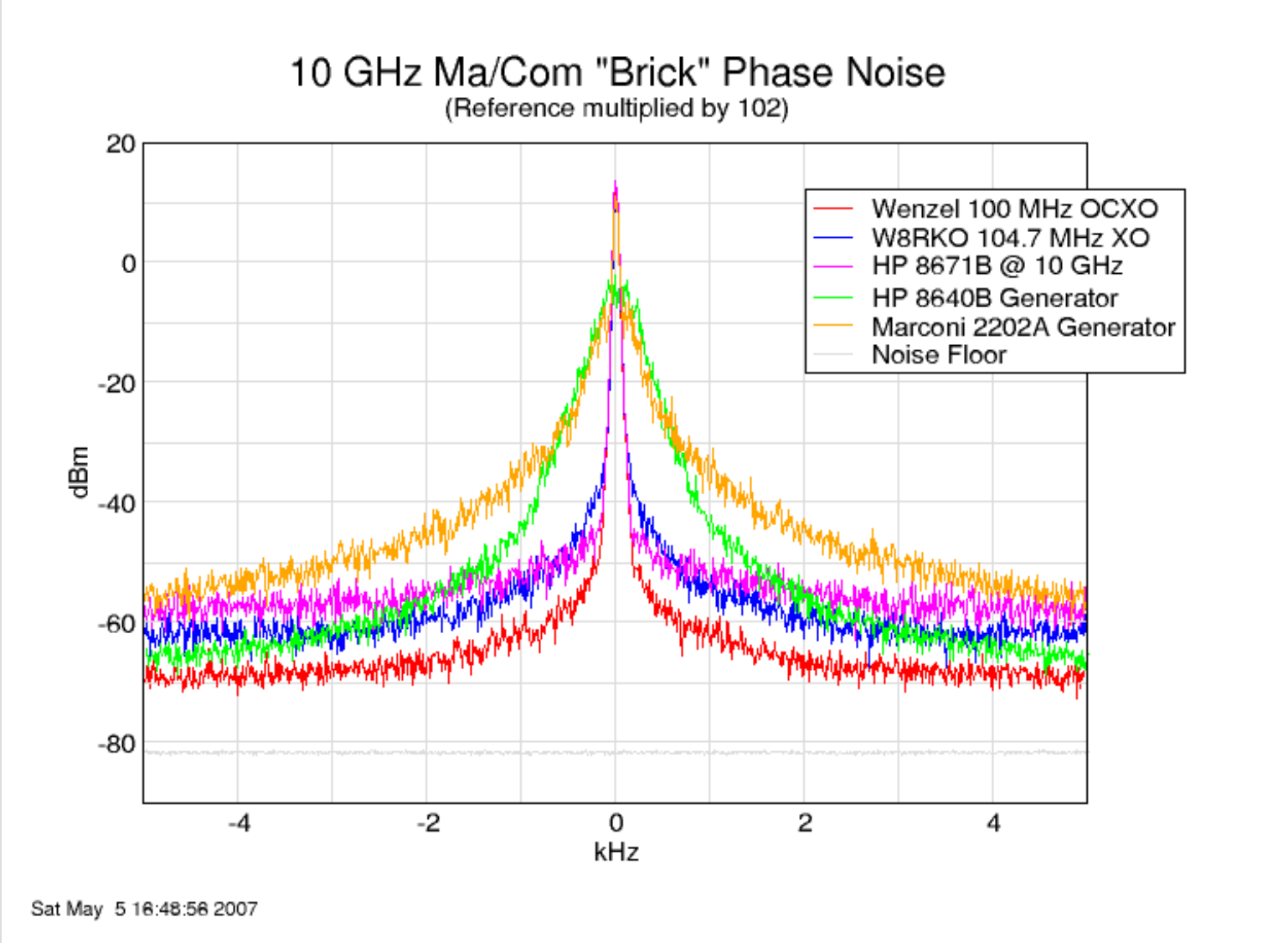
10 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
kHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
Noise Floor
Sat May 5 16:47:44 2007

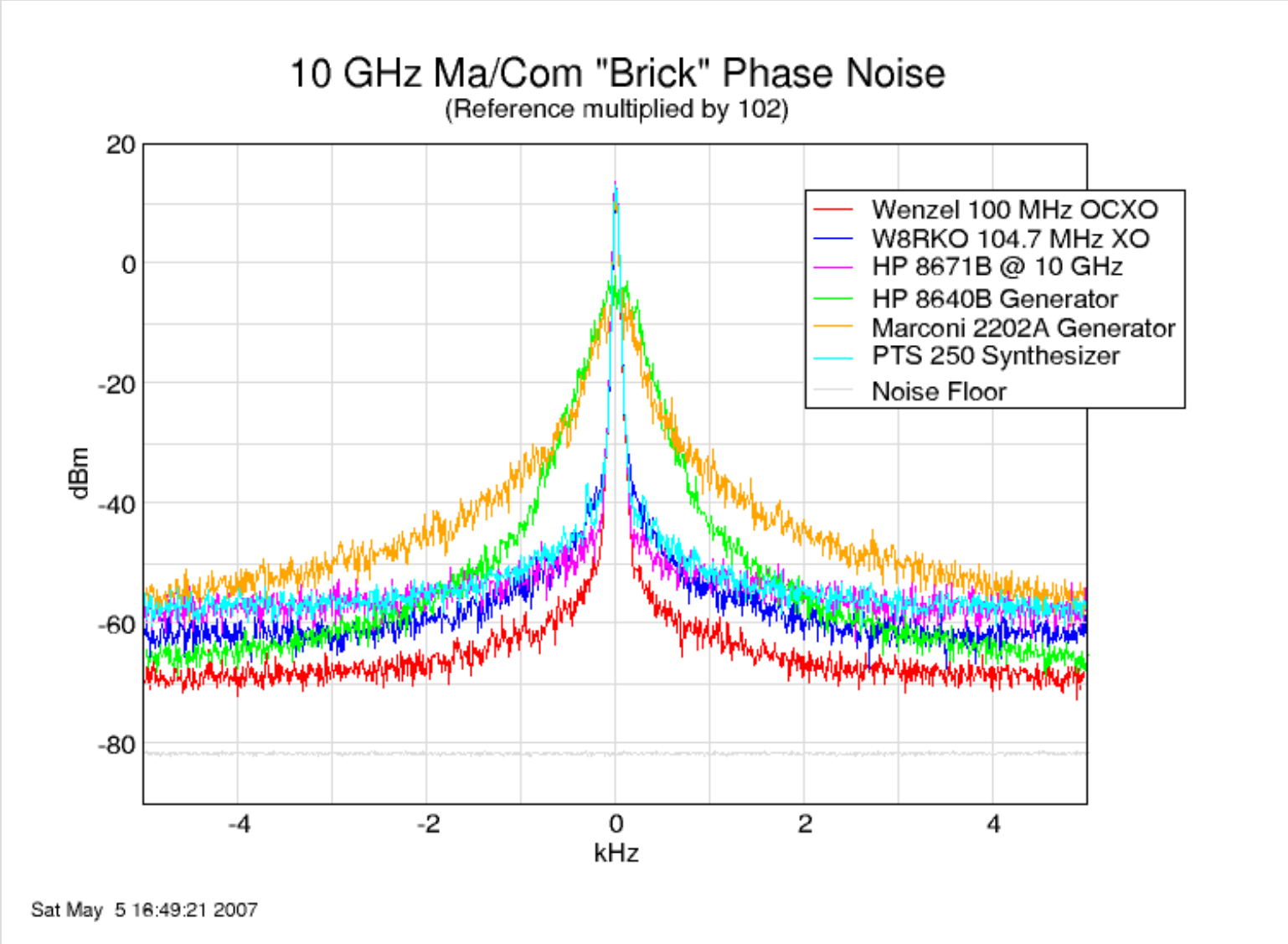
10 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
kHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Noise Floor
Sat May 5 16:48:34 2007

10 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
kHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
Noise Floor
Sat May 5 16:48:56 2007

10 kHz Span


10 GHz Ma/Com "Brick" Phase Noise
(Reference multiplied by 102)
20
0
-20
-40
-60
-80
dBm
-4
-2
0
2
4
kHz
Wenzel 100 MHz OCXO
W8RKO 104.7 MHz XO
HP 8671B @ 10 GHz
HP 8640B Generator
Marconi 2202A Generator
PTS 250 Synthesizer
Noise Floor
Sat May 5 16:49:21 2007

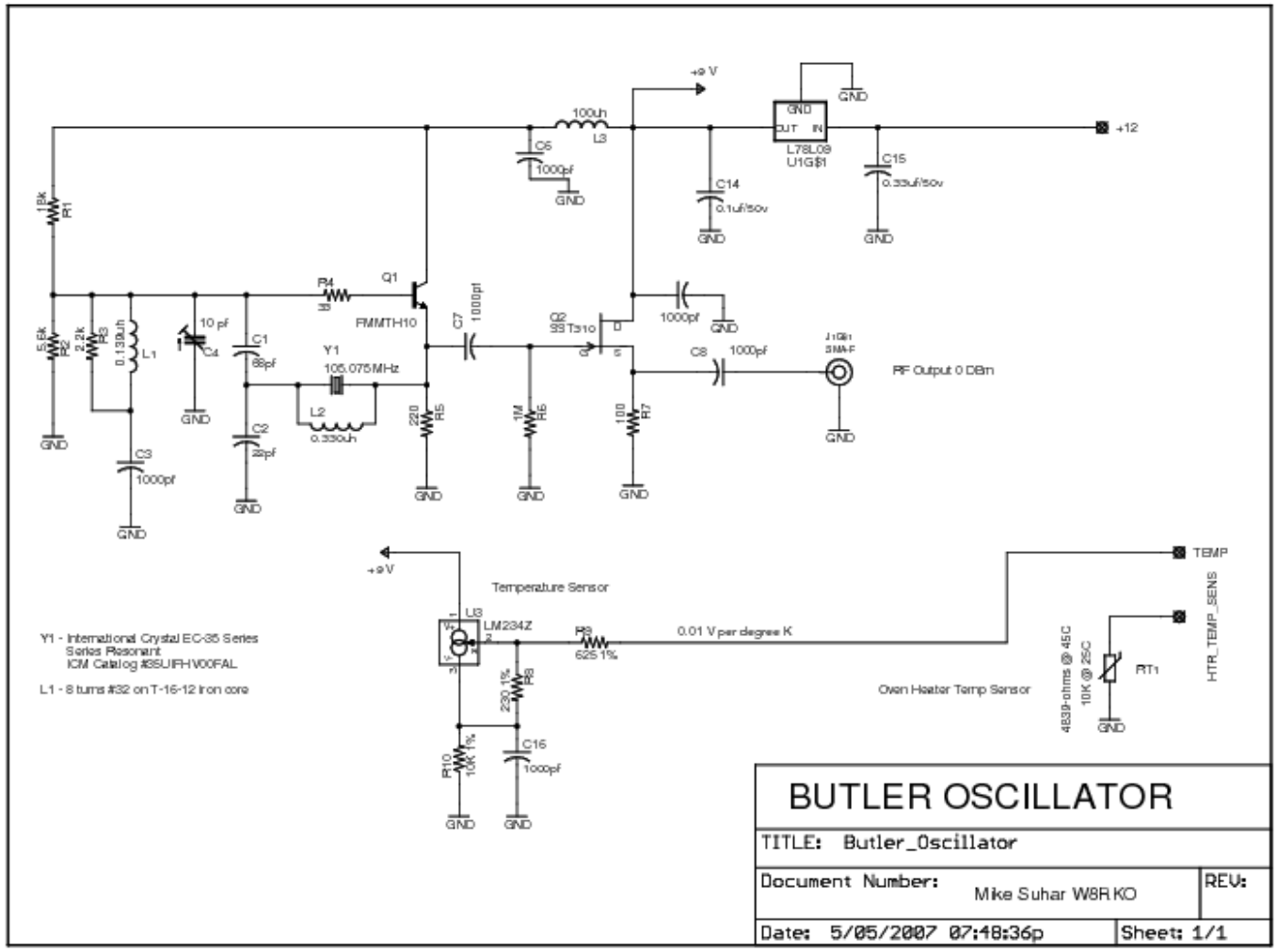
The Moral

- 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?

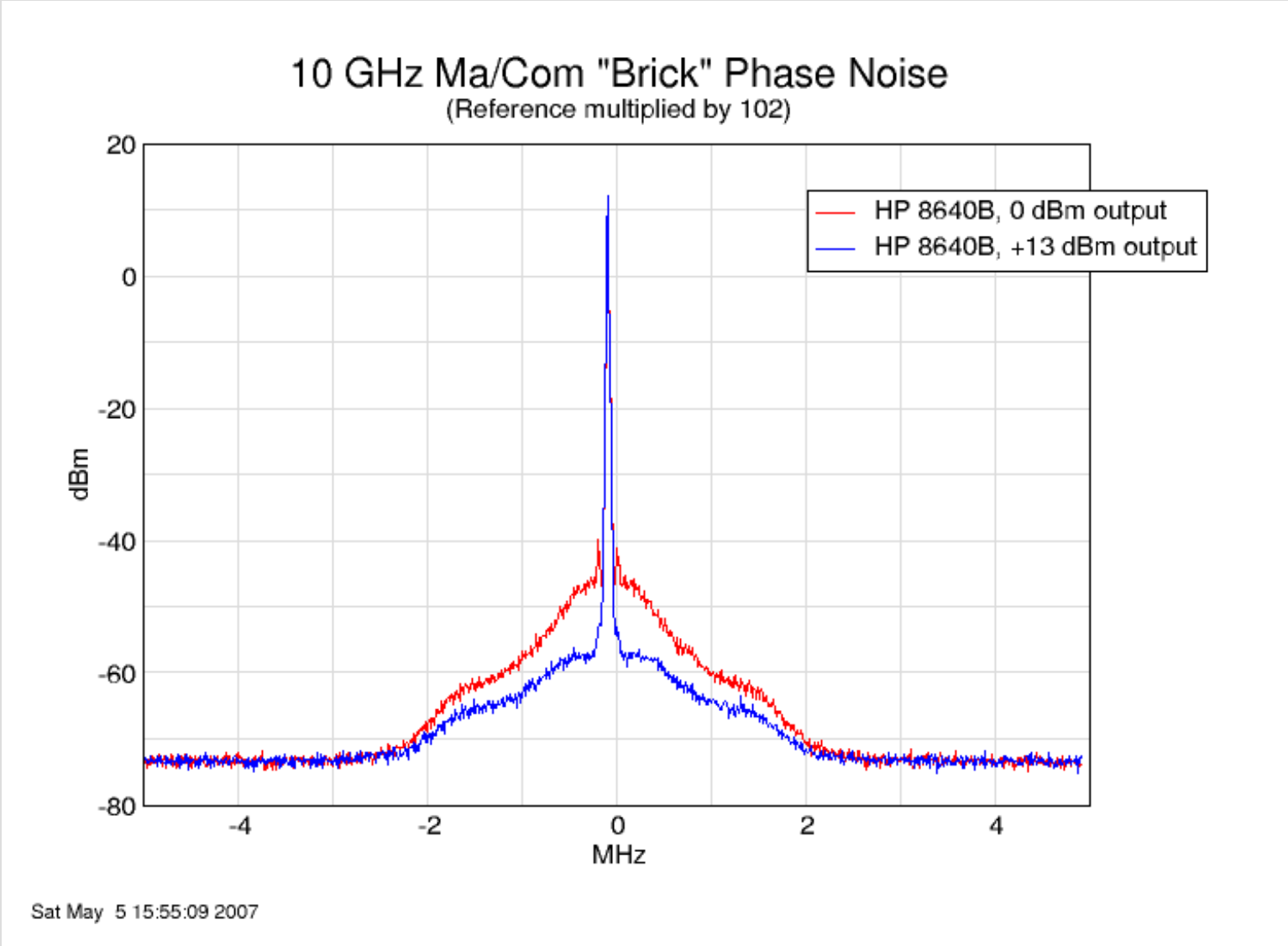
- Give a geek a “brick” and a spectrum analyzer, and you'll keep him in the basement for days!

Backup

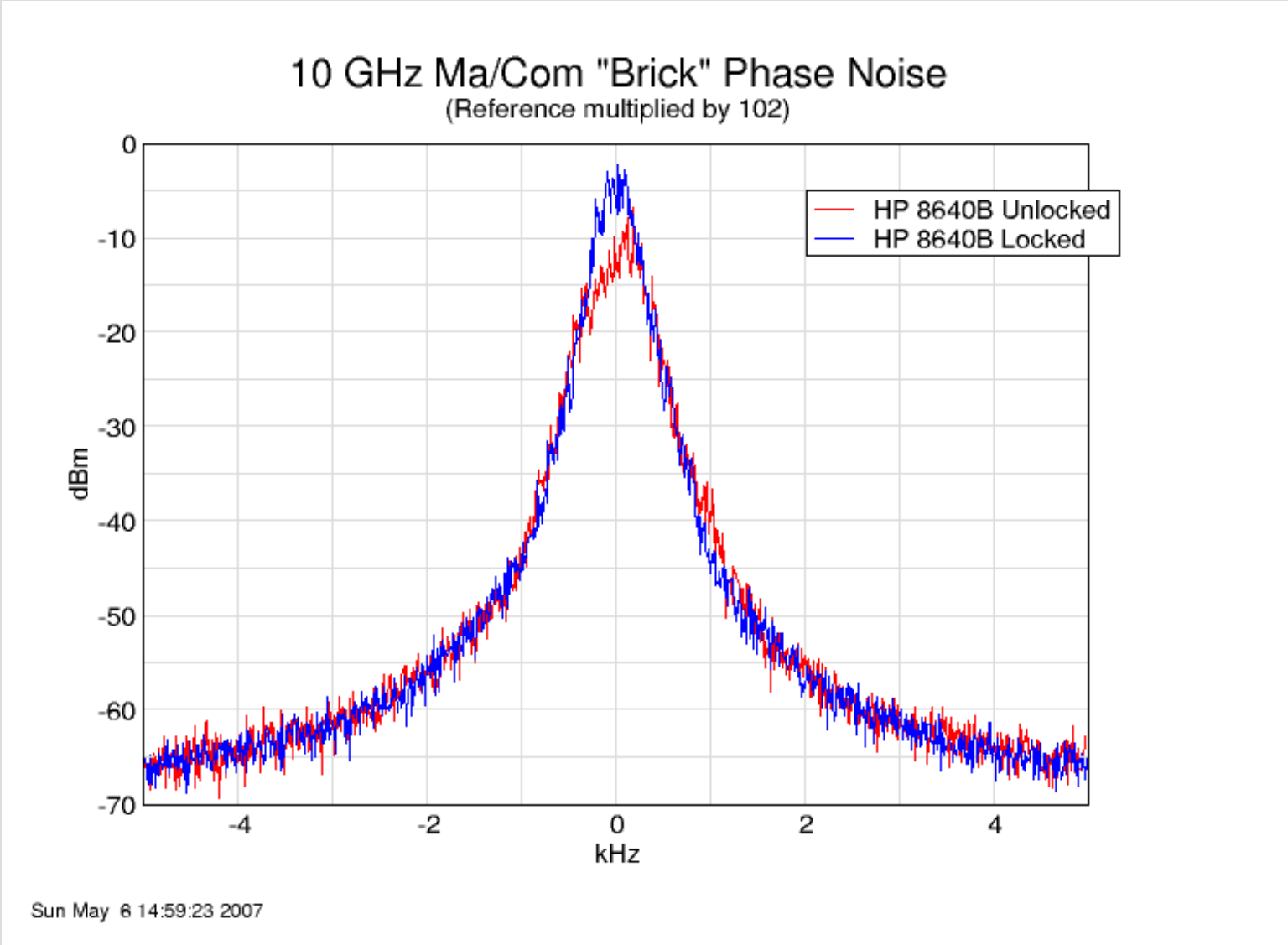
W8RKO Oscillator



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