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Low-noise Receiver / Scope Combinations For PDV

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Background

- Currently using high-gain receivers with fast digitizers
- With new generation of digitizers with useful sensitivity below 20 mV/div, there is an opportunity to use lower-gain receivers
- What PDV requires is measurement of multiple frequencies across a very wide variety of signal levels: High dynamic range
- What PDV does not require:
  - accurate phase across long records
  - exquisitely low harmonic distortion
- We will use SNR as a means to estimate the frequency-domain effective number of bits (“FNOB”) across a wide array of input signal levels

SNR relationship to ENOB

$$SNR_{TIME-DOMAIN,dB} = 6.02*ENOB + 1.76 + 20 \log (2*RMS/V_{full-scale})$$

ENOB = effective bits for digitizer, V = full scale range, A = RMS amplitude of applied signal
See Wiley Encyclopedia of Electrical and Electronics Engineering, Vol. 18, J. Blair

$$SNR_{f,dB} = 6.02*ENOB + 1.76 + 20*\log(2*RMS/V_{FS}) + 10*\log(N_{FFT}/2)$$

Normalize for fraction of full-scale used

SNR increase by using frequency-domain analysis

Number of bits as function of SNR, fraction of full-scale, FFT RBW

"Frequency-domain Number of Bits"

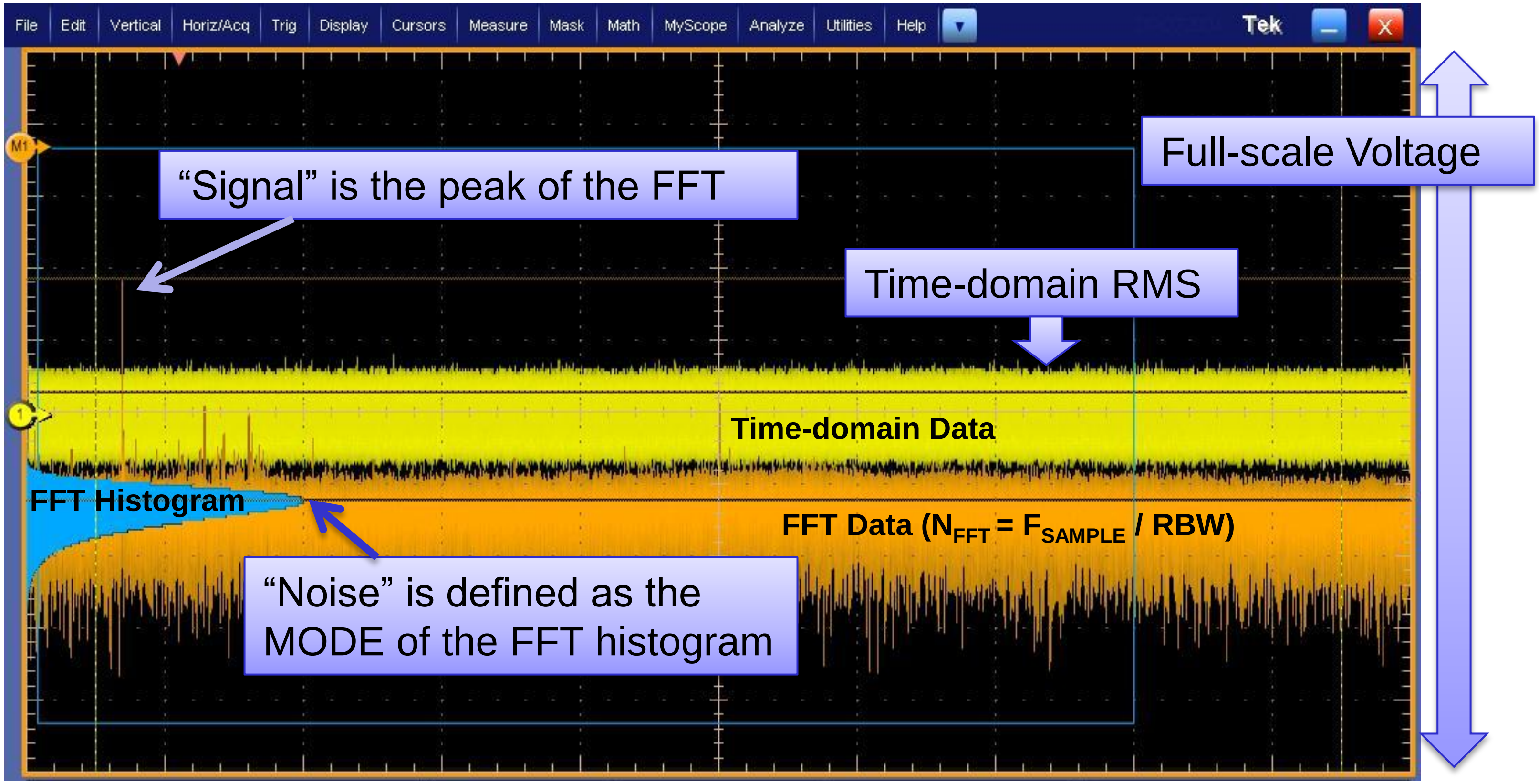
$$\text{"FNOB"} = (1/6.02) *(SNR_{f,dB} - 1.76 - 20*\log(2*RMS/V_{FS}) - 10*\log(N_{FFT}/2)$$

Measure this

Measure this

Fix this using Resolution Bandwidth (RBW) for FFT

On-board analysis for Lab data



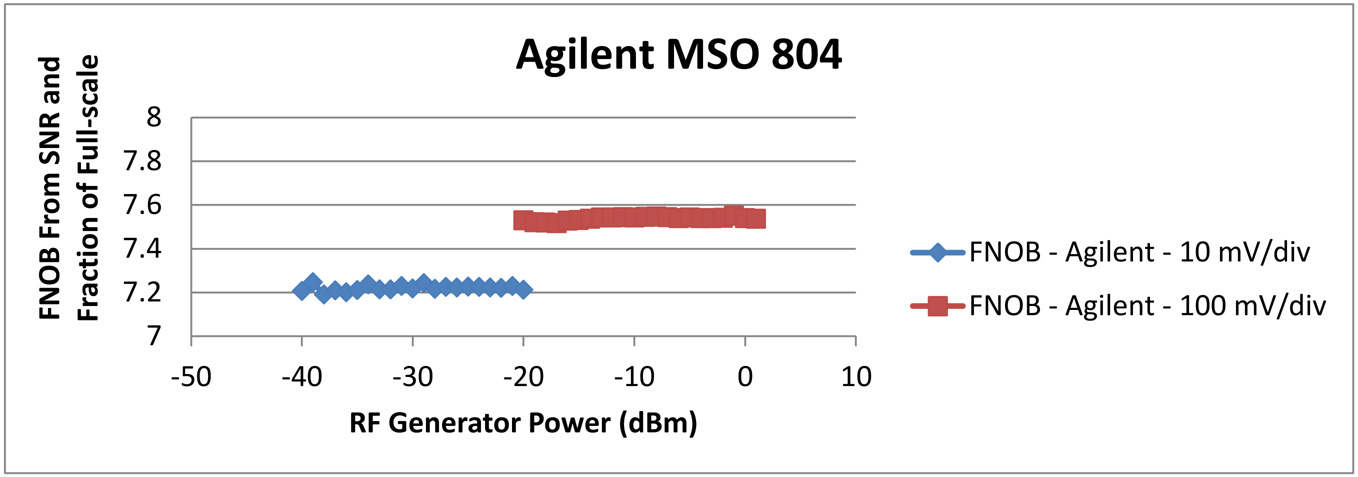
$$\text{“FNOB”} = (1/6.02) *(SNR_{f,dB} - 1.76 - 20*\log(2*RMS/V_{FS}) - 10*\log(N_{FFT}/2)$$

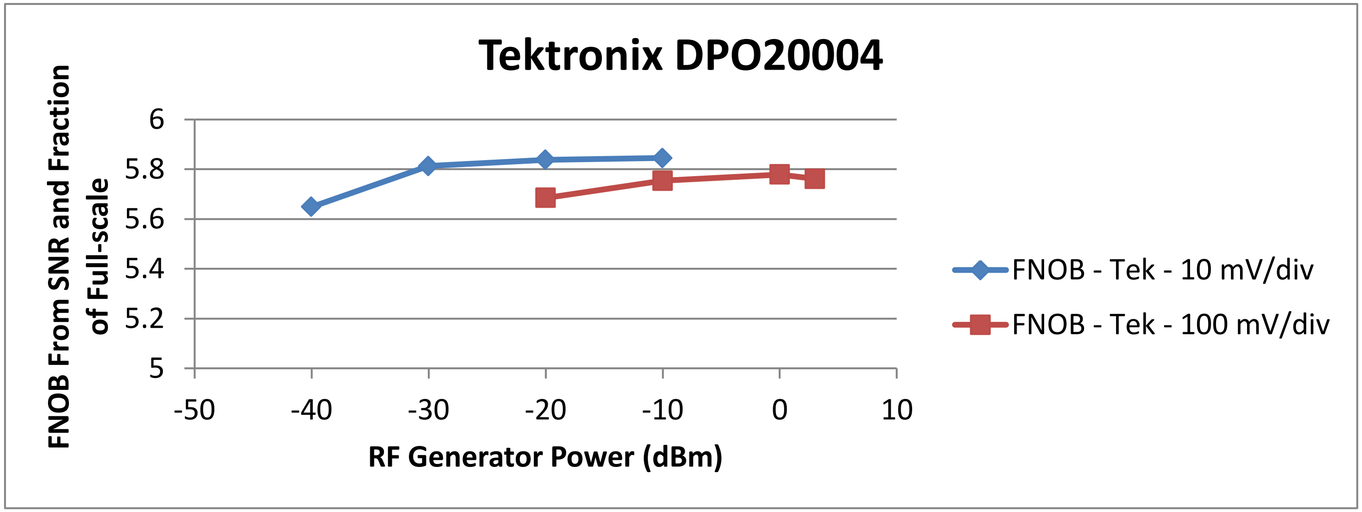
Lab Measurements: Scopes and receivers

- Purely electrical:
  - Scope + RF Generator: SNR at select sensitivities → FNOB
- Optical and electrical
  - Scope + Receiver dark-noise vs. Sensitivity
    - This returns the setting below which there will be no improvement in SNR
    - Comparison with 50 Ω Termination
  - Scope + Receiver + 1 GHz interference from two RIO ORION lasers
    - SNR: Adjust LO level at fixed “signal” power
    - SNR: Adjust “signal” power at fixed LO power

- By measuring SNR and fraction of scope full-scale, we can calculate the frequency-domain number of bits, “FNOB”

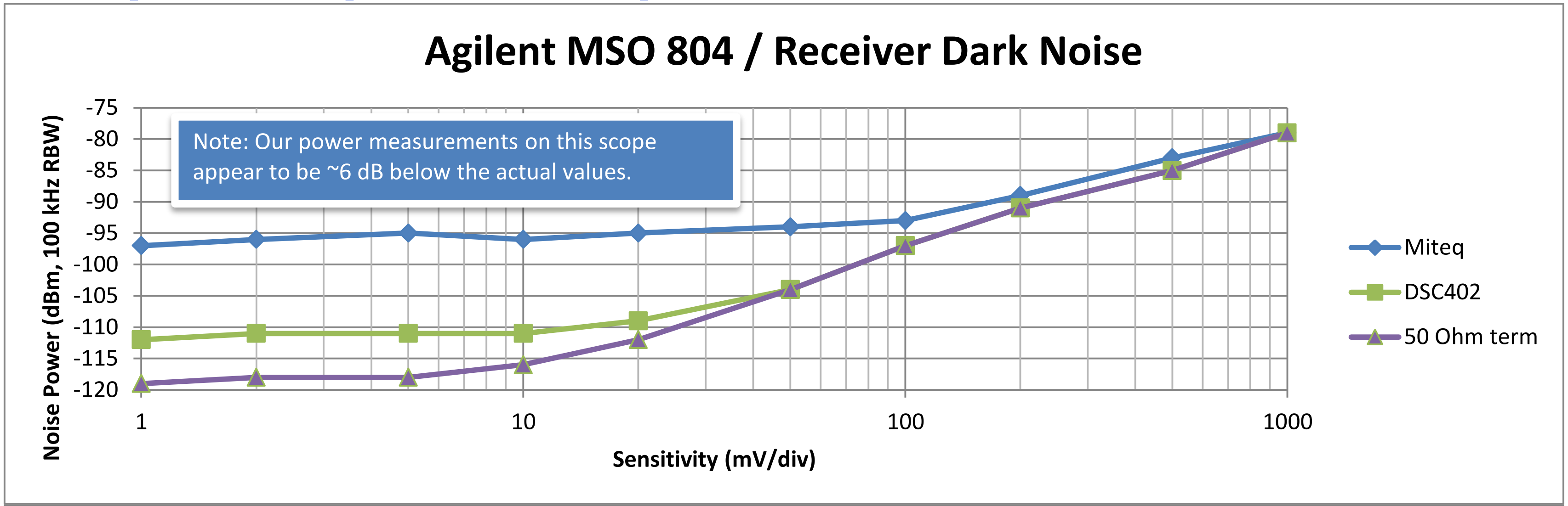
Scope comparison: Electrical (1.05 GHz)

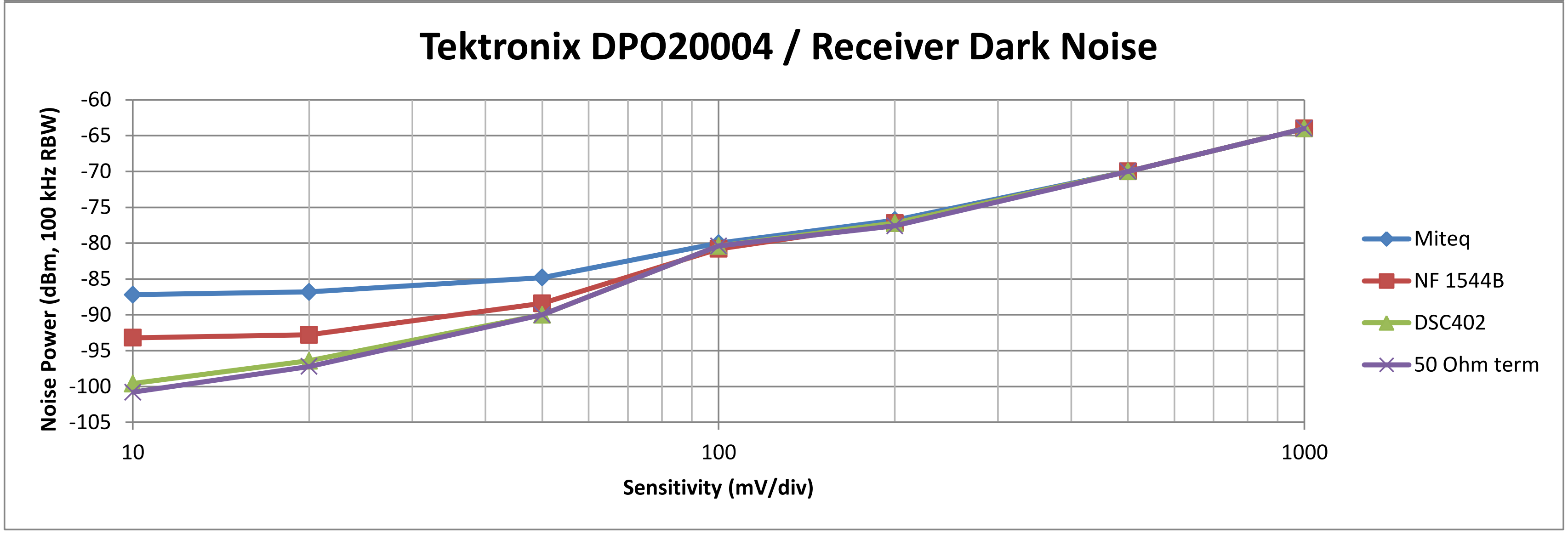




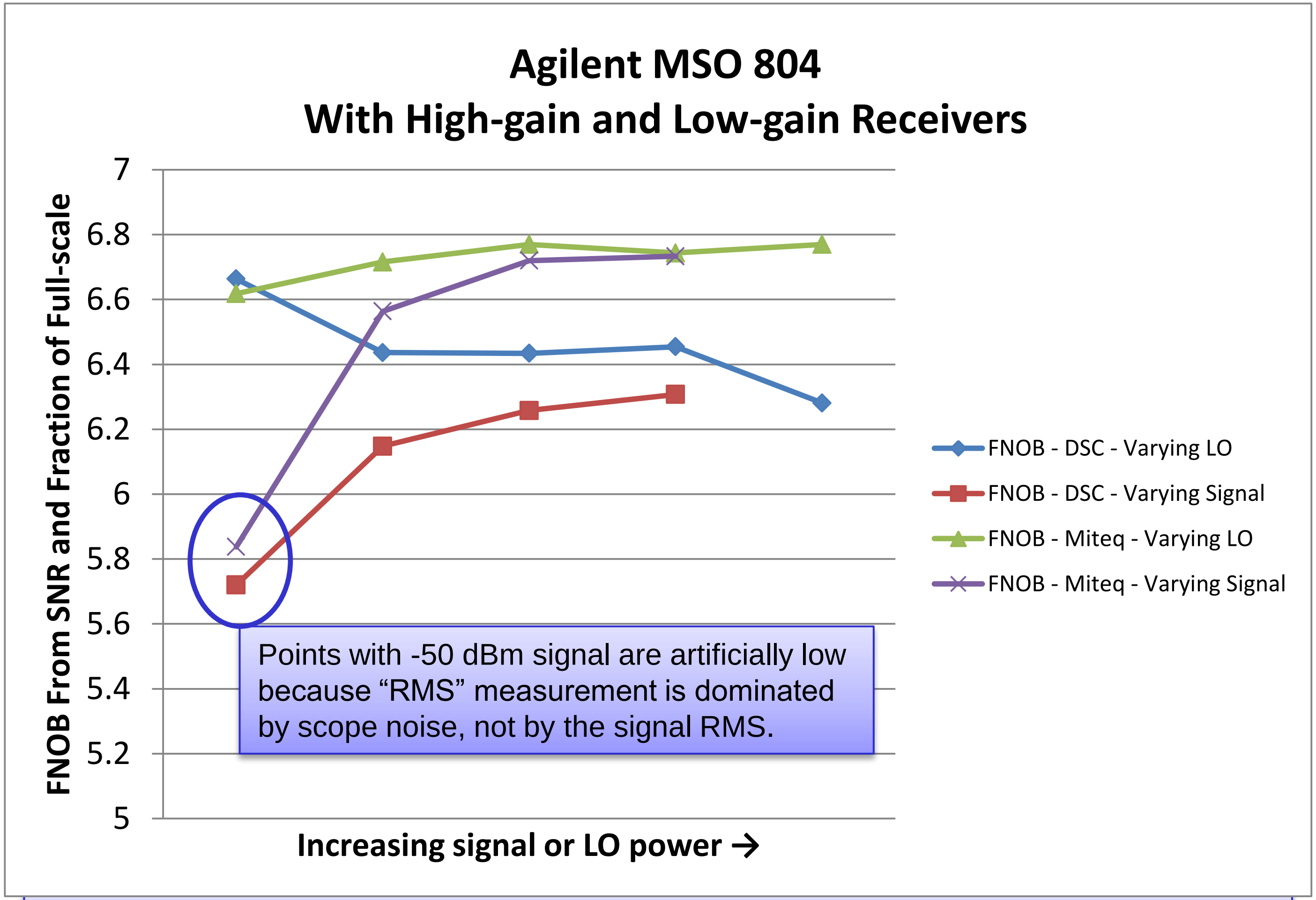
"FNOB" = $(1/6.02) *(SNR_{f,dB} - 1.76 - 20*\log(2*RMS/V_{FS}) - 10*\log(N_{FFT}/2)$

Scope Comparison: Optical Receiver Dark Noise



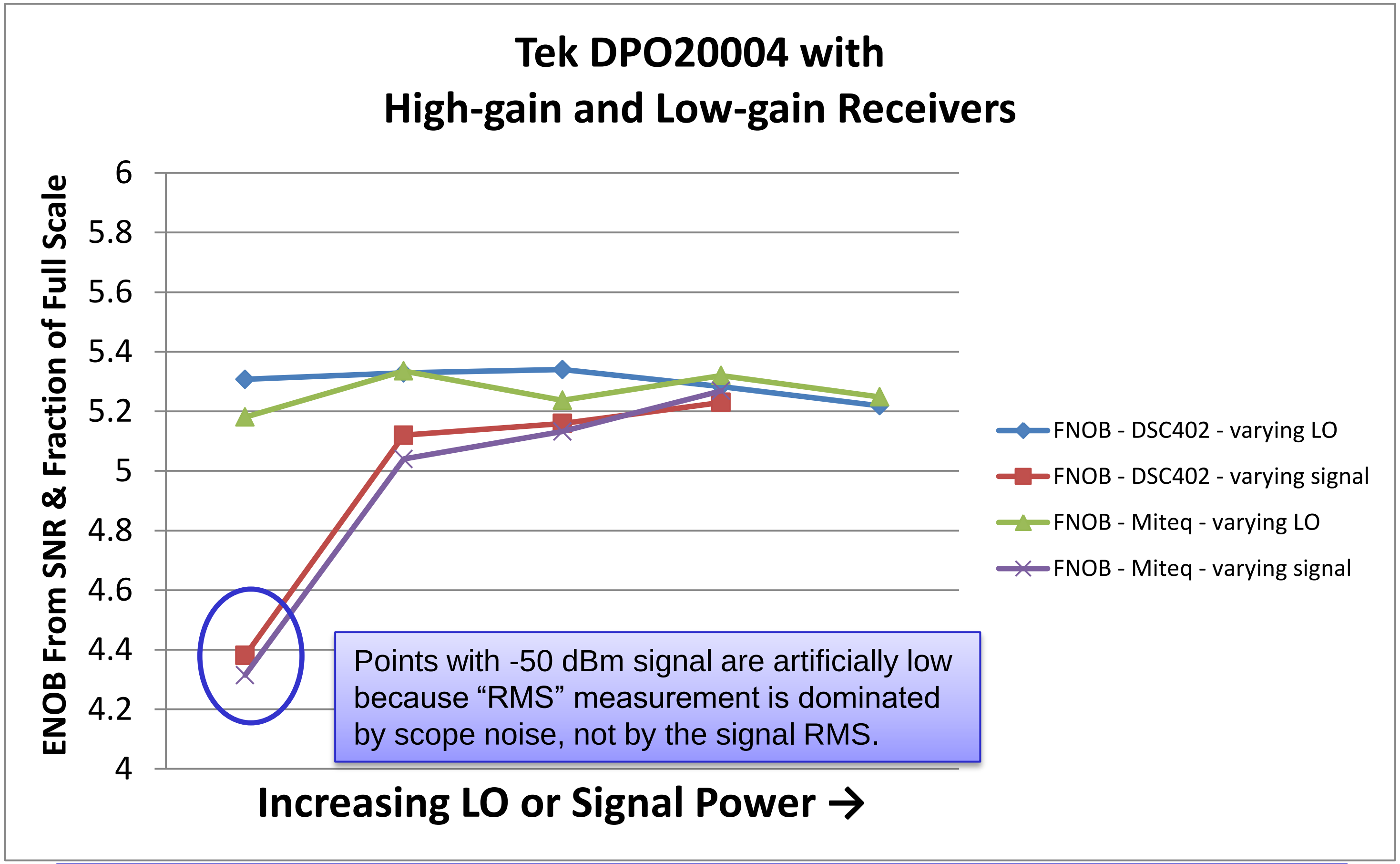


Lab Data: Optical signals on the Agilent MSO 804



Varying LO: -20 dBm to 0 dBm in steps of 5 dBm; Signal = -20 dBm
Varying Signal: -50 dBm to -20 dBm in steps of 10 dBm; LO = 0 dBm

Lab Data: Optical signals on the Tektronix DPO20004



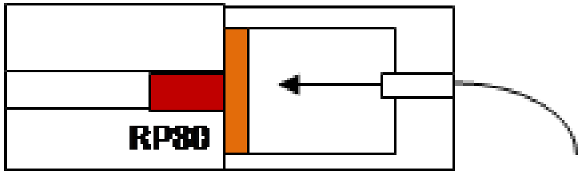
Varying LO: -20 dBm to 0 dBm in steps of 5 dBm; Signal = -20 dBm
Varying Signal: -50 dBm to -20 dBm in steps of 10 dBm; LO = 0 dBm

Lab data: Conclusions

LAB DATA	Electrical FNOB	Optical FNOB
Agilent MSO 804	7.4 ± 0.2	6.5 ± 0.3
Tek DPO20004	5.8 ± 0.1	5.25 ± 0.1

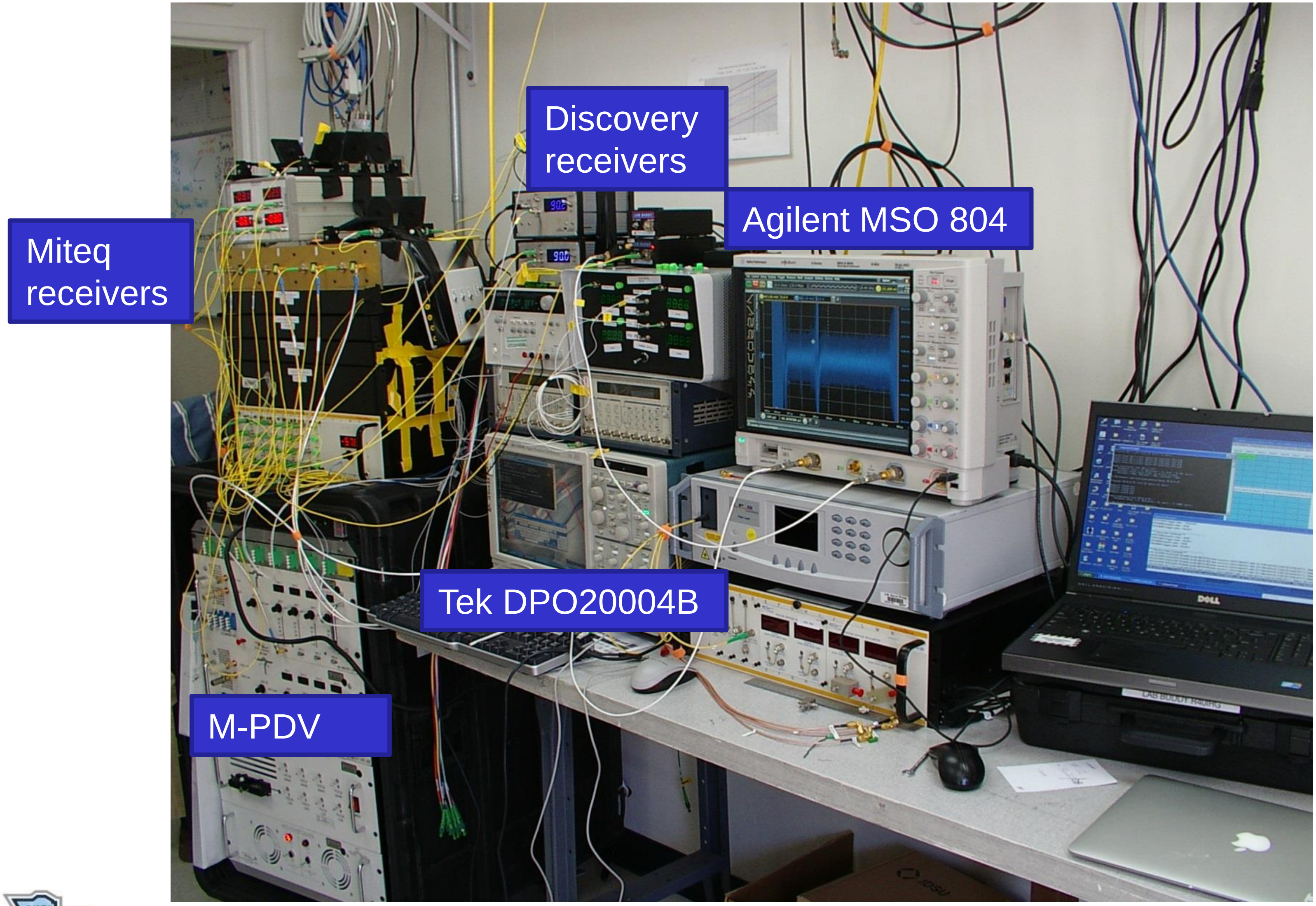
- Idealized conditions:
  - No circulators
  - No long transmission fibers
  - No back-reflections
- Agilent MSO 804 seems to give higher dynamic range
  - Can we exploit this on shot data?
- Comparable performance with both receiver configurations
  - Discovery 402 (0.35 V/W) at 10 mV/div
  - Miteq DR125G (2 V/W) at 100 mV/div

Shot data

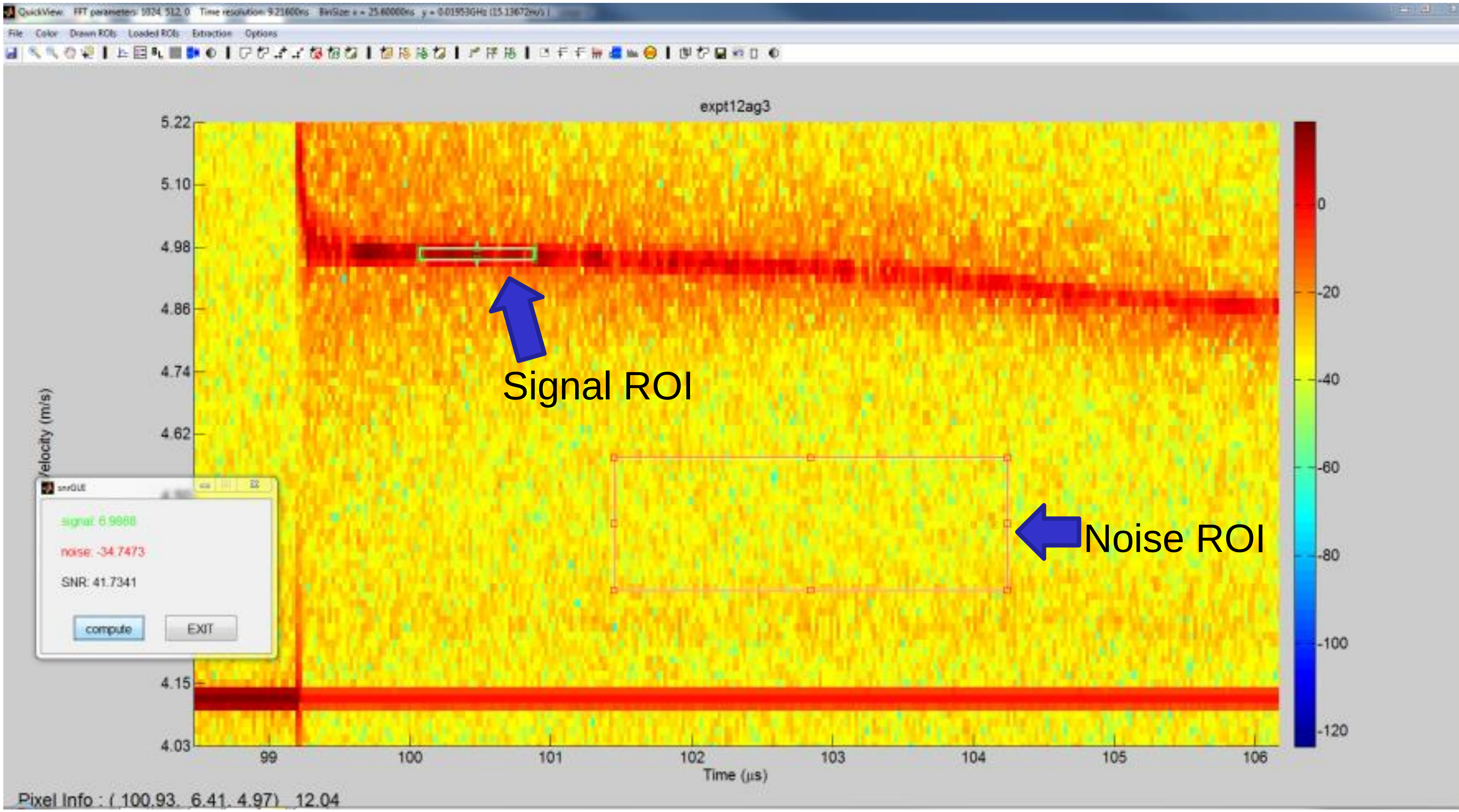


- STL BoomBox
- RP-80 detonators driving 1” diameter copper coupons
- Single PDV probe with multiple wavelengths, demux on back-end
- Velocities ~ 800 m/s
- All systems are heterodyne, zero-velocity frequencies from 1 – 6 GHz
- Variety of recording setups were tested
- Analysis using “Quick-view” with FFT window of 1024 points
- Two scopes used:
  - Tek DPO72004B (run at 25 GS/s, 12.5 GHz)
  - Agilent MSO 804 (run at 20 GS/s, 8.4 GHz)
- Two receivers used:
  - Miteq DR125G (12.5 GHz), ~2 V/mW
  - Discovery DSC402, ~0.35 V/mW

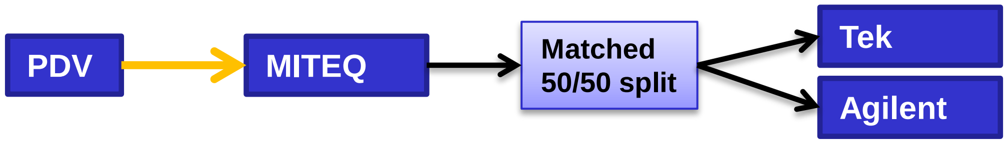
Recording setup

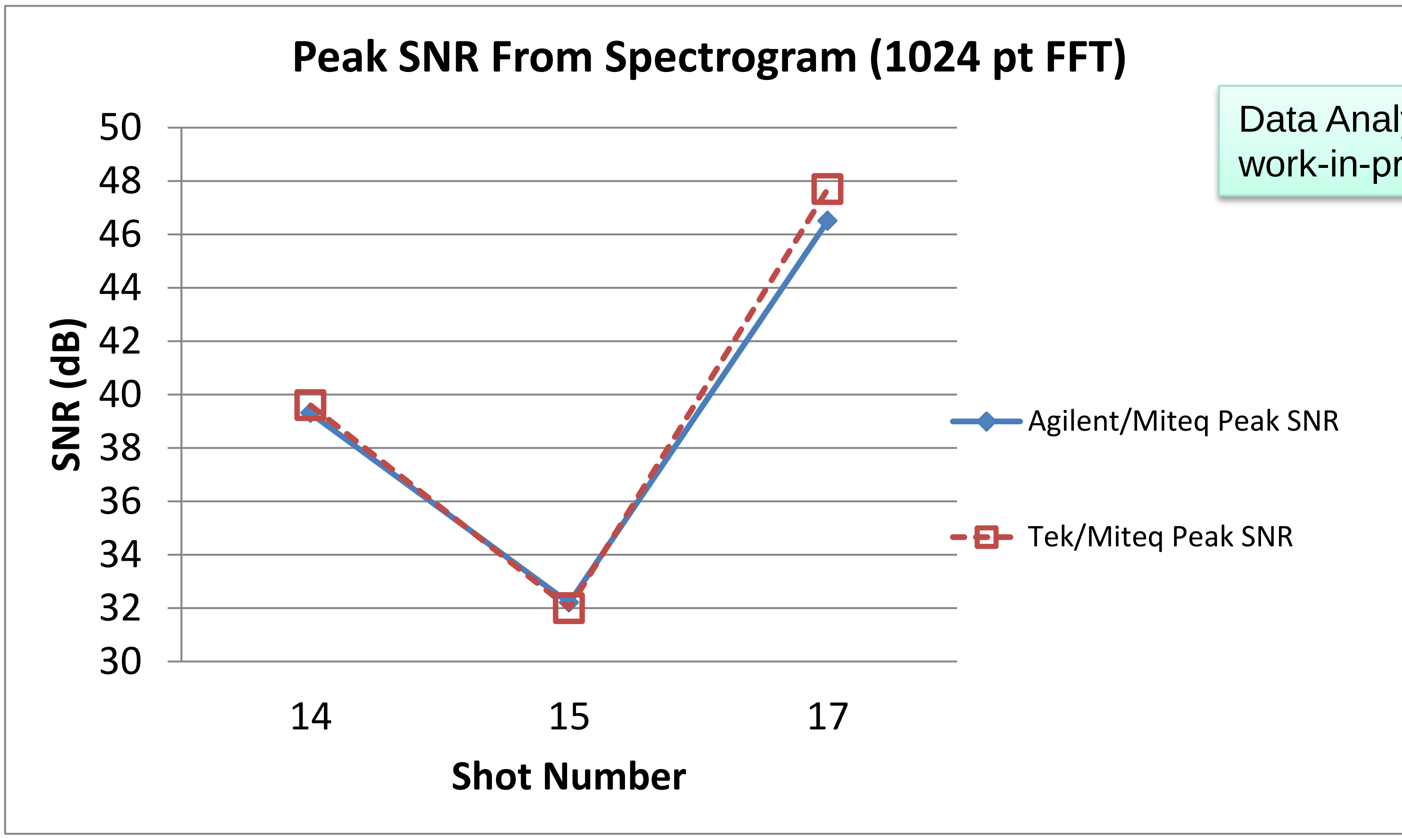


Typical Spectrogram and Analysis



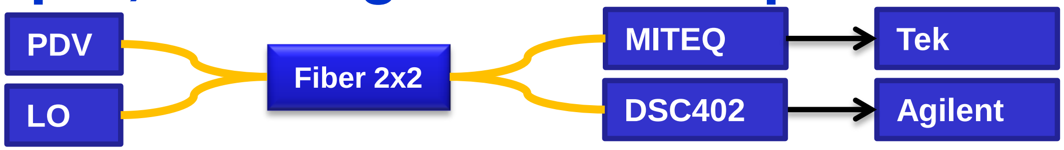
Shot data:
Electrical split, Miteq, Agilent and Tek, both on 100 mV/div

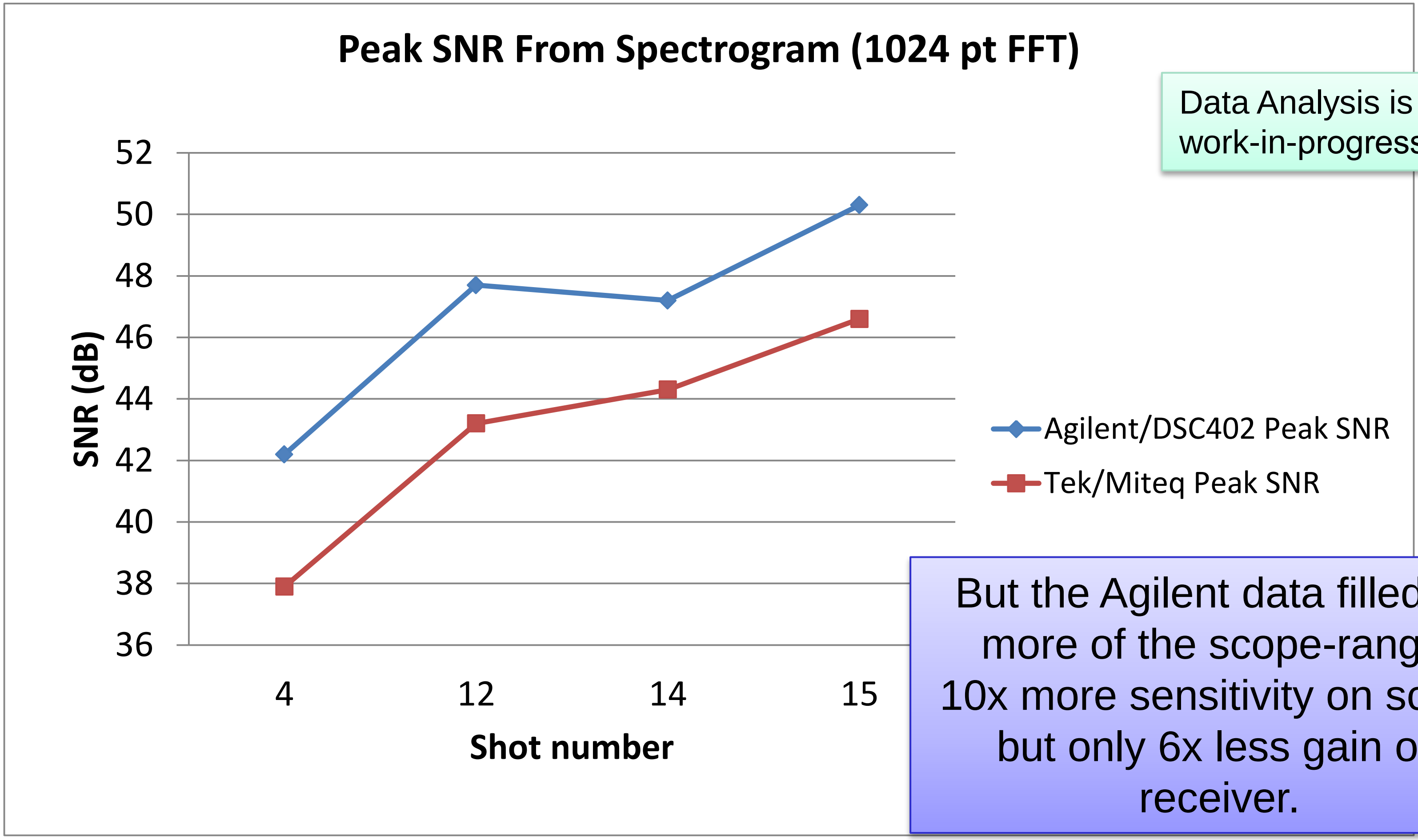




Data Analysis is work-in-progress….

Shot data:
Optical split, DSC/Agilent & Miteq/Tek





Data Analysis is work-in-progress….

But the Agilent data filled up more of the scope-range: 10x more sensitivity on scope but only 6x less gain on receiver.

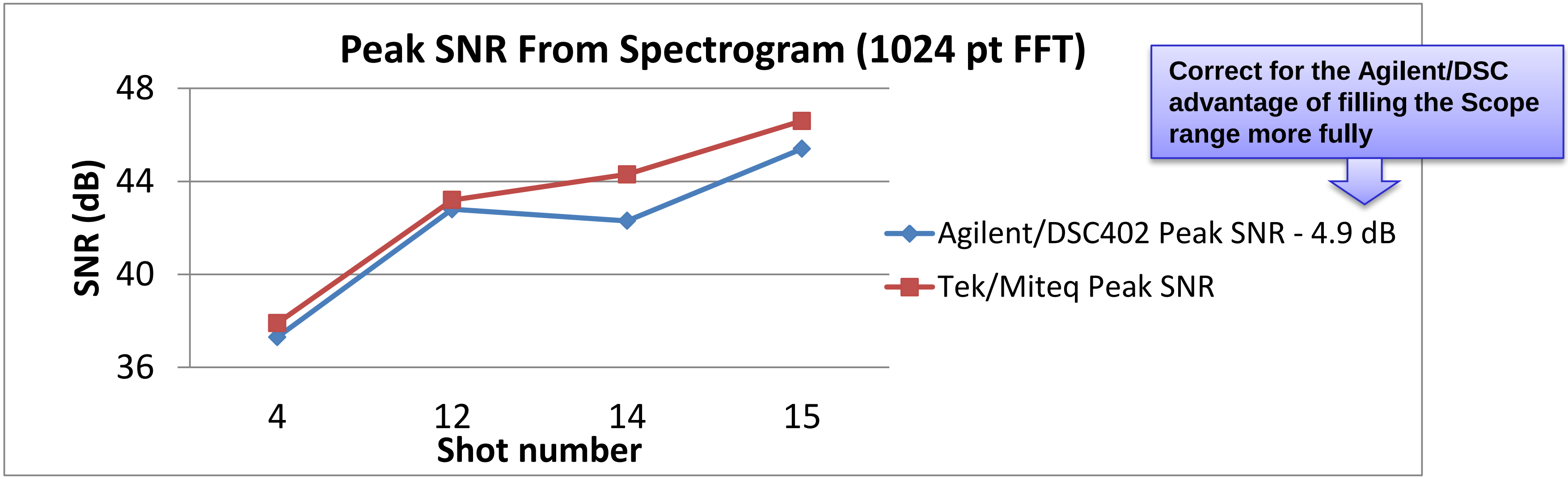
Normalize for scope range

$$SNR_{f,dB} = 6.02*FNOB + 1.76 + 20*\log(2*RMS/V_{FS}) + 10*\log(N_{FFT}/2)$$

This will be proportional to (Receiver Gain) / (Scope Sensitivity)

DSC / Agilent: 20 log (0.35 V/mW / 0.1 mV) = 10.9
Miteq / Tek: 20 log (2.00 V/mW / 1.0 V) = 6.02

So, just based on fraction of full-scale, the DSC/Agilent setup is getting a bonus 4.9 dB of SNR
Correct for coverage difference, and the result will be purely the "FNOB" difference



Conclusions

- Shot data:
  - No clear difference on coverage-normalized shot data
  - With small signals, the DSC receiver will fill up more of the full-scale range at 10 mV/div… potential for better SNR

- Outstanding questions
  - Why does the dynamic range on actual shot data seem to be limited by the PDV hardware?
    - Circulator leakage?
    - Brillouin backscatter?
    - Something else?
  - What about the tin shots, where there was no distinct surface?
  - What conditions (system design, experiment…) would allow us to exploit the extra dynamic range we see in the lab?

- Shot-data experiments I'd like to do in the future:
  - DSC receiver vs Miteq receiver on the same scope
  - Homodyne PDV – DC-block the zero-velocity signal
  - Put circulator near probe to reduce Rayleigh backscatter

Thank you

- Agilent for loaning the MSO 804 for this work
- NSTec Program Support
  - Detectors & Instrumentation Project
  - Shock-wave R&D Project
- LANL team
- NSTec STL team
- NSTec NLV team
- All the vendors who are making enabling components for PDV systems!

- *And of course, to Ed and Larry for making this workshop possible!*