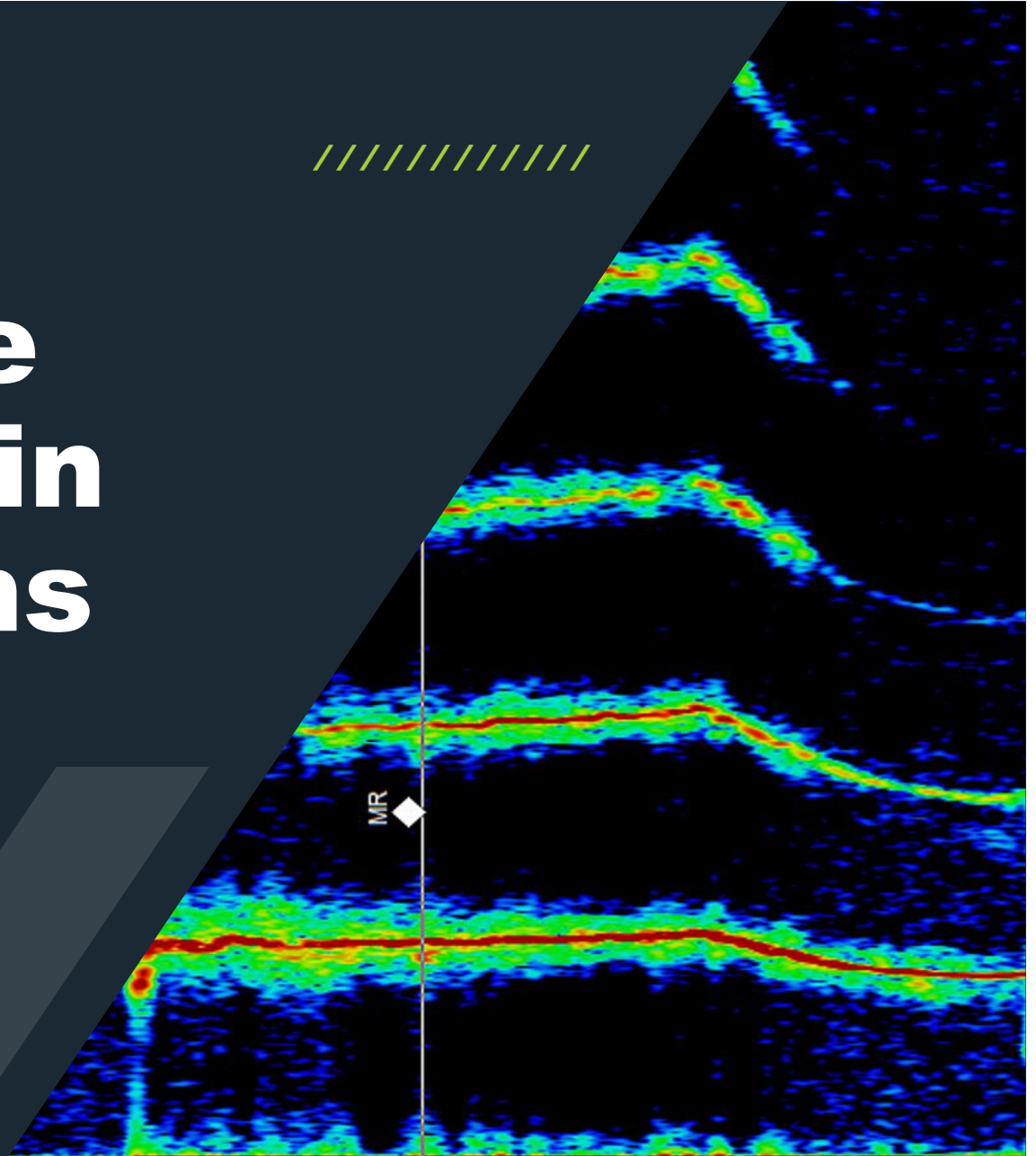


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Digitizer Sample Rate trade-offs in PDV Applications

Dan Knierim

2026 PDV Workshop





Digitizer Sample Rate trade-offs in PDV Applications

ABSTRACT:

A digitizer's Total Sample Rate (TSR) is defined as the product of the maximum sampling rate per channel and the number of channels which can be simultaneously digitized at that rate. As TSR drives a significant portion of the cost* of a digitizer (and in turn, a PDV system), it makes sense to optimize use of this resource. Many digitizers offer a programmable choice of sample rate and channel count to allow for this optimization on a use-case basis.

This presentation covers from a theoretical perspective the pertinent trade-offs between sample rate, channel count, bandwidth, and noise floor in relation to PDV and similar optical diagnostics. In many cases, if the optics are available, higher channel counts provide better data redundancy than higher sample rates for the same TSR.

** Note that "cost" as used here has many metrics, including price (\$), size (1.75" rack units), power dissipation (W), etc. all of which increase with TSR.*

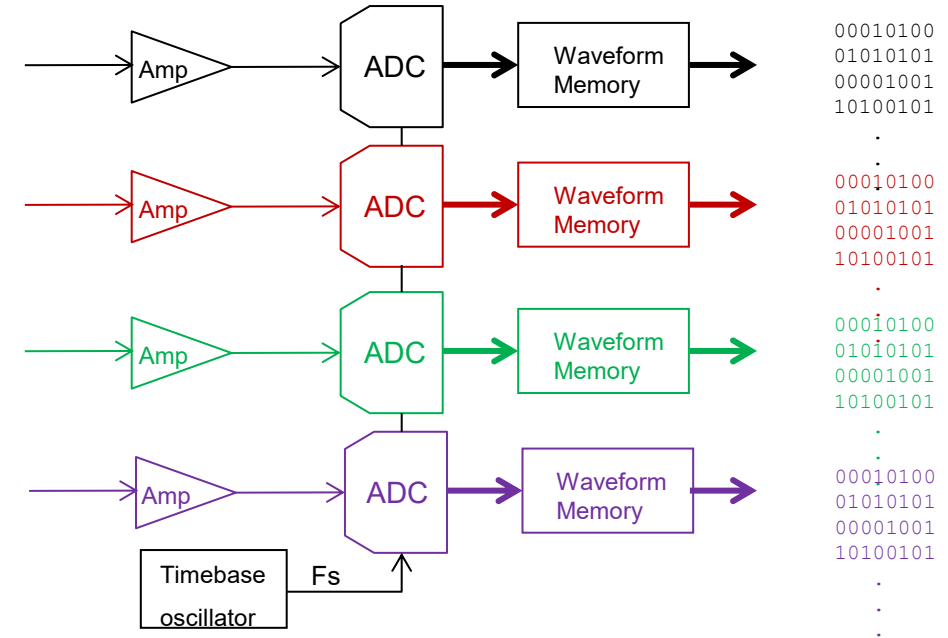
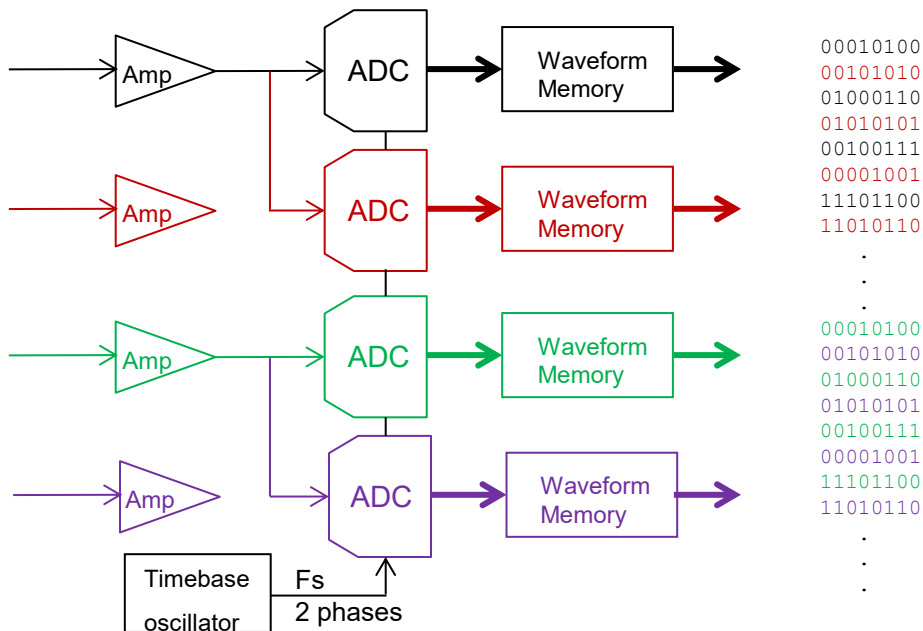




Digitizer Sample Rate trade-offs in PDV Applications

Flexible Interleaved Digitizer Architecture

- 4 Channels @ F_s (shown to right)
- 2 Channels @ $2 \cdot F_s$ (shown below)
- 1 Channel @ $4 \cdot F_s$ (not shown)



Note: Amplifiers often include programmable anti-alias filters to automatically lower bandwidth at lower sample rates.



Digitizer Sample Rate trade-offs in PDV Applications

Choice of Sample Rate vs Channel Count

- There is no “one-size-fits-all” choice of Sample Rate vs channel count
- If optics are available, use Nyquist sample rate and receiver diversity
 - Determine maximum velocity V_{\max} (including guardband for the unexpected)
 - $F_{\max} = 2 \cdot V_{\max} / \lambda$ ($\sim 1.3\text{GHz} / (\text{km/s})$ at 1550nm)
 - $F_{\max} = 4 \cdot V_{\max} / \lambda$ (*if observing double-round-trip reflections*)
 - $F_s = 2.5 \cdot F_{\max}$ (*to allow anti-alias filter headroom*)
 - Select digitizer sample rate at or above F_s , then maximize channel count
- If optics are limited, select channel count to support optics, then use maximum available F_s

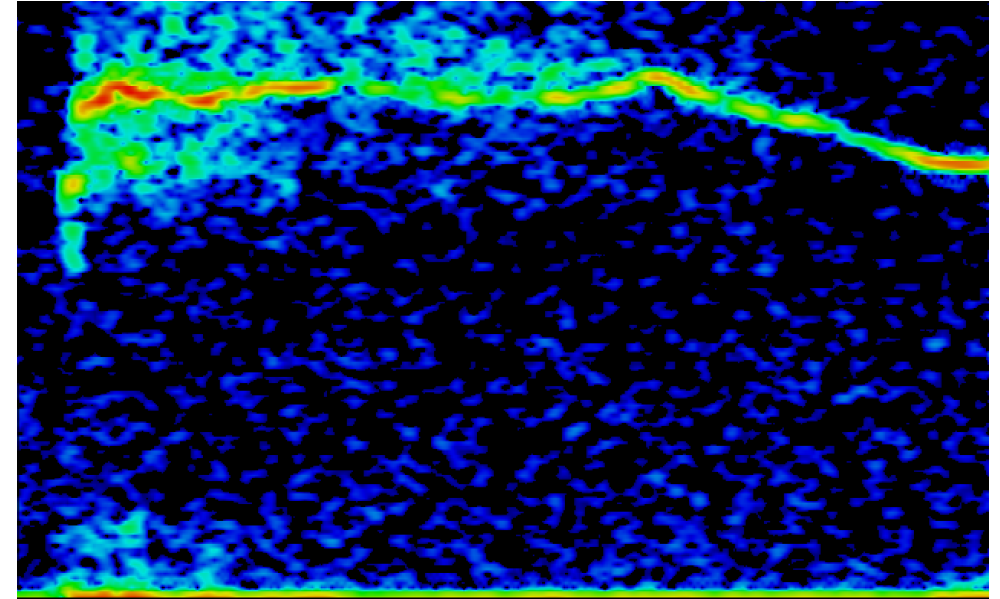


Digitizer Sample Rate trade-offs in PDV Applications

Sub-Nyquist options

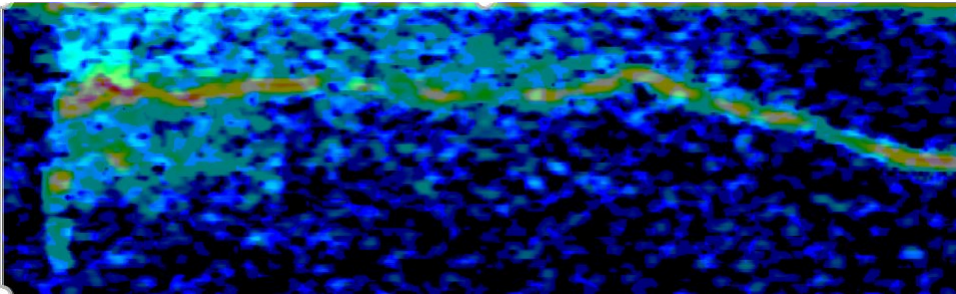
- There are sub-Nyquist options available
 - Negative-offset (heterodyne) PDV
 - Requires stable illumination and reference lasers
 - Digitizer aliasing
 - Requires digitizer without anti-alias filter
 - Both techniques increase noise and risk velocity ambiguity

2 GHz



0 GHz

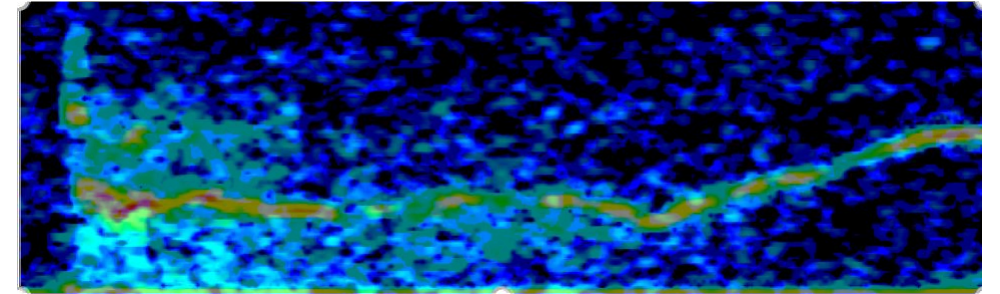
1 GHz



0 GHz

Offset PDV

1 GHz



0 GHz

Aliased PDV





Digitizer Sample Rate trade-offs in PDV Applications

Uses for “excess” TSR (Total Sample Rate)

- Sample redundancy
 - Noise reduction from spreading ADC noise across wider Nyquist bandwidth
 - From 0 to 3dB improvement per octave, depending on portion of noise in Amplifier vs ADC
 - Typically 1 to 2 dB improvement, depending on digitizer settings (smaller considering system noise)
 - Does **not** improve time resolution of velocity profile
- Channel redundancy (aka receiver diversity)
 - Protection from speckle drop-outs (assuming speckle is independently random between beams)
 - Ability to observe target distortion, rotation, non-homogeneity
 - Noise reduction from averaging velocity profiles of redundant beams (full 3dB per octave)
- Bandwidth redundancy (ability to analyze double-round-trip reflections)





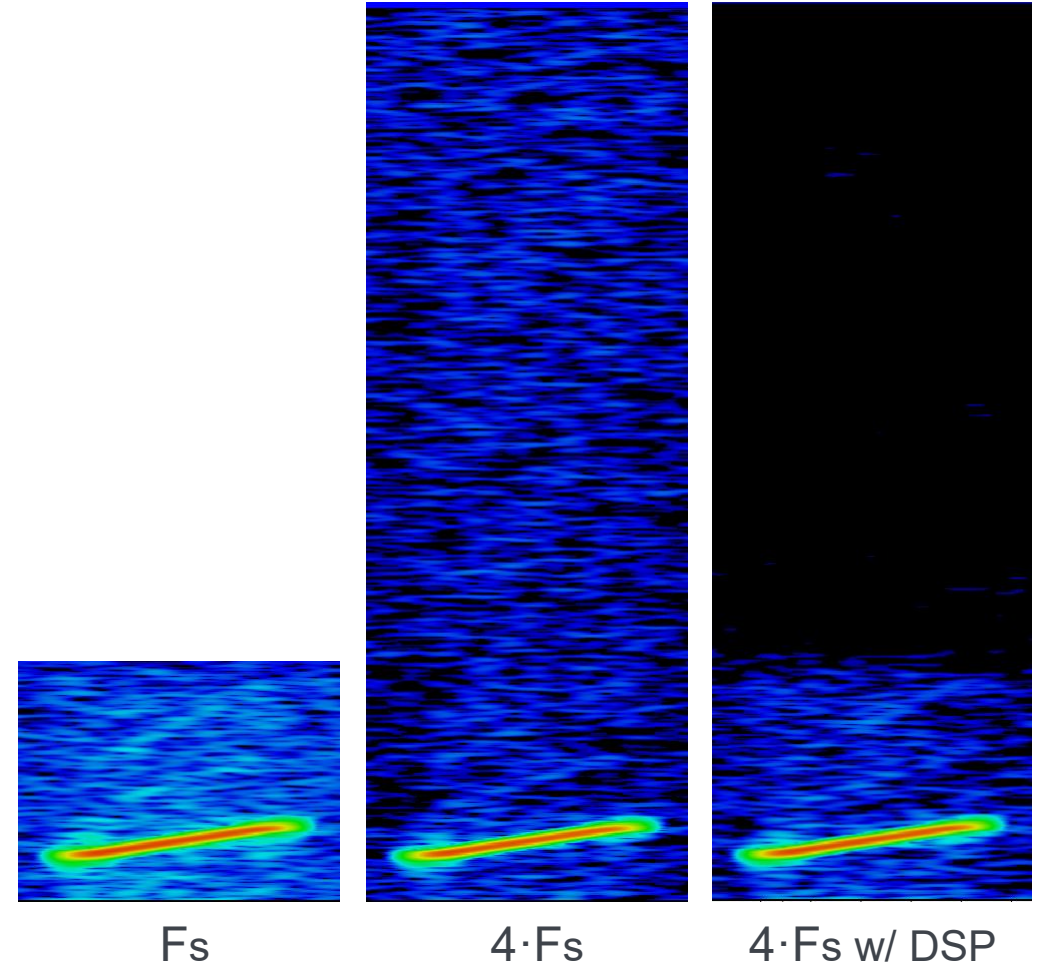
Digitizer Sample Rate trade-offs in PDV Applications

Oversampling for noise reduction

Example: MSO68B digitizer @ 1VFS

- 2, 4, or 8 channels at 50, 25, or 12.5 GS/s
- Interleaving to higher sample rate does not reduce noise, but spreads it spectrally (which is what benefits frequency-domain analyses such as PDV)
- Subsequent digital filtering reduces the total noise (useful in time-domain analyses)
- The noise advantage is already included in noise tables – do not double-count!

Fs \ BW	10GHz	5GHz
2 channels @ 50 GS/s	3.50mV	2.04mV
4 channels @ 25 GS/s	4.41mV	2.59mV
8 channels @ 12.5 GS/s	n/a	2.74mV
50 vs 25	-2.0dB	-2.1dB
25 vs 12.5	n/a	-0.5dB

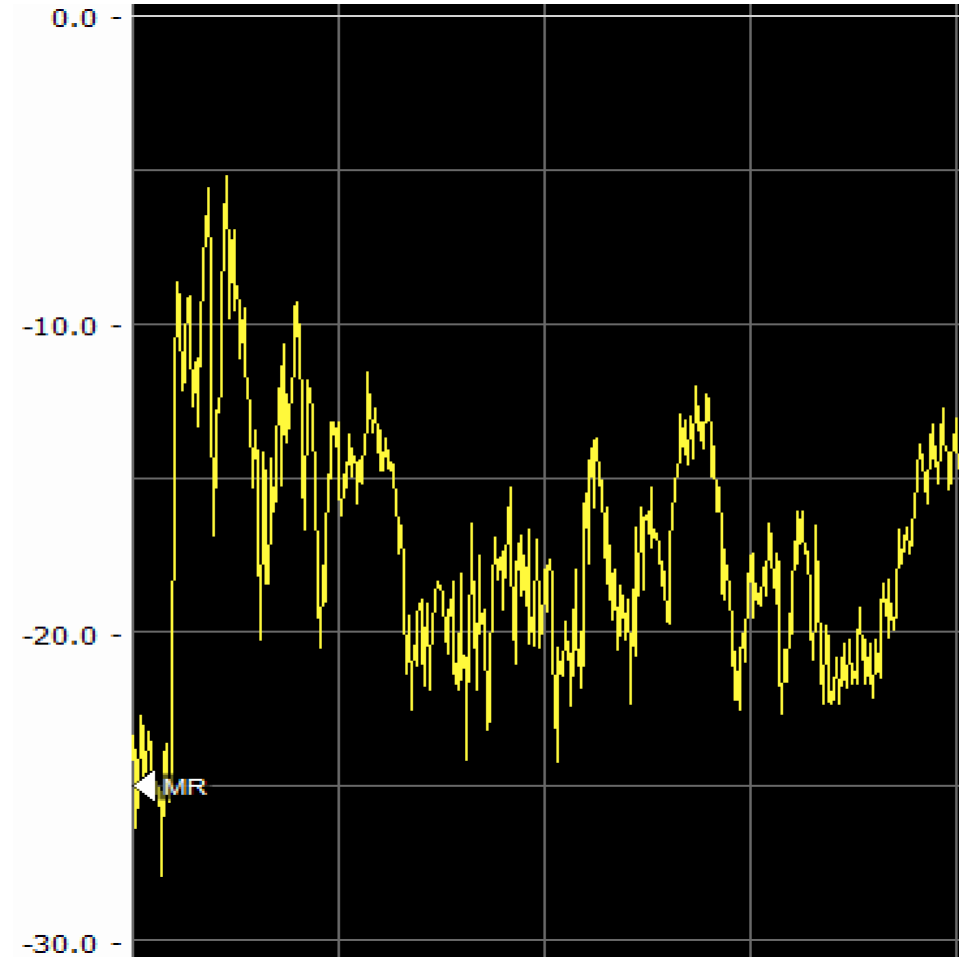
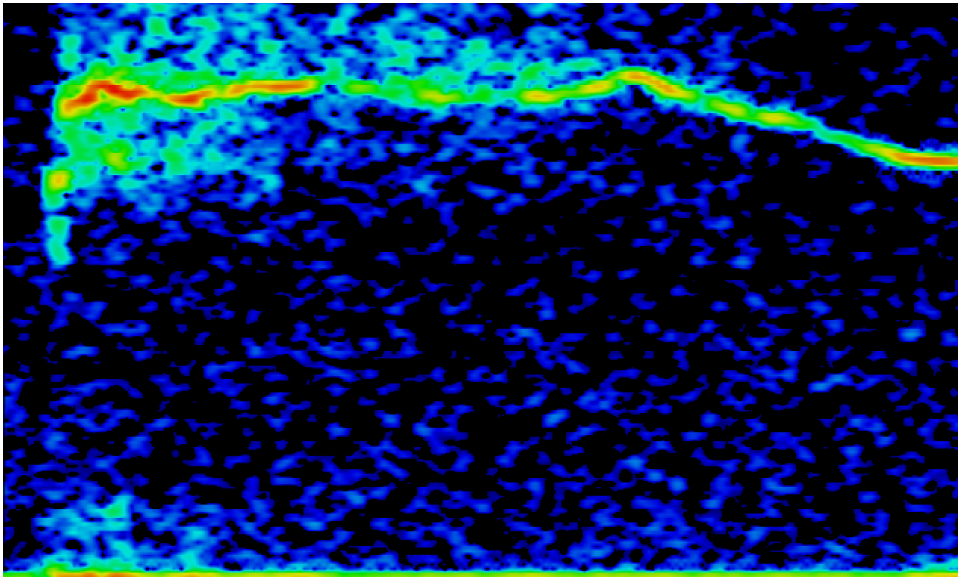




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Speckle drop-outs

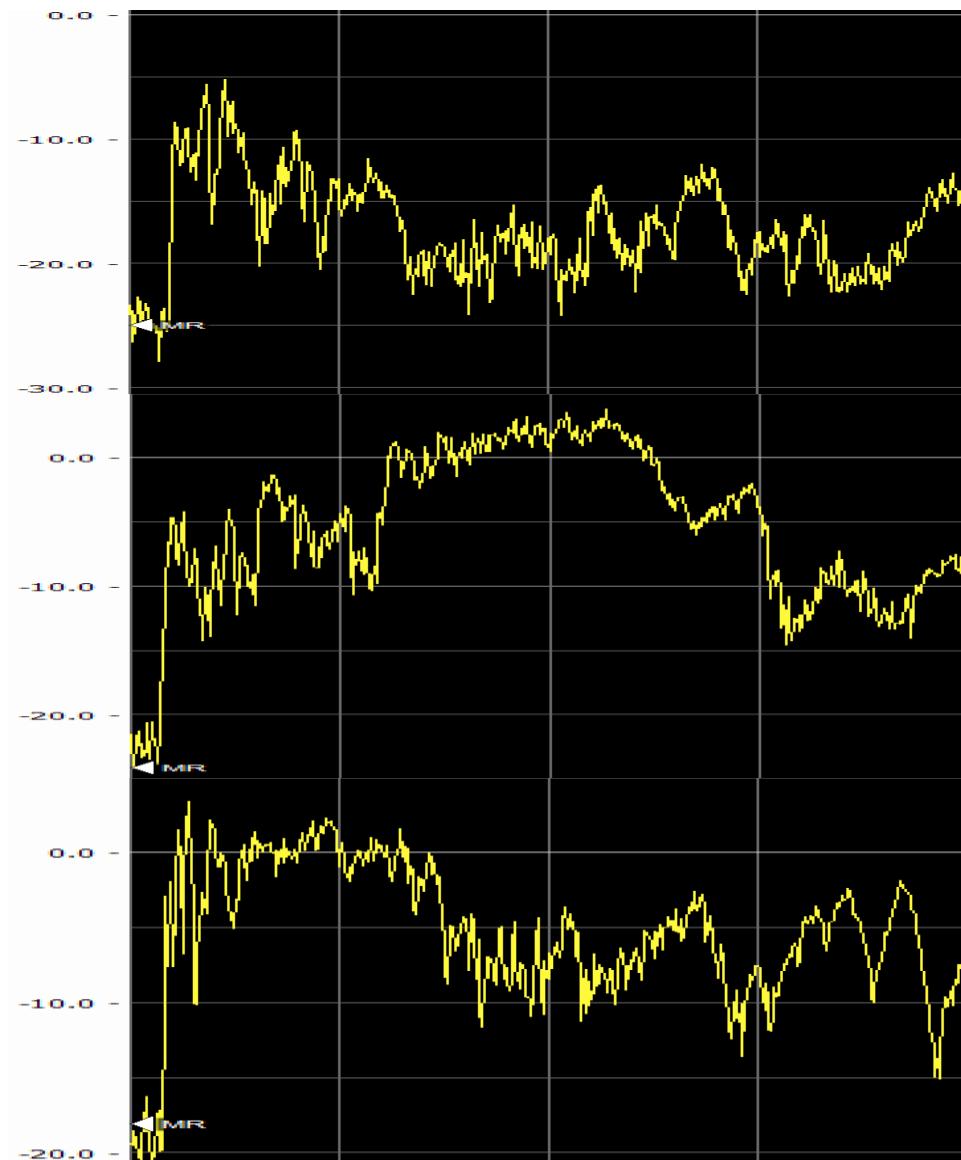
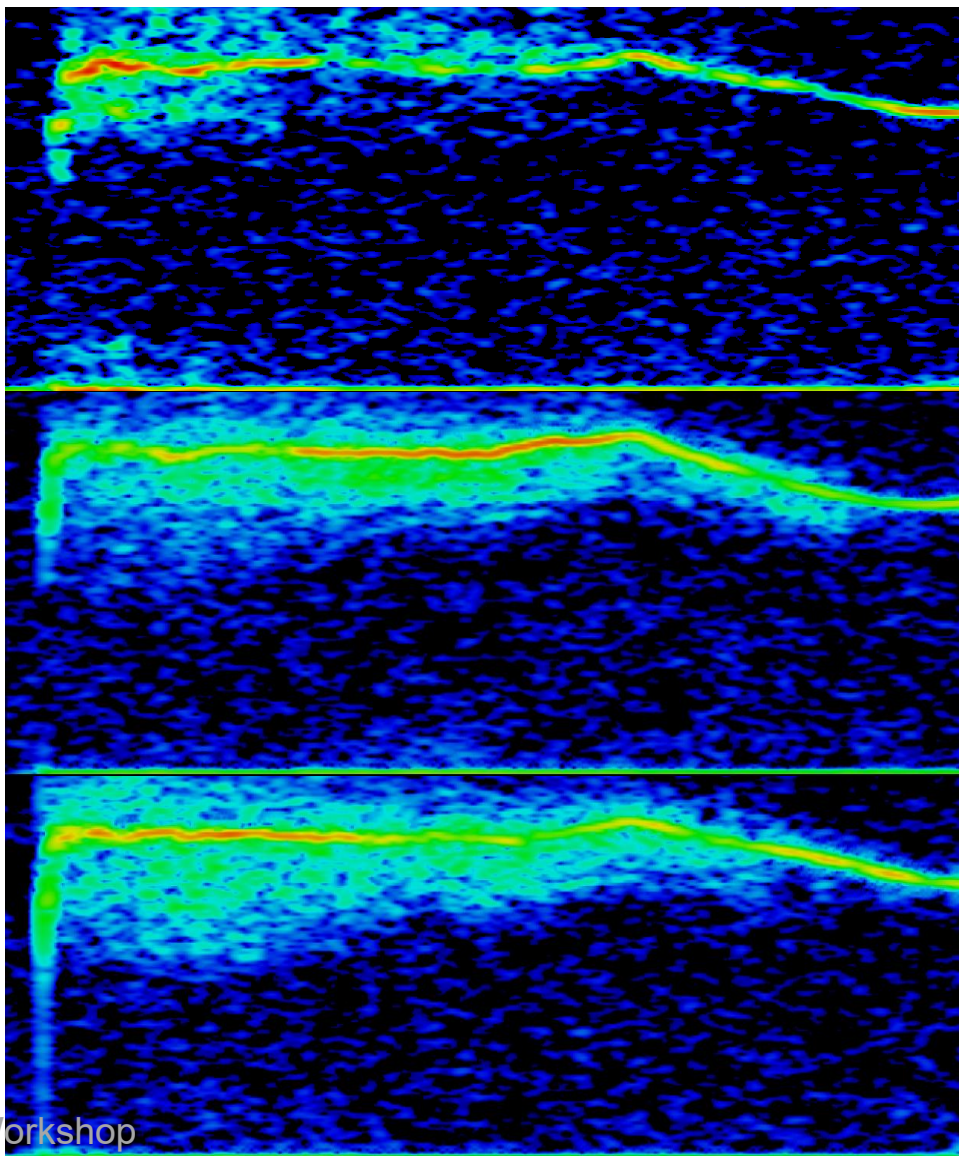
- Noise advantage of “extra” sample rate pales in comparison to Signal loss due to speckle
- “Speckle diversity” optimizes SNR





Digitizer Sample Rate trade-offs in PDV Applications

Channel (beam) diversity
for speckle drop-outs





Digitizer Sample Rate trade-offs in PDV Applications

Co-located measurement diversity for speckle drop-outs

A few theoretical ideas to cover speckle drop-outs at a particular point on the target:

In each case, the trick is seeking correlated velocity sensitivity with uncorrelated speckle.

- “Parallel” probes aimed at the same point on target
 - Surface roughness $> \lambda/2$, beams separated by beam width
 - Surface roughness $< \lambda/2$, beams at slightly different angles
- Wavelength diversity in a single probe
 - Surface roughness $> \frac{1}{2} \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2}$ should be sufficient, perhaps not necessary
 - $\frac{1}{2} \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2} = 4.23\mu\text{m}$ for $\lambda_1 = 1550\text{nm}$ & $\lambda_2 = 1310\text{nm}$
- Double-round-trip reflection analysis in a single probe (*see next slides*)
 - *Note: harmonic distortion may also produce a “double-velocity” trace. Double-round-trip reflection should have uncorrelated speckle, harmonic distortion will have highly correlated speckle.*

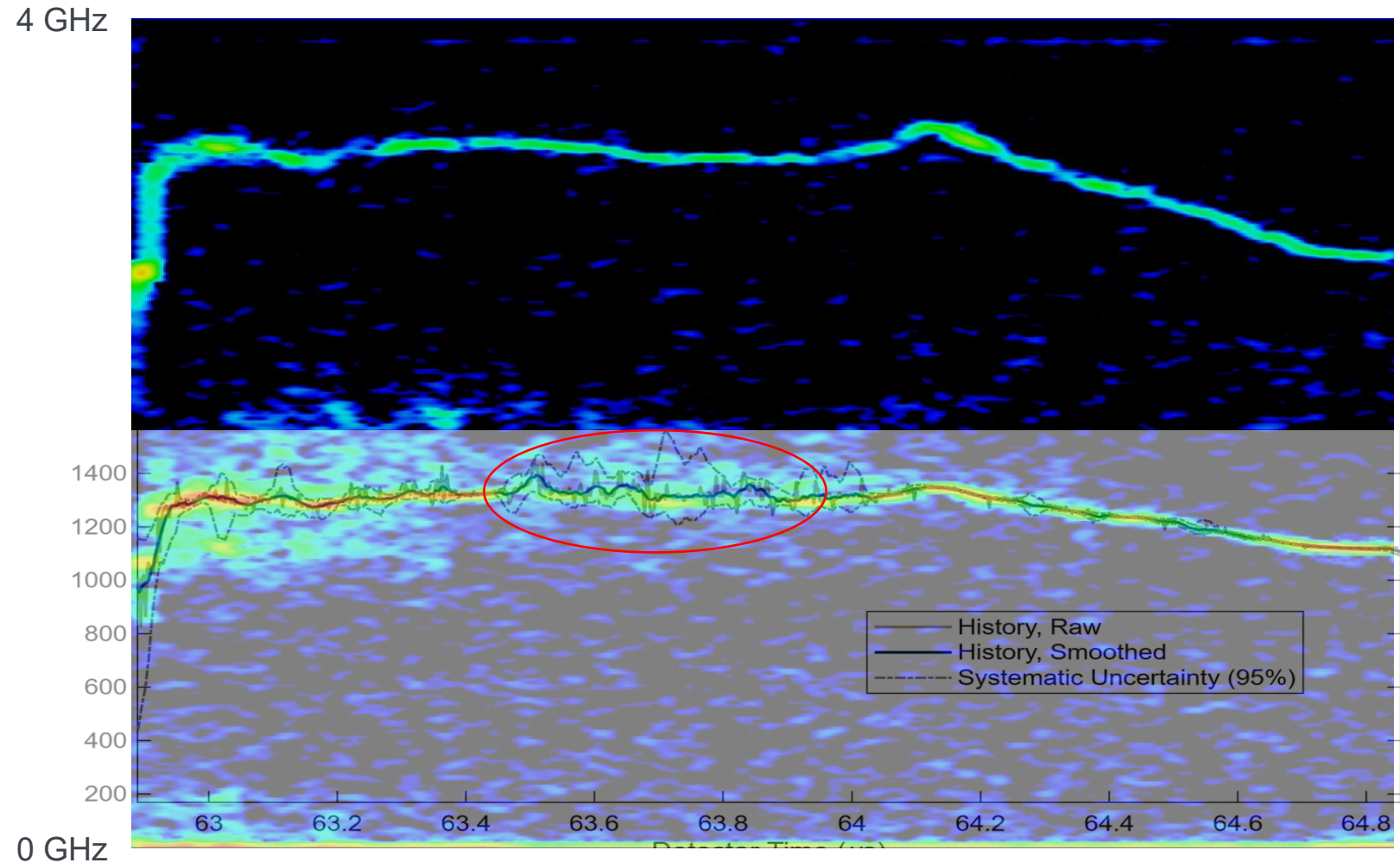


Digitizer Sample Rate trade-offs in PDV Applications

Double-round-trip reflection analysis in a single probe

HiFiPDV2 analysis overlaid on main trace of Spectrogram

- Velocity “bumps” at 63.5 to 63.8 μ s line up with speckle drop-outs



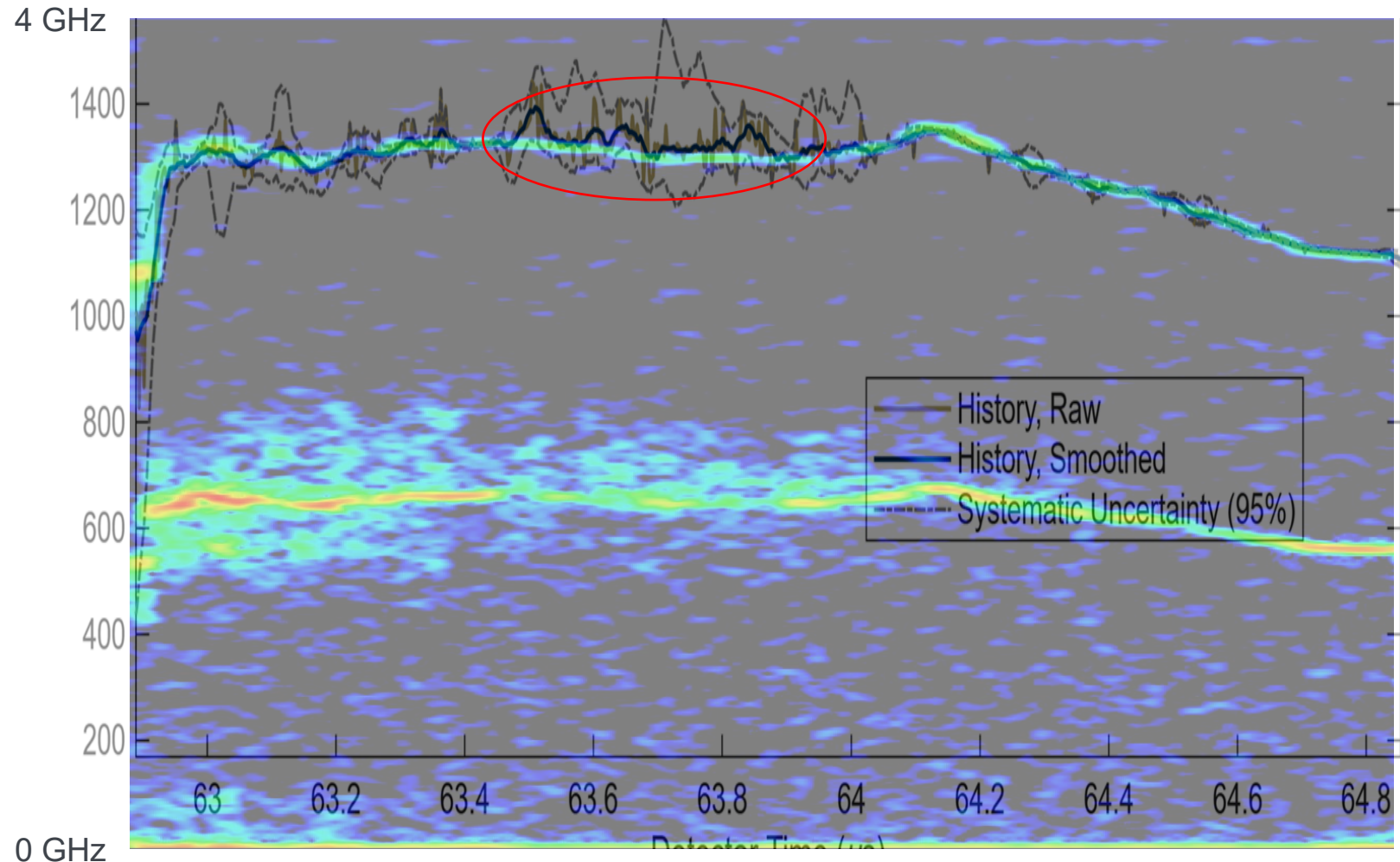


Digitizer Sample Rate trade-offs in PDV Applications

Double-round-trip reflection analysis in a single probe

HiFiPDV2 analysis overlaid on double-round-trip trace of Spectrogram

- Speckle is randomized due to reflection off window and second reflection off target
- No speckle drop-outs or velocity “bumps” at 63.5 to 63.8 μ s
- Spectrogram trace “fits” within HiFiPDV2 uncertainty bounds





Digitizer Sample Rate trade-offs in PDV Applications

Conclusion

- There is no “one-size-fits-all” choice of Sample Rate vs channel count
- Prefer flexible digitizer architectures that allow a choice on a use-case basis
- If optics are available, use Nyquist sample rate and receiver diversity
- If optics are limited, select channels to support optics, and maximum available F_s

- *I would appreciate hearing from anyone who has experimented with any co-located measurement diversity ideas (whether mentioned here or not)*



Dan Knierim

dan.knierim@tek.com

503-627-2866



**THANK
YOU**



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