10GBASE-T Transmitter SNDR Definition

(System ID Approach)

IEEE P802.3an Task Force

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OUTLINE

- **Transmitter Performance Evaluation Block Diagram and Example Tx Impairment Walk-through**
- **System ID Methodology: Transmitter Characterization Metric Definition**
- **10GBASE-T Transmitter Compliance Specification at MDI: Estimated Signal-to-Total-Noise and Distortion Ratio (SNDR) in a given Bandwidth**
- **Conclusion**

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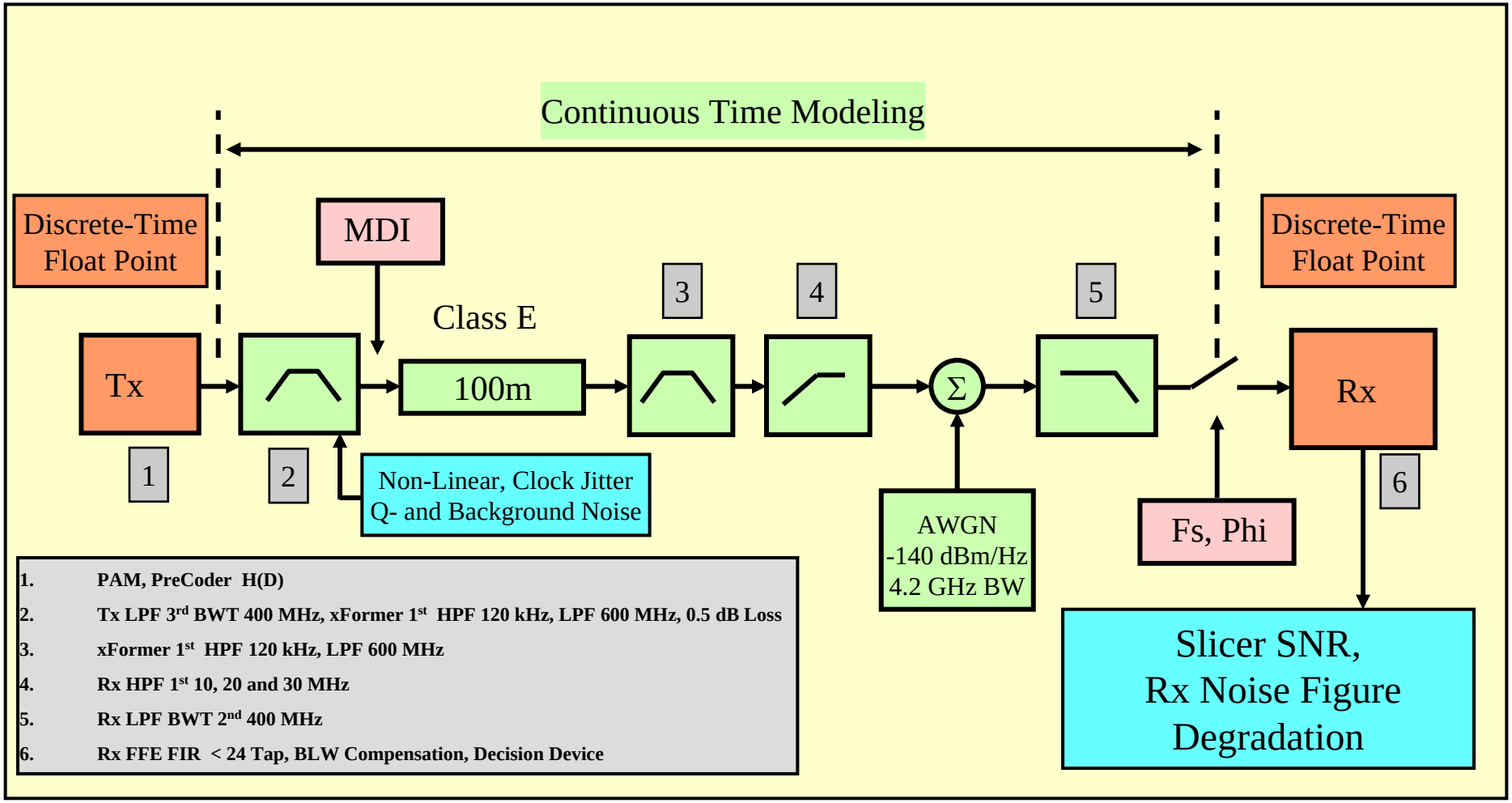
Transmitter Performance Evaluation Block Diagram



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Tx Chain Key Impairments – Analog and Digital

- Non-Linear Distortion (Active and Passive: xFormer, …)
- Quantization and Background Noise
- Noise due Tx Clock Jitter
- Slew Rate Limitations Related
- Imperfect DSP
- Spurious – Clock Leakage, Supply, Parasitic Coupling, etc…
- Need a Compact and Meaningful Metric to Account for the Net System Impact

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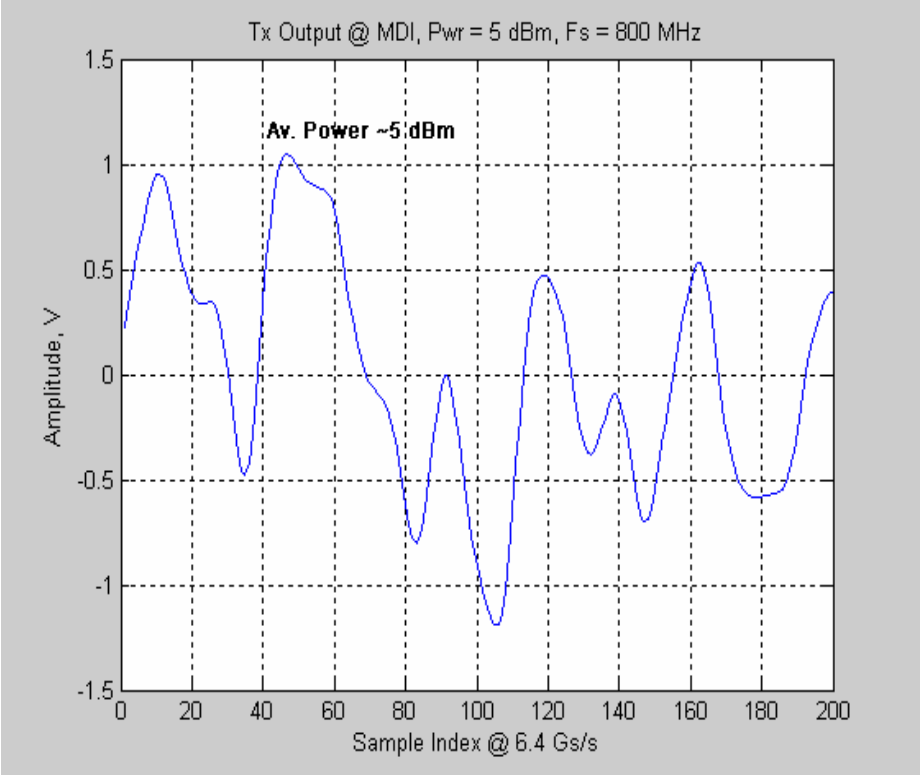
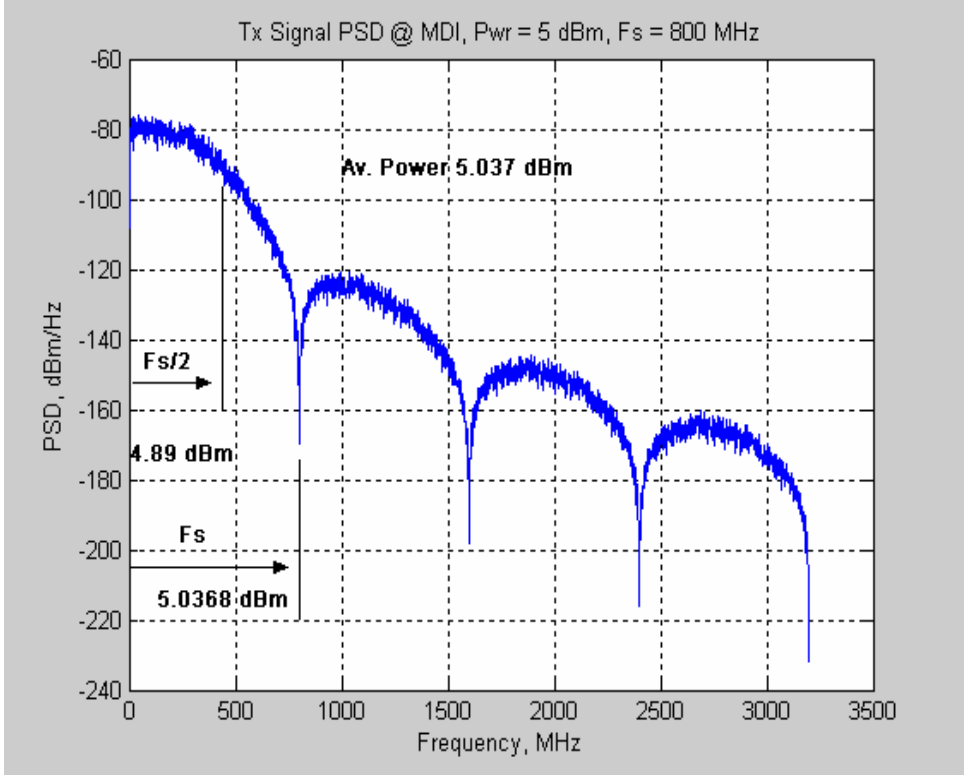
Transmitter Noise-Like Broadband Output:

Need Specialized Characterization Methodology



Tx Ideal Output at MDI – Noise-Like Time Domain Waveform



Tx Ideal Output at MDI – Frequency Domain PSD

Signal Power →

$$pwr = \int_0^f psd(f)df$$

Note – Signal Power Converges fast with f

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Tx Impairments – Non-Linear Distortion

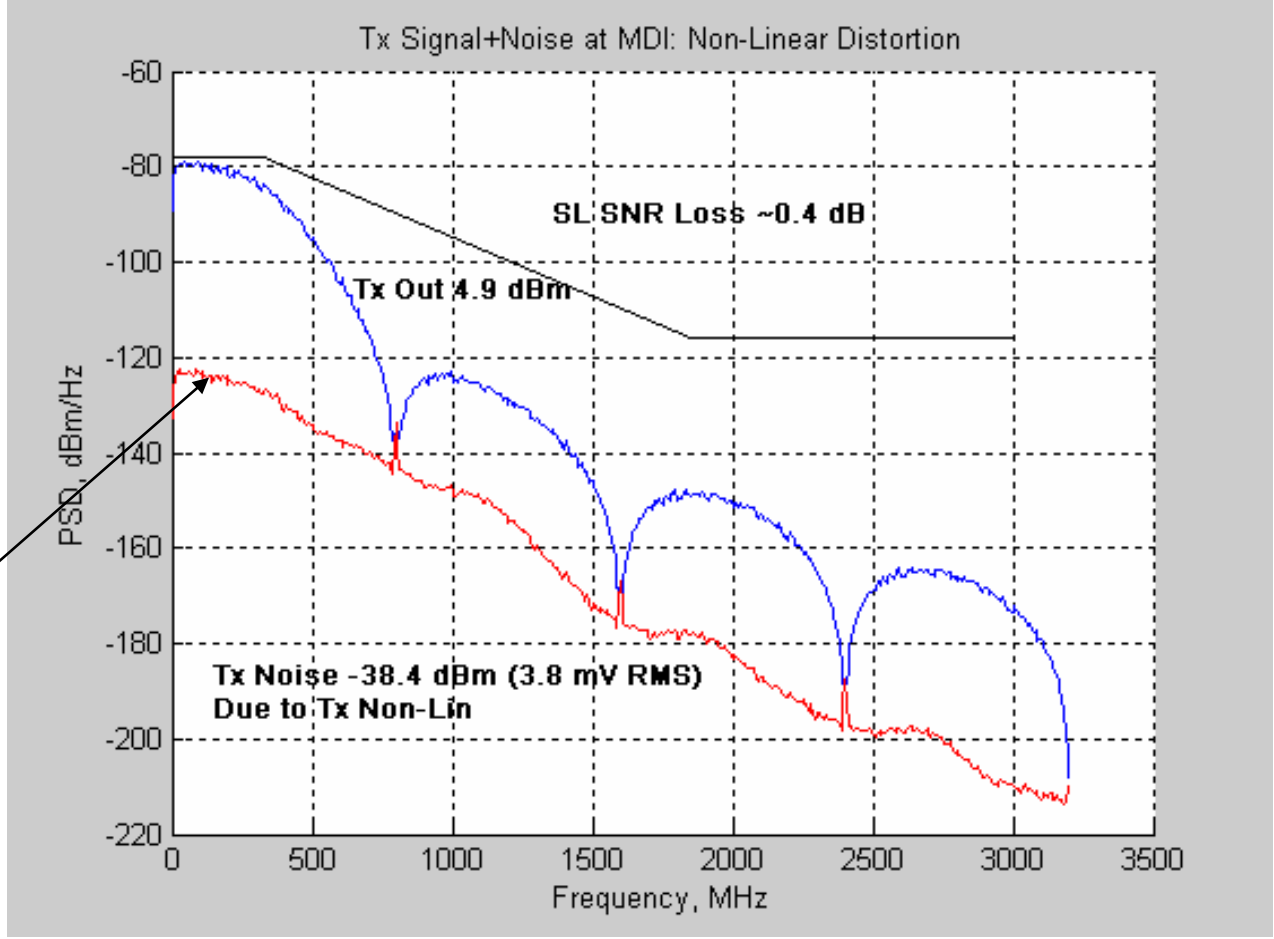
Frequency Domain

Single-Tone Dist. Yields 49-50 dB

Act. Tx SNR 43.3 dB
SL SNR Loss ~0.4 dB

-122 dBm/Hz max

Low-Pass type



Asymmetrical Compression

$a_1 = 1.0$
$a_2 = 0.005$
$a_3 = -0.007$

$$v_o(t) = a_1 v_{in}(t) + a_2 v_{in}^2(t) + a_3 v_{in}^3(t) \qquad |v_o| < 1.25\ \text{V}$$

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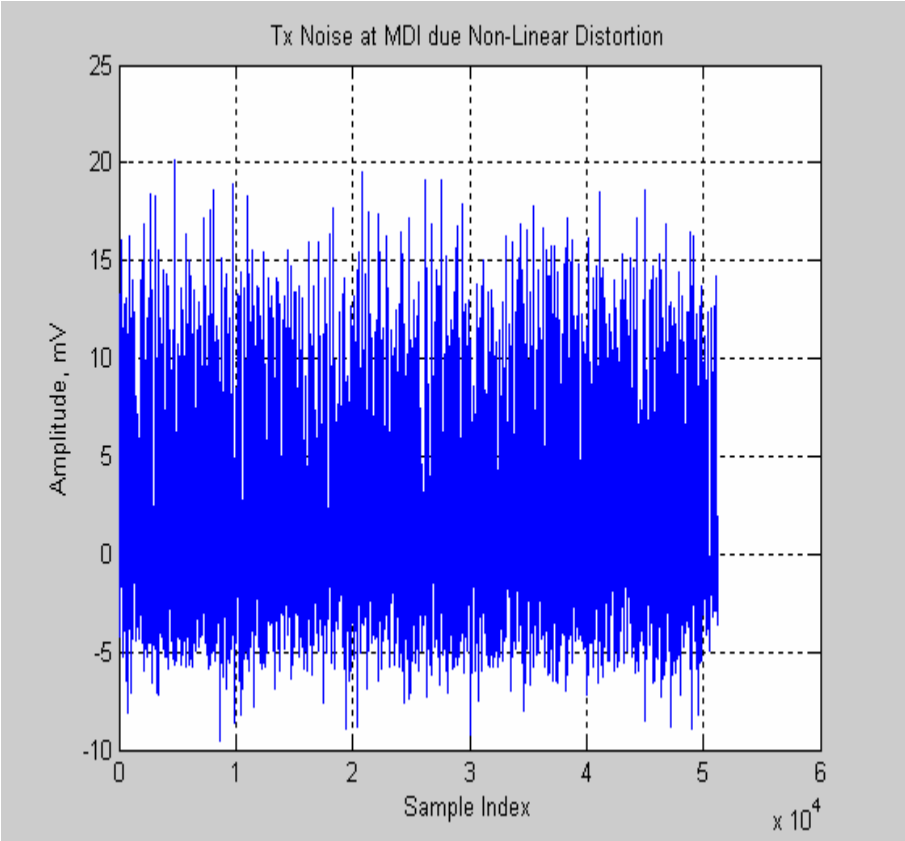
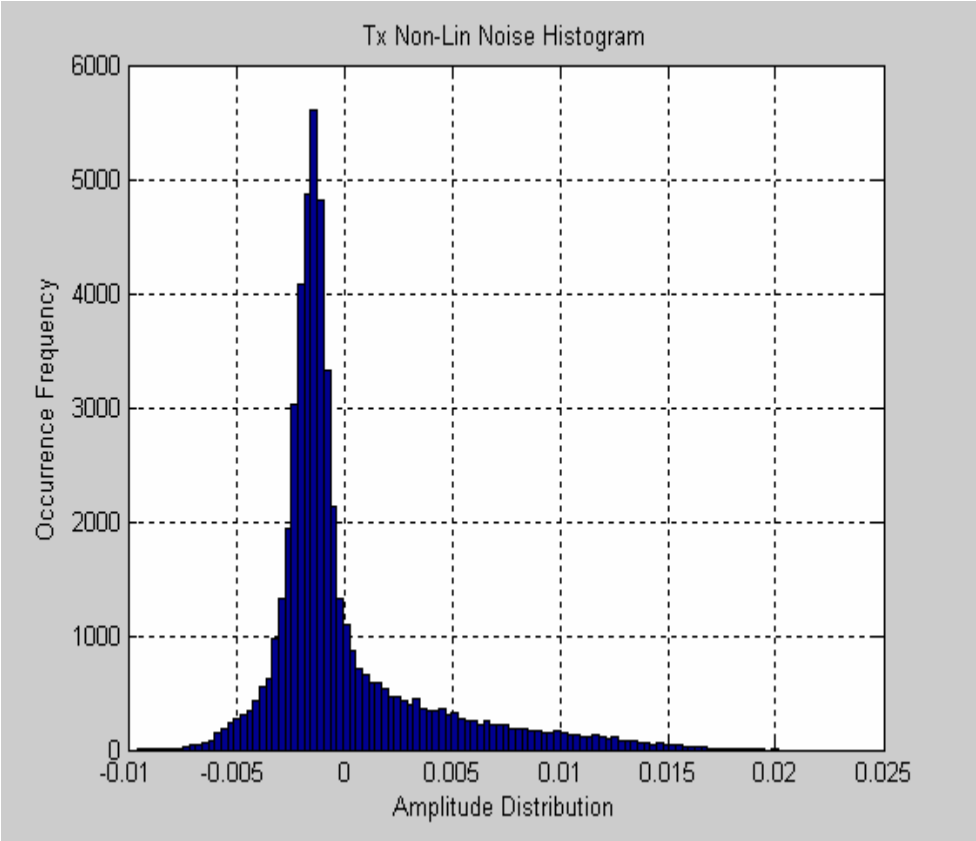
Tx Impairments – Non-Linear Distortion

Time Domain



Non-Linear Distortion Noise due to Asymmetrical Compression in Tx Chain



Skewed Non-Gaussian Distribution

Will Reduce with Power Back-off → SNDR Improves

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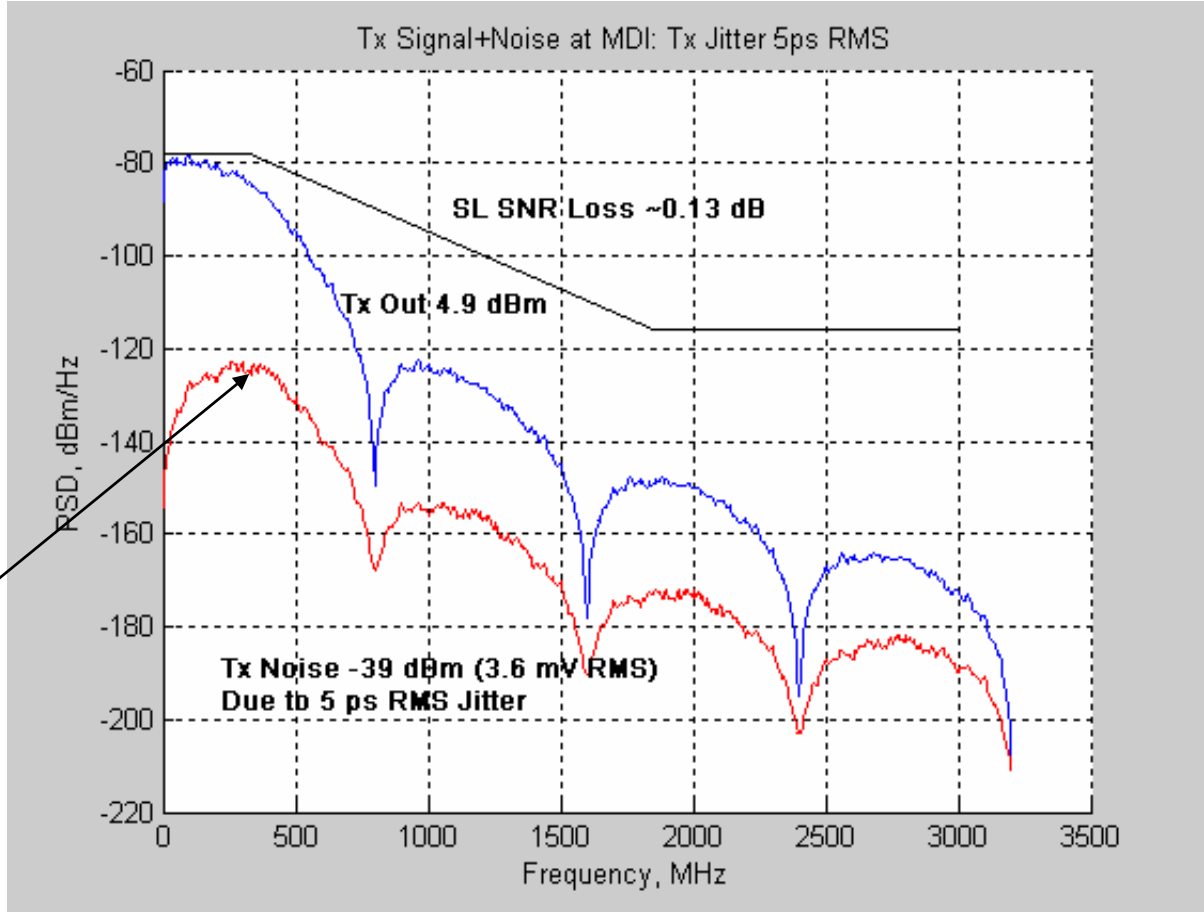
Tx Impairments – Fast Tx Clock Jitter

Frequency Domain

Tx CLK
Jitter ~5 ps rms
BW 1-10 MHz

-121 dBm/Hz max

High-Pass type



Tx SNR 44 dB
SL SNR Loss 0.13 dB

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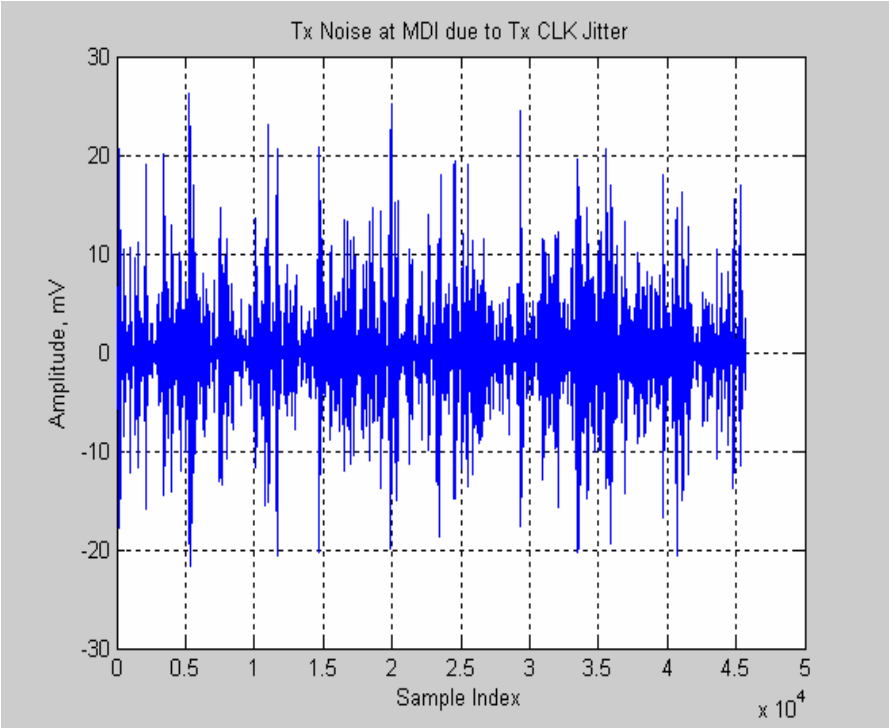
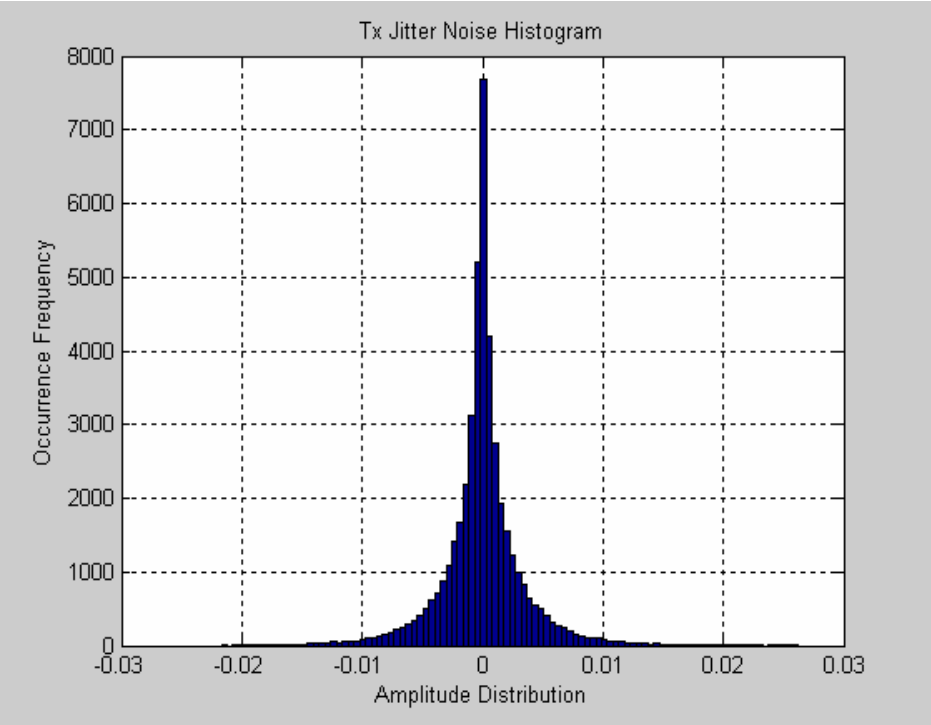
Tx Impairments – Noise due to Fast Tx Clock Jitter

Time Domain



Noise due to 5 ps rms Tx CLK Jitter, BW 1-10 MHz



Centered Non-Gaussian Distribution

Will Reduce with Power Back-off → SNDR Maintained

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Tx Impairments – Q- and Background Noise

Frequency Domain

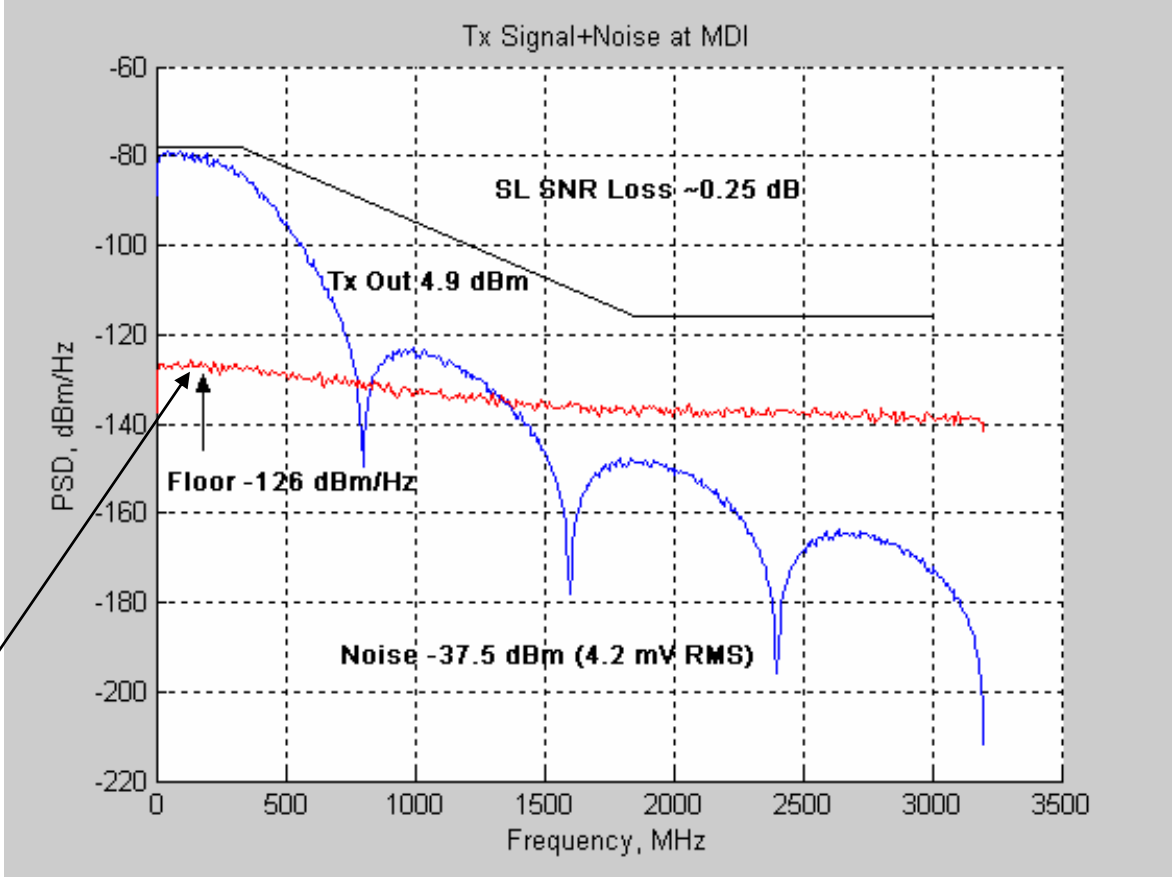
Q- and Thermal Noise -126 dBm/Hz

Budget:

9 ENOB DAC
Therm. -129 dBm/Hz
Gain < 2

-126 dBm/Hz max

App. White in-Band



Tx SNR 42.4 dB
SL SNR Loss 0.25 dB

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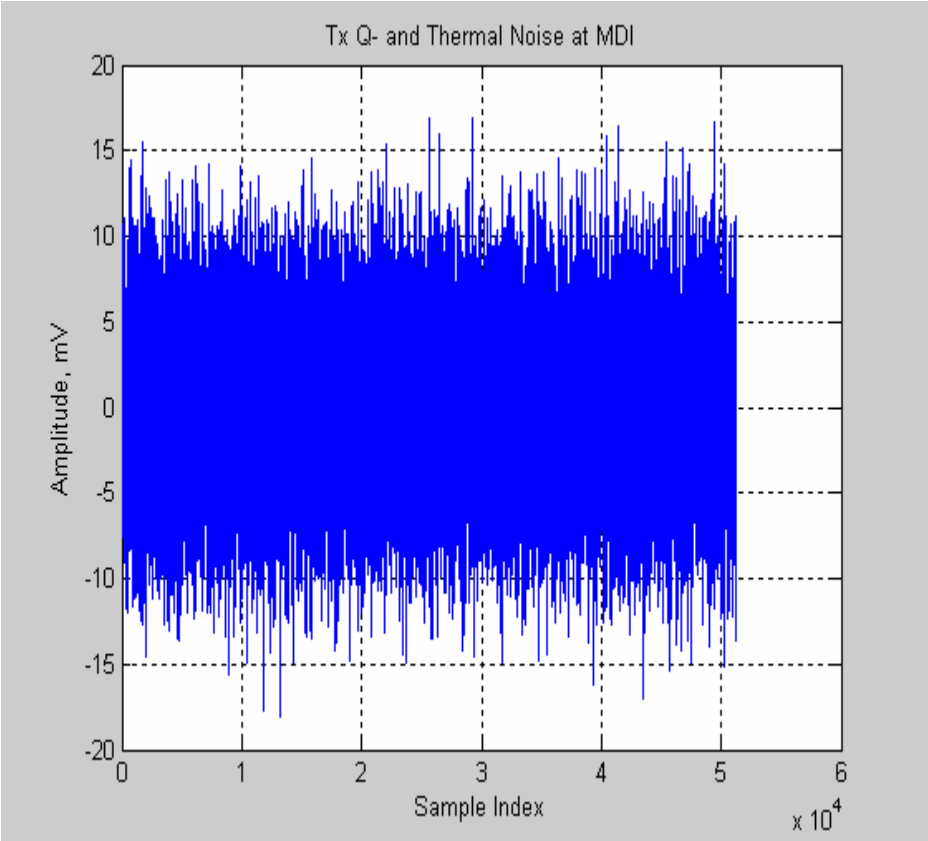
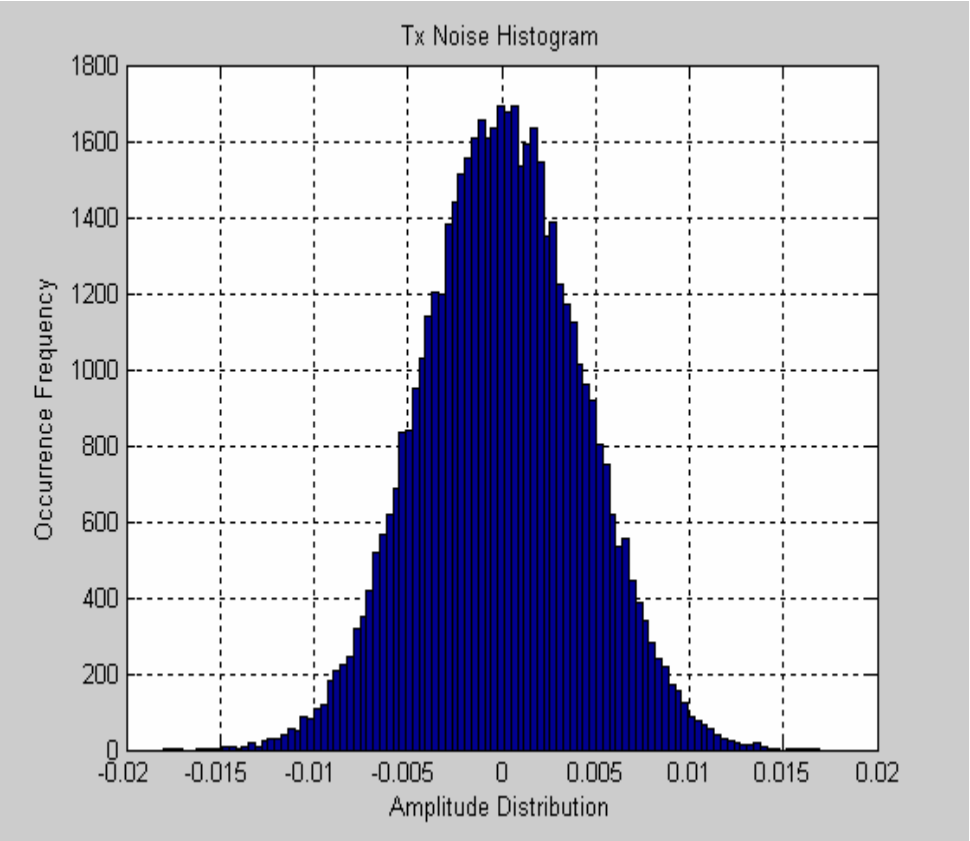
Tx Impairments – Q- and Background Noise

Time Domain





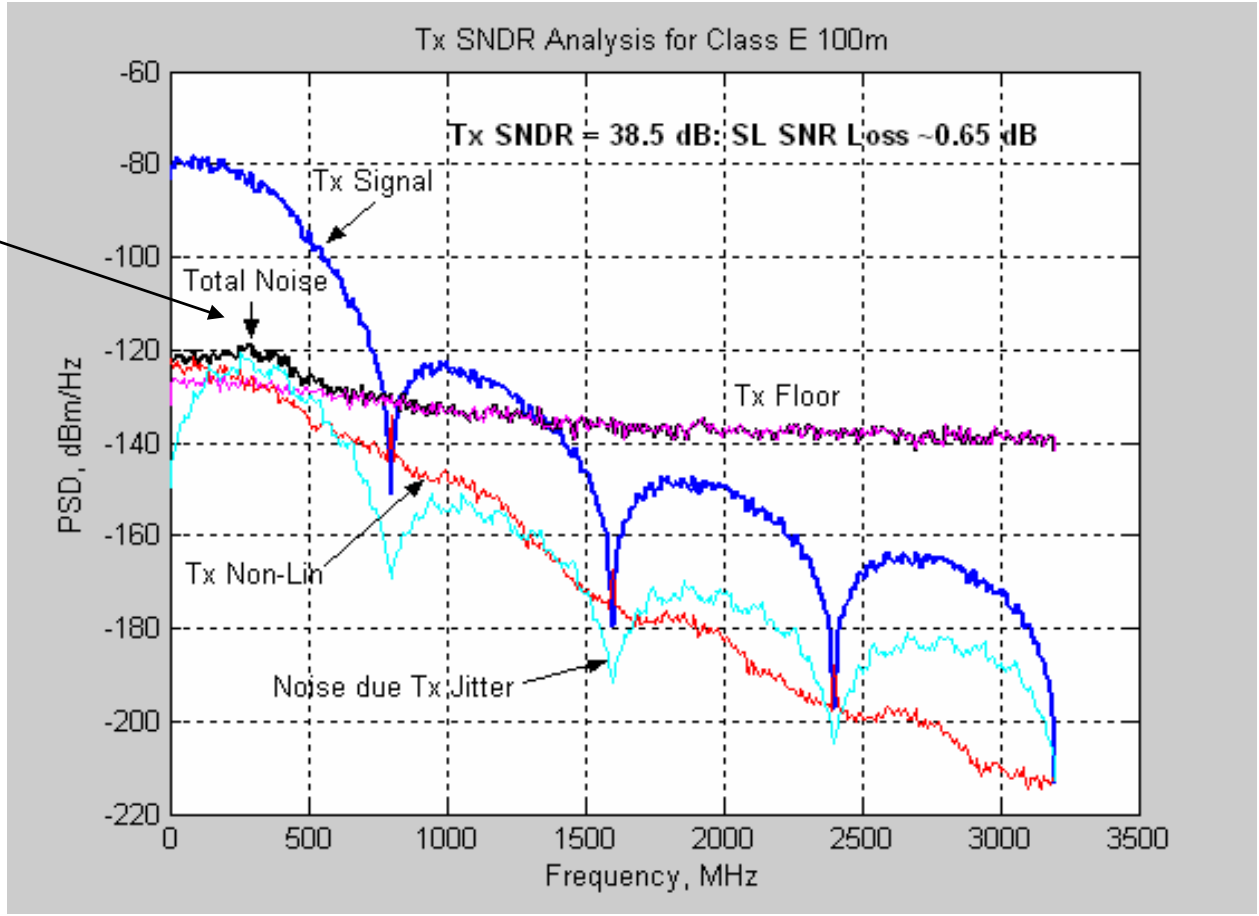
Quantization and Background Noise -126 dBm/Hz

Centered Gaussian-like Distribution

May or May NOT Reduce with Power Back-off → SNDR May Degrade

Tx Impairments – Overall Noise and Distortion

Frequency Domain



TOTAL Noise
-119 dBm/Hz max
Slightly Colored

Tx SNDR 38.5 dB
SL SNR
Loss < 0.65 dB

"Normal" Operation Waveform SNDR in BW > = Fs is a Good Metric for Transmitter Characterization

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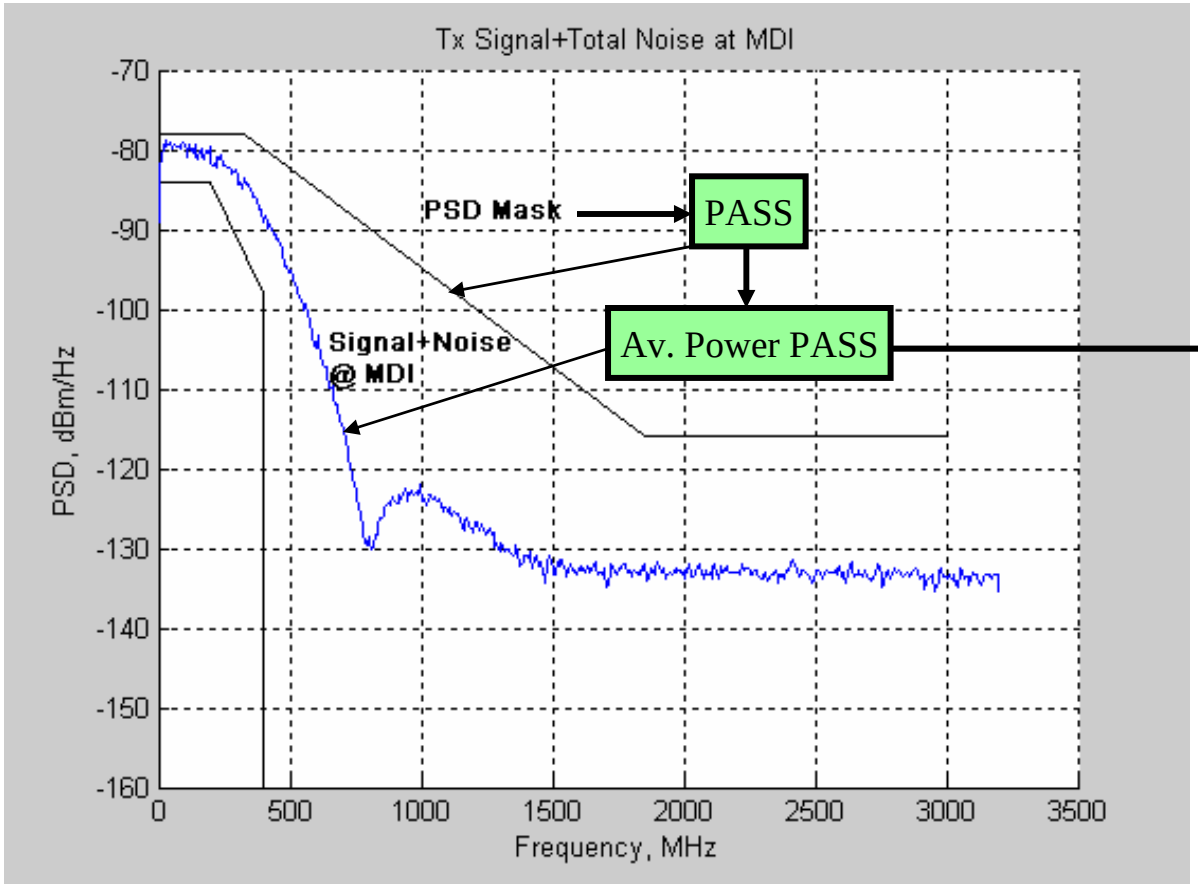
Tx Impairments – What is Observed at MDI

Time-Domain Sequence → Frequency Domain Analysis

How to Separate: TOTAL NOISE From SIGNAL



PSD Mask and Average Output Power Compliance Checked Before SNDR

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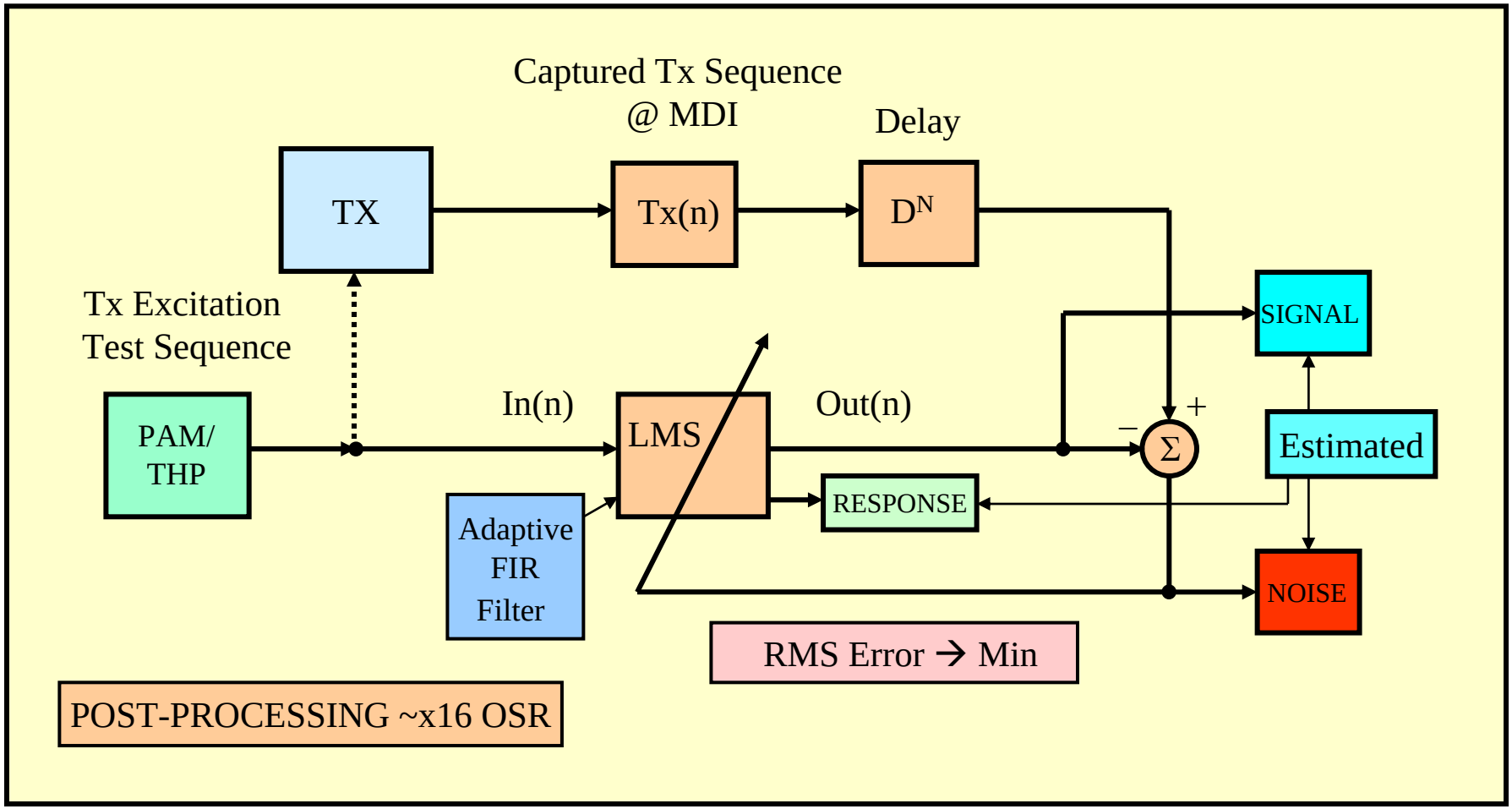
System ID Signal Post-Processing Scheme



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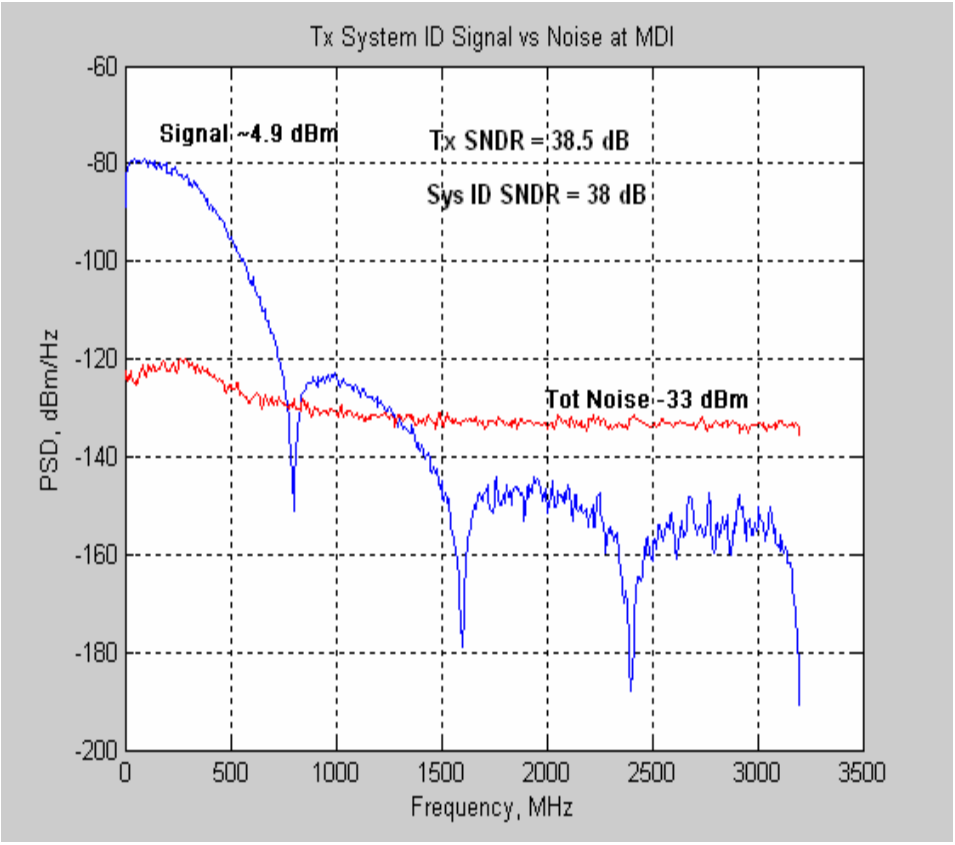
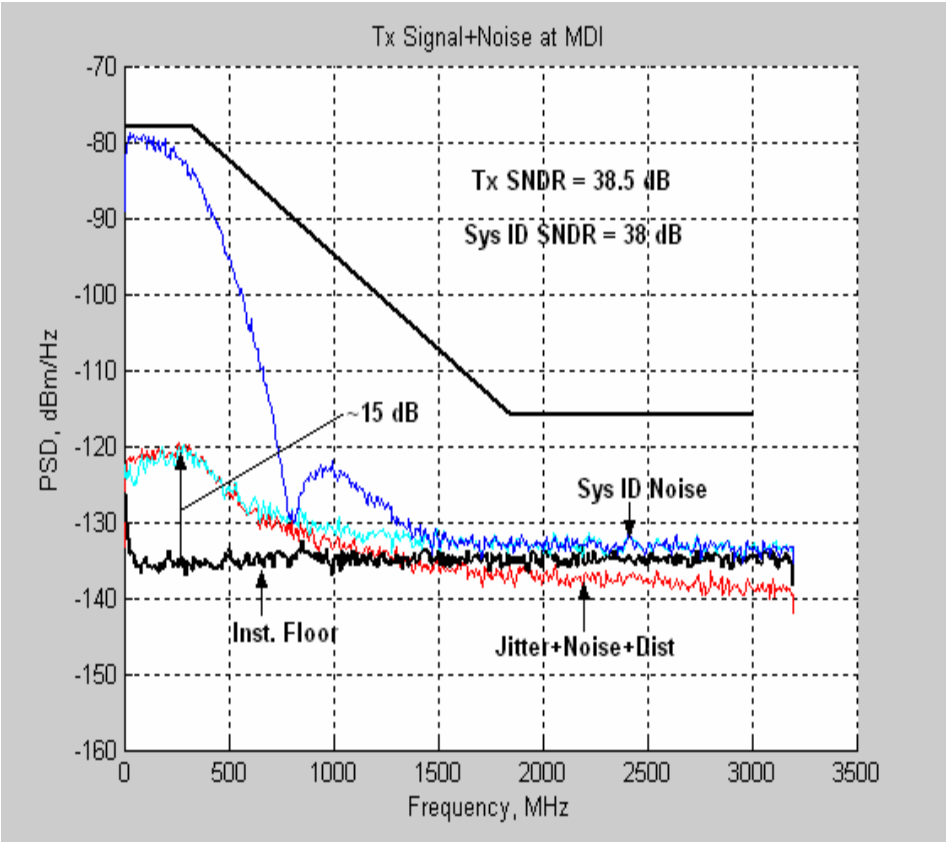
System ID Estimated Signal and Total Noise

Time-Domain Processing → Frequency Domain Analysis





Example Tx Impairment SNDR: Actual 38.5 vs 38 dB System ID Estimated in ~ 3GHz BW

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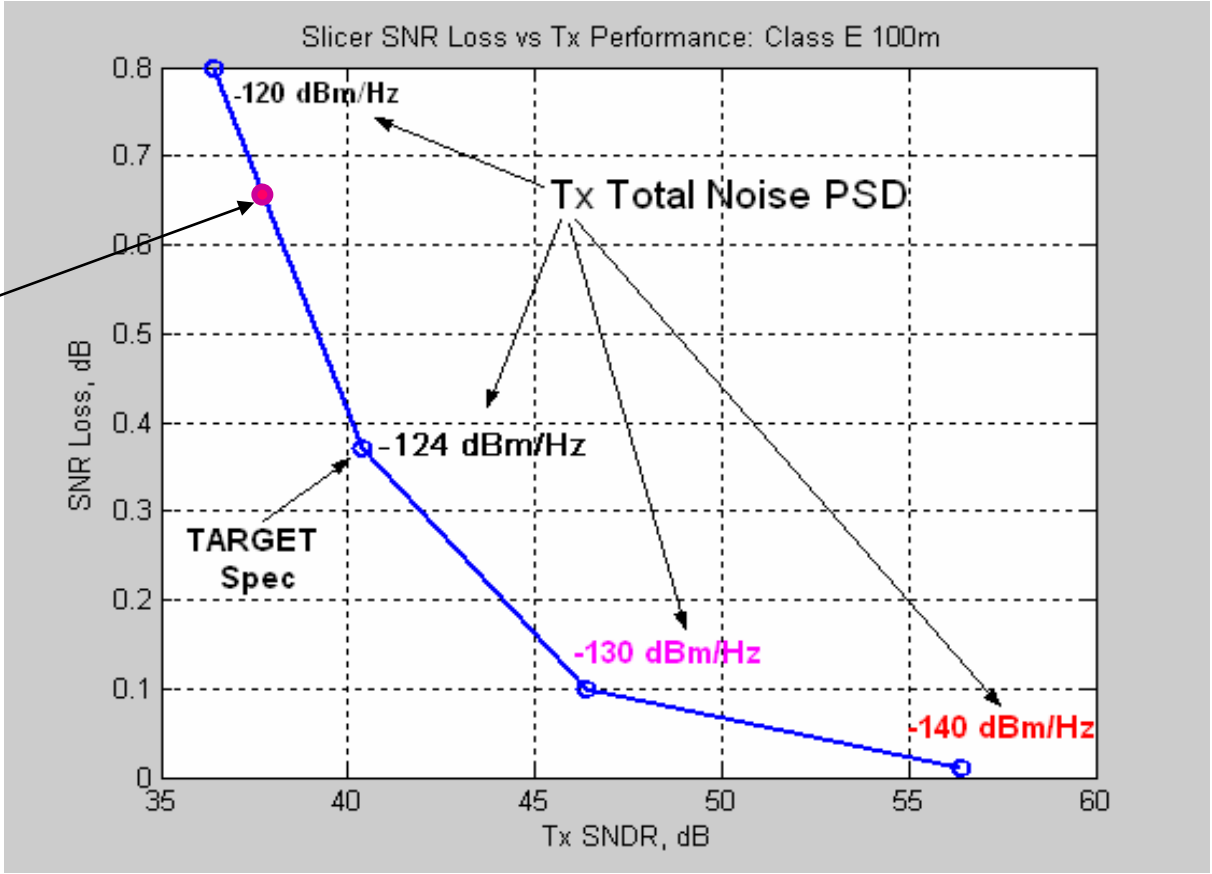
Proposed System ID Tx SNDR Specification

Analyzed EXAMPLE SYSTEM:

Reasonably High Performance/ Difficulty



@ MDI

Into 100 Ohm

$$\text{Tx\_SNDR} = \frac{\text{Estimated \{Tx Output Signal Power\}}}{\text{Estimated \{Tx Output Total Noise Power\}}} >= 40\ [\text{dB}]$$

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Conclusion

- **Based on Detailed Analysis of Transmitter Major Impairments SNDR >= 40 dB Objective Provides a Reasonable Feasibility and Complexity Trade-off between Transmitter and Receiver Sections, and is Proposed for the PHY Interoperability Compliance Testing at MDI**
- **Transmitter Qualification SNDR Metric at MDI and its Derivation Methodology Based on System ID Approach is Introduced**
- **Complimentary THP Processor Interoperability Compliance Method Needs to be Additionally Defined**

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Back Up Slides

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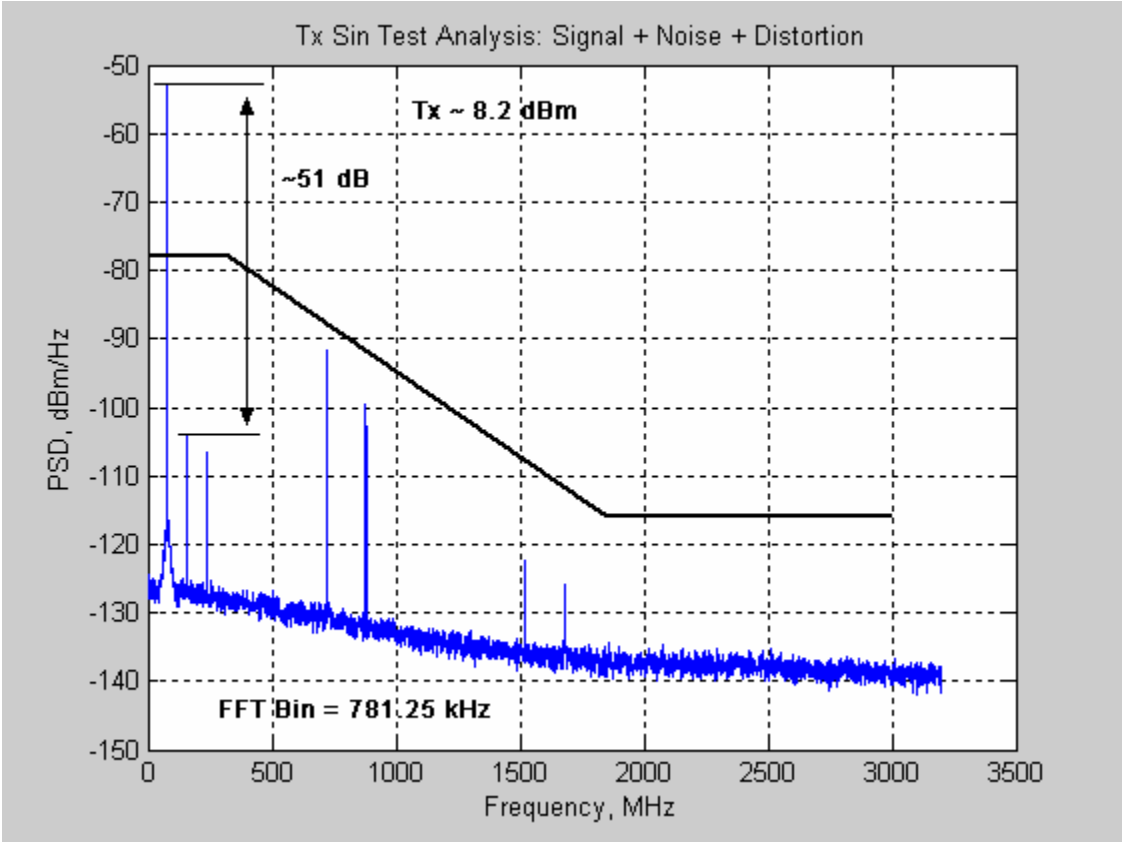
Non-Linear Distortion Single-Tone Test



Total Output Power
Tx +16, -16 Sym
> 8 dBm
OVERLOAD

Single Tone SNDR Test: Non-Linear, 5 ps Jitter, Q- and Background → Pass

Actual Normal Operation SNDR = 38.5 dB < 40 dB → Fail

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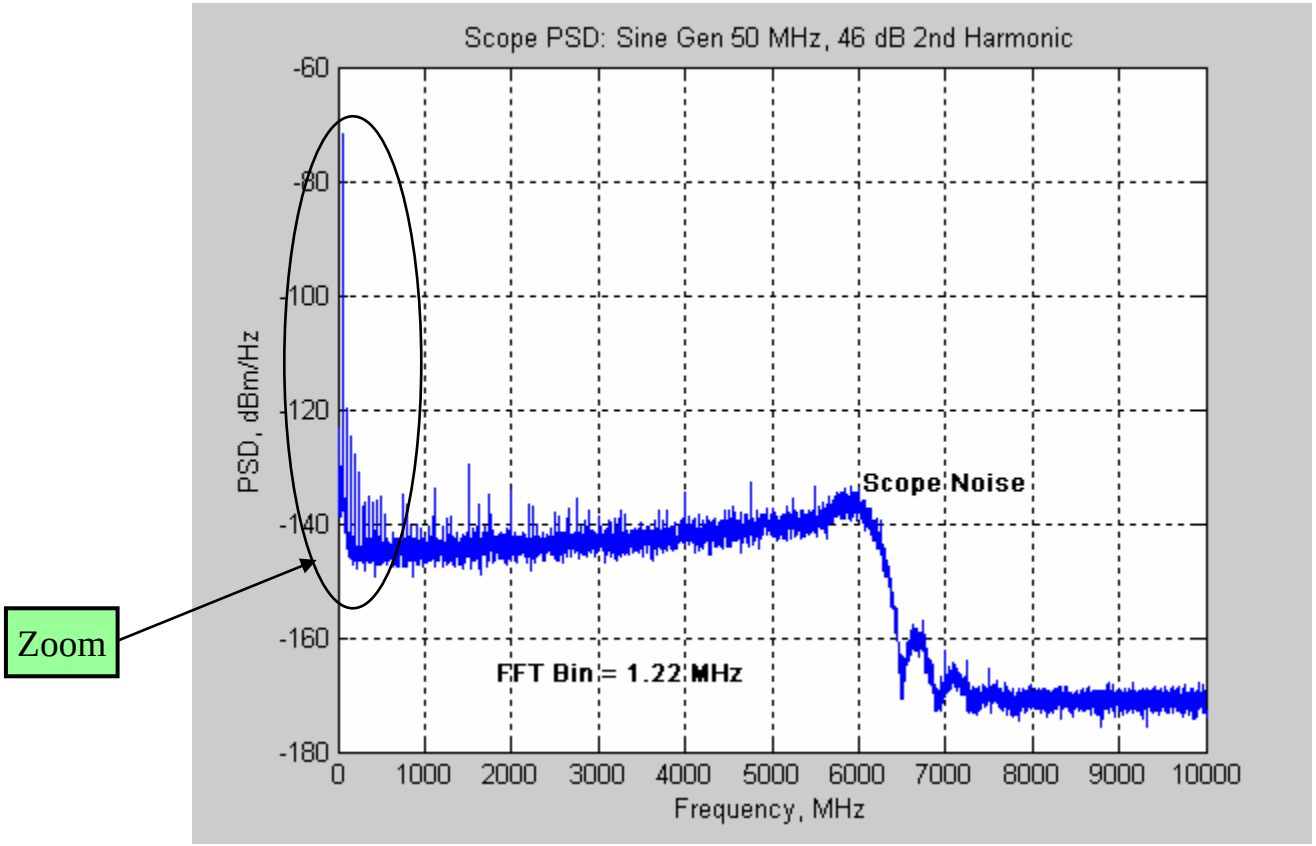
Scope Source 50 MHz, ~46 dB 2nd



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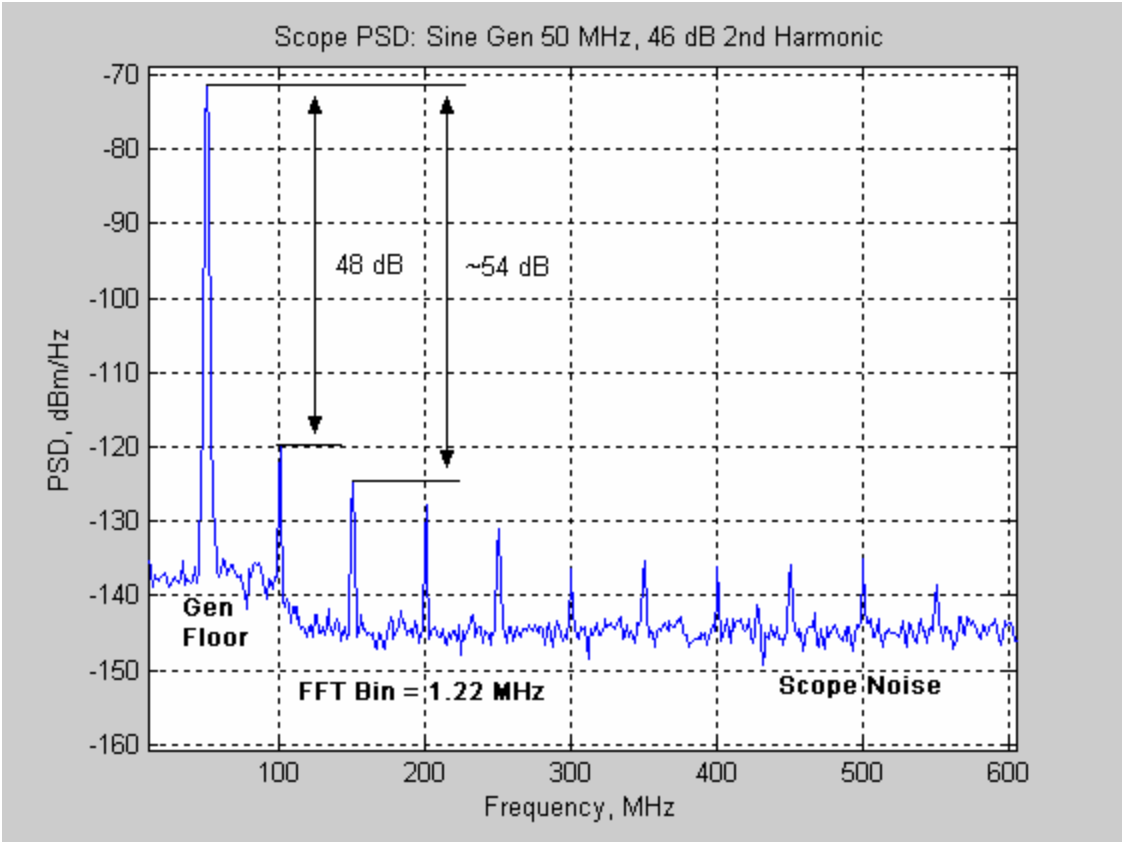
Scope Source 50 MHz, ~46 dB 2nd → Zoom



Scope Captured Sine Generator THD – Confirmed by Spectrum Analyzer

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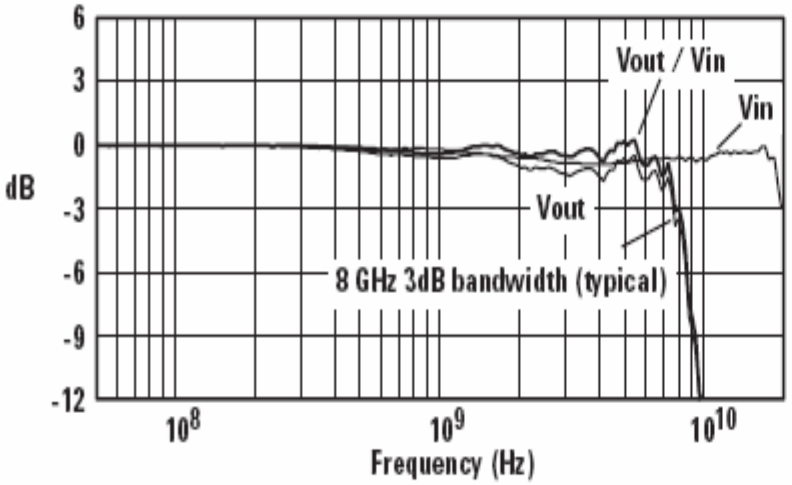
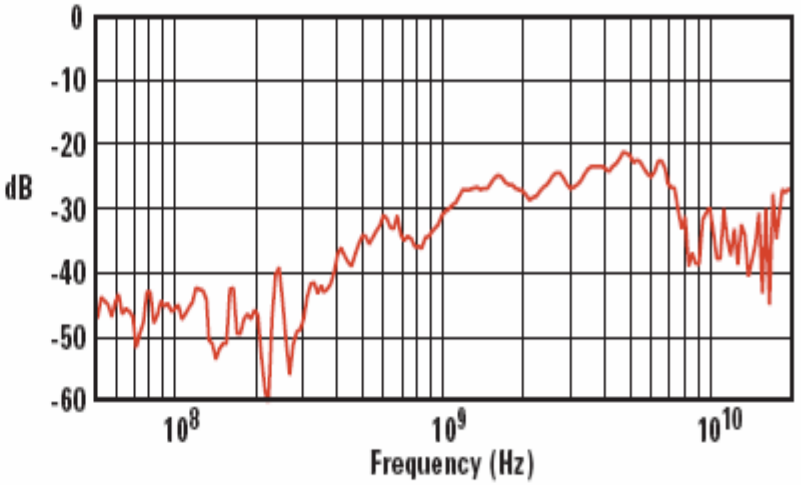
Diff Probe Characteristics

Input Noise = 3 mV in 7 GHz → 36 nV/sqrt(Hz)
-139 dBm/Hz
Ref. to 316.2 mV into 100 Ohm (0 dBm)



Swept frequency response



Common mode rejection vs. frequency

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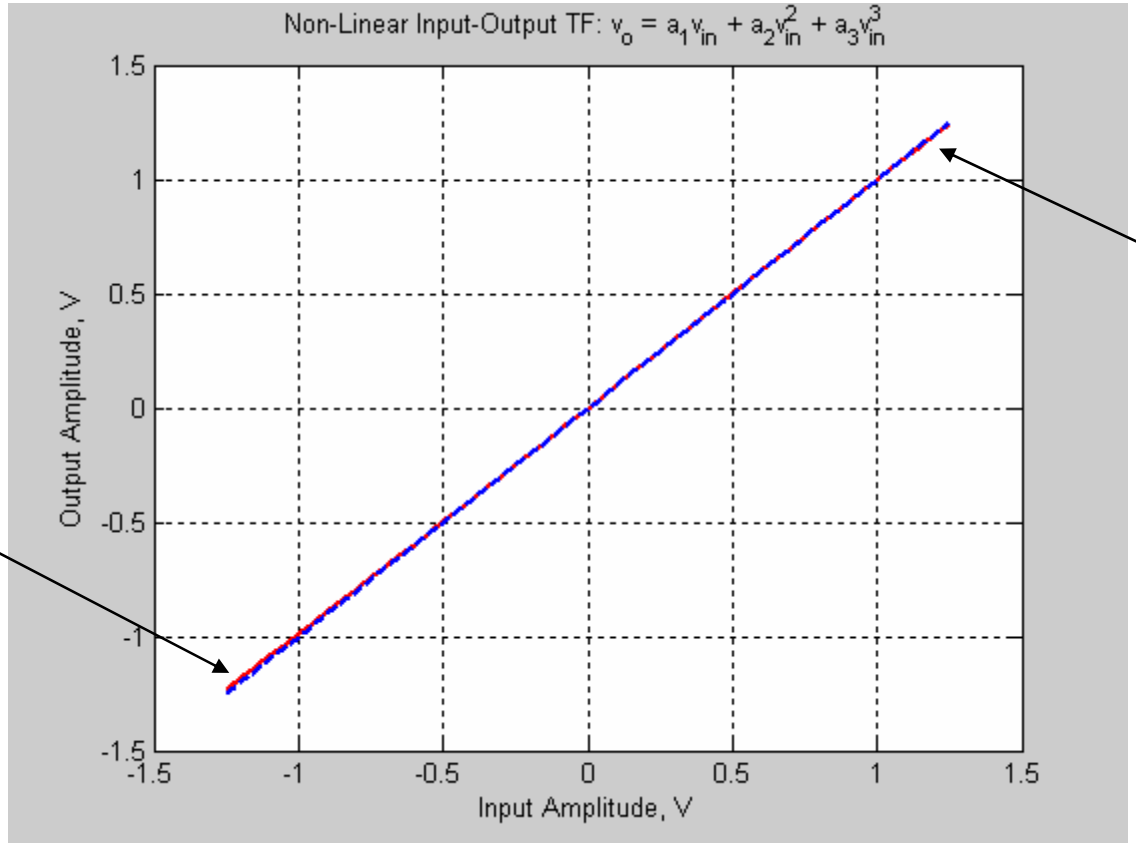
Non-Linear Input-Output TF



Level Compression app 21.5 mV

Level Compression app 5.9 mV

Non-Linear 3rd-Order Asymmetric Input-Output Transfer Function
(Frequency-independent)

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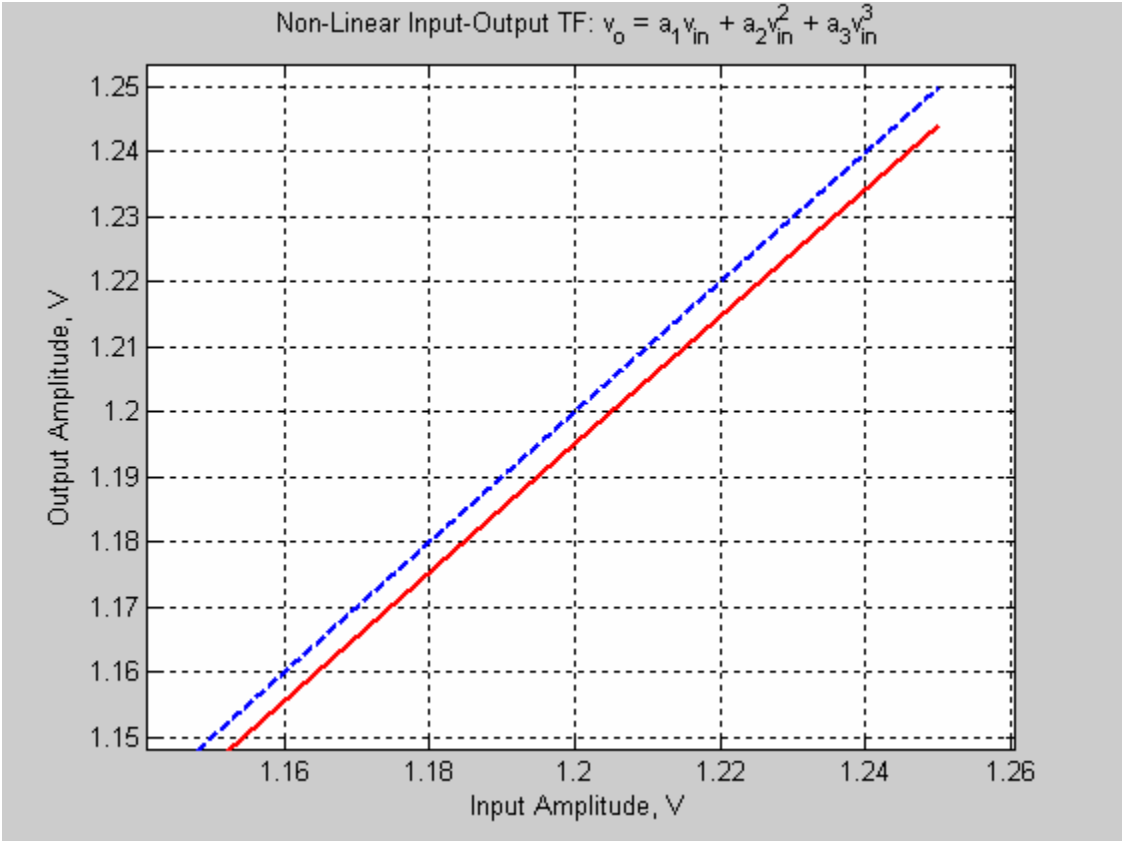
Non-Linear Input-Output TF



Non-Linear 3rd-Order Asymmetric Input-Output Transfer Function
Compression "Positive"

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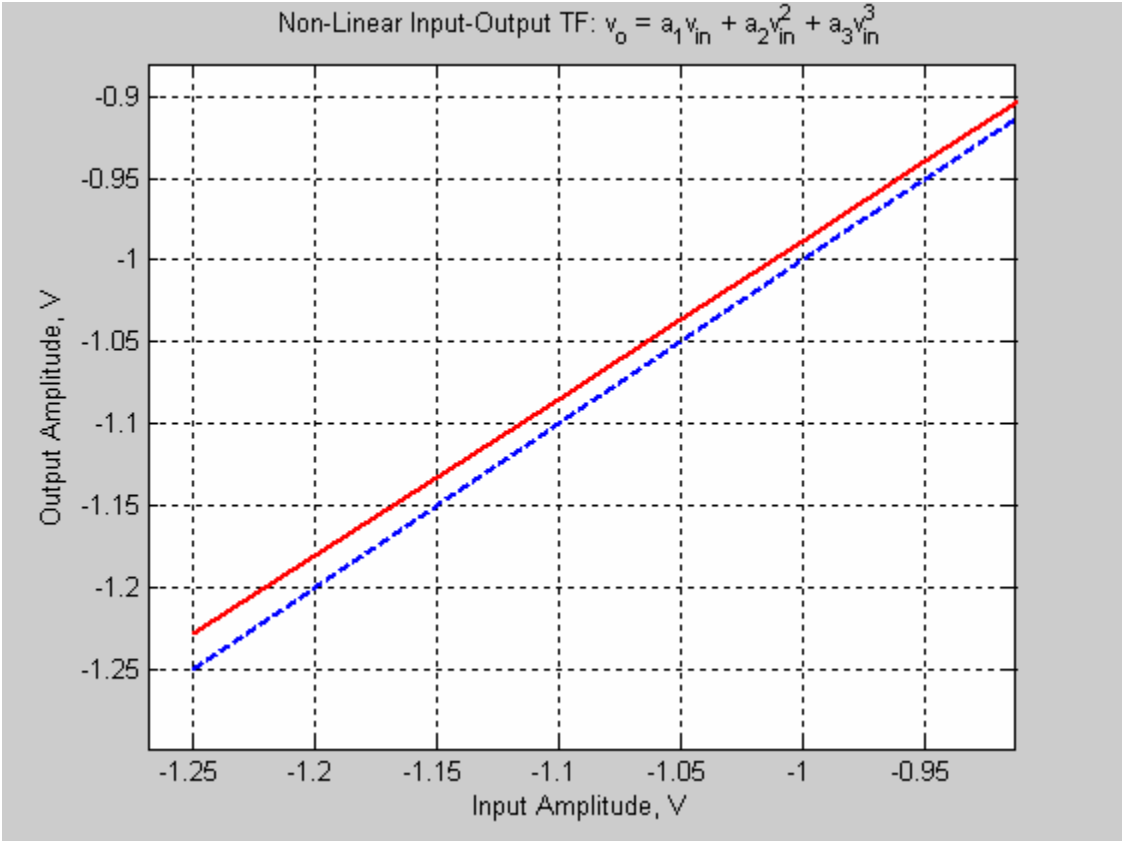
Non-Linear Input-Output TF



Non-Linear 3rd-Order Asymmetric Input-Output Transfer Function
Compression "Negative"

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