SAND2007-7074C

MEASUREMENT OF SYSTEM DYNAMIC RANGE IN THE TIME DOMAIN

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at AMTA 2007

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Introduction
- Simple design considerations
- Demonstration of signal-dependent noise
- Causes of diminished time-domain dynamic range
- Understanding and diagnosing deficiencies
- Summary

Introduction

- Time-domain radar-cross-section response of a target is often utilized to evaluate objects comprised of both small and large scatterers
- To do so requires a large dynamic range in the time domain
- Wideband frequency-domain measurements are often used to determine time-domain response
  - Collect complex frequency-domain data
  - Apply correlation operation to the data to produce a processed time-domain response
- Of interest for our application is a PNA based measurement system that uses a frequency-stepped source, and a fast Fourier transform algorithm to produce the time-domain response

Time-Domain Dynamic Range

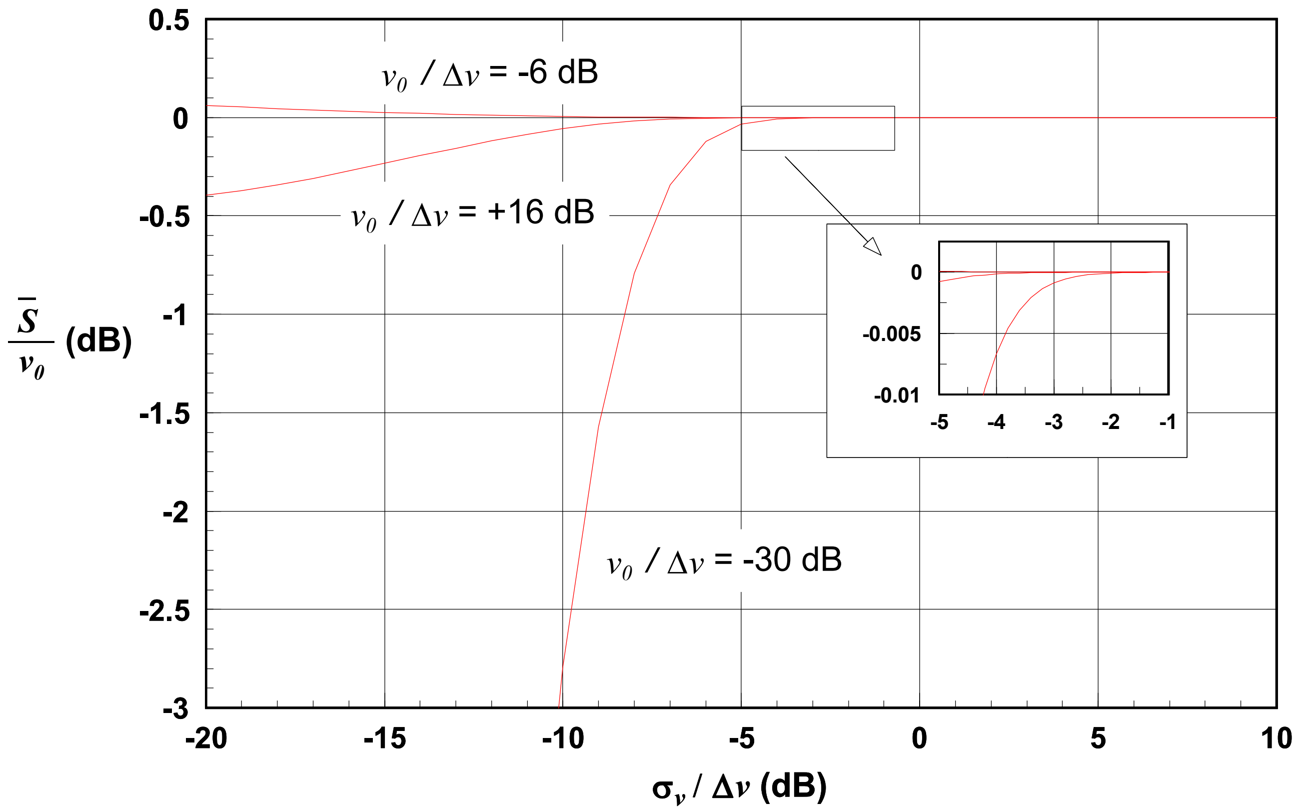
- **Important:** the instantaneous dynamic range associated with frequency-domain measurements *is not* the same as the time-domain dynamic range
- The coherent integration inherent in the correlation process serves to enhance the time-domain dynamic range, while gain compression, phase noise in the source, quantization noise, calibration errors, and other noise sources serve to degrade the dynamic range
- Time-domain dynamic-range specification for a radar is the range of signal-levels between the noise+clutter level and the response of the large target that corresponds to the top of the linear-response region of the radar

Simple Design Considerations

- The maximum instantaneous dynamic range of the system is determined by the number of bits in the A/D when the system gain is adjusted for proper noise level
- The system dynamic range can be extended downward below the least-significant bit through coherent digital signal processing
- The process of quantizing a continuous signal introduces quantization error that is additive noise
- The analog-to-digital converter has a finite number of bits that limits the maximum signal that can be accommodated
- The noise level at the input to the analog-to-digital converter must be adjusted properly for the mean signal to be determined to higher precision than the least-significant bit of the quantizer

Simple Design Considerations

- For the mean output of the A/D to be a linear function of the input signal, the noise level must satisfy $\sigma_v / \Delta v \geq -4\ \text{dB}$



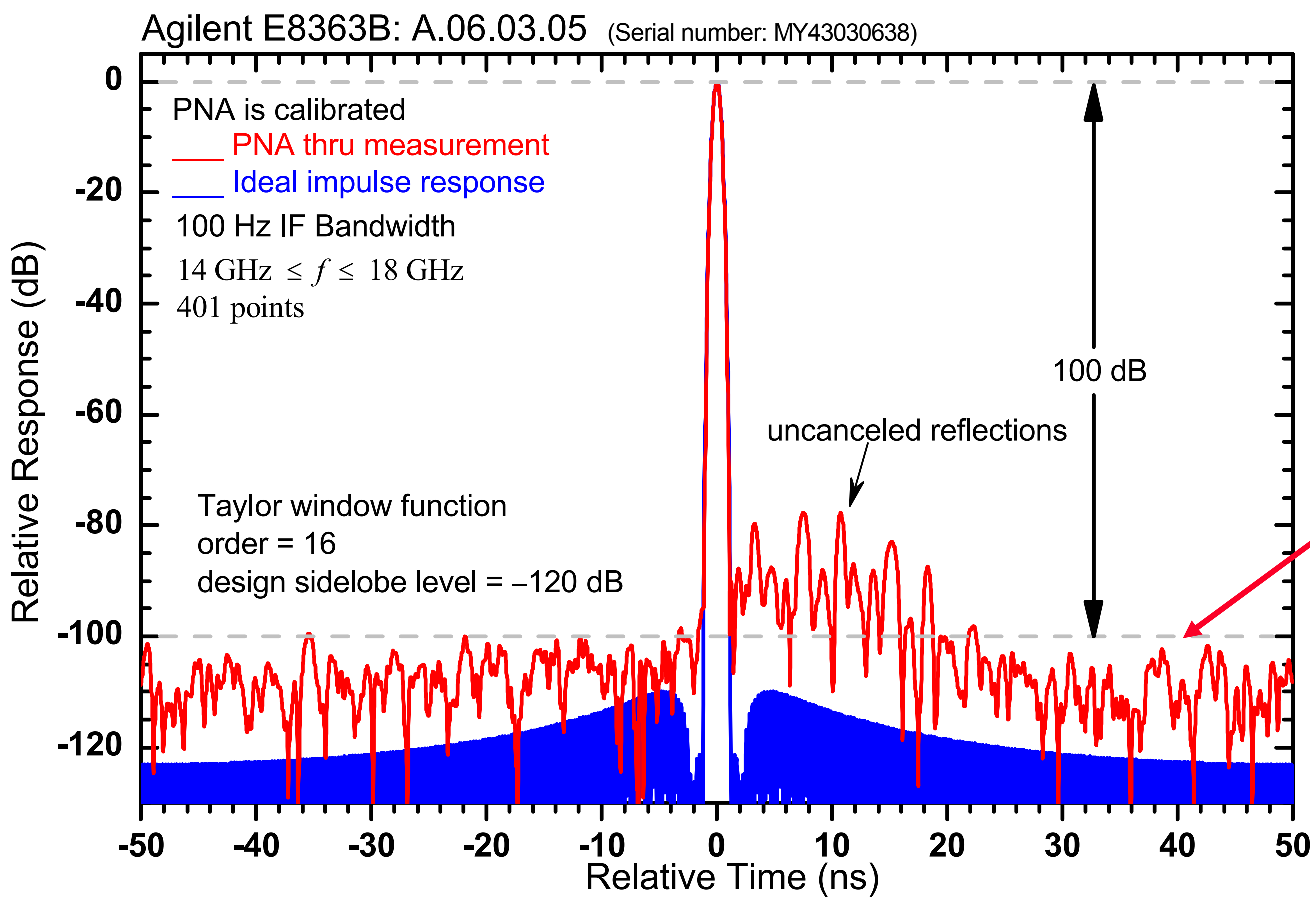
$\bar{S}$ = normalized mean output

σ_v = rms noise voltage

Δv = voltage corresponding to the least significant bit

v_0 = input voltage

Demonstration of Signal-Dependent Noise



Measured time-domain dynamic range of this PNA is greater than 100 dB

Noise floor of processed signal

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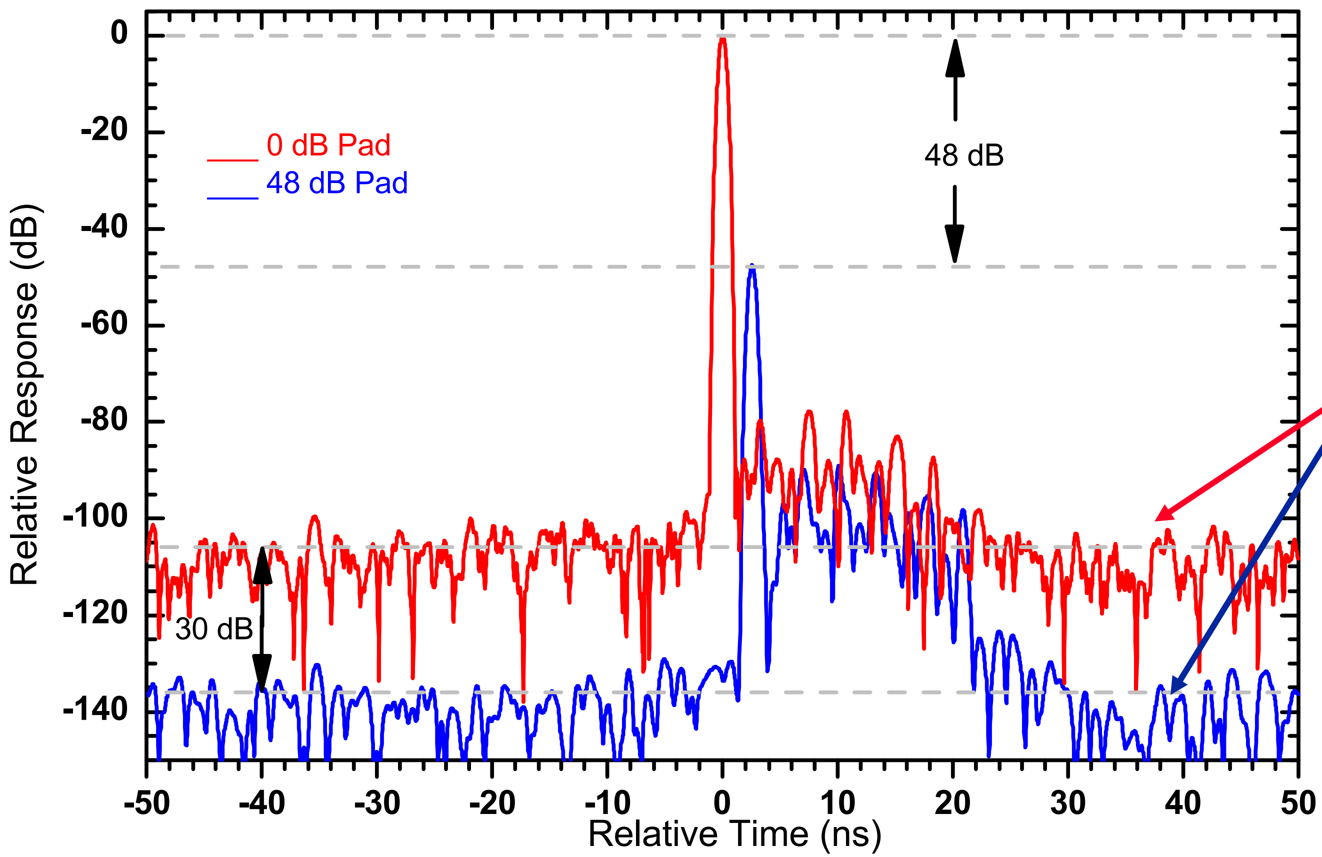
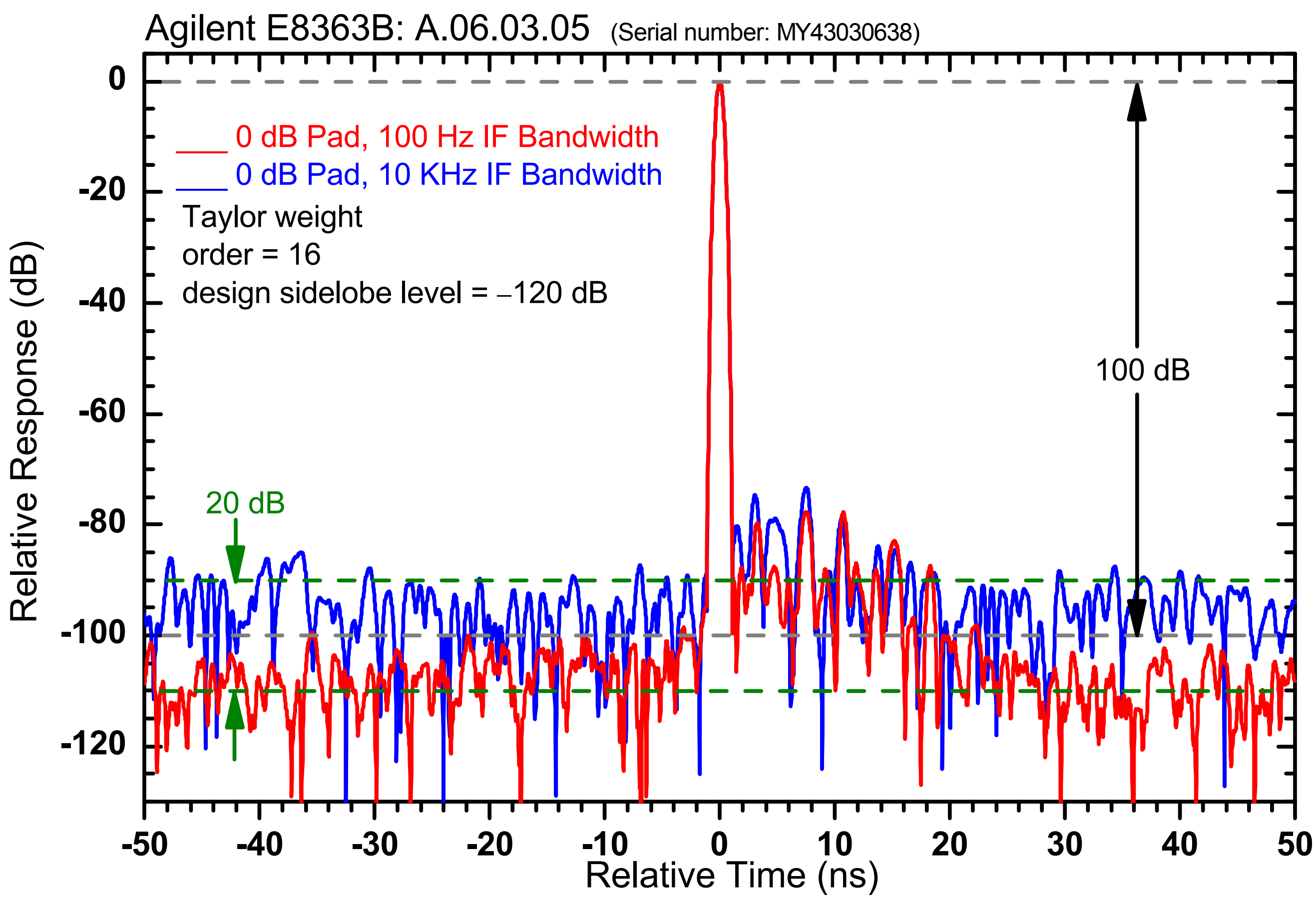
Add 48 dB Attenuation to Signal Path



Noise floor depends on the amplitude of the signal

Decreasing signal by 48 dB decreases noise floor by 30 dB.

Increase IF Bandwidth from 100Hz to 10KHz



Noise level increases by ratio of IF bandwidths or 20 dB

Causes of Diminished Time-Domain Dynamic Range

1. Gain compression and non-linear response
2. Inadequate signal-to-(noise+clutter) for calibration
3. Improper gain distribution throughout the system
4. Excessive numerical error in characterization of calibration target
5. Excessive phase noise in the RF source
6. Timing jitter

Gain Compression and Nonlinear Response

- In a nonlinear system, thermal noise can be mixed with the signal, becoming a multiplicative factor, and leading to a noise component whose amplitude is a function of the signal

- Consider a system with a voltage gain $g[V]$. For an input signal s with noise n, the output would be

$$s_{out} = (s+n)g[s+n] = g_0(s+n) + g_2(s+n)^3 + \cdots$$

- To first order in input noise, the output noise is

$$n_{out} = n\left(g_0 + 3g_2 s^2 + 5g_4 s^4 + \cdots\right)$$

- If the signal is large enough that $g_0 < 3g_2 s^2$, then the noise will be dominated by the signal-dependent component

- Maximizing the linearity of the entire system over the range of expected signals will reduce the hardware's contribution to signal-dependent noise

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Inadequate Signal/(Noise+Clutter) at Calibration

- Calibrated RCS measurement can be written:

$$\gamma_{tgt} = \left(s_{tgt} + \varepsilon_{tgt}\right)\frac{\gamma_{cal}}{s_{cal} + \varepsilon_{cal}}$$

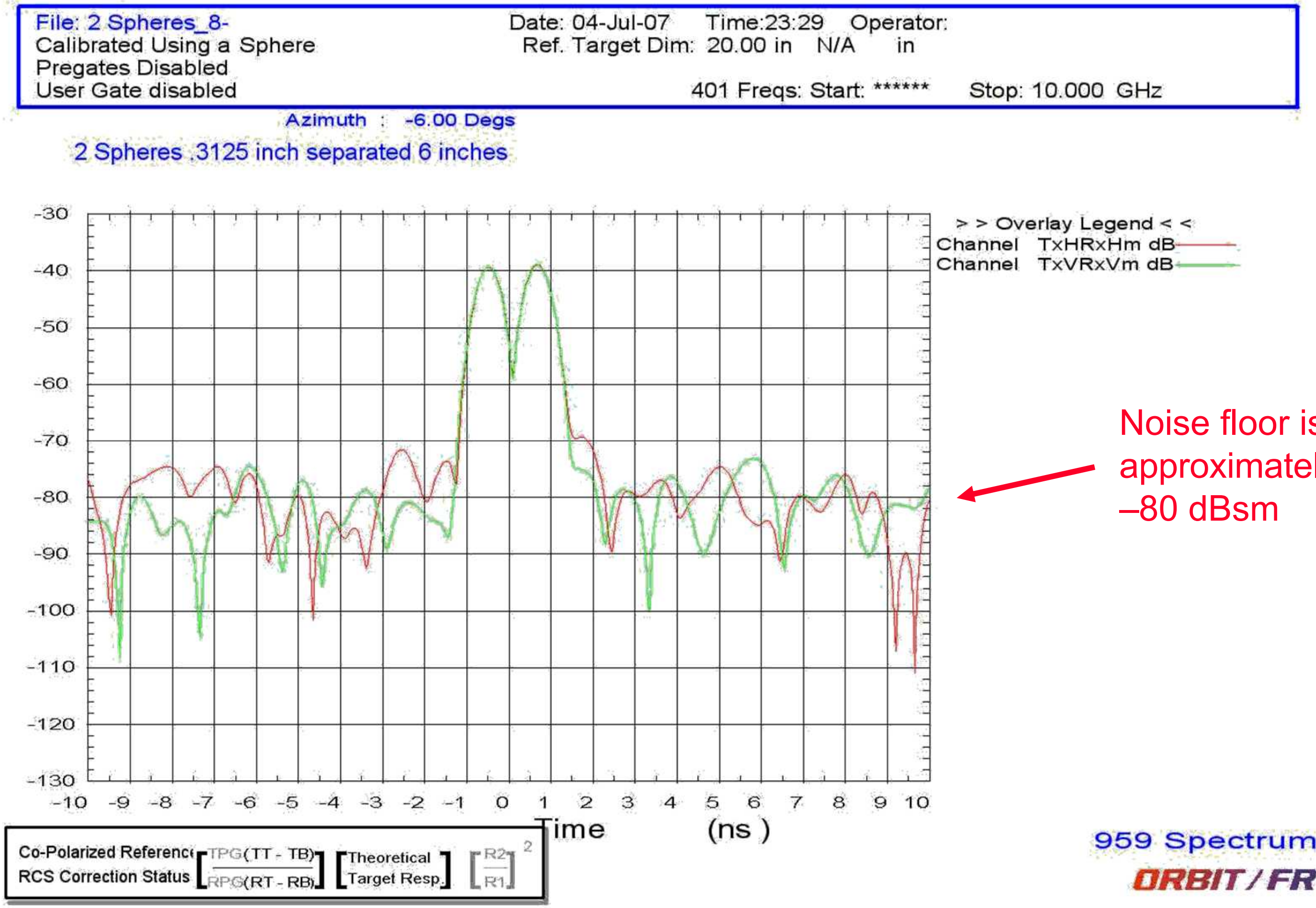
- Using a binomial expansion for the denominator

$$\gamma_{tgt} = \left(s_{tgt} + \varepsilon_{tgt}\right)\frac{\gamma_{cal}}{s_{cal}}\left(1 - \frac{\varepsilon_{cal}}{s_{cal}} + \frac{\varepsilon_{cal}^2}{s_{cal}^2} - \cdots\right)$$

- The term $s_{tgt}\frac{\gamma_{cal}}{s_{cal}}\frac{\varepsilon_{cal}}{s_{cal}}$ is signal dependent noise+clutter brought in from the calibration

- Maximizing the signal-to-noise ratio, $s_{cal}/\varepsilon_{cal}$, during calibration measurement will reduce the calibration contribution to signal-dependent noise and clutter

Time-Domain Response of Two 5/16" Spheres



Noise floor is approximately –80 dBsm

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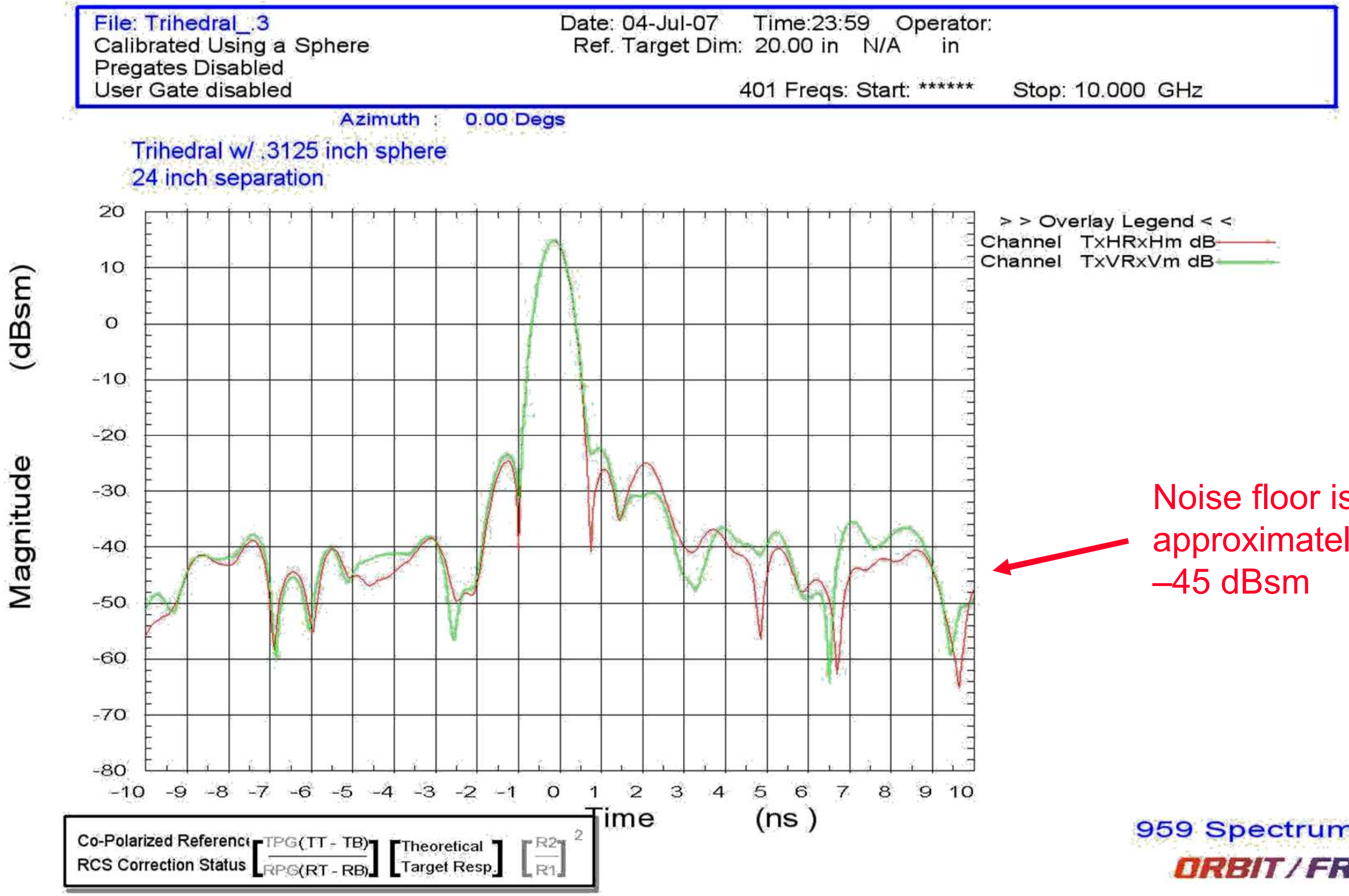
Time-Domain Response of a Large Trihedral



Noise floor is approximately –45 dBsm

Improper Gain Distribution

- Gain must be distributed properly throughout the system to minimize the thermal noise at the output of the system
- Adequate gain early in the receiver chain is required
  - Low noise amplifiers as close as possible to the antenna ports
- Gain carefully distributed throughout the system to overcome losses introduced by switches, cables, etc. and minimize the effect of additional thermal-noise contributions
- The result will maximize the dynamic range and minimize the signal-dependent noise

Inaccurate characterization of calibration target

- Suppose the calibration target is not characterized accurately
- Error in the computation will introduce signal-dependent noise
- Replace the term γ_{cal} with $\gamma_{cal} + \varepsilon_{comp}$ in the earlier equation introduces a new signal-dependent term

$$s_{tgt} \frac{\varepsilon_{comp}}{s_{cal}}$$

- This term can destroy the time-domain dynamic range of a system

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Phase Noise in the RF Source and Timing Jitter

- Both phase noise in the RF source and timing jitter are another source of signal-dependent noise in the system
- RF-source and timing-clock characteristics will provide an upper limit on the obtainable dynamic range
- It is always good practice to lock all timing signals to a single, stable clock

Summary

- Reviewed and discussed design and performance aspects of a measurement radar system relative to time-domain dynamic range
- A qualitative understanding can be extracted from this review that is useful for understanding and evaluating radar performance
- This review serves as a reminder of the numerous opportunities for degradation of time-domain dynamic range

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