VNA MASTER CLASS – IMPORTANT VNA PERFORMANCE PARAMETERS

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WHAT ARE THE IMPORTANT PARAMETERS?

- The data sheet for a Copper Mountain Technologies S5065, 6.5 GHz VNA gives expected uncertainties for measurements at various values of S21 as shown
- We'll focus on behavior above 300 kHz

Measurement Accuracy[3]

Accuracy of transmission measurements[4]	Magnitude / Phase
9 kHz to 300 kHz	
-25 dB to +10 dB	±0.2 dB / ±2°
-45 dB to -25 dB	±1.0 dB / ±6°
300 kHz to 6.5 GHz	
0 dB to +10 dB	±0.2 dB / ±2°
-45 dB to 0 dB	±0.1 dB / ±1°
-65 dB to -45 dB	±0.2 dB / ±2°
-85 dB to -65 dB	±1.0 dB / ±6°

WHAT ARE THE IMPORTANT PARAMETERS?

- If we can understand some important, general parameters, we can understand what kind of performance to expect from the VNA
- We can also use this information to compare one VNA to another without going line by line through tables which might not have matching frequency ranges
- Specifically, we'll be looking at Dynamic Range, Transmission tracking and the Noise Floor

Dynamic range[2]	
9 kHz to 300 kHz	85 dB (100 dB typ.)
300 kHz to 6.5 GHz	125 dB (130 dB typ.)

300 kHz to 6.5 GHz	
Directivity	46 dB
Source match	40 dB
Load match	46 dB
Reflection tracking	±0.10 dB
Transmission tracking	±0.08 dB

Noise floor	
9 kHz to 300 kHz	-90 dBm/Hz
300 kHz to 6.5 GHz	-130 dBm/Hz

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WHAT ARE THE IMPORTANT PARAMETERS?

- We can calculate the Dynamic Range if we don't already have it since we have the noise floor specified
- The (10 Hz) Dynamic Range derived from the (1 Hz) Noise floor and the +5 dBm maximum output power is:
- Dynamic Range = +5 – Noise Floor = 5+120 = 125 dB
- (Noise Floor is 120 dB in 10 Hz BW)

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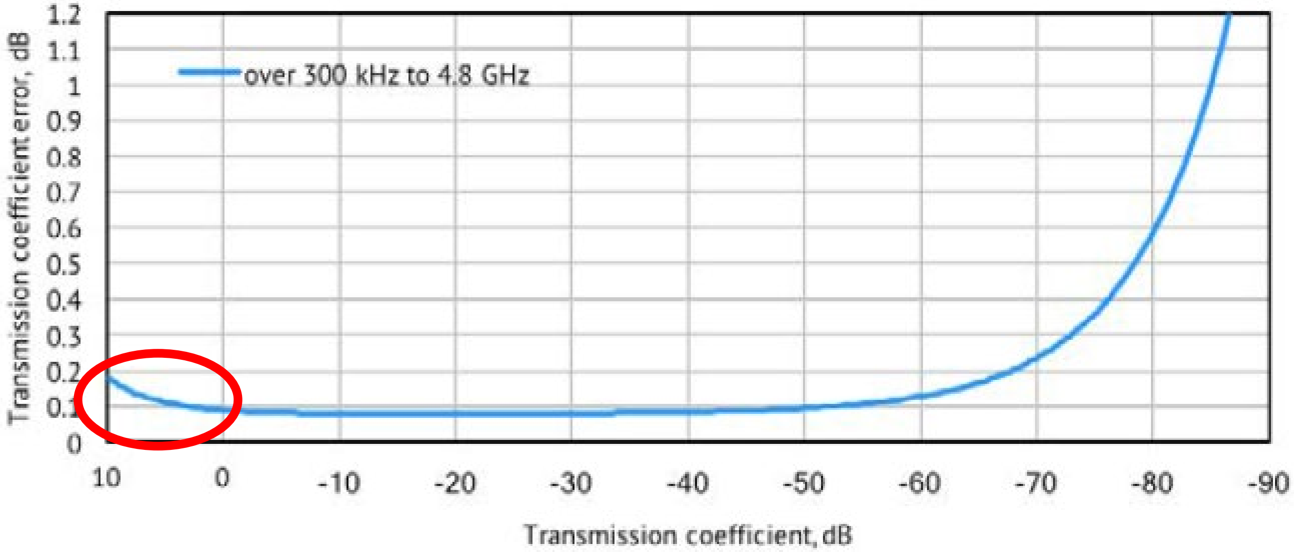
UNDERSTANDING THE UNCERTAINTY PLOT

- Here is the plot for Transmission (S21) uncertainty
- Note that the uncertainty increases for input level above +5 dB. This is due to receiver compression and assumes the VNA is being operated at full +5 dBm output level.
- If output level is reduced, receiver compression can be avoided



Specifications are based on matched DUT, and IF bandwidth of 10 Hz

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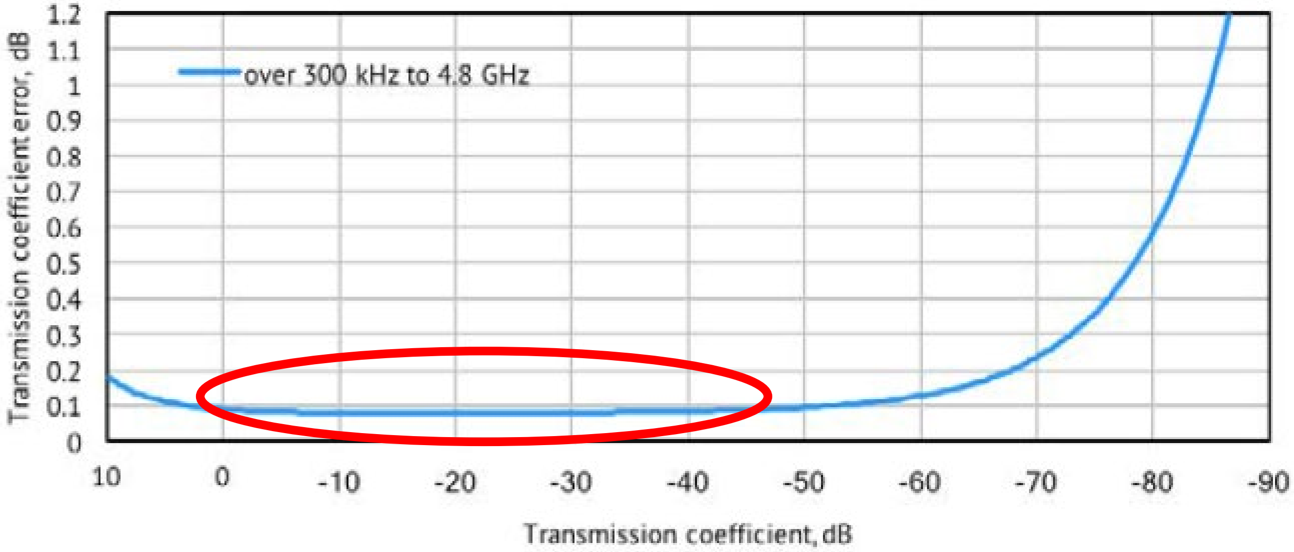
UNDERSTANDING THE UNCERTAINTY PLOT

- Below the compression area, from 0 to -45 dB, Transmission Tracking error dominates and sets the uncertainty at +/-0.08 dB
- Over most measurements, Transmission Tracking will dominate making it a very important parameter



Specifications are based on matched DUT, and IF bandwidth of 10 Hz

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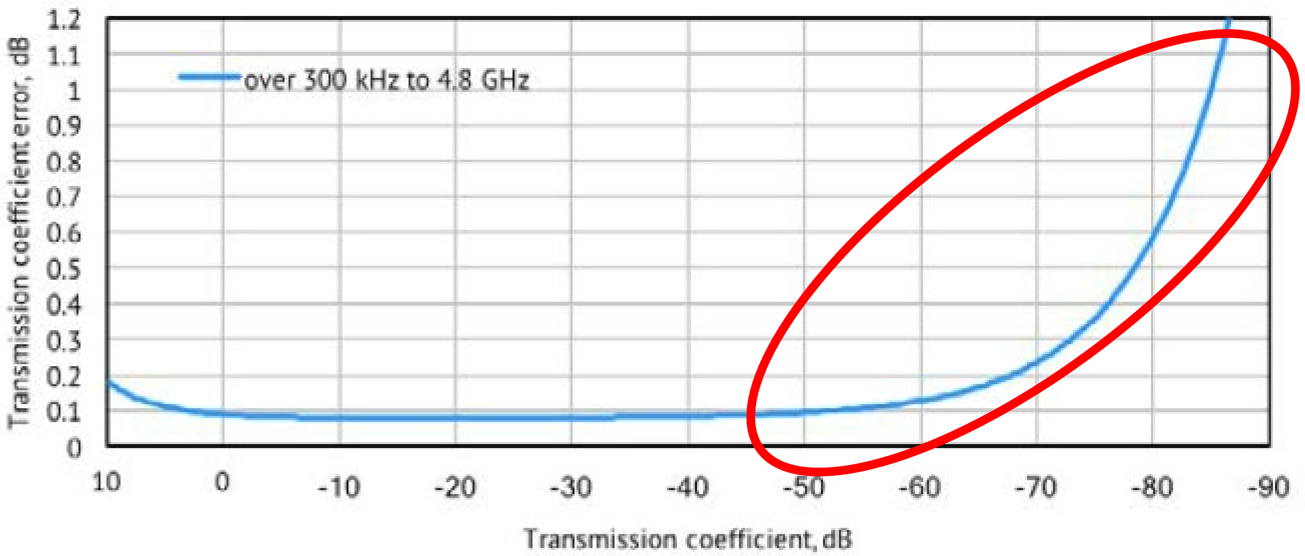
UNDERSTANDING THE UNCERTAINTY PLOT

- Below -45 dB, the noise floor begins to affect the measurement.
- To understand this properly we'll need to turn to statistics and Raleigh probabilities in particular
- In RF Engineering, the Raleigh Distribution is used to describe the amplitude fluctuations of an RF signal



Specifications are based on matched DUT, and IF bandwidth of 10 Hz

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RALEIGH PROBABILITY

- The magnitude $|\Gamma|$ of a random complex variable, a+jb with -1<= a,b <= 1 where a and b are uncorrelated is $|\Gamma| = \sqrt{a^2 + b^2}$
- That magnitude is always positive and has a Raleigh probability distribution function

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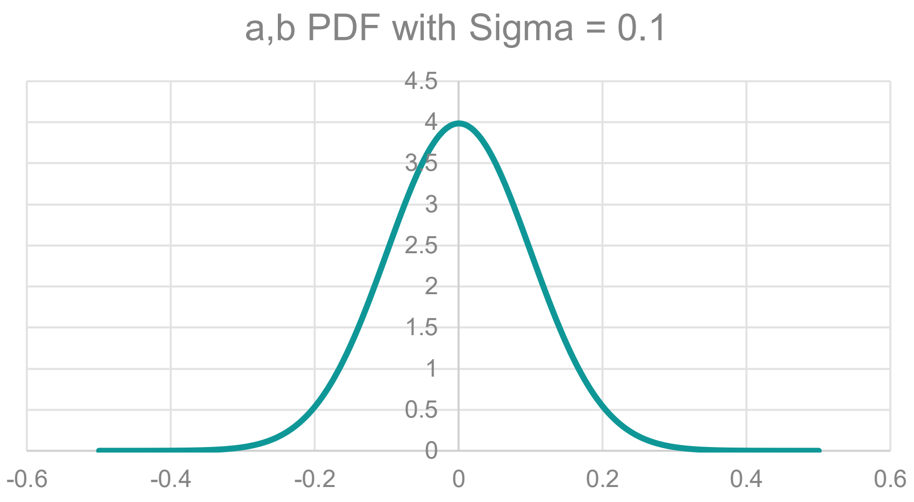
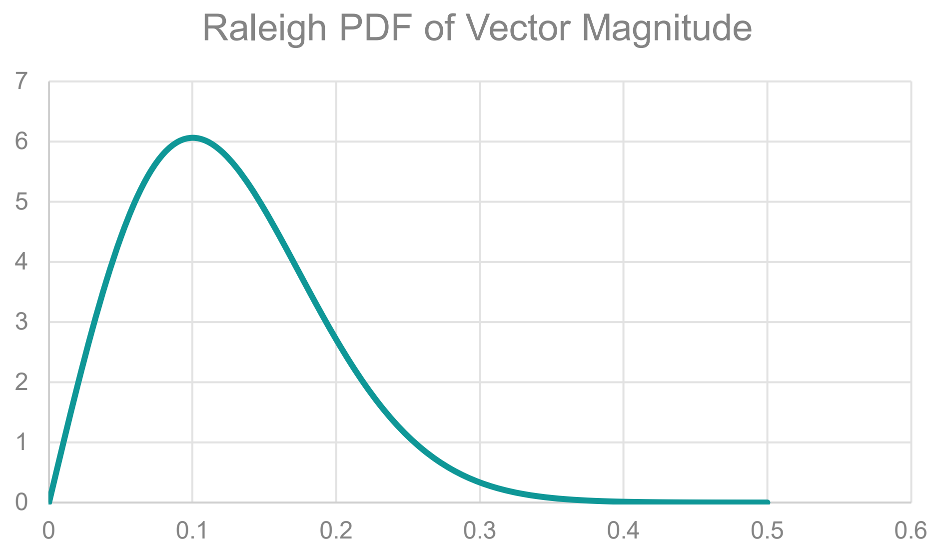
RALEIGH PROBABILITY DISTRIBUTION FUNCTION

- Here are example PDFs of a complex variable where a and b are zero centered with sigma 0.1
- The Raleigh distribution of the magnitude is shown on right





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RALEIGH PROBABILITY DISTRIBUTION FUNCTION

- The mean of a Raleigh Distribution is $\mu = \sigma\sqrt{\frac{\pi}{2}}$, where σ is of the “a” and “b” complex values
- The Standard Deviation of the Raleigh Distribution is $\sigma_R = \sigma\sqrt{2 - \frac{\pi}{2}}$
- If we know the mean noise level, μ and want 3 sigma deviations above that (95% Confidence) then that ratio delta is $\frac{\mu+3\sigma_R}{\mu}$
- Calculating that ratio gives $1 + 3\sqrt{\frac{4}{\pi} - 1} = 2.568\ or\ 8.2\ dB$ which we’ll round up to 10 dB

ADDING IT ALL UP

- The mean noise floor of an S5065 VNA is -130 dBm/Hz
- We specify the Transmission Accuracy in a 10 Hz IF BW so the noise is -120 dBm/10Hz (mean)
- Noise floor MAX at 10 Hz is then -120dBm + 10 dB (Rayleigh 3 sigma) = -110 dBm
- Subtracting the -5 dBm output level gives a relative -105 dB
- The expected error at -85 dB is then:
- $20 * Log_{10}\left(1 - \frac{10^{\frac{-105}{20}}}{10^{\frac{-85}{20}}}\right) = 20 * Log_{10}(1 - 0.1) = 0.91$ dB
- The specification calls out +/- 1 dB so this result passes the sanity check

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REFLECTION UNCERTAINTY

- What about Reflection Uncertainty?
- This uncertainty is mostly attributed to the uncertainty of the calibration Load
- Here is the formula (Courtesy of METAS):

$$\Delta S_{ii} = D + T \cdot S_{ii} + M \cdot S_{ii}^2 + L \cdot S_{21} \cdot S_{12} + R$$

where S_{ii} is measured reflection coefficient;

S_{21}, S_{12} are measured transmission coefficients in forward and reverse directions;

D is residual directivity;

T is overall effect of tracking and non-linearity;

M is residual test port source match;

L is residual test port load match

R represents all the random contributions.

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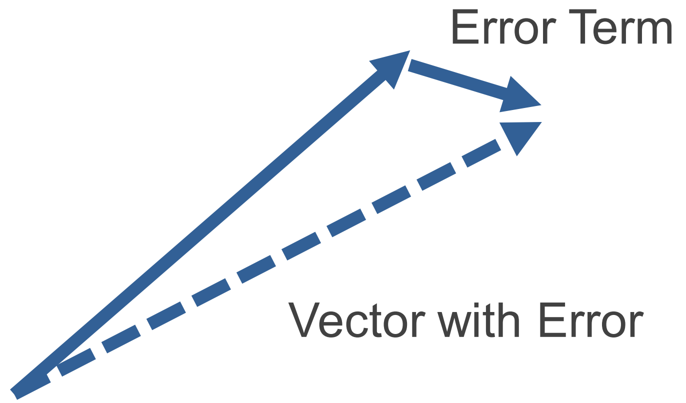
REFLECTION UNCERTAINTY

- For the most part, Reflection Uncertainty is not "Noise-Like"
- The components of the previous formula are small vectors which must be added to arrive at the final uncertainty as shown
- Vectors are added in the linear domain and are worst when pointing along the direction of the true vector



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REFLECTION UNCERTAINTY

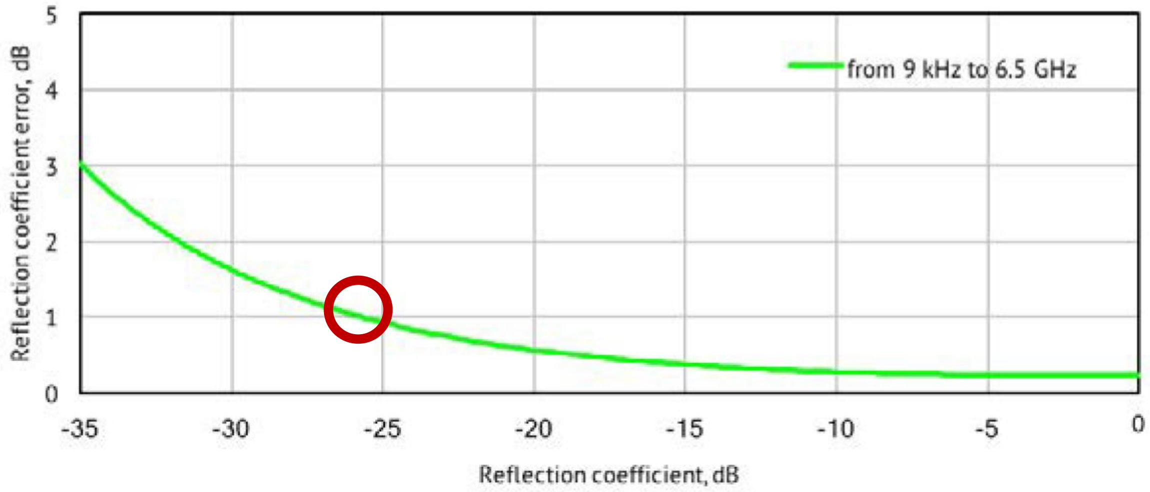
- As an easy rule of thumb, an error vector 10 dB smaller will add an uncertainty of approximately +/- 3.3 dB
- An error vector 20 dB smaller will add an uncertainty of approximately +/- 1.0 dB

20*LOG10[1-10^(-10/20)] = -3.3

20*LOG10[1-10^(-20/20)] = -1.0

REFLECTION UNCERTAINTY

- We can see how the reflection uncertainty applies in this chart
- The 1 dB error point is at -26 so the Uncertainty of the calibration load is approximately 46 dB
- Since S12 and S21 can't be known they are assumed to be zero which eliminates the Load Match contribution



Specifications are based on isolating DUT ($S_{21} = S_{12} = 0$)

$$\Delta S_{ii} = D + T \cdot S_{ii} + M \cdot S_{ii}^2 + \cancel{L \cdot S_{21} \cdot S_{12}} + R$$

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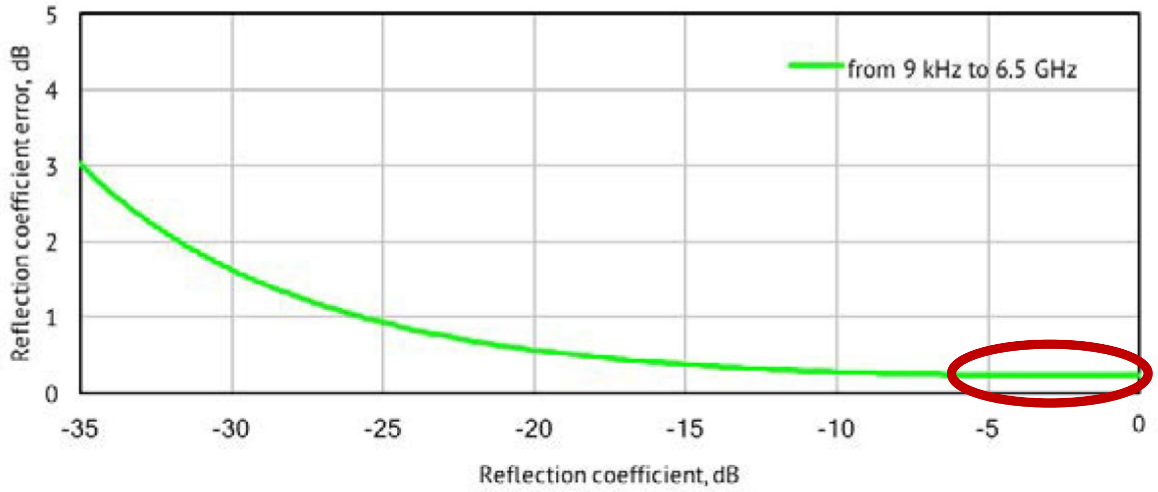
REFLECTION UNCERTAINTY

- Finally, the Source Match (M) term and the Reflection Tracking (T) terms dominate the Uncertainty at the other end of the chart



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CONCLUSION

- We've shown how the performance specifications of a VNA can be approximated with knowledge of certain key VNA parameters
- This gives us an intuitive understanding of the uncertainty on S11 and S21 and a way to quickly compare one VNA model to another
- It is also helps us understand how important it is to have a high-quality calibration standard set such as an Automatic Calibration Module (ACM)

REFERENCES

- Guidelines on the Evaluation of Vector Network Analysers (VNA) | TC-EM | Version 3.0, 03/2018 Euramet
- VNA Transmission Measurement Accuracy, https://coppermountaintech.com/video-vna-transmission-measurement-uncertainty/
- Reflection vs Transmission Accuracy in Vector Network Analyzer Measurement, https://coppermountaintech.com/reflection-vs-transmission-accuracy-in-vector-network-analyzer-measurement/

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