Thermal Stability and VNA Measurement

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Introduction

A Vector Network Analyzer (VNA) is an essential tool in the RF Engineer's toolbox. As such, the engineer should understand how to obtain the best measurement so that its meaning is clear and the accuracy is understood. Two kinds of errors contribute to measurement inaccuracy: systematic and random. For the most part, systematic errors can be removed from a measurement through the calibration process, but random errors cannot be removed and may only be mitigated through control of the test environment.

Here, we'll examine measurement errors attributed to thermal drift and see how they might be minimized.

Warming up the VNA

The VNA must be allowed to warm up and reach thermal equilibrium after applying power. As temperature varies, material thermal expansion and the gain of amplifiers in the internal signal chain alter slightly.

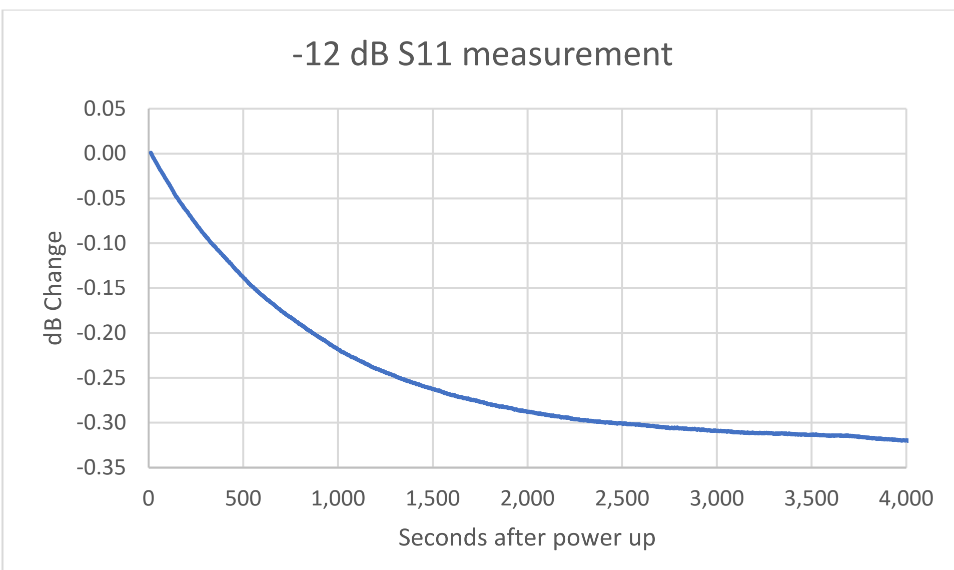

Figure 1 - Reflection Measurement after Power up

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Figure 1 This shows the change in the measurement of a 12 dB return loss at 16 GHz over a one-hour period after first applying power to the S5180B, 18 GHz VNA. A 45 to 60-minute warm-up period is recommended to ensure that subsequent calibration will be effective and that accurate measurements are possible.

After the warm-up period, perform user calibration on the VNA. The correction applied will then remain valid for many hours.

Ambient Thermal Effects on VNA Accuracy

After user calibration, the ambient temperature in the VNAs' environment should be controlled as much as possible. The temperature inside the VNA will be 15 to 20 degrees C higher than ambient and will track with it. Internal temperature changes will affect reflection and transmission measurements to some extent.

The user calibration process corrects systematic measurement errors that depend on the VNA hardware, such as Source Match, Load Match, Directivity, and Reflection and Transmission tracking.

This calibration process applies correction vectors to measurements, and any significant changes to the error sources will result in measurement “ripples.”

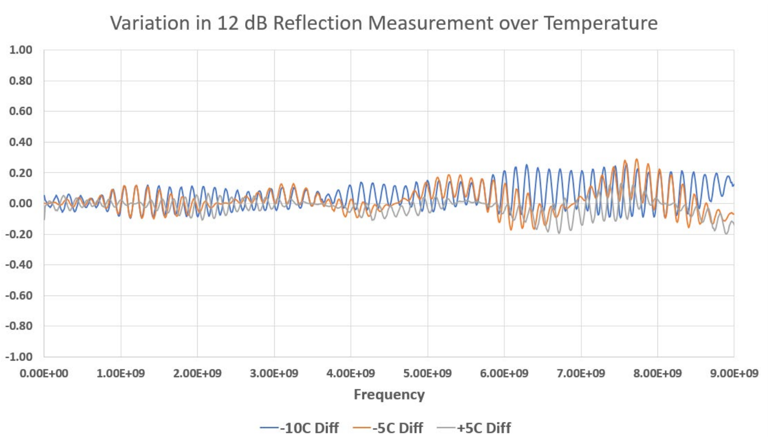

Figure 2 - Change in 12 dB RL over Temperature

Figure 2 shows measurement variation of a 12 dB return loss with the VNA exposed to 15ºC, 20ºC, and 30ºC ambient temperature after being calibrated at 25ºC. The return loss standard was kept at 25°C outside the chamber. Ripples in the measurement are due to changes in the directivity of the VNA bridge. Measurements of higher return loss

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values, such as 25 dB, are expected to have even larger variations. Here, the 0.2 dB variation after a 10°C change in ambient temperature is still reasonable, but if the temperature in the lab is not controlled and there are large fluctuations in temperature you will need to repeat the calibration. The thermal change in directivity error responsible for the ripples is a constant low value so ripples will be more pronounced for lower return loss measurements such as 20 or 25 dB.

Temperature changes also affect transmission measurements. A VNA was calibrated at 25C, then a 10 dB attenuator was measured with the VNA exposed to 15ºC, 20ºC, 25ºC, 30ºC, and 35ºC ambient temperatures. The measurement variation over temperature is shown in Figure 3.

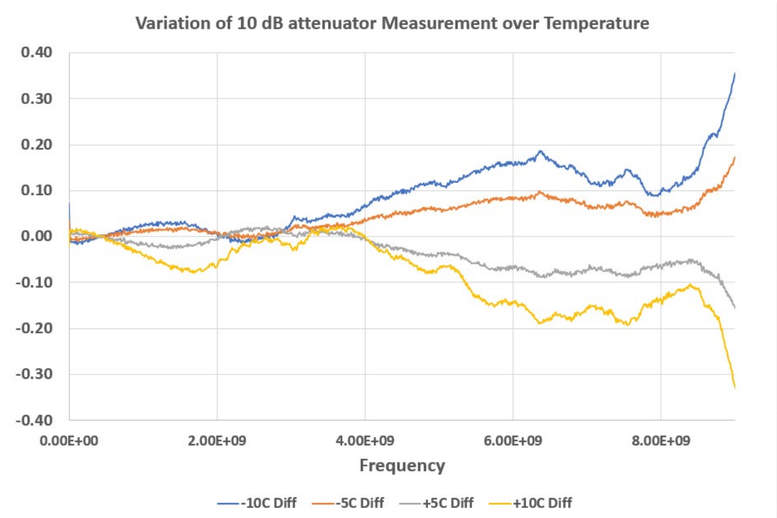

Figure 3 - Transmission measurement variation over Temperature

These changes are most likely due to small changes in amplifier gain between the R1 and B receiver channels used in the S21 measurement. It is clear from the chart that temperature variation up to 5°C might be tolerable, but 10°C—a very large change indeed—will require a new calibration, particularly at the high end of the frequency range.

Larger VNAs like the “A” series from CMT exhibit less thermal drift for reflection and transmission measurements due to the larger physical size of the device's directional bridge and analog sections.

75Ω Matching Pads

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Matching pads like the one shown schematically in Figure 4 are used to convert a 50Ω port to a 75Ω port and do a reasonable job of fixing the Source and Load match for a 75Ω environment. Unfortunately, they also attenuate the incident signal by 3.96 dB and the reflection by 7.48 dB or 11.44 dB altogether. This loss degrades the residual directivity for reflection measurements and dynamic range for transmission measurements. Additionally, the resistors in the pad have thermal variation, resulting in increased residual Source Match, Load Match, Reflection, and Transmission Tracking errors as the ambient temperature changes. Small ripples will develop on measurements as this occurs.

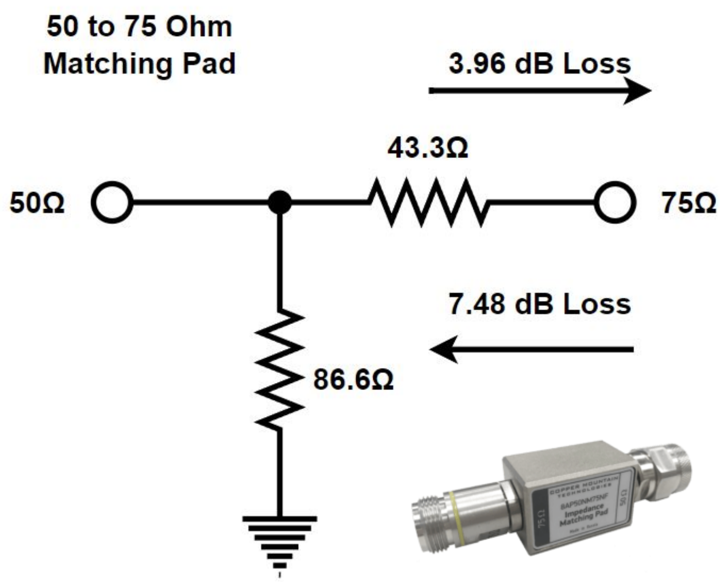

Figure 4 - 50 to 75 Ohm Matching Pad

Placing the matching pads at the ends of the 50Ω test cables is often advantageous. 75Ω cables are generally lower quality with limited bandwidth. Pay attention to the difference between a 50Ω and 75Ω N connector! **Warning**! Attempting to mate a 50Ω male connector with a 75Ω female will destroy the female connector.

Embedded Modules

Copper Mountain Technologies produces modular VNAs, which may be “bolted in” to a more extensive system. In such cases, attention must be paid to the VNA's thermal dissipation, and allowances must be made to pull heat away from it and keep the internal temperature rise under control. The internal temperature of the VNA may be queried through a SCPI command and should not exceed 60ºC. A 20ºC difference between the VNA internal and external ambient temperatures is typical.

If the VNA module is mounted within an enclosure, it may be necessary to provide airflow to promote convection, particularly if other heat-generating electronics are present. Attaching the VNA to a metal surface or a heat sink is also recommended to allow conductive cooling.

Conclusion

Understanding the effect of ambient thermal variation is essential to obtaining the best accuracy from your vector network analyzer. If too much change has occurred, calibration should be updated. The information presented here should help the user understand qualitatively how much change to expect.

Copper Mountain Technologies provides a wide range of metrology-grade Vector Network Analyzers from 1.3 to 330 GHz. A complete list of our products is available on our website at www.coppermountaintech.com. Also, peruse the informative technical resources, white papers like this, videos, and webinars. CMT is ready to fulfill your VNA needs and support users making sophisticated measurements or those who are just getting started.