APPLICATION NOTE

The Bird BNA Series
Why Calibration Matters

Ensuring Precision: The Importance of Vector Network Analyzer Calibration and How to Calibrate Your Bird BNA1000 VNA

In the realm of electronic and communication systems, Vector Network Analyzers (VNAs) serve as indispensable tools for measuring and characterizing the electrical performance of devices like antennas, filters, and amplifiers. However, to guarantee the accuracy and reliability of these measurements, regular calibration of Vector Network Analyzers is paramount. In this application note, we explore the reasons behind VNA calibration and emphasize its crucial role in achieving precise and trustworthy results.

Reasons for Vector Network Analyzer Calibration

While you may want to reason that there is no immediate need for calibration if your VNA came calibrated when you ordered it as a new purchase and it is still well within the 1-year recommended calibration cycle, it is important to make the distinction between a factory calibration and a measurement calibration. Factory calibration is focused on verification of the instrument performance with the possibility of adjusting internally preserved scaling or offset coefficients so that the instrument meets and maintains its published specifications. This process is typically quite involved and may require certification that the instrument meets a certain calibration based on an accredited standard. This is typically performed annually or biannually by a qualified technician at the equipment manufacturer's facility or a designated service center.

Due to the sensitivity of your VNA as well as the devices or circuits you are evaluating, a measurement calibration is almost certainly required. The factory calibration only considers instrument performance to the point the instrument ports. This virtual stopping point is referred to as the reference plane. As you start adding cables, connectors, adapters, fixtures, or other, you are extending the reference plane beyond the instrument port, adding losses, reflections, phase shifts, and impedance mismatches that are not accounted for by the factory calibration thus resulting in a degradation in accuracy. While measurement calibration cannot account for and resolve all sources of uncertainty (for example, temperature drift), it greatly helps to compensate for most system imperfections and provides you with the best possible accuracy.

Just as not all mechanical setups will be the same for different device configurations, the same can be said with respect to their signal operating conditions. Since your device will be tuned to operate in a certain RF band you will want to ensure that your vector network analyzer is corrected using similar conditions to what the device's application calls for. Any time there are changes to the start or stop frequencies, the intermediate frequency bandwidth (IFBW), or the number of points in a sweep, a measurement calibration should be performed.

Tools for Performing Measurement Calibration

Traditional measurement calibration typically involves the use of up to four different device standards – open, short, load, and through – with each connected for its specific measurement and allowing for the characterization and capture of electrical coefficients used to compensate for system losses. These devices often come in the form of a kit, sometimes as individual pieces (**Figure 1**) and sometimes as an aggregate tool (**Figure 2**).

Figure 1: Multi-piece VNA calibration kit.

Figure 2: One-piece VNA calibration kit, SK-CAL-FN-C9.

The kit or standards are selected such that they share the same connector type and gender that is used by the device under test (DUT). For instance, if the DUT has SMA female jack connections, then you will want to choose a calibration kit that offers the same. Your VNA will most likely provide on-screen options to allow you to choose the connector type (**Figure 3**) corresponding to your cal kit connectors provided that the kit offers standards with both genders.

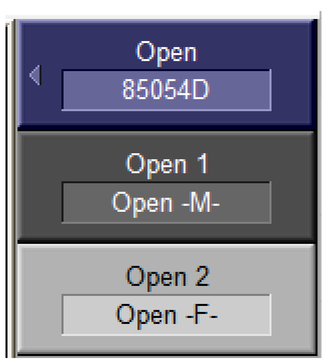

Figure 3: The Keysight 85054D calibration kit comes with standards of both genders and you will have to select accordingly.

While traditional calibration standards are the most widely used, they do require you to add and remove connections for each step of the measurement calibration procedure. Every connection takes time. Even in cases where a single port or multi-port calibration offers some relief by not requiring one standard, this ends up eliminating data points that might otherwise bring an added level of accuracy to your end measurements. Furthermore, connectors don't last forever even when they're of the highest quality, and after some number of insertion or connection cycles those connectors will need to be replaced.

To remedy this, VNA manufacturers have come up with auto-calibration kits. These devices require only one connection to a port or ports for a given measurement calibration instance and automates the switching between the open, short, load, or through connections (**Figure 4**). These are controlled either by the VNA itself or through connection to a PC.

Figure 4: The Bird E485A 4-port SMA automatic calibration kit.

1-Port Calibration and Port Extensions

For a 1-port calibration, the correction process addresses a singular reflection parameter entirely, specifically S11 (or S22, etc., depending on the number of ports available on the vector network analyzer, see **Figure 5**). This type of measurement calibration is necessary when testing devices such as connectors, antennas, or passive devices. While all ports are accessible during calibration, the correction focuses solely on refining reflection measurements for the given port. This calibration method proves advantageous for scenarios exclusively involving reflection measurements. For VNAs having multiple ports, the 1-port calibration may be performed on each allowing for the potential execution of several simultaneous reflection-only measurements.

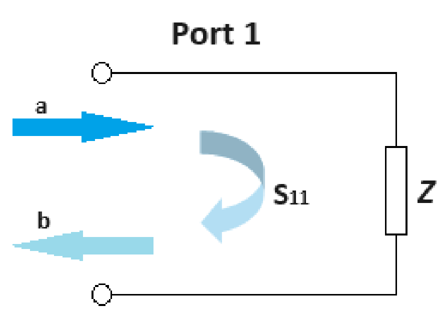

Figure 5: 1-port calibration will provide corrections with respect to the reflection parameter, S11.

A 1-port calibration can be accomplished by capturing correction measurements on the Open, Short, and Load (or match) standards, connecting each in turn if you are using a manual calibration kit option. Your vector network analyzer will have made the process of performing a 1-port calibration straightforward by way of on-screen menu options where the specific calibration kit can be selected (or, if not present, added) and control buttons can be clicked for each step of the process (**Figure 6**).

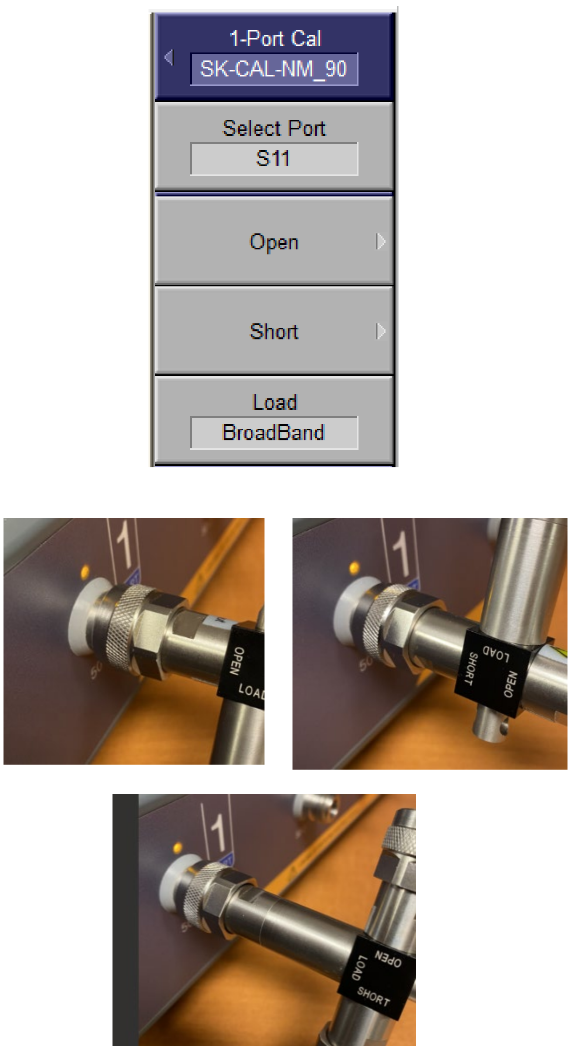

Figure 6: Images of tools used in the 1-port measurement calibration process: a. VNA calibration menu options, b. Open standard connection to the VNA, c. Short standard connection to the VNA, and d. Load standard connection to the VNA

You may then wish to perform a confidence check using a Smith chart view with the S11 measurement, using the load standard to qualify your calibration with the measurement being centered at the 50 Ω location in the plot (**Figure 7**).

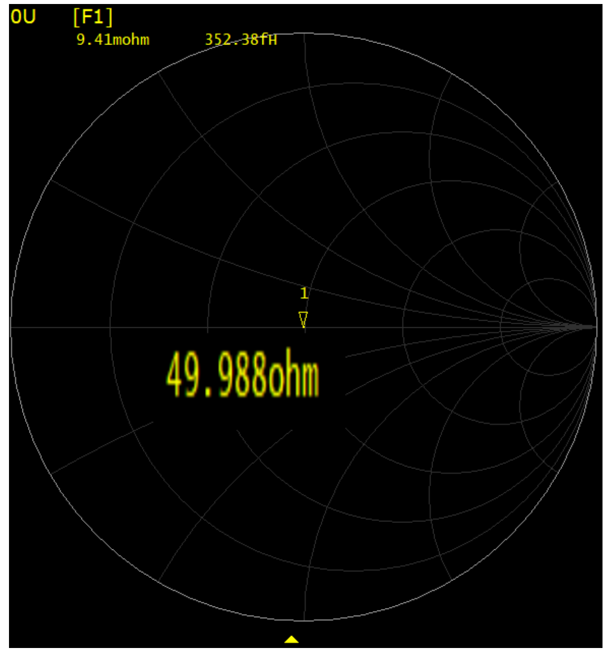

Figure 7: Using the load standard, the S11 (reflection) measurement will be centered on the plot.

While the images above provide you with some idea of calibration standard connection, bear in mind that there are fewer applications instances than otherwise where performing measurement calibration directly at the port is common. As noted earlier, connections to the DUT regularly involve cables and connectors. While these items will be accounted for in the measurement calibration, there is a chance that the connector pairing with the DUT is not ideal and an adapter is required. For instance, if you were planning to characterize a batch of antennas which all have SMA male connections and want to do so right at the port of the VNA, you would need to use a type N male to SMA female adapter (**Figure 8**). In doing so, this introduces an offset against the calibration plane that was established during calibration. This is because the additional signal path length through the N-to-SMA adapter moves the calibration plane that we established during the calibration procedure. Even just a few millimeters can influence the resulting measurements.

Figure 8: Type N(m) to SMA (f) adapter.

We can correct for this by defining a time-based electrical delay using the port extension feature. The electrical delay value recognized by the port extension depends on the length of the signal path that the adapter adds. You could opt for determining the electrical delay via search of the internet for a formula, or you might reference other recommendations on how to perform adjustments based on phase angle flatness. However, a much easier approach is to let the VNA do the work for you by using the Auto Port Extension feature that will perform the measurement for you and then automatically adjust when the DUT is added to the system (**Figure 9**).

Figure 9: The DUT can be mated to the VNA with the adapter in between and measurement uncertainties can be accounted for by defining a port extension.

2-Port Calibration

2-port calibration stands out as the most widely employed and comprehensive calibration technique involving two ports, proving necessary when testing devices such as amplifiers, filters, or attenuators. This method ensures the thorough correction of all four S-parameters—namely, S11, S12, S21, and S22 (**Figure 10**).

- As noted earlier, S11 corresponds to the reflection coefficient at port 1, representing the reflection of a signal transmitted from port one of the VNA and received at the same port.
- S12 denotes reverse transmission (gain/loss), illustrating the transmission of a signal from port 2 of the VNA and its reception at port 1.
- S21 signifies forward transmission (gain/loss), capturing the scenario where a signal is sent from port one of the VNA and received at port 2.
- S22 represents the reflection coefficient at port 2, indicating the reflection of a signal transmitted from port 2 of the VNA and received at the same port.

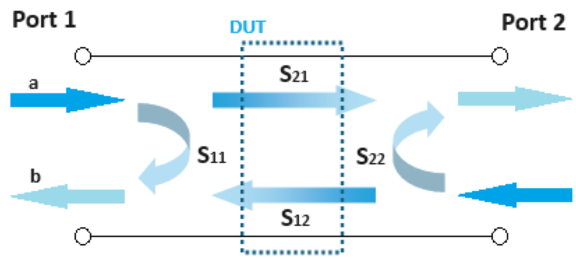

Figure 10: A 2-port calibration will provide corrections with respect to parameters S11, S22, S21, and S12.

A 2-port calibration can be accomplished similar to what was described earlier, capturing correction measurements on both ports using the open, short, and load standards while also including the through standard to couple the ports and account for the S21 and S12 parameters. Again, your vector network analyzer will have made the process of performing a 2-port calibration straightforward by way of on-screen menu options where the specific calibration kit can be selected (or, if not present, added) and control buttons can be clicked for each step of the process (**Figure 11**).

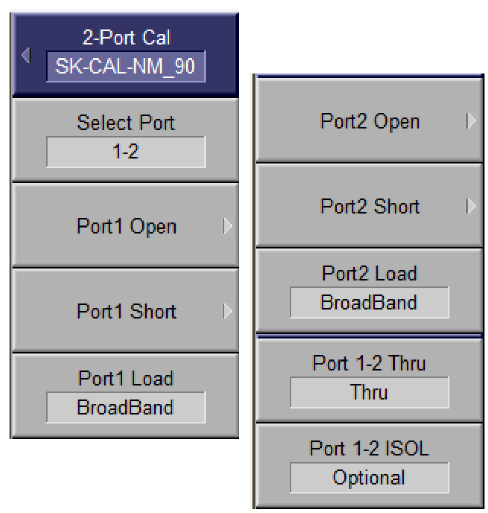

Figure 11: Primary calibration steps and options encountered while performing a 2-port measurement.

Note that the isolation step (ISOL) is optional since it is only truly necessary when the DUT exhibits high losses at different points in the measurement band. The isolation error pertains to any signal that traverses from Port 1 to Port 2 without going through the DUT. This may include internal VNA leakage as well as unintended coupling, such as parasitic input-to-output coupling in a test fixture or probe-to-probe coupling in a semiconductor test probe station. Typically, internal VNA leakage is negligible compared to thermal noise, allowing it to be disregarded when employing well-designed fixturing. If the operator were to choose to include the isolation error correction step, both ports must be terminated with a load.

Conclusion

Vector Network Analyzer calibration is not merely a technical procedure; it is a fundamental practice for removing systematic errors that underpin the accuracy and reliability of measurements in diverse user setups. By compensating for imperfections, minimizing reflections, and ensuring consistent and accurate measurements, VNA measurement calibration plays a pivotal role in driving innovation, assuring quality, and facilitating compliance with industry standards. Embracing the importance of VNA calibration is essential for organizations seeking to uphold the highest standards in their electronic and communication endeavors.

It is important to understand the distinction between factory calibration and measurement calibration, with the former acting as verification of instrument performance to meet specifications and the latter being crucial for corrections beyond the instrument ports, compensating for losses and reflections caused by additional elements like cables and adapters.

Tools for performing measurement calibration include traditional calibration standards (open, short, load, through) and auto-calibration kits that automate the process. For either option it is important to select connectors compatible with the device under test, and the time-consuming nature of manual calibrations can be alleviated by use of the auto-calibration option.

The 1-port calibration, suitable for devices like connectors, antennas, or passive devices, is a correction process focusing on a singular reflection. Additionally, port extensions can be used to correct for offsets caused by adapters that are not present during the calibration process. It should be noted that port extensions are available for multi-port configurations as well.

The 2-port calibration is a more comprehensive technique that covers all four S-parameters. The optional isolation step can be included if your device type makes it a necessity, though it will require both ports to be terminated – something likely made more convenient with the auto-calibration kit.

For more information about Vector Network Analyzers such as the Bird BNA1000 Modular Vector Network Analyzer and BNA100 USB Vector Network Analyzer, please visit https://birdrf.com.