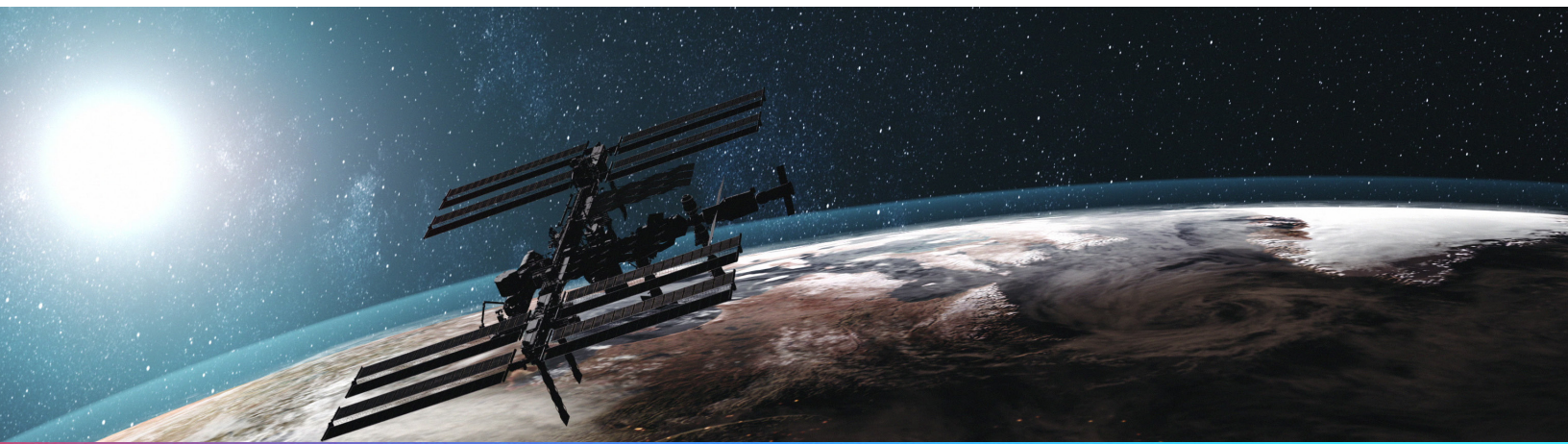


Hidden Variable in High-Speed Measurements: RF Cable Stability

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Abstract

As high-speed interfaces move toward data rates of 100 Gb/s and beyond, signal integrity measurements increasingly depend on the integrity of the measurement path itself. Engineers routinely focus on the device under test (DUT), test fixture, connectors, calibration methodology, and test instruments (e.g., vector network analyzer), but one critical element is often overlooked – the RF cable assembly.

In high-speed differential measurements, the RF cable is not merely a passive connection between the instrument and the DUT. Cable insertion loss, return loss, phase stability, amplitude stability, connector repeatability, and mechanical sensitivity can directly influence the measured characteristics of a differential channel. Cable movement after calibration can introduce measurement variations that may be incorrectly attributed to the DUT. This becomes particularly important when measuring differential insertion loss, return loss, phase, group delay, and mode conversions, where small amplitude or phase errors between measurement paths can affect the extracted results.

Maury Microwave StabilityPlus™ and StabilityPlus Low Profile cable assemblies are designed to address these challenges. StabilityPlus provides phase- and amplitude-stable performance with flexure, while the low-profile version combines this electrical stability with a lightweight, compact form factor suited to high-density instrumentation, PXI/PXIe systems, and switch matrices. Maury specifies StabilityPlus cable assemblies across applications extending to 110 GHz, while StabilityPlus Low Profile assemblies are available up to 67 GHz, depending on the configuration. This paper examines why cable stability matters in high-speed differential measurements, how cable instability can affect measurement confidence, and how stable RF interconnects can help create a more repeatable and reliable measurement environment.

The Measurement Path in High-Speed Setups

The semiconductor and electronics industries are rapidly moving toward higher data rates, wider bandwidths, and increasingly complex signaling architectures. Interfaces operating at 56 Gb/s, 112 Gb/s, 224 Gb/s, and beyond are driving the development of sophisticated transmitter and receiver architectures, advanced packaging, high-density interconnects, and increasingly demanding signal-integrity validation methodologies.

At these speeds, engineers are no longer simply asking, "What is the performance of the DUT?" Instead, the question becomes, "How much of what I am measuring actually belongs to the DUT, and how much belongs to the measurement system?" This distinction is fundamental to understanding and evaluating measurement results.

A typical high-speed measurement setup may contain a VNA or high-performance oscilloscope, differential probes or probe fixtures, RF cable assemblies, adapters and connectors, calibration standards, switch matrices, test fixtures, PCB launches, signal conditioning components, and the DUT itself. Each element contributes electrical characteristics to the measurement chain. As operating frequencies increase, seemingly small changes in amplitude and phase can become significant. Consequently, the measurement interconnect should be treated as an active contributor to the measurement uncertainty budget rather than simply as a mechanical connection.

Among these contributors, cable stability is particularly important because cables are inherently exposed to mechanical movement. A cable may be bent, twisted, moved, compressed, routed differently, or disturbed by an operator or automated test system. Even when the VNA has already been calibrated, mechanical changes to the cable can alter its electrical behavior. The result can be a measurement that is repeatable only when the entire physical setup remains unchanged.

High-speed differential measurements introduce another level of sensitivity. A differential channel consists of two electrical paths that ideally behave identically but with opposite polarity:

$$V_{diff} = V_+ - V_-$$

The measurement therefore depends not only on the absolute characteristics of each path but also on the relationship between the two paths. For example, consider two measurement cables:

- > **Cable A:** amplitude response A_1 , phase response ϕ_1
- > **Cable B:** amplitude response A_2 , phase response ϕ_2

The differential measurement is influenced by:

$$\Delta A = A_1 - A_2$$

$$\Delta \phi = \phi_1 - \phi_2$$

Even when each individual cable appears acceptable, differences between the two paths can influence the extracted differential parameters. This becomes increasingly important when evaluating differential insertion loss, differential return loss, common-mode rejection, mode conversion, differential phase, group delay, skew, time-domain reflectometry (TDR) and time-domain transmission (TDT) characteristics, S-parameters, eye-diagram-related parameters, or channel operating margins. Thus, differential measurement quality depends not only on cable performance but also on cable-to-cable consistency and stability.

Cable Movement: A Hidden Measurement Variable

One source of measurement variation is often overlooked – cable movement. An RF cable is a transmission line with distributed electrical properties that can change under mechanical deformation. A simplified transmission-line model is expressed in terms of distributed parameters as follows:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

where:

R = distributed resistance

L = distributed inductance

G = distributed conductance

C = distributed capacitance

Mechanical deformation can modify the physical relationship between the conductors and dielectric materials, resulting in changes to the effective electrical parameters. These changes can manifest as phase variation, amplitude variation, return-loss variation, insertion-loss variation, impedance changes, and electrical-length changes. The consequences are particularly important in calibrated measurements.

Consider the following sequence:

1. The VNA is calibrated.
2. The RF cables are positioned in a particular orientation.
3. The DUT is connected and the measurement is performed.
4. The user moves one cable to improve access to the DUT.
5. The measurement changes.

In this scenario, the DUT, calibration, and instrument remain unchanged, but repositioning the RF cable changes the measurement path. As a result, changes in the measured response are caused by the cable rather than the DUT.

The impact of cable movement on measurements depends on several characteristics. Cable stability therefore cannot be defined by a single specification. One important consideration is phase stability, which describes how much the electrical phase of a cable changes when the cable is mechanically disturbed.

A cable with poor phase stability may exhibit measurable phase changes when they are bent, twisted, flexed, moved or vibrated. This becomes critical at higher frequencies since a minor change in physical or electrical length can lead to a significant phase change.

For a transmission line:

$$\Delta\phi \approx \beta l$$

where:

ϕ = phase

β = phase constant

l = electrical length

Therefore:

$$\Delta\phi \approx \beta \Delta l$$

As frequency increases, β increases, making the system increasingly sensitive to small changes in electrical length.

Phase is not the only parameter affected by cable movement. Mechanical deformation can also influence attenuation and impedance characteristics, resulting in changes in measured amplitude.

Since cable movement can affect several characteristics such as phase and amplitude stability, maintaining cable stability is particularly important across a range of industries and applications that demand consistent, repeatable measurements, including:

- > **Semiconductor Characterization:** Device S-parameters, RF transistor characterization, load pull measurements, noise measurements, and millimeter-wave device characterization.
- > **High-Speed Digital:** SerDes characterization, PCIe, Ethernet, high-speed differential channels, backplane characterization, and cable and connector characterization.
- > **Aerospace and Defense:** Radar, EW systems, RF modules, phased-array systems, and high-frequency communications.
- > **Satellite and Space:** RF payloads, high-speed data links, transceiver characterization, and millimeter-wave systems.
- > **Production Test:** Automated RF testing, multiport testing, switch-matrix systems, and high-volume characterization.

High-Speed Differential Test Architecture

Every RF cable in the signal path can contribute to the uncertainty of the measurement, and this challenge becomes greater as systems incorporate more ports for complex DUTs, multiplexed measurements, or automated probe stations. As the number of interconnects increases, so does the opportunity for mechanical variation.

Figure 1 shows a typical high-speed differential measurement setup with two signal paths between the VNA and DUT. However, selecting two individually high-quality cables is not always sufficient. The two paths should ideally exhibit closely matched phase, electrical length, and stability characteristics. Furthermore, the pair should maintain that relationship when subjected to the mechanical environment of the measurement. As a result, cable stability should be considered both individually and across the matched measurement path for differential measurements.

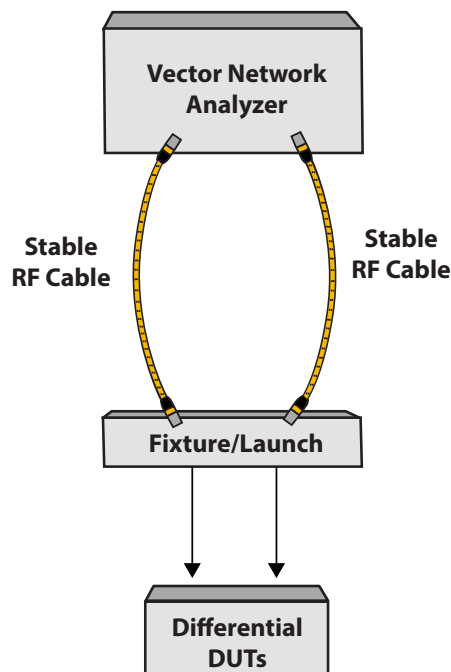


Figure 1. Typical high-speed differential measurement architecture.

Understanding measurement uncertainty is important when evaluating the influence of the measurement path. The total measurement uncertainty can be represented as:

$$U_{TOTAL} = fn\{U_{INST}, U_{CAL}, U_{FIXTURE}, U_{CONNECTOR}, U_{CABLE}, U_{DUT}, \dots\}$$

As shown in the equation, cable uncertainty is only one component of the total measurement uncertainty. However, reducing one component can improve overall measurement confidence. When cable-related uncertainty is significant relative to the DUT variation being investigated, improving the cable can have a substantial effect on the quality of the measurement. This becomes even more critical in high-speed testing, where small measurement margins, high operating frequencies, differential signaling, multiple ports, mode conversion measurements, and repeated or automated testing increase sensitivity to measurement-path variation.

Of particular interest are the mode-conversion terms S_{dc} (differential mode to common mode) and S_{cd} (common mode to differential mode). These parameters can be substantially smaller than the primary transmission response, making them more difficult to measure reliably. If the desired mode-conversion signal is very small, even relatively small systematic errors in the measurement paths can become significant compared with the parameter being measured. This creates a fundamental requirement that measurement system must have sufficient stability and symmetry to distinguish DUT behavior from measurement-path behavior. Cable stability is therefore directly connected to the credibility of low-level differential measurements.

StabilityPlus Versus Conventional Flexible Cables

Not every flexible RF cable is optimized for precision measurement. A general-purpose cable may provide acceptable insertion loss, VSWR, and power handling under static conditions. However, precision measurements also require consideration of how these parameters change when the cable is moved. Table 1 highlights key differences between conventional flexible cables and cables designed for measurement stability.

Parameter	Conventional Flexible Cable Assemblies	Stable Cable
Static insertion loss	Generally specified	Specified
Static return loss	Generally specified	Specified
Phase stability	Limited	Specified / Critical design parameter
Amplitude stability	Limited	Specified / Critical design parameter
Flexure performance	Application dependent	Designed for measurement use
Post-calibration movement	Potential concern	Minimized
High-frequency measurement	Application dependent	Optimized
Automated test suitability	Variable	Strong
Differential measurement	Application dependent	Relevant

Table 1. Comparison of conventional flexible and stable RF cable characteristics

The key difference is that a measurement-grade cable must be evaluated not only by its static RF specifications but also by its behavior under mechanical stress. Further, most high-speed differential tests require TDR/TDT measurements, which are highly sensitive to phase and amplitude behavior. This sensitivity places greater demands and importance on cable stability.

The traditional RF cable selection process often begins with the question, "What frequency does the cable support?" For precision measurements, however, frequency range alone is only part of the selection criteria. A cable rated to 67 GHz or 110 GHz may meet the required frequency range, but its electrical performance must also remain consistent as the cable is installed, routed, and manipulated. This leads to a more complete question when selecting the right RF cable for a test setup: "How stable is the cable across the mechanical and electrical conditions of the measurement?"

A broader distinction exists between selecting a cable simply for connectivity and treating it as part of the measurement system. Table 2 summarizes the shift from a traditional view of the RF cable as an interconnect to a measurement-focused view in which the cable forms part of the measurement architecture.

Traditional View	Modern Measurement View
Instrument > Cable > DUT	Instrument > Stable Measurement Path > Fixture > DUT
The cable is simply a connection.	The cable is part of the measurement architecture.

Table 2. Traditional and measurement-focused views of the RF cable in a test setup.

This change in perspective becomes increasingly important as measurement bandwidth expands and allowable uncertainty decreases.



Maury StabilityPlus: Enabling Confidence in High-Speed Measurements

Maury StabilityPlus family is designed to maintain electrical stability while allowing the mechanical flexibility required in advanced RF and high-speed measurement systems, including laboratory and automated environments. Table 3 provides an overview of the primary applications for StabilityPlus and StabilityPlus Low Profile cable assemblies.

StabilityPlus	StabilityPlus Low Profile
Designed for high-performance measurement applications requiring stable phase and amplitude behavior under flexure, with configurations extending to very high frequencies, including applications up to 110 GHz depending on configuration.	Designed for applications where electrical stability must be combined with compact size and reduced physical footprint, with configurations available to 67 GHz depending on configuration.

Table 3. Comparison of StabilityPlus and StabilityPlus Low Profile cable assemblies.

Together, these cable families address applications ranging from conventional VNA characterization to high-density PXI/PXIe and switch-matrix architectures for high-speed characterization, as illustrated in Figure 2.

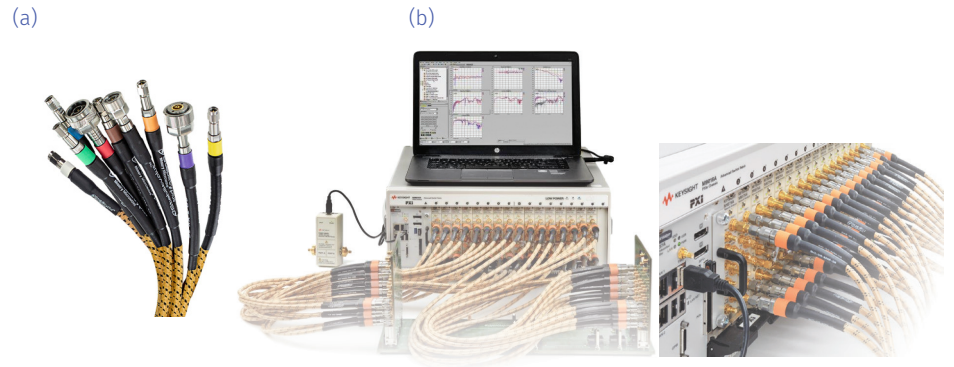


Figure 2. StabilityPlus cable assemblies (a) and their use in a multiport PXI VNA system (b).

Creating a Stable Measurement Environment

High-speed measurement accuracy depends on the performance of the complete measurement path and not solely on the instrument. RF cable assemblies influence the amplitude, phase, timing, and balance of signals traveling between the measurement instrument and DUT. In differential measurements, these effects can be especially significant because the measurement depends on the relative behavior of multiple signal paths.

Cable movement after calibration can introduce variations that may be mistakenly attributed to the DUT. Phase instability can influence group-delay measurements and differential phase, amplitude instability can affect insertion-loss measurements, and path mismatch can influence mixed-mode parameters and mode-conversion measurements. As measurement frequencies extend into the millimeter-wave range and data rates progress toward and beyond 100 Gb/s, the physical behavior of the measurement interconnect has a greater impact on results.

In demanding high-speed and RF characterization environments, stable RF cable assemblies such as Maury StabilityPlus and StabilityPlus Low Profile can help reduce cable-induced variations and support more consistent, repeatable measurements. RF cable assemblies should be considered part of the measurement path rather than simply a connection between the instrument and DUT. Ultimately, a measurement is only as stable as the measurement path that carries the signal.



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