APPLICATION NOTE

Benefits of De-embedding and Match-Corrected Measurements

KEYSIGHT

Introduction

Wireless communication technologies are continuously evolving to meet the demands of ever-advancing technology. In wireless communication, increasing signal bandwidth, higher-order modulation and spatial multiplexing enable faster data rates. The user experience must keep pace with these faster data rates. Quality-of-service expectations from users require wireless systems to deliver predictable system-level performance. As wireless designs move from simulation to testing, driving down uncertainty is crucial to successful product development.

Minimizing Uncertainty in Measurement Setups

A fundamental aspect of verifying wireless designs is measurement, which enables characterization of a device under test (DUT). The goal is to isolate and measure the DUT itself, but this is not always straightforward in practice. Measurement setups have test fixtures, ranging from simple cables to complex fixtures including splitters, couplers, and signal conditioning. Designers want to measure the performance of the DUT, excluding the impact of the test fixtures.

One common measurement setup utilizes signal generators and signal analyzers for evaluating performance of a DUT. In this measurement setup, isolating the DUT requires delivering a known signal to the measurement plane. Delivering a known signal to the measurement plane allows a user to:

- Reliably compare different DUTs
- Ensure repeatability and reproducibility of measurement results across the design flow from modeling to R&D to design verification to production
- Ensure repeatability and reproducibility between different test stations in the same stage of the design flow
- Minimize measurement uncertainties to enable tighter limit lines

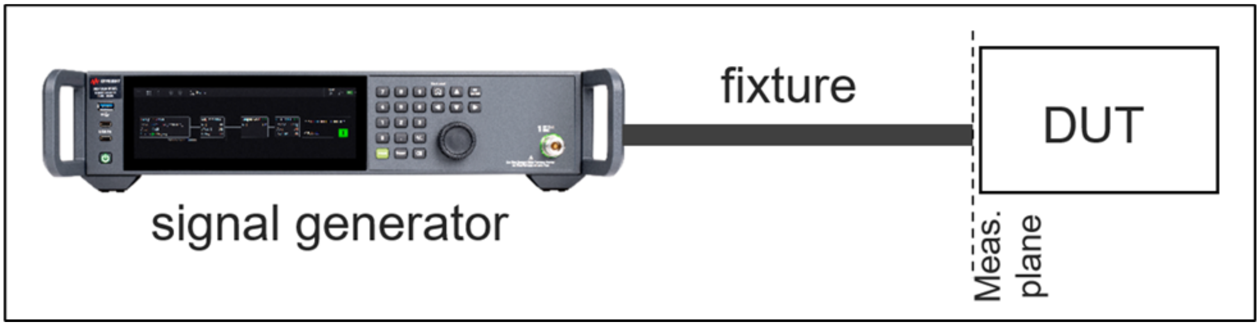

Figure 1. A signal generator delivers an incident signal to the DUT through a fixture.

Defining incident wave and reflected wave

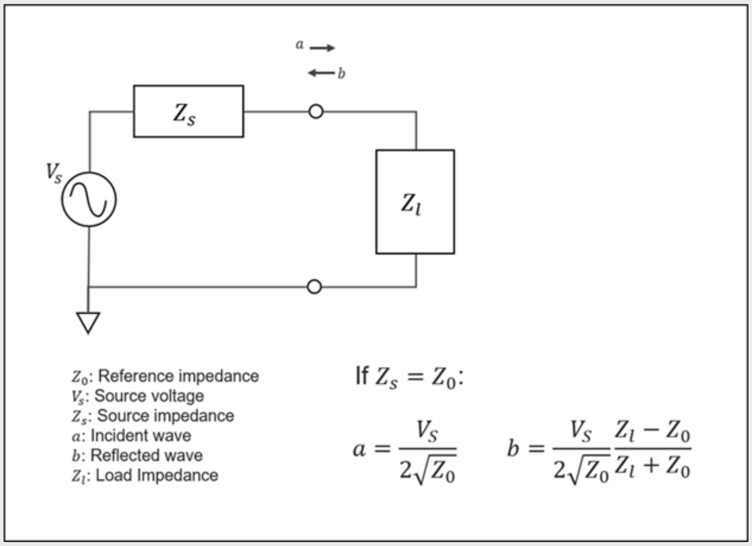

Figure 2. Definition of reference impedance (Z_0) and illustration of interactions between incident wave and reflected waves.

In practice, the test fixture contributes error to the measurement. The primary sources of error are:

- Path loss through the test fixture, resulting in power at the measurement plane being lower than the set power from the signal generator
- Error due to reflected waves in the transmission line resulting from impedance mismatch at the DUT (e.g., $Z_l \neq Z_0$)
- Error due to reflected waves in the transmission line resulting from impedance mismatch at the source (e.g., $Z_S \neq Z_0$)

The combination of these errors often appears as ripple in frequency response.

Impact of Path Loss on Measurement Results

Path loss is a well-understood challenge and must be managed. Signal energy is lost along the transmission path resulting in decreased power delivered at the measurement plane compared to what is generated at the output of the signal generator.

Path loss can be compensated with Auto Level Control (ALC) or de-embedding or a combination of both. ALC, implemented in the architecture of traditional signal generators, compensates for path loss through the fixture to deliver set power at the reference plane.

Traditional ALC works best when either the DUT or test system impedance mismatch is minimized (e.g., equal to Z_0). To improve the match, attenuation is often added (ex. 3 dB pad).

De-embedding, removing the systematic errors associated with test fixtures, is a common procedure where .S2P files from a vector network analyzer (VNA) are imported into the signal generator. The precise characterization from the VNA enables the signal generator to compensate for path loss and deliver set power to the measurement plane.

These corrections, used individually or in combination, result in delivery of set power to the measurement plane.

Impact of Frequency Response on Measurement Results

Frequency response is the measure of the magnitude and phase of the output signal as a function of input frequency. Errors may appear as ripple in the frequency response. When frequency response across a given bandwidth is not flat, it alters both the magnitude and phase of signals at the DUT input. Wider bandwidths are especially susceptible to impairments from frequency response, even at RF frequencies. In addition to the noise inherent in the physical world, any error in frequency response across the instantaneous bandwidth adds an impairment at the output of the DUT, which, if it cannot be separated out of the measurement result, gives the appearance of degraded DUT performance.

As noted above, errors from impedance mismatch may appear as ripple in frequency response. The complexity of correcting impedance mismatch is multiplied when multiple DUTs and multiple test systems are in use. Therefore, if you test a DUT with different test systems, this will produce different measurement results and challenges for reproducibility. Reproducibility across different test systems can be achieved by correcting impedance mismatches. This may be especially important for design verification and manufacturing, where multiple test stations are typically in use.

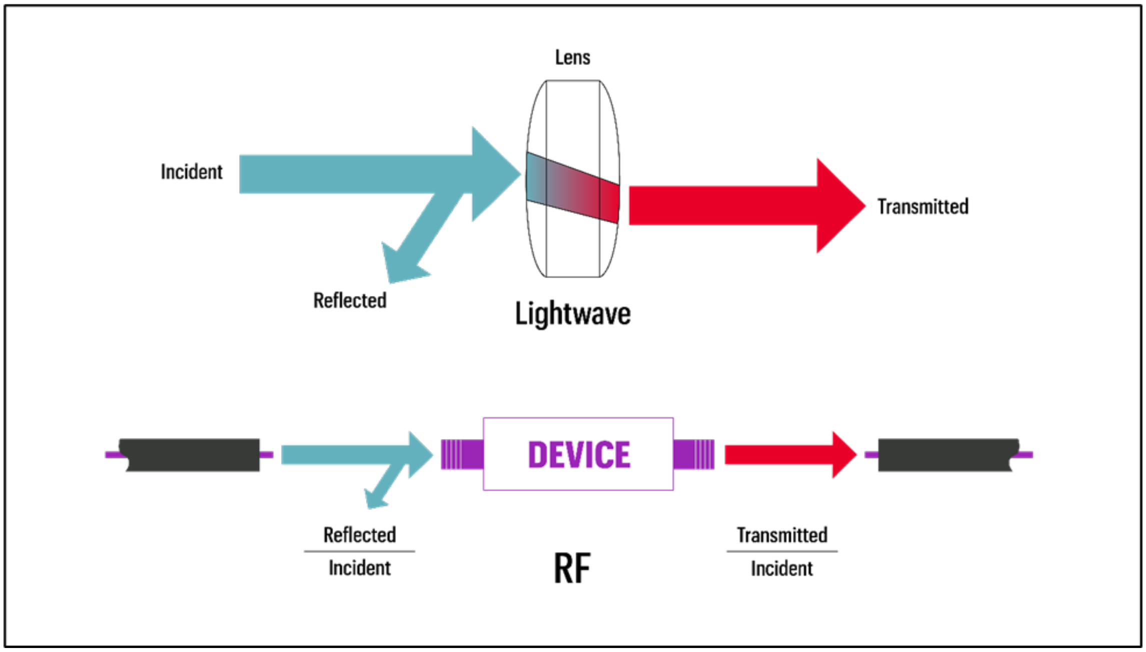

Figure 3. Some signal energy is reflected due to impedance mismatch.

Errors from impedance mismatch occur on both ends of the measurement setup. Errors due to impedance mismatch result in reflected waves interacting with the incident signal. This error is not corrected by either de-embedding or ALC. If the impedance match at the measurement plane does not equal Z_0, then the reflected wave (b) returns to the signal generator. If the impedance match at the signal generator does not equal Z_0, then re-reflection from the signal generator is added to the incident signal (a). The elimination of ripple in the incident signal requires impedance mismatch correction.

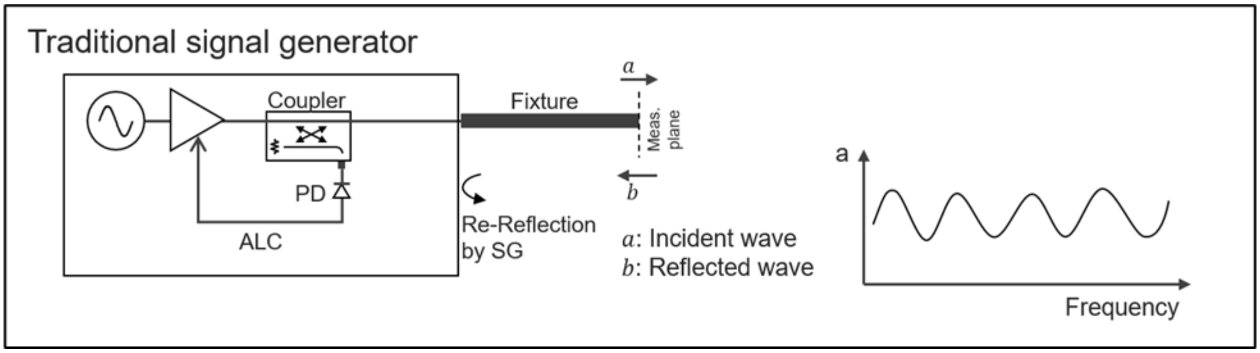

Figure 4. Re-reflection along the signal path results in added ripple in the incident wave (a wave). However, the a wave can have ripples due to interaction of the generated signal and re-reflection from the signal generator. This a wave ripple cannot be measured directly without a reflectometer.

Impedance mismatch is typically corrected with the use of a reflectometer. Vector network analyzer users will be familiar with the embedded reflectometer in the VNA architecture which enables match corrected signal generation at the reference plane. For signal generator and signal analyzer measurement setups, external reflectometers are commercially available, but the complexity of implementing corrections results in infrequent use.

An embedded reflectometer measures both the incident wave (a) and reflected wave (b) using a pair of directional couplers. As shown in Figure 2, if we can measure b, then we can calculate the correction for a to deliver both the desired power level at the measurement plane and remove ripple. Modifying the output level of the source so the incident power at the measurement plane is at the desired level without undesirable effects (e.g. no ripple).

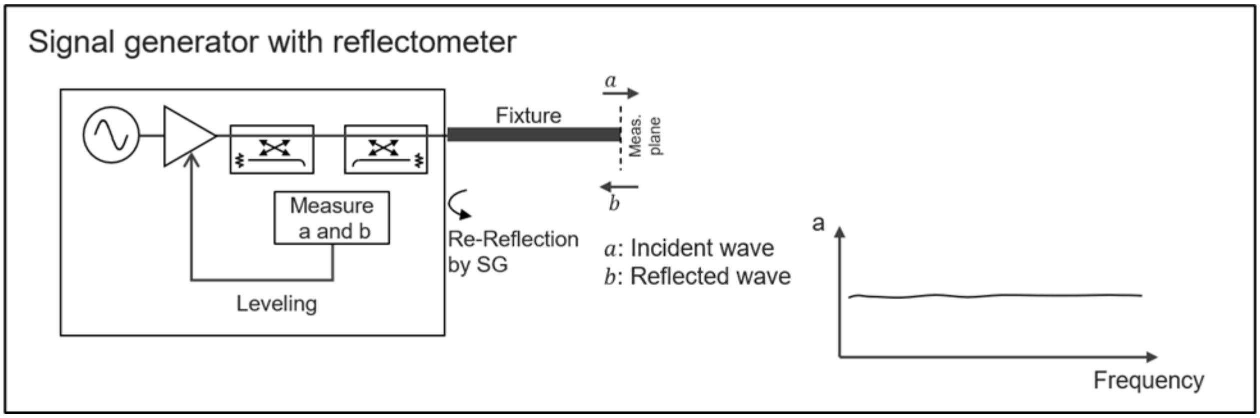

Figure 5. With an embedded reflectometer, users can measure a and b at the measurement plane. Then correct the a wave to be at the desired level.

Today, measurement setups using signal generators and signal analyzers regularly utilize path loss correction and de-embedding. With the addition of an embedded reflectometer, match corrected signal generation is possible. The combination of these allows users to de-embed the combination of signal generator + test fixture + impedance mismatch across the frequencies of interest. However, most signal generators and signal analyzers setups are not using match-corrected signal generation due to the complexity of calculating this correction.

The N5186A MXG is the world's first signal generator to feature an embedded reflectometer, which enables in-situ generation of a match corrected signal incident to current load with a single button press. This feature improves measurement results without the need for padding and the corresponding impact on system performance. In addition, the N5186A can import S2P files from a VNA with the PathWave Signal Generation De-Embedding Software to extend the calibration plane closer to the DUT input. The combination enables users to improve the accuracy of the test result by removing fixture and mismatch interaction between the test system and DUT.

Conclusion

The combination of VNAs, external reflectometers and the expertise to generate and apply the corrections can help in measurement setups, but it can be complex to do this in-situ. One innovative solution to this challenge is the incorporation of a reflectometer directly into the signal generator. This integrated approach enables in-situ generation of a match corrected signal incident to current load with a single button press. The inclusion of an embedded reflectometer in the N5186A MXG vector signal generator demonstrates Keysight's commitment to improving measurement accuracy.

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