

Skyworks De-embedded Scattering Parameters

Introduction

An integral part of modern RF/microwave circuit design is circuit simulation and evaluation in which scattering parameters (S-parameters) for each element of a system are utilized to predict the overall small signal performance as the elements are cascaded to form the entire system. The value and effectiveness of these evaluations are directly related to the accuracy of the S-parameters for each component, among other factors. This paper describes the methodology employed by Skyworks to make accurate S-parameter measurements for discrete RF/microwave components.

Measurement of Scattering Parameters

Measurement of S-parameters is typically accomplished with a vector network analyzer (VNA), typically incorporating coaxial transmission media and well-characterized short, open, load and through (SOLT) coaxial calibration standards, most often supplied by the VNA manufacturer. As a result, calibration is usually accomplished only to the ends of the coaxial cables, and not to the reference planes of the device under test, when these calibration standards are utilized.

Most modern RF/microwave components are either surface-mount-packaged devices or discrete chips, which are more compatible with planar geometry transmission media such as microstrip or coplanar waveguide (CPW) printed circuit board transmission lines. In order to measure performance of a device under test (DUT) in an environment which is similar to that in which the component will typically be used, the DUT is generally mounted on a microstrip or coplanar waveguide printed circuit board test fixture. The performance of the printed circuit board appears to alter the performance of the DUT and consequently affects the measured data.

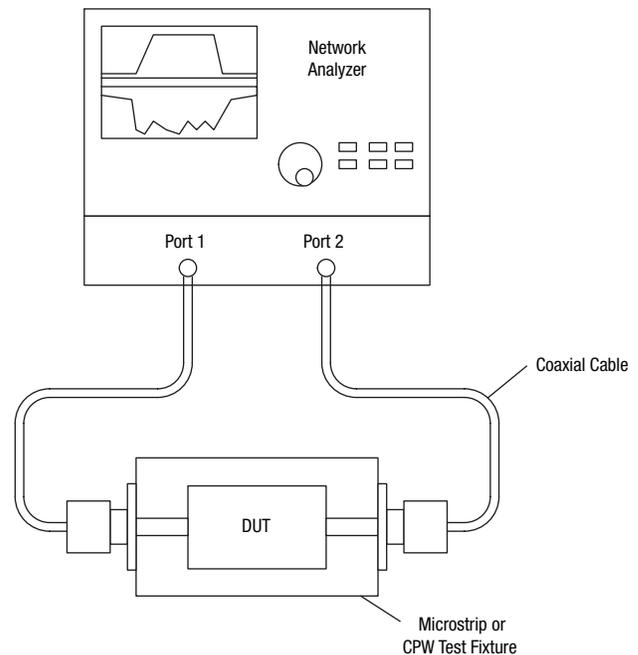


Figure 1. Measurement System for S-Parameters

In order to produce valid S-parameters for the DUT and accurate simulation results, the effects of the test fixture must be removed from the measured data. The process of removal of the test fixture performance effects from measured S-parameter data is known as “de-embedding.” De-embedded S-parameters for Skyworks discrete components are available from www.skyworksinc.com.

The coaxial SOLT calibration standards are in most cases not compatible with the surface-mount test fixturing utilized to characterize devices. It is difficult to design and even more difficult to verify, accurate microstrip or CPW calibration standards for use in the SOLT calibration method, especially the open and short standards. There are better ways to characterize a purpose-built microstrip or CPW test fixture.

Transmission-Reflect-Through Calibration

Skyworks utilizes the through-reflect-line (TRL) calibration method to calibrate the VNA/DUT test fixture system used to make S-parameter measurements. This essentially removes the effects, both phase and magnitude, of the DUT test fixture transmission lines, test fixture coaxial connectors, etc.

The TRL method requires at least three calibration standards:

1. A through transmission line (T) with equal characteristic impedance to that of the VNA and with a short electrical length (defined as zero length);
2. A transmission line terminated at the DUT reference plane with a large reflection coefficient magnitude (R), the exact value of which is not critical, but with reasonably well-known phase
3. A transmission line (L) with equal characteristic impedance to that of the VNA and electrical length which is at least one-quarter wavelength longer than the T line at the center frequency of the band of interest, with a known electrical length.

Measurements made of the performance of these three calibration standards are sufficient to solve the 12-term error model that describes the performance of multiple port VNAs. (Agilent Product Note 8510-8A).

Skyworks characterization test fixtures are designed with transmission lines which are equal in impedance and length on all RF ports of the DUT, and equal in impedance and length to the T standard described above. This allows the reference plane of the VNA measurements to accurately be placed at the terminals of the DUT. Consequently, all S-parameters, and in particular the insertion loss and insertion phase of these transmission lines are accurately “calibrated out” or de-embedded out of the measured S-parameter data a priori.

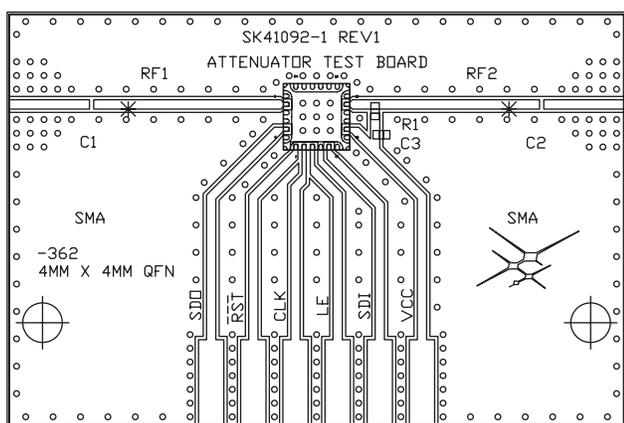


Figure 2. A Typical Skyworks Characterization DUT Test Fixture

A characterization printed circuit board for a two port device packaged in a 4 x 4 mm QFN package is shown in Figure 2. This board has two main RF signal paths, labeled as “RF1” and “RF2.” The remaining signal paths are used for control signals and connection to a power supply. The goal is to remove the effects of the test fixture RF transmission lines in order to obtain the de-embedded S-parameters of the device under test (DUT).

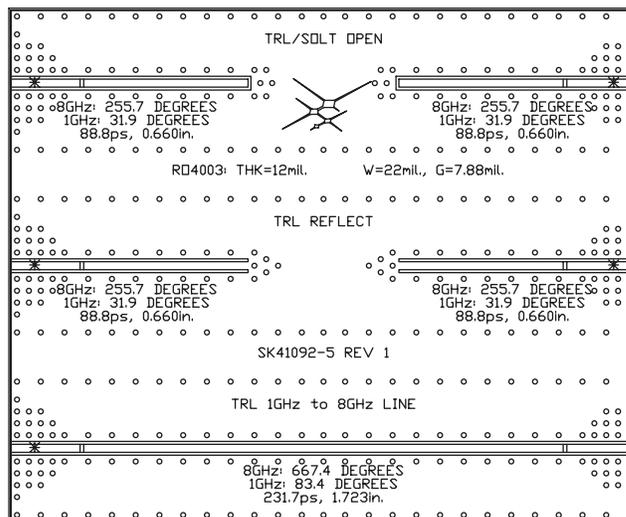


Figure 3. A Typical TRL/SOLT Calibration Standards Fixture

Figure 3 shows an example of a TRL/SOLT standards printed circuit board which was designed to be compatible with the evaluation printed circuit board shown in Figure 2. The board in figure 3 contains a through (T) transmission line and two reflect (R) standards: a pair of identical shorted transmission lines; and, a pair of identical open transmission lines. All of these lines were designed to have the same characteristic impedance as the lines RF1 and RF2 in Figure 2.

Some products, such as PIN diodes, tuning varactor diodes and some amplifiers require the application of bias voltage or current via a DUT RF port to perform their intended function. These signals are applied via the bias tees which are built into the VNA, so any RF performance effects of these bias tees are also inherently calibrated out of the performance measurement.

Other products, such as RF switches, digital attenuators, voltage variable phase shifters, etc., have separate bias and/or power supply terminals which are connected to non-RF traces. Many of these products require DC blocking capacitors or other bias components on their RF ports during operation. Therefore, these components are designed into the characterization printed circuit boards for such parts. Provisions are made in the TRL standards to also include the same DC blocking capacitors in order to remove the bias component performance effects from the DUT/ test fixture measurements.

Limitations of the TRL Calibration Method

The TRL calibration process is valid over a limited bandwidth, which is determined by the characteristics of the L standard. Typically, an L standard gives reasonable performance over an 8:1 bandwidth. Additional L standards are necessary for greater than 8:1 calibration bandwidth. For wide bandwidth, low frequency measurement accuracy, the necessary number of L standards and the physical length of low frequency L standards may limit the practical TRL calibration bandwidth. Most modern VNAs which can employ the TRL calibration method can accept up to 3 L standards, enabling measurements over 512:1 bandwidth, in theory. Fortunately, this bandwidth limitation does not present a problem for the characterization of most Skyworks products over the frequency ranges of interest.

References

Agilent Network Analysis Applying the 8510 TRL Calibration for Non-Coaxial Measurements, product note 8510-8A, <http://cp.literature.agilent.com/litweb/pdf/5091-3645E.pdf>

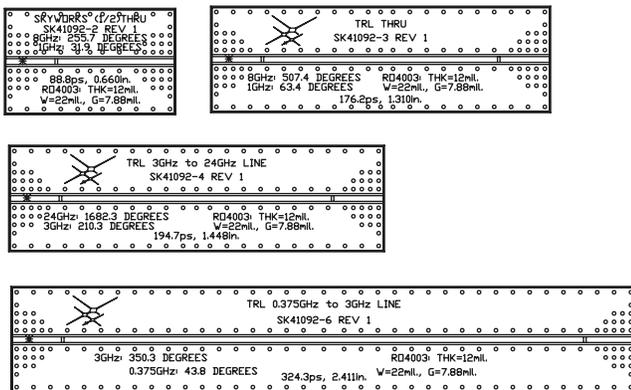


Figure 4. Additional Through Line Calibration Standards

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