Agilent 8510C, 8720ES

Vector Network Analyzer

White Paper

Use Agilent EEsof and an Agilent Technologies Vector Network Analyzer to Simplify Fixture De-embedding

Agilent Technologies
Innovating the HP Way

At RF and microwave frequencies, it becomes difficult to directly measure devices with nonstandard connectors (for example, devices using surface-mount packaging). Often a test fixture is required to transition the network analyzer's coaxial connectors to the non-coaxial environment of the device under test. In this case, the calibration plane is not at the device plane fixture (see Figure 1), and the uncharacterized test fixture introduces a measurement uncertainty. By modeling the test fixture, a calculation can be performed to remove the effects of this transition. The fixture *de-embedding* procedure can result in very accurate measurements for the non-coaxial device under test without the need for complex test fixtures and non-coaxial calibration standards.

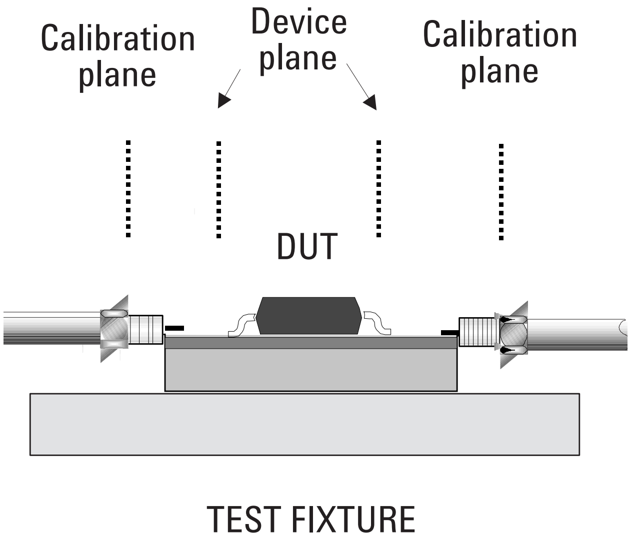
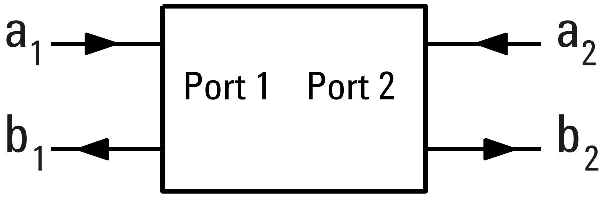


Figure 1. Measurement configuration of the non-coaxial device and test fixture

Fixture de-embedding using scattering transfer parameters

RF and microwave two port network parameters are often characterized using scattering or S-parameters. The S-parameters are defined using the reflected or emanating waves, b_1 and b_2, as the dependent variables and the incident waves, a_1 and a_2, as the independent variables[1] (see Figure 2).



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

Figure 2. Two-port network defined using S-parameters

In this way, the S-parameters of the network can be directly measured without the need for terminating the device in undesirable loads. For example, to determine S11, you measure the ratio b1/a1 at port 1 of the network with the output port 2 terminated in a perfect Z_0, in this case, a2=0. In practice, it may be difficult to terminate the network in an ideal Z_0 but using a vector network analyzer, such as the Agilent Technologies 8510C and 8720ES, you can calibrate the test system to mathematically create the ideal Z_0 load at the ports. The problem occurs when a test fixture is placed between the calibration plane and the device under test. The text fixture generally does not place an ideal Z_0 on the ports of the device and as a result, errors are introduced into the measurement because of undesired reflected signals. For the example above, to accurately measure S11, we need to make a2=0, but if the test fixture is not an ideal Z_0 then reflections from the fixture are combined into the measurement and an error occurs. If we create a mathematical model of the test fixture, the errors introduced are removed from the measurement of all four S-parameters of the device under test. Note that the process of calibrating a vector network analyzer improves the load seen by the device and corrects a total of twelve errors that occur in the measurement system[2].

The scattering parameters of a network give a clear and meaningful physical interpretation of the transmission and reflection performance of the device. They also form a set of parameters that are used with signal flow graphs. Signal flow graphs are a way of writing a set of equations where the variables are points and the interrelations are given by directed lines. The flow graph of a system of cascaded networks are constructed by simply joining the flow graphs of individual networks[3]. Figure 3 shows the cascaded signal flow graph for the device including a test fixture placed between the calibration plane and the device plane. It is assumed the characteristics of the two fixture networks have been previously determined empirically or through modeling. S-parameters measurements and algebra are used to solve for the unknown device under test but, mathematically, it is found more convenient to perform the fixture de-embedding using scattering transfer parameters or T-parameters.

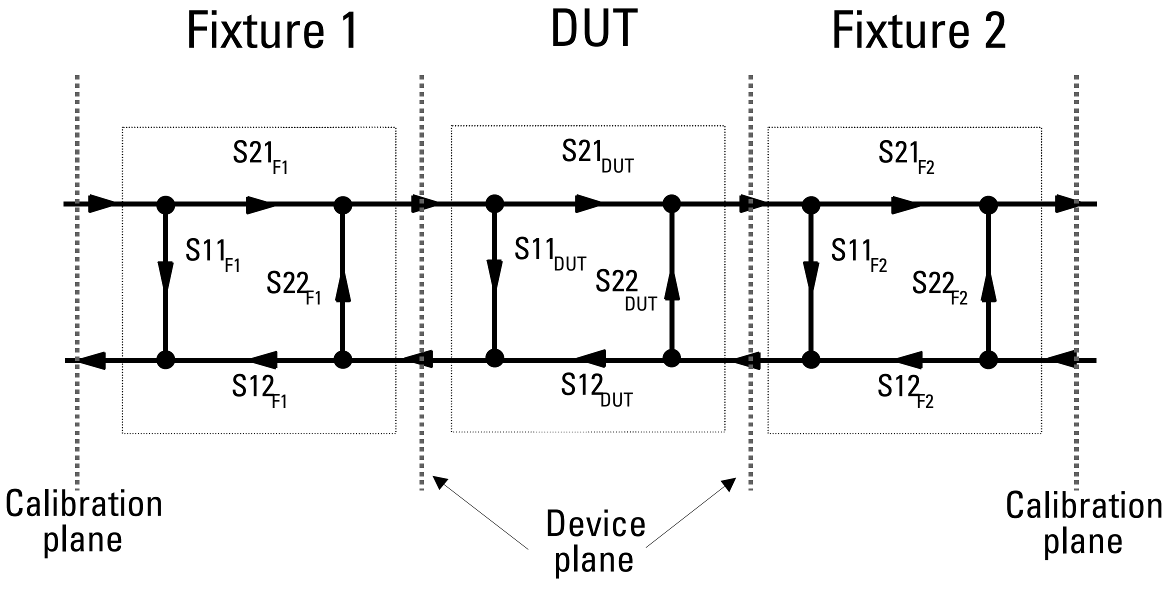
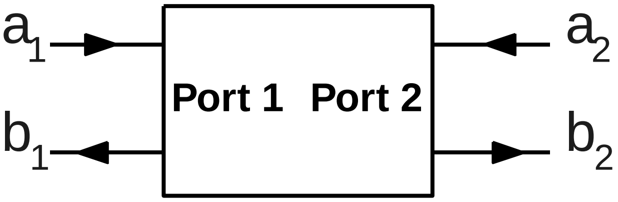


Figure 3. Cascaded signal flow graph of the DUT and test fixture

To determine the T-parameters of a two-port network, rearrange the incident and reflected waves so the dependent waves are related to port 1 of the network and the independent waves are a function of port 2. In this case, the dependent waves are a1 and b1, and the independent waves are a2 and b2 (see Figure 4). The relationship between the S-parameters and T-parameters are shown in Figure 5.



$$\begin{bmatrix} b_1 \\ a_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} a_2 \\ b_2 \end{bmatrix}$$

Figure 4. Two-port network defined using T-parameters

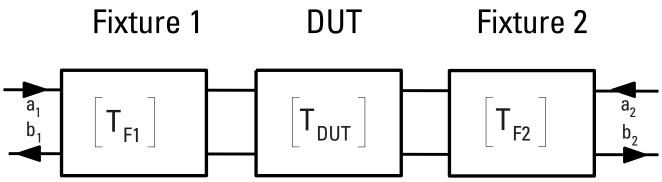
$$\begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} = \begin{bmatrix} -\dfrac{S_{11}S_{22}-S_{12}S_{21}}{S_{21}} & \dfrac{S_{11}}{S_{21}} \\ -\dfrac{S_{22}}{S_{21}} & \dfrac{1}{S_{21}} \end{bmatrix}$$

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} \dfrac{T_{12}}{T_{22}} & -\dfrac{T_{11}T_{22}-T_{12}T_{21}}{T_{22}} \\ \dfrac{1}{T_{22}} & -\dfrac{T_{21}}{T_{22}} \end{bmatrix}$$

Figure 5. Mathmatical relationships between S-parameters and T-parameters

When cascading a series of two-port networks, the output waves of one network are identical to the input waves of the next. In other words, when using T-parameter definitions of the cascaded networks, the total network can be characterized by the multiplication of individual T-parameter networks (see Figure 6).

To de-embed the T-parameters of the device placed between the two sections of a test fixture, begin by measuring the S-parameters of the complete network at the calibration plane. Then convert the measured S-parameters to T-parameters. Using the known T-parameters of the test fixture, it is possible to mathematically determine the T-parameters of the device under test. Finally, converting the T-parameters back to the S-parameters, we are left with the de-embedded S-parameters of the device. Fortunately much of the tedious mathematics for this process is eliminated using the Agilent EEsof tools and a vector network analyzer, such as the 8510C and 8720ES.



$$[T] = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}$$

$$[T_M] = [T_{F1}][T_{DUT}][T_{F2}]$$

$$[T_{DUT}] = [T_{F1}]^{-1}[T_M][T_{F2}]^{-1}$$

Figure 6. Matrix Multiplication of cascaded T-parameter networks

S-parameter data shared between software and hardware

By using the EEsof Advanced Design System (ADS) in conjunction with the 8510C and 8720ES vector network analyzers (VNAs), the test fixture effects from the measurement are easily removed. EEsof ADS allows direct connection of the software environment to the network analyzer hardware over the GPIB interface. This direct connection allows S-parameter data to be shared between the software simulation and the measurement equipment (see Figure 7). After developing a model of the test fixture either through empirical measurements or computer modeling on ADS, the actual measurement of the device, including the test fixture, is directly transferred into the simulation for de-embedding. Using the fixture model, ADS mathematically removes the test fixture effects from the actual measurement, and the corrected device data is displayed on the ADS screen or placed back into the network analyzer for viewing.

ADS implements a two-port de-embedding model that is used to negate the effects of its S-parameters from the total S-parameter simulation. For two-port devices, the test fixture is modeled in two parts: One, for each side of the coaxial-to-non-coaxial transition where the test fixture is not required to have two symmetrical sides. Two, by placing two de-embed models on each side of the measured dataset, where the fixture effects can be easily removed by the simulation.

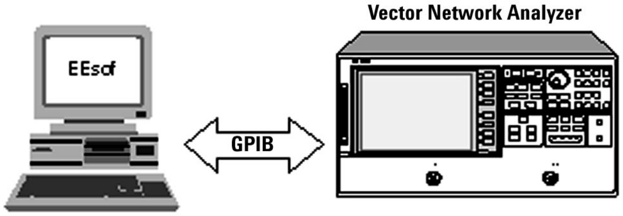


Figure 7. Configuration for direct transfer of S-parameter data between the network analyzer and Agilent EEsof ADS software

Figure 8 shows the three blocks required to perform the de-embedding calculation. The first two-port Deembed2 component holds the S-parameter dataset for the left-hand side of the text fixture. Similarly, the second Deembed2 component contains the S-parameter information for the right-hand side of the fixture. The center S2P component contains the measured S-parameter dataset transferred from the network analyzer. This dataset holds the complete measurement of both the device and test fixture. The two term components terminate the simulation in the characteristic impedance of the system, which is nominally 50 ohms. Before the measured data is transferred to ADS, the network analyzer is calibrated with a standard coaxial calibration kit, and the device and test fixture are measured using a full two-port calibration. The ADS software uses the instrument server function to obtain the measured dataset directly from the network analyzer, and temporarily stores this data to a file for use by the simulation. The instrument server can read and write datasets to a variety of Agilent test equipment and files. After the measurement is read from the network analyzer and stored as an S-parameter file, the ADS S-parameter simulation can be run over the frequency range of interest. The de-embedded measurement of the device is then available for display within ADS or can be transferred back to the network analyzer through the instrument server.

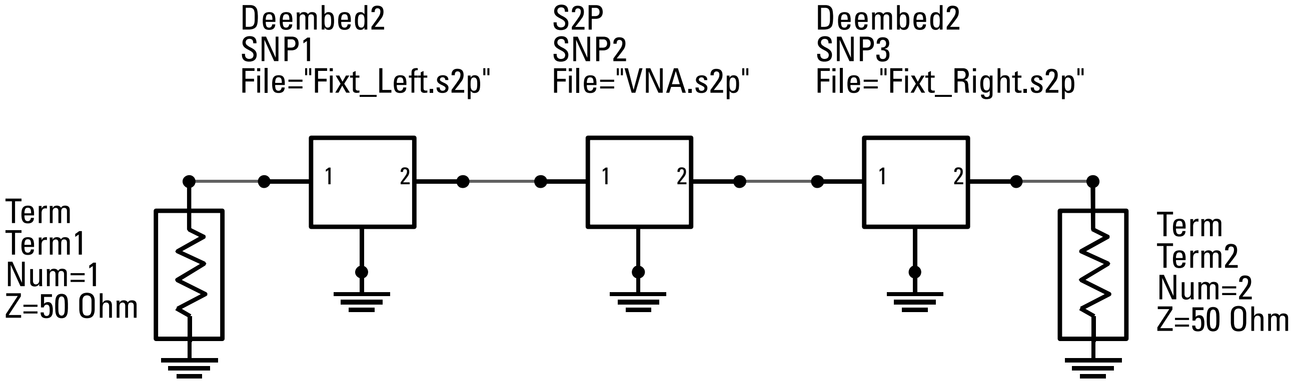


Figure 8. ADS circuit diagram for test fixture de-embedding

De-embedding a PCS amplifier

As an example, let's look at the de-embedded measurement of a surface-mount PCS amplifier using ADS and the 8720ES vector network analyzer. Figure 9 shows the data before and after the test fixture has been de-embedded. As shown in Figure 9, before de-embedding, the overall amplifier gain is lower due to the additional insertion loss of the coax-to-microstrip test fixture. Also, the uncorrected gain is lower at the band edges due to mismatch interaction between the test fixture and the amplifier. Once the fixture is de-embedded from the measurement, the amplifier gain shows the specified performance across the full operating bandwidth.

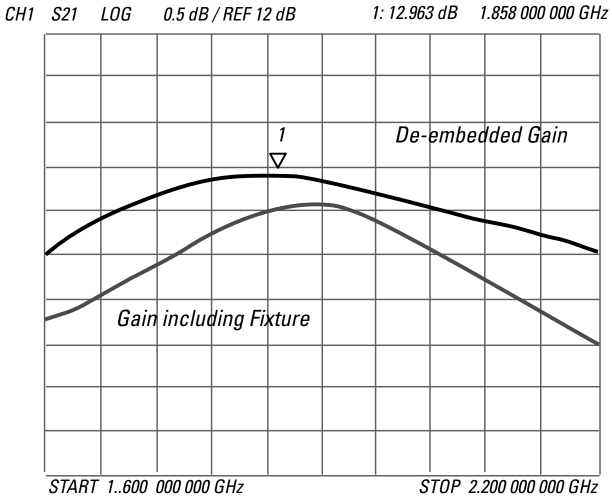


Figure 9. PCS amplifier gain showing the effects of fixtured de-embedding

References

1. "S Parameter Design," Agilent Technologies Application Note 154, April 1972.
2. "Applying Error Correction to Network Analyzer Measurements," Agilent Technologies Application Note 1287-3, May 1997.
3. J.K. Hunton, "Analysis of Microwave Measurement Techniques by Means of Signal Flow Graphs," IRE Transactions on Microwave Theory and Techniques, Vol. 6, MTT-8, No. 2, March 1960.

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