Compensation Technique Improves Measurements for a Range of Mechanically Compatible Connectors

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Introduction

As the need to make accurate measurements at greater microwave frequencies grew, a new type of connector to make these measurements was needed. The 3.5 mm precision connector evolved to meet this need and is now regularly used on network analyzer test ports. These precision connectors, in conjunction with good quality calibration kits, provide an interface that supports high quality measurement up to 26.5 GHz.

For many applications, the devices or components to be measured have SMA or 2.92 mm connectors, because they are easier to make and less costly, while meeting the specifications for the devices. Although the 3.5 mm connectors mechanically interface with SMA and 2.92 mm without the need of an adapter, there is a discontinuity at the interface that needs to be resolved. The discontinuity, shown in Figure 1, results in degraded effective directivity and port match (similar to the effect introduced by an adapter) and reduced measurement accuracy.

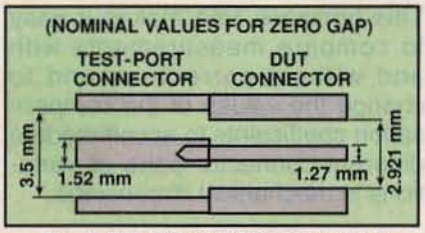

Fig. 1 The discontinuity of the 3.5 to 2.92 mm connector interface.

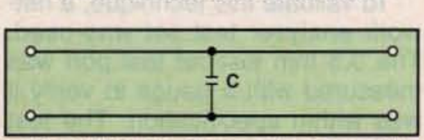

Fig. 2 The shunt susceptance model of the connector interface.

A connector compensation technique is available to minimize the effect of this connector discontinuity and improve measurement accuracy. The technique is applicable to 3.5 mm/SMA, 3.5 mm/2.92 mm connections, and to other connector families that are dissimilar yet mechanically compatible, such as 2.92 mm/SMA and 2.4 mm/1.85 mm.

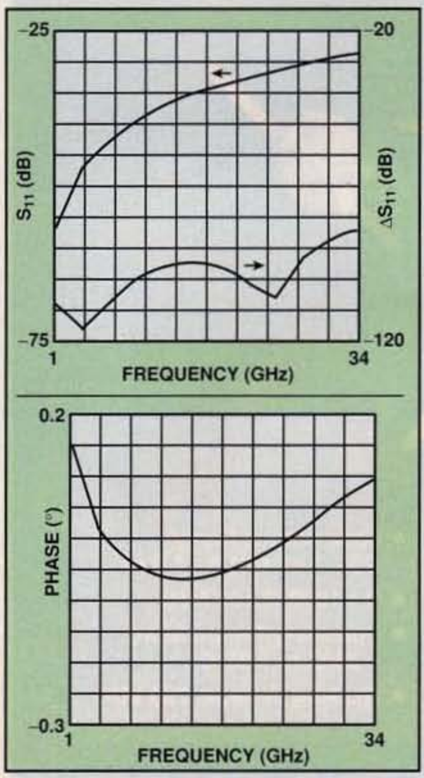

Fig. 3 The calculated values and optimized model of the 3.5 to 2.92 mm connector interface discontinuity.

Connector Compensation Technique

This connector compensation technique assumes that the discontinuity at the interface is abrupt and that the transmission lines on either side of the discontinuity have a characteristic impedance of 50 Ω. With these assumptions, the discontinuity can be modeled reliably as a single shunt susceptance,[1] as shown in Figure 2, where $C = C_0 + C_1f + C_2f^2 + C_3f^3$. There is invariably a gap in the center conductor of a mated pair of connectors due to the pin setback, which is necessary to ensure reliable mechanical connection with realistic mechanical tolerances. Calibration standards and test ports are usually designed to approach zero center conductor setback with the inner and outer conductors at the same plane. After calibration, a test port connector with zero setback has inner and outer conductors that are electrically flush. It is assumed that any center conductor gap will be measured as part of the device under test (DUT).

In this technique, a CAE finite element solver[2] is used to determine the S-parameters, providing a model for the connector interface. A susceptance model is optimized that best fits the finite element data. The resulting values are then used to compensate the corresponding connector pair. Figure 3 shows the calculated and modeled traces for a 3.5 mm to 2.92 mm airline interface and the difference between the vectors and phases for S_{11}. The vectors agree within –80 dB and 1°.

Similar calculation and modeling was done to determine the capacitance coefficients for several connector combinations, as listed in Table 1. These calculations were based on the nominal dimensions specified by the IEEE standard[3] for the connector types. If connector dimensions meet those nominal dimensions, these values can be used in the polynomial series capacitance equation. If not, recalculation for any changes in the dimensions from the nominal values will be necessary.

TABLE I

CAPACITANCE COEFFICIENTS

Connector Combination	C_0 (fF)	C_1 (aF/GHz)	C_2 (aF/GHz^2)	C_3 (aF/GHz^3)
3.5 mm/2.92 mm	6.956	–1.026	–0.014	0.0028
3.5 mm/SMA	5.959	–11.195	0.508	–0.0024
2.92 mm/SMA	13.420	–1.945	0.546	0.0159
2.4 mm/1.85 mm	8.984	–13.992	0.324	–0.0011

With the interface discontinuity calculation and modeling complete, it is a straightforward procedure to apply the compensation to a vector network analyzer measurement. The network analyzer is calibrated over the frequency range of interest at the test port (or ports) and stored as a calibration set. It is not necessary for both test ports to employ the same connector type. Any connector that can be mated to the DUT will suffice as long as a calibration kit is available that matches the test-port connector type. The error correction coefficients are modified to include the appropriate discontinuity model for the DUT connector. Then, the modified error correction coefficients are stored as a separate calibration set, and the device to be tested is connected and measured using the modified calibration set.

By switching between calibration sets, it is easy to evaluate the effect of the compensation. The effects of the center conductor gap can also be included in the error correction coefficients, although this will give an artificially optimistic measurement of the DUT's performance.

This connector compensation technique is included in the operating firmware of the latest network analyzer (revision 7.0) and can be applied with the touch of a button. This firmware also makes it easy to compare measurements with and without correction, and to change the values of the compensation coefficients to accommodate different connector pairs or variations in mechanical dimensions.

Measurement Results

To validate this technique, a network analyzer test set was used. The 3.5 mm test-set test port was measured with a gauge to verify it was within specification. The test

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port was calibrated in the usual way with good quality standards, a sliding load, and short and open circuits. Then the calibration was verified with a 3.5 mm airline.

Figure 4 shows the results of connecting a 2.92 mm airline/load combination with the 3.5 mm test port. By implementing the compensation technique, an improvement of about 10 dB is achieved, although a ripple remains, as seen in the time-domain response in Figure 5. This ripple is due to the mismatch of the load element.

Similar behavior occurs with a calibrated, exactly flush, 2.4 mm test port when measuring a 1.85 mm airline terminated with a fixed load, as shown in Figure 6. The performance improvement achieved with compensation becomes evident where the return loss of the airline/load combination is below –30 dB up to 50 GHz over the entire frequency range. Interesting insights are gained from examining the time-domain transformations of the data. As shown in Figure 7, without compensation, the return loss of the interface discontinuity dominates the response; with compensation, the connector-interface effect is reduced by nearly 30 dB, and because of the quali-

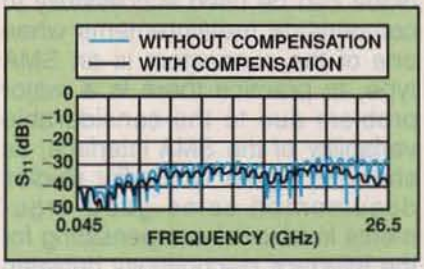

Fig. 4 The frequency domain measurements of a 3.5 to 2.92 mm connector interface.

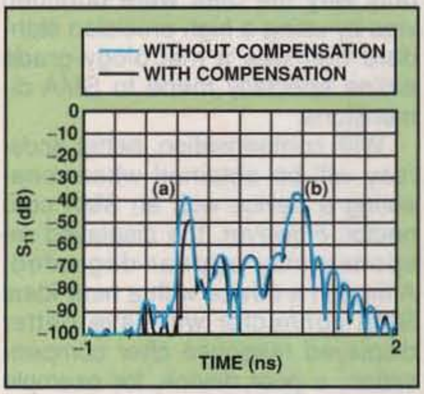

Fig. 5 The time domain measurements of a 3.5 to 2.92 mm connector interface; (a) the step interface and (b) the load.

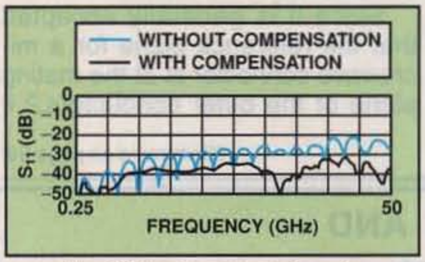

Fig. 6 The frequency domain measurements on a 2.4 to 1.85 mm connector interface.

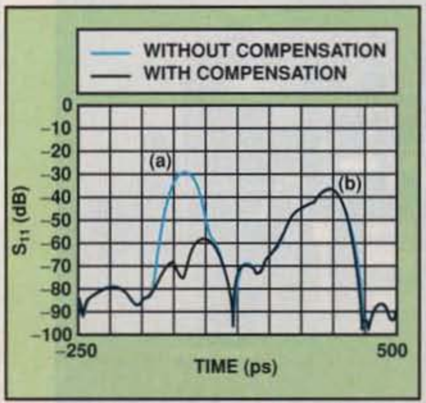

Fig. 7 The time domain (bandpass) measurements of a 2.4 to 1.85 mm connector interface; (a) the step interface and (b) the load.

ty of the airline, the response of the load is displayed. As shown in Figure 8, the impulse response[4,5] clearly demonstrates that the interface discontinuity is purely capacitive and completely removed by the compensation.

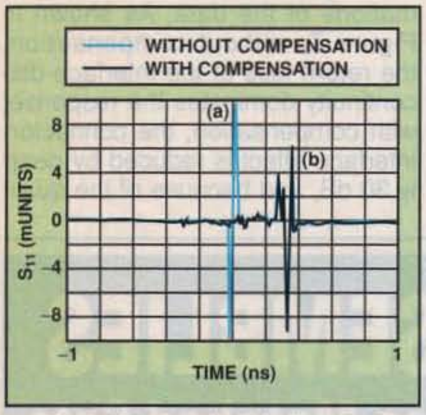

Fig. 8 The time domain (impulse) measurements of a 2.4 to 1.85 mm connector; (a) the test port and (b) the load.

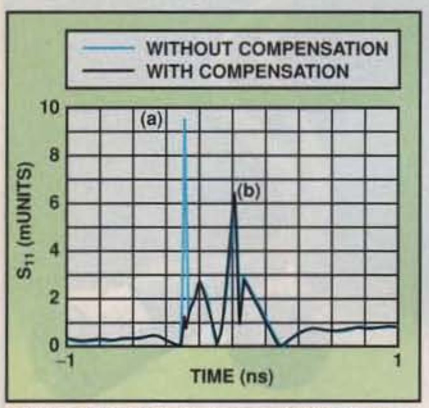

Fig. 9 The effect of a 0.0005" test port center-pin setback on the time domain response; (a) step interface and (b) the load.

In Figure 9, the step time-domain response shows that a small residual bump remains in the corrected response, which is due to the 0.0005" center conductor setback of the test port, that is the inner and outer conductors are not at the same plane.

In Figure 10, by removing the response of the load using a gate in the time domain, the effect of the compensation on the test port return loss can be demonstrated. By examining this series of plots, the effects on measurement accuracy that the interface discontinuity causes and connector compensation minimizes can be more clearly understood.

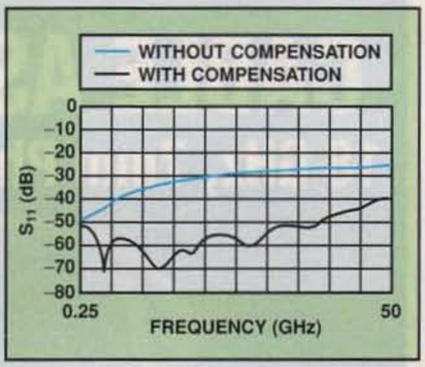

Fig. 10 The frequency domain response after the load effect was removed by gating.

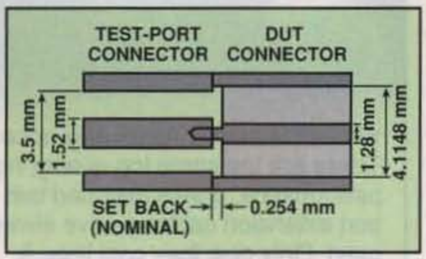

Fig. 11 An APC-3.5 to SMA interface.

The SMA Problem

Although the described technique can be used successfully to compensate measurements when one of the connectors is an SMA type, in practice there is a major problem due to the considerable variability of the SMA interface, as shown in Figure 11. Earlier studies documented some good arguments in favor of compensating for the interface discontinuity between SMA and other mechanically compatible connectors.[6] However, the only way the data were obtained was by using a high precision standard that was a metrology-grade airline specially made to SMA dimensions.

With compensation, better accuracy will be obtained when measuring a device with an SMA connector. However, the displayed response may appear degraded. Although a device with a near-ideal SMA connector will have better displayed response after compensation, a poor device, for example a device with a large conductor-pin setback, will seem worse after compensation.

Since it is generally accepted that the reference plane for a microwave connector is at the mating plane of the outer conductors,[3] it

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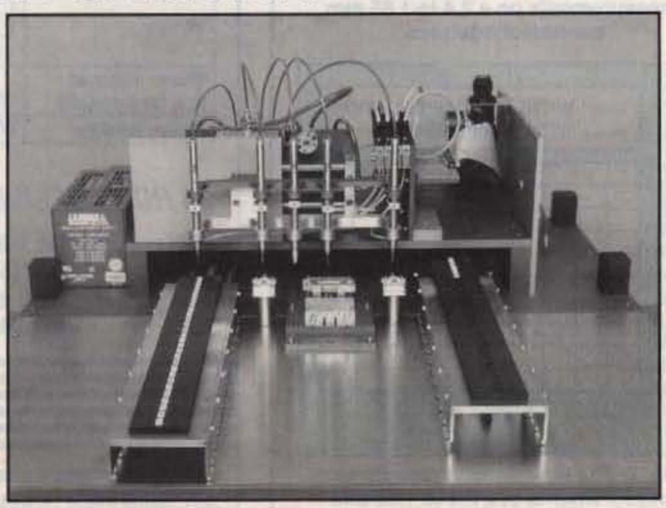

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should be argued that the SMA connector is part of the DUT. Therefore, the effects of the inner conductor setback should not be removed because they are part of the DUT characteristics and best describe how the device will perform in an SMA environment.

Application for On-Wafer Probing

In on-wafer probing, the transition from the probe to the DUT is not typically identical to the transition from the probe to the calibration substrate. The connector compensation technique can be used to absorb the transition discontinuity in the error coefficient (calibration set). The capacitance due to the discontinuity is obtained by a simple measurement procedure carried out on the DUT wafer.

The procedure begins by calibrating the probe tips with a standard calibration substrate (for example, OSLT, LRM). Next a minimal length thru is measured on-wafer with the same transition as the DUT transition; and the electrical delay is set so that the real part of the measured admittance is 20 ms (1/50 Ω) at the highest frequency that is not near any resonances. Finally, the susceptance value B, is read and converted to capacitance ($C = B/2\pi f$) and divided by two to get the capacitance for each transition; and the appropriate capacitance coefficient is modified to the calculated value for the transitions and the compensation procedure is applied.

Conclusion

The use of a single, shunt susceptance has been demonstrated to model accurately the discontinuity at the interface between mechanically compatible connectors. Applying the discontinuity model to vector network analyzer error coefficients will minimize the effect of the discontinuities for many types of transitions, including connectors and probe-to-substrate, and thereby provide a significant improvement in measurement accuracy. The coefficients provided in this article can be used to compensate for 3.5 mm/SMA, 3.5 mm/2.92 mm, 2.92 mm/SMA and 2.4 mm/1.85 mm connector types, or can be optimized for variations in connector dimensions.

Acknowledgment

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