Keysight Technologies

Achieving Higher Measurement Accuracy and Better Correlation for PCB Impedance Test

Application Note

KEYSIGHT TECHNOLOGIES

Overview

As the operating speed of electronic circuits increases, signal integrity of printed circuit boards (PCB) drastically affects system performance. There is an increasing requirement for controlled impedance PCBs. Impedance tolerance becomes tighter from ± 10 % to ± 5% or even less, and impedance measurements with higher accuracy and better correlation are required as a result. Offset error compensation has been used as a standard compensation method for PCB impedance measurements. However, it has become more difficult to achieve the measurement accuracy and correlation required in PCB manufacturing. The result is lower product yield and measurement discrepancy between PCB suppliers and end users.

This application note describes the difficulties with offset error compensation in PCB impedance measurements and how to overcome them using Keysight's ENA series network analyzers with TDR.

- Offset error compensation is inadequate for measurement accuracy and correlation to meet impedance tolerance required today due to the inability to remove errors in measurement systems.
- Preparation and compensation operation can be cumbersome when measuring multiple impedance values because offset error compensation is effective when the impedance range is limited.

Keysight's ENA series network analyzers with TDR measurement features can achieve higher measurement accuracy and better correlation at a wide impedance range by performing full calibration.

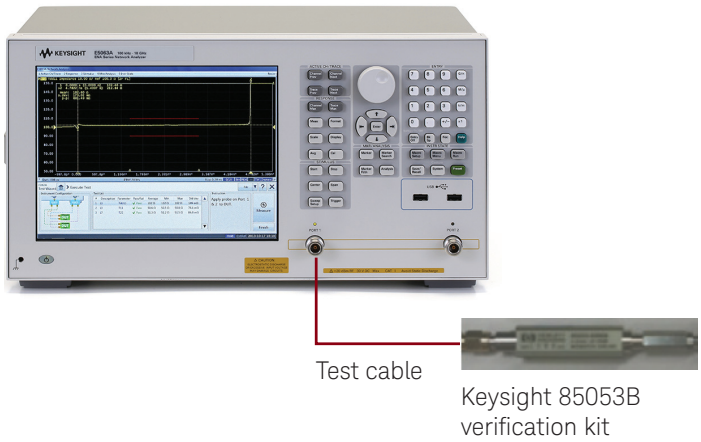

Figure 1. Setup for offset error compensation measurements

Accuracy of Offset Error Compensation

Figure 1 illustrates a measurement setup to perform measurements with offset error compensation. Keysight's 85053B verification kit, which consists of 25 Ω and 50 Ω airlines traceable to National Institute of Standards and Technology (NIST), are measured using Keysight's E5063A PCB analyzer with rise time set at 35 ps. An assessment of the measurement accuracy is performed according to the following procedure.

1. Measure 50 Ω airline to obtain the offset error from 50 Ω
2. Measure 25 Ω airline, apply offset error compensation to the measurement result, and record measurement accuracy from 25 Ω
3. Repeat step 1) and 2) with a different test cable connected and compare measurement results

Figure 2 and 3 shows measurement results for identical 25 Ω airline when two different test cables (A and B) are connected. The measurement values vary because measurement errors were introduced from two different test cables. Offset error in each test cable is measured with identical 50 Ω airline prior to the measurements using 25 Ω airlines. By applying offset error compensation, it is expected to have errors compensated for accurate measurements for both cables. Table 1 is the summary of measurement results with offset error compensation.

	Cable A	Cable B
50 Ω airline	51.4 Ω	50.2 Ω
Offset error	–1.4 Ω	–0.2 Ω
25 Ω airline	27.9 Ω	25.9 Ω
Apply offset	26.5 Ω	25.7 Ω
Error from 25 ohm	+1.5 Ω	+0.7 Ω
% Error from 25 ohm	6.0 %	2.8 %
± 10 % tolerance	PASS	PASS
± 5 % tolerance	FAIL	PASS

Table 1. Results of offset error compensation

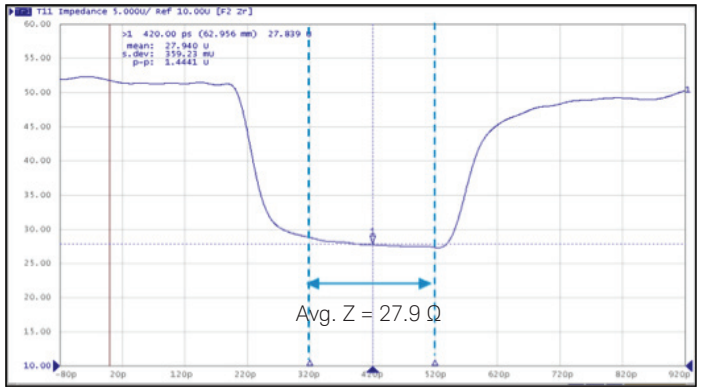

Figure 2. 25 Ω airline (cable A)

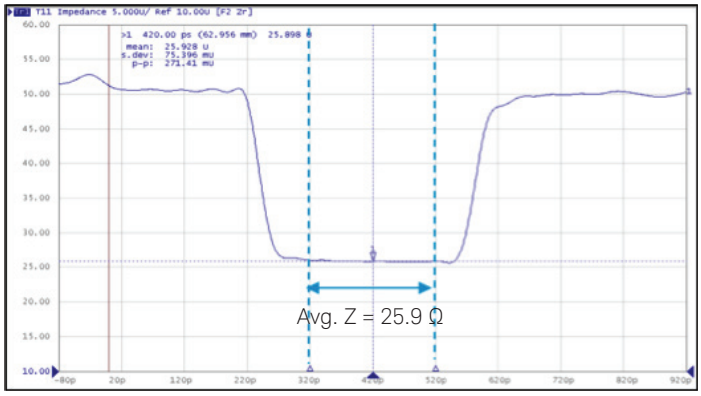

Figure 3. 25 Ω airline (cable B)

As shown in Table 1, measurement results with offset error compensation for cable A and B have a measurement error of 6.0 % and 2.8 % respectively from the 25 Ω airline. Both measurement results pass ± 10 % tolerance, but cable A fails ± 5 % tolerance. Although the measurement result for cable B passes ± 5 % tolerance, this measurement accuracy is not enough to assure guard bands at production for higher yields. More importantly, the measurement discrepancy between cable A and B will require further investigation into the measurement inaccuracy. This is a serious problem that often happens between PCB suppliers and their end users because it can delay product design cycle and time to market.

As bit rate becomes faster, errors in measurement systems such as cables, switches, and fixtures are not ideal. To get the most accurate information about the device under test, errors caused by delay, loss, and mismatch in measurement systems must be taken into account. Offset error compensation cannot remove these errors from measurement systems. In other words, measurement results can include errors from each measurement system to degrade measurement accuracy and correlation. Figures 4 and 5 are examples of insertion loss and rise time measurements for cable A and B. Insertion loss at 20 GHz is > 5.0 dB for cable A and > 1.5 dB for cable B, and rise time is slowed down to 54 ps and 39 ps respectively, although 35 ps is set at the instrument. Without removing errors caused by delay, loss, and mismatch in measurement systems, measurement accuracy is directly affected as shown in Figure 2, 3 and Table 1. Moreover, measurement results can vary between measurement systems which results in poor measurement correlation because errors in measurement systems are usually different from each other as shown in Figures 4 and 5.

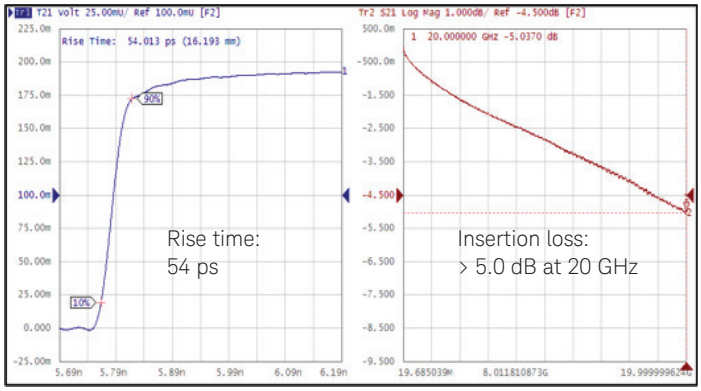

Figure 4. Insertion loss and rise time (cable A)

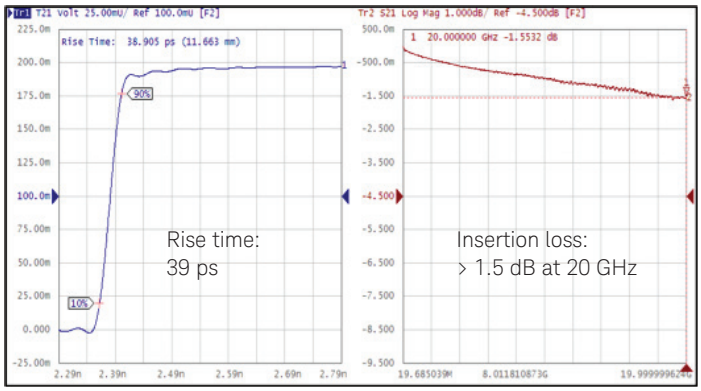

Figure 5. Insertion loss and rise time (cable B)

Full Calibration for Accurate Measurements

Delay, loss, and mismatch in measurement systems can be characterized and removed from measurement results by performing a full calibration. Keysight's ENA series network analyzers with TDR measurement features can help reduce the calibration procedure to a few mouse clicks using the calibration wizard. Figure 6 and 7 are examples of insertion loss and rise time measurement results similar to Figure 4 and 5 but after performing a full calibration with N4433A ECal module. All errors including loss in cable A and B are removed after full calibration. Rise time degradation due to loss at a high frequency is also calibrated to have a similar rise time with the instrument at 35 ps. Figure 8 and 9 show measurement results of 25 Ω airline at cable A and B after performing full calibration. Now that the errors in measurement system are completely removed, measurement results now have good traceability to NIST standard of 25 Ω and are correlated between cable A and B.

Full calibration prior to device measurements can characterize all errors introduced from the measurement system and extend the calibration plane from instrument test ports to the point where full calibration is performed. High measurement accuracy and correlation can be achieved because errors introduced from measurement systems can be removed completely from measurement results, and the most accurate device information can be acquired.

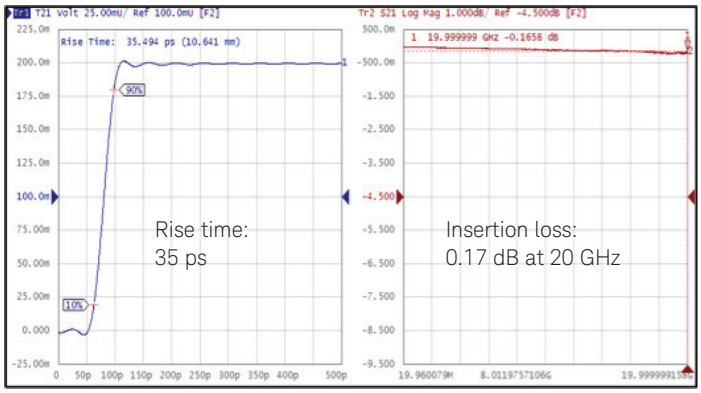

Figure 6. Insertion loss and rise time after full calibration (cable A)

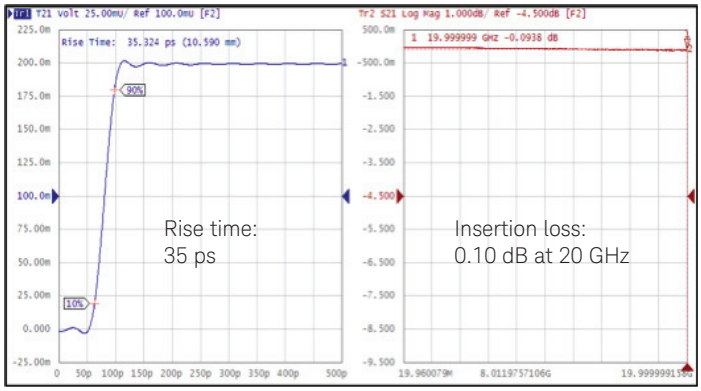

Figure 7. Insertion loss and rise time after full calibration (cable B)

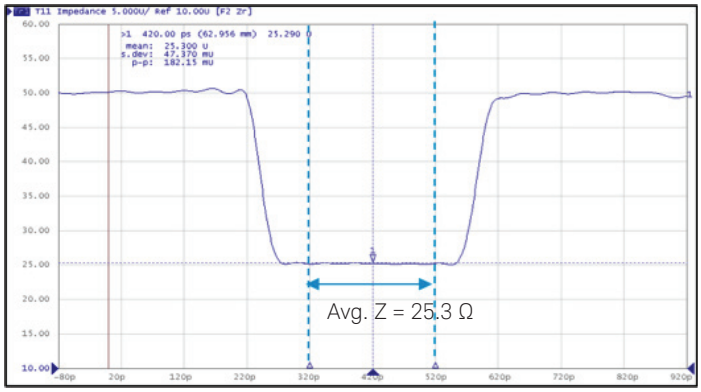

Figure 8. 25 Ω airline after full calibration (cable A)

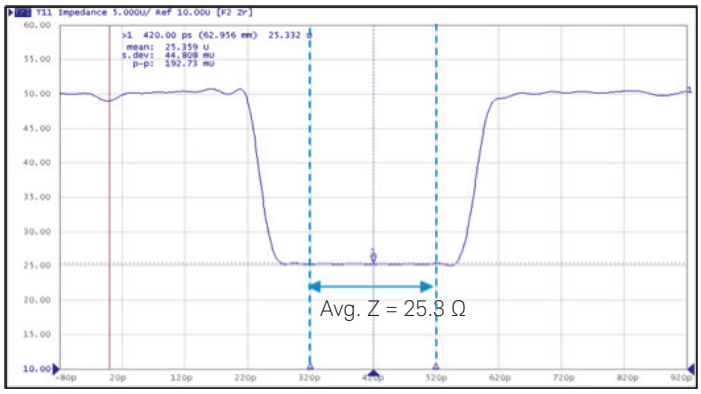

Figure 9. 25 Ω airline after full calibration (cable B)

Impedance Measurement Range Comparison

To understand impedance measurement range with offset error compensation, NIST traceable standards for 25 Ω, 50 Ω, and 75 Ω are connected in series and measured (Figure 10). As illustrated in Figure 10, offset error is different for each impedance standard. In other words, offset compensation can effectively compensate offset errors only when the standard and the device have the same impedance. Therefore, the impedance measurement range with offset error compensation is limited. If there are multiple impedance values to measure, corresponding impedance standards must be prepared and measured prior to device measurements in order to calculate the amount of offset at each impedance point. In most cases, it is difficult to prepare standards that have the same impedance as the device under test or vice versa because device impedance is usually unknown. In addition, 28 Ω, 85 Ω, 90 Ω are commonly used impedance values in commercial products but are difficult to find in traceable standards. Substituting these impedance standards with different impedance standards for offset error compensation can result in measurement errors as previously described in Table 1.

On the other hand, full calibration covers a wide impedance range. Figure 11 shows the measurement result with the same setup as illustrated in Figure 10 but after a full calibration is performed. A one-time full calibration prior to device measurements can achieve high measurement accuracy and correlation at a wide impedance range for PCB impedance measurements because full calibration characterizes all errors from measurement systems and completely removes them from the measurement results.

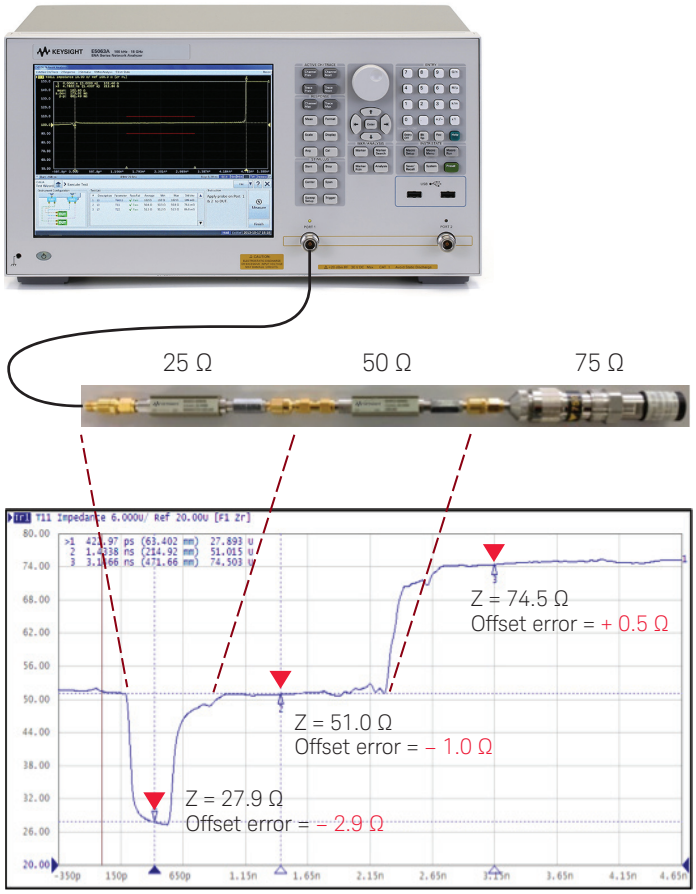

Figure 10. Offset errors at a different impedance

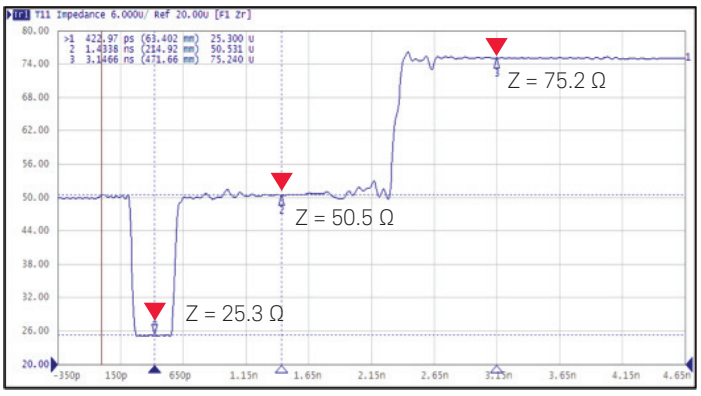

Figure 11 Different impedance after full calibration

Summary

PCB Impedance tolerance has become tighter from ± 10 % to ± 5 % or less for the latest printed circuit boards in order to assure signal integrity at higher data rates. Traditional offset error compensation method used for PCB impedance tests is inadequate to meet these accuracy requirements, which often results in lower product yield as well as measurement discrepancy between PCB suppliers and their end users. Full calibration using Keysight's ENA series network analyzers with TDR measurement features can completely remove unwanted errors introduced from measurement systems and achieve higher measurement accuracy and better correlation at a wide impedance range. It is the best measurement solution to meet these measurement requirements.

References

Accuracy Verification of ENA Option TDR Time Domain Measurement Using a NIST Traceable Standard, Application Note, 5990-5728EN

Correlation Between TDR Oscilloscope and VNA Generated Time Domain Waveform, Application Note, 5990-5238EN

Web Resources

E5063A PCB Analyzer
www.keysight.com/find/ena-pcb

E5071C-TDR Enhanced Time Domain Analysis
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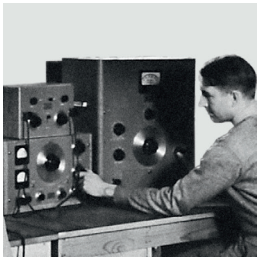

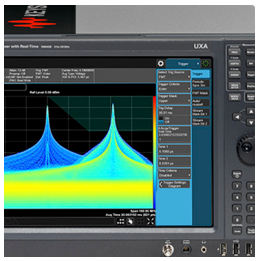



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