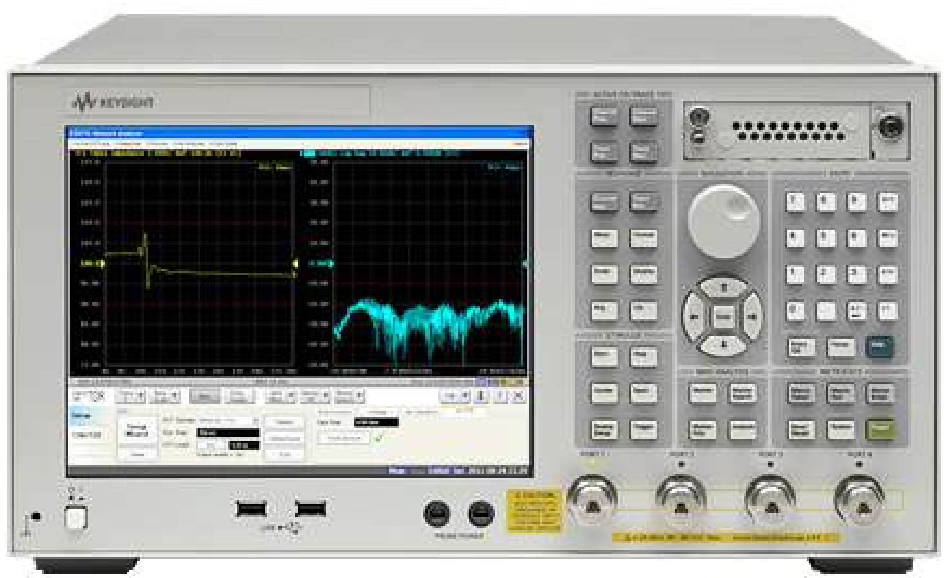
Keysight Technologies

Effective Hot TDR Measurements of Active Devices Using ENA Option TDR

Application Note



KEYSIGHT TECHNOLOGIES

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Introduction

Impedance matching is essential in the design of high speed applications, because signal reflections due to impedance mismatches may have a significant impact on signal integrity. Since transmitters and receivers may cause significant reflections, they should be evaluated with great care. In fact, many modern high speed digital standards specify limits for impedance and return loss. Most of the standards require that the devices be operating during measurements, because the device characteristics are different between the power-on state and the power-off state. The purpose of this application note is to describe an effective evaluation method for the impedance measurement of active devices under actual operating conditions.

Importance of Impedance Matching on Transmitter/Receiver

The eye diagram is a key measurement parameter and signal integrity designers particularly interested in eye opening. Eye closure occurs due to a variety of reasons. One of these factors is signal reflections due to impedance mismatches. If there is more than one impedance mismatch in the link, multiple reflections occur and degrade signal integrity. A portion of the transmitted signal is reflected from the receiver due to non-ideal impedance match as shown in Figure 1. If the transmitter is not impedance matched, the signal is re-reflected back again into the channel. This re-reflected signal causes eye closure when it reaches the receiver. This effect becomes more critical for multi-gigabit systems such as SATA. Therefore, impedance matching on the transmitter and receiver is essential to improve signal integrity and open up the eye diagram.

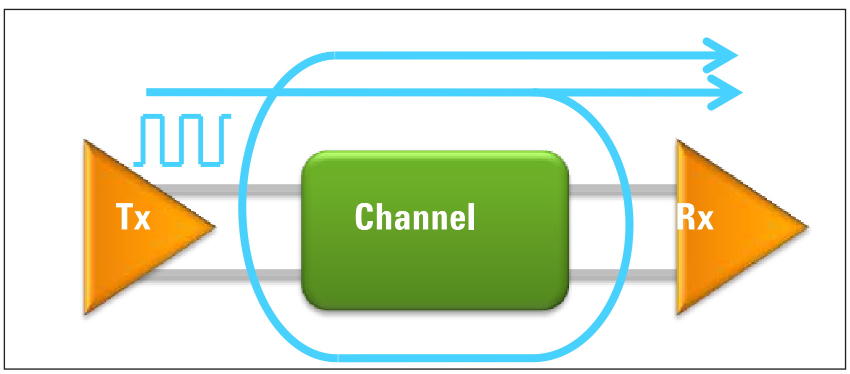

Figure 1. Multiple reflection between transmitter and receiver

Figure 2 shows simulation result comparing eye diagrams of different termination conditions. The eye diagram on the left was computed using the return loss extracted from an actual transmitter, which is not impedance matched. The eye diagram on the right was computed assuming a perfectly terminated transmitter. The eye diagram on the right has a wider eye opening and it verifies that impedance matching of the transmitter can dramatically improve eye opening.

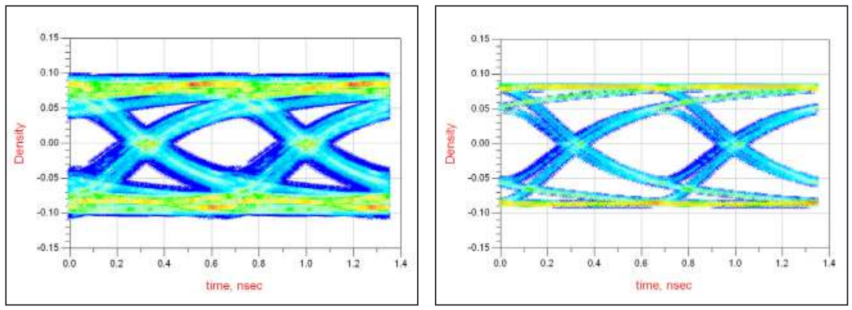

Figure 2. Comparison of simulated eye diagram, with (right) and without (left) perfect transmitter termination

Reflection from a device can be quantified with time domain reflectometry (TDR) and return loss (S-parameter) measurements. TDR provides an impedance profile of the device, which is useful to determine the location and magnitude of discontinuities. Return loss represents the reflections as a function of frequency, which is useful to determine the frequency components which contribute to the discontinuity. Both measurements have been widely used to evaluate passive transmission channels and they can be applied to impedance measurement of active devices.

Since the device characteristics can vary between the power-on state and the power-off state, the devices should be evaluated in a condition similar to the actual operating condition. The TDR measurement in the power-on and operating state is called Hot TDR. The return loss measurement in the power-on and operating state is called Hot Return Loss. These measurements are often required in the compliance tests of high speed digital applications. At the same time, they give new insight into signal integrity, so that the design loop can converge more quickly (Figure 3).

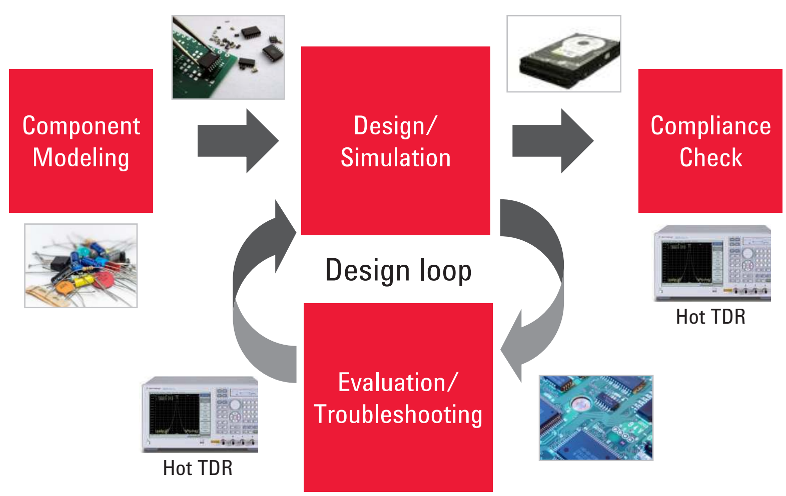

Figure 3. A typical design cycle of high speed application

Hot TDR and Hot Return Loss Measurement Using ENA Option TDR

Hot TDR and Hot Return Loss measurements can be performed in a similar way as for passive device characterization. TDR oscilloscopes and Vector Network Analyzers (VNA) can be used for this purpose. Traditionally, the TDR oscilloscope was dedicated to time domain measurements and the VNA was dedicated to frequency domain measurements. Modern instruments provide measurements in both domains, because the time domain waveform and frequency domain waveform are related by Fourier theory.

VNA based solutions have advantages over TDR oscilloscopes for Hot TDR measurements, but it has been less commonly used among digital engineers. Many digital engineers assume that the VNAs are difficult to use and require a lot of work to setup measurements. Keysight Technologies, Inc. offers the E5071C ENA Option TDR, which is an application software embedded in the ENA network analyzer, which provides a simple and intuitive GUI for Hot TDR measurements, while taking advantage of the inherent strengths of a VNA.

Fast and Accurate Measurement

The most valuable advantage of the ENA Option TDR is measurement accuracy and speed. For Hot TDR measurements, there are some measurement challenges which do not occur for passive device characterization. When testing a transmitter, the biggest issue is the transmitter output signal which causes measurement errors.

ENA Option TDR can significantly reduce the errors from the transmitter output. Observed in the frequency domain, the transmitter output is represented by a number of line spectra, or spurious, as shown in Figure 4. Since the TDR oscilloscope uses a wideband receiver that captures all of the signal energy including the transmitter spurs, the measurement result is highly unstable. To stabilize the trace, extensive averaging is necessary. On the other hand, the VNA sweeps across the desired frequency range and acquire data on discrete frequency points. The narrow band receiver used in the VNA can filter the unwanted transmitter spurs. Therefore, the VNA can complete the measurement quickly without being affected by the data signals. In many cases, averaging is not necessary.

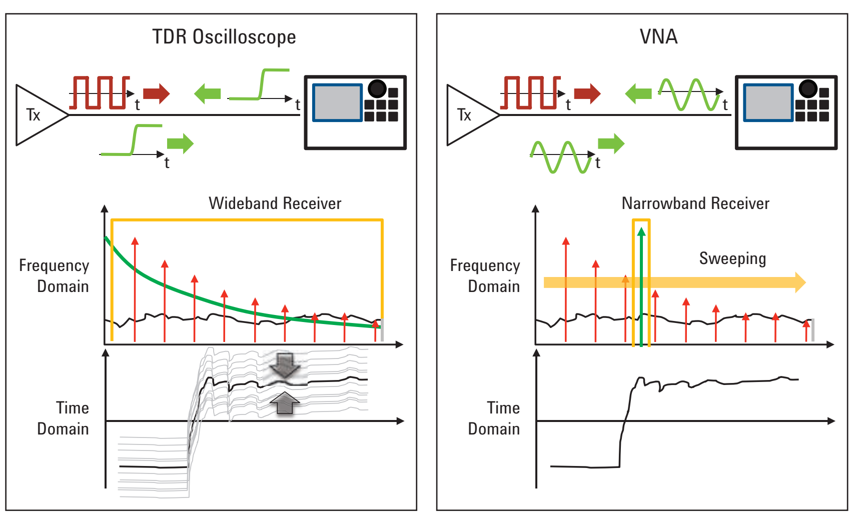

Figure 4. Hot TDR measurement principle for TDR oscilloscopes and vector network analyzers

Although VNAs can avoid the data signal using a narrow band receiver, the transmitter spurs can coincide with the measurement points during the frequency sweep. Therefore, the measurement points should be adjusted to avoid the transmitter spur frequencies. ENA Option TDR calculates the spurious frequencies from the data rate (user input) and avoids those frequencies during the sweep. Figure 5 shows an example of how the ENA Option TDR effectively avoids the spurious signals from the transmitter. The transmitter spurs in the left figure are avoided when the "Avoid Spurious" feature is activated.

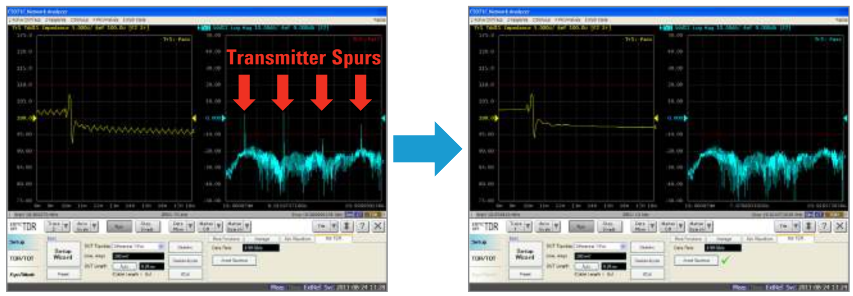

Figure 5. ENA Option TDR automatically avoids the transmitter spurs

To verify the ENA Option TDR measurement results, comparisons were done with the Keysight 86100D TDR oscilloscope. Figure 6 shows the differential return loss and impedance profiles (TDR) of a SATA transmitter. The measurement results are highly comparable between the two instruments. However the measurement times are extremely different. The TDR oscilloscope needed 512 times averaging and spent more than 10 minutes until achieving a stable trace. On the other hand, the ENA Option TDR gave the same result without averaging and required less than 1 second.

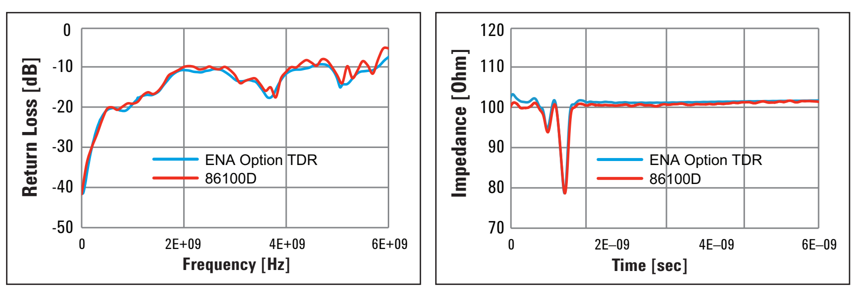

Figure 6. Correlation between 86100D TDR oscilloscope and ENA Option TDR for return loss (left) and impedance (right) measurements

ESD Robustness

Electrostatic discharge (ESD) is another big issue when measuring transmitters and receivers. TDR oscilloscopes are prone to failure due to ESD. Sufficient ESD protection circuits are difficult to implement on the TDR oscilloscope due to the internal structure. The stray capacitance of the protection circuit would form a low pass filter to distort the step rise time as shown in Figure 7. On the other hand, the performance of ENA Option TDR is not affected by a protection circuit. A sine wave stimulus is swept across frequency and the vector ratio between the input and output is calculated. Even if there was some loss associated with the protection circuit, the loss is canceled out by taking the vector ratio. Thus, the measurement accuracy is not affected.

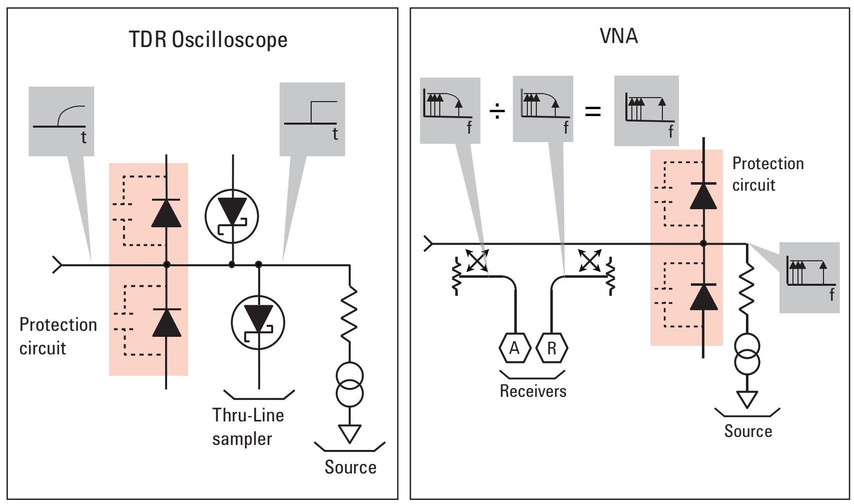

Figure 7. Effect of ESD protection circuit on the TDR oscilloscope and VNA

ENA Option TDR implements protection circuits inside the instrument. Figure 8 shows the proprietary ESD protection chip implemented in ENA Option TDR. It significantly increases ESD robustness, while at the same time maintaining excellent RF performance (22ps rise time for 20GHz models). ENA Option TDR can withstand up to 3,000 V (typ) of ESD.

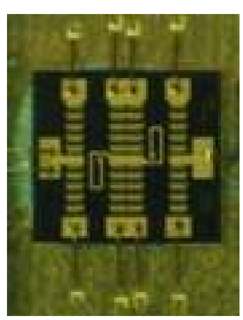

Figure 8. Proprietary protection chip implemented inside the ENA Option TDR

Simple Setup

Simple measurement setup is another benefit of ENA Option TDR. The availability of internal bias-tees help to reduce the number of accessories required when the DUT must be biased. In many cases, a blocking capacitor is not necessary. Figure 9 shows the Hot TDR measurement setup for SATA hard disk drive test. Minimizing the required number of external accessories, the risk of operation error and ESD issues should decrease.

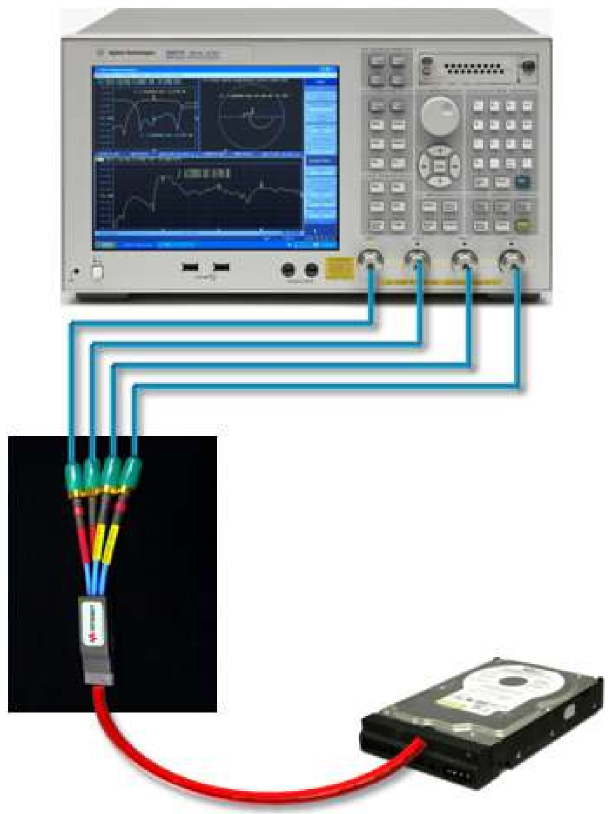

Figure 9. Hot TDR measurement example for SATA HDD

Summary

The importance of impedance matching of active devices and an effective measurement methodology was described. With the increase in bit rates, impedance matching becomes more critical and the impedance of active devices should be evaluated quantitatively. Hot TDR measurement is the most suitable measurements for this purpose and provides new insight into signal integrity issues. ENA Option TDR brings many advantages over the traditional TDR oscilloscope solution, taking advantage of the VNA based architecture.

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