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TDR Application Note

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APPLICATION NOTE

Introduction

High speed signals require high quality signal paths to maintain signal quality and prevent loss of signal power. Time Domain Reflection (TDR) is a technique for measuring the quality of a signal path. This application note will explain the basics of transmission lines and how TDR can be used to assess the quality of the transmission line and locate where the transmission line deviates from ideal behavior.

Transmission Lines in High Speed Interfaces

In today's high speed data world, much of the information exchange, from one location to another or from one device to another, relies on high speed interface standards and cables. Their speeds vary from a few Kb/s to more than 5 Gb/s. Examples of high speed interfaces include USB2.0, USB3.0, HDMI, Ethernet, eSATA, MIPI and so on. In order to maintain the quality of the signals transmitted and minimize power loss, cables with transmission line characteristics must be employed. One of the characteristics of transmission line is uniform impedance throughout the signal carrying medium. This uniform impedance minimizes or even eliminates the reflections as the signals travel down the medium and maintains the quality of the signals. For most high speed interface standards, the target impedance, Z_0, is 50 Ω to ground and 100 Ω differential between a signal pair. USB is the exception with 45 Ω to ground and 90 Ω differential.

A transmission line can be modeled as a two−port network.

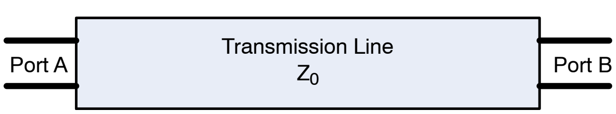

Figure 1.

Assume a transmission line has a uniform impedance of $Z_0 = 50\ \Omega$. A source signal is transmitted from Port A through the transmission line to Port B. When the signal reaches Port B, the signal may or may not get reflected back through the transmission line to Port A governed by the reflection coefficient, ϱ:

$$\rho = \frac{Z_B - Z_0}{Z_B + Z_0}$$

where Z_B is the impedance at Port B.

If Z_B is the same as Z_0, i.e. matched impedance, the reflection coefficient is 0 and there is no reflection. In general, matched impedance is the best case for signal transfer. For any mismatch in the signal path, part of the signal will be reflected back to Port A and will cause lost of signal power and quality. For example, a connector interfacing between a coaxial cable and a PCB may not be perfectly matched. The mismatch will cause some reflection back to the source and degrade the signal quality.

What is TDR?

A Time−Domain Reflectometer (TDR) is an electronic instrument for measuring the impedance of a signal carrying medium. TDR can show the impedance of the whole signal path. Any mismatch in the signal path can be observed on the TDR. Designers can use the information to improve the impedance matching and therefore signal quality of their products. Figure 2 is an example of a TDR measurement system.

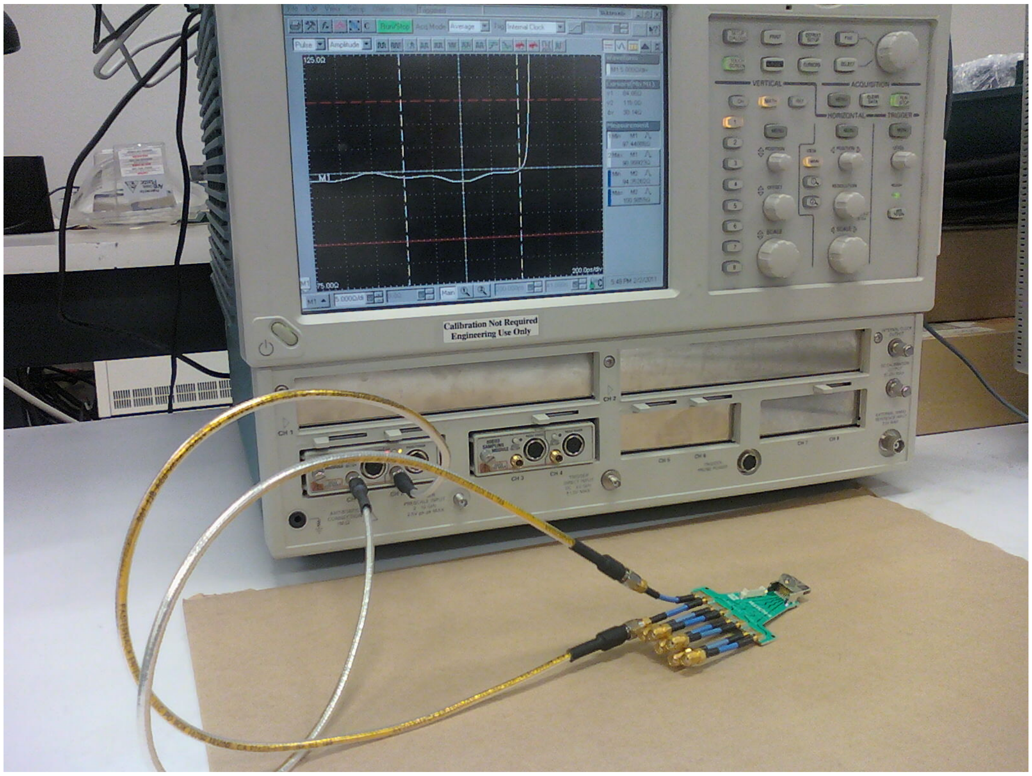

Figure 2.

TDR works by sending a short rise time pulse down the medium and record the reflected signal from the medium. As the signal travels down the medium, reflections from different locations on the medium are displayed along the X−axis of the screen. The Y−axis displays the impedance of the medium at that location.

Most of the standards, like USB and HDMI, specify the TDR measurements of the impedance across a differential pair of the signal instead of just a single signal trace to ground.

Below is an example of how position of the medium corresponds to time axis on the screen display.

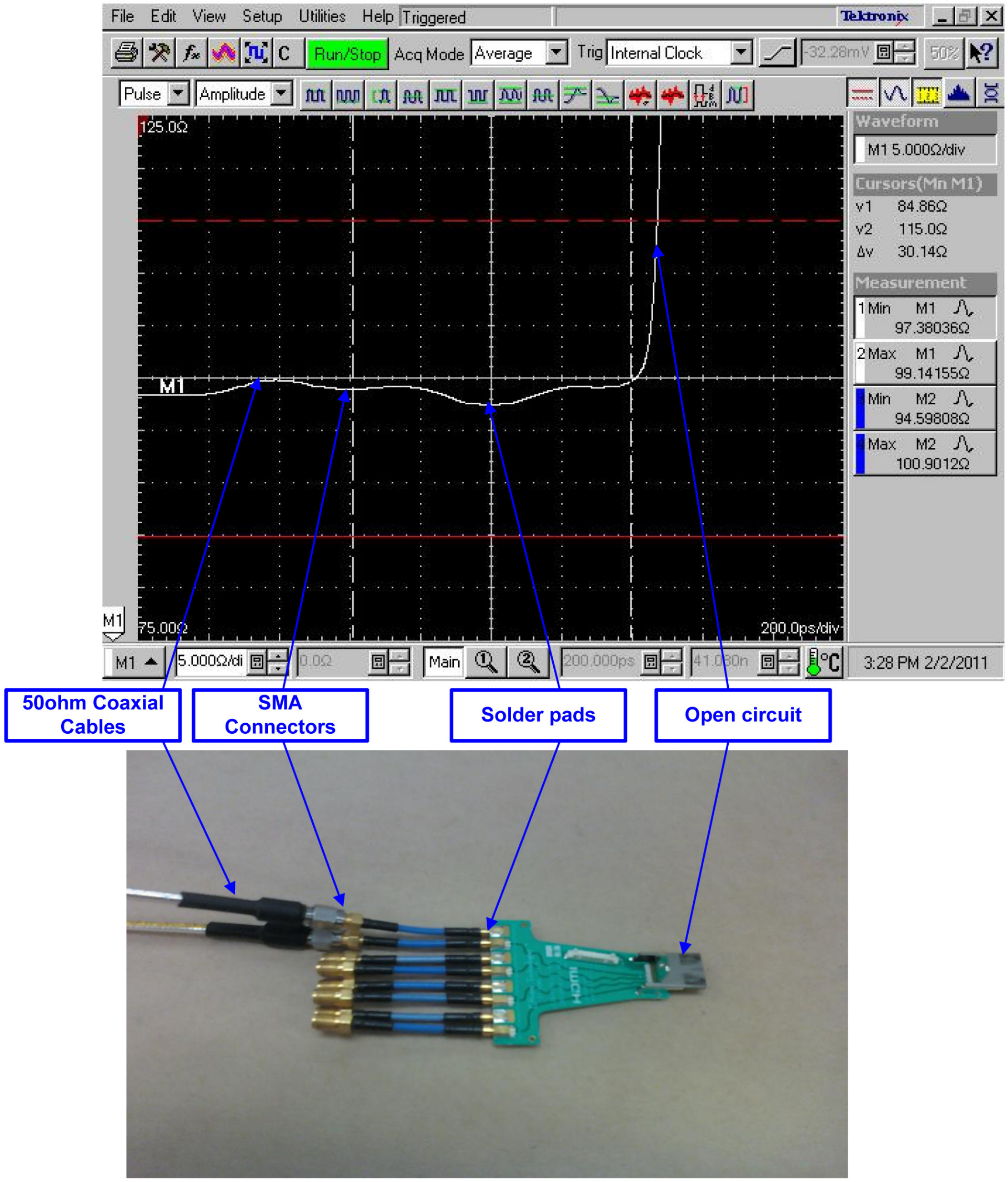

Figure 3.

What Factors Impact TDR Measurement?

TDR measures the impedance of the signal path. Any components that affect the impedance would have an impact on the TDR measurement. Discontinuities or added components hanging on the signal path can change the capacitance or inductance and hence the impedance of the path. Discontinuities, like connectors, on signal paths are common examples that could change the impedance of the signal paths. Other examples are ESD protection, surge protection components and noise filters sitting on the signal paths. Most of these components have some inherent capacitance. Few are inductive. Any increase in capacitance along the signal path would cause the line impedance to go down. Looking at the example above, at the location where the solder pads connecting to the PCB, there is some inherent capacitance due to the solder and the pad. It might not be much but it does cause the impedance at that point to go down to about 98 Ω. Any increase in inductance would make the line impedance to go up. A short in the signal path would cause the impedance to go to zero. An open would make the impedance line to go up and off the chart. This is shown in the example above. At the right side where the HDMI connector is open, the corresponding impedance goes off the chart.

Best Impedance Matching Products for High Speed Interfaces

It is vital for high speed interfaces to maintain impedance matching throughout the signal paths. Any traditional ESD, surge or filter components added to the signal paths must have minimum capacitance so the signal quality can be maintained at the highest level. ON Semiconductor manufactures a wide line of low capacitance ESD protection devices for high speed interfaces. Below is a partial list of the products.

ESDR0524, NUP4114, MG2040, ESD7004

Below is an example of the TDR measurement of the ESD7004. The waveform shows that ESD7004 has minimum impact on the TDR and the impedance stays around the target 50 Ω line.

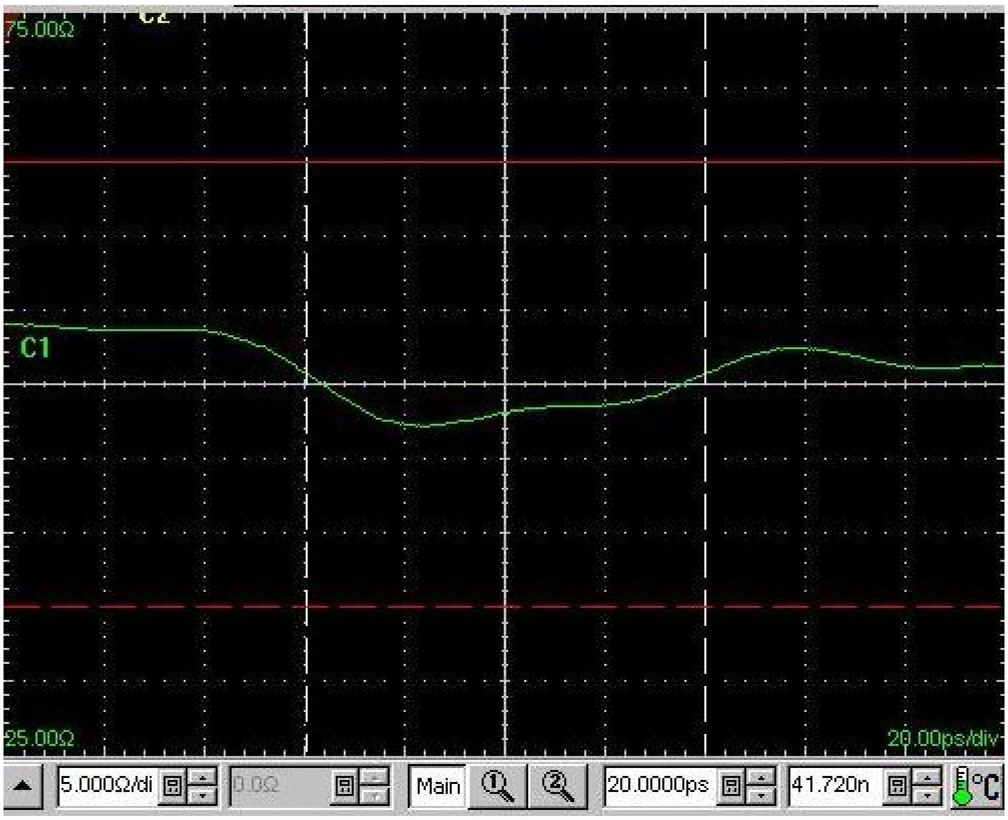

Figure 4.

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