

# S-parameters, Insertion and Return Loss Measurements Using TDR Oscilloscope

## Introduction to S-parameters

Frequency-domain scattering parameters (S-parameters) are a useful way to visualize the electrical properties of a system. They are a dual representation of the time domain data in the frequency domain.  $S_{11}$  is related to Time Domain Reflection (TDR), and  $S_{21}$  is related to Time Domain Transmission (TDT), via an enhanced FFT algorithm developed in the early 90's at the US National Institute of Standards and several universities [1], [2].

Although S-parameters have historically been measured in the frequency domain using a network analyzer, much of the same information is contained in TDR and TDT measurements.

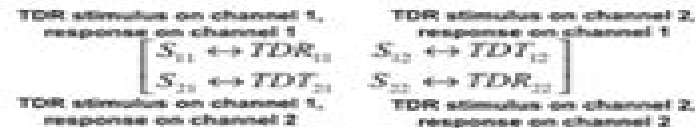


Figure 1. Relationship between the TDR/T data and the single-ended S-parameters

Scattering-parameter computation is just as valid for TDT (through) measurements as it is for TDR (reflection) measurements. TDT results in insertion loss ( $S_{21}$ ), TDR in return loss ( $S_{11}$ ). Differential and mixed mode S-parameters can also be obtained from corresponding TDR oscilloscope data.

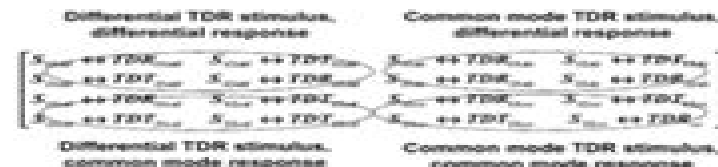


Figure 1. Relationship between the TDR/T data and the differential S-parameters

From practical standpoint, TDR/T-based S-parameters are much simpler and quicker to obtain, while providing more than sufficient dynamic range. In addition, if a designer already has a TDR oscilloscope, he or she

can save money by postponing the purchase of a network analyzer, and using TDR oscilloscope with IConnect TDR software instead.

## S-parameter Measurements

In order to obtain high-quality S-parameter diagrams, the designer has to follow sound measurement practices when working with the 18-20 GHz TDR oscilloscope, such as: letting the instrument warm up for 20-30 minutes before performing measurements, using good quality low loss cables and good probes with small signal-to-ground spacing, using averaging in the TDR oscilloscope to reduce noise. Two waveforms need to be acquired: the DUT and the reference open waveforms - without changing the timebase on the TDR oscilloscope.

For the TDR-based S-parameter measurement, it is particularly important to select an acquisition window that is long enough that it allows the DUT waveforms to completely settle to its steady state DC level. We are about to start making high-frequency analysis of the DUT, and we need to allow the signal to settle to perform this analysis accurately. At the same time, the window must not be any longer than necessary, to maximize the effective dynamic range and accuracy of the measurement.

In addition, we need to make sure that a sufficient number of data points is selected in the oscilloscope acquisition window. This is particularly critical for analyzing long interconnects, such as cables. The frequency step and the upper frequency limit of your measurement is determined as

$$f_{upper} = \frac{1}{2T_{step}} = \frac{N}{2T_{window}} \quad f_{upper} = \frac{1}{T_{window}} \quad (1)$$

where N is the number of points in the acquisition window,  $T_{step}$  is the time step, and  $T_{window}$  is the acquisition window length. Thus, to get S-parameter data to the desired upper frequency  $f_{upper}$ , you will need to make sure that the ratio between the number of points and window length is sufficient. To get the desired frequency step, you will need to make sure that the window length is sufficient.

When working with long cables, it is generally a good idea to keep the number of points at the maximum number allowed for a given instrument.

# Tektronix S Parameters Insertion And Return Loss

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