Radiofrequency Measurements

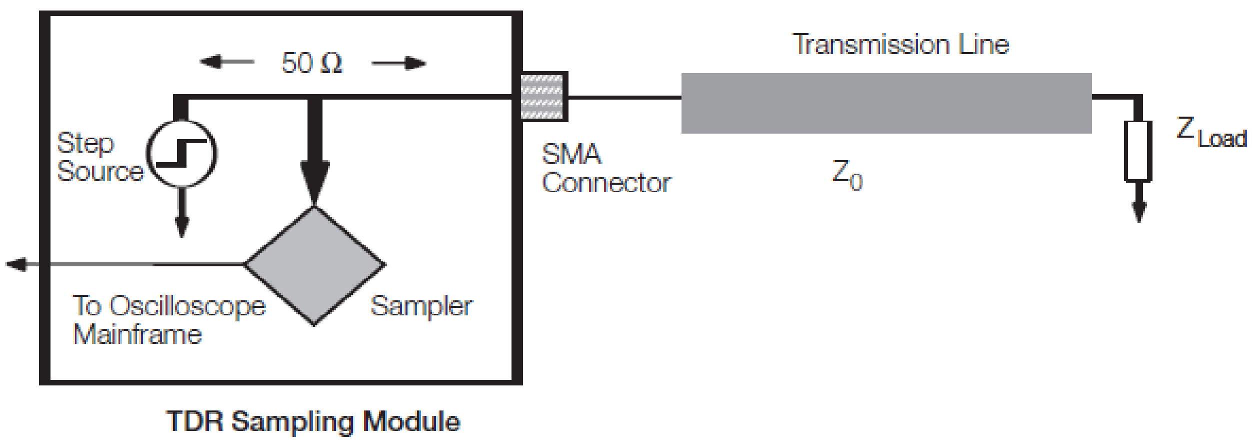
Time-Domain Reflectometry (TDR)

The next slides material is taken from

- AGILENT “**Time Domain Reflectometry Theory**”, Application Note 1304-2
- TEKTRONIX’ “**TDR Impedance Measurements: A Foundation for Signal Integrity**”
- AGILENT “**Network Analyzer Basics**”

What is Time Domain Reflectometry?

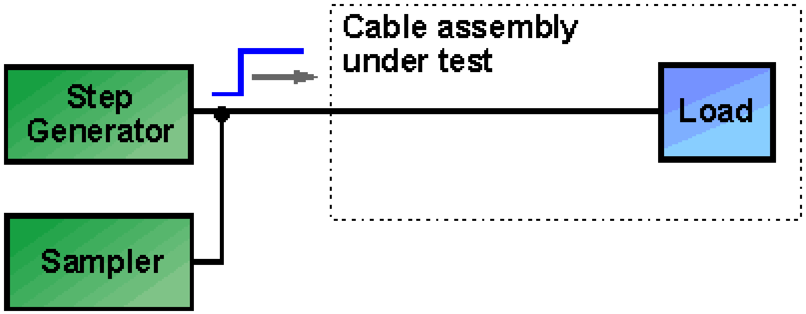
Time Domain Reflectometry (TDR) measures the reflections that result from a signal travelling through a transmission environment of some kind – a circuit board trace, a cable, a connector and so on. The TDR instrument sends a pulse through the medium and compares the reflections from the “unknown” transmission environment to those produced by a standard impedance.



What is Time Domain Reflectometry?

Using a step generator and an oscilloscope, a fast edge is launched into the transmission line under investigation. The incident and reflected voltage waves are monitored by the oscilloscope at a particular point on the line.

This echo technique reveals at a glance the characteristic impedance of the line, and it shows both the position and the nature (resistive, inductive, or capacitive) of each discontinuity along the line. TDR also demonstrates whether losses in a transmission system are series losses or shunt losses. All of this information is immediately available from the oscilloscope's display.



Locating Mismatches

The reflected wave is readily identified since it is separated in time from the incident wave. This time is also valuable in determining the length of the transmission system from the monitoring point to the mismatch. Letting D denote this length:

$$D = v_\rho \cdot \frac{T}{2} = \frac{v_\rho T}{2}$$

v_ρ = velocity of propagation

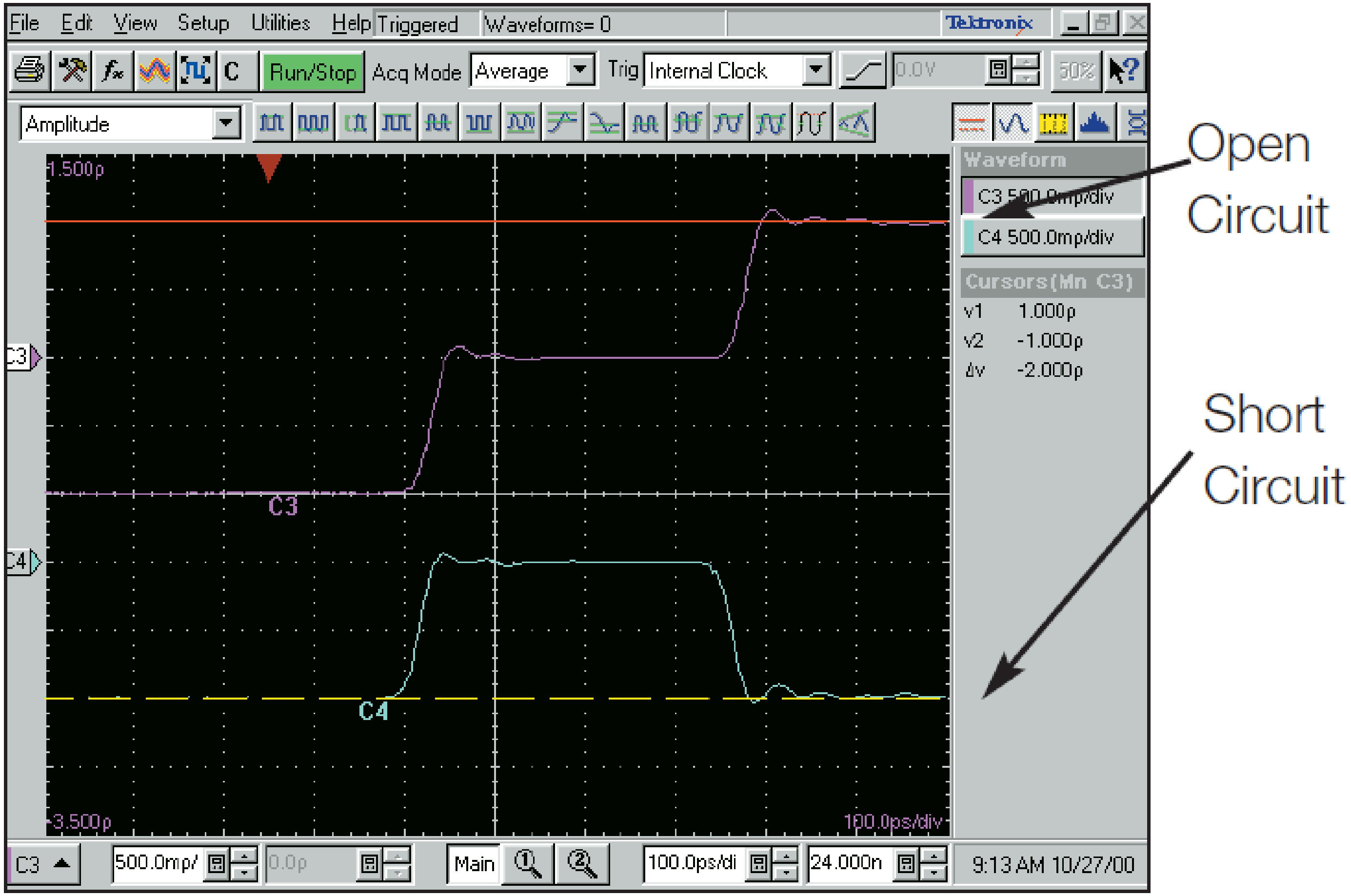
T = transit time from monitoring point to the mismatch and back again, as measured on the oscilloscope

The velocity of propagation can be determined from an experiment on a known length of the same type of cable (e.g., the time required for the incident wave to travel down and the reflected wave to travel back from an open circuit termination at the end of a 120 cm piece of RG-9A/U is 11.4 ns giving nr = 2.1 x 10 cm/sec. Knowing nr and reading T from the oscilloscope determines D. The mismatch is then located down the line.

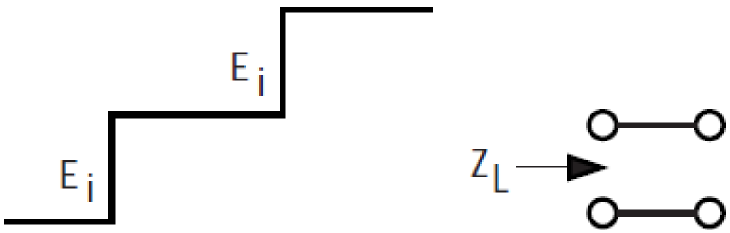
Line and Load Impedance

The characteristic impedance Z_0, or the load impedance Z_L, can be calculated with the value of ρ.

$$Z_L = Z_O * \frac{(1+\rho)}{(1-\rho)}$$



Measured Signals



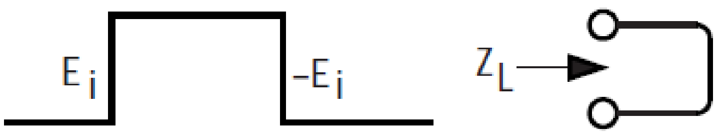
(A) Open Circuit Termination ($Z_L = \infty$)

(A) $E_r = E_i$

Therefore $\frac{Z_L - Z_o}{Z_L + Z_o} = +1$

Which is true as $Z_L \rightarrow \infty$

$\therefore$ Z = Open Circuit



(B) Short Circuit Termination ($Z_L = 0$)

(B) $E_r = E_i$

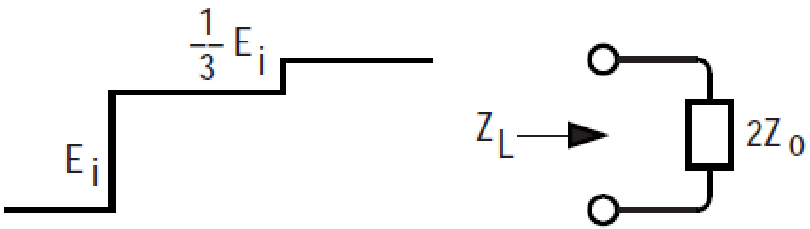
Therefore $\frac{Z_L - Z_o}{Z_L + Z_o} = -1$

Which is only true for finite Z_o

When $Z_L = 0$

$\therefore$ Z = Short Circuit

Measured Signals

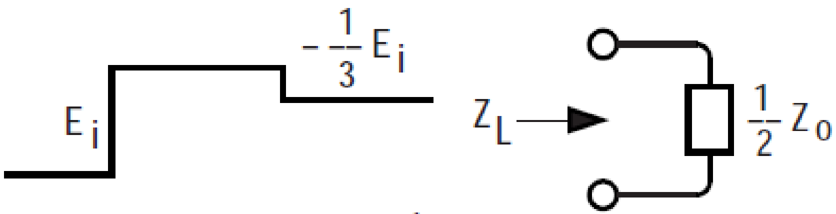


(C) Line Terminated in $Z_L = 2Z_0$

(C) $E_r = +\frac{1}{3} E_i$

Therefore $\frac{Z_L - Z_0}{Z_L + Z_0} = +\frac{1}{3}$

and $Z_L = 2Z_0$



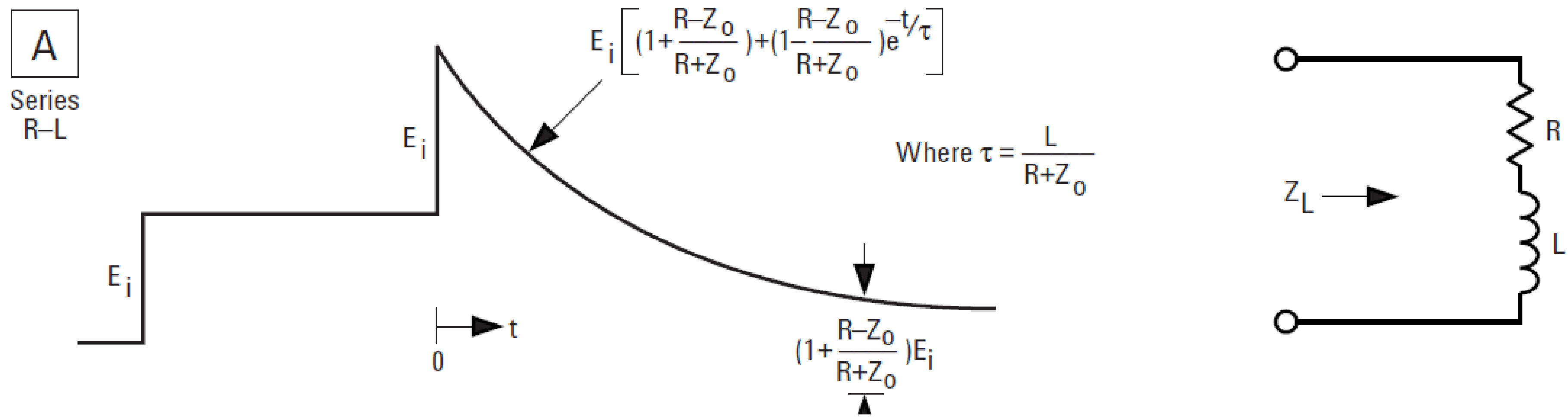
(D) Line Terminated in $Z_L = \frac{1}{2} Z_0$

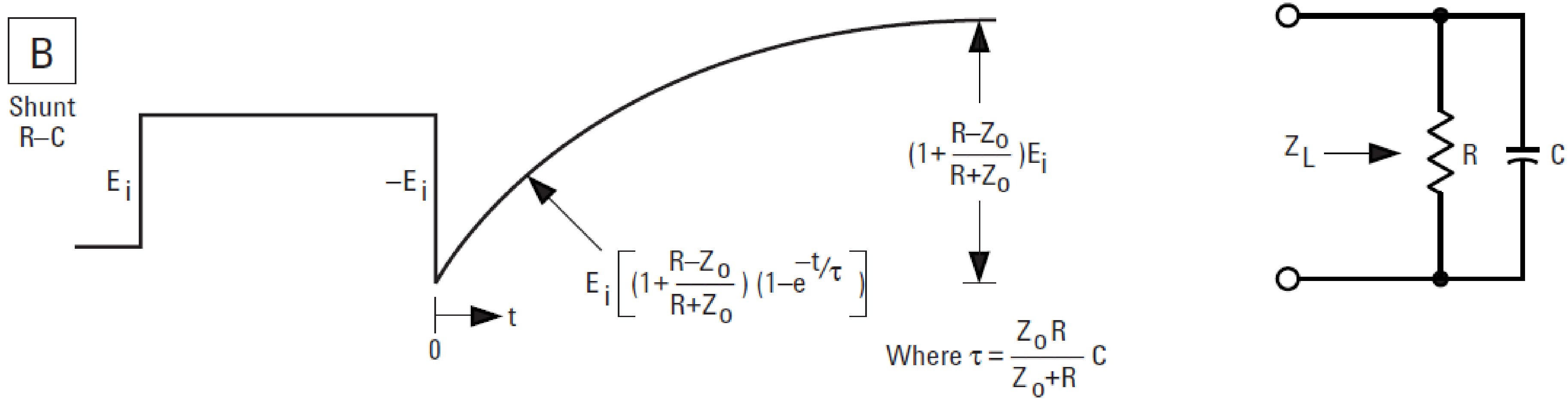
(D) $E_r = -\frac{1}{3} E_i$

Therefore $\frac{Z_L - Z_0}{Z_L + Z_0} = -\frac{1}{3}$

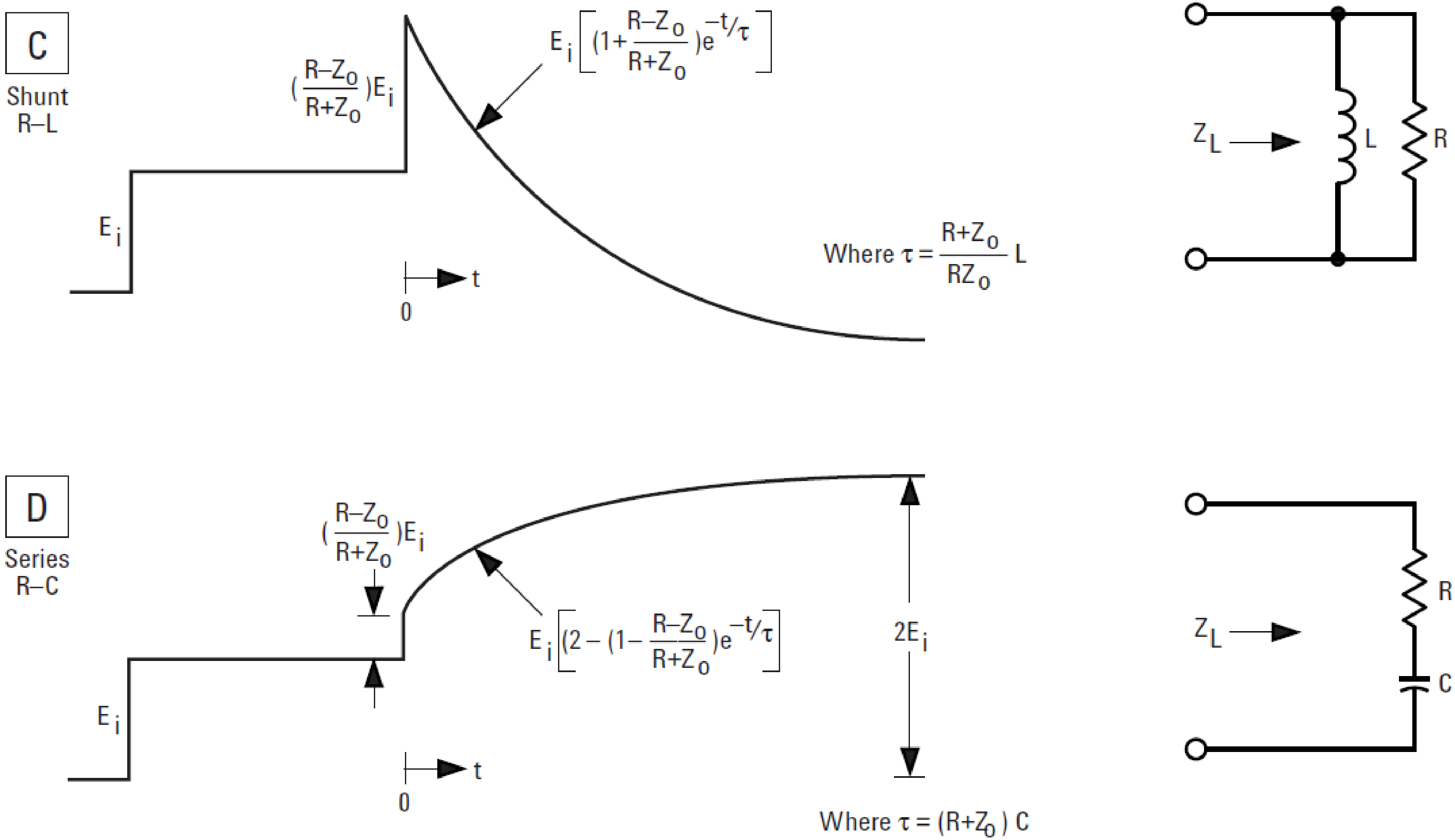
and $Z_L = \frac{1}{2} Z_0$

Measured Signals for complex Z



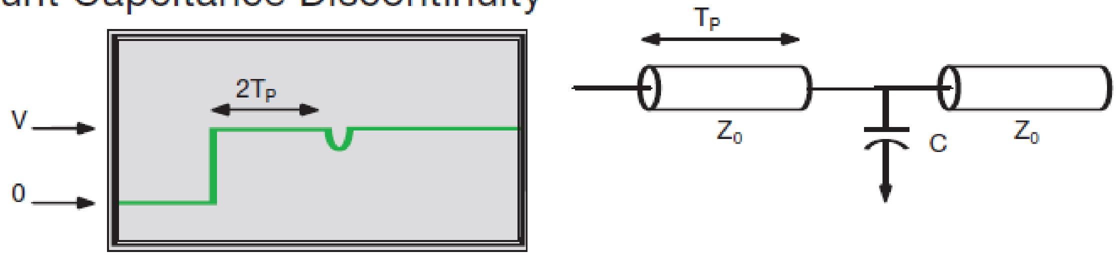


Measured Signals for complex Z

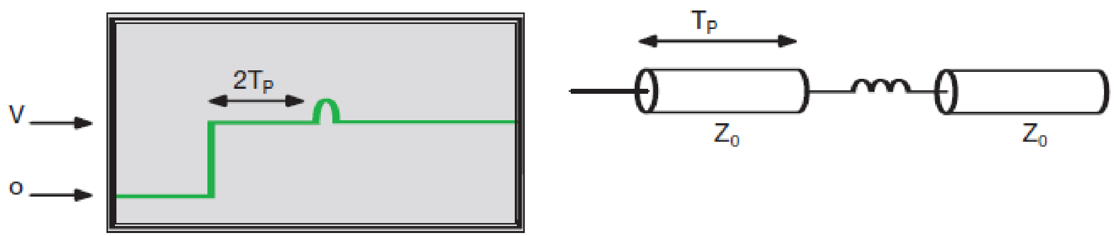


Discontinuities

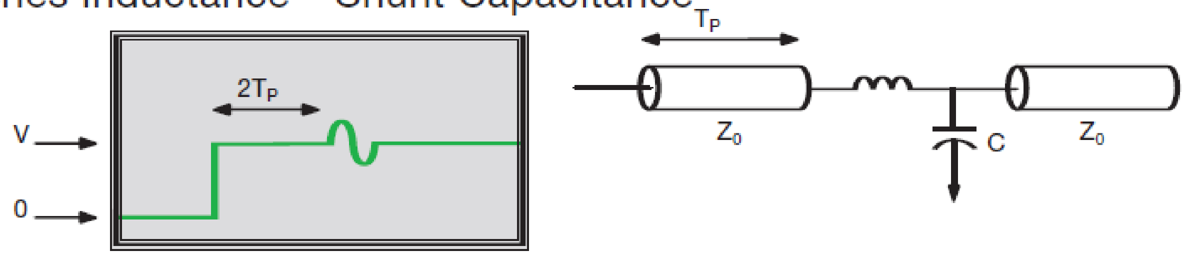
- Shunt Capcitance Discontinuity



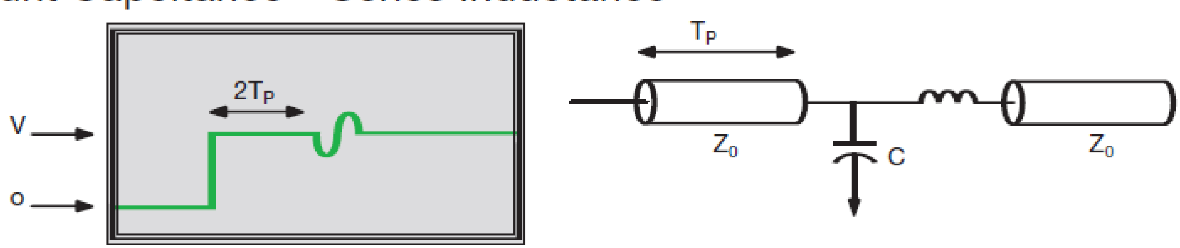
- Series Inductance Discontinuity



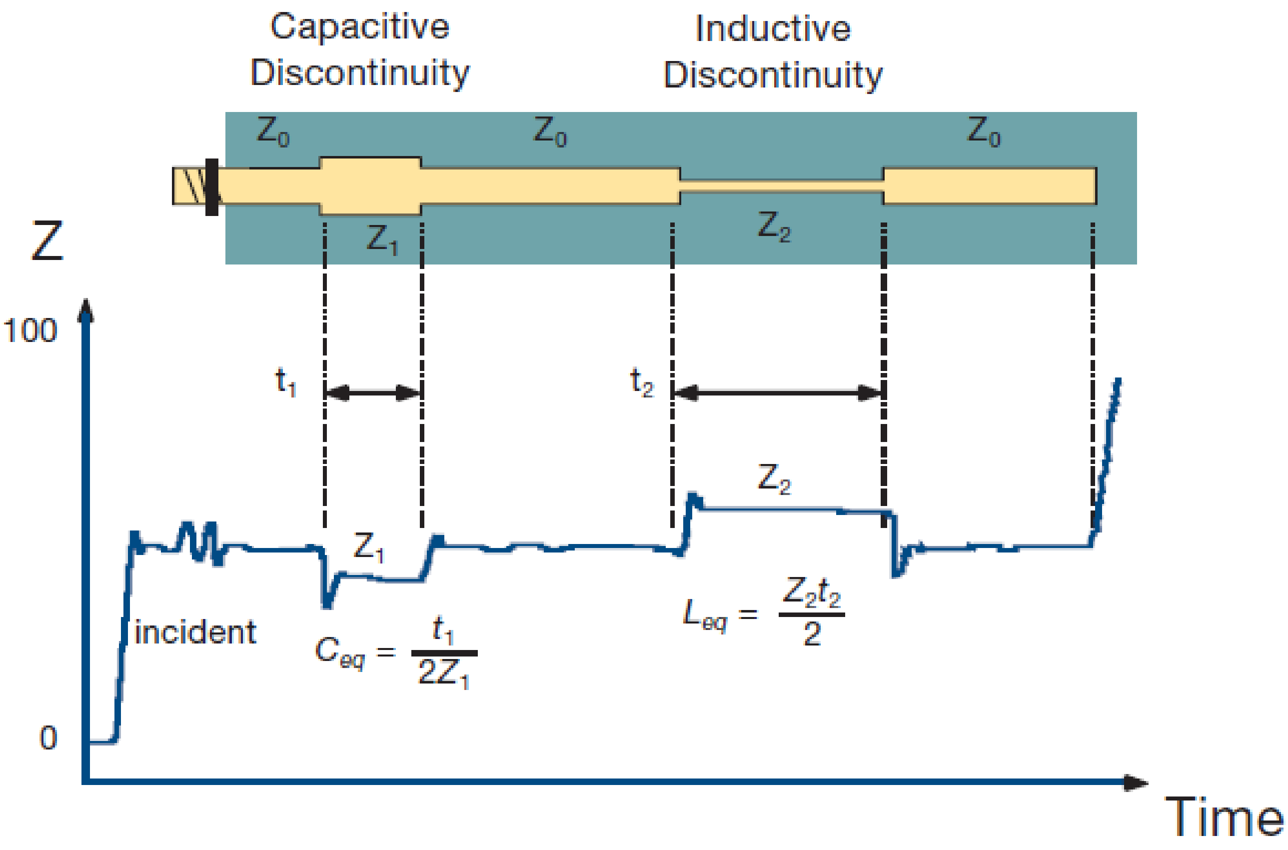
- Series Inductance – Shunt Capacitance



- Shunt Capcitance – Series Inductance



Example of a real signal



TDR with a Network Analyzed

TDR measurements using a vector network analyzer start with a broadband sweep in the frequency domain. The inverse-Fourier transform is used to transform frequency-domain data to the time domain. The figure on the left of the slide shows a simplified conceptual model of how a network analyzer derives time-domain traces. For step-response TDR, we want to end up at the lower left-hand plot. The network analyzer gathers data in the frequency domain (upper right) from a broadband sweep (note: all the data is collected from a reflection measurement). In effect, we are stimulating the DUT with a flat frequency input, which is equivalent to an impulse in the time domain. The output response of our DUT is therefore the frequency response of its impulse response. Since a step in the time domain is the integral of an impulse, if we integrate the frequency-response data of our DUT, we will have frequency-domain data corresponding to the step response in the time domain. Now, we simply perform an inverse-Fourier transform to get from the frequency domain to the time domain, and *voilá*, we have the step response . Note that we could also perform the inverse-Fourier transform first, and then integrate the time-domain data. The result would be the same. The actual math used in the network analyzer is somewhat more complicated than described above, in order to take care of other effects (one example is extrapolating a value for the DC term, since the analyzer doesn't measure all the way down to 0 Hz).

To get more resolution in the time domain (to separate transitions), we need a faster effective rise time for our step response. This translates to a sharper (narrower) effective impulse, which means a broader input-frequency range must be applied to our DUT. In other words, the higher the stop frequency, the smaller the distance that can be resolved. For this reason, it is generally necessary to make microwave measurements on the fixture to get sufficient resolution to analyze the various transitions. Providing sufficient spacing between transitions may eliminate the need for microwave characterization, but can result in very large fixtures. The plot above of a fixtured-load standard shows the extra resolution obtained with a 20 GHz sweep versus only a 6 GHz sweep.

TDR Basics Using a Network Analyzer

- start with broadband frequency sweep (often requires microwave VNA)
- use inverse-Fourier transform to compute time-domain
- resolution inversely proportionate to frequency span