Time-domain reflectometer (TDR) theory and implementation

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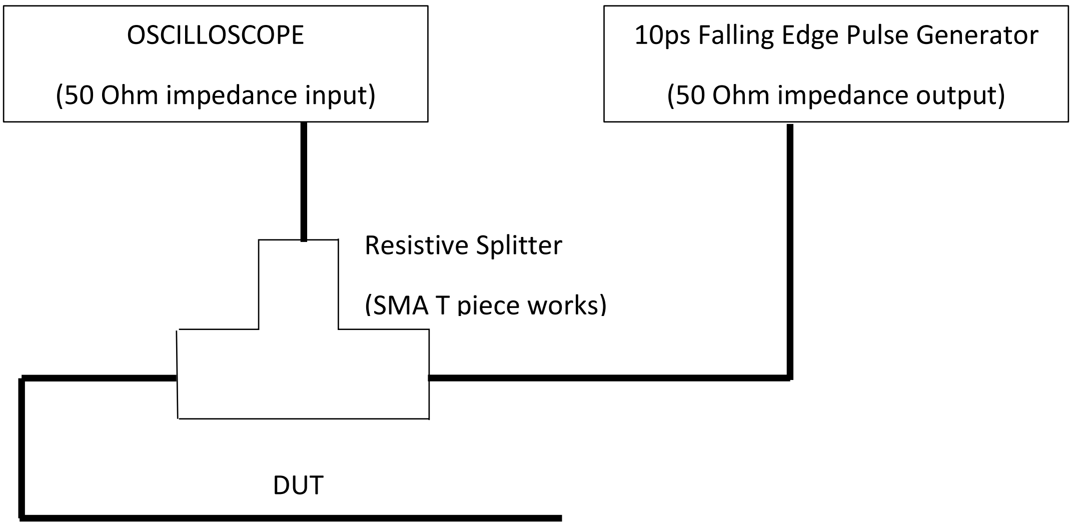
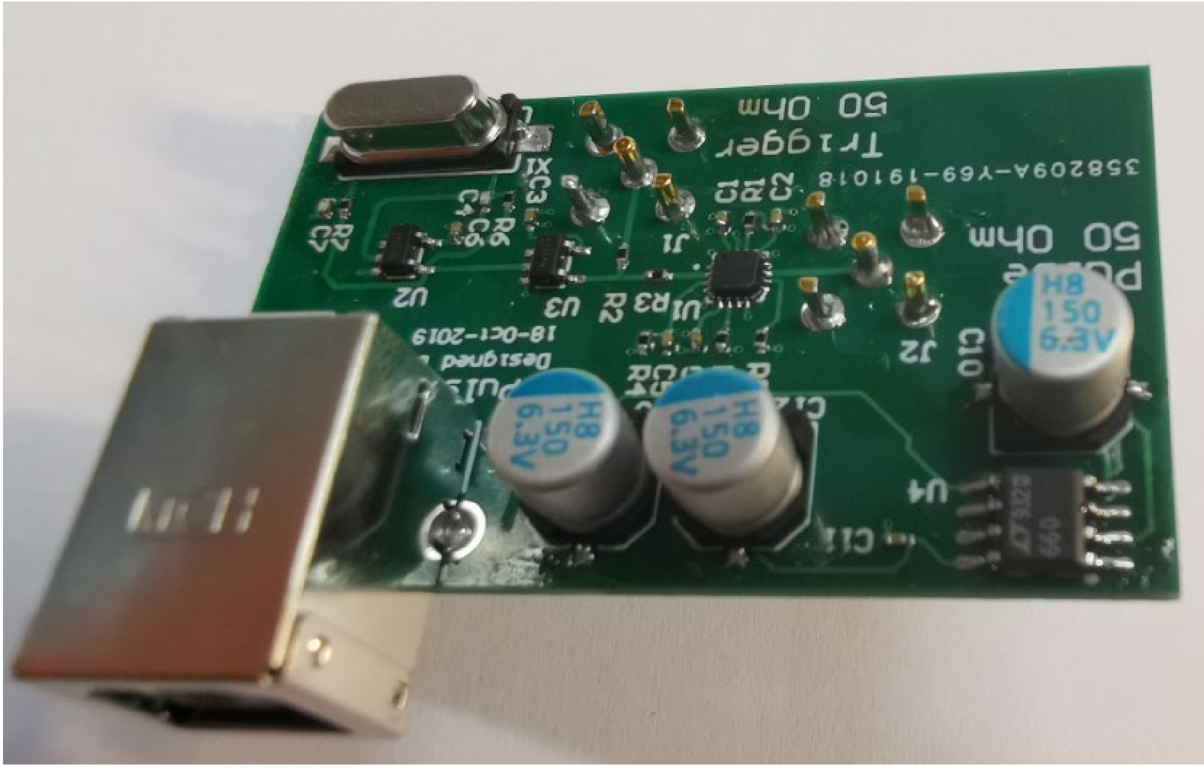
Part I: Understanding the Time-domain reflectometer (TDR)

Today, most of manufacturers in mainland China still belonged to the 2nd tier or lower tier for high frequency PCB manufacturing. They still used and only used legacy TDR equipment such as Polar CITS500s Controlled Impedance Test System. Only several top tier multinational corporations in mainland china had capabilities to adopt frequency domain equipment in the manufacturing process control. Therefore, top tier manufacturers took place in the less competitive position. Usually, less competitive in upstream manufacturing causes lower value for money in downstream manufacturing. Thus, as an electronic product designer, understanding the TDR theory and the different between TDR and frequency-domain controlled impedance testing may help to improve the cost control by choosing 2nd tier manufacturers.



Note: All cables used in the above diagram are 50 Ohm SMA Coaxial Cable.

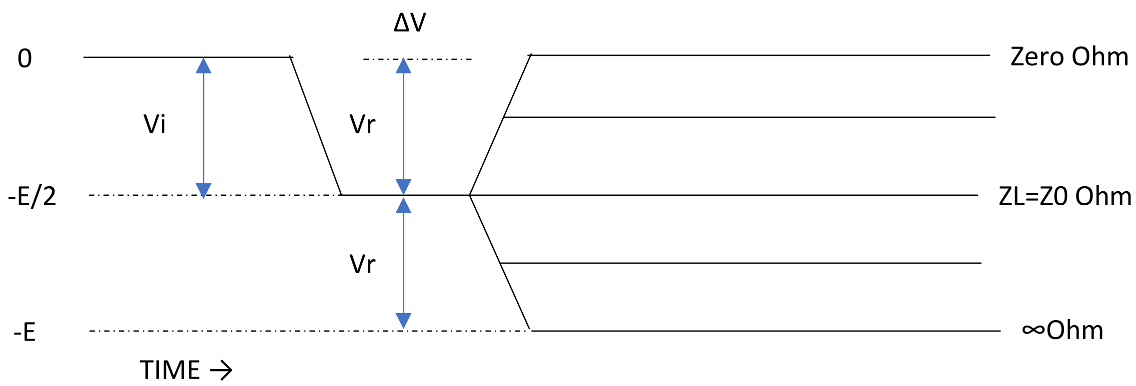
According to the above diagram, a TDR instrument is generally a large, expensive instrument that mainly has three major components, a high-speed edge pulse generator, a sampling oscilloscope with 50ohm input option and a resistive splitter. A relative low-cost TDR had been implemented by using a 10ps Falling Edge Pulse Generator which designed by myself, a SMA T piece and a Tektronix 1Ghz bandwidth MDO3104 Mixed Domain Oscilloscope.



First stage 100ps Falling Edge Pulse Generator

TDR technology can be used in multi domains, such as measuring soil moisture, dielectric properties of liquid, etc. In electrical industry, TDR is usually used to measure the impedance line on the PCB which assuring the PCB stack-up and the accuracy of the PCB microstrip lines.

Part II: Impedance measurement using TDR



Reflection Coefficient:

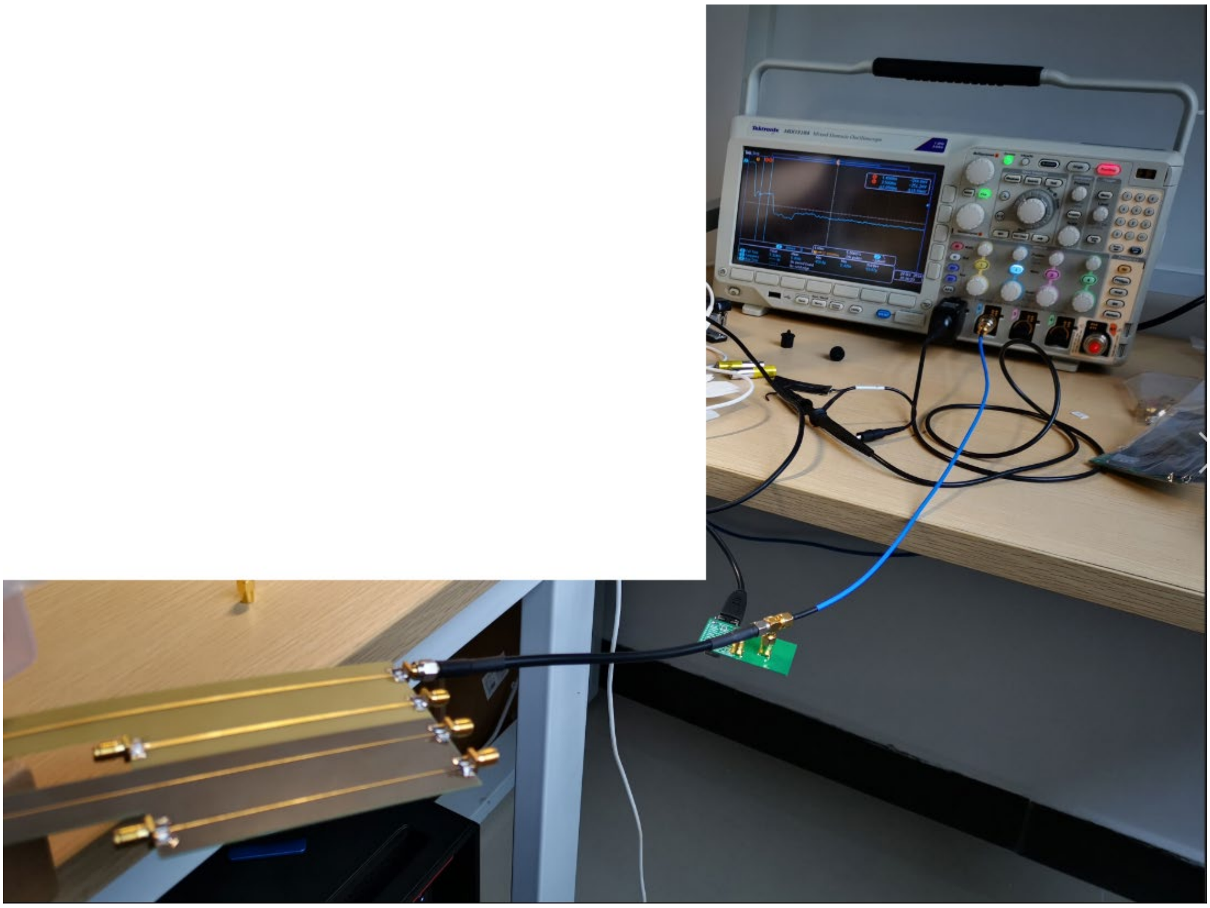
$$\rho = \frac{Vr}{Vi} \tag{1}$$

ρ: How much was reflected.

Impedance calculated from source impedance and reflection coefficient:

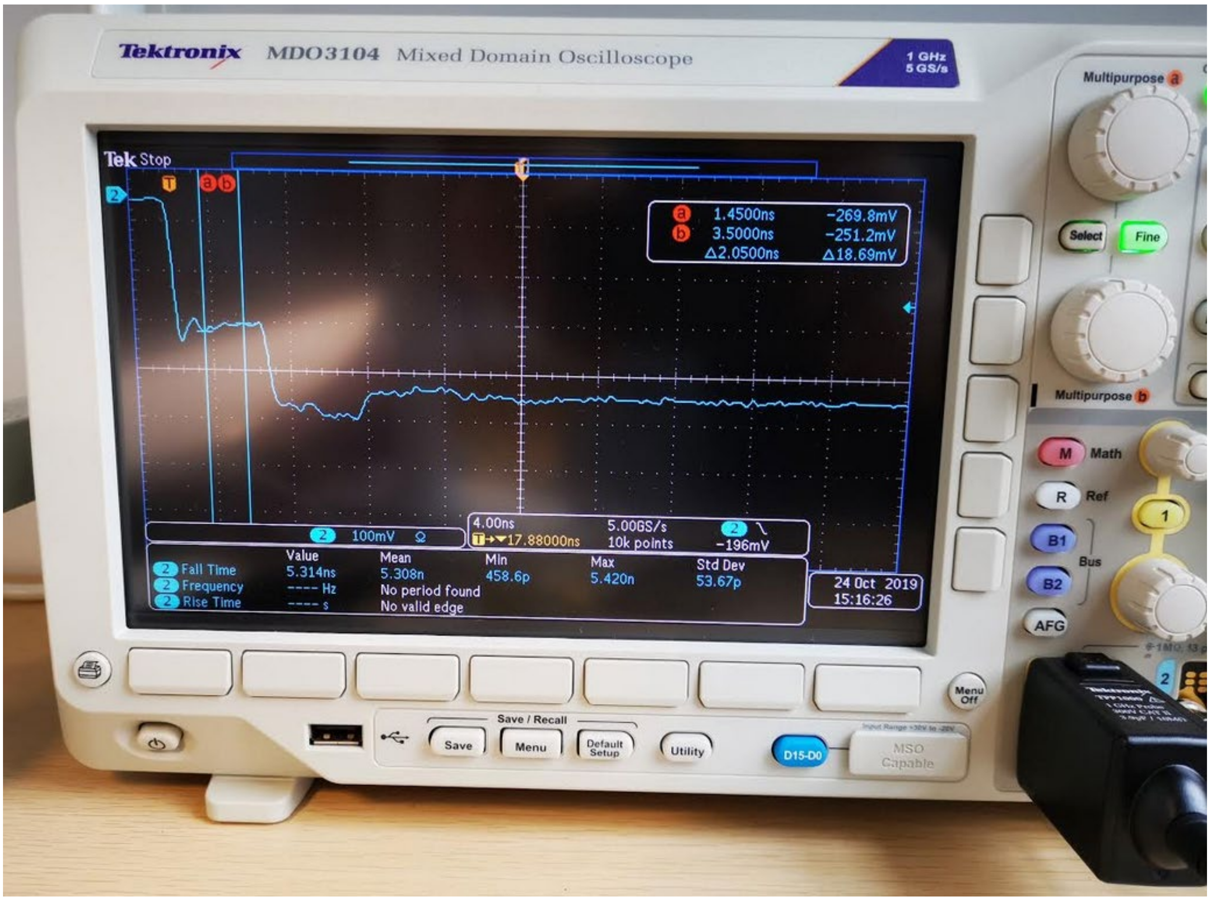
$$ZL = Z0\frac{1+\rho}{1-\rho} \tag{2}$$

Measurement Example:



Instrument Setup

Set the input impedance of the oscilloscope to be 50 Ohm. And then, configure the oscilloscope to the falling edge trigger mode and set the trigger close to the left side of the screen. The result should be similar as the following picture.



TDR result

The point at cursor “a” is -E/2 and the point at cursor “b” is Vr, thus:

Vi=-269.8mV

Vr=-251.2-(-269.8)=18.6mV

$$\rho = \frac{Vr}{Vi} = -0.06893995552$$

$ZL = Z0 * \frac{1+\rho}{1-\rho} = 50 * \frac{1+(-0.06893995552)}{1-(-0.06893995552)}$ =43.55062411 Ohms

Part III: Dielectric constant measurement using TDR

The relationship between the velocity factor and the dielectric constant is:

$$Vf = \frac{1}{\sqrt{Dk}} \qquad (3)$$

The relationship between the one-way time, trace length and the velocity factor is:

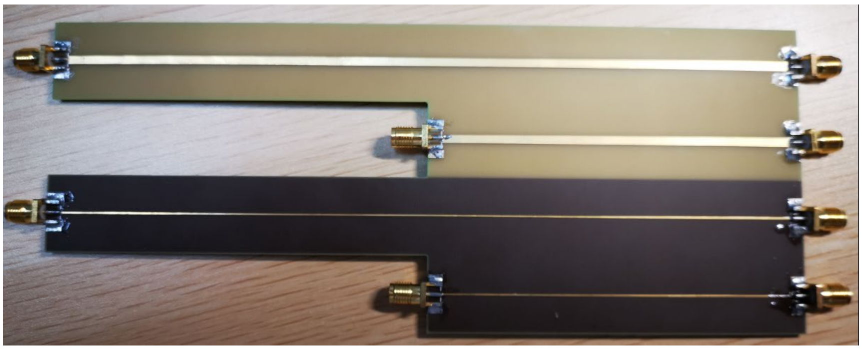
$$One\ Way\ Time = \frac{length\ in\ meter}{Vf*3*10^8\ in\ m/sec} \qquad (4)$$

$$One\ Way\ Time\ = \frac{Round\ Way\ Time\ in\ second}{2} \qquad (5)$$

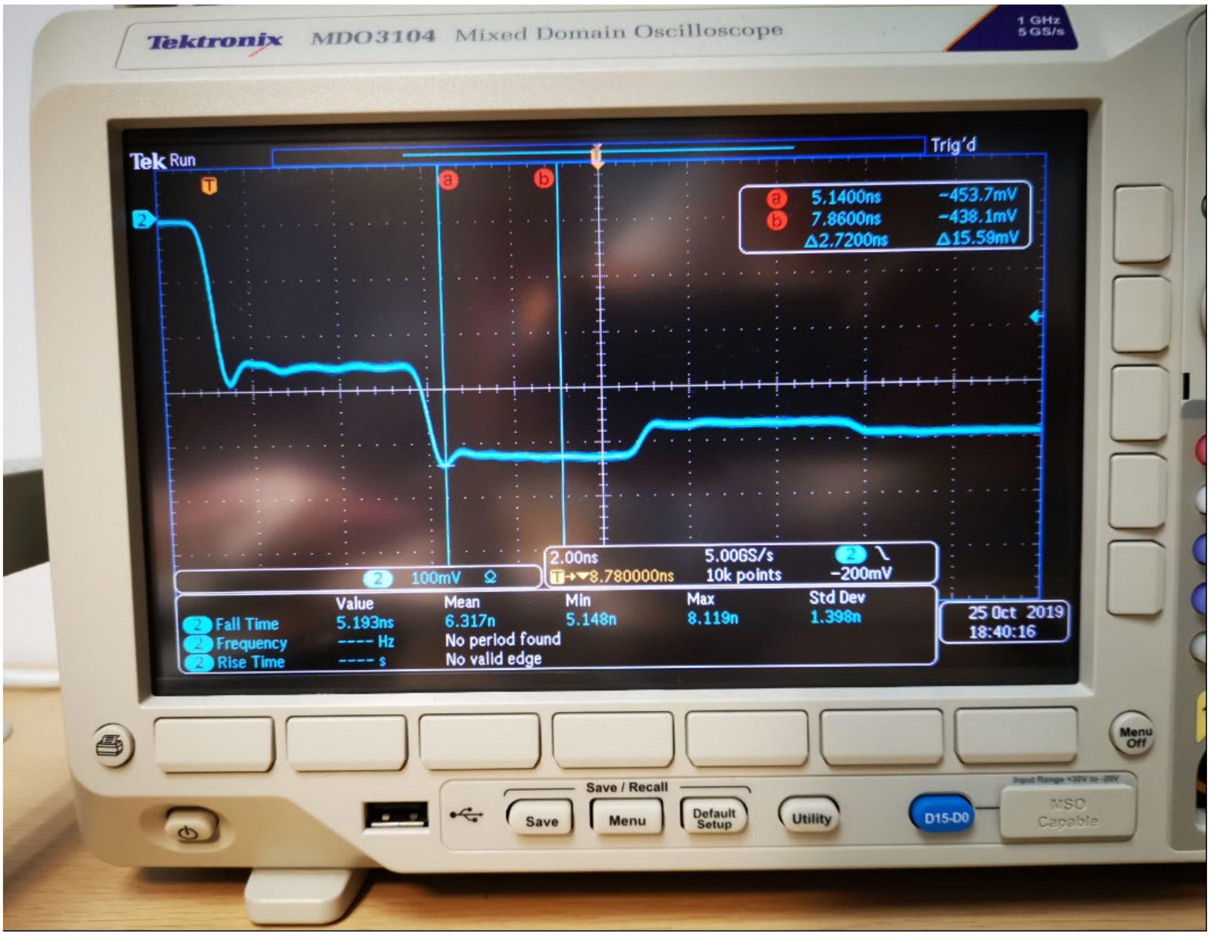
According to the equations (3), (4) and (5):

$$Dk = \frac{2.25*10^{16}*(Round\ Way\ Time\ in\ Second)^2}{(Length\ in\ Meter)^2} \qquad (6)$$

Measurement Example:

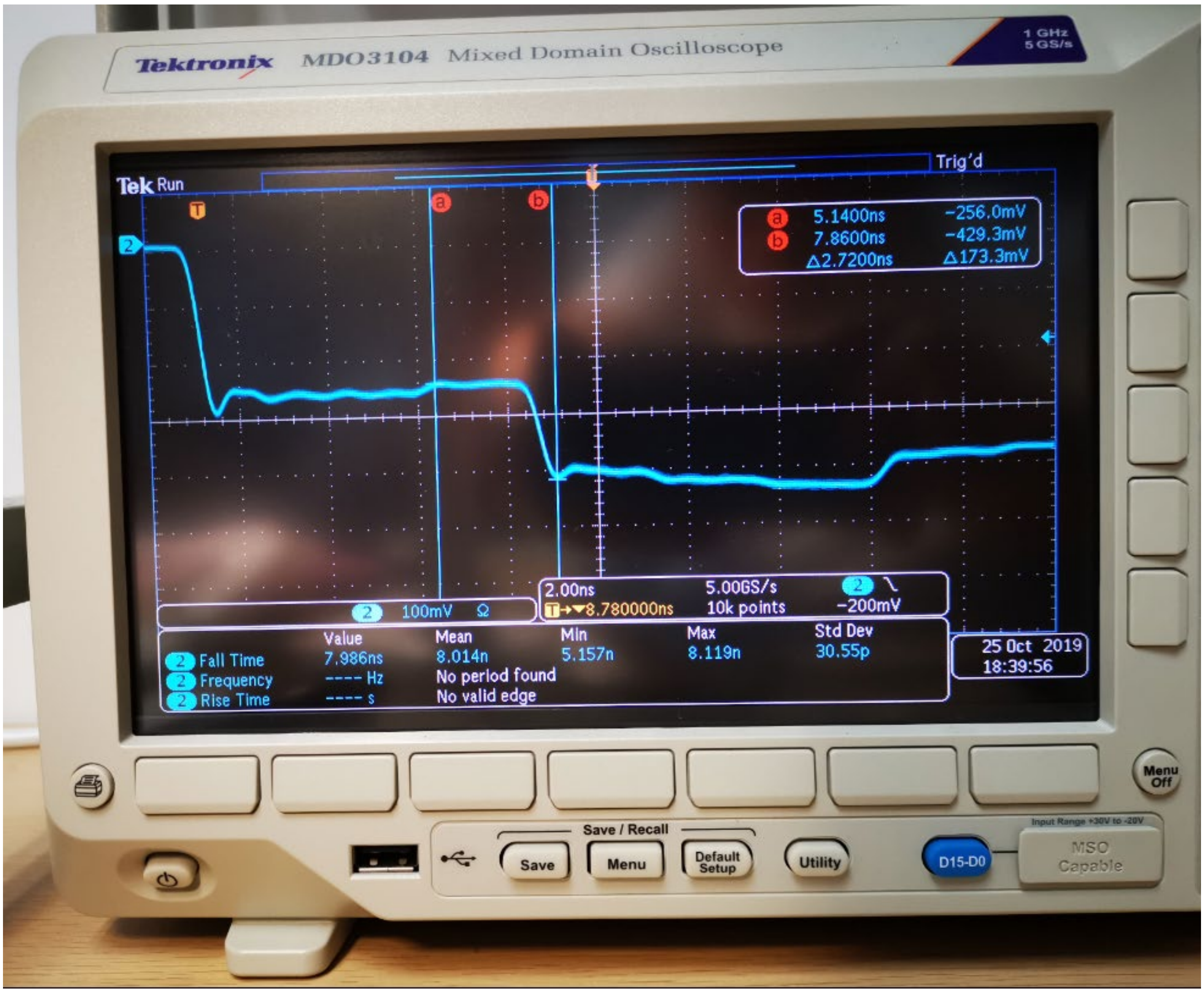


Impedance traces, the first 20cm trace is used in this example



TDR result without DUT

The point at cursor “a” is the starting point for the round way trip of the falling edge.



TDR result with DUT

The point at cursor “b” is the ending point for the round way trip of the falling edge.

Round Way Time = 2.72ns = $2.72 * 10^{-9}$ s

The Length is 0.2 m

Thus,

$$Dk = \frac{2.25 * 10^{16} * (Round\ Way\ Time\ in\ Second)^2}{(Length\ in\ Meter)^2}$$

$$= \frac{2.25*10^{16}*(2.72*10^{-9})^2}{(20*10^{-2})^2}$$

$$= 4.1616$$

Part IV: Velocity factor measurement using TDR

According to the equation (3):

$$Vf = \frac{1}{\sqrt{Dk}}$$

We already know that the Dk is 4.1616, thus

$$Vf = \frac{1}{\sqrt{4.1616}} = 0.4901937226$$

Part V: References

[1] TDR, S-Parameters & Differential Measurements. Retrieved Nov 05, 2019, from https://www.keysight.com/upload/cmc_upload/All/TDR_S-Parameters_Differential_Meas-0906.pdf