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Low Frequency TDR for Measurement of Cable Length

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Abstract - A Time Domain Reflectometer (TDR) is developed using a Digital Storage Oscilloscope having sampling rate of 200MHz, data storing capacity of 2000 data points for a single waveform and a pulse generator with rise time of nearly 5ns. Several different coaxial transmission lines (cables) have been used to measure their length using this TDR. The length of transmission line is measured using given VOP of transmission line and the time taken to travel through it. This measured value was found same as the actual length of cable under measurement.

Index Terms - *Cable Length, Impedance, Pulse generator, TDR, VOP*

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I. Introduction

TDR is generally used for remote sensing electrical measurement to determine the nature of different reflectors. The working principle of TDR is similar to radar that consists of a directional antenna and a sensitive radio frequency receiver with transmitter which emits a short pulse of electromagnetic energy. The time between the transmitted and reflected pulse and speed of light is used to find the length of cable.

TDR is used for different applications such as to identify bridged taps, wet sections, load coils, shorts, opens, and splices on copper cabling [1-4]. It is also used to find the fault in cables, length of cable, dielectric constant of different samples, electrical conductivity of different liquids, reflection coefficient, etc.[5-6] These TDRs are working at higher frequency range nearly more than 10GHz. Due to this higher range of working, they have higher cost. So it is not possible for all researchers to use them frequently for finding the different properties as mentioned above. So a low frequency TDR that works at frequency up to 1GHz is developed to find the length of cable. This TDR includes a DSO of 200MHz, a pulse generator circuit, SMA connectors and a cable.

II. Principle of TDR

A TDR system consists of a pulse generator providing a step increase in voltage with a very fast rise time and a fast oscilloscope that captures the waveform reflected from the transmission line under test. TDR is based on the transmission line theory in the time domain that aids in the study of heterogeneities in coaxial lines based on change of the shape of a test signal [7-10]. In this case, the signal is partially reflected from the interface and partially passes through it. The amount of energy reflected is a function of the transmitted energy and the magnitude of the impedance change. The time lapse between energy transmission and the reflection is a function of the distance from the source to the impedance discontinuity and the energy's propagation velocity that helps in finding the fault as well as the length of the cable.

The cable under test is connected to TDR and the waveform is recorded and stored using the DSO. The length of the cable is measured using VOP of the cable and total travel time through cable. The simplified block diagram of the TDR setup is shown in figure 1.

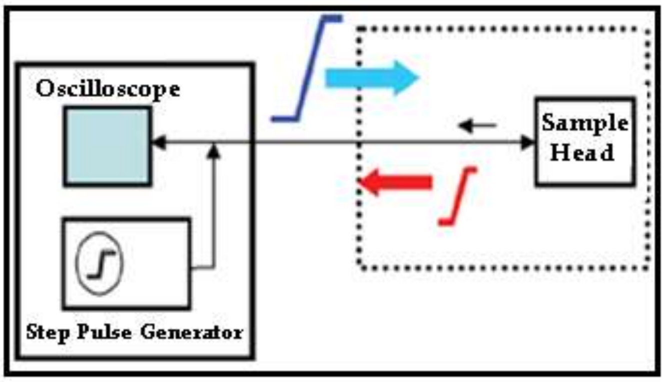


Figure 1: Block diagram of TDR

III. Development of TDR

The major part to develop TDR is a pulse generator having very fast rise time and impedance matching of cables and connectors. So a pulse generator is made using an IC and some peripheral components to get the rise time of nearly 5ns. A TDR is developed using this pulse generator along with a higher sampling rate oscilloscope, transmission line and connectors (BNC and SMA) of matched impedance.

A DSO with sampling rate of 200 MHz is used to display and store the reflected and incident pulse. The reflected pulse for different waveforms during test is digitized with 2000 points in a time window of 10ns for analysis [11-12].

IV. Selection of Transmission Line and Connector

Several coaxial cables have been tested and finally a transmission line "Prime RG 58 C/U coaxial cable 50Ω" is selected and used in developed TDR. It is observed using waveform that the impedance of ordinary connectors apart from MX connector was showing distortion in reflected waveform. So the matching impedance connectors (SMA and BNC) are used in this system. The image of the developed TDR is shown in figure 2. This TDR is used to measure the length of different cables as explained in this paper.

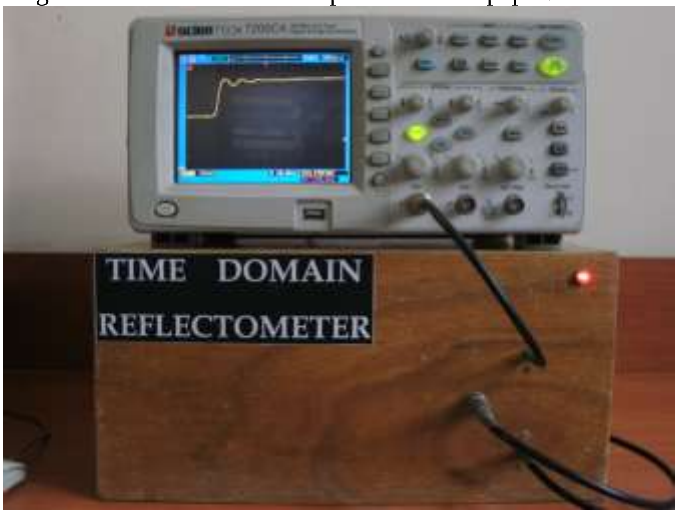


Figure 2: Image of Developed TDR

V. Measuring Impedance of Transmission Line and Load

A multi-turn variable resister (POT) is connected at the end of transmission line of TDR unit for impedance measurement. The measured impedance of transmission line is found nearly equals to 48Ω (i.e. $Z_0 \approx 48\Omega$). This obtained impedance of transmission line is used to calculate the load impedance for different load connected at the end of transmission line. Figure 3 shows V_0 and V_f which is used to calculate ρ.

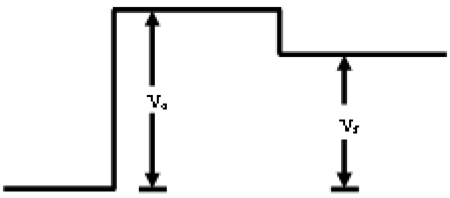


Figure 3: Vo and V_f of the waveform

The values of Z_L for developed TDR is calculated using following equation,

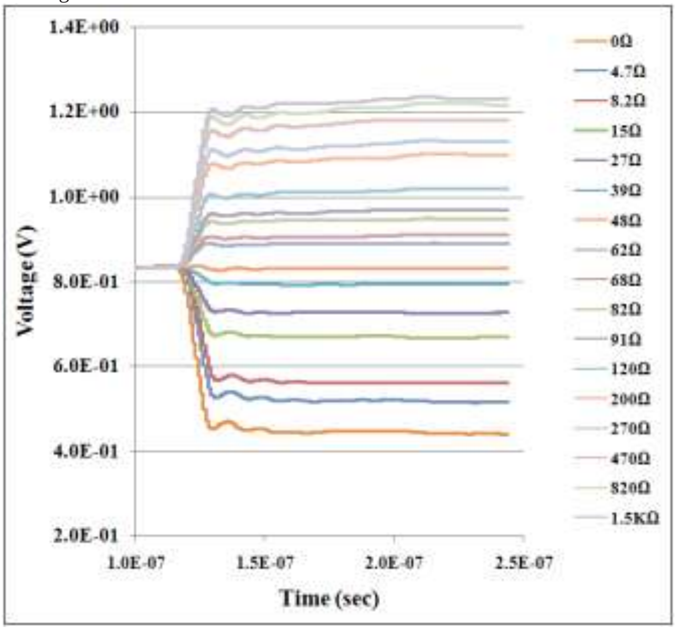
$$Z_L = Z_0 \times \frac{(1+\rho)}{(1-\rho)} \quad (1)$$

where,

$$\rho = \frac{V_f - V_o}{V_o} \quad (2)$$

Figure 4 shows the waveform obtained after connecting different value of resistors at the end of transmission line to find Z_0. The voltage reading for V_0 and V_f are recorded by connecting different load resistors. Table 1 shows the calculated values of ρ and Z_L using figure 4. A computer program is developed that calculates these values on the basis of waveform.

Figure 4: Different resistors connected at the end of transmission line



Resister (R)	V_o (mV)	V_f (mV)	ρ	Z_L (Ω)
0Ω	384	0.0	-1.0000	0.0000
4.7Ω	384	64	-0.8333	4.3636
8.2Ω	384	94	-0.7552	6.6944
15Ω	384	168	-0.5625	13.4400
27Ω	384	280	-0.2708	27.5410
39Ω	384	344	-0.1042	38.9434
48Ω	384	384	0.0000	48.0000
62Ω	384	440	0.1458	64.3902
68Ω	384	456	0.1875	70.1538
82Ω	384	504	0.3125	91.6364
91Ω	384	520	0.3542	100.6452
120Ω	384	572	0.4896	140.0816
200Ω	384	652	0.6979	269.7931
270Ω	384	682	0.7760	380.6512
470Ω	384	722	0.8802	753.3313
820Ω	384	752	0.9583	2256.00
1.5KΩ	384	762	0.9844	6096.00

Table 1: Calculated value of ρ and Z_L

VI. Measuring Length of Different Cables

Several cables have been tested and the result six cables which are generally available and used are tabulated in table 2. The waveform after connecting these cables is shown in figure 5 to 10. The length of these cables is calculated using equation (3) and it was found same as their actual length.

$$\text{Length of TDR Cable} = \frac{c \times V_p \times t}{2} \quad (3)$$

Where,

c = Velocity of light ($3x10^8$ m/s)
V_p = Velocity of Propagation (VOP)
t = Round trip time between onset pulse and first reflection

Figure 5 to 10 are the snap shots of the DSO screen showing the change in impedance of cable 1 to 6 respectively along with the time taken to travel through the added cable. The cursor is set at the starting of the reflected waveform and the cable is connected to measure the time period traveled by the wave through it. The second cursor is used to find the difference in time after connecting the cable.

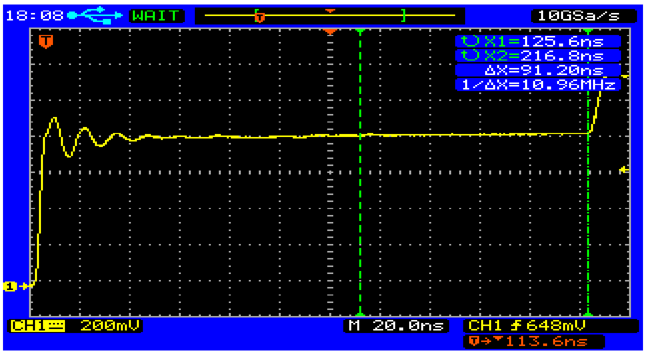


Figure 5: (Cable 1) - Prime RG 58 C/U Coaxial Cable 50Ω

Figure 5 shows a straight line even though the cable is connected. This is due to reason that the added cable and the used cable in the TDR are same. So there is no mismatch in impedance but a small change close to first cursor can be observed due to a joint between two cables.

The travel time through cable 1 is t = 91.20ns which is shown by DSO as ΔX = 91.20ns in figure 5.

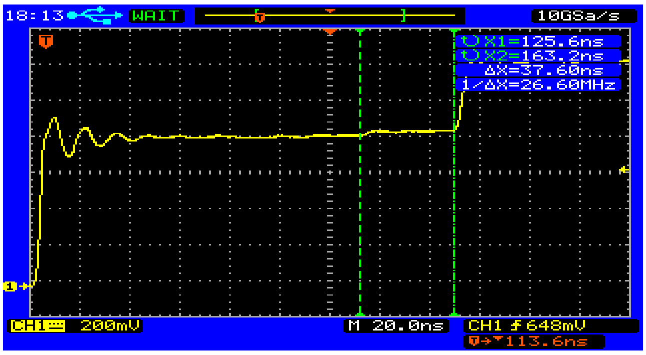


Figure 6: (Cable 2) - MX Technologies RG 58/U Digital Fully Shield

The travel time through cable 2 is t = 37.6ns which is shown by DSO as ΔX = 37.6ns in figure 6.

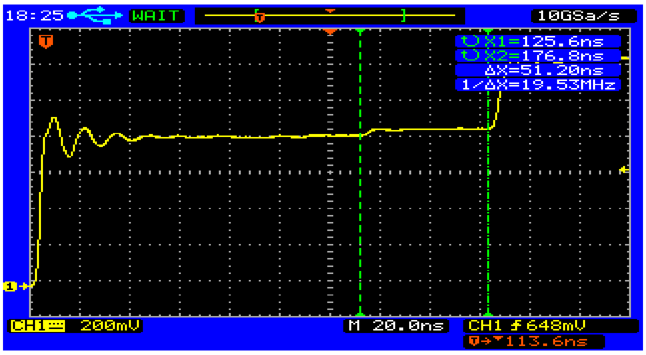


Figure 7: (Cable 3) - Prime RG 58 C/U Coaxial Cable 50Ω

The travel time through cable 3 is t = 51.20ns which is shown by DSO as ΔX = 51.20ns in figure 7.

Cable 1 and 3 have the same label but the impedance these cable is different due to the difference in their VOP as mentioned in Table 2.

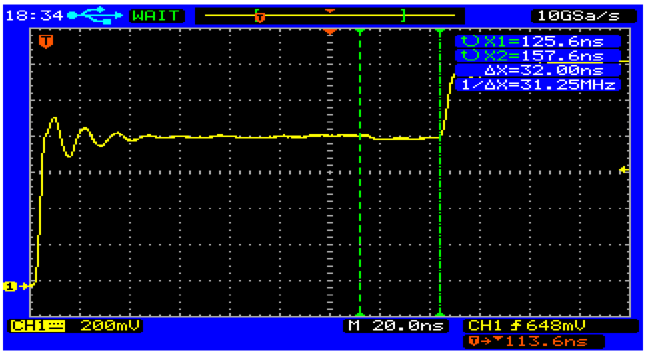


Figure 8: (Cable 4) - Prime (14/36) 4mm Coaxial Cable

The travel time through cable 4 is t = 32.00ns which is shown by DSO as ΔX = 32.00ns in figure 8.

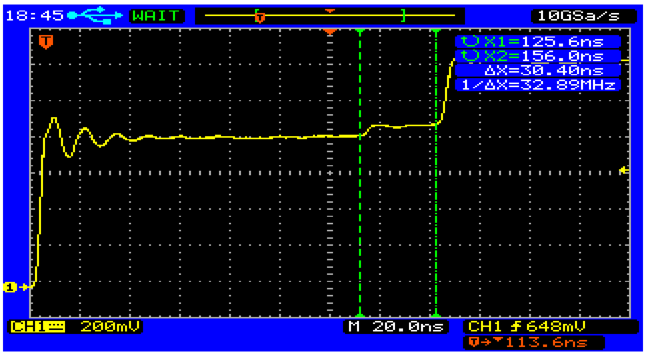


Figure 9: (Cable 5) - SATYAM RG 59 Coaxial cable 50Ω

The travel time through cable 5 is t = 30.40ns which is shown by DSO as ΔX = 30.40ns in figure 9.

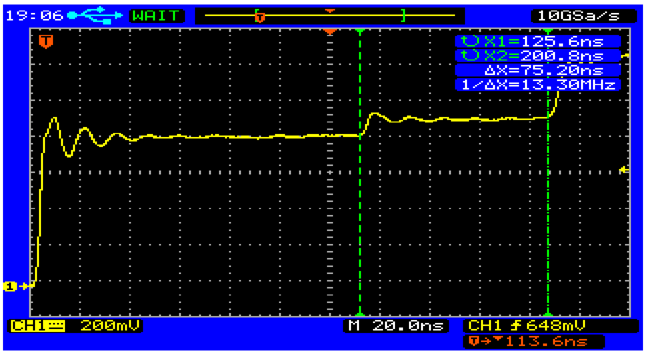


Figure 10: (Cable 6) - YJ52818-75 DHM RG6

The travel time through cable 6 is t = 75.20ns which is shown by DSO as ΔX = 75.20ns in figure 10.

Table 2 shows the label (printed name) on the cable, their VOP, calculated and actual length of the measured cables. The length of the cable is measured using equation 3 and it is compared with the actual cable length. The result is tabulated in this table which shows a good functioning of TDR.

Cable No.	Label on Cable	VOP of Cable	Calculated Length (in meter)	Actual Length (in meter)
1	Prime RG 58 C/U Coaxial Cable 50Ω	0.66	9.03	9.05
2	MX Technologies RG 58/U Digital	0.66	3.72	3.75
3	Prime RG 58 C/U Coaxial Cable 50Ω	0.68	5.22	5.26
4	Prime (14/36) 4mm Coaxial Cable	0.65	3.12	3.14
5	SATYAM RG 59 Coaxial cable 50Ω	0.69	3.15	3.16
6	YJ52818-75 DHM RG6	0.73	8.23	8.25

TABLE 2: CALCULATED LENGTH OF COAXIAL CABLES

VII. CONCLUSION

As shown in table, the measured and the actual length of the cable are found same. Also this TDR has shown any junction after addition of any cable with its impedance. This result shows that the developed TDR works properly and can be used for various applications.

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