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Low Impedance Measurement Using Indigenous Developed Time Domain Reflectometry

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***Abstract*—This paper explains the measurement of load impedance of a transmission line using a developed Time Domain Reflectometer (TDR). This TDR has the rise time of 5.6ns and consists of 60MHz DSO to store the digital data and observe the waveform on its screen. The open end of the transmission line of TDR is used to connect the different value of resistors and the voltage of waveform for each resistor is recorded using the cursor of DSO. The rho (ρ) is calculated using the incident and the reflected voltage. This rho value is used to find the impedance of the connected resistors which works as load impedance of transmission line. A best fitting polynomial equation obtained using the graph of this calculated load impedance vs reflected voltage can be used to determine the load impedance of any transmission line. This TDR can measure the load impedance of transmission line between 0Ω to 180Ω.**

Keywords—amplitude, impedance, pulse generator, TDR, transmission line

I. INTRODUCTION

An electronic components and the material which is used to develop these components can be characterized by a parameter which is known as impedance. It is the total opposition that a circuit or device offers during flow of an alternating current [1-3]. This impedance is also related to the transmission line and there are different ways for measuring the impedance at high degree of precision [4-5]. One more method for the measurement of this impedance is the use of Time Domain Reflectometer (TDR). In this method, the reflected wave helps in determination of electrical properties such as the open and short location in transmission line (cable), characteristic or load impedance in cable etc [6-8]. Seeing the importance of this impedance measurement, a TDR is developed and used to determine the impedance of transmission line.

II. WORKING OF TDR

Time Domain Reflectometer (TDR) works on the principle of RADAR and displays the voltage waveform that returns when a fast step signal is propagated down a transmission line. The resulting waveform is the combination of the incident pulse and reflected pulse which is generated when the step signal encounters impedance change in its path of travel [9-11].

Figure 1 shows the image of developed TDR. This TDR is developed using the entire basic requirement like fast rise time pulse generator, Digital Oscilloscope, Impedance matching transmission line and connectors. The rise time of this system is 5.6ns and the DSO has sampling rate of 60MHz which can store 600 digital points for single waveform.

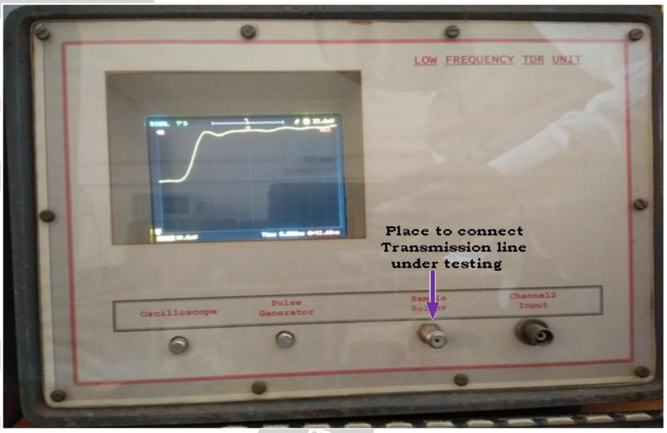

Fig. 1. **Image of developed TDR**

Reflection Coefficient

The TDR measurements are described in terms of a Voltage Reflection Coefficient, ρ (rho). It is the ratio of reflected voltage (Vr) to the incident voltage (Vi) and is represented [12,13] using equation (1).

$$\rho = \frac{V_r}{V_i} \quad (1)$$

Figure 2 shows the incident (Vi) and reflected (Vr) waveform of a transmission line having load impedance less than the transmission line used in developed TDR.

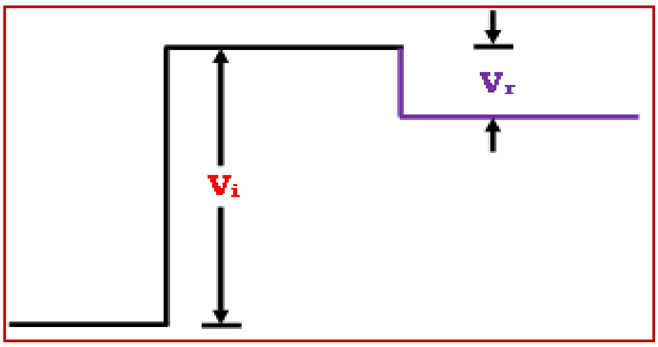

Fig. 2. **Incident and Reflected waveform on TDR**

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The Reflection Coefficient (ρ) can also be expressed in terms of the transmission line characteristic impedance (Z_0) and load impedance (Z_L) and given as,

$$\rho = \frac{V_r}{V_i} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \textbf{(2)}$$

Case 1: When Z_L is equal to Z_0, it indicates that the load impedance is matched with the characteristic impedance of the transmission line. So, there will not be any reflected wave and the value of ρ becomes 0.

Case 2: When Z_L is equal to 0, it indicates the short circuit. In this case, the reflected wave will be equal to the incident wave with opposite polarity and the value of ρ becomes -1.

Case 3: When Z_L is equal to ∞, it indicates an open circuit. In this case, the reflected wave will be equal to the incident wave with same polarity and the value of ρ becomes +1.

So the value of ρ ranges between +1 to -1.

Equation (3) can be modified to make for simplicity of the measurement of incident voltage and reflected voltage on DSO for the users. The modified equation is given as,

$$\rho = \frac{V_f - V_o}{V_o} \quad \textbf{(3)}$$

Figure 3 shows the incident (Vo) and reflected (V_f) waveform of a transmission line having load impedance less than the transmission line used in developed TDR.

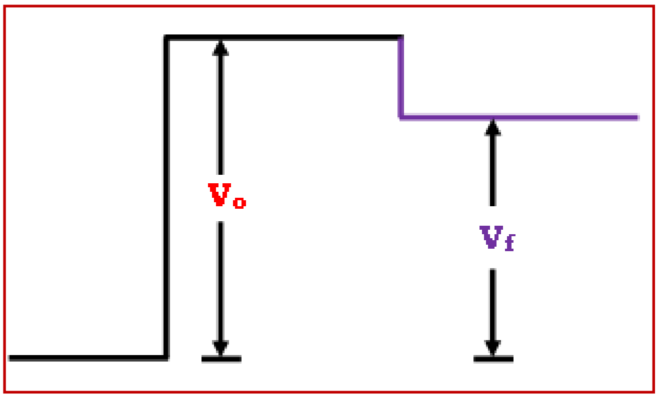

Fig. 3. **Different way of measuring Reflected waveform on TDR**

Impedance of Transmission Line and Load

Apart from the several ways to find the impedance of transmission line, the easiest one is to connect a small variable resistor across the open end of the cable and adjust it so that there is no reflection. Now disconnect the variable resistor and measure the value using multimeter. This measured value is equal to the characteristic impedance (Z_0) of transmission line. This calculated value was found to be equal to 75Ω. At this point of measurement, the characteristic impedance Z_0 is equal to the load impedance (Z_L).
The load impedance of the transmission line can be calculated using equation (4).

$$Z_L = Z_0 \times \frac{(1+\rho)}{(1-\rho)} \quad \textbf{(4)}$$

III. WAVEFORMS FOR DIFFERENT LOADS

This developed TDR is used to determine the load impedance of transmission line using the reflected waveform technique. In this technique, different values of resistors are connected one after other and the change in reflected voltage (V_f) is recorded for all. Some resistors are used as single one and some are connected in series to get the required value. Figure 4 shows the nature of reflected waveform of short ended transmission line. Some unwanted reflections have been observed due to different types of connectors used in development. The display shows V_f = 36.8mV (or Vr = -36.8mV) for the short ended transmission line.

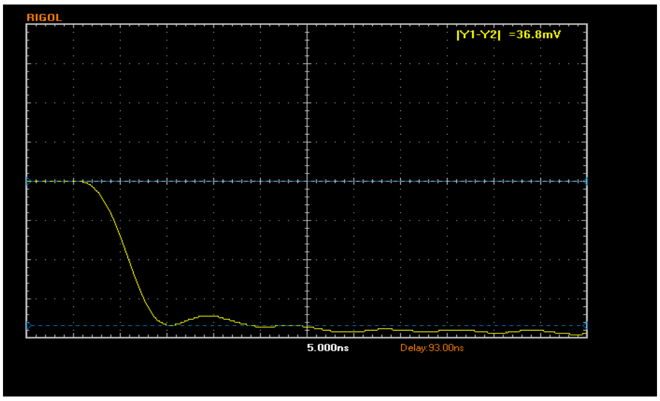

Fig. 4. **Voltage of reflected waveform with short end**

Figures 5 to 10 show the change in reflected voltage due to connection of different values of resistors at the end of transmission line.

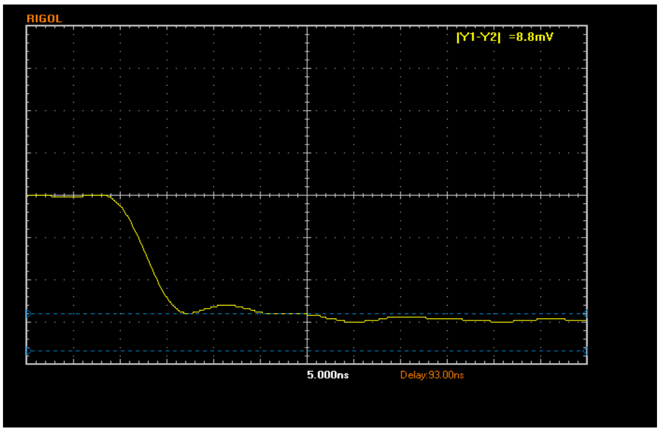

Fig. 5. **Voltage of reflected waveform with 10Ω resistor**

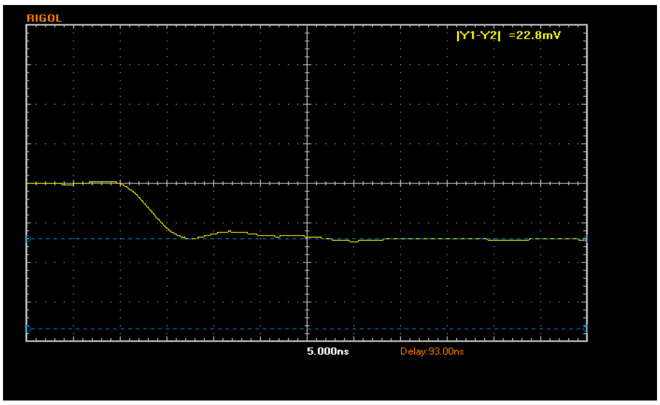

Fig. 6. **Voltage of reflected waveform with 33Ω resistor**

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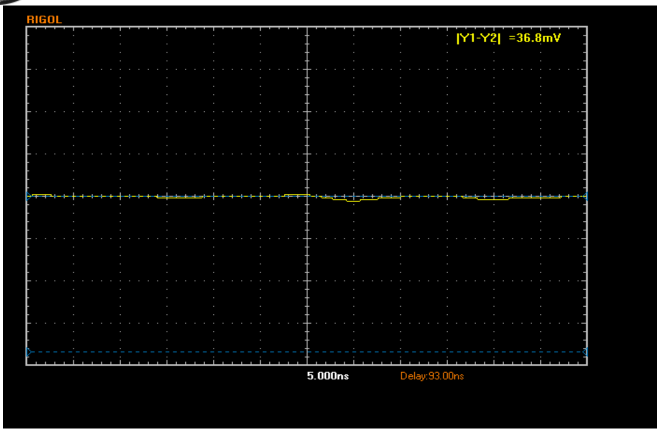

Fig. 7. **Voltage of reflected waveform with 75Ω resistor**

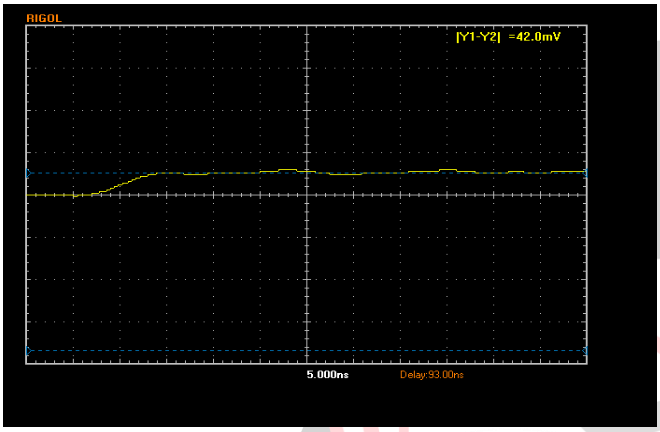

Fig. 8. **Voltage of reflected waveform with 100Ω resistor**

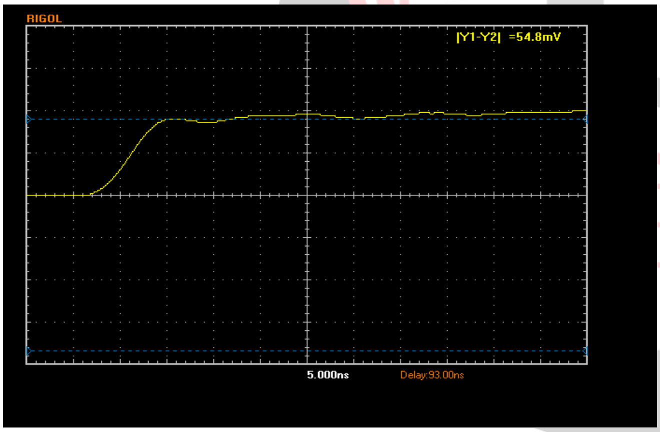

Fig. 9. **Voltage of reflected waveform with 227Ω resistor**

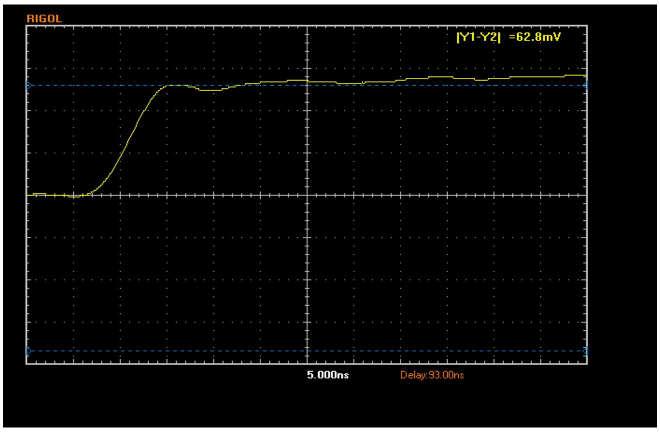

Fig. 10. **Voltage of reflected waveform with 470Ω resistor**

Figure 5, 6 and 8 to 10 shows the mismatch in characteristic impedance of transmission line due to connected load resistor. The ρ values in all these case are non zero. This indicates that the ohm value of load resistor and the characteristic impedance of transmission line are different. But figure 7 shows a straight line which indicates the matching impedance of transmission line with connected load resistor. As the value of connected resistor is 75Ω and the calculated value of ρ = 0 so the characteristic impedance of cable is 75Ω.

Figure 11 shows the voltage of reflected waveform when the end of transmission line is kept open. The value of Vr was found same with opposite sign (Vr = 36.8mV or V_f = 73.6mV) as compared to reflected voltage of short ended transmission line.

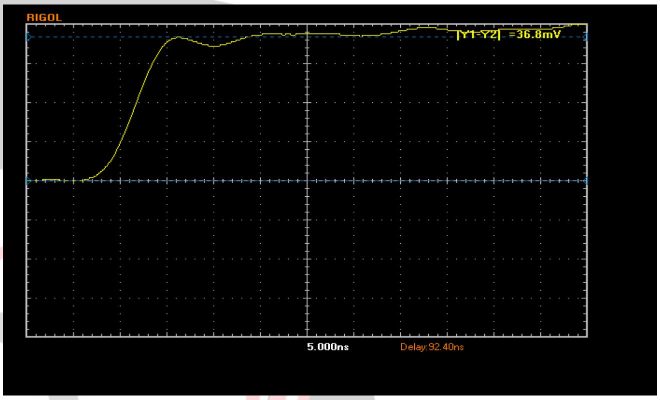

Fig. 11. **Amplitude of reflected waveform with open end**

IV. RESULT AND DISCUSSION

The value of V_f is recorded using the cursors of used DSO in TDR for every connected resistors at the end of transmission line. This recorded value of V_f is used to calculate the values of reflection coefficient (ρ) and load impedance of transmission line (Z_L) using equations 3 and 4. The table 1 shows used resistors, recorded value of V_f, the calculated value of reflection coefficient (ρ) and load impedance of the transmission line (Z_L) using the developed TDR.

TABLE I. CALCULATED VALUES OF ρ AND Z_L FOR DIFFERENT VALUES OF REFLECTED VOLTAGE

Resistors	V_f (mV)	ρ	Z_L (Ω)
0Ω	0	-1.00	0.00
1Ω	1.2	-0.97	1.24
2.2Ω	2.4	-0.93	2.53
5.1Ω	4.8	-0.87	5.23
6.2Ω	5.6	-0.85	6.18
10Ω	8.8	-0.76	10.19
15Ω	12	-0.67	14.61
33Ω	22.8	-0.38	33.66
39Ω	25.2	-0.32	39.05
47Ω	28.8	-0.22	48.21
56Ω	31.2	-0.15	55.19
62Ω	33.2	-0.10	61.63
68Ω	34.8	-0.05	67.27

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75Ω	36.8	0.00	75.00
82Ω	38.8	0.05	83.62
91Ω	40.4	0.10	91.27
100Ω	42	0.14	99.68
110Ω	43.6	0.18	109.00
120Ω	45.2	0.23	119.37
130Ω	46.8	0.27	130.97
139Ω	48	0.30	140.63
147Ω	48.8	0.33	147.58
156Ω	49.6	0.35	155.00
162Ω	50.4	0.37	162.93
180Ω	52	0.41	180.56
200Ω	53.2	0.45	195.59
227Ω	54.8	0.49	218.62
282Ω	57.2	0.55	261.59
470Ω	62.8	0.71	436.11
820Ω	66	0.79	651.32
1.5KΩ	68.4	0.86	986.54
2.2KΩ	70	0.90	1458.33
3.3KΩ	71.2	0.93	2225.00
4.7KΩ	72.4	0.97	4525.00
5.1KΩ	72.8	0.98	6825.00
5.6KΩ	72.8	0.98	6825.00
6.8KΩ	72.8	0.98	6825.00
8.2KΩ	72.8	0.98	6825.00
15KΩ	72.8	0.98	6825.00
27KΩ	72.8	0.98	6825.00
120KΩ	72.8	0.98	6825.00
560KΩ	72.8	0.98	6825.00
820KΩ	72.8	0.98	6825.00
1MΩ	72.8	0.98	6825.00
2.2MΩ	72.8	0.98	6825.00
4.7MΩ	72.8	0.98	6825.00
Open	73.6	1.00	∞

The calculated value of Z_L is approximately equal to the used value of connected load resistor value up to 180Ω as shown in table 1. The load impedance beyond this range cannot be determined accurately using this developed system due to slow rate of change in reflected voltage.

A graph of Z_L vs V_f is plotted and the values are fit using a polynomial equation of order 4 as shown in figure 12. The obtained equation is given in equation (5).

$$y = 3.70339e\text{-}5\times x^4 - 0.00223\times x^3 + 0.07083\times x^2 + 0.57065\times x + 0.72158 \quad \textbf{(5)}$$

and

$R^2 = 0.99991$

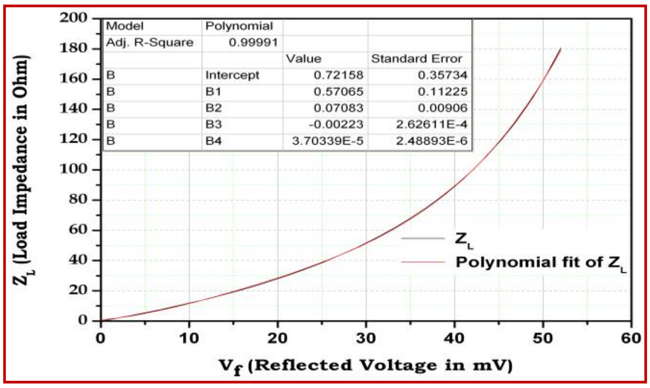

Fig. 12. **Graph of Z_L vs V_f**

Some different impedance value cables have been tested and their calculated values were found to be approximately same as given by its datasheet. Figure 13 shows the waveform obtained after connecting a 50Ω cable with this TDR.

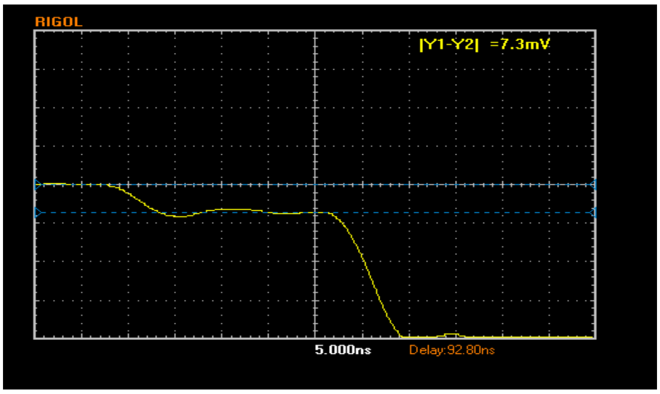

Fig. 13. **Voltage of reflected waveform of 50Ω cable**

As the value of reflected voltage (V_r) shown by the display is 7.3mV so V_f = 36.8mV – 7.3mV = 29.5mV. Equation 5 is used to calculate Z_L with V_f = 29.5mV. The calculated value of Z_L is 49.99328Ω which is approximately same as its actual value.

V. Conclusion

The obtained value of V_f for any transmission line can be used to determine the characteristic and load impedance of that transmission line using this developed TDR. As the calculated value of Z_L is approximately same in the range of 0Ω to 180Ω so the load impedance of transmission line between this ranges can be determined using the used reflected waveform technique. The TDR can also be used to find the different types of faults in cables based on the nature of reflected waveform.

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