RS-485

How to Determine the Length and Characteristic Impedance of a Data Transmission Cable

Abstract

Cost reduction efforts in RS-485 networks can motivate network designers to switch from high-quality RS-485 cable to less costly CAT-5 cable. To ensure the new cable is correctly terminated to prevent signal reflections, the engineer must know its length and characteristic impedance. This application note shows a simple procedure to measure and calculate this information.

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1. Introduction

The measurement concept is straight forward and is based on the transmission line principle.

In data transmission a cable or conductor is said to be a transmission line when the signal rise time (t_r) is much shorter than its propagation time (t_P); which is the time it takes a signal wave to travel from its source to a remote cable end. Here, a cable represents two parallel conductors, twisted or straight.

Each cable has a so-called characteristic impedance, Z_0.

- If the cable is terminated with a resistor (R_T) whose value matches Z_0, the energy of the wave is absorbed by the resistor and no reflection occurs.
- If the cable end is open, a positive reflection of the signal occurs that travels back to the signal source.
- If the cable end is shorted, a negative reflection occurs, traveling back to the source.

The propagation time is the ratio of cable length to signal speed or velocity, V: $t_P = L_{CABLE}/V$.

The velocity of a transmission cable is commonly expressed through the velocity factor (v), which defines velocity as a percentage of the speed-of light, c ($3 \cdot 10^8$m/s): $V = c \bullet v$.

Inserting this velocity term into the above t_P equation and solving for the cable length gives:

(EQ. 1) $$L_{CABLE} = t_P \bullet c \bullet v$$

Example: The velocity factor of the common CAT-5 Ethernet cable is specified with v = 0.64. If a signal takes 100ns to propagate through a CAT-5 cable of unknown length, the calculated cable length is:

$$L_{CAT5} = 100 \times 10^{-9} s \bullet 3 \times 10^{8} m/s \bullet 0.64 = 19.2m(63ft)$$

2. Measurement Procedure

To measure t_P, use a generator that can produce a single pulse of about 1ns rise time and 10ns to 20ns pulse length. Connect the generator output using Coax cable to the scope using a BNC-T connector (Figure 1).

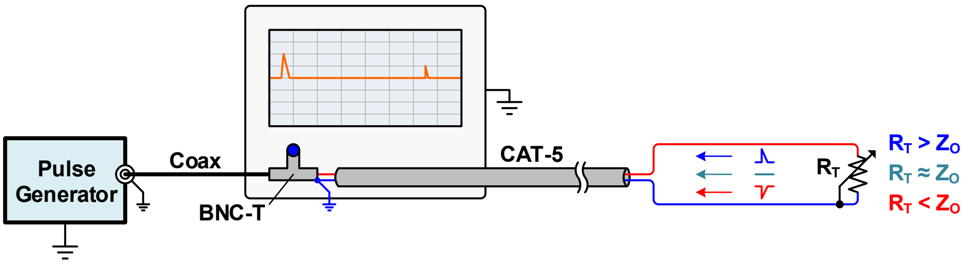

Figure 1. Setup to Measure Cable Length and Characteristic Impedance

Connect the CAT-5 cable to the other end of the BNC-T by connecting one conductor of a signal pair to the center and the other conductor to the outer shell of the BNC-T, which is grounded using the oscilloscope (Figure 2).

Figure 2. BNC-T Connections

Leaving the far cable end open causes a positive signal reflection that travels back to the source and appears as a short positive spike on the scope screen. If it does not, increase the scope time base until you see it.

Figure 3 shows the reflected positive pulse occurring about 80ns after the initial pulse, which is measured from pulse start to pulse start, not from peak to peak.

Note: The 80ns is twice the propagation time as the pulse travels to the cable end and back before appearing on-screen. Therefore, the calculated length is twice the cable length. Hence:

(EQ. 2) $$L_{CAT5} = \frac{80 \times 10^{-9}s \bullet 3 \times 10^{8} m/s \bullet 0.64}{2} = \frac{15.4m}{2} = 7.68m(25.2ft)$$

which is close enough to the actual cable length of 25ft.

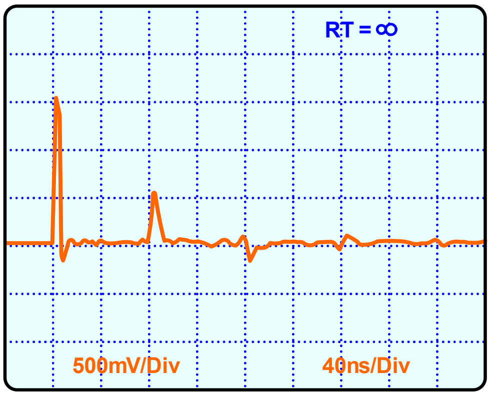

Figure 3. Reflection - Open Cable End

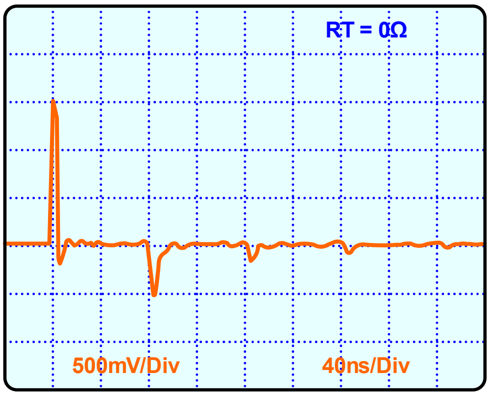

Figure 4. Reflection - Shorted Cable End

Shorting the cable end causes a negative reflection to occur after the same roundtrip time (Figure 4). **Note:** There are many smaller pulses following because of the signal reflecting at both cable ends. However, it is the time until the first reflected pulse occurs that represents the roundtrip delay.

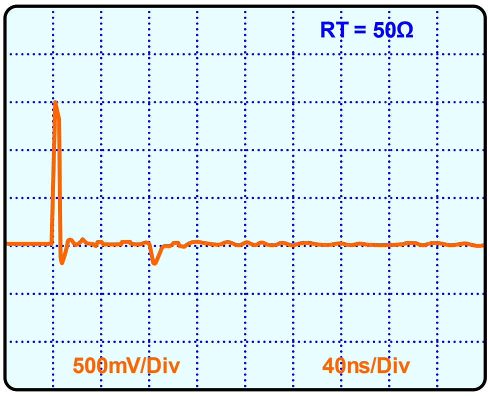

Figure 5. Reflection - Under-Terminated Cable End

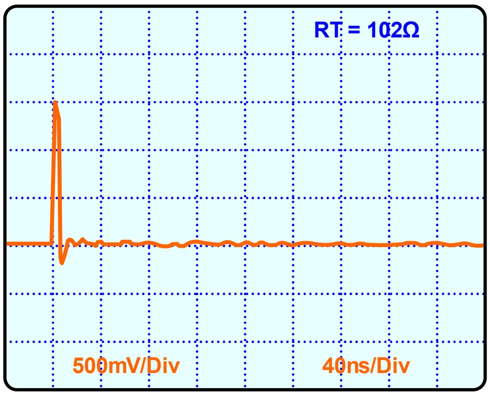

Figure 6. No Reflection - Correctly Terminated Cable End

Terminating the cable with a 50Ω resistor still causes a negative reflection, although of much smaller pulse height (Figure 5). To find the termination resistance that matches the characteristic cable impedance, connect a 200Ω potentiometer at the cable end and tune it until no reflections occur. Then take the potentiometer and measure its resistance with an ohmmeter. In this case, the measured resistance is 102Ω, which is well within the Z_0 range of 100Ω ±15Ω specified for CAT-5.

3. Conclusion

This measurement procedure is commonly applied to Coax cable. This application report; however, demonstrates that it can be also applied to twisted pair cable.

4. Revision History

Rev.	Date	Description
1.00	Jul.29.20	Initial release

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