TN-005 Technical Note

Time Domain Reflectometry with Acquitek CH Boards

Time Domain Reflectometry (TDR) is a technique used to measure the characteristics of electromagnetic transmission mediums, e.g. electrical cables. Any discontinuity in the characteristic impedance of the cable will generate a reflection. With TDR, a signal is injected into the cable, and then the cable is observed to detect the reflected signal. The time required for the signal to reach the discontinuity, and then for the reflection to return to the receiver is measured. Given the known speed of light – 300e6 m/s in free space, or 200e6 m/s in a typical cable - the distance to the discontinuity can be computed.

The magnitude of the reflection, or reflection coefficient (Γ), is related to the magnitude of the impedance discontinuity as follows, where Z_d is the discontinuity impedance and Z_o is the characteristic impedance of the cable:

$$\Gamma = \frac{Z_d - Z_o}{Z_d + Z_o} \qquad (1)$$

Voltage Standing Wave Ratio (VSWR) and Return Loss are other common terms for expressing the severity of the reflection. Return loss is conceptually simple – it is simply the ratio of the reflected power to the incident power, or:

R.L. = 20*log10(Γ) (2)

An explanation of VSWR is beyond the scope of this Tech Note, but:

$$\text{VSWR} = \frac{1 + \Gamma}{1 - \Gamma} \qquad (3)$$

The largest reflections are caused by breaks or shorts in a cable, as can be seen by evaluating the formulas above with $Z_d = 0$ or $Z_d = \infty\Omega$

Thus, one common application of TDR is in measuring lengths of cable on reels, or measuring distance to a break in a cable in a deployed system, e.g. to expedite repairs in CATV or telephony.

Similar to radar or sonar, the design of the TDR signal ranges from simple to extremely complex depending upon the requirement of the system to be deployed in terms of cost, complexity, accuracy, etc. However, given the extremely fast speed of light, it is important to precisely determine the edge of the reflection in order to make accurate distance measurements. With a simple pulse, the sharpness of the edge is related to the bandwidth of the signal. From radar theory, range accuracy and bandwidth are related by:

$$\text{Range Accuracy} = \frac{C_m}{4 * BW * \sqrt{SNR}} \qquad (4)$$

where C_m is the speed of light in the medium, BW is the signal bandwidth, and SNR is the signal to noise ratio.

From the discussion above, it is apparent that a TDR system requires both a high speed, wide bandwidth signal generator and receiver. The Acquitek CH/XH family offers such capability. For this tech note, the simple case involving the use of a short pulse will be examined. More complex schemes involving longer duration signals, such as swept sine waves, can also be used to measure reflections, but in general they require external hardware, such as a directional coupler, to provide isolation between the transmitted and reflected signals. In the case of the short pulse, such isolation is not required because the criteria for “short” is that the transmission has completed before the reflection returns.

Setup - A short pulse as shown in Figure 1 is generated by the CH board. This pulse is output at 20 MSamples/sec. The pulse has soft edges to prevent ringing which would be introduced as a result of Gibbs Phenomena due to bandlimiting by the 8 MHz analog filter on the CH output. Such ringing could distort the shape of a reflected pulse in close time proximity to the transmitted pulse. As can be seen from Figure 1, the frequency content of the pulse is minimal above 8 MHz.

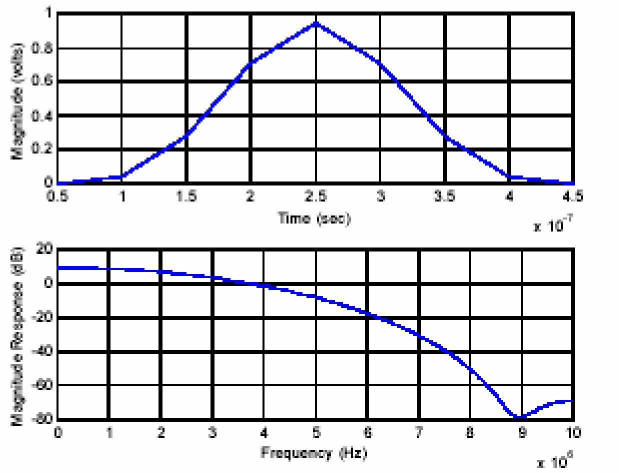

Figure 1 – TDR Pulse

The CH output is internally terminated in 50Ω (75Ω on a CH-3151) to match the cable under test. A "T" connector is used to connect the input as shown in Figure 2. The CH input has a switchable termination – it should be set to unterminated mode for this test to prevent double termination of the cable.

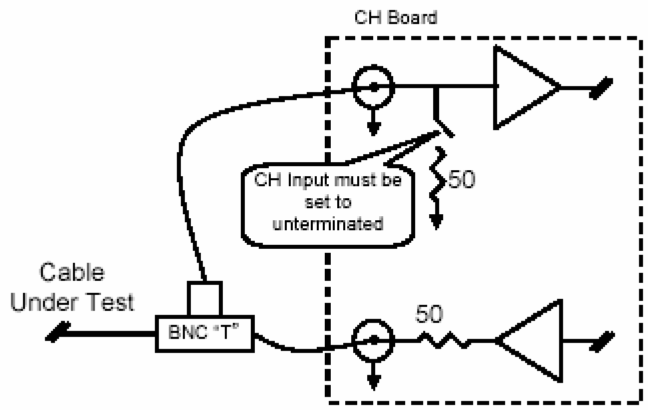

Figure 2 – TDR Test Setup Diagram

Results – Various TDR trials were conducted on both 50 and 75 coaxial cables. Clearly, opens and shorts are obvious as seen in Figure 3. A simple 2nd order interpolating peak detection is performed on the received signal, which contains both the transmitted and reflected pulses. The time between the peaks measures distance to the discontinuity, and the relative amplitude of the peaks is a measure of return loss. From the "Terminated" response in Figure 3, it is apparent that there is very little ringing of the transmitted pulse introduced by bandwidth limiting in the CH analog circuitry. Since an open or short reflects the transmitted pulse entirely, the reduced amplitude of the reflection is due to cable loss.
The frequency range used by this pulse exhibits low loss – approximately 0.7dB/100 ft of RG-58 is shown in Figure 3. Pulses with higher frequency content will exhibit higher cable losses. This has an effect on accuracy per equation (4).

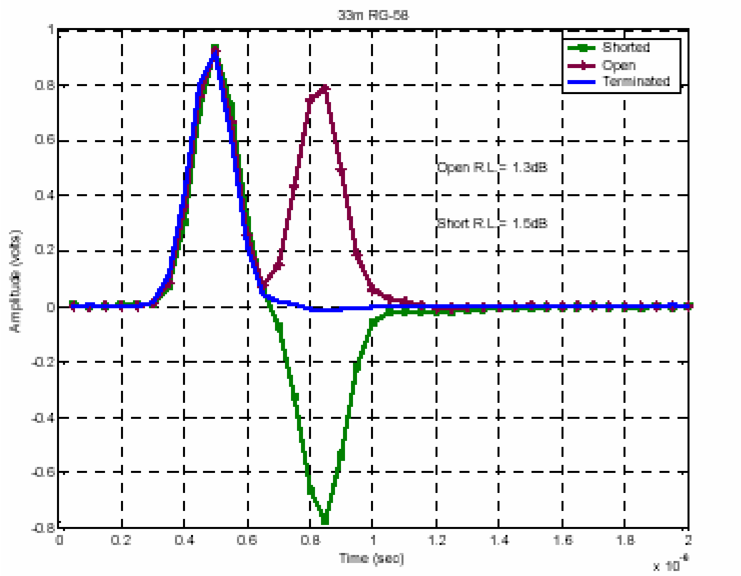

Figure 3 – TDR in 50 Ω Cable

Because of the 12-bit resolution of the CH board, low-level impairments are possible to detect. In Figure 4, an unterminated 10dB pad causes a 20dB R.L. reflection, which, when combined with cable loss, results in a reflection down 22dB. This is still easily detected. Figure 5 shows how measurement accuracy is degraded by the reduced SNR. Even with a reflection down 22dB, measurement standard deviation is less than 0.5m. The slight change in measurement mean value is due to the small effects of ringing in the transmitted pulse, which have a larger effect on the relatively smaller reflections. Figure 4 shows reflections from a cable approximately 100ft (30m) long. With reflections at a greater distance – approximately 150ft – the transmitted pulse ringing is completely gone and this shift in mean value would not be present.

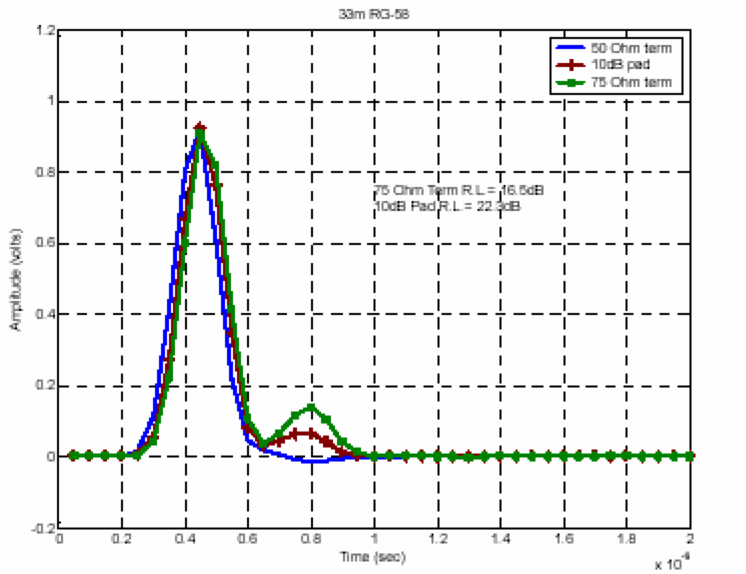

Figure 4 – 50 Ω Low-Level Impairments

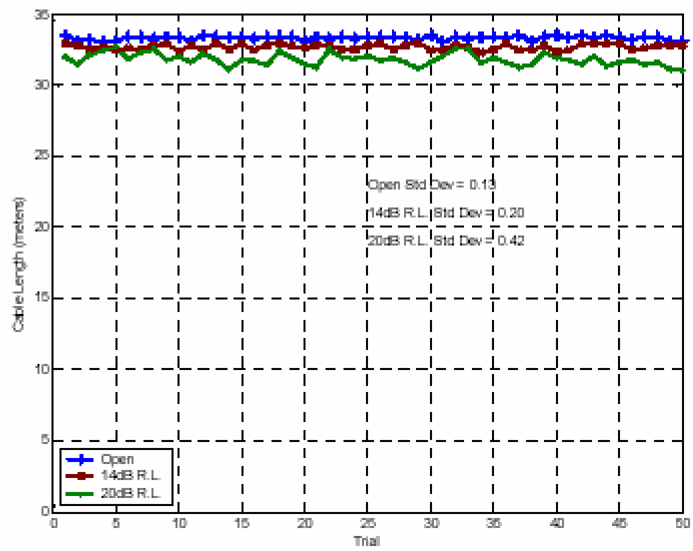

Figure 5 – Distance Variation with SNR

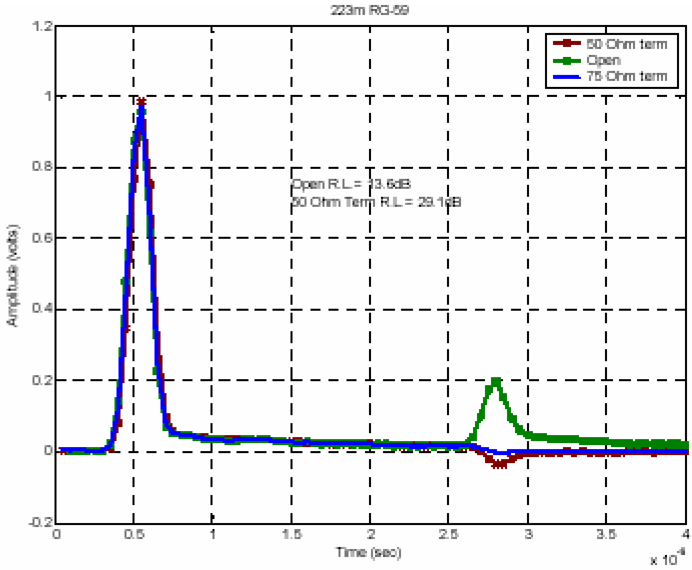

Figure 6 – 75 Ω Low-Level Impairments

Figure 6 shows results from testing in a 75Ω cable using a CH-3151, which has 75Ω input and output impedance. This section of cable is much longer, exhibiting nearly 14dB of roundtrip loss. A higher frequency pulse exhibiting higher loss could be lost in the noise over such a long measurement. Also interesting from this figure is the continuous reflection at approximately -30dB. This appears to be structural return loss from this CATV cable. Such cable has a copper clad steel center conductor, and because of the high resistive losses of this structure, it does not achieve its 75Ω characteristic impedance until 5 MHz or higher.

Conclusion – The Acquitek CH board can be used successfully for cable length and loss measurements in 50Ω and 75Ω cables. Due to the board's 12-bit resolution and analog bandwidth limit of 8 MHz, it is most effective at measuring reflections a long distance down the cable from the transmitter. With opens or shorts at a distance of 33m, measurements with repeatability of approximately 10cm have been demonstrated. The software used to perform these measurements was written in a combination of C and Matlab. This code is available from Acquitek, and will be included in all software releases beginning with version 1.5.