Design low-cost, high-resolution time measurement app

Learn how to design a robust, low-cost TDR, which can determine transmission-line length, faults due to opens, and faults due to shorts.

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Time domain reflectometry (TDR) is a measurement of the impedance of a transmission line using the reflected energy of a pulse sent down that transmission line. As a pulse is sent down a transmission line, it travels at the speed of light for the media it is in (typically, 60% to 80% of the speed of light in free space). As the pulse arrives at an impedance, mismatch energy is reflected back to the pulse source and arrives at a time that is two times the electrical distance from the pulse source to the impedance mismatch. **Figure 1** shows the typical waveform at the pulse source of an un-terminated transmission line.

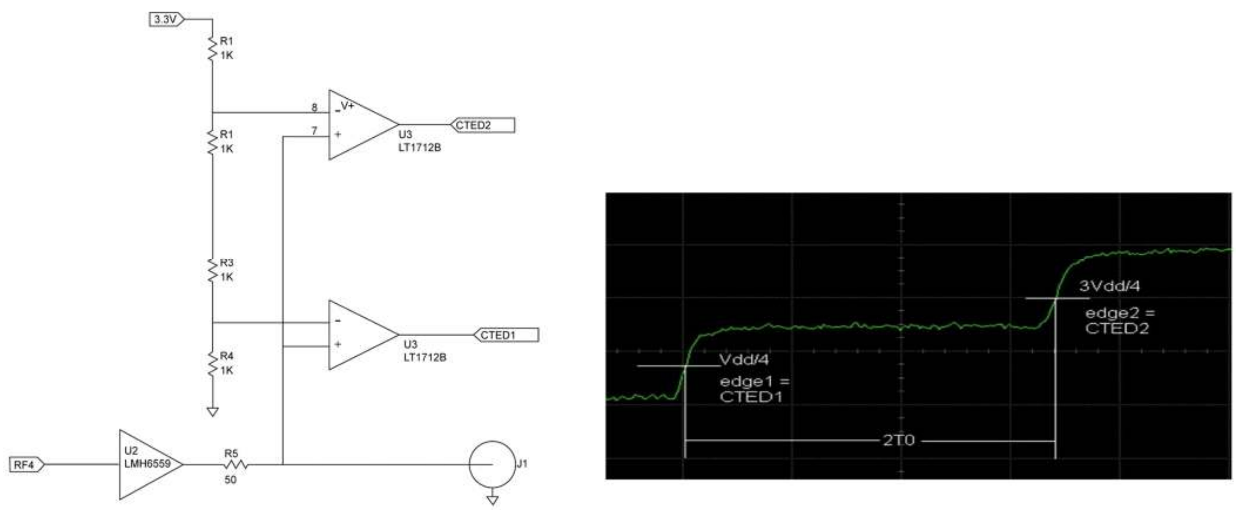

Figure 1: (Left) simplified TDR schematic ; (right) resulting waveform.

Goal of design

A great deal of information can be determined using a TDR, such as the consistency of the impedance along the transmission line, quality of connectors, location of connectors, length of transmission lines, faults due to shorts, or faults due to opens. But the cost of the test equipment involved is not cheap—typically many thousands of dollars. In most cases, we are interested in one of three pieces of information—the length of the transmission line, faults due to shorts or faults due to opens.

This brings us to the subject of this article. If we limit our need for information to the following, then a low-cost solution can be implemented:

- Transmission-line length
- Location of faults due to opens
- Location of faults due to shorts

The goals for this design are:

- Worst-case time resolution of 1 ns (better then 0.5ft)
- Overall accuracy of time measurement on the order of +-1%
- Maximum length of measurement with 0.5 ft. resolution greater then 200 ft.
- Cost to be less then $10, for component costs associated with the TDR

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Time measurement with CTMU peripheral

The heart of the low-cost TDR system is a peripheral called the Charge Time Measurement Unit (CTMU). A CTMU peripheral on a microcontroller can be used to measure time with a high degree of precision and resolution [typical resolution is less then 1ns].

A simplified CTMU block diagram is shown in **figure 2** and consists of the following:

- Constant current source and high-speed switch
- Analogue-to-digital converter (ADC)
- Discharge switch
- Analogue multiplexer

All of these blocks are integrated onto a single microcontroller.

The CTMU is a constant current source that can be turned on and off in less then 1ns. This current can be converted to a time-dependent voltage with the addition of a capacitor, using the following standard equation:

$I = C(dV/dT)$ Equation 1

Solving for dT and integrating, we arrive at

$T = (C/I)V$ Equation 2

I is the output current of the CTMU current source, C is the input capacitance of the ADC plus any stray capacitance, and V is measured by the ADC. This results in the ability to calculate what T is.

The current output of the CTMU is connected to the on-chip 10bit ADC, which uses a capacitive digital-to-analogue converter (DAC) for an input. So, we have a current source that can be turned on and off in less then 1 ns and an ADC with a fixed capacitance for an input. The analogue-to-digital input is charged for an unknown amount of time, after which a voltage measurement is made using the ADC. Knowing C and I, and measuring V, we can calculate T.

Figure 2 shows a typical waveform generated by the CTMU. The first pulse closes the switch, starts the charging of the analogue-to-digital input capacitor and creates a linear voltage ramp (**figure 1**). The second pulse opens the switch and stops charging the analogue-to-digital input capacitor. The voltage can now be measured and the time calculated using equation 2.

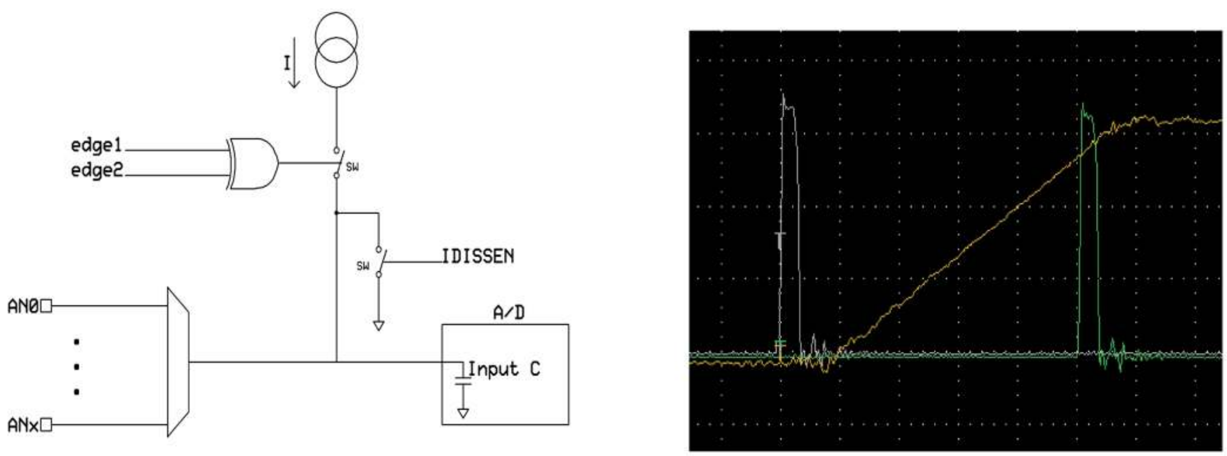

Figure 2: (Left) Simplified CTMU block diagram; (right) typical CTMU waveform.

Software calibration can be accomplished by measuring two known times and calculating a value for C/I.

Implementation of TDR design

Figure 1 shows a simplified schematic of the TDR circuitry and the TDR waveform. Not shown is a 16bit microcontroller with the CTMU peripheral on-chip, in this case a PIC24FJ32GA102. The microcontroller provides a pulse that goes to a high-speed buffer, which drives a 50 ohm coax through a 50 ohm resister. This results in the waveform shown in **figure 1**. The resulting waveform is fed to a set of dual high-speed comparators with respective trip points of $1/4V_{PULSE}$ and $3/4\ V_{PULSE}$, where V_{PULSE} is the amplitude of the pulse generated by the microprocessor and output to RF4. The comparator provides the edges CTED1 and CTED2 needed to measure time, as shown in **figure 2**. CTED1 provides the start edge and CTED2 provides the stop edge. The resulting voltage is measured by the ADC and represents the time between EDGE1 and EDGE2, or 2 times the electrical length of the 50 ohm coax. The CTMU peripheral's resolution is less then 1 ns, resulting in an overall resolution of less then 0.5 ft. With a 10bit ADC, the max length is 500 ft.

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Vendor	Components	Price
Microchip Technology	PIC24FJ32GA106 16bit MCU	$2.12 each
National Semiconductor	LMH6559 Buffer	$0.95 each
Linear Technology	LT1712 Dual Comparators	$3.35 each
BNC Connector	1 Connector	$1.58 each
Misc. Components	Resistors, Capacitors, etc.	$1.00 each
Total		**$9.00**

Table: Approximate costs for the TDR related components.

Conclusions

Referring back to the goals, first with a resolution of 1 nS or better the CTMU can easily provide a resolution of 0.5ft when measuring cable length. With software calibration and the use of a 0.01% crystal, the system can easily be calibrated to 1% accuracy with no electrical adjustments. The 10bit ADC gives a maximum range of .5 ft times 1024, which exceeds the 200 ft range requirement. Finally, looking at approximate costs for the TDR related components, system cost is below $10 (**table**). So, the cost goals have been met. The end result is a robust, easily implemented and low cost TDR. ■

About the author

Jim Bartling has nearly three decades of experience in the semiconductor industry. After serving in the United States Air Force, Jim earned his Bachelor of Science Degree in Electrical Engineering from the University of Wyoming (Laramie, WY). He joined Texas Instruments (TI) in 1982, where he designed semiconductor test equipment. Jim worked at TI until 1989, when he joined Dallas Semiconductor designing 8051-based microcontrollers. Jim went to work at Microchip in 2000 and, in his current role as Senior Technical Staff Engineer with the Advanced Microcontroller Architecture Division, has helped design the architectures of numerous Microchip devices and peripheral modules, including the patented Charge Time Measurement Unit (CTMU) peripheral onboard many PIC® microcontrollers. Over the years, Jim has received 10 patents, with others pending.

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