WAVECREST Corporation

MEASURING TIME DOMAIN CHARACTERISTICS OF TRANSMISSION LINES

Application Note No. 101-A

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Measuring Time Domain Characteristics of Transmission Lines

Introduction

This application note provides an in-depth study of the time-domain characteristics of electrical transmission lines and the techniques used to measure these characteristics.

A transmission line (or cable) transfers electrical energy from one point to another. In many instances, the time it takes to transfer this energy (time delay) is important and must be determined. The physical properties of the cable and its operating environment influence this time delay.

This note helps the reader understand transmission lines, their environmental properties, how to control them and how to obtain the most accurate measurements of the time delay. The *WAVECREST* Timing Measurement Instrument is introduced and compared to time domain reflectometers. Hardware implementation of these techniques is also discussed.

Why Make Transmission Line Measurements?

High-speed computer systems use a master clock to synchronize various individual computing circuits. This clock must be distributed throughout the computer system, arriving at thousands of individual destinations at the same time. Often, this distribution system employs cables, and the accuracy of these cables affects the speed of the computer.

Typically, a transmission line distribution system is used to feed discrete antenna elements such as those in phased-array radar systems that are individually fed with microwave energy. The performance of the antenna, and consequently that of the radar, is dependent on how well the phase relationship of the antenna elements can be maintained.

Semiconductor automatic test equipment has hundreds of electronic channels to exercise the pins of the device-under-test. These channels are distributed throughout the test system before being connected to the device, and the overall accuracy of the test is a function of the accuracy of this distribution system. A more accurate test allows semiconductors to be manufactured more efficiently.

Aside from these examples, there are hundreds of applications where accurate measurement of transmission line time delay is critical to system performance. These applications include nuclear research, fiber optic or laser systems, communications networks, and calibration laboratories. Often these measurements must be performed with an accuracy of greater than 100 picoseconds.

Cable Characteristics

Real-life transmission line cables have a number of properties that affect the time delay through the cable. These effects can vary from cable to cable and are dependent on environmental characteristics such as temperature, humidity, and proximity to other objects.

The values of these properties are determined by measurements. Usually these measurements are made on a large number of cables, of the same cable type, from various production lots. These values are usually specified as *nominal values* meaning the actual value may be substantially different from the catalog specification. An understanding of these properties and how they affect time delay can help make cable delay measurement easier and more accurate.

Velocity of Propagation

The velocity of propagation, υ, of a transmission medium is a fundamental physical property which indicates the speed at which a signal can travel through a unit length of the medium. The simplest example is a traveling wave through free space (a vacuum), where the velocity of propagation is equal to the speed of light, υo:

$$\upsilon_O = 3 \text{ X } 10^{10} \text{ cms/sec}$$

In a medium other than the perfect vacuum, the velocity of propagation is slowed by an amount related to the relative dielectric constant of the medium, ε, according to the following relationship:

$$\upsilon = \upsilon_O / \sqrt{\varepsilon}$$

The relative dielectric constants of several transmission media are given below:

Media	Velocity of Propagation, ε
Air	1.00068
Solid Polyethylene	1.5174
Air Polyethylene	1.1363
Teflon (PTFE)	1.4409
Foam Teflon	1.1111

The time delay through a transmission line, t_d can be determined from the velocity of propagation if the length of the line, L, is known.

$$t_d = l/\upsilon$$

The velocity of propagation is the most important property in determining the time domain characteristics of transmission lines. In most cases, however, the actual time delay through the cable is longer than predicted by the above equation because of many effects on the cable by its environment.

υ	-	velocity of propagation
Zo	-	impedance
C	-	capacitance /unit length
L	-	inductance/unit length
al(f)	-	attenuation frequency, f

The above values for a specific cable type are derived from measurements made on many different runs of that cable. The values can be and usually are different from those of a single cable sample. They also vary from manufacturer to manufacturer. The following information simply illustrates that manufacturers' technical specifications are always nominal values, and a single cable sample may vary. Therefore, for time domain applications, awareness of these variations must constantly be considered, especially when applications require specific lengths and specific time delays.

The accuracy that can be achieved in the high performance time measurement of cables is in direct proportion to the amount of effort expended on good engineering practices. The following paragraphs describe the above characteristics in detail.

Velocity

The delay per unit length of a single cable sample is related to the velocity of propagation, υ. The velocity of propagation is the transmission velocity of an electrical signal through a cable, and is expressed as a percentage of the velocity of light. υ is the velocity of propagation and E is the dielectric constant.

$$\upsilon = \frac{1}{\sqrt{E}}$$

Velocity of propagation is also related to the inductance per unit length, L, and the capacitance per unit length, C, and is expressed in unit length delay per second.

$$\nu = \frac{1}{\sqrt{LC}} \text{ unit length/second}$$

The specific time delay, T, of a single cable sample is dependent on the dielectric constant, E, and is expressed in ns/foot.

$$T = 1.016 \sqrt{E} \text{ ns/foot}$$

The following table provides velocity factors and computed time delays for typical cable dielectric. It illustrates that actual cable lengths differ greatly between cable types.

Cable Dielectric	Velocity (nsec)	Time Delay (feet)
Solid Polyethylene	65.9	1.54
Foam Polyethylene	80.0	1.27
Air Space Polyethylene	84.0	1.21
	88.0	1.15
Solid Teflon69.4	1.46	
Expanded Teflon	85.0	1.27
Air Space Teflon	85.0	1.20
	90.0	1.13

There are advantages and disadvantages associated with each type of dielectric. Solid polyethylene is easy to process, low in cost, has high dielectric strength, and a relatively low dielectric constant. Foamed polyethylene contains extruded materials that have been expanded by numerous individual air cells. These materials reduce the dielectric constant significantly and provide greater design flexibility. Irradiating polyethylene increases the thermal stability and resistance to soldering iron heat. Teflon, while more expensive, has high dielectric strength, a low dielectric constant, withstands temperature extremes, and withstands exposure to gases and liquids that would destroy other materials.

Impedance, Capacitance, Inductance

Expressed in ohms, impedance is important for matching signals and maintaining the most efficient transfer environment. In coax cable:

$$Zo = \frac{101600}{vC} = \frac{138}{\sqrt{E}} \log \frac{D}{d} \quad \text{ohms}$$

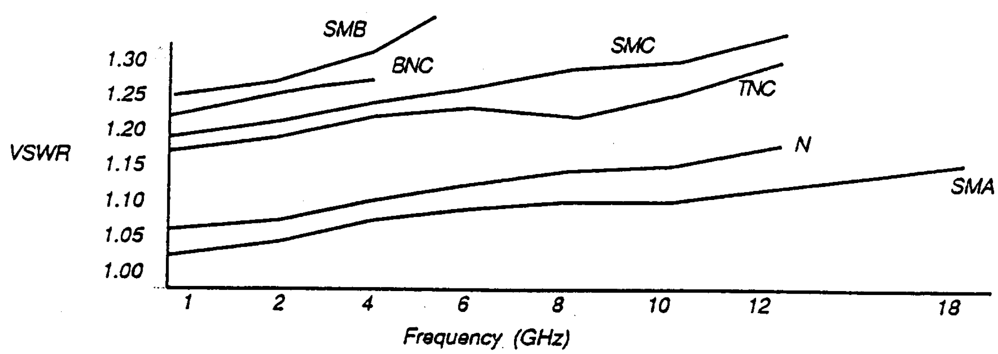
Zo is the nominal impedance
v is the velocity factor
E is the dielectric constant
D is the dielectric outside diameter
d is the inner conductor diameter

In all cables, the nominal or high frequency characteristic impedance, Zo, is dependent upon L and C.

$$Zo = \frac{\sqrt{L}}{\sqrt{C}} \text{ ohms}$$

However, it is important to understand that the actual impedance of a single cable sample *varies with frequency,* and can be different from the characteristic impedance because of reflections in the cable.

The total of all random and periodic reflections, as well as connector and line termination reflections, is the voltage standing wave ratio (VSWR). The VSWR indicates the difference between real input impedance and the average characteristic impedance. The following diagram illustrates some typical cable/ connector combinations, and their resulting VSWR over frequency.



If C is specified, a knowledge of ∨ or Zo determines L. By rearranging the formulas, ∨ and Zo can be specified so that L and C can be determined.

$$L = \frac{Zo}{\vee} \qquad C = \frac{1}{\sqrt{Zo}}$$

Capacitance is the ratio of electrostatic charge on a conductor to the potential difference between the conductors required to maintain that charge. It is expressed in picoFarads per foot.

$$C = \frac{7.36E}{\log \frac{D}{d}} \text{ pF/ft}$$

The above formulas show that capacitance, C, figures significantly in determining Zo. Some dielectric materials cause changes in capacitance when the cable is stressed or bent, if the dielectric moves, or even when the temperature varies. Careful system design and good engineering practices are mandatory for maintaining consistent capacitance.

This table shows capacitance values for some typical cable types. Capacitance is normally specified in picofarads per foot.

Nominal Capacitance (pF/foot)	Cable Types
30.8	50 ohm Solid Polyethylene Coax
25.4	50 ohm Foam Polyethylene Coax
29.4	50 ohm Solid PTFE Coax
20.6	75 ohm Solid Polyethylene Coax
16.9	75 ohm Foam Polyethylene Coax
19.5	75 ohm Solid PTFE Coax
16.3	95 ohm Solid Polyethylene Coax
13.5	95 ohm Air space Polyethylene Coax
15.4	95 ohm Solid PTFE Coax
10.0	125 ohm Air space Polyethylene Coax
6.5	185 ohm Air space Polyethylene Coax
12.0	Low Capacitance Twisted Pair ELA Data Cable
22.0	Foil Shielded Single Twisted Pair (UL#2092)
20.0	Foil Shielded Two Twisted Pair (UL#2094)

Several other items also affect cable capacitance and impedance. The capacitance and impedance of long lengths of cable generally vary less than 2% over their operating temperature range. However, dielectric movement at the connector interface can cause the VSWR to vary significantly; and adding an integrated circuit input, or other passive components on any cable path can change the capacitive load.

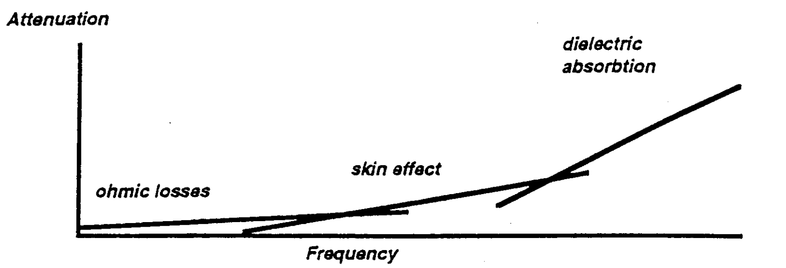
Attenuation

Attenuation is the power loss in a cable. It is due to heating loss because of conductor resistance, skin effect, and dielectric loss caused by poor dielectric materials. The total loss is expressed in decibels per unit length of cable. The decibel is a unit that expresses the ratio between two amounts of power existing at two points.

$$dB = 10 \log \frac{PI}{P2}$$

The attenuation of a single cable sample can vary as the frequency, rise times, or pulse widths change. Random and periodic impedance variations give rise to varying attenuation responses. In addition, attenuation usually increases with time. This is usually caused by corrosion, contamination of the primary insulation, by moisture penetration, and/or dielectric deterioration.

Silver plated copper is much more effective long term, than bare copper and tinned copper. Foam polyethylene dielectric has approximately 15% less attenuation than solid polyethylene cables. However, when using foam polyethylene cable, impedance increases if moisture is absorbed. Flexing also impacts attenuation (see the following section on flexibility and mechanical strength). The following diagram illustrates the different attenuation factors that impact a cable as frequency changes.



Additional Cable Information

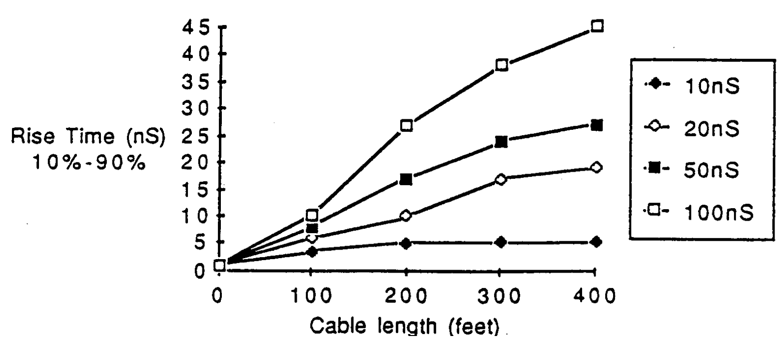
A variety of other items affects cable measurements. These include pulse response, shielding and cross-talk, self generated cable noise, flexibility and mechanical strength.

Pulse Response

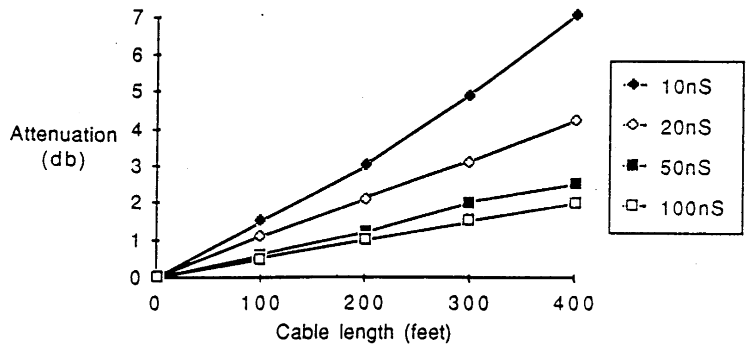
Five characteristics affect pulse response when making time domain measurements on cable. They include impedance and reflection, rise time, amplitude, overshoot or pre-shoot, and pulse echoes.

Impedance and reflection: the impedance along a length of the cable varies, sometimes up to +/- 5%. One cannot assume that the correct impedance is selected throughout the entire system.

Rise time and amplitude: rise times are affected as they pass through a cable. The output rise time is a function of input rise time, pulse width, and cable attenuation. The faster the rise time, the greater the energy imparted to a signal, and the more reliably the signal passes through the cable for measurement. The following diagram illustrates rise time variations versus cable lengths for 10, 20, 50, and 100 nanosecond pulses.



Amplitude is attenuated as cable length increases. The following diagram illustrates peak amplitude attenuation versus cable length.



Raising the cable temperature results in increased rise time and decreased amplitudes. Therefore, short cables are beneficial to most electronic applications because they not as susceptible to degradation.

Overshoot or pre-shoot: overshoot disrupts signal quality, and is typified by ringing. It is caused by periodic reflections due to impedance discontinuities within the cable. Pre-shoot is seen in some balanced delay lines and is minimized by good cable design and termination.

Pulse echoes: pulse echoes can occur when a narrow pulse is sent through a cable. In addition, periodic reflections can cause a small pulse of energy to be created after the initial pulse has arrived. Normally this echo level can be neglected.

Shielding and Cross-talk

The shielding efficiency of cable depends on the construction of its outer conductor. These shielded cable include single braid, double braid, triaxial, strip braids, and solid sheath. The relative shielding efficiencies of the different cables are rated by the amount of signal that leaks through the outer conductor, and can be detected outside the shield.

Efficiency depends on the shield type. In cable using a single copper braid, the leakage typically -30 to -50 dB down from the signal level in the cable. In solid sheath cable, the leakage is typically -300 to -1000db down. Double braid, strip braid and triax have -70 to -100 dB down. All of these specs are over the 10 to 1000 MHz range.

The signal leakage and other factors allow signals to transfer in and out of a cable, and indicate cross talk susceptibility. Cross talk factors include isolation and leakage with other cables, relative spacing and positioning of cable runs, distance from certain objects, and grounding practices.

Self-Generated Cable Noise

When a cable is flexed, it generates acoustical and electrical noise. Acoustical noise is a function of the mechanical motion within the cable, and is minimized by good cable design. Electrical noise is a function of an electrostatic effect; it is minimized by preventing motion between dielectric and conductors and by dissipating electrostatic charges.

Flexibility

Cables are classified as flexible or semi-flexible. Flexible cables are intended for applications where the cables flex repeatedly while in service. These cables are made with a stranded center conductor and braided outer conductors. They typically withstand over 1000 flexes through 180 degrees with a bend radius equal to 20 times the outside diameter of the cable. The minimum recommended bend radius is five times the cable outside diameter.

Semi-flexible cables are intended for applications where the cable remains flexed while in service. These cables are made with a tubular outer conductor. They typically withstand only 10 flexes through 180 degrees with a bend radius equal to 20 times the outside diameter of the cable. The minimum recommended bend radius is ten times the cable outside diameter.

Mechanical Strength

The break strength of coax cable is dependent on the strength of the outer conductor. Coax cables typically have a break strength of 70% of their outer conductor. Other cables depend on the strength of their inner conductors. In all cases, cable strength is enhanced if the center conductor stretches up to 10% before actually breaking. The following table illustrates typical conductor materials and their properties.

Conductor Material	Conductivity	Tensile Strength (Psi)	Elongation
Annealed copper	100%	35,000	20%
Copper covered steel			
bard drawn	40%	120,000	2%
soft drawn	40%	60,000	12%
ITT Alloy 63	90%	60,000	12%

Care must be exercised using conductor sizes of less than 26 AWG, since breakage easily occurs, especially during assembly.

Cable Connectors

Connectors and the cable/connector attachments are ultimately the greatest limitation on performance of a system. The same rules that apply to cables also apply to connectors. Resistance, inductance, capacitance, and impedance all impact the quality of signal integrity. Oftentimes skew from cable assembly is derived from problems associated with connectors rather than the cable itself (for example, coaxial cable typically holds specifications within 2% to 5%). Also, like cable, silver and gold plated parts maintain impedance better, and provide a mechanical interface that lasts longer.

Manufacturers' assembly instructions are important to follow. Manufacturers' tool sets for specific connectors can also be used when they are available. Soldering, rather than clamping or crimping, is the preferred method of attachment. It ensures a constant impedance connection and a low VSWR when done correctly. For best results, attention must also be given to nut tightening torque.

All of these techniques are important in obtaining specific lengths or delays in cable measurement. The standard mechanism for measuring cable length is to measure from connector face to connector face. The "face" is usually the plane where the two connectors mate. This face varies among different types of connectors. Check the specifications for specific connectors.

Standard cable measurements are usually made with one male and one female connector installed. As opposed to a male/male or female/female cable, this preferred cable configuration prevents any ambiguity. The standard male/female cable configuration also allows easy insertion into a test setup for substitution measurement.

Nonstandard cables can be measured, but not as easily. For a male/male cable configuration, a female/female adapter is inserted on one end of the cable. Likewise, for a female/female cable configuration, a male/male adapter is inserted on one end. The adapter must be physically measured to determine the delay through the adapter; then it is divided by two and subtracted from the reading of the entire cable being measured. This is the most accurate technique available for measuring the absolute length of non-standard cables; unfortunately, it relies on measuring the adapter mechanically. In many applications, it is not necessary to determine the exact length of a cable, but only to assure that two cables are electrically the same. This requirement simplifies the use of nonstandard cable since the adapter can be ignored.

The most important factor in cable and connector interface, is constant impedance. There is a variety of constant impedance connectors available—in typical impedance of 50 and 70 ohms (many others are also available)—and for all shapes of cable (including coaxial, triaxial, parallel, flat, and twisted). The following connectors are typical constant impedance connectors.

SMA connectors are semi-precision, 50 ohm subminiature connectors designed to exhibit low loss, low VSWR, and operate to 18GHz with semi-rigid and flexible cables. They are threaded (1/4-36) connectors, originally designed to duplicate the performance characteristics of 0.141 inch diameter semi-rigid cable. SMA connectors are the preferred connector for high-performance applications.

APC-3.5 connectors are precision, 50 ohm coaxial connectors designed to exhibit low VSWR, low loss, and operate to 34GHz with rigid air line and semi-rigid cable. They are threaded (1/4-36) connectors and mate with SMA connectors (providing VSWR performance typical of SMA mated pairs). These connectors also provide an air dielectric mating face and thicker outer conductor shoulders.

APC-7 connectors are precision, 50-ohm coaxial connectors designed to exhibit low VSWR, low loss, and operate to 18GHz with rigid air line (7 mm line size), precision semi-rigid coax and some flexible coaxial cables. These connectors are sexless, coplanar connectors, with an air dielectric mating face and thicker outer conductor shoulders. Therefore, any two connectors can be connected.

TNC connectors are weatherproof, 50 ohm miniature connectors designed for extreme vibration or where safety is paramount, such as in medical and test equipment. They operate to 11GHz with flexible cables, and have a threaded (7/16-28) coupling.

BNC connectors are lightweight, 50 ohm miniature connectors designed for extreme vibration or where safety is paramount, such as in medical and test equipment. They operate to 4GHz (11GHz usable) with flexible cables, and have a bayonet-type coupling for quick connect/disconnect.

N connectors are weatherproof, 50 or 70 ohm medium size, higher power connectors designed to exhibit a consistently low VSWR and operate to 11GHz with flexible cables. They are threaded (5/8-24) connectors designed to impedance match 50 or 70 ohm cables.

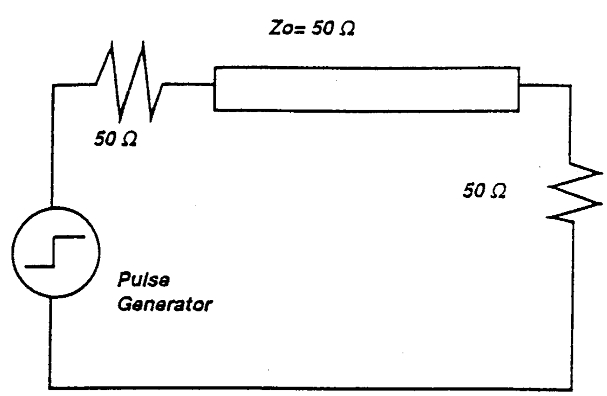
SMB connectors are semi-precision, 50 ohm subminiature connectors designed for system OEM use in video and IF systems (4GHz) with flexible cables. They are snap-on connectors.

SMC connectors are semi-precision, 50 ohm subminiature connectors designed for low frequency applications, such as system OEM use in video and IF systems (10GHz) with flexible cables. They are screw-on connectors.

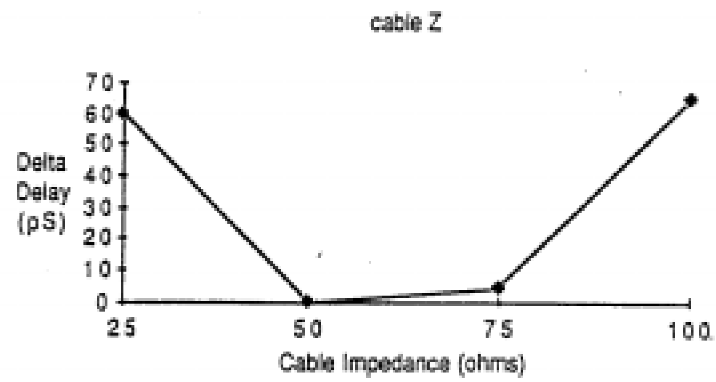
Effects of Discontinuities

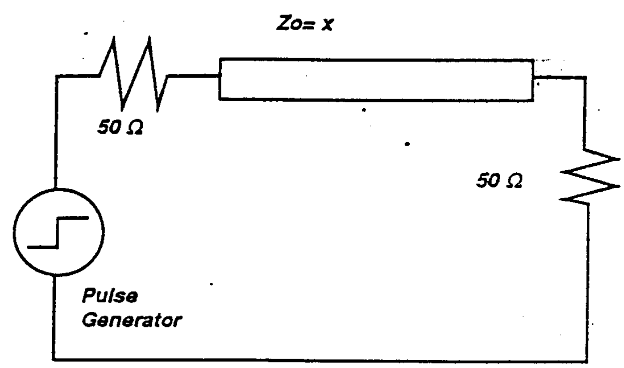
The following data and diagrams illustrate the impact of discontinuities on time measurement. The four models are the result of computerized circuit emulation using Micro-Cap II (Spectrum Software, Sunnyvale, CA). The fifth model is an actual example.

The ideal model, which is the starting point for all of the variations, is illustrated in the following.

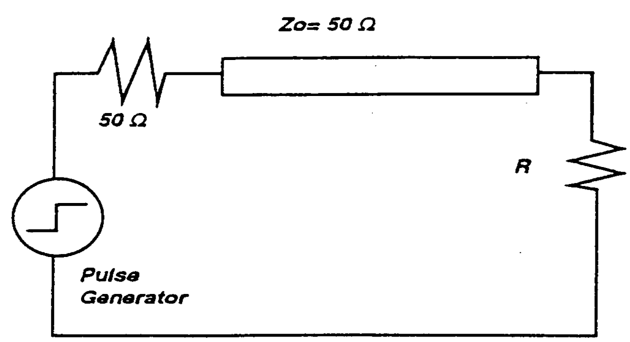


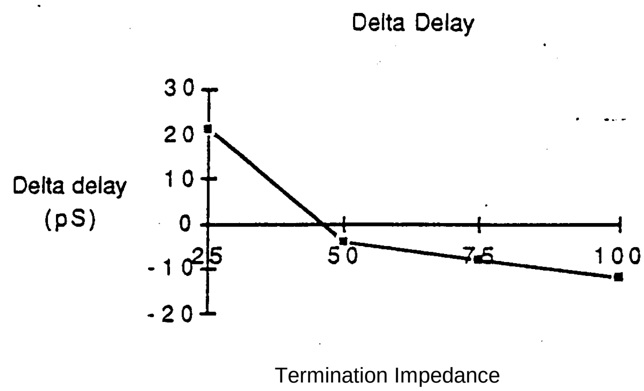
The following diagram illustrates the delay in cable measurement that results from placing a cable of mismatched impedance into the ideal model.



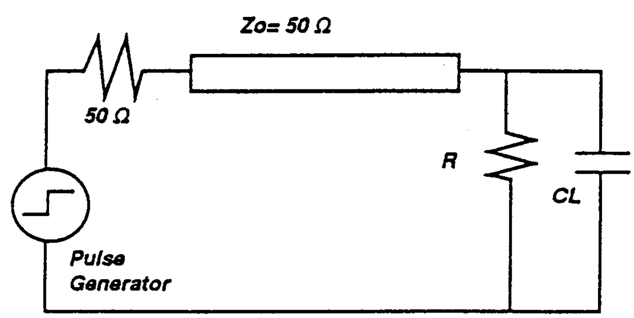


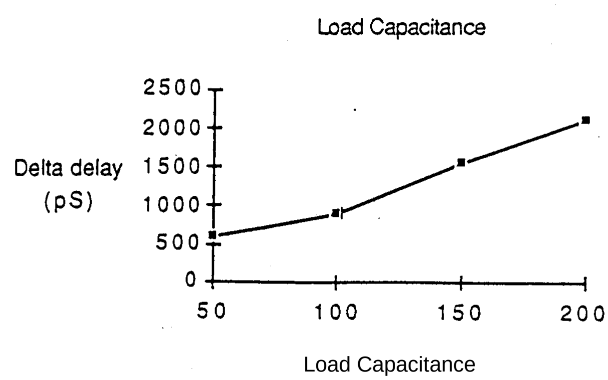
The following diagram illustrates the change in delay readings when the terminating impedance is mismatched.



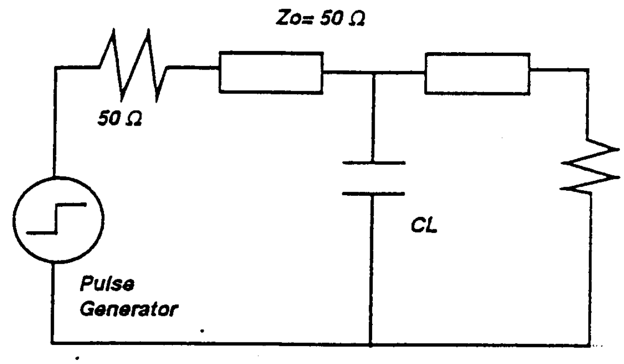


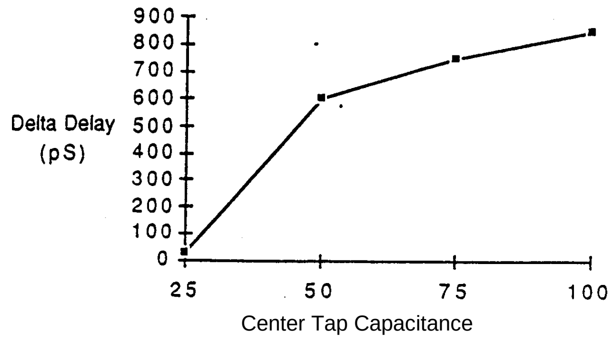
The following diagram illustrates the change in delay readings when the terminating capacitance is mismatched.



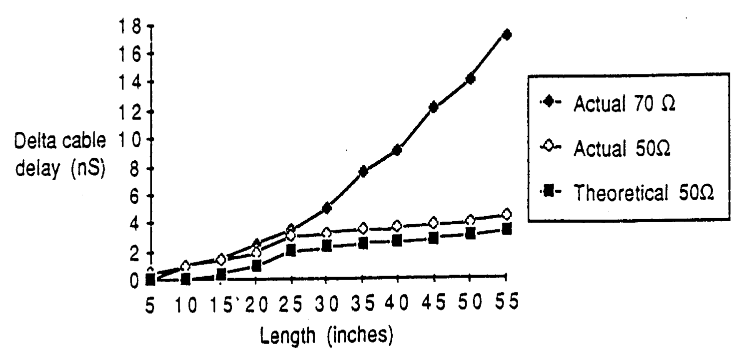


The following diagram illustrates the change in delay readings when a capacitive element is introduced into the middle of the ideally-matched cable.





The following diagram illustrates an actual series of measurements, showing the delay in cable measurement that results from placing a cable of mismatched impedance in a test setup.



Conclusions

Manufacturers' technical specifications are always representative values and a single cable sample may vary. Therefore, all of the nominal values of a cable can be, and usually are, different from those of a single cable sample. They also vary from manufacturer to manufacturer.

For time domain applications, awareness of these variations must constantly be taken into consideration, especially when applications require specific lengths and specific time delays. *The accuracy that can be achieved in the high performance time measurement of cables, is in direct proportion to the amount of effort expended on good engineering practices.*

Current Measurement Practices

Mechanical

The easiest, yet least accurate, way to measure cable lengths is the mechanical method. The time delay required from a single cable sample is computed using the dielectric constant and the mechanical information supplied by the connector manufacturer. The cable is mechanically cut to length and the connectors are installed. The total calculation must consider not only the time delay through the cable, but also the delay added by the connectors. The total time delay is measured from the face of one connector to the face of the other connector of the cable (see the above paragraphs on cable connector installation).

It is very difficult to mechanically measure a piece of cable to thousandths of an inch. This difficulty in cutting the length correctly, and cutting it perfectly perpendicular, affects the total accuracy. Additional errors occur when installing the connectors, since the cable conductors can be slid into a variety of positions within the connectors. Soldering and crimping move and bend conductors and dielectric, which cause changes in impedance and capacitance. Add to this the variations that occur in impedance, capacitance, inductance, and velocity from cable sample to cable sample, and it is easy to understand the limitations of this method.

Time Domain Reflectometry

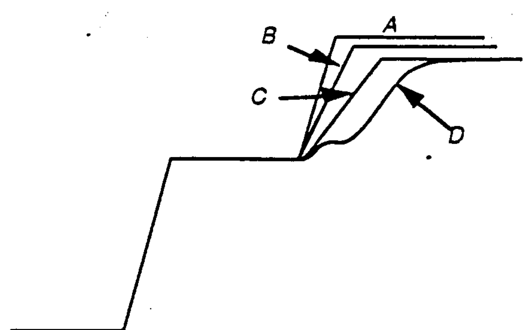
Time Domain Reflectometry (TDR) is the most common means of measuring cables. It is also a good way to perform strip line evaluations, computer backplane measurements, and printed circuit board testing. The following discussion deals specifically with cable measurement.

TDR equipment sends a pulse through a transmission line and measures the reflections caused by any impedance change. The pulse sent into the cable is called the incidental traveling wavefront. The magnitude of the reflected wave, called the reflection coefficient, is dependent on the impedance discontinuities encountered as the incident wave passes through the cable.

The TDR is calibrated for length or time on the horizontal axis of a display. The reflection coefficient is displayed on the vertical axis. The TDR can detect and display any impedance discontinuity, including opens, shorts, and step changes. This allows cable lengths to be measured with moderate accuracy.

The primary disadvantage of the TDR technique is that the TDR signals seldom represent the actual signals that are ultimately sent through the cable. Second, the signal is not only passed through the cable once, but its reflection is passed back through. This doubles the signal's exposure to attenuation. The following figure illustrates a typical TDR display.

Point A illustrates a theoretically ideal signal. Point B shows how the signal has been attenuated after one pass through the cable. Point C is the signal after it has passed through the cable twice. Notice that attenuation reduces the rise time of the signal. Point A is the ideal signal. Point C is the actual signal. A slow rise time delays the signal because of the slope introduced. The signal at point D illustrates that further reading errors can occur. In this case, an impedance mismatch has changed the rising edge and caused an even more erroneous reading.



TDR Display

Another fact to consider is that the triggering point is not the typical 50% point. The incidental signal must be measured at 25% of the total signal, and the reflected signal must be measured at 75% of the total signal. The measurement is further complicated by the total signal amplitude. While the incidental signal is 1/2 the intended total signal, the reflected signal is attenuated by passing through the cable twice, and therefore, is actually less than 1/2 of the total signal intended. The 50% point of the reflected signal is not necessarily 150% of the incidental pulse, but is actually 50% of the amplitude of the reflected signal after it has fully settled.

The most practical cable measuring technique calls for a signal to be measured at its 50% point, at the input and at the output. The amplitude as it enters the cable is the amplitude measured on its output. This can be the trip point for most digital electronic applications, even if the signal is attenuated.

The *WAVECREST* Digital Time System (DTS)

The *WAVECREST* DTS allows a simple mechanical mechanism to size cables, and at the same time provides greater timing accuracy over the TDR. Several practical mechanical means of cable measurement are discussed as follows.

The DTS not only provides greater timing accuracy over the TDR method, but also greatly simplifies and speeds the measurement process. As with most techniques, there are advantages and disadvantages.

The disadvantages to the TDR method include difficulty in setup and use among others. The TDR test measurement signals applied to the cable usually bear no resemblance to the actual signals used, and therefore, introduce errors. The reflected signal edge is always different from the initial signal, which introduces further potential for error.

Using the DTS measurement method holds only two minor disadvantages. First, the DTS cannot measure impedance directly, since the DTS measures the actual time through the cable without known impedance. If impedance must be determined, the formulas specified earlier in this document can be used for computation. Second, the total length of cable that can be measured is limited by the source signal to less than 25 feet for picosecond accuracy. In most applications, this is not a problem. Picosecond accuracy is typically only required in cables that are less than 10 feet long.

Because the DTS is an instrument designed to measure the quantity of a signal, rather than the quality, it does not present a picture of the waveform. A precision voltage measurement is similar in that an oscilloscope is not used, because it is not accurate enough. Rather, a precision volt meter is used, usually with several decimal places of accuracy. Likewise, while an oscilloscope can provide a qualitative look at time delay, when real precision is required, it is not accurate enough. The DTS provides that added precision needed for a true quantitative *repeatable* measurement.

DTS Cable Measurement Techniques

The following examples describe real and practical methods for measuring cables. These examples take into consideration that all test setups use the shortest possible cable fixtures to maintain good wave forms and that good engineering practices are followed.

Bench Setup

The DTS allows two methods of measuring coax cables. The first method uses the internal 20MHz signal source built into the DTS, and the second method uses an external signal source. See the "Ext Cal Option on the DTS" section for details on method one.

Method two requires a DTS, a programmable signal generator, and the appropriate cabling/fixturing including the correct cable connectors for the cable to be tested. The signal generator must be set to provide 0 to 5 volt into a power splitter at a rep rate equal to or greater than the TPD of the cable to be measured at point A. The connectors at points B and C must be connected to provide a signal to the "Stop" input on the DTS.

The output of the signal generator is very important in assuring that the generator output has a fast, clean rising edge. The slew rate must be 1.25 volts/nsec or faster to obtain good readings. A good frequency for the signal generator is around 2.5KHz. This is less than the DTS sampling capability, but simplifies the setup and use of the DTS (it does not require an external trigger or gate signals). Setting the pulse width at the 2.5KHz rate is not critical, but a few hundred nanoseconds is consistent and easy to use with cables under a few feet long.

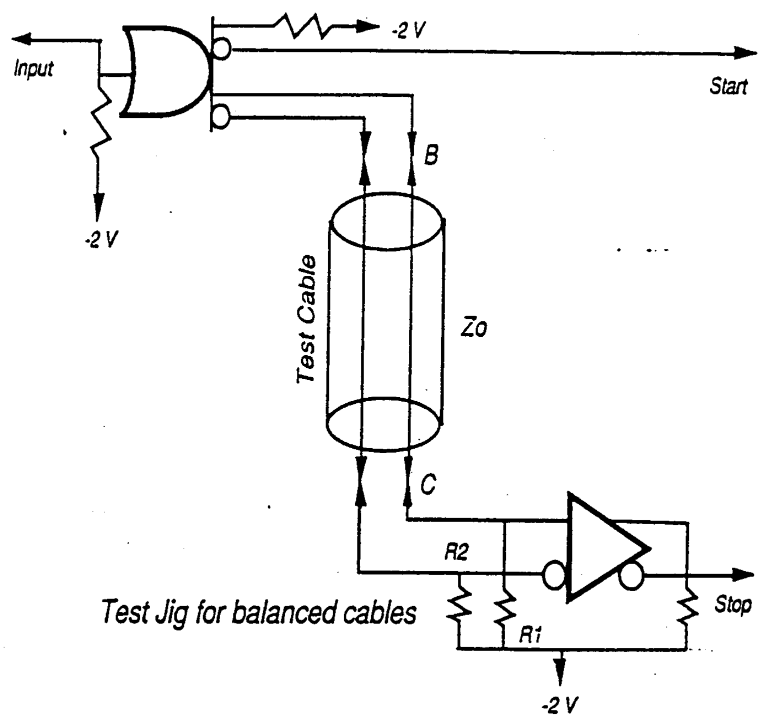
The DTS should be set to Burst mode with automatic trigger. Adjust the number of samples to around 500. Allow the split signal from the signal generator to operate the DTS in the TPD++ FCN mode. Press the "Func" key to invoke the "Pulse Find" function. The DTS is now ready to take readings.

The lower cable is designed with two connectors that match the cable ends of the cable to be tested. Insert the cable under test between points B and C. Operate the DTS to obtain a new reading on the display. The difference between the two obtained readings represents the time delay of the cable under test.

This technique of adding in an unknown length of cable and measuring the change in time is called the substitution method. It is the most accurate method for measuring cables. Ultimate accuracy of less than a few picoseconds is achievable for cable lengths under 10 feet.

Test Jig for Balanced Cable (or impedance other than 50 ohm)

The DTS and the following illustrated test jigs, operate in 50 ohm environments. *WAVECREST* designed and built the following cable test jig, which can test balanced or unbalanced cables, and provides the ability to change impedance.



Test Jig for balanced cables

This example is another variation on the previously illustrated substitution techniques (see Bench Setup). The input of the cable test set, A, fed by an ECL level signal, is terminated to -2 volts, and provides a 50 ohm impedance match. This input can be fed with a signal generator. The 100112 buffer splits the signal, one for the Start input of the DTS, and the other for the Stop input.

Select and install the correct resistor values for RI and R2. For example, if the test cable is 70 ohm cable, use 70 ohm resistors for RI and R2.

Again, the optimum frequency for the signal generator is around 2.5KHz. This is less than the DTS sampling capability, but simplifies the setup and use of the DTS (it does not require external trigger or gate signals). The pulse width at the 2.5KHz rate is not critical, but a few hundred nanoseconds is consistent and easy to use with cables under a few feet long.

The DTS should be set to the Burst mode with automatic trigger. Adjust the number of samples required to obtain the accuracy desired. Allow the source signal to operate the DTS, and note the displayed reading. During this initial measurement, ensure that points B and C are connected to provide a signal to the "Stop" input of the DTS. After the initial measurement is made, the cable to be measured is inserted between connectors at B and C. A new measurement is then made, and the difference is noted. The difference between the two obtained readings represents the time delay of the cable under test.

Golden Cable

The golden cable concept is a simple way to compare similar cables. One cable, designated the golden cable, can be a cable that has a "known" time delay. This can be a NIST traceable cable, or a known good working cable that is "the standard" by which all other cables are measured. Any of the test setups described above can be used to accomplish the golden cable measurement.

To start this measurement in any of the above test setups, insert the golden cable between connectors B and C. Make the initial measurement, the value of golden unit. Then insert the cables to be measured. Take the new reading and calculate the difference between the two readings. Then add or subtract this difference to the "known" value of the golden cable.

For example, suppose a golden cable exists which has been calibrated by the NIST, and has a "known" delay value stamped on it of 1.042 nanoseconds. This golden cable is inserted between connectors B and C in one of the test setups. The DTS displays 1.035 nanoseconds. The difference is 0.007 nanoseconds. Then, the new cable to be measured is inserted and measured. The new reading is 1.050 nanoseconds. Since the difference established with the golden cable is 0.007 nanoseconds, it is added to 1.050, establishing a value of 1.057 nanoseconds as the value for the new cable. Accuracy of less than a few picoseconds is achievable using this golden cable technique.

Ext Cal Option On the DTS

For testing short cables under 10-feet in a 50 ohm environment, an option is available on the DTS for self-contained cable measurement.

This DTS cable measurement option is simple and easy to use. It is a variation of the DTS external calibration software. Complete operating instructions are provided with the DTS. The main limitations are the fixed 50 ohm environment and cables less than 10 feet in length.

During normal cable measurement use, the aforementioned cable fixture is connected between the Ext Cal output connectors and the "Start/Stop" input connectors. The DTS then makes a measurement of this fixture. After this measurement, the cable to be measured is inserted. If the same connectors are used on Ext Cal, and on the cable to be measured, the cable to be measured is simply inserted between the cable fixture connector and the Ext Cal connector.

If special connectors are required, they are installed in the cable fixture at points B and C. If they is used, points B and C must be connected to provide the signal to the start input on the DTS during the initial measurement. After inserting the cable to be measured, allow the DTS to operate and note the displayed time delay reading. Refer to your DTS operating guide for details on using the "Cable Delay Menu."

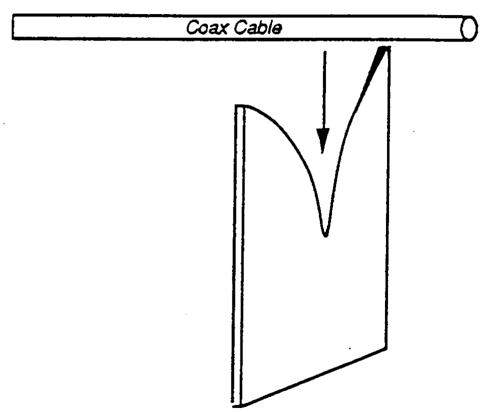
Trimming Cables

Measuring a cable is one task. Cutting or trimming a cable to the correct length is entirely another. However, *WAVECREST* has worked with a variety of vendors and users of cables and has developed at least three trimming techniques that work well in practice. The first technique presented is primarily for balanced or twisted wire cable. The second technique is for coaxial cable. The third can be used on either.

Trimming Balanced or Twisted Wire Cable

This method works best with the test jig for balanced cable, or cable impedance other than 50 ohm described above. The following descriptions refer to test points in the previous diagram associated with that test jig.

Installation begins with the appropriate cable connector placed on one end of the cable only. This is typically plugged into the test jig at point B. Point C is modified with the cable piercing mechanism shown below. Point C is set up to allow both the cable piercing mechanism and the cable connectors to provide signal into the stop input of the DTS. This allows the cable insulation to be breached with minimum damage to the cable.

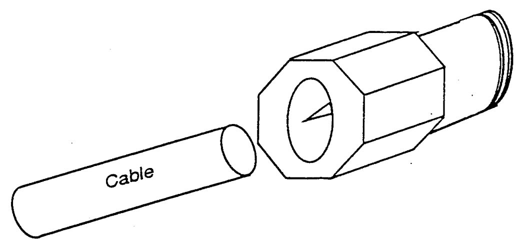


The cable is inserted and reinserted into the mechanism until the correct reading is obtained. The cable is cut at this point and the correct connector is installed. When the cable piercing mechanism is connected into the system test jig, it is connected to equal the delay introduced by the connector to be installed. This results in the finished cable being electrically identical in length to the cable as inserted into the piercing mechanism. Finally, the completed cable is inserted into the test jig to assure the final assembly results in the correct length.

Trimming Coaxial Cable

This method works best with the simple 50 ohm test jig described previously. The following descriptions refer to test points in the diagram associated with that test jig.

Installation begins with of the appropriate cable connector placed on one end of the cable only. It is typically plugged into the testing jig at point B. Point C is modified with the cable probe mechanism shown below. It is set up to allow either the cable probe mechanism or the cable connectors, to provide signal into the stop input of the DTS. This allows the cable insulation to be breached with minimum damage to the cable.



The cable is inserted into the mechanism half way, and then the cable is forced onto the barb located on the side of the mechanism. Because the center conductor and shield are both in mechanical contact, a reading can be taken. The cable can be removed and cut until it is "close" to the required length. Then the cable can be slid in and out of the mechanism until the exact reading is obtained. The cable is cut at this point and the correct connector is installed. When the cable probe mechanism is connected into the system test jig, it can be to equal the delay introduced by the connector to be installed. This results in the finished cable being electrically identical in length to the cable inserted into the probe mechanism. Finally, the completed cable is inserted into the test jig to assure the final assembly results in the correct length.

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