Advances in test technology for metal cables

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Slides for the oral presentation at the IEEE Central Texas Section of the ComSoc/SPSoc meeting in Austin Texas
in May 2005 (Including the results of a live demo of SD/TDR measurements on cable conducted during the meeting)

Advances in test technology for metal cables

I. Background

II. Basic Propagation Properties of the SD Signal on a uniform Lossy Transmission Line with Frequency dependent Parameters (LFTL)

III. SD/TDR Application

IV. Live SD/TDR measurements on cable

V. Comparision with spatial resolution of conventional TDR

VI. Applications of SD Signal in communications

VII. Summary

I. Background

"In a medium in which all waves have the same velocity of propagation (such as vacuum for electromagnetic waves) a signal of any form at all will propagate without deformation. The form of the wave plays no part in the propagation. The velocity of propagation can be defined as the phase velocity, since it also represents the velocity with which the energy or any other quantity is transported.

In a dispersive medium, the situation is otherwise. All propagation is accompanied by a change in the form of the signal, except for an infinitely long sinusoidal wave. In one word—if there is dispersion, there is also distortion. The example of propagation of electrical perturbations along cables is well known."

L. Brillouin, *Wave propagation and group velocity*. NY: Acad. Press, p96, 1960.

Background (continued)
Signal Propagation without Distortion in Dispersive Lossy Media

The distortion of most signals while propagating in dispersive lossy media (DLM) is well known. An important exception is the single frequency sinusoidal waveform, which does not undergo shape distortion during propagation in DLM after reaching steady state.

It was recently discovered that another waveform behaves like a sinusoid during propagation in DLM. The similarities of the behavior of this waveform, called “Speedy Delivery” (SD) with the sinusoid extend beyond preservation of shape. Changing a shape parameter of the SD signal alters the SD signal’s propagation velocity and rate of attenuation in DLM. This is analogous to the effects of changing the frequency of a sinusoid.

II. Basic Propagation Properties of the SD Signal on a uniform Lossy Transmission Line with Frequency dependent Parameters (LFTL)

a. Preserves shape during propagation

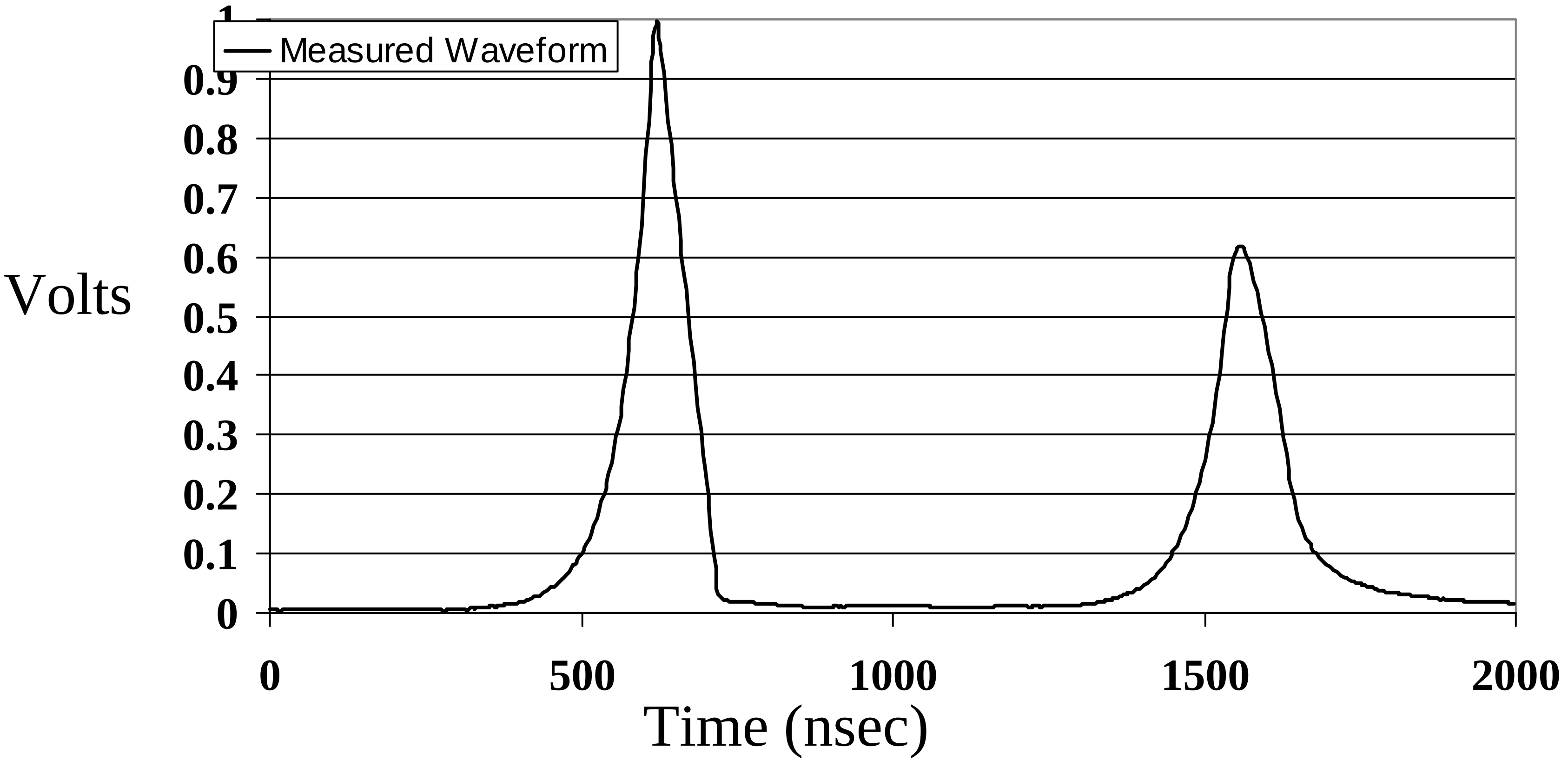
b. Measurement of propagation velocity

c. Propagation velocity is controllable

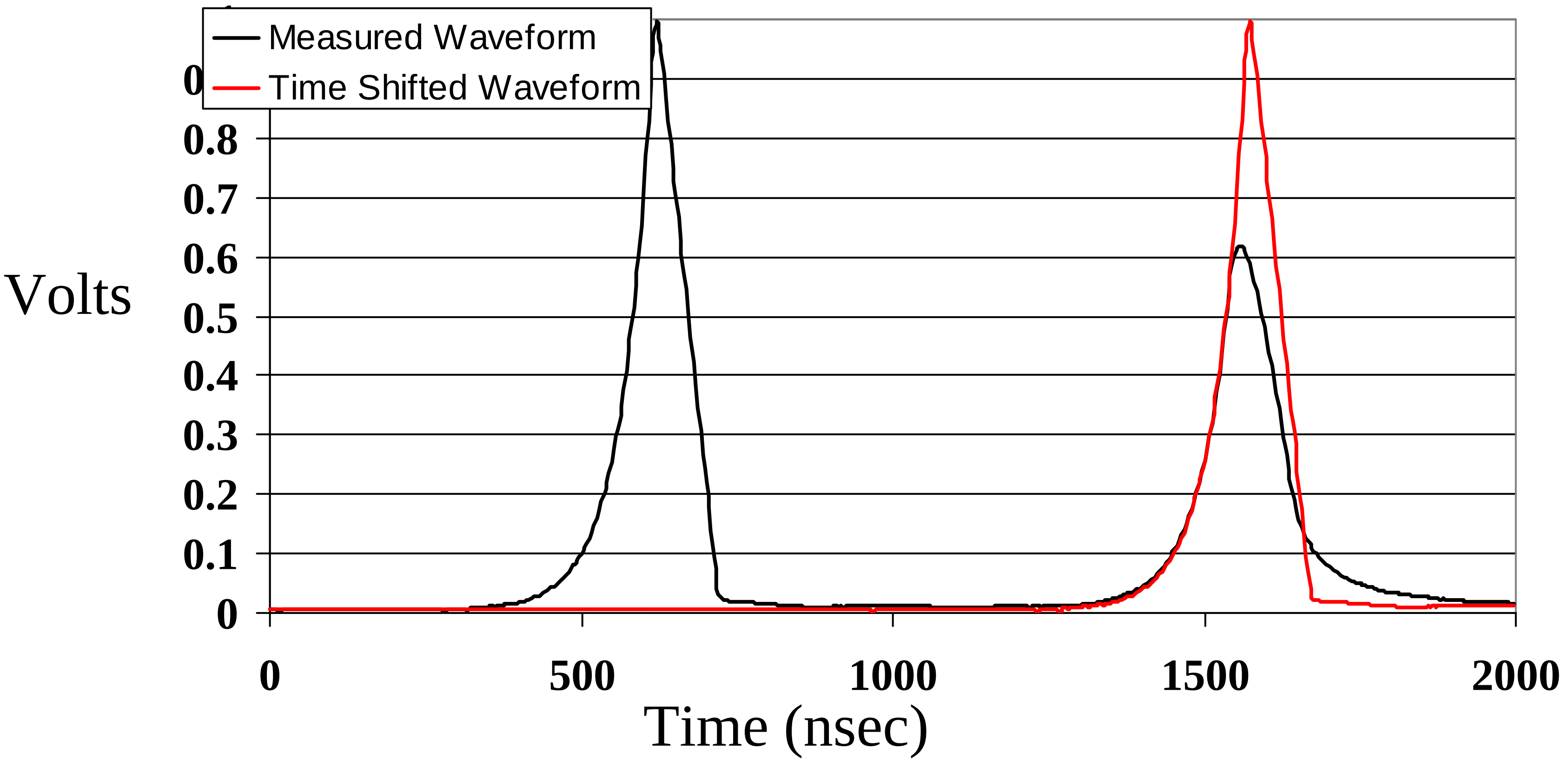
d. Propagation attenuation of truncated SD signal

e. Temperature effect on signal propagation speed in Cable

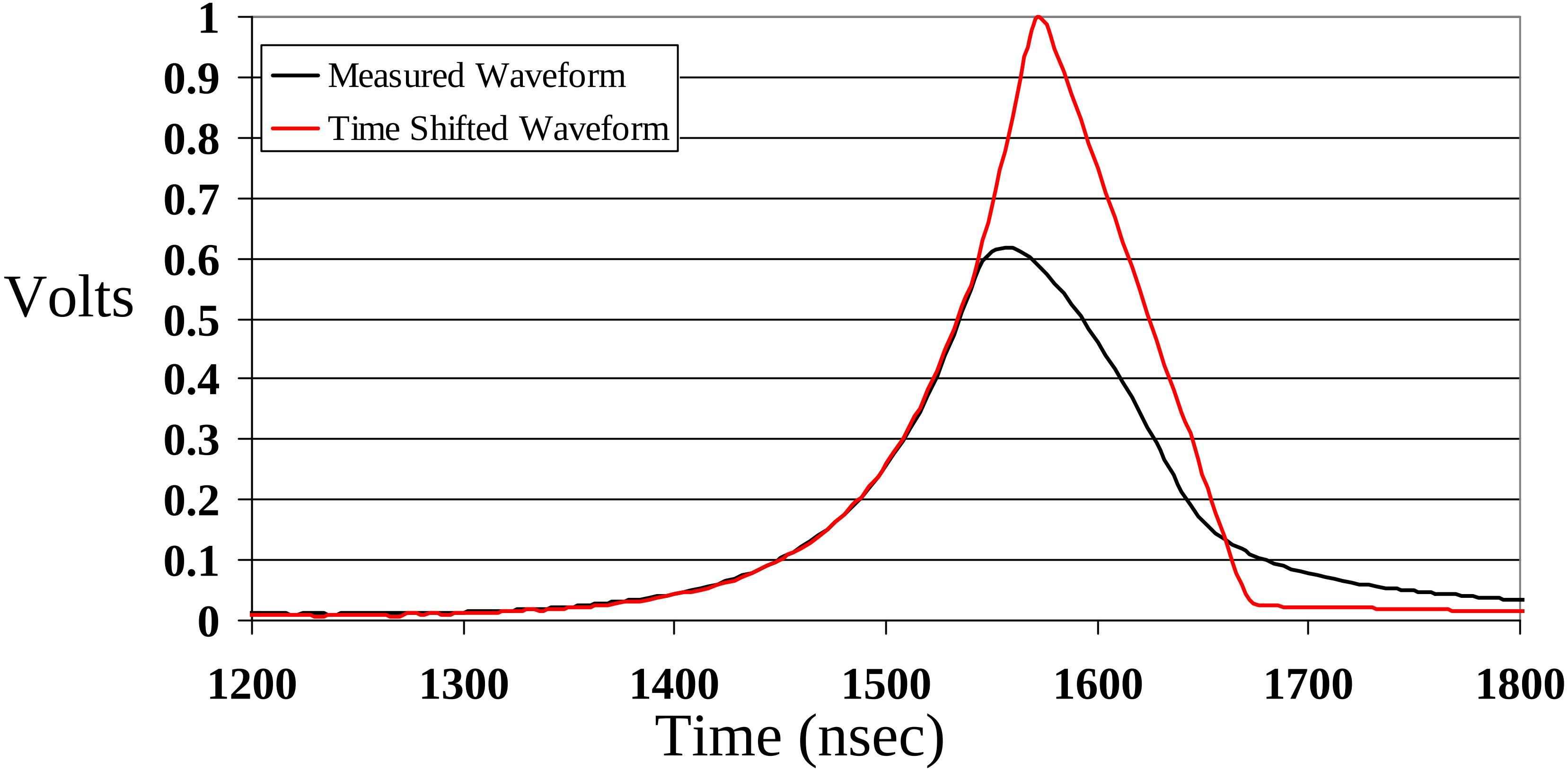
Preserves Shape: 200m Propagation of Speedy Delivery Waveform on Coaxial Cable (TDR Measurement)



Preserves Shape: 200m Propagation of Speedy Delivery Waveform In Coaxial Cable (with input translated)

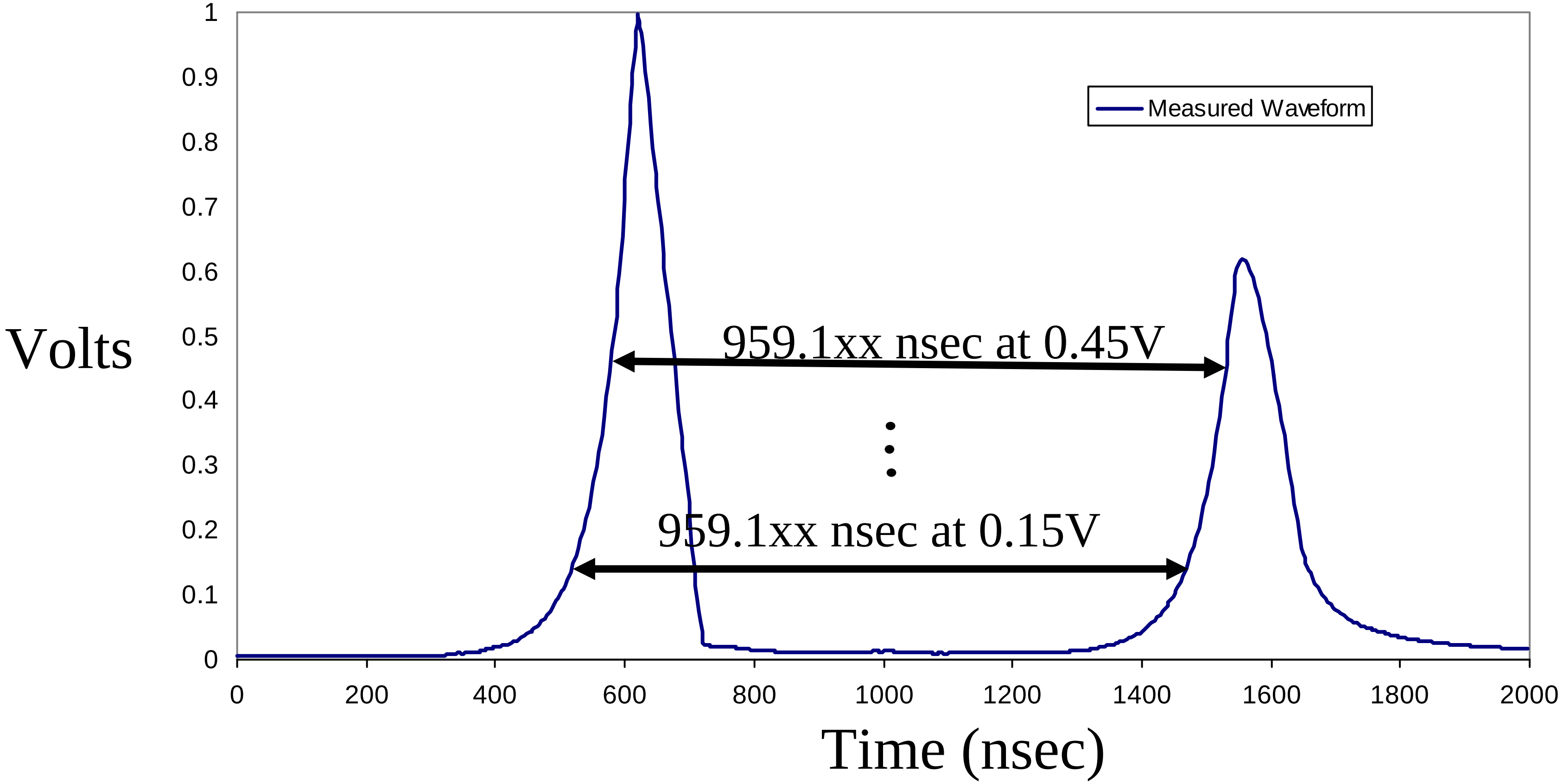


Preserves Shape: 200m Propagation of Speedy Delivery Waveform In Coaxial Cable (with input translated)



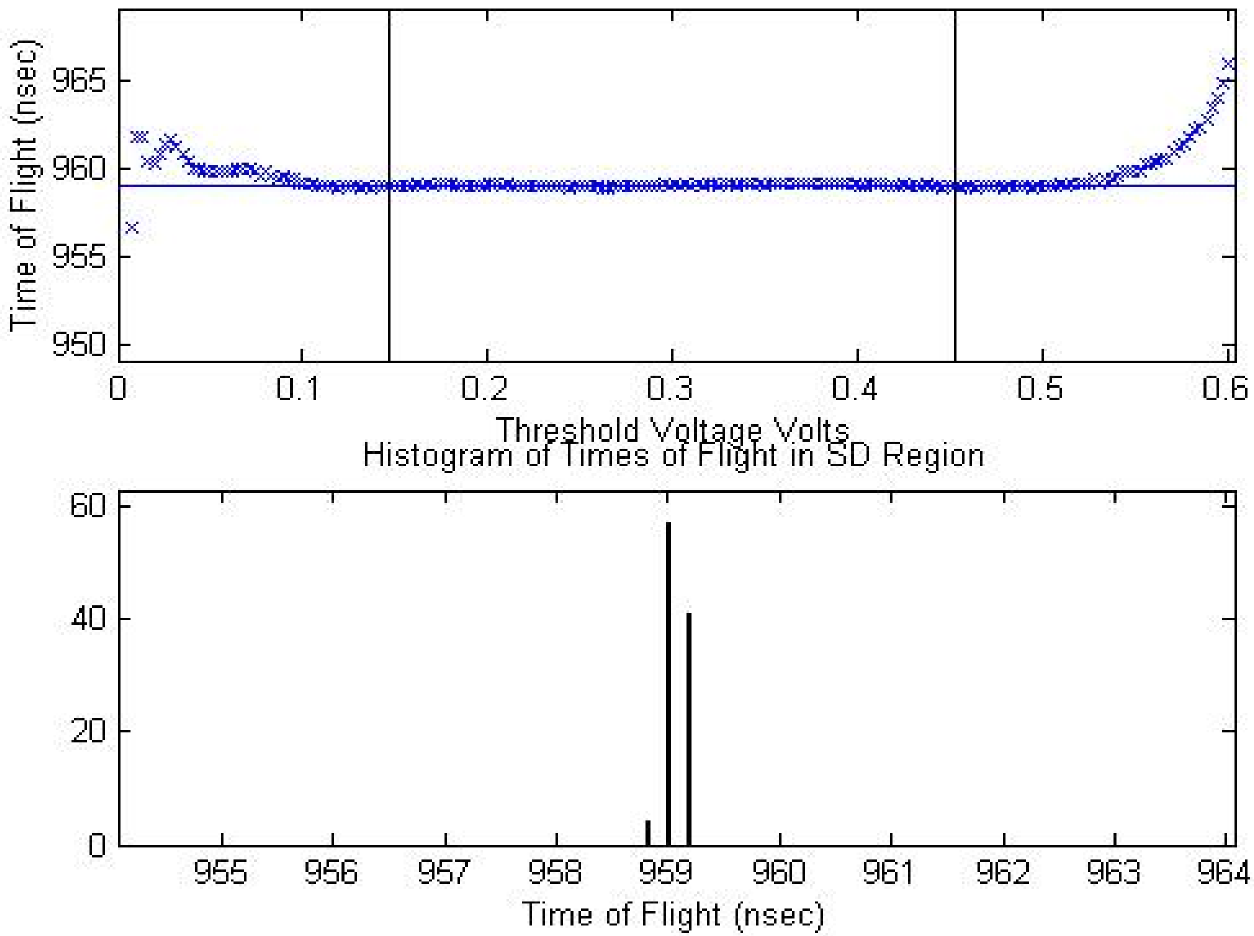
Measurement of Propagation Velocity

(Distance Traveled / measured TOF)



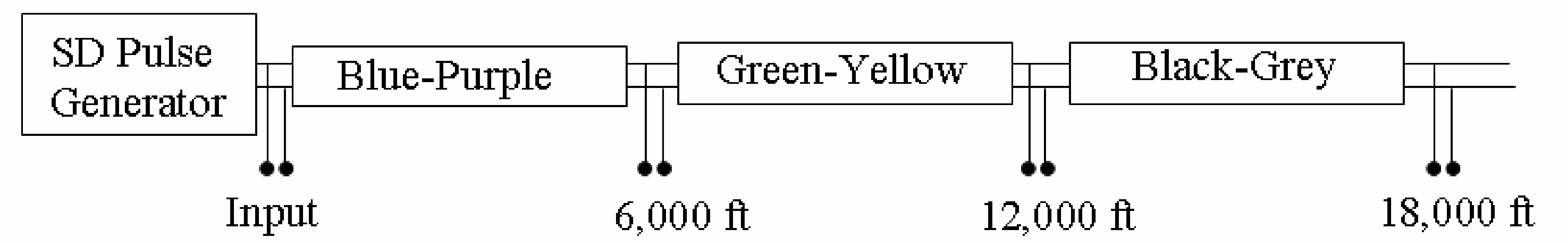
Measurement of Propagation Velocity

(Distance Traveled / measured TOF)

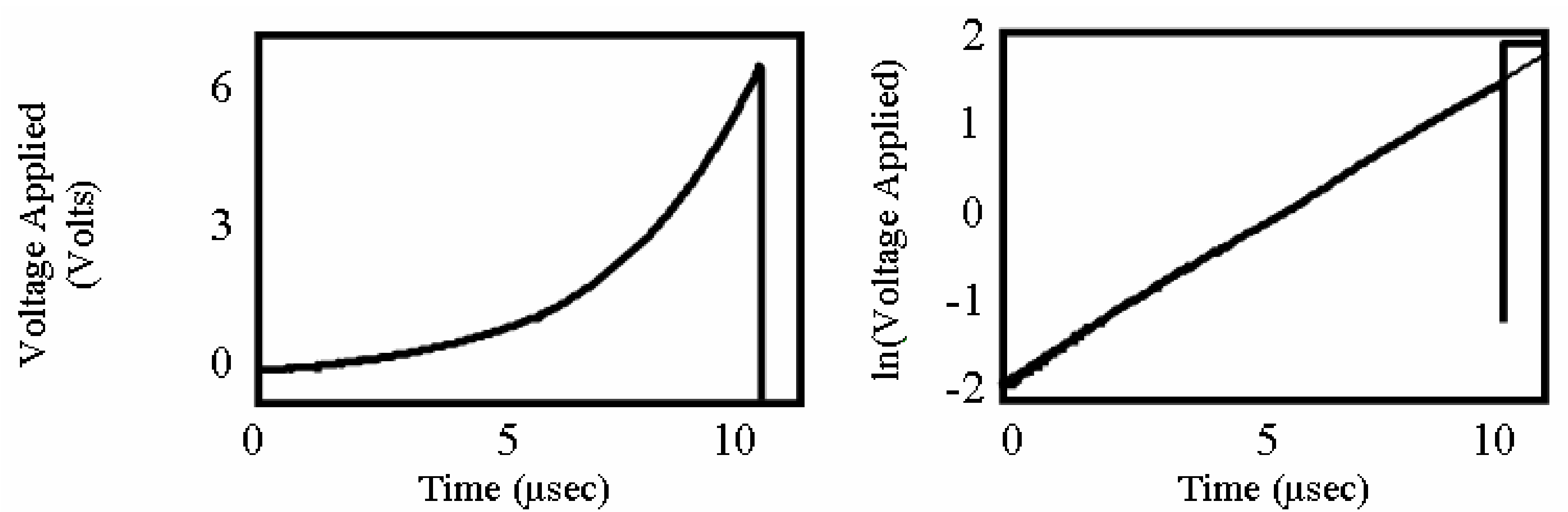


Twisted Wire Pair Configuration

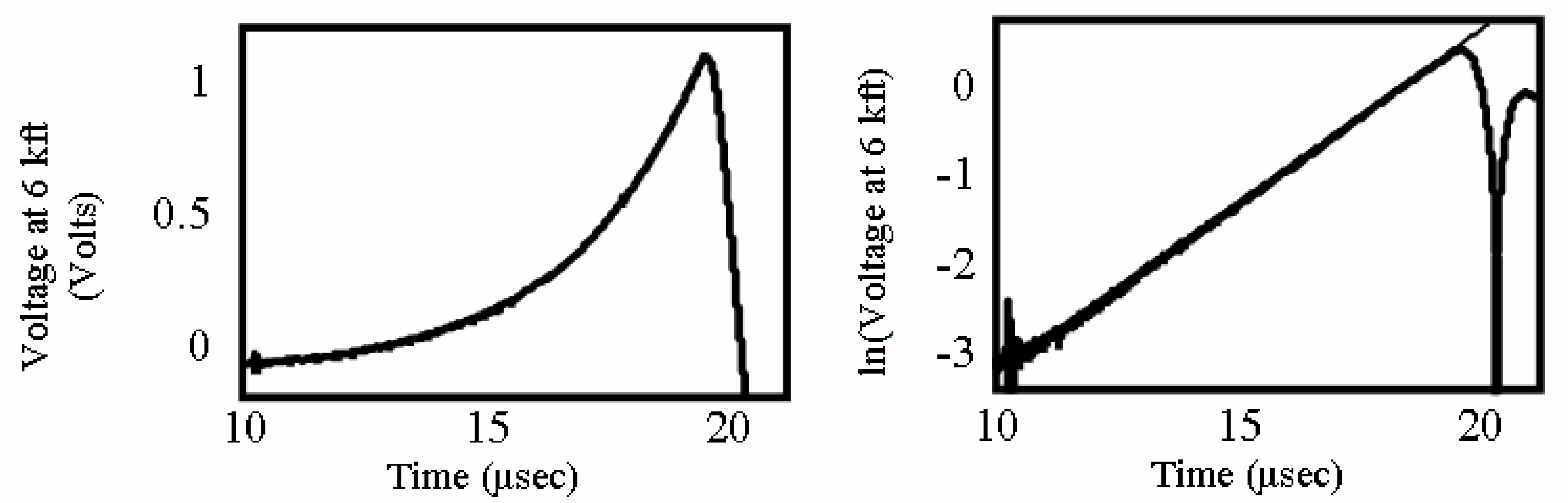
- Three of 50 TWP lines connected in series inside the sheath of a 6000 ft spool of telephone line



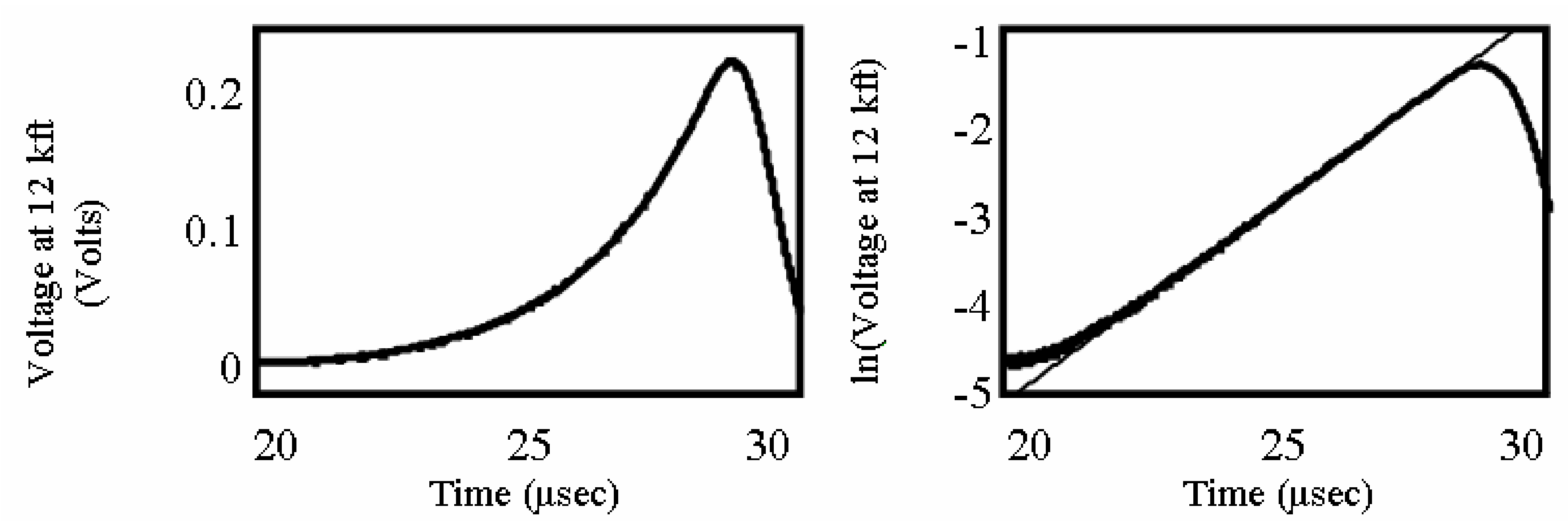
Speedy Delivery Waveform Measured as Applied to the Blue-purple Cable Input



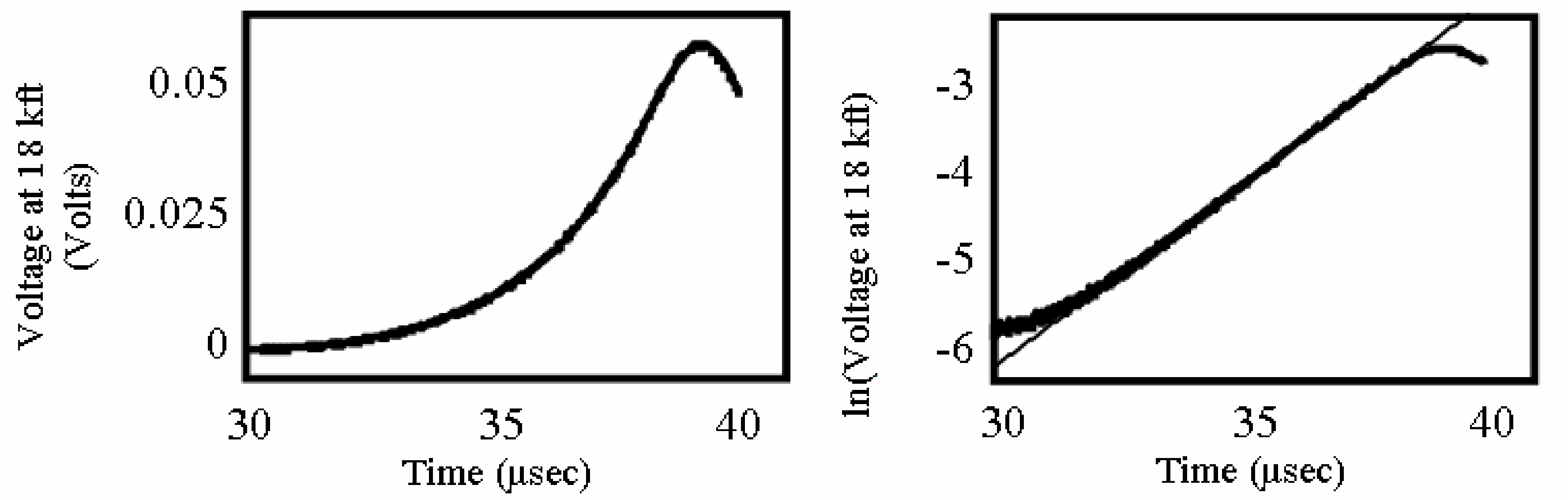
Speedy Delivery Waveform Measured at Six Thousand Feet between the Blue-purple and the Green-yellow Cables



Speedy Delivery Waveform Measured at Twelve Thousand Feet between the Green-yellow and Black-gray Cables

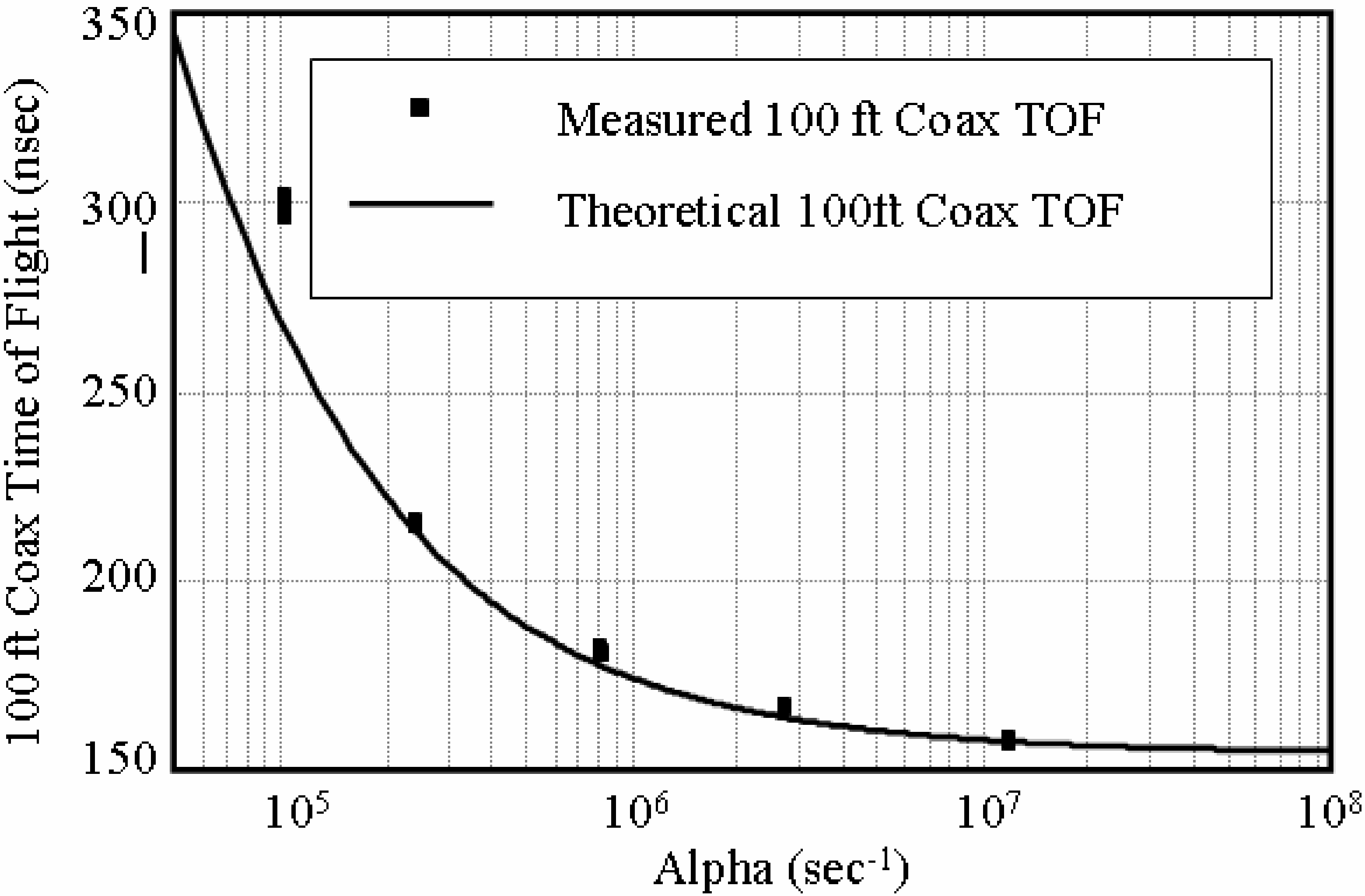


Speedy Delivery Waveform Measured at Eighteen Thousand Feet at the End of the Black-gray Cable

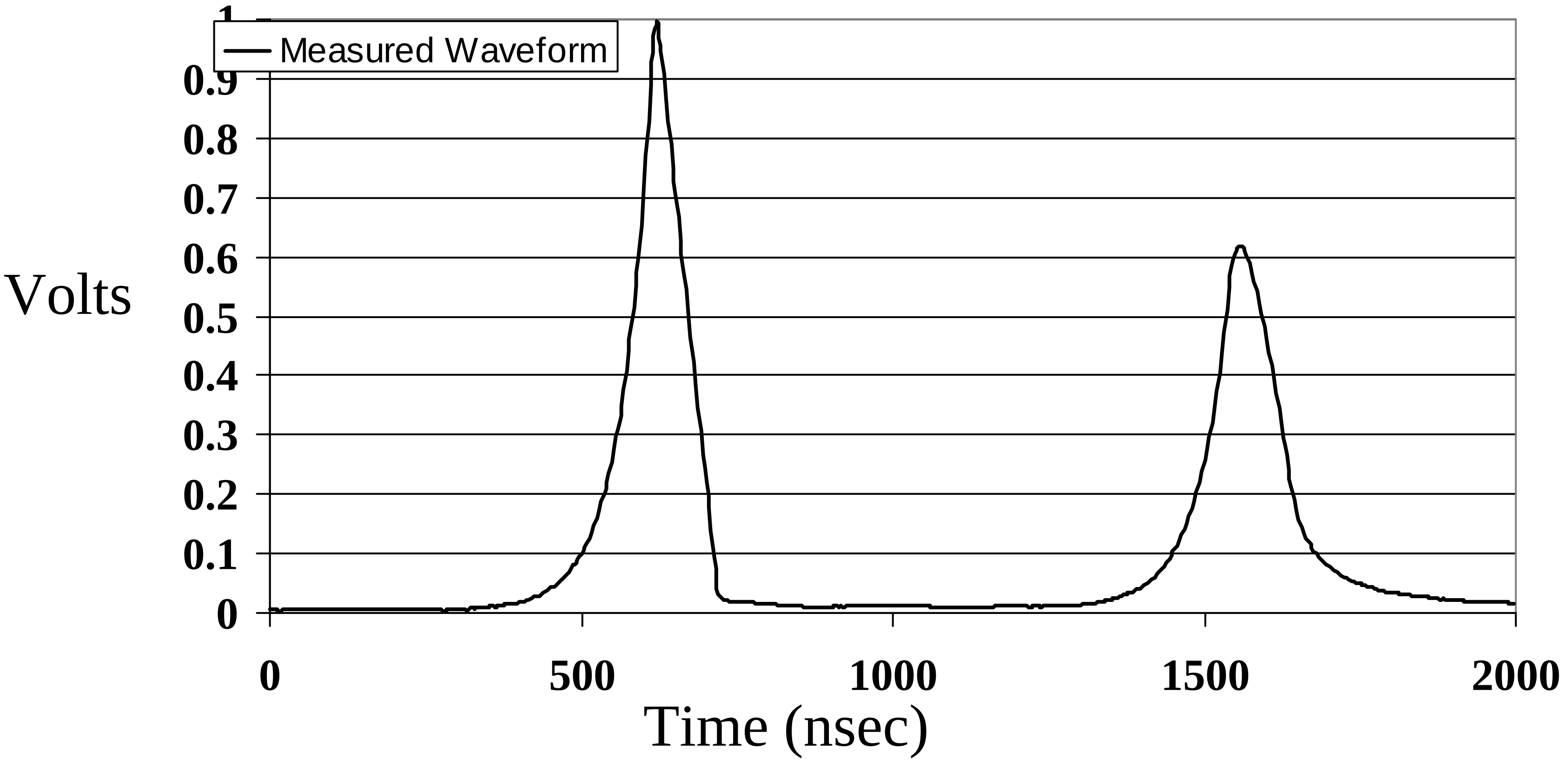


Propagation velocity is controllable

Cable Input Voltage $= De^{\alpha t}$



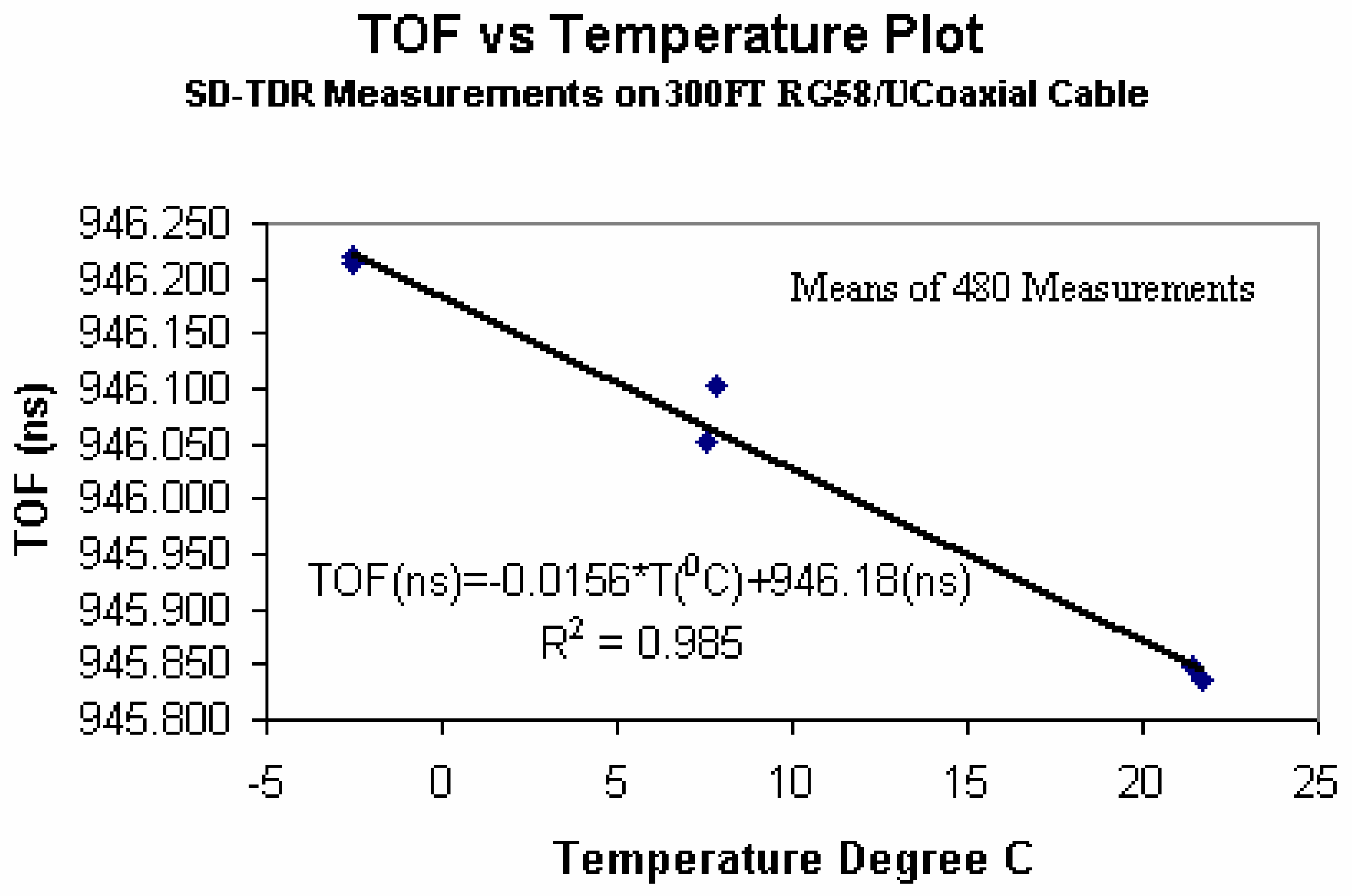
Propagation attenuation of Truncated SD signal



Propagation attenuation of Truncated SD signal

- Any application of the SD signal in a circuit will require that this exponential signal be truncated at some maximum amplitude. The result of truncating the amplitude of the SD signal at the line input is that the responses measured at different locations along the transmission line are also truncated SD signals having the same shape, but whose peak amplitudes decline with distance.
- Note that using a truncated SD signal as the forward edge of a closed pulse and closing the pulse with a non-SD waveform, results in dispersion of the pulse wave form as a whole, with only the leading SD edge retaining it's shape as it propagates in DLM.

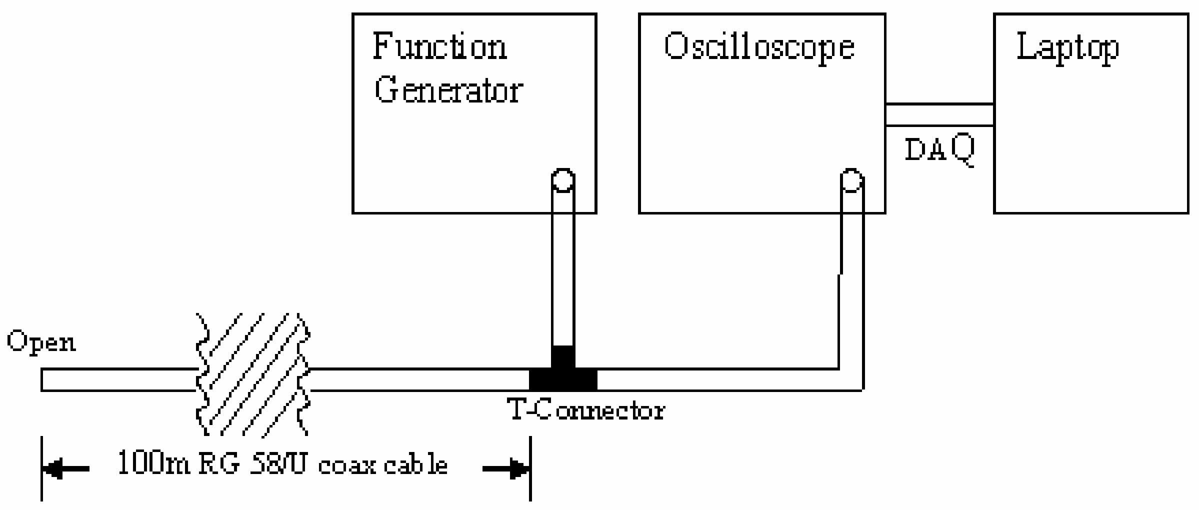
Temperature/Signal delay effect



III. SD/TDR application

Virtual Instrument SD/TDR set up

The Virtual Instrument hardware/software used to implement this SD/TDR consists of a laptop, TEK TDS 3054B dig scope(500 MHz, 5GS/s) and an Agilent 33250A (80MHz) AWG with Labview and Matlab software.



IV. Live demo of SD/TDR measurements on cable made during the Central Texas IEEE Communication/Signal Processing section meeting, May 19th, 2005

Brief Summary

TDR measurements were made on 300 ft. of RG/U cable using the "Speedy Delivery" signal as the test pulse. The average of 30 SD signal delay measurements on the un-terminated cable was first obtained and then a short length of the cable was cut off and the delay measurements were repeated to obtain a second average of 30.

When the TDR instrument finished these measurements, the second delay mean (Mean2=967.160 ns after the cut) was subtracted from the mean cable delay before the cut (mean1=967.189 ns). The TOF difference (29 ps) was divided by 2 (two-way signal travel on the cut piece) and then divided by 130 ps/in. (our calibrated SD signal delay/ length for this cable). The result, 0.111 in. (2.82mm), was displayed on the TDR computer monitor.

Caliper measurements of the length of the cut off piece were made by two attendees: 0.118 in. (3.00mm) and 0.121 in. (3.08mm). The differences between the SD/TDR estimated cut off length and the two attendee caliper measurements were .007 in. (0.18mm) and .010 in. (0.25mm), which when divided by 3600 in. (300 ft.) resulted in a 1.9 ppm and 2.8 ppm discrepancies or estimates of SD/TDR spatial resolution.

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued

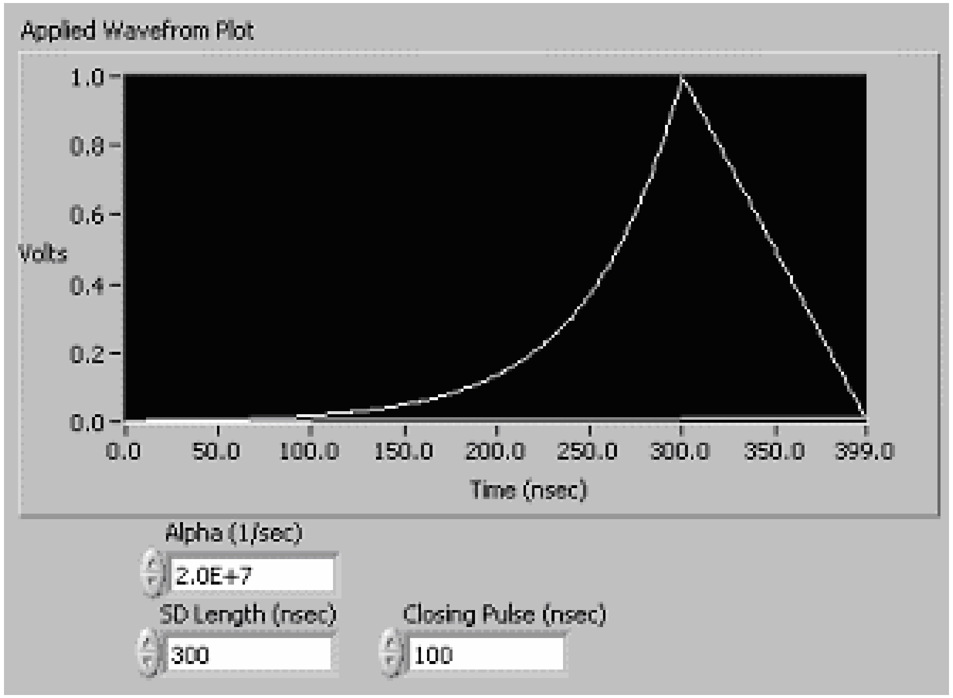
The SD/TDR used an SD signal as the test pulse. This test pulse is generated by an AWG. The computer display showing this generated SD test signal appears below.

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued

SD waveform loaded in the AWG

Exponential coefficient (Alpha) of the SD test waveform = 2.0E+7 (1/sec); SD exponential duration at the front of the pulse = 300 (nsec)

Closing (ramp) pulse duration= 100 (nsec)



- Figure 1 -

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued

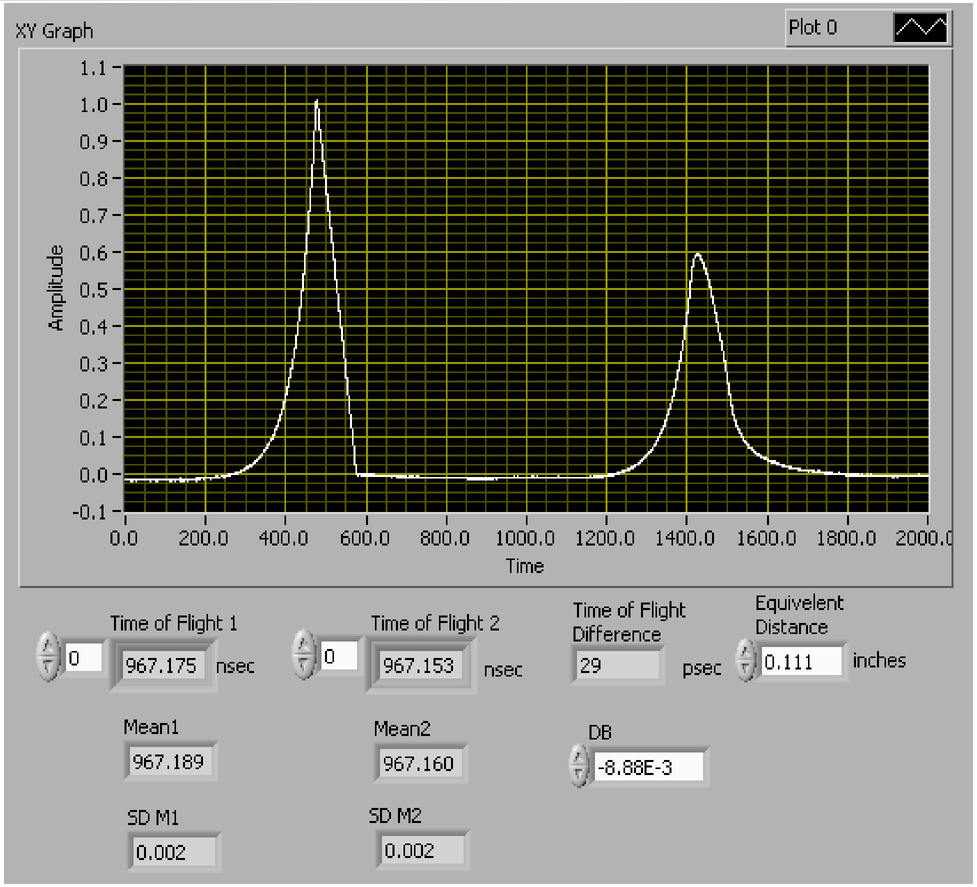
Figure 2 contains the following:

Reproduces the scope display showing the transmitted and reflected pulse on the cable.

The mean (average of 30 measurements) delays, "Mean 1" (= 959.189 ns.), before the cut and "Mean 2" (= 959.160 ns.) after the cut.

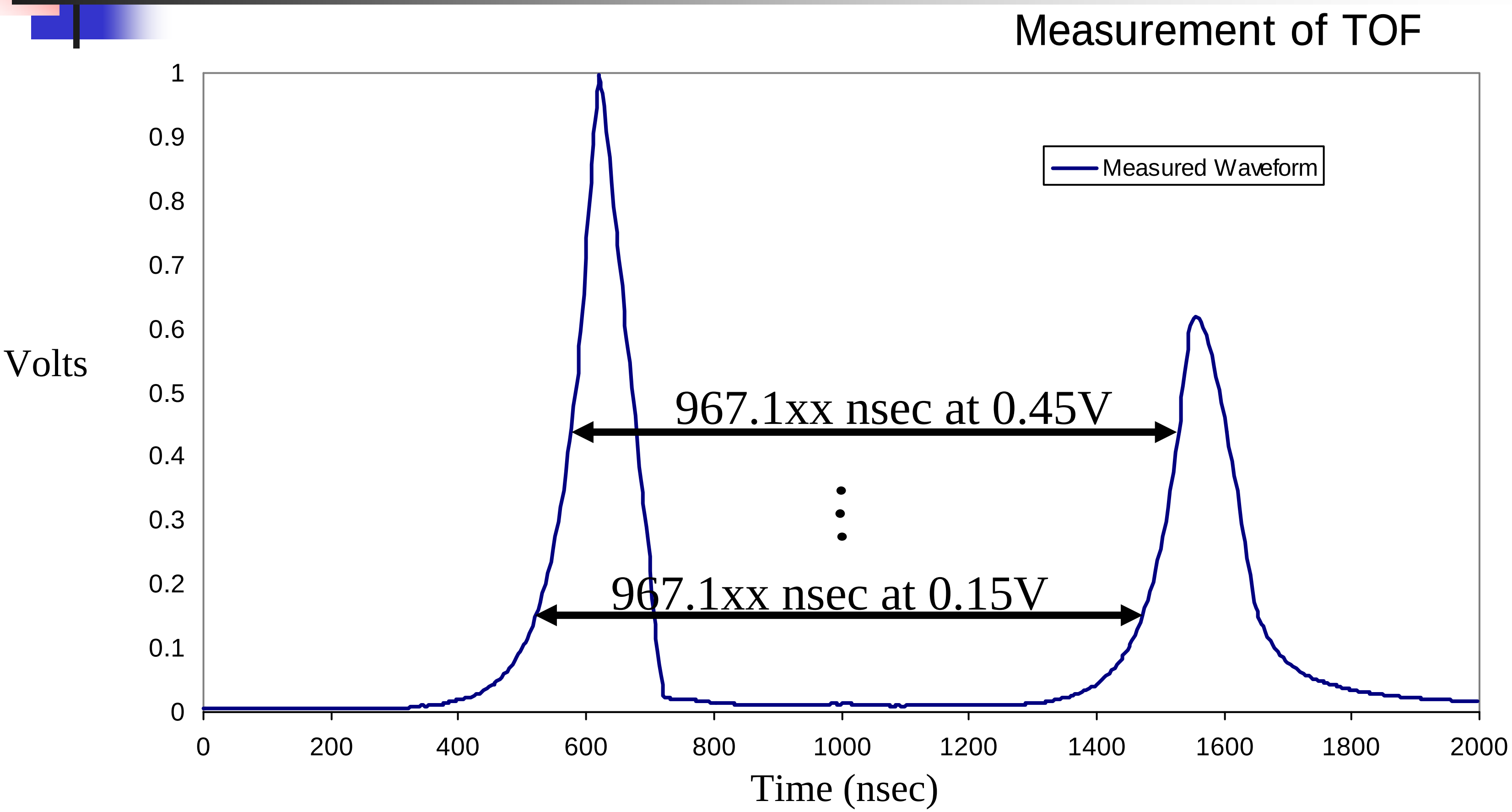
Mean2 subtracted from Mean1 equals "Time of Flight Difference" (= 29ps.)

(29ps/2)/(130 ps/in) = "Equivalent Distance" (= 0.111 in. or 2.82mm) i.e., estimated length of the cut off piece of cable



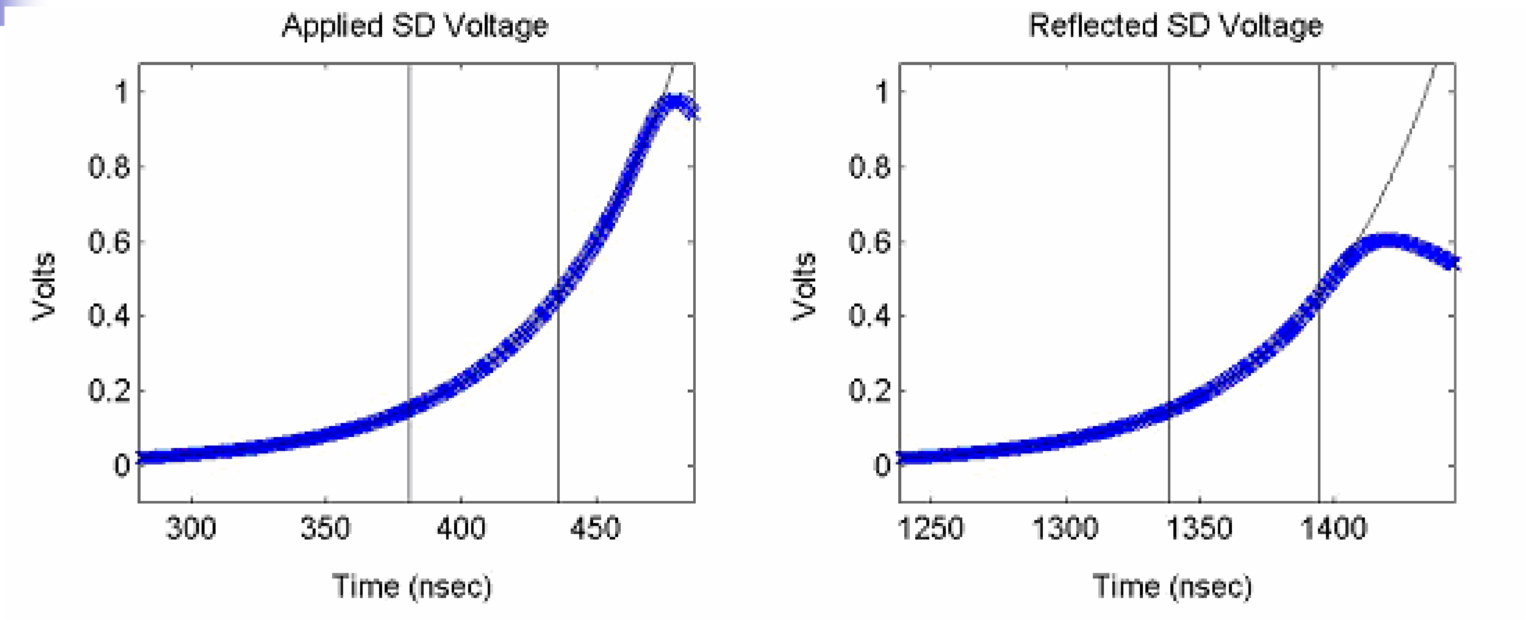
- Figure 2 -

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued



- Figure 3 -

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued



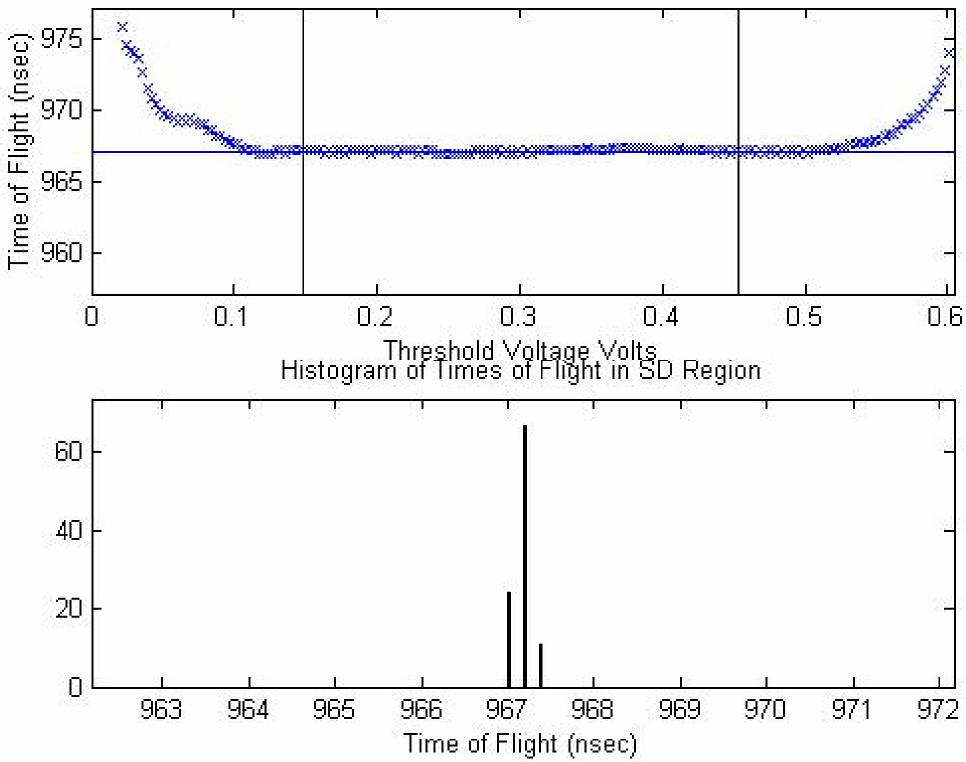
- Figure 4 -

The graphs show the amplitude regions of the applied and reflected signals where the delay values between the two signals (at 100 different voltage thresholds) are measured and averaged to obtain the delay estimate for the test pulse.

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued

The top figure shows the individual constant threshold time of flight measurements vs. the threshold voltage values where these SD signal delay measurements were made. The vertical lines indicate the range of threshold values of the 100 time of flight measurements used to obtain the average estimate of delay between the input and reflected signals.

The second graph is a histogram of the 100 constant threshold time of flight measurements obtained between the vertical lines in the top figure. The buckets in this histogram are separated by 200 ps, which is the sampling period for the digital scope.

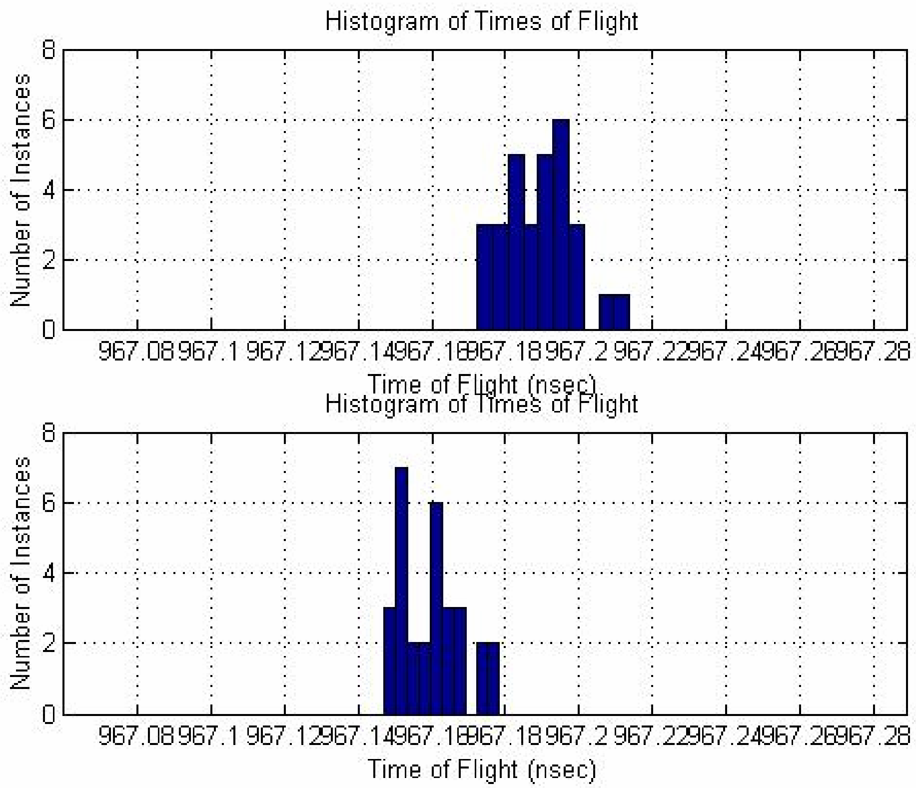


- Figure 5 -

IV. Live demo (05/19/05) of SD/TDR measurements on cable-continued

The top graph shows the histogram of the 30 SD signal delay measurements made before the cut that were averaged to obtain Mean1 (967.189 ns) shown in Fig 2.

The bottom graph is the histogram of the 30 delay measurements made after the cable was trimmed. These measurements were averaged to obtain Mean2 (967.160 ns) shown in Fig 2.



- Figure 6 -

V. Comparison with spatial resolution of conventional TDR

In a conventional TDR, the spatial resolution is a function of the rise time of the incident TDR test pulse and the dielectric constant of the metal interconnect being measured. This minimum spatial resolution is:

$$\ell = \frac{t_r c}{2\sqrt{\varepsilon_r}}$$

Where ℓ is the length of the minimum spatial resolution

c is the speed of light in vacuum

t_r is the rise time if the incident test pulse

ε_r is the relative dielectric constant

Comparison with spatial resolution of conventional TDR - continued

The spatial resolutions of the SD/TDR measurements on the cable were 0.007 inch (0.18mm) and 0.010 inch (0.25mm), the value of ε_r for the coaxial cable was 2.3. Conventional TDRs with these spatial resolutions would have test pulse rise times,

$$t_r = \frac{\ell * 2\sqrt{\varepsilon_r}}{c} = \frac{(0.18*10^{-3})*2\sqrt{2.3}}{3*10^8} = 1.82\,ps$$

and

$$t_r = \frac{\ell * 2\sqrt{\varepsilon_r}}{c} = \frac{(0.25*10^{-3})*2\sqrt{2.3}}{3*10^8} = 2.53\,ps$$

A pulse with either of these rise times from a conventional TDR would not be detectable after 600 FT traveling in the RG58/U coaxial cable.

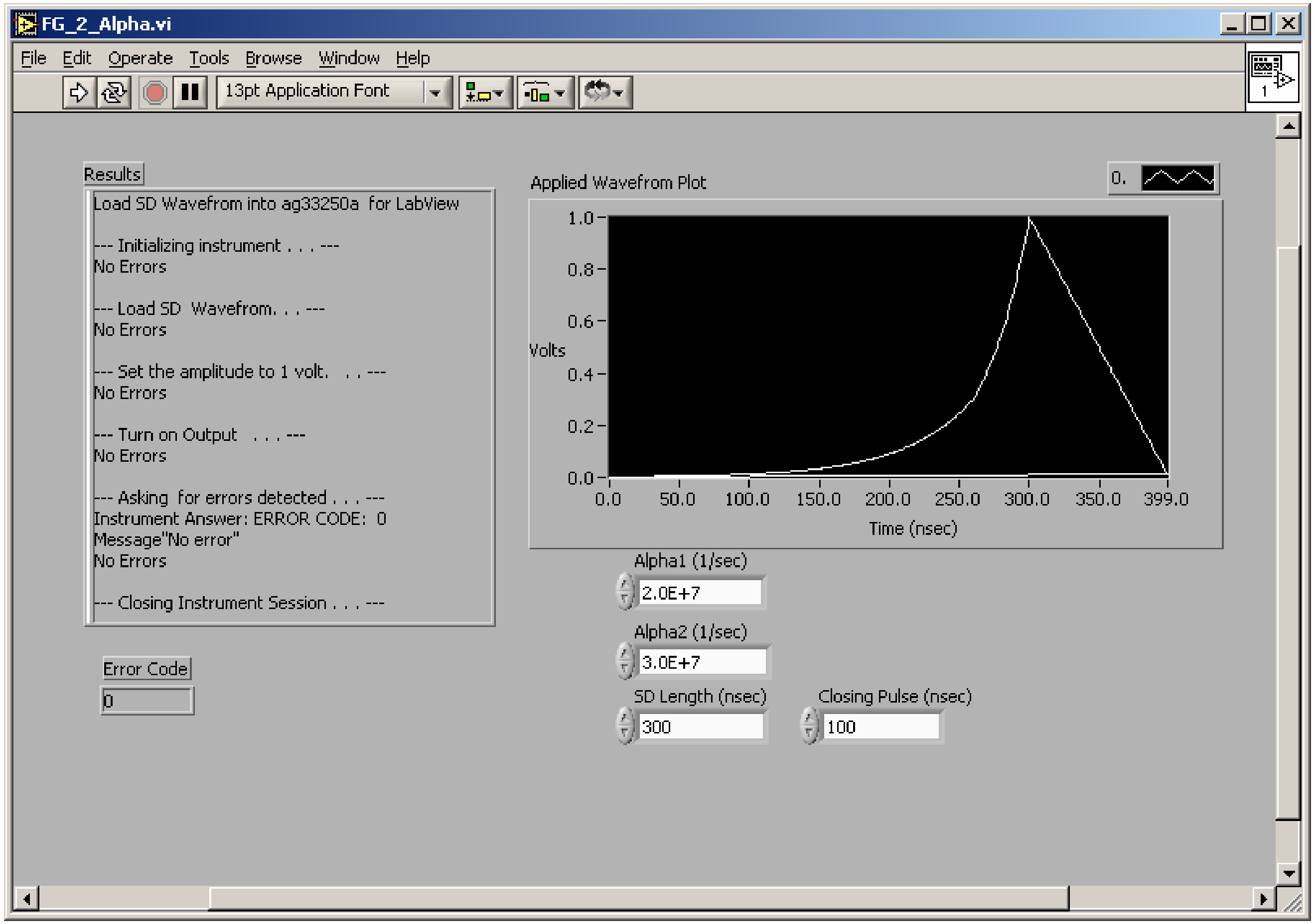
VI. Applications of SD Signal in communications

The SD waveform and accompanying propagation properties can be incorporated into the signal waveforms of digital and communication systems. In communication systems, new coding modalities unique to the SD waveform can be utilized that complement current communication waveform coding techniques.

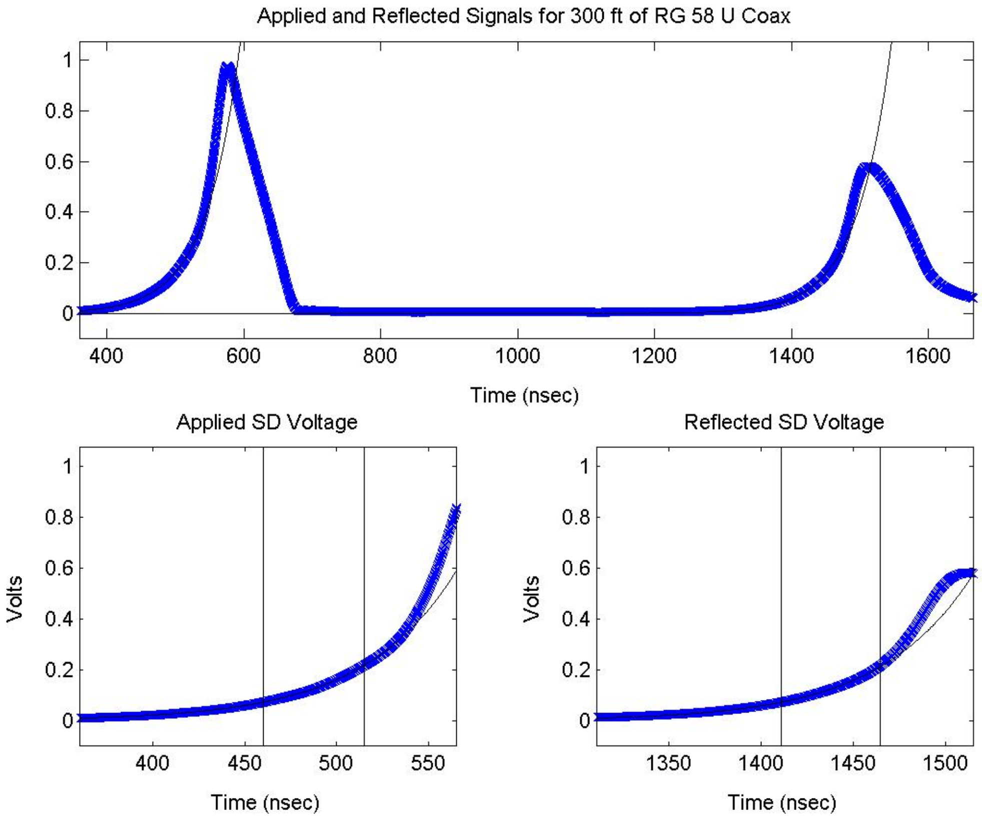
For example, since the SD waveform does not change shape during propagation in dispersive and lossy media, the SD shape parameter a (exponential coefficient) may be varied from one transmitted SD pulse to another with the pattern of change in a detected at the receiver. In this manner, the value of α may be coded to convey information transmission in the channel. It should be noted that this process of modulation produces essentially no increase in bandwidth of the transmitted symbols.

Another observation is that this process of encoding also allows multiple distinct values of α to be simultaneously incorporated into SD portions of the leading edge of a pulse. An example of encoding two values of α in the leading edge of a pulse is illustrated in the figures that follow. Two bits of information may be coded in this manner.

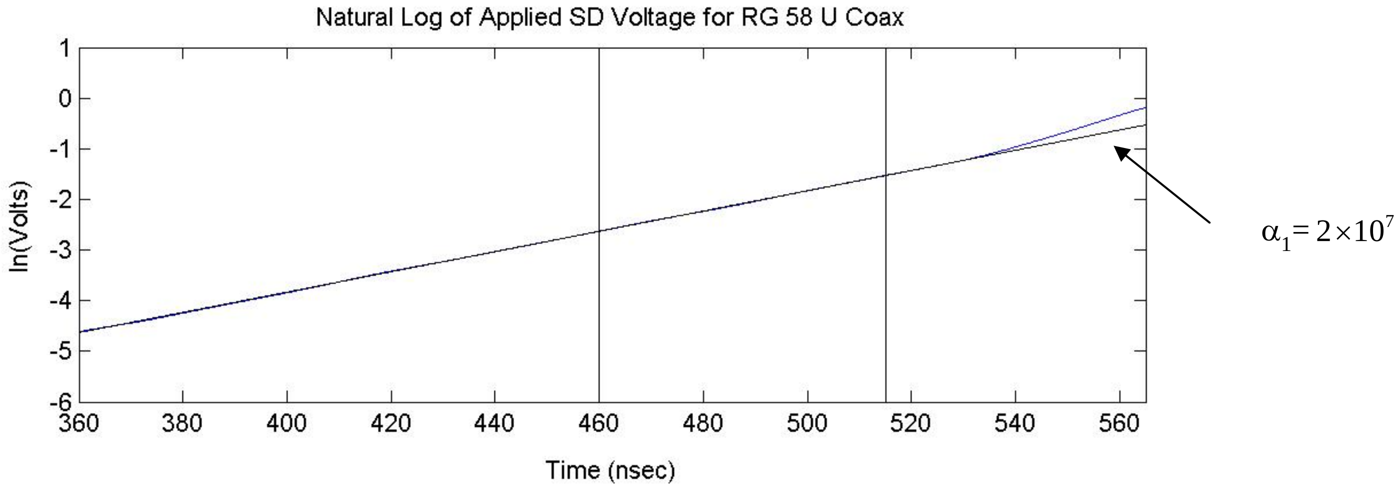
VI. Applications of SD Signal in communications -Continued

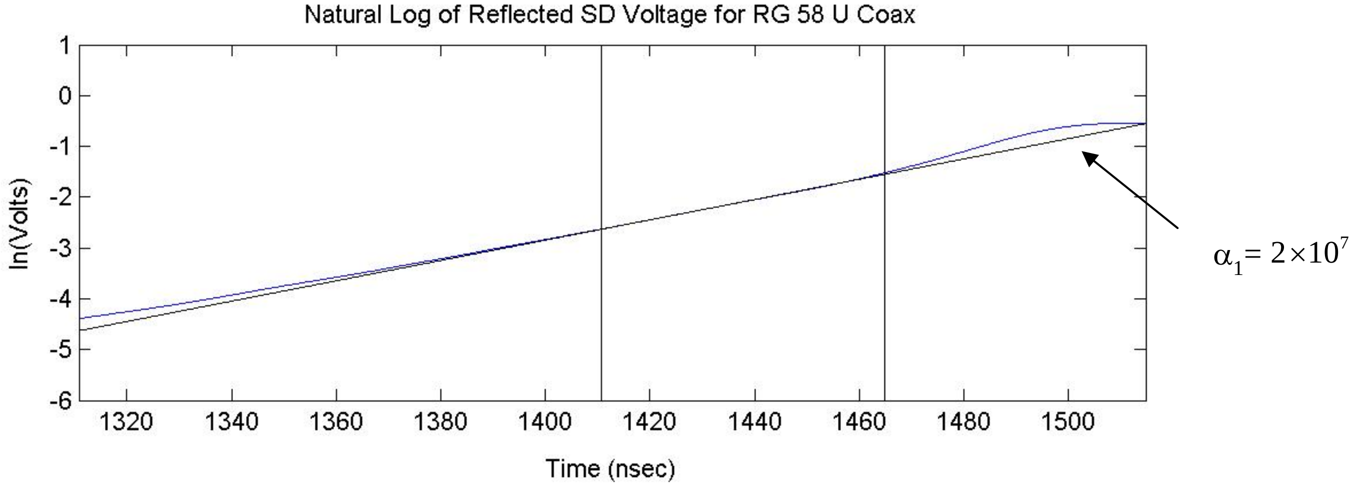


VI. Applications of SD Signal in communications -Continued

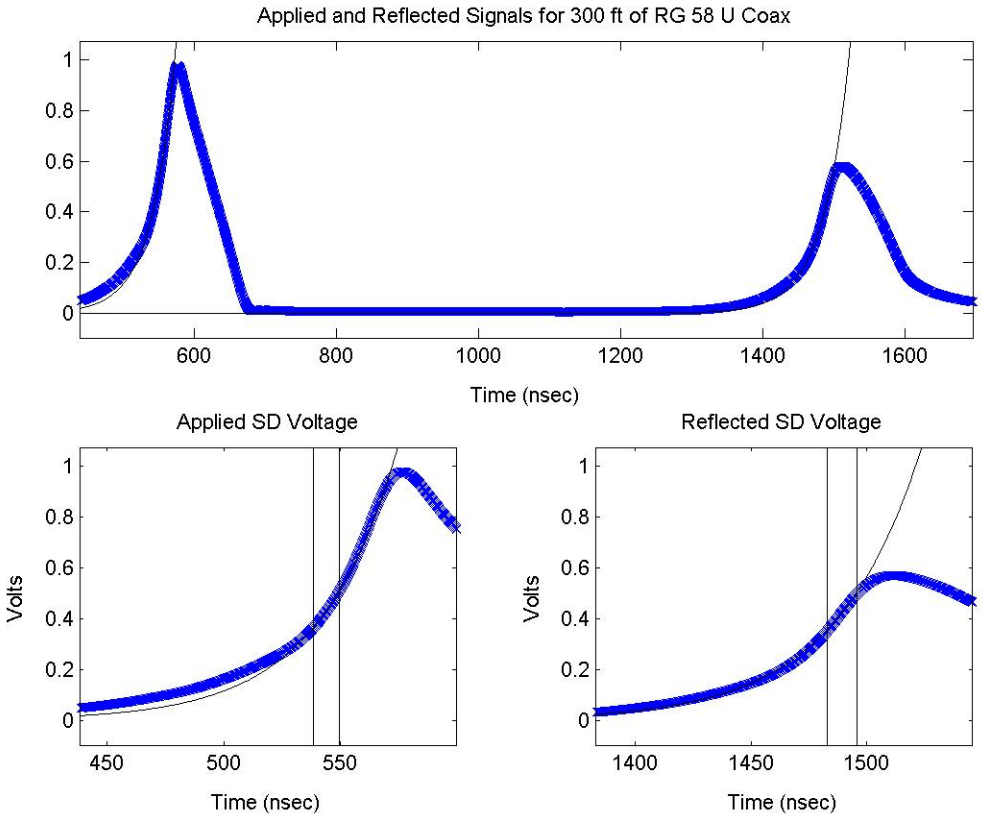


VI. Applications of SD Signal in communications -Continued

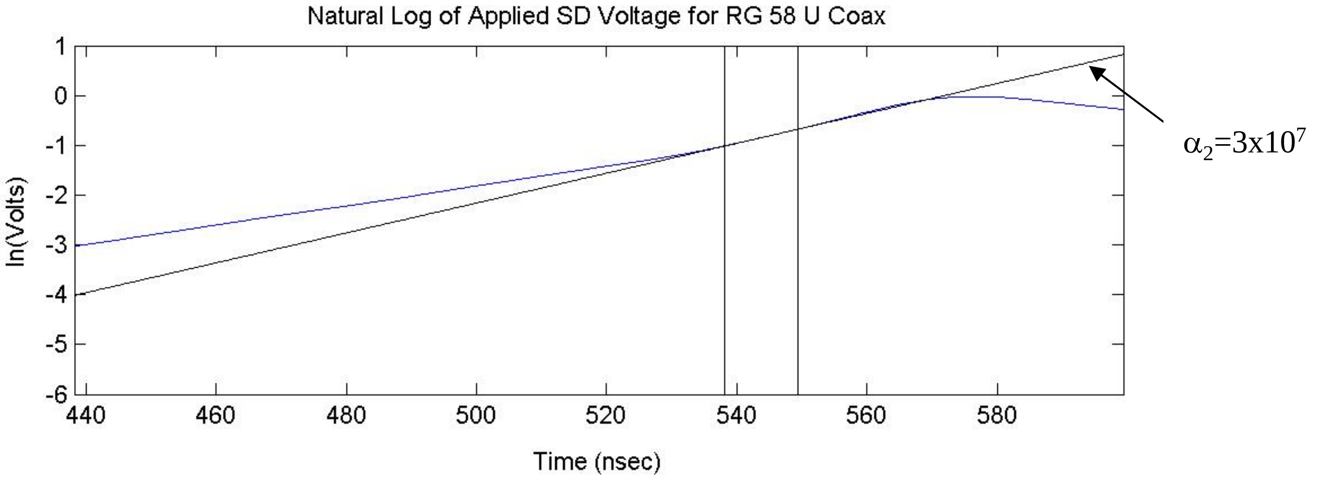


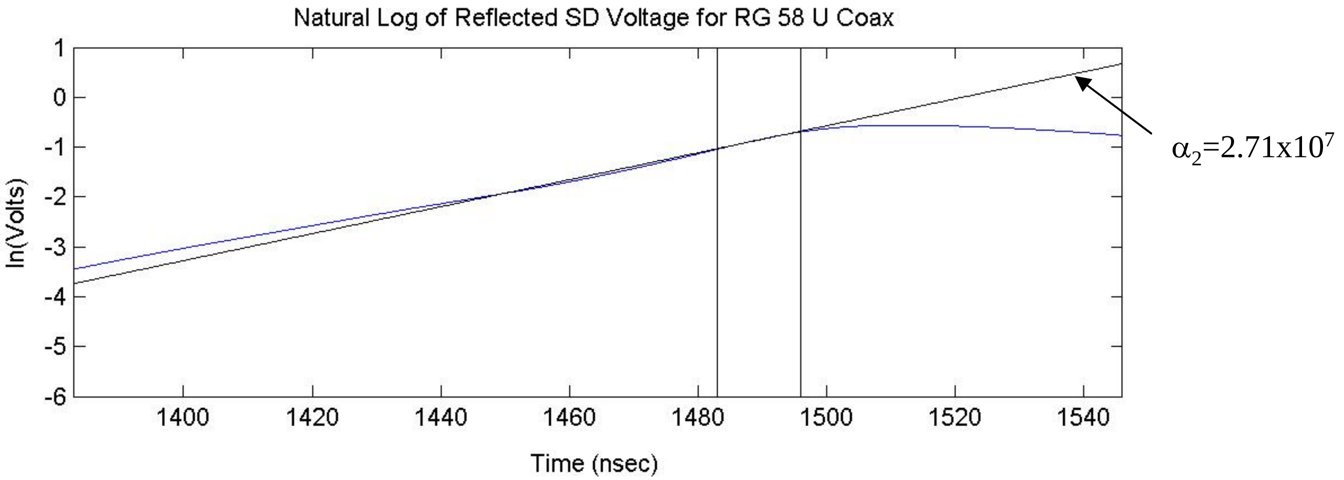


VI. Applications of SD Signal in communications -Continued

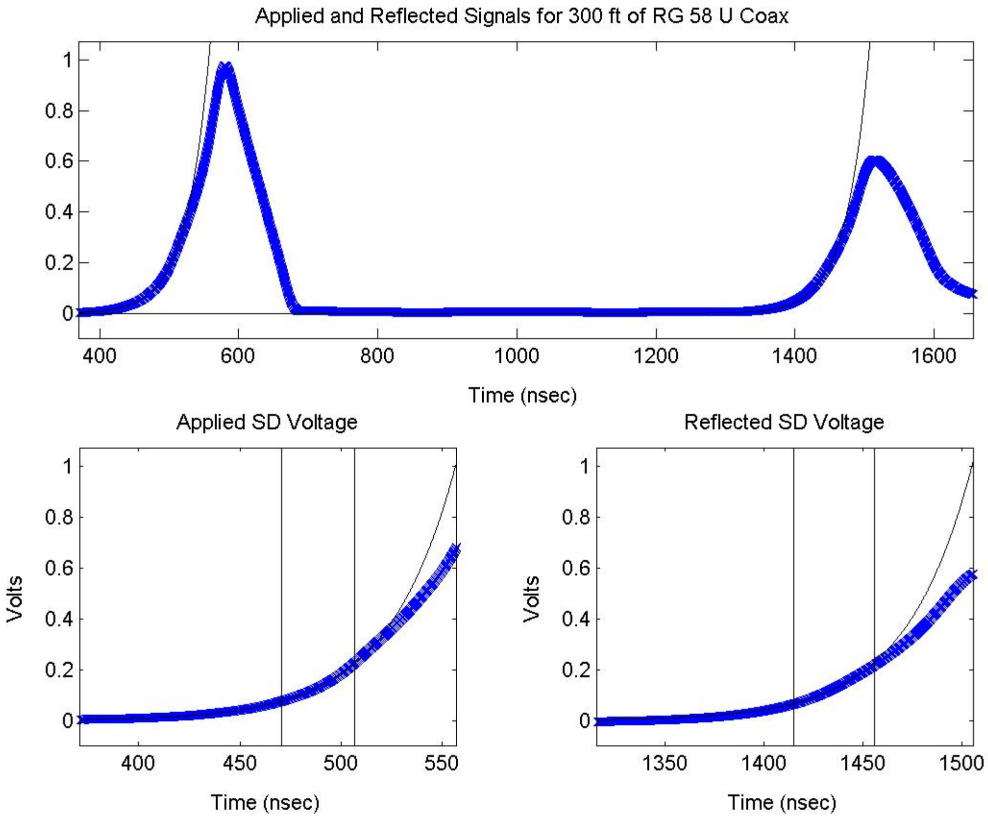


VI. Applications of SD Signal in communications -Continued

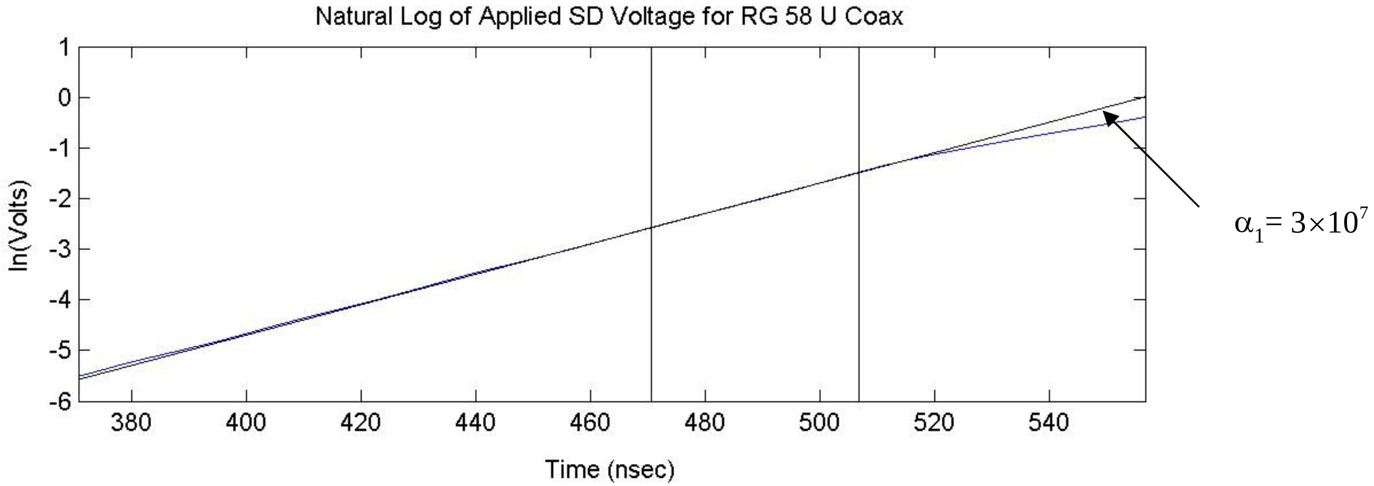


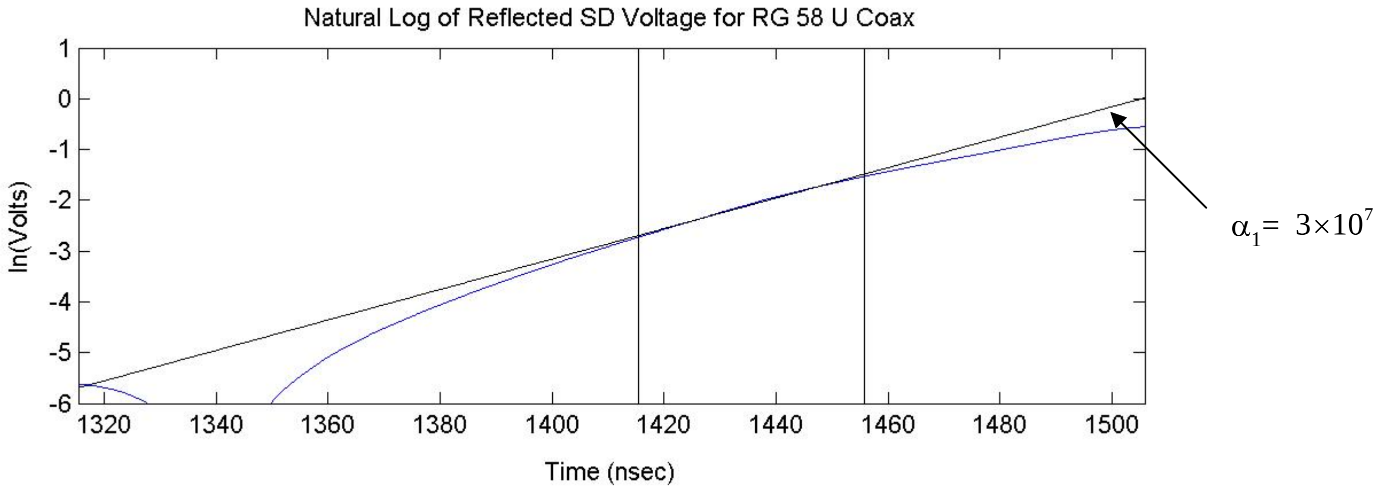


VI. Applications of SD Signal in communications -Continued

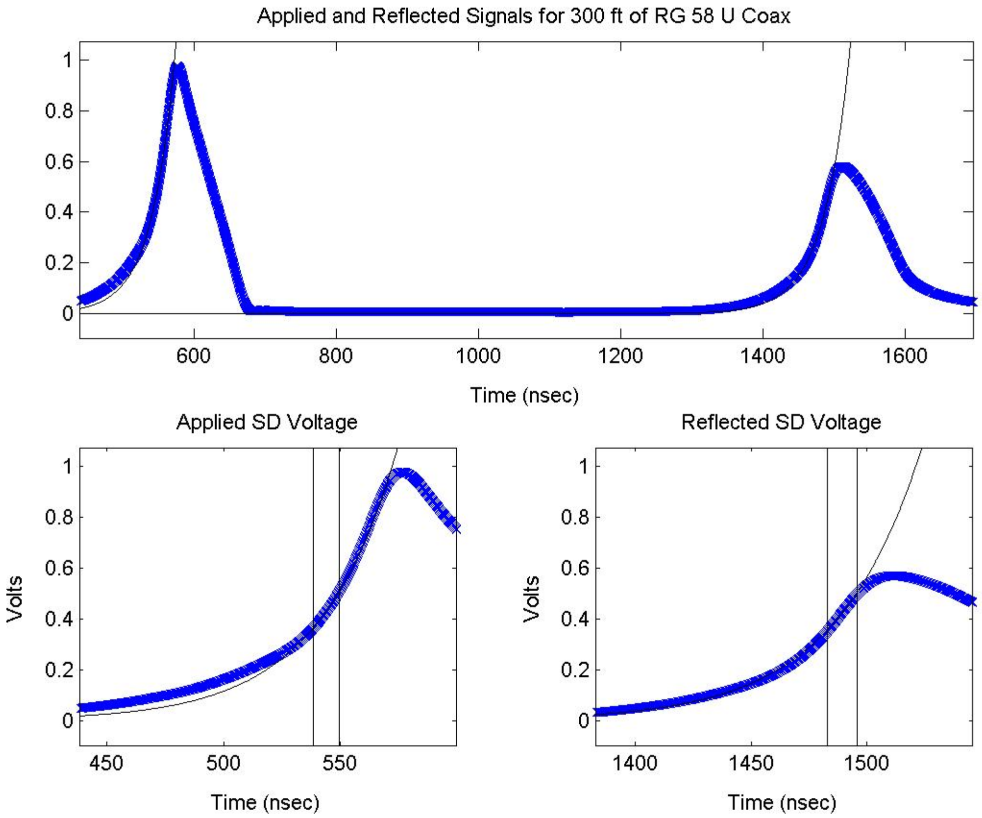


VI. Applications of SD Signal in communications -Continued

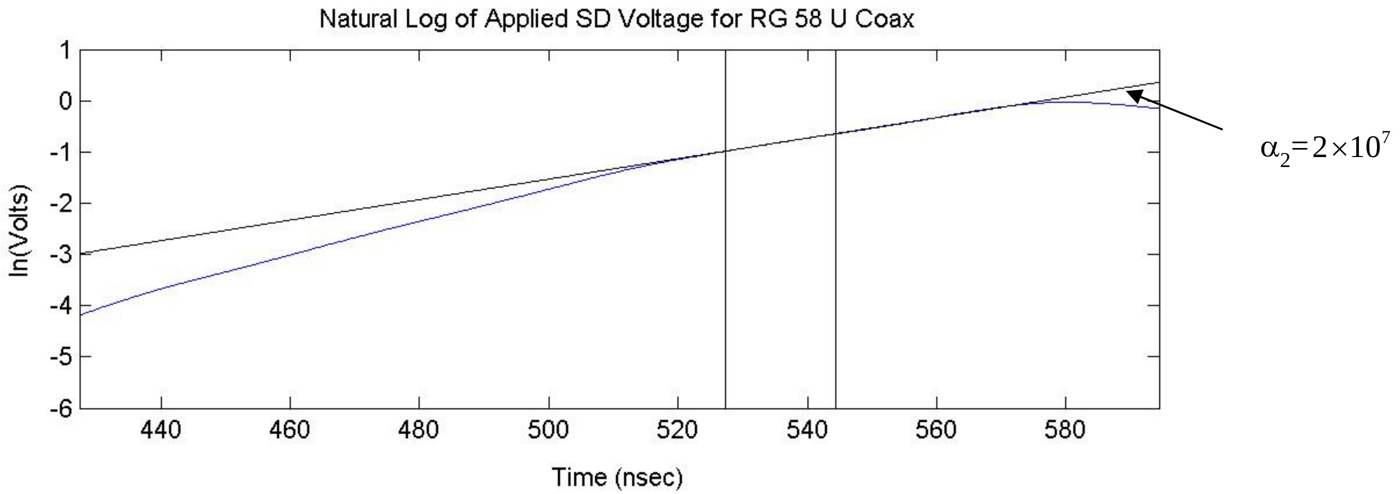


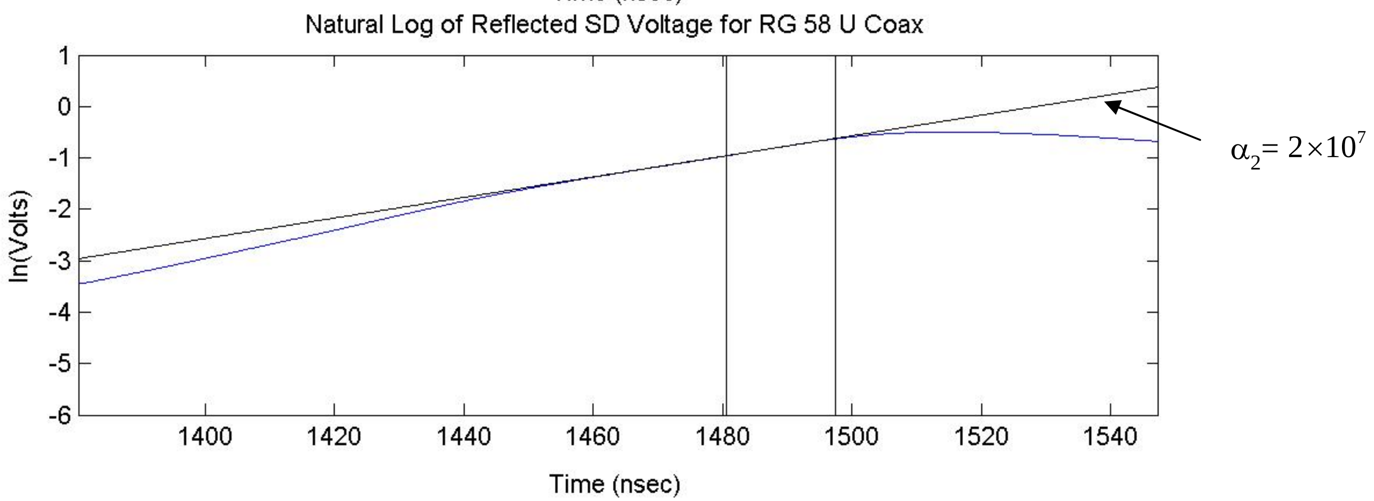


VI. Applications of SD Signal in communications -Continued



VI. Applications of SD Signal in communications -Continued





VII. Summary

- Experiments illustrate that the shape and velocity of the SD signal is preserved during propagation on long (18kft) lossy transmission (POTS) lines having frequency dependent parameters (LFTL).

- Experiments on coaxial cable illustrate that changing the shape parameter of the SD signal wave form applied to the cable results in varying the propagation delay of the signal on the cable. This results in the attainment of a variable delay line without physically altering the cable.

VII. Summary -continued

- The application of the SD signal in a virtual instrument version of a TDR (SD/TDR) was discussed. Experimental results of the instrument used to measure electrical lengths of coaxial cables were presented. Remarkable minimum spatial resolution was obtained with low frequency SD test pulses on long (100m) cables when compared with expected results for the resolution of precise high frequency conventional laboratory TDRs.
- The cable temperature effect on signal delay in long (100m) cables was illustrated by SD/TDR electrical length measurements at a series of near isothermal conditions. The warmer cable temperatures resulted in shorter electrical lengths.
- An Application of the SD signal in communications was described. Coding the SD parameter yields higher data rates without increasing channel bandwidth requirement.

SD Signal Technology

	Digital Interconnects	Communication Channels
Reducing Signal Latency	**V**	**V**
Eliminate Latency Skew	**V**	**V**
Add "Shape" Bits to New Waveform Increasing Symbol Bit Rate without Increasing Bandwidth		**V**

SD Signal Technology

Additional discussion of the background and theory underlying the SD Signal behavior on lossy dispersive transmission lines is contained in the following articles:

R. H. Flake and J. F. Biskup, “Signal propagation without distortion in dispersive lossy media”, 11th IEEE International Conference on Electronics, Circuits and System Proceedings, pp. 407-410, Dec 2004, ISBN 0-7803-8715-5.

R. H. Flake, “Part I (Theory) Signal Propagation without Distortion on Lossy Transmission Lines Having Frequency Dependent Parameters”, 9th IEEE workshop on signal propagation on interconnects, pp. 43-45, May 2005, ISBN 0-7803-9054-7.

Robert H. Flake and John Biskup, “Part II (Experiments) Signal Propagation without Distortion on Lossy Transmission Lines Having Frequency Dependent Parameters”, 9th IEEE workshop on signal propagation on interconnects, pp. 51-54, May 2005, ISBN 0-7803-9054-7.