WAVECREST Corporation

USING THE DTS 2070 IN A TDR CONFIGURATION

Application Note No. 119

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Introduction

The DTS 2070 Digital Time System is designed to be an integral part of any automated bench or ATE installation. The DTS, with its 800fS one-shot time interval measuring unit, is capable of analyzing a multitude of user problems including signals reflected down an open or shorted transmission line. The DTS 2070 with optional VirtualWare software tools can perform the following functions:

1. Low and high frequency jitter versus pulse analysis.
2. Strobe volt meter/oscilloscope function.
3. Time window analysis results for setting time.
4. Time domain spectrum analyzer histograms.
5. Function versus time/pulse analysis.
6. TDR function for cable distance.

This application note describes using the DTS 2070 as a TDR in a stand- alone fashion or with our VirtualWare 4.X software tools.

The TDR Function

This application note discusses a technique that enables the DTS 2070, in conjunction with other equipment, to measure the round trip distance/time of coax cables or printed circuit board traces with accuracy on the order of ±10 picoseconds.

One application may be to accurately measure load board traces used on ATE systems. In this environment, delay variations of individual traces on load boards going from tester pin electronics to DUT pins can vary depending on how the board was laid out. These individual round trip delays cause timing errors during the testing of integrated circuits on an ATE system.

With today's ATE systems having Overall Timing Accuracy (OTA) of ±500pS and load boards with trace lengths of 2 to 5 nanoseconds, the load board delay time becomes a significant part of the total test accuracy equation. Most ATE companies provide their customers with TDR software routines so the customer can use the ATE tester test head drivers and comparator strobes to perform a TDR function quickly and easily.

TDR Function on ATE Systems

The TDR function on an ATE system works fast and accurately to within the limits of the timing system of the particular ATE system. For example, if the ATE system has strobe/driver edge placement accuracy of ±250pS each, pin-to-pin, the best round trip delay estimate of each path is ±500pS. In other words, the correction factor used in the ATE calibration table for each path of the load board could vary as much as ±500pS or 1nS in time. This represents a 30% error if the load board begins with 3nS traces.

In this example, the timing errors of the ATE system show up twice instead of once. The first happens when the Time Domain Reflectometry (TDR) runs on the load board, as an error in determining the path length associated with each pin's driver and comparator. The second happens when the device is tested with those same pin drivers and comparators.

Most ATE timing system errors change with frequency and the pattern being run on that particular pin. For example, if the DUT board runs TDR on the test head at 1 MHz with a 50% duty cycle signal; and later a device is tested with that same load board at 20 MHz and a random pattern, this error shows up as a dynamic difference in time. Using the ATE system TDR routines only partially resolves the problem of path length skew and round trip delay.

The technique discussed in this application note has the advantage that the same driver/pulse source and measurement system is used for each pin path. It is unlike the ATE system where each path has its own driver and comparator, each with different static/dynamic errors. Therefore, the user can reduce the timing errors seen by the DUT from 30% to less than 1% in most cases—to only those errors exhibited by the drivers and comparators during normal testing.

Time Domain Reflectometry

Time Domain Reflectometry (TDR) is a process whereby a very fast voltage step is sent down a transmission line and returns various responses back to the driver. See Figure 1.

This application note defines the characteristics of Time Domain Reflectometry only as it relates to determining the end distance of a line or trace. It does not discuss sending a rise time fast enough to accurately measure small impedance discontinuities along the signal path.

Consequently, for our purpose, a signal rise/fall time from 1nS to 2nS is sufficient and desirable because it acts as a filter for small discontinuities caused by pogo pins and sockets. For the fixture, which in this case is 50Ω, the pulse driver needs to be back matched in the characteristic impedance of the line to be used.

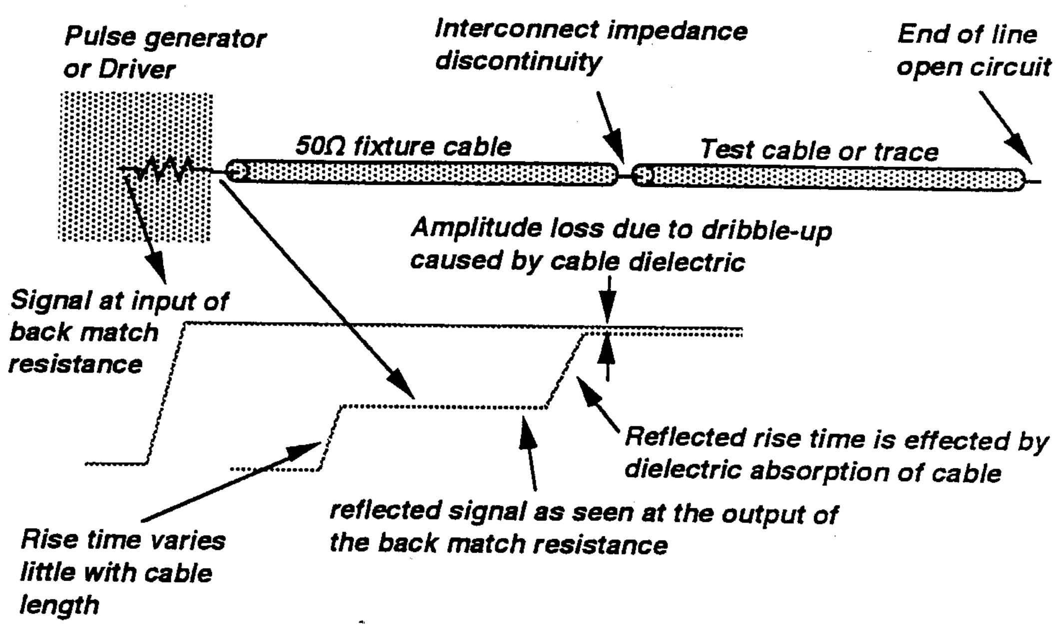


Figure 1

The formula for calculating the time delay of the test cable or trace is the round trip time delay of the Step response divided by two. See Figure 2. This formula is simple as long as the bandwidth of the cable is very high, on the order of 10GHz or more. In practical applications cable bandwidths are usually less than 1 to 4GHz. Consequently, a correction factor is required.

In Figure 2, the following steps are executed to measure the test cable to within ±10 picoseconds:

1. Accurately measure the voltage amplitude of the above signal without the test cable. This sets the measurement points for all future time measurements and calibrates the distance/time of the fixture or test setup being used.
2. Measure the 20% to 80% rise time of the reflected step as-shown in Figure 2. This calibrates the fixture and sets a reference point by which the test cable or trace is measured.
3. Set the measurement voltage reference points to ±10% of the 80% point. This determines the slew rate of the reflected wave of the fixture.
4. Measure the rise time of the reflected wave at the points set in step 3. This measurement represents "Tr1" for future calculations.
5. Connect the test cable or load board trace to be measured.
6. Using the same 20% to 80% voltage reference points, measure the new rise time which now includes the test cable.
7. Now measure the slew rate using the same ±10% points as in step 3. This measurement represents "Tr2" for future calculations.
8. Finally, calculate the results by taking the ((("fixture + test cable delay") -("fixture delay")) /2) - ((Tr2 - TO) /4). This formula corrects for the error incurred due to rise time roll off when the test cable or trace is added to the fixture.

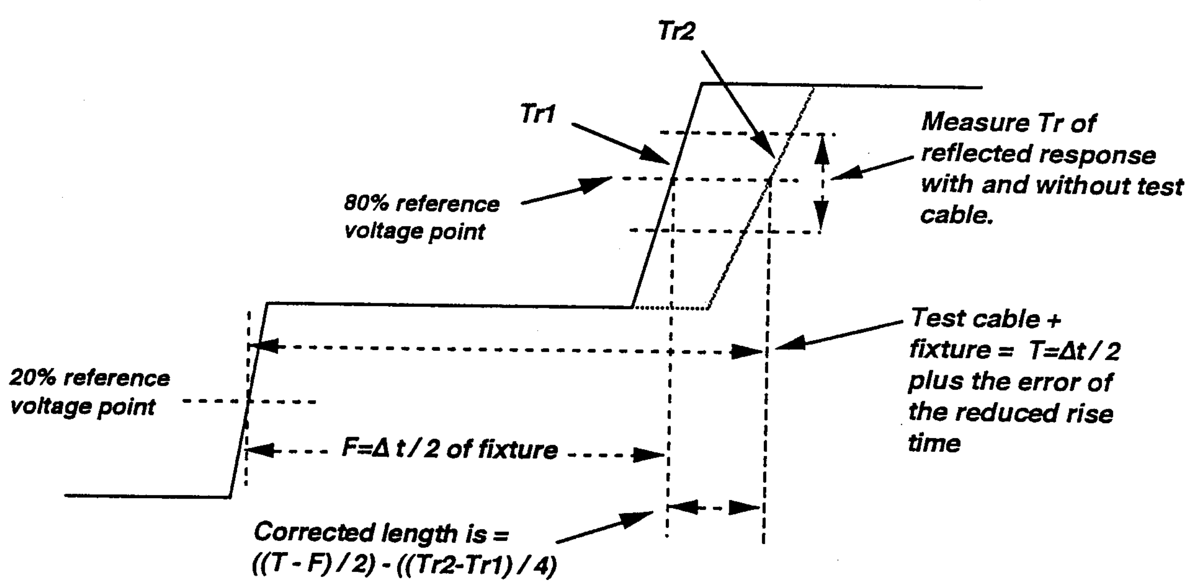


Figure 2

The test cable used in these experiments is certified by an outside testing laboratory for a certain delay. In these experiments, we compared the certified delay value against the TDR results. See the section on “Test Results.”

Using the DTS as a TDR

Figure 3 shows the test configuration required to use a TDR technique in conjunction with the DTS 2070 to accurately measure overall delay times of coax cables and traces on printed circuit load boards. In Figure 3, a pulse generator sends a signal of about ±0.5V amplitude with a period of 1MHz and 50% duty cycle to a high bandwidth power splitter connected to a DTS channel. The frequency of the signal is not critical but needs to be at least six times the round trip delay from the power splitter to the end of the test line. The duty cycle or pulse width of the signal needs to be at least three times the same round trip delay. The 10% to 90% rise and fall time of the signal should be around 1nS to 2nS.

Depending on the dielectric constant of the trace to be measured, the velocity of the pulse along the line can vary from around 1nS/ft to 1.5nS/ft for line with velocity factors of 0.65. Today, high bandwidth coax cables have velocity factors of greater than 0.80, which is about 1.27nS/ft.

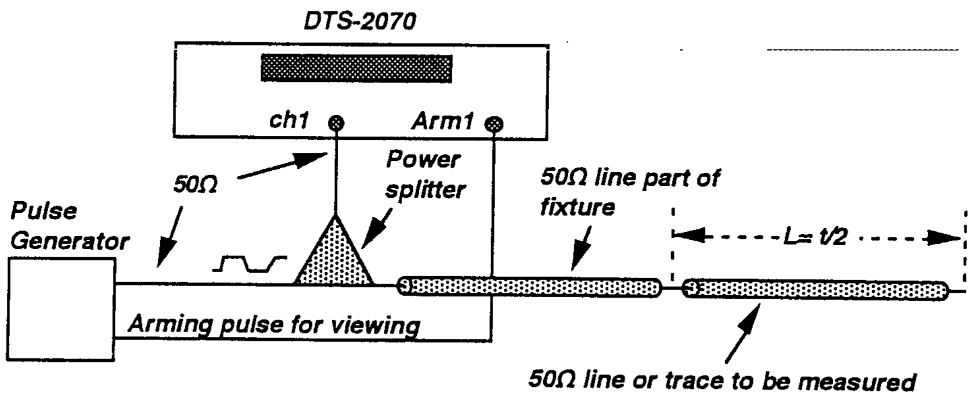


Figure 3

It is necessary to know the dielectric constant of the dielectric being used so the velocity of the cable or trace can be determined accurately. In cases where the *time*, not distance, is important, the dielectric constant can be ignored. This is normally the case with DUT load boards. Only the round trip delay time is important for ATE calibration tables.

With the aforementioned 1 MHz signal, up to 100 feet of coax cable or trace can be accurately measured (velocity factor of 0.65 the speed of light) and even more with faster cables. Because the DTS 2070 has an internal crystal-controlled time standard and a built-in patented calibration technique that calibrates every bit of its 800fS resolution, the DTS measures the long periods necessary for long cables with little loss in accuracy or usable resolution.

With the TDR setup shown in Figure 3, and the time measuring accuracy of the DTS 2070, a high degree of precision can be realized when measuring overall reflected time as a function of distance.

Error Sources

Discontinuities in the signal path affect the overall path length as seen by a signal such as a square wave. Minor discontinuities, such as 10% changes in impedance along the path, affect the ATE to DUT signal timing in the same manner as the TDR test signal does. A TDR signal of similar rise time to the pin card rise time is delayed by the same amount.

One major issue when the DUT is placed in the socket is that some ‘L’ and ‘C’ are lumped at the end of the line. A “Spice” model is required to determine what effect the DUT pin load impedance has on the overall path length. Figure 4 shows a typical path from the ATE or TDR driver to the DUT.

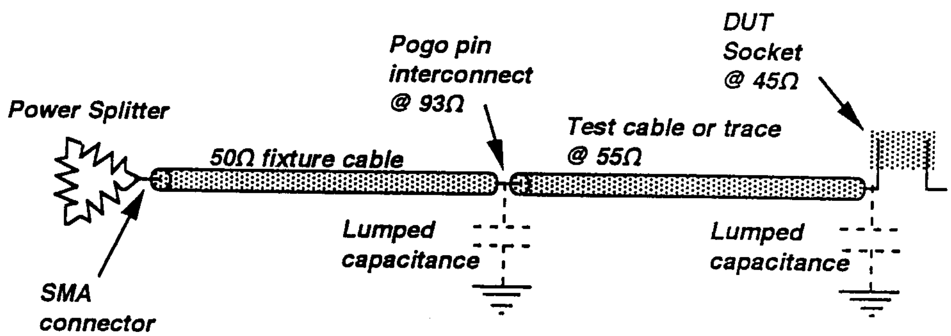


Figure 4

Listed as follows are a few of the items that can affect the overall accuracy of measuring cable or trace path lengths in time using a TDR technique:

1. Any impedance discontinuities in the line from the power splitter to the end of the cable or trace.
2. Impedance mismatches between the fixture cable and the test cable or trace. (Both are not 500Ω for example.)
3. Lumped capacitance or inductance along the transmission path that distorts the signal waveform. (The 1 to 2nS rise time of the TDR signal filters small aberrations along the path.)
4. Terminated versus unterminated transmission line under test. (In a terminated environment, end of line lumped capacitance has less of an effect.)
5. Electrical path delay affected by the rise time of the signal to pass down the line and the dielectric properties of the cable or trace. *Delay dispersion* is a property of a transmission where the propagation delay of any line varies with changes in these factors. (The propagation delay of the “test cable” used here (see Figure 4) varies by +7 to -2pS as the rise time of the signal varies traveling down the cable or trace. This delta would be much greater if smaller diameter coax cable had been used.)

Test Results

The TDR tests performed use two different lengths of coax fixture cable (see Figure 3). The cables used for the fixture had bandwidths of from 2 to 4GHz. The 3' cable had a bandwidth of 2GHz and the 20' cable had a bandwidth of 4GHz. The "Test Cable" was certified by Micro Coax components, Inc, Collegeville, PA 19426. The part number of the cable was UT-250A-TP-DL-2.5. The cable was characterized at three different frequencies to determine its delay dispersion. At 50 MHz the TPD was 2597pS, at 200MHz the TPD was 2590pS and at 500MHz the TPD was 2588pS. All measurement results are reported in pS.

Fixture	"F"	"T"	Δ/2	"Tr1"	"Tr2"	Δ/4	Results
3′	9082.9	14262.9	2590	1084	1100	4	2586
20′	48988.6	54195.2	2603.3	1154.7	1192.8	9.4	2593.8

Table 1

The test cable used in Table 1 was certified to be 2590pS at a 200MHz sine wave rise time. The frequency components of a Sine X/X square wave at 2nS rise time are centered at about 200MHz. The results are very close to what one would expect.

See the Appendix for oscilloscope pictures of each of the above test in Table 1 using "VirtualWare" 4.1. The DTS 2070 setup used to collect the data in Table 1 are as follows. Channel=1, Function=TT+, trig=20%- Auto Arm, Burst= 1000. "Peak pulse find" was used to find the zero and 100% points, so the 20 and 80% points could be calculated by the DTS. All other setups are defaulted to normal startup conditions.

The 3' fixture test was repeated with a 0.55" long SMA adapter to the test cable, see graph G, page 18. At 1.27nS/ft or 105.8pS/inch, a 0.55" long adapter delays out about 58.19pS. The TDR setup in Figure 3 measured a 57pS increase in time. This shows the ability of the slow rise time TDR to resolve small differences in time/distance.

In the Appendix, the incident wave in both graphs B and E show no change in rise time without the signal travelling down the cable. Also, the reflected rise times in graphs C and F show roll off consistent with the bandwidth filtering of the cables. Consequently, we must account for this error in the previous calculations.

About the Digital Time System

The DTS is a precision time interval measurement instrument with 800fS one-shot resolution. This resolution can be further increased by dividing the hardware resolution (800fS) by the square root of the number of samples taken. For example, if the user takes 1000 one-shot measurements of an event, the effective resolution is 25fS. Because the DTS can resolve very small amounts of time, it can resolve very small amounts of distance.

In air dielectric coax cable, electrons travel at the speed of 84.7475pS per inch. This number is larger or slower when the dielectric is changed from air to some other material, as is the case in most coax cables. The previous example shows that the one-shot hardware resolution of the DTS can resolve 1/100th of an inch without averaging. *With* averaging, this number increases dramatically.

The DTS series of precise high speed time measurement instruments is designed for use in ATE automated lab environments where large amounts of accurate and repeatable data are required.

Because of the *patented* calibration technique used in the DTS design, the linearity and repeatability of all timing measurements can be guaranteed to tight tolerances. Calibration is based on a built-in standard with 0.1 femtoseconds or accuracy in 10.0 nanoseconds.

The input threshold resolution of the DTS 2070 is 150 µV. The DTS also provides for calibration of the DC offset and AC propagation delay of the users test probes/fixtures for the utmost in repeatability and accuracy.

References

The following references provide additional information on TDR fundamentals and coax cable/PC board trace characteristics:

1. Application Note No. 101 -A, *Transmission Line Characteristics*, *WAVECREST*, 7275 Bush Lake Road, Edina, MN, 55439.

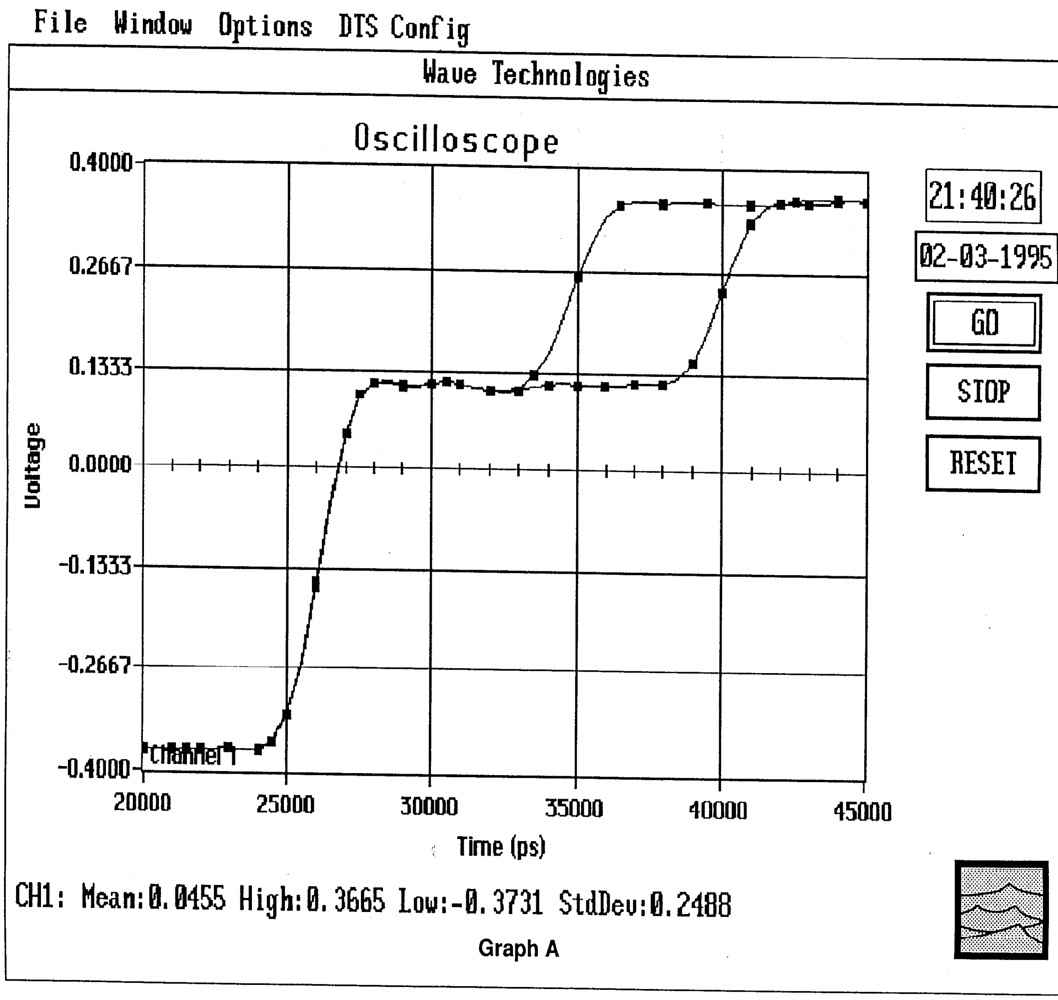
2. MECL Systems Design Handbook, pages 132-144, Motorola Inc.

3. TDR Fundamentals, Application Note 62, Hewlett/Packard Inc.

Appendix

A key for the following graphs included in this application note:

Graph A	3’	Overall TDR view of 3’ fixture plus test cable.
Graph B	3’	TDR view of rise time of incident wave with and without test cable.
Graph C	3’	TDR view of rise time of reflected wave with and without test cable.
Graph D	20’	Overall TDR view of 20’ fixture plus test cable.
Graph E	20’	TDR view of rise time of incident wave with and without test cable.
Graph F	20’	TDR view of rise time of reflected wave with and without test cable.
Graph G	3’	TDR view of rise time of reflected wave with and without 0.55" SMA adapter.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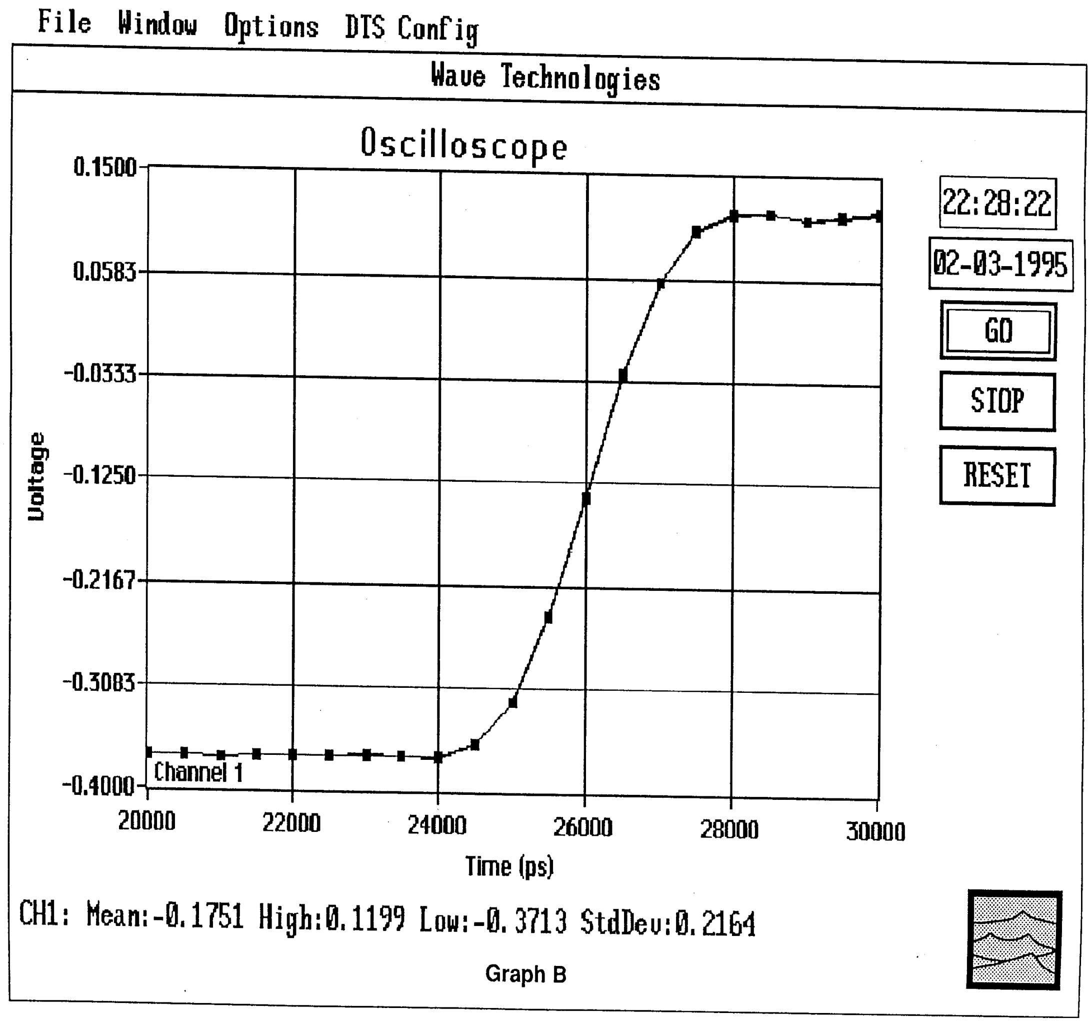
Wave Technologies
Oscilloscope
0.4000
0.2667
0.1333
0.0000
-0.1333
-0.2667
-0.4000
Voltage
Channel 1
20000
25000
30000
35000
40000
45000
Time (ps)
21:40:26
02-03-1995
GO
STOP
RESET
CH1: Mean:0.0455 High:0.3665 Low:-0.3731 StdDev:0.2488
Graph A


File Window Options DTS Config
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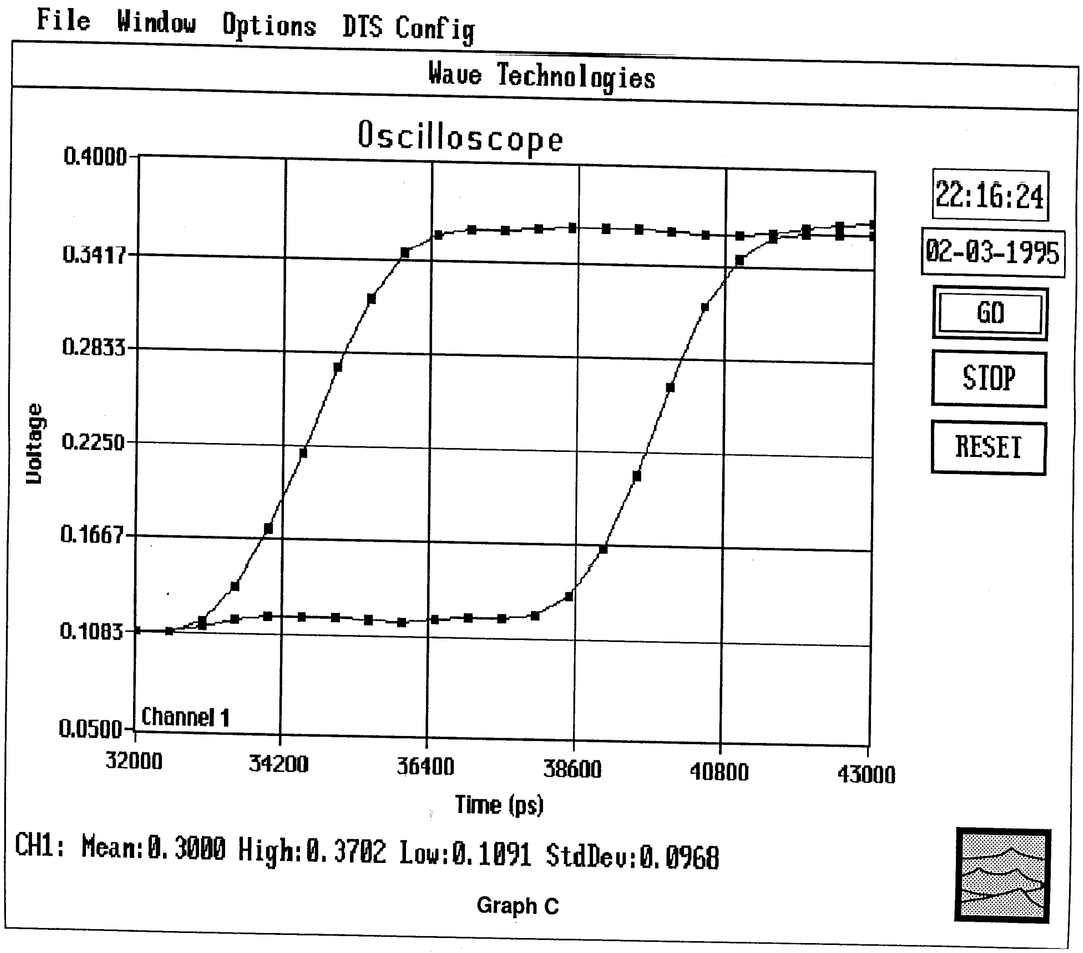
Oscilloscope
0.1500
0.0583
-0.0333
-0.1250
-0.2167
-0.3083
-0.4000
Voltage
Channel 1
20000
22000
24000
26000
28000
30000
Time (ps)
22:28:22
02-03-1995
GO
STOP
RESET
CH1: Mean:-0.1751 High:0.1199 Low:-0.3713 StdDev:0.2164
Graph B


File Window Options DTS Config
Wave Technologies
Oscilloscope
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0.3417
0.2833
0.2250
0.1667
0.1083
0.0500
Voltage
Channel 1
32000
34200
36400
38600
40800
43000
Time (ps)
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RESET
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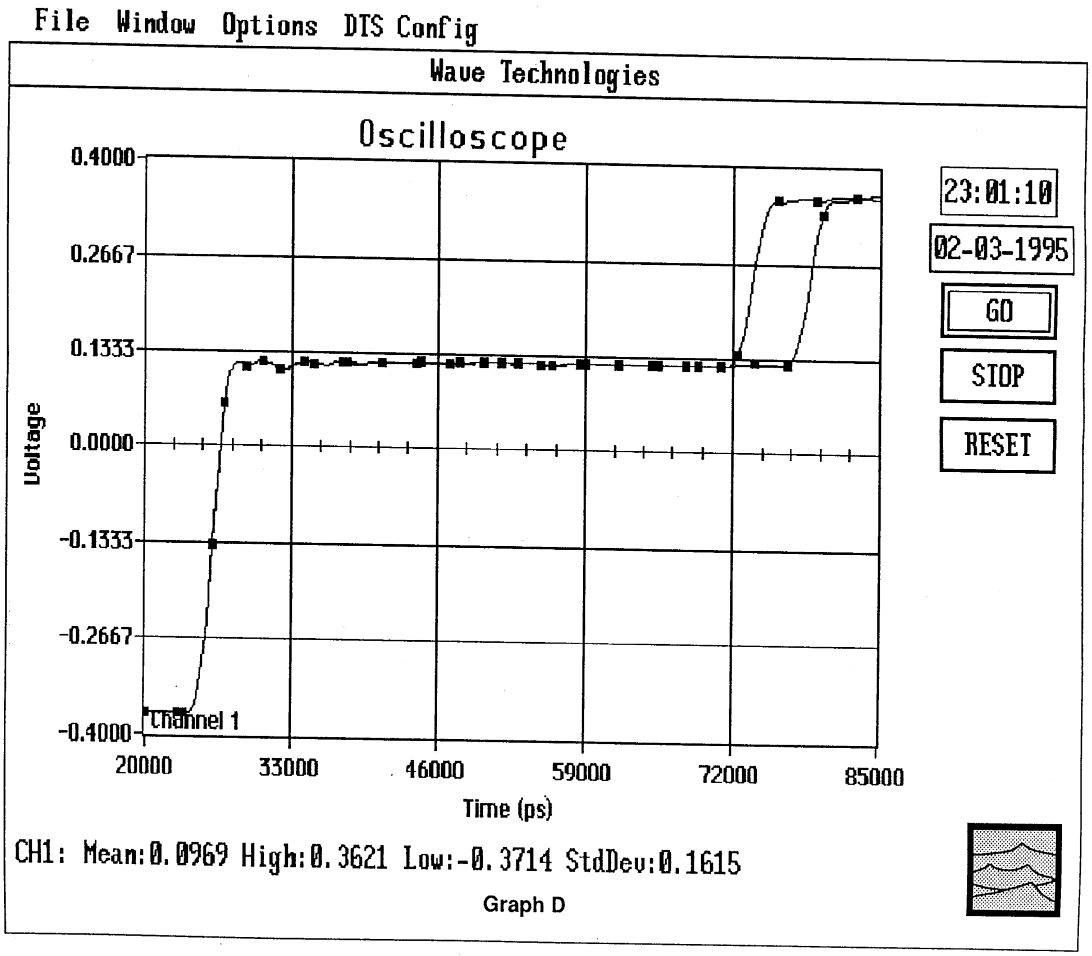
Graph C



File Window Options DTS Config
Wave Technologies
Oscilloscope
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0.2667
0.1333
0.0000
-0.1333
-0.2667
-0.4000
Voltage
Channel 1
20000
33000
46000
59000
72000
85000
Time (ps)
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02-03-1995
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STOP
RESET
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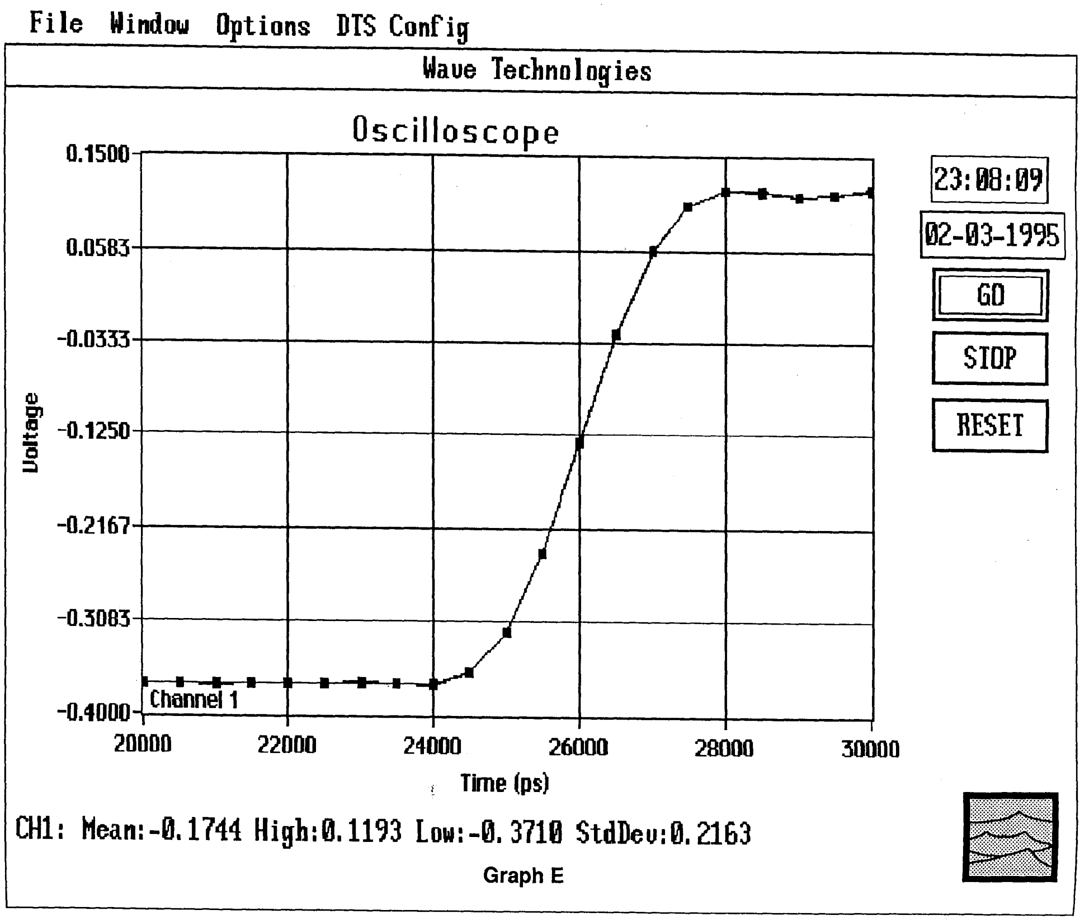
Graph D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-0.0333
-0.1250
-0.2167
-0.3083
-0.4000
Voltage
Channel 1
20000
22000
24000
26000
28000
30000
Time (ps)
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STOP
RESET
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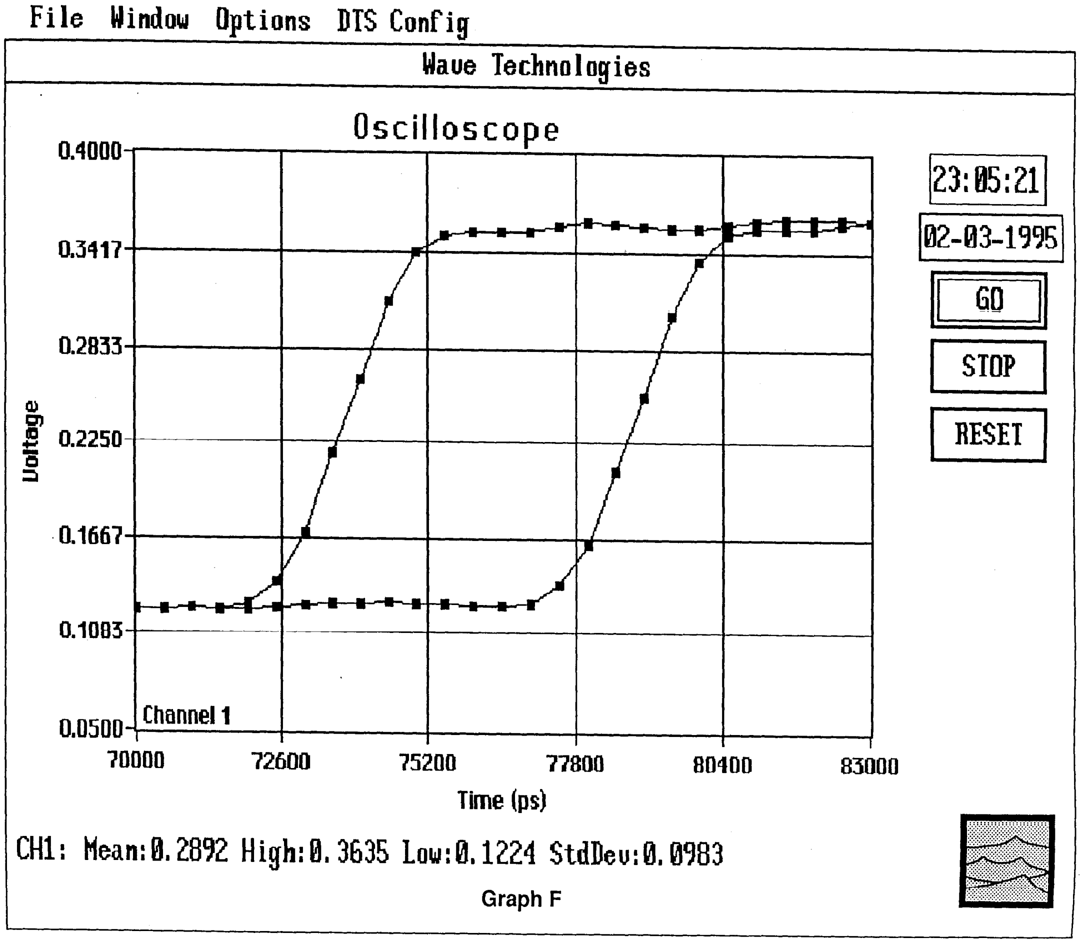
Graph E


File Window Options DTS Config
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Oscilloscope
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0.3417
0.2833
0.2250
0.1667
0.1083
0.0500
Voltage
Channel 1
70000
72600
75200
77800
80400
83000
Time (ps)
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02-03-1995
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RESET
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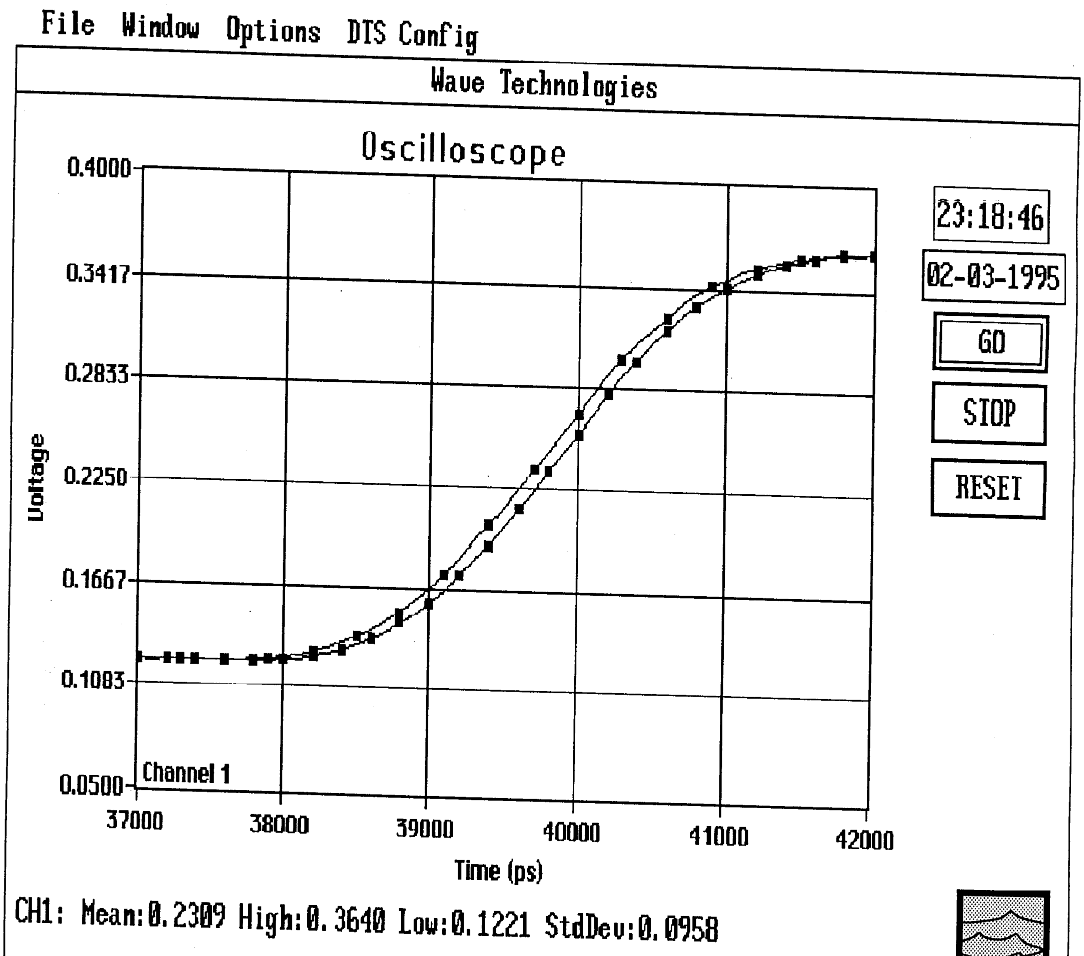
Graph F



File Window Options DTS Config
Wave Technologies
Oscilloscope
0.4000
0.3417
0.2833
0.2250
0.1667
0.1083
0.0500
Voltage
Channel 1
37000
38000
39000
40000
41000
42000
Time (ps)
23:18:46
02-03-1995
GO
STOP
RESET
CH1: Mean:0.2309 High:0.3640 Low:0.1221 StdDev:0.0958

Graph G

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