X3T10/94-232R0

adaptec
Adaptec, Inc.
691 South Milpitas Blvd.
Milpitas, CA 95035

FAST-20 (Double Speed) SCSI I/O Subsystem Study

Executive Summary

Based upon further testing it is evident that a FAST-20 SCSI Bus is viable in both maximum number of devices and also maximum cable length configurations as defined in the specification. Further analysis of data presented in this paper implies that proper cable construction is a must for reliable data transfer at proposed speed of 20 MB/sec. In addition it is concluded that current cabling materials are adequate for Double Speed (20 MHz) operation given that they are properly screened for impedance values as defined by the specification.

Based on this investigation, it is concluded that to gain additional margin designers should pay special attention to match cable impedance throughout the SCSI I/O subsystem, to reduce and distribute equally the SCSI bus nodal capacitance, to reduce device stub lengths, and to the proper design of the SCSI I/O cell drivers.

Test Configurations and Procedures

Three SCSI BUS configurations were designed to determine the available margins in the current specifications to support the 20 MB/sec transfer rate. Each configuration was adopted to test a certain aspect of the specification. Each configuration was tested and waveforms were analyzed at 20 MB/sec using a modified silicon with standard peripherals, hard drives and CD ROMs , from various manufacturers. These three general configurations have been depicted in Figure 1 as case A through C.

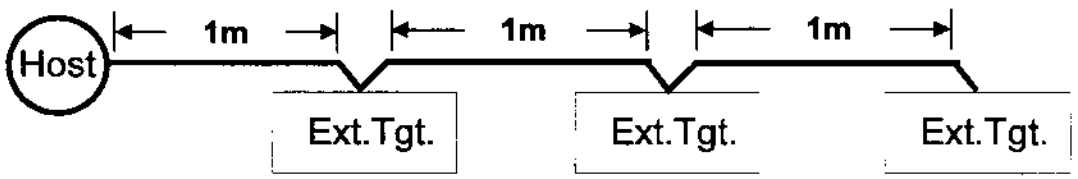
- Case A was designed to test for maximum (3 meter) external cable length specification.
- Case B was included to test for maximum (8) number of internally connected devices.
- Case C was selected to test for a most typical Host Adapter configuration.

These configurations were tested under three different environments; (1) Fast-20 compliant cabling environment, (2) Off-the-shelf standard cabling environment, and (3) Standard cabling with additional capacitive loads added to each SCSI devices. The results of these three different environments with their different configurations have been documented and discussed next in this report under sections 1 to 3. In each instance a tabulated summary of the ACK* and DB6* signal assertion and negation periods at each unit along the SCSI bus is given. Finally the actual signals of each case at the I/O connector have been depicted in the appendixes A through E.

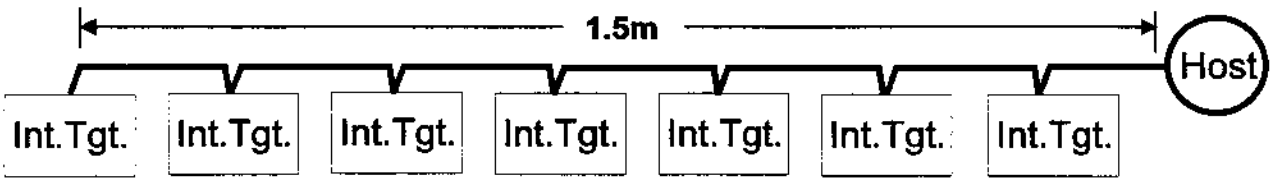
As part of the experiment the nodal capacitances of all the devices used for this experiment have been measured across the frequency range of 1 to 20 MHz. In addition, nodal capacitance of peripherals from various manufactures were measured . All of these measurements have been summarized in Appendix G. Furthermore, Appendix F documents the TDR (Time Domain Reflectometer) measurements for all the SCSI cables used in the experiment.

Fast-20 Test Topologies

Case A



Case B



Case C

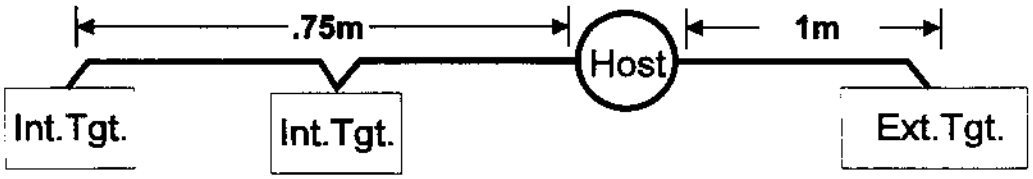


Figure 1

Section 1 FAST-20 Compliant Cabling Environment

All three configurations were tested using Fast-20 compliant cables. For external connectivity 50-pin high-density to 50-pin high-density round shielded SCSI cables (1 meter) were used. For internal connectivity 90 ohm Teflon flat ribbon cables were chosen. Case A configuration [3 external SCSI devices up to 3 meters long] was tested under three different loading. First three low capacitance hard drives were tested. Next, higher capacitance hard drives were tested. Finally three CD-ROMs were selected. Table 1 below summarizes the results for this case. For a complete summary of this case refer to Appendix A. For Case A assertion period varies from 16.6ns to 24.8ns and negation period varies from 23.8ns to 24.2ns for ACK* and DB6* signals. These data were sampled at the receiver end of the SCSI targets. Fast-20 spec allows a minimum of 11ns for both receive assertion and negation period which would provide about **5.6ns to 13.8ns of margin** for the ACK* signal.

Table 1. Case A- Assertion and Negation Period Summary

		Assertion (Note 1)		Negation	
Target Device		**ACK***	**DB6***	**ACK***	**DB6***
Unit 1 - 15 PF Hard Drive		20.6	19.8	24.0	23.8
Unit 2 - 15 PF Hard Drive		23.6	23.0	24.0	24.2
Unit 3 - 15 PF Hard Drive		24.8	24.2	23.6	24.0
Unit 1 - 18 PF Hard Drive		25.2	23.5	24.0	23.8
Unit 2 - 18 PF Hard Drive		23.6	23.2	24.0	24.2
Unit 3 - 18 PF Hard Drive		24.0	24.4	24.0	25.0
Unit 1 - 12 PF CD-ROM		16.6	17.0	24.0	24.0
Unit 2 - 15 PF CD-ROM		24.2	23.2	23.8	24.0
Unit 3 - 12 PF CD-ROM		24.2	24.0	24.4	24.0

Note 1. The assertion and negation timings were measured per the thresholds specified in the Annex B portion of the current Fast-20 proposal (1.0V and 1.6V for assertion and 1.9V and 1.3 V for negation).

For Case B configuration [8 internal SCSI devices up to 1.5 meters long] eight hard drives with similar nodal capacitance were picked to represent a RAID type environment that is most likely to be used in this configuration. The assertion and negation period for this case are tabulated in Table 2. These periods vary from 20.6ns to 27.6ns for ACK* and DB6* signals yielding a **9.6ns to 16.6ns** margin. The signals for this case have been depicted in Appendix B.

Table 2. Case B Assertion and Negation Period Summary

		Assertion		Negation	
Device		**ACK***	**DB6***	**ACK***	**DB6***
Host Adapter		27.6	27.2	21.0	21.6
Unit 1 - 15 PF Hard Drive		27.6	27.6	21.6	21.6
Unit 2 - 15 PF Hard Drive		27.2	27.4	21.0	21.6
Unit 3 - 15 PF Hard Drive		27.4	27.4	21.2	21.0
Unit 4 - 18 PF Hard Drive		27.6	27.2	20.8	21.4
Unit 5 - 18 PF Hard Drive		27.2	27.0	21.0	20.8
Unit 6 - 18 PF Hard Drive		26.8	27.0	22.0	22.0
Unit 7 - 18 PF Hard Drive		27.2	27.4	21.0	20.6

The last configuration tested in the FAST-20 cabling environment was Case C [2 internal Hard drives and 1 external CD-ROM]. Although various mixes of devices were tested like one internal HDA and one internal CD-ROM with an external HDA only the results for one case has been documented in this report since no significant variation was observed. Appendix C documents the detailed setup and depicts signal quality at all the nodes of this case. Table 3 summarizes the result for this case. The assertion and negation periods varies from 18ns to 29.2ns yielding a **7ns** to **18.2ns** of margin.

Table 3. Case C Assertion and Negation Period Summary

		Assertion		Negation	
Device		**ACK***	**DB6***	**ACK***	**DB6***
Unit 2 - 15 PF Hard Drive		29.2	27.0	18.0	21.0
Unit 1 - 15 PF Hard Drive		28.4	26.2	19.0	22.0
Host Adapter		27.2	27.0	22.0	22.0
CD-ROM - 12 PF CD-ROM		26.4	25.6	24.0	22.0

The figures show that the driven SCSI signals attenuates more for Case B (with more loads attached to the SCSI cable) than for Case A or C. The signal quality when using Fast-20 compliant cable would yield enough margins in most applications to ensure reliable operation at 20 MHz.

Section 2 Standard Cabling Environment

This part of the experiment was focused on examining the signal quality on today's regular off-the-shelf standard SCSI cables. For this investigation cases A and B were picked. Case A was chosen to examine the effect of the externally shielded standard high-density to low-density (Centronics) cables. Case B was chosen to examine the effect of standard off-the-shelf ribbon cables commonly used for internal connections. The results of these cases were compared to the specific FAST-20 cables that were used in the original experiment (Section 1). Appendix D depicts the actual waveforms for ACK* and DB6* for worst case unit under the test for each of the case A and case B. The worst case unit in both cases was the unit closest to the Host Adapter. Appendix F includes the TDR measurements for the standard cables that were used in this experiment.

Tables 4 and 5 tabulate the assertion and deassertion periods for Case A and B respectively for both standard and FAST-20 cable environment.

Table 4: Standard vs. Fast-20 External cable comparison under Case A

		Fast-20 Cables				Standard Cables			
		Assertion		Negation		Assertion		Negation	
Target Device		ACK*	DB6*	ACK*	DB6*	ACK*	DB6*	ACK*	DB6*
Unit 1 - 15 PF Hard Drive		20.6	19.8	24.0	23.8	28	28	20	20
Unit 2 - 15 PF Hard Drive		23.6	23.0	24.0	24.2	20	20	24	22
Unit 3 - 15 PF Hard Drive		24.8	24.2	23.6	24.0	27	28	21	22

Table 5: Standard vs. Fast-20 Internal Ribbon cable comparison under Case B

		Fast-20 Cables				Standard Cables			
		Assertion		Negation		Assertion		Negation	
Target Device		ACK*	DB6*	ACK*	DB6*	ACK*	DB6*	ACK*	DB6*
Host Adapter		27.6	27.2	21.0	21.6	26.0	24.0	24.0	25.0
Unit 1 - 15 PF Hard Drive		27.6	27.2	21.0	21.6	22.0	22.5	26.0	26.0
Unit 2 - 15 PF Hard Drive		27.2	27.4	21.0	21.6	24.0	24.0	24.0	24.5
Unit 3 - 15 PF Hard Drive		27.4	27.4	21.2	21.0	24.0	24.0	24.0	24.0
Unit 4 - 18 PF Hard Drive		27.6	27.2	20.8	21.4	22.0	24.0	24.0	25.0
Unit 5 - 18 PF Hard Drive		27.2	27.0	21.0	20.8	24.0	24.5	24.0	24.0
Unit 7 - 18 PF Hard Drive		27.2	27.2	21.0	20.6	24.5	24.5	24.0	24.0

Examining the data above and also the signal quality as shown in Appendix D it can be concluded that a Double Speed operation could be achievable using currently available cables. The caveat is that the cables should meet the impedance guidelines as specified in SCSI spec. This also implies that no exotic or special materials/cables are required for a FAST-20 environment. This would mean the purchasers of FAST-20 cables should now make sure to specify a FAST-20 impedance requirement. Suppliers of FAST-20 assemblies would probably be required to implement quality control procedures to ensure that both their incoming materials and outgoing materials meets the impedance specification of FAST-20.

It is our opinion that low impedance cables used carelessly in the system will not allow reliable operation at Double Speed (20 MHz). There seems to be enough margins for 10 MHz operation in such cables (as low as 60 Ohms) but they will start to have a marked impact at 20 MHz operation. Therefore, tighter impedance control is essential for Double Speed operation.

Section 3 Effects of Added Capacitance

This last part of our experiment was designed to examine the effects of target capacitance on signal integrity. For this experiment Case C was adopted since it is believed that it represents the most typical end-user environment. As such this case is the most susceptible to both cable mismatches and also devices with capacitances higher than specification allows. Therefore the standard cable environment was chosen since these cables are commonly available to end users. Ceramic disc capacitors ranging from 10 PF to 50 PF were added to all the three targets on the SCSI bus.

Appendix E shows the waveforms taken for this configuration when no additional capacitance was added (baseline) and when additional 10 PF and 50 PF were added to the SCSI devices. Comparing these waveforms with those of Section 1 of this report indicates that adding these capacitive loads does not increase signal degradation as much on the receiver input of the SCSI device as compared to signal degradation due to cable impedance mismatch as discussed in Section 2 of this report. However, we have seen on other configurations that at certain cable spacing the capacitive loads causes severe signal degradation due to positive reflections that occur during high to low transitions or negative reflections that occur during low to high transitions. Therefore, low capacitive loading is still much desired in a heavily loaded configurations but for this special configuration there seems to be enough margins to support Double Speed operations reliably. Table 6 summarizes the results of our testing for this section.

Table 6: Case C with added Capacitors Assertion and Negation Period Summary

		Assertion		Negation	
Device Baseline		**ACK***	**DB6***	**ACK***	**DB6***
Unit 1 - 18 PF HDA		28.0	27.2	20.8	21.2
Unit 2 - 18 PF HDA		28.6	28.2	20.2	20.8
Ext. 15 PF CD-ROM		27.6	27.8	20.8	20.6
Devices with 10 PF					
Unit 1		28.2	26.0	21.2	21.2
Unit 2		28.8	29.0	22.0	20.2
Ext. CD		27.8	27.8	20.4	20.8
Devices with 20 PF					
Unit 1		28.2	27.8	19.4	19.8
Unit 2		27.6	27.4	20.0	20.4
Ext. CD		27.8	28.0	21.2	21.4
Devices with 39 PF					
Unit 1		28.6	27.8	19.6	19.8
Unit 2		27.8	27.2	19.8	19.4
Ext. CD		27.4	28.2	21.0	19.6
Devices with 50 PF					
Unit 1		29.0	28.6	18.2	18.6
Unit 2		29.4	27.2	16.8	19.4
Ext. CD		28.6	28.8	19.2	18.0

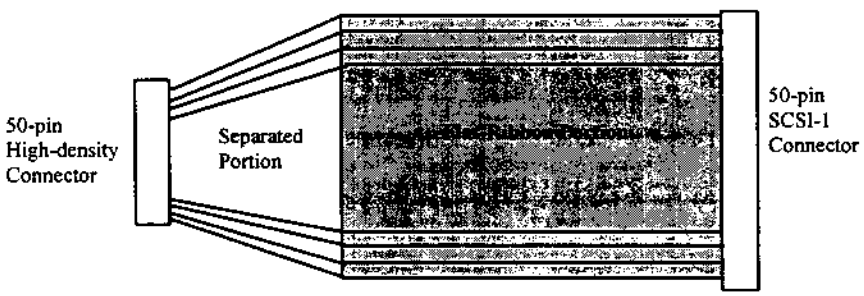
Section 4 External Enclosure Design Concerns

During the course of studying nodal capacitance we made an interesting observation on cable construction of external enclosures. In most such systems a butterfly type (or V shape) cable assembly is utilized to make the connection from external casing to the connector on the device and back to the external casing. The industry as a whole is moving toward using high-density connectors. However, the move to 50-pin high-density connectors for external enclosures is out pacing their usage on SCSI devices. Therefore, for a period of time a special butterfly cable is required to connect high-density connectors at each end of the cable to the standard 50-pin connector sitting in the middle of the cable. To construct such cable one needs to separate the treads to make connection to 50-pin high-density connectors because of the size mismatch between the two types of connectors.

It has been observed in our experiments that if the flat ribbon cable treads are separated the inductance between both ends of the butterfly cable increases. The larger the portion of the separated treads the larger is the end-to-end inductance. This inductance in series with the drive capacitive loading has a large impact on the total capacitance of the external enclosure. To make things worse this effective capacitance will increase with increasing frequency in a non-linear fashion. So where the capacitance of the device itself could be constant over the frequency range of 1 MHz to 30 MHz the effective capacitance of the external enclosures could vary substantially. In the cases that were tested, the effective capacitance of the external enclosure at 20 MHz was as much as two to three times the capacitance at 1 MHz with the effective capacitance increasing non-linearly above 12 MHz. See Appendix G.

To overcome this problem for our Case A and C measurements that used external enclosures the standard butterfly cables inside the enclosures were replaced with cables that had minimized the separated portion of the cable. The effective capacitance of the enclosure using the new butterfly cables only changed minimally (less than 5 PF) over the frequency range of 1 to 20 MHz.

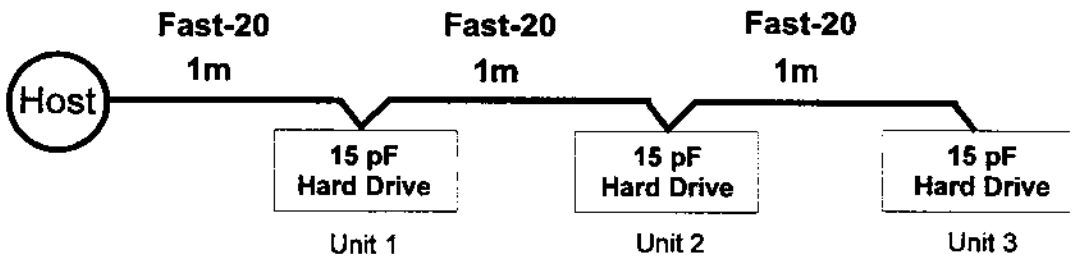
Based on our observation it is a strong recommendation of this study that if external connectivity is required for Double Speed operation vendors of such systems must take special care in construction of their butterfly cables. If at all possible one should avoid a 50-pin regular type connection to a high-density connector. However, this could be not be feasible until all 8-bit SCSI devices use 50-pin high-density connectors. So in the mean time it is recommended to keep the wings of the butterfly cable as short as possible but more importantly to keep the portion of the separated treads of the cable to a bare minimum and keep the flat-ribbon portion as much as possible.



Appendix A: Case A Analysis under Three Different Loading

Tested Configuration

Case A



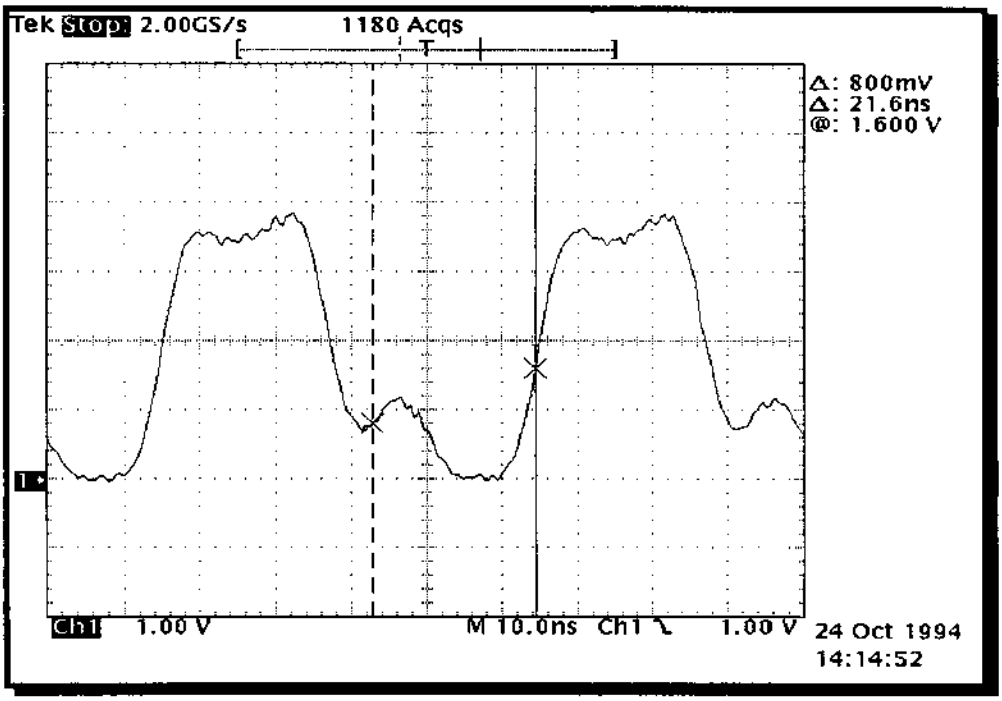
- **Configuration:** Test Case A - using three 15 pF identical hard disk drives

  Cables: 1 meter Fast-20 compliant (90 ohm) round shielded
- **Host Adapter:** Adaptec AHA-2940 PCI Host Adapter modified to supply ACK/Data pulses at 20 Mhz
- **Terminator:** Active (regulated) on last drive

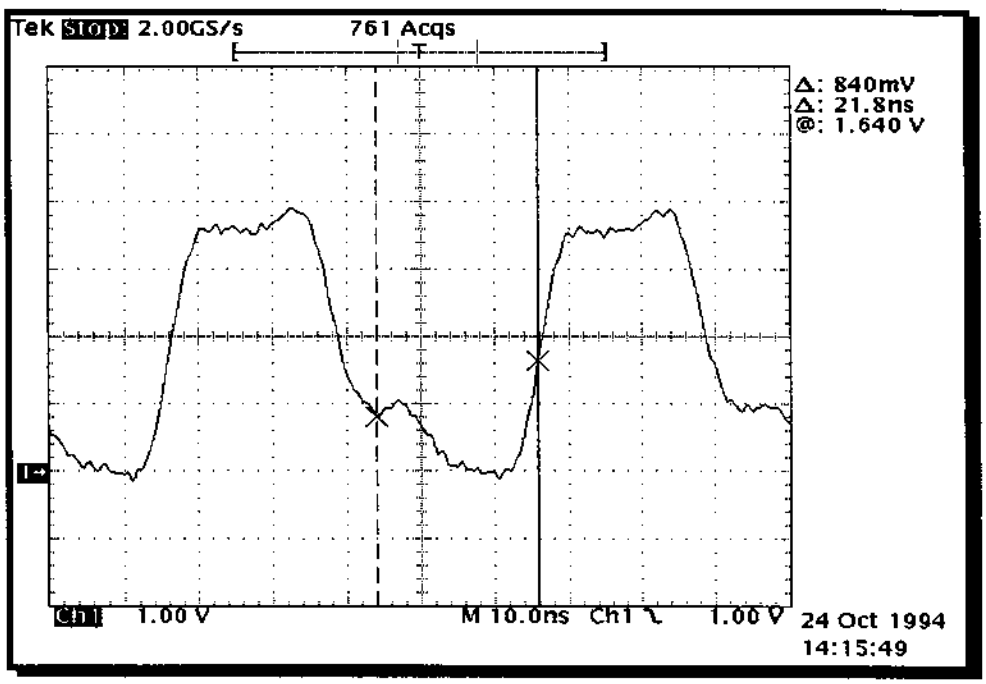
Table A1: Test Case A- Assertion and Negation Period Summary

		Assertion		Negation	
Target Device		**ACK**	**DB6**	**ACK**	**DB6**
Unit 1 - 15 pF Hard Drive		20.6	19.8	24.0	23.8
Unit 2 - 15 pF Hard Drive		23.6	23.0	24.0	24.2
Unit 3 - 15 pF Hard Drive		24.8	24.2	23.6	24.0
Unit 1 - 18 pF Hard Drive		25.2	23.5	24.0	23.8
Unit 2 - 18 pF Hard Drive		23.6	23.2	24.0	24.2
Unit 3 - 18 pF Hard Drive		24.0	24.4	24.0	25.0
Unit 1 - 12 pF CD-ROM		16.6	17.0	24.0	24.0
Unit 2 - 15 pF CD-ROM		24.2	23.2	23.8	24.0
Unit 3 - 12 pF CD-ROM		24.2	24.0	24.4	24.0

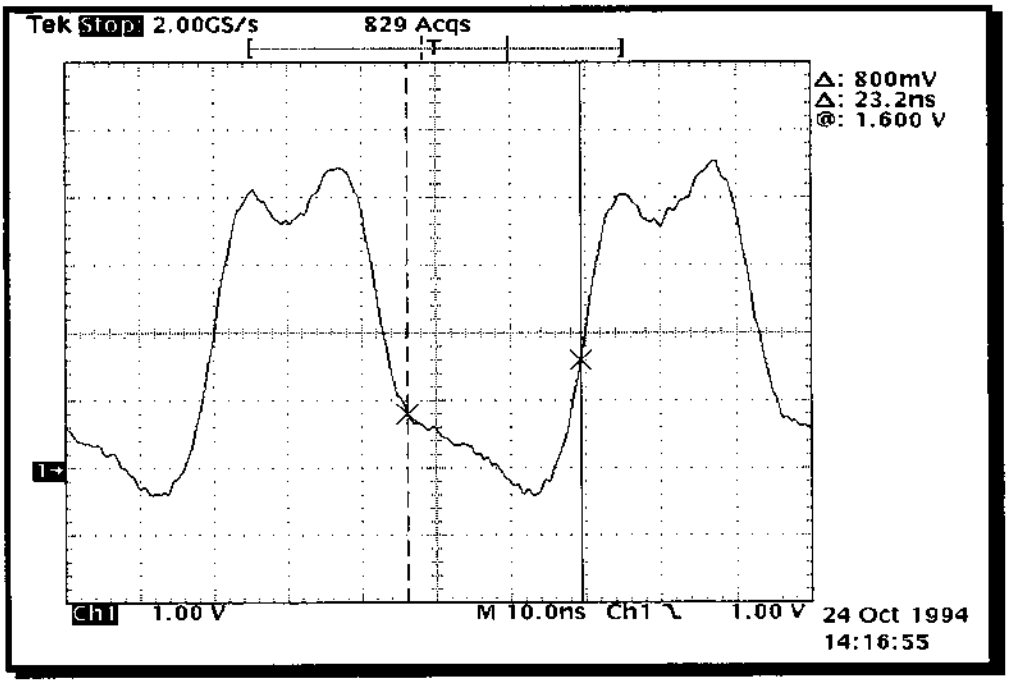
Test Case A with 3 15 pF Targets - ACK @ Unit 1



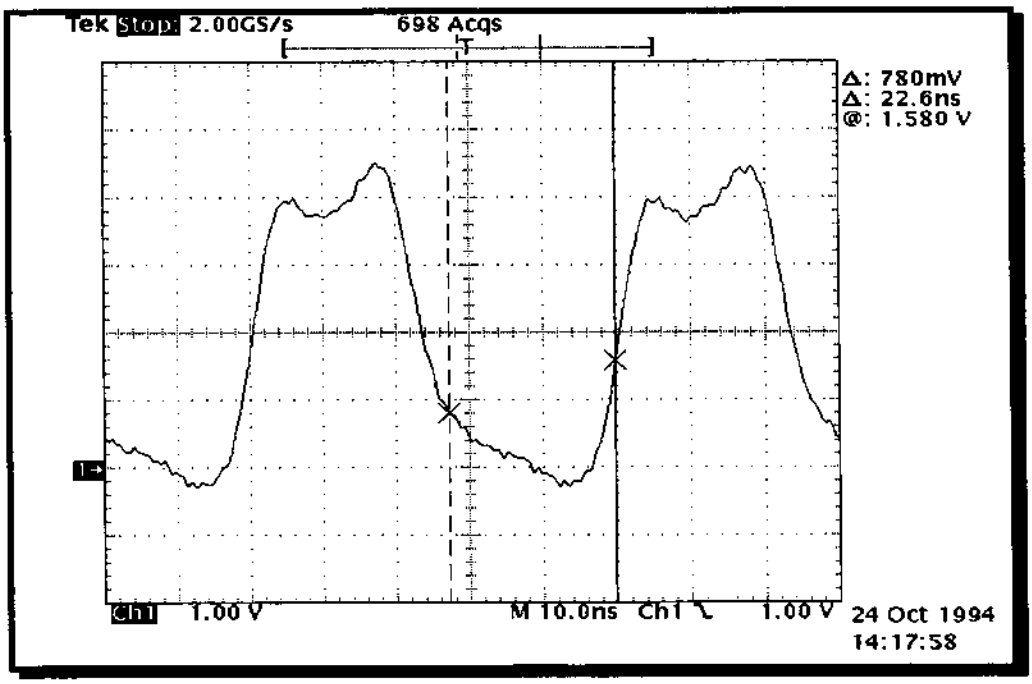
Test Case A with 3 15 pF Targets - DB6 @ Unit 1



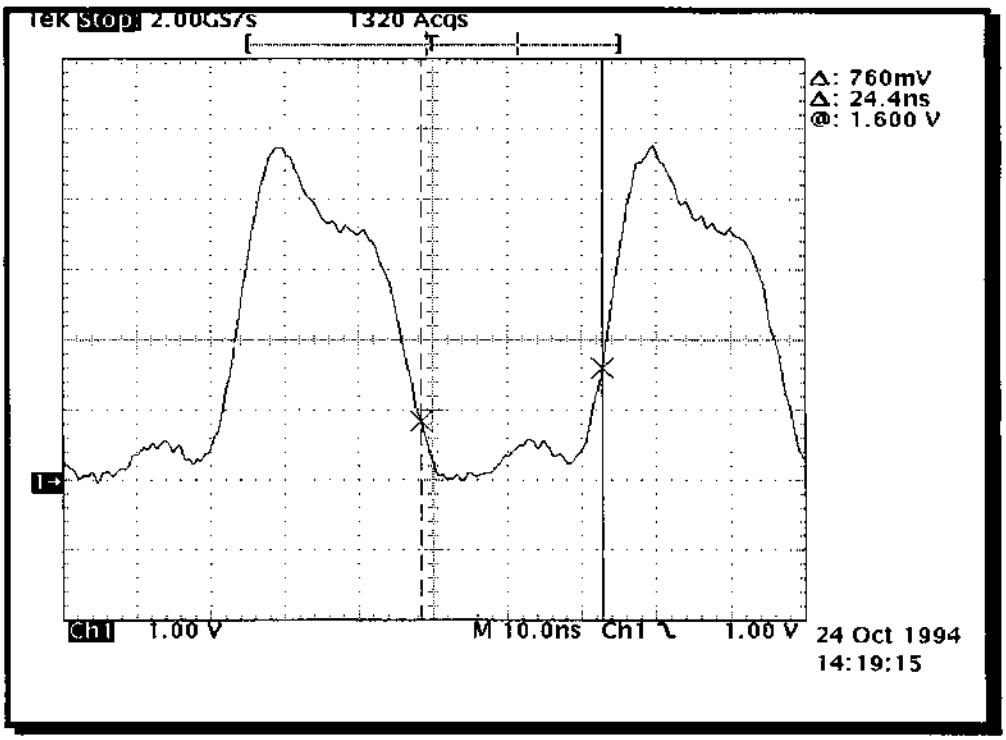
Test Case A with 3 15 pF Targets - ACK @ Unit 2



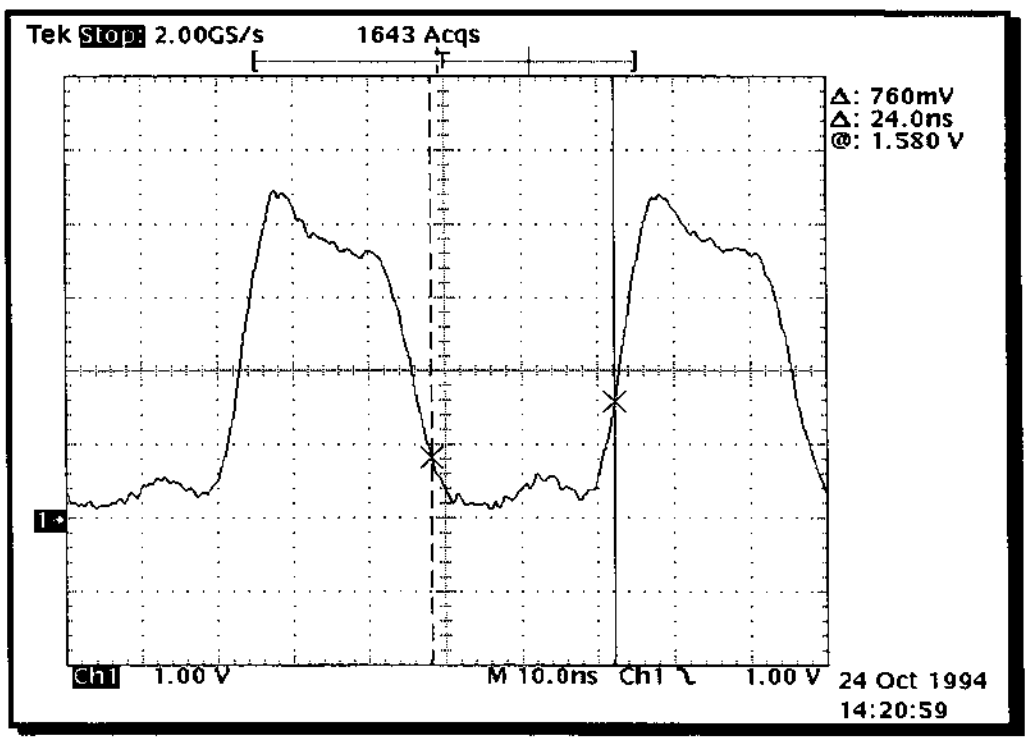
Test Case A with 3 15 pF Targets - DB6 @ Unit 2



Test Case A with 3 15 pF Targets - ACK @ Unit 3

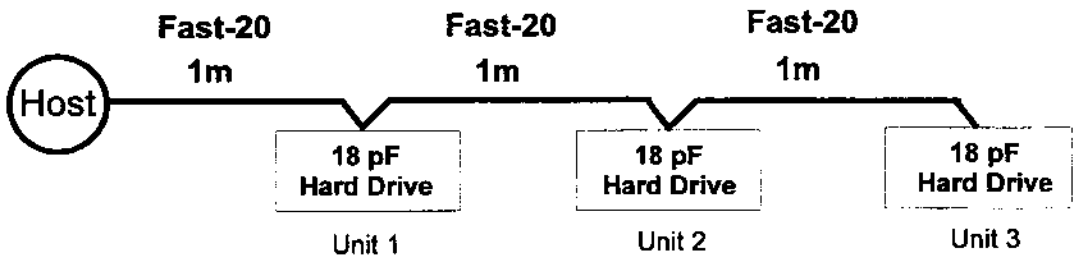


Test Case A with 3 15 pF Targets - DB6 @ Unit 3



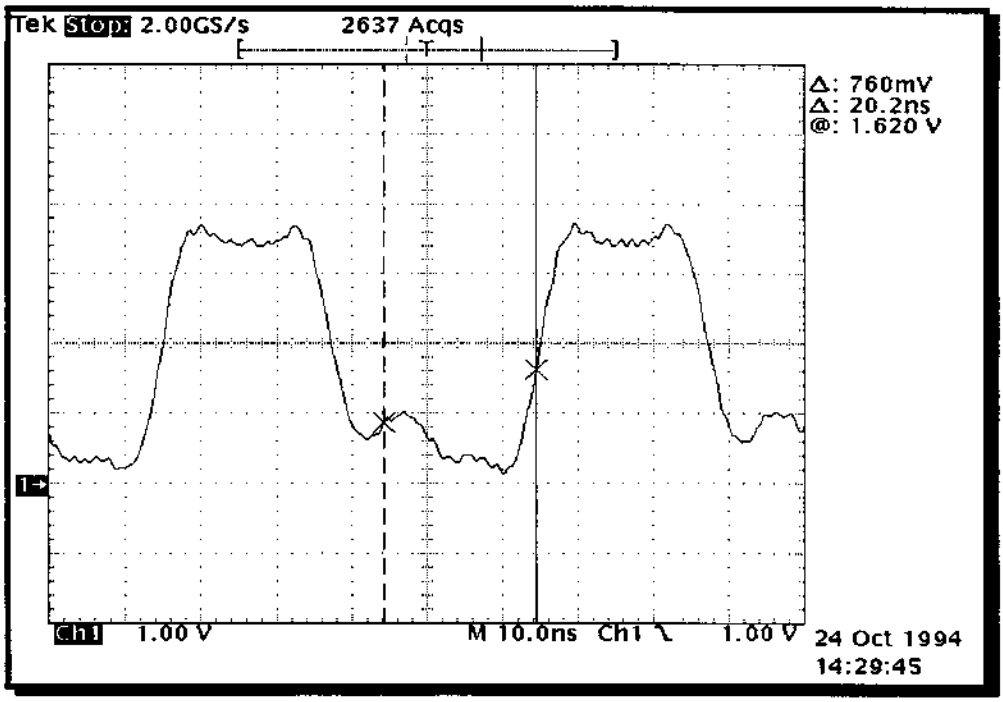
Tested Configuration

Case A

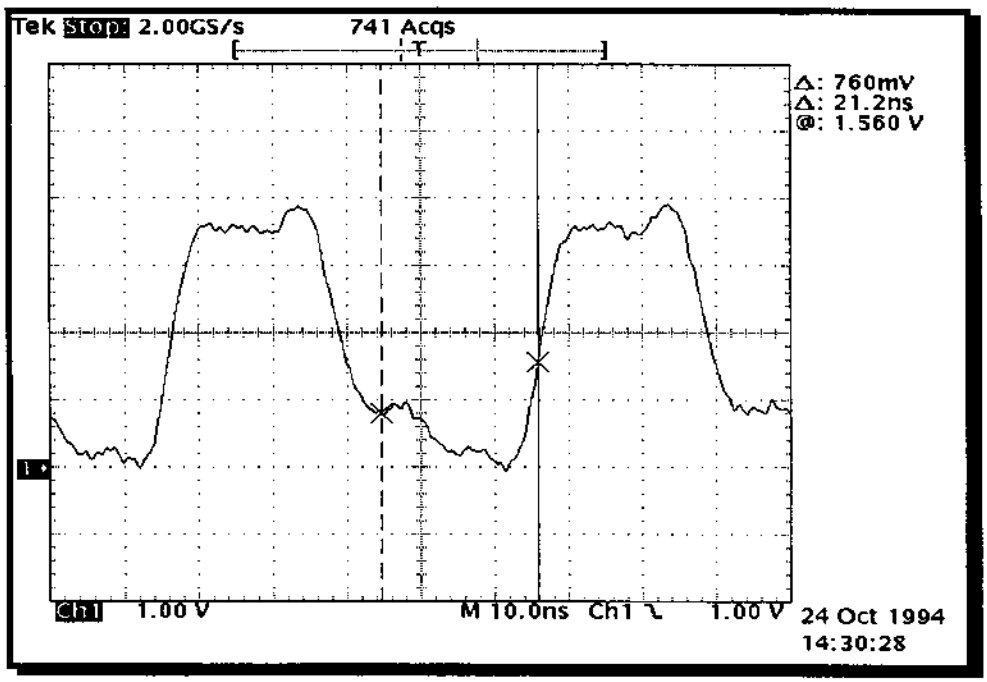


- **Configuration:** Test Case A - using three identical 18 pF hard disk drives

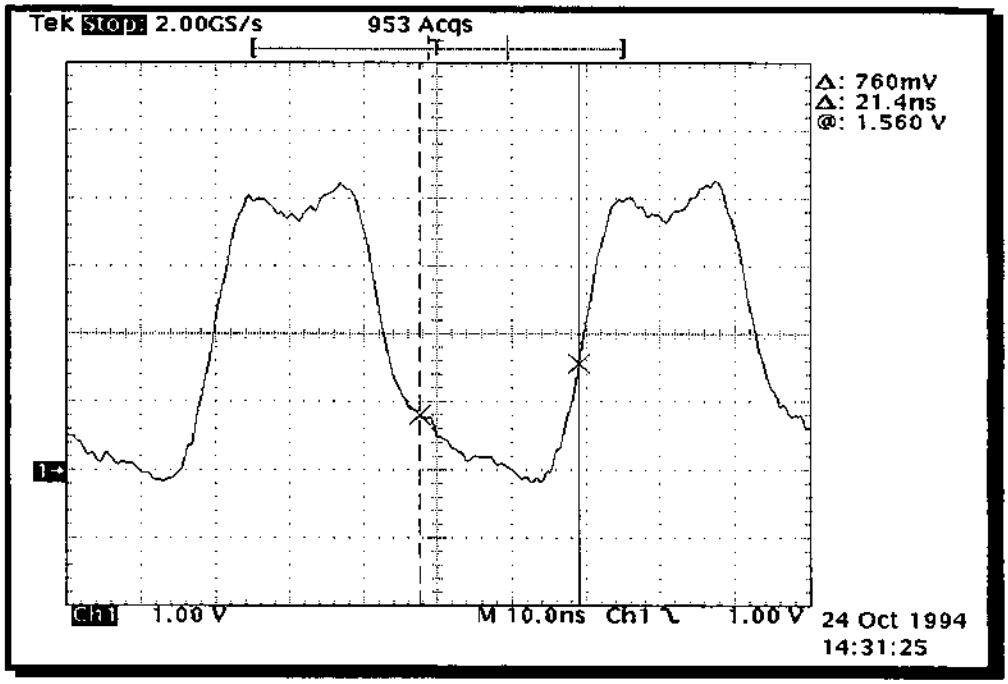
Test Case A with 3 18 pF Targets - ACK @ Unit 1



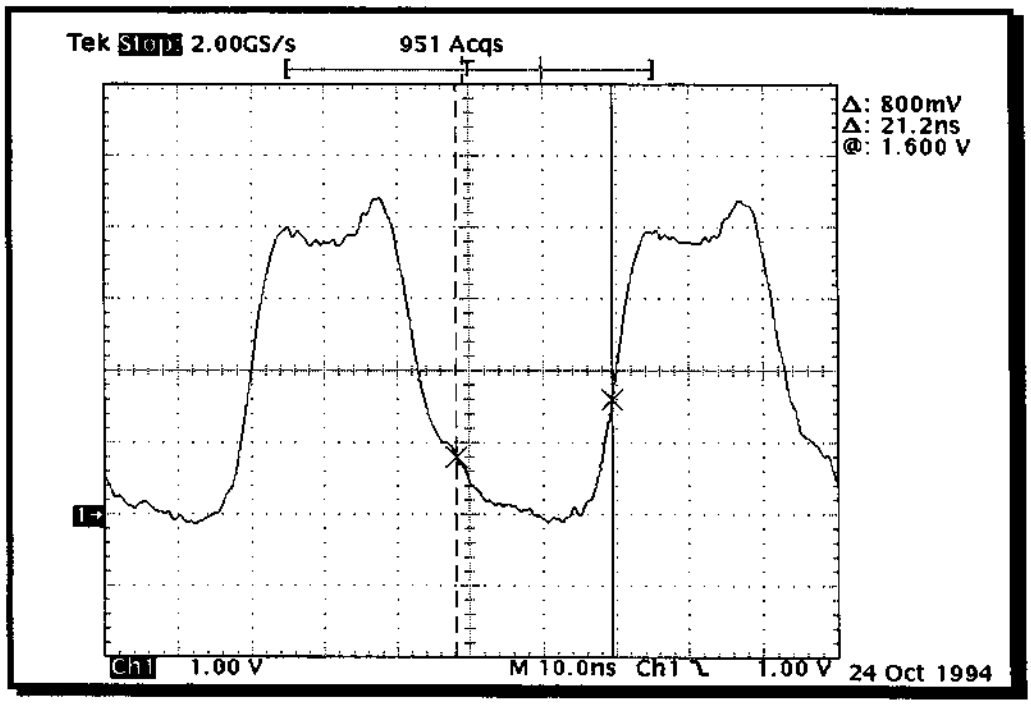
Test Case A with 3 18 pF Targets - DB6 @ Unit 1



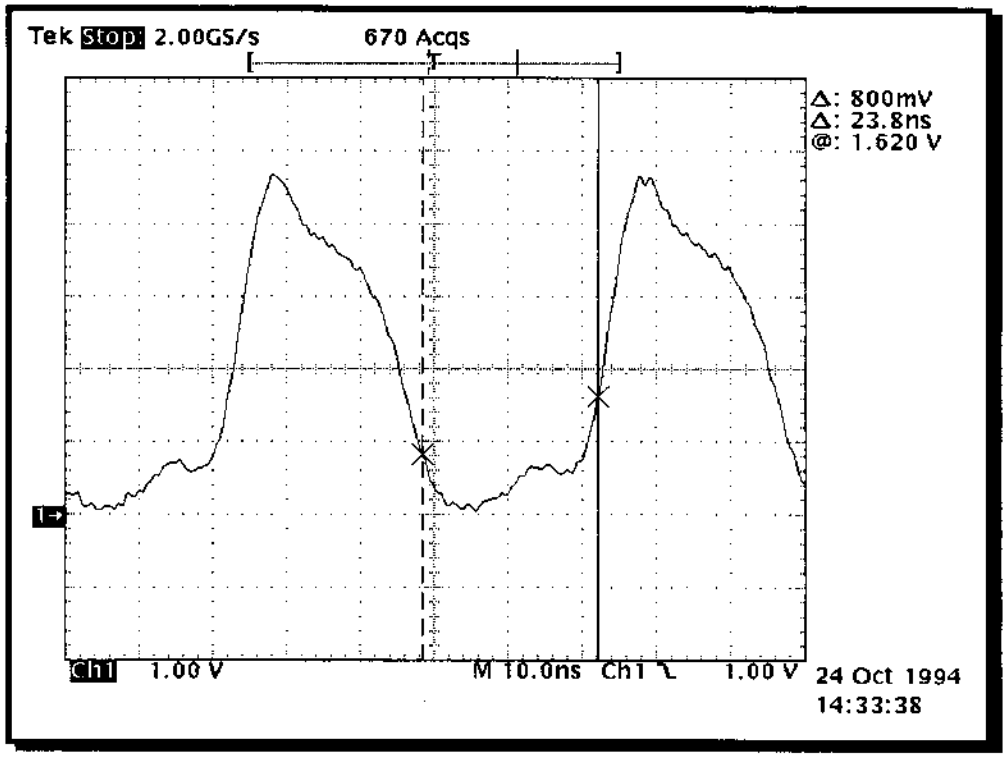
Test Case A with 3 18 pF Targets - ACK @ Unit 2



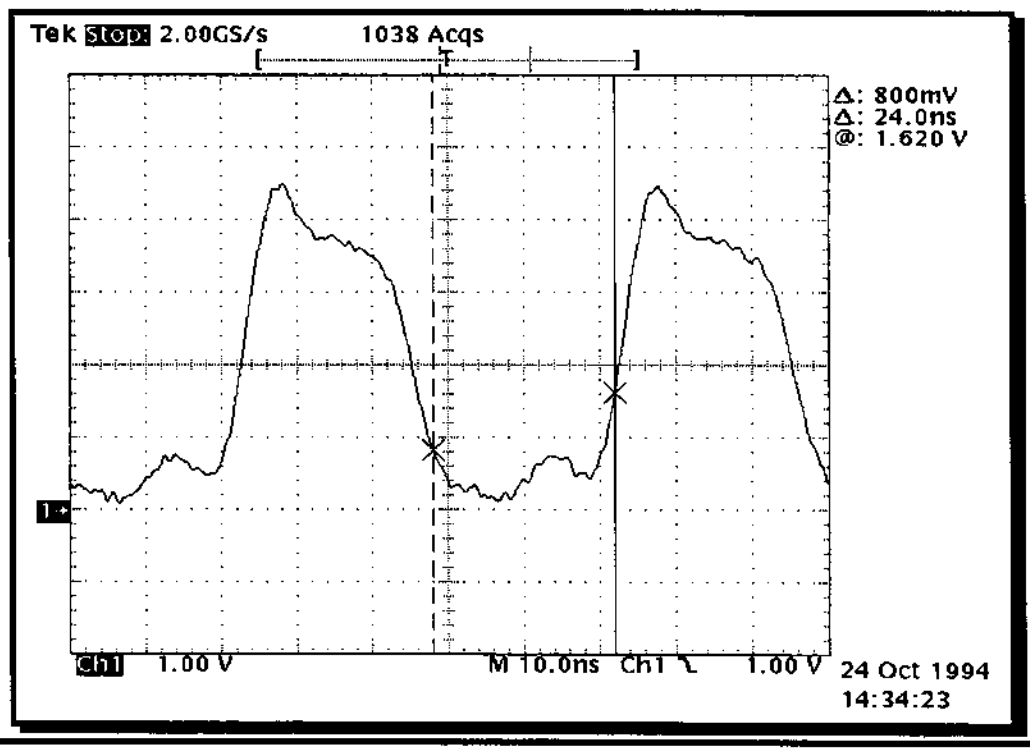
Test Case A with 3 18 pF Targets - DB6 @ Unit 2



Test Case A with 3 18 pF Targets - ACK @ Unit 3

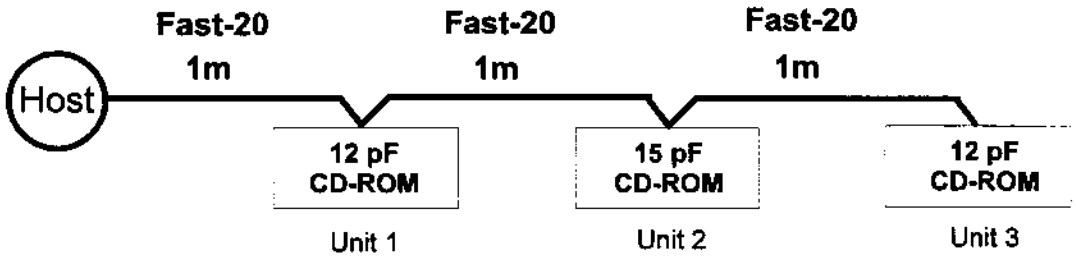


Test Case A with 3 18 pF Targets - DB6 @ Unit 3



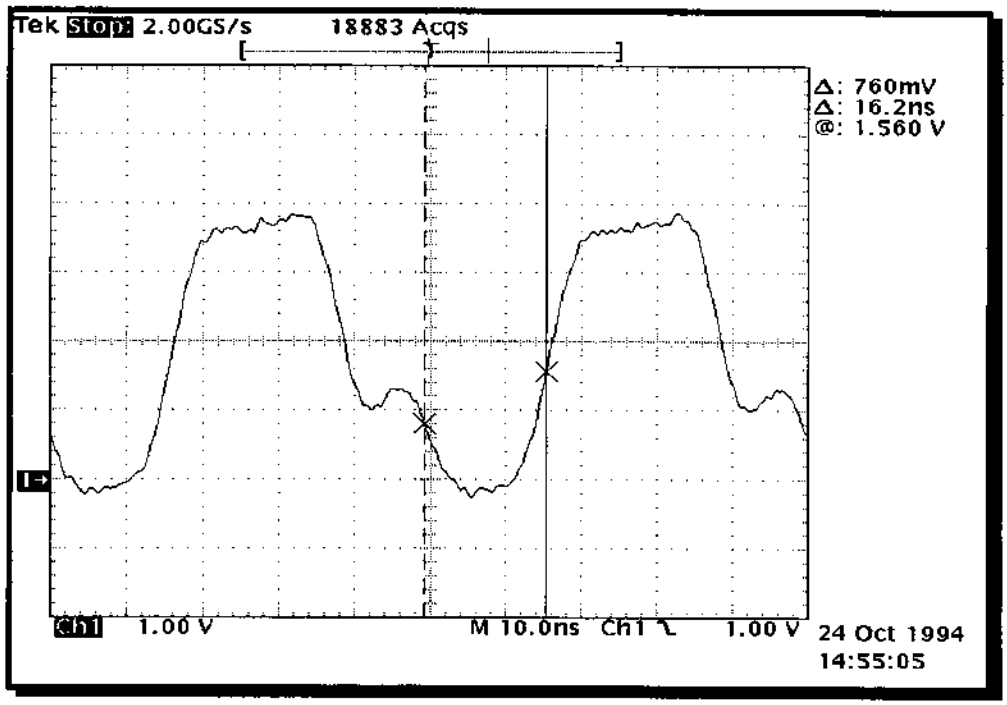
Tested Configuration

Case A

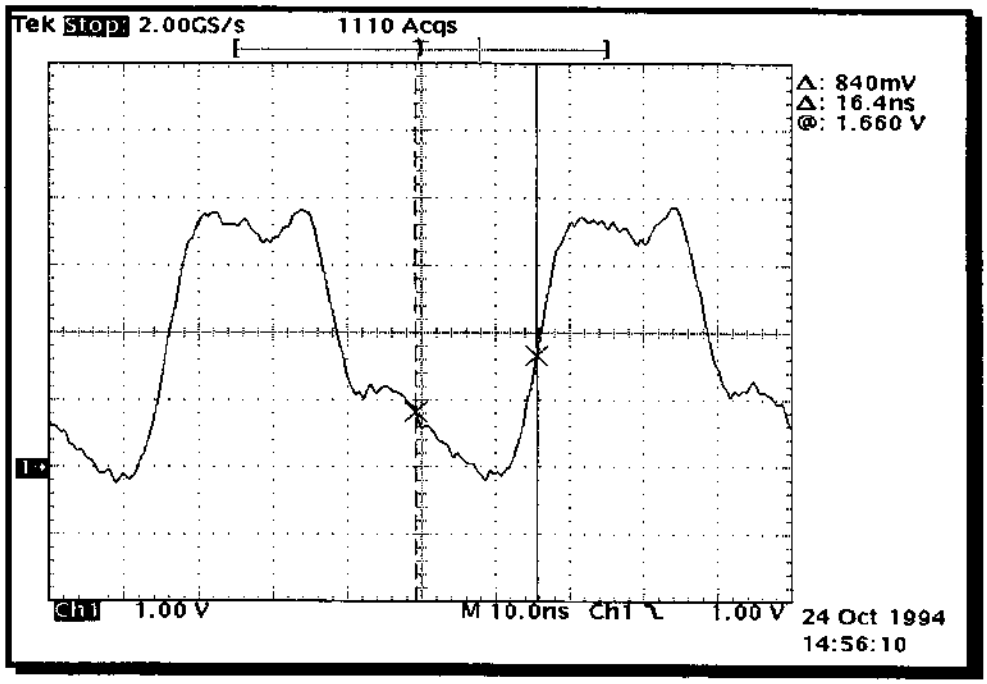


- **Configuration:** Test Case A - using three CD-ROM drives

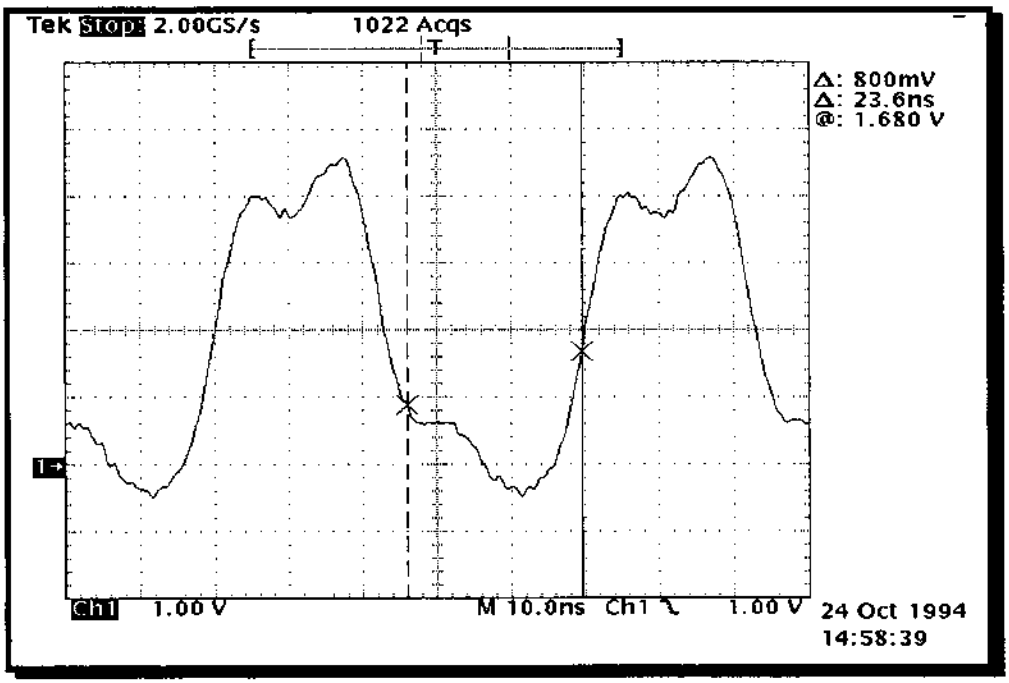
Test Case A with 3 CD-ROM Targets - ACK @ Unit 1



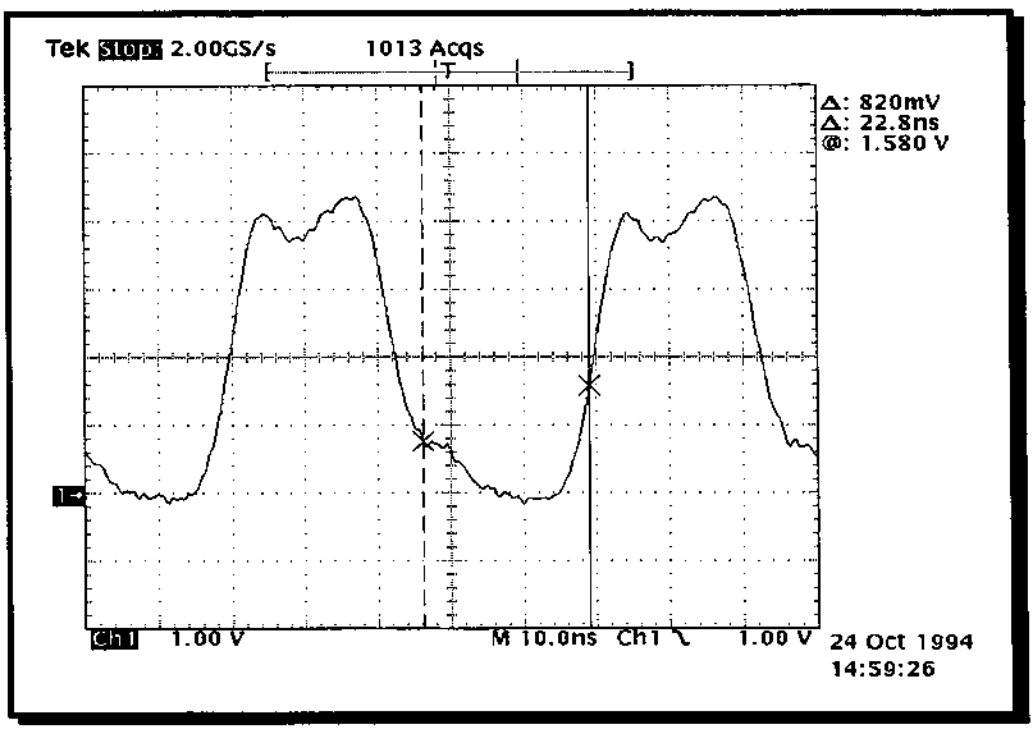
Test Case A with 3 CD-ROM Targets - DB6 @ Unit 1



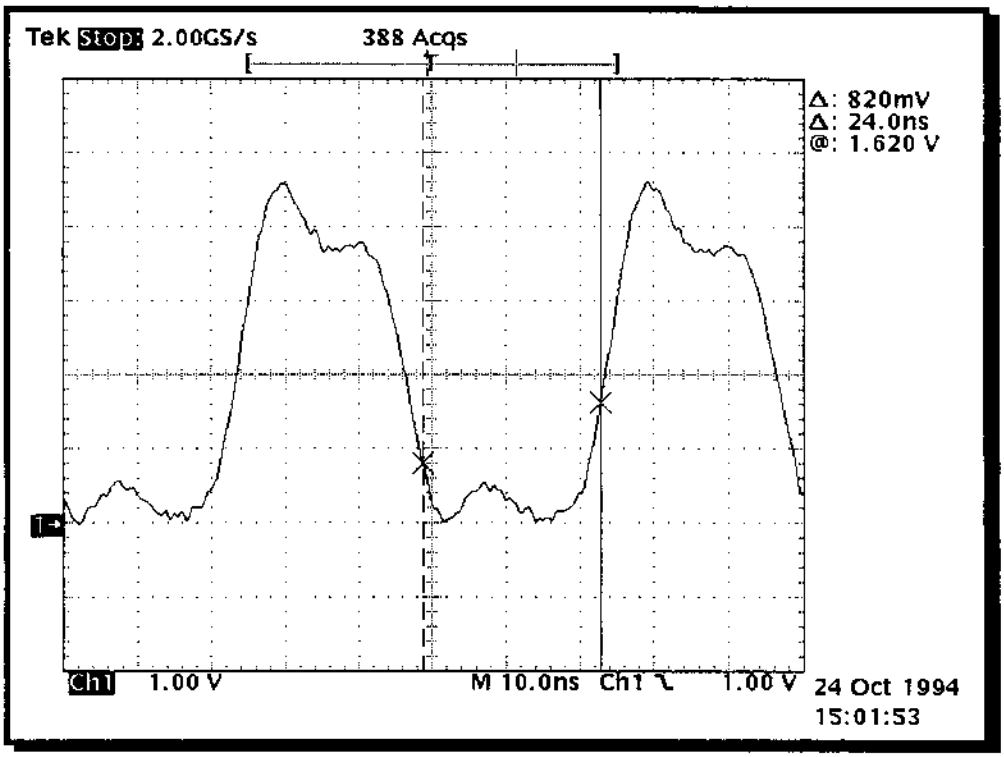
Test Case A with 3 CD-ROM Targets - ACK @ Unit 2



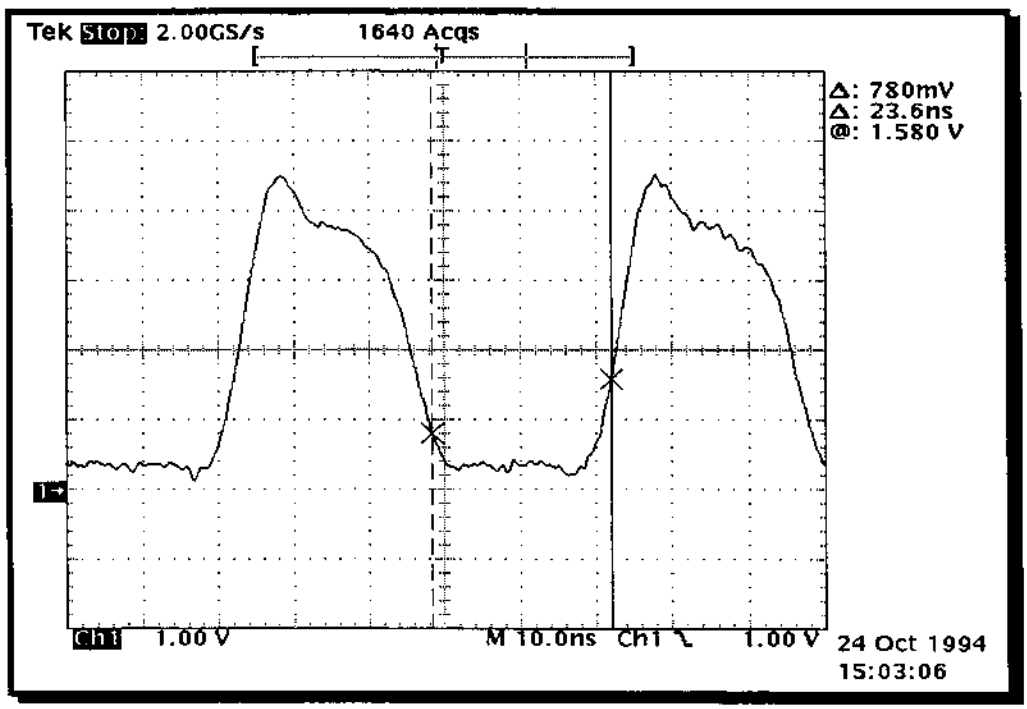
Test Case A with 3 CD-ROM Targets - DB6 @ Unit 2



Test Case A with 3 CD-ROM Targets - ACK @ Unit 3



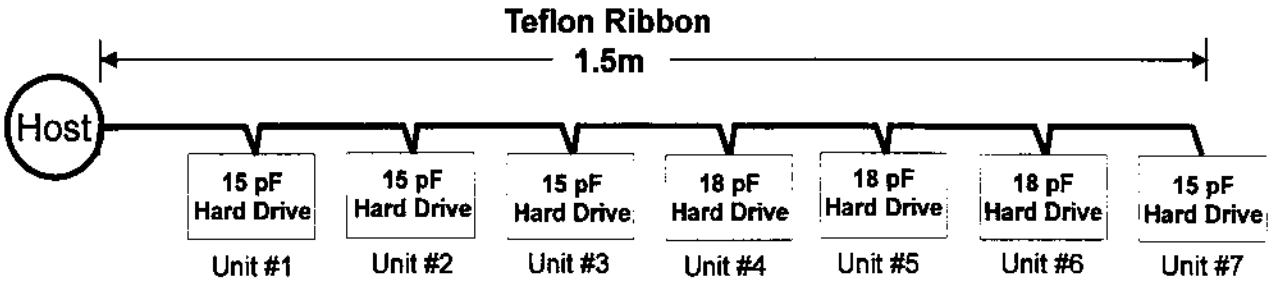
Test Case A with 3 CD-ROM Targets - DB6 @ Unit 3



Appendix B: Case B Analysis

Tested Configuration

Case B



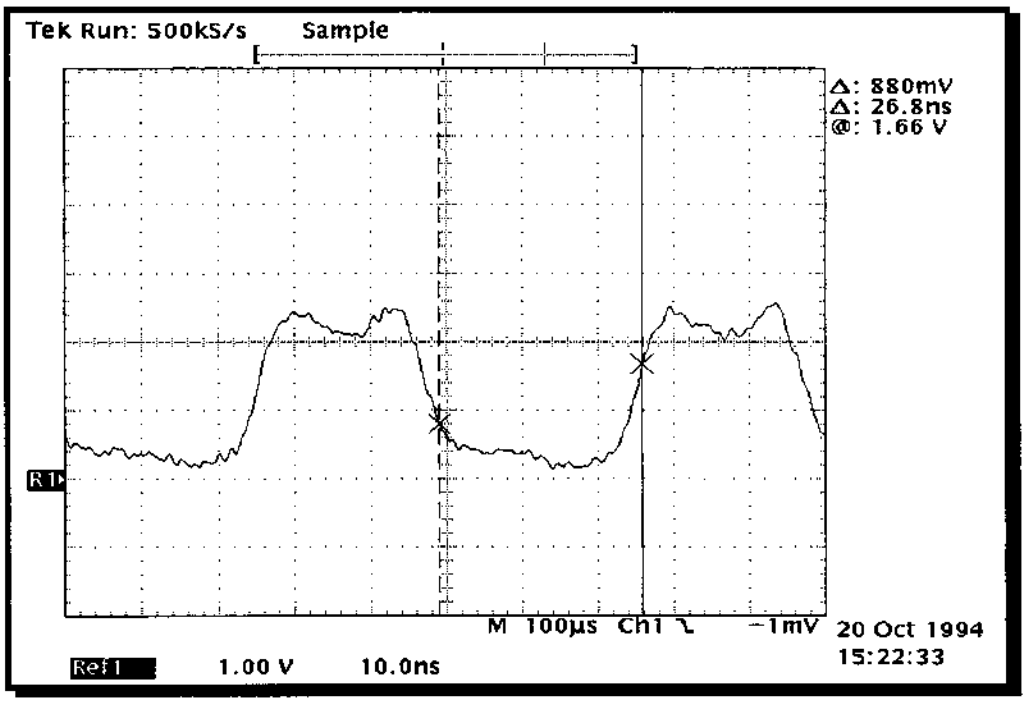
- **Configuration:** Test Case B using seven hard disk drives
- **Cable:** 1.5 meter 8 connector Teflon ribbon
- **Host Adapter:** Adaptec AHA-2940 PCI Host Adapter modified to supply ACK/Data pulses at 20 Mhz
- **Terminator:** Active termination on the drive

Table B1: Test Case B Assertion and Negation Period Summary

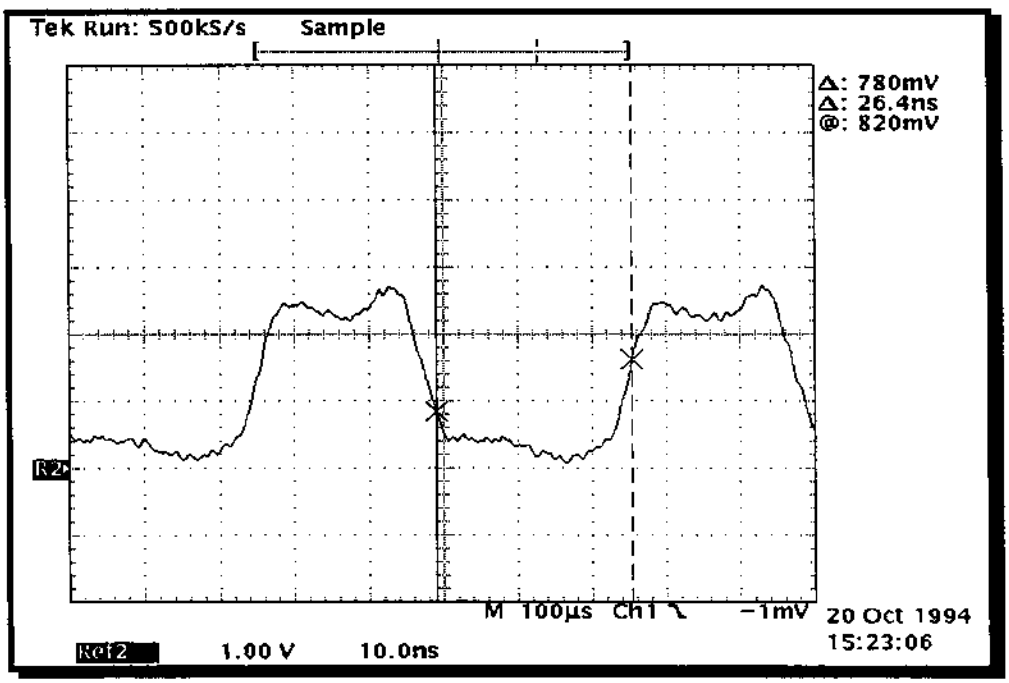
		Assertion		Negation	
Device		**ACK**	**DB6**	**ACK**	**DB6**
Host Adapter		27.6	27.2	21.0	21.6
Unit 1 - 15 pF Hard Drive		27.6	27.6	21.6	21.6
Unit 2 - 15 pF Hard Drive		27.2	27.4	21.0	21.6
Unit 3 - 15 pF Hard Drive		27.4	27.4	21.2	21.0
Unit 4 - 18 pF Hard Drive		27.6	27.2	20.8	21.4
Unit 5 - 18 pF Hard Drive		27.2	27.0	21.0	20.8
Unit 6 - 18 pF Hard Drive		26.8	27.0	22.0	22.0
Unit 7 - 18 pF Hard Drive		27.2	27.4	21.0	20.6

The following pages of waveforms from the oscilloscope give more detail as to the signal degradation.

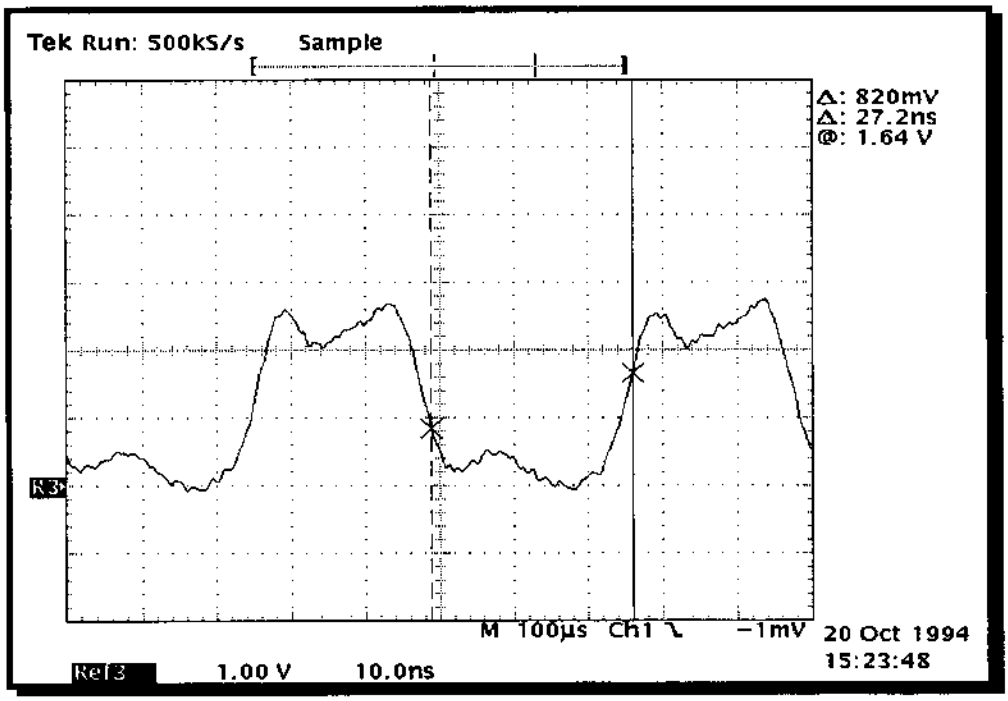
Test Case B with 7 Targets - ACK @ Host Adapter



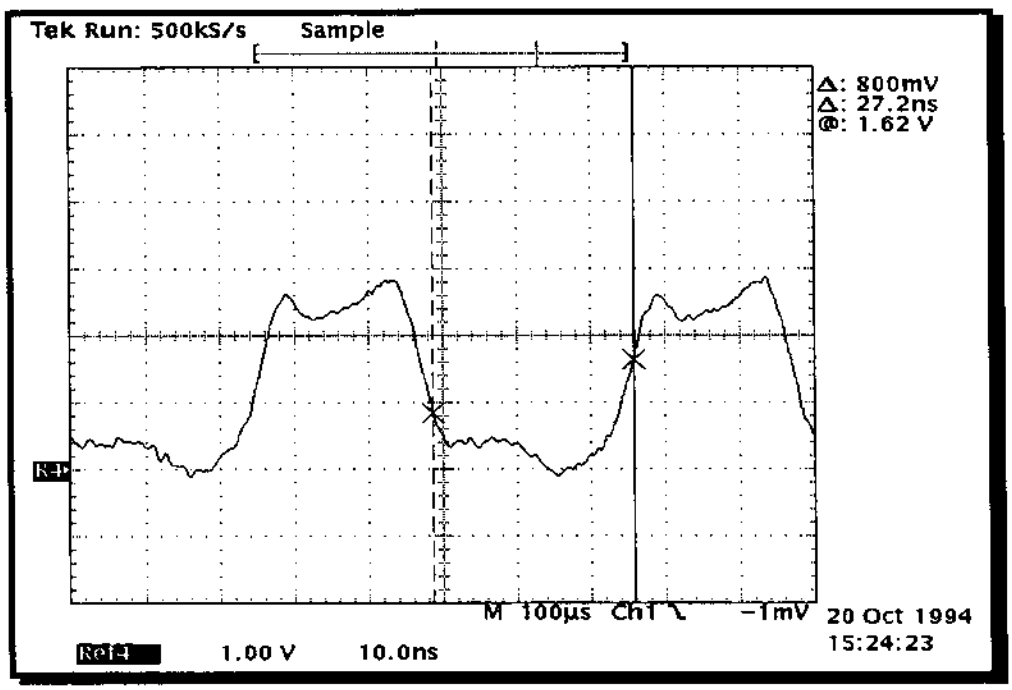
Test Case B with 7 Targets - DB6 @ Host Adapter



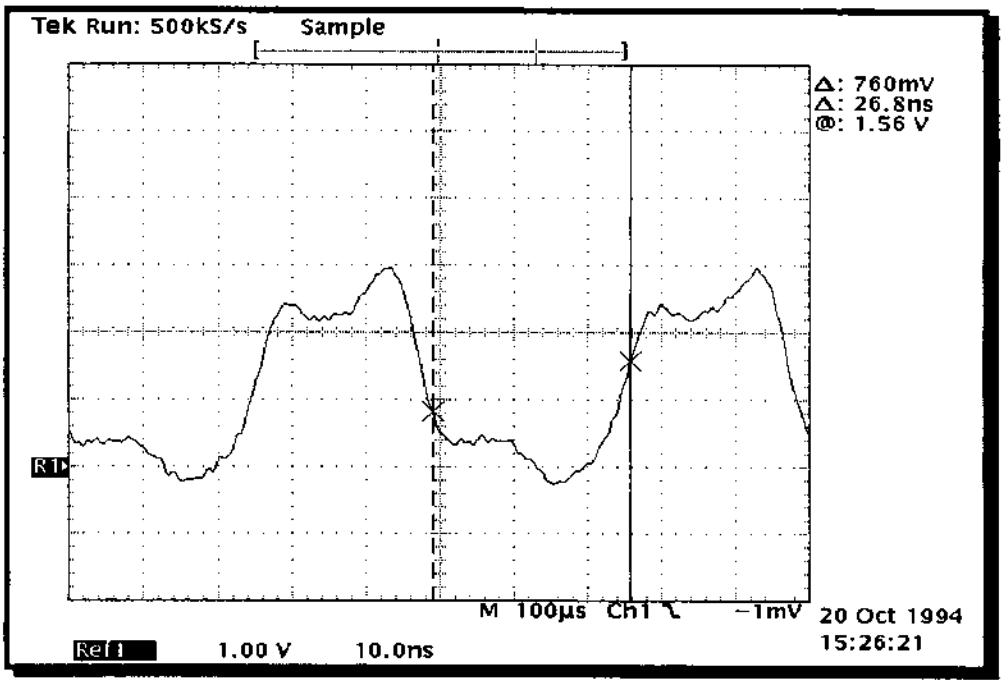
Test Case B with 7 Targets - ACK @ Unit 1



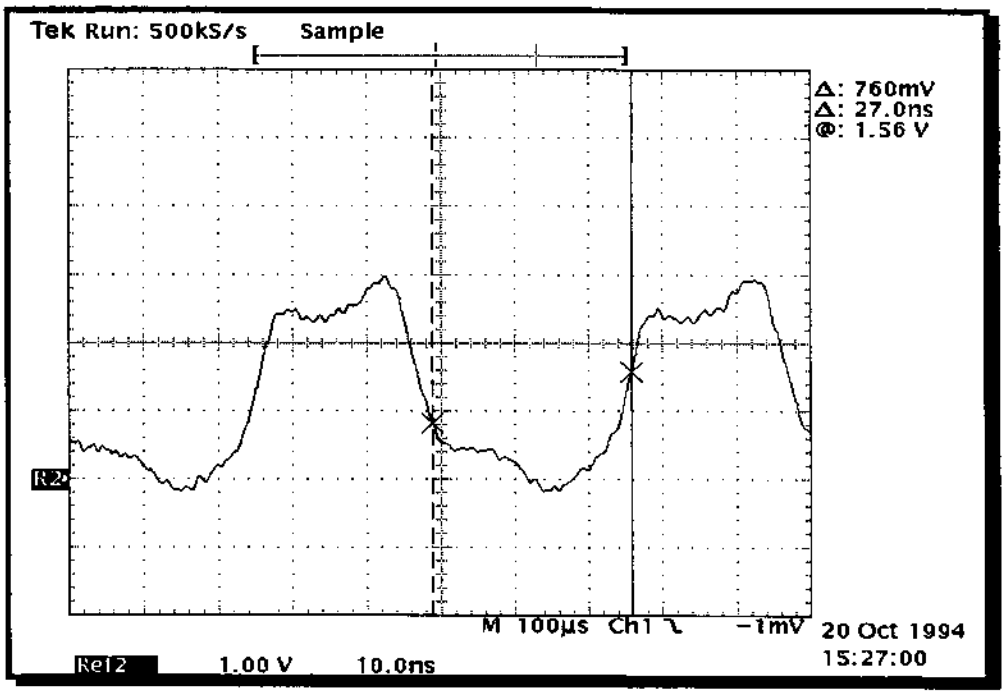
Test Case B with 7 Targets - DB6 @ Unit 1



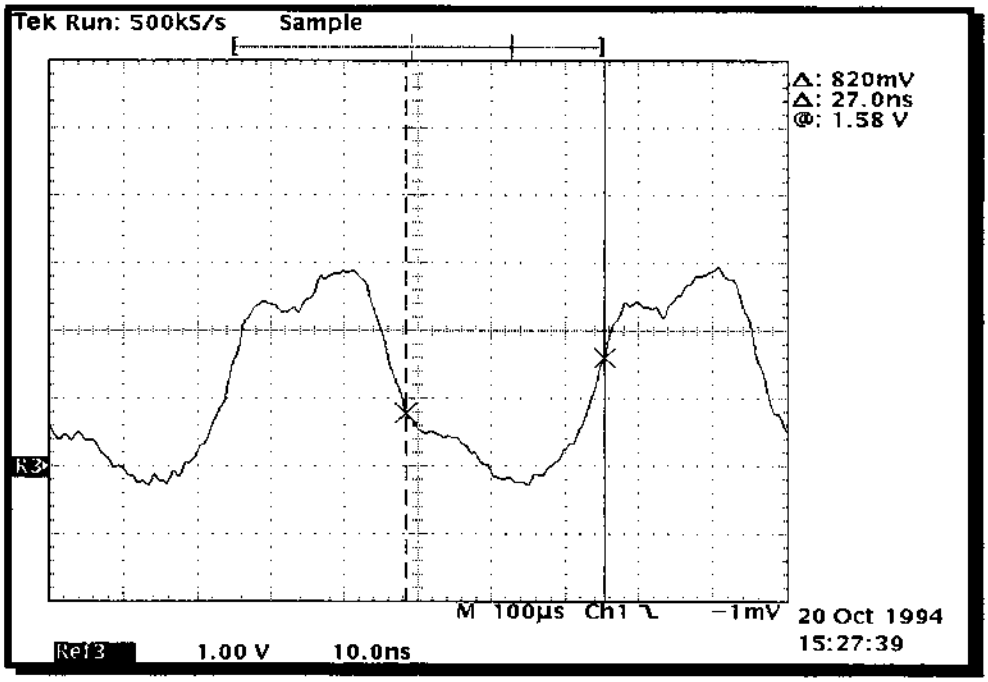
Test Case B with 7 Targets - ACK @ Unit 2



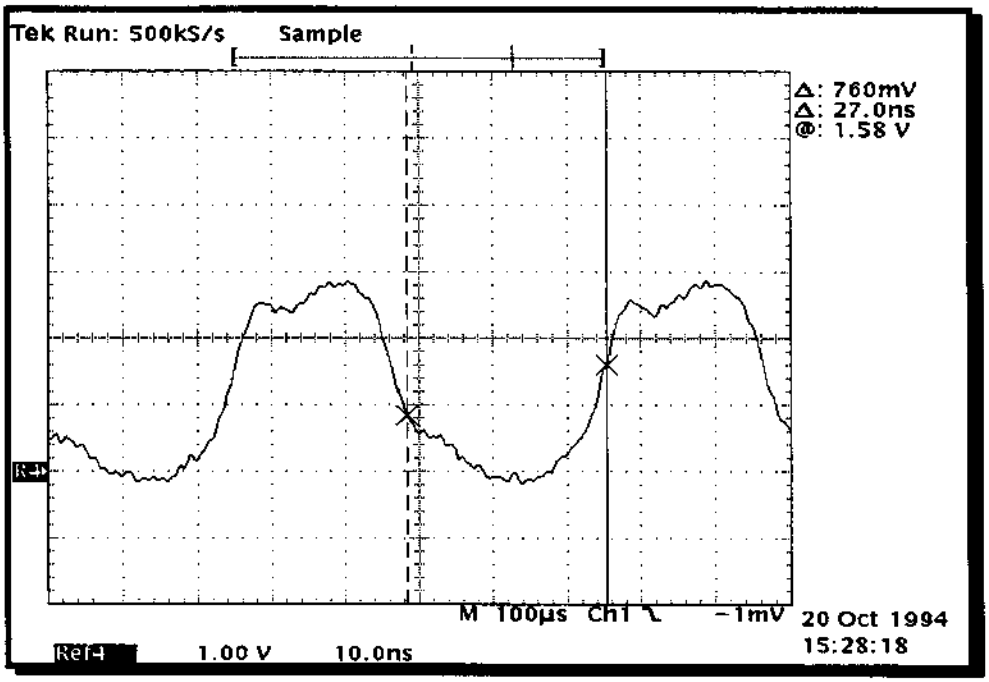
Test Case B with 7 Targets - DB6 @ Unit 2



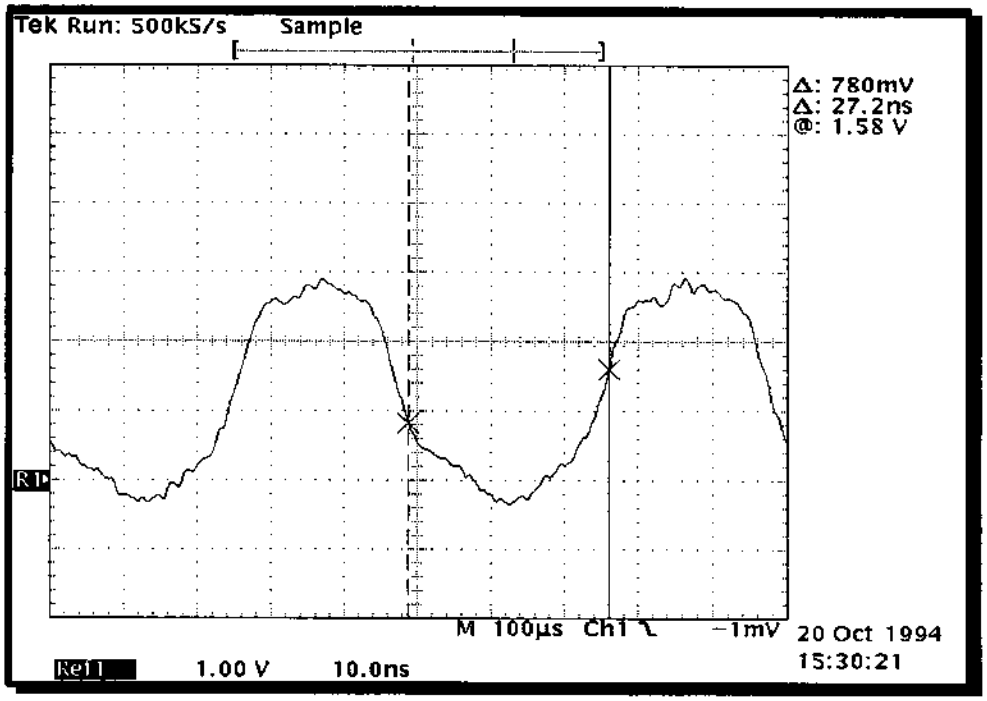
Test Case B with 7 Targets - ACK @ Unit 3



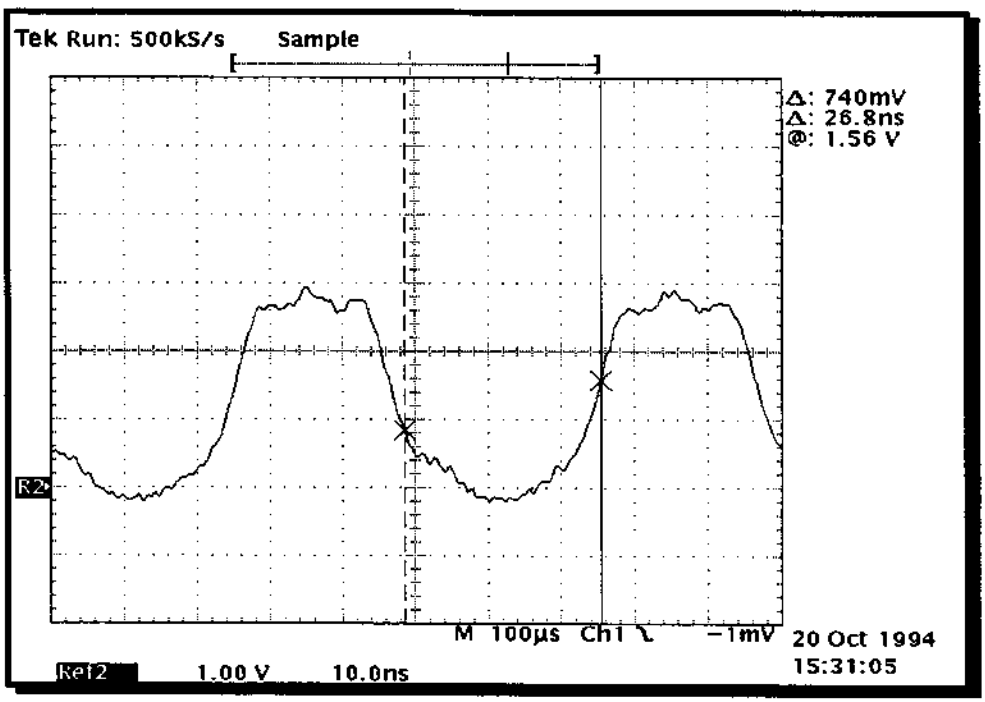
Test Case B with 7 Targets - DB6 @ Unit 3



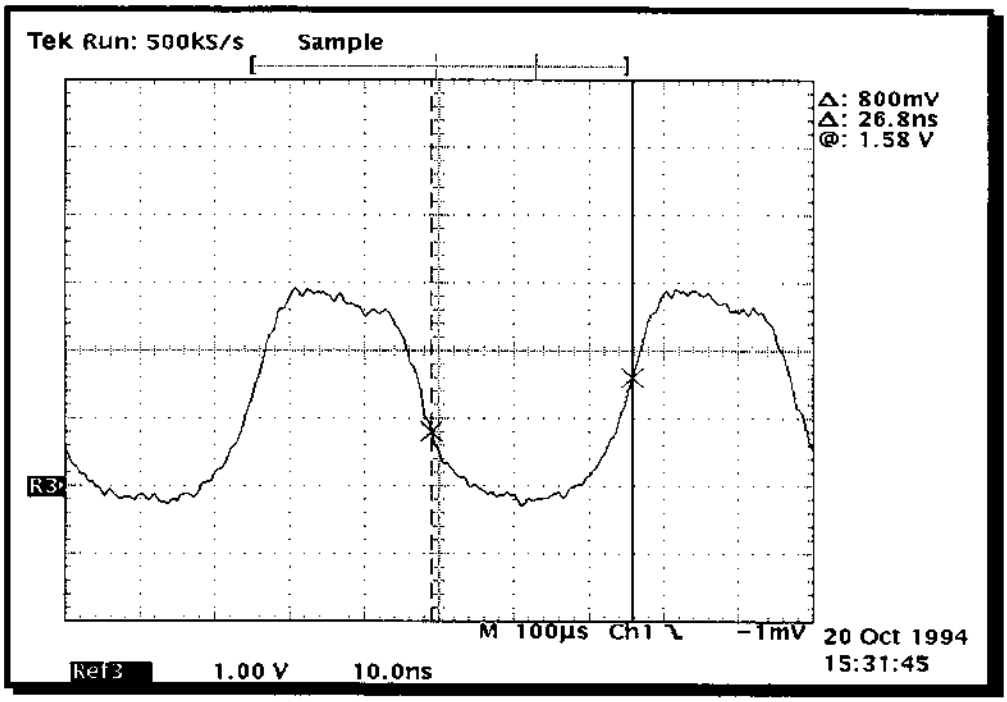
Test Case B with 7 Targets - ACK @ Unit 4



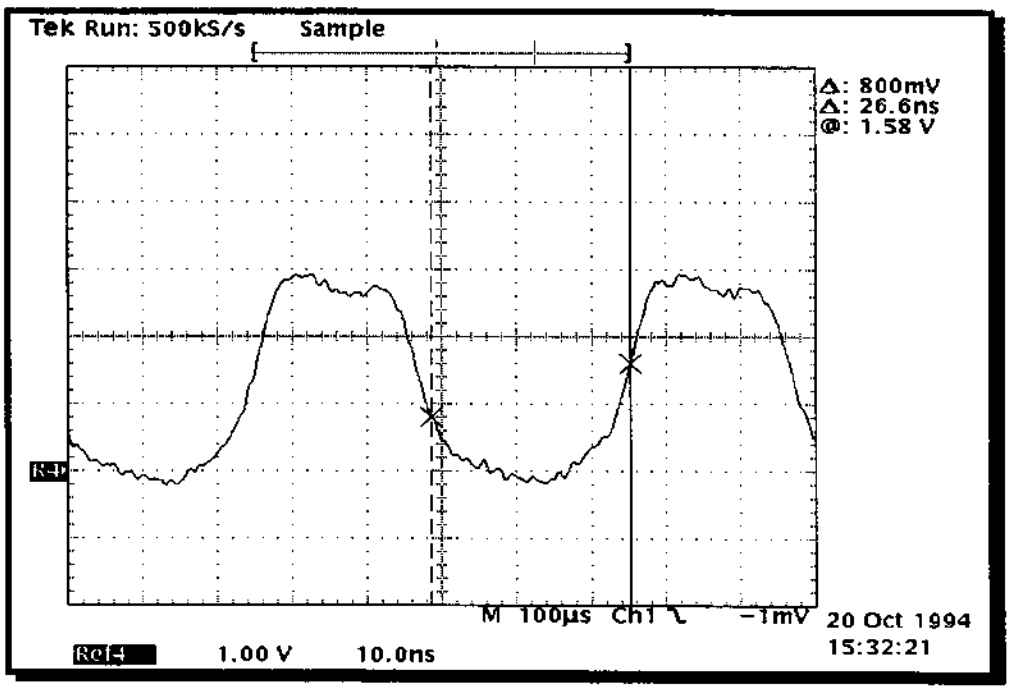
Test Case B with 7 Targets - DB6 @ Unit 4



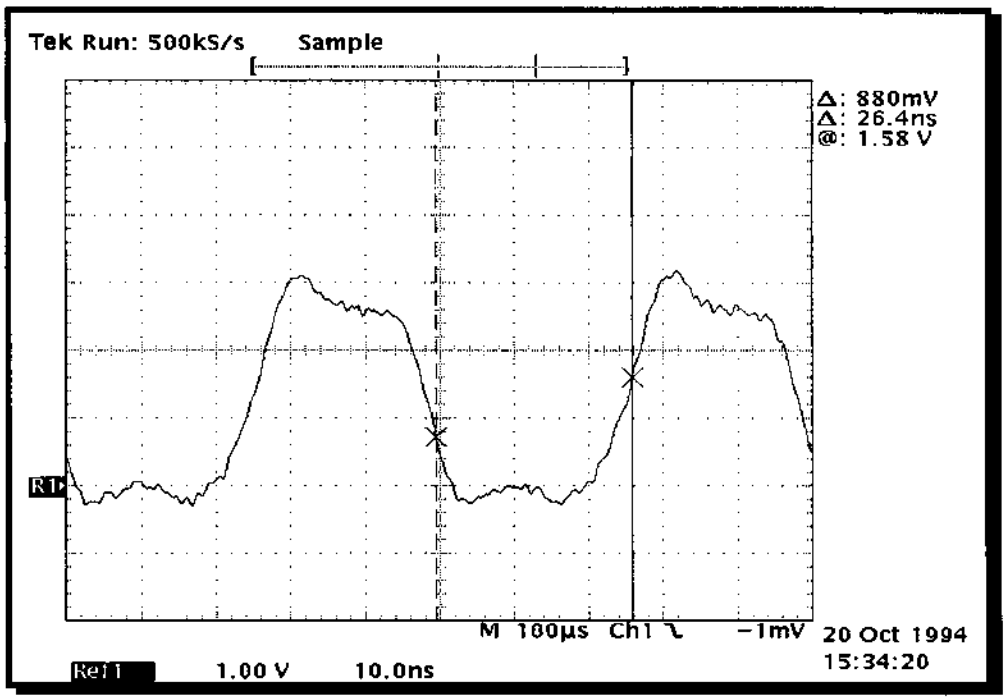
Test Case B with 7 Targets - ACK @ Unit 5



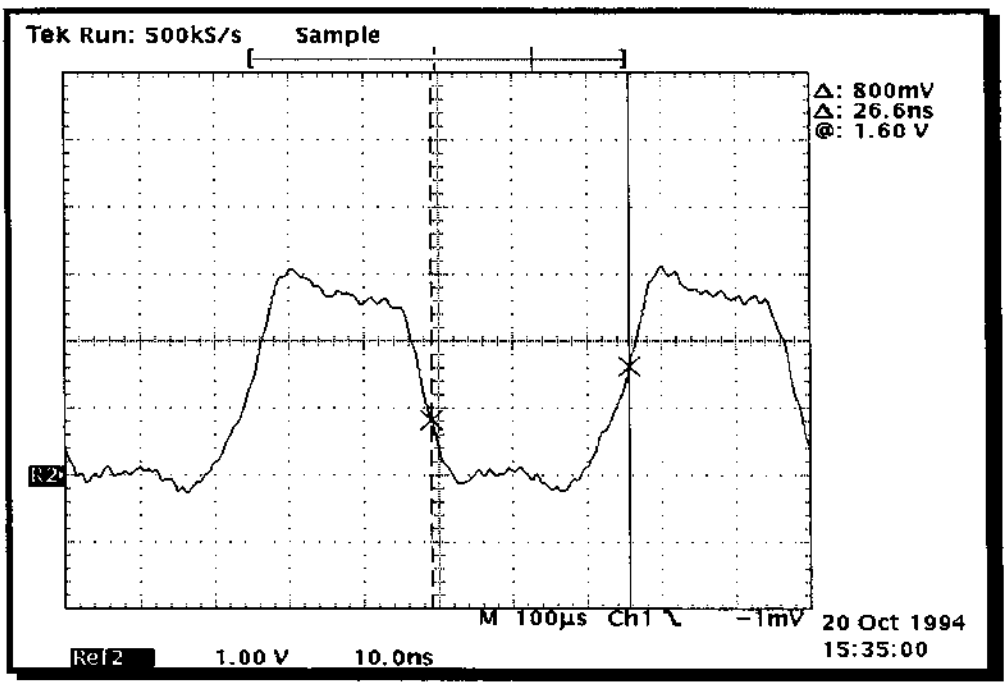
Test Case B with 7 Targets - DB6 @ Unit 5



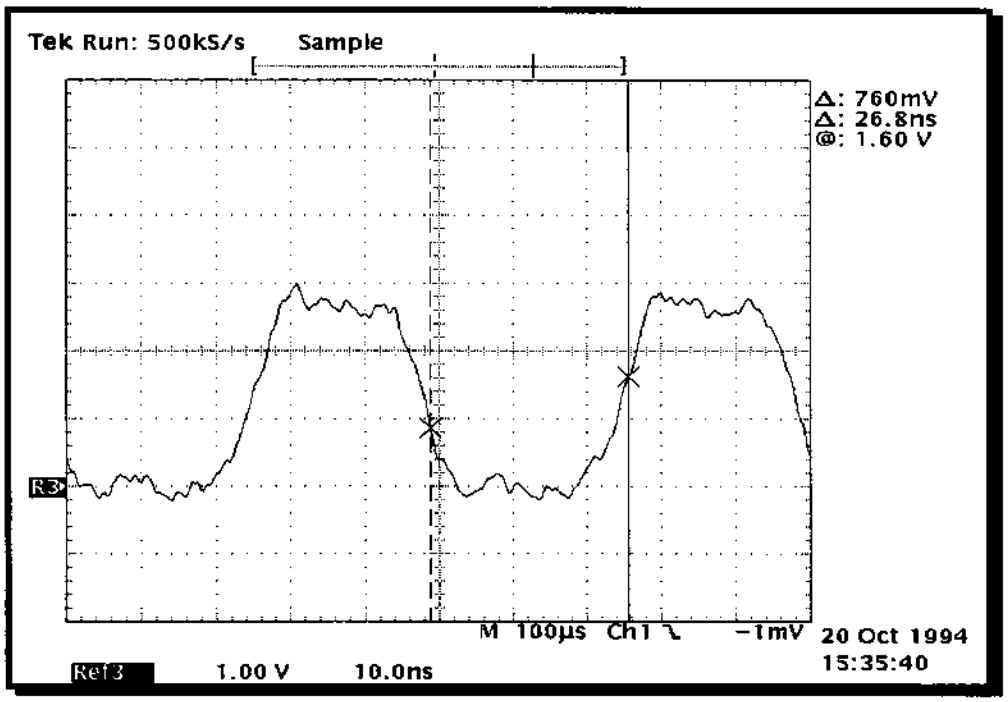
Test Case B with 7 Targets - ACK @ Unit 6



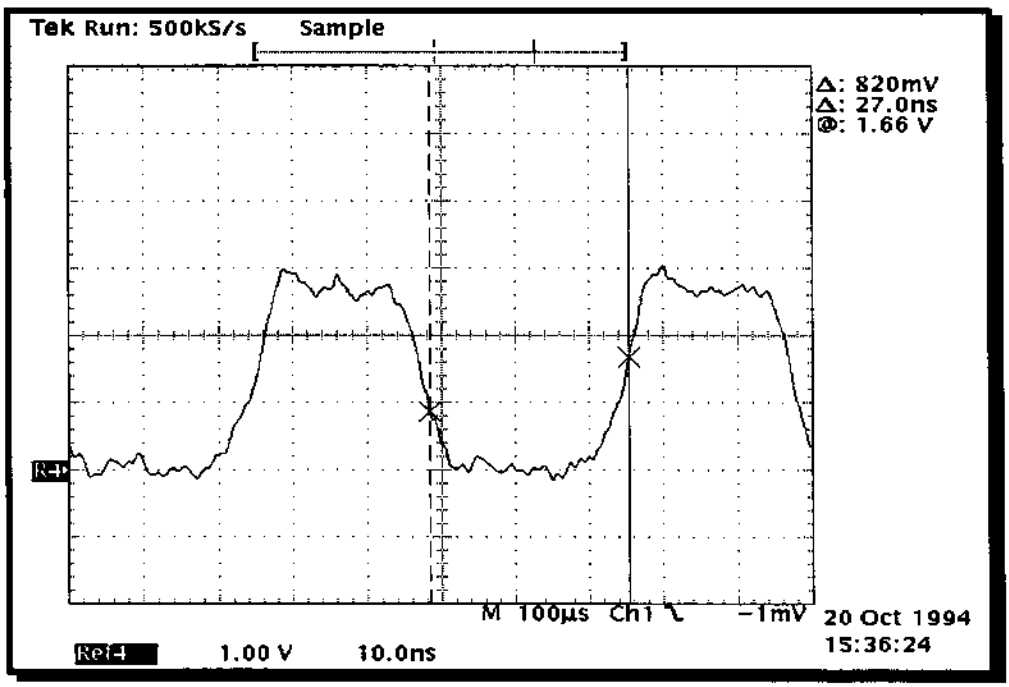
Test Case B with 7 Targets - DB6 @ Unit 6



Test Case B with 7 Targets - ACK @ Unit 7



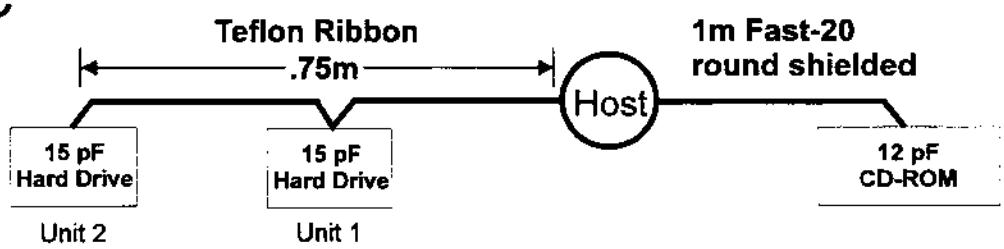
Test Case B with 7 Targets - DB6 @ Unit 7



Appendix C Case C Analysis

Tested Configuration

Case C



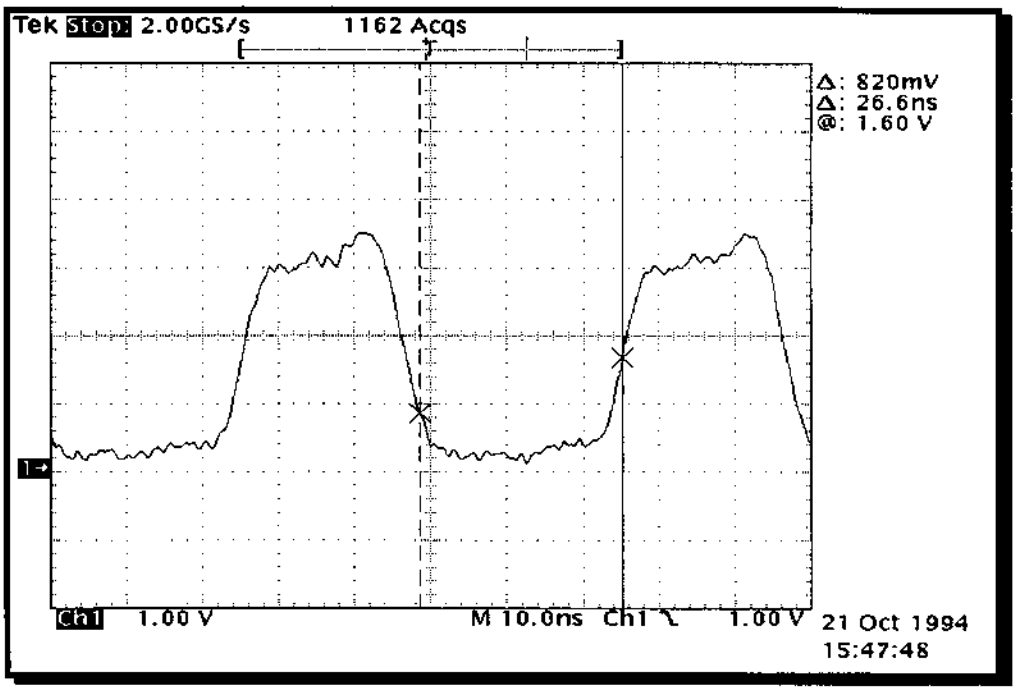
- **Configuration:** Test Case C - using 2 hard disk drives and a CD-ROM
- **Cables:**
  .75 meter 3 connector internal teflon ribbon cable
  1 meter Fast-20 compliant round shielded
- **Host Adapter:** Modified AHA-2940 which supplies ACK/Data pulses at 20 Mhz
- **Terminator:** Active termination at the CD-ROM - active termination from the hard drive

Table C1: Case C Assertion and Negation Period Summary

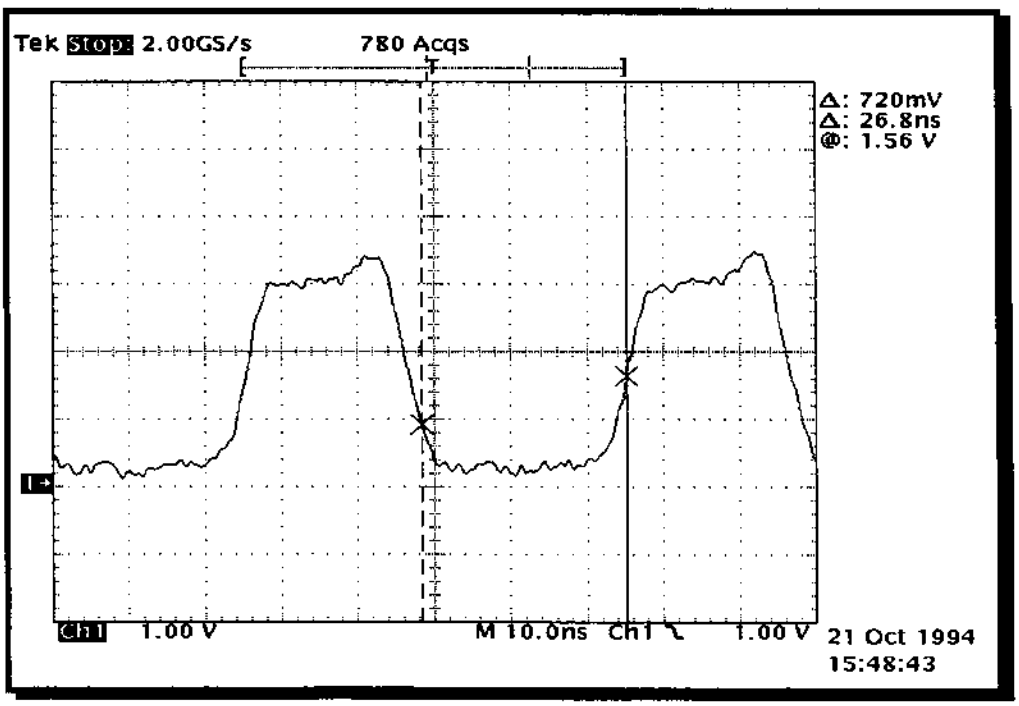
		Assertion		Negation	
Device		**ACK**	**DB6**	**ACK**	**DB6**
Unit 2		29.2	27.0	18.0	21.0
Unit 1		28.4	26.2	19.0	22.0
Host Adapter		27.2	27.0	22.0	22.0
CD-ROM		26.4	25.6	24.0	22.0

The following pages of waveforms from the oscilloscope give more detail as to the signal degradation.

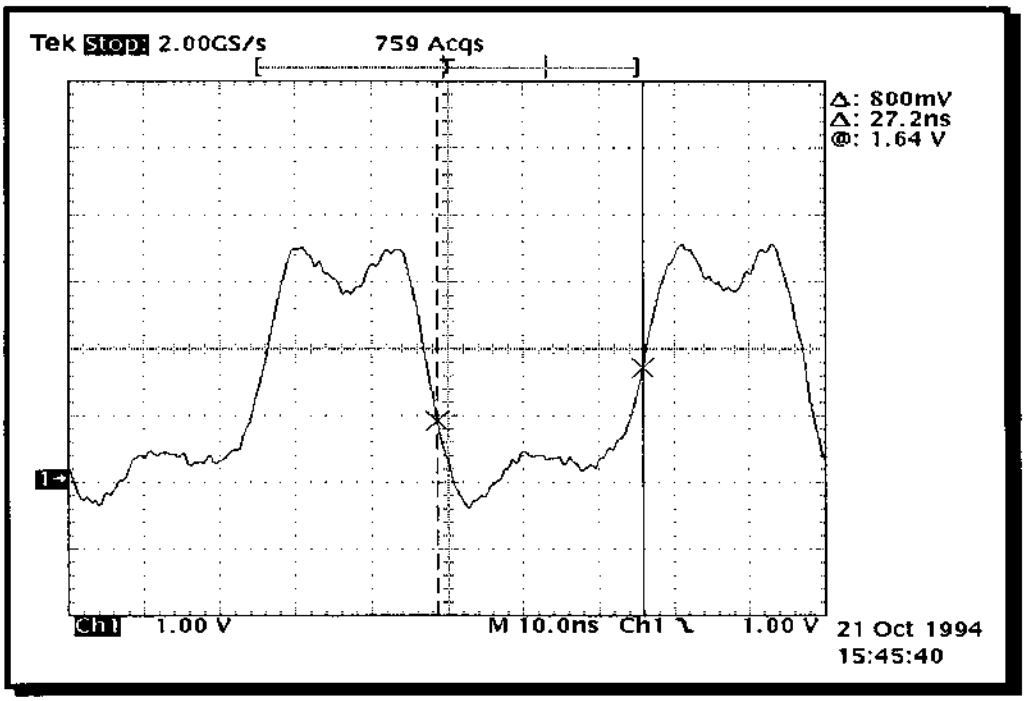
Test Case C - ACK @ Host Adapter



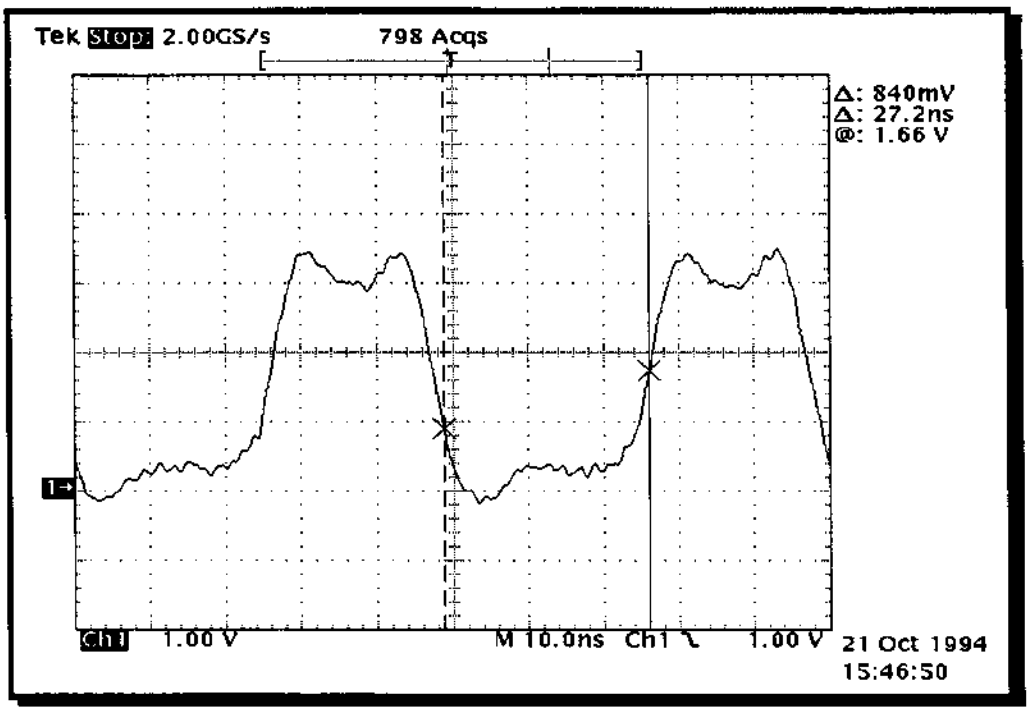
Test Case C - DB6 @ Host Adapter



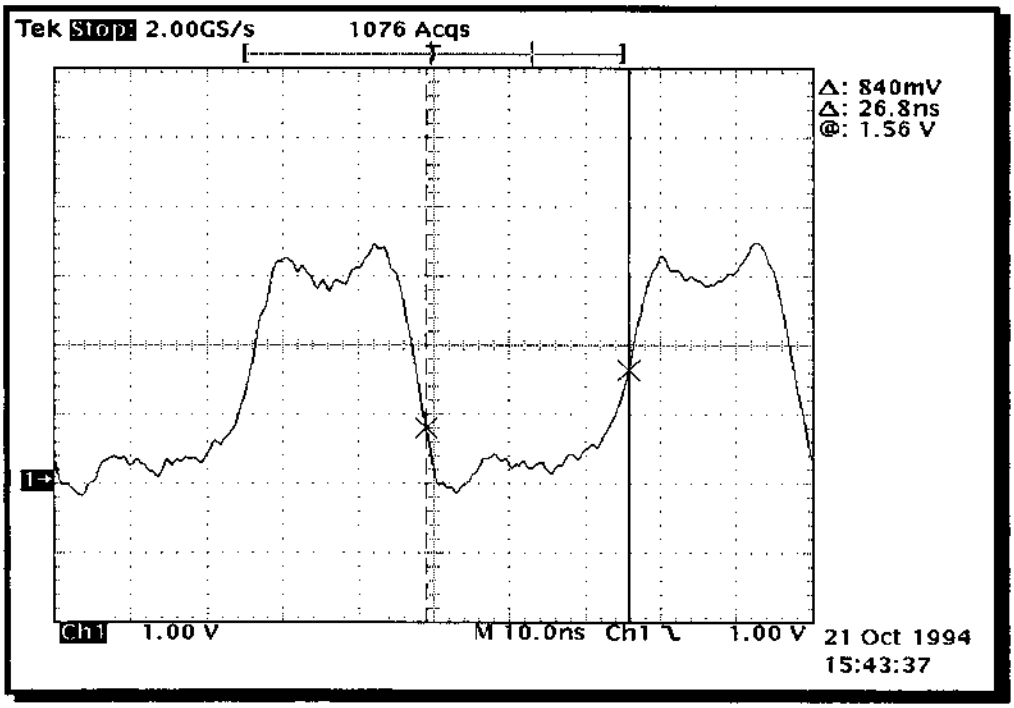
Test Case C - ACK @ Unit 1



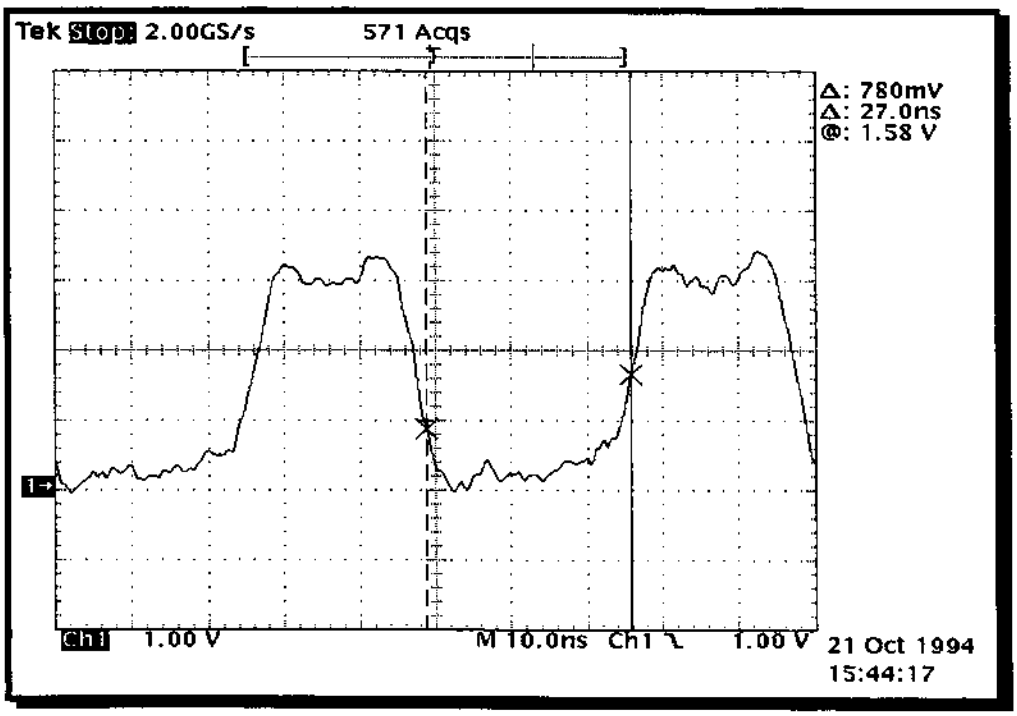
Test Case C - DB6 @ Unit 1



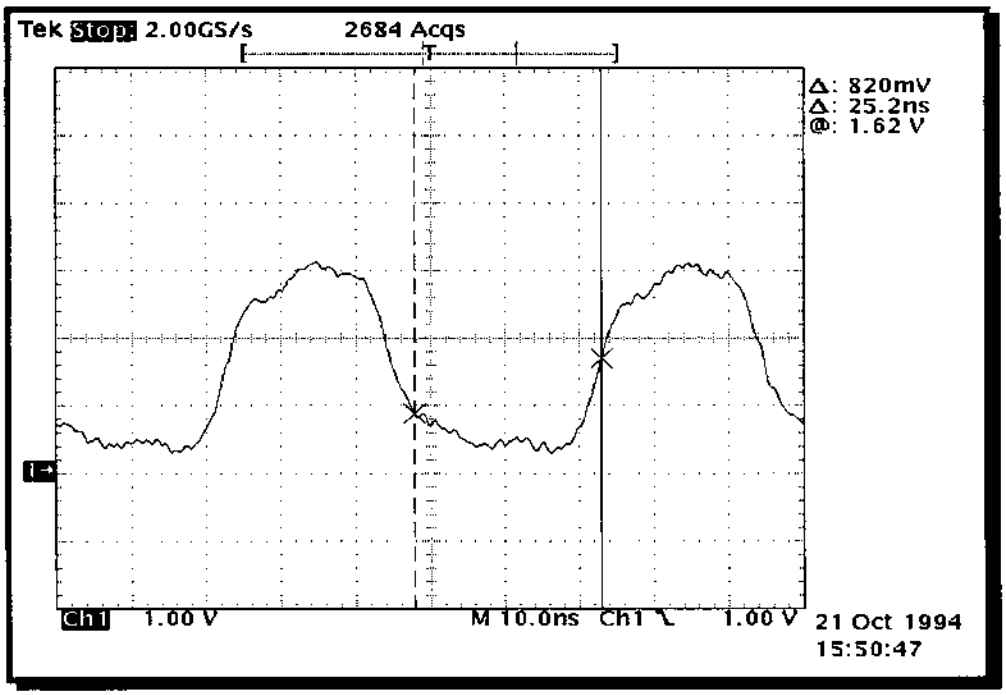
Test Case C - ACK @ Unit 2



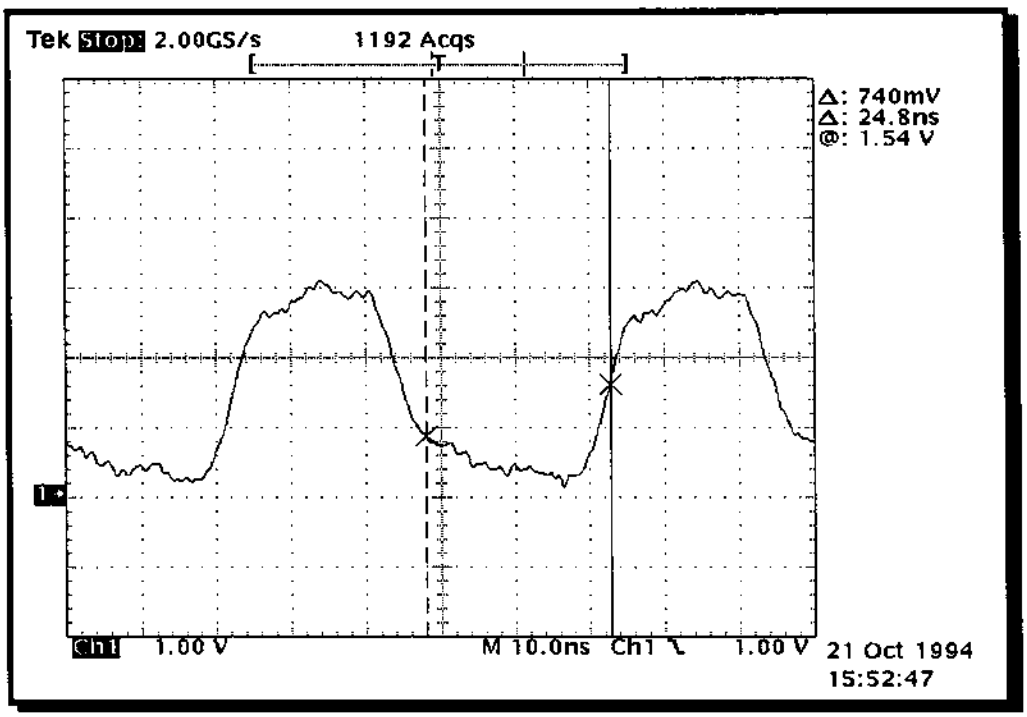
Test Case C - DB6 @ Unit 2



Test Case C - ACK @ CD-ROM



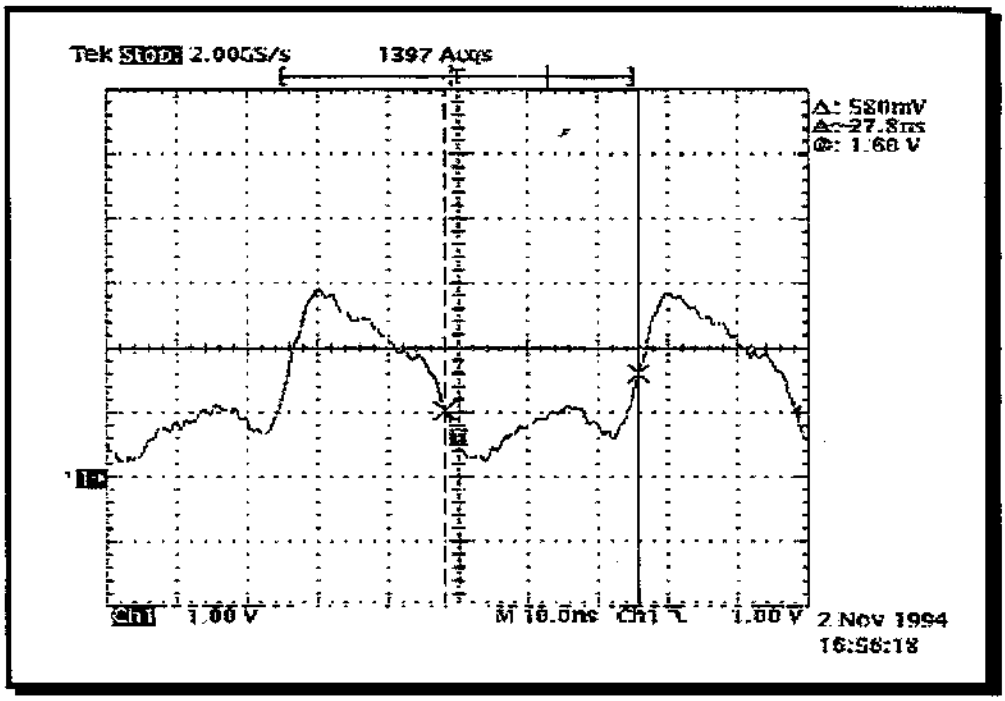
Test Case C - DB6 @ CD-ROM



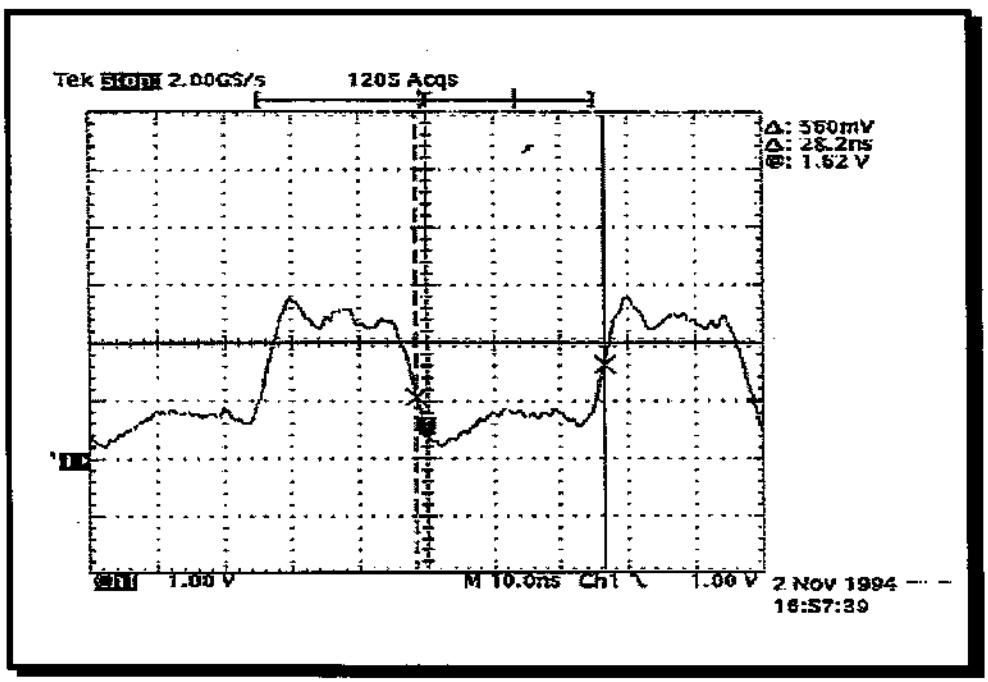
Appendix D Waveforms for Section 2

This appendix shows the waveforms discussed in section 2 of this report. These waveforms have been derived from Case A and Case B (refer to Figure 1 of main report). They show the signal at Unit 1 which is the worst case in both cases.

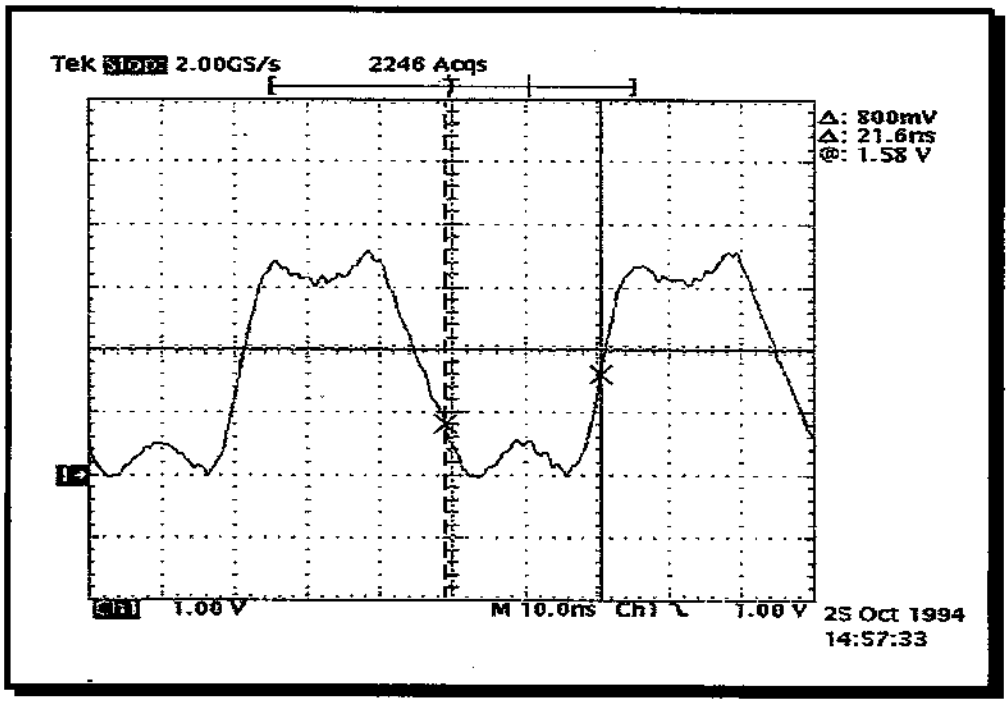
Test Case A with Stand. External Centronics - ACK @ Unit 1



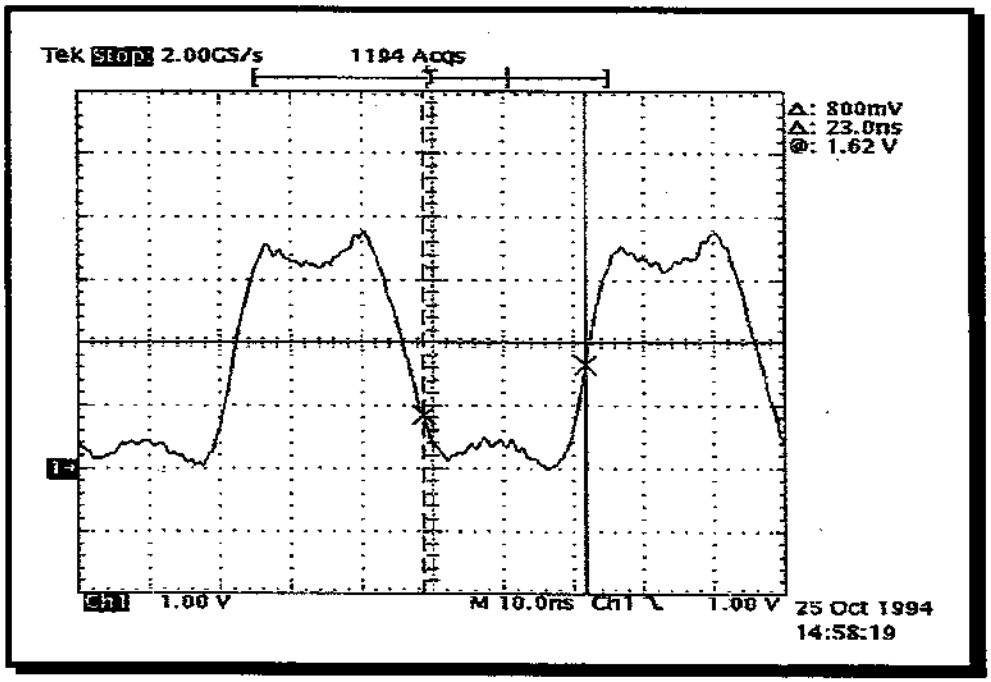
Test Case A Stand. External Centronics - DB6 @ Unit 1



Test Case 7 Units with Standard Ribbon - ACK @ Unit 1



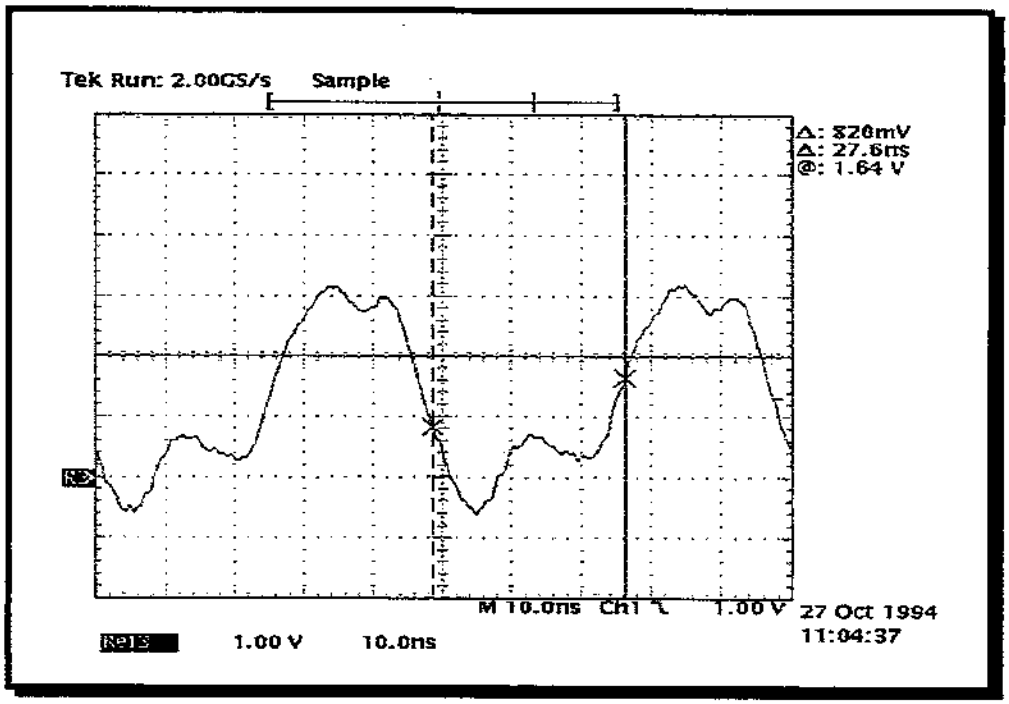
Test Case 7 Units with Standard Ribbon - DB6 @ Unit 1



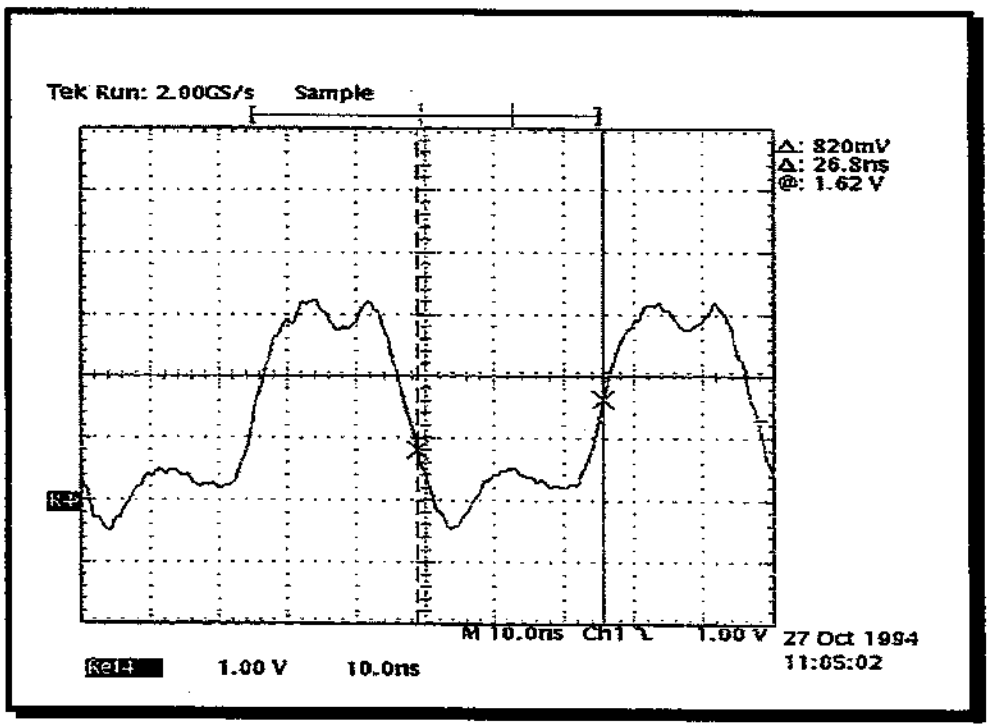
Appendix E Waveforms for Section 3

Three waveforms have been depicted. The first is the baseline, with no added capacitance. The second and third are waveforms for 10 PF added capacitance at each node and 50 PF added capacitance for each node. Remember that standard cables have been used and the configuration that is used in Case C (see Figure 1 of main paper). The waveforms for ACK* and DB6* is shown at Unit 1 which is the worst case scenario in each case.

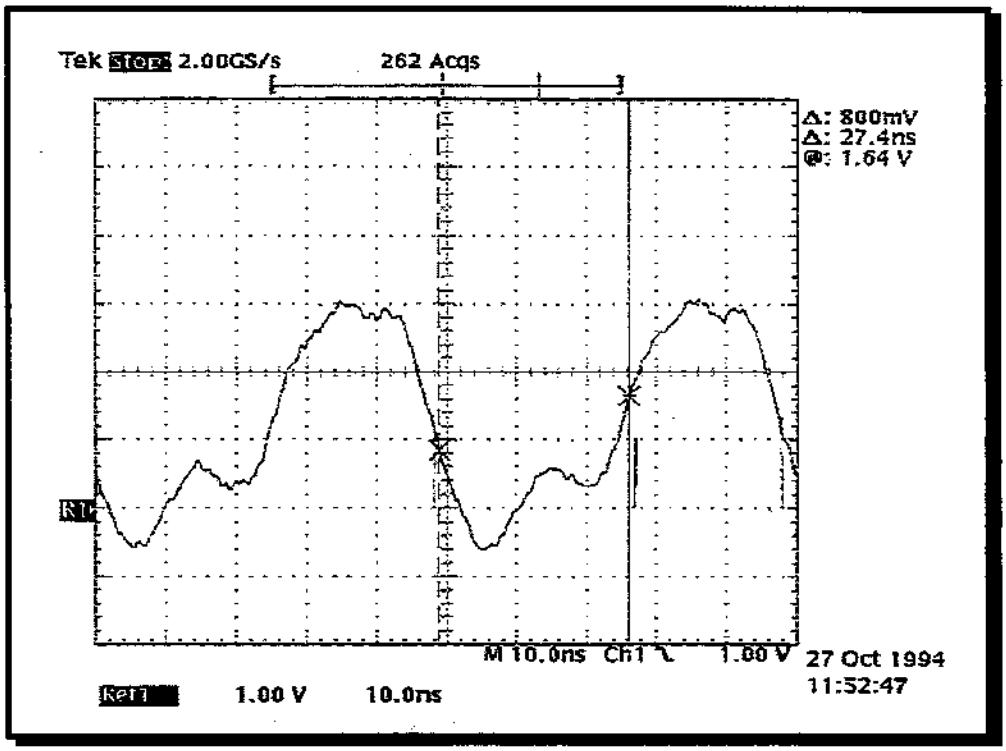
Test Case Baseline - ACK @ Unit 1



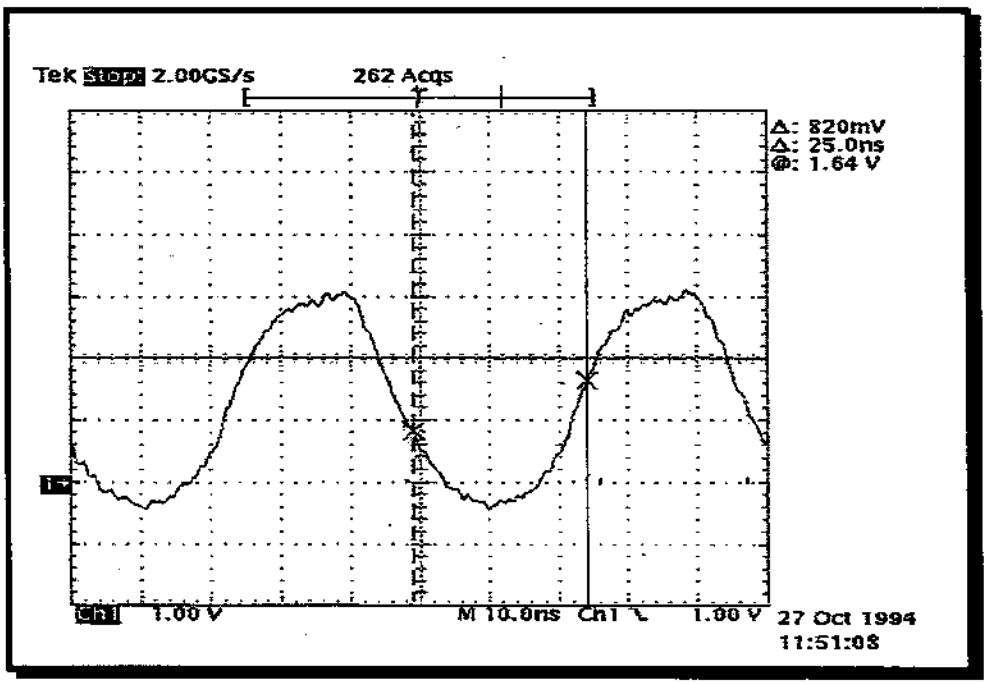
Test Case Baseline - DB6 @ Unit 1



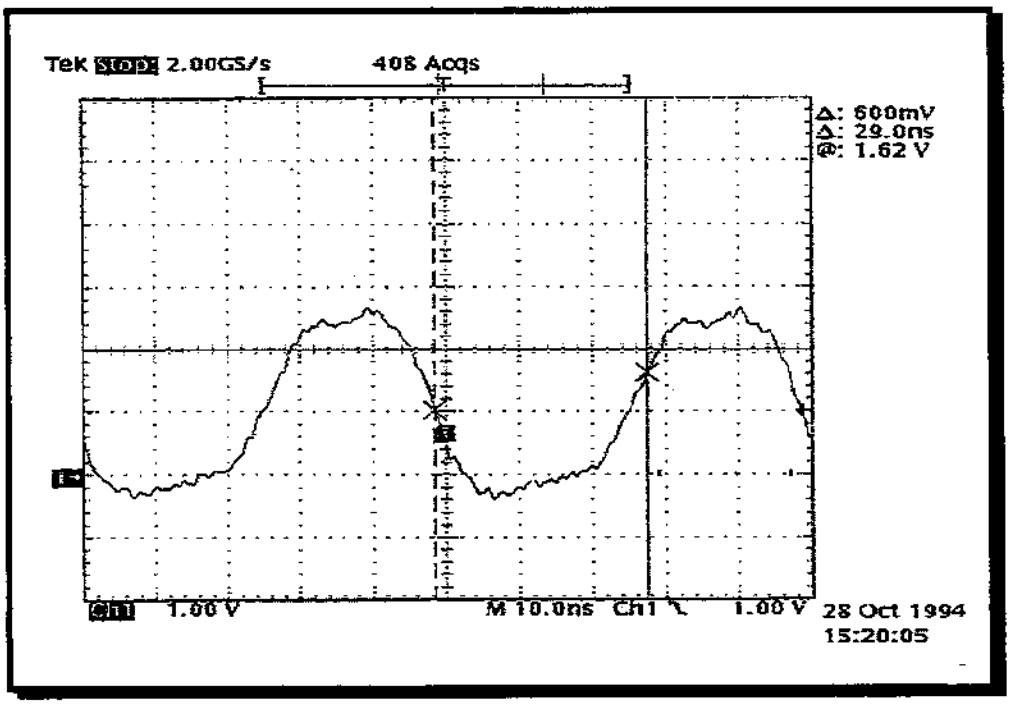
Test Case with 10 PF - ACK @ Unit 1



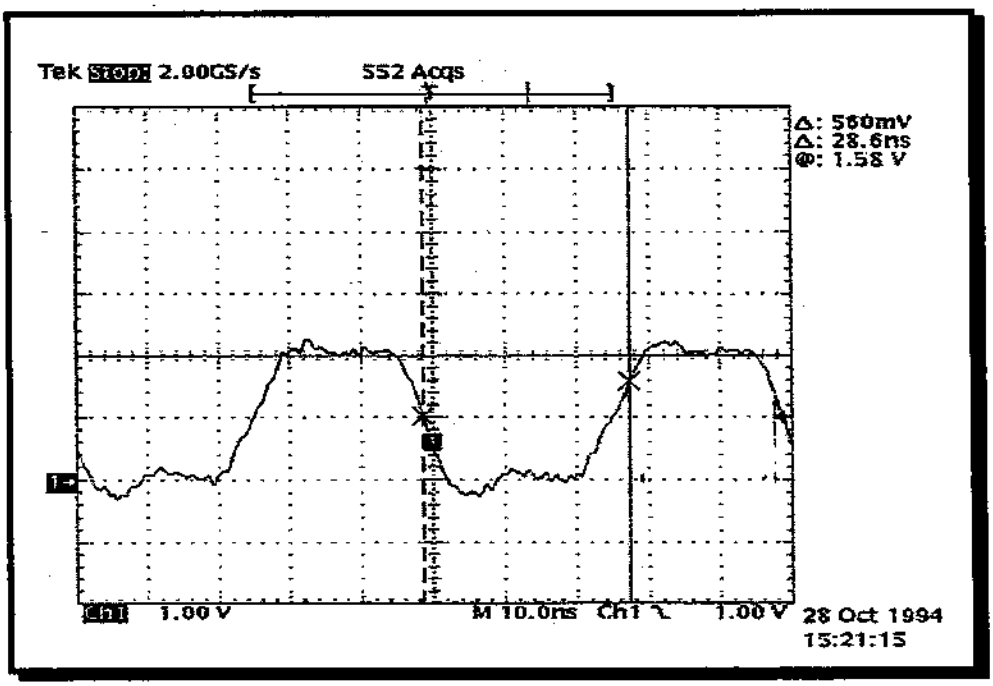
Test Case with 10 PF - DB6 @ Unit 1



Test Case with 50 PF - ACK @ Unit 1



Test Case with 50 PF - DB6 @ Unit 1



Appendix F TDR Measurement

The testing was performed using a Tektronix 1502C Metallic Time Domain Reflectometer (TDR). This instrument sends an electrical pulse down the cable and detects any reflections. It can measure the return loss of the pulse as well as the impedance at any point along the cable. The rise time of this unit is less than 200 ps which meets the SCSI-3 spec of less than 500 ps.

Measurement Technique

The test fixture consists of a short coaxial cable from the TDR which is terminated in clip leads which are clipped on to the mating connector of the cable being tested. The cable is terminated on the other end by utilizing a small PC board which has two female connectors which acts as a gender changer. The grounds are connected together by soldering a bus wire across them for single ended testing as called out in the SCSI-3 spec. The cable impedance is measured between the signal wire of a particular wire and the and the ground of all pairs connected to the shield. For more details on the cable measurement method consult the SCSI-3 specification.

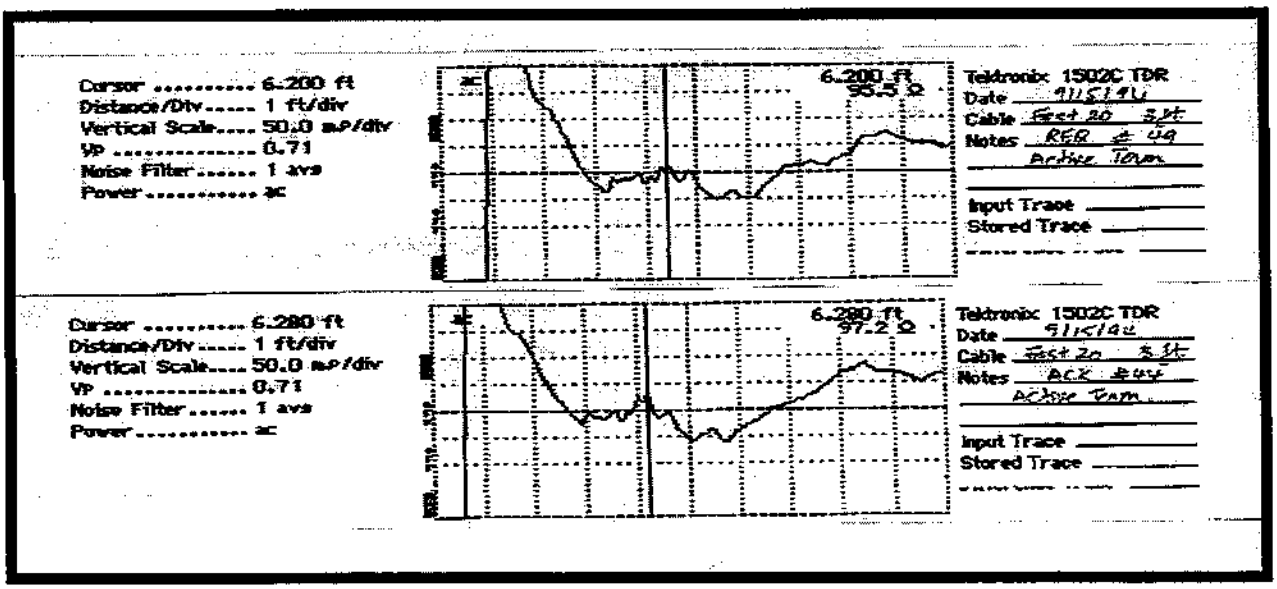
The proposal for Fast-20 currently states that for single-ended applications the maximum cumulative length of the signal path from terminator to terminator shall be 3.0 meters, 25 meters for differential. The signal path shall have a characteristic impedance of 90 ohms +/- 6 ohms for the REQ and ACK signals and 90 ohms +/- 10 ohms for all other signals. This is different from the SCSI-3 specification of 84 ohms +/- 12 ohms for all signals. Differential impedance is currently not stated in the Fast-20 proposal. The stub length shall not exceed .1 meter for single-ended and .2 meter for differential. The spacing of devices shall be at least three times the stub length to avoid clustering. The bus width shall be constant, that is 8-bit and 16-bit devices cannot be mixed on the same bus.

Cables

The cables tested were 1 meter and 3 meter prototypes. The TDR can "look" more in depth than the techniques used by cable vendors. They simply do not have the time to check all their cables to that extent. These cables use polyolefin insulation and have a velocity of propagation (Vp) of .71. This is a ratio of the speed that electrical energy travels through the cable relative to the speed that electrical energy travels through a vacuum (which happens to be the speed of light).

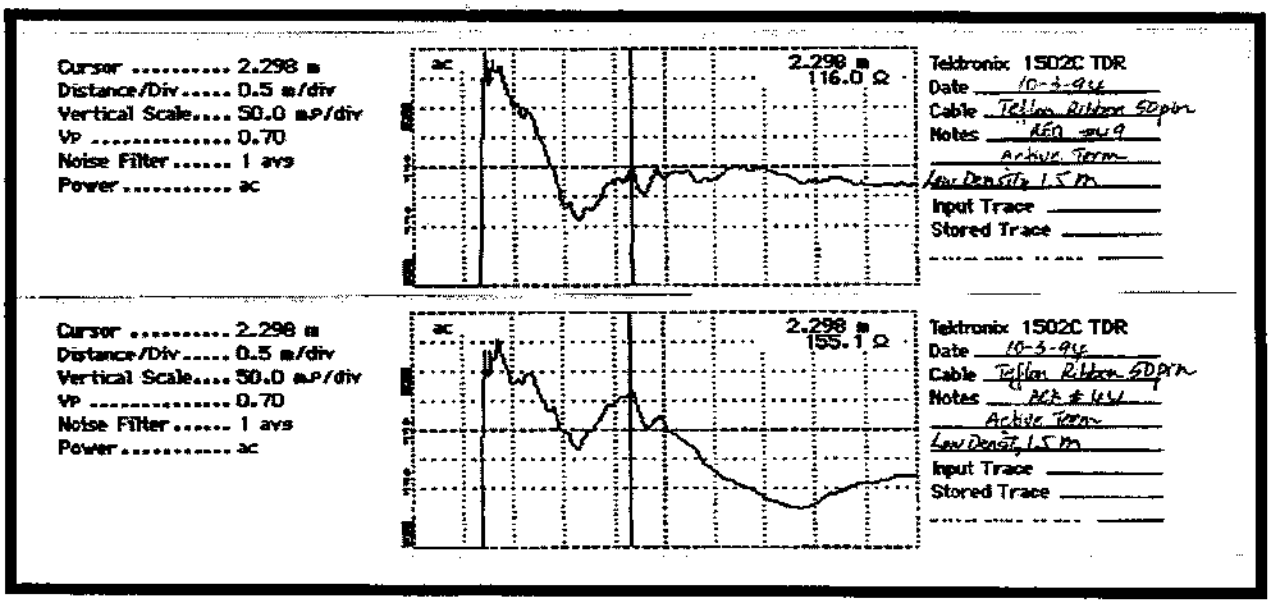
Fast-20 1 Meter High Density Active Terminated

Cable Name:Lynn Fast-20 External 50 Conductor	Length: 1 m.	Term: Methode Active				Summary	
Test Cases - Single-Ended Primary Bus		Min	Max	Delta		All Lines Delta	
Measure between	and						
Connector contact# 2 - DB0	Ground	82.20	92.50	10.30		Ave. Min.	84.42
Connector contact# 4 - DB1	Ground	83.90	93.70	9.80		Ave. Max.	93.21
Connector contact# 6 - DB2	Ground	84.50	92.40	7.90		Min. Minimum	81.90
Connector contact# 8 - DB3	Ground	82.10	89.60	7.50		Max. Minimum	88.70
Connector contact# 10 - DB4	Ground	83.30	90.10	6.80		Min. Maximum	88.70
Connector contact# 12 - DB5	Ground	83.00	90.80	7.80		Max. Maximum	98.50
Connector contact# 14 - DB6	Ground	83.40	90.50	7.10		Total Delta	16.60
Connector contact# 16 - DB7	Ground	84.30	90.60	6.30			
Connector contact# 18 - DBP	Ground	82.60	90.60	8.00		Data Lines Delta	
Connector contact# 32 - ATN	Ground	87.90	97.00	9.10			
Connector contact# 36 - BSY	Ground	88.70	98.50	9.80		Ave. Min.	83.26
Connector contact# 38 - ACK	Ground	86.70	97.20	10.50		Ave. Max.	91.20
Connector contact# 40 - RST	Ground	88.00	96.70	8.70		Min. Minimum	82.10
Connector contact# 42 - MSG	Ground	81.90	88.70	6.80		Max. Minimum	84.50
Connector contact# 44 - SEL	Ground	83.10	90.10	7.00		Min. Maximum	89.60
Connector contact# 46 - C/D	Ground	85.90	95.80	9.90		Max. Maximum	93.70
Connector contact# 48 - REQ	Ground	84.50	95.30	10.80		Total Delta	11.60
Connector contact# 50 - I/O	Ground	83.50	97.70	14.20			
						Req/Ack Lines Delta	
						Ave. Min.	85.60
						Ave. Max.	96.25
						Min. Minimum	84.50
						Max. Minimum	86.70
						Min. Maximum	95.30
						Max. Maximum	97.20
						Total Delta	12.70



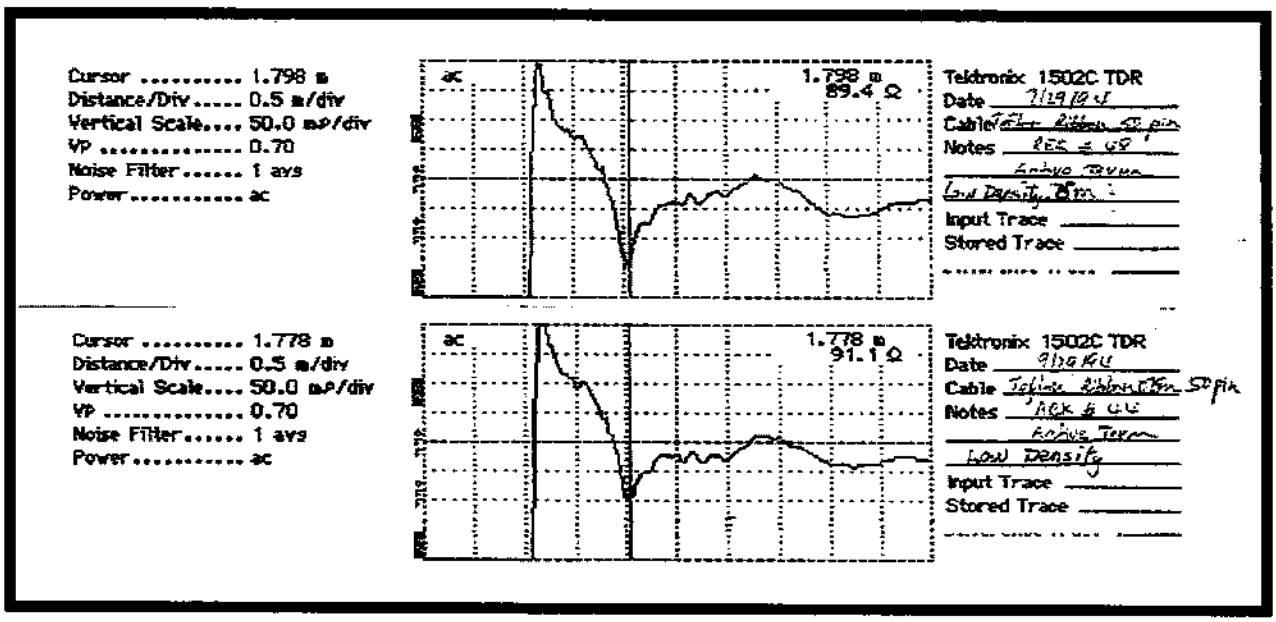
1.5 Meter Normal Density Teflon Ribbon Active Terminated

Cable Name:Teflon Ribbon	Length: 1.5 m.	Term: Methode Active				Summary	
Low density 50 Conductor							
Test Cases - Single-Ended Primary Bus		Min	Max	Delta		All Lines Delta	
Measure between	and						
Connector contact# 2 - DB0	Ground	92.90	105.70	12.80		Ave. Min.	106.41
Connector contact# 4 - DB1	Ground	93.40	108.90	15.50		Ave. Max.	120.36
Connector contact# 6 - DB2	Ground	95.10	106.10	11.00		Min. Minimum	92.90
Connector contact# 8 - DB3	Ground	96.40	105.90	9.50		Max. Minimum	134.50
Connector contact# 10 - DB4	Ground	97.20	105.10	7.90		Min. Maximum	104.40
Connector contact# 12 - DB5	Ground	95.90	104.40	8.50		Max. Maximum	163.20
Connector contact# 14 - DB6	Ground	108.70	121.70	13.00		Total Delta	70.30
Connector contact# 16 - DB7	Ground	118.30	144.10	25.80			
Connector contact# 18 - DBP	Ground	106.70	118.40	11.70		Data Lines Delta	
Connector contact# 32 - ATN	Ground	134.50	163.20	28.70			
Connector contact# 36 - BSY	Ground	132.60	156.10	23.50		Ave. Min.	100.51
Connector contact# 38 - ACK	Ground	110.80	125.70	14.90		Ave. Max.	113.37
Connector contact# 40 - RST	Ground	104.70	114.40	9.70		Min. Minimum	92.90
Connector contact# 42 - MSG	Ground	105.40	114.20	8.80		Max. Minimum	118.30
Connector contact# 44 - SEL	Ground	99.70	110.40	10.70		Min. Maximum	104.40
Connector contact# 46 - C/D	Ground	99.70	110.60	10.90		Max. Maximum	144.10
Connector contact# 48 - REQ	Ground	105.50	116.70	11.20		Total Delta	51.20
Connector contact# 50 - I/O	Ground	117.90	134.90	17.00			
						Req/Ack Lines Delta	
						Ave. Min.	108.15
						Ave. Max.	121.20
						Min. Minimum	105.50
						Max. Minimum	110.80
						Min. Maximum	116.70
						Max. Maximum	125.70
						Total Delta	20.20



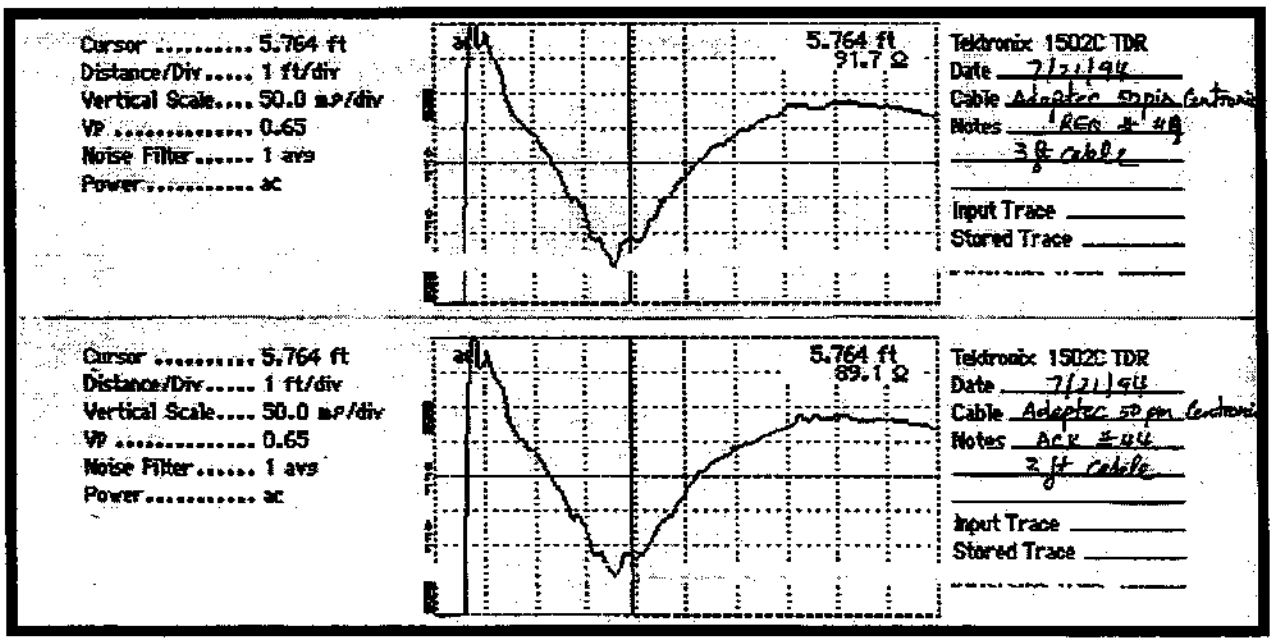
0 .75 Meter Normal Density Teflon Ribbon Active Terminated

Cable Name:Teflon Ribbon	Length: .75 m.	Term: Methode Active				Summary	
Low density 50 Conductor							
Test Cases - Single-Ended Primary Bus		Min	Max	Delta		All Lines Delta	
Measure between	and						
Connector contact# 2 - DB0	Ground	105.80	114.90	9.10		Ave. Min.	101.08
Connector contact# 4 - DB1	Ground	105.90	113.30	7.40		Ave. Max.	118.68
Connector contact# 6 - DB2	Ground	104.20	112.10	7.90		Min. Minimum	95.20
Connector contact# 8 - DB3	Ground	104.60	114.50	9.90		Max. Minimum	108.40
Connector contact# 10 - DB4	Ground	103.60	114.80	11.20		Min. Maximum	112.10
Connector contact# 12 - DB5	Ground	104.30	113.50	9.20		Max. Maximum	125.80
Connector contact# 14 - DB6	Ground	101.50	122.40	20.90		Total Delta	30.60
Connector contact# 16 - DB7	Ground	95.20	125.80	30.60			
Connector contact# 18 - DBP	Ground	100.50	121.70	21.20		Data Lines Delta	
Connector contact# 32 - ATN	Ground	97.30	120.50	23.20			
Connector contact# 36 - BSY	Ground	98.80	121.50	22.70		Ave. Min.	102.84
Connector contact# 38 - ACK	Ground	99.10	119.10	20.00		Ave. Max.	117.00
Connector contact# 40 - RST	Ground	96.80	118.40	21.60		Min. Minimum	95.20
Connector contact# 42 - MSG	Ground	96.70	120.20	23.50		Max. Minimum	105.90
Connector contact# 44 - SEL	Ground	97.30	119.80	22.50		Min. Maximum	112.10
Connector contact# 46 - C/D	Ground	98.70	121.00	22.30		Max. Maximum	125.80
Connector contact# 48 - REQ	Ground	100.70	120.20	19.50		Total Delta	30.60
Connector contact# 50 - I/O	Ground	108.40	122.50	14.10			
						Req/Ack Lines Delta	
						Ave. Min.	99.90
						Ave. Max.	119.65
						Min. Minimum	99.10
						Max. Minimum	100.70
						Min. Maximum	119.10
						Max. Maximum	120.20
						Total Delta	21.10



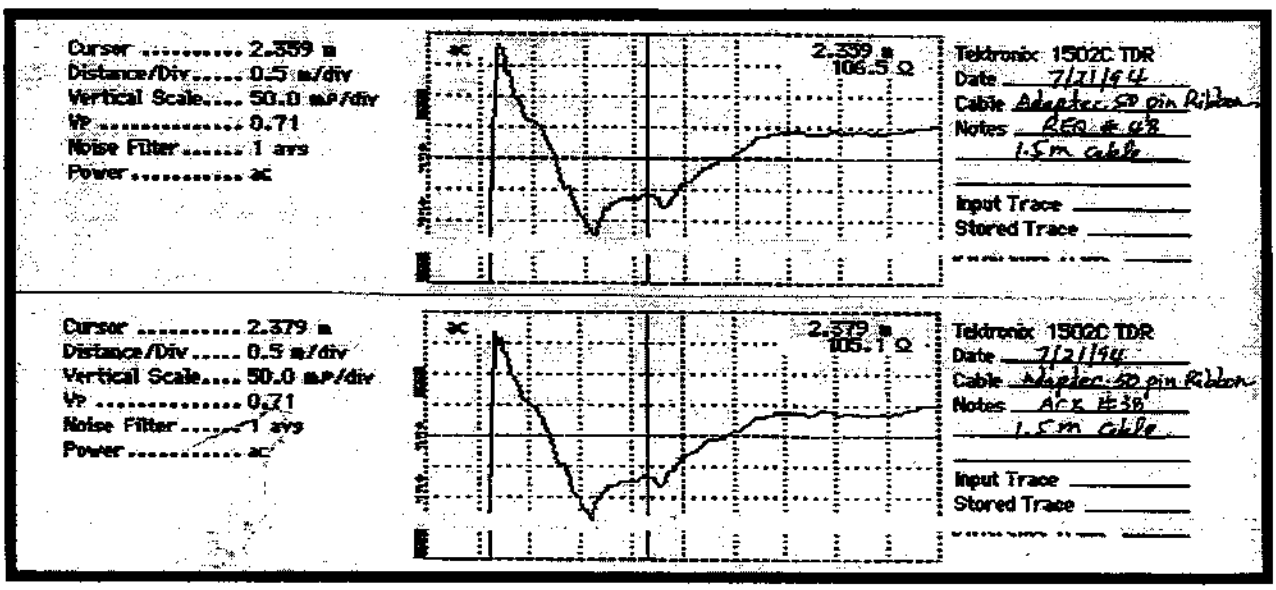
External Centronics 3 Ft. Single-Ended Active Terminated

Cable Name:Adaptec External	Length: 3 ft.	Term: Methode Active				Summary	
50 Conductor							
Test Cases - Single-Ended Primary Bus		Min	Max	Delta		All Lines Delta	
Measure between	and						
Connector contact# 2 - DB0	Ground	81.30	88.40	7.10		Ave. Min.	83.02
Connector contact# 4 - DB1	Ground	81.20	88.80	7.60		Ave. Max.	89.08
Connector contact# 6 - DB2	Ground	81.90	88.00	6.10		Min. Minimum	78.50
Connector contact# 8 - DB3	Ground	81.70	87.10	5.40		Max. Minimum	86.40
Connector contact# 10 - DB4	Ground	81.60	87.00	5.40		Min. Maximum	84.10
Connector contact# 12 - DB5	Ground	80.90	86.90	6.00		Max. Maximum	92.20
Connector contact# 14 - DB6	Ground	80.50	86.40	5.90		Total Delta	13.70
Connector contact# 16 - DB7	Ground	79.60	86.30	6.70			
Connector contact# 18 - DBP	Ground	78.50	84.10	5.60		Data Lines Delta	
Connector contact# 32 - ATN	Ground	85.20	90.70	5.50			
Connector contact# 36 - BSY	Ground	84.80	90.80	6.00		Ave. Min.	80.80
Connector contact# 38 - ACK	Ground	86.10	91.00	4.90		Ave. Max.	87.00
Connector contact# 40 - RST	Ground	84.90	92.20	7.30		Min. Minimum	78.50
Connector contact# 42 - MSG	Ground	84.10	90.70	6.60		Max. Minimum	81.90
Connector contact# 44 - SEL	Ground	84.60	90.60	6.00		Min. Maximum	84.10
Connector contact# 46 - C/D	Ground	84.80	90.80	6.00		Max. Maximum	88.80
Connector contact# 48 - REQ	Ground	86.40	91.90	5.50		Total Delta	10.30
Connector contact# 50 - I/O	Ground	86.20	91.80	5.60			
						Req/Ack Lines Delta	
						Ave. Min.	86.25
						Ave. Max.	91.45
						Min. Minimum	86.10
						Max. Minimum	86.40
						Min. Maximum	91.00
						Max. Maximum	91.90
						Total Delta	5.80



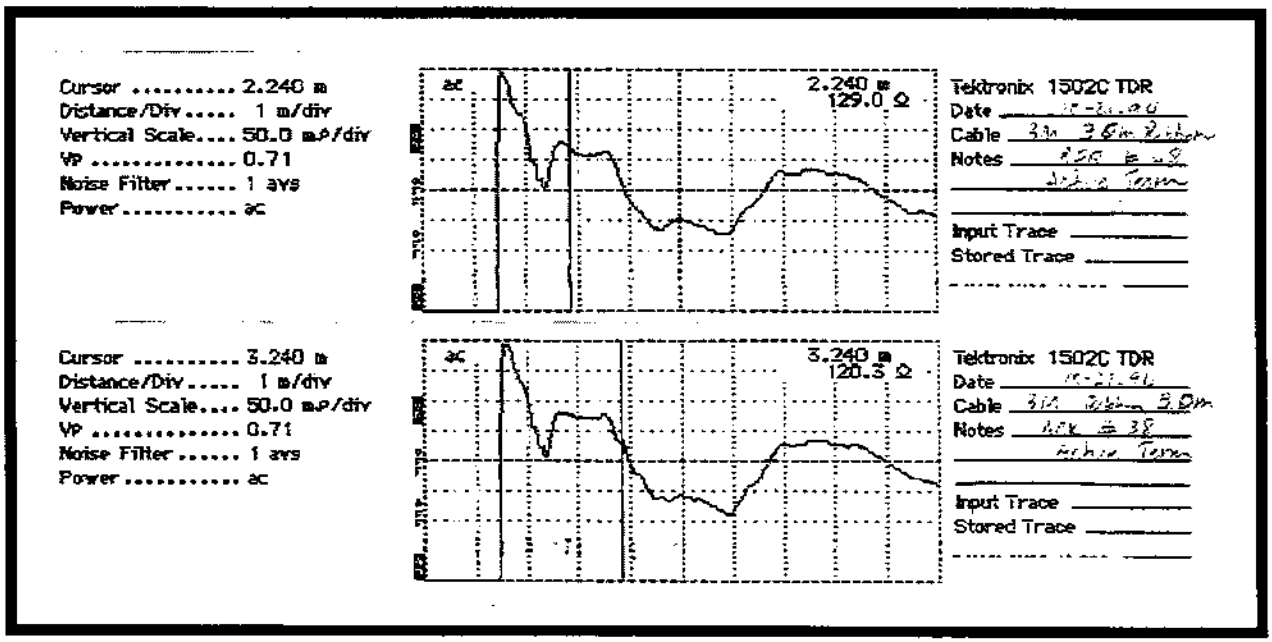
1.5 Meter Ribbon Single-Ended Active Terminated

Cable Name:Adaptec ribbon	Length:1.5 m	Term: Methode Active				Summary	
50 Conductor							
Test Cases - Single-Ended Primary Bus		Min	Max	Delta		All Lines Delta	
Measure between	and						
Connector contact# 2 - DB0	Ground	93.60	102.90	9.30		Ave. Min.	104.08
Connector contact# 4 - DB1	Ground	90.80	102.40	11.60		Ave. Max.	119.49
Connector contact# 6 - DB2	Ground	91.80	105.30	13.50		Min. Minimum	90.60
Connector contact# 8 - DB3	Ground	91.30	105.20	13.90		Max. Minimum	154.30
Connector contact# 10 - DB4	Ground	90.60	103.70	13.10		Min. Maximum	102.40
Connector contact# 12 - DB5	Ground	93.60	105.10	11.50		Max. Maximum	179.90
Connector contact# 14 - DB6	Ground	115.30	127.90	12.60		Total Delta	89.30
Connector contact# 16 - DB7	Ground	137.00	156.40	19.40			
Connector contact# 18 - DBP	Ground	110.10	127.90	17.80		Data Lines Delta	
Connector contact# 32 - ATN	Ground	154.30	179.90	25.60			
Connector contact# 36 - BSY	Ground	109.40	129.00	19.60		Ave. Min.	101.57
Connector contact# 38 - ACK	Ground	90.70	105.50	14.80		Ave. Max.	115.20
Connector contact# 40 - RST	Ground	106.10	123.50	17.40		Min. Minimum	90.60
Connector contact# 42 - MSG	Ground	106.70	124.30	17.60		Max. Minimum	137.00
Connector contact# 44 - SEL	Ground	91.10	105.10	14.00		Min. Maximum	102.40
Connector contact# 46 - C/D	Ground	91.30	105.40	14.10		Max. Maximum	156.40
Connector contact# 48 - REQ	Ground	92.60	106.70	14.10		Total Delta	65.80
Connector contact# 50 - I/O	Ground	117.20	134.60	17.40			
						Req/Ack Lines Delta	
						Ave. Min.	91.65
						Ave. Max.	106.10
						Min. Minimum	90.70
						Max. Minimum	92.60
						Min. Maximum	105.50
						Max. Maximum	106.70
						Total Delta	16.00



3 Meter Ribbon Single-Ended Active Terminated

Cable Name:3M Ribbon	Length: 3 m.	Term: Methode Active					Summary	
50 Conductor								
Test Cases - Single-Ended Primary Bus		**Min**	**Max**	**Delta**			**All Lines Delta**	
Measure between	and							
Connector contact# 2 - DB0	Ground	102.40	108.30	5.90			Ave. Min.	112.93
Connector contact# 4 - DB1	Ground	98.50	105.80	7.30			Ave. Max.	128.06
Connector contact# 6 - DB2	Ground	98.20	106.50	8.30			Min. Minimum	97.60
Connector contact# 8 - DB3	Ground	97.60	105.10	7.50			Max. Minimum	155.00
Connector contact# 10 - DB4	Ground	98.50	107.20	8.70			Min. Maximum	105.10
Connector contact# 12 - DB5	Ground	98.90	106.20	7.30			Max. Maximum	200.00
Connector contact# 14 - DB6	Ground	113.90	129.90	16.00			Total Delta	102.40
Connector contact# 16 - DB7	Ground	125.00	164.40	39.40				
Connector contact# 18 - DBP	Ground	113.40	131.70	18.30			**Data Lines Delta**	
Connector contact# 32 - ATN	Ground	155.00	200.00	45.00				
Connector contact# 36 - BSY	Ground	146.50	180.30	33.80			Ave. Min.	105.16
Connector contact# 38 - ACK	Ground	120.60	133.90	13.30			Ave. Max.	118.34
Connector contact# 40 - RST	Ground	103.20	112.00	8.80			Min. Minimum	97.60
Connector contact# 42 - MSG	Ground	102.60	112.50	9.90			Max. Minimum	125.00
Connector contact# 44 - SEL	Ground	99.80	107.40	7.60			Min. Maximum	105.10
Connector contact# 46 - C/D	Ground	110.60	127.00	16.40			Max. Maximum	164.40
Connector contact# 48 - REQ	Ground	116.20	128.30	12.10			Total Delta	66.80
Connector contact# 50 - I/O	Ground	131.90	138.50	6.60				
							Req/Ack Lines Delta	
							Ave. Min.	118.40
							Ave. Max.	131.10
							Min. Minimum	116.20
							Max. Minimum	120.60
							Min. Maximum	128.30
							Max. Maximum	133.90
							Total Delta	17.70



Appendix G Nodal Capacitance vs. Frequency

In this appendix the nodal capacitance of all the drives that were used in the study has been measured over the frequency range of 1 MHz to 20 MHz. Other peripherals that were not used in the experiment were also measured to get a sense of the capacitance loading in today's environment. All drives tested were off-the-shelf drives. At the time of this study no Fast-20 drives were available although some became available at the end of the study they were not included here.

The last column here presents the percentage of change of each device measured over the frequency range. Please note the extend of the change for the external enclosures. Refer to the section 4 of the main paper for further explanation of this rather large delta.

Target Node Capacitance Table

			1 MHz			10 MHz			20 MHz			%Delta		
	Device	Req	Ack	Data Lines	Req	Ack	Data Lines	Req	Ack	Data Lines	Req	Ack	Data Lines
	Hard Drives												
1	Brand A #1	20.60	20.20	17.70	18.79	18.41	15.88	20.00	19.60	16.88	6.44	6.46	6.30
2	Brand A #2	17.48	16.98	14.69	16.66	16.49	14.12	17.20	16.77	14.24	3.24	1.70	0.85
3	Brand A #3	17.39	16.80	14.50	16.82	16.30	13.95	17.13	16.60	14.11	1.84	1.84	1.15
4	Brand B	15.60	14.83	14.28	15.95	15.13	14.48	16.50	15.66	15.00	3.45	3.50	3.59
5	Brand C	14.67	14.50	12.01	14.69	14.62	12.13	14.93	14.93	12.27	1.63	2.12	1.15
6	Brand D	23.95	19.45	14.60	23.22	19.11	14.72	23.95	19.34	15.50	3.14	1.20	5.30
	Internal CD-ROM												
7	Brand E	14.80	14.78	13.64	14.73	14.77	13.59	15.83	16.06	14.69	7.47	8.73	8.0
8	Brand F	12.79	11.80	10.45	12.68	11.65	10.39	13.51	12.32	10.93	6.55	5.75	5.20
9	Brand G	28.28	27.10	26.30	26.83	25.64	26.41	27.19	26.83	29.28	1.34	4.64	10.87
10	Brand H	14.70	7.80	18.08	14.43	7.82	17.98	14.53	7.86	18.32	0.69	0.51	1.89
11	Brand J	35.08	41.35	51.68	35.39	41.95	52.48	38.53	45.68	58.10	8.87	8.89	10.71
12	Brand K	25.80	24.30	25.30	24.03	23.87	24.40	24.88	24.52	25.37	3.54	2.72	3.98
13	Brand L	13.04	11.90	10.35	13.14	11.98	10.46	13.45	12.15	10.61	2.36	1.42	1.43
	External CD-ROM												
14	Brand M	29.27	30.09	29.61	29.22	30.14	29.80	33.72	34.74	32.95	15.40	15.26	10.57
15	Brand N	42.50	42.75	42.75	45.24	45.50	44.93	56.82	57.10	55.65	25.60	25.49	23.86
16	Brand P	38.27	40.88	37.32	41.24	43.83	39.21	59.00	65.62	55.44	43.06	49.71	41.39