TEXAS INSTRUMENTS

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TO: John Lohmeyer, Chairman, X3T9.2

FROM: Bill Spence, TI

SUBJECT: S/E Reliability Enhancements

As requested in today's Working Group meeting, the following summary of the last year's developments in single-ended SCSI reliability is presented, with emphasis on the results of the cable rump meeting which followed the X3T9.2 Plenary meeting at Ft. Lauderdale, 16 Oct 1990.

Note: Rev 1 makes minor corrections to the original document.

S..MARY

The activities of the X3T9.2 cable workers over the past year have developed six approaches to enhancing S/E reliability. Nos. 1 and 2 are probably vital; nos. 3 and 4 are powerful medicine also.

1. Utilize transmission-grade cables of 28 AWG minimum wire size.
2. Control the cable assy pinouts so as to isolate -REQ and -ACK from the data and parity lines.
3. Utilize the 110-ohm regulated terminator.
4. Utilize positive deassertion of -REQ and -ACK.
5. Insure 0.4 v minimum hysteresis, centered between the asserted and deasserted signal levels, in the receivers.
6. Employ glitch filtering in the receivers.

Assuming that each of these approaches might move one 20% of the way to perfection in S/E operation, it would appear that one can improve one's operations to 120% of perfection. Probably few system integrators, however, will find it practical to implement all six approaches. The good news from studying all the reports to date is that it seems likely that implementing that selection of these approaches which one finds practical is pretty likely to result in quite acceptable performance.

These reliability enhancements are presented in more detail below and more or s in the order of ease of implementation.

CABLE--BACKGROUND

I have recently been told of a S/E SCSI system which works with high reliabi y over a total bus length of 80 feet--5 or 6 host adapters all accessing a disk. The bus comprises unshielded ribbon cable. Names are withheld to protect the guilty from being smashed by the FCC. But the moral is that if you build a S/E SCSI system of cables of reasonably high impedance and low crosstalk, the purely pragmatic 6-meter (20-foot) overall length limit of the standard can be disregarded.

The key to SCSI bus reliability in large, spread-out systems seems to be to respect the fact that the bus is a transmission-line system; not just an interconnection system. S/E transmission lines ideally utilize coaxial cables. Denis Springer of 3M Austin has developed an experimental SCSI cable which incorporates 25 quasi-coaxial cables by pleating foil around the conductors of a specially-fabricated ribbon cable, achieving a S/E characteristic impedance of 93 ohms. 3M refers to it as Pleated-Foil (PF) SCSI cable. We at TI set up a large system with cable assy's using this cable. The results, reported in my S/E Cable Test Report, X3T9.2/89-148, 1 Dec 1989, were beautiful--night and day above the waveforms observed with what had been traditional 25-pair cables in our usage. The total bus length was about 70 feet, with three 22' PF cable assy's interconnecting four boxes, within which the bus was daisy-chained using ordinary ribbon cable. The operation was synchronous.

3M's PF cable is somewhat bulky and inflexible compared to typical 25-pair round shielded cable. Gore and DuPont make shielded ribbon cables which achieve quasi-coaxial performance similar to the 3M PF cable, but they have much smaller dimensions and conceivably are not rugged enough for inter-cabinet service. ll three cables lack an overall shield which can be connected to chassis, enveloping the inner shield which carries circuit common, but they may be available in double-shield options. Partly for these reasons, and partly because of precedent, there continues to be considerable pressure to achieve acceptable S/E system operation using traditional round cable. The obvious question: can the beautiful results achieved with the PF cables be approximated with any type of the usual 25-twisted-pair round shiel cable. The answer: yes. Tests performed by Bob Snively and Vit Novak at Sun d Kurt Chan at HP Roseville indicated that some high-grade, reasonably high impedance cables currently available show great promise.

CABLE--EMPIRICAL APPROACH

It now seems clear that the requirements for round shielded 25-twisted-pair cable for SCSI S/E use include the following:

1. The conductor insulation must be a low-loss, low-dielectric-constant type such as polypropylene or high-density polyethylene--i.e., one of the polyolefins, not PVC.

2. The S/E characteristic impedance must be high, preferably more than 80 ohms. (When a cable sample is configured for S/E testing, with one conductor of each twisted pair as well as the outer shield grounded, the characteristic impedance typically is only 60-70% of the value spec'ed for the cable in differential operation.) S/E impedances of 90 and 100 ohms and more ca e obtained in special cables (e.g., with foamed insulations). These allow

noise margin improvements over 80 ohm cables but are unsuitable for some cable assy fabrication techniques. General purpose twisted-pair round shielded cables, suitable on the surface for SCSI service but not of signal transmission quality, have been measured with impedances as low as 45 ohms.

3. As one step toward the above objective, the wire diameter must not be larger than 28 AWG.

4. As another step toward the above objective, there must be a buffer layer of dielectric between the outer layer of twisted pairs and the outer shield.

5. The uniformity of insulation extrusion, of pair twist, of cable construction must all be of a high order.

We at TI have set up test systems with a SCSI host and 7 disks in 4 boxes interconnected by a set of three 20-foot shielded cable assy's--total bus length approximately 70 feet, operated both synchronously and asynchronously. With a set of Madison Spec 4099 cable assy's (there is a CSA-listed equivalent, Spec 4179), the results were reported in my S/E Cable Test Report No. 2, X3T9.2/90--124, 16 Aug 1990. With a set of Astro 52-107-C cable assy's, the results were reported in my S/E Cable Test Report No. 3, X3T9.2/90-157, 14 Oct 1990. Tests with other candidate cables will be performed and reported as cable assy's and testing time become available.

In the tests performed to date, the results have not quite measured up to the 3M PFS cables in height of rise of the released (deasserted) line, corresponding to their somewhat lower characteristic impedance, but in all other respects they performed remarkably similarly. It should be noted that these cable assy's incorporate the isolation of the -REQ and -ACK lines which is discussed in the second following section below. Again, the systems under test performed faultlessly over many hours of operation, at total bus lengths over 3 times the S/E limit in the standard, with a full load of 8 devices on the bus, synchronously as well as asynchronously.

CABLE--ANALYTICAL APPROACH

Jim Fiala of 3M's cable lab in Austin, along with others in the labs of various cable manufacturers, has performed a lot of cable characterization testing for the committee. In addition, in his Rough Draft of Cable Test Parameters, Test Procedures, and Test Philosophies (wow!), X3T9.2/90-134, 24 Aug 1990, Jim proposed a set of of parametric requirements for SCSI cables, along with test methods, etc. Many of them are unexceptional measured against popular cable specs. Empirical evidence as well as analysis suggest that crucial parameters are S/E Impedance, Rise-time Degredation, and Square-wave Voltage Attenuation. S/E Capacitance and Inductance are important mainly as they contribute to establishing the S/E Impedance. Rise-time degredation and square-wave voltage attenuation are not, unfortunately, commonly spec'ed cable parameters. They may be regarded, however, as the digital equivalents of a transmission loss vs frequency plot. Continuing efforts are going into characterizing the various candidate cable types for these parameters to further establish their relevance. The recommended limits of the above parameters are as follows:

Rise-time degredation	< 1 ns/20 ft
Square-wave voltage attenuation	< 15%/20 ft
Characteristic impedance	> 80 ohms

ISOLATION OF -REQ AND -ACK

In some of the testing reported by Jim Fiala and Kurt Chan, it appears that at the impedances and frequencies of the SCSI bus, crosstalk is predominately an inductive phenomenon. It appears that it may vary with the way the twists of adjacent pairs lie with respect to each other, but it seems impossible to eliminate it to any significant degree with respect to adjacent pairs. The nature of data transmission over a SCSI bus, however, is that there is adequate time for crosstalk-induced noise in data and parity conductors to settle out before they are clocked by a -REQ or -ACK line. Bob Snively and crew at Sun developed the concept that a key secret of good S/E SCSI cables may be to isolate the -REQ and -ACK lines in the core of the cable assy, surround them with GROUND, TERMPWR, -RST, and other lines which are quiescent during data transfer, and confine the data and parity lines to the outer layer of the cable assy. This concept apparently was validated in the TI tests reported above, and it has been tentatively adopted for SCSI-3 in my proposal, Pinout Control of SCSI Round Cable Assemblies, X3T9.2/90-160, 15 Oct 1990, modified by the committee to mandatory form.

110-OHM TERMINATORS

A key contributor to unsatisfactory S/E bus perfomance is inadequate rise of a just released (deasserted) line. As presented in my S/E Cable Best-Case Analysis, X3T9.2/90-123R1, this is controlled by the product of the current fed into the asserted line by the terminators and the S/E characteristic impedance of the line. Line impedance has been discussed above. The current delivered by the standard Alternative 1 S/E SCSI terminator is well below the maximum allowed by the drivers and the standard because of the 132-ohm output impedance of such terminators. If the TERMPWR voltage sags, the delivered current falls further still. In a brilliant contribution, Paul Boulay of LMI-OSD brought the current up to the maximum allowed level and fixed it there by using precision 110-ohm output resistors backed by a precision regulated 2.85 voltage source (X3T9.2/89-004R2, 21 Aug 1989), thus presenting the SCSI-2 standard with its Alternative 2 S/E SCSI terminator. Use of this terminator is equivalent to an increase of about 15 ohms in cable characteristic impedance. For external mounting at an end of a SCSI bus, these terminators are available from Methode, Fujitsu, and DDK. Even applied at one end of a bus only, they add significantly to its noise margin.

From a classical impedance-matching viewpoint, it can be seen that combining external shielded cables at 80 ohms or above, internal PVC ribbon cables at a little over 100 ohms, and 110-ohm terminators results in a pretty well matched bus system. This match is degraded, however, if the ribbon cable is allowed to lie against a metal surface for a significant distance--i.e., 0.1 meter (four inches) or more. Minimizing such breaks in continuity and minimizing stub lengths are to sub-objectives to be striven for.

Parenthetically, it may be noted that the same cable assys in differential mode exhibit impedances in the 130-ohm vicinity and are reasonably well matched with the 122-ohm standard differential terminator. Thus the paths to goodness in SCSI cables follow the same roadbed in both S/E and differential.

ACTIVE DEASSERTION

Essentially instantaneous voltage rise at a released end of a transmission line can be achieved by a resistive pullup. The capacity of the line is buffered by the line's inductance, and the result is a resistive input impedance which can respond instantaneously in a resistive divider. In the real world, however, lump capacitances exist in the form of stubs, bulkhead connectors, and other elements, and the result is that observed voltage rises may be slower as well as smaller than desired. John Lohmeyer has speculated that one reason differential SCSI performs so well may be that typical differential line drivers actively deassert the lines. Kurt Chan has applied the same technique to single-ended. In his REQ/ACK Signal Quality and Fast Single-ended, X3T9.2/90-159R1, 17 Oct 1990, he presents analytical results showing greatly improved signal rises resulting from adding 3-state totem-pole outputs. One proposal is that a new generation of SCSI drivers and protocol-chip-mounted drivers incorporate such outputs for the -REQ and -ACK lines. David Steele of NCR Colorado Springs points out, however, that super-fast transition times may generate more ringing and other noise.

INCREASED HYSTERESIS--TRANSITION LEVELS

In the same report referenced above, Kurt Chan notes that 0.4 volts or more hysteresis in the receivers adds significantly to the noise margin provided by the 0.2 volts minimum hysteresis prescribed in the standard. He proposes that the standard figure be increased to 0.4 volts, but he also indicates that most modern receivers already exhibit at least 0.4 volts hysteresis.

To be maximally effective, the span of the hysteresis must be pretty well centered in the voltage range between the asserted and deasserted signal levels. Generally, this means centered in the vicinity of 1.4 to 1.5 volts. Many widely used SCSI receivers meet this requirement, but not all.

GLITCH FILTERING

Harlan Andrews of Apple has reported on finding that systems which were reliable became less so when receivers with faster silicon architecture were introduced. He has moved to counter this effect with explicit glitch filtering in the silicon, so that transition pairs spaced closely together are not recognized.