X3T9.2/93-052

1/14/93,4:48 PM

To: SPI Working Group, ANSI X3T9.3

Copy: Bill Spence, Chairman
Larry Lamers, Secretary

Sbjct: Test of differential drivers for SCSI

From: Kevin Gingerich, Texas Instruments

Ref: Suggested changes to Figure 8 (Differential driver test circuit) for SCSI-3 SPI document , John Goldie, National Semiconductor

Are all of the grounds of each SCSI device on a bus at the same potential energy at all times? This question needs answering before any specification of the test requirements for the differential interface circuits. If the answer is yes, then there is zero common-mode voltage on the signal wires and the differential buffers may be integrated with the CMOS controllers. If the answer is no, then the proposed test requirements in reference 2 does not accurately represent the electrical environment that can exist on the SCSI bus.

Point 4 of the referenced document states that the test circuit of figure 8 of X3T9.2/91-010R7 models a DC shift in the grounds and that assigning six ground wires in the SCSI cable will prevent it. Indeed, the six grounds will prevent low frequency ground shifts. However, they most likely will also create as many ground-loops with earth ground magnifying higher frequency inductive noise coupling with the outside world and inducing ac common-mode noise. The bus driver must absorb this noise energy in addition to driving the DC load presented by the differential SCSI bus. My experience has been that there will be installations with electromagnetic environments that will induce ground potential shifts. The probability as well as the magnitude of these shifts increases with cable length.

EIA RS-485(1983) defines the common-mode requirements for the bus as, "Generators and receivers conforming to this standard can operate with a common-mode voltage between -7 V and 7 V (instantaneous). The common-mode voltage is defined to be any uncompensated combination of generator-receiver ground potential difference and longitudinally coupled peak noise voltage measured between the receiver circuit ground and cable with the generator ends of the cable short circuited to ground, plus the generator offset voltage (V_{OS})."

This standard is complied with, in part, by drivers with a minimum of 60 mA source and sink current capability. This number comes from driving a differential load of 60 Ω and 32 receiver inputs at 12 kΩ each. The differential signal output current would be

$$Io = 1.5V \times \left(\frac{1}{0.06k\Omega} + \frac{1}{12k\Omega} \times 32 \right) = 29mA .$$

With ground potential shifts of -7 V to 7 V and 5 V of driver common-mode output, the driver must drive the load over a voltage range of -7 V to 12 V. The maximum common-mode output current from or to 32 receivers is then

$$Ioc = 12V \times \left(\frac{1}{12k\Omega} \times 32\right) = 32mA.$$

The SCSI load changes the termination and bias network of the baseline RS-485 load while relaxing the minimum differential output voltage to 1 V. The unbalancing of the load affects the + and - signal unequally resulting in two equations for the output current. Using the same analysis on the proposed differential test circuit of figure 4 from the referenced document, the signal output current requirements are

$$Io_- = 1V \times \frac{1}{0.075k\Omega} + 4.3V \times \frac{1}{0.165k\Omega} = 39.3mA \qquad \text{for assertion and}$$

$$Io_- = -1V \times \frac{1}{0.075k\Omega} + 4.3V \times \frac{1}{0.165k\Omega} - 1V \times \left(\frac{1}{12k\Omega} \times n\right) = 12.7 - \frac{n}{12}mA$$

for negation and where n = the number of receivers. For the + line

$$Io_+ = -1V \times \frac{1}{0.075k\Omega} - 1V \times \frac{1}{0.165k\Omega} - 1V \times \left(\frac{1}{12k\Omega} \times n\right) = -19.4 - \frac{n}{12}mA$$

for assertion and

$$Io_+ = 1V \times \frac{1}{0.075k\Omega} = 13.3mA \text{ for negation.}$$

As can be seen above, the highest driver output current demands are for I_{O-} and I_{O+} when asserted .

To model ground potential shift in the proposed test circuit add a voltage source between the generator ground and the test load. The contribution from the common-mode voltage for either output is then

$$Ioc = -Voc \times \left(\frac{1}{0.165k\Omega} + n \times \frac{1}{12k\Omega}\right).$$

Summing the worst load and common-mode currents,

$$I_{OUT-} = Io_- + Ioc = 39.3 - VCM \times \left(\frac{1}{.165} + \frac{n}{12}\right) \text{ and}$$

$$I_{OUT+} = Io_+ + Ioc = -19.4 - VCM \times \left(\frac{1}{.165} + \frac{n}{12}\right).$$

93-052

1/14/93,4:48 PM

From the equations above, a table can be constructed showing the relationships of driver output currents, the maximum number of nodes on the bus, the allowable common-mode voltage range and ground potential shifts across the bus. V_{GND} is calculated assuming the RS-485 maximum common-mode output voltage of -1 V to 3 V.

Max Driver Current	Number of Nodes	V_{CM} min	V_{CM} max	$\|V_{GND}\|$
60 mA	8 V	-3.1 V	6.0 V	2.1 V
60	16	-2.8	5.5	1.8
60	32	-2.4	4.7	1.4
70	8	-4.6	7.5	3.6
70	16	-4.2	6.8	3.2
70	32	-3.5	5.8	2.5
80	8	-6.1	9.0	5.1
80	16	-5.5	8.2	4.5
80	32	-4.7	6.9	3.7
90	8	-7.5	10.5	6.5
90	16	-6.9	9.5	5.9
90	32	-5.8	8.1	4.8
100	8	-9.0	12.0	8.0
100	16	-8.2	10.9	7.2
100	32	-7.0	9.2	6.0

Table 1. Allowable common-mode voltage range of a SCSI bus for various combinations of driver output currents and nodes on the bus.

Since Differential SCSI does not appear to be broken, does it need fixing? There are several possible reasons that problems have not surfaced with Differential SCSI. Most RS-485 drivers are over-designed and can typically deliver more than 60 mA, SCSI systems are not experiencing these worst-case loading or common-mode conditions, and the system impact may not be readily visible to the users.

The committee needs to define the system requirement for usable common-mode voltage range and the driver requirements should follow or accept the liability of a specification compliant bus that doesn't work. Texas Instruments agrees to provide RS-485 devices with the additional requirements of the Differential Test Circuit (figure 8) from SPI R7 or 86 mA drivers.

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