TEXAS INSTRUMENTS

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MEMORANDUM -- 16 Aug 1991 -- Revised 9 Sep 1991

TO: John Lohmeyer, Chairman, X3T9.2

FROM: Bill Spence, TI

SUBJECT: Comparison of S/E Cable/Terminator Options for SCSI-3

Note: Rev 1 adds the SLIM terminator and the V-I Characteristics concept to the original paper.

For our future deliberations as to what cable/terminator options should be set forth in the Standard for the single-ended bus, the following rundown is offered. It recognizes the following principles:

1. Most critical is the shape of the signal transitions on the -REQ and -ACK lines. It is during these transitions that double-clocking may occur and corrupt the data transfer operation. Proper SCSI signals will have swift, monotonic transitions from well above 2.0 v to well below 0.8 v, and vice-versa, at the receivers.

2. The objective of the physical bus design is that proper signals be presented to signal receivers. In a classic signal generator/receiver model, equality of the source, cable, and receiver impedances is optimum for delivering proper signals. A single-ended SCSI bus is very different from the classic model, however, and matched impedance is not optimum. Note: Line impedance must be specified in single-ended mode.

3. The choice of cable impedance and terminator characteristics is dictated by the balance of two opposing constraints:
   - The current available to an asserted line from the terminators must never exceed 44.2 ma and must be small enough in all cases not to impede an adequate downward step of signal voltage when a low-going signal is received from the far end of the line (Ref: X3T9.2/90-185R1).
   - The current available to an asserted line from the terminators must be great enough in all cases to produce an adequate upward step of signal voltage when the line is released (Ref: X3T9.2/90-123R1). (Note: This constraint is of negligible importance with active-negation drivers.)

   With linear terminators and release-on-negation drivers, optimum design is achieved with the cable impedance/terminator impedance ratio near to 0.75. With active negation drivers, the ratio should be lower. With non-linear terminators, impedance gives way to voltage and current requirements as set forth in 1 and 2 above.

4. Excessive stub length and loading and excessive driver slew rate can introduce damaging signal distortions and noise transients into a bus. Non-linear terminator circuits may be beneficial in such cases. In fact,

the most basic statement of the terminator function points directly to non-linear implementations.

OPTIONS

There follows below a listing of terminator alternatives, with their description, characteristics, and proper application. Note: the TERMPWR line must be bypassed at or quite near to each terminator.

1. The original 220/330 ohm terminator, as described in 4.4.1.(1) of SCSI-2. Impedance: 132 ohms. Open-circuit voltage and short-circuit current vary with Vterm. For the maximum legal Vterm, 4.95 v (assuming the mandatory Schottky diode is present), the open-circuit voltage is nominally 2.97 v; for a more typical 4.6 v it is 2.76 v. Corresponding currents-into-0.5-v are nominally 18.7 ma and 17.1 ma. The precision of the resistors in the device controls the precision of these quantities. As it turns out, practically a perfect choice for buses comprising common 28 AWG, 0.050 pitch, PVC ribbon cable, with impedance a little over 100 ohms. For buses comprising principally round, shielded, twisted-pair cables with considerably lower impedance, the deficiency in delivered current, compared to the allowed 22.4 ma, leads to sharply reduced noise margin for negated signals.

2. A modified original terminator, with 1% resistances of 187 and 267 ohms. Impedance: 110 ohms. Again, open-circuit voltage and short-circuit current vary with Vterm. For Vterm = 4.95 v, the open-circuit voltage and current-into-0.5-v are 2.91 v and 21.9 ma. For Vterm = 4.6 v, they are 2.71 v and 20.0 ma. These resistances are chosen to provide the same 110 ohm impedance as the Boulay terminator (see 3 below) and to limit the current-into-0.5-v to 22.4 ma under worst-case conditions. With Vterm held at 4.85 v, this terminator performs identically to the Boulay terminator, without the expense and complication of the regulator. Compared to the original terminator, the 17% increase in currents gives a tremendous increase in noise margin for negated signals on buses comprising principally "standard" 28 AWG, polyolefin-insulated, round, shielded, twisted-pair cables with impedances of approximately 80 ohms. Equally superior with 0.025 pitch PVC ribbon cables, with impedances from 85 ohms down, as used with the high-density connectors introduced in SCSI-2.

3. The Boulay terminator, as described in Figure 4-9, Alternative 2, ignoring Note 2, of SCSI-2. Impedance: 110 ohms. Performance independent of Vterm down to Vterm = 4.1 v. Open-circuit voltage = 2.85 v. Current-into-0.5-v = 21.4 ma. All the benefits of the modified original terminator in 2 above plus independence of Vterm. Commercially available in several forms from several sources. Note: the advent of active negation drivers into the S/E SCSI environment may require a maodification of the original Boulay design. The regulator should be able to sink as well as source current so as to prevent the inner bus voltage from rising above 2.85 v and thus exceeding current limits.

4. A modified Boulay terminator, with the individual terminal resistors being 133 ohms instead of 110 ohms. Impedance 133 ohms. Performance independent of Vterm down to Vterm = 4.1 v. Open-circuit voltage + 2.85 v. Current-into-0.5-v = 17.7 ma. The same characteristics as the original terminator (see 1 above) plus independence of Vterm. Conceivable application: an unusually long bus comprising .050 pitch ribbon cable or some exotic twisted-pair cable with impedance in the 100 ohm range. The high cable impedance reduces the need for current, and the lower current permits better assertion of received signals.

5. The Trung Le terminator, as described in X3T9.2/91-37, -38. Briefly, each terminated line is fed current from Vterm through a 191 ohm resistor but is clamped from going above about 3.0 v or below 0 v. Non-bilaterally-linear circuit elements make the impedance undefined. Open-circuit voltage of about 3.0 v independent of Vterm, but current-into-0.5-v varies with Vterm: 23.2 ma (exceeds max allowed) for Vterm = 4.95 v, 21.5 ma for Vterm = 4.6 v. The non-linear elements permit the terminator to meet whatever conditions are required for the line to stabilize at the appropriate signal voltage without the delay for reflections to make round trips along the bus. The referenced document reports excellent performance under adverse circumstances, although the lack of current regulation would suggest impaired performance for severely low Vterm. Should be equally applicable to essentially all good quality cable types, although seemingly too much length of high-impedance (>100 ohms) line could lead to assertion signals too weak to override the vigorous pull-up current provided. In such case, obviously the 191 ohms resistance could be increased. The Trung Le terminator is commercially available in various forms from Aeronics as well as Methode. Note: one report has it that proper functioning requires using the exact diodes specified in Figure 6 of 91-37 and Figure 3 of 91-38 with no substitution.

6. The Methode SLIM terminator. Probably available in various characteristics. In one form documented by Methode, identical to the Boulay terminator except for the -REQ and -ACK terminals. In these two cases, the line is fed current from the 2.85 volt node through a 121 ohm resistor and is clamped to limits similar to the Trung Le terminator. Non-bilaterally-linear circuit elements make the impedance undefined. Performance independent of Vterm down to Vterm = 4.1 v. Open circuit voltage = 2.85 v. Current-into-0.5-v = 19.4 ma. With respect to the -REQ and -ACK lines, similar virtues to the Trung Le terminator, with the current-into-0.5 volts regulated, but regulated to the relatively low level of 19.4 ma.

7. A generalized non-linear termination approach. Non-linear circuit concepts may permit very straightforward approaches to satisfying the basic requirements of line temination. They all could be comprehended under the section 4.4.1.(2) of the SCSI-2 standard if specification (a) for characteristic impedance were deleted. Fundamentally, what is required of a terminator is that it deliver a proper maximum level of current into an asserted line and maintain a proper minimum level of voltage on a negated line.

TERMINATOR CHARACTERISTICS

The concept presented in Option 7 above is illustrated in Figure 1 below. The heavy solid line represents ideal terminator functioning. Whenever the line terminal at the terminator is below 2.85 volts, the terminator delivers 21.4 ma into the line, creating maximum drive to bring the line up when released without exceeding the driver rating when the line is asserted. (This target current is chosen to be 1 ma below the absolute maximum 22.4 ma.) Whenever the terminal voltage achieves 2.85 volts, whatever current the line requires to maintain that voltage is provided. (Note: these statements apply to the transient conditions following line switching; in the steady state, conventional line values obtain.) If the line terminal voltage tends to be pulled above 2.85 volts by ringing effects, it desirably should be clamped to provide immediately signal stability and reduce bus noise. If, on the other hand, it is pulled above 2.85 volts by active negation, the current drawn by the terminator from the line should be limited to a safe value, e.g., - 10 ma. Finally, if the line terminal voltage tends to be drawn below e.g. 0.15 volts by transient conditions, it should be clamped at that level. (Note: if desired, it can be posited that this terminator has an effective, or average, impedance of 110 ohms, since its characteristic passes through the endpoints of the Boulay terminator characteristic.

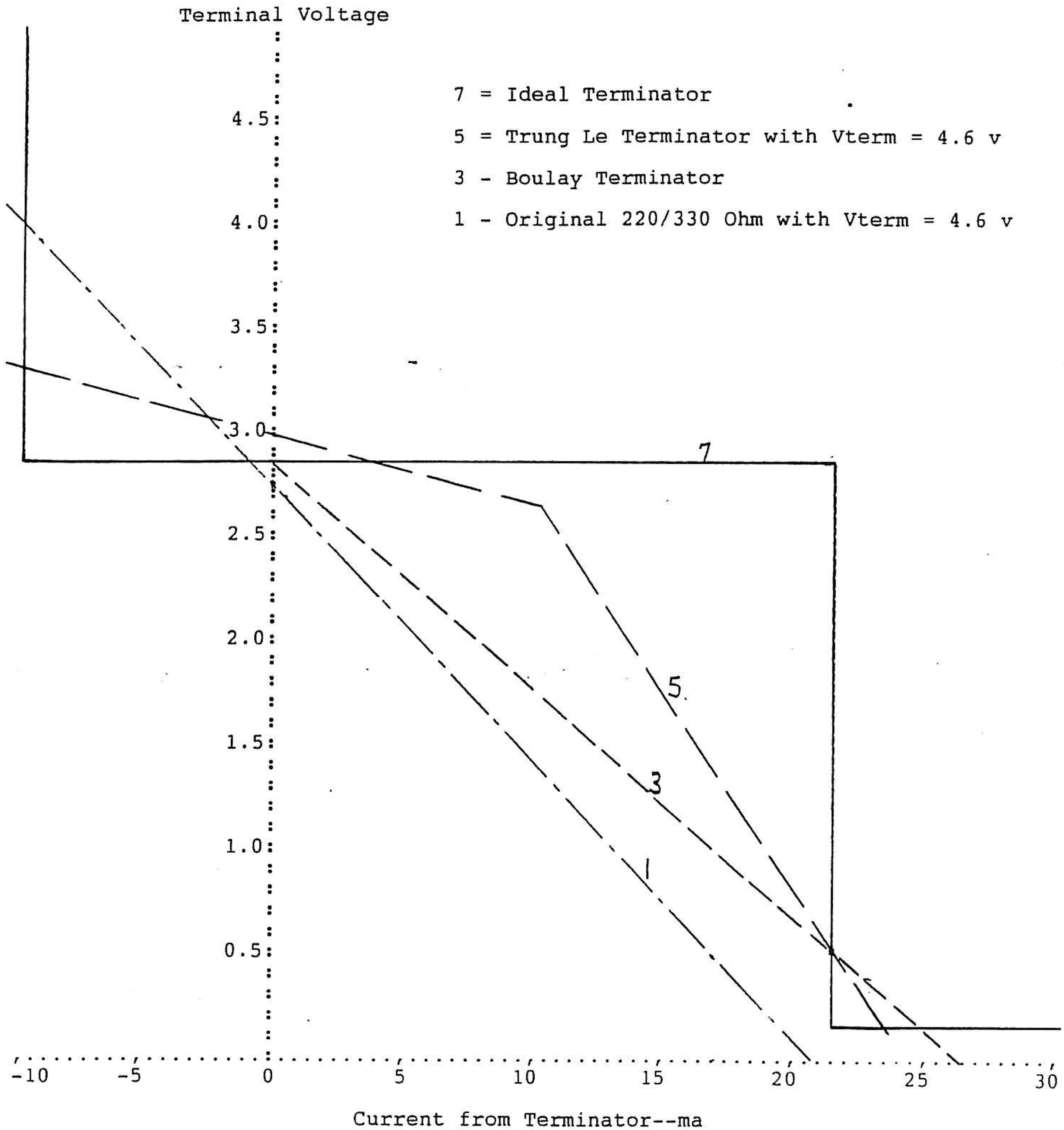

Figure 1. V-I Characteristics

The Trung Le terminator characteristic is calculated from its circuit and from the test results Kurt Chan reported in 91-93. The fact that it has similar end points to the Boulay characteristic but is much closer to the ideal characteristic in shape suggests the reason for its success in difficult circumstances. The anemia of the the current provided by the 220/330 ohm terminator even at Vterm = 4.6 volts is obvious. For a truly low Vterm, the current inadequacy becomes very serious. The 187/267 ohm terminator, by contrast, has the same characteristic as the Boulay terminator for Vterm = 4.85 v and provides 17% more current than the 220/330 ohm terminator at all levels of Vterm.

The Boulay characteristic is undefined in the active-negation, or negative-current, region because it depends on how many lines are asserted and how many negated.

SUGGESTIONS

1. The original 220/330 ohm 5% terminator should be relegated to a historical footnote and replaced, for low-end purposes, by the 187/267 ohm 2% or 1% terminator. The lower impedance device is superior in all cases except for the exclusively .050 pitch ribbon cable bus, and in such cases the bus is almost always short enough that terminator optimization is irrelevant.

2. 4.4.1.(2) should be relieved of its impedance specification and should be further refined to describe in the most general terms what the terminator must accomplish. Some kind of mushy statement might be contrived pointing to the Boulay, Trung Le, and other commercially available devices which meet the requirements of this section of the standard. Actual circuits of public domain devices might be presented in an appendix.

3. The present Boulay circuit should be deleted from the standard, in its present form at least, because it seemingly is not suited to service with active negation drivers.

4. Without attacking the use of 90-ohm and higher impedance cables, it should be made clear that with the modern terminators, ideal results can be achieved with the "standard" AWG 28 solid polyolefin-insulated round shielded twisted-pair cables with approximately 80 ohm impedances.

5. And, of course, the advisability of proper signal placement within the cable needs to be brought forth.

It is intended that specific proposals for implementing these suggestions be offered for debate at a meeting in the near future.