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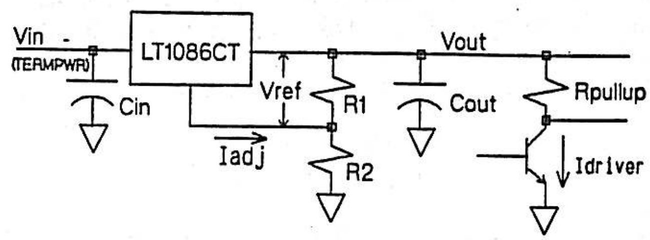
Date:	August 17, 1989
To:	X3T9.2 SCSI Committee Members
From:	Kurt Chan, Gordon Matheson
Subject:	Alternative 2 Termination: Worst-Case Analysis and Recommendations
Reference:	X3T9.2/86-109 Revision 10, Sections 4.2 and 4.4.1 and 4.4.3

A few wording changes are needed to make the Alternative 2 ("active") termination compatible with the rest of Revision 10, and to account for worst-case operating conditions. The circuit is shown below:



1. Voltage Analysis

The equations defining the output voltage are (assuming R_1 and R_2 are 1%):

$$V_{low} = (1\text{-Stability}_{longterm})V_{ref(low)}\left(1+\frac{0.99R_2}{1.01R_1}\right) \geq 2.5V$$

$$V_{typ} = V_{ref(typ)}\left(1+\frac{R_2}{R_1}\right)+\left(R_2 I_{adj(typ)}\right)$$

$$V_{high} = (1+\text{Stability}_{longterm})V_{ref(high)}\left(1+\frac{1.01R_2}{0.99R_1}\right)+\left(1.01R_2 I_{adj(max)}\right)$$

Overall, the worst-case regulated voltage is about 4% accurate and stable from its nominal value, which is equal to if not better than most three-terminal regulator designs. The following constants are taken from the manufacturers data sheet:

$$V_{ref(low)} = 1.225 \qquad V_{ref(typ)} = 1.25 \qquad V_{ref(high)} = 1.27$$

$$I_{adj(min)} = 0 \qquad I_{adj(typ)} = 50\mu A \qquad I_{adj(max)} = 120\mu A$$

$$\text{Stability}_{longterm} = 1.0\%$$

Using the R_1 and R_2 values from Rev 10 in these equations results in:

CASE	R(pullup)	R1	R2	V(low)	V(typ)	V(high)
1	110	121	154	2.725	2.846	2.966
2	100	110	127	2.585	2.698	2.808

Note that implementations with a *nominal* voltage of 2.85V may actually produce a voltage between 2.725 and 2.966 volts.

2. Current Analysis

The maximum regulator output current, assuming 2% pullup resistors, is:

$$I_{regulator(max)} = \frac{V_{ref(high)}}{0.99R_1} + 18\left(\frac{V_{high} - V_{ol(min)}}{0.98R_{pullup}}\right) \le \frac{I_{termpwr(min)} - 8I_{termpwr\_leakage}}{2}$$

and the maximum driver current is:

$$I_{driver(max)} = 8I_{IL(max)} + 2\left(\frac{V_{high} - V_{ol(min)}}{0.98R_{pullup}}\right) \le 48\text{ mA}$$

where the following constants apply (from Rev 10):

$$I_{IL(max)} = 400\mu A \qquad I_{termpwr(min)} = 900mA \qquad I_{termpwr\_leakage} = 1mA$$

Calculating the currents creates somewhat of a dilemma due to the different assumptions made in the Alt 1 and Alt 2 designs. The 220 ohm pullups in the Alt 1 design will source no more than 48 mA, even with TERMPWR=5.25V and V_{ol} = 0.0 volts. This also forms the basis for the 900 mA minimum TERMPWR current requirement in section 4.2:

$$\left(\frac{5.25V}{(220/2)\ \Omega}\right)(18\text{ signals}) = (47.7\text{ mA})(18) = 859\text{ mA}$$

The Alt 2 terminator currently allows a termination to be chosen such that 48 mA is drawn from the pullup when V_{ol} is at its *maximum* value of 0.5V. This is backwards - the maximum current should only be possible when V_{ol} is at its anticipated *minimum*, and V(out) is at its maximum. If we make the somewhat optimistic (and technology-dependent) assumption that $V_{ol(min)}$ = 0.2V (about one-half of the typical values for 48 mA TTL open-collector drivers) we get the following:

CASE	I(regulator)@V(ol)=0.2V	I(driver)@V(ol)=0.2V	I(termpwr) required
1	472 mA	54.5 mA	952 mA
2	490 mA	56.4 mA	989 mA

which causes violation of both the I_{driver} and $I_{termpwr}$ specifications. Keeping the values of R_1 the same, here are the 1% values of R_2 that keep driver current closer to 48 mA:

CASE	R2	I(regulator)@V(ol)=0.2V	I(driver)@V(ol)=0.2V	I(termpwr) required
3	124	417 mA	48.4 mA	843 mA
4	93.1	415 mA	48.1 mA	840 mA

The tradeoff, of course, is that to get the lower currents, we must give up some high-level noise margin. The typical output voltages for cases 3 and 4 are 2.537 and 2.313 volts, respectively.

3. Regulator Dropout Voltage Considerations

The other consideration in selecting R_1 and R_2 is related to regulator dropout due to TERMPWR losses. For 28AWG wire over 6 meters:

$$R_{wire} = (0.23\Omega/m)(6m) = 1.38\Omega$$

which results in a voltage drop across the wire and far TERMPWR values of:

$$V_{wire} = (I_{regulator(max)})(1.38)$$

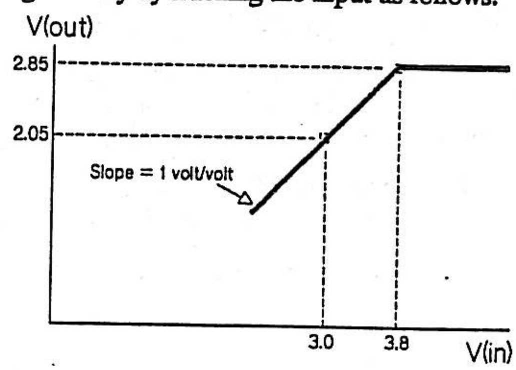
$$V_{far\text{-}termpwr(min)} = 4.25 - V_{wire}$$

$$V_{dropout} = V_{far\text{-}termpwr(min)} - V_{high} \geq 1.1V$$

At 450 mA over its commercial operating conditions, the LT1086 requires ($V_{dropout} = V_{in} - V_{out}$) to be approximately 1.1V or more. Cases 1 and 2 clearly violate this requirement when $V_{in} = V_{far\text{-}termpwr}$ and $V_{out} = V_{high}$:

CASE	I(regulator)	V(wire)	V(far-termpwr)	V(far-termpwr)-V(high)
1	472 mA	652 mA	3.59	0.631
2	490 mA	677 mA	3.57	0.763
3	417 mA	576 mA	3.67	1.034
4	415 mA	573 mA	3.67	1.274

Fortunately, the way in which the linear regulator works prevents failure. Below the dropout voltage, the regulator output degrades gradually by tracking the input as follows:



If TERMPWR falls below ($V_{dropout} + V_{out}$), the regulator will fail to regulate at its setpoint but will continue to output a lower voltage (and current) in direct proportion to $V_{termpwr}$:

$$V_{out(dropout)} = V_{in} - V_{dropout} = V_{termpwr} - 1.1$$

For example, in case 1 the nominal 2.85V output voltage can fall as low as (3.59-1.1) = 2.49V. The following table summarizes the four cases with respect to lowest output voltage (including dropout considerations), highest TERMPWR current, and highest driver current possible:

CASE	V(low)	I(termpwr)	I(driver)	VIOLATIONS
1	2.49	952 mA	54.5 mA	I(termpwr), I(driver), V(dropout)
2	2.47	989 mA	56.4 mA	I(termpwr), I(driver), V(dropout)
3	2.43	842 mA	48.4 mA	V(pullup) - see section 4.4.1(d)
4	2.22	838 mA	48.1 mA	V(pullup) - see section 4.4.1(d)

4. TERMPWR: How to Sustain 4.0V Across the Bus

A 28 AWG bus supplying 430 mA to a device 6 meters away will drop 0.59V across the wire, resulting in a 3.66V TERMPWR at the far end if 4.25V is supplied at the near end. There are several ways to guarantee that 4.0V is provided at both ends of a 6 meter single-ended system:

1. Supply at least 4.0V TERMPWR at each end of the bus.
2. Supply at least 4.3V TERMPWR from the the center of the bus.
3. Supply at least 4.6V TERMPWR from one end of the bus.
4. Supply at least 4.25V TERMPWR from one end of the bus using 24 AWG wire.

24 AWG wire has a resistivity of about 0.505 Ω (vs. 1.38 Ω for 28 AWG) over 6 meters, and also solves the dropout voltage problem with the Alt 2 terminator:

CASE	V(24AWG)	V(far-termpwr)	V(far-termpwr)-V(high)
1	0.238	4.01	1.04
2	0.247	4.00	1.19
3	0.210	4.03	1.40
4	0.210	4.03	1.64

I'll leave it to our cable representatives to tell us how impossible it is to twist a 24 AWG pair in with 24 pairs of 28 AWG...

5. Recommendations (changes in **bold** type):

1. In 4.4.1(c), change $V_{ol(max)}$ to $V_{ol(min)}$ for the purposes of calculating maximum driver current:

   "The current available to any signal line driver shall not exceed 48 milliamps when the driver asserts the line and pulls it to **0.2 volts dc**. Only 44.8 mA of this current shall be available from the two terminators."

2. In figure 4-9, change the dropout voltage from 1.0 to **1.1V**, per the manufacturers data sheet (commercial temperature range, guaranteed worst-case).

3. Modification to Alternative 2 termination preferred values: alternative (b) describes the changes necessary to prevent ambiguity with other sections of the standard if we want to leave Figure 4-9 as is.

   a. In figure 4-9, change R_2 from 154 to 124 Ω and "2.85V" to "**2.54V nominal**",

   b. *-OR-* change "2.85V" to "**2.85V nominal**" and change the 900 mA requirement to **1000 mA** in 4.4.3 and knowingly exceed the 48 mA spec by 6.5 mA under worst-case conditions.

4. Modification to Alternative 2 termination alternate values: alternative (b) describes the changes necessary to prevent ambiguity with other sections of the standard if we want to leave Figure 4-9 as is.

   a. In figure 4-9, under note 2, change R_2 from 127 to 93.1 Ω and "2.6V" to "**2.3V nominal**" (case 4), and change 4.4.1(d) to "**2.3** volts dc **(nominal)**",

   b. *-OR-* change "2.6V" to "**2.7V nominal**" and change the 900 mA requirement to **1000 mA** in 4.4.3 and knowingly exceed the 48 mA spec by 8.4 mA under worst-case conditions.

   c. *-OR-* delete Note 2 from figure 4-9 altogether.