HEWLETT PACKARD
Roseville Networks Division
8000 Foothills Blvd., Roseville, CA 95678

X3T9.2/91-93 R0

Date: 21 June 91
From: Kurt Chan, X3T9.2 Principal, Hewlett-Packard
To: X3T9.2 Membership
Subject: Analysis of Nonlinear SCSI Bus Termination

Recent SCSI termination circuits involving nonlinear elements (IBM "FPT", Methode "SLIM") have evoked great interest. The benefits of nonlinear termination in terminating stubs, backplanes, and high speed interconnects on printed circuit boards are well understood (see References section). However, their applicability to SCSI has been questioned. In testing the two samples given to me by Methode, I took a "black box" approach in which I made no assumptions about the internals of the terminators. Here are the DC measurements:

Parameter	SLIM	FPT at 5.25V	FPT at 4.75V	FPT at 4.25V
TERMPWR Current, all 18 signals shorted	486 mA	464 mA	419 mA	374 mA
TERMPWR Current, all signals open	29 mA	196 mA	172 mA	149 mA
Open Circuit Voltage	2.83 V	3.15 V	2.80 V	2.55 V
Output Short Circuit Current	25.4 mA	25.5 mA	23.2 mA	20.6 mA
Output Current at V(ol) = 0.5V	21.1 mA	21.1 mA	19.1 mA	16.3 mA

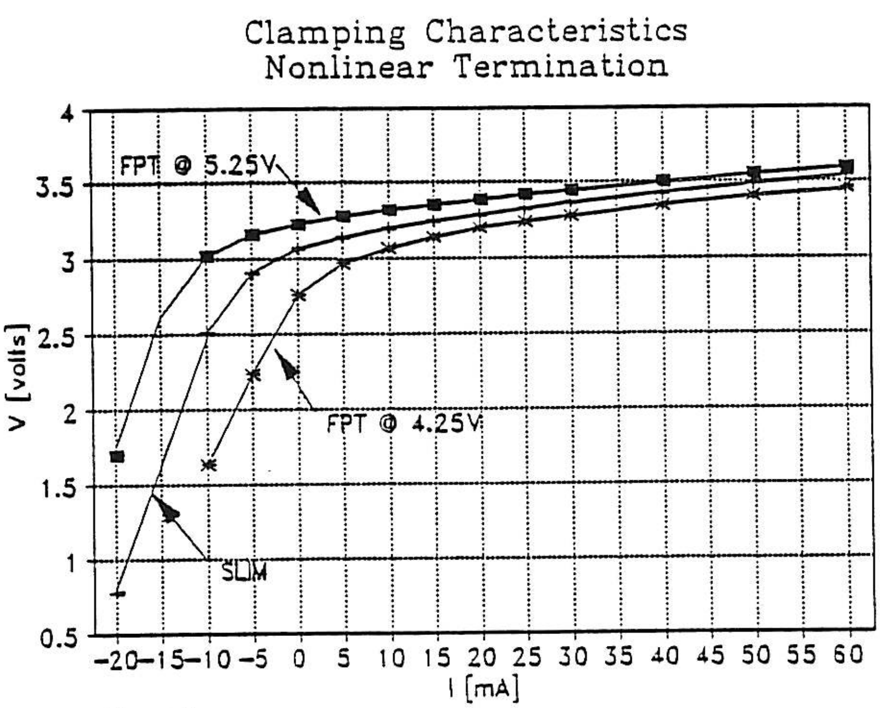


Figure 7

Notes:

- Above V(oc), the curves represent the load line for the 10 ohm resistor. Without the current limiting resistor shown in Figure 8, the curves would be even more horizontal.

- Below V(oc) and above 0V, the curves represent the load line of the internal pullup resistor in the terminator.

- Below 0V, the curves would represent the load line of the current-limiting resistor in the V(ref) biasing circuit.

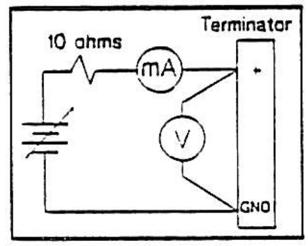


Figure 8 - Test circuit

TEST CONFIGURATIONS

Some AC measurements were made. The following oscilloscope traces correspond to these configurations:

1. Hybrid: 2m 75 ohm shielded cable + 2m 100 ohm ribbon cable + 2m 75 ohm shielded cable
2. Same as above but with four 1m, 50 ohm stubs (using coax cable) spaced 18" apart on the ribbon cable
3. 2m, 75 ohm shielded cable only
4. 5m, 75 ohm, shielded cable only
5. 10m, 85 ohm shielded cable + 0.5m, 75 ohm shielded cable

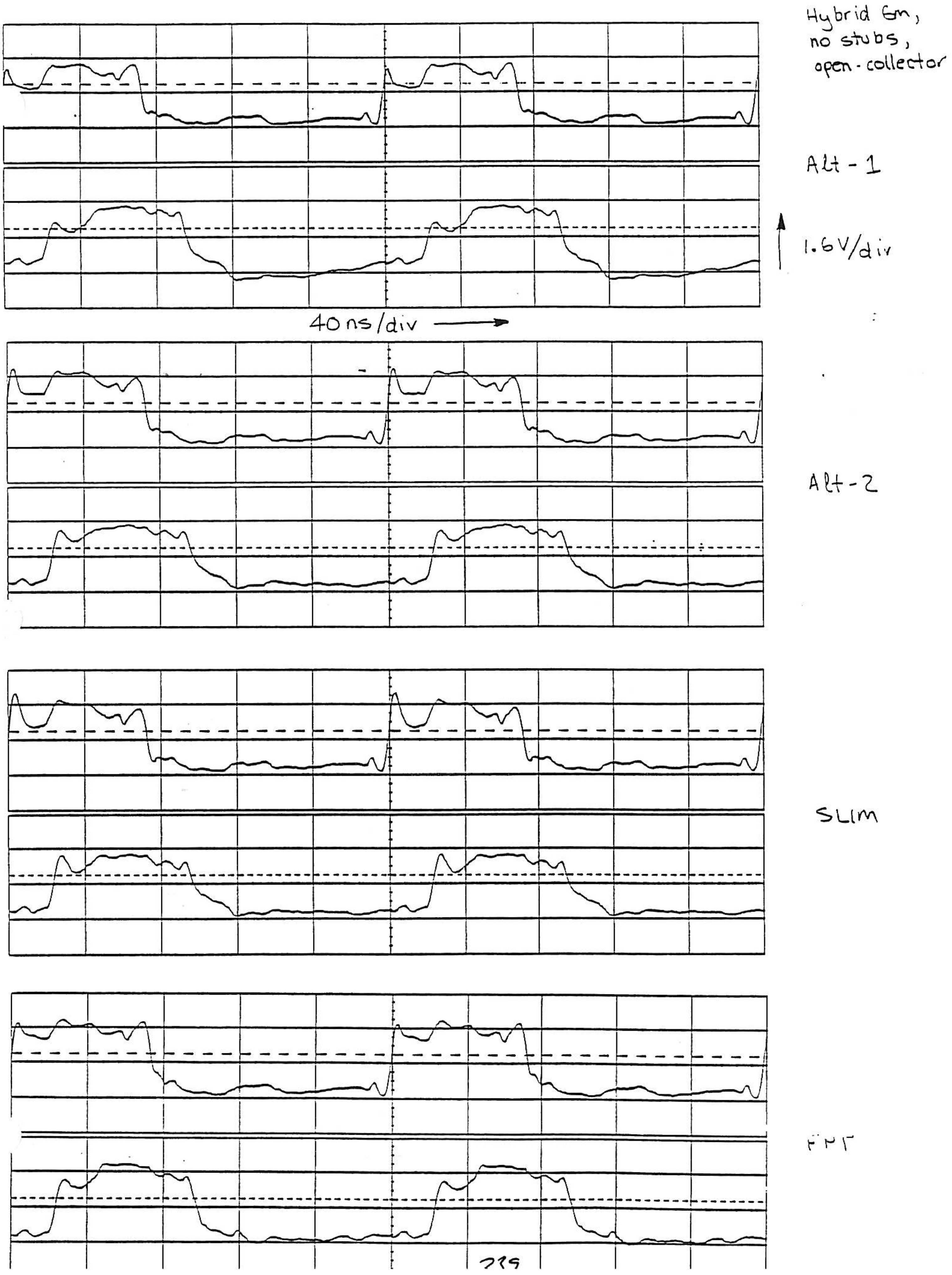
Configuration 1 was tested with both open-collector and active negation drivers (F641 and ABT245, respectively)
Configuration 2 was tested only with open-collector drivers
Configuration 3 was tested only with active negation drivers
Configuration 4 was tested with both drivers
Configuration 5 was tested with both drivers

In each configuration, the REQ- signal oscillating at 5MHz was measured using an HP54111D digitizing oscilloscope (1.6V/div). The dotted line in each trace is the 2.0V marker. TERMPWR = 4.25V in all cases. Four terminator combinations were tested:

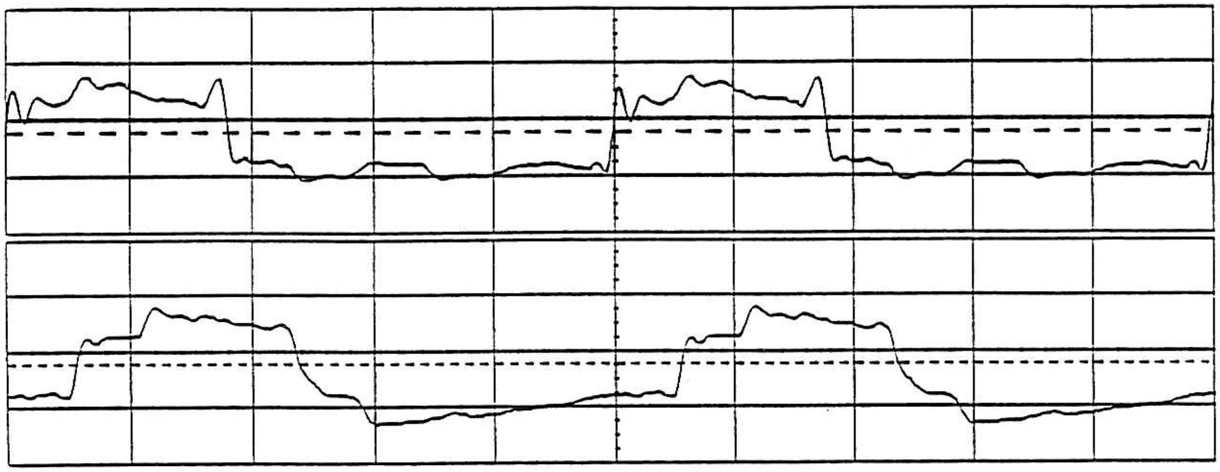
1. Alt-1 ("passive") at both ends
2. Alt-2 ("active") at both ends
3. "SLIM" at both ends
4. "FPT" at both ends

The top trace is always at the driver. The second trace in the hybrid configurations is 2/3 (4m) down the cable, at the transition from unshielded to shielded. The second trace in the shielded-only configurations is at the far end terminator.

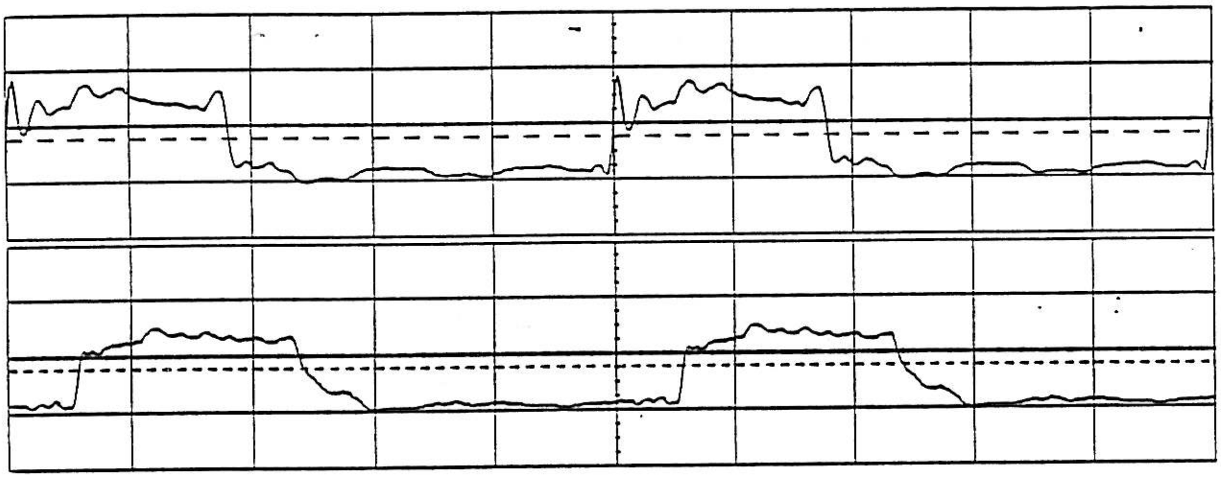
74F641 drivers are Advanced Schottky 64mA drivers (@ 0.42V typ, 0.55V max).
74ABT245 drivers are Advanced BiCMOS -32mA (@ 2.4V typ, 2.0V min) / 64mA (@ 0.42V typ, 0.55V max)


Hybrid Gm,
no stubs,
open-collector
Alt-1
1.6V/div
40ns/div
Alt-2
SLIM

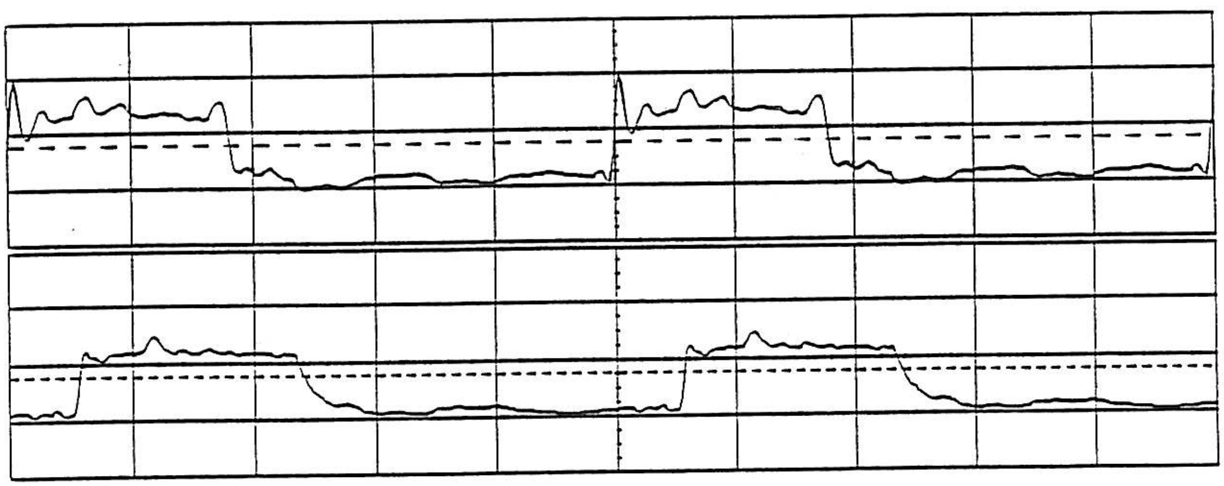
Hybrid 6m, no stubs, active negation



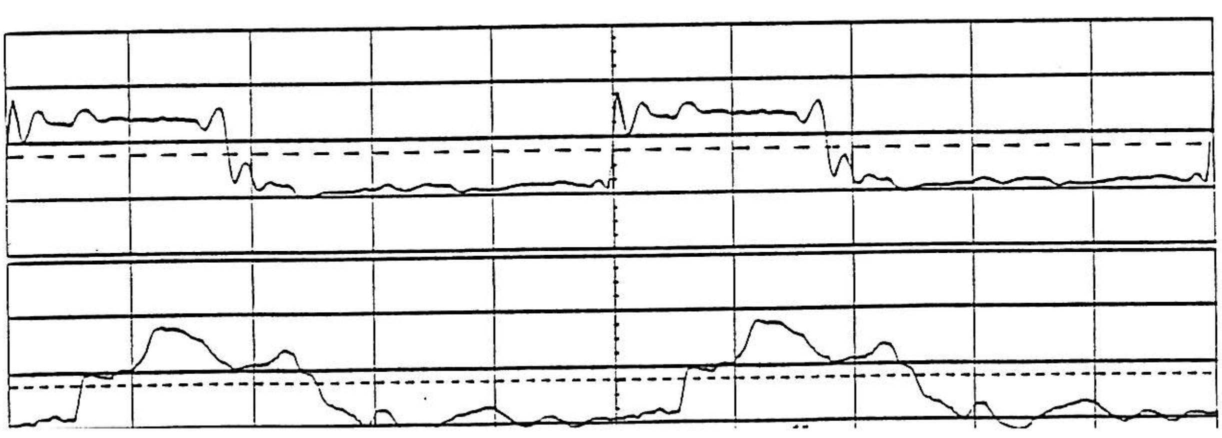
Alt-1



Alt-2

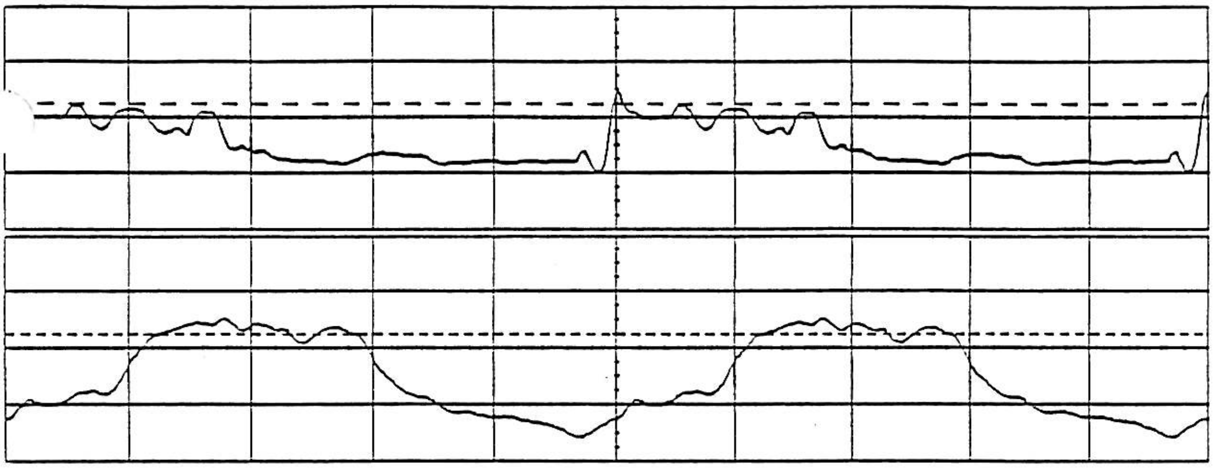


SLIM

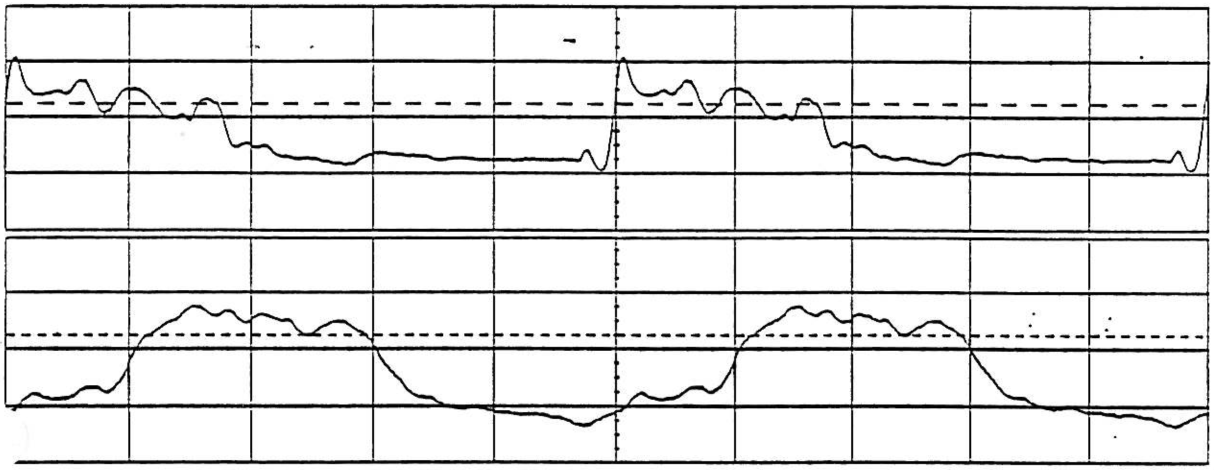


FPT

Hybrid 6m,
4 1m stubs
open-collector



Alt-1



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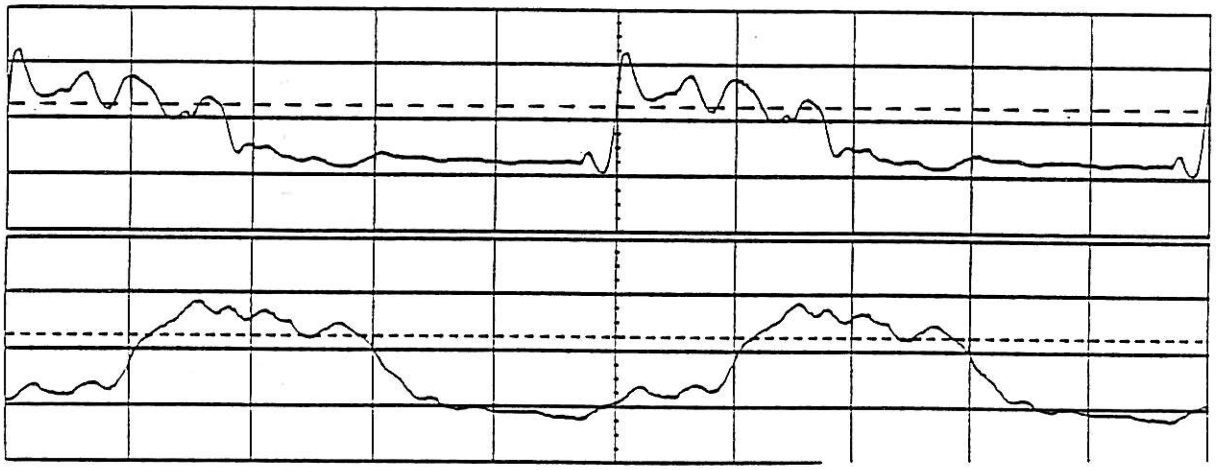
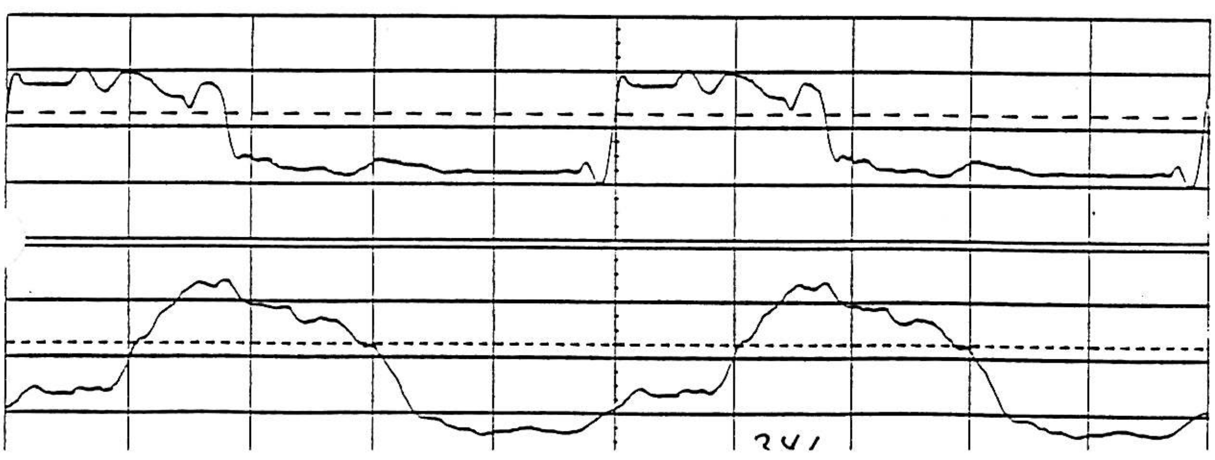
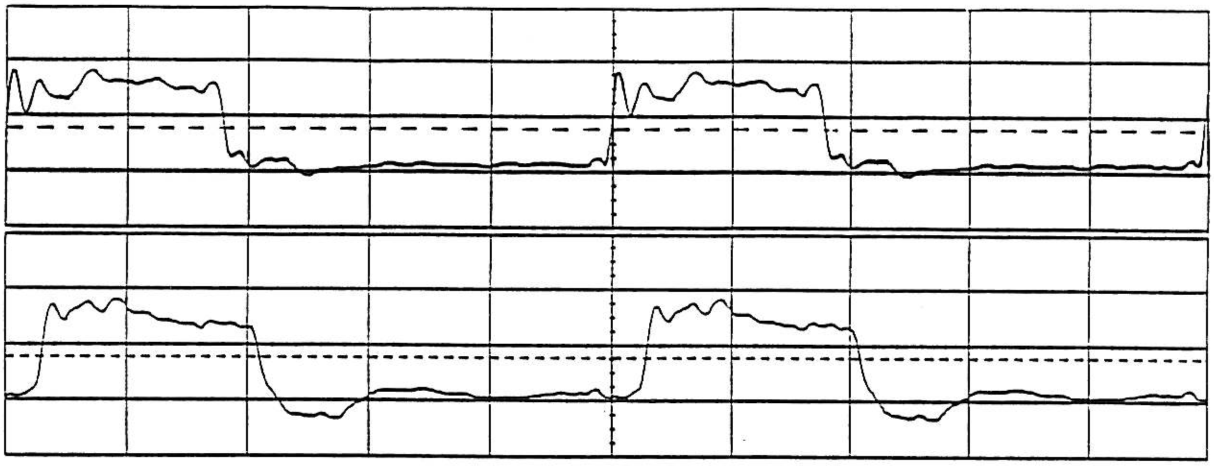


SLIM

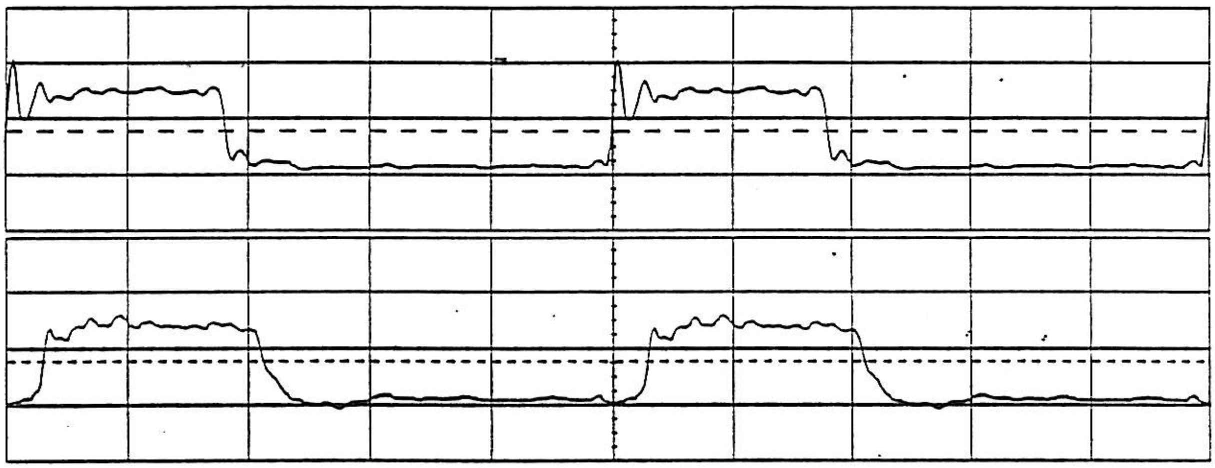


FPT

2m, 70Ω shielded cable, active neg[illegible]



Alt-1



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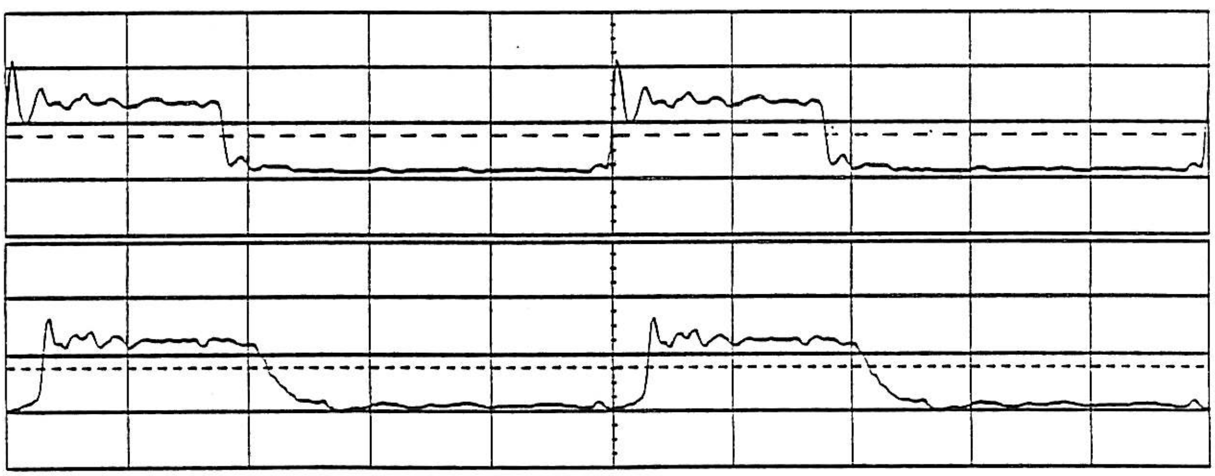
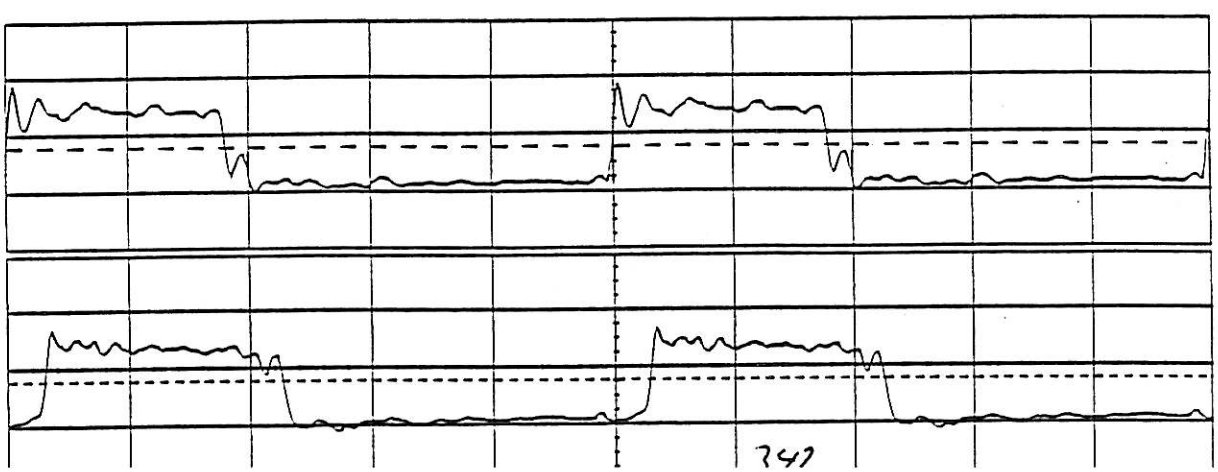
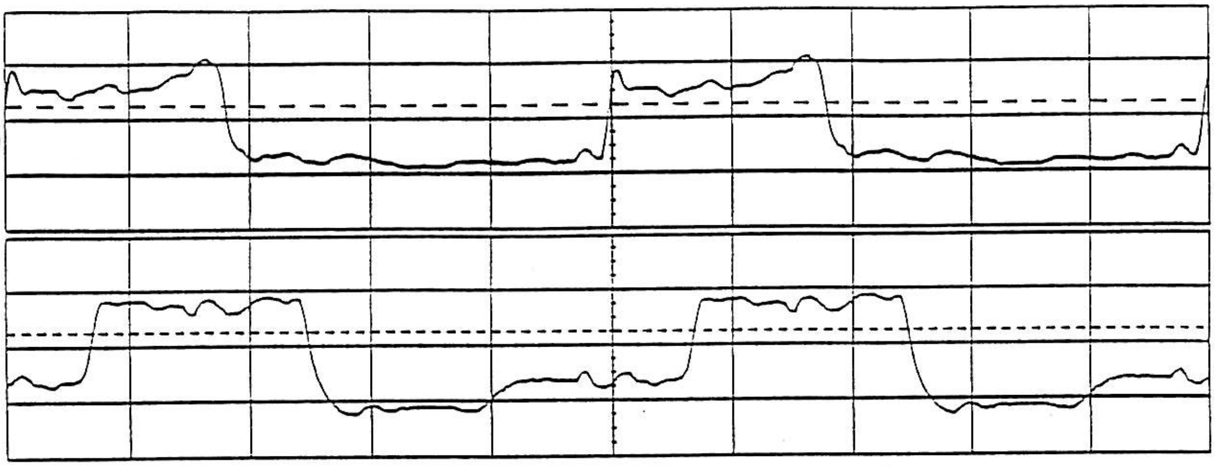


SLIM

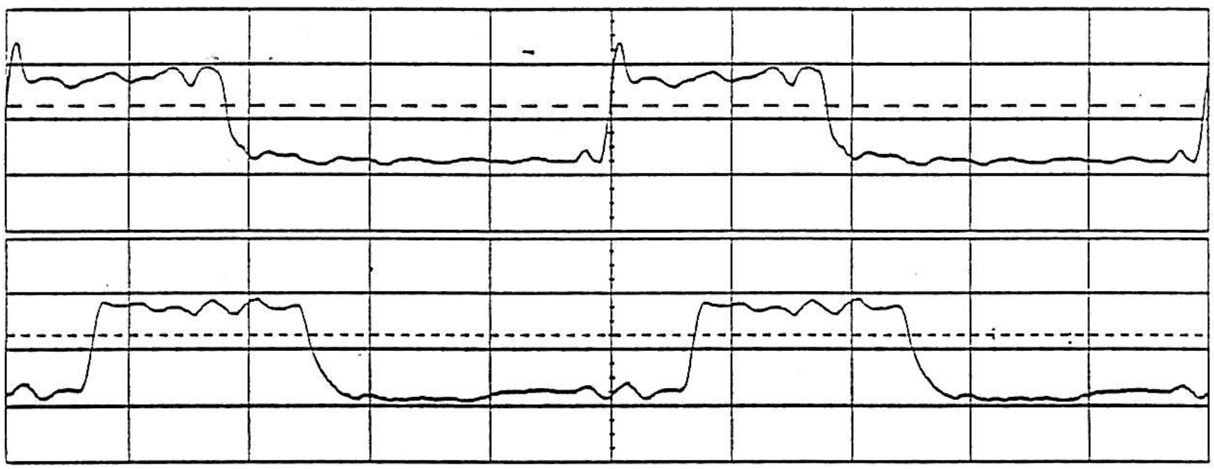


FP-

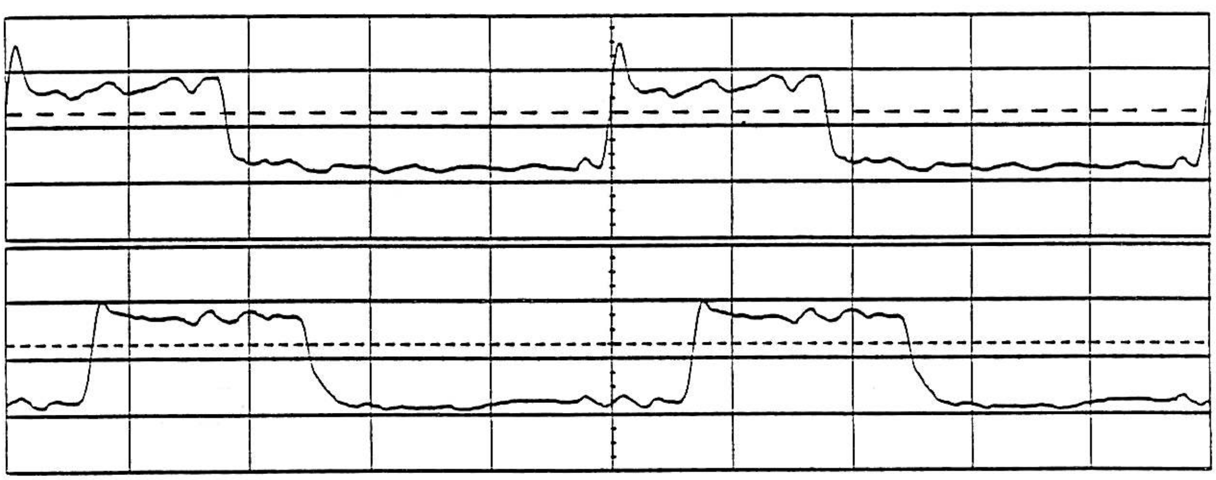


5m, 70Ω shielded cable, open collecto

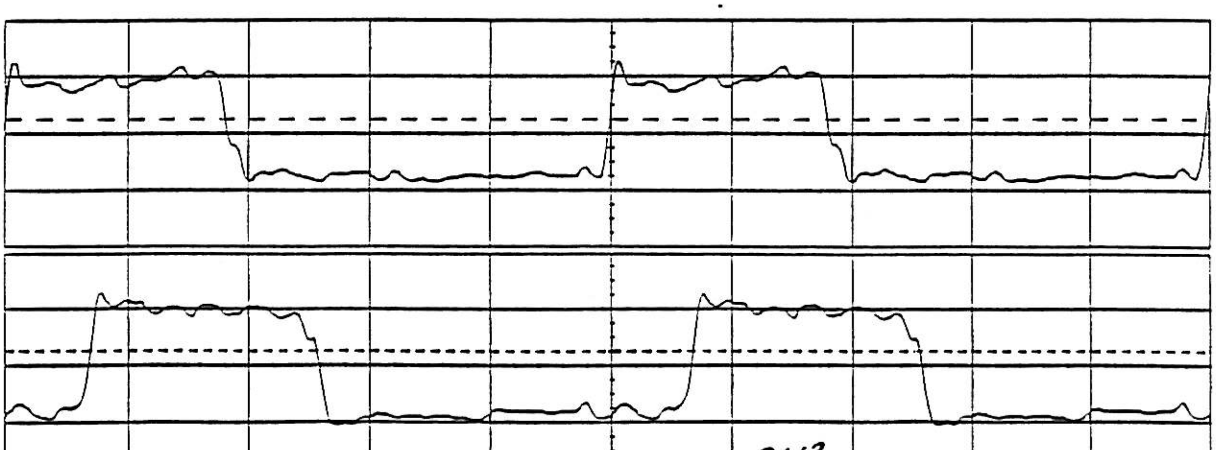
Alt-1



Alt-2

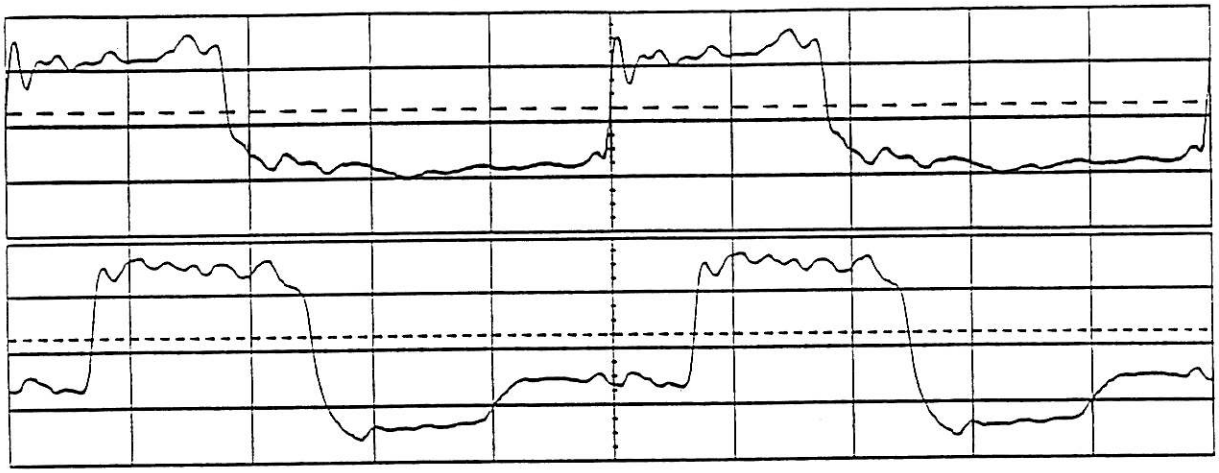


SLIM

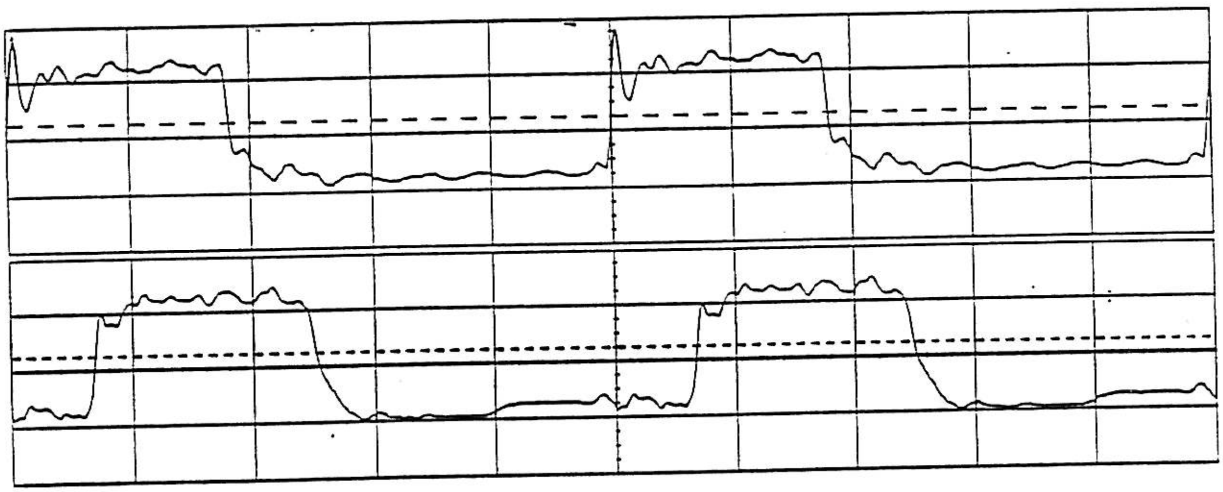


FOT

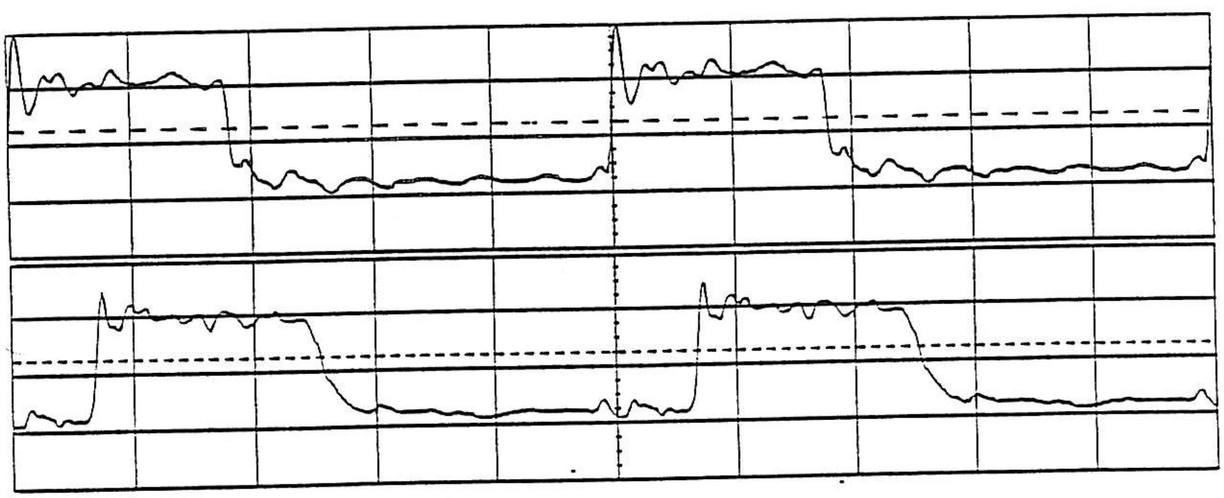
5m, 70Ω shielded cable active negation



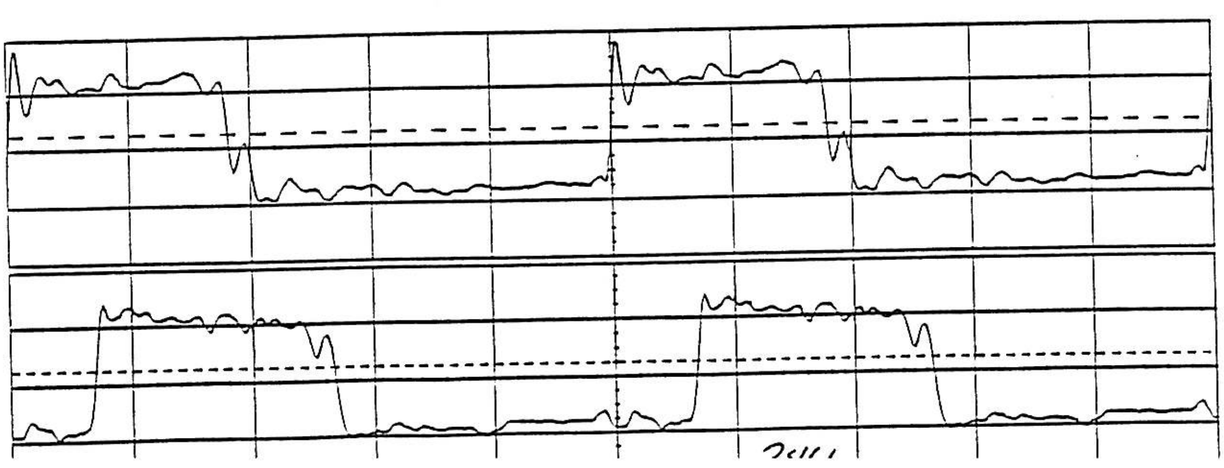
Alt-1



Alt-2

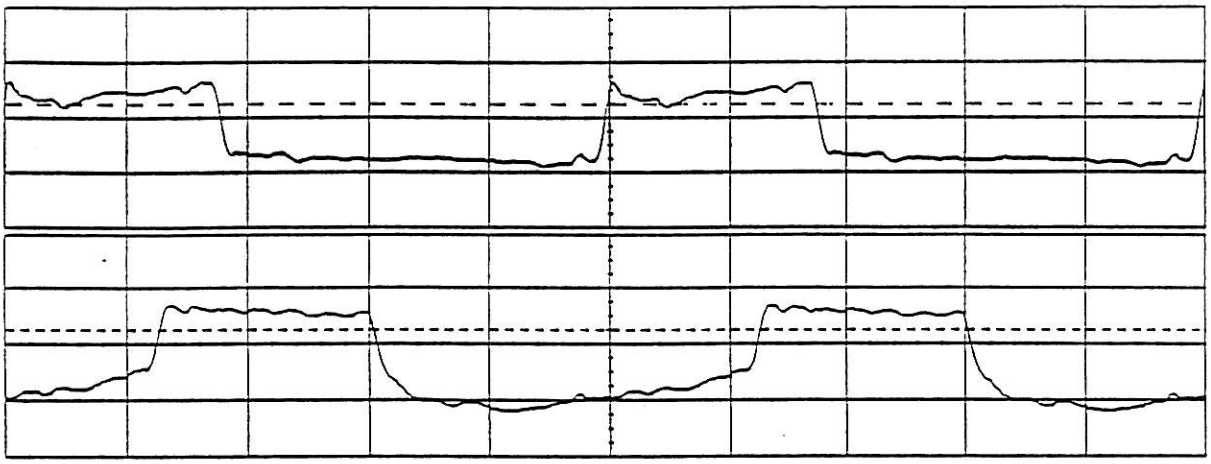


SLIM

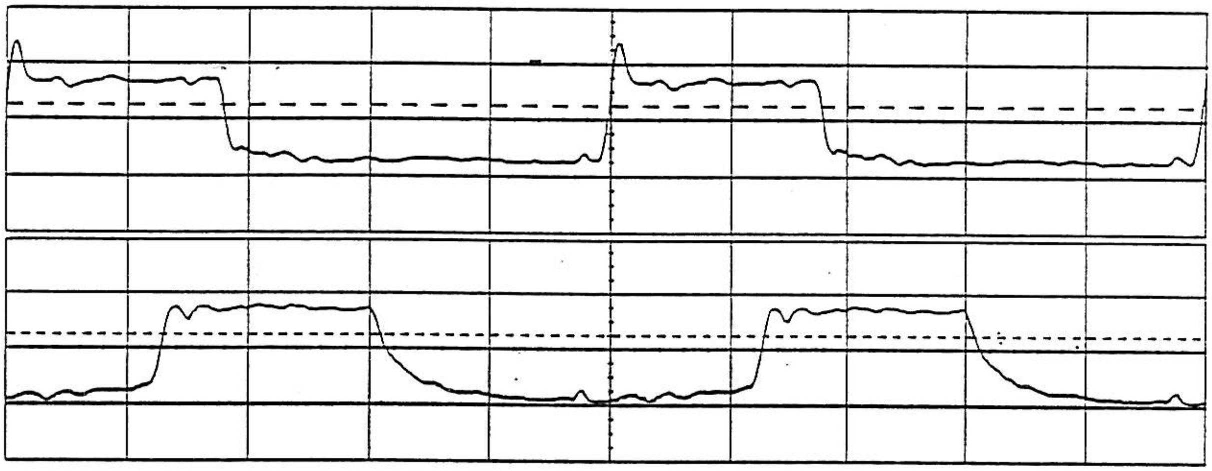


FPT

10m, 90Ω shielded + ½ m, 70Ω shielded, open collector



Alt-1



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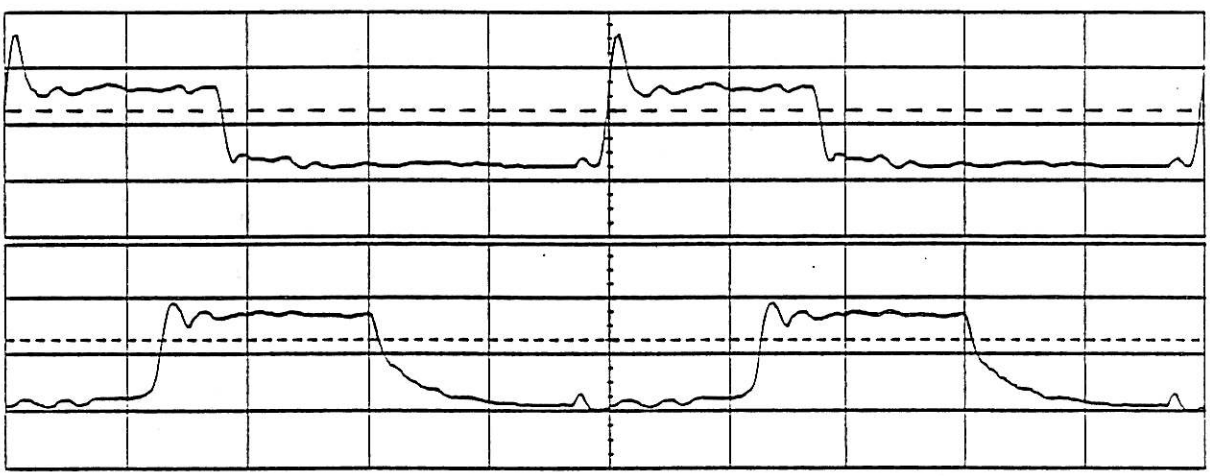
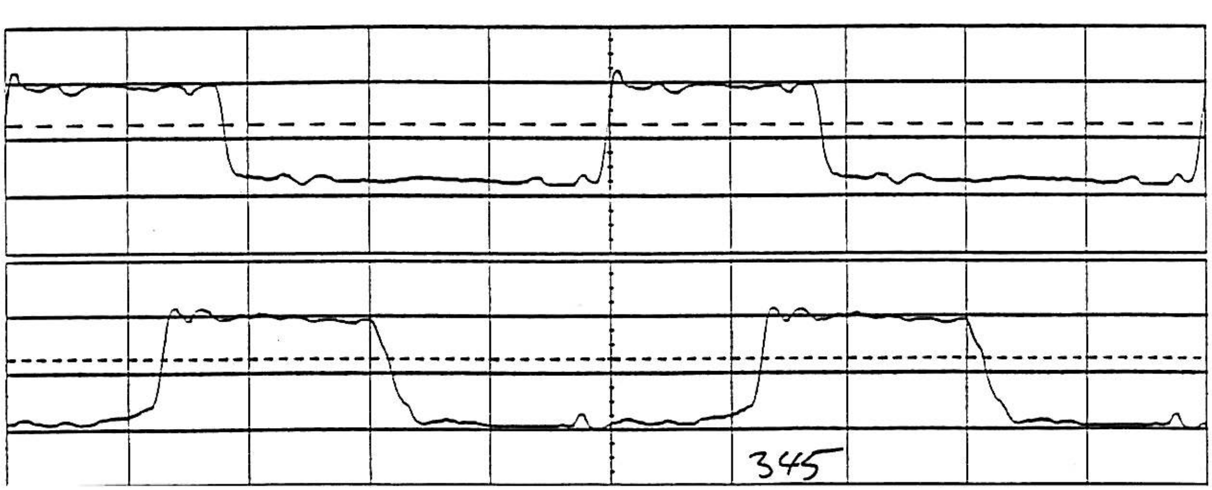
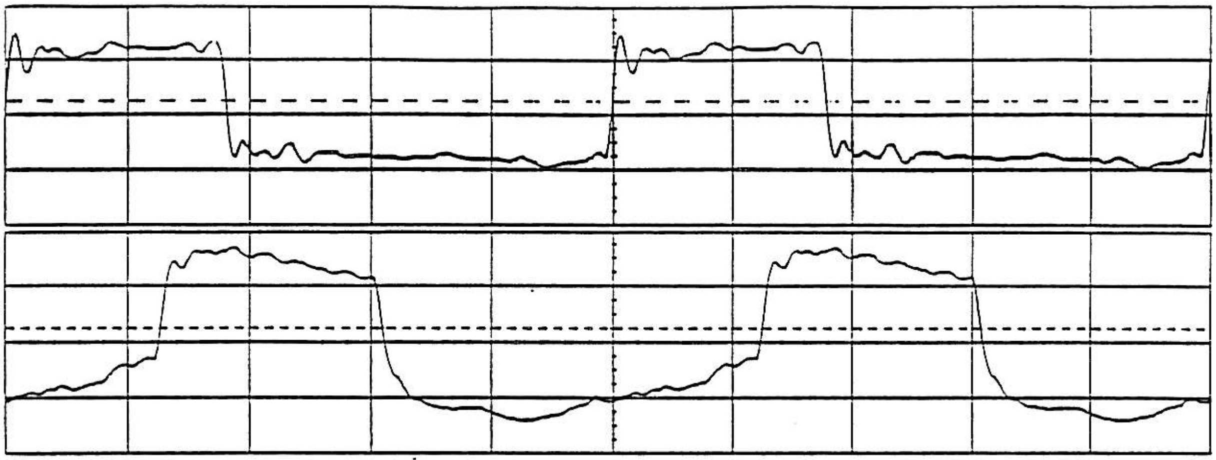


SLIM

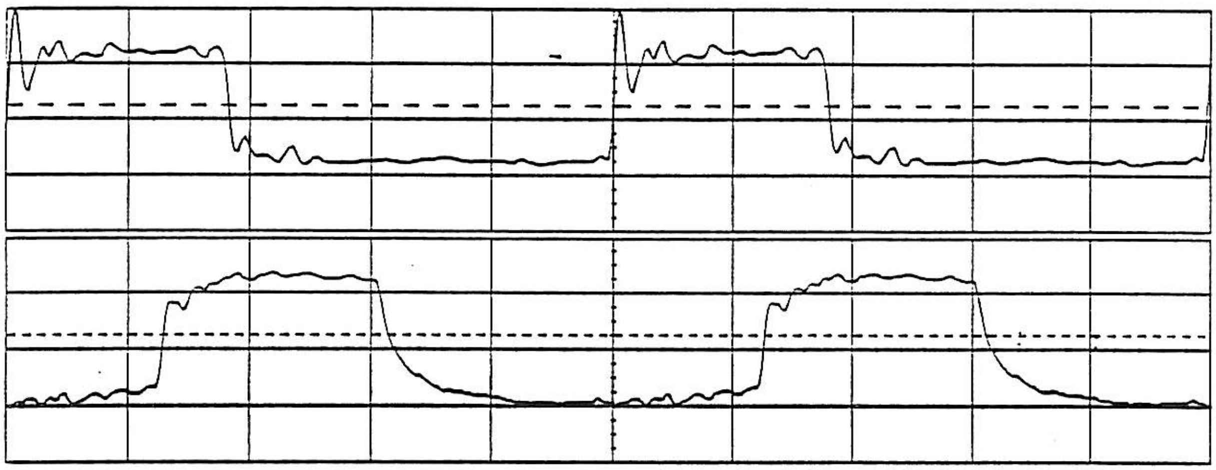


FPT

10m, 90Ω shielded + ½ m, 70Ω shielded, active nega



Alt-1



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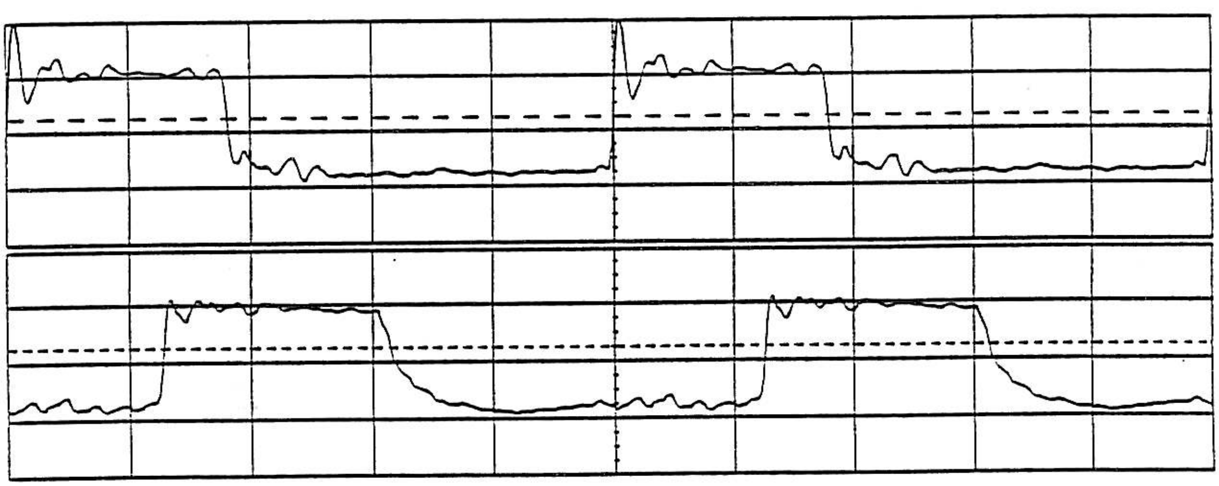
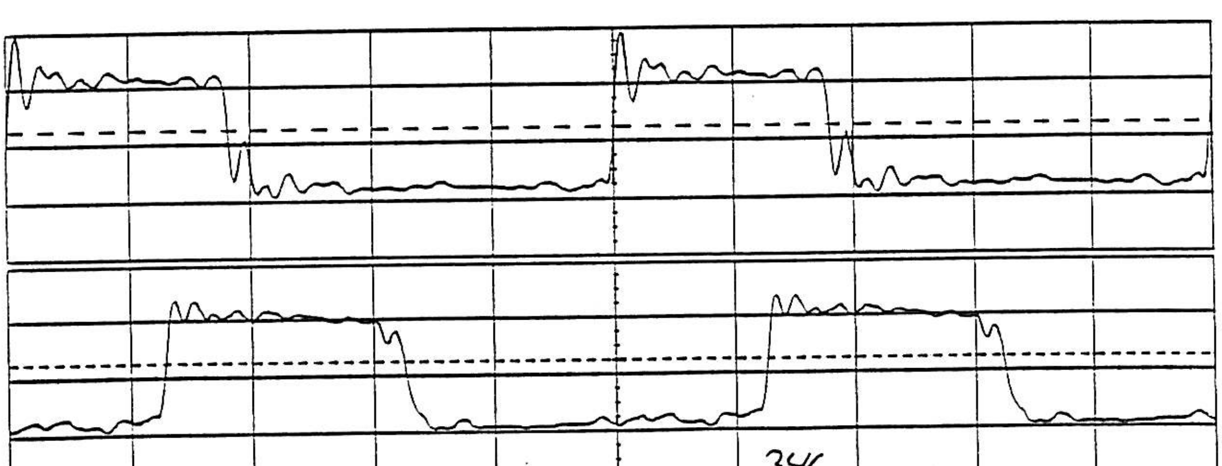


SUM



FPT

OBSERVATIONS

Observing the waveforms closely reveals that FPT was a slight improvement over all other terminators for open-collector drivers in all configurations. With active negation drivers, Alt-1 termination improved far end high level noise margin more than all other terminators but exhibited more undershoot.

A word of caution regarding both FPT and SLIM termination however: the high sink current behavior of nonlinear termination above 3-4V may mean that those SCSI drivers which can drive to the VCC rail may not be compatible with such terminators due to the high transient currents that could result. For TTL drivers, or for most integrated drivers which employ current/voltage limiting this is not a problem. For high-current CMOS drivers, it may be.

Disclaimer:

Since the output characteristics of the drivers used are likely to be different than the silicon you're using, the results of this testing should not be used to arrive at general conclusions regarding what's best for your systems. Also, these tests were only conducted at 4.25V TERMPWR with no silicon other than the drivers attached to the cable - these variables in your systems may result in differences between terminators not observed in my tests.

SUMMARY:

For Open Collector drivers:

- Nonlinear termination schemes have merit and are at least equivalent to Alt-2, even at 4.25V TERMPWR.
- **Alt-1 termination is still the least desirable termination.**

For Active Negation drivers:

- The choice of termination is much less critical to signal quality when using active negation drivers.
- Avoid FTP and SLIM termination if large currents could result from driving to the VCC rail.

APPENDIX - BACKGROUND THEORY AND REFERENCES

The following theory does not provide an explanation for the improved SCSI signal quality seen in the previous traces. Instead it describes the traditional benefits of diode termination in applications other than SCSI.

Figure 1 shows a recommended diode termination for ECL. CR1 and CR2 are Schottky barrier diodes, used for their desirable switching properties. The forward transfer characteristic for these devices is shown in Figure 2.

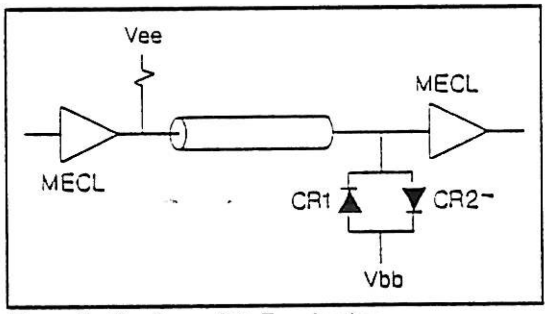


Figure 1 - Nonlinear ECL Termination

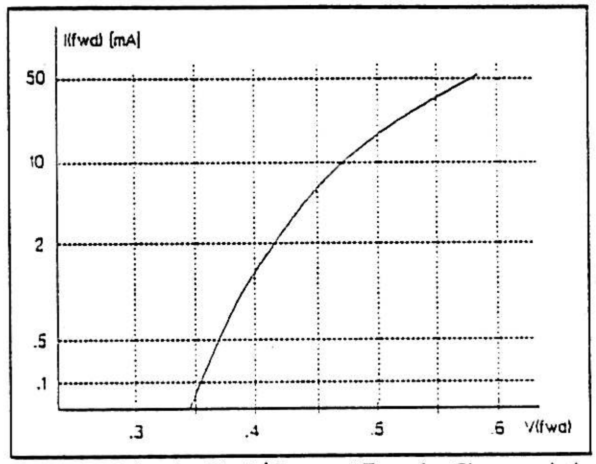


Figure 2 - Schottky Diode Forward Transfer Characteristic

The theory is that the diode will "adjust" the impedance of the terminator to the line by providing a current source or sink of the magnitude necessary for the forward voltage of the diode to cancel any overshoot/undershoot transients.

The clamping voltages are (Vbb - Vfwd) and (Vbb + Vfwd). With Vbb at -1.29V, these are close to output rails of ECL. The desired effect of this termination is to clamp the signal to the upper and lower threshold voltages as determined by the reference voltage(s).

The theoretical advantages of nonlinear termination:

1. It is not necessary to match the transmission line to a termination impedance
2. Signal overshoot and undershoot are effectively clamped to the 0 or 1 logic level
3. Subsequent ringing is eliminated
4. Where line impedance is unknown or not well defined, diode termination is convenient.
5. Stubs may be terminated with diodes in an identical fashion with identical results.
6. No quiescent current is drawn (on SCSI, this means no additional TERMPWR loading).

The FPT terminator operates on the same principles. It can be thought of as two circuits - a reference voltage circuit and the terminator:

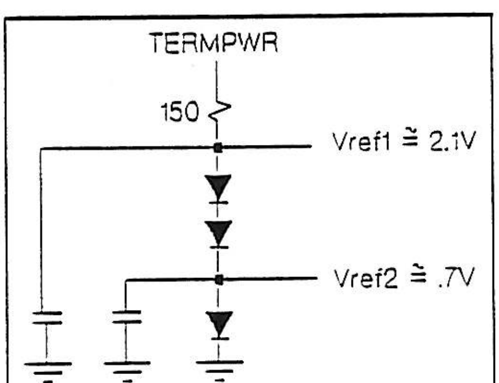


Figure 4 - FPT Voltage Reference

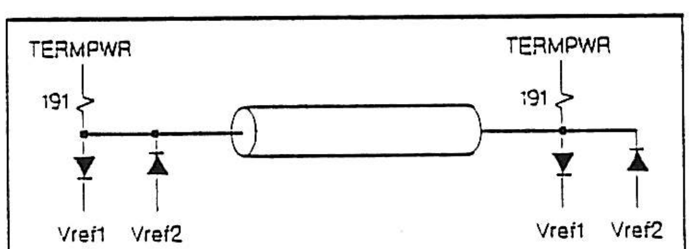


Figure 5 - FPT Termination

V(ref1) is equal to the forward voltage of three diodes, and V(ref2) is equal to the forward voltage of one diode. The pullup resistor keeps these diodes regulating in their forward biased states, and the reference voltages will not vary too significantly in response to changes in TERMPWR.

Instead of one reference voltage, two are used. Since Vref1 = 3*Vfwd and Vref2 = Vfwd, the clamp thresholds are about:

V(clamp_hi) = Vref1 + Vfwd = 4Vfwd
V(clamp_lo) = Vref2 - Vfwd = 0V

V(clamp_hi) is 2.5-3.0V, depending on the characteristics of the diodes being used and the bias circuit shown in Figure 4.

The "SLIM" termination is very similar. It uses the regulator from the Alternative-2 terminator in addition to the diodes:

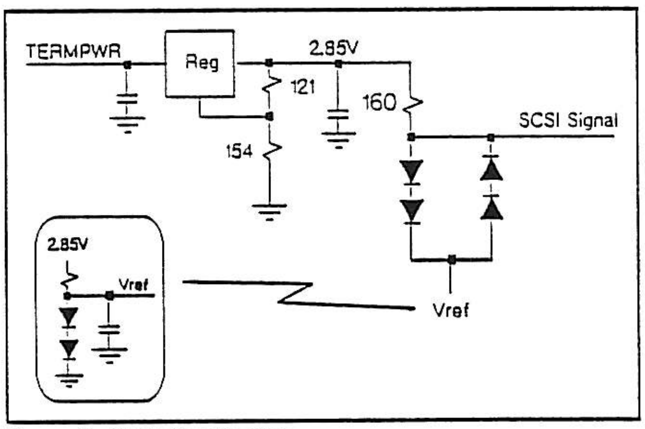


Figure 6 - SLIM Termination

Only one reference voltage is used. Vref is equal to 2Vfwd which makes the clamp points:

2Vfwd + 2Vfwd = 4Vfwd and
2Vfwd - 2Vfwd = 0V

Note that these voltage references are adequate AC sources, but relatively poor DC sources, due in part to the weak biasing imposed by TERMPWR limitations.

REFERENCES:

[1] Horna, O.A., "Nonlinear Termination of Transmission Lines", IEEE Transactions on Computers, Sept 1972, pp 1011-1015

[2] Bode, J; Montegari, F; "Dynamic Active Terminator Circuit", IBM Technical Disclosure Bulletin, Vol. 19, No. 10, March 1977

[3] Buckley, Prymak, Zeidenbergs, "Non-Linear FET Driver for Transmission Line with Low Termination Impedance", IBM Technical Disclosure Bulletin, Vol. 23, No. 7A, Dec 1980

[4] Householder, "Schottky Barrier Diode Transmission Line Termination", IBM Technical Disclosure Bulletin, Vol. 19, No. 8, Jan 1977

[5] Blood, W., MECL System Design Handbook, Fourth Edition, Motorola, 1988