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Active SCSI Termination for Higher Reliability of Operation in Fast SCSI-2 and SCSI-3 Buses

SCSI (Small Computer Systems Interface) is increasingly becoming a popular peripheral interface by virtue of its salient features which help to overcome the I/O bottleneck in computer systems today. With the increasing transfer speeds and cable lengths, come the associated transmission line effects, thus requiring termination. Passive termination schemes provided reliable operation in SCSI-1 systems, however meeting the promised performance goals of SCSI-2's fast SCSI at 10MB or SCSI-3's ultra fast SCSI at 20MB with any degree of reliability requires the use of active termination schemes. Higher speed, more peripherals and longer cables require the use of optimized active termination schemes on SCSI buses to maintain data integrity. This application note discusses the need for terminating a (transmission line) bus, the popular termination schemes and finally an optimized active termination scheme implemented through Micro Linear's ML6509, that helps achieve the goals of SCSI bus termination better with higher data integrity.

INTRODUCTION

The SCSI interface has evolved into a popular industry standard over the last couple of years. This is because the interface offers a cost effective means of boosting the I/O performance of mini and microcomputers. A flexible and versatile system, SCSI directs and manages the flow of information to and from up to eight devices per system, allowing each device to perform various functions simultaneously. The current SCSI-2 standard incorporates many specifications from the original SCSI-1 standard and additionally incorporates a number of enhancements, the most notable being the fast SCSI and wide SCSI options. These improvements coupled with the efforts of the ANSI committee on the proposed SCSI-3 standard, promise a bright future for SCSI.

SCSI devices are daisy-chained together using a common 50-conductor “A” cable and optionally, a 68-conductor “B” cable, making the signals common to all devices. Terminators applied at the ends of the cables assure communication-signal quality by matching the impedance encountered at the end of the cable to that of the cable itself. In other words, terminators at each end of the bus must have an impedance equal to that of the cable's characteristic impedance. Thus the pulse energy arriving at the cable termination is completely absorbed and none is reflected. Terminators may be connected either internally or externally to a SCSI device (refer Figure 1) Internal terminators are installed on the device's PC board. External terminators are built into connectors and encased in a connector shell. The terminators connector plug is then mated to a second rear-panel SCSI connector socket on the device as shown in Figure 1. Using internal terminators relieves the end user from worrying about terminations, especially with the advanced active terminators ICs available today that can be disconnected through software, however they do pose some difficulty to untrained users. External terminators eliminate the need to place internal terminators in every device because they are inserted only where necessary — at the ends of the bus. External terminators hence result in lower costs, easy identification and removal, and also provide a sturdy package to prevent damage, especially when reconfiguring the system.

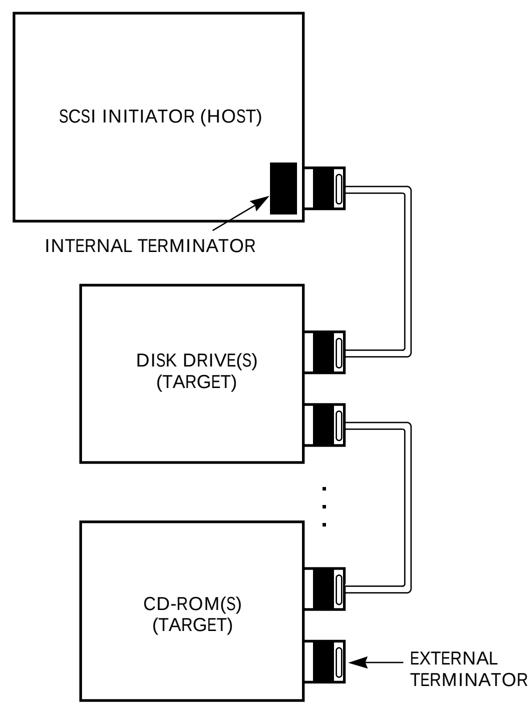


Figure 1. SCSI Bus Termination

With the advent of SCSI-2 and SCSI-3, it is clear that passive termination is often insufficient and must give way to active termination schemes. The SCSI-2 specification calls out for operation at 10MB over a 6 meter cable length (single ended, fast SCSI mode) while SCSI-3 is expected to up it to 20MB. The slower transfer rates of

SCSI-1 were very forgiving when it came to the physical interface. However with fast SCSI, stub lengths, the distance between stubs, cable designs and termination have become critical in order to get reliable operation. The primary problem is double clocking on the strobe lines which can occur as a result of reflection in the strobe lines due to impedance mismatches on the SCSI bus. One source of reflection is due to mismatch, when two cables of slightly different impedance are connected. Another source of reflection is stubs — the length of cable that hangs off the primary SCSI bus, (maximum allowed is 0.1m) and its position on the SCSI bus. Yet another source of reflection is the terminator, due to the difference between the impedance of the terminator and that of the line and its position, which is usually at the end of the cable. Most efforts by SCSI vendors are directed at the reflection problem using various termination techniques.

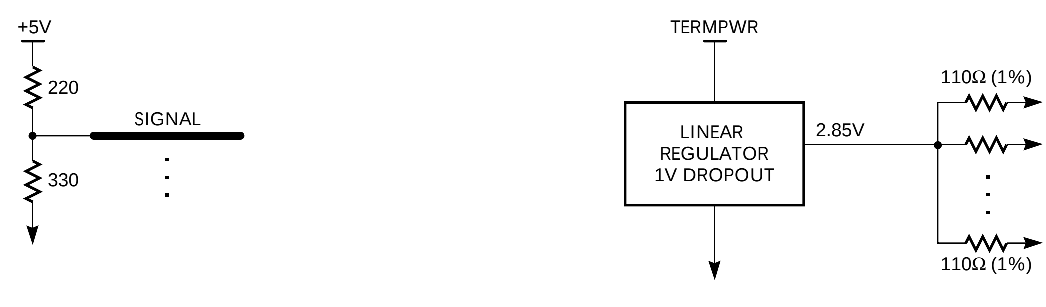
Active termination offers a potential solution to the reflection problem by attempting to address impedance mismatches by compensating for voltage drops and always maintaining a stable voltage to the terminating resistors. However, conventional active termination schemes have not proved to be effective with a fully loaded SCSI-2 bus. Another technique known as FPT (Forced Perfect Termination) uses the high speed switching capability of hot-carrier Schottky diode to approximate the "perfect" termination, however this technique currently exceeds the power guidelines presented in the SCSI-2 specification and hence is not usable.

Micro Linear has developed a MOSFET based active termination technique, which attempts to achieve a V-I characteristic that is close to the desired ideal characteristic, thus resulting in the realization of a "close to perfect" termination.

PASSIVE TERMINATION

The passive terminations used on single-ended SCSI-1 devices provided reliable operation even when fully configured systems were run at maximum cable lengths. SCSI bus lines are terminated into a resistive load consisting of a 220Ω (5%) connected to the TERMPWR line and 330Ω connected to ground, with an effective resistance equal to 132Ω, as shown in Figure 2. This technique has a number of disadvantages, the main one being that a resistive path always exists between TERMPWR and ground, hence dissipating power continuously, even when all the lines are negated. For a TERMPWR voltage of 4.8 volts, the terminator will dissipate 41mW per inactive line (8.6mA x 4.8V).

Another disadvantage of the passive termination technique is that the Thevenin voltage is not regulated and thus varies with TERMPWR. For a TERMPWR variation of 4.25V to 5.25V the output voltage varies from 2.55V to 3.15V. This creates a correspondingly large variation in the amount of current supplied to an asserted line through the 220Ω resistor. 1% resistors may be required to limit the amount of current supplied with a 5.25V TERMPWR line, to be less than the maximum specification called out by the SCSI standard. An added inconvenience of this technique is that disconnection of termination is a manual process. The main advantage of the passive termination scheme is that it offers low cost and low system complexity. However, meeting the promised performance goals of SCSI-2 and SCSI-3, with any degree of reliability, has turned out to be more difficult than anticipated. To cope with the more stringent requirements of SCSI-2, the standard recommends the use of active termination techniques like the one propounded by Paul Boulay.



Passive Terminator (Resistor Network)

Active Terminator (Boulay Type)

Figure 2. Termination Techniques

BOULAY TERMINATOR

The Boulay terminator, as shown in Figure 2, includes a voltage regulator as an active element. The voltage regulator provides a voltage source of 2.85V in series with a 110Ω resistor. This scheme is better suited to terminate lines with lower characteristic impedance, which is fairly common. Also the active voltage regulation improves noise immunity and a substantial reduction in average power dissipation is achieved because a negated or high impedance line conducts zero current through its 110 ohm termination resistor. Thus the only power dissipated is the 5–10 mA (typical) of current required to power the regulator.

Because the Thevenin voltage is regulated, the output current is for the most part immune to TERMPWR variations. However, in order to provide the maximum current permitted by the SCSI standard, without exceeding it, the 110Ω resistors must be 1%. If the resistors are incorporated on chip with the regulator, laser trimming is required, thus resulting in higher manufacturing costs.

To disconnect a Boulay terminator from the SCSI bus, it depends on whether the resistors are incorporated on chip or not. In the configuration where they are external, the resistor pack must be removed manually to achieve disconnection. In the configuration where the resistors are incorporated on chip with the regulator, an active switch is usually placed in series with each terminating resistor and a single pin is used to disable the regulator and open all switches.

The Boulay terminator overcomes many of the problems associated with the passive termination technique, thus resulting is more reliable system operation at higher speeds and over longer cables. However, the Boulay scheme is optimal only for a SCSI cable with a characteristic impedance of 110Ω.

TERMINATOR V-I CHARACTERISTICS

In the real world, however, 110Ω cables are few and far between. In a typical system, SCSI cable stock is in the 80 to 90Ω range and the impedance could even be lower for a heavily loaded bus. In a typical SCSI subsystem, the open collector driver, when asserted, pulls low and when it is negated, the termination resistance serves as the pull-up. A typical cable response for a pulse is shown in Figure 3. The receiving end of the cable will exhibit a single time delay, but when negated the initial step will reach an intermediate level, defined as V_{STEP}. The main problem of double clocking happens if the sampling occurs during this step portion. In order to get the most noise margin, the step needs to be as high as possible. V_{STEP} is defined as follows :

$$V_{STEP} = V_{OL} + (I_O \times Z_O)$$

where
V_{OL} = the Driver output low voltage
I_O = current from receiving terminator
Z_O = characteristic impedance of cable

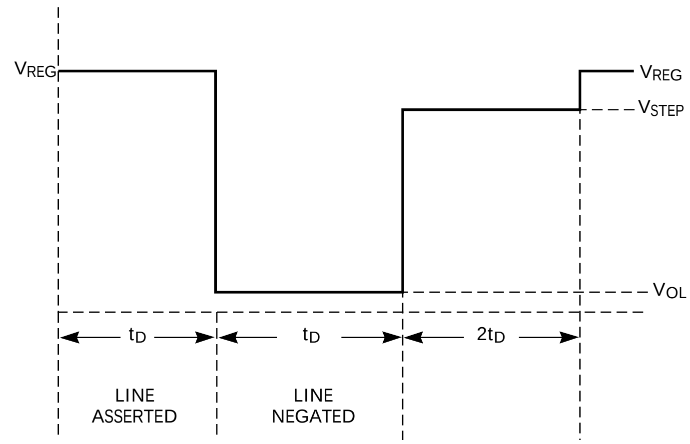


Figure 3. Cable response due to reflection

Lower impedance cables require a higher source current to achieve a sufficient voltage step when the traveling wavefront reaches the terminator end, from the driver impulse.

The V-I characteristics of the various termination schemes are shown in Figure 4. As can be inferred from this figure, a higher I_O suggests that the desired terminator V-I characteristics follow the 'ideal' V-I curve, i.e. 24 mA current source all the way up to 2.85V, for signal negation. However in the case of signal assertion, the 'ideal' curve poses a problem. This is because when the driver impulse wavefront reaches the terminator, it encounters what looks like a high impedance current source, which results in a large reflection back to the driver end, especially when the cable characteristic impedance is not 110Ω. This manifests itself as ringing in the middle of the line, in the case of middle of the line driver. Extensive simulation suggests that the Boulay V-I characteristic is desired for signal assertion transients, while the 'ideal' current source V-I characteristic is desired for signal negation transients. This implies that the V-I characteristics of the 'perfect' terminator falls somewhere in between, for optimum performance.

A terminator architecture which provides this type of V-I characteristic will have sufficiently better transient response for signal negations in systems with low cable impedances (Z_O). Signal assertion transients would be degraded somewhat but this can be partially offset with the use of appropriately designed negative clamping circuits. Interestingly enough the VDS-ID characteristic of a MOSFET transistor approximates this target characteristic, thus resulting in the design of an optimized active SCSI terminator like the ML6509.

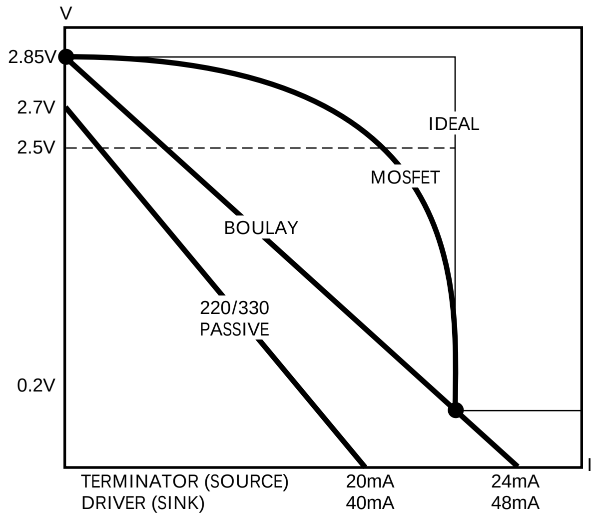


Figure 4. Terminator V-I characteristics

ML6509 - MOSFET BASED TERMINATOR

Architecture

This active SCSI terminator architecture also includes a voltage regulator as an active element (like the others discussed above), which provides a voltage source of 2.85V. However instead of 110Ω series resistors, MOSFETs are used, as shown in Figure 5. If a P-Channel MOSFET is biased in the triode region, it looks like a resistor most of the way down, to within VT of ground. If the P-Channel MOSFET were biased in the saturation region, it looks like a current source most of the way down. The VDS-ID characteristic of the MOSFET follows a trajectory that is in between the 'ideal' and the Boulay V-I characteristic, which coincidently happens to be the optimal characteristic desired to implement a 'perfect' terminator, as close as possible.

Operation

From an operating standpoint when a termination line is at high impedance, the MOSFET will pull the line up to 2.85V reference, since ID = 0. Feedback forces the ID = 24mA (max) when VD = 2.85V – 0.2V because this is what the reference MOSFET is biased at. In order to ensure the consistency of the V-I characteristic of this terminator, all the gates of the MOSFETs are tied together and require only one poly fuse trim resistor to trim the desired V-I characteristic. This work towards reducing the manufacturing cost significantly. Disconnection of the terminator from the SCSI bus is achieved by pulling a single gate line low. The line capacitance is typically less than 5 pF and the ML6509 is the only SCSI terminator to guarantee this specification. For more details on the capacitance and thermal issues associated with active SCSI terminators, please refer to Application Note 25.

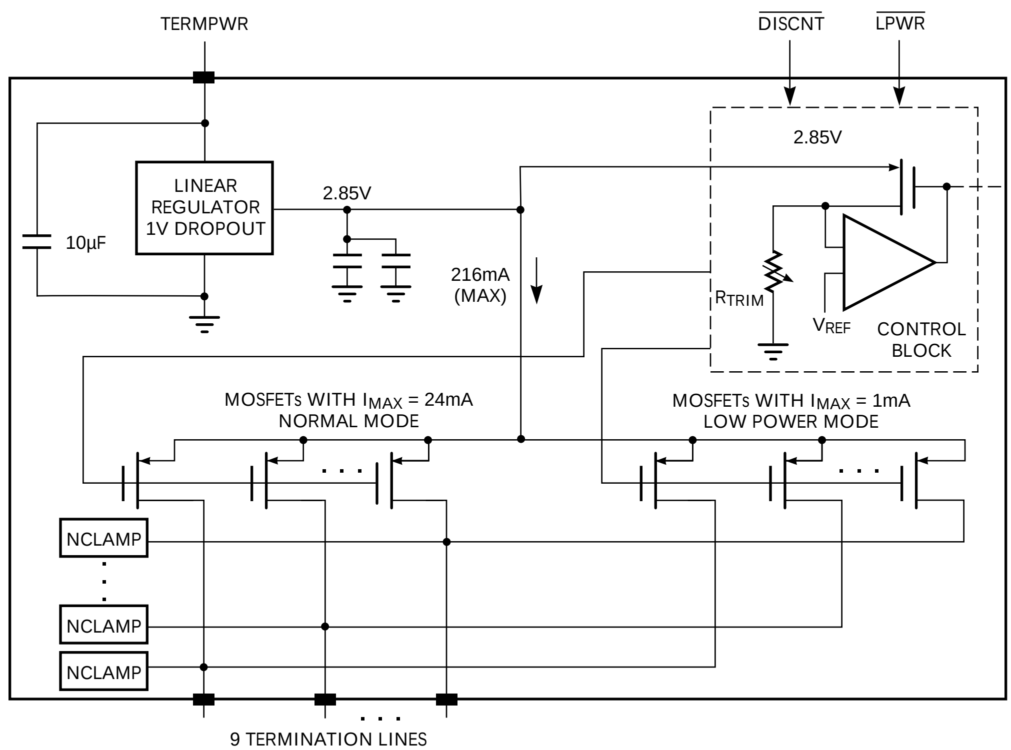


Figure 5. ML6509's MOSFET based active SCSI termination scheme

Lowpower Termination mode

With more and more notebook computers starting to offer SCSI on the motherboard and with the development of power conscious peripherals like the small form factor disk drives for such applications, even the lower power dissipation with conventional active termination schemes is not sufficient. In such applications, internal SCSI devices do not need the 24mA termination as the cables are short and the signals are very fast, hence transmission line effects are minimal. However when an external SCSI device is connected, the terminator needs to source the full 24mA current, to conform to the SCSI-2 specification. The MOSFET based active termination architecture essentially facilitates the offering of a lowpower termination mode implemented with smaller geometry MOSFETs (~1mA termination) biased by the same MOS gate reference voltage. This results in a very minimal silicon overhead, while the power dissipation is reduced by a factor of 24. With the help of a single pin ($\overline{\text{LPWR}}$), the termination can be switched to the full 24mA mode when connecting to an external SCSI-2 device.

OTHER FACTORS IN TERMINATION

There are a couple of other factors that are important with respect to active terminator solutions. These need to be taken care of to achieve the goals of a 'perfect' termination. Conventionally these were done with external components, however they are incorporated in the ML6509 chip, thus providing savings in real estate and cost.

Negative Clamp

A negative clamp circuit is essential to handle the signal assertion transients. This limits the amount of ringing when a line pulls low by sourcing additional current. It is not a violation of the SCSI-2 specification to source this additional current in a dynamic state, as long as the line doesn't settle on the clamp in the steady state. For this reason negative clamp circuits should start sourcing current when the line falls down close to ground (<0.2V). By default all active terminator implementations will provide some negative clamping due to the ESD diodes, but the turn-on is usually too low to make a difference.

Current sink capability

Most of the systems today use active negation drivers to drive the line back up to 2.85V, which is faster than if allowed to 'float up' through the resistor. Since the SCSI-2 specification allows the active negation driver to overshoot 2.85V to a maximum of 3.2V, in such a case current is sourced back through the termination element, thus requiring the regulator to sink current. Boulay terminators need to ensure that the regulator is designed to sink current, otherwise it will loose regulation. Even if the sink capability is implemented, it is limited to 3.5mA @ 3.2V overshoot, per line, as it is going through a 110Ω resistor. In the case of the MOSFET based terminator, current sinking is much better since the MOSFETs are biased in the triode region at 2.85V and they can sink up to 10 mA per line @ 3.2V and still maintain regulation.

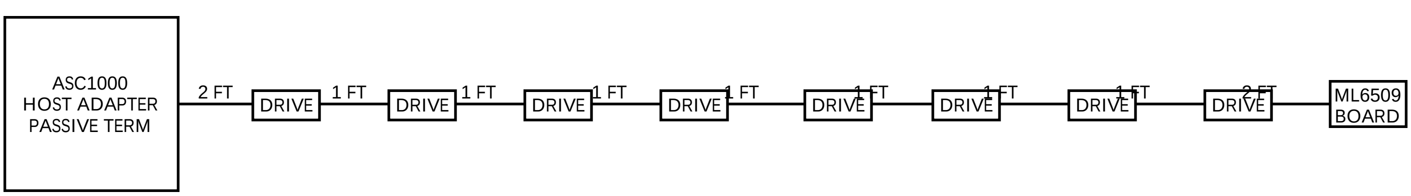
SYSTEM EVALUATION RESULTS

Some tests were done in the lab on a SCSI subsystem using ASP Inc.'s ASC1000 SCSI Host Adapter (which performs up to 12MB/s fast SCSI transfers and uses ML6509 active terminators) and also Adaptec's AHA1542 SCSI Host Adapter (which performs up to 10MB/s fast SCSI transfers). The host adapters were connected to a number of SCSI peripheral devices. These setups with the results are outlined below.

TEST 1

An full SCSI network was realized with a host adapter card having passive termination at one end, connected to seven SCSI disk drives daisy chained by 1 foot ribbon cables and the other end of the SCSI bus was terminated with a ML6509 eval board. The total cable length worked out to be 10 feet. The tests were done using both an Adaptec and ASP Inc. SCSI host adapter cards as the initiator. The signals were observed to be clean with 0.8V maximum low bounce and 2.5V minimum high ringing for a short duration.

10 FT SCSI RIBBON CABLE



Test 1

TEST 2

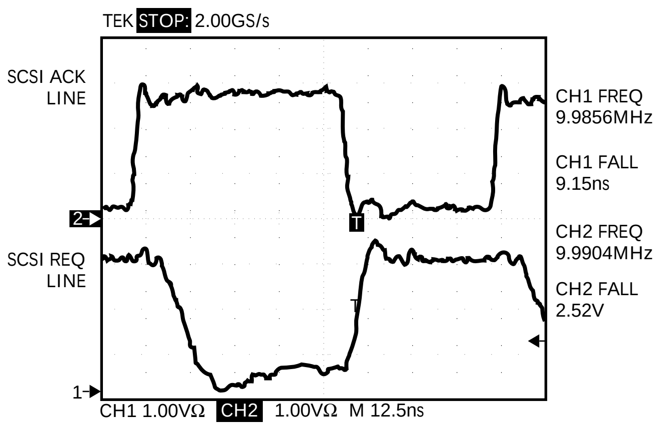
An ASC1000 SCSI host adapter with ML6509 based active termination was connected to a Maxtor 540 SCSI disk drive, with passive termination, using only a two feet SCSI ribbon cable. The REQ and ACK lines observed are shown. The terminator ensures that the signals are practically clean.

TEST 3

An ASC1000 SCSI host adapter with ML6509 based active termination was connected to a Maxtor 540 SCSI disk drive with passive termination, using a six feet SCSI ribbon cable. The REQ and ACK lines observed are shown. The effect of the slightly longer cable can be seen, however the terminator ensures that the signals are practically clean.

TEST 4

An ASC1000 SCSI host adapter with ML6509 based active termination was connected to three Maxtor 540 SCSI disk drive, with passive termination on the last drive, using a thirty feet SCSI ribbon cable. The REQ and ACK lines observed are shown. The terminator ensures that the signals are practically clean.



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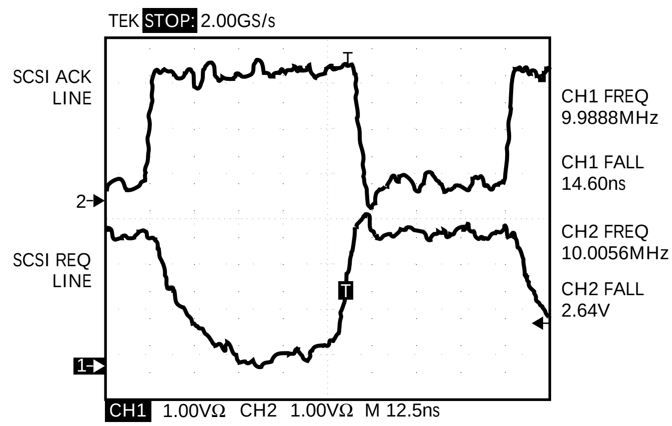
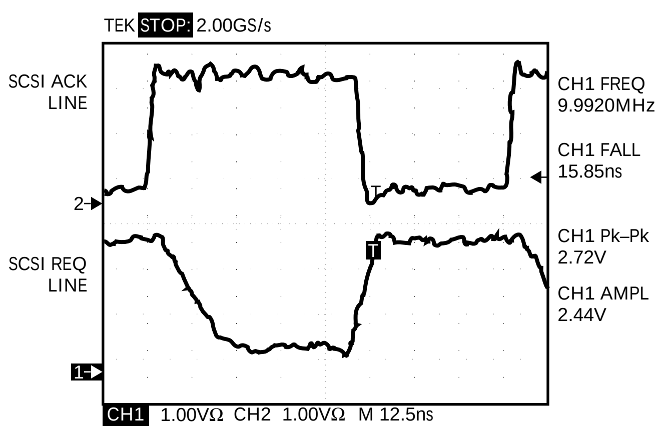


Test 3



Test 4

CONCLUSIONS

In order to ensure a very high level of data integrity and reliability of operation in either the SCSI-2 or SCSI-3 bus environments, an optimized active termination technique that offers close to the 'pseudo perfect' termination for both signal assertion and signal negation is desired.

The passive termination technique is cheap but very far away from the desired V-I characteristics for signal negation and assertion. This starts making an impact especially with fast SCSI transfer rates and the utilization of full cable lengths.

The Boulay termination technique offers a characteristic that suits signal assertion but not quite what is desired for signal negation. A pure current source implementation could result in a characteristic that suits signal negation by following the 'ideal' curve however it is not quite acceptable for signal assertion.

The MOSFET based active SCSI termination technique implemented in the ML6509, discussed in this application note, attempts to realize a characteristic that is optimal for both signal assertion and signal negation.

A typical SCSI bus configuration using the ML6509 active SCSI terminator with the associated external components, is shown in Figure 6.

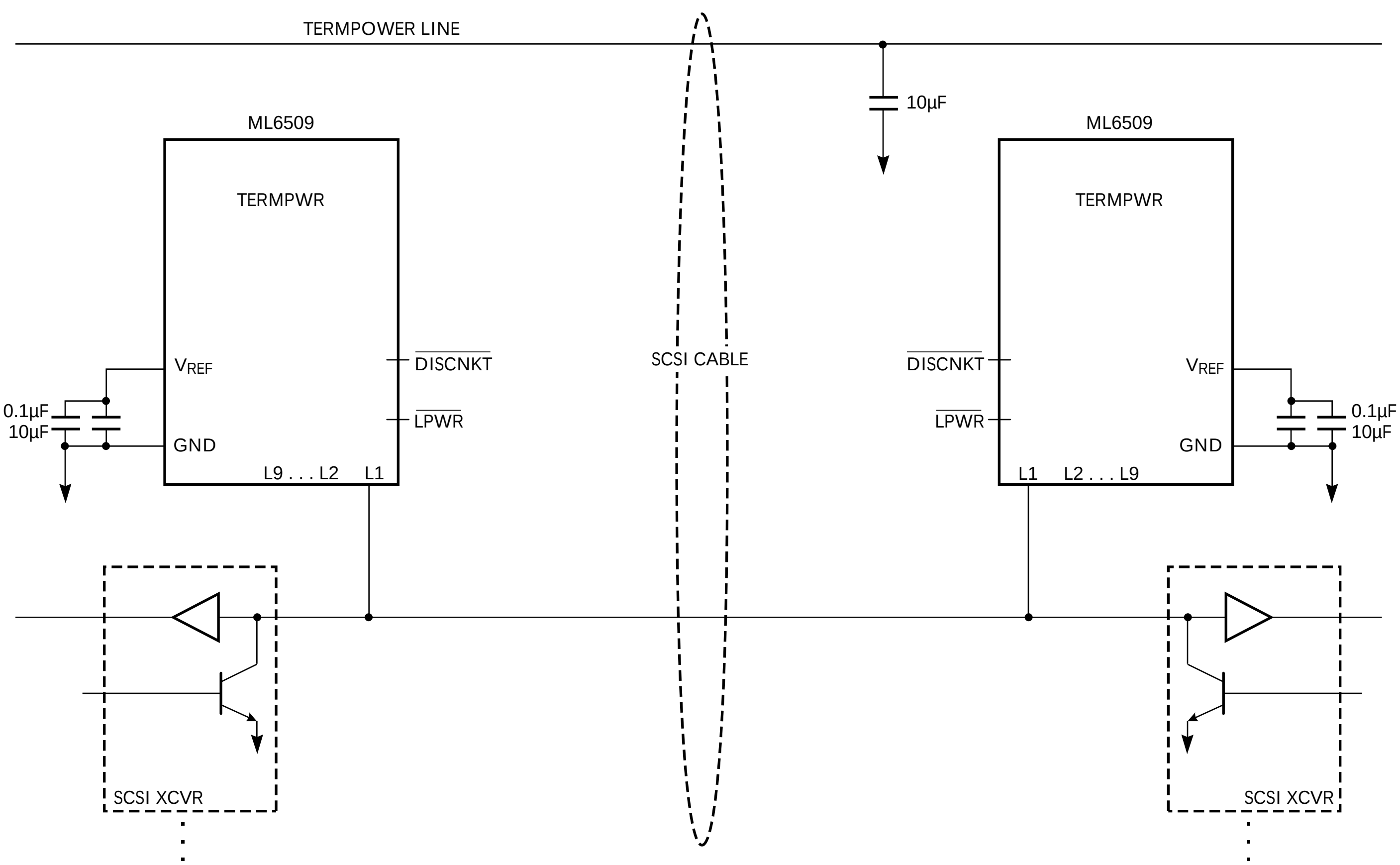


Figure 6. A typical SCSI termination configuration