LINFINITY APPLICATION NOTE

UNDERSTANDING THE SINGLE-ENDED SCSI BUS

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STANDARDS

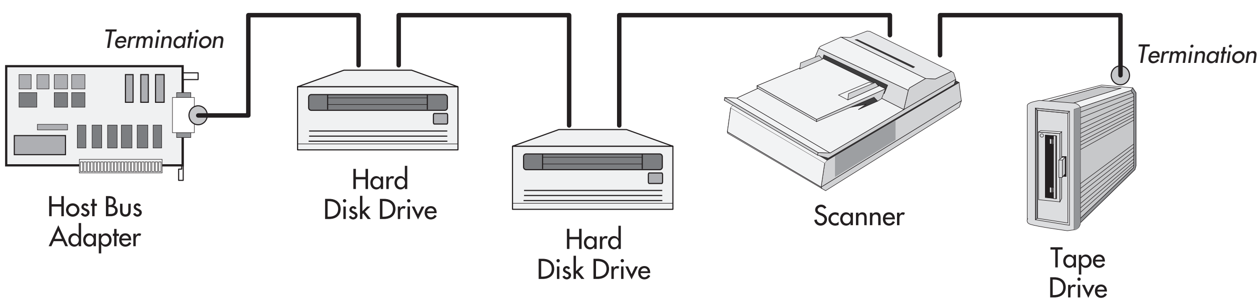
1.0 INTRODUCTION AND BACKGROUND

The Small Computer Systems Interface (SCSI) is a local I/O bus that is used to connect up to seven peripherals to a host computer. A wide variety of peripherals can be connected including, hard drives, tape drives, CD-ROMs, scanners, etc. The SCSI physical interface is either parallel or serial. This application note discusses the parallel SCSI standard. The SCSI parallel interface is either a differential or single-ended interface (one of the pairs of conductors grounded) with a maximum cabling length of 6 meters. The differential interface has better noise immunity, allowing systems with cable lengths up to 25 meters. The differential interface requires external transceivers (high powered drivers cannot be integrated without these transceivers) making it a higher cost solution. The single-ended interface comprises about 95% of the SCSI market and is the topic of this application note.

SCSI peripherals are connected either via cable or backplane. Data is either 8-bits (narrow) or 16-bits (wide). The number of addressable devices per system is determined by the width of the data path, i.e. wide SCSI can have 16 devices. A System can be multi-initiator and multi-target. Data transfer is either synchronous or asynchronous (REQ offset 0). The two signals that trigger data transfer on the bus are REQ (request) and ACK (acknowledge).

The trend since SCSI's introduction has been for SCSI systems to operate at increasingly higher transfer rates (1 Megatransfers/sec increased to 20 Megatransfers/sec) while maintaining backward compatibility. Because of these requirements and the fact that the cable environment is uncontrolled, proper termination of the SCSI bus (it must be terminated at both ends) is very important to maintain signal integrity.

Typical SCSI System



The function of a SCSI terminator is to source current when the line is asserted, and to maintain the proper open circuit voltage when the line is deasserted. Since the cable environment is not controlled, the termination impedance does not match the cable impedance (there will be reflections). Reflections contribute to improper bus performance.

All signal lines should be terminated at each end of the bus. The only lines that do not require termination are those labeled Reserved, Ground, and Termpower. A SCSI terminator is required to source current to the line when the voltage is below 2.5V DC and this current should not exceed 24mA for any voltage above 0.2V DC (SCSI-3, ULTRA [FAST-20]). Also, the terminator should not source current when the voltage is above 3.24V. Along with these requirements the SCSI terminator should be active negation compatible, have low-disabled output capacitance and low channel-to-channel crosstalk, and have good power supply rejection.

1.1 SCSI STANDARDS

SCSI-1

The SCSI-1 standard was approved in 1986 (ANSI X3.131-1986). The SCSI-1 standard called for an 8-bit wide parallel bus. The maximum transfer rate was 5 Megatransfers/sec and a maximum of 7 peripherals plus the controller were permissable. The termination was a 220/330 ohm voltage divider. A typical SCSI-1 system implemented a short bus with one target and one initiator, had a transfer rate of 1 Megabyte/sec (asynchronous mode only), and was single-ended only (no differential). SCSI-1 also had some compatibility problems between different vendors because vendors implemented different aspects of the specification.

STANDARDS

1.1 SCSI STANDARDS (CONTINUED)

SCSI-2

SCSI-2 was approved May 1994 with the following features:

- Typical transfer rate of 5 Megatransfers/sec (synchronous)
- Bus can be 32-bit wide, although the 16-bit wide bus is what became popular
- Differential interface added (IEEE-485 version)
- More SCSI peripherals supported

At this time, SCSI-1 became a subset of SCSI-2 and backward compatibility was preserved. It was at this point that termination became important to improve signal integrity.

SCSI-3 *(SPI X3T9.2 855D Rev 12)*

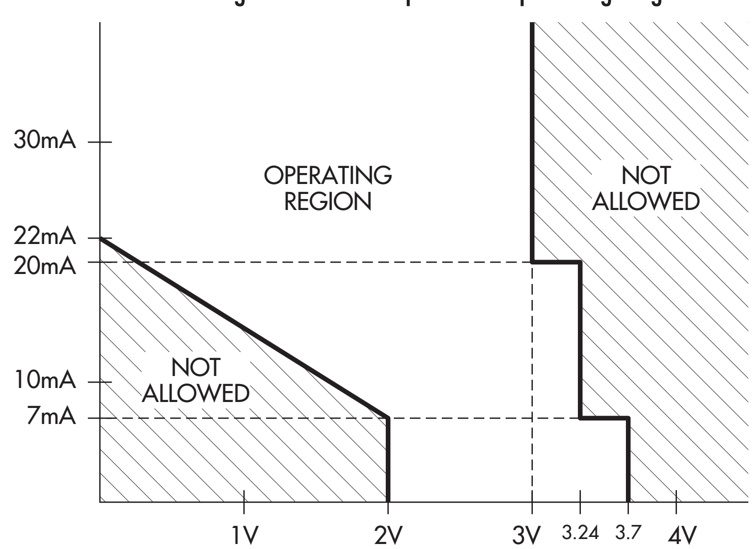
The SCSI-3 parallel interface (SPI) is the hardware section of the SCSI specification. Fast SCSI-3 has a maximum transfer rate of 10 Megatransfers/sec. The maximum cable length at this speed is 3 meters. Using a 3-meter cable length and 0.3 meter spacing between devices, ULTRA (FAST-20) SCSI will support a maximum of 11 peripherals. If the speed is 5 Megatransfers/sec or less, then 6-meter cable can be used. With the advent of the SCSI-3 specification, the cable impedance was specified as 72 ohms to 96 ohms with a maximum difference between any conductor of 12 ohms. A 68-pin connector and a hot-swap specification were also added. The 220/330 ohm termination is specifically no longer allowed. At this point SCSI is expanded to cover both parallel and serial interfaces.

ULTRA *(FAST-20) / (X3T10/94-061)*

Ultra is an annex to SPI that specifies the system configuration to operate at 20 Megatransfers/sec. The cable configuration specifies a maximum cable length of 1.5 meter if there are 5 to 8 devices (25 pF maximum) on the bus. If there are four or less devices, the maximum cable length can be 3 meters. The following changes were also made;

- Reduced skew budget
- Receiver threshold tightened, 1V to 1.9V (300mV hysteresis)
- Driver slew rate 520mV/ns (0.7V to 2.3V DC)
- Receiver glitch filter removed
- Cable impedance 90 ±6Ω for REQ and ACK
- Active negation drivers are required (See Figure below)

Active Negation Driver Specified Operating Regions



CABLE PERFORMANCE

2.0 CABLE PERFORMANCE

2.1 CABLE

The cables used for interconnecting SCSI devices must be treated as transmission lines. The types of cable typically used for SCSI are, unshielded flat ribbon cable, unshielded flat twisted pair ribbon cable, unshielded round twisted pair cable, and shielded round twisted pair cable.

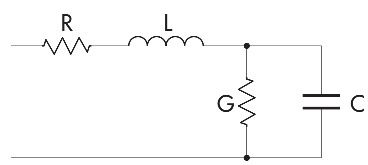
The SCSI standard specifies the maximum cable length, cable impedance, and attenuation. For SCSI-3, the cable impedance can range from 72 ohms to 96 ohms (single-ended) with no more than 12 ohms difference between conductors in a cable. The ULTRA (FAST-20) annex specifies a range of 80 ohms to 100 ohms (84 ohms to 96 ohms for the clock signals REQ and ACK).

The standard also specifies the maximum cable length. The maximum (single-ended) cumulative cable length is 6 meters if the data transfer is 5 Megatransfers/sec or less. The maximum cable length is 3 meters if the transfer rate is above 5 Megatransfers/sec. The ULTRA (FAST-20) annex further specifies the cable length based on loading. If there are 4 or less devices, the cable length can be 3 meters, if there are 5 to 8 devices, the maximum cable length is 1.5 meters. The maximum cable length for differential SCSI is 25 meters.

The impedance is specified as either differential or single-ended. If the measurement is not specified it is usually differential. The differential impedance is usually larger that the single-ended impedance by 30% to 50%. The differential impedance is measured one pair at a time with all the other conductors floating. The single ended impedance is measured with the other conductor and shield at Ground. The closest conductors are also grounded.

The cable characteristics are easily calculated if the cable inductance per unit length, capacitance per unit length, and resistance per unit length are known. The figure below shows a segment (unit length) of a lossy transmission line.

R = Series resistance L = Inductance
G = Shunt conductance C = Capacitance



The cable impedance is $Z(\varpi) = [(R+j\varpi L)/(G+j\varpi C)]^{1/2}$. In most cases the shunt conductance (leakage between conductors) and the series resistance can be ignored. The equation for impedance then simplifies to $z = (L/C)^{1/2}$. Typical values for L and C are 16pF/ft and 130nH/ft (Z = 90 ohms).

The propagation delay is $T(x) = x\,(LC)^{1/2}$. The inductance and capacitance are per unit length, and x is the number of segments.

The attenuation is $att(x) = e^{-[Rx/\{2(L/C)^\wedge 1/2\}]}$. This can be simplified and defined in dB per unit as $att(x) = 4.34\,[R/(L/C)^{1/2}]\,dB$. The three basic equations for defining cable impedance, propagation delay, and attenuation are summarized below.

$$Z = (L/C)^{1/2}, \quad T(x) = x\,(LC)^{1/2}, \quad att = 4.34\,[R/(L/C)^{1/2}]\,dB$$

From a cable standpoint, smaller conductor size and greater conductor spacing increase inductance (yielding a higher cable impedance). The capacitance is increased by using a higher dielectric constant insulation, larger conductor size, and closer spacing of conductors (yielding lower cable impedance).

Signal attenuation can became a problem for long buses or as speeds increase. The SCSI standard sets the maximum attenuation at 0.095 dB/meter. The attenuation is measured differentially. Attenuation typically increases with frequency and is higher when measured single ended. To have low attenuation cables, the conductor should be no smaller than AWG 28 and should have a good dielectric insulator.

For long twisted pair cables, crosstalk can be a problem. The clock signals REQ and ACK have the largest crosstalk problem. The recommendation for reducing crosstalk for single-ended operation, is to use the following conductor configuration: REQ/ACK use the cable core, data/parity use the outer conductors, and for GND, V_{TERM}, RESET, and the phase lines use the middle layer conductors. The highest impedance conductors are usually in the core and the lowest impedance conductors are on the outside.

In general, power should be distributed on the lowest impedance lines and data, and REQ/ACK on the highest impedance lines.

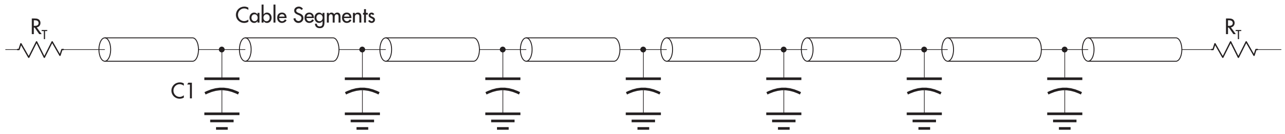
CABLE PERFORMANCE

2.2 EFFECT OF CAPACITIVE LOADING

A SCSI system can consist of up to 16 devices (wide) daisy-chained along a cable. The capacitance of the devices and their spacing along the cable change the characteristics of the bus. The SCSI standard specifies the following physical characteristics to assure proper system performance. The maximum capacitance cannot exceed 25pF, peripherals have to be separated by 0.3 meter (stub spacing), and the stub length cannot exceed 0.1 meter. If the stub length exceeds 1/3 of the rising edge, then you should terminate at the stub.

If the capacitive loads are evenly spaced and the length of the rising edge exceed the spacing between loads, then the following parameters are changed.

1) *The effective line impedance is reduced*
2) *The propagation delay is increased*
3) *The attenuation in increased*



The capacitance added by the peripherals is defined as $C' = (N * C_{LOAD})/length$, where N is the number of loads, C_{LOAD} is the capacitance of each load and length is the total length of the bus expressed in the same units as the unloaded capacitance of the bus, i.e. pF/ft. The effective parameters are then:

$Z = (L/(C+C'))^{1/2}$ (loaded bus impedance)
$T(x) = x(L * (C+C'))^{1/2}$ (increase in propagation delay)
$att(x) = 4.34\ [Rx/(L/(C+C')^{1/2})]\ dB$

As an example, consider a system with seven loads separated by 1 foot (as in figure above). The unloaded cable characteristics using L = 130nH/ft and C = 16pF/ft are:

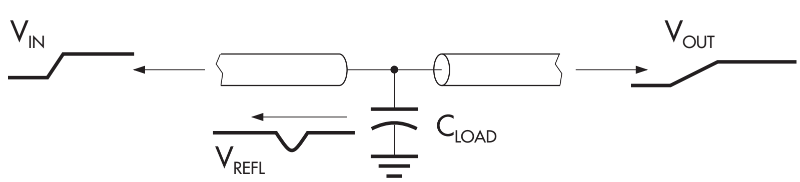
$Z_C = (130nH/ft\ /\ 16pF/ft)^{1/2} = 90\ ohms$
$T = (130nH/ft * 16pF/ft)^{1/2} = 1.44\ ns/ft$
$att = 4.34\ [.01\Omega/ft\ /\ (130nH/ft\ /\ 16pF/ft)^{1/2}]\ dB = 0.00048dB/ft$

If seven 15pF loads are separated by 1ft (0.3m) then the effective system parameters become:

$C' = 7 * 15pF/7ft = 15pF$
$Z_O' = (130nH/ft\ /\ (16pf/ft + 15pf/ft))^{1/2} = 65\ ohms$
$T' = (130nH/ft\ (16pf/ft + 15pf/ft))^{1/2} = 2ns/ft$
$att' = 4.34\ [0.01\Omega/ft\ (130nh/ft\ /\ (16pf/ft + 15pf/ft))^{1/2}]\ dB = 0.00067dB/ft$

Note that in the above example, the overall system characteristics were degraded by adding the capacitive loads. As system speeds increase, it becomes important that the load capacitance from line to line remain constant since these capacitor mismatches will add to the system skew. A 1pF mismatch at a peripheral would add approximately 0.4ns skew. If the mismatch was systematic, this would be a problem for ULTRA (FAST-20), since there is only a 6ns Set-Up and 11ns Hold Skew Budget.

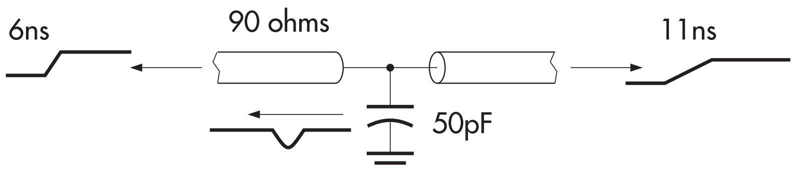
If the system has a single lumped capacitive load and the cable length on each side exceeds the signal's rising edge, the propagated rise time is reduced and there is a reflected signal from the load.



CABLE PERFORMANCE

2.2 EFFECT OF CAPACITIVE LOADING (CONTINUED)

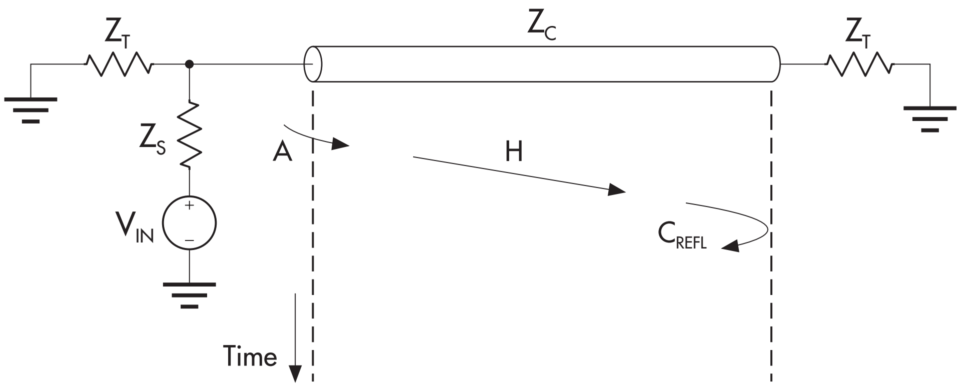
The rise time degradation is $T = 2.2CZ_O/2$, where C is the capacitive load and Z_O is the unloaded cable impedance. There will also be a reflection that is given by $V_{REF} = -C (Z_O/2) (dV/T_{RISE})$, where dV is the voltage step of the incoming signal and T_{RISE} is the rise time (10% to 90%). The frequency above which the bus would be unable to transmit is $f = 1/ (CZ_{OPI})$. For SCSI, the loaded unusable frequency is below this, and a good rule of thumb is not to use a load over twice the size of the distributed bus capacitance, i.e. if the bus is 16pF/ft, don not use a load above 32pF. An example of a single load is given below.



The rise time degradation is $T = 2.2 * 50pF * 90/2 = 5ns$. The rise time after the load then becomes 11ns. The reflected voltage is $V_{REFL} = -50pF * 90/2 * 3V/6ns = -1.1V$. It is apparent from the example that large lumped loads adversely affect system performance and should be avoided if possible.

2.3 REFLECTION COEFFICIENTS AND NOISE MARGIN

To calculate overall system performance and noise margin, a reflection and acceptance diagram can be used. One of the most important aspects of this diagram is how much of the signal is reflected from the impedance mismatch between the terminator and the cable. The reflection coefficient is defined as $\Gamma = (Z_T-Z_C) / (Z_T+Z_C)$, where Z_T is the terminator impedance and Z_C is the loaded cable impedance.



The parameters in the diagram are:

- Z_T = Termination impedance
- V_{IN} = Input step from driver
- Z_C = Cable impedance (loaded)
- A = Acceptance defined as $A = Z_C/(Z_C+Z_S)$
- H = Attenuation
- Γ = Reflection coefficient

A perfectly terminated system will have a zero reflection coefficient. Another important figure of merit is the voltage standing wave ratio (VSWR). This is defined as $VSWR = (1+ |\Gamma|) / (1- |\Gamma|)$. Ideally the standing wave ratio is 1. Generally, standing waves are not a problem because of the cable lengths and operating frequencies of SCSI systems. Standing waves are every 90 degrees or lamda/4 where the wavelength Γ is defined as $\Gamma = 1/(f(LC)^{\wedge}1/2)$.

CABLE PERFORMANCE

2.3 REFLECTION COEFFICIENTS AND NOISE MARGIN (CONTINUED)

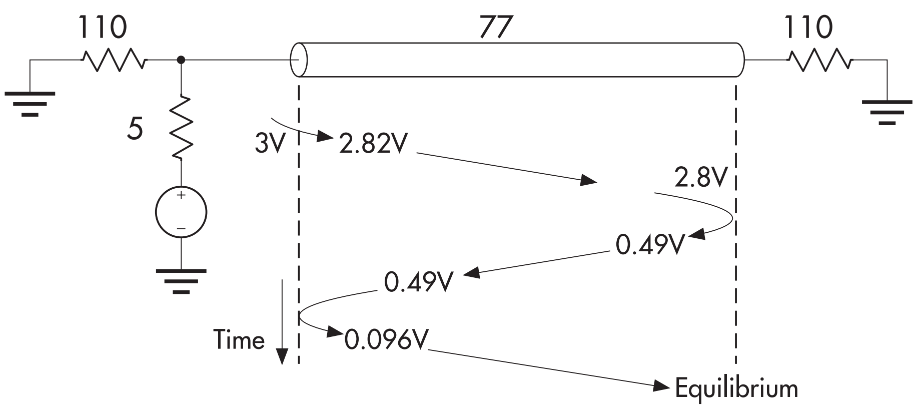
To use this basic model of a reflection and acceptance diagram, the minimum amount of information required is:

1) Bus length, unloaded cable inductance and capacitance per unit length, resistance
2) Number of loads, capacitance per load, load spacing
3) Open drain or active negation driver

From the above information you can then calculate the following:

1) Loaded impedance
2) Loaded attenuation
3) Reflection coefficient
4) Acceptance (assume 5 ohm driver impedance for initial step and then high impedance after)
5) Wavelength if you are concerned about standing waves.

As an example, let's assume you have a system that has a cable impedance of 90 ohms (L = 130nH/ft and C = 16pF/ft) and three 15pF loads with two feet between each stub. Also assume the driver source impedance is 5 ohms and the input step is 3V. The termination impedance is 110 ohms. The added distributed capacitance is $C' = (3 * 15pF)/6ft = 7.5pF$. The loaded cable impedance then becomes $Z_C = (130nH/ft\ /\ 22pF/ft)^{1/2} = 77\ ohms$. The reflection coefficient then is $\Gamma = (110\text{-}77)/(110+77) = 0.18$. The acceptance is $A = 77/(77+5) = 0.94$. The reflection diagram then becomes:



The attenuation factor used is $att = e^{-[(0.01ohm/ft * 6ft/(2(130nH/ft\ /\ 22pf/ft)\text{^}1/2)]} = 0.996$ after six feet. In this case the attenuation factor was not worth using in the reflection diagram. This system is over terminated so it is worth considering the voltage standing wave ratio, $VSWR = (1.0+0.176)/(1\text{-}0.176) = 1.427$. If the operation frequency is 10MHz then the wavelength is $\Gamma = 1/(10MHz * (130nH/ft * 22pF/ft)^{1/2} = 59ft$. The nodes for the standing waves are $\Gamma/4 = 59ft/4 = 14.75ft$. However, standing waves will not be a problem in this configuration. The reflection diagram shows that this configuration reaches equilibrium after one reflection.

If the line is being asserted, the only differences you use are 0.2V for the level while the driver sets the reflection coefficient at the driver end as long as it is asserted. This reflection coefficient is $\Gamma = (5\text{-}77)/(5+77) = -0.87$. Using these numbers, you can go through the same procedure.

The other case is an open drain driver that goes high impedance and depends on the current in the line for the first step. In this case, the amount of current supplied by the terminator becomes very important. The first step upon deassertion (at the driver) is $V_{STEP} = V_{OL} + IZ_O$. The voltage V_{OL} is the driver output low voltage (usually around 0.2V), I is the current available from one terminator and Z_O is the loaded cable impedance. In this example, the first step is $V_{STEP} = 0.2V+22mA * 77ohms = 1.894V$. This is then the voltage that is used for the voltage step (vs. 3V with the negation driver) and the same calculations can be done as before. In this case, it will take several reflections to reach a 2.5V level.

To calculate the overall system margin, use the maximum and minimum conductor impedance coupled with the minimum and maximum terminator impedance. Once these values are known, do the calculations and see if any of the signals have insufficient noise margin.

POWER DISTRIBUTION

3.0 TERMINATION POWER DISTRIBUTION AND BYPASS CAPACITOR SELECTION

The power for remote terminators is available from the cable (Termpower line). In general, if you are an initiator, you should supply Termpower to the bus. Termination power may also be provided by a local VDD. The minimum Termpower voltage is 4.25V and the maximum Termpower voltage is 5.25V. The minimum current is 1.5A and the maximum current is 2.0A. Termpower is supplied through a backflow diode (1N5820 is sufficient) and a fuse or electronic circuit breaker. The backflow diode prevents a powered down system from grounding Termpower. The minimum allowed conductor size for Termpower is AWG28.

If Termpower is being supplied through a long cable the DC voltage drop can become significant. To calculate the voltage drop use the appropriate ohms/ft for your cable (depending on wire gauge) and approximately 0.05ohm for each connector. For the worst case current, use 648mA for wide SCSI and 432mA for narrow SCSI.

As an example, a wide SCSI system has 27ft of cable (at 0.01 ohm/ft) and 6 connectors (at 0.05 ohm/connector) and the Termpower voltage is 4.5V. The total resistance is *(27ft * 0.01ohm/ft) + (6 connectors * 0.05ohm/connector) = 0.57ohm*. The voltage drop is $V_{DP} = 0.57ohm * 0.648mA = 0.37V$. The voltage at the terminator is $V_{TERM} = 4.5V\text{-}0.37V = 4.13V$.

Every peripheral needs to have a bypass capacitor on termination power. This capacitor should be located as close as possible to the terminators. This capacitor supplies the transient current and the SCSI standard recommends a 2.2µF minimum capacitor.

To calculate the size of the bypass capacitor:

1) Calculate the maximum common path impedance. This is the maximum voltage drop that your terminator can tolerate without degrading it's performance and the needed current. For the current use 648mA for wide SCSI and 432mA for narrow SCSI. The maximum common path impedance is then $Z_{CP} = V/I$.
2) Calculate the frequency above which a bypass capacitor is needed. For this calculation, use the common path impedance from above and the total line inductance (*L/ft * #of ft*). The frequency is the $f_{CO} = Z_{CP}/(2 * \pi * L_{TOT})$.
3) Calculate the bypass capacitor size using the common path impedance from number one and the frequency from number two. The size of the required bypass is $C_{BY} = 1/(2 * \pi * f_{CO} * Z_{CP})$.

As an example, a wide SCSI system has 9 feet of cable with an inductance of 100nH/ft. The terminators can tolerate a change in voltage of 400mV.

1) The maximum common path impedance is $Z_{CP} = 0.4V/0.648A = 0.62$ *ohms*.
2) The total inductance is *9ft * 100nH/ft = 900nH*. The frequency above which a bypass is required is $f_{BY} = 0.62ohm/(2 * \pi * 900nH) = 110kHz$.
3) The size of the bypass is $C_{BP} = 1/(2 * \pi * 110kHz * 0.62ohm) = 2.33\mu F$.

If possible, it is best to supply termination power locally. If power is supplied locally, a smaller bypass capacitor can be used and the minimum terminator operating voltage is less of a concern.

TERMINATION

4.0 TERMINATION

In a SCSI system, termination is required at both ends of the bus. All signals not defined as Reserved, Ground, or Termpower should be terminated. The terminator should supply current to the line when the DC voltage is below 2.5V and the current should not exceed 24mA for any voltage above 0.2V (for SCSI-3 and ULTRA [FAST-20]) (0.5V for SCSI and SCSI-2). If an undershoot clamp is used, it cannot source current at any voltage above 0.2V. The open circuit voltage of the terminator should be at least 2.5V and the terminator should not source current above 3.24V. An enabled terminator should add a maximum capacitance of 25pF to each signal. For the terminator to be hot-pluggable, it must meet the following conditions:

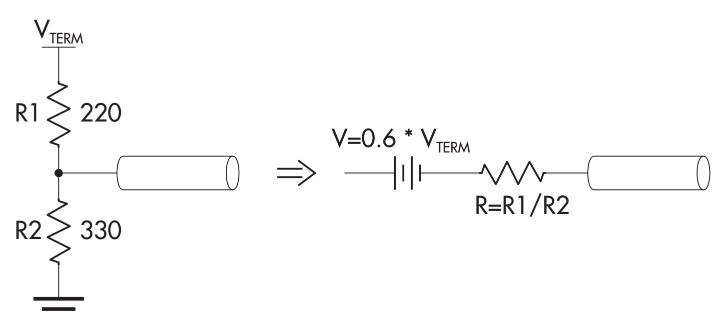
a) Maximum peak current value 1.5mA at V_I = 2.7V DC.
b) Current decays to 10% of peak value within 20µs.

Below is a list of some desirable terminator characteristics.

1) Active negation compatible (can sink current)
2) Low disabled output capacitance
3) Low channel-to-channel crosstalk
4) Electronic disable
5) Good power supply rejection
6) Low quiescent current
7) Tight output current tolerance (as close to 24mA as possible)
8) Hot-plug compatible
9) Thermal shutdown
10) Current limit

There are generally three types of SCSI terminators: (1) A passive 220/330 ohm voltage divider (V_{TH} = 2.85V, R_{TH} = 132 ohms). (2) An active linear terminator, which consists of a 2.85V voltage regulator and 110 ohms resistors. (3) An active non-linear terminator. There are also other types of terminators such as FPT (forced perfect termination) that claim to enhance signal quality, but which are often not SCSI compliant (exceed maximum allowed current).

4.1 220/330 TERMINATOR



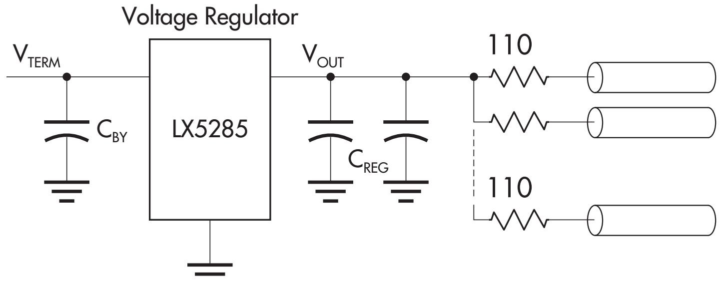
The 220/330 ohm resistor divider was the original SCSI terminator. This terminator has been dropped from the SCSI-3 parallel interface. The output current is adequate only when V_{TERM} is at the maximum voltage of 5.25V. The current is then *(3.15V - 0.2V)/132 = 22.3mA*. If the line voltage is 4.25V then the current is *(2.55V-0.2V)/132 = 17.8mA*, which gives inadequate noise margin. The 220/330 ohm terminator has no power supply rejection $V_{CC} = 0.6 * V_{TERM}$. The resistors also have high quiescent current. The quiescent current requirement for a wide SCSI system is *4.75V/550ohms * 27 = 233mA*.

The resistor packs have to be physically removed from devices that don't contain the active terminator (no electronic disable). The 132 ohm output impedance also yields a large positive reflection coefficient. This is good for open drain drivers, but is not good if active negation drivers are being used. Without sink current capability, this termination is not active negation compatible.

The 220/330 ohm termination can be used for older systems if cost is more important than performance. The 220/330 can also be used if multiple reflections (not incident waves) are adequate to achieve valid data levels or the peripherals used in the system do not contain active negation drivers.

TERMINATION

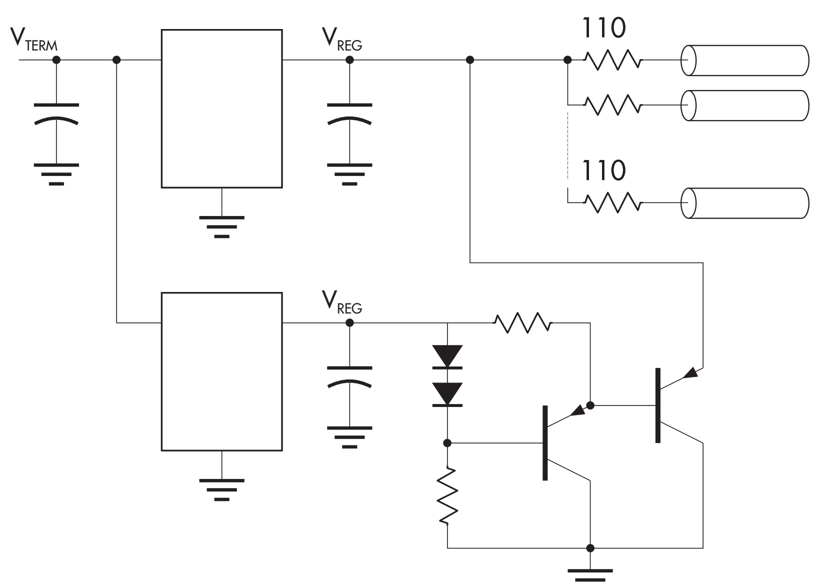
4.2 ACTIVE LINEAR TERMINATION



An active terminator consists of a voltage regulator (approximately 2.85V output) and one or more 110 ohm resistors. The active terminator can either be integrated (resistors on the IC) or reside as a stand-alone voltage regulator with separate resistor packs. The integrated version is nine or eighteen channels. The active terminator has the following advantages compared to the 220/330 ohm terminator:

1) Reduced power consumption
2) Better power supply rejection
3) Increased output current
4) Electronic disable (integrated version)

If a stand-alone voltage regulator is used with resistor packs, the regulator should have an output current of at least 650mA (27 lines times 24mA). The 800mA output current regulators are the best due to adequate output current margin. The regulator dropout voltage should be low enough to maintain regulation at the lowest Termpower voltage encountered. If the system has active negation drivers, a source/sink regulator should be used, such as Linfinity's LX5285. If a source only regulator is used, additional components must be added to sink active negation current; the example below illustrates the use of two regulators.



When using the above approach, the emitter of the sink transistor should be on the regulator side of the resistor packs. This keeps the terminator from looking like a low impedance to the bus during negation. The easiest approach, but also the least effective is to add a shunt resistor to or from the regulator output to ground. This gives limited sink current capability, but also increases quiescent current.

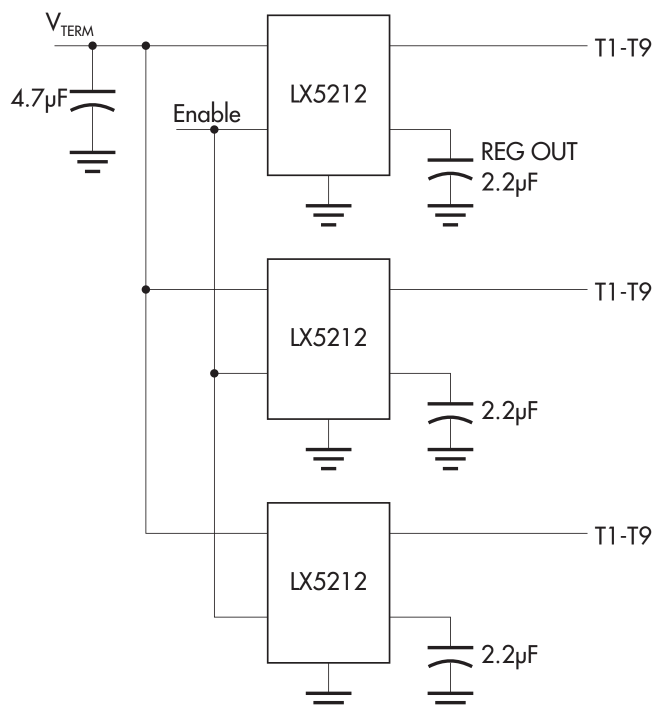
TERMINATION

4.2 ACTIVE LINEAR TERMINATION (CONTINUED)

Integrated Active Terminator

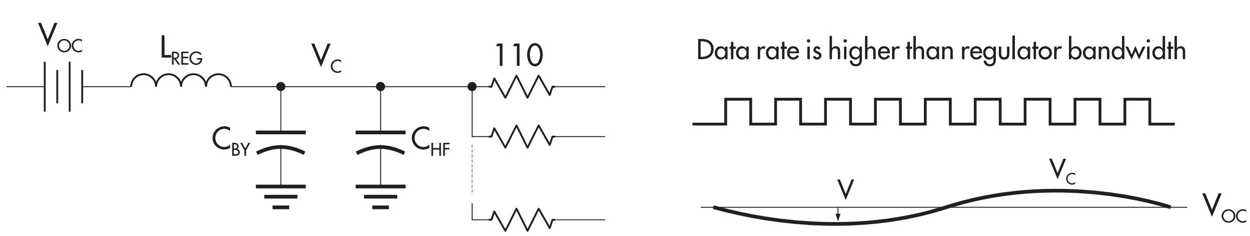
The integrated terminator is available as either a nine or eighteen channel configuration. The only external components required are a compensation capacitor for each regulator and one Termpower bypass capacitor. These terminators have electronic disable, trimmed output current, low quiescent current, and can be hot-swap compatible.

LX5212 9-Line Terminators in a Wide SCSI Application



The enable pins can be either active high or active low. The Plug and Play terminators have a dual disconnect pin and are disabled when both disable inputs are low or floating.

Proper selection of the regulator capacitor becomes important as the data rates continue to increase. The capacitor serves two purposes, i.e. stabilization for the regulator and transient current for the bus. The regulator capacitor has to be able to supply the single-step current (CdV/dt) to the bus and also compensate for the regulator bandwidth.



TERMINATION

4.2 ACTIVE LINEAR TERMINATION *(CONTINUED)*

The regulator output can be approximately modeled as an inductor in series with an open circuit voltage. The bandwidth of the regulator is much lower than the data rate, causing the voltage (V_C) to droop and then overshoot at the bandwidth of the regulator. To keep the voltage droop (or overshoot) at a minimum, a 4.7µF capacitor should be use to cover all cases (2.2µF in most). If the bandwidth of the regulator is high, the compensation capacitor will not be required.

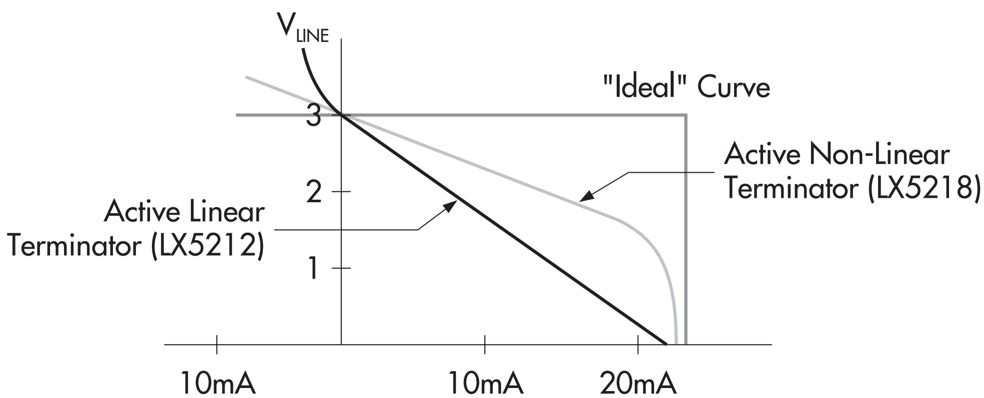
A high-frequency bypass capacitor in parallel with the compensation capacitor can be useful for high-speed transients. This is because the voltage divider between the output impedance of the regulator and the termination lines. If all the terminator lines were pulled low in phase, the equivalent resistance would be approximately 12 ohms. If a 150mV droop on the regulator voltage could be tolerated that would correlate to a 0.6 ohm impedance at the regulator pin. This case would require a capacitor of approximately 0.03µF. A high-frequency bypass capacitor in the 0.01µF to 0.1µF in parallel with the compensation capacitor will be adequate in most cases. When selecting a capacitor, a low ESR capacitor should be used.

When characterizing active linear terminators, the output impedance should be characterized over a wide voltage range. A range of 0V to 3.5V should be sufficient. Any impedance discontinuities over this voltage range could be a problem. These changes in impedance are most likely caused by undershoot or overshoot clamps that are on the cable side of the resistor. These types of clamps, if they have a slow response, can present a low impedance to the line and cause large negative reflection coefficients. Also, terminators where the output impedance is generated from an active component (i.e. MOS elements, etc.) can have impedance discontinuities. The terminator characteristics, sink current, source current, and voltage should be specified (or at least characterized) at the terminator pin and not at the regulator pin.

In ULTRA (FAST-20) systems, the disabled output capacitance should be below 5pF when measured at 400mVpp (at 1MHz). For integrated terminators the worst case output capacitance is usually at a bias voltage of 0V.

4.3 ACTIVE NON-LINEAR TERMINATION

The non-linear active terminators have a non-linear output current characteristic and represent the latest innovation in active terminators. The non-linear terminator emulates high bandwidth, channel-independent current sources which provide a continuous 24mA of output current. This concept closely matches the "ideal" terminator curve as illustrated in the figure below. As indicated earlier in our discussion of cabling and capacitance, the non-linear terminator will always provide optimal performance by maximizing the line current until the de-asserted voltage is reached.



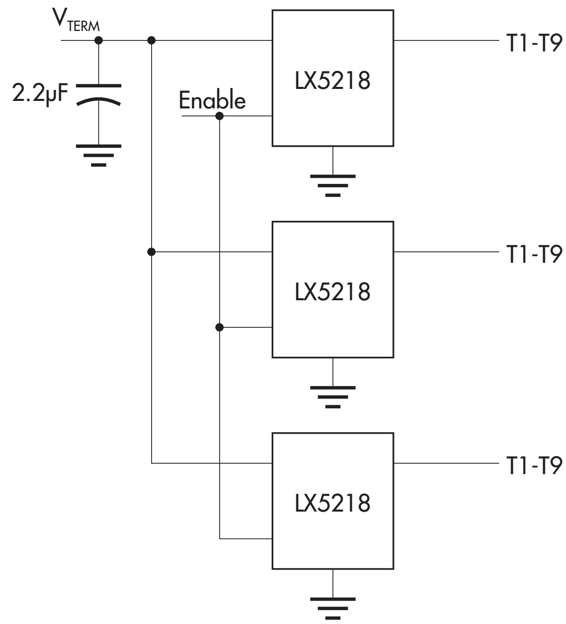
The active non-linear terminator supplies higher current than the resistive terminators at any line voltage below 2.5V. For open drain drivers, this amounts to a higher first step on deassertion and increased noise margin.

The non-linear terminator has a high bandwidth output. The LX5218 family bandwidth is approximately 35MHz. The response is fast enough that capacitors are not required to supply transient current to the bus. This removes the extra variable of selecting capacitors for high data rates. The figure on the following page shows that the only capacitor needed is the Termpower bypass.

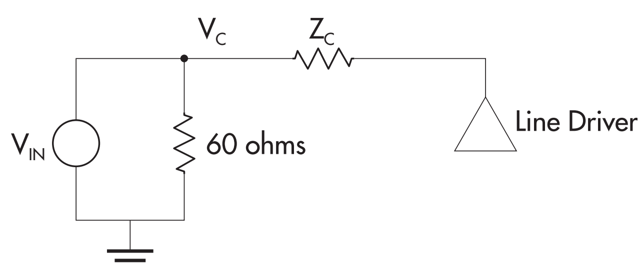
TERMINATION

4.3 ACTIVE NON-LINEAR TERMINATION (CONTINUED)

LX5218 in a Wide SCSI Application



The output characteristics of the non-linear active terminator can be modeled as a Norton equivalent. The output resistance is 60 ohms and the output current is a non-linear function of the line voltage.



This model can be used to compare the performance of the non-linear active terminator with the resistive terminators (use the Thevenin equivalent for the resistive terminators).

The advantages of the active non-linear terminator are:

1) Highest allowed output current
2) No regulator capacitors required
3) Trimmed output current
4) Active negation compatible
5) Low operating voltage
6) Electronic disable (active high or active low)
7) Low disabled output capacitance
8) Thermal shutdown

POWER PACKAGES / THERMAL EFFECTS

5.0 POWER PACKAGES AND THERMAL EFFECTS

The total system power dissipation and the corresponding junction temperature is important to calculate, because if the terminators junction temperature becomes too high, system performance can be degraded and the long-term reliability of the terminator can be reduced.

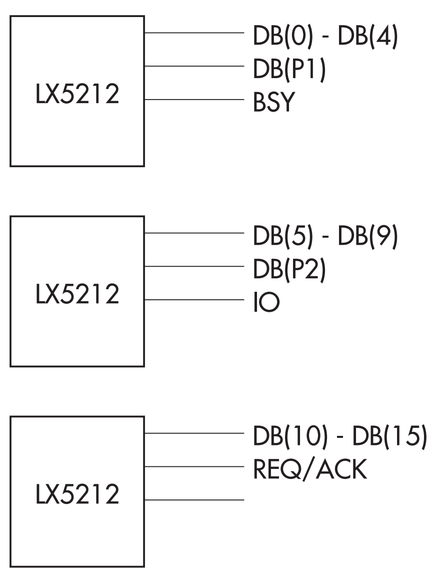
The temperature characteristics of the package should be given along with the thermal shutdown temperature of the IC (if there is hysteresis). The temperature coefficient of the output current and output voltage should be specified.

Linfinity offers both SOIC and TSSOP power packages. The die attach pad is connected to the external leads labeled Heatsink Ground (HS-GND). The Heatsink Ground pins should be attached to an external heatsink (large etch area, etc.). The characteristics of these packages is listed below:

Package	***Theta J_A***	***Theta J_C***
16-pin SOIC	44°C/W	20°C/W
28-pin SOIC	30°C/W	18°C/W
20-pin TSSOP	85°C/W	34°C/W
24-pin TSSOP	70°C/W	27°C/W

To calculate the total power dissipation use $PD = (V_{TERM} - V_{OL}) * (I_{OUT}) * (\# \text{ of lines asserted})$. V_{TERM} ranges from 4.25V to 5.25V. In an application where all the data lines are low, V_{TERM} could be 4.25V or below due to DC resistance in the cable. V_{OL} is the driver output low voltage. V_{OL} usually ranges from 0.2V to 0.5V. I_{OUT} is the terminator output current per line. I_{OUT} is usually between 20mA and 24mA. The rise in junction temperature is then $T = \theta J_A * PD + T_A$ where T_A is the ambient temperature.

The worst-case power dissipation would occur in a wide SCSI application with all the data lines asserted. This could yield 21 lines asserted, 16 data, 2 parity, REQ or ACK (or 50% duty cycle), BSY, and I/O. The other lines ATN, RST, MSG, SEL, and C/D are deasserted. In this case, the lines could be divided between terminators to reduce power dissipation per terminator. A nine-channel terminator example is illustrated below.



The rest of the lines can be placed in the most convenient order. Dividing data lines between different terminators is a good practice, but in most cases, the number of lines and associated duty cycle yields a much lower power dissipation then the worst-case calculation.