Multimode Ultra2 SCSI Terminators and Low-Voltage Differential (LVD) Signalling

Introduction

This application note defines and describes the Ultra2 SCSI physical interface and discusses differential signaling. The advantages of the parallel SCSI interface and the evolution from parallel SCSI to Ultra2 SCSI are also discussed.

Parallel SCSI Advantages

The Small Computer Systems Interface (SCSI) was originally defined as a universal parallel, system-level interface for connecting up to eight devices along a single cable, called the SCSI bus. SCSI is an independent and intelligent local I/O bus through which a variety of different devices and one or more controllers can communicate and exchange information independent of what the rest of the system is doing.

The parallel SCSI interface has a product depth and breadth that exceeds any other I/O interface. SCSI is supported by a wider variety of peripherals than any other type of interface. The list of supported peripherals includes tape drives, optical drives, hard disk drives, scanners, printers, disk array subsystems (RAID) and CD-ROM drives. This vast array of products, coupled with the maturity and proven performance of parallel SCSI, make it very difficult for any new peripheral interface to garnish enough clout or gain enough market share to begin to compete successfully with parallel SCSI. Even if such an interface were developed, issues such as interoperability with existing devices, backward compatibility and the support infrastructure required to address field problems preclude such a change. There are currently more than 120 computer, subsystem and peripheral manufactures that rely on parallel SCSI for their interconnect requirements.

The fact that parallel SCSI supports such a broad base of peripherals and applications is no accident. The interface was created with the goal of making a common interface that could be used across all peripheral platforms and system applications. No other interface can address as wide a range of applications or has a command set broad enough to support the multitude of peripherals supported by SCSI. In addition, the parallel SCSI interface allows systems equipped with this interface to perform to their maximum potential because the I/O is not the system bottleneck.

Some Parallel SCSI advantages are:

- Multitasking
- Low overhead
- High bandwidth
- Extensive connectivity
- Small form factor interconnect
- High velocity cable

In addition, a powerful SCSI feature is command queuing. A peripheral that is connected to the bus can receive a command set and then disconnect from the bus and execute the commands, as another device connects to the bus. Command queuing is highly bandwidth efficient and is becoming widely used in systems running Windows NT™. This is a powerful performance advantage SCSI offers over ATA systems.

For many reasons, SCSI continues to offer computer and peripheral manufacturers the best I/O choice, allowing them to deliver their customers the performance that those customers demand. To illustrate this point, it can be noted that the introduction of new drive technology first employs the use of the parallel SCSI interface, while the introduction into alternate interfaces is typically delayed until the “next generation” of this new technology. Obviously, computer and peripheral manufacturers see parallel SCSI as the best path to introduce new technology. In addition, because of its upgrading ease, parallel SCSI also continues to evolve new technology without sacrificing existing markets and applications.

The Evolution of Parallel SCSI

Over time, the parallel SCSI interface has evolved to meet the needs of faster and more complex peripherals. The parallel SCSI interface has been modified to handle increased data rates to satisfy the ever-increasing bandwidth demanded by peripherals. It also has accommodated the increased complexity employed by those peripherals, such as complex data error recovery and system management functions.

Looking at how data rates have increased historically, it can be noted that SCSI performance has doubled approximately every five years. This is summarized in *Table 1*.

Table 1. SCSI Performance

STA Term	SCSI Bus Width (bits)	SCSI Bus Speed (MB/s)	X3T10 Specification
SCSI-1	8	5	Small Computer Systems Interface [X3.131-1986]
Fast SCSI Fast Wide SCSI	8 16	10 20	Small Computer Systems Interface-2 (SCSI-2) [X3T9.2 375R] SCSI-3 Parallel Interface (SPI) [X3.277]
Ultra SCSI Wide Ultra SCSI	8 16	20 40	SCSI-3 Fast-20 Parallel Interface (Fast-20) [X3.277-1996]
Ultra2 SCSI Wide Ultra2 SCSI	8 16	40 80	SCSI Parallel Interface-2 (SPI-2) [X3T10/1142D Rev 11]

A key point in the evolution of parallel SCSI is that "backward compatibility", or "upgradability", has been maintained as each increase in parallel SCSI performance has occurred. This has allowed parallel SCSI technology to be enhanced without sacrificing existing or previous SCSI customers. Ease of upgrading has been a key enabler for the evolution from SCSI to Fast SCSI to Ultra SCSI. As a result, devices equipped with any of these three interfaces can be mixed and coexist on a common SCSI bus, operating off that common bus at the speed specified by that device.

As the SCSI data rate has increased, the robustness of the systems equipped with SCSI has also increased because of advancements in things such as SCSI termination, controller I/O pad technology and physical configuration (i.e. cable length, impedance and loading). For example, the parameters for physical configuration of Fast SCSI is 16 loads and 6 meters of cable. The Ultra SCSI standard, because it pays careful attention to loading and cabling, made further improvements. As such, single-ended Ultra SCSI supports a maximum cable length of 3 meters with 4 loads, or 1.5 meters with 8 loads. Ultra SCSI is also the last speed increase for single-ended active negation drivers. The Ultra2 standard is the next step in this evolution and will overcome a number of issues associated with performance increases including connectivity and cable length. The SCSI maximum bus length and number of devices is summarized in *Table 2*.

Table 2. SCSI Maximum Bus Length and Number of Devices

	Maximum Bus Length (m)			Maximum Devices
	SE	HVD	LVD	
SCSI-1	6	25	—	8
Fast SCSI Fast Wide SCSI	6 6	25 25	— —	8 16
Ultra SCSI	1.5 3	25 —	— —	8 4
Wide Ultra SCSI	— 1.5 3	25 — —	— — —	16 8 4
Ultra2 SCSI	(1) (1)	25 12	25 12	2 8
Wide Ultra2 SCSI	(1) (1)	25 12	25 12	2 16

(1) Single-Ended configurations are not defined at Ultra2 speeds.

The Evolution of Parallel SCSI

The form factor and functionality of the interconnect has also evolved. The following interconnect enhancements have been made:

- SCA (single connector assembly)
- SCA-2 (enhancement that allows hot plugging)
- VHDCI (very high density cable interconnect)

The SCA connector eliminates interior cables. This connector was optimized for the backplane and gives a direct connection for a backplane or enclosure, thus improving throughput and performance on the systems on which it is used. The VHDCI has a small form factor and allows 4 Wide SCSI cables to be attached to a single PC option card. The VHDCI also fits Type II PCMCIA cards thus expanding its use into a widely used PC medium. A big advantage of these improvements is that cables are now available that are half the size of earlier cables. In essence, this yields a cable size only slightly larger than serial cables.

As one examines advances in increased SCSI data rates, the size (form factor) and connectivity improvements in cabling options, along with features such as auto configuration capability (SCAM), Plug and Play (PnP) compatibility and hot swap capability, parallel SCSI emerges as the most robust I/O interface available.

The next step in the evolution of parallel SCSI is Ultra2, which uses low-voltage differential drivers, known as LVD. Ultra2 technology offers increased flexibility in peripheral configuration and provides an easy migration path to Ultra-3 technology, all the while providing an upgrade path for the vast existing base of SCSI users.

Differential Signaling

The Ultra2 standard shifts from a single-ended (unbalanced) physical interface to a low-voltage, differential (balanced) interface. A high-voltage differential (HVD) interface (IEEE-485), which has been used in the past, comprises approximately 5% of the current SCSI market. These HVD transceivers are high powered and, as such, cannot be integrated into a controller chip, requiring at least three separate external transceivers (if 9 channel devices are used). These external devices add significant cost and additional skew to the system, making them impractical for many applications.

The Ultra2 transceivers feature power low enough that they can be integrated into controller chips and still maintain the advantages gained through differential signaling. Those advantages include:

- Noise immunity
- Reduced EMI
- Insensitivity to ground shifts
- Extended cable lengths

As *Figure 1* shows, in a balanced system the logical state of the bus is determined by a differential signal (V_{OD}). If (V+) - (V–) is positive, the receiver detects a logical one. If (V+) - (V–) is negative, the receiver detects a logical zero. In single-ended (or unbalanced) operation, one conductor of the twisted pair is grounded and the receiver detects the magnitude of the voltage, i.e. TTL.

The differential interface will tolerate large amounts of common-mode noise and is relatively insensitive to ground voltage shifts, since those shifts affect each line equally. The insensitivity to ground shifts can be a big advantage in systems with separate grounds. Also, in most balanced systems, the common-mode current is less than the primary current by at least a factor of 100, which greatly reduces EMI.

The key to a balanced interface is a well-designed differential driver. A well-designed differential driver will have propagation delays from input high to input low that are equal. If the delays aren't equal, propagation delay skew results, which distorts the signal and can result in corrupted data. In addition, the rise and fall times of the complementary outputs should be equal. Unequal rise/fall times will increase EMI. Finally, the impedance looking into each of the complementary inputs should be identical. If there is imbalance, common-mode rejection will be degraded.

Fail-safe biasing is used to present a known state to the bus when all the drivers are high impedance. This biasing can either be built into the receivers or can be provided by termination. If provided by the termination, the terminator will be a three-resistor stack or a terminator with a built-in offset voltage.

The balanced interface works very well for extending cable length, minimizing interference and rejecting common-mode noise.

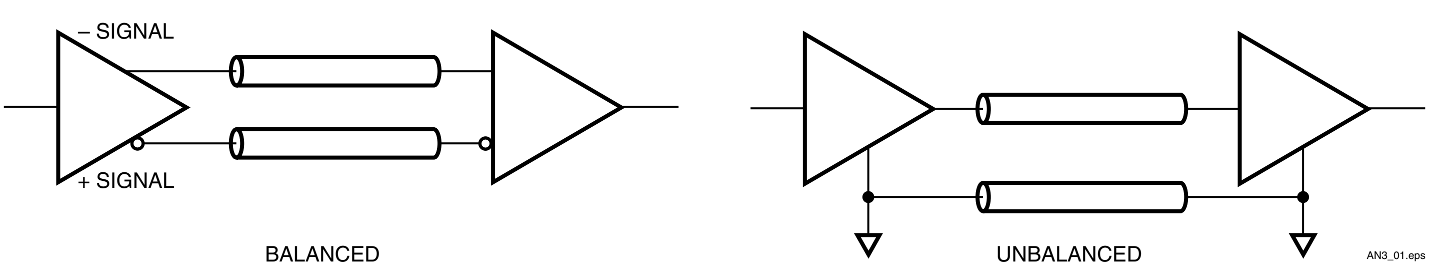

Figure 1. Balanced vs. Unbalanced Transmission

Low-Voltage Differential (LVD) SCSI

Ultra2 SCSI is a low-voltage differential interface that takes advantage of the benefits of differential signaling. In the development of Ultra2 SCSI, the goal was to develop a robust physical interface that utilizes drivers with power low enough to allow them to be integrated within the designs of SCSI controller chips. The starting point for this development was the EIA-644 (LVDS) standard. This interface is a point-to-point differential interface that has fail-safe biasing built into the receivers.

In Ultra2 SCSI, changes were made to the transceivers and termination scheme to accommodate a multi-point SCSI bus. An example of the Ultra2 bus is depicted in *Figure 2*.

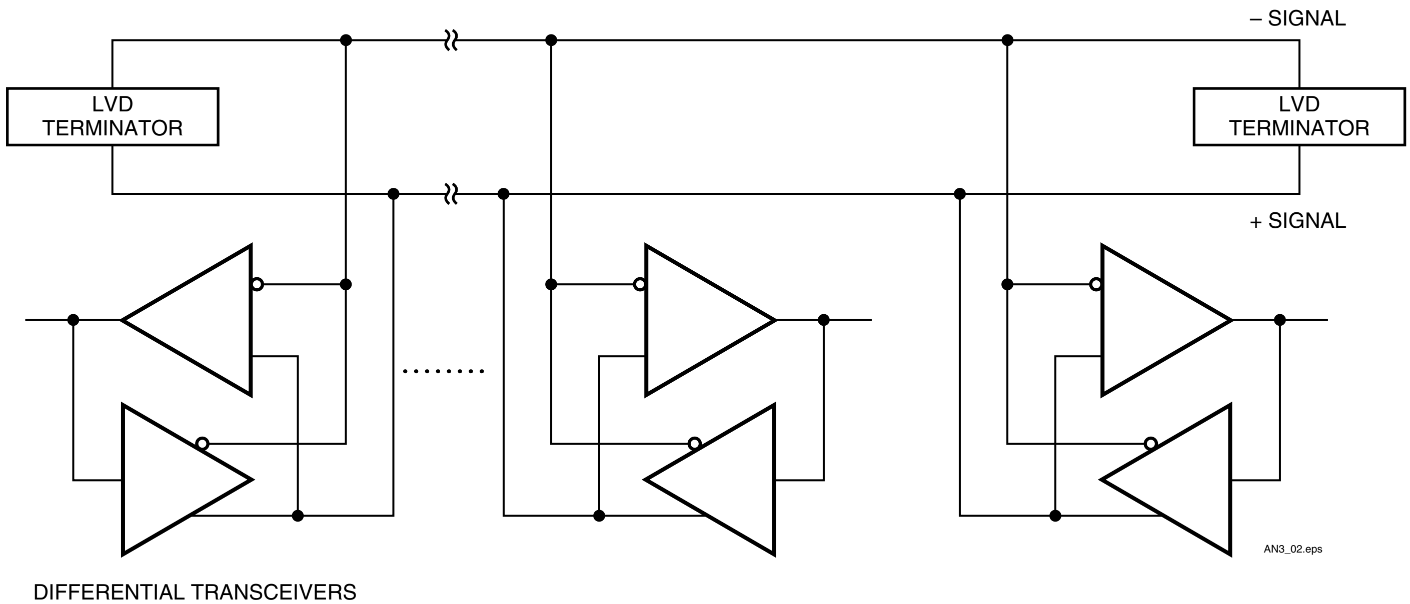

Figure 2. LVD Bus

As can be seen in *Figure 2*, the LVD bus is terminated at each end, and differential devices are connected along this bus. The polarity of the signals on the LVD bus is shown in *Figure 3*.

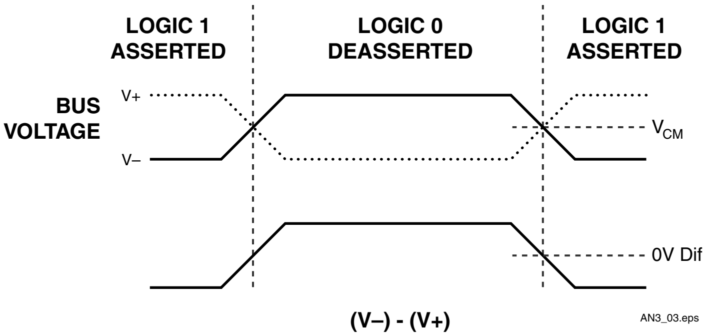

Figure 3. LVD Signal Polarities

As can be seen in *Figure 3*, the receiver detects a logic 1 when (V+) - (V–) is at least 60mV and a logic 0 when (V+) - (V–) is at least –60mV. The state of the bus is determined by the active driver; if no drivers are active, the state of the bus is set by the terminators as a logic 0.

The drivers have complementary outputs that are balanced and can be either current-mode or voltage-mode. Because of the fail-safe bias from the terminator, the assertion current is 2mA to 3mA higher than the negation current. This asymmetry in output current does not affect the driver balance. The drivers are current-limited at 24mA so that contention on the bus does not cause excessive current problems.

The bus is terminated at each end with an LVD terminator. The terminator supplies a common-mode voltage of 1.25V. This sets the midpoint for the differential signals if current-mode drivers are used. If voltage-mode drivers are used, the drivers set the common-mode voltage when they are active because they are low impedance outputs.

The terminator also has a common-mode resistance (100Ω to 300Ω), which, if the system is truly balanced, does not affect system performance because there is no common-mode energy. Two key parameters for the terminator are the differential impedance (100Ω to 110Ω) and the fail safe bias voltage (100mV to 125mV).

The terminator also outputs a voltage to the diffsense line of 1.3V. Because backward compatibility, or upgradability, is being maintained, the diffsense line has added importance since it must detect single-ended, LVD and HVD characteristics. If the voltage on the diffsense line is less than 0.5V, the bus will be single-ended. If it is between 0.7V and 1.9V, the bus will be LVD. If it is greater than 2.4V, the bus will be HVD. If LVD devices detect something other than LVD, they will become high impedance.

Multimode Devices

As stated previously, as the performance of parallel SCSI has evolved, upgradability has been maintained. For LVD, this upgradability between single-ended SCSI and LVD can be accomplished by using multimode devices. From a system standpoint, when a system is configured, both the transceivers and terminators need to be multimode devices. These devices can operate as single-ended or LVD devices, based on the value of the diffsense line. All multimode devices have ground drivers on all the positive (+) signal pins. When diffsense is less than 0.5V, the LVD driver output changes to single-ended by grounding the positive (+) pins, and the negative pins become Ultra SCSI-compliant drivers and receivers. When the terminators also transition, the positive (+) pins become ground and the negative (–) pins become Ultra SCSI-compliant single-ended termination.

Any time a single-ended device is attached to the bus, all attached devices will change to single-ended. Therefore, if the bus contains only LVD devices, a user would not want to add non-LVD devices to the bus, thereby reducing potential performance on the bus. Because multimode devices only accommodate single-ended and LVD performance parameters, high-voltage differential (HVD) devices should never be added to these busses.

The advantage of using multimode devices are that they help systems integrators make a smooth transition as they move from supplying single-ended to LVD system configurations. This approach allows integrators to inventory and stock a device for use on both busses. For these reasons, one might expect that the multimode approach would be initially favored by the industry.

The multimode approach does have several drawbacks when compared with either single-ended or LVD, however. First, the physical configuration for LVD has more devices and longer cable lengths than Ultra SCSI. Thus, if single-ended devices are added to an LVD bus, the bus length and number of devices needs to comply with single-ended Ultra SCSI parameters. This type of approach in configuring the system underutilizes the performance benefits gained with using Ultra2. Also, the use of single-ended configurations yields a maximum data rate of 20Megatranfers/sec when compared to 40Megatransfers/sec achieved when using LVD. Multi-mode devices also have a higher output capacitance than either single-ended or LVD, respectively. In addition, the terminators have a ground driver on the + pin and a LVD output and single-ended output on the – pin, resulting in higher output capacitance. In addition, when using multimode devices, the capacitance will have to be balanced so that the delta capacitance between the – pin and the + pin is low. The result of this is that disabled terminators along the bus will have higher capacitance, thereby reducing the impedance and slowing the propagation time.

The transceivers (or I/O pads) require a differential driver and differential receiver, a single-ended receiver (– pin) and single-ended active negation driver (– pin), and a ground driver on the + pin. This necessitates making the I/O pads considerably larger and adds capacitance to the outputs. In addition, if one uses a multimode device only for single-ended operation, the device has an additional 27 LVD + pins that are unused.

Even with the above drawbacks, multimode devices do maintain upgradability and will help in the transition from single-ended to LVD-based system configurations. It should be noted, however, that LVD and single-ended devices should not be mixed on the same bus as this will result in underutilization of the LVD devices.

LVD Physical Configuration

The Ultra2 bus is a multi-point bus that can have up to 16 stub connections with a maximum bus length of 12 meters. If the bus is a point-to-point (2 devices - target and initiator) configuration, the bus length can be up to 25 meters. When configuring the system, care should be taken in cable selection. The SPI-2 specification recommends an unloaded differential impedance of 110Ω to 135Ω. When adding peripherals to the system, care should also be taken in placing devices so they are not clustered on the bus and that stubs are short and approximately the same length. When spacing peripherals, it would be most ideal if the separation of the peripherals is such that that space is greater than the equivalent length of the rising edge. With this in mind, the SPI-2 document specifies minimum stub spacing.

Media Capacitance	40pF/m	65pF/m	90pF/m	115pF/m	140pF/m
LVD stub spacing	0.36m	0.22m	0.16m	0.13m	0.1m

The more capacitive the cable, initially, the closer the stubs can be spaced. When the loads are spaced this way, the additional load capacitance affects the bus uniformly and has the affect of reducing the impedance and increasing propagation delay. When adding devices to the bus, those devices should be low capacitance and the capacitance between the – and + signals should be balanced. The maximum allowed capacitance for the – signal to ground and the + signal to ground is 20pF. The maximum capacitance – signal to + signal is 10pF. If 20pF loads are added to a 110Ω cable (40pF/m) at 1 meter increments, they will reduce the loaded cable impedance to 81Ω. Since the signaling is differential, the capacitive balance between the – and + signal (same signal) is very important. Capacitive mismatch will cause different propagation delays, which result directly in skew. To address this, the SPI-2 document specifies a maximum of 0.5pF mismatch between the – and + lines of the same signal for REQ, ACK, DATA and PARITY. Skew is a critical parameter because of the decreasing setup and hold times. Since the capacitance will need to be balanced at the connector, printed circuit board traces might need different lengths to compensate for capacitive mismatches on controller chips and terminators. The differential – and + pin assignments for each pair are adjacent, which should help in routing traces to minimize capacitive mismatch problems.

Also, the SPI-2 document allows all SCSI-2 and SCSI-3 SPI connectors and specifies SCA-2 and VHDCI connectors. This gives users a wide range of connectivity choices.

Conclusion

The Ultra2 interface provides a doubling of the data rate over the Ultra SCSI interface, while increasing cable lengths and permitting a larger number of devices on the cable. While significant performance gains were accomplished, upgradability of the existing SCSI user base has been maintained and a physical interface has been developed that should allow an easy migration to even higher data rates in the future.

IMP Multimode/LVD SCSI Terminators

	IMP Part Number	Package Type	Dallas	Linfinity	Unitrode
9-Lines, Multimode	IMP5241CDB	36-pin SSOP	DS2118ME	LX5241CDB	UCC5630MWP
	IMP5241CPW	24-pin TSSOP		LX5241CPW	
	IMP5242CDB	36-pin SSOP		LX5242CDB	
	IMP5242CPW	24-pin TSSOP		LX5242CPW	

ISO 9001 Registered

IMP, Inc.
Corporate Headquarters
2830 N. First Street
San Jose, CA 95134-2071
Tel: 408-432-9100
Tel: 800-438-3722
Fax: 408-434-0335
e-mail: info@impinc.com
http://www.impweb.com

Printed in USA
Publication #: 7010
Revision: A
Issue Date: 06/15/98
Type: Product