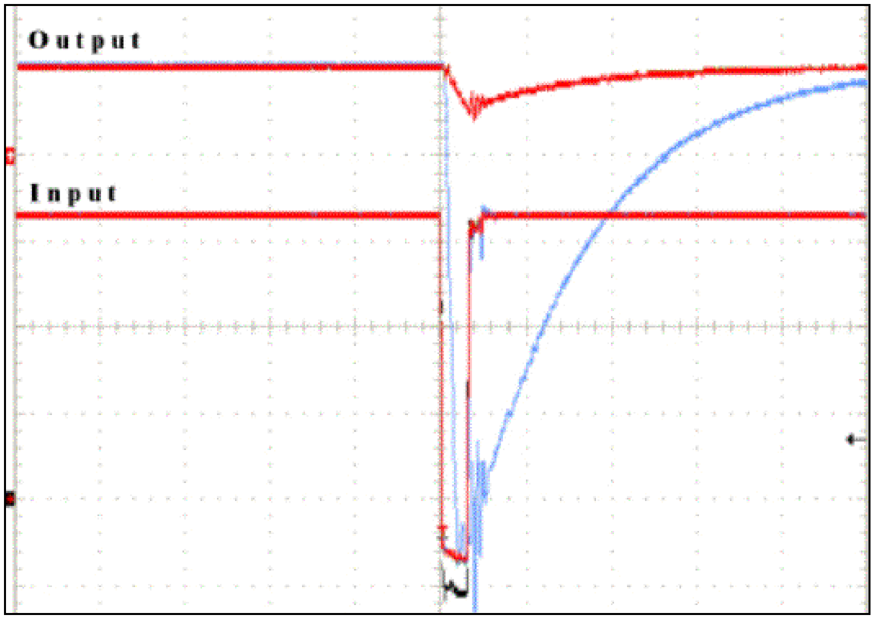
APPLICATION NOTE



AN10217-01
Cross Bar Switch Undershoot Protection

CBTS3306, CBTS3384, CBT6810, CBT6820, CBTS3253, CBTS3257, CBT6832, CBT6832C, CBT6832D, CBT6832E

Abstract - If the driver's output impedance is less than the line impedance, the signal will tend to undershoot below ground and could cause the Cross Bus Switch transistor to turn on and inadvertently pass a high signal. This application note discusses how the Schottky Diode provides protection when the signal undershoots below ground.

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OVERVIEW

Description

Cross Bar Switch Technology (CBT), also known as Quick Switch (QS), Fast Switch Technology (FST) or Pericom Interface (PI5C), consists of simple N-channel MOS transistors. When the switch is open, it provides circuit isolation (high-impedance). When the switch is closed, it provides a near-zero propagation delay through a 5 Ω resistance. The N-channel transistor on the CBT output clamps the voltage by approximately 1.0 V.

CBT devices operate between 4.5 V to 5.5 V and -40 to +85 ^{o}C and are offered in various functions, bit widths and pinouts in SO, SSOP, QSOP and TSSOP packages.

CBT applications include:
- General Purpose Switching
- Memory Interleaving
- Notebook Docking Support
- Processor Termination
- PCI Hot Card Insertion
- Voltage Level Translation.

The internal Schottky diode (CBTS) option provides negative voltage undershoot protection on both inputs and outputs. This protection is required to prevent inadvertently turning on the NMOS transistor if the line voltage becomes very negative. This effect and experiments conducted on devices with and without Schottky diodes are explained in this application note.

There are two different types of CBT devices offered with Schottky Diode Protection:
- Digital switch
- Multiplexer/demultiplexer.

Digital Switch

In line N-channel MOS switch turns the digital signal on and off. One of the two channels of the CBTS3306 is shown in Figure 1. When the /OE pin is low, the associated bus switch is on and Port A is connected to Port B. When /OE is high, the switch is open, and a high-impedance state exists between the two ports. Digital switch device packages will have either the input on one side of the package and the output on the other side of the package (flow through pinout) or both the input and output will be on the same side of the package.

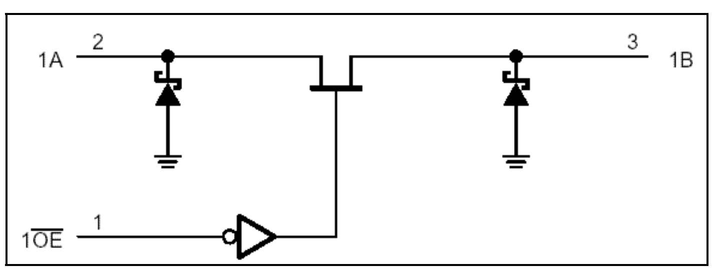

Figure 1. CBT3306 Digital Switch with Schottky Diode Protection Against Undershoot

Multiplexer/Demultiplexer

Similar to the digital switch but internally routed to multiplex/demultiplex one line to two, four or eight lines. The 1:4 CBTS3253 is shown in Figure 2.

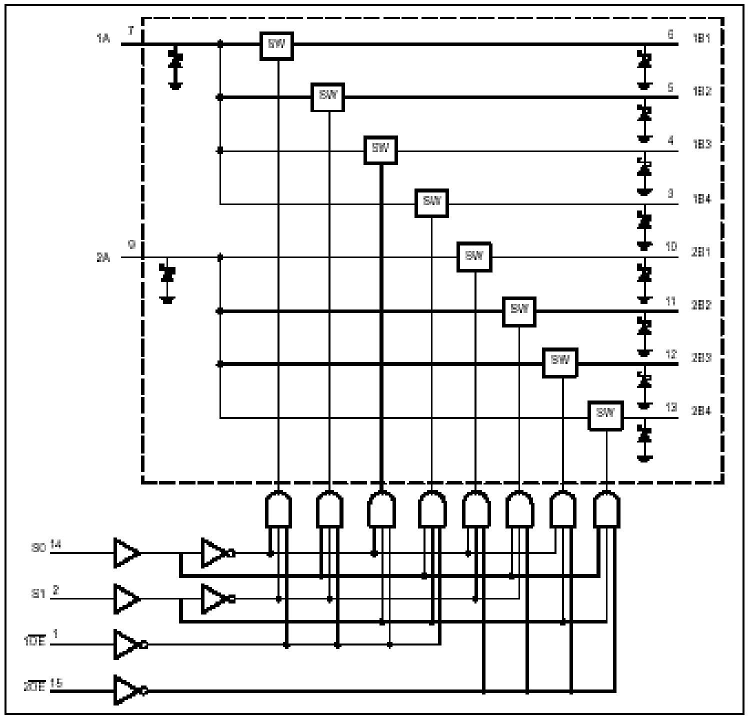

Figure 2. CBTS3253 Multiplexer/Demultiplexer with Schottky Diode Protection Against Undershoot

Why use Schottky Diodes

Schottky diodes are used to prevent the inadvertent turn on of the transistor when voltages with a value 0.4 V below ground are present on the line. Without Schottky Diode protection the low signal could be passed through the device as shown in Figure 3.

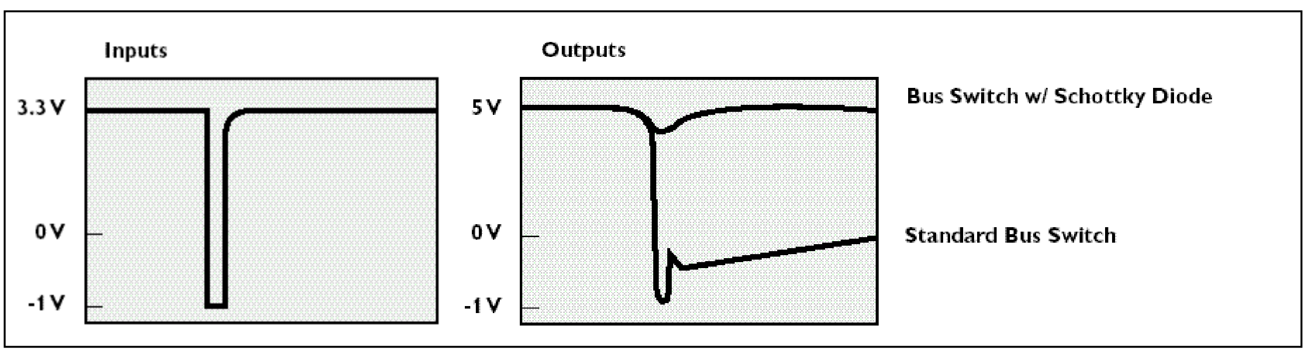

Figure 3. Schottky Diode Protection vs No Protection Against Undershoot

Device Operating Characteristics

- 5 Ω switch connection between two ports
- TTL-compatible input levels
- Schottky diodes on I/O clamp undershoot
- Propagation delay of 0.25 ns maximum through the switch

- ESD protection exceeds 2000 V HBM per JESD22-A114, 200 V MM per JESD22-A115 and 1000 V CDM per JESD22-C101
- Latch-up testing is done to JESDEC Standard JESD78 that exceeds 100 mA

Device Selection Table

Application	Features			Device	Option			Operating Range				Package Offerings			
	# of Bits	# of Enables	Mux/Demux		Schottky Undershoot Diode	Charge Pump Undershoot	Precharged Outputs	Voltage Range (Volt)	Temperature Range (°C)	Flow Through Pinout	# of Pin in Package	SOIC	SSOP	QSOP	TSSOP
Digital Switch															
General Purpose	2	2		CBTS3306	❷			4.5 to 5.5	-40 to 85		8	D			DP
General Purpose	10	2		CBTS3384	❷			4.5 to 5.5	-40 to 85		24	D	DB	DK	PW
PCI Hot Plug	10	1		CBT6810	❷		❷	4.5 to 5.5	-40 to 85	❷	24			DK	PW
PCI Hot Plug	20	2		CBT6820	❷		❷	4.5 to 5.5	-40 to 85	❷	48				DGG
Multiplexer/Demultiplexer															
General Purpose	2	2	1 of 4	CBTS3253	❷			4.5 to 5.5	-40 to 85		16	D	DB	DS	PW
General Purpose	4	1	1 of 2	CBTS3257	❷			4.5 to 5.5	-40 to 85		16	D	DB	DS	PW
PCI Hot Plug	16	1	1 of 2	CBT6832	❷		❷	4.5 to 5.5	-40 to 85		56				DGG
PCI Hot Plug	16	1	1 of 2	CBT6832C	❷	❷	❷	4.5 to 5.5	-40 to 85		56				DGG
PCI Hot Plug	16	1*	1 of 2	CBT6832D	❷	❷	❷	4.5 to 5.5	-40 to 85		56				DGG
PCI Hot Plug	16	1*	1 of 2	CBT6832E	❷		❷	4.5 to 5.5	-40 to 85		56				DGG

* = enable delay

Table 1. CBTS Device Selection Matrix

The "S" used in the CBTS device nomenclature was not used for the CBT6810/20 and the CBT6832 series of devices. The CBT6832C and CBT6832D have a charge pump in addition to the Schottky Diode to provide undershoot hardening.

The CBT6832 series of 1:2 PCI Hot Swap multiplexer/demultiplexer has a maximum enable and disable delay of 6-7 ns. The enable delay of the CBT6832D and CBT6832E has been increased to 25-30 ns for applications where the designer need a longer delay between when /OE is deactivated and when the I/O pass signals.

Device Pinout

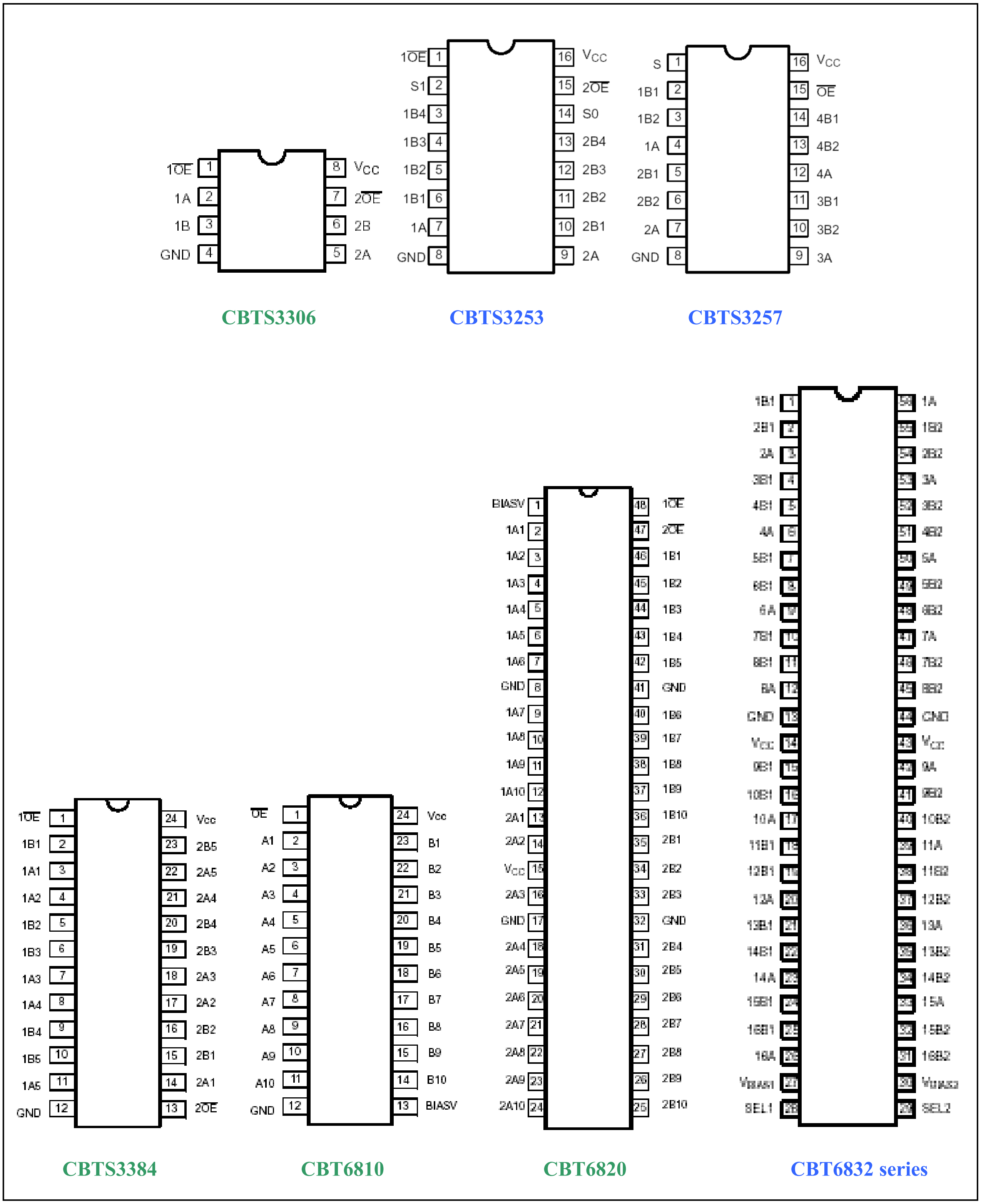

Figure 4. Device Pin Out

Ordering Information

Package	Container	CBTS3306	CBTS3384	CBT6810	CBT6820
SO	Tube	CBTS3306D	CBTS3384D	Not available	Not available
	T & R	CBTS3306D-T	CBTS3384D-T	Not available	Not available
SSOP	Tube	Not available	CBTS3384DB	Not available	Not available
	T & R	Not available	CBTS3384DB-T	Not available	Not available
QSOP	Tube	Not available	Not available	Not available	Not available
	T & R	Not available	CBTS3384DK-T	CBT6810DK-T	Not available
TSSOP	Tube	Not available	CBTS3384PW	CBT6810PW	CBT6820DGG
	T & R	CBTS3306PW-T	CBTS3384PW-T	CBT6810PW-T	CBT6820DGG-T

Table 2. Digital Switch Ordering Information

Package	Container	CBTS3253	CBTS3257	CBT6832	CBT6832C	CBT6832D	CBT6832E
SO	Tube	CBTS3253D	CBTS3257D	Not available	Not available	Not available	Not available
	T & R	CBTS3253D-T	CBTS3257D-T	Not available	Not available	Not available	Not available
SSOP	Tube	CBTS3253DB	CBTS3257DB	Not available	Not available	Not available	Not available
	T & R	CBTS3253DB-T	CBTS3257DB-T	Not available	Not available	Not available	Not available
QSOP	Tube	CBTS3253DS	CBTS3257DS	Not available	Not available	Not available	Not available
	T & R	CBTS3253DS-T	CBTS3257DS-T	Not available	Not available	Not available	Not available
TSSOP	Tube	CBTS3253PW	CBTS3257PW	CBT6832DGG	CBT6832CDGG	CBT6832DDGG	CBT6832EDGG
	T & R	CBTS3253PW-T	CBTS3257PW-T	CBT6832DGG-T	CBT6832CDGG-T	CBT6832DDGG-T	CBT6832EDGG-T

Table 3. Multiplexer/Demultiplexer Ordering Information

Table 2 and 3 nomenclature is for North America. Europe and Asia use ,112 for tube and ,118 for tape and reel (e.g., CBTS3306D,112 and CBTS3306D,118).

Data Sheets and IBIS Models

Data sheets and IBIS models can be downloaded from www.philipslogic.com

TECHNICAL INFORMATION

Transmission Line Background

When considering undershoot, it is necessary to understand its origin. The simplest example starts by considering an ideal, open transmission line. If the transmission line is driven by a CMOS driver from 0 to 5 V on one end, the 0 to 5 V wave propagates to the other end of the line and reflects off the open end back towards the driver at twice the original amplitude (10 V). When this 10 V wave arrives back at the CMOS driver, the driver will pull the line back down to 5 V. This negative going transition, 10 V to 5 V, then travels down the line to the open end and is reflected back at the open end, this time at 0 V. This sets up an oscillation from 0 V to 10 V and back to 0 V at the open end of the line, which would continue undampened in an ideal, open transmission line.

When working with transmission lines, this tendency to oscillate has to be mitigated. Methods for controlling it include terminating the line with a resistance that matches the characteristic impedance of the line, thus eliminating reflections, and driving the line with a first reflected wave driver, which essentially drives the line to one half the desired voltage and then lets the reflection drive the line up to the full voltage. The terminated line has a major drawback in that it requires a lot of power to drive the termination, so the reflected wave driver is the more commonly used method of driving signals on a transmission line.

An ideal first reflected wave driver would have an output impedance equal to the characteristic impedance of the line. However, such a driver like used on BTL/FB+ and GTLP devices is not usually available, so reflections have to be considered in the design of a transmission line. The reflections will be different depending on the driver's impedance compared to the line's impedance. If the driver's output impedance is less than the line impedance, the signal will tend to undershoot below ground. The purpose of this application note is to address the situation where the signal undershoots below ground.

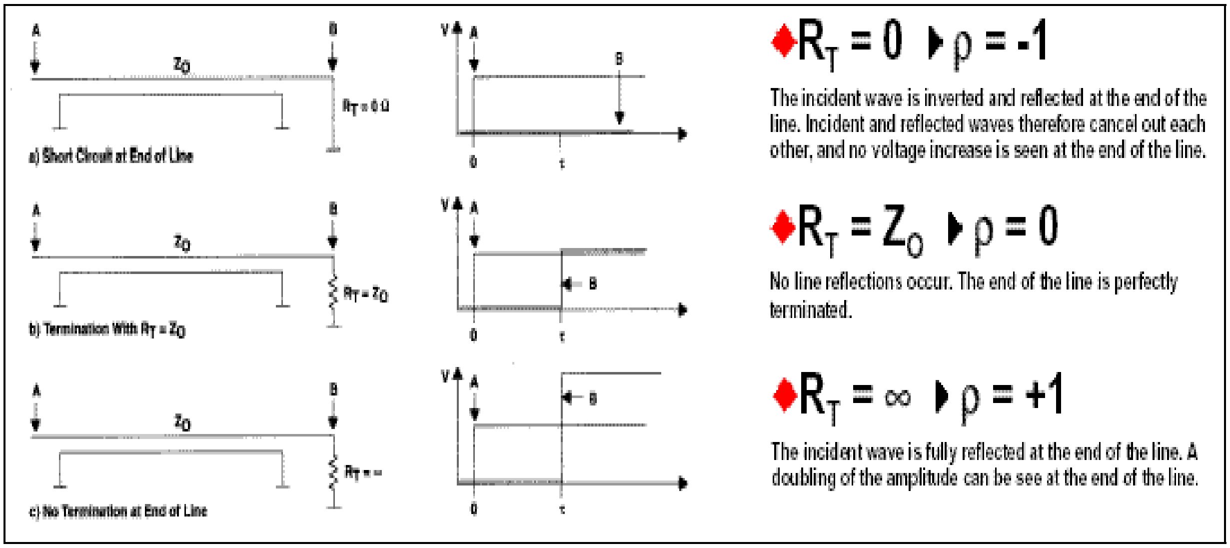

Figure 5. Reflected vs Incident Wave Switching

For a driver with output impedance that is half the line characteristic impedance in a point to point configuration, when the line is transitioning from 5 V towards ground, the reflected voltage will be a negative one third of the high value (-1.67 V). Any time the input voltage on a CMOS part that is connected to the transmission line goes below ground by about -0.5 V, the parasitic diode to ground in that device becomes sufficiently forward biased to conduct current. The affect of undershoot on a device at the end of the transmission line will be determined by the length of time the line is below ground and by how far below ground the voltage drops. The length of this negative signal's duration is equal to twice the end to end propagation delay of the line. In most applications, the duration of the reflection below ground is relatively short because wire lengths are deliberately kept short. For example, the typical propagation delay for a transmission line is between 3 and 4 ns / ft, and if the trace length is 3 feet, the round trip time would be a maximum of 24 ns. This would be the length of time that the line will stay below ground.

In terms of negative voltage reflections on a bus, the point to point transmission line is the worst case. Busses or backplanes, which are more commonly used, tend to have many closely spaced branches or stubs which reduce the magnitude of the voltage reflection below ground and the length of time the bus stays below ground.

Measurement methods

When measuring the undershoot voltage experienced by a part in a transmission line, it is necessary to remove the device from the transmission line and measure that point in the line where the device connects with a high impedance, low capacitance probe.

In the waveforms in Figure 8, the device's behavior is being measured in a simulated system environment using a signal generator. When measuring a device's behavior that is subject to an undershoot with a signal generator, the characteristics of the signal generator have to be understood and considered in the testing setup and measurement results. The signal generator is typically designed to drive a terminated 50 Ω transmission line and the effective output impedance of a terminated 50 Ω transmission line is 25 Ω. If the device conducts no current, as is the case when the voltage in moving from 5 V to 0 V, the difference between the 25 Ω impedance of a terminated transmission and the 50 Ω impedance of the unterminated transmission line is irrelevant. However, when the voltage level drops below ground, the input protection diode begins to conduct current and limits the negative voltage. Therefore, the resulting waveform shows the line dropping only to a negative 0.8 V, instead of the negative 1.0 V that would be seen if the line were open and no device was connected in this 25 Ω environment. If the environment were a 50 Ω open line, the undershoot would be a negative 2.0 V.

Physics of undershoot feed through

When the path through a CBT device is off (open), the expectation is that the output is isolated from the input. For input levels between 0 V and V_{DD}, good isolation is achieved, but, if the input voltage drops below ground, or undershoots, there can be feed through from the input to the output of the off-state device. Feed through is defined to be when a below-ground low on the input causes the high-level output to be pulled down. The design of the part will determine how low the high-level output gets pulled down and, depending on how low the output gets pulled down, it may cause problems for other devices on the bus. If the output of the CBT device has a weak pull-up, such as a high value pull-up resistor or an internal "bias" pull-up, feed through can cause the output to change states. The mechanism for the feed through is either a parasitic NPN transistor in the device being turned on or the pass gate (NMOS transistor) conducting. If the output is already low, this feed through does not cause any problems.

To disable a CBT channel, the gate of the NMOS transistor is held at ground. The input and output of the channel are the source and drain on the NMOS transistor. Assuming the source to be the input, when the source is driven below ground, the gate to source voltage increases, and, if it reaches the NMOS transistor turn on threshold voltage, the channel turns on and conducts current. When the input (source) is pulled below ground, the source region becomes negative with respect to the backgate, and as this happens, a parasitic NPN transistor turns on, thus connecting the input to the output.

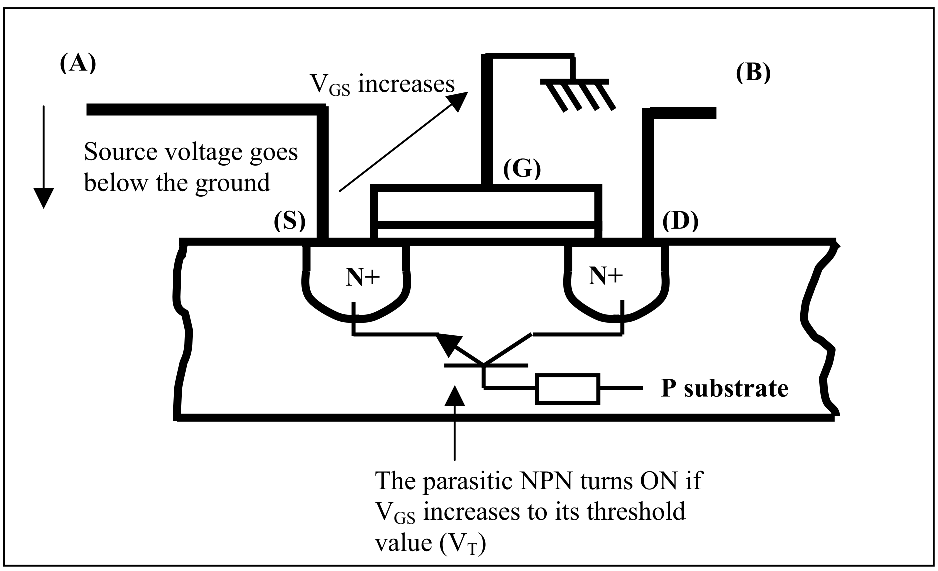

Figure 6. CBT Transistor Operation

As the source transitions from a high to the undershoot condition, the drain to gate capacitance as well as the drain to substrate capacitance will tend to keep the NMOS and parasitic NPN off by initially pulling the gate and substrate below ground. But, as the input stays below ground, the gate pull-down tends to pull the gate back to ground, which turns the NMOS on, and the substrate connection tends to pull the substrate back to ground which turns the parasitic NPN between the I/Os on.

Block Diagram

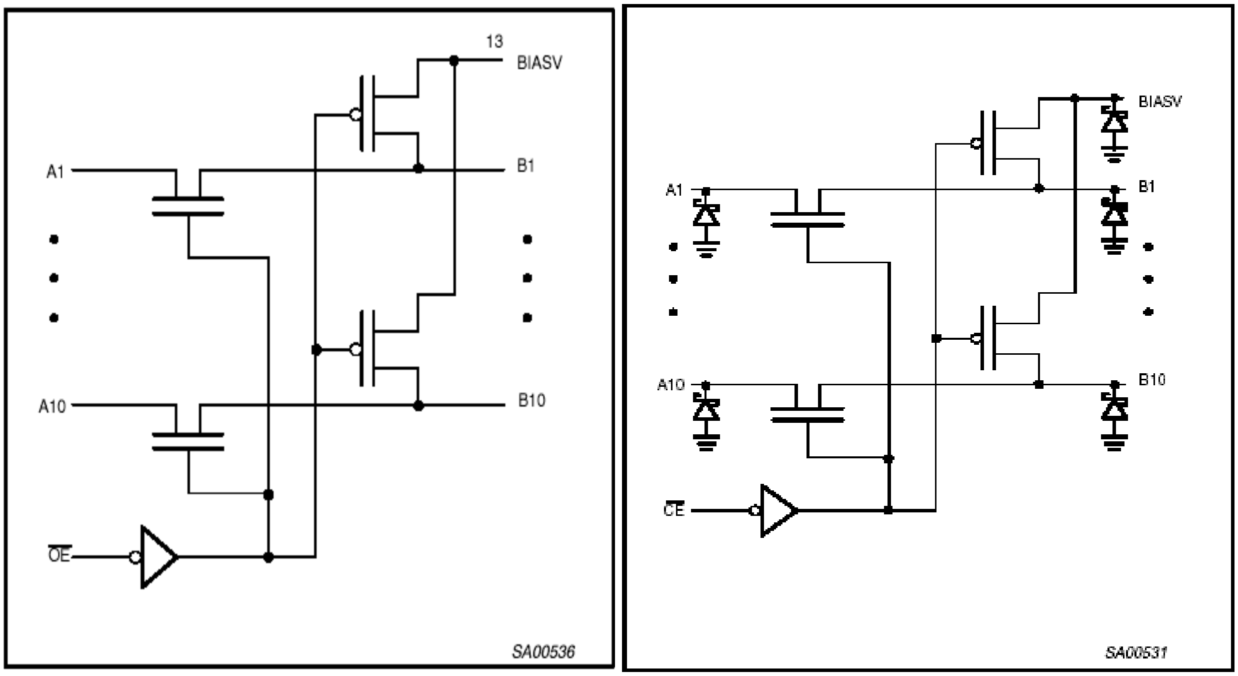

Figure 7. Comparison of CBT6800 with CBT6810 Block Diagram

The only difference between the CBT6800 and the CBT6810 is that Schottky Diodes have been added to the I/O pins to provide undershoot hardening.

Hardening Methods

Undershoot hardened parts address these problems in a number of ways, but the objective is always the same, which is to keep the drain to gate voltage small enough that the NMOS transistor does not turn on and to keep the substrate to drain junction reverse biased, or at least to keep its forward voltage low enough that the parasitic NPN does not conduct. The CBT6810 and the other CBTS devices use a combination of Schottky diodes and gating to minimize feed through. Schottky diodes are used to short out the parasitic NPN. A combination of Schottky diodes and MOS logic are used to force the gate to follow the drain negative during an undershoot event.

Results

As can be seen in Figure 8, even the standard CBT6800, with no undershoot hardening, does not have its output fall immediately but it starts falling after 2 or 3 ns. Also, if the undershoot is less than about -0.4 V, the standard CBT device shows no feed through. If the undershoot is more negative than -0.4 V, and is longer than about 3 ns, the resulting feed through may be unacceptable.

The input signal in Figure 8 is represented by the lower curve, which swings from 3.3 V to -1 V in a terminated line (25 Ω) environment. The black line shows the open jig result of slightly more negative than -1 V. The lower red and blue lines, which are on top of each other, are the input with the CBT6810 and the CBT6800 in the test circuit.

The position of the red and blue lines above the black line clearly shows the clamping action of the diodes on the input. The plot also show that high currents are flowing, which can be calculated from the more than 0.3 V into a 25 Ω transmission line. Because of the high currents, the stress is equivalent to -2 V in an unterminated 50 Ω environment. The top lines show the output has been precharged to 5.0 V. The CBT6810 shows about a

0.5 V droop during the undershoot event, but it is clearly still in a high state. The CBT6800 output has dropped to -0.6 V and is clearly in a low state. The test performed on the parts here, where the equivalent -2 V undershoot is a large undershoot and the 25 ns duration is a very long duration undershoot, shows that the CBT6810 will perform very well in nearly all system applications.

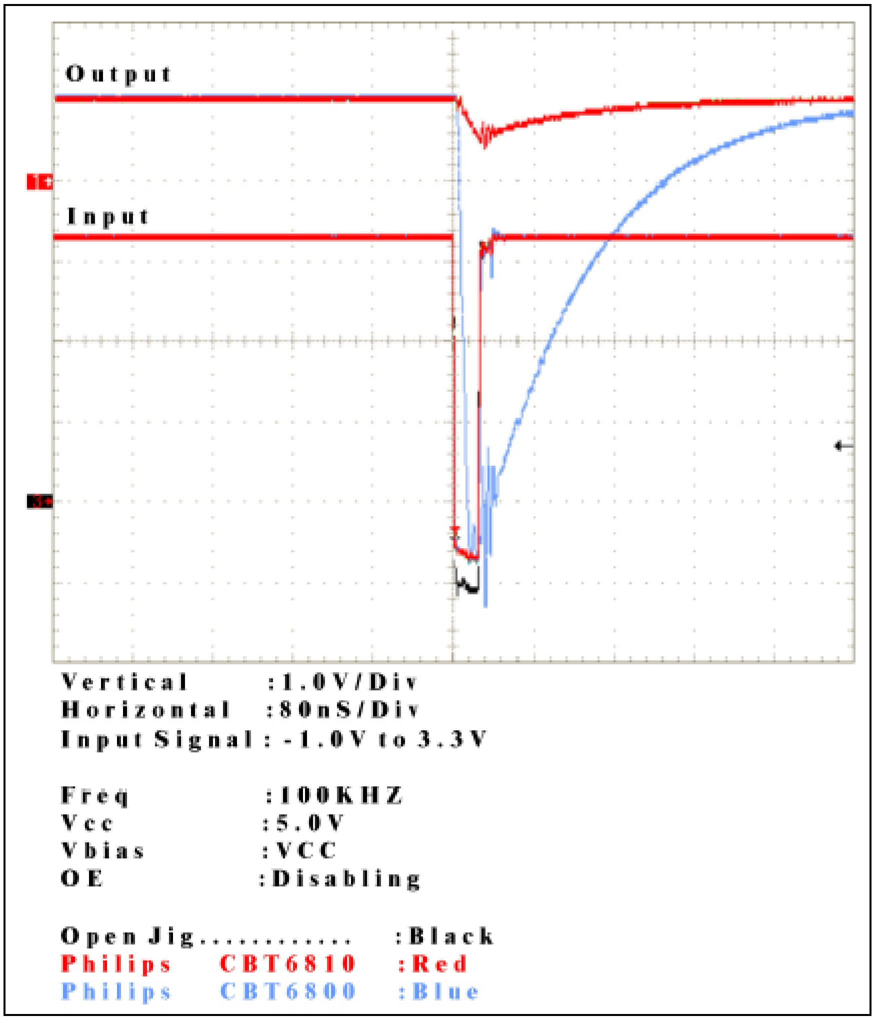

Figure 8. Illustration of Schottky Diode Effectiveness

APPLICATIONS

Multiplexing

The CBTS3253, CBTS3257 and CBT6832 series can be used as multiplexers that split the main bus into several sub-branches and allow the system bus to select and communicate with one of these sub-branches at a time, to avoid address conflict issues or allow the system bus to communicate with multiple different devices, one at a time. Multiplexer/Demultiplexers are used for general purpose digital signal switching for many applications in the computing, telecom and consumer segments in high end workstations, portable computers, hard disk drives and industrial control systems. The CBT3257 quad 2:1 multiplexer/demultiplexer bus switch is shown in Figure 9 and is a typical example, switching two peripherals to a common bus.

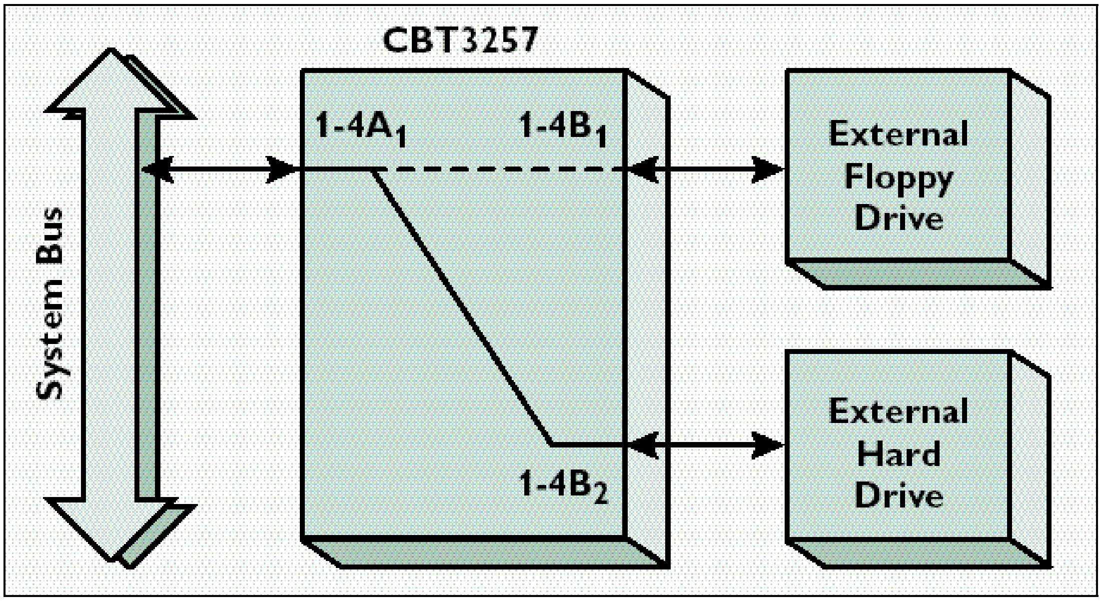

Figure 9. Typical Multiplexer/Demultiplexer Application

PCI Hot Plug Applications

CBT Switches provide a safe and effective method of making older technology devices capable of hot card insertion. This is particularly important in fault tolerant computing and telecommunications switching applications. The PCI Hot Plug devices, CBT6810, CBT6820 and the CBT6832 series, are designed with both the Schottky diodes on the I/O to prevent undershoot and a precharge circuit to precharge the I/O prior to card insertion. The BIAS V_{CC} precharge circuit, as shown on the CBT6810 in Figure 10, precharges the outputs to a user selectable voltage for live insertion applications, to prevent glitching active data on the bus line.

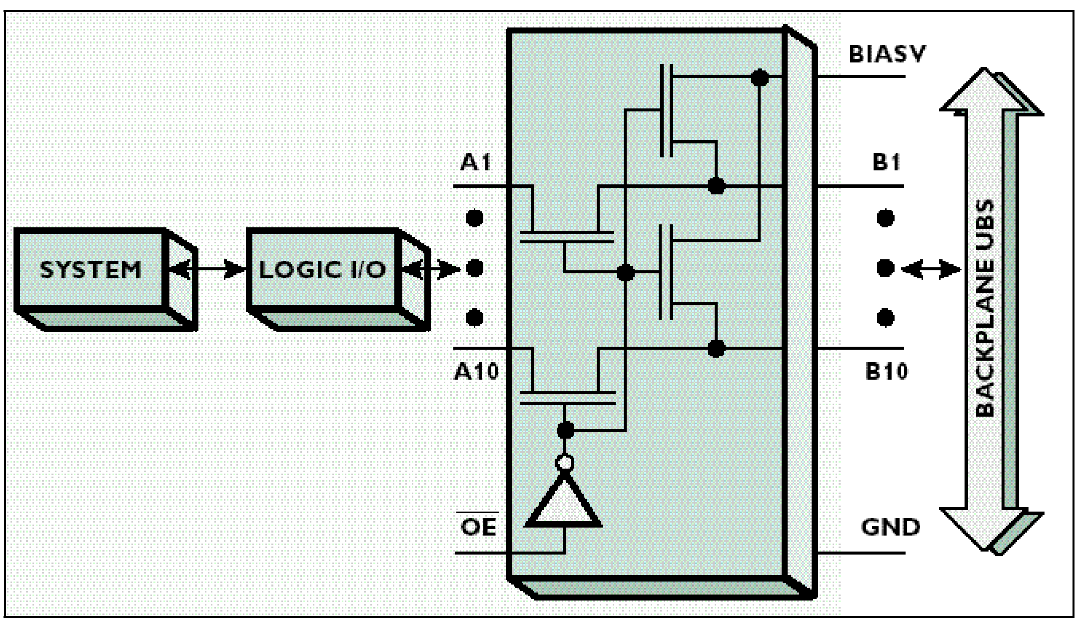

Figure 10. Typical PCI Hot Swap Application

Bus Switch Isolation Application

The CBTS3306 and CBTS3384 are 2 bit and 10 bit respectively digital switches that can be used to isolate transmission lines/system buses in different applications with the Schottky diodes hardening the device against undershoot. One bit switch is shown in Figure 11.

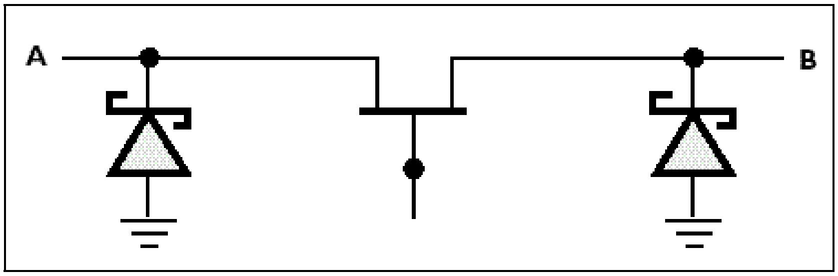

Figure 11. Typical Bus Isolation Application

FREQUENTLY ASKED QUESTIONS

1. **Question:** CBT6832D and CBT6832E are used in our server application. We would like to know the R_{on} characteristics while the V_{CC} is changing from 5V to GND. We would also like to know the R_{on} change while the Vin voltage is changing from 5 V to GND.
   Answer: The CBT6832D and the CBT6832E both use NMOS pass transistors. When the pass transistor is turned on, its gate is at V_{CC} (5 V). If the input is at 5 V, the NMOS pass transistor will pass something on the order of 4 V (that is, 5 V minus the threshold of the pass transistor). During live insertion, the device is predischarged so that the internal control nodes are at 0 V, which keeps the pass transistors off. If the power supply is disconnected with the pass transistor on, it may take a long time to discharge and turn off (this was not an original design criteria). If the device is powered and the pass transistor is on, as soon as the input falls ~ 1 V below the power supply voltage the other side will start to fall.

2. **Question:** On the CBT6820, I have a question on the BIASV as seen on page 3 of the data sheet. The minimum voltage is 1.3 V. The CompactPCI specs requires a 1.0 V +-5%.
   Answer: The BIASV is applied to the source of a PMOS device, which is turned on by grounding the gate, the closer to ground the voltage the weaker the PMOS is turned on. It should pass 1 V but the "resistance" will be higher.

ADDITIONAL INFORMATION

The latest datasheets for the Cross Bar Switch family of products can be found at the Philips Semiconductors website:
http://www.philipslogic.com/specialty

Additionnal technical support for Cross Bar Switch devices can be provided by e-mailing the question to:
Email: pc.mb.svl@philips.com