

# ***Electrical Overstress Damage of TI 1394 PHY Devices***

*Connectivity Interface Solutions*

## **ABSTRACT**

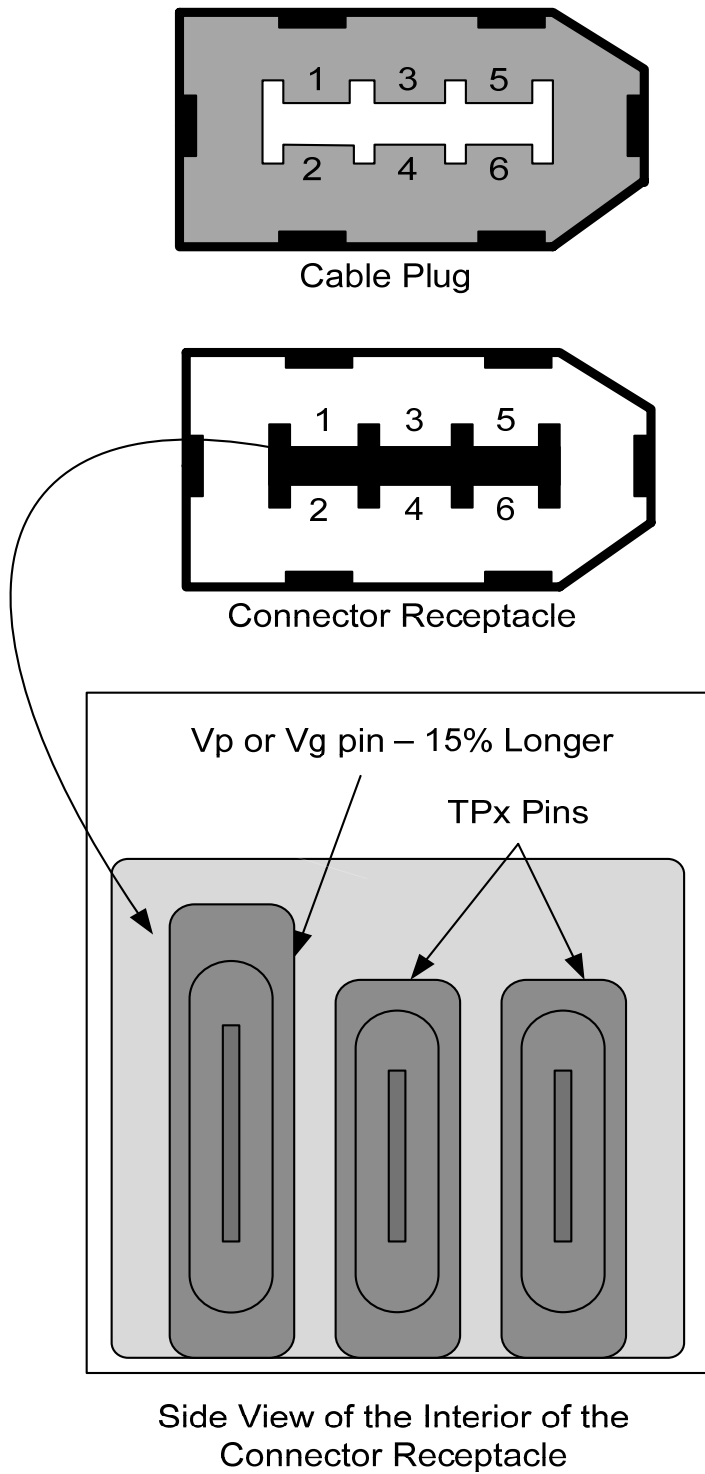
All 1394 PHY devices are susceptible to electrical overstress damage when exposed to a combination of high-voltage cable power and a faulty cable or connector system that allows data (TPx) and cable power (Vp) connections to engage before the cable ground (Vg) connection. This set of circumstances is known as a “late Vg” event. This application report provides information on how to recognize a 1394 PHY device that has been damaged by a late Vg event, an explanation of how the damage occurs and suggestions on both decreasing the frequency of late Vg events in a system and protecting 1394 PHY devices from damage due to late Vg events.

## **1 Introduction**

The IEEE 1394A-2000 specification calls for 1394 cable power (Vp) to range from 8 VDC up to 30 VDC with a maximum current of 1.5 A. Legacy IEEE 1394-1995 systems can support cable power of 8 VDC up to 40 VDC, also with a maximum current of 1.5 A. A typical 1394 PHY device has an absolute maximum input voltage rating of  $-0.5$  VDC to  $V_{DD} + 0.5$  VDC, where the maximum value of  $V_{DD}$  is 4.0 VDC. There is an obvious potential for catastrophic damage to a 1394 PHY device if the voltage levels of Vp are expressed on the differential pair signals of the 1394 PHY device.

If the Vp connection and any of the data (TPx) connections of two 1394 nodes are engaged before the Vg connection high voltage can appear on TPx signals in what is known as a late Vg event. The IEEE 1394-1995 specification requires the Vg and the Vp pins of the connector receptacle to be approximately 15% longer to help ensure that these connections are “first make, last break”, but this can be compromised if a cable is inserted at an extreme angle. For example in Figure 1, pins 1 and 3 can be connected before the pin 2 Vg connection. Also, if the Vg connection is not well connected due to distressed cables or connectors, there is also a potential for a late Vg event.

The Vp voltage appears on the TPx signal(s) because the data connection is used as a ground return path in lieu of the Vg connection. The high voltage and current on the return ground path can damage the TPx inputs of the 1394 PHY devices on both sides of the cable. ESD protection circuitry implemented inside the 1394 PHY device cannot protect against a late-Vg event because it is of longer duration and higher current than a typical ESD event. It should be noted that only one of the TPx connections is required for a late Vg event to occur. For example, a node with only Vp and TPB\* connected would still be susceptible to late Vg damage.



**Figure 1. 1394 6-Pin Receptacle (Connector) and Plug (Cable) Diagrams**

**Table 1. 1394 6-Pin Description Table**

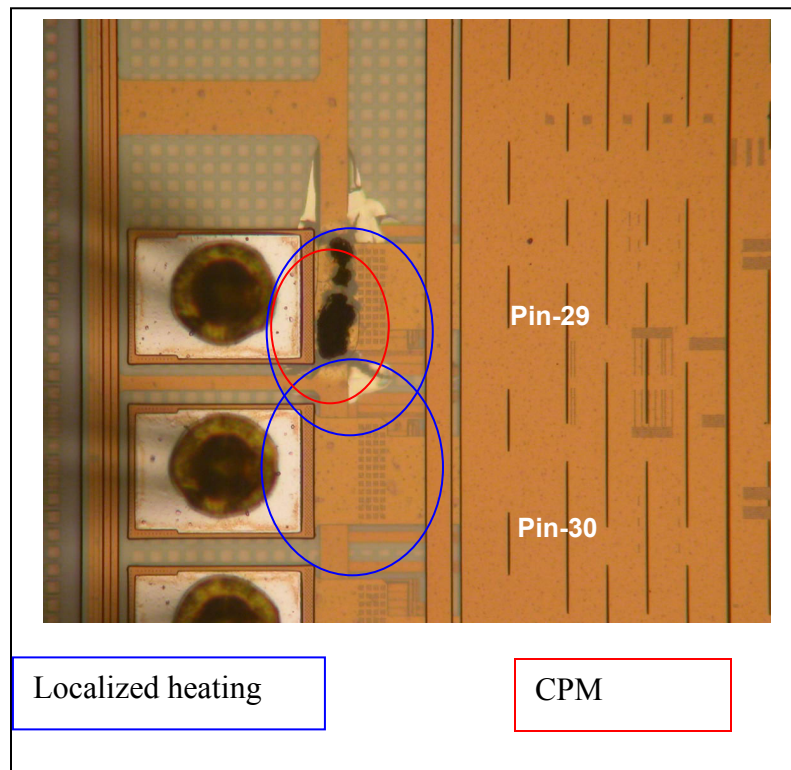
PIN NUMBER	CONTACT NAME	COMMENT
1	Vp	Cable power
2	Vg	Cable ground
3	TPB*	Differential pair B
4	TPB	
5	TPA*	Differential pair A
6	TPA	

## 2 Symptoms of 1394 PHY Device Damage due to a Late Vg Event

To the end user, a 1394 port damaged by a late Vg event will simply fail to operate. In most cases, the other ports of the same 1394 PHY device are not affected and continue to work properly. Replacing the damaged 1394 PHY will fix the issue completely since no other portion of the application is typically affected.

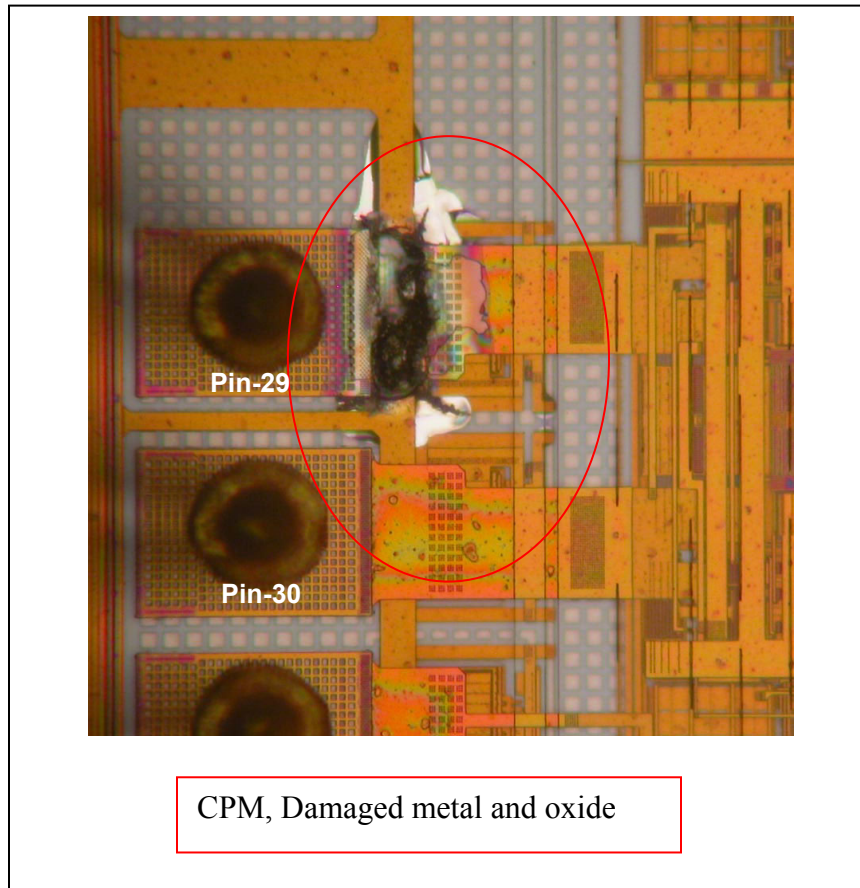
When a damaged PHY device is bench tested, it is likely to show continuity failures. Most often there is an open or short on one of the TPA lines of the failing port. Alternately, damage on the TPB pair is seen in 1 out of 4 cases. Ancillary damage to the TPBIAS circuitry has been observed in some cases as well.

A full failure analysis of a 1394 PHY device that has experienced a late Vg event often shows a failure mechanism of damage to metal, polysilicone and die substrate resulting in the short to ground or open, consistent with electrical overstress. Excerpts from previous failure analyses of EOS damaged PHY devices are shown below. This is damage which is indicative of a late Vg event. Not every 1394 PHY damaged by a late Vg event will show the exact same damage pattern.



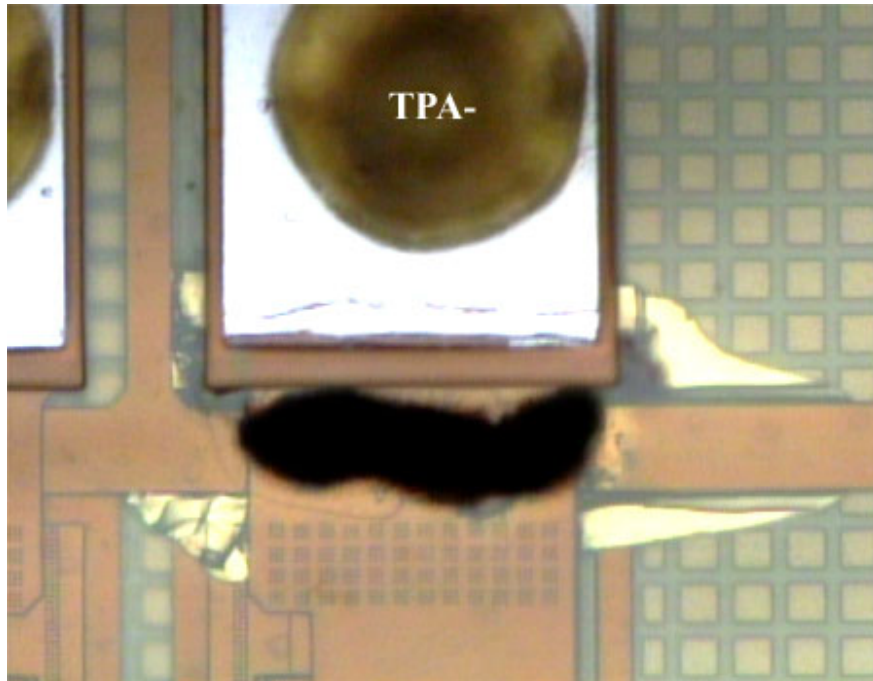
**Figure 2. Optical Photo of the Localized Heating on the TPA\* Pin (#29) and the TPA Pin (#30)**

On this PHY device that was damaged by a late Vg event, liquid crystal analysis was performed, and localized heating was observed in the carbonized package material (CPM) and circuitry right off the bond pad. The TPA\* pin was most likely shorted to the TPA pin through the metal extrusions.



**Figure 3. Optical Photo of the CPM, Damaged Metal and Oxide in the Area of Localized Heating**

This 1394 PHY device was selectively deprocessed. The passivation and top metal were removed. Carbonized package material (CPM), damage to the metal and oxide were observed in the area of localized heating on TPA\* pin (see Figure 3). The optical view at the Metal3 level shows visible evidence of localized heating at the bond pad for the TPA pin. The heating damage caused fused-open and re-flowed metallization



**Figure 4. Optical Photo of a 1394 PHY Device Damaged by EOS**

Another optical view from a different PHY device shows visible evidence of localized heating at the bond pad for the TPA pin. The heating damage caused degraded mold compound along with fused-open and re-flowed metallization.

### 3 Characteristics of Applications Susceptible to Late Vg Event Damage

Some 1394 applications are more susceptible than others to 1394 PHY damage due to late Vg events. Characteristics of these applications are listed below for reference. These characteristics are not required for a late Vg event nor do they indicate that a late Vg event will definitely occur. This list is purely informative. It is provided to allow a designer to determine if late Vg is likely to be a concern for their application.

**Cable Powered System.** The damage caused by a late Vg event is linked to cable power that is seeking a return path, thus systems that rely heavily on 1394 cable power are more likely to see late Vg damage. A late Vg event cannot occur on a 1394 node where only a 4-connection (TPA, TPA\*, TPB, TPB\*) receptacle is used. If there is no Vp connection, by extension there can be no damage. In addition, self-powered applications (a system that never sources or sinks current from the 1394 cable) typically do not see damage due to late Vg events. It is, however, theoretically possible for a 1394 self-powered node to experience damage due to a late Vg event, if it is a two port application that is repeating power to a 1394 device that is cable power consumer.

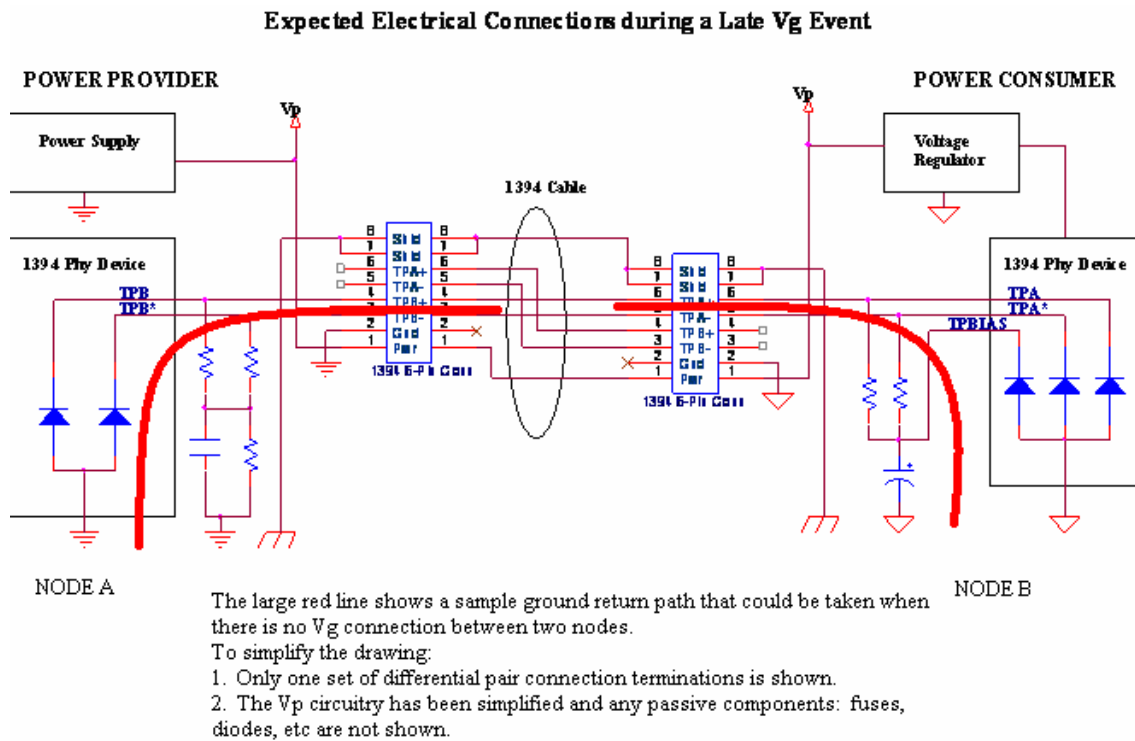
**High Voltage on Vp.** The IEEE 1394A-2000 specification limits Vp supported on the 1394 bus to 30VDC. Typical PC applications source 10 VDC–12 VDC on Vp driven by the PCI bus. Damage to 1394 PHY devices due to a late Vg event occurs most often on systems with greater than 15VDC on Vp. This is because any increase in the voltage that a PHY device is exposed to during a late Vg event increases the likelihood of device damage.

**1394 6-Pin Connectors.** Late Vg events can occur on 1394B systems implementing 9-pin connections, however the 1394 6-pin connector is much more susceptible to angled cable insertion or even cable reversal due to its geometry. This increases the likelihood of a late Vg event and subsequently 1394 PHY device damage.

**Repetitive Cable Use.** In the majority of cases of 1394 PHY devices with EOS damage investigated by Texas Instruments, the root cause has been traced back to a single cable or system in the manufacturers test process. Heavily used 1394 cables or connectors can become worn or damaged after thousands of insertions, resulting in a degraded or nonexistent Vg connection which translates to an extremely high incidence of late Vg events and Phy device damage.

#### 4 Explanation of an Example Late Vg Event

When the Vp connection and any of the four data (TPx) connections between two 1394 nodes, one a power provider and the other a cable power consumer, are engaged without a Vg connection, the data connection becomes the lowest impedance ground return path to the Vp provider. The voltage and current on the ground return path can damage the TPx inputs of the 1394 PHY devices on both sides of the cable.



**Figure 5. Late Vg Electrical Connections**

Figure 5 shows a schematic of possible electrical connections between a power provider node (NODE A) and a cable power consumer (NODE B) during a late Vg event. For this explanation, it can be assumed that there is no direct ground connection between the two 1394 nodes anywhere in the design. The cable shield in the figure is shown as shorted to chassis ground with no connection to signal ground on either 1394 node.

The Vp connection can be assumed to occur first because it is a longer pin in the connector, thereby raising all signals on NODE B to the level of Vp. Once a data connection is made between the two nodes, the ground of NODE B is pulled down and the voltage regulator on NODE B engages. Since the data connection is acting as the ground return path, this forces the TPA/TPA\* of NODE B in the figure to be pulled below the 1394 PHY device ground. This low voltage is most likely in excess of the absolute maximum rating input voltage rating of  $-0.5$  VDC on the 1394 PHY device and can result in damage to the 1394 PHY device on NODE B.

As the voltage regulator of NODE B begins driving out, additional current is returned through the data connection raising the voltage on the TPB/TPB\* signals of NODE A in the example. Depending on the cable power voltage of the system, the voltage on TPB/TPB\* could be in excess of the absolute maximum input voltage rating of  $V_{DD} + 0.5$  VDC on the 1394 PHY device and can result in damage to the 1394 PHY device on NODE A.

Thus a late Vg event can cause damage on either the power provider node or the power consumer node. In a real world situation, the Vg connection is likely to appear after a short delay or in the case of damaged cables or connectors, the connection could be intermittent. While this may limit the exposure of the 1394 PHY devices to the effects of acting as the ground return path, it also can introduce transients that may cause additional damage to the devices.

## 5 1394 PHY Device Protection

It is possible to decrease the frequency of late Vg events by addressing cable and connector quality issues, however, these events remain a concern for many 1394 applications. There is no way to conclusively protect 1394 PHY devices against all EOS damage that could be caused by late Vg events, but it is possible to limit the effects.

One easy-to-implement suggestion is to provide an alternate low-impedance ground return path by shorting the chassis ground of the cable shields to digital (signal) ground. This can be done through a low impedance filter to prevent excess noise if needed.

Another option is to add low capacitance high-speed switching double-diode circuits like the BAV99 to each of the TPx lines to protect them from damaging voltages. A Zener diode biased via a current limiting resistor should also be added to provide a path for any late Vg voltage to return to ground. For a S800 application, the diodes on the TPx signals should be extremely low capacitance or they will affect signal integrity. Figure 6 shows how these preventative measures can be implemented in a typical 1394 application.

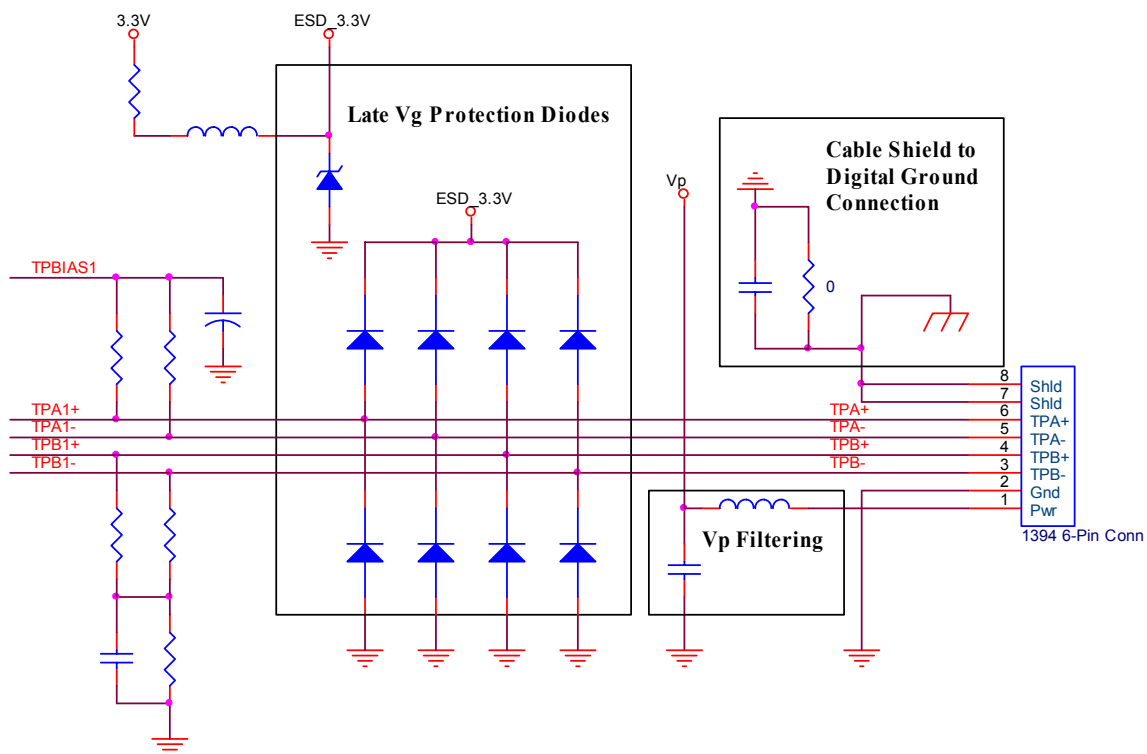


Figure 6. Late Vg Protection Circuitry

In addition, it is important for both EMI and ESD concerns to have some low pass filtering on Vp near the connector. TI recommends a ferrite bead (up to 1000 ohms at 100 MHz) with a capacitor. These components will slow the current rush and potential voltage spike during cable connection thereby reducing the effects of a late Vg event.

## 6 Summary of Recommendations

To prevent electrical overstress damage to 1394 PHY devices efforts should be made to both decrease the frequency of late Vg events in the system as well as protect the 1394 PHY devices from damage due to late Vg events. Here are some recommendations on how to do that which are applicable to almost all 1394 applications.

**Cables / connectors** – The biggest step in decreasing the frequency of late Vg events is to ensure that the 1394 cables and any on-board connectors are intact. Things to watch out for include worn or damaged cables, or improperly modified test cables. In the case of connectors, the metal shell of the receptacle should be checked for solid construction. If the metal shell is loose this can allow a loose or unstable 1394 connection or even allow a cable to be inserted backwards.

**Ground return** – The best way to combat the effects of a late Vg event is to provide a secondary low impedance ground return path. We recommend having the cable shield connected to the digital board ground to provide a return path if Vg is not present.

**Protection diodes** – If it is not possible to use the cable shield as a secondary low impedance ground return path due to isolation requirements or other system implementation concerns, we recommend using diodes to help limit the amount of voltage that can appear on the TPx lines.

There are other options to decrease the frequency or effects of late Vg events that include lowering the cable power voltage, using 4-pin connectors, or making the 1394 node self powered. While these are all effective suggestions, they are not feasible for many mass market 1394 applications.

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