2011
Protection Design Guide for Portable Device Interfaces





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Table of Contents

Portable Device Interfaces Protection

Section I: Introduction & Background

Trends in circuit protection > 4

Semtech advantages process & technology > 5

Threat environment > 6

TVS diode basics > 8

Clamping voltage > 9

Layout guidelines > 10

Section II: Protection Solutions

Parts & features > 11

Antenna protection (RClamp® 0531T) > 14

High speed interfaces protection (RClamp® 0544T) > 15

USB protection (RClamp® 0542T) > 16

USB with integration VBus protection (RClamp®1624T, RClamp® 3624T) > 17

SD/MicroSD protection (EClamp® 2410P) > 18

Audio port protection (EClamp® 2422N) > 19

SIM card protection (EClamp® 2465T) > 20

LCD display and camera protection (EClamp® 250xK) > 21

Keypads and sidekeys protection (µClamp® 0501T, µClamp® 0511T) > 22

Low voltage keypads and sidekeys (µClamp® 2511T, µClamp® 3311T) > 23

Section III: Protection Applications

IEC61000-4-x Transient Immunity Standards > 25

HDMI protection > 29

LVDS protection > 30

USB protection > 31

EPD low voltage TVS > 32

TVS diode selection > 33

Unidirectional vs. bidirectional protection > 34

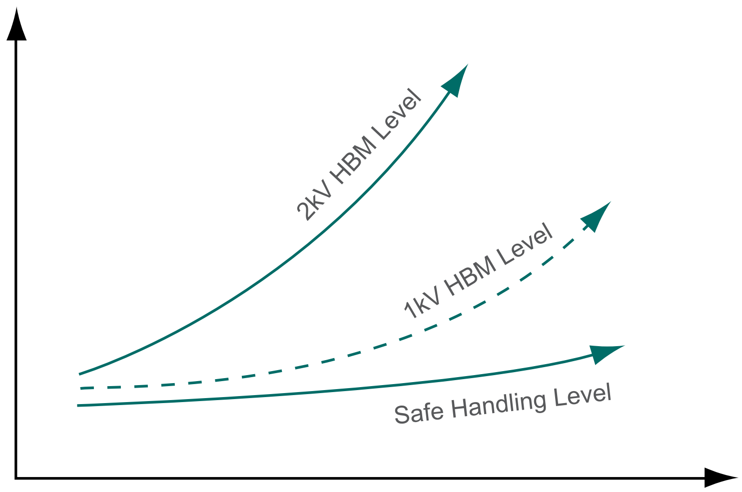
TVS package drawings > 35

The Need for Robust Circuit Protection

Today's mobile communication integrated circuits (ICs) are faster, more efficient, consume less power, and are smaller than ever before. Yet the advances in IC technology and enhanced chip performance has come with a notable trade off: increased susceptibility to damage from ESD, cable discharge and lightning. Not only are transistor geometry sizes scaling down at a remarkable pace, leading to more sensitive circuits, but the on-chip protection is increasingly being sacrificed in favor of accommodating greater performance in the chip. As this trend progresses, high performance system level transient voltage protection will be needed more than ever before.

Cost of ESD design dependent on:

- Chip area
- Respins
- Resources
- Circuit performance
- Time-to-market



ESD Association's Recommended
Safe-Handling Level for On-Chip Protection

Semtech Advantages
Process & Technology

The Semtech protection portfolio offers key advantages over industry standard TVS protection devices. These performance advantages are achieved with Semtech's advanced processing technology. This process technology enables the production of TVS diode arrays with sub 5 volt working voltage, low clamping voltage, and sub-picofarad capacitance. The compact design of the Semtech process allows devices to be housed in low-profile, space-saving packages. Lower working voltage means that the protection device can respond more quickly, shunt transient voltage spikes at a lower threshold, and thus provide a lower clamping voltage. As the transient voltage sensitivity of transceivers increases, designing low working voltage protection devices is a critical component for protecting today's systems.

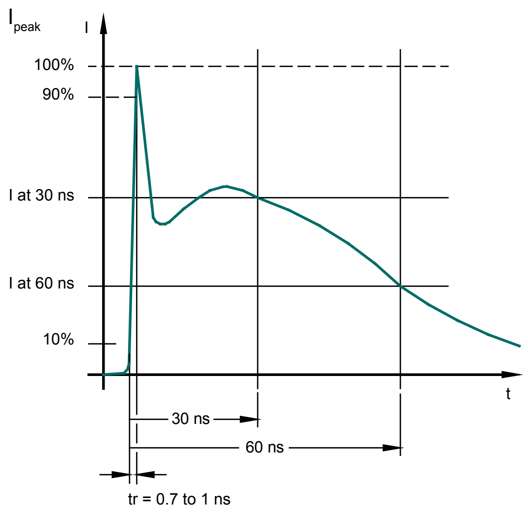
Threat Environment

Portable electronics interfaces are vulnerable to a variety of different transient voltage threats. These threats include Electrostatic Discharge (ESD) and Cable Discharge Events (CDE). Interfaces that are accessible to human contact, such as USB ports, are vulnerable to transient voltage threats from ESD and cable discharge transients. When choosing and designing an appropriate protection scheme, you should consider these transients and their inherent electrical characteristics.

Electrostatic Discharge (ESD)

Several models exist to simulate ESD events. Each is designed to describe the threat in a real world environment. The discharge model is typically a voltage source feeding a resistor/capacitor network. Resistor and capacitor values vary depending upon the standard. Today the most internationally recognized ESD standard is IEC 61000-4-2. IEC 61000-4-2 is a system level standard used by manufacturers to model ESD events from human contact. The test is performed by discharging a 150pF capacitor through a 330Ω resistor. Discharge into the equipment may be through direct contact (contact discharge) or just prior to contact (air discharge).

IEC 61000-4-2 divides the ESD into four threat levels. Test voltages at the threat levels range from 2kV to 15kV with peak discharge currents as high as 30A. Most manufacturers adhere to the most stringent level, level 4, which defines a +/-15kV air discharge test and a +/-8kV contact discharge test. However, many manufacturers test their equipment beyond these levels. The ESD waveform as defined by IEC 61000-4-2 reaches peak magnitude in 700ps to 1ns and has a total duration of only 60ns. While the ESD pulse contains little energy, the resulting effect can be devastating to sensitive semiconductor devices. Sensitive points of the equipment are to be tested with a combination of positive and negative discharges.



ESD Waveform per IEC 61000-4-2

ESD Discharge Levels per IEC61000-4-2					
Level	Test Voltage Air Discharge (kV)	Test Voltage Contact Discharge (kV)	First Peak Current (A)	Peak Current at 30 ns (A)	Peak Current at 60 ns (A)
1	2	2	7.5	4	2
2	4	4	15	8	4
3	8	6	22.5	12	6
4	15	8	30	16	8

ESD Immunity: System Level vs. Device Level

For ESD immunity, it is important to distinguish between system level immunity and device level immunity. The JEDEC JESD22-A114E which is equivalent to the earlier Mil-Std-883 is a device level standard appropriate for the level of ESD threat seen in the manufacturing environment. The IEC 61000-4-2 standard is intended to describe the level of ESD threat seen in the system environment. In the case of transceiver ICs, most are rated to 2kV Human Body Model (HBM) according to the JEDEC Standard/Mil-Std 883. This is not the same as 2kV for the system level standard (IEC 61000-4-2). In fact, the IEC pulse, for a given voltage level, will render over 5 times higher current levels than the JEDEC standard. The chart illustrates this difference: a 2kV ESD pulse for the JEDEC Standard renders a peak current of approximately 1.33A. For the system level, that same 2kV charge level corresponds to a peak current of 7.5A.

Peak Current IEC vs JEDEC			
IEC Level (Contact discharge)	ESD Voltage (kV)	JEDEC JESD-A114E Ipp (kV)	IEC 61000-4-2 Ipp (A)
1	2	1.33	7.5
2	4	2.67	15
3	6	4.00	22.5
4	8	5.33	30

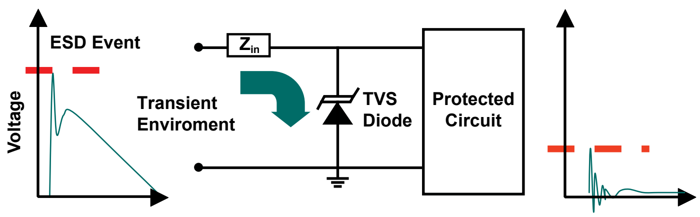
ESD Immunity Standards: IEC61000-4-2 vs. JESD22-A114E

To achieve high system level ESD immunity, you should adhere to the IEC 61000-4-2 standard. The IEC standard is more closely representative of the real world ESD threats seen by electronic systems. Most commercial designs require passing minimum of ±8kV for the Human Body Model of IEC (level 4) contact discharge.

TVS Diode Basics

Transient Voltage Suppression (TVS) Diodes

Transient Voltage Suppressor (TVS) diodes have long been used to provide robust circuit protection. As shown in the following diagram, TVS diodes are generally connected as shunt elements across a transmission line. Under normal operating conditions the TVS diode presents a high impedance to the protected circuit. During a transient event, the TVS achieves breakdown, presents a low impedance shunt path, and the transient current is shunted through the TVS diode. A good TVS protection circuit must divert transient current and clamp transient voltage below the failure threshold of the protected IC.

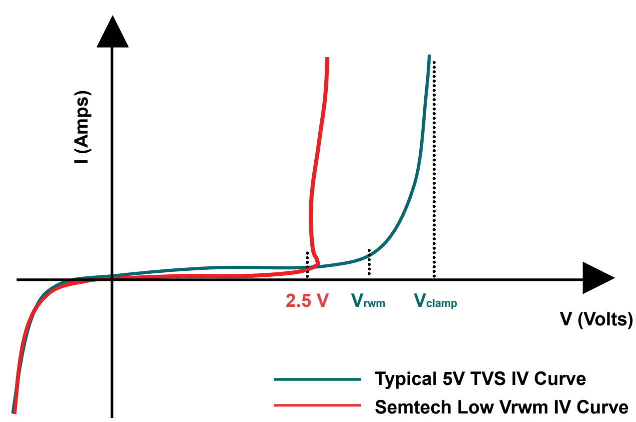


TVS Diode Operation

Parameters for Effective Circuit Protection

A good TVS device for protecting dataline communications interfaces must have some key parameters. First, **low working voltage** is a critical TVS parameter for safeguarding submicron integrated circuits. The working voltage, or Vrwm, is the maximum rated DC voltage for the TVS device. At the Vrwm voltage, the TVS is still a non-conducting device. Once the transient voltage rises above the working voltage, the TVS quickly achieves breakdown and presents a low impedance path to divert the transient. Thus, a low working voltage is essential for clamping a transient to a level well below the damage threshold of the IC that the TVS is protecting. The I-V curve illustrates the advantage of a lower working voltage. The green line represents a typical I-V curve for a standard TVS device while the red I-V curve illustrates the Semtech's low working voltage technology. The lower working voltage means the transient voltage is arrested more quickly and thus can be clamped to a lower voltage. Using TVS devices with lower working voltage is critical to reducing the stress energy seen by the application processor. To address this need, Semtech has designed a family of 2.5V working voltage protection devices for safeguarding next generation application processors and baseband ICs.

Secondly, the TVS should present **low capacitance** to preserve signal integrity on the high-speed interface. If the capacitance of the TVS diodes is too high, adding excessive loading to the circuit, signal distortion and data errors will result.



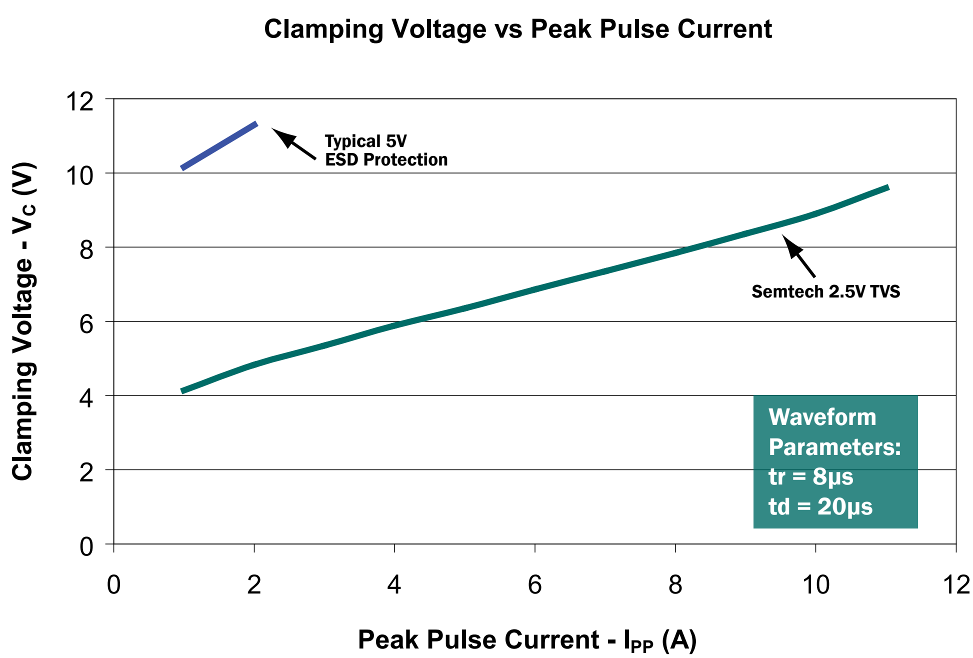
IV Curve for Semtech Low Working Voltage Process

Clamping Voltage

Clamping voltage, by definition, is the maximum voltage drop across the protection device during a transient event, which is also the stress voltage seen by the protected IC. The clamping voltage is the most critical parameter to consider when choosing a TVS device.

It is important to note that a device rated at IEC 61000-4-2 does not guarantee the system will pass ESD testing. This is because the IEC is a system level standard that was originally intended to be applied as pass/fail criteria for showing system level ESD immunity. The purpose of a protection device is to reduce a transient voltage spike down to a safe voltage for the protected IC, and the best way to insure that your TVS protection device adequately protects your interface circuitry is by choosing components that offer the lowest clamping voltage performance.

To illustrate the unique protection benefits of Semtech's proprietary EPD technology, the following chart compares the clamping voltage of an industry standard 5V TVS device with the clamping voltage of the Semtech 2.5V TVS device. Built on the EPD platform, this device offers a very low 2.5V working voltage. Notice that the Semtech 2.5V TVS provides a nice low, flat clamping voltage over a wide range of peak pulse current values. As a 2.5V working voltage device, the clamping performance of the 2.5V TVS is significantly lower than the typical 5V TVS protection device. As the sensitivity on next generation ICs increases, selecting TVS devices with a lower clamping voltage as illustrated in the chart can impact the difference between safeguarding an IC or resulting in catastrophic damage.



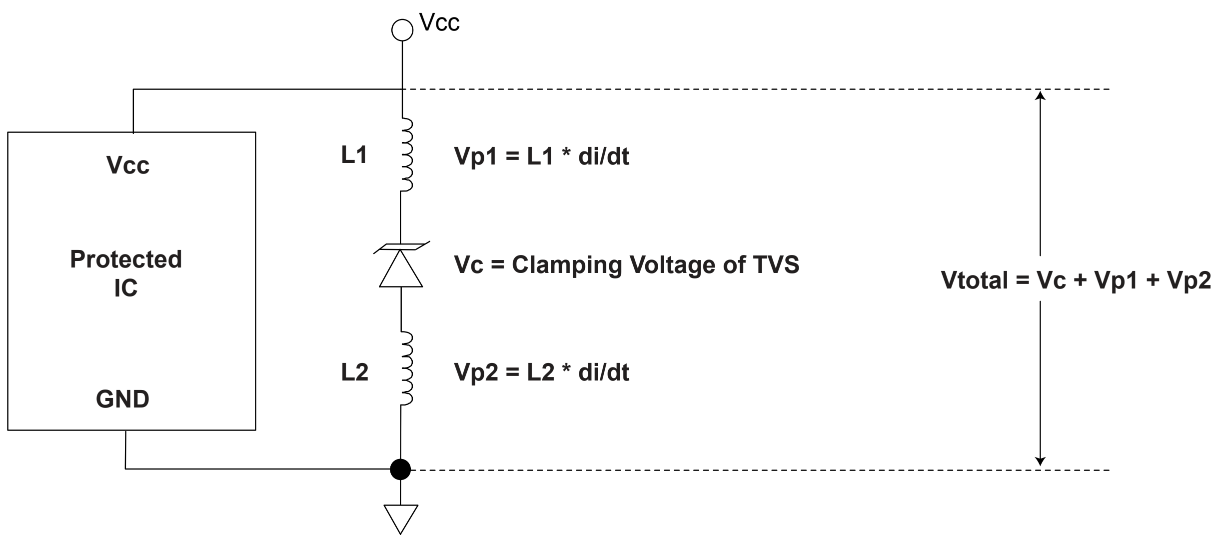
Clamping Performance for Semtech 2.5V TVS

Layout Guidelines

PC board layout is an important part of transient immunity design. This is especially critical in portable device applications, where protecting the constant threat of ESD and CDE from normal use is further complicated by the high speed of the link rates. Parasitic inductance in the protection path can result in significant voltage overshoot and may exceed the damage threshold of the protected IC. This is especially critical in the case of fast rise-time transients such as ESD or EFT. Recall that the voltage developed across an inductive load is proportional to the time rate of change in current (V = L di/dt). An ESD induced transient reaches a peak in less than 1ns (per IEC 61000-4-2). Assuming a trace inductance of 20nH per inch and a quarter inch trace, the voltage overshoot will be 50 volts for a 10A pulse.

The primary rule of thumb is to minimize the effects of parasitic inductance by making the shunt paths as short as possible. All inductive paths must be considered including the ground return path, the path between the TVS and the protected line, and the path from the connector to the TVS device. Additionally, The TVS device should be placed as close to the entry point of ESD as possible to reduce transient coupling into nearby traces.

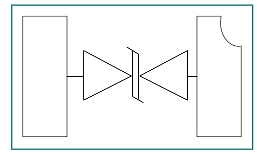
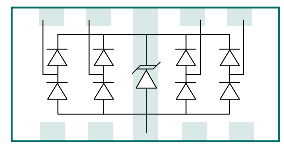
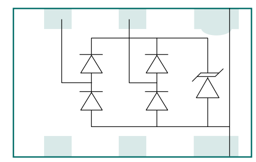
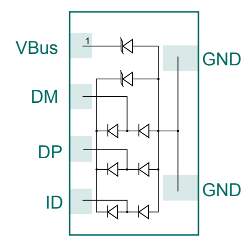
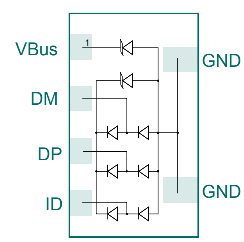
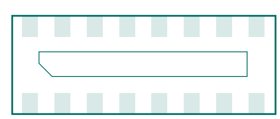
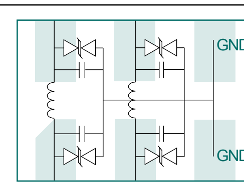
The secondary effects of radiated emissions can cause upset to other areas of the board even if there is no direct path to the connector. Long signal traces will act as antennas to receive energy from fields that are produced by the ESD pulse. By keeping line lengths as short as possible, the efficiency of the line to act as an antenna for ESD related fields is reduced. Minimize interconnecting line lengths by placing devices with the most interconnects as close together as possible. Finally, avoid running critical signal lines near board edges or next to protected lines.

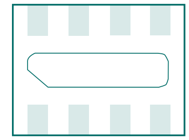
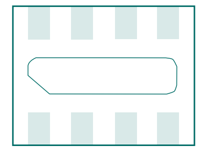
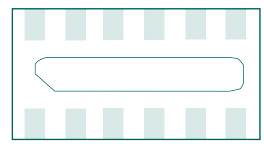
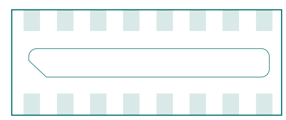
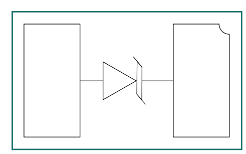
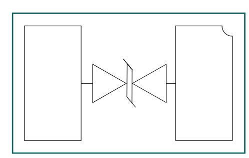
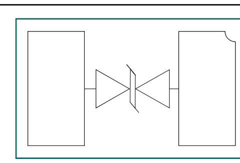
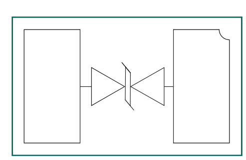


* L1 represents the parasitic inductance of the trace between TVS and Vcc
* L2 represents the parasitic inductance of the trace between TVS and GND
* Vtotal represents the voltage that will be see between Vcc and GND of the IC during a transient.

Parts & Features

ESD sensitive interfaces are found through out today's advanced portable devices increasing the need for high performance protection solutions. Semtech's industry leading low-clamping voltage, low capacitance, and innovative packaging provide advanced performance solutions to safeguard your systems from transient voltage threats. This section will highlight some of the newly released key portable product devices within the Semtech protection portfolio.

Part Number	Lines	V_{rwm}	Cap I/O to I/O	Ipp max (8x20µs)	Application	Circuit Diagram
RClamp® 0531T	1	5V	0.5pF	4A	Antenna	 1.0 x 0.6 x 0.4 mm
RClamp® 0544T	4	5V	0.3pF	5A	HDMI MicroSD LVDS	 2.0 x 1.0 x 0.4 mm
RClamp® 0542T	2	5V	0.4pF max	5A	HDMI LVDS USB2.0 & 3.0	 1.6 x 1.0 x 0.4 mm
RClamp® 1624T	3 1	5.5V 12V	0.4pF max	5A 5A	USB V_{BUS}	 1.7 x 1.0 x 0.4 mm
RClamp® 3624T	3 1	5.5V 28V	0.4pF max	6A 8A	USB V_{BUS}	 1.7 x 1.0 x 0.4 mm
EClamp® 2410P	6	5V	-	-	MicroSD	 4.0 x 1.6 x 0.58 mm
EClamp® 2422N	2	5V	100pF	-	Audio	 1.45 x 1.0 x 0.58 mm

Part Number	Lines	V_{rwm}	Cap I/O to I/O	Ipp max (8x20µs)	Application	Circuit Diagram
EClamp® 2465T	4	5V	10pF	-	SIM Cards	 1.7 x 1.3 x 0.4 mm
EClamp® 2504K	4	5V	15pF typ	-	LCD Display Camera	 1.7 x 1.3 x 0.5 mm
EClamp® 2506K	6	5V	15pF	-	LCD Display Camera	 2.5 x 1.3 x 0.5 mm
EClamp® 2508K	8	5V	15pF	-	LCD Display Camera	 3.3 x 1.3 x 0.5 mm
µClamp® 0501T	1	5V	10pF max	2A	Keypads Sidekeys Connectors	 1.0 x 0.6 x 0.4 mm
µClamp® 0511T	1	5V	7pF max	2A	Keypads Sidekeys Connectors	 1.0 x 0.6 x 0.4 mm
µClamp® 2511T	1	2.5V	7pF max	5A	Keypads Sidekeys Audio Antenna	 1.0 x 0.6 x 0.4 mm
µClamp® 3311T	1	3.3V	10pF max	5A	Keypads Sidekeys Audio Antenna	 1.0 x 0.6 x 0.4 mm

RClamp® 0531T

ESD Protection for Low Frequency Antenna

Features

- 5V working voltage
- 1-line bidirectional
- Capacitance: typical 0.5pF
- Low clamping voltage
- No insertion loss up to 2.5GHz
- Ultra small package (1.0 x 0.6 x 0.4 mm)

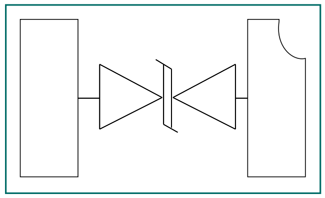
Applications

- GPS antennas
- FM antennas
- LVDS
- High speed data lines

Description

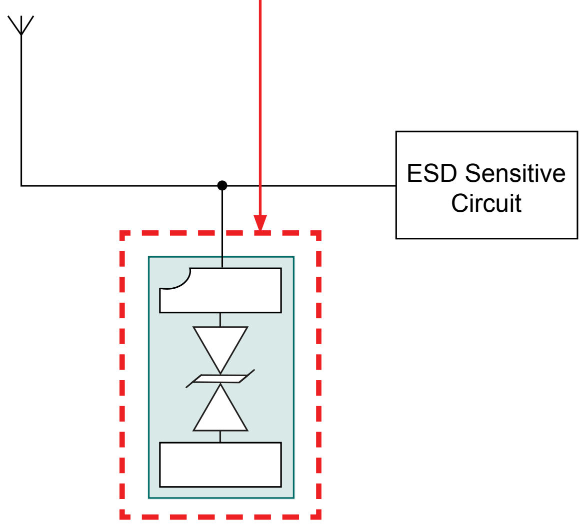
The RClamp0531T is a bidirectional single line protection device offering a maximum capacitance of 0.80pF. This allows it to be used on circuits operating in excess of 2.5GHz without signal attenuation. They may be used to meet the ESD immunity requirements of IEC 61000-4-2, Level 4.

This device is packaged in a 2-pin, RoHS/WEEE compliance, SLP1006P2T package measuring 1.0 x 0.6 x 0.4 mm. Each device protects one high-speed line operating at 5 volts. It gives the designer the flexibility to protect single lines in applications where arrays are not practical.



RClamp0531T

Ultra low capacitance RClamp0531T featuring superior clamping performance protecting today's sensitive IC's.



High speed single line ESD protection

RClamp® 0544T

ESD Protection for HDMI and other High Speed Interfaces

Features

- 5V working voltage
- 4-line protection
- Capacitance: typical 0.3pF Line-to-Line
- Low-clamping voltage
- No impedance matching required
- No Insertion loss up to 3.0GHz
- Ultra-small leadless package (2.0 x 1.0 x 0.4 mm)

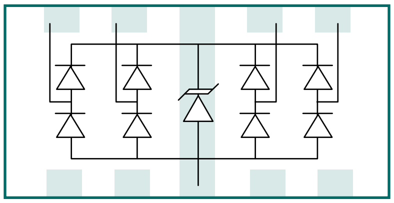
Applications

- Mini HDMI
- HDMI 1.3 / 1.4
- LVDS
- DisplayPort
- USB 2.0

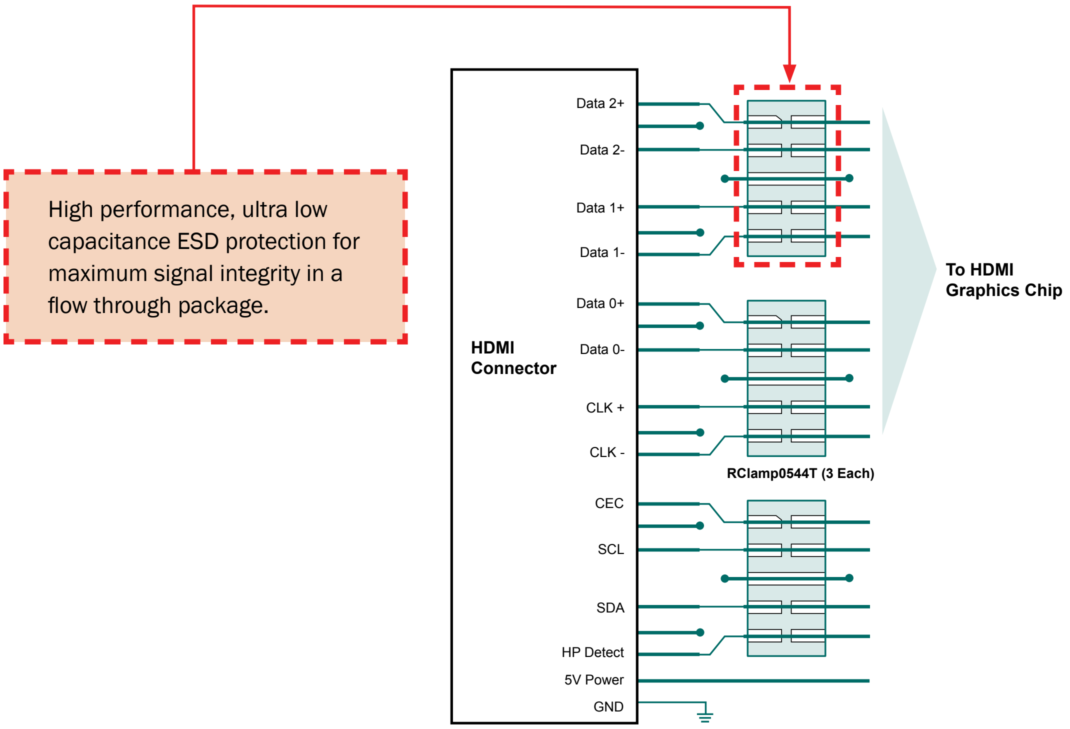
Description

The RClamp0544T is a 4-line protection device operating at 5V. It has a typical capacitance of only 0.30pF between I/O pins. This allows it to be used on circuits operating in excess of 3GHz without signal attenuation. They may be used to ESD immunity requirements of IEC 61000-4-2, Level 4 (±15kV air, ±8kV contact discharge).

The RClamp0544T is in a 8-pin, RoHS/WEEE compliant, SLP2010P8T package. It measures 2.0 x 1.0 x 0.4 mm. The leads are spaced at a pitch of 0.4mm and are designed for easy PCB layout by allowing the traces to run straight through the device.



RClamp0544T



Protection for HDMI Interface

RClamp® 0542T

ESD Protection for USB 2.0 / 3.0 and other High Speed Interfaces

Features

- 5V Working Voltage
- 2-line protection
- Capacitance: typical 0.3pF Line-to-Line
- Low-clamping voltage
- No insertion loss up to 3.0GHz
- Small leadless package: 1.6 x 1.0 x 0.4 mm

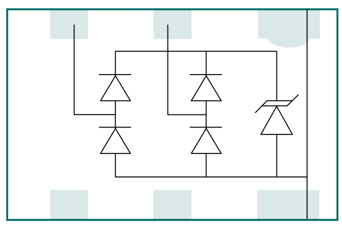
Applications

- USB 2.0 / 3.0
- HDMI 1.3 / 1.4
- LVDS
- DisplayPort

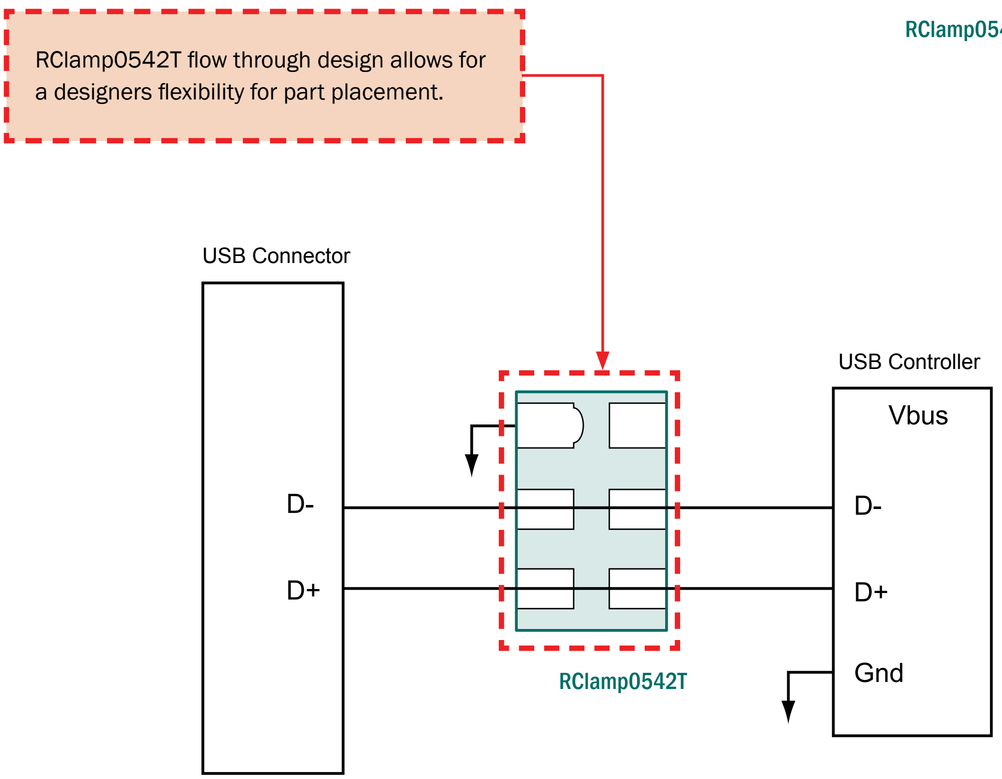
Description

The RClamp0542T has typical capacitance of only 0.3pF (line-to-line). This means it can be used on circuits operating in excess of 3GHz without signal attenuation. They may be used to meet the ESD immunity requirements of IEC 61000-4-2, Level 4 (±15kV air, ±8kV contact discharge). Each device can be configured to protect 1 bidirectional line or two unidirectional lines.

These devices are in a small leadless package (SLP1610P4T) package and feature a lead-free, matte tin finish. They are compatible with both lead free and SnPb assembly techniques. They are designed for use in applications where board space is at a premium.



RClamp0542T



RClamp0542T USB 2.0 Protection

RClamp® 1624T/RClamp® 3624T

ESD Protection for USB 2.0 with Integrated 5V VBus Protection

Features

- Protects three I/O lines operating up to 5.5V
- RClamp1624T protects Vbus line operating up to 12V
- RClamp3624T protects Vbus line operating up to 28V
- Capacitance: typical 0.8pF Line-to-ground
- Low clamping voltage
- No insertion loss up to 2.0GHz
- Large ground for increased ESD performance
- Small package (1.7 x 1.0 x 0.4 mm)

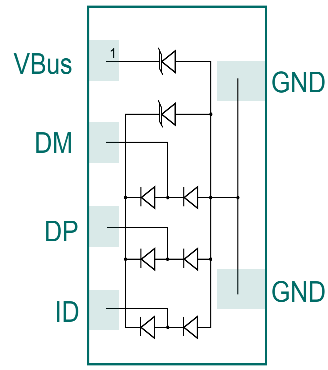
Applications

- USB 2.0
- USB OTG

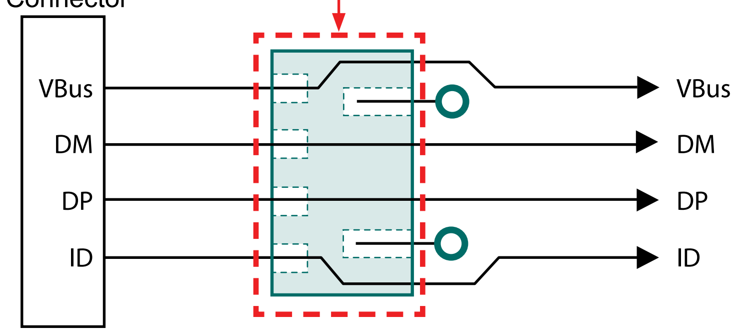
Description

The RClamp1624T and Rclamp3624T are specifically designed to protect one USB port. The flow through layout design of the package enables designers greater flexibility with maximum signal integrity. The unique design of this device features low capacitance TVS diodes for protection of the USB data (DP, DM) and USB ID pins operating at 5V. Loading capacitance on these lines is <1pF for maximum signal integrity. An integrated 12V or 28V TVS diode is used for protection of the USB voltage bus, which ensures isolation between power and data lines. Leakage current of the Vbus protection is <50nA when operating at 5.5V.

These devices are in a 6-pin, RoHS compliant, SLP1710P4T package. It measures 1.7 x 1.0 x 0.4 mm. The leads are spaced at a pitch of 0.4 mm and are finished with lead-free NiPdAu. They may be used to meet the ESD immunity requirements of IEC61000-4-2, Level 4 (15kV air, 8kV contact discharge).



Flow through design maximizes signal integrity. Separate TVS for VBus protection ensures isolation between power and data lines.



RClamp1624T or RClamp3624T

EClamp® 2410P

ESD/EMI Protection for Multimedia Cards

Features

- 5V working voltage
- Protection & termination for six lines & Vdd
- Capacitance: typical 12pF per line
- Termination resistors: 45Ω
- Pull up resistors: 15kΩ (2 each) and 50kΩ
- 16 Pin leadless package (4.0 x 1.6 x 0.58 mm)

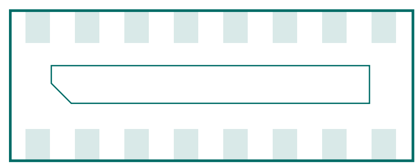
Applications

- T-Flash / MicroSD interfaces
- MMC interfaces

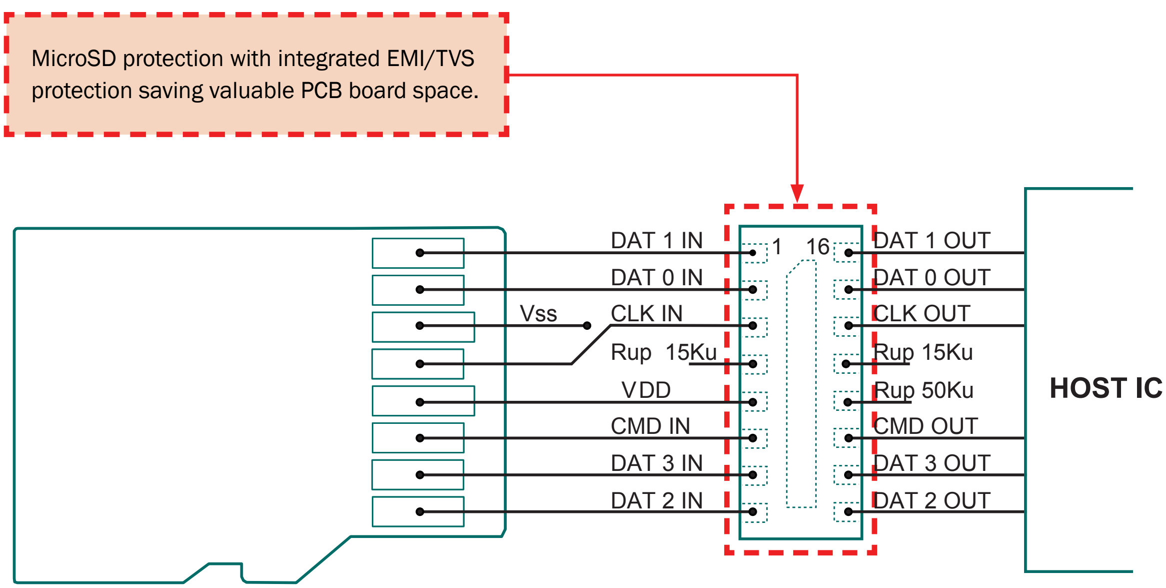
Description

The EClamp2410P is a combination EMI filter and line termination device with integrated TVS diodes for use on Multimedia Card Interfaces. They have been optimized for protection of T-Flash/MicroSD interfaces in cellular phones and other portable devices. The device consists of six circuits that include series impedance matching resistors and pull up resistors as required by the SD specification. TVS diodes are included on each line for ESD protection.

An additional TVS diode connection is included for protection of the voltage (Vdd) bus. Termination resistor value of 45Ω is included on the DAT0, DAT1, DAT2, DAT3, CMD, and CLK lines. Pull up resistors of 15kΩ are included on DAT0, DAT1, DAT 2, and CMD lines while a 50kΩ pull up resistors included on the DAT3 line. These may be configured for devices operating in SD or SPI mode.



EClamp2410P



Protection for MicroSD Interface

EClamp® 2422N

ESD/EMI Protection for Audio Interfaces

Features

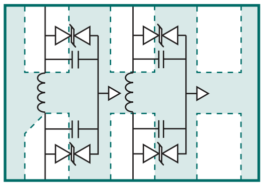
- 5V working voltage
- Protection and filtering for two lines
- Capacitors: 100pF (Typical VR=0v)
- Inductor: 2nH (Typical)
- Small leadless package (1.45 x 1.0 x 0.58 mm)

Applications

- Speaker ports
- Microphone ports

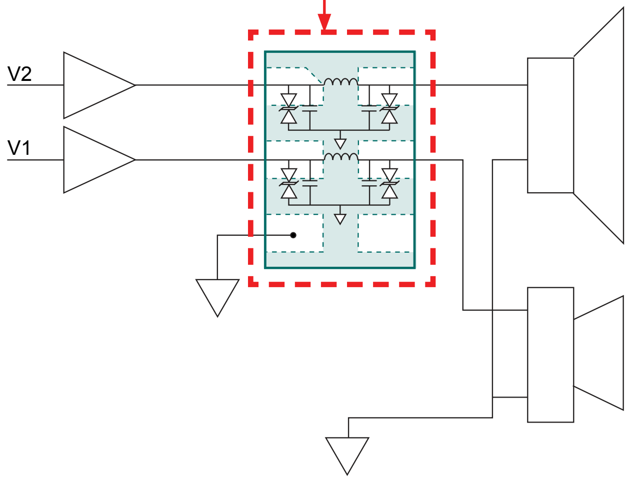
Description

The EClamp2422N is a (C-L-C) low pass filter array with integrated TVS diodes. It is designed to suppress unwanted EMI/RFI signals and provide ESD protection for audio interfaces. Two identical circuits consisting of an inductor of 2nH and capacitor value of 100pF, which are used to achieve 10dB minimum attenuation from 800MHz to 2.7GHz. It has a very low series resistance of 2.0Ω, making it ideal for use on speaker/microphone interfaces.

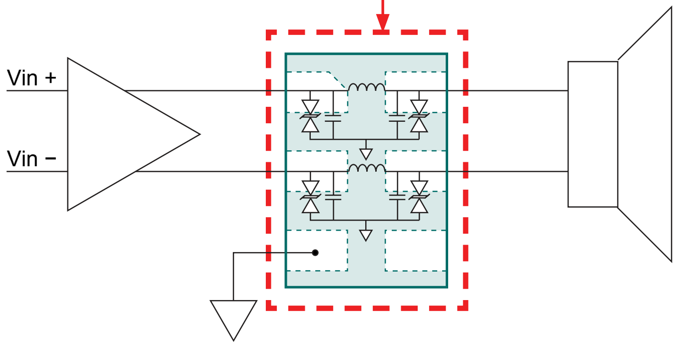


EClamp2422N

Flow through design allows for efficient PCB layout.
Integrated low pass filter reduces part count.



Protection of Single-Ended Mode Microphone with Speaker Output



Differential Mode Protection with Speaker Output

EClamp® 2465T

ESD/EMI Protection for SIM Card in Portable Products

Features

- 5V working voltage
- 4-line protection and filtering
- Capacitance: 10pF
- Termination resistors: 100Ω & 47Ω
- Low ESD clamping voltage
- Very small package (1.7 x 1.3 x 0.4 mm)

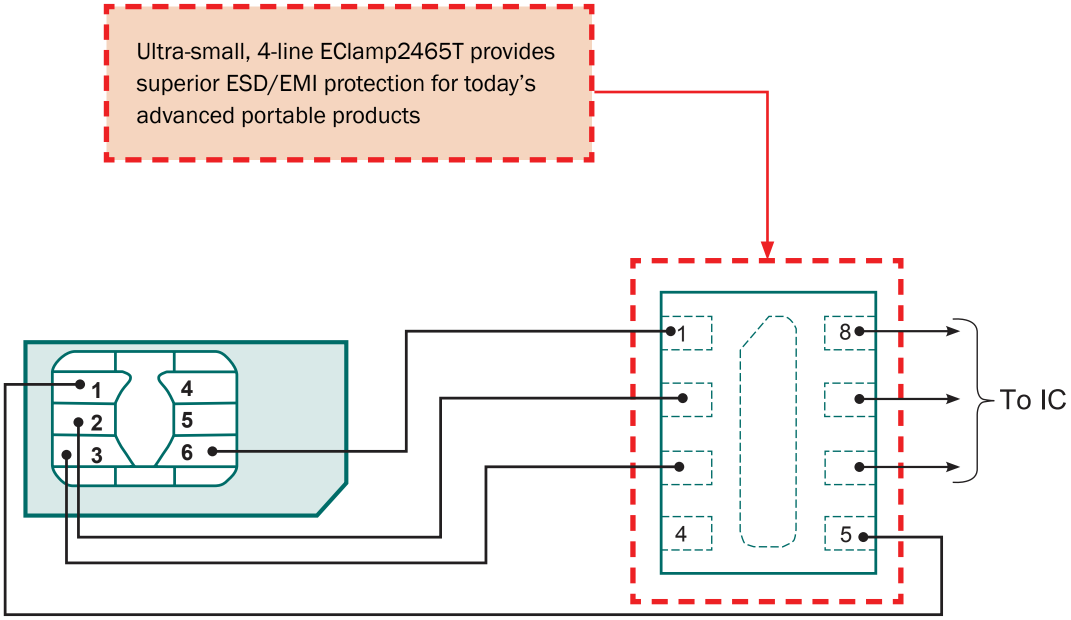
Applications

- Smartphones
- Portable electronics
- MIDs
- Tablet computers

Description

The EClamp2465T is a combination EMI filter and line termination device with integrated TVS diodes for use on SIM card interfaces on cellular phones and other portable electronics. The device consists of three circuits that include series impedance matching resistors for proper termination of the SIM card interface. Termination resistor value of 100Ω is included on the Reset and Data lines and 47Ω on the CLK line. TVS diodes are also included on each line for ESD protection in excess of ±15kV (air discharge) and ±8kV (contact discharge) per IEC61000-4-2, level 4. An additional TVS diode connection is included for protection of the voltage (Vcc) bus.

Pin	Description
1	Data to Connector
2	CLK to Connector
3	Reset to Connector
4	N/C
5	Data to IC
6	CLK to IC
7	Reset to IC
8	Vcc to Connector



Protection for SIM Card Interface

EClamp® 250xK

Advanced EMI Filtering and ESD protection for portable applications

Features

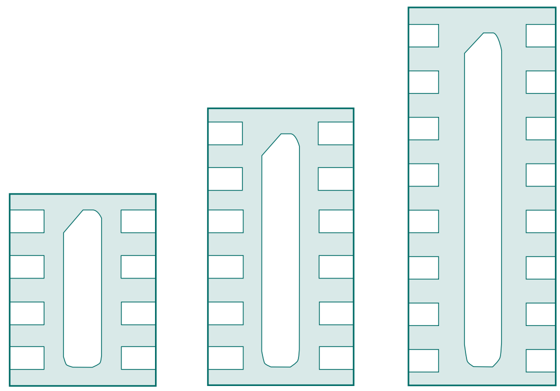
- 5V working voltage
- Three pole LC filter
- Inductor: 17nH (Typical)
- Total capacitance: 24pF (Typical)
- Available in 4, 6, and 8 line protection
- 20dB minimum attenuation between 800MHz to 2.7GHz
- Meets IEC61000-4-2 level 4

Applications

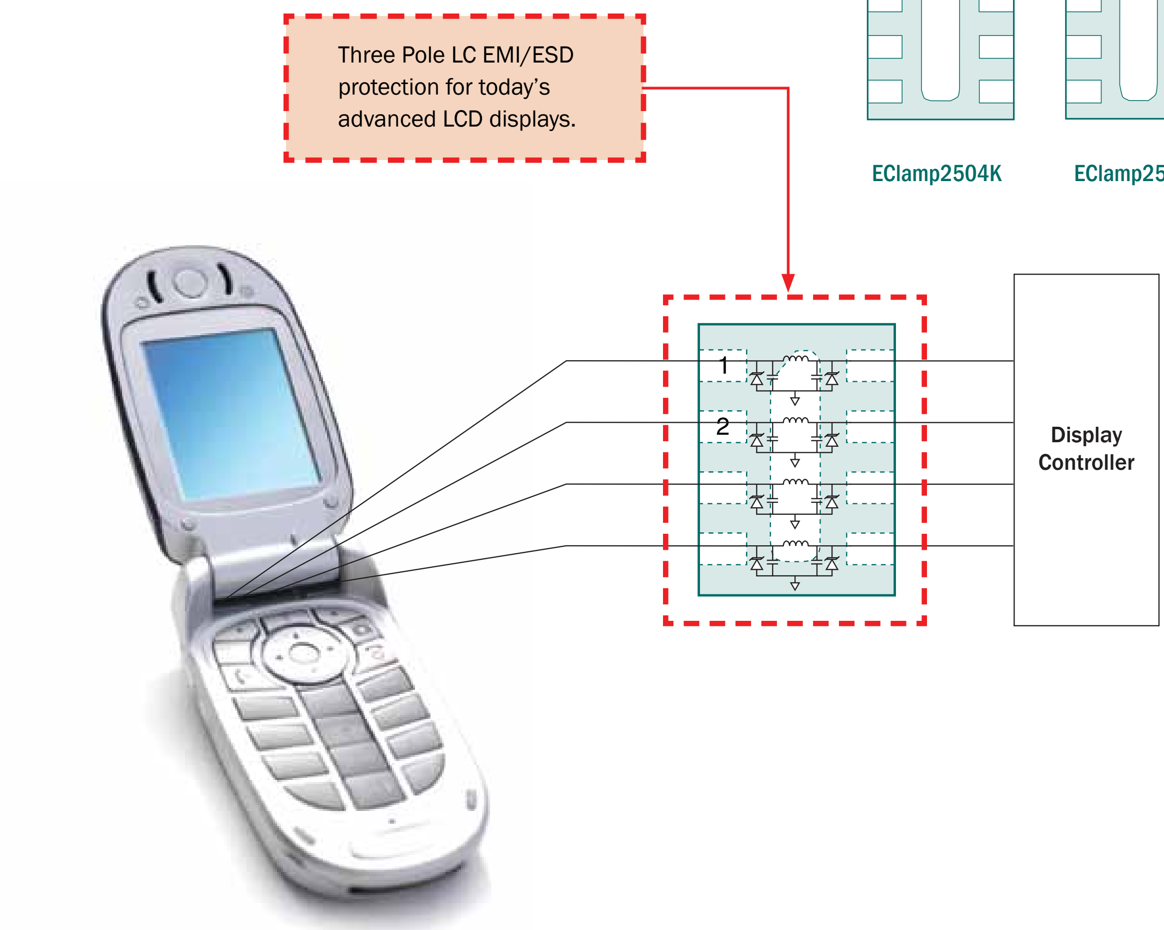
- Color LCD protection
- Cell phone CCD camera lines

Description

The EClamp250xK family are low pass filter array's with integrated TVS diodes. They are designed to suppress unwanted EMI/RFI signals and provide ESD protection in portable electronics. These devices consist of four, six, or eight identical circuits comprised of TVS diodes for ESD protection and a 3-pole inductor-capacitor network for EMI/RFI filtering. A typical inductor value of 17nH and a capacitor value of 12pF are used to achieve 20dB minimum attenuation from 800MHz to 2.7GHz. The TVS diodes provide effective suppression of ESD voltages in excess of ±15kV (air discharge) and ±8kV (contact discharge) per IEC 61000-4-2, level 4.



EClamp2504K EClamp2506K EClamp2508K



μClamp® 0501T & μClamp® 0511T

ESD Protection for keypads and sidekeys

Features

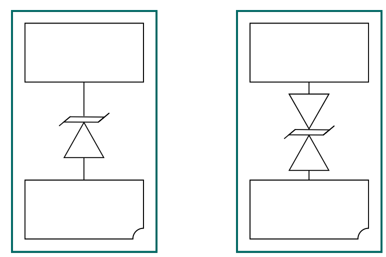
- 5V working voltage
- Single line protection
- μClamp0501T Unidirectional protection
- μClamp0501T Capacitance: 10pF (max)
- μClamp0511T Bidirectional protection
- μClamp0511T Capacitance: 7pF (max)
- Excellent ESD Clamping

Applications

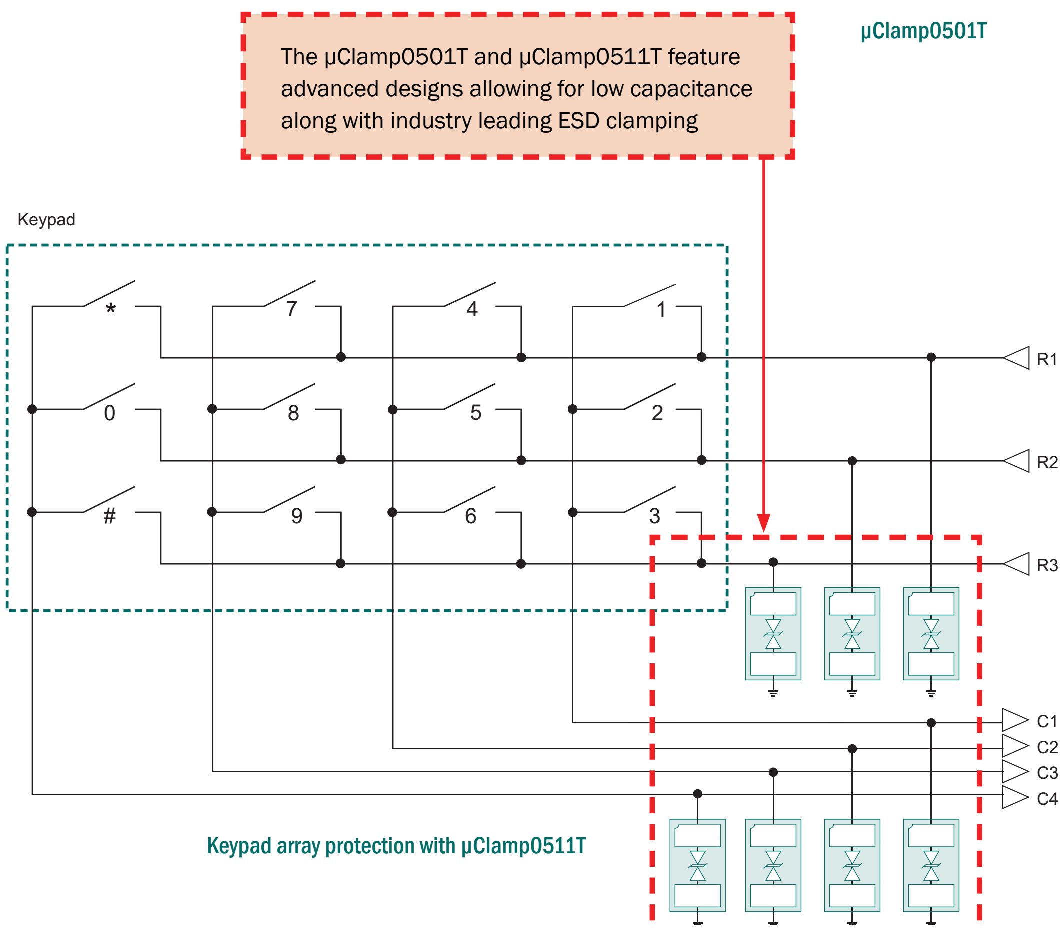
- Keypad protection
- Sidekey protecion
- Portable electronics
- Multimedia card interfaces

Description

These μClamp devices are designed to protect sensitive electronics from damage or latch-up due to ESD. It is designed to replace multilayer varistors (MLVs) in portable applications such as cell phones, notebook computers, and other portable electronics. It features large cross-sectional area junctions for conducting high transient currents. They offer desirable characteristics for board level protection including fast response time, low operating and clamping voltage and no device degradation. It may be used to meet the ESD immunity requirements of IEC 61000-4-2, Level 4 (±15kV air, ±8kV contact discharge).



μClamp0501T μClamp0511T



Keypad array protection with μClamp0511T

µClamp® 2511T & µClamp® 3311T

ESD protection for low voltage applications

Features

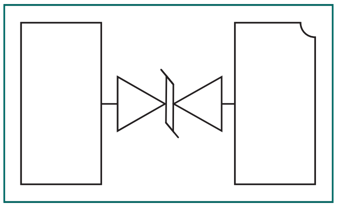
- µClamp2511T - 2.5V working voltage
- µClamp3311T - 3.3V working voltage
- Single line protection
- Low clamping voltage
- Low leakage current: 10nA (typ)
- Low capacitance: 10pF (max)
- Bidirectional protection

Applications

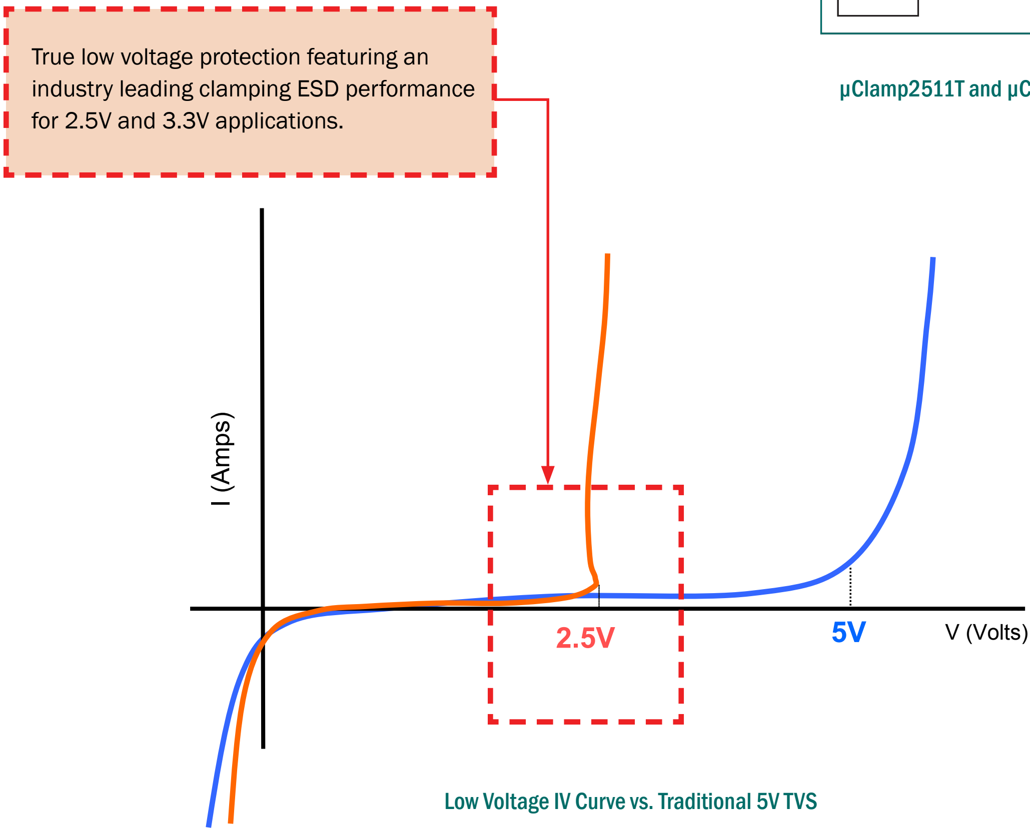
- Keypads and sidekeys
- GPS, TV, and FM antennas
- Audio

Description

The low voltage uClamp series of TVS devices are designed to replace multilayer varistors (MLVs) in portable applications such as cell phones and notebook computers. They are designed to protect sensitive semiconductor components from damage or upset due to electrostatic discharge events. Both devices are constructed using Semtech's proprietary EPD process technology. The EPD process provides a low standoff voltage with a significant reduction in leakage current and capacitance. They feature true operating voltages of 2.5V and 3.3V for superior protection when compared to traditional pn junction devices.



µClamp2511T and µClamp3311T



Low Voltage IV Curve vs. Traditional 5V TVS

Circuit Protection Applications

As high speed interfaces can be subject to wide variety of transient conditions and operating environments, the need for good circuit protection solutions are often unique to the application. This section will examine in deeper detail some of the more subtle aspects of protecting circuit interfaces from overvoltage threats.

IEC 61000-4-x Transient Immunity Standards

The International Electrotechnical Commission (IEC), a worldwide organization promoting international cooperation on questions concerning standardization in electrical & electronic fields, has developed transient immunity standards which have become minimum requirements for manufacturers wanting to do business in the European Community (EC).

Three of the IEC standards deal with transient immunity:

- IEC 61000-4-2 : Electrostatic Discharge (ESD)
- IEC 61000-4-4 : Electrical Fast Transient/Burst (Electrical Fast Transients)
- IEC 61000-4-5 : Surge Immunity

The following sections provide a summary of each of the transient immunity standards.

IEC 61000-4-2 – Electrical Discharge (ESD) Standard

IEC 61000-4-2 addresses one of the most common forms of transients in electronic systems: Electrostatic discharge (ESD). ESD results from conditions which allow the build up of electrical charge from contact and separation of two non-conductive materials. When the charged body is brought in proximity of another object of lower potential, energy is released in the form of electrostatic discharge.

The standard defines immunity requirements for ESD which can be coupled into the equipment directly or through radiated effects. Direct coupling includes any user accessible entry points such as I/O ports, switches, computer keyboards, panel displays, and equipment housings. Radiated coupling results from the discharge between two bodies which are external to the system.

Because the human body is one of the most common generators of ESD, the IEC standard defines a test set up which is designed to simulate an ESD event from a human body. The “Human Body Model” (HBM) as it is referred to, is considered a valid representation of worst case ESD stresses. Discharge into equipment may be through direct contact (contact discharge method) or just prior to contact (air discharge method). Contact discharge is the preferred test method, but air discharge is used where contact discharge cannot be applied.

The ESD threat is divided into four threat levels. Threat level 1 is considered the least severe while threat level 4 is the most severe. Most manufacturers will adhere to level 4: ±8kV contact discharge, ±15kV air discharge. IEC 61000-4-2 also specifies the ESD current waveform and parameters shown in Figure 1 & Table 1.

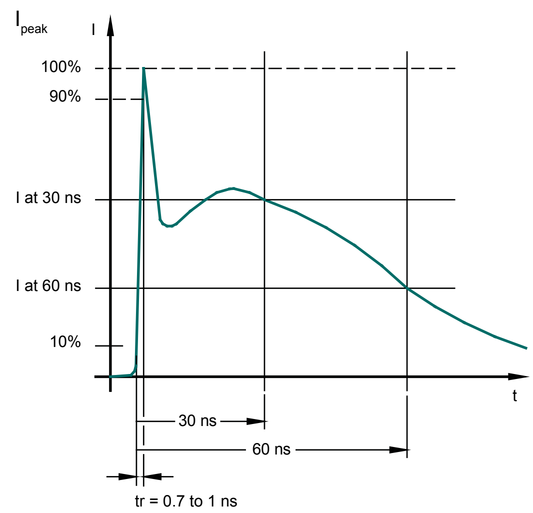


Figure 1 - ESD Waveform per IEC 61000-42

The rise time is extremely fast, defined as 0.7 to 1ns, with a second peak at 30ns and a total duration of only 60ns. The total energy contained within the pulse is approximately a few hundred microjoules.

Transient Voltage Suppression (TVS) diodes are an ideal choice for meeting the ESD transient immunity requirements of IEC 61000-4-2 and are proven solutions for suppressing system level ESD events. The extremely fast response time of the TVS diode is essential for responding to the 1ns rise time of the ESD pulse. Additionally, TVS diodes are capable of clamping the incoming transient to a low enough level as not to cause damage to the protected semiconductor. All TVS diode devices and families offered by Semtech may be used to suppress ESD to level 4 of IEC 61000-4-2. The fast response and low clamping levels make TVS diodes suitable for ESD suppression on data and I/O ports.

Level	Indicated Voltage	First peak current of discharge +/- 10%	Rise time (tr) with discharge switch	Current (+/- 30% at 30 ns)	Current (+/- 30% at 60 ns)
	kV	A	ns	A	A
1	2	7.5	0.7 to 1	4	2
2	4	15	0.7 to 1	8	4
3	6	22.5	0.7 to 1	12	6
4	8	30	0.7 to 1	16	8

Table 1 – IEC61000-4-2 Waveform Parameters

IEC 61000-4-4 – Electrical Fast Transients (EFT) Immunity Standard

Electrical fast transients occur as a result of arcing contacts in switches and relays. EFT disturbances are common in industrial environments where electromechanical switches are used to connect and disconnect inductive loads. IEC 61000-4-4 specifies the EFT threat in both power and data lines. The electrical fast transient is described in terms of a voltage across a 50Ω load from a generator having a nominal dynamic source impedance of 50Ω. The output occurs as a burst of high voltage spikes at a repetition rate ranging from 2kHz to 5kHz. The burst length is defined as 15ms with bursts repeated every 300ms.

Each individual burst pulse is a double exponential waveform with a rise time of 5ns and a total duration of 50ns. A diagram showing the EFT waveform and the EFT burst repetition rate and burst period is shown in Figure 2. Four severity levels are defined in terms of an open circuit voltage as a function of installation environment.

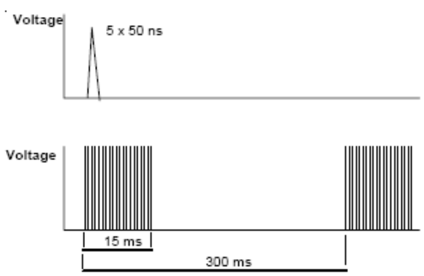


Figure 2 – EFT Burst

The installation environments are defined as :
1 - Well Protected
2 - Protected
3 - Typical Industrial
4 - Severe Industrial

Table 2 provides the open-circuit voltages for each threat level and for both power supply and data lines. Short circuit current values are estimated by dividing the EFT open-circuit voltage by its 50Ω source impedance. This represents the worse case stresses seen by the suppression element. Like ESD, EFT can be especially fatal on data and I/O lines. The fast rise time of the EFT pulses demands a suppression element with the same characteristics as that which are required for suppression of an ESD pulse. Again TVS diodes offer the best solution for suppressing the expected transient energy while keeping clamping voltages across the protected elements to a minimum.

Additionally, the extremely fast response time of TVS diodes is essential for responding to the 5ns rise time of the EFT pulse. Due to the repetitive nature of the EFT pulses, TVS diodes with slightly higher power handling capability will be required for protection at threat level 4.

Level	Peak Amplitude			
	Power Supply Port		I/O Signal, Data & Control Lines	
	V_{OC} (kV)	I_{SC} (A)	V_{OC} (kV)	I_{SC} (A)
1	0.5	10	0.25	5
2	1	20	0.5	10
3	2	40	1	20
4	4	80	2	40

Table 2 – IEC61000-4-4 Severity Levels

IEC 61000-4-5 – Surge Standard

IEC 61000-4-5 addresses the most severe transient conditions on both power and data lines. These are transients caused by lightning strikes and switching. Switching transients may be the result of power system switching, load changes in power distribution systems, or short circuit fault conditions. Lightning transients may result from a direct strike or induced voltages and currents due to an indirect strike. The IEC 61000-4-5 standard defines a transient entry point and a set of installation conditions. The transient is defined in terms of a generator producing a given waveform and having a specified open circuit voltage and source impedance. Two surge waveforms are specified : The 1.2 x 50µs open-circuit voltage waveform and the 8 x 20µs short-circuit current waveform (Figures 3 & 4 respectively).

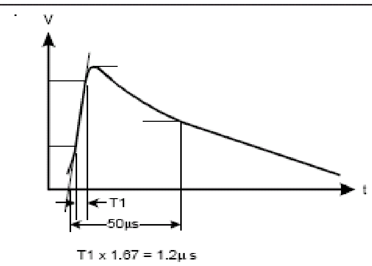


Figure 3 – IEC 61000-4-5 Voltage Impulse

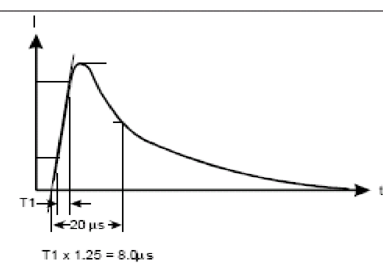


Figure 4 – IEC 61000-4-5 Current Impulse

Transient stress levels for each entry point into the system are defined by installation class. The six classes are defined as :

Class 0 : Well protected environment
Class 1 : Partially protected environment
Class 2 : Well separated cables
Class 3 : Cables run in parallel
Class 4 : Multi-wire cables for both electronic & electrical circuits
Class 5 : Connection to telecommunications cables
and overhead power lines (Low density populated areas)

A class 0 environment is considered the lowest threat level and has no transient stress requirements. The class 5 environment is the most severe and requires the highest transient stress level testing. Table 3 summarizes threat levels as a function of installation class. Values of voltage stress using the 1.2 x 50μs waveform are given. Corresponding current values are calculated by dividing the open-circuit voltages by the source impedances. The short-circuit current values are more useful in choosing a suppression element.

The short circuit current stress levels are defined with the 8 x 20μs waveform for power supply applications with a 2Ω source impedance. For data lines requiring a 42Ω source impedance, the short-circuit current waveform is defined as 8 x 20μs. For telecommunications applications, the open-circuit voltage is defined as 10 x 700μs and the short-circuit current is a 5 x 300μs waveform. The source impedance is given as 40Ω.

The type of suppression element needed for IEC 61000- 4-5 class surges depends upon the threat level and installation class. For power supply applications high power devices are required. A discrete device or an assembly may be required depending on the application. TVS diodes are the best choice for data line applications and secondary board level protection because of their superior clamping voltage characteristics and fast response time.

Class	Voltage Current	Power Supply		Unsym Lines (Long Distance Bus)		Sym Lines	Data Bus (Short Distance)
		Coupling Mode		Coupling Mode		Coupling Mode	Coupling Mode
		Line-Line Zs = 2Ω	Line-GND Zs = 12Ω	Line-Line Zs =42Ω	Line-GDN Zs =42Ω	Line-GDN Zs =42Ω	Line-GND Zs = 42Ω
0	Voltage	NO REQUIREMENT					
	Current						
1	Voltage	(n/a)	0.5KV	(n/a)	0.5KV	1.0KV	(n/a)
	Current		42A		12A	24A	
2	Voltage	0.5KV	1.0KV	0.5KV	1.0KV	1.0KV	0.5KV
	Current	250A	83A	12A	24A	24A	12A
3	Voltage	1.0KV	2.0KV	1.0KV	2.0KV	2.0KV	(n/a)
	Current	500A	167A	24A	48A	48A	
4	Voltage	2.0KV	4.0KV	2.0KV	4.0KV	(n/a)	(n/a)
	Current	1KA	333A	48A	95A		
5	Voltage	(Note 1)	(Note 1)	2.0KV	4.0KV	4.0KV	
	Current			48A	95A	95A	
WAVE FORMS	Voltage	(1.2 x 50μs)	(1.2 x 50μs)	(1.2 x 50μs)	(1.2 x 50μs)	(1.2 x 50μs)	(1.2 x 50μs)
	Current	(8 x 20μs)	(8 x 20μs)	(8 x 20μs)	(8 x 20μs)	(8 x 20μs)	(8 x 20μs)

Note 1: Depends on class of local power supply system.

Table 3 – IEC61000-4-5 Severity Levels

Summary

Any OEM equipment manufacturer who plans to sell in the European market will have to meet the requirements of IEC 61000-4. IEC defines three transient immunity standards which provide equipment suppliers with a susceptibility level. Designing in accordance to the IEC standard enables manufacturers to produce more reliable products. Each of the transient immunity standards defines transient sources, entry paths into a system, severity levels, and test methods. Equipment application will determine what level of transient protection is needed. Transient suppression devices must be carefully chosen for each of the standards.

References

Makowski, Leo P., “IEC 1000-4-X (801) Series of Standards,” EMC Test & Design, October 1994 Clark, O.M., “Electrical-Transient Immunity: A Growing Imperative for System Design,” Electronic Design, January 23, 1992

IEC Publication 1000-4-2 “Electromagnetic Compatibility for Industrial Process Measurement and Control Equipment - Part 4, Electrostatic Discharge Requirements,” International Electromechanical Commission, 1995

IEC Publication 1000-4-4 “Electromagnetic Compatibility for Industrial Process Measurement and Control Equipment - Part 4, Electrical Fast Transient/ Burst Requirements,” International Electromechanical Commission, 1995

IEC Publication 1000-4-5 “Electromagnetic Compatibility for Industrial Process Measurement and Control Equipment - Part 4, Surge Immunity Test,” International Electromechanical Commission, 1995

ESD Protection Solutions for HDMI

High Definition Multimedia Interface (HDMI) is an uncompressed, all-digital audio/video interface. It provides a high speed interface between audio/video source devices, such as DVD players, and sink devices, such as digital displays. The HDMI plug is frequently exposed to Electrostatic Discharge (ESD) directly from the user or Cable Discharge (CDE) from hot plug cable.

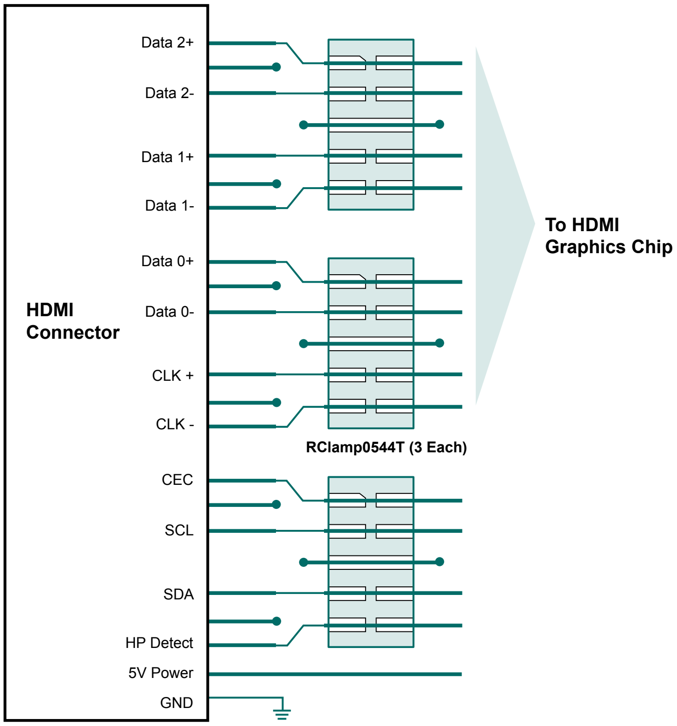
To ensure proper functionality, HDMI-based systems must protect all potentially exposed interface signals and power pins to meet or exceed the EOS (electrical over stress) specification of IEC 61000-4-2, Level 4 (+/-15kV Air, +/-8kV Contact) without damage. Current HDMI silicon runs at 2.25Gbps with 3.4Gbps in the near future. At such a high data rate, signal integrity and impedance requirements are given more focus than ever before, as put forth in the HDMI Compliant Test Specification (CTS). The HDMI CTS requires all HDMI sink devices to maintain the differential impedance of the high speed lines at 100Ω ±15%.

Semtech's RClamp0544T has a typical capacitance of 0.3pF between I/O pins which allows it to be used on HDMI running at a typical transmission speed of 2.25Gbps. Furthermore, this ultra low capacitance eliminates the need to add capacitive compensation while maintaining signal integrity.

From a mechanical point of view, the RClamp0544T is housed in a leadless SLP2010P8T package that measures only 2.0 x 1.0 mm. Its unique design allows the traces to run straight through the device further simplifying PCB design.

RClamp0544T features a very low clamping voltage and low turn on voltage, which means RClamp0544T will respond quickly in an event of ESD and instantly clamp the stress voltage seen by sensitive ICs to well below the destructive threshold.

RClamp0544T provides reliable ESD protection in excess of IEC 61000-4-2 Level 4 (+/- 8kV Contact, +/-15kV Air) as well as IEC61000-4-4 EFT(40A, 5/50ns) and IEC61000-4-5 lightning (5A, 8/20µs).



Protection for HDMI Interface

ESD Protection Solutions for LVDS

Low-voltage differential signaling (LVDS), is now used extensively in several applications in portable applications, most notably used in MIDDI and MIPI Interfaces. It provides an attractive solution - A small-swing differential signal for fast data transfers at significantly reduced power and with excellent noise immunity.

LVDS in mobile applications are used for high-speed serial communications, replacing slower parallel interfaces. They are ideal for implementing a variety of different applications including next generation camera designs and high-speed display communications.

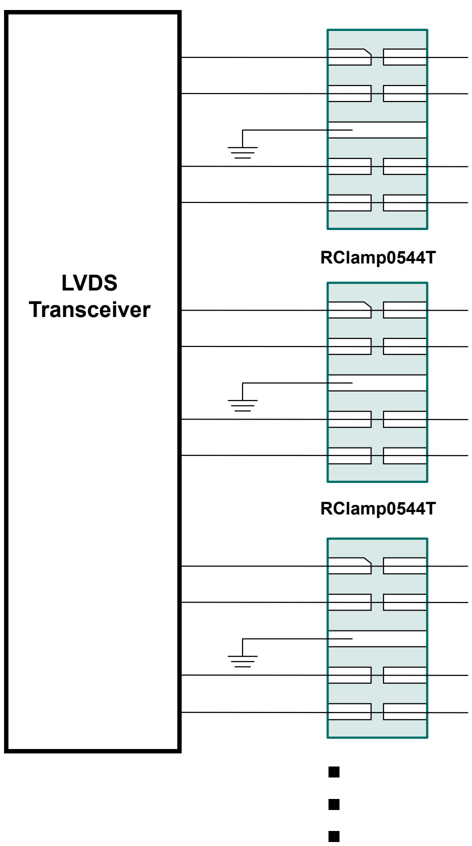
At these higher speeds it is critical that the selected TVS protection devices do not impact signal integrity and at the same time offer ESD protection for next generation IC’s.

Semtech’s RClamp0544T is a 5V TVS array that offers low capacitance and low clamping voltage, which makes it an ideal solution for transmission speed of 500Mbps and above.

The typical differential mode capacitance of the Semtech RClamp0544T is less than 0.3pF. The ultra low capacitance ensures that the signal integrity will be maintained at 655Mbits/s, the maximum data rate recommended, without the need for capacitive compensation. Further more, RClamp0544T provides reliable ESD protection in excess of IEC 61000-4-2 Level 4 (+/- 8kV Contact, +/- 15kV Air) as well as IEC61000-4-4 EFT(40A, 5/50ns) and IEC61000-4-5 lightning (5A, 8/20μs).

Regardless of the level of threat environment, Semtech’s RClamp0544T responds quickly to an ESD event and its low clamping voltage ensures the stress voltage seen by sensitive ICs are well below the destructive threshold.

From a mechanical point of view, the RClamp0544T is housed in a leadless SLP2010P8T package that measures only 2.0 x 1.0 mm. Its unique design allows the traces to run straight through the device which simplifies PCB layout and improves signal integrity.



Protection for LVDS Interface

ESD Protection Solutions for USB

USB stands for universal serial bus. It is the most successful interface in the history of PC and has been virtually adopted 100% in PC and peripherals.

Even though ESD protection requirement is not explicitly called out in USB specifications, USB is susceptible to ESD as a hot insertion and removal system. The high speed data transfer rate of 480Mbps and ever increasing complexity of USB2.0 controllers make its ESD protection quite a challenge. The variations between different manufacturers further complicate the situation.

The selection criteria for protecting most advanced USB2.0 ports are:

1. Low capacitance for minimal signal degradation at 480Mbps
2. Fast response time and low turn on voltage to allow device to turn on and limit the current going into protected IC in an event of ESD
3. Low clamping voltage to limit the voltage across sensitive IC
4. Low leakage current for minimal power consumption

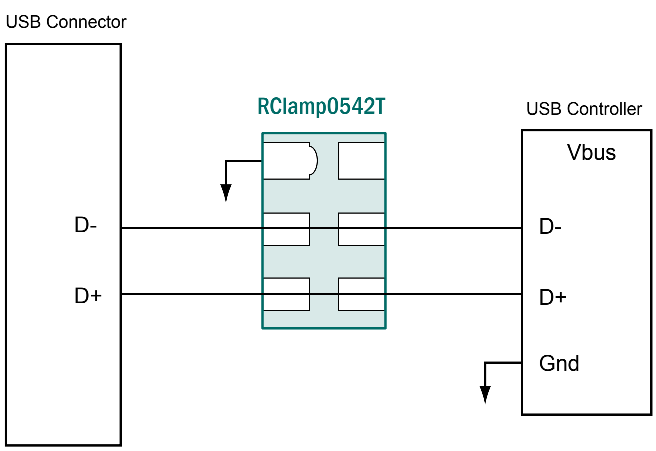
Semtech offers two options for USB2.0 protections depending on whether VBUS protection is required.

RClamp0542T:

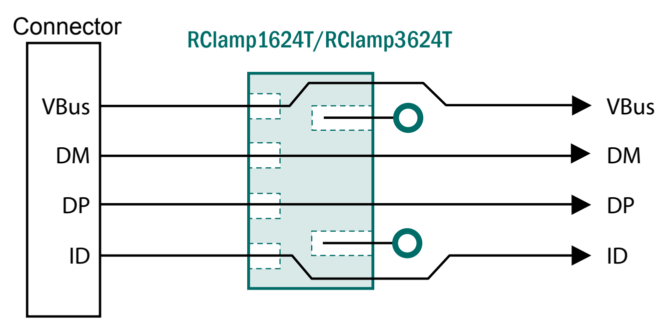
- Protects one pair of high speed datalines with reliable ESD protection in excess of IEC 61000-4-2 Level 4, without the need for capacitive compensation
- Responds quickly in an event of ESD and its low clamping voltage ensures the stress voltage seen by sensitive ICs are well below the destructive threshold
- Has a typical capacitance of 0.3pF between I/O pins which has minimum electrical effects on the high speed signal lines and allows it to be used on circuits operating in excess of 3GHz without signal degradation

RClamp1624T & RClamp3624T:

- Offers Vbus protection as well as data line protection in excess of IEC 61000-4-2 Level 4
- Has a separate TVS to protect Vbus therefore provides isolation between power and datalines
- Available in two different Vbus voltages; RClamp1624T protects the Vbus to 12V Vrwm and the RClamp3624T protects the Vbus to 28V Vrwm
- Has a maximum capacitance of 0.5pF between I/O pins which allows it to be used on circuits operating in excess of 3GHz without signal degradation



Protection for USB 2.0 Interface



USB 2.0 Protection with Vbus and ID Pin Protection

Semtech Low Voltage TVS

Conventional TVS diodes are silicon avalanche, p-n junction devices designed to operate at voltages as low as 5 volts. They are specifically designed with large junction areas for handling high transient currents. However, many of today's semiconductor devices operate at voltages below 3.3 volts, and thus require lower voltage protection devices. Unfortunately, for operating voltages below 5 volts, conventional TVS diodes technology becomes impractical. This is due to the adverse effects of high leakage current and high capacitance caused by the high impurity concentrations that are needed to lower the device voltage below 5 volts. Semtech's proprietary low voltage EPD device technology was developed to provide protection for today's circuits operating at voltages as low as 2.5 volts. Unlike TVS diodes with a conventional p-n junction structure, the EPD device utilizes a more complex four layer (n-p-p-n) structure. The construction of these devices results in very low operating and clamping voltage without the adverse effects mentioned above.

Device Operation

Since the EPD TVS devices use a 4-layer structure, they exhibit a slightly different IV characteristic curve when compared to conventional devices. Figure 1 compares the IV characteristics curves of a low voltage TVS with a working voltage (V_{RWM}) of 3.3 volts to the conventional device with a working voltage of 5 volts. During normal operation, each device represents a high-impedance to the circuit up to its working voltage. During an ESD event, they begin to conduct and will enter a low impedance state. For the 3.3 volt device, this happens when the punch-through voltage (V_{PT}) is exceeded. Unlike a conventional 5 volt device, the low voltage TVS will exhibit a slight negative resistance characteristic as it conducts current. This characteristic aids in lowering the clamping voltage of the device, but must be considered in applications where DC voltages are present. The reason is the device can latch up if the DC bias voltage is present. To better understand why, consider the IV curve for a 3.3 volt device shown in Figure 2. During and ESD event the device will conduct along the curve until the transient subsides. In order for the device to turn off, the voltage must fall below the snap-back voltage (V_{SB}). The value is normally a minimum of 2.8 volts for a 3.3 volt device. If the device is biased at 3.3 volts, it will never fall below the snap-back voltage and will therefore stay in a conducting state. The amount of the current the device will sink depends upon the bias voltage and the DC supply capability. If the amount of current that is conducted exceeds the device steady state capability, the TVS device can become damaged or destroyed.

Low Voltage TVS

- Working Voltage (V_{RWM}): Maximum rated operating voltage at which the device will appear as a high impedance to the protected circuit
- Punch-Through Voltage (V_{PT}): Minimum rated voltage at which the device will become a low impedance (i.e. Minimum Turn-on Voltage). When VPT is exceeded, the device will conduct.
- Snap-Back Voltage (V_{SB}): Minimum rated voltage when the device is in conducting state measured at Isb=50mA. This voltage is less than the working voltage. The voltage must full below Vsb for the device to turn off.
- Clamping Voltage (V_C): Maximum voltage drop across the device at a defined peak pulse current (I_{PP}). This is the voltage seen by the protected circuit during a transient event.

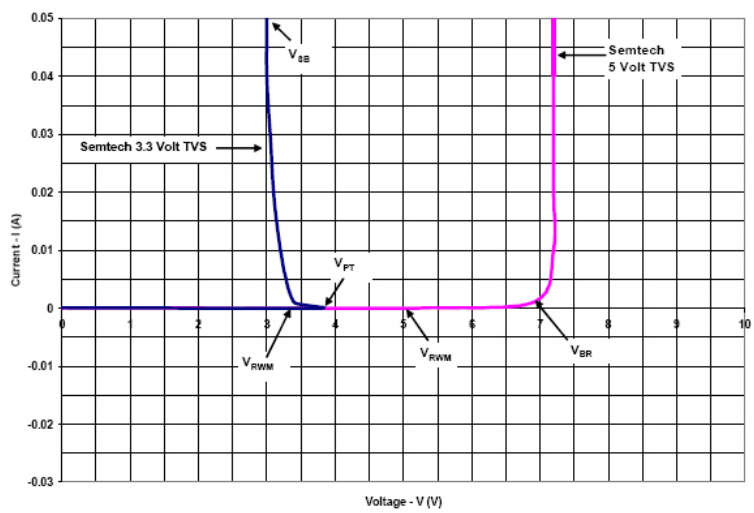


Figure 1 - 3.3V vs. 5V TVS IV Curve

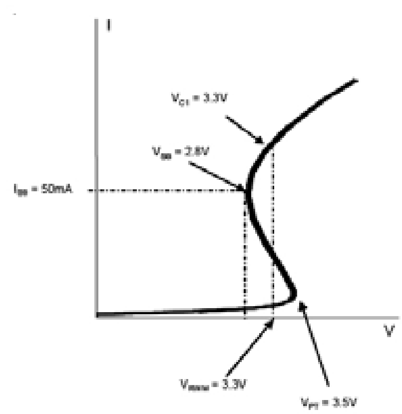


Figure 2 - 3.3V TVS IV Characteristic Curve

TVS Diode Selection

Selection of a suitable component will depend on the number of lines to be protected, the available board space, and the electrical characteristics of the circuit to be protected. TVS diodes are available in a variety of packages and configurations suitable for use in today's advanced electronic systems.

No matter what the applications is, however, certain device parameters and guidelines form the basis for device selection.

TVS Diode Terminology

- A typical IV characteristic curve for a bidirectional TVS diode is shown in Figure 1. The key device parameters
- Reverse Standoff Voltage (V_{RWM}): This is the normal DC operating voltage of the device. At this point, the device will appear as a high impedance to the protected circuit. Discrete devices are available with standoff voltages ranging from 2.5V to 70V. This parameter is also referred to as working voltage.
- Reverse Breakdown Voltage (V_{BR}): This is the point where the device begins to conduct in avalanche mode and becomes a low impedance path for the transient. Breakdown voltage is measured at a test current (I_T), typically 1mA or 10mA.
- Peak Pulse Current (I_{PP}): Maximum permissible surge current which the device can withstand without damage. TVS diode data sheets specify a peak pulse capability for a particular transient waveform. Most TVS diodes are rated using a 8/20μs or 10/1000μs impulse waveform.
- TVS diodes can withstand higher peak pulse current for shorter duration pulses.
- Clamping Voltage (V_C): Maximum voltage drop across the TVS for a particular peak pulse current.

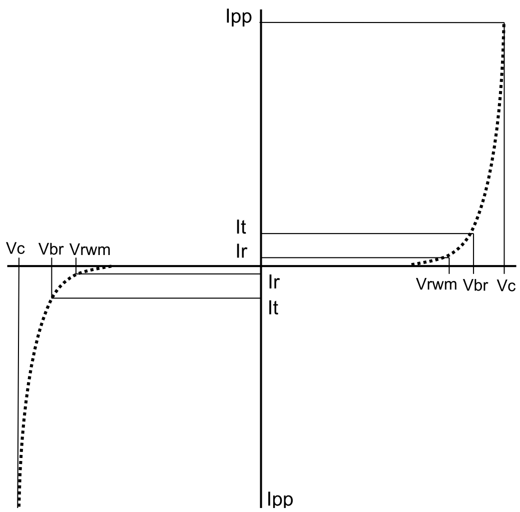


Figure 1 - Bidirectional IV Characteristic Curve

Selection Guidelines

TVS diode selection involves comparison of device parameters with circuit conditions. The following selection guidelines are recommended:

- Select a device with a reverse standoff voltage greater than or equal to the normal operating voltage of the circuit.
- Select a device which is capable of dissipating the expected transcient peak pulse current.
- The device clamping voltage should be less than the maximum voltage handling capability of the protected circuit for the same pulse waveforms.
- For systems using high speed data rates, device junction capacitance will have to be considered. Semtech manufactures special low capacitance devices for those applications.

There may be applications where the actual transient current cannot be defined. Often, the designer will have to meet the requirements of certain transient immunity specifications. At the very least, identification of the source of the threat is necessary; lightning, inductive switching, ESD, etc.

Device Parameter		Circuit Conditions
V_{RWM}	≥	Normal circuit operating voltage
I_{PP}	≥	Expected transient current
V_C	≤	Maximum allowable voltage across the protected component
C_J	<	Maximum loading capacitance for signal integrity

Figure 2 - Selection Summary

Unidirectional and Bidirectional Protection

Unidirectional Protection

Figure 1 illustrates a large transient at the input of a circuit protected by a unidirectional TVS diode. During the positive spike, the TVS diode junction is reversed biased. The device acts in avalanche mode as the transient current i_1 flows. The spike is clamped at or below the maximum clamping voltage of the protection device. During the negative spike, the TVS diode junction is foward biased. The negative spike is clamped to one diode drop as the device conducts i_2 in the foward direction.

Bidirectional Protection

Figure 2 illustrates a large transient at the input circuit protected by a bidirectional TVS diode. The positive and negative spikes are both clamped at or below the maximum clamping voltage of the device. During the positive spike, D1 conducts in the forward direction (i3) and D2 is reversed biased conducting in avalanche mode. During the negative spike, D2 conducts in the forwards direction (i4) and D1 is reversd biased conducting in the avalanche mode.

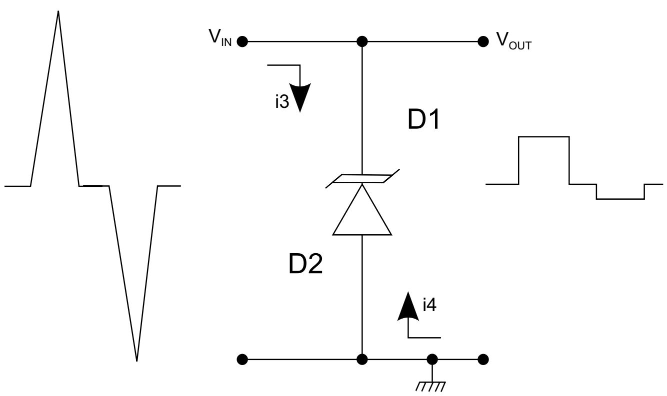


Figure 1 - Unidirectional Device
(Asymmectric Clamping)

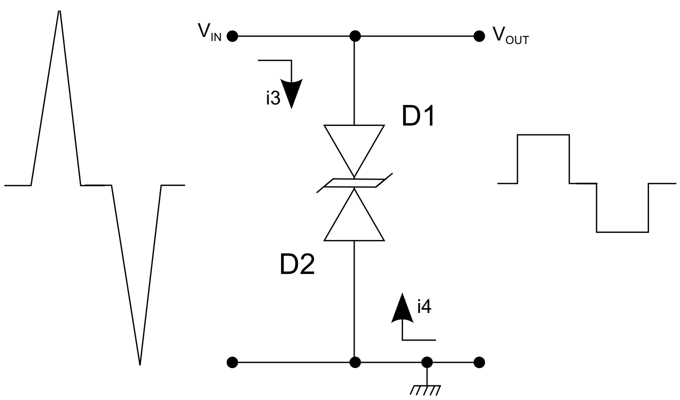


Figure 2 - Bidirectional Device
(Symmectrical Clamping)

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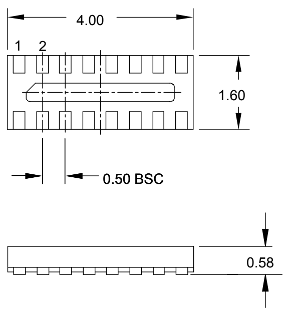

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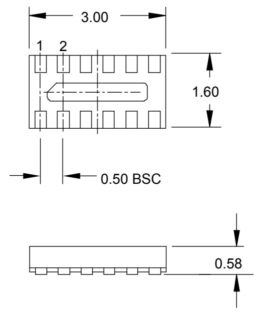

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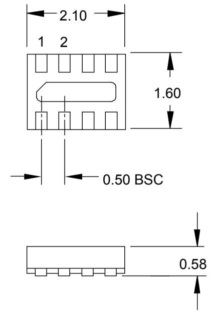

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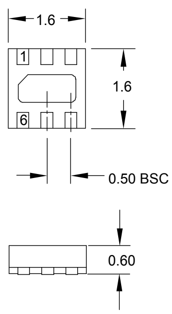

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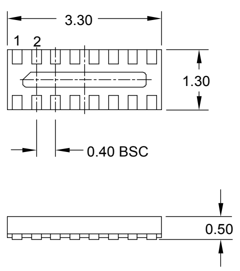

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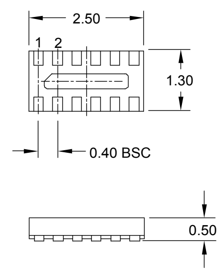

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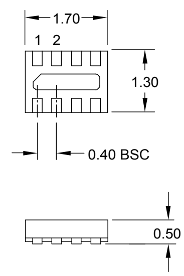

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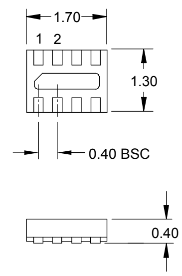

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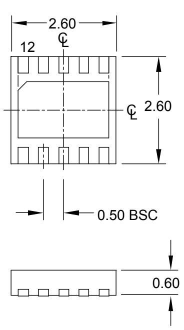

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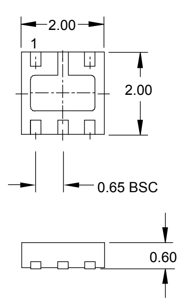

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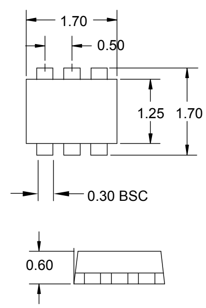

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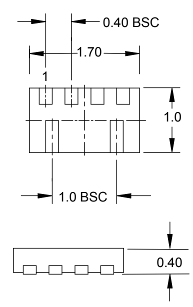

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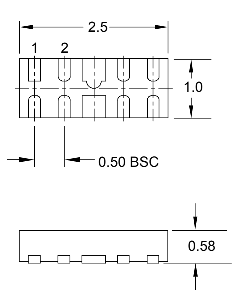

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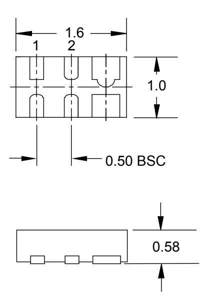

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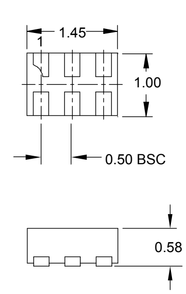

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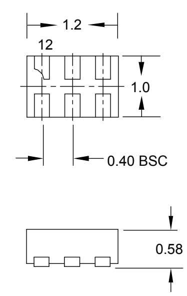

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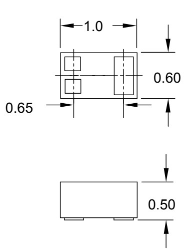

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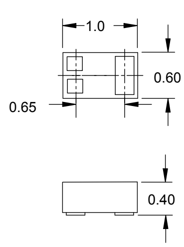

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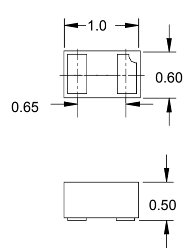

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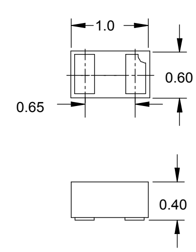

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