Electrical Protection

Designing a circuit to give long life is partly a matter of using the right components to withstand the stresses applied. But it is also prudent to ensure that those components are guarded against excess current or voltage!

Current overload

Whilst over-stress due to uneven heat distribution can only be guarded against by correct manufacture, other kinds of over-current protection can be effective. The table below compares three devices in common use:

device	advantages	disadvantages
Fuse	Will isolate high current	Once only operation; No fault indication
PTC resistor[1]	Returns to normal operation once cool	Restricted current range; Long trip time; No fault indication
Silicon switch	Controllable rise and fault times; Fault indication can be built in	Restricted current range

[1] A resistor with a Positive Temperature Coefficient of resistance. Typically these switch between low and high resistance states over a relatively short temperature range.

For reliable operation of electrolytic capacitors, it is also important to limit inrush current in applications such as switching circuits and charge/discharge circuits, and this is normally accomplished by building in appropriate series resistance. Note that, like semiconductors, electrolytic capacitor failures are likely to be short-circuit, rather than open circuit, and that the rest of the assembly may need to be protected against destructive failure. For this reason, some tantalum capacitors incorporate built-in fuses.

Transient voltages

To be effective, transient voltage suppression (TVS) devices must activate before system components react catastrophically to transient pulses, and must be capable of dissipating the resultant transient energy, whilst clamping the voltage to a safe level. This is normally done with devices that limit the over-voltage rise by shunting the transient away from protected components, usually to ground. The table below compares four devices in common use, listed in approximately descending order of transient energy clamping capability:

device	advantages	disadvantages
Gas discharge arrestor	Very high current capability High insulation resistance	High overshoot voltage (200V–2kV) Slow response time (several µs) Non restoring under DC

		Limited life
MOV[2]	High transient current capability Clamp voltage up to 1.5kV	Clamp voltage 30+V Performance gradually degrades Difficult to make as SM part
TVS thyristor	Does not degrade High current handling Fast response time	Non restoring under DC Narrow clamp voltage range (28+V)
TVS diode	Does not degrade Wide voltage range 3V to 400V Very fast response time (few ns) Readily available as SM part	Limited surge current rating Low voltage types have high capacitance

[2] Metal Oxide Varistor: made of a low cost ceramic-like material formed into a disc shape typically 3mm to 20mm diameter, and usually presented as a radial through-hole component

Protection circuits

Board level protection is against residual transients from earlier stages of protection, system generated transients, and ESD. Transients at this level range from tens of volts to several thousand volts with peak currents usually tens of amps. Board level transient voltage protection is typically provided by:

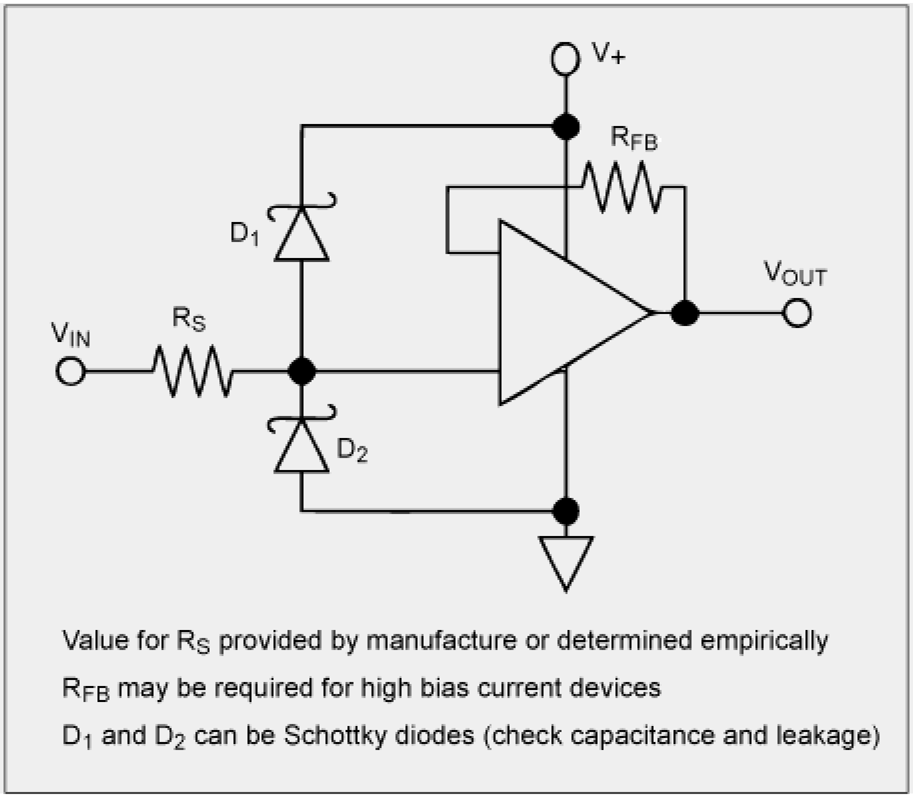
- A series resistor or resistors, to limit current
- Diode protection ('damping'), to prevent voltages from moving beyond a safe range of values, usually clamping the protected input to power supply and ground.

This protection works on the general principles that:

- Junctions may be forward biased, provided that the current is limited. A typical safe limit is 5mA.
- Reverse bias junction breakdown is damaging, regardless of the current level.

An implementation for a generic operational amplifier is shown in Figure 2. Here the manufacturer suggests that the value of RS be determined empirically, notes that RFB may be required for high bias current amplifiers, and allows the use of Schottky diodes for faster, tighter clamping, provided that their capacitance and leakage current meet the circuit requirements.

Figure 2: Typical protection circuit for an operational amplifier



At the board level, there may also be a capacitor between the voltage line to be protected and ground, to absorb high frequency transients ('buffering'). This is especially common in power supply connections to integrated circuits, where a 100nF low-inductance ceramic capacitor is often fitted. This should be located as close as possible to the device being protected.

Similar circuits may be incorporated in the actual integrated circuit. Figure 3 shows a simple resistor-diode configuration for CMOS; Figure 4 shows a more complex circuit incorporating thyristors, which is used to create high-immunity devices.

Figure 3: Input protection circuit for metal gate CMOS

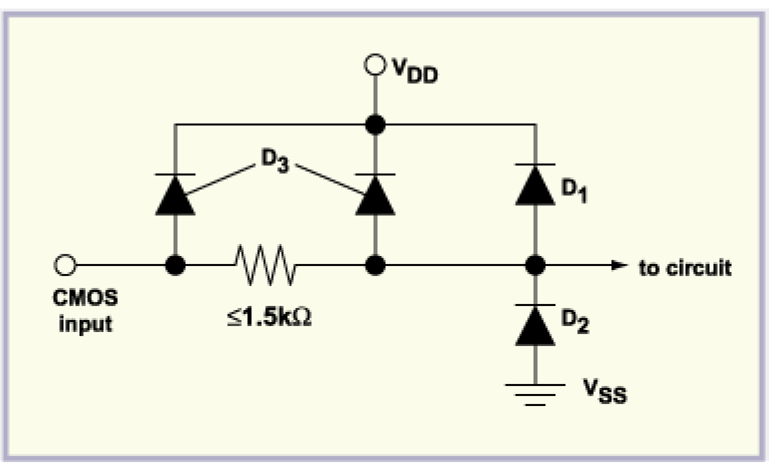
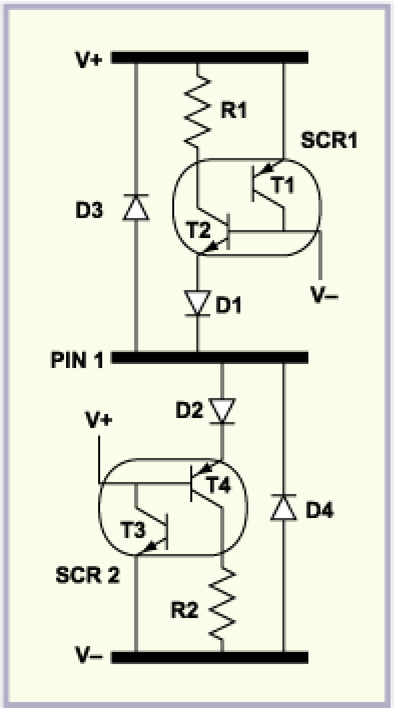


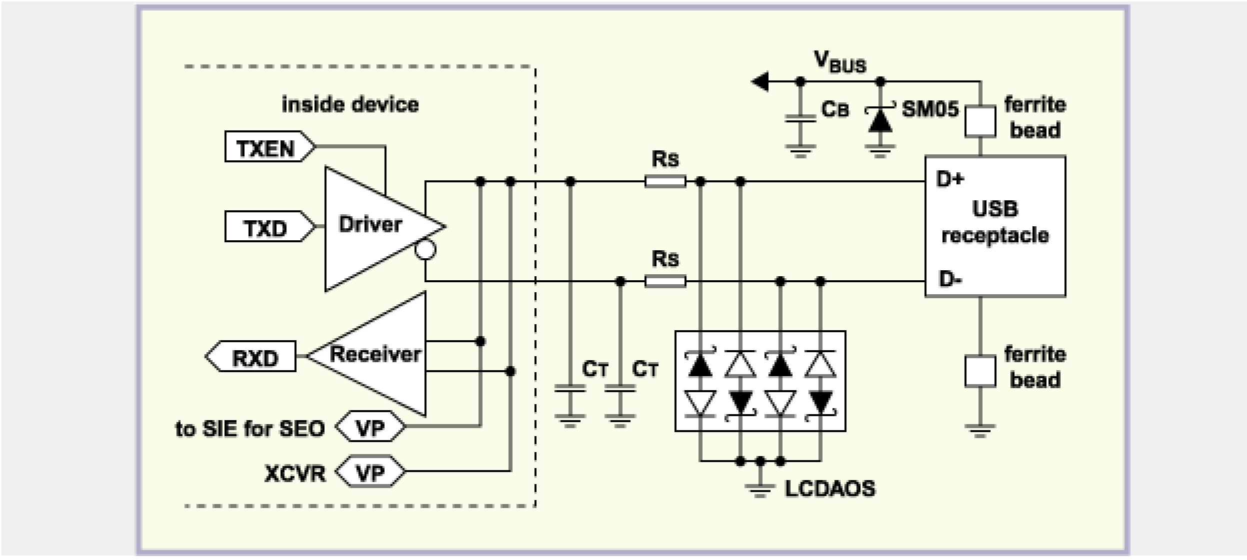
Figure 4: Protection circuit for high-immunity applications



Such circuits are limited in capability, and their connection to the power supply is a particular problem, because destructive voltages can be back-driven into it by multiple transient events. Modifications are therefore needed for equipment inputs, where the transient suppression power requirements are more severe: voltages can exceed several kilovolts, and peak currents range from several hundred to several thousand amps.

Typically, the arrangement is similar in concept, but the diodes are replaced by a back-to-back pair of TVS parts, as shown in Figure 5. For multiple-input use, sets of TVS parts are supplied in integrated packages, but these are chip arrays, rather than monolithic ICs, in order to maintain isolation. Unfortunately, however, suitable TVS devices are not available for logic applications below 3.3V.

Figure 5: Protection circuit for an external bus application using transient voltage suppression devices



ESD management

So far, our discussion on electrical protection has focussed on problems either within the circuit or conducted into the circuit along the leads, and caused by such phenomena as switching transients. Particularly given the extra sensitivity of modern electronic components, it is worth reminding ourselves that very high electrostatic potentials can be generated by triboelectric effects on clothing, packaging material, and automatic handling and assembly equipment. If these are discharged into sensitive components, either directly by contact with their pins, or via conductors in the system, damage or destruction is likely.

Electrostatic damage (ESD) can destroy some active components even when the circuits are not powered. MOS devices are particularly vulnerable, and require special protection, both on chip and externally. Antistatic precautions are therefore necessary during all operations involving handling, both during assembly and afterwards.

Although assembled components are generally less vulnerable, with some protection given by the circuits in which they are embedded, both test and maintenance procedures also have to take account of potential ESD sensitivity.

If you are unsure about how to implement protective measures against ESD, now would be a good time to read or review *ESD control during manufacture*.

Source : http://www.ami.ac.uk/courses/topics/0191_elp/index.html