Chapter 3

Active Discrete Components

There are almost as many applications for active discrete semiconductors as there are for the passive component; however, the selection of device type for specific applications is usually more stringent than with passive devices. Consequently, the choice of final component may not be influenced as much by its potential electromagnetic compatibility (EMC) effect as can be applied with passive devices, but probably more with respect to its functional performance in the application.

This sounds like an excuse to ignore or gloss over EMC issues within discrete semiconductor devices. This is not the case, but it should be borne in mind that some of the suggestions and design tips quoted here may ultimately not be as applicable to the circuit as the suggestions for other components, due to the functionality of the final circuit. The EMC issue should never stop a circuit design for a specific application being produced and it is not intended to either specifically increase design complexity or eliminate certain circuits from the world. The suggestions contained here are just that, suggestions. At the end of the day it is the circuit functionality in its end application that is paramount; EMC at the design stage should only guide a designer, not completely restrict their output, and should hopefully have a minimal influence on overall circuit costs.

3.1 Discrete Component Packaging

The number of types of packages available for discrete semiconductor devices probably exceeds that for integrated circuits (ICs). The packages tend to have between two and four contacts (leads) for the component itself, sometimes with additional pins for multiple components in the same package or for heat dissipation of the device. Either way the devices have few contact points and the device of interest may be available in a choice of package styles.

The assembly of a discrete device into a package is similar to an IC, the device is usually bonded by epoxy die attach or eutectic metal to the leadframe of the package. Bond wires are used to connect the device to the other package leads; hence, unlike passive devices, many of the device terminals have a 'wire' inside the package. The bond wire length and dimensions are similar between package and component types, typically having in the region of 0.5 nH of inductance, this is usually less than the lead inductance itself; hence lead inductance is the dominating parasitic element.

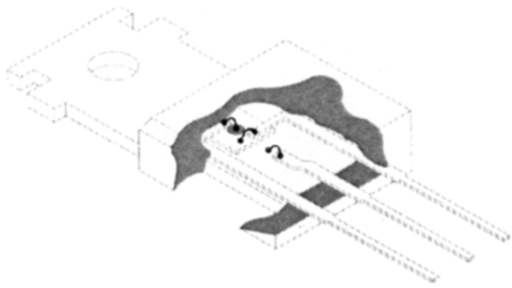


Figure 3.1
TO220 packaging of discrete semiconductor

As with virtually all device packaging with respect to EMC, surface mount is preferred. If the parasitic associated with a small transistor or diode pack are compared, using SOT23 as the surface mount pack and E-line (similar to TO92) for the leaded package, it is observed that even with minimum lead length on the through hole package it still has twice the parasitic inductance and capacitance as the surface mount package (Table 3.1).

Table 3.1 *Comparison of surface mount (SOT23) and through hole (E-line) package parasitics*

Package type	Lead and bond wire inductance (nH)	Inter-lead capacitance (pF)
SOT23	2.5	0.08
E-line	5	0.15

Not all package styles have such a marked difference between surface mount and leaded types, but the surface mount versions always have lower parasitic elements for a similar size package as it minimises the lead lengths within the package design. Shorter lead lengths also minimise the magnitude of return loops and potential aerial sizes, but at this level of dimension the differences between surface mount and through hole are negligible compared with printed circuit board (PCB) track lengths contributing to radiated effects.

3.2 Diodes

Diodes are the simplest of active semiconductor devices, they consist essentially of two dissimilar materials, either two oppositely doped semiconductors (p- and n-type) or a metal and a semiconductor (Schottky diode). Other more exotic combinations do exist, but essentially the diode is as straightforward as a semiconductor can be.

Like inductors and capacitors, diodes are a potential cure to many EMC ills, especially electrostatic discharge (ESD) problems. There are several diode circuits and formulations of diodes, which are in fact specifically aimed at EMC solutions. Hence, although the simplest of semiconductor parts, diodes are probably the most relevant to EMC issues at the discrete component level.

A feature of diodes which is generally unique in terms of EMC, is that the faster components are generally better for the EMC performance. This is unusual as most of the time the designer is trying to limit bandwidth and reduce the frequency response of the circuit (outside of the operational frequency response) to reduce EMC problems. Diodes are possibly the only device in which a fast response time is beneficial to EMC, but again there is the caveat that this is only in certain applications and most of the time slower diodes that are perfectly adequate for their function will not have a noticeable effect on EMC.

The parameter which most effects a diode's response or speed of operating is its reverse recovery time (τ_r). This is the time taken for the potential barrier created under a forward bias (typically the potential barrier is 0.6 V for a p–n junction diode) to recombine and prevent reverse current flow. Until the barrier is recombined a reverse current can flow through the junction, hence potentially a reverse current spike can be observed with a pulse width equal to the reverse recovery time. The reverse recovery time is often in the nanosecond region, but varies with diode size (increasing with diode size and current carrying capability), construction (lower for low barrier types such as Schottky diodes) and bias conditions (lower recovery times at lower reverse bias, but this is only a marginal effect). Consequently, as a quick check on diode performance for EMC considerations, lower transit time devices (i.e. fast switching diodes) are preferred.

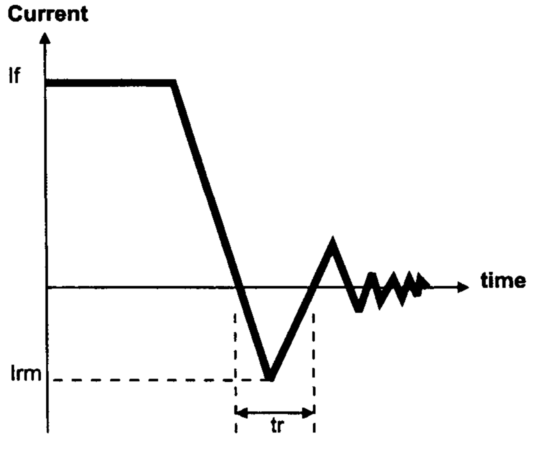


Figure 3.2

Diode reverse recovery

3.2.1 Small Signal Diodes

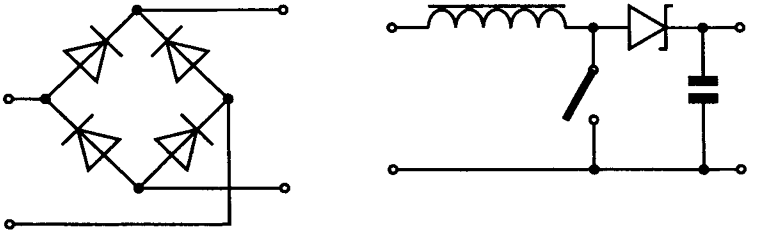
Diodes used in applications involving signal clipping or providing offset voltage levels can be classified as small signal diodes. The applications do not involve large current handling (typically under 1 A) and often the diode is only used under low signal voltage conditions. Owing to the lower current requirement the diodes are quite small and most commonly p–n junction diodes are used in these applications because of their low cost and wide availability.

As this type of diode is geometrically small the recovery times are quite low (about 10 ns would be typical), and hence usually react to all but the fastest transient signals. The standard small signal diode is therefore quite useful for a low-cost method of protecting circuits from low current discharge and small transients, such as DC line spikes and in-board ESD residues. It is not necessary to have this type of diode protection on all signal lines, only those which are accessible to external contacts, sockets or cables.

Often many ICs feature p–n junction diodes immediately beneath the bond pad on the silicon. This gives the IC a level of ESD protection, the lead frame of the package and bond wire add a small inductance to reduce the total discharge current into the IC circuit. Being beneath the bond pad means that the structure takes up no additional silicon area, hence it is a popular feature and usually available 'free' to both designer and user of the IC.

3.2.2 Rectifier Diodes

Some small signals are used to rectify low level AC; however, the main application of rectifier diodes are in linear power supply units (PSUs), rectifying transformed or direct mains AC, and in switched mode power supplies (SMPS). There are significant differences in these applications, in linear supplies the diodes deal with a slow AC signal (50 or 60 Hz) and generally are large slow diodes of p–n junction construction and relatively low cost. The rectifiers used in SMPS applications are



a) full bridge rectifier for 50Hz and 60Hz linear power supplies

b) fast rectifier in SMPS rectification

Figure 3.3

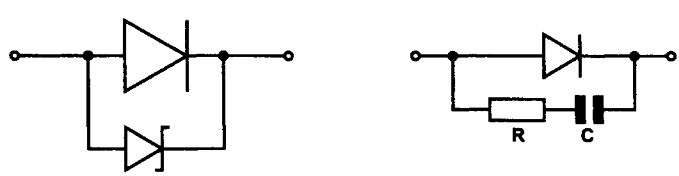
Rectifier diode circuits

usually fast action diodes as switching can be in the kHz to MHz frequency range, often of Schottky construction and relatively expensive.

With linear PSUs the diode is used solely as a rectifier and not for any ESD, transient or mains line protection purposes. If transient or ESD protection is required it has to be provided elsewhere as the rectifier diodes only connect between the supply lines and load, not usually to the mains earth. The rise times seen by the diodes from the mains to load may not be as slow as the mains frequency sinusoid due to the supply storage capacitors holding up the voltage; hence the diodes may experience relatively short bursts near the peak of the mains sinusoid. Even with these short bursts the rise times are relatively slow and, consequently, it is quite acceptable to use slow, low cost, bulk silicon diodes and EMC considerations are applied elsewhere in the circuit.

In SMPS circuits there are potentially fast transient spikes from the magnetics within the circuit, as well as any harmonics from the switching circuit pulses themselves. Consequently, fast-acting diodes are required in this application and the speed of response is critical to minimising the amount of noise generated, therefore energy wasted, by the SMPS circuit. By their very nature SMPS circuits are noisy, using fast switching waveforms to pulse a magnetic storage element. As well as the switching action with its characteristic switching frequency, the rise and fall times of the pulse generate harmonics. There may also be some ringing and overshoot in the magnetic circuit; hence there can be a large amount of high frequency harmonic content which is unrelated to the actual switching frequency of the circuit.

Fast rectifiers and Schottky diodes are most commonly used for the catch diode or feed diode in SMPS circuits (see next section for Schottky diode). Fast rectifiers are essentially p–n junction diodes with a construction which produces a fast transit time (i.e. a thin junction barrier within the diode) and are more popular in boost and feed-forward applications. The faster the diode the more of the harmonic content it will handle, hence the lower the potential conducted EMC of the completed circuit as higher frequency pulses are passed on to the storage capacitor and are not reflected by the diode. The capacitor has to be able to handle these high frequency signals for the fast diode to be useful and often a combination of capacitors and passive filtering is used.



a) parallel diodes for improved transient response

b) RC snubber network

Figure 3.4

Improved transient circuits

At high current levels the diode junction area is going to prevent fast switching, the capacitance of a diode is proportional to its junction area, hence the high current diodes (> 1 A) are likely to be slow (τ_r > 15 ns). One solution to this is to have a smaller diode in parallel that has a higher reverse breakdown and higher forward voltage drop. Under normal conditions this diode is not in operation as the lower voltage drop bulk diode takes the current. On transients and fast edges this small diode can catch the lower current transient and dissipate this small amount of power before the slower diode operates on the bulk energy. This paralleling can be effective at removing the majority of fast transient spikes providing they have a low power content, but pairing diodes for this application can be difficult as the amount of power in the transient is not known.

A common diode noise suppression circuit is the RC snubber network. This uses a small capacitor as a DC block and a low value resistor to dissipate the transient energy. Low values of resistor and capacitor are selected so that the RC time constant is significantly lower than the transit time of the diode (see Equation 3.1).

3.2.3 Schottky Diodes

Schottky barrier diodes offer a very low forward voltage drop, high current density and fast reverse transit times compared with similar sized p–n junction diodes. This makes the Schottky diode a good protector against fast transient signals and spikes. The cost of a Schottky diode is generally higher than a p–n junction so they are used sparingly in circuit design.

One of the common uses of Schottky diodes is as an alternative to a fast rectifier diode in an SMPS circuit. All the arguments previously raised for a fast rectifier apply (i.e. fast reaction to both forward current and reverse transient, spike protection) with the additional benefit in SMPS circuits of a low forward voltage drop, hence low loss.

The EMC of a circuit using Schottky diodes should be slightly better than with junction diodes; however, the actual magnitude of the benefit may be small. It is unlikely that switching from p–n junction to Schottky barrier diodes will produce a cost-effective improvement in the EMC performance of most circuits. However, additional efficiency savings due to the lower forward voltage drop and consequent better voltage regulation characteristics should justify the cost in power circuits and especially in high frequency SMPS circuits.

3.2.4 Zener Diodes

Zener diodes are normally operated in the reverse mode, they feature a sharp (abrupt) reverse voltage current transport action. The Zener action reacts quickly to reverse voltage transients. Zener diodes are often used as protection against over voltage, hence are a good protection against ESD discharge providing they can tolerate the power level (i.e. current) of the discharge.

Zener diodes are used in signal lines for ESD protection as they offer a low cost alternative to specialist protection and can be used easily at the voltage levels found in the majority of signalling applications. In signal lines a Zener diode can offer a low capacitance compared with other solutions, hence do not cause significant signal distortion on high data rate signalling lines.

In applications where the Zener diode is being used in-board (i.e. not at the input circuits as protection devices) the operation of a Zener diode can act as a potential EMC noise problem. Owing to the fast nature of the Zener action, when this occurs a relatively large current surge can be observed as the Zener conducts the reverse over voltage current. Consequently, circuits using in-board Zener diodes for over voltage protection will require some localised decoupling for the Zener action. Another method to limit the magnitude of the surge is to use an in-line feed resistor to the Zener. If using a feed resistor it needs to be relatively low value to ensure that the action occurring is the Zener action and not another effect, such as avalanching within the junction.

Zener diodes with 12 V operation are particularly prone to becoming wideband noise generators if a feed resistor limits the current and the diode skips between Zener action and avalanche. This activity can be used to make a noise generating test circuit, but should be avoided in most applications.

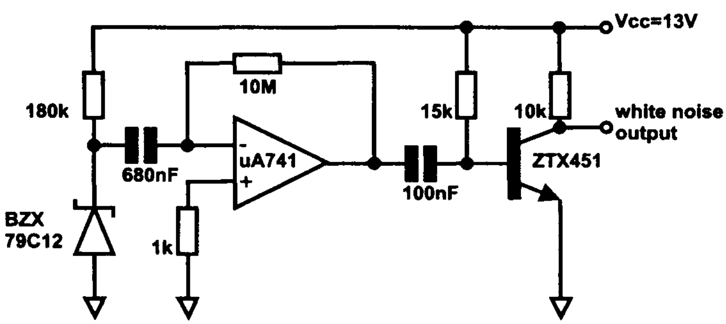


Figure 3.5

Noise-generating circuit using 12 V Zener diode

3.2.5 Light Emitting Diodes (LEDs)

In themselves LEDs are unlikely to be a problem with regards to circuit EMC. The device is most often operated under a DC bias in forward conduction mode and therefore has little direct effect on the circuit.

The main application problem that could occur is when the LED is mounted into a panel at a distance from the circuit whose operation it is an indicator for. If the leads to/from the LED act as an aerial they could pick up radiated emissions from other circuits or from external sources. Likewise, if the DC bias for the indicator has a noise from the indicated circuit superimposed on it the leads could act as a radiating aerial. These problems are strictly in the application of long leads and the LED itself is not an EMC threat.

3.2.6 EMC Specific Diodes

Transient voltage suppressor (TVS) or transorbs are a form of silicon diode that feature similar characteristics to Zener diodes, but act in an avalanche mode. One main difference is the absolute value of clamp voltage, a Zener will have a very tight specification, say 12.3 V±2%, whereas a TVS rated for 12 V lines may have an avalanche voltage between 13 and 19 V. TVS diodes in general can cope with higher current levels than a similarly sized Zener diode and can be configured to operate unidirectionally (i.e. have similar forward and reverse characteristics) and hence can cope with both positive and negative transients. These devices are usually specifically designed to cope with the very high voltage transients seen from ESD, lightning-induced transients and mains spikes (>500 V transients). The unidirectional device is particularly suited to signal lines which signal between a high value and ground (single-ended schemes), bi-directional devices are used where both positive and negative voltage signalling levels are used (differential signalling) or on AC lines. A feature of bi-directional devices which make them popular in many signalling applications are their very low junction capacitance (typically 5 pF) compared with a similar power rated unidirectional device (500 pF).

Varistors are a formulation of metal-coated ceramic pills pressed into a single assembly. Each ceramic pill works as a Schottky diode with a high potential barrier of approximately 3.6 V per boundary; hence voltage types are made up from layers of these pills. Production techniques have enabled the devices to be made in a controlled multilayer approach (multilayer varistor, MLV), similar to a ceramic capacitor; hence surface mount versions are quite popular providing a large barrier area (i.e. high current capability) in a small volume. The devices are also sold under various names including voltage-dependent ceramic resistors (VDR) and metal oxide varistors (MOV). It is more common to find this type of product being manufactured by ceramic capacitor suppliers than silicon diode vendors due to the manufacturing processes involved.

The varistor is a very good alternative to a Zener or TVS diode for line protection particularly on mains inlets. The main drawback of a varistor compared with diode clamping is that the value of clamping voltage tends not to be as well defined; hence the circuit needs to be able to cope with this clamp voltage tolerance. The varistor can be used on signal lines (e.g. RS232, EIA485, SCSI), although its higher capacitance tends to limit the speed of data or size of varistor. Compared with Zener diodes, varistors can be obtained in smaller package sizes for a similar current handling capability. Varistor reaction time is in the sub-nanosecond region for the smaller devices; hence it can offer the fastest responses to transients when compared with Zener and TVS diodes and would be the recommended choice for first-line ESD protection and on high voltage, high transient risk lines (e.g. entry/exit cabling, power lines, etc.).

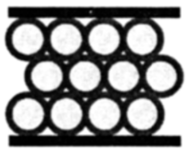


Figure 3.6
Varistor cross-section

3.2.7 Diode Applications for EMC Control

The majority of the above diode components have been discussed in relationship to their effect on transients, assuming that the transient is incident to the system (i.e. not generated within the circuit). There are of course instances where the circuit is operating inductive loads or switching large currents that cause transients to be generated within the system. Again the diode can be used at the source of the noise as a transient voltage suppressor.

Where diode noise is a problem a simple RC snubber filter across the diode should be adequate to reduce any switching transients from the diode reaching other circuits. A very low capacitor and resistor value are usually used, say 47 pF and 50Ω for τ_r >2 ns, depending on the diode noise pulse duration and rise time.

$$RC < \tau_r \qquad 3.1$$

Inductive loads are a particularly common source of transients and one that is usually easy to identify and deal with. Typically, relay energising circuits see a back EMF transient from the relay coil when the relay is de-energised; the energising current can also see an inductive overshoot creating a transient. These transients are best

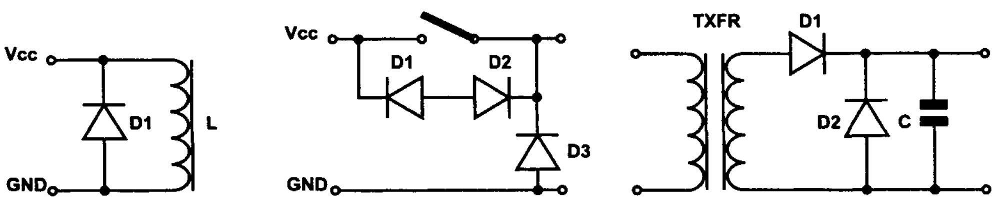


Figure 3.7
Diode suppression applications.

suppressed using clamping diodes across the relay coil. The diode should be positioned close to the relay even if the switching transistor is remote, the transient should be prevented from travelling in any conductor and hence radiating or coupling with other circuits.

In power transformer circuits the transients can be difficult to suppress without affecting the efficiency of the circuit. Some overvoltage protection can be included using relatively low-cost Zener or Schottky diodes to clip the maximum voltage excursion. This protects the output circuit from excessive output voltages without limiting the efficiency under load conditions.

Motor circuits are another inductive load that can benefit from diode suppression of commutator or brush noise. The exact configuration will depend on the motor type (DC, three-phase, etc.), but the suppressor should be located as close as possible to the motor contacts to reduce the risk of emissions from the connecting control or power cables.

Switch bounce can also generate a transient pulse into a system, these are often difficult to characterise and usually connected with high voltage switches rather than low voltage types. A varistor or Zener diode across the switch contacts usually provides a good level of protection.

In digital signal lines transients internal to the system are usually of relatively low energy, hence low cost Zener or low breakdown small signal diodes can be used. Where the signal exits the system then a higher level of protection would be recommended. In parallel data bus communications system the cost is going to be high if significant numbers of suppressor are required. It would be usual to use the lower cost varistors or small TVS diodes in this type of application.

On power line inlets the protection device has to be able to tolerate higher stresses than most board level components under normal operation. Consequently, high energy transorbs, TVS diodes or high voltage varistors are most commonly employed on inlet power lines. The power line could have transients from many sources, including other equipment connected to the same mains ring and even lightning-induced transients. The power line is one of the most useful places to place this type of component, it not only protects the equipment from incident transients, but suppresses transients from the system being conducted down the mains ring.

At signal connector interfaces to the outside world, ESD is probably the most common EMC problem to be encountered. This is especially true for connectors, which will have user contact due to their function (e.g. RS232 interfaces, printer ports, keyboard connectors, etc.). The cost of ESD protection can be reduced by protecting the contacts in a shielded connector with recessed pins and cabling with earthed screen. Without recessed pins in a shielded connector housing, varistor or TVS protection on the signal lines is likely to be required. Passive low pass filters could be used, but the advantage of active devices over passive filters are the low capacitance these add to the signal line, therefore very low distortion or skew is added to the signal.

3.3 Transistors

Transistors are traditionally classified as either bipolar or unipolar. The nomenclature describing the current carrier within the semiconductor, bipolar having both electrons and holes carrying current, unipolar having only one carrier particle. There has been a recent addition to the family of transistors that slightly clouds the simplicity of this; the insulated gate bipolar transistor. In the majority of cases when people talk about transistors they are describing the bipolar junction transistor, otherwise the unipolar devices are usually known by their acronym (e.g. FET, see below).

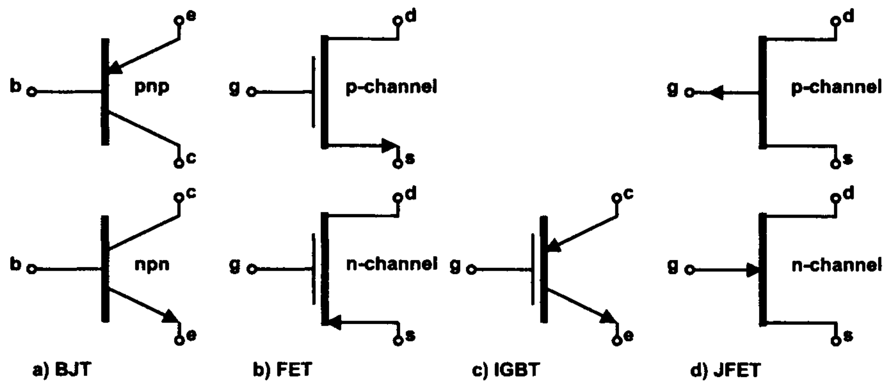


Figure 3.8
Transistor schematic symbols

Transistors are generally not employed for EMC performance but purely for their functional operation. Consequently, there is not as much EMC data that can be found on transistors as on diodes and applications where the transistor choice has affected the EMC are very difficult to find. However, there are still some component choices and options that may help with the EMC performance of the circuit if not affecting the individual components or function greatly.

3.3.1 Bipolar Junction Transistor (BJT)

A common way of describing a bipolar transistor in student textbooks is as two back to back diodes. This relatively simplistic description is a good enough analogy for examination of the bipolar transistors EMC characteristics. Because of the diode structure bipolar transistors are relatively insensitive to ESD and many of the diode arguments can be applied to the bipolar transistor. Consequently, bipolar transistors are a good choice for discrete input or output buffer circuitry which is accessible by the user, especially discrete amplifiers and user accessible analogue buffer ports.

Although relatively insensitive themselves, bipolar transistors should not be considered as protection against ESD. Usually the individual transistor junction diodes are too slow to react to transients on their terminals. The reference potential for the transistor may also not be the ground connection, and almost certainly won't be the safety ground. Consequently, it is probable that some other ESD protection will still be required if using bipolar transistors at an input or output, but at least the circuits containing bipolar transistors are less likely to suffer damage from ESD.

Smaller transistors are faster and consequently able to react to transient voltages better than larger bipolar transistors; however, having a smaller junction means the device is less able to cope with larger energies. Larger bipolar transistors can be slow compared with their small signal counterparts, hence as well as having good immunity to ESD damage, large transistors tend not to behave as transient or noise amplifiers. Some small signal bipolar transistors can be operated as switches or mixers in the GHz region, so unless the circuit requires this level of performance for its functional requirement, it is better to use lower cost slower bipolar transistors.

The main EMC threat to bipolar transistors is probably conducted noise. The base drive to a bipolar transistor works on a low voltage (typically 0.6 V) and the device is essentially a current amplifier. Consequently, a low amount of noise on the base would be amplified by the transistor. It is for this reason that the transistor should be selected with an appropriate switching speed, use devices with as low a switching speed as possible for the circuit function. It is also important to include any filtering at the base terminal as this is where the noise has its greatest effect.

Modulated radio-frequency (RF) signal fields can become demodulated by small signal bipolar transistors. The non-linearity of the voltage–current relationship (being exponential for both diodes and bipolar transistors) can allow a strong RF signal to be demodulated within the transistor. The RF itself is usually not conducted out of the transistor, but can build up a DC offset, possibly sufficient to cause forward conduction. The demodulated signal can fall within the operating frequency range of the circuit, hence can then become an interference signal within the circuit. The effect is most noticeable with demodulated audio signals, particularly with the proliferation of mobile telecommunications. The problem is not as acute in discrete circuits as in integrated circuits due to the larger dimensions of discrete transistor junctions and leads and interconnect between components acting as filters, but if using very small, fast transistors the potential for interference does exist and tests with a modulated RF source will be necessary to check circuit immunity.

3.3.2 Field Effect Transistor (FET)

Field effect transistors work on a gate charge rather than a base current as in bipolar transistors. This produces two effects as far as EMC performance is concerned. First, the gate is sensitive to charge rather than actual current flow so can be easily upset by a transients. As there is no conduction path from the gate transients or other noise can cause a charge build up. Secondly, at large gate junction areas the device can still operate at high speed; hence unlike bipolar devices where larger transistors represent reduced conducted EMC problems the FET is still a sensitive component, almost regardless of size.

A problem that was common with early FETs was latch-up, this is where a transient, usually on the drain or source connection, would charge the gate and latch the transistor permanently on. Most modern FET structures incorporate a body diode between the drain and source and a separate substrate connection (this is sometimes common with the drain). Modern FET components no longer suffer from latch up and are often used for switching inductive loads and lines containing transient spikes (e.g. relay coils, motors).

Transient protection of FET circuits should generally be applied to the gate. The gate is isolated from the drain and source connections by an oxide layer within the device, and hence does not have the benefit of the body diode protection. Usually, gate control circuits would be expected to incorporate this protection; however, if the FET is being operated remote from the control circuit (e.g. near its load, a motor for instance) then there may be a requirement for diode or varistor protection between the gate connection and a local safety ground. The leakage current of this additional component also reduces gate charge build up.

Gate bias voltage for a FET is usually in the high volt region (8 V for many power devices), although there are now popular 2.5 V devices for direct logic drive. The higher gate level can give the FET a higher immunity to conducted noise than a bipolar transistor. At the small feature size level FETs can also exhibit lower gate capacitance, this may be useful for the circuit functionality to achieve a high speed input at high impedance; however, on the EMC front this allows a small noise signal to achieve possibly enough charge to operate the gate. Unless the circuit requires the low gate capacitance and high impedance, an easy way to reduce the risk of noise-charge build up on a gate is to include an additional bleed resistor to ground on the gate, this should maintain the high switching speed characteristic.

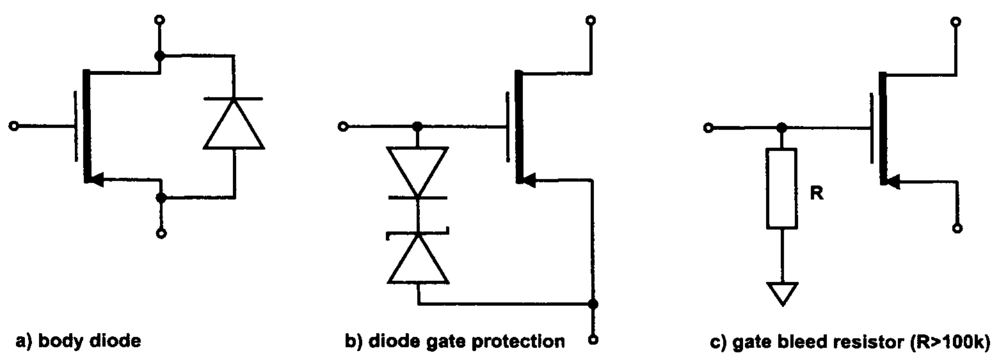


Figure 3.9
FET protection circuits

Modulated RF signals can also be demodulated by small FETs as well as small signal bipolar transistors. The non-linearity of the voltage–current relationship is a square law for unipolar devices, hence the demodulation characteristics are not as strong as in bipolar devices. The potential for charge build up due to RF creating a DC bias offset is possibly greater with FET devices due to the high impedance gate compared with the current drive requirement for a bipolar device. The effects of RF interference and bias offset are again more likely to manifest in an IC than a discrete circuit. High performance analogue circuits (i.e. high resolution, highly sensitive circuits) are much more susceptible to this type of interference than switching, power train, line drivers or digital circuits.

3.3.3 Insulated Gate Bipolar Transistors (IGBTs)

The insulated gate bipolar transistor is a combination of the insulated gate drive capability of the FET and the collector-emitter current handling of the bipolar transistor. The component was developed to achieve low loss switching at high speeds in power supply and motor applications, hence the construction. With regards to EMC little has been written but its analogy to the FET and bipolar transistor allow some estimation of its performance.

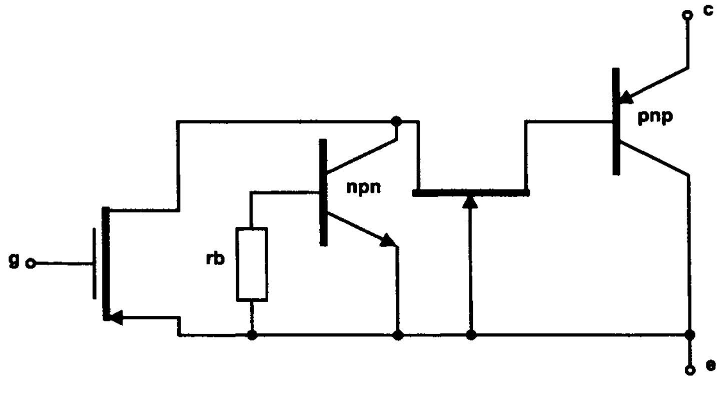


Figure 3.10
IGBT equivalent circuit

Having an insulated gate charge drive would suggest the device would be as sensitive to transients and ESD as a FET. Similar drive circuits are used for FET and IGBT devices, hence the same level of static and transient protection should be used. Having a bipolar structure across the other terminals does eliminate the need for a body diode and reduces the threat of transient interference from these terminals affecting the gate and the device may be slightly less sensitive than a standard FET, but it is unlikely to be significantly better. So like its structure, the IGBT has EMC characteristics between the FET and bipolar transistor.

Many IGBTs do not have a reverse diode optimised into the device across the emitter-collector terminals, in fact the reverse diode is a parasitic diode and a poor performance part. To reduce ringing and conduction losses when switching inductive loads either an external diode should be used across the collector-emitter terminals or an IGBT with a built in optimised diode should be sought.

3.3.4 Junction Field Effect Transistor (JFET)

The FET described in a previous section is strictly speaking a metal-oxide-semiconductor construction (MOSFET). The junction field effect transistor was a precursor to the MOSFET using a p–n barrier as the control element with the conduction usually occurring when no gate drive was present. These devices are not as popular in discrete form as the MOSFET but are still common on ICs where the structure is used to create high value resistors.

There is a recent circuit development in EMC protection that may increase the popularity of JFETs. The main reason for the reduction in popularity is the fact that the devices are 'on' when no gate control is present. This effect can be utilised in a circuit called a transient blocking unit (TBU) for protecting lines against transients by having the transient impulse operate the gate. The circuit requires some form of diode to ensure that the line is 'on' during normal operation and that the gate can only be operated by a rise at the input of greater than the gate turn-on voltage (V_{gs}) plus the diode forward voltage drop (V_f). The circuit as shown is a very simple implementation of the TBU, a bi-directional circuit can be made using three JFETs and four diodes.

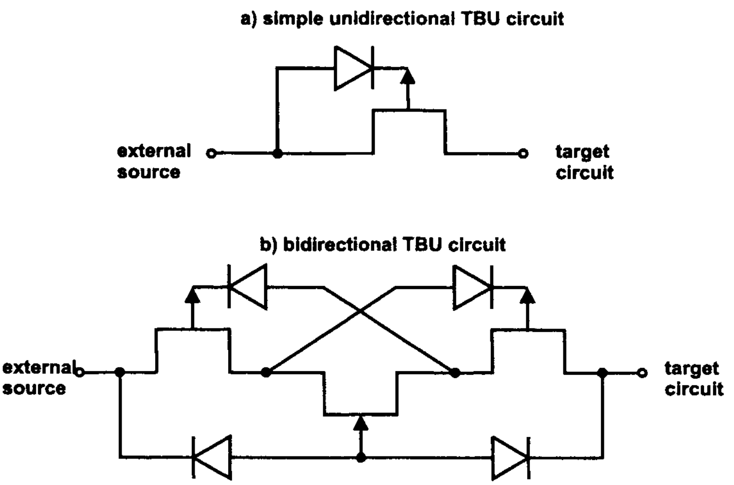


Figure 3.11

Transient blocking unit

The diodes need to be very fast to enable the gate reaction to cut off the transient before it reaches the target circuit. For power lines the devices will have to feature very low resistance in the 'on' state. The main benefit of this type of circuit is its position in series in the line means that it avoids dumping the energy to ground (possibly creating a ground bounce) and dissipates it in the body resistance. The circuit also can react proportionally to the incident energy. The availability of JFET structured resistors on ICs also means the circuit could be integrated into line driver/receiver ICs with minimum design or silicon overhead.

3.4 Other Active Discrete Devices

Diodes and transistors certainly account for the vast majority of discrete semiconductor devices used, however, there are other devices that sell in large numbers, sometimes for specific applications, and some are considered below.

3.4.1 Silicon-Controlled Rectifier (Thyristor)

The silicon-controlled rectifier (SCR) or thyristor is a semiconductor structure primarily used to control AC power. The construction is similar to two back-to-back bipolar transistors. Hence many of the notes for the bipolar transistor could be applied. Some critical differences are that the gate contact requires a current drive much higher than a bipolar transistor and usually operates at a much higher voltage, hence the device is relatively insensitive to conducted noise.

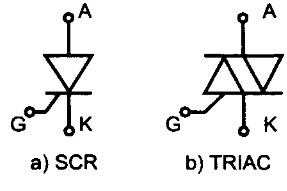


Figure 3.12
(a) SCR and (b) TRIAC schematic symbols

The bipolar structure and large junction area provides some degree of ESD and transient protection. The rate of gate rise usually has to be controlled to prevent device burn-out, hence transients of sufficient energy on the gate node could be a problem. These devices rarely suffer in use from EMC problems themselves and it is usually the drive circuitry that requires most consideration with regards to EMC and noise performance.

The main EMC concern would occur if using in a DC circuit with a derived AC gate drive. Potentially, a transient signal on the gate could drive the circuit into a latched condition. The gate circuit therefore would need to ensure this condition is protected against using some suppression protection at the gate such as a diode or TVS. Alternatively, a transformer isolator drive circuit could be used, hence a latch in the DC circuit will decay to zero in the transformer and the AC signal passing through its zero crossing point will deactivate the SCR.

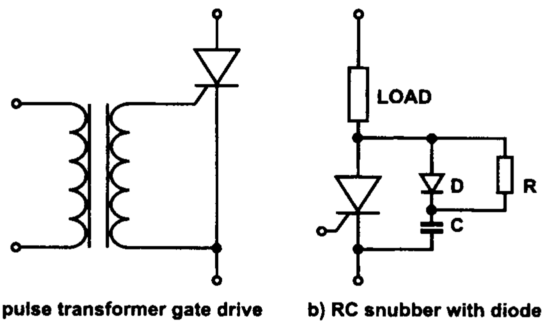


Figure 3.13
(a) Gate and (b) snubber circuits

3.4.2 TRIAC

The TRIAC is essentially a bi-directional SCR, hence AC signals pass during both cycles of the waveform. The driving of the TRIAC gate is essentially the same as the SCR and the above discussion should be applied.

3.4.3 Gas Surge Arresters

Gas (or plasma) surge arresters (sometimes referred to as gas discharge tubes, GDT) are constructed of two metal plate electrodes in a hermetically sealed package, usually ceramic, filled with an inert gas. When the potential across the electrodes is sufficient to ionise the gas a discharge occurs dissipating most of the energy creating the potential difference.

Gas surge arresters are used in similar applications to TVS devices. The main advantage of gas surge arresters over TVS or other protection components is the high currents they can handle (20 kA surge), hence large energy dissipating ability. Gas surge arresters are well suited to operation at constant high operating voltages and are most often applied to mains lines, three-phase power and telecommunication systems. The devices feature very low capacitance characteristics (<1 pF) and have typical operating times in the 1 μs region.

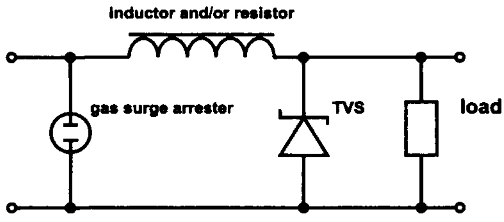


Figure 3.14
Full transient suppression using gas surge arrester and TVS diode

Compared with fast diodes for ESD protection the gas surge arrester can seem large and bulky and are usually only available in through hole packages. They do, however, offer some of the highest energy handling capacities of any protection device and are one of the few devices that can be used to protect mains and telecommunication lines against severe EMC threats such as lightning strike.

A problem on low voltage lines with the gas surge arrester is the high level of voltage at which the arrester can stop arcing (20–50 V); hence there may still be a large voltage present on the system even though the majority of the energy has been dissipated. When a system requires both large energy surge suppression on a low voltage line a combination of gas surge arrester and TVS diode or MOV would be used.