APPLICATION NOTE

POWER TRANSISTORS - DEVICES AND DATASHEETS

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ABSTRACT

The purpose of this paper is to give a general overview of how to read a transistor specification. We will discuss bipolar transistors, power MOSFETs and IGBTs, and introduce some intelligent power circuits that resemble discrete transistors. The emphasis is on switching transistors. Rules of thumb often followed in the selection of the right transistor are discussed. Some common pitfalls are mentioned and the reader is advised as to which parameters are more important.

1. INTRODUCTION

1.1 Using the specifications with care

The specifications for each power switching transistor today cover between three and ten pages. Some of these specifications are more important than others. In fact, from a user's point of view, there is a real danger in over-specifying a transistor. Broadly speaking a general power transistor specification gives information that will enable the user to use the component in a variety of applications. Parameters that are not critical in the particular circuit designed should not be specified; this will result in eliminating potentially usable and more economical components which will function perfectly well. A good understanding of the operation and the construction of transistors will teach the user which parameters are important.

This paper will concentrate only on commercial switching transistors used in the common emitter configuration. Transistors designed for military operations are typically specified and tested much more rigorously than their commercial equivalents.

1.2 Derating

In general, it is a good idea to derate some important parameters (i.e. allow an additional safety margin) in power switching transistors. The most important parameters to derate are the maximum voltage applied in the off-state, and the power dissipated. In general, heat is the most important reason for degradation of power semiconductors. Studies have shown that even a 7°-10°C increase in junction temperature can result in halving the Mean-Time-Between-Failures (MTBF) of the device. Therefore in many applications, the switch is chosen such that under the worst case, steady-state operating conditions, the transistor junction temperature does not exceed about 125°C.

1.3 Testing

In general, most commercial transistors are only 100% tested in production at 25°C, and also only static characteristics of the devices are tested. The dynamic performance and certain other characteristics of the device at other temperatures are guaranteed by design. Unless otherwise specified, all graphs show only the typical characteristics of a typical sample of the device. The trends, not individual limits, of a particular sample are shown by these graphs.

1.4 Standardisation of information

For over twenty years, power semiconductor manufacturers have tried to tackle the tricky problems related to standardisation of specifications between one manufacturer and another. However, most power switching transistor datasheets have a first page discussing absolute maximum characteristics that should never be exceeded. The Absolute Maximum system currently in use was defined by the American organisation JEDEC and accepted by various organisations such as EIA and NEMA. Similar organisations in Europe and Japan also help in similar efforts at standardisation. However, it is unrealistic to expect complete standardisation. The user has come to expect that no two manufacturers' specifications are exactly alike. Some specifications that one manufacturer may choose to emphasise find only a passing mention in another transistor datasheet.

2. POWER TRANSISTOR PACKAGES

The package style and size often important in the circuit performance of the power transistor. The thermal performance of the transistor depends on

the package chosen. High temperature performance of different types of transistors - MOSFETs, IGBTs or bipolar transistors - are quite different. Generally speaking, choose a transistor whose die size is between 40-100% of the maximum die size that can be accommodated in the package with good reliability. Too small a die size for a given package will lead to an unnecessarily large circuit board and circuit parasitics. A smaller package may also have a lower cost.

Certain power transistor module packages - for example the TO-240 - result in high parasitic inductances and capacitances which affect the device performance. A cross-section of the TO-240 package reveals that about 60% of the package consists of air, and the needless increase in height can result in unacceptable levels of circuit parasitics in high frequency applications. Other packages, such as the ISOWATT series of isolated packages, are to be used only if the application demands electrical isolation of the device from heatsinks. Otherwise we run the risk of unnecessarily increasing the junction temperature and needlessly compromising device reliability. The mounting methods of power transistors, including the maximum values of mechanical parameters such as screw torque or pressure exerted by mounting clip, need careful attention to avoid damage to the device.

In certain applications, the transient thermal impedance (that is the ability of the device to absorb short pulses of energy) is also important. This characteristic is dependent on the package and the die size. It is explained in detail in reference [5].

3. POWER BIPOLAR TRANSISTORS

Power bipolar transistors represent the most mature of the three kinds of discrete transistors discussed here. They have been in common use for over thirty years, but these devices and their manufacturing technologies are still evolving. There are a number of different technologies used in the manufacture of power bipolar transistors. Each technology has its own advantages and disadvantages, and has found its niches in certain applications.

3.1 General Characteristics

It should be remembered that power bipolar transistors resemble rectifier diodes in their on state. Their on-state voltage does not increase as significantly as unipolar devices when the current carried by them is doubled. They switch on and off much slower than similar MOSFETs, and the drive currents necessary to keep the device in the on state and to switch the device off are quite significant. Most Darlington transistors are too slow and have too high an on-state voltage to be considered for most switching transistor applications. However, today it is possible to use fast Darlingtons for switching applications in the tens of kilohertz in colour television horizontal deflection.

3.2 Bipolar Transistor types

3.2.1 General Purpose Transistors

Epitaxial base transistors are some of the most common general purpose transistors in use today. They are used mainly in low voltage applications (below say 100 to 200V) where low cost is most important. The popular “TIP” series of power transistors are manufactured using this technology. Single epitaxial layer planar transistors are general purpose devices used in low voltage applications (up to 100 to 200 V). These transistors however are very fast compared to epitaxial base transistors with “f_T” values of around 40Mhz, against about 1MHz for epi-base devices. Their on-state voltage is usually lower than equivalent epitaxial base transistors. Examples of these transistors are the well-known “D44” and “D45” series of transistor.

3.2.2 Switching transistors

The above two technologies are known as general purpose transistors rather than switching transistors. Higher voltage transistors, which have V_{CEO} values up to say 1000V use multiple epitaxial planar or mesa technologies. Examples of multi-epitaxial mesa transistor the BUV48, BUV98 etc.

In the early 1980s, multi-epitaxial mesa transistors with “hollow” emitters became popular. These devices, with part numbers such as the SGSF or MJH16 series are significantly faster than their non-“Hollow Emitter” counterparts since their hollow emitter designs decreased current crowding and this resulted in faster switching. One small disadvantage of these faster transistors was that they were less rugged during the turn off time.

3.3 Important Parameters

3.3.1 Breakdown voltages: $V_{(BR)CEO}$, $V_{(BR)CES}$.

These values represent the maximum voltage which the device can withstand across its collector and emitter terminals when turned off, specified with the base terminal open, and shorted to the emitter

respectively. If this value is exceeded, the transistor will go into breakdown and will be destroyed.

These breakdown voltages of course do not relate very well to the voltages actually experienced during normal switching. If the voltage at turn-off plus the safety margin exceeds the $V_{(BR)CES}$ of the device, then the device must simply not be used for the application.

In most applications the power transistor is never used with its base terminal opened, hence the $V_{(BR)CES}$ is the value used to choose the transistor. The $V_{(BR)CEO}$, generally around 60% of the $V_{(BR)CES}$, becomes important when the both currents and voltages are present in the device simultaneously, for example when switching an inductive load. This topic is discussed in more depth in the later section on RBSOA.

3.3.2 $I_{C(max)}$, Maximum Collector Current .

This specifies the maximum current that should be allowed into the collector terminal. However, as a general rule the maximum current that the device experiences in normal operation should depend not only on the maximum current but also the current at turn off. Most switching transistors are used with inductive or resistive loads where the current at turn off is the maximum current through the transistor. The current at turn off should be close to the level used by the manufacturer to test the switching times of the transistor, as shown in the “Conditions” column of the specifications of the switching times of the device. This allows the dynamic performance of the device to be predicted with some confidence.

3.3.3 Reverse Bias Safe Operating Area.

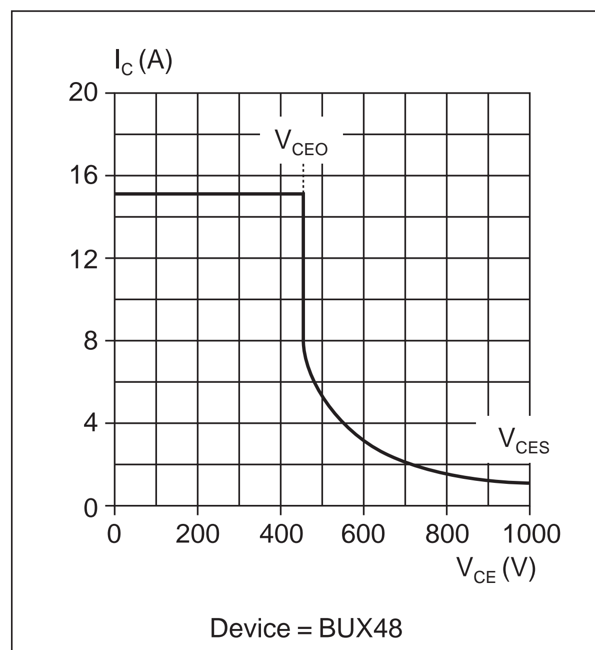
During inductive switching, it is possible that collector current and collector-emitter voltage can exist at the same time as the transistor turns off. The simultaneous high values of current and voltage is stressful to the transistor and can often result in device destruction. The transistor manufacturer often provides a diagram of the V_{CE}-I_C locus below which the transistor operation is guaranteed to be non-destructive - an example is shown in figure 1. This curve is called the RBSOA. Values of the Ic-Vce locus straying outside the specified RBSOA curve may lead to the transistor reverse bias second breakdown, a destructive phenomenon. The mechanisms of reverse bias second breakdown phenomenon of the bipolar transistor is very complex. However, it simply must be remembered that excessive turn-off base drive current extraction could lead to failures that are difficult to explain.

Where possible, the application circuit should switch the transistor on and off with base drive values similar to those mentioned during the switching times in the electrical characteristics section of the datasheet. Turn-off snubber circuits delay the rise of voltage across the transistor and can help ensure that the RBSOA of the transistor is not exceeded.

Usually, switching transistors can be turned with the maximum possible extraction base currents between $V_{(BR)CEO}$ and $I_{C(max)}$. For applications such as switching power supplies or halogen lamp ballasts, how high the current switched between the $V_{(BR)CEO}$ and $V_{(BR)CES}$ of the transistor is of primary importance.

The silicon die design of the modern high voltage switching transistor involves a certain compromise between the switching speed and the dc transistor gain. High frequency transistors often have a minimum dc gain (hFE) of only between 4 and 8 over the operating temperature range. In these cases, we have to pay special attention to the on-state and turn off base currents. Too low a base current or too slow a turn off base drive will increase the losses of the transistor significantly. Too large an on-state base current can result in driving the transistor into hard saturation which will then require high turn off

Figure 1. The RBSOA of a typical bipolar transistor



base currents. Excessive turn off base drive can result in exceeding RBSOA of the transistor and could cause destruction.

Base drive currents - On-state Current I_{b1} and Extraction Base Current I_{b2}

Poor base drive design is responsible more than any other single factor for destruction of power bipolar transistors. Not only should the maximum values of base drives in the forward (into the base of the transistor) and reverse (out of the base of the transistor) be optimised, but also, as far as possible the oversaturation of the transistor during the on time and driving the transistor too fast during turn off of the transistor should be avoided.

The on-state base current I_{b1} should ideally resemble the collector current waveform. In many inductive switching applications, the base current waveforms are roughly rectangular whereas the collector current is roughly triangular. The transistor is usually forced into hard saturation in the beginning of the drive waveform. Proportional base drive circuits and Baker clamps may be used to prevent the excess base current from sending the transistor into hard saturation.

The turn off base current, I_{b2} should be high enough to prevent excessive turn off times and power losses. It should be low enough to keep the locus of the switching collector current and V_{CE} within the RBSOA specified in the datasheet. The values of the base currents mentioned in the "switching times" section of the datasheet serve as a rough guide in choosing the values of I_{b1} and I_{b2}.

3.3.4 Switching times

The switching times of a bipolar transistor consist of the delay time and rise time at turn-on, and the storage time and fall time at turn-off; see figure 2.

In general, the losses due to switching times are most significant at turn-off. The storage time is generally longer than the fall time, but the voltage across the device is smaller and so losses in both phases are of the same order.

An optimised base drive will reduce the storage and fall times, and hence reduce losses.

3.3.5 High Temperature Performance and thermal runaway.

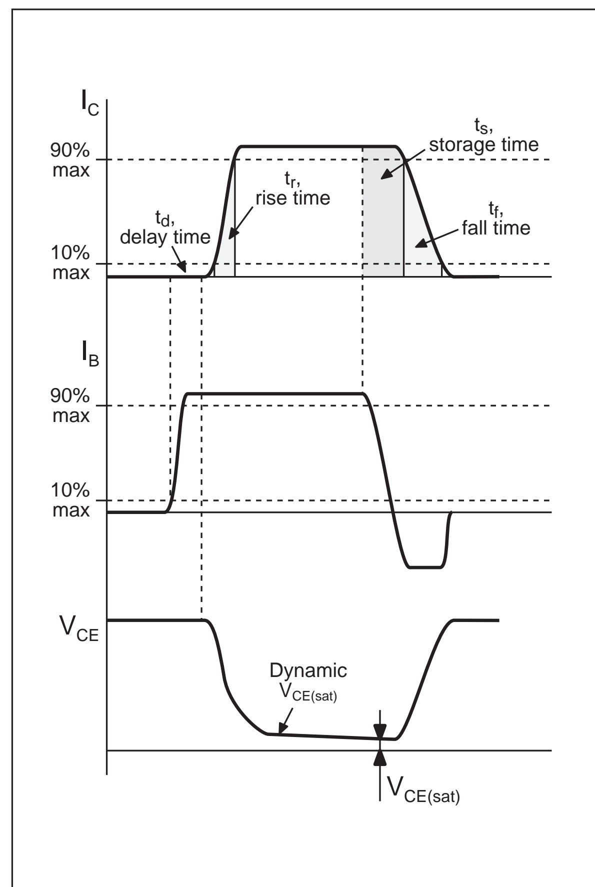
BJT turn-off times and h_{FE} increase with temperature. This means that as temperatures increase, the switching losses also increase, which will in turn increase the junction temperature of the device (if the heatsinks etc. are insufficient). This positive feedback effect is called thermal runaway, and can easily lead to the destruction of the device if care is not taken with thermal management.

This effect also makes BJT devices difficult to parallel, as the device with the largest losses will tend to heat up more, causing it to "hog" the current (i.e. conduct a disproportionately large amount) and go into thermal runaway.

3.3.6 Polarity - NPN or PNP.

Most applications which use switching transistors - power supplies, lamp ballasts, horizontal deflection and some motor drives - use faster switching NPN bipolar transistors or N-channel MOSFETs. PNP transistors (and in the case of power MOSFETs, p-channel devices), are used in applications such as low voltage motor drives only when their simplified drive design is preferred to device performance and reduced power losses.

Figure 2. Bipolar Transistor switching times



3.3.7 Second Breakdown Current with base forward biased, Is/b and Forward Biased Safe Operating Area FBSOA

These parameters are often used in linear power supplies where external transistors especially PNP transistors are used to increase the power output of the linear series regulator.

3.4 Some rarely specified parameters

Certain parameters which are not often specified could be very useful in certain types of applications or designs but are not needed in others. The challenge of the transistor manufacturer is to condense as much information as relevant in a wide variety of applications all within a few pages. Invariably some items that could be useful in some applications do get left out. Two examples of parameters are:

3.4.1 Dynamic Saturation.

In very fast switching applications or applications with short on times, the on voltage of the transistor may not reach the steady-state $V_{CE(sat)}$ value. For these applications, a dynamic saturation voltage better reflects the real application conditions and allows a more accurate calculation of the power losses.

3.4.2 Very low current transistor gain - especially at low temperatures

Some applications such as lamp ballasts and self-oscillating power supplies depend on the gain of the transistor at very low current levels for circuit start up. Here, the gain specified at low current levels such as around 10mA or even less , is very important. As this is temperature dependent, the worst case condition is start up at the minimum ambient temperature.

4. POWER MOSFETS

Generally speaking, power MOSFETs are more similar from one manufacturer to another than power bipolar transistors. However it is increasingly seen that in high frequency applications, the performances can vary quite significantly even thought the datasheet values are quite similar.

4.1 Important Parameters

4.1.1 $V_{(BR)DSS}$, Drain-Source Breakdown Voltage

This value indicates the maximum voltage which can be withstood by the drain and source terminals of the MOSFET. If this value is exceeded, the device will break down and begin to conduct. The effect can be thought of as similar to the reverse breakdown of the intrinsic anti-parallel diode. It is specified with the gate and source terminals shorted together.

This parameter represents the worst case sustained voltage that the MOSFET should experience in normal operation. However, exceeding this value is not instantly destructive. It is possible that the power MOSFET can withstand pulses of low energy at voltages above this published breakdown level. This phenomenon is called Avalanche breakdown. During this time, the voltage across the drain-source terminals of the MOSFET is clamped (in a similar way to the clamping of a Zener diode), but the current through the device and hence also its power dissipation start to increase. For this reason the power MOSFET is often shown schematically as having an anti-parallel diode, even though it is not a true Zener.

Having said this however, it is always best to treat the avalanche energy breakdown withstand capability of the MOSFET as an extra level of safety margin that we give to the design. During normal operation, the breakdown voltage of the MOSFET is not to be exceeded.

However too high a safety margin in $V_{(BR)DSS}$ leads to other problems. The on resistance of MOSFETs rise steeply as the breakdown voltage increases. For the same die size, doubling the breakdown voltage results in a five fold increase in on-resistance. The challenge of the circuit designer is choosing the MOSFET with the optimum safety margin. $V_{(BR)DSS}$ is essentially independent of temperature though the worst case (minimum) for the circuit designer is at the lowest operating temperature.

4.1.2 $R_{DS(on)}$, Static Drain-Source On-Resistance

The on-resistance, and not the current carrying capacity, is the fundamental factor in the design and specification of power MOSFETs. In fact, the continuous current rating I_D is normally a derived value that supposes ideal conditions such as infinite heatsinks.

The on-resistance is highly temperature dependent. Between room temperature (25ºC) and the maximum operating temperatures (150 or 175ºC), the on-resistance often more than doubles. The variation in on-resistance at elevated temperatures is somewhat higher for higher voltage transistors. The positive

temperature coefficient of resistance makes the MOSFET an easier device to parallel than a bipolar transistor.

4.1.2 $V_{GS(th)}$ and $V_{GS(on)}$

$V_{GS(th)}$ is the value of the gate-source voltage required to make the device start to conduct. The drain current at which this parameter is measured is usually small - for example 1mA .

The value of the gate voltage which should be used to drive the device in normal operation, $V_{GS(on)}$, is not specified explicitly in the datasheet. A value should be chosen which is around that given in the "CONDITIONS" column of the $R_{DS(on)}$ specification.

In terms of $V_{GS(on)}$ requirements, power MOSFETs fall into two basic categories: standard and logic-level. Standard power MOSFETs are meant to be driven on with a positive voltage of +10V. Logic-level devices can be driven with a voltage of +5V, compatible with the TTL logic level voltage. Thanks to a need for automotive and digitally driven applications, these power MOSFETs are becoming increasingly popular, especially at lower voltages (below about 100V $V_{(BR)DSS}$). These lower voltage components have a thinner gate oxide than the normal threshold equivalents.

4.1.3 $V_{GS(MAX)}$

Exceeding this value when driving the device can lead to punch-through of the gate oxide, and destruction of the device.

Currently, the specified maximum values of gate-source voltages are generally around +/-20V for normal (10V) MOSFETs and +/-15V for logic level (5V) MOSFETs. In reality modern MOSFETs have a considerably higher V_{GSS} max. than that stated on datasheets, and as control of the thickness and integrity of the gate oxide in the manufacturing process improves, this is increasing. For high voltage MOSFETs (400V-1000V) a value of +/-30V is guaranteed when state-of-the art manufacturing processes are used. However, it is best to treat this as additional insurance against spikes in the drive circuit and not drive the MOSFET on at voltages far higher than the 10V suggested in the datasheet.

Negative voltages are sometimes used to ensure that MOSFETs do not accidentally turn on in noisy environments.

4.2 Other parameters

The next few characteristics of mosfets are less important in most applications than the first three mentioned above.

4.2.1 Switching Times [$t_{d(off)}$, t_f, $t_{d(on)}$, t_r]

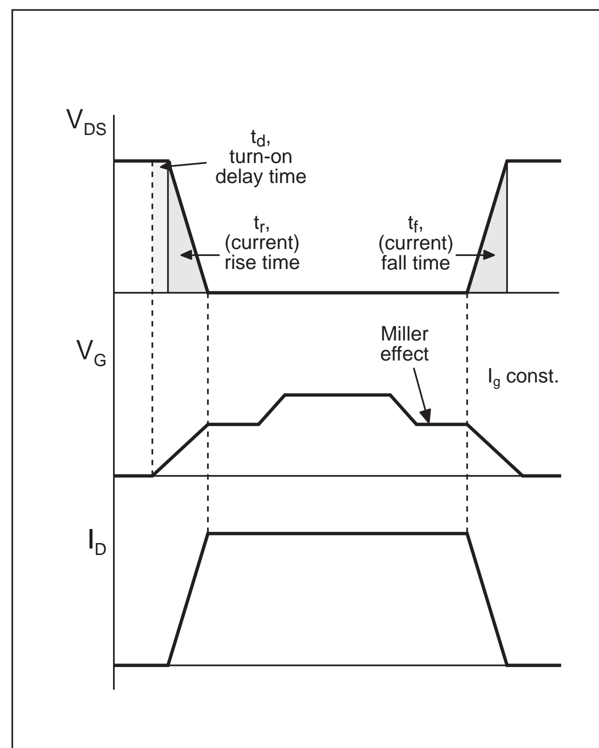
The turn on delay , rise time, turn-off delay and the fall time of the MOSFET comprise the switching times of the MOSFET - see figure 3. In general, MOSFET switching times do not mean much to the user. Careful design may result in a faster switching MOSFET but, since the switching times are in the order of tens of nanoseconds, the differences are small. Furthermore, faster switching mosfets may result in other system problems such as noise and EMI.

4.2.2 Total Gate Charge, Q_g and Input Capacitance, C_{iss}

Qg represents the amount of charge required to turn the device fully on; that is to charge the input capacitance to $V_{GS(on)}$. It allows the currents and switching times at turn-on and turn-off to be deduced.

The input capacitance of a MOSFET, C_{iss} is the sum of two components - C_{gs} and C_{gd}. To a first approximation, C_{gs} does not vary whereas C_{gd} varies quite significantly with the applied voltage with the highest value of C_{gd} (and hence C_{iss}) being at low

Figure 3. Power MOSFET switching times



impressed gate-source voltage. Because of the widely varying nature of C_{iss} and since it is of limited value to the user, the parameter Q_g, introduced relatively recently, is used to describe the charge necessary to turn the device on. However C_{iss} is still used on datasheets to give a rough estimate of the peak currents necessary to turn on the device in a certain time period.

4.2.3 Other Parasitic Capacitances : Output Capacitance, C_{oss} and Reverse Capacitance, C_{rss}

The Output capacitance and the reverse or "Miller" capacitance of the MOSFET are represented by the symbols "C_{oss}" and "C_{rss}" respectively. These parameters are not very important in circuit design. C_{oss} and C_{rss} are functions of die size and to a lesser extent, breakdown voltage. It is interesting to note that there is a certain equivalent output capacitance, C_{oss}, for MOSFETs. This capacitance is charged at every MOSFET turn off and discharged through the MOSFET at turn on. This means that in certain high frequency switching circuits, where frequencies run into hundreds of kilohertz, a smaller die with lower total gate charge and lower parasitic capacitances could result in not only a lower device die size (and hence cost) but also lower overall losses (since lower switching losses will be more than adequate to offset any higher on-state losses).

5. IGBTS

Insulated Gate Bipolar Transistors are relatively new devices that have the potential to replace bipolar transistors in many low frequency applications. The notable improvements in IGBTs have led to their replacing bipolar Darlington transistors in numerous medium and high power high voltage applications.

The important advantages of the IGBTs are the easy of drive thanks to its (MOSFET like) MOS gate and low on-state drop thanks to bipolar, diode-like conduction during the on state. The disadvantages are the relatively slow turn off rate which cannot be influenced significantly by turn- off circuit design (because of the MOS gate!) and the possibility under certain extreme conditions to "latch". Latching is the accidental turn on of a suppressed parasitic transistor which results in a thyristor like condition, loss of gate control and usually device destruction.

5.1 Important parameters

5.1.1 Breakdown Voltage $V_{(BR)CE}$

This specification is not to be exceeded under any condition. Unlike avalanche rated MOSFETs, we do not have much to gain and we have much to lose by choosing an IGBT with a breakdown voltage very close to the highest impressed instantaneous voltage. The on state voltage of the IGBT increases when the breakdown voltage of the IGBT is increased, but the rate of increase is much less than that of similar parameters in a power MOSFET.

5.1.2 Switching Times and Switching Losses.

Below about 300 or 400V, the power MOSFET is a more suitable power device in most applications. Between 400V and 1200V, the IGBT is more likely to be used in low frequency applications such as automotive ignition (about 100Hz) and industrial motor control (2 to 25kHz). Ultrafast IGBTs which can switch at 50 or even 100kHz are possible but currently the economies of scale favour the MOSFET over the IGBT in most high-frequency applications. IGBTs can be used in resonant applications.

A major disadvantage of IGBTs results from being unable to extract excess charge from the n- epi and p region of the IGBT at turn-off. This results in the turn-off collector current exhibiting a non-linear tail. In order to compute the turn-off losses, this can divided into two piece-wise linear regions: t_{f1}, where the collector current falls from 100% to 20% of its maximum value; and t_{f2}, where the collector current falls from 20% to 0%. The second portion of the tail, t_{f2} can be a very dissipative region because of the high voltage across the part at the same time when there is current flowing through the device.

The structure of IGBT gives the device manufacturers the ability to optimize the performance for a given breakdown voltage and switching frequency, or in other words, manufacture IGBTs targeted to a certain application.

5.1.3 On-State Collector-Emitter Voltage, $V_{CE(on)}$

The voltage drop across the collector-emitter of the IGBT when it is full on is identified by the symbol $V_{CE(on)}$. The maximum value for the on-state voltage is very important for low frequency applications such as solid state relays and automotive ignition. As discussed in the above paragraph, very fast IGBTs can have significantly (three or four times) higher on-voltage compared to IGBTs optimised for low frequency operations.

In high voltage applications, above about six hundred volts, the on-state voltage of the IGBT is very significantly smaller than that of an equivalent

MOSFET. The IGBTs are therefore most popular in high voltage, relatively low frequency applications.

5.1.4 On-State Gate-Emitter Voltage, $V_{GE(on)}$

The positive voltage placed on the gate to keep the IGBT in the on-state is called its on-state Gate-Emitter Voltage,$V_{GE(on)}$. This gate voltage value specified in IGBT datasheets is usually +15V for IGBTs (against 10V for MOSFETs). Here too, reliability studies have shown that values of the gate-emitter voltage much higher than necessary are not recommended. The absolute maximum value specified for the gate source voltage is usually$\pm$20V or $\pm$25V. In the off-state, since many motor drive IGBTs operate in noisy environments, a negative voltage is sometimes used. Usually, the expense of a negative power supply and a more complicated drive scheme is to be weighed against the possibility of destruction due to accidental turn on and if absolutely necessary, negative gate -emitter voltages are used to keep the device in the off state. In rare cases the on-state gate voltage of an IGBT drive circuit is deliberately lowered to increase short circuit immunity at the expense of on state losses.

5.1.5 Energy Dissipated Per Turn Off Cycle, W_{off}.

Since the turn off voltage exhibits a tail, this specification is especially popular for slow, low $V_{CE(sat)}$ IGBTs. This measure, multiplied by the switching frequency forms the bulk of the switching losses. Usually speaking, the turn on losses of the IGBT are far less than the turn off losses.

5.1.6 $I_{C(max)}$ Collector Current at 100°C

This shows the maximum continuous current that the device must see during normal operation. IGBTs in general cannot handle “peaky” currents (High peak, low RMS currents) the way MOSFETs can because of this tendency to latch. Therefore it is a fairly common practice to derate the peak instantaneous current IGBT to the maximum specified current level at 100°C.

5.2 Special IGBTs

5.2.1 Logic Level IGBTs

These devices require a drive voltage lower than standard IGBTs. They are ideal for high voltage solenoid/plunger applications, automotive ignition applications where low battery voltage operation (7V) is possible. The technology used to create logic level IGBTs is similar to that of power MOSFETs.

5.2.2 Short Circuit Proof IGBTs

By decreasing the transconductance or g_{FS} of the IGBT, the device manufacturer can make the device withstand overload currents until the a short circuit detect circuit can be triggered. Normally the device designer attempts to have as high a device transconductance as possible. In the case of short-circuit proof IGBTs, however, the transconductance is deliberately lowered. This results in a higher on state voltage but the ability of the MOSFET to withstand a high short circuit for a few milliseconds till a short circuit detect and turn-off circuit comes into operation.

Similarly, as described in section 5.1.5 above, it is possible to lower the on-state drive voltage to increase the overload current withstood.

6. “SMART” TRANSISTORS

A new trend in the transistor industry is the recent appearance of a variety of self protecting, three pin intelligent power ICs that are pin compatible with and functionally equivalent to power transistors. The added advantages of these transistors is the additional features possible thanks to monolithically integrating these protection, status and alarm functions on to the same piece of silicon. These sophisticated power intelligent circuits all have device specifications characteristic to the intelligent power technology used. While some of these transistors will find use on diverse applications, most of the smart transistors are designed specifically for one main application area. A number of three pin intelligent “transistors” are used today in the automotive industry.

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