International
IOR Rectifier

# APPLICATION NOTE

AN-1045

International Rectifier • 233 Kansas Street El Segundo CA 90245 USA

## AC TIG Welding: Output Inverter Design Basics

By A. Roccaro, R. Filippo, M. Salato

### Topics Covered



## 1. Introduction

A common use of *IR Standard Speed* IGBTs is in the output inverter stage of the AC TIG[1] welding machines. IR has designed application specific modules and the aim of this document is to provide information on how using them. Considerations and guidelines to connect several devices in parallel are also provided for very high current applications.

| Configuration | Part number | IR IGBT Type | Diode type | $V_{CES}$ (V) | $I_C$ @25ºC (A) | $I_C$ @100ºC (A) | Package |
|---|---|---|---|---|---|---|---|
| Single switch without freewheeling diode | GA200SA60S | *Standard Speed* | - | 600 | 200 | 100 | SOT-227 |
| Half bridge without freewheeling diode | GA200HS60S | *Standard Speed* | - | 600 | 380 | 250 | IAP |
| Half bridge with freewheeling diode | GA100TS60SQ | *Standard Speed* | *Fast QuietIR* | 600 | 220 | 200 | IAP |

***Table 1.*** IR recommended products for switching output stage of AC TIG welding machines

[1] TIG, Tungsten Inert Gas, also called GTAW (Gas Tungsten Arc Welding)

## 2. Application on TIG welding

Unlike other welding machines, TIG ones are not suited to work with magnetic-type power supplies. These deliver an alternating current of line frequency (50Hz or 60Hz depending on geographic area) with slow reversals that hamper reignition of the arc at next half wave; auxiliary means can provide high frequency ionizing voltage (HF), but often the instantaneous current is too low [3]. Nowadays, this problem is avoided by using an output inverter stage connected to a regulated dc power supply.

The output inverter stage provides an ac square-wave (rapid zero crossover) that improves ac performance enhancing arc reignition (deionization does not occur) to the extent that HF systems are unnecessary [3]. As HF generates abnormal high electromagnetic emission, its use could cause interference especially in electronic equipment as radio or television (EMI).

The frequency of this ac-wave is kept low (few hundreds Hz) for intrinsic application requirements.

Two commonly used configurations of an output inverter are discussed in the following sections.

### 2.1 Full Bridge Inverter

Consider the full-bridge inverter output stage shown in figure 1. Every IGBT symbol in the picture is equivalent to one or more IGBTs connected in parallel. The inverter consists of two legs: $X_1$, $X_2$ form leg A, while $X_3$, $X_4$ form leg B. Commonly, the IGBTs are arranged to switch in pairs, ($X_1$, $X_4$) and ($X_2$, $X_3$); the IGBTs in each pair are turned off and on simultaneously. Also, the pairs are switched in such a way that when one of them is in its ON state, the other is OFF: when $X_1$ and $X_4$ are ON, $X_2$ and $X_3$ are OFF and vice versa (although in practice this is not always true, and it will be addressed later). In figure 1 are also included anti-parallel protection diodes connected to the IGBTs ($D_1$, $D_2$, $D_3$, $D_4$). The use of these diodes is highly recommended since they provide a path to the reverse current to ensure a low, safe $V_{EC}$.

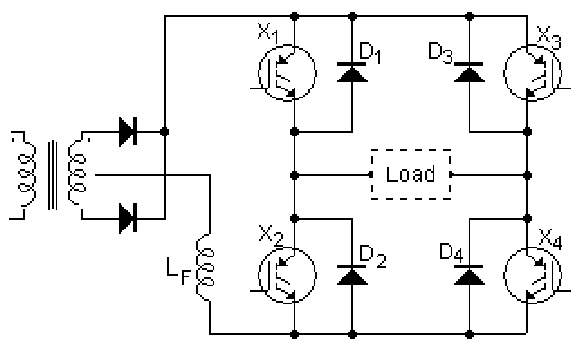



***Figure 1.*** Simplified circuit of the Full-Bridge output Inverter.

The reverse current can be named a “reactive” current, because it would not be present with a purely resistive load (the arc). Under some conditions the reverse current is neither present nor harmful, but in other circumstances it is; since many times the operating conditions are totally unpredictable, protection diodes should always be used.

The arc just resists to the current flow and has low reactive components. The real threat is the inductive component introduced by the wires connecting the inverter output to the electrode and the work piece (inductance is proportional to cable length). Hence, an inductor in series with the arc composes a more accurate model of the load (figure 2b). When a pair of IGBTs is ON and the current $I_L$ flows through the load, energy is stored in the stray inductance of the wires. When the inverter switches, the current $I_L$ changes direction, but the inductance rejects this sudden change and pumps the reverse current. If protection diodes were not present, this current would cause undesirable under stress operation of the IGBTs and might even lead to exceed the maximum allowed $V_{EC}$ voltage damaging the device.

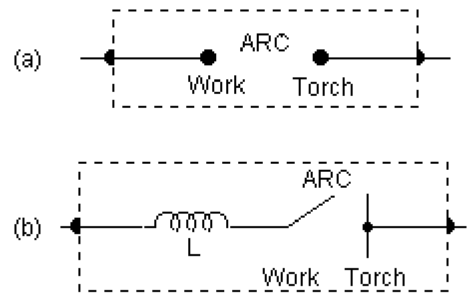



***Figure 2.*** Models of the load: (a) basic and (b) more accurate

Another consideration arises. All the IGBTs should not be OFF at once during switching, since the power source feeding the inverter continuously supplies current. It follows that a pair of IGBTs should be turned ON a time $t_\Delta$ before turning OFF the other pair; time $t_\Delta$ depends on turn-on and turn-off times associated to the devices (normally is some hundreds of nanoseconds long).

As a result, for a finite short time, a cross-conduction of current takes place through the legs and the IGBTs must withstand it. During this interval of time, the only harmless path for the reverse current is through a “free-wheeling” diode and an IGBT; thus a further reason for using the diodes.

To reduce reverse current and cross conduction effects, most designers use the approach of “shaping” the current waveform through an appropriate control of the primary inverter. It consists in reducing the magnitude of the load current to few amperes before changing its polarity (switching the IGBTs). In this case, relatively small clamps avoid unsafe voltage spikes during intervals in which all the IGBTs are kept OFF. Current shaping also allows to build very accurate current profiles to optimize the welding process.

When selecting the protection diodes, it is important to consider parameters such as the maximum peak, average and RMS forward current, the dissipated power, the breakdown voltage, and the speed.

In most cases, the discrete diode 40EPF06 can be a good choice: it has 40A of average forward current, its maximum peak reverse voltage is 600V, it has an ultra soft recovery, and it is optimized for short reverse recovery time and low forward voltage. It also ensures stable and reliable operation in severe temperature and power cycling conditions.

Another valid option can be the rectifier bridge SA55BA60[2] that contains, in one single device, all four freewheeling diodes arranged to allow a direct connection to "H-Bridge" inverters (figure 3). It has 55A of average forward current, its maximum peak reverse voltage is 600V and it has fast recovery time. Also, the SOT-227 package with an electrically isolated base plate and its bridge configuration allow common heat sinks usage, simplified mechanical designs, and compact and rapid assemblies.

Where the "current-shaping" technique results in very low switching current, even smaller diodes can be used, such as the 10ETF06, which has the same characteristics of the 40EPF06 except for a lower average forward current of 10A.

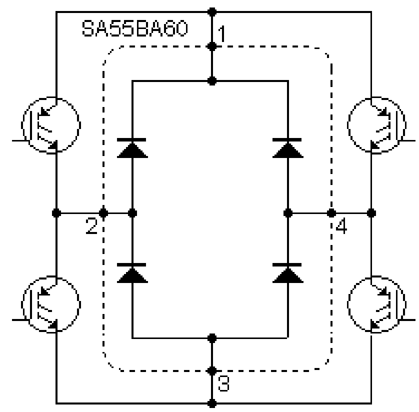



***Figure 3.*** Application and pinout of SA55BA60 in "H-Bridge" inverters (load not shown)

## 2.2 Half-Bridge Inverter

Consider now the inverter circuit of figure 4. The number of diodes in the output rectifier is doubled, in respect to the "Full-Bridge" configuration, but the number of equivalent IGBTs is now a half. This circuit usually leads to system simplifications and cost savings.

The IGBTs are switched in such a way that when one of them is in ON, the other is OFF. During the positive half wave, $X_1$ is ON and $X_2$ is OFF thus $D_A$ and $D_B$ work as output rectifier while $D_C$ and $D_D$ are OFF. Vice versa, during the negative half wave, $X_2$ is ON and $X_1$ is OFF, thus $D_C$ and $D_D$ work as output rectifier while $D_A$ and $D_B$ are OFF.

The following considerations arise:

- In this circuit, cross conduction must be accurately avoided. $X_1$ and $X_2$ must never be ON at the same time. This is accomplished by switching $X_2$ ON a time $t_\Delta$ after $X_1$ is switched OFF. Again, this blanking time depends on turn-on and turn-off times associated to the devices.

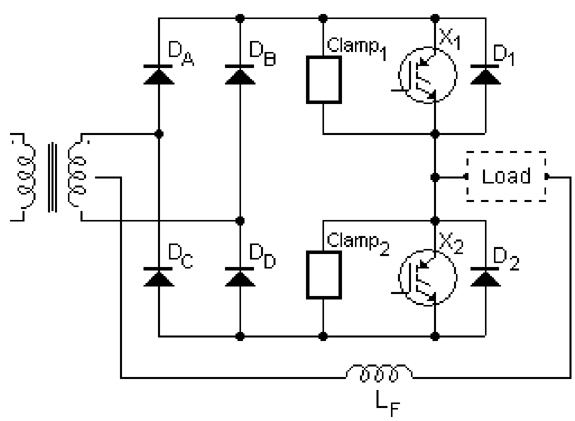



***Figure 4.*** Simplified circuit of the Half-Bridge output inverter

[2] Now available on request as S1223

- There is no freewheeling current. $D_1$ and $D_2$ are protection diodes which ensure that $V_{EC}$ is always well below the safety limit, in particular during switching transients. Very low current diodes can therefore be used, provided they are fast enough. The 8ETH06 or the 10ETF06 suit well to the purpose.

- During the blanking time, the energy stored in the load and in the filter inductor $L_F$ has to be somehow dissipated prior of the current reversal. RC-Diode clamps are often used. Sometimes, the IGBT which is switching OFF is used in linearity as part of the clamp. Caution and accurate design verification must be performed in such a case, since the IGBTs are designed for switching operation and are not intended for linear use. The energy to be dissipated in the clamp can be made very small by implementing the current shaping technique, resulting in additional cost saving.

### 2.3 Transient voltage and output rectifier

In most cases open circuit output voltages are around 80V, which is considerably higher than the arc voltage. However, the transient voltage peaks might represent an issue, and for this reason the IGBTs used must have a high enough collector-emitter breakdown voltage.

When an IGBT is turned off, it dissipates the stored energy in the circuit stray inductance, causing a voltage overshoot across the device. The magnitude of this transient voltage is mostly determined by the gate drive circuit, and is proportional to the stray inductance, the magnitude of the switched current and its rate of fall at turn-off. Hence, performing the shaping of the load current reduces overshoots.

Semiconductor devices having blocking voltages of at least 400V are normally used. For the output rectification, IR offers a wide series of 400V Ultrafast Recovery Epitaxial Diodes which provide a safe margin against transient voltages. In particular, for a full modular approach, IR has developed the UFB200FA40 which provides two independent, insulated diodes in SOT-227 package. More modules can be paralleled together to reach higher current. The IRUD360CW40 (containing two common-cathode diodes in non-insulated TO-244 package) is another interesting choice for very high current application whenever the insulation can be easily provided by the designer.

IR IGBT modules for output inverters can instead withstand at least 600V of collector-emitter voltage ($V_{CES}$) while in the OFF state.

## 3. Advantages of paralleling IGBTs

The main reason to parallel IGBTs is to increment the driven current. Sometimes, the only way to achieve the desired current level is by using similar devices in parallel.

Paralleling helps to reduce the conduction losses and the junction to ambient thermal resistance.

However, switching losses remain the same, or may even increase due to non-symmetrical layout or high current unbalance. The maximum utilization will only be achieved in the case of ideal static and dynamic operation. Therefore, symmetry conditions are of significant importance for parallel connections.

To successfully parallel IGBTs, some items must be considered: the current and temperature unbalance between devices (due to the IGBTs themselves), and gate circuitry and layout (which come up due to external circuitry).

# 4. Issues and guidelines on paralleling: Static considerations

## 4.1 Current and temperature unbalance

When paralleling any power semiconductors, the first issue that comes to mind is how well they share the total current. Given several IGBTs, the $V_{CE(on)}$ for different current levels will be slightly different. When these IGBTs are operated in parallel, the $V_{CE(on)}$ across the devices is forced to be the same. Thus, for a given load current, one IGBT will carry more current than the others, creating an unbalance that at lower currents can be up to 100% (one IGBT carries all current). However, *as long as the current remains below the maximum specified on the data sheet, current unbalance is not critically important* [1].

IR TIG modules are designed to have output characteristics with a very narrow spread, favoring current balance and easing paralleling since, normally, screening is not necessary.

However, generally speaking, semiconductors are temperature limited rather than current limited, so the real issue is whether or not one of the devices approaches the rated junction temperature and how closely they are matched in junction temperature in order to avoid the thermal runaway and obtain the maximum system efficiency. The device carrying more current has a higher junction temperature that may exceed the maximum rated value: This factor should be the designer primary concern [1].

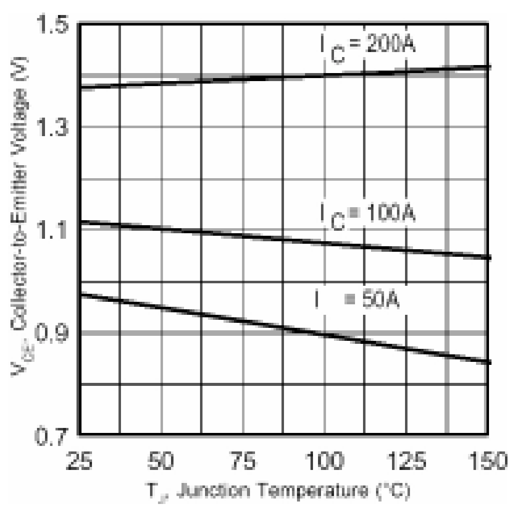



***Figure 5.*** $V_{CE(on)}$ voltage drop vs. temperature in the GA100TS60SQ

## 4.2 Thermal runaway

The temperature dependence of the output characteristics is low in *IR Standard Speed* IGBTs and the temperature dependence of the voltage drop is different at different current levels.

In paralleled IGBTs, the one with the lower saturation characteristic conducts the major current share. Therefore it will have higher forward and switching losses and when operation starts its junction temperature will increase. In this respect, the temperature coefficient (TC) of the saturation voltage is of decisive importance. If positive (the saturation voltage rises together with the temperature), the conduction characteristic degenerates (its impedance increases) and a share of the current will be shifted to the transistors that carried less current initially, so that the current will be evenly distributed over the paralleled transistors. If TC is negative the device carrying more current lowers its impedance, thus resulting in further current increase, and so on until a thermal failure occurs. This is why the power semiconductors with a positive TC are preferred in parallel connections.

The IGBT, being a combination of a power MOSFET and a BJT, cannot be simply described as having either negative or positive temperature coefficient. The temperature coefficient is dependent on the technology used in the IGBT design. Even within the same technology, it changes depending on the current density. As an example, in the GA100TS60SQ the TC is negative for low currents and positive for high currents (see figure 5). However, in *IR Standard Speed* technology, even when the device operates in the negative TC zone, thermal runaway does not occur, as will be discussed in section 4.3.

### 4.3 Balancing mechanisms

There are three factors that help to reduce the current unbalance: good thermal coupling, different TC of the devices, and high currents [1].

The first factor that keeps the unbalance in check is the thermal feedback between the junctions. The one with higher power dissipation increases the sink temperature and consequently the junction temperature of the others by an amount that is inversely proportional to the thermal resistance between the junctions. If the thermal coupling between the dice is tight, the temperature differential cannot be significant.

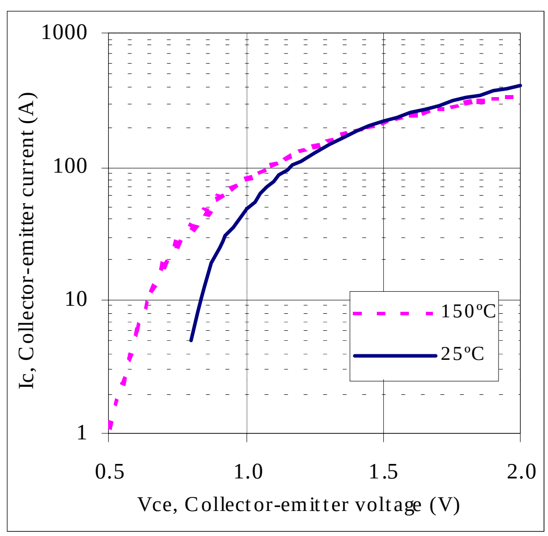



***Figure 6***. Typical output characteristic of the GA200SA60S

Using a common heat sink establishes a thermal coupling between the dice that limits their temperature differential, remaining in the order of few degrees. It is also very important that the devices are mounted correctly (see paragraph 6.3). The use of separate heat sinks, instead, would cause large current unbalance and very significant temperature differentials, hence, their use should be avoided.

The second factor that reduces the current unbalance is the different TC of the voltage drops. Even if it is negative for all the devices, the IGBT carrying less current has a lower TC (in other words, it has a higher absolute value of TC, as shown in fig. 5). As temperature increases, voltage drop of the major carrier changes slightly; while voltage drop of the IGBT that was carrying little current comes down significantly, forcing an increment of conduction, thereby closing the gap in current, as well as temperature. If the temperature differential is kept low, an increase in temperature reduces the current unbalance.

Third balancing mechanism: As the collector current increases, the voltage drop of IGBTs converges toward a common value independent of the junction temperature (figure 6). This reduces the unbalance at higher currents. The junction temperature increases together with the current, and this results in further reduction of the unbalance.

## 4.4 Paralleling IR Standard Speed IGBTs

To ensure parallel operation of IGBTs, all conditions mentioned above in paragraphs 2, 3 and 4 must be taken into account, especially the use of a common heat sink.

Yet, even if all those conditions are met, optimal performance is not guaranteed: Current distribution depends on the tolerances of output characteristics. To reduce unbalance as much as possible, matched devices should be used. Several methods exist to match devices, and the choice could depend on operation mode (switching or not), impact of lifetime killing on the behavior of the devices, and others.

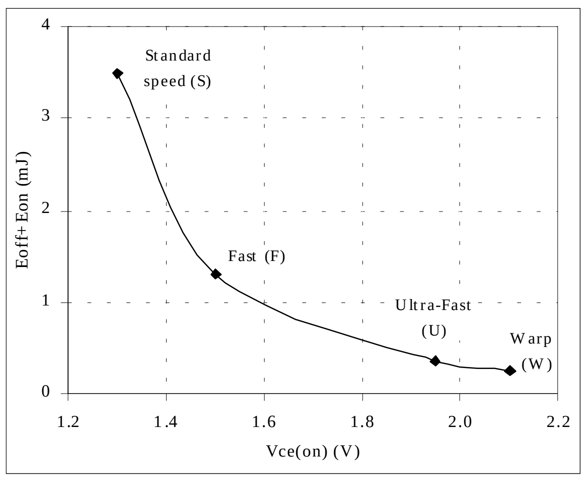
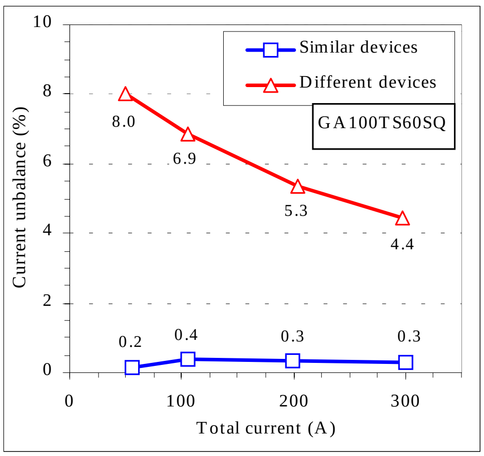



***Figure 7.*** Example of $E_{tot}$ vs. $V_{CE(on)}$ trend (Size 3, Gen. 4 IGBT @ $I_C$=12A)

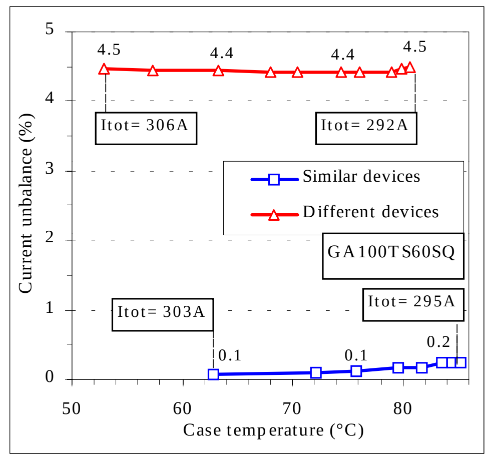
The High-Speed/Low-$V_{CE(on)}$ trade-off In the fabrication process of IGBTs, is of relevance, as represented in the example of figure 7. Lower speed devices give superior conduction efficiency first, and less deviation of the $V_{CE(ON)}$ distribution then. Such a narrow distribution favors current balance when more devices are paralleled together. This explains why IR TIG products are easier to be paralleled (do not require screening), providing very high output currents in heavy-duty operation.

Furthermore, in *IR Standard Speed* devices the TC increases with current and becomes positive at a certain[3] current (figure 5), this guarantees operation without thermal runaway.

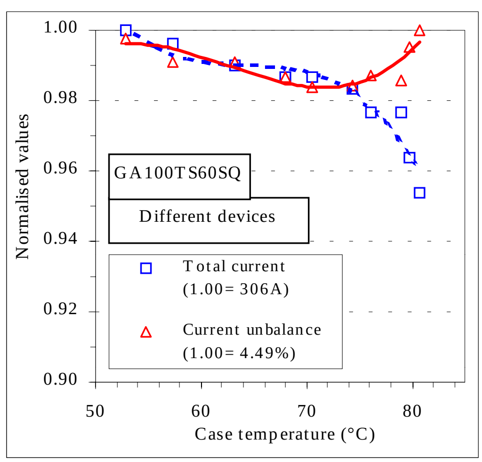
**a)**




**b)**




**c)**




***Figures 8a, b and c.*** Operation of two GA100TS60SQ connected in parallel to a DC power supply

[3] 200A for the GA100TS60SQ and GA200SA60S; 280A for the GA200HS60S

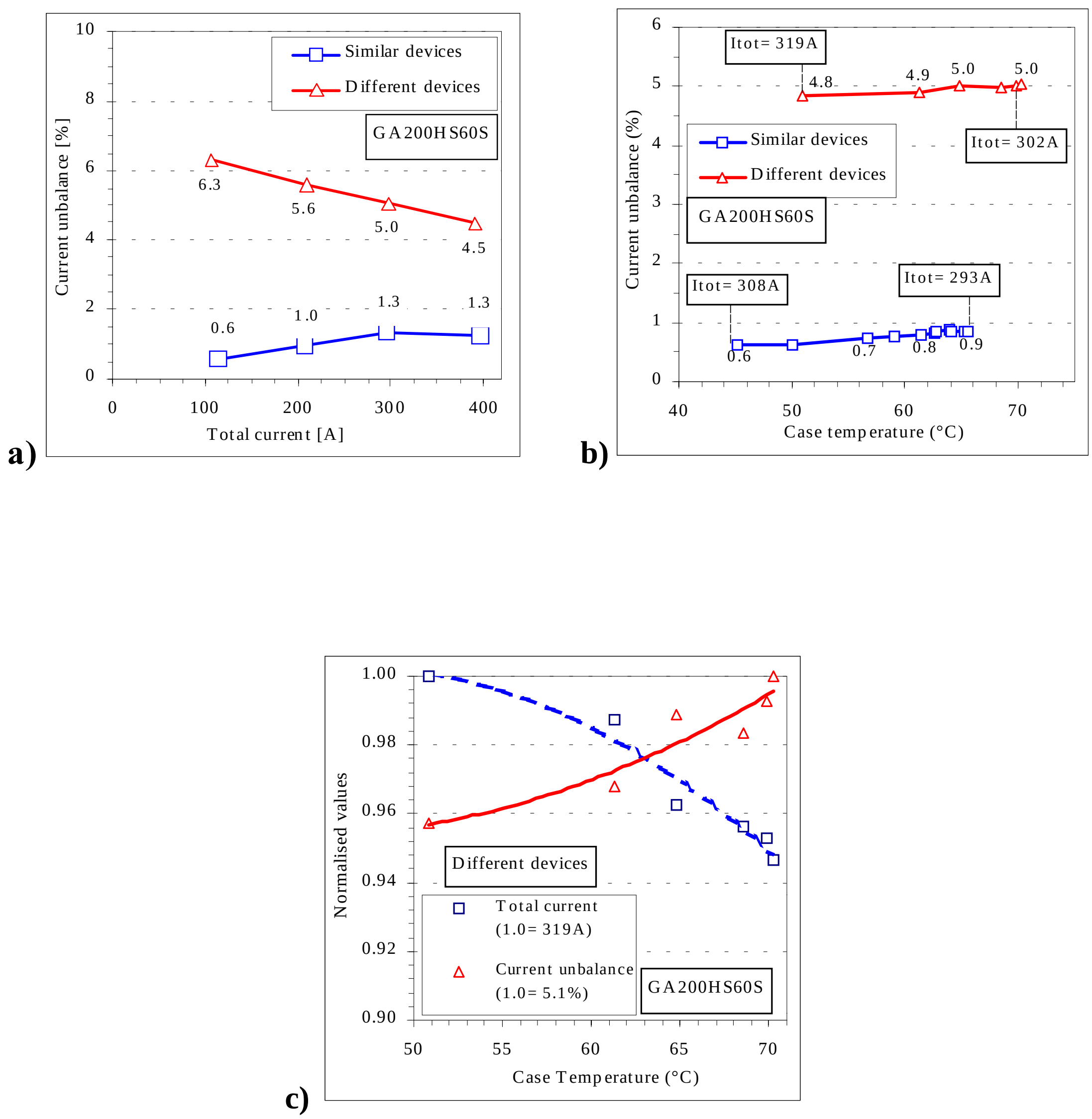
The charts in figure 8 show how all the factors mentioned above influence the current unbalance when two GA100TS60SQ are connected in parallel to a DC power supply. The modules measured are the pair of most “similar” and most “different” devices, selected from several devices of three different lots, comparing the values of $V_{CE(on)}$ at different currents and at different temperatures.

Fig. 8a shows how increasing the current decreases the current unbalance. When current in each module is 100A (that is, total current 200A), in the worst case (different devices), the current unbalance is about 5%, while is below 0.5% in the similar devices.

The charts in figure 8b and 8c are correlated and are made with the results of the same measurements. They show the change of the current unbalance with the temperature. The temperature dependence of the modules is minimal. The unbalance is nearly constant even when devices operate in the negative TC zone and thermal runaway not occurs due to a good thermal coupling and different TC of the voltage drops. Changes in unbalance are mainly due to the decrease of the total current.

The same measurements were carried out using selecting 4 modules GA200HS60S from several devices of different lots. The results are shown in the charts of figure 9. It can be seen how what concluded previously for the GA100TS60SQ applies equally well: increasing current decreases current unbalance (figure 9a); the temperature dependence of the current unbalance is minimal (figure 9b); changes in the unbalance are mainly due to the decrease of total current (figure 9c).

These results confirm how the IR modules are well suited to work in parallel, even if devices from different lots are used.




***Figures 9a, b and c.*** Operation of two GA200HS60S connected in parallel to a DC power supply

# 5. Issues and guidelines on paralleling: Dynamic considerations

## 5.1 Drive circuit

The input capacitance of the IGBT, whose gate is essentially identical to that of the MOSFET [2], and the inductance of the gate driving circuit form together a LC loop that may cause undesired and unsafe oscillations. To eliminate the risk of oscillations, some recommendations should be followed:

- Use of individual gate resistors located physically close to the gate lead of the device. Impedance deviations of the driver circuits should be avoided. An approximated value of this resistance may be calculated through the following formula:

$$R_G \geq 2 \cdot \sqrt{\frac{L_{tot}}{2 \cdot C_{ies}}}$$

where $R_G$ : gate resistance
$L_{tot}$ : gate emitter (drive circuit) loop inductance
$C_{ies}$ : input capacitance

The value of $L_{tot}$ is the sum of two components: the first is the parasitic inductance of the PCB tracks and the wires used to connect the gate drive circuit to the module; the second, named $L_S$, includes the internal connections of the module. The values of $L_S$ and $C_{ies}$ for each device are shown in table 2 ($C_{ies}$ is also reported in datasheets). The value of $L_S$ is calculated with measurements, FEM and BEM simulations (Finite Elements Method and Boundary Elements Method).

| Device part number | $L_S$ (nH) | $C_{ies}$ (pF) | Package |
|---|---|---|---|
| GA200SA60S | 20 | 16250 | SOT-227 |
| GA100TS60SQ | 120 | 16250 | Int-A-Pak |
| GA200HS60S | 90 | 32500 | Int-A-Pak |

***Table 2*.** Reference table used to calculate the minimum value of $R_G$

- Twist or run on parallel tracks the gate lead and the gate return lead to minimize gate emitter loop inductance.

- Ensure that the gate of the IGBT is looking into a stiff (voltage) source with as little impedance as practical. This advice applies equally well to both paralleled and single device designs.

- Do not place Zener diodes or Transient Voltage Suppressors directly between gate and emitter. If over voltage protection is required on the gate, place the Zener diodes on the driver side of the gate resistor(s).

- Do not place capacitors directly gate to emitter to control switching times, instead increase the gate resistor. The capacitors may cause oscillations and slow down switching, which increases the dynamic unbalance between devices.

### 5.2 Power circuit

First of all, it is very important to state that all the threats issue associated with the dynamic behavior are dramatically reduced and even eliminated through the output current shaping technique explained earlier. Anyway, for completeness, some hints about switching of paralleled devices are given in this section; for a deeper analysis of switching operation of paralleled IGBTs refer to application notes AN-990.

Generally speaking, voltage equality is ensured by the fact that the devices are in parallel. However, under transient conditions voltage differentials can appear across the devices, due to di/dt effects in unequalized stray inductances. If the overshoots at turn-off do not violate the ratings of the IGBT, the difference in the turn-off losses is negligible [1].

Yet, the impact of the common emitter inductance on switching is far from negligible. The IGBT with lower common emitter inductance turns off before the others, which are left to shoulder the entire load current during the turn-off transient. This will increment the difference in power dissipation between devices, leading to an increment in junction temperature and thermal runaway, at worst. It follows that switch mode operation of paralleled IGBTs should not be undertaken unless the common emitter inductances are matched in value.

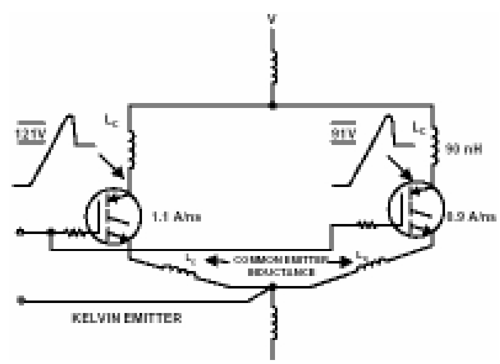



***Figure 10***. Parallel connection of two IGBT and example of difference in transient voltage

It is also important that stray components are minimized by a tight layout and equalized by symmetrical position of components and routing of connections. In any case, IR modules are designed looking after to minimize the inductance of the internal connections.

In practical applications the IGBTs could be operated at some frequency and losses of the devices would have a switching component proportional to the operating frequency. The switching losses depend on junction temperature and load current [2].

The IGBT carrying more current will have higher switching losses, as well as higher conduction losses. However, the switching frequency helps bringing balanced operation, due to different TC of voltage drop. When the power losses increase the junction temperature, the unbalance is reduced and the rate of unbalance reduction increases with frequency [1].

If the RMS value of the output current is kept constant, a reduction in duty cycle reduces the current unbalance. This is due to the third balancing mechanism, because to generate the same output current with a lower duty cycle a higher peak current is necessary.

## 6. Using IR products

IR application specific products for AC TIG output inverter stages are shown in table 1. Below are summarized some advantages of these IR products. Some hints about discrete IGTBs for the same application are also given.

### 6.1. Output inverter stages

The TIG welding machines have operation frequencies as low as few hundreds Hz. The use of fast switching devices, hence, is not recommended, since they have greater conduction losses. Slower, *IR Standard Speed* devices are better suited for this application.

The key rating to calculate conduction losses is $V_{CE(on)}$. The IR TIG switch modules are designed to have the lowest-available $V_{CE(on)}$ and their use allows to achieve a more efficient circuit. The very narrow distribution of $V_{CE(on)}$ simplify the use of IR TIG products in parallel (do not require screening), providing very high output currents in heavy-duty operation

The value of 600V for collector-emitter breakdown voltage ($V_{(BR)CES}$) provides a very safe margin against transient voltages.

### 6.2 Multi-process welding

Besides driving high AC or pulsed DC current (typical of TIG welding machines), the IR switch modules are also designed to drive high continuous currents: continuous collector current can be as high as 50% maximum collector pulsed current. This characteristic makes TIG family useful for multi-process welding machines, where the output stage needs to drive current in both pulsed and continuous modes. It is also very useful when considering effects of cross-conduction in switching operation, since a high current pulse through the devices will be harmless.

## 6.3 Mounting instructions

For proper mounting and exchanger surface preparation the following procedure is recommended.

**Heat sink Preparation**

The contact surface of the heat sink must be flat, with a recommended tolerance of <0.03mm (1.18 mil) and a leveling depth of <0.02mm (0.79 mil), according to DIN/ISO 1302. In general, a milled or machined surface is satisfactory if prepared with tools in good working condition. The heat sink mounting surface must be clean, with no dirt, corrosion, or surface oxides.

**Visual Inspection**

Inspect the module to insure that the contact surface of the base is clean, that there are no lumps or bulges on the base plate that could damage the base or reduce heat transfer across the surfaces.

**Thermal Compound**

Coat uniformly the heat sink mounting surfaces and power module base plate with a good quality thermal compound (a small rubber roller can be used). A guide for choosing the right thermal compound is in IR application notes AN-1012.

Apply uniform pressure on the package to force the compound to spread over the entire contact area. If the layer of the compound is too thick then the thermal resistance will be increased. To determine the correct amount of the compound for a particular application a series of experiments should be performed. When the quantity is correct a very small amount of the compound should appear around the perimeter of the device as it is slowly torqued to the heat sink.

**Module Fastening**

Bolt the module to the heat sink using the two fixing holes. The recommended torque (reported in datasheets) is 1.3Nm for the SOT-227 and 4Nm for the IAP. An even amount of torque should be applied for each individual mounting screw. A torque wrench, accurate in the specified range, must be used for mounting the module, in order to achieve optimum results. The mounting screws must be tightened in sequence. The first mounting screw should be tightened to one third of the maximum torque; the second screw should then be tightened to the same torque. Full tightening of both screws can then be completed.

After a period of about 3 hours, check the torque with a final tightening in opposite sequence to allow the spread of the compound.

**Electrical Connection**

Tight the screws to the power terminals avoiding any pressure on the module. The maximum torque is reported on the datasheets. For the SOT-227, the M4 screws should be used with lock washers (included with the packages).

### 6.4 ESD and correct handling

All IGBTs are sensitive to ESD (Electro Static Discharge) and is important to take appropriate precautions when handling them.

IR modules are packaged and shipped following standards to ensure protection against ESD. In the same way, care must be taken when using and manipulating the devices. The workplaces and the staff should be specially prepared with conductive tables, ground connections, wrist strap, etc.

The SOT-227 modules are provided in conductive plastic tubes, while the Int-A-Pak modules come with their terminals short-circuited by conductive foam.

For more information about ESD and its threats also refer to IR application notes AN-955.

### 6.5 Discrete devices approach

So far, only circuits based on IGBT modules have been considered, since the module approach gives benefits in terms of ease of assembly, high current, and compactness of the resulting equipment. However, in certain cases, circuits based on discrete IGBTs may be still preferred. That is usually due to low current welding machines requirements, or to designer habits and existing manufacturing tools and operators skills. In such cases, IR provides a complete line of discrete Standard Speed IGBTs, with different current ratings and in different package styles, including TO-220, TO-247 and SMD packages.

Of course, the benefits of the *IR Standard Speed* technology are still valid. The easy of paralleling can be helpful to reach higher currents.

In the same way, for the the output rectifier IR offers a complete series of Ultrafast recovery rectifiers in a wide choice of discrete packages.

Particular care should be taken for obtaining low case-to-junction thermal resistance, specially when the devices need to be insulated from the heat sink. Refer to IR application notes AN-1012 “Mounting Considerations for International Rectifier’s Power Semiconductor Packages” and AN-1023 “Surface Mounting of Larger Devices” for proper mounting guidelines.

| Configuration | Part number | $V_{CES}$ (V) | $I_C$ @25ºC (A) | $I_C$ @100ºC (A) | Package |
|---|---|---|---|---|---|
| Single switch without FW diode | IRG4PC50S | 600 | 70 | 41 | TO-247AC |
| | IRG4PC50S-P | | | | SM TO-247 |
| Single switch without FW diode | IRG4PC40S | 600 | 60 | 31 | TO-247AC |
| | IRG4BC40S | | | | TO-220AB |
| Single switch without FW diode | IRG4PC30S | 600 | 34 | 18 | TO-247AC |
| | IRG4BC30S | | | | TO-220AB |
| | IRG4BC30S-S | | | | D2-Pak |
| Single switch without FW diode | IRG4IBC30S | 600 | 23.5 | 13 | TO-220 FullPak |

***Table 3.*** Discrete *IR Standard Speed* for switching output stage of TIG welding machines

## 7. Conclusion

The TIG welding machines have low operating frequencies (few hundreds of Hz) and high DC or AC currents (up to 500A). *IR Standard Speed* IGBTs are very well suited to work under these conditions. Another important item to consider is the use of anti-parallel diodes for protecting the IGBTs and the power source. The discrete diode IR 40EPF06 or the rectifier bridge SA55BA60 represent a valid option. If the current waveform is shaped (the magnitude of current is reduced to few amperes before changing its polarity) and/or the Half-Bridge configuration is used, the diode 10ETF06 or 8ETH06 could be a better alternative. Shaping the current waveform helps to reduce voltage overshoots and reduces switching losses, improving switching operation.

IR modules help to achieve a more efficient circuit, since they have the lowest-available $V_{CE(on)}$. They also provide a very safe margin against transient voltages with 600V for $V_{(BR)CES}$ . High current driving capability in both AC and DC modes makes the TIG family useful for multi-process welding machines.

To improve the current capability, IR modules can be paralleled, since they will operate with very low current unbalance. Thanks to the manufacturing process, normally there is no need for screening, thus easing parallel connection. Their temperature dependence is minimal. The modules have an electrically isolated base plate that eases handling.

Increasing current drive helps to reduce unbalance in paralleled *IR Standard Speed* IGBTs: $V_{CE(on)}$ converges towards a common value independent of the junction temperature and the TC increases with the current, and, becomes positive at 50% of maximum current. The use of a separate heatsink in paralleled devices must be avoided. Proper mounting of devices limits junction temperature differential keeping a good balance.

When designing the drive circuit is important to use individual gate resistors placed close to gate terminals and twist or run in parallel tracks the gate leads to minimize gate emitter loop inductance. The use of Zener diodes, TVS, and capacitors should be avoided.

IR wide choice of IGBTs and output diodes both in module and discrete packages can satisfy almost all multi-process welding machine design needs.

## 8. References

[1] International Rectifier, IR AN-990 “Application characterization of IGBTs”.
[2] Ned Mohan, Tore Undeland, Willliams P. Robbins. “Power electronics, converters, applications and design”. 2nd edition. John Wiley & Sons, Inc. New York 1995 (USA)
[3] Tomsic M.J, N. Crump and others “The welding handbook: Welding processes”. Volume 2. 8th edition. American Welding Society. Miami (USA). pp 2-29, 73-80.
[4] International Rectifier, IR AN-955 “Protecting IGBTs and MOSFETs from ESD”.
[5] International Rectifier, AN-1012 “Mounting Considerations for International Rectifier’s Power Semiconductor Packages”
[6] International Rectifier, AN-1023 “Surface Mounting of Larger Devices”.

International
IOR Rectifier
**WORLD HEADQUARTERS:** 233 Kansas St., El Segundo, California 90245 Tel: (310) 252-7105