

Connecting IGBTs in Parallel (Fundamentals)

1 Introduction

Apart from looking for an IGBT which is designed for a particular power range there is also the possibility, particularly at high currents, of connecting two or more smaller IGBTs in parallel.

Noteworthy advantages of this are a more flexible and individual organization of the layout, the heat sources can be distributed so that higher levels of power loss can be dissipated, and possibly also cost advantages by comparison with module attachments, depending on the device type and power.

The disadvantage is the unequal split in losses. The main reason for this lies in the uneven current split between devices which results from differences in V_{CEsat} , g_{fs} and V_{th} (variability in parameter values), which are manufacturer-dependent. Differences can arise in addition due to asymmetrical power and drive circuits, which are exhibited chiefly in the dynamic switching behavior.

2 Representation of the Switching Behavior

2.1 Static Behavior

The blocking characteristics of parallel-connected IGBTs can be ignored, because in relation to the conducting state behavior many small sources of power loss have very little effect.

For the behavior in the conducting state, then when the gate-emitter voltage is constant the static current split is determined by the conducting state voltage. **Figure 1** shows the output characteristics for two PT IGBTs (BUP 402) with different collector-emitter saturation voltages. The conducting state voltage across the parallel-connected IGBTs is the same. The static current ($I_{load} = I_{C2} + I_{C1}$) splits as determined by the set of output characteristics.

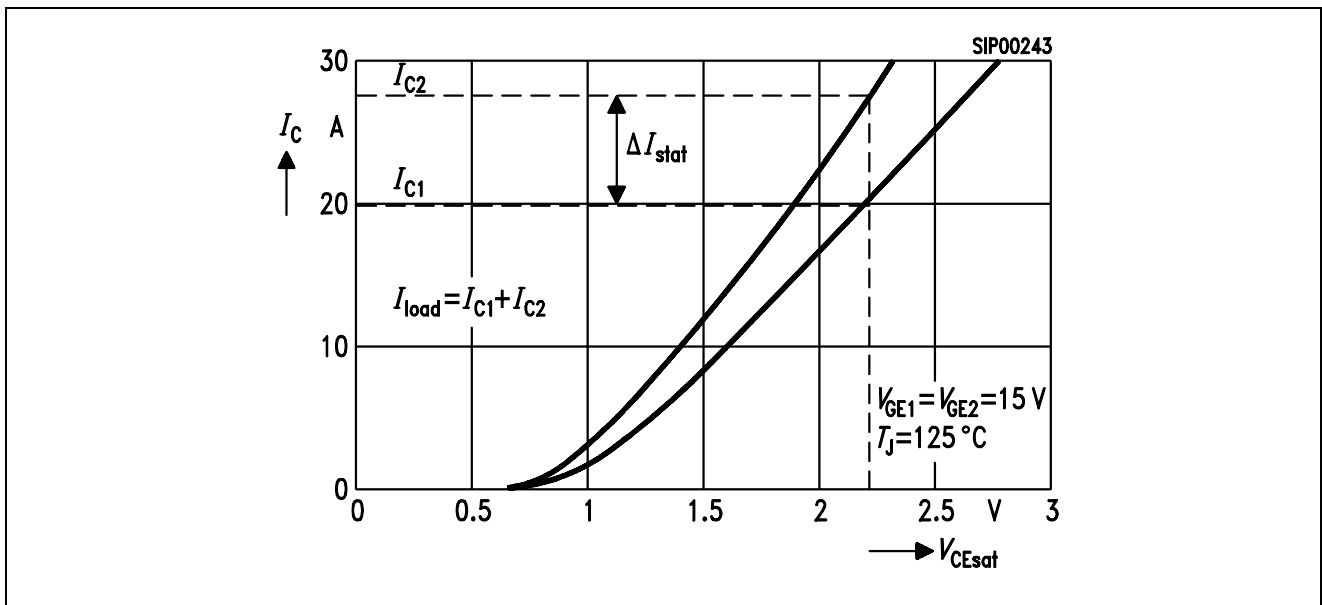


Figure 1
Set of Output Characteristics for two BUP 402 with different Saturation Voltages, V_{CEsat}

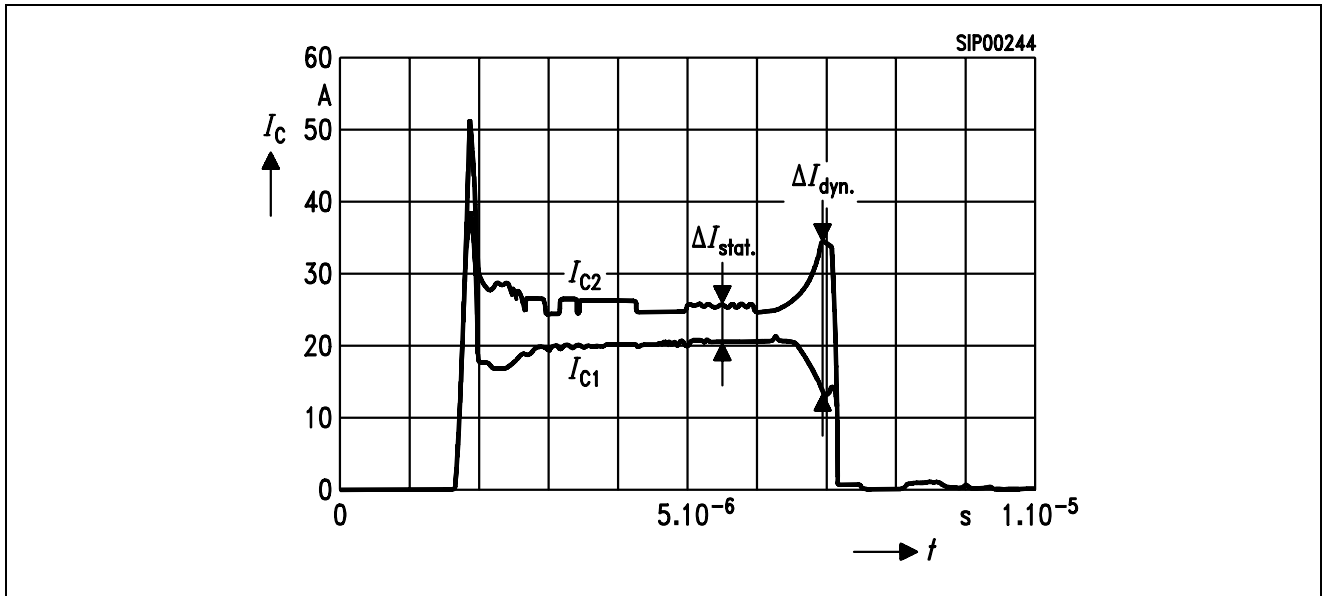


Figure 2
Collector Current Waveforms for two Parallel-connected BUP 402 in a Buck Converter Layout ($T_j = 125 \text{ }^\circ\text{C}$)

Figure 2 shows oscillograms of the collector currents for the IGBTs shown in **Figure 1**, arranged in a buck converter layout. The different split of the current between the devices results in different heating, and different power losses, for the IGBTs. When connected in parallel, the IGBT with the smaller saturation voltage must carry the greater partial current, has higher conducting-state losses and gets warmer.

Another point affecting the current split is the temperature coefficient (TC) of the set of output characteristics (**Figure 3**).

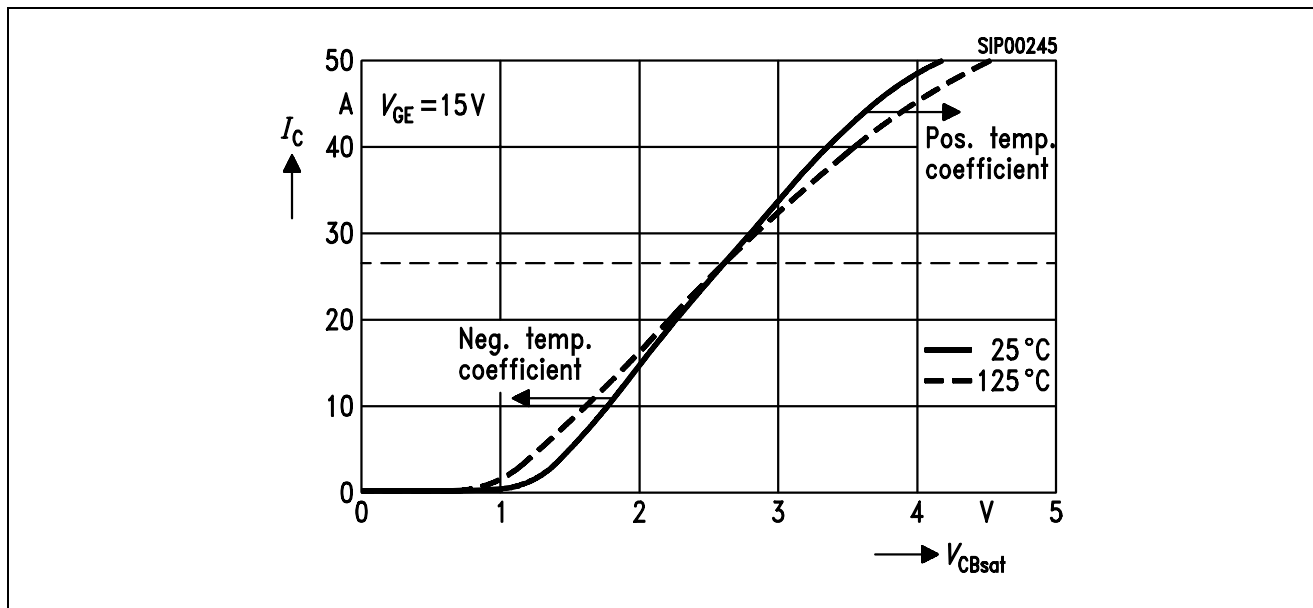


Figure 3
Showing the TC of the Set of Output Characteristic Curves

Where the temperature coefficients are negative it is possible for a steadily increasing divergence of the current levels to occur, because the IGBT which warms up more because of its higher conducting-state losses must then, as indicated by its characteristic curve (**Figure 3**), conduct an even higher current. From this it follows that ΔI_{stat} will become larger. When the TC is positive then the warming of an IGBT reduces ΔI_{stat} . A balancing of the currents can occur.

What is decisive here is the size of the temperature difference when the TC is the same.

There are two IGBT structures: the punch-through (PT) IGBT with a negative TC up to the nominal current (**Figure 3**) and the non-punch-through (NPT) IGBT with a positive TC in the nominal current range.

2.2 Dynamic Behavior

The main reason for differences between the partial currents during the dynamic phases of switching is that there are differences in the transfer characteristics (**Figure 4**). The temperature coefficient is positive because the IGBT is a MOS-controlled device.

During switch-off, the same gate-emitter voltage is developed while the Miller effect lasts. As implied by the transfer characteristics in **Figure 4**, the current is split dynamically (see also **Figure 2**). The switch-off losses follow a similar pattern.

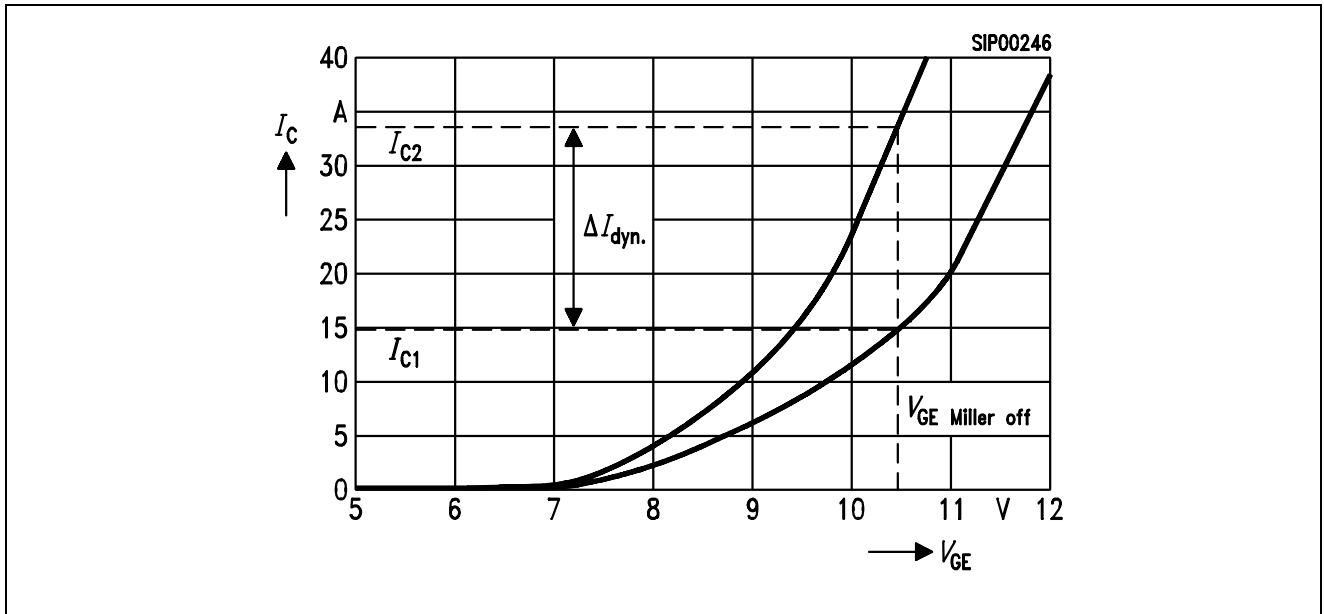


Figure 4
Different Transfer Characteristics of Two BUP 402 ($T_j = 25\text{ °C}$)

The IGBT with the steeper transfer characteristic slope has to conduct the greater current, and thus also has the greater switch-off losses.

The switch-on behavior is mainly affected by the freewheeling diode. The losses are primarily dependent on di/dt . Differences between the transfer characteristics have no significant effect on the switch-on losses.

3 Balancing Measures

The IGBTs should have a symmetrical layout. The most sensitive parameter is the emitter stray inductance in the gate circuit (**Figure 5**). For the same drive voltage (V_{drive}), unequal emitter stray inductances produce different gate-emitter voltages (V_{GE}) during switching. This results in an asymmetrical dynamic split of the current, or different switching losses. In addition, the switching behavior can be balanced by using separate gate dropping resistors (**Figure 5**).

If the temperature coefficient of the output characteristic curve set is to be exploited to achieve a balance, then PT IGBTs must be thermally coupled, or NPT IGBTs thermally decoupled.

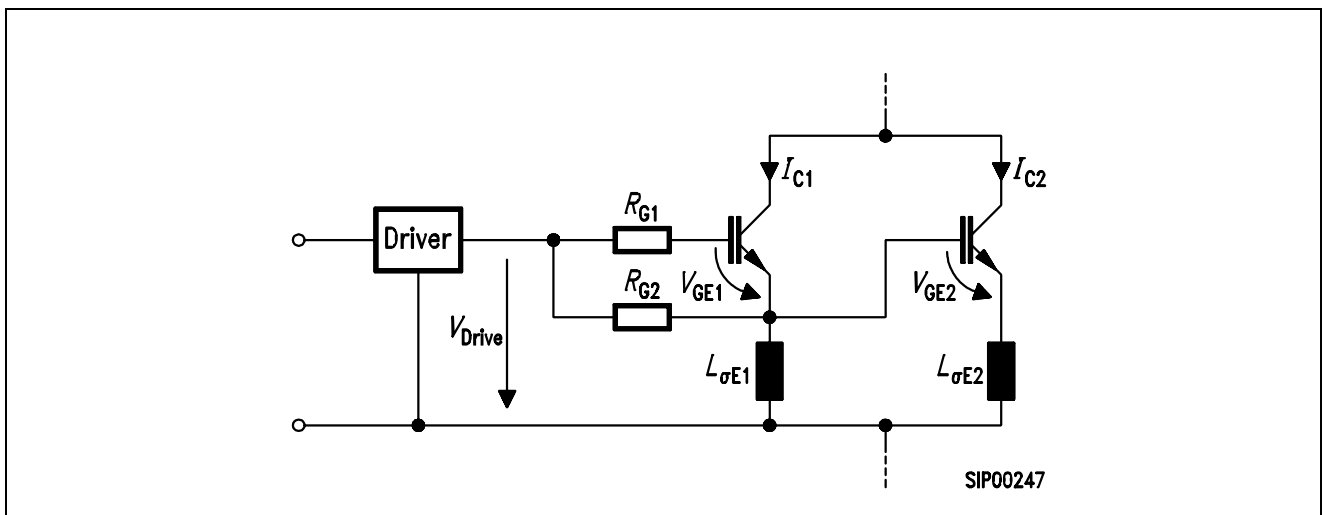


Figure 5
Parallel-connected IGBTs and Driver Circuit