An electronic ballast: base drive optimisation

Introduction

This Factsheet investigates the transistor base drive circuit in a **current fed half bridge ballast**. Figure 1 shows the simplified circuit. The effect on switching waveforms of progressing from a simple base drive circuit to the optimised solution will be shown.

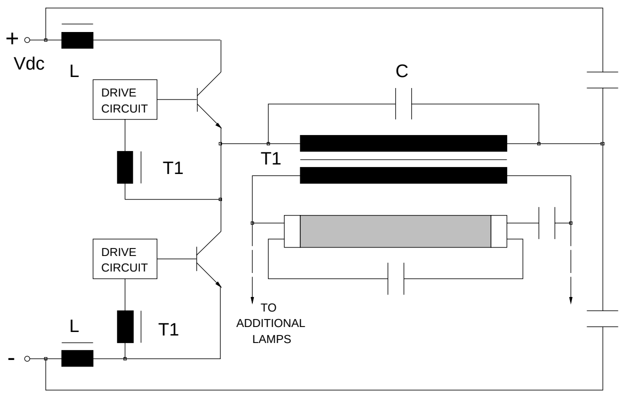


Fig. 1. Current fed half bridge ballast.

Base drive requirements

1. Each transistor must not be overdriven when conducting because this will result in excessive base power dissipation. In addition, the resulting oversaturation of the transistor will increase the time required to bring it out of conduction during turn-off, leading to excessive switching losses.

2. The transistor must not be underdriven because this will result in excessive collector-to-emitter voltage (V_{CE}) during conduction, leading to excessive ON-state losses or inability to sustain oscillation. However, because the transistor is unsaturated, there will be less charge to extract from the base, resulting in a shorter storage time and faster turn-off.

3. Reliable and correct circuit operation should be maintained for all expected transistor gains, maximum and minimum load, maximum and minimum supply voltage and all component tolerances.

Base drive optimisation

The transformer's auxiliary windings which provide base drive might contain just one or two turns each. In order to provide rapid transistor turn-off, their peak loaded output voltage would need to be such that the transistor 'sees' a turn-off voltage of around minus 5V. An approximation to this drive voltage could be arrived at empirically by increasing the number of auxiliary turns one by one. Any final voltage adjustment, if necessary, can be achieved by varying the base drive components.

- Simple base drive

In order to meet the requirements of non-saturation and rapid turn-off, the simplest base drive might consist of a resistor to limit the positive base current and a Schottky diode in parallel with it to discharge the base as quickly as possible. See Fig. 2.

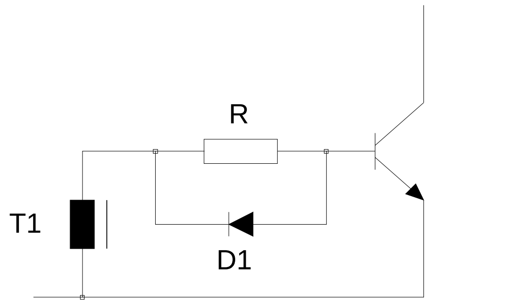
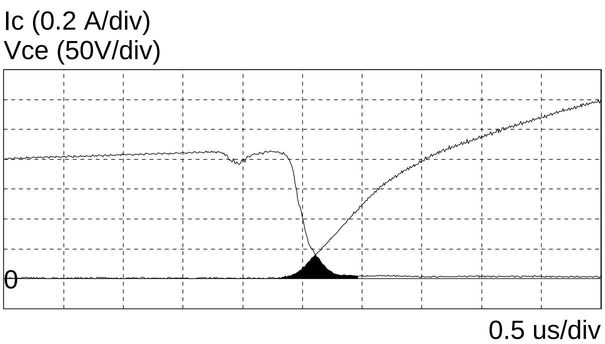


Fig. 2. Simple base drive.

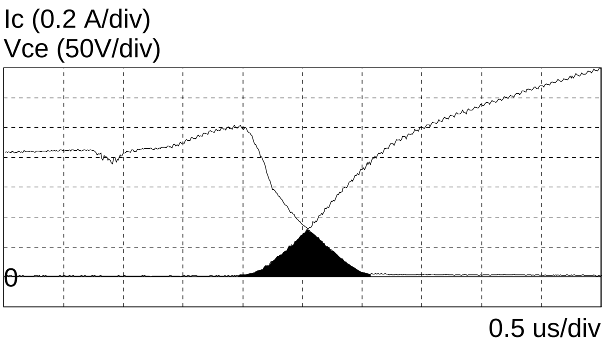
A Schottky diode is specified for its fast switching and low forward voltage drop to best meet the rapid turn-off requirements. A 1A 40V device such as the BYV10-40 is ideally suited.

If the resistor is selected empirically so that the transistor is barely saturating, this simple circuit will work, but only for a given load current, supply voltage, transistor gain and base drive voltage from the transformer auxiliary winding. Altering any of these conditions will either cause underdriving of the transistor and, ultimately, cessation of oscillation, or else the transistor will be overdriven, causing increased collector current fall time and excessive switching losses.

For example, the resistor value was optimised for transistors with low gain limits. Figure 3 shows the resulting I_C fall at transistor turn-off, while Fig. 4 shows the effect of replacing the transistor with a high gain limit sample. The shaded areas bounded by the I_C and V_{CE} curves represent transistor power dissipation during switching.



Simple base drive.
Fig. 3. Low h_{FE}. I_C fall with V_{CE}.



Simple base drive.
Fig. 4. High h_{FE}. I_C fall with V_{CE}.

- Improved circuit

What is required is a means of providing enough base drive under worst case conditions of maximum load current, minimum supply voltage, minimum transistor gain and minimum base drive voltage, while avoiding excessive saturation in the opposite condition. This can be achieved by diverting excess positive base drive current into the collector path when the transistor is fully turned on. This requirement is partly met by a Baker Clamp arrangement as shown in Fig. 5.

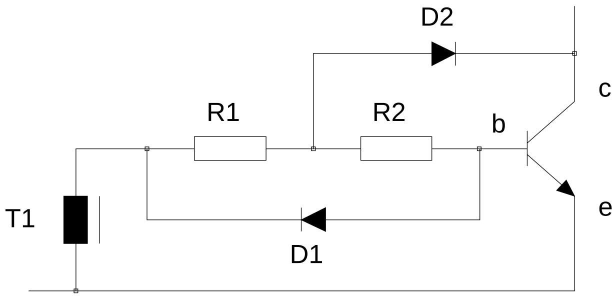
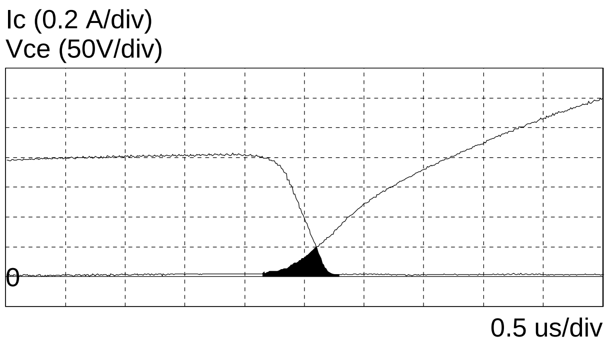
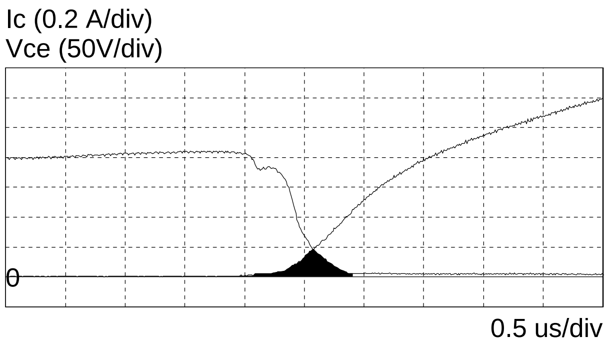


Fig. 5. Improved base drive.

When the transistor is fully conducting, V_{CE} will be at a minimum. This will bring V_C close to V_B so that any excess base drive will then flow through anti saturation diode D2 to the collector. As a first approximation, the single resistor R is divided equally into two and D2 taps its voltage from the mid point. Figs. 6 and 7 show the resulting I_C fall waveforms. Considerably reduced transistor saturation is evident.



Improved base drive.
Fig. 6. Low h_{FE}. I_C fall with V_{CE}.



Improved base drive.
Fig. 7. High h_{FE}. I_C fall with V_{CE}.

D2 will have the same voltage rating as the transistor. A fast, soft recovery diode from the BYD33 range is suitable.

If we now consider the base current waveforms, where the simple circuit produces more base drive current than is necessary, as shown in Fig. 8, the improved circuit reduces this to that shown in Fig. 9.

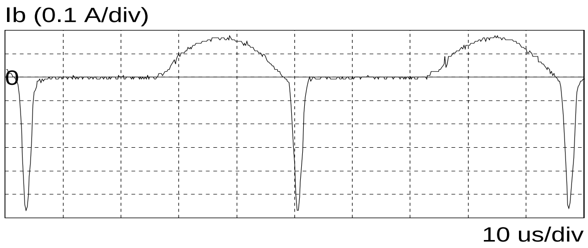


Fig. 8. Simple base drive.
High h_{FE}. I_B.

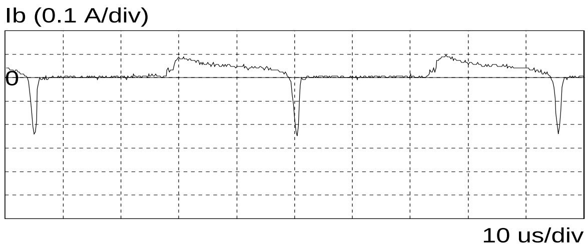


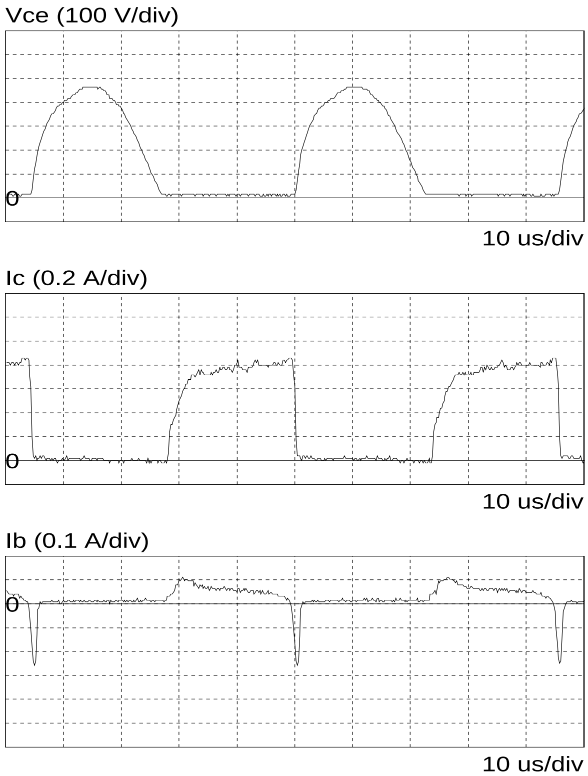
Fig. 9. Improved base drive.
High h_{FE}. I_B.

- Optimised base drive

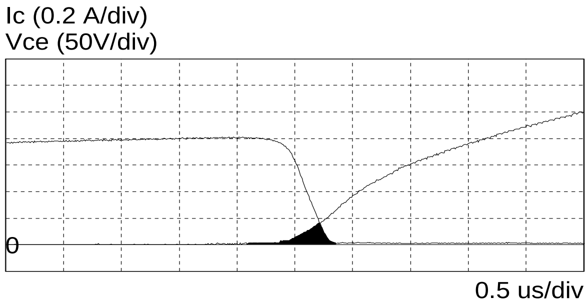
To ensure correct operation under all conditions, base drive can be optimised by adjusting the ratio of the two resistors to vary the amount of tap-off voltage.

With the base resistor divided equally into two, the circuit used for this investigation suffered from a lack of base drive at low supply voltage. Too much drive had been diverted away from the base. This was corrected by moving the tap-off point to the right to split the resistor two thirds to one third to reduce the amount of diverted base drive. Referring to Fig. 5, R1 becomes two thirds of R and R2 becomes one third of R.

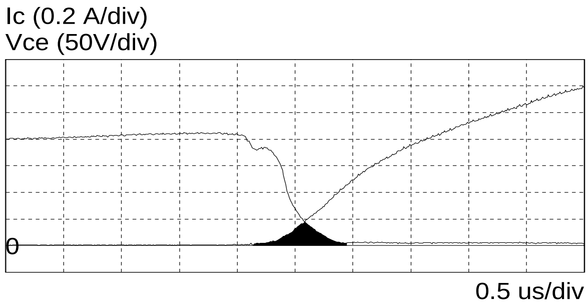
Figures 11 and 12 show the optimised I_C fall waveforms. A few cycles of the switching waveforms with optimised base drive are shown in Fig. 10.



Optimised base drive.
Fig. 10. High h_{FE}. V_{CE}, I_C and I_B.



Optimised base drive.
Fig. 11. Low h_{FE}. I_C fall with V_{CE}.



Optimised base drive.
Fig. 12. High h_{FE}. I_C fall with V_{CE}.

Startup circuit

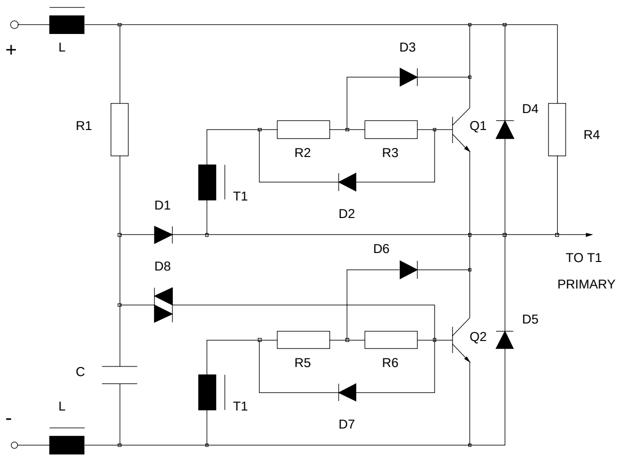


Fig. 13. A classic startup arrangement. (Part of current fed half bridge circuit.)

The half bridge circuit as described so far cannot start of its own accord. Both transistors are off and will remain off when power is applied until one of them is artificially turned on to draw current through the transformer primary. This will then induce a voltage in the auxiliary windings which will provide the necessary base drive to maintain self oscillation.

Startup is usually achieved using a diac such as the BR100/03. The circuit is shown in Fig. 13. When power is first applied, oscillator start-up is achieved as follows:

Transistors Q1 and Q2 are initially non-conducting. Resistor R4, whose value will be several hundred kilohms, provides a high impedance path between Q2's collector and the positive rail to ensure that Q2 has the full DC rail voltage across it prior to start-up.

Capacitor C charges up via R1 until the breakover voltage of the diac D8 is reached. The diac breaks over and dumps the capacitor's charge into the base of Q2 to turn it on. Q2 draws current through the transformer primary. From now on, oscillation is maintained by the voltages induced on the auxiliary base drive windings.

Diode D1 discharges C every time Q2 turns on, thereby preventing the diac's breakover voltage being reached during normal circuit oscillation. This avoids repeated triggering of the diac when it is not required, so preventing oversaturation of Q2. (The length of time for C to charge to the diac's breakover voltage is much longer than the time between ON periods of Q2.)

"Freewheeling" diodes D4 and D5 conduct the load current during Q1 and Q2 switching transitions. D4 and D5 are fast, soft recovery diodes. Suitable types can be selected from the following ranges: BYV26, BYM26, BYV36, BYM36, BYV95, BYW95, BYV96, BYW96, BYV97, BYW97, BYD33.

For recommended transistors please refer to Factsheet 045 entitled "Philips bipolar transistors for electronic lighting".

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