PHILIPS SEMICONDUCTORS

APPLICATION NOTE

Philips' BUJ100 transistor in TO-92 suits all Compact Fluorescent Lamp powers

Philips Semiconductors has developed a new generation of planar passivated, fast switching bipolar lighting transistor that breaks new ground in lighting-transistor technology. Rated at 700 V V_{CBO}, 400 V V_{CEO} and 1A I_C (DC) and housed in the TO-92 package, the BUJ100 offers unparalleled performance in mains-operated (230 V) self-oscillating half-bridge fluorescent lamp ballasts with powers exceeding 26 W. This covers all the 230 V integrated Compact Fluorescent Lamps (CFLs) used in the home.

Restrictions imposed by the TO-92 package

The limitations of conventional lighting transistors housed in TO-92 have restricted their use to miniature CFLs with powers in single figures. Typical examples are 3 W and 5 W candle bulbs. This is because the TO-92 package has such a high junction-to-ambient thermal resistance of, typically, 150 K/W that any slight increase in the transistor's power dissipation will cause a big rise in its junction temperature governed by:

$T_j = T_a + (P \times R_{th\ j\text{-}a})$,

where T_j = junction temperature, T_a = ambient temperature, P = transistor power dissipation and $R_{th\ j\text{-}a}$ = junction-to-ambient thermal resistance for the transistor.

What's more, because the ambient temperature inside the CFL housing can be very high, excess transistor temperature rise can very easily lead to its destruction. For example, a transistor dissipation of 400 mW will cause a junction temperature rise of 60 °C. An ambient temperature of 100 °C is quite possible. This will result in a junction temperature of 160 °C, which is above the T_j max of 150 °C and is likely to lead to destruction of the transistor.

The answer - Philips' new BUJ100

The arrival of the BUJ100 has now solved this problem. Its technology, free of former limitations, gives exceptional performance and remarkably low transistor temperature rise at all domestic CFL power levels. The key to this success is the new transistor's low power dissipation.

The BUJ100 exhibits very low switching and conduction losses in electronic ballast circuits in which the base drive has been correctly optimised. The resulting low transistor temperature rise makes high ambient temperature less of a problem and brings higher power ballast circuits within the scope of the TO-92 lighting transistor.

CFL circuit tests

The BUJ100 has been tested in various CFL circuits with input powers ranging from 10 W to 26 W. The best indicator of the transistor's efficiency is its free-air case temperature rise, so this measurement has been used for comparison. Table 1 shows the temperature rise results. Transistor power dissipation has been calculated, based on the assumption that $R_{th\ j\text{-}a}$ = 150 K/W.

TABLE 1
BUJ100 thermal performance in CFL circuits

Input power (W)	Transistor temperature rise (°C)	Transistor power (mW)
10	11	73
13	10	67
18	14	93
26	6	40

Switching losses

Switching losses can arise at transistor switch-on and at switch-off when there is simultaneous voltage across the device and current flowing through it. In a correctly-optimised circuit, there should be no switch-on losses since the transistor's blocking voltage will have fallen to zero before its current starts to rise. This Zero-Voltage-Switching condition applies to the four circuits tested here, so switch-on waveforms are not shown.

At transistor switch-off, there will always be some power dissipation as its collector current falls to zero and its collector-emitter voltage starts to rise. The amount of dissipation depends on the circuit conditions but it is also strongly dependent on the transistor's switching performance: the faster its collector current falls to zero, the lower the area bounded by the I_C-V_{CE} waveforms and the lower the switching loss. The shaded areas in Figs 1 to 4 indicate switching loss.

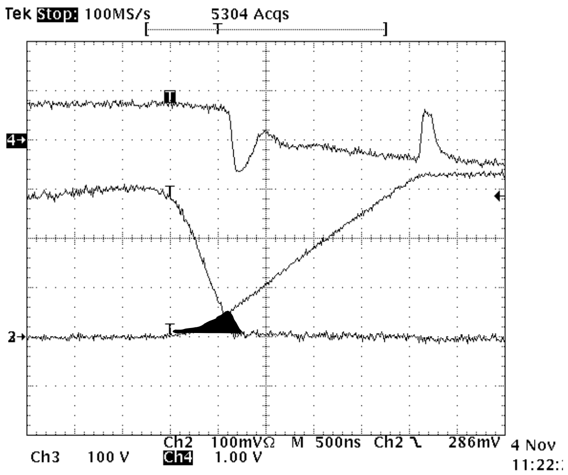

Fig.1 10 W
Transistor switch-off. Frequency = 28.8 kHz.
V_{BE} : 1 V/div, I_C: 0.1 A/div, V_{CE} : 100 V/div,
timebase: 0.5 μs/div

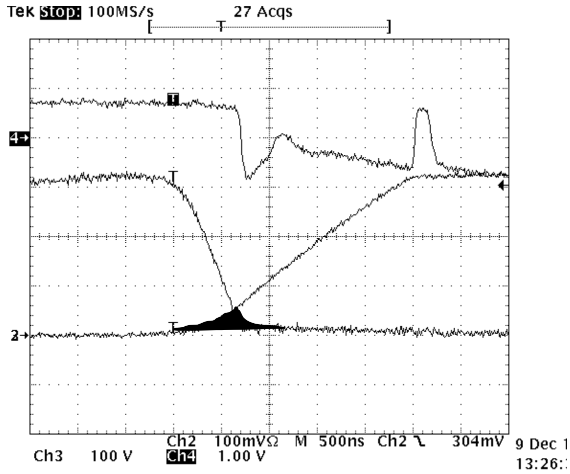

Fig.3 18 W
Transistor switch-off. Frequency = 33.7 kHz,
V_{BE}: 1 V/div, I_C: 0.1 A/div, V_{CE} : 100 V/div,
timebase: 0.5 μs/div

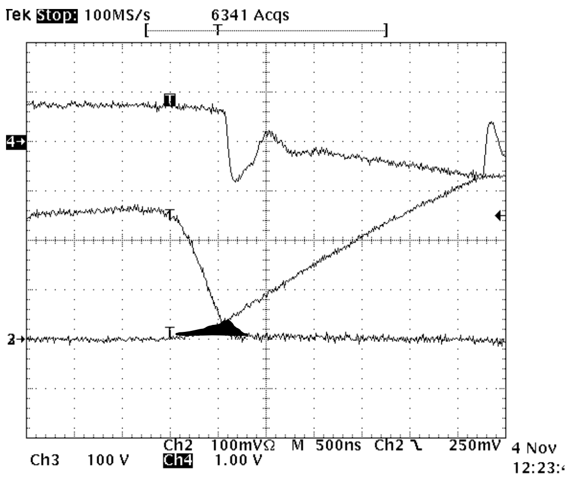

Fig.2 13 W
Transistor switch-off. Frequency = 31.1 kHz,
V_{BE} : 1 V/div, I_C: 0.1 A/div, V_{CE}: 100 V/div,
timebase: 0.5 μs/div

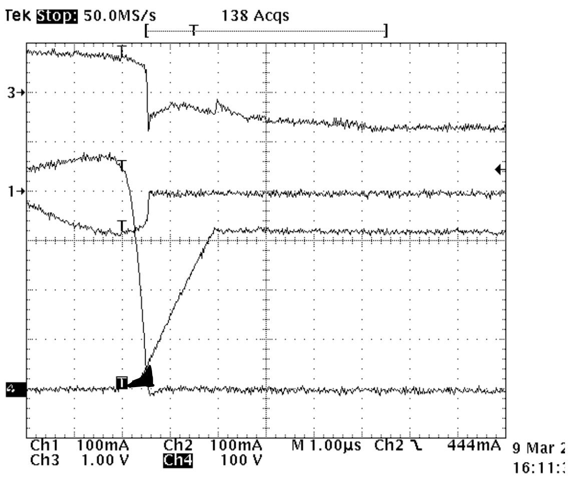

Fig.4 26 W
Transistor switch-off. Frequency = 29.5 kHz,
V_{BE}: 1 V/div, I_B : 0.1 A/div, I_C : 0.1 A/div,
V_{CE} : 100 V/div, timebase: 1 μs/div

Conduction losses

Conduction losses occur as a result of the transistor's forward voltage drop when conducting. The transistor must be fully saturated by sufficient base drive to reduce this V_{CEsat} to a minimum. It is not visible on the waveforms because, at around 0.24 V, it is negligible compared with the blocking voltage of over 300 V.

Why the BUJ100 is so cool

- Fast inductive fall time t_{fi}. This is an important requirement for low switching losses in electronic ballast circuits: t = 130 ns max @ 100 °C for the BUJ100.
- Smooth turn-off. A fast and smooth fall in I_C is desirable to avoid high-frequency ringing that might otherwise cause additional radiated interference and power dissipation in the circuit.
- Tightly-controlled storage time t_s. This is important for consistent performance from lot to lot in self-oscillating circuits whose oscillating frequency is dictated partly by t_s. The inductive storage time t_{si} = 1.4 µs max @ 100 °C for the BUJ100.
- Tightly-controlled h_{FE}. This is also important for consistent and reliable circuit performance. Optimum circuit performance can be guaranteed from lot to lot without the requirement for gain band selection.
- Flat gain/current characteristic. The BUJ100 does not suffer from the severe gain fall-off at low collector current that affects other designs. Correct circuit start-up and running is guaranteed at all power levels and under all operating conditions.
- Wide safe operating area. This exceeds the capabilities of equivalent transistors to withstand abnormal and stressful operating conditions, leading to better circuit reliability.
- Inherent avalanche ruggedness. The design and manufacturing process give the BUJ100 a degree of avalanche ruggedness so it will not automatically be destroyed by transient events that cause brief avalanche current flow. This also leads to better circuit reliability.
- The base can be overdriven. It is possible and advantageous to overdrive the BUJ100's base without incurring the penalty of dramatically increased switching losses - a universal problem with other transistor designs. The BUJ100 maintains the quick and efficient removal of mobile charge carriers from its junction, even from a state of severe over saturation. This forgiving performance yields the following benefits:
    - The lowest possible V_{CEsat} can be achieved by driving the base hard to give the lowest possible conduction losses without increasing switching losses.

      It is not necessary to add anti-saturation components such as a Baker Clamp.
    - Provided the base drive is sufficient to minimise V_{CEsat} for the worst-case conditions of minimum supply voltage and maximum load current, optimum performance will be maintained over the full range of circuit operating conditions.
    - It is easy to design reliable circuits with the BUJ100 that are guaranteed to work under all conditions.
- The lowest power dissipation. The BUJ100 can conduct higher current than any other TO-92 lighting transistor while keeping its own power dissipation within the capabilities of the package.
- Lower cost to the OEM. The unmatched performance of the BUJ100 enables it to replace all SOT82, SOT32 (TO-126) and some TO-220 transistors in suitable lighting ballasts. This allows reductions in board space and cost.

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