Trick A BJT-Based Converter Into Starting At Only 250 mV DC

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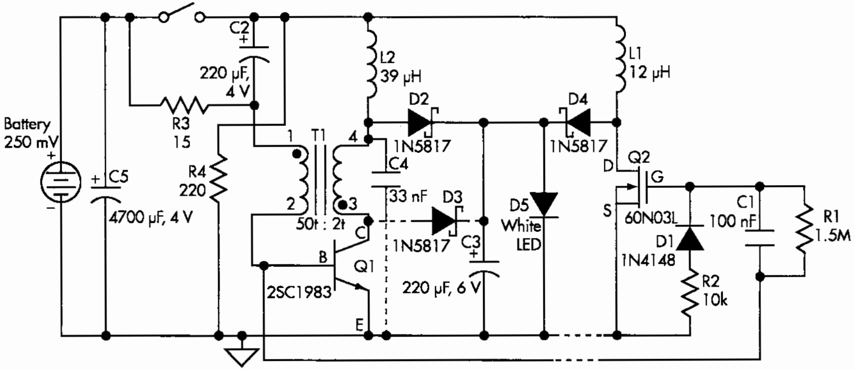
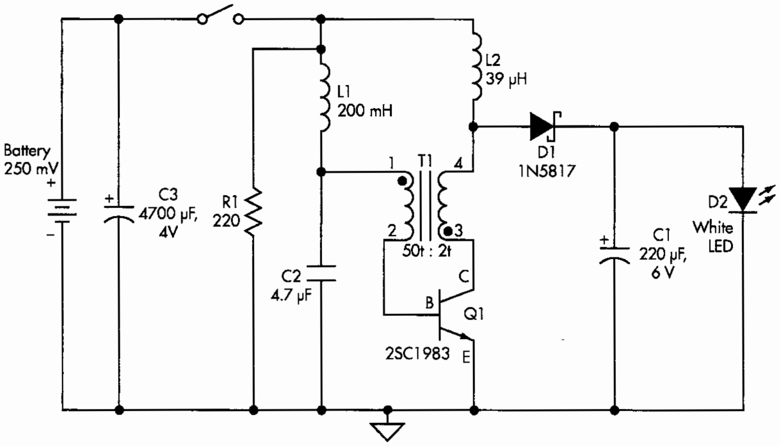
The converter described below, based on a silicon bipolar-junction transistor (BJT), can operate at as low as 250 mV, which is probably a record for a converter not based on a JFET or germanium transistor. How is this possible? The V_{BE} threshold is not clear-cut, depending on current density and other factors. But 250 mV is way below the lowest accepted values. There has to be a trick and there is, sort of.

The big difficulty is in the starting. Once started, a converter can easily provide sufficient voltages, even if the supply drops well below the conduction threshold. The trick is to "kick-start" the oscillation using a third wire connected upstream of the power switch. When the switch is in the "off" state, this third wire pre-charges C2 via R3 *(Fig. 1)*.

The circuit is completed by R4, charging C2 to the supply voltage. When the switch is closed, the negative side of C2 is brought to V+, meaning its positive armature now has a potential of twice the supply voltage, 500 mV. This potential biases Q1 via the reaction transformer, T1. The 500 mV is low, but sufficient to generate a small current into transistor



1. This converter circuit uses a third wire connected upstream of the power switch to "kick-start" operation at less than 250 mV, while using a BJT rather than a JFET or germanium transistor.



2. A variant of the circuit in Figure 1 eliminates the third wire, but performance is not as good as the three-wire circuit.

Q1, allowing oscillations to build up until, finally, the blocking regime is reached.

The second key feature of this circuit is the use of a current transformer instead of the usual voltage feedback taken from an auxiliary winding of the main choke. This ensures strong and stable oscillations by minimizing the influence of voltage variations and providing positive feedback increases when the load increases.

The current transformer is built on a small saturable ferrite toroid or bead, with two turns at the primary and 50 turns at the secondary. The number of turns isn't critical and can be adjusted for the best results with the components used.

In this example, Q1 operates at a forced beta of 25. The output is taken off the main inductor, L2, via a Schottky diode, D2. The circuit is shown feeding a white LED, but other voltages and applications are possible by substituting a suitable Zener diode. For voltages higher than 5 V, it's better to use a step-up winding on L2, because with an actual boost ratio in excess of 30, L2 must be of high quality.

C4 and D3 are optional and can improve efficiency. C4 tunes L2, while D3 recycles part of the energy stored in T1, providing a boost of about 5% in the efficiency. These components may render the startup more difficult, though.

The prototype delivered 8.85 mA at 3.02 V, with an input current of 269 mA. The oscillation frequency was 8.3 kHz. Efficiency ranges between 30% and 50%, depending on the components and the degree of tweaking. Once started, the oscillations can be sustained down to a voltage of 110 mV. Below 150 mV, however, no useful power can be extracted.

If more power is required, an obvious solution is to use the output voltage to feed a switch-mode, power-supply controller chip. A simpler solution is to use the converter's waveform directly to drive a low-$R_{DS(ON)}$ MOSFET, Q2. The clamping network—R1, R2, C1, and D1—level-shifts the base drive waveform to ensure a proper level to the gate of Q2. With suitable components, a tenfold increase in power is possible.

To maximize efficiency, the losses in the wiring and components must be reduced. This includes the resistance of the coils, the contact resistance of the switch, the equivalent series resistance of the capacitors, and Q1's saturation voltage. Each milliohm has an impact on the final result.

The 2SC1983 (Q1) is an early model of a super-beta transistor. More modern types, such as those manufactured by Zetex, would provide better results. Tests made on a number of samples from Zetex (ZTX1047, ZTX869, and the NPN-plus-Schottky combo ZX3CDBS1M832; see *www.zetex.com* for more information) confirm this fact. The output power was pushed from 26.7 mW to 102 mW, with the efficiency reaching 52% against the original 39.7%. This means that many applications wouldn't need an additional converter stage.

This circuit enables a wide range of energy-harvesting applications and makes it practical to use sources like single solar cells, thermoelectric generators, electro-osmotic cells, fuel cells, and low-yield electrochemical couples. You can stick a pair of dissimilar metal rods into the soil and get useful power. The circuit provides no regulation because a luxury of energy harvesting is the ability to dump any excess power—in a Zener diode, for instance.

The variant in Figure 2 addresses any objections that the circuit doesn't really start at 250 mV and that the third wire is sort of "cheating." The variant is a two-wire circuit. L1 and C2 form a resonant circuit, and when the power is applied, a damped oscillation appears at the junction of L1 and C2. After half a period, the voltage is reversed with respect to the positive rail, applying 500 mV to T1.

This circuit is more of a statement that it is a possibility, rather than being a practical proposition. To work properly, L1 and C2 have to be low-loss types, with a plastic dielectric for C2 and ferrite core for L1, making each of them as large as the whole circuit. Even so, the performance is lower than for the kick-started version: 255 mV is required for a reliable startup, versus 235 mV for the three-wire circuit.

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