DC-DC POWER CONVERTER

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This high-efficiency step-up converter supplies up to 30 V at 75 W when powered from a 12 V car battery. The converter is ideal for many mobile and other out-of-doors applications: it functions as a power source for your DC-operated soldering iron, RF power amplifier, or NiCd battery charger for portable equipment such as a flasher or a video camera.

DC-DC converters for stepping up the car battery voltage are generally based on a switched-mode power supply (SMPSU) or a power multivibrator driving a transformer. The power converter described here is based on the first principle, and uses the Type TL497A integrated circuit from Texas Instruments. This device enables good voltage regulation with low output noise to be achieved fairly easily, and in addition guarantees a relatively high conversion efficiency.

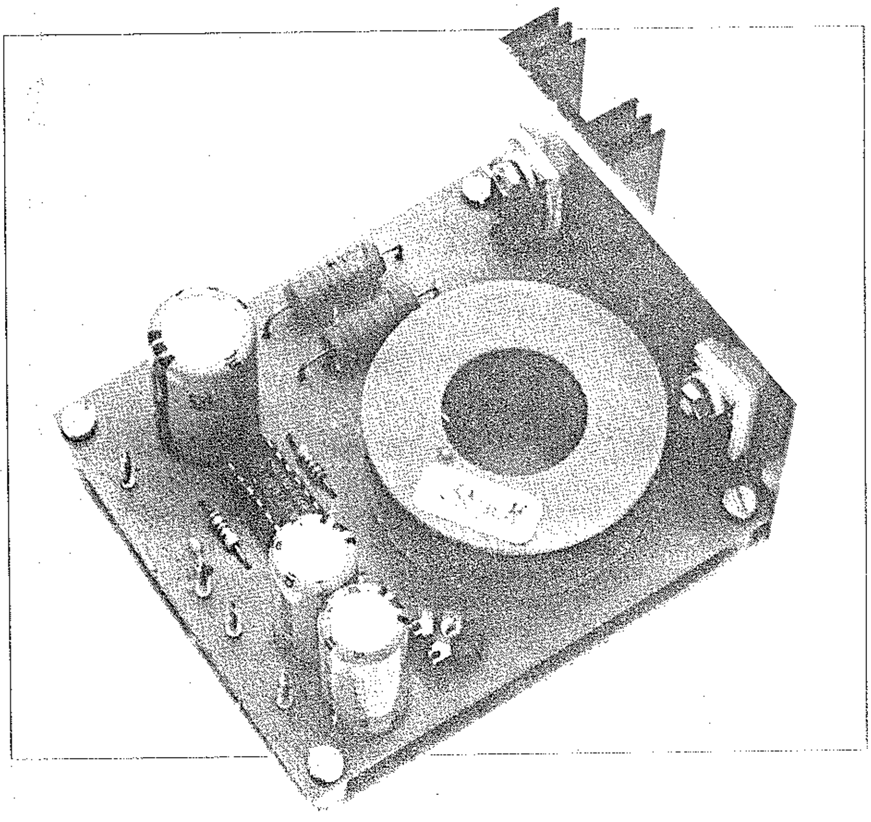
- Flyback-type step-up converter
- no special inductor required
- input voltage: 12 VDC
- output voltage adjustable between 20 and 30 V
- maximum output power: 75 W
- efficiency: 70%, independent of load current
- voltage reduction at load variation from zero to maximum: <200 mV
- ripple voltage: <500 mV_{pp}.

Design background

The converter described is of the flyback type. The flyback principle is the only practical way of generating a direct output voltage from a lower direct input voltage.

The central switching element in the converter is power SIPMOS transistor T_1 (see Fig. 1). When it conducts, the current through L_1 rises linearly with time. During the on-time, magnetic energy is stored in the inductor. The moment the transistor is turned off, the inductor functions as a source of magnetic energy, which is supplied as an electric current to the load via D_1. In this process, it is important that the transistor remains off during the time taken by the magnetic field to decay to zero. When this condition is not met, the current through the inductor rises to the saturation level. An avalanche effect then causes the current to increase very rapidly. The relative on-time, or duty factor, of the transistor control signal must, therefore, not be allowed to reach the value of one.

The highest permissible duty factor is dependent, among other factors, on the output voltage, because this determines the rate of decay of the magnetic field strength. The maximum output power that can be supplied by the converter is governed by the maximum permissible peak current through the inductor, and the frequency of the switching signal. The limiting factors here are mainly the saturation instant and the maximum tolerable ratings for the copper losses in the inductor, and the peak current through the switching transistor (remember that a 'burst' of a particular energy content is supplied to the output at each switching period).



TL497A

The operation of this integrated circuit is rather unconventional, so that a brief description is given below.

In contrast to widely used *fixed frequency, variable duty-factor* SMPSU controller ICs, the TL497A is qualified as a *fixed on-time, variable frequency* device. This means that the duty factor is controlled by means of frequency variation to maintain a constant output voltage. This method results in a fairly simple circuit, but has the disadvantage of the switching frequency reaching down into the audible range when the load current is low. In actual fact, the switching frequency becomes lower than 1 Hz when the converter is not loaded. The slow ticks heard as a result are the charge pulses applied to the output capacitors to maintain a constant output voltage. In the absence of a load, the output capacitors are, of course, slowly discharged by the voltage sensing resistors.

The on-time of the oscillator on board the TL497A is fixed, and determined by C_1. The oscillator may be disabled in three ways: first, if the voltage at pin 1 exceeds the reference voltage (1.2 V); second, if the current through the inductor exceeds a certain maximum; and third, via the inhibit input (this is not used here).

During normal operation, the oscillator causes T_1 to conduct so that the inductor current rises linearly. When T_1 is switched off, the magnetic energy stored in the inductor is used to charge the output capacitors. The output voltage, and with it the voltage at pin 1 of the TL497A, rises a little, so that the oscillator is disabled until the output voltage has dropped to a sufficiently low level. This process is repeated cyclically, at least, in theory.

In a configuration with real components, however, the voltage rise caused by the charging of the capacitors within one oscillator period is so small that the oscillator remains enabled until the inductor current reaches the maximum value defined with R_2 and R_3 (the voltage drop across R_2 and R_3 is 0.7 V at this stage). The current rises in steps as shown in Fig. 2b because the duty factor of the oscillator signal is greater than 0.5.

When the maximum current is reached, the oscillator is disabled, and the inductor is allowed to pass its energy to the capacitors. In this condition, the output voltage rises to a level high enough to keep the oscillator disabled via pin 1. The output voltage drops, and a new charge cycle commences.

Unfortunately, the switching operations outlined above are coupled to relatively high losses. In a practical application, this problem is resolved by making the on-time (i.e., C_1) large enough to ensure that the inductor current does reach the maximum within a single oscillator period (see Fig. 3). The solution in this case is the use of an air-cored inductor, which has a relatively low self-inductance.

Some waveforms

The timing diagrams in Fig. 3 show the signal waveforms at the main points in the circuit. The central oscillator in the TL497A operates at a low frequency (lower than 1 Hz if the converter is not loaded). The switch-on instant, shown as the rectangular pulse in Fig. 3a, is determined by capacitor C_1. The switch-off time is determined by the load current. During the on-time, T_1 conducts so that the inductor current rises (Fig. 3b). In the non-conductive period after the current pulse, the inductor functions as a current source. The TL497A compares the attenuated output voltage at pin 1 with its internal reference voltage of 1.2 V. If the measured voltage is smaller than the reference voltage, T_1 is driven hard again to enable the inductor to store energy.

The above charge and discharge cycles cause some ripple voltage on the output capacitors (Fig. 3c). The feedback arrangement enables the oscillator frequency to be adjusted for optimum compensation of voltage losses caused by the load current.

The timing diagram in Fig. 3d shows considerable swing of the drain voltage owing to the relatively high Q (quality) factor of the inductor. Although the parasitic oscillations do not affect the normal operation of the power converter, they may be damped with the aid of a 1 kΩ resistor in parallel with the inductor.

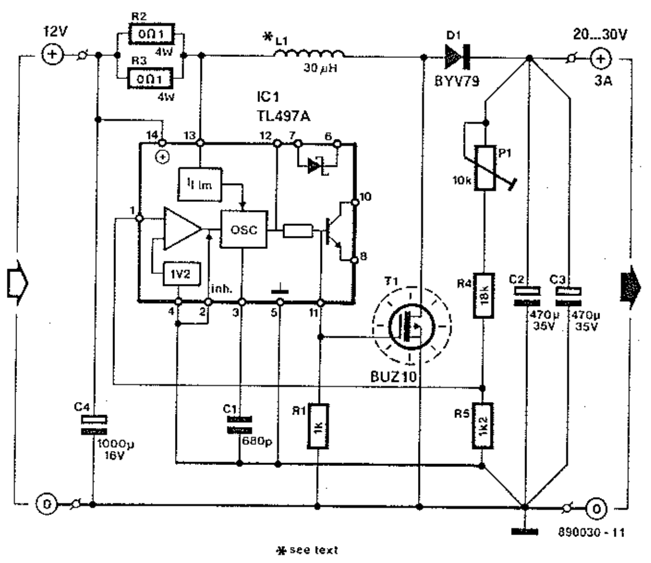


Fig. 1. Circuit diagram of the step-up converter.

From theory to practice

Naturally, a switch-mode power supply is designed for maximum rather than quiescent output current. High efficiency and a stable output voltage with little ripple are also prime design goals.

In general, the load regulation characteristics of a flyback type switch-mode power supply give little cause for concern. During every cycle, the on/off ratio is adjusted in accordance with the load current, so that the output voltage remains fairly stable in spite of large load current variations.

The situation looks a little different as far as the overall efficiency is concerned. A step-up converter of the flyback type typically generates relatively large current surges, which cause considerable power losses (remember that power rises exponentially with current). In practice, however, the proposed converter has a total efficiency higher than 70% at maximum output current, which is remarkable given the simplicity of the design.

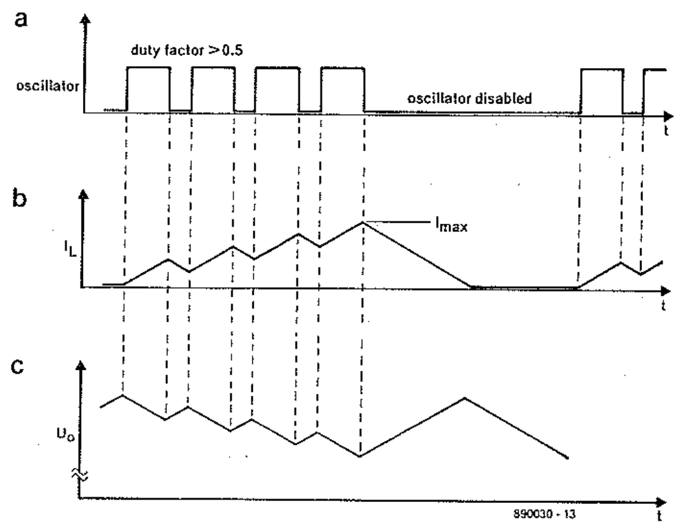


Fig. 2. Showing how the inductor energy is built up under the control of the oscillator signal.

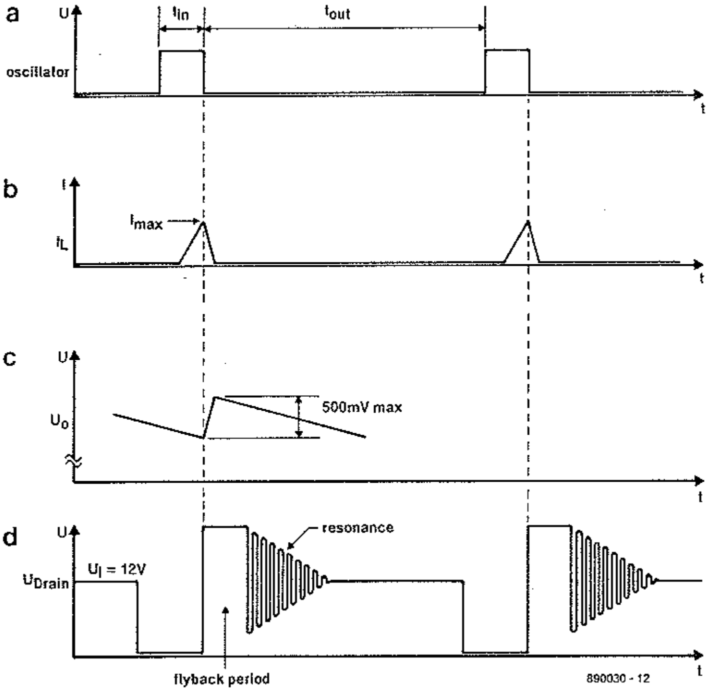


Fig. 3. Timing diagrams of the main signals in the circuit. The current reaches its maximum value within one period of the oscillator signal.

The switching frequency at maximum load is made as high as possible to allow the use of a relatively small self-inductance. The practical circuit is based on an air-cored inductor. Significant losses caused by a ferrite core are thus avoided.

A fast power-FET of the SIPMOS type is used to switch the inductor current. The Type BUZ10 or BUZ10A was chosen because of its short recovery time. To achieve acceptable efficiency, the transistor must be used as a switching element.

Parts list

Resistors (±5%):
R_1 = 1k0
R_2;R_3 = 0Ω1; 4 W
R_4 = 18kΩ
R_5 = 1k2
P_1 = 10kΩ preset H

Capacitors:
C_1 = 680p
C_2;C_3 = 470µ; 35 V; radial
C_4 = 1000µ; 16 V; radial

Inductor:
L_1 = 30 µH (home-made, see text)

Semiconductors:
D_1 = BYV79
T_1= BUZ10 or BUZ10A
IC_1 = TL497A

Miscellaneous:
Heat-sink for T_1.
PCB Type 890030 (not available through the Readers Services).

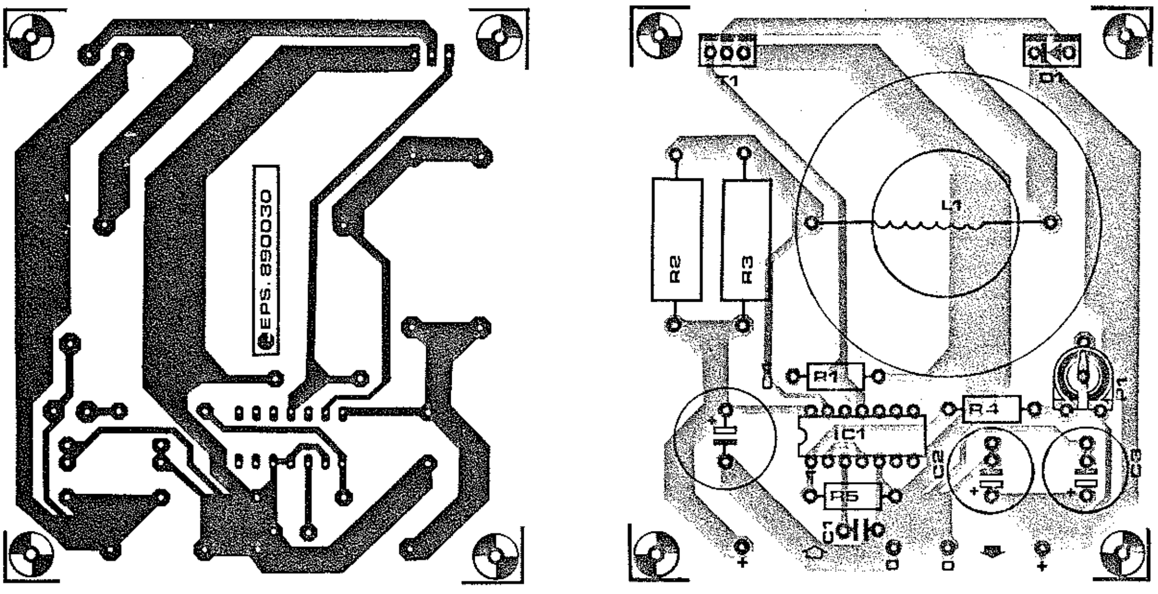


Fig. 4. Printed-circuit board for the DC–DC converter.

This, in turn, requires it to be driven into saturation, resulting in a relatively long turn-off time. Obviously, the longer it takes for the transistor to interrupt the inductor current, the lower the overall efficiency of the converter. Unconventionally, the BUZ10 is driven by the oscillator test-output of the TL497A (pin 11) rather than the internal output transistor.

Diode D_1 is another essential part in the circuit. The requirements for this device are an ability to withstand high current surges, and a low forward drop. The Type BYV79 meets these conditions, and must not be replaced with a general-purpose type.

Returning to the circuit diagram of Fig. 1, it should be borne in mind that current peaks of 15–20 A are not uncommon in the circuit. To prevent problems arising with batteries having a relatively high internal resistance, capacitor C_4 forms a buffer at the input of the converter. Since the converter charges the output capacitors with short, surge-like current pulses, two capacitors are connected in parallel to ensure that stray capacitance remains as low as possible.

The power converter is *not* short-circuit resistant. Short-circuiting the output terminals is the same as short-circuiting the battery via D_1 and L_1. The self-inductance of L_1 is not so high as to limit the current for the time required by a fuse to blow.

A home-made inductor

Inductor L_1 is wound from 33½ turns of enamelled copper wire. Figure 5 shows the dimensions. Most manufacturers supply enamelled copper wire on an ABS reel, which is suitable as the former for making the inductor. Drill two 2 mm holes in the lower rim to pass the inductor wires: one hole beside the cylinder and the other at the outside of the rim.

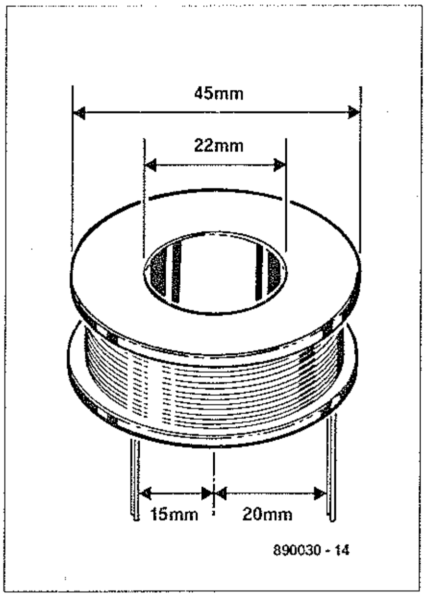


Fig. 5. Suggested construction of the inductor on an ABS reel.

There is little point in using thick wire to wind the inductor, because the skin-effect, i.e., the displacement of charge carriers towards the outside of the wire, must be taken into account given the frequencies used in the converter. To ensure a low resistance at the required inductance, it is recommended to use two wires of 1 mm diameter, or even three or four wires of 0.8 mm diameter in parallel. Three 0.8 mm wires result in a total diameter that is roughly the same as that of two 1 mm wires, but has the advantage of resulting in a 20% larger effective surface.

The inductor is close-wound and may be encapsulated in a suitable resin or potting compound to limit the sound level (remember that the frequency of operation is within the audible range).

Construction and alignment

The printed-circuit board designed for the DC-DC converter is shown in Fig. 4. A number of constructional points require attention.

Resistors R_2 and R_3 run fairly hot and must, therefore, be mounted at a few millimeters above the board surface. The peak current through these resistors can be as high as 15 A. The power-FET also runs hot, and requires a medium-size heat-sink and the usual insulating material. The diode can do without cooling, although it is conveniently bolted on to the same heat-sink as the power-FET (do not forget to insulate it electrically). During normal operation, the inductor heats up.

Heavy-duty terminals and wires must be used at the input and output of the converter. The battery is protected by a 16 A delayed action fuse inserted in the input supply line. Remember that the fuse does not protect the converter!

The circuit is simple to align: adjust P_1 for the desired output voltage between 20 and 30 V. The output voltage may be made lower, but not lower than the input voltage, by using a smaller resistor in position R_4. The maximum output current is about 3 A.

CORRECTION

"Simple Transmission Line Experiments"

(September 1989, p. 38)

Some serious errors have crept into the translation of the author's sketches into the published illustrations. Unfortunately, since the final proofs sent to author were apparently lost in the mail, these errors remained undetected until the magazine was printed. It should, therefore, be clear that the errors can not be attributed to the author.

Corrected illustrations are shown here, but for clarity's sake the errors in the originally published article are:

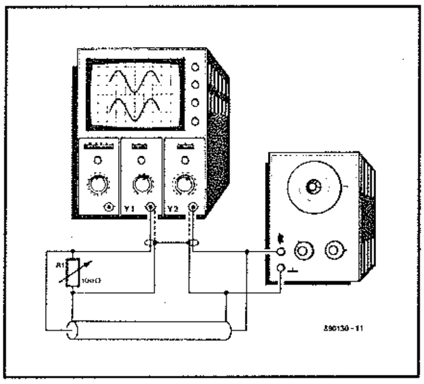


Fig. 1.

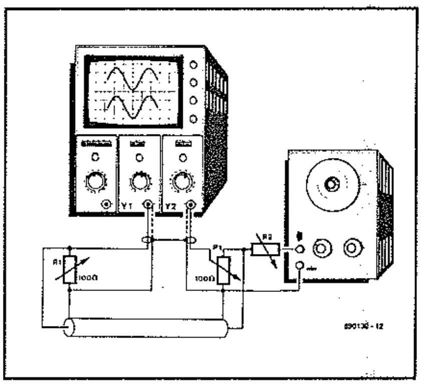


Fig. 2.

1. the Lissajous' figures shown on the oscilloscope give a false impression: they are NOT used;

2. it is not clear that the Y-amplifiers on the oscilloscopes have coaxial inputs: the first impression may well be that two wires are connected to a single input;

3. the connections to the signal generators give the false impression that the earth line is connected to the upper terminal, whereas, where such instruments have 4 mm terminals, one above the other, it is always the lower one that is at earth potential.

We apologize to the author and those readers who may have been inconvenienced by these errors.