Contents

# SYMMETRICAL SUPPLY IN CARS

**There is a problem if you want to use a car battery to power a circuit which requires a symmetrical supply voltage. Having abandoned the idea of mounting a second battery in your car for that purpose, take a serious look at the circuit discussed here. It converts the car battery voltage into symmetrical ±12 V or even ±15 V rails. Since the converter is able to supply a continuous output current of about 0.5 A, and a peak current of up to 1 A, it is eminently suited to powering control amplifiers and small power amplifiers.**

Design by K. Walraven

IF you want to obtain a symmetrical supply voltage of ±12 V from a car battery, it is always necessary to first double the battery voltage. The only way to 'step up' a direct voltage is by using a switch-mode power supply. Such a DC-DC converter operates on one of two principles. Low-power supplies usually rely on a clever switching system by which capacitor charges are 'stacked' rapidly to give the higher voltage. If more output current is demanded, however, DC-DC converters almost invariably use an inductor for energy storage. By periodically interrupting the current through an inductor, a relatively high induction voltage is generated. This voltage may be rectified and stabilized, but it may also be 'stepped up' beforehand.

## Flyback principle

Two concepts are available for the design of a DC-DC converter based on the 'switched-inductor' principle. The best known are the forward converter, the boost converter and the flyback converter. Only the latter is considered here because it is applied in the practical circuit discussed further on.

The principle is illustrated in Fig. 1. While the switch is closed, the current flowing through the inductor causes a magnetic field to be built up in the inductor core. During that period, no current flows through load resistor *R*. When the switch is opened, the inductor starts to act as an energy source. The diode then ensures that the current supplied by the inductor flows through the load. Although the output voltage may be taken directly from the inductor, it is also possible to replace the inductor by a transformer.

As regards the current through the inductor, there are two different operating conditions. The first is illustrated by the voltage and current graph in Fig. 2. After the switch is closed, energy is stored in the inductor core during period 'A' of the voltage graph. This energy is released again a little later during the period marked 'B'. Nothing happens for a while after all anergy has been released, which can be seen by the ringing of the signal during period 'C'. The lower graph shows the consequences for the current, which rises linearly during period 'A', decreases linearly again during period 'B', and drops to nought during period 'C'. Because the current drops to nought intermittently, this mode is called 'discontinuous current mode'. The advantage of this operating mode is that it allows the control system to give good response to changes in the input voltage as well as to output load variations. The disadvantage is the relatively high peak current carried by the switch.

Another possible condition is 'continuous current operation'. As illustrated by the upper curve in Fig. 3, all available time is then used to store energy and release it again. The period so created is even a little too short, because the inductor is still busy supplying energy at the end of the interval. This is indicated by the section marked 'D' in the current graph printed at the bottom. It shows that the current jumps immediately to a certain value when the switch is closed, and then rises linearly. Because the current does not drop to nought again at the end of the period, this is called 'continuous current

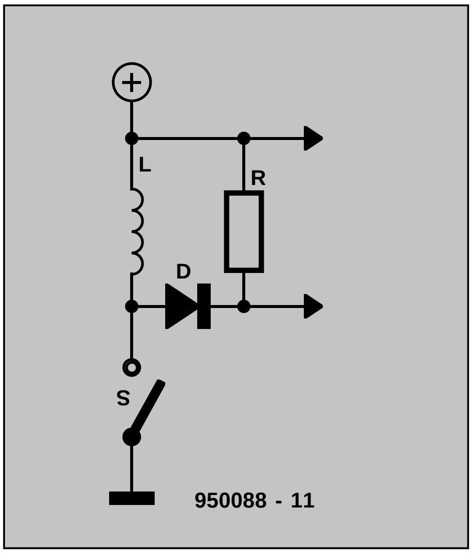


**Fig. 1. As long as the switch is closed, a certain amount of energy is stored in the inductor. This energy is released when the switch is opened.**

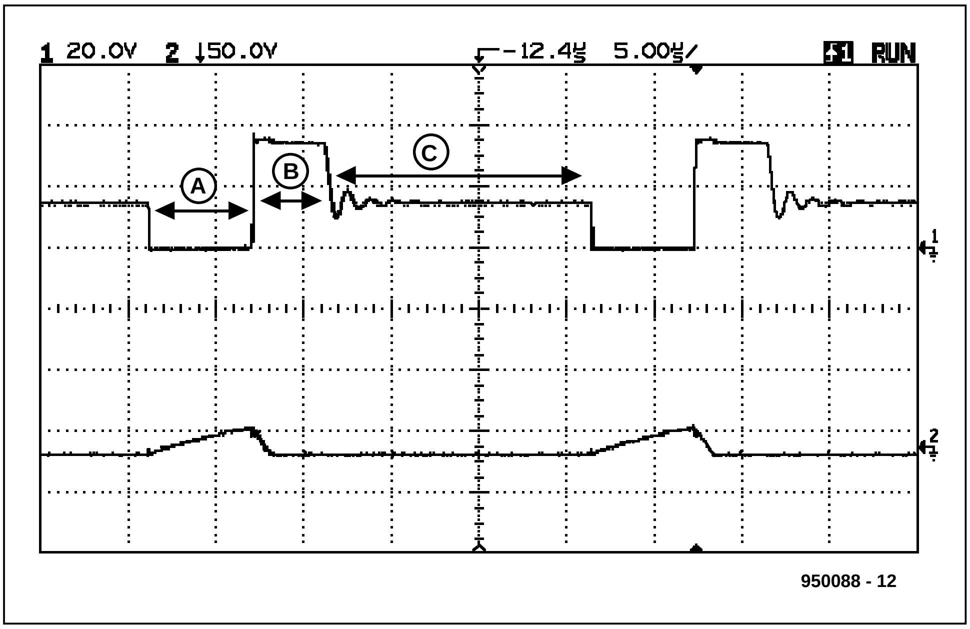


**Fig. 2. Voltage and current graph of a converter in non-continuous current mode. The current graph (below) clearly shows that the current actually drops to nought between the 'down' and 'up' slopes.**

mode'. An advantage of this mode is that the ripple current through the inductor is small with respect to the load current. On the down side, this mode offers not so good response to load variations.

It goes without saying that non-continuous operation is the best mode for lighter loads, while larger output currents are best handled in continuous mode. A system capable of switching between these modes depending on the current demand is, therefore, the best of both worlds. Such a control system is far from easy to stabilize, however, and that is why we have resorted to an integrated circuit which is 'easy going' and specially designed for the purpose.

## The LT1070

The heart of the circuit is formed by an integrated switching regulator type LT1070. The manufacturer, Linear Technology, calls this IC a 'current mode switcher'. The internal structure of this IC is shown in Fig. 4. On board the LT1070 are all the standard ingredients of a switch-mode power supply. In fact, the LT1070 requires only a handful of external components. The most important elements are a robust high-efficiency switch, an oscillator and a measurement and control section. All of this is contained in a compact 5-pin TO-220 style case, so that the LT1070 is almost as easy to use as any of the familiar three-pin fixed voltage regulators. The LT1070 accepts input voltages between 3 V and 60 V, and works happily with a quiescent current of only 6 mA. Despite its 'modest' appearance, the regulator is capable of supplying a maximum output power of about 100 W without the help of an external power transistor.

The designation 'current mode switcher' means that the duty factor of the switch is controlled directly by the output current rather than the voltage. Referring to the block diagram, the switch starts to conduct at the start of every oscillator cycle. Regulation of the output voltage is achieved by changing the toggle level of the output current on the basis of the output voltage supplied by an error amplifier.

An internal low-drop regulator supplies a reference potential of 2.3 V for all circuits. The reference source allows input voltages between 3 V and 60 V to be used without any adverse effects on the performance of the IC. A 1.24-V bandgap voltage source is used as a reference for the error amplifier. The – input of the error amplifier is bonded out to a pin ('FB') and acts an the output voltage sensor. This feedback connection has a second function: when pulled low by an external resistor, the output of the error amplifier is decoupled from the comparator, and the latter is connected to the flyback amplifier. Because the output voltage is directly proportional with the flyback pulse, it may be adjusted without a direct link between input and output.

The error signal at the input of the comparator is also fed to a pin, '$V_c$', which has four different functions. It is used for frequency compensation, soft-start, current limiting, and for complete shut-down of the regulator. The level at this pin is normally between 0.9 V (low output current) and 2.0 V (high output current). This voltage may be limited externally to set the maximum current. Soft-start may be implemented with the aid of a capacitor-coupled external clamp circuit. If $V_c$ is pulled to ground by means of a diode, the regulator enters a kind of stand-by state, while pulling the voltage under 0.15 V causes the regulator to be switched off completely. In the latter state, the quiescent current is reduced to a mere 50 µA.

## Practical circuit

As already mentioned, the LT1070 works happily with a minimum of external components. Consequently, Fig. 5 shows a very simple circuit diagram. Indeed, had we limited ourselves to the parts required for the function of DC-DC converter only, the circuit would have been even simpler, because a fair number of components serves for buffering and cleaning of the input and out-

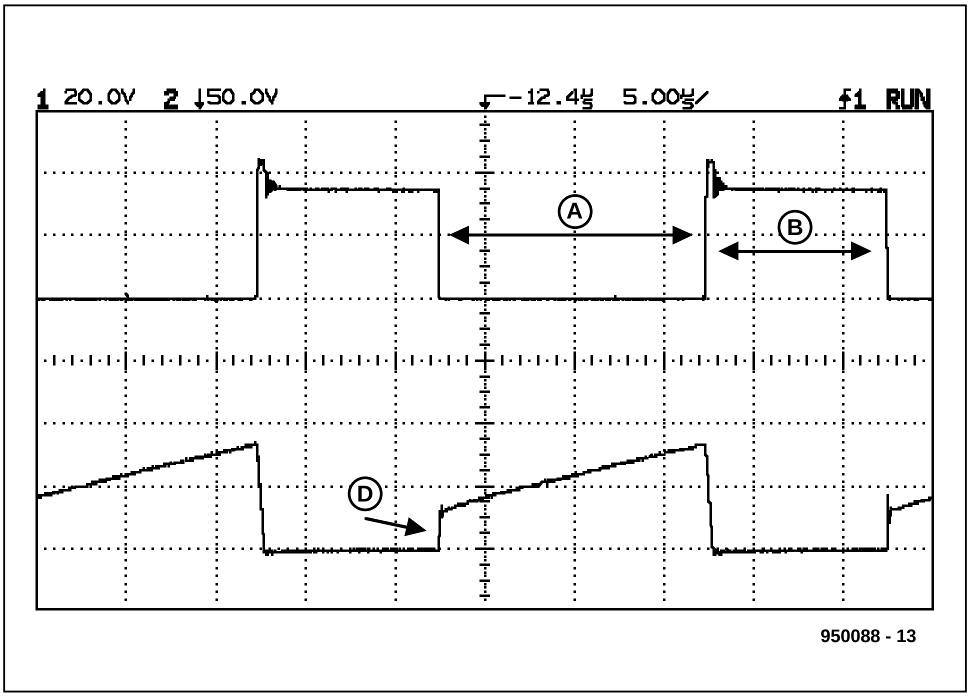


**Fig. 3. The same graphs as in Fig. 2, but measured on a converter operating in continuous current mode. All available time is used to store and release energy.**

Contents

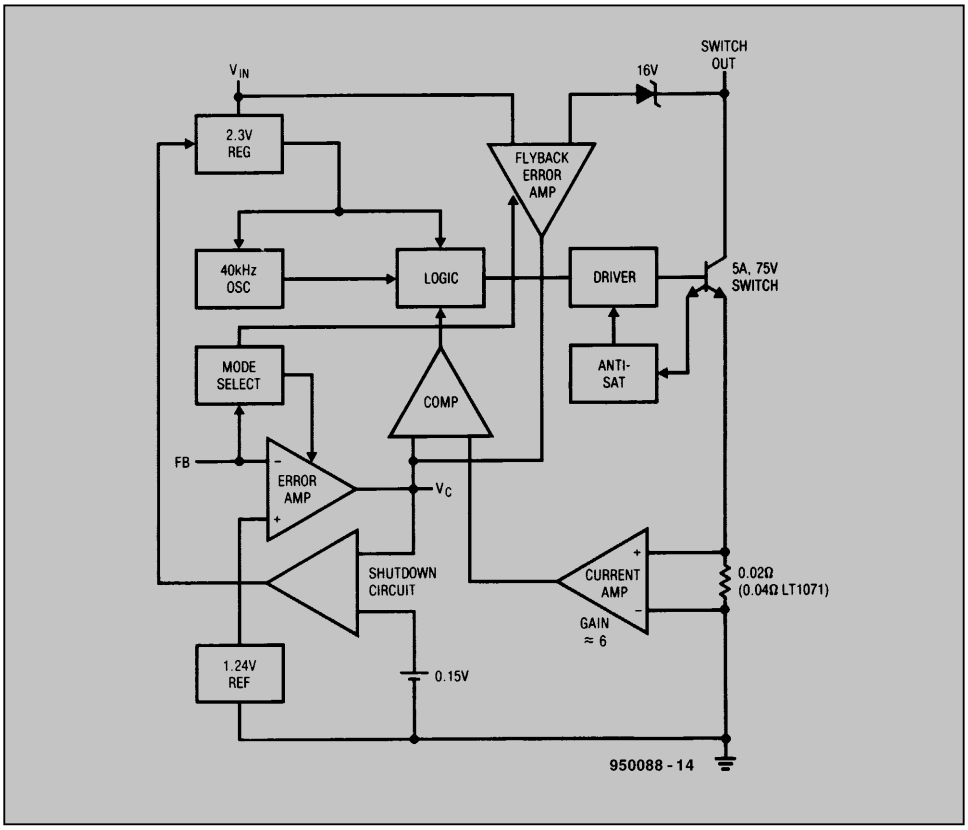


**Fig. 4. The internal structure of the LT1070 is fairly complex, and contains just about everything you need to build a DC-DC converter.**

put voltages.

The core of the converter is actually restricted to $IC_1$, transformer $Tr_1$, the rectifiers connected to secondary windings of $Tr_1$, and resistor network $R_3$-$R_4$. As stated earlier, a flyback-type regulator allows the output voltage to be set by feeding (a part of) the output voltage back to the feedback input. Here, that is done with the aid of $R_3$ and $R_4$. The ratio between these two resistors therefore enables the output voltage to be set to ±12 V or ±15 V without the need of changing the turns ratio of the transformer. The resistor values indicated in the circuit diagram gave an output voltage of ±13.8 V on the prototype of the converter.

The LT1070 keeps the output voltage constant within a few millivolts (which can be measured only when changing from no load to full load). Note, however, that only the positive output voltage is used as a reference for the regulator. As long as the converter is symmetrically loaded (i.e., roughly equal current consumption on the positive and negative output rails), there will be no undue unbalance, and the regulation on the negative rail will be hardly worse than that on the positive rail. However, when only the negative rail is loaded, that output voltage may drop appreciably. So, if you want to load the negative rail only, be sure to provide a continuous load on the positive rail, for instance, with the aid of a resistor. If you are after a 'rock-steady' supply, connect a linear regulator to each of the converter outputs.

Components $D_1$, $R_2$ and $C_7$ form a so-called snubber network, which serves to prevent the LT1070's output voltage from exceeding its maximum value (65 V). Because of the stray inductance in the circuit, a large voltage surge may occur the moment the chopper switch opens. This surge is diverted via $D_1$ and $C_7$, while the capacitor, in turn, is discharged slowly by $R_2$.

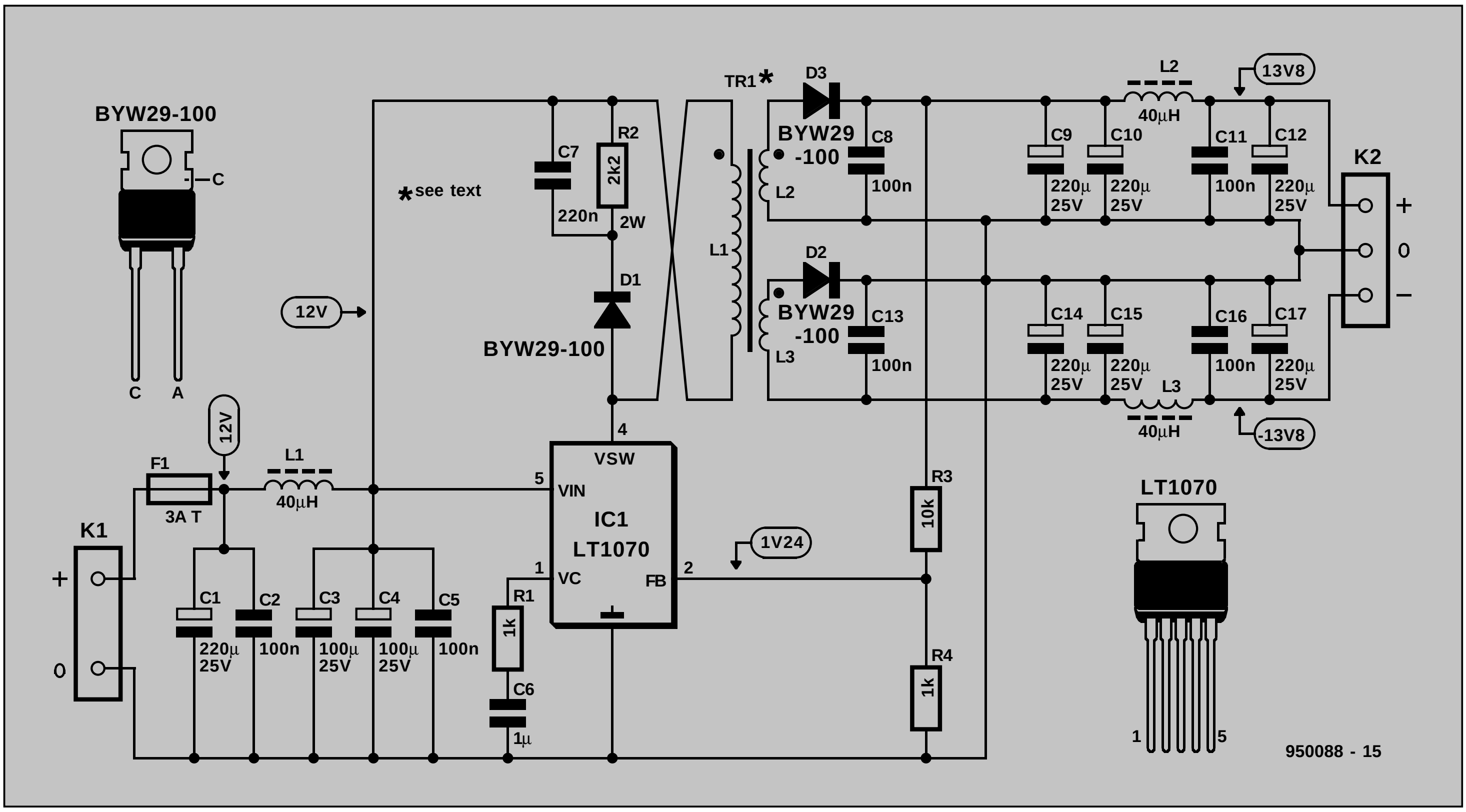


**Fig. 5. Apart from the IC and the transformer, the circuit diagram contains only a double rectifier, a number of reservoir capacitors and noise suppression filters.**

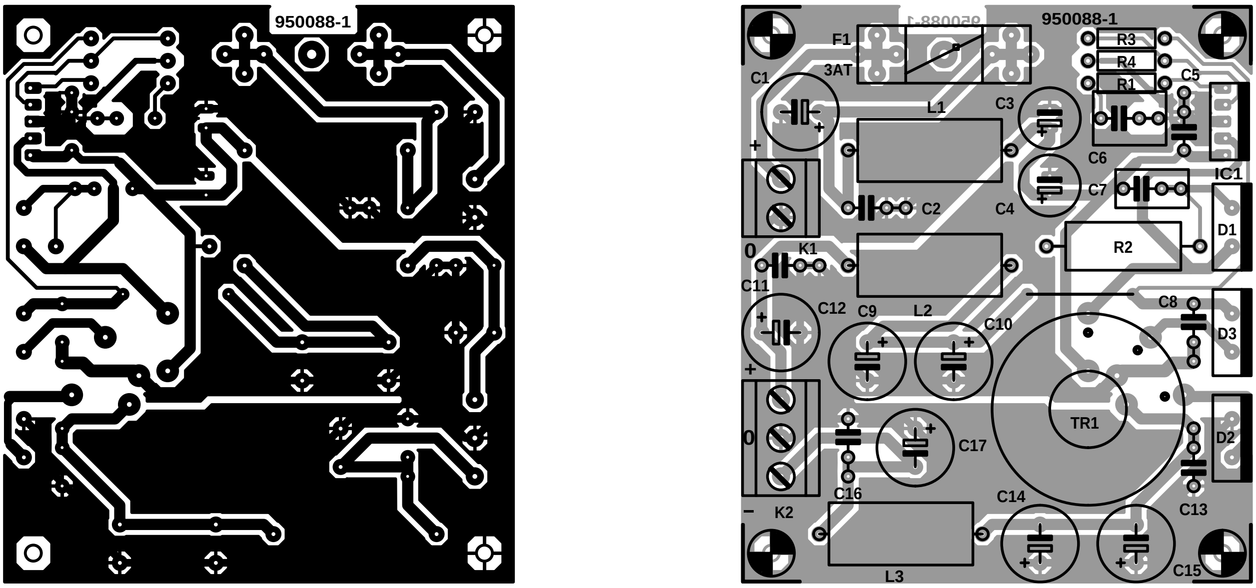


**Fig. 6. Populating the board is easy. Its moderate size allows the board to be fitted in many different types of metal enclosure (board not available ready-made).**

To keep unwanted emissions to a minimum, the circuit has no fewer than three *LC* filters: one for the input voltage ($L_1$-$C_2$), and one on each of the output rails ($L_2$-$C_{11}$ and $L_3$-$C_{16}$). For $L_1$, $L_2$ and $L_3$ it is best to use those well-known triac suppressor coils with a minimum current rating of 1 A (usually 2.5 A). If your demands are not so high, the coils may be replaced with 6-hole ferrite beads with a few turns of wire through them. Although the suppression of the 40-kHz fundamental component is then slightly less effective, the effect on higher harmonics above 500 kHz is nearly identical.

The relatively high pulse currents in the circuit cause the electrolytic reservoir capacitors to run fairly hot (up to about 50 °C). To keep their heat dissipation within reasonable limits, these capacitors are therefore fitted in pairs. To ensure the highest possible efficiency and life expectancy of the converter, it would be better to use electrolytic capacitors specially designed for use in switch-mode power supplies. However, these costly and difficult to obtain parts are not strictly required in the present circuit. Our prototype gave satisfactory results with 'ordinary' caps fitted.

Do not use ordinary diodes (like 1N4002 etc.) in positions $D_1$, $D_2$ and $D_3$, because they are too slow in this application. Almost any real switching diode may be used, as long as it is capable of passing a current of at least 3 A. It is best to use fast diodes with soft recovery — the latter feature is important to keep spurious emission to a minimum. The diode indicated in the circuit diagram is a Schottky type rated at 100 V, 8 A, which has an additional advantage in not dropping too much voltage.

## Construction

The printed circuit board designed for the DC-DC converter is shown in Fig. 6. The size is modest, while the tracks are laid out generously. Populating the PCB with step-by-step reference to the component overlay and the parts list is not expected to cause undue problems. The IC and the diodes are purposely located at the edge of the board, so that they are easily secured to a heat-sink (using washers and plastic bushes). Alternatively, if you use a metal (die-cast or aluminium) case for the converter, that may be used as a heat-sink as well. However, we haven't got as far as fitting the board into a case. First, concentrate on making the transformer, $Tr_1$. The core is that of an ordinary triac suppressor coil with an inductance between 25 μH and 100 μH, and a current rating between 3 A and 5 A. The parts list states a few types that may be used. Usually, such coils have between 30 and 50 turns of enamelled copper wire on the core. This winding may be left in place, and becomes the primary winding of the transformer. Count the number of turns. Next, apply two secondary windings over the primary, each having the same number of turns as the primary. Use 0.5-mm dia (24SWG) enamelled copper wire, and wind the two secondaries simultaneously, that is, with two wires at the same time. Be sure to observe the same winding direction as the primary. It does not matter whether you start winding the wire from the left or the right — the thing to keep an eye on is whether the wire is inserted into the core from below or from the top. So, look carefully at how the primary is wound. Distribute the two new windings as evenly as possible across the circumference of the core. The final construction is illustrated in Fig. 7.

A final remark on the transformer. If a

## COMPONENTS LIST

**Resistors:**
R1;R4 = 1kΩ
R2 = 2kΩ2 2W
R3 = 10kΩ

**Capacitors:**
C1;C9;C10;C12;C14;C15;C17 = 220µF 25V radial
C2;C5;C8;C11;C13;C16 = 100nF
C3;C4 = 100µF 25V radial
C6 = 1µF MKT
C7 = 220nF

**Inductors:**
L1;L2;L3 = SFT10-30 or SFT1030 (40µH) (TDK)
Tr1 = SFT12-50 or SFT1240 (see text)

**Semiconductors:**
D1;D2;D3 = BYW29-100
IC1 = LT1070 (Linear Technology)

**Miscellaneous:**
K1 = 2-way PCB terminal block.
K2 = 3-way PCB terminal block.
F1 = fuse 3A (slow) w. PCB mount holder.
Metal case, e.g., Hammond 1590S, 110x82x44mm.
Insulation set (washer and bush) for IC1, D2, D3.

Most components for this project are available from C-I Electronics, P.O. Box 22089, NL-6360-AB, Nuth, The Netherlands. Fax (+31) 45 5241877

Contents

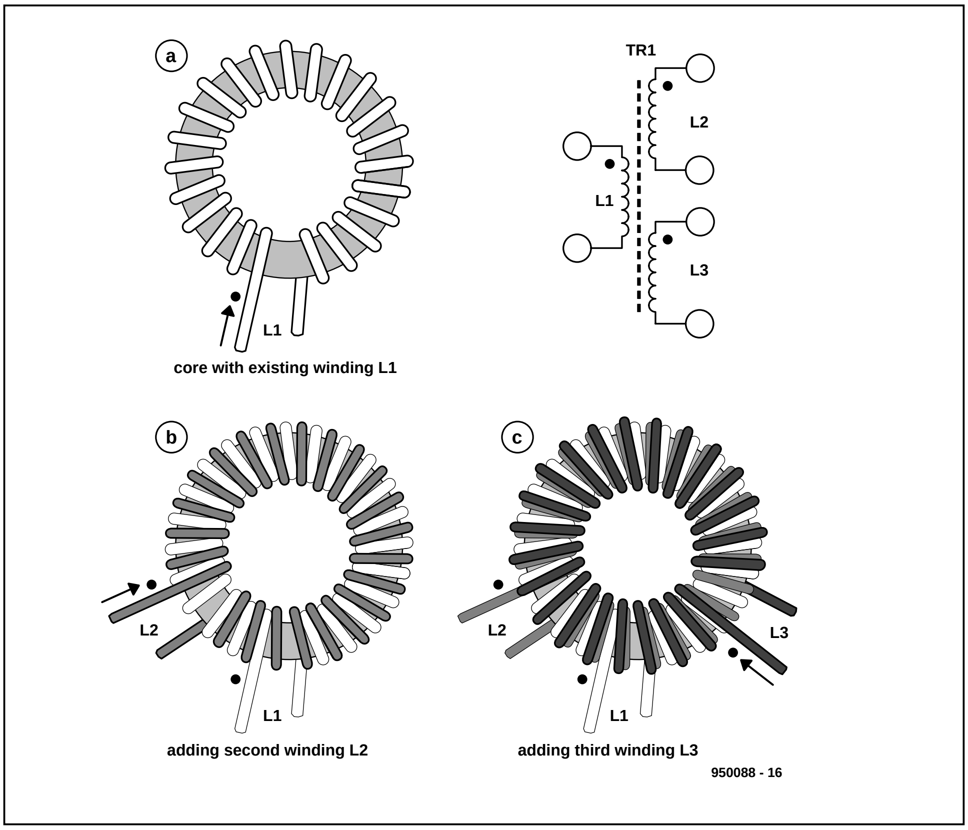


**Fig. 7. Transformer Tr1 consists of a normal ring core suppressor choke, whose existing winding is used as the primary winding. A bifilar secondary is wound over the primary, observing that the winding direction is the same as that of the primary.**

higher output voltage is desired (more than ±15 V), the efficiency of the converter may be improved by making the secondary windings a little larger — for example, 60 turns instead of 50. Fortunately, the exact number of turns is not critical, so gross errors are hard to make.

## Testing and setting up

The photograph in Fig. 8 shows the completed prototype of the converter. To be able to test the circuit properly, diode $D_2$ should not be fitted for the moment. Connect two 1-kΩ load resistors to the output rails of the converter (one to the positive rail and one to the negative rail). In the interest of safety, it is best at this stage to use an adjustable power supply instead of a car battery. Connect it to the converter, and increase the voltage slowly. The converter should start to work at an input voltage of between 3 V and 5 V. If you do not have an adjustable supply, connect a 12-V, 5-W lamp in series with the battery. The lamp will limit the current in case something goes wrong.

Use an oscilloscope to check the voltage at pin 4 of the LT1070 against the oscillogram in Fig. 2. It is essential to be able to discern three levels: zero volts, the supply voltage and the doubled supply voltage. If you find that there are only two levels, the winding direction of the secondaries on $Tr_1$ is wrong. Remove the transformer and wind it again.

If the waveform is okay, the input voltage may be increased to 12 V, or the lamp may be removed. The positive output voltage should then be around 13.8 V. If that is the case, $D_2$ may be fitted on the board. Next, run another check on the waveform shape at pin 4 of $IC_1$. Also check the level of the negative output voltage at the – clamp of $K_2$.

If the circuit behaves properly so far, it is time to increase the load current. Secure the heat-sink to the IC and the diodes, and exchange the 1-kΩ resistors with 5-watt car lamps. The waveform at both outputs should be as shown in Fig. 3. If you use an adjustable supply for this test, be sure to turn it up to 12 V first, and not connect the lamps until the output voltages of +12 V and –12 V are present. If you do it the other way around, the power supply may actuate its current limiter. That may happen because the converter always tries to supply the necessary output current. Where a power of, say, 12 W requires a current of 1 A at an input voltage of 12 V, that goes up to 2 A at 6 V, and 4 A at 3 V. Such output currents are beyond the capacity of most (hobby) power supplies, hence you have to start without the load connected to the converter.

For the sake of completeness, the circuit diagram shows a number of measurement values. Although the input voltage is given as 12 V nominally, the actually allowed level here is up to 15 V. Using the indicated component values and an input voltage of 12 V, the output voltage should be about ±13.8 V. This voltage may be changed within certain limits by changing the ratio between $R_3$ and $R_4$. In all cases, however, a voltage of 1.24 V (±5%) should be present at pin 2 of $IC_1$. If not, the regulation of the IC does not function properly. This voltage should correspond to the internal reference voltage. At a too high voltage, the output of the converter is probably not loaded, while a too low voltage at pin 2 indicates a too heavy load or a too low input voltage.

The internal regulation voltage of the IC may be measured at pin 1. This voltage depends on the output current, and changes between 1.1 V at no load to about 2 V at full load.

## Final remarks

Having passed all tests and experiments without serious mishaps, the circuit is ready for the finishing touches, and the test gear and car lamps may be put away. To keep unwanted electromagnetic radiation as low as possible, the circuit should be built into a sturdy metal case. The prototype was housed in a die-cast case from Hammond. The type number is 1590S and the outside dimensions are approximately 110×82×44 mm. The circuit board fits exactly in this case, and is easily secured to the bottom with the aid of four PCB pillars. The IC and the three diodes may be secured to the side panel using insulating washers. This arrangement will afford sufficient cooling for not too heavy use. The input and output cables to be connected to $K_1$ and $K_2$ enter the case through suitable grommets, and should be fitted with a heavy-duty strain relief at the inside.

As already mentioned, the converter is capable of supplying a peak output current of up to 1 A, and a continuous current of up to 0.5 A. Note, however, that these ratings are achieved at normal room temperatures only (up to about 25 °C). In the blazing sun, however, the temperature inside a car may easily reach about 60 °C, which means that the converter is not able to supply its maximum power because the thermal shut-down will be actuated much earlier than under normal circumstances. Fortunately, the same thermal protection ensures that the IC can not be damaged or destroyed by high temperatures.

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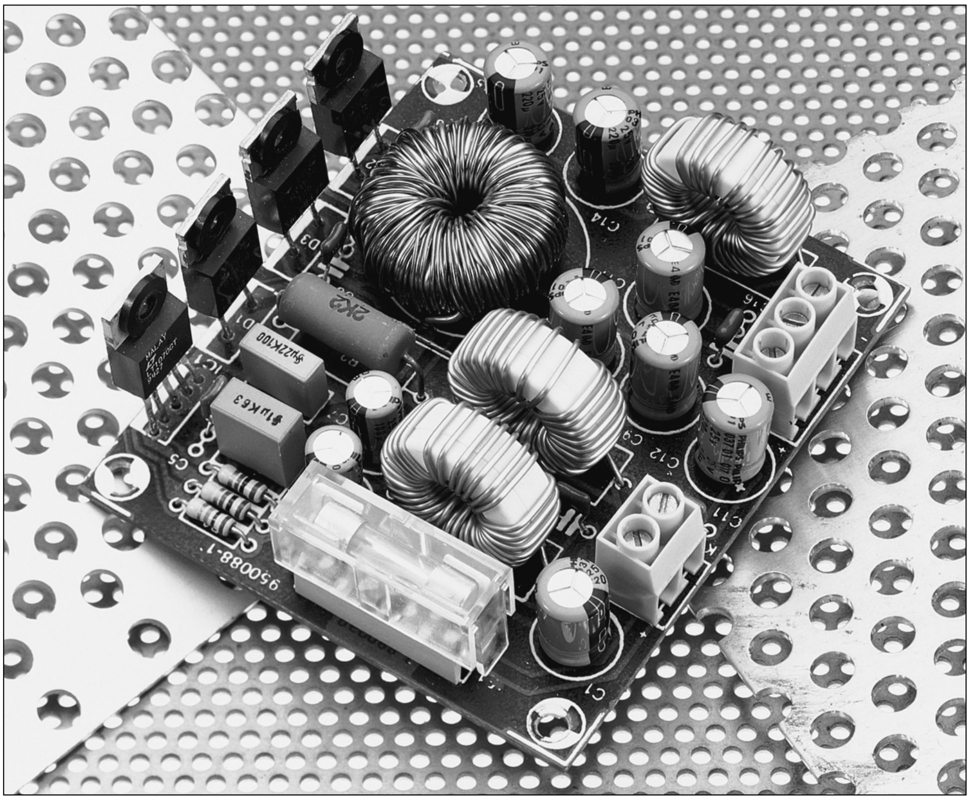

Fig. 8. Completed prototype board. Diode D2 should be omitted for the purpose of testing the circuit.