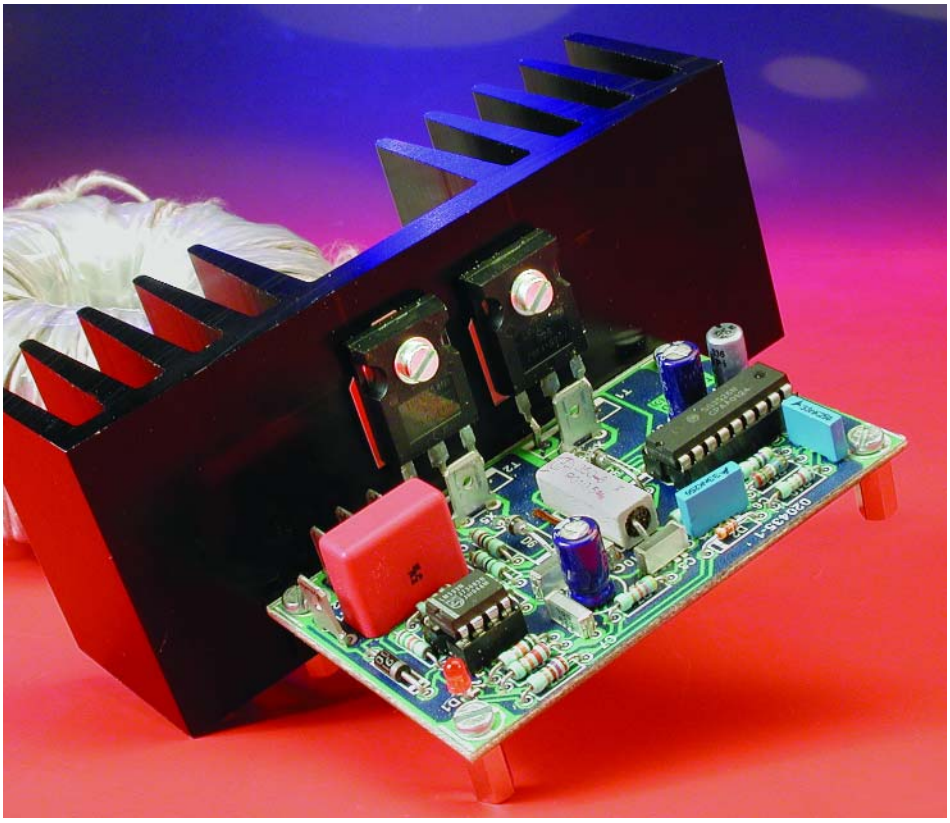
Simple 12-to-230V Power Inverter

A mobile power outlet

Design by G. Gerards www.aixcon.de

The absence of a mains power outlet is often keenly felt on camping sites, with car repairs in the middle of nowhere and with picnic or party events in the countryside. In some cases, mains power can only be brought to a remote site by running a very long cable — which either dangerous, impossible or not available. Whatever the occasion, planned or unexpected, it is great to have a power inverter available capable of changing the 12-V car battery voltage into 230 volts AC.



The idea for a simple, portable 'power outlet' was first suggested by a trainee at the Aixcom company, which is normally involved with high-tech power inverters and special high-current power supplies. The trainee, called Dirk, had been trying for quite some time to build a power inverter for his model aircraft club. In his enthusiastic attempts he ran into problems obtaining the special integrated circuit that was to form the heart of his project. When he was finally successful in obtaining the elusive chip, albeit at horrific costs, all the circuit did was produce a loud bang at switch-on, wrecking a lot of components.

The company decided to continue the design, and the result is presented here: a power inverter that was not only successfully reproduced by nearly all trainees at Aixcom, but also presented as a Christmas or anniversary gift to dad, used on a camping site and, last but not least, deployed in a (very loud) music parade. A beefed up version of 1,000 watts was developed and installed by Dirk at his model aircraft club, where it has performed beautifully for over a year despite rough conditions.

Concept

Arguably, the circuit represents the simplest way of creating a power outlet for on the road. In the design phase, the aim was a 100% bare bones circuit, stripped of anything that could be, well, stripped! For example, there's no voltage regulation, and a sagging battery voltage also causes the ac output voltage to sag. However, because most mains powered equipment continues to work just fine in the face of ac voltage variations of ±10-15%, the mobile power outlet does so too. Rather than perfecting the design for performance, Aixcom went for simplicity, low component count and utter reliability in practical use. None the less, the 230-Vac output is short-circuit resistant and an undervoltage protection switches the inverter off before the battery has been drained to level that would no longer allow the car to be started. The circuit is simple enough to be reproduced successfully by beginners, too, provided they realise that 230 Vac is a really dangerous voltage.

Pulsewidth modulation

The central part in the circuit is an SG3526 low-cost switch-mode regulator, which is supplied by a number of manufacturers under the component identifier xx3526, where xx is a manufacturer-specific letter combination. The 3526 supports all known switch-mode PSU topologies. Its complete datasheets may be obtained free of charge from www.unitrode.com (part search: UC3526 and Datasheet).

The basic operation of the power inverter is illustrated in **Figure 1**. The SG3526 alternately switches the current through the 12-V windings of a mains transformer, the two central ends of the windings having been taken together and connected to the positive battery terminal (+12 V). At each switching action, the direction of the current changes and with it the direction of the magnetic field in the transformer core. The result is a square-wave(-like) alternating voltage at the 230-V side of the transformer.

In real life, the switch consists of two FETs in complementary arrangement (push-pull). The source connections of the FETs are taken to ground by way of very low resistances (compare the circuit diagram in Figure 3).

The internal architecture of the SG3526 is shown in **Figure 2**. The input voltage $+V_{in}$ may be between 7 V and 35 V, and is used to create a reference voltage V_{REF} of 5 V. A voltage guard blocks the drivers stages when the input voltage drops below 7 V. The drivers are separately powered via the $+V_c$ connection. Using resistor RT and the capacitor at CT

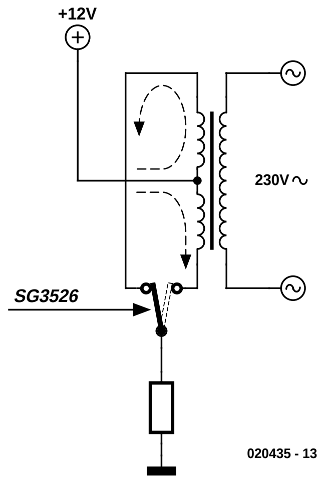


Figure 1. Block diagram of the power inverter. In the actual circuit, the switching element consists of two power FETs, while the resistor to ground acts as a current sense (shunt) for the current limiter circuit inside the SG3526.

(again compare with circuit diagram in Figure 3) the frequency is determined, which is 50 Hz in this case. The resistor at R_D causes a fixed dead time between the driver's Output A and Output B. This is done to eliminate the risk of the two drivers (and consequently the two power FETs) conducting at the same time when the switch-over takes place.

The capacitor at the $C_{SOFTSTART}$ pin (Css, pin 4) allows the pulse mark/space (on/off) ratio of the outputs to be slowly raised to 48% after the supply voltage is switched on, or after a reset. The 'Amp' voltage regulator is not used as such in our application, alternatively it takes the role of an impedance converter using the reference voltage as the controlling quantity. In this way it is assured that the outputs supply the full mark/space ratio after the start-up phase.

The current limiter using shunt resistor R8 triggers a shutdown sequence when the voltage between +CS and –CS (in other words, the drops across R8) exceeds 100 mV. However, the shutdown control may also be used externally by connecting it to ground. Because shutdown and Reset (pins 8 and 5 respectively) are interconnected in this circuit, the modulator starts again with a soft start after an overload condition or an external disconnect.

More design thoughts

The transformer for the project should be a toroidal type with a primary of 230 V and two 12-V secondary windings. Readers in countries with 110 V, 117 V or 127 V mains voltage are, of course, advised to use a matching 200-

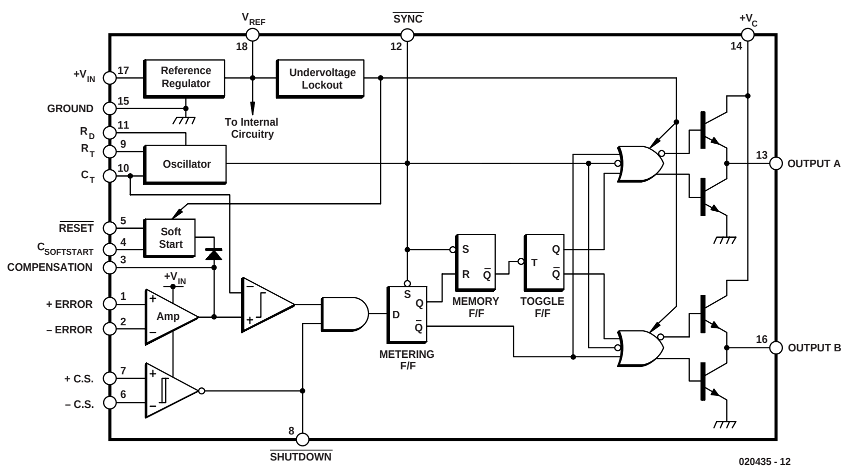
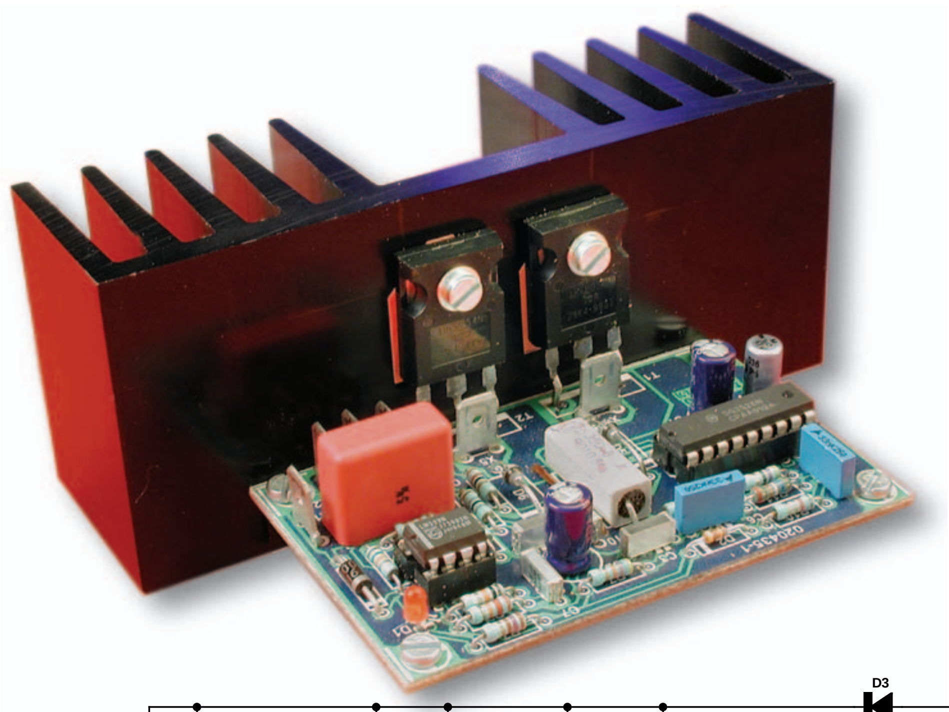


Figure 2. Internal diagram of low-cost SMPSU regulator type SG3526.

watt transformer. If you are lucky to have an old toroidal transformer lying around in a drawer or a junk box, it should not be too difficult to 'retro-fit' two 12-V windings. Simply wind ten turns of litze wire around the core and connect the primary to the mains. Measure the voltage across your new winding and then calculate how many turns you need to get at 12 V. At an output power of 200 watts, the average current will be about 10 A, so the cross-sectional area (c.s.a.) of the litze wire you're using should be 1.5 mm^2 or greater.

It is vital that the two 12-volt windings have **exactly the same number of turns**. If there is a difference of just one turn then the transformer core will saturate the instant the 12-volt battery is connected, causing the regulator to 'hang' in shutdown mode. The sense direction) of the windings is equally important. Before installing the transformer, connect the ends of the two 12-volt windings in series and apply 230 Vac to the primary. You should measure 24 Vac across the free ends of the secondaries.

The FETs used in the circuit can handle up to 72 A at 55 V, and are marked by an $R_{D\text{-}S(ON)}$ of just 12 mΩ. Of course, other types may be used provided you are sure they can handle at last 40 A at 40 V, and have an $R_{D\text{-}S(ON)}$ not exceeding 50 mΩ. Usually, power FETs may also be connected in parallel, but please make sure each one gets its own gate resistor. The parallel configuration is of interest if you wish to configure the inverter for output powers greater than 200 watts. In that case, the current limiter has to be adapted, which is easiest done by



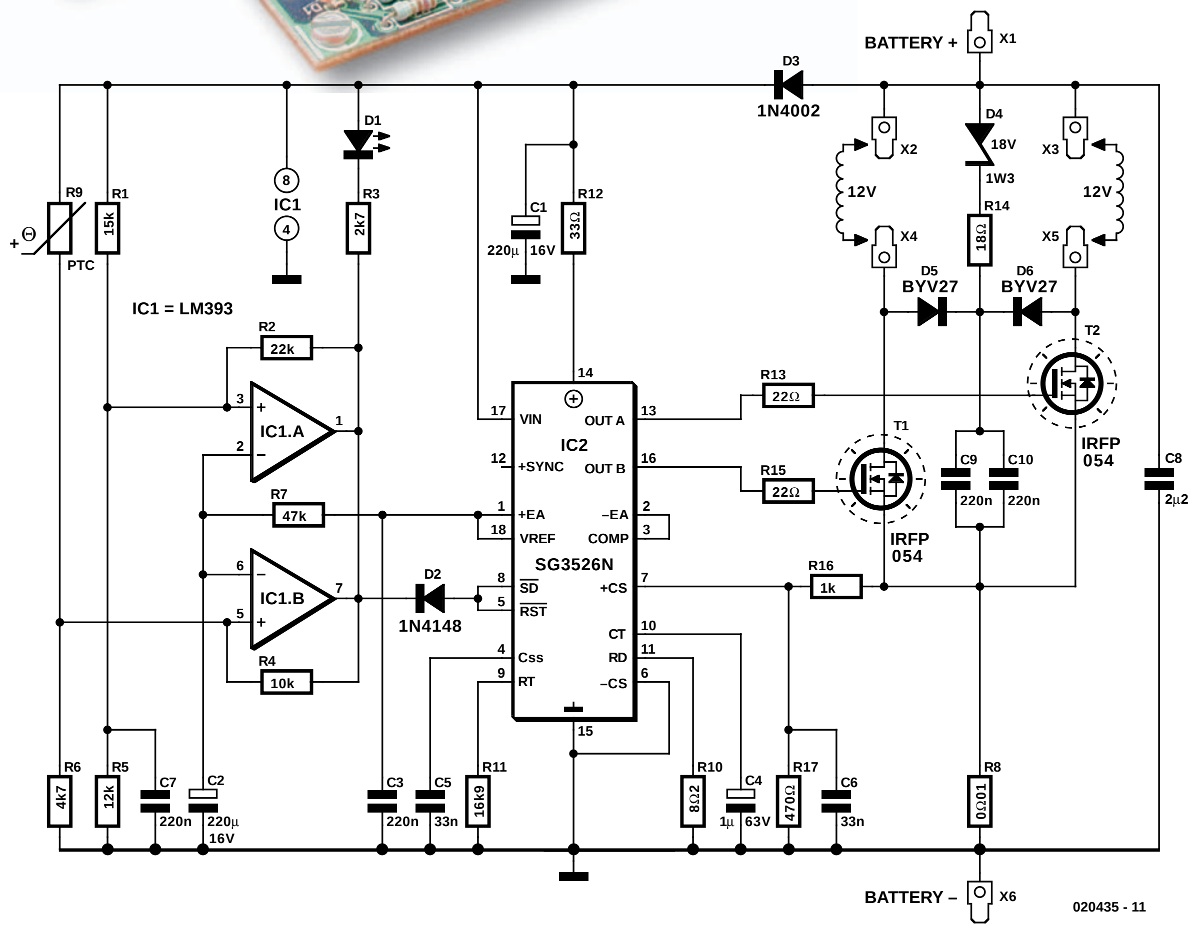


Figure 3. Circuit diagram of the 12V-to-230V Power Inverter. Comparator IC1 acts as a guard for temperature as well as battery voltage.

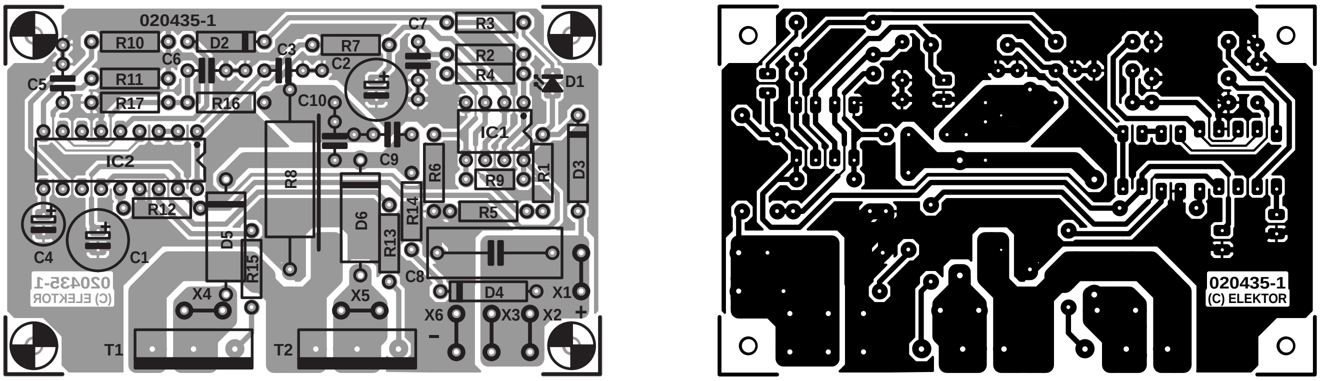


Figure 4. Copper track layout and component mounting plan of the PCB designed for the project. The board is single-sided and available ready-made through Readers Services.

using a smaller value for shunt R8 and/or by modifying voltage divider R16-R17.

Ordinary bulbs and halogen (flood-) lights are sure sources of trouble with most power inverters. Both present a very low 'cold' resistance, causing the inverter to reduce its output voltage or even actuate the shutdown. The result is a lock-up with isufficient voltage to heat up the filaments to their normal operating temperature. Fortunately, the 200-watt version of the inverter described here should be capable of turning on lamps of up to 150 watts without problems. Should problems arise, the value of capacitor C6 may be increased — but not to any extent because the ability of the circuit to withstand short-circuits may well suffer. Using C5 it is also possible to increase the soft-start time considerably, or do without it altogether. That, in all likelihood, is the safest solution.

Comparator IC1 monitors the battery voltage and ambient temperature and compares its measured results with the 5-V reference voltage from the 3526. The two open-collector outputs pull the shutdown control input (pin 8) to ground in case of an error. The PTC used determines the switch-off temperature. Depending on the exact type in your circuit, R6 may need slight redimensioning. Early Aixcom prototypes of the inverter used a D901-D60-A40 from Epcos (trip temperature 60 degrees C). However, it should also be possible to use a temperature switch of 60 to 80 degrees C or a temperature fuse of 90 degrees C. Although the latter component is extremely cheap at just a few pence, you'll need to exchange it when it has 'gone off'.

Provided a large enough heatsink is used, a simple wire link may be used instead of the PTC. The voltage monitor switches off at about 12 volt and this may be adapted to suit other levels by changing R1 and R5. On the comparators, R2 and R4 define an amount of hysteresis that prevents the power inverter from switching itself on again after a fault condition. After switching on, the reference voltage rises slowly as determined by the charge time of C2, hence the monitors are only activated a few seconds later.

Car batteries supply dangerously high currents. To prevent the inverter going up into flames and causing a fire, you **must** protect it with a car fuse of between 25 A and 35 A. The 230 Vac output voltage is also **very dangerous** even if it is generated by means of a battery.

Construction

The design of the printed circuit board is shown in **Figure 4**. Despite large ground areas and wide tracks it may be necessary to strengthen the tracks carrying the transformer current by tinning them. It is recommended to start by mounting the AMP ('fast-on') lugs (spade terminals), because they require considerable force to insert into the board. After all, a mishap with the use of pliers at this point could cause con-

COMPONENTS LIST

Resistors:
R1 = 15kΩ
R2 = 22kΩ
R3 = 2kΩ7
R4 = 10kΩ
R5 = 12kΩ
R6 = 4kΩ7
R7 = 47kΩ
R8 = 0Ω01 (max. lead pitch 24mm)
R9 = 1kΩ (PTC, see text)
R10 = 8Ω2
R11 = 16kΩ9
R12 = 33Ω
R13,R15 = 22Ω
R14 = 18Ω
R16 = 1kΩ
R17 = 470Ω

Capacitors:
C1,C2 = 220µF 16V radial
C3,C7,C9,C10 = 220nF
C4 = 1µF 63V radial
C5,C6 = 33nF
C8 = 2µF2 63V, 15mm lead pitch, MKS4 (Wima)

Semiconductors:
D1 = LED, red, low current
D2 = 1N4148
D3 = 1N4002
D4 = 18V 1.3W zener diode
D5,D6 = BYV27-200
IC1 = LM393N
IC2 = SG3526N
T1,T2 = IRFP054N (IRF)

Miscellaneous:
X1-X6 = AMP spade terminals, PCB mount
PCB, order code **020435-1** (see Readers Services page)
Toroidal mains transformer, see text, e.g., Aixcon 230V / 12-0-12 V / 200W (www.geist-electronic.de)

Table 1

Output voltage vs. battery voltage (150 watt load)

Battery voltage [Vdc]	Output voltage [Vac]
11.5	182.4
12	194.6
12.5	202.4
13	214.3
13.5	223.0
14	231.2

siderable damage to other components on the board. The wire link beside the shunt resistor R8 should not be forgotten. R8, by the way, should be mounted a little above the board surface to help it stay as cool as possible. If desired a higher-wattage resistor may be substituted (5 watts). Finally, do make sure you mount all polarised components (transistors, electrolytic capacitors, diodes and ICs) the right way around on the board. Insulating washers must be used when fitting the transistors onto the heatsink.

Powering up

Commissioning this project only requires a multimeter. Initially, you use the inverter **without the transformer connected**. Connect it to an adjustable bench supply and check the two guard circuits: the voltage guard by adjusting the input voltage, and the temperature guard with the aid of your soldering iron, a potentiometer or any other means you see fit. In any case, the outputs will switch to ground and the LED will light when the voltage at the positive input of the comparators drops below that at the negative input. If the guard circuit appears to work, you proceed by measuring the two gate signals. If an error is present, both will read 0 V. In the case of an error-free circuit, an oscilloscope will show two clean rectangular-wave signals with 10-ms long pulses. Using your multimeter, the same measurement yields a readout of about half the supply voltage.

All approved so far, you are in a position to connect the toroidal transformer. At this point, it makes sense to remove IC1 from its socket, as in that case the shutdown can only be triggered by the current limiter. If an ordinary 100-watt bulb does not light up within a few seconds, measure the voltage at the shutdown control (pin 8 on the 3526 or the anode of D2). If you measure less than 5 V, the current limiter or the soft-start time has to be tweaked as described above.

Once the bulb lights, you may (carefully!) check if the inverter is short-circuit resistant. If an oscilloscope is available, the FET current may be measured (= the voltage across R8) and use R16 to increase the current limit point to about 20% below the permissible drain current. This is of course done with the 230-Vac output short-circuited.

It is normal for the transformer to make more noise under no-load conditions than you would expect when in normal use. This is caused by the rectangular wave switching the magnetic field hard and fast. Core saturation under no-load conditions is signalled by ugly sounds from the transformer. Measured with an oscilloscope the currents will not rise in sawtooth-wise but with peaks (overshoot). In that case, the 12-V windings on the transformer require just a few more turns. If that is problematic, the alternative is to raise the oscillator frequency a little by using a slightly lower value for R11. The resulting output frequency may well be 55 Hz, but that is immaterial for most loads and the circuit is not suitable anyway to power an alarm clock.

Practical results

Because a voltage regulation loop omitted for the sake of simplicity and cost, the output voltage is dependent on the battery voltage. The output voltage of the author's prototype loaded with a 150-watt halogen lamp is shown in **Table 1**, as a function of battery voltage.

The output voltage is dependent on the transformer's winding ratio and output current. If you want to reach the nominal output voltage of 230 Vac at 13 Vdc input, you should consider using a transformer with two 11-volt windings. On the prototype, a maximum efficiency of 94% was measured and the circuit was found to be Dirk-proof.

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