# 95-wat Laptop PSU

12 V in, 19 V at 5 A out!

Michael Schön

Anyone who regularly uses a laptop or notebook computer while they are away from the home or office knows that sooner or later they will need to plug into a mains outlet to top up the batteries. The car cigarette lighter socket in the car is also an electrical outlet but it can only supply 12 V. That's no problem for the Laptop PSU Adaptor described here; it can deliver ample voltage and current for today's portable computers from a car battery. It's also simple to build and has excellent efficiency. Modellers will also be interested in this design to recharge their battery packs in the field.

Adaptor
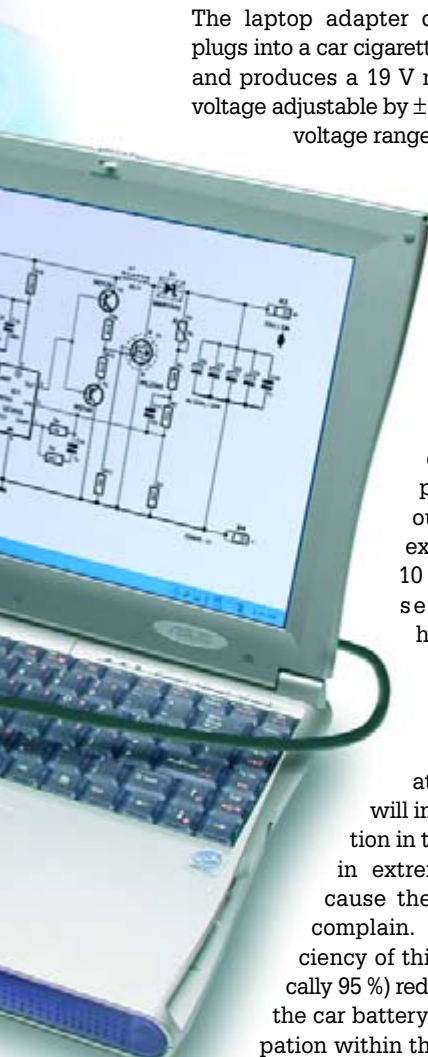
The laptop adapter described here plugs into a car cigarette lighter socket and produces a 19 V nominal output voltage adjustable by ± 0.5 V. The input voltage range is from 9.2 V to 15 V and the output voltage shows good regulation even with large fluctuations of the input voltage. The output can supply 5 A continuously with brief excursions up to 10 A. The power semiconductor heatsinks are dimensioned for 5 A continuous so extended operation up to 10 A will increase dissipation in the adapter and in extreme cases will cause the input fuse to complain. The high efficiency of this design (typically 95 %) reduces loading on the car battery and also dissipation within the adapter unit. At 60 mm _ 100 mm the PCB outline is not much bigger than the mains adapter unit that was supplied with the laptop or notebook PC.

The step-up Converter

The majority of laptops require a supply voltage in excess of the 12 V available at the cigarette lighter output socket, even with the engine running the supply will not rise much above 13.8 V and this is still too low for most laptops which typically require 19 V. The 12 V supply can be boosted with the help of a step-up converter design. The basic principle is simple: an inductor is repeatedly 'charged up' and 'dis-charged' and the resultant induced voltage is added to the supply voltage to produce an output voltage higher than the supply. Unlike a standard transformer inverter the basic circuit requires just three components: a coil, a power switch (in this case a MOS-FET) and a diode. All the control functions are performed by IC1, this device produces the pulse width modulated (PWM) switching signal for the power switch. The input and output voltages are smoothed by a series of low-loss capacitors.

The principle of the step-up converter operation is shown in **Figure 1**. When the power switch (MOSFET T) conducts (**Figure 1a**) current flows through the coil and produces a magnetic field. The anode of the diode (D) will be at ground potential (almost) so it will not be conducting and any energy previously stored in the capacitor C will be supplied to the load (R_L). The coil core has a 1 mm air gap to ensure that the core material is not driven into saturation during this phase of the cycle. When saturation occurs it is not be possible to store any more energy in the magnetic field and the coil effectively becomes just a low impedance resistor which would short-circuit the input voltage.

When T turns off (**Figure 1b**) current through the coil no longer has a path to ground through T, the magnetic field starts to collapse inducing a voltage across L of the opposite polarity to the switch-on phase. The induced voltage rises above the supply voltage, forward biasing D and transferring energy to C and R_L. Energy stored in C during this phase is transferred to the load during the next switch-on phase.
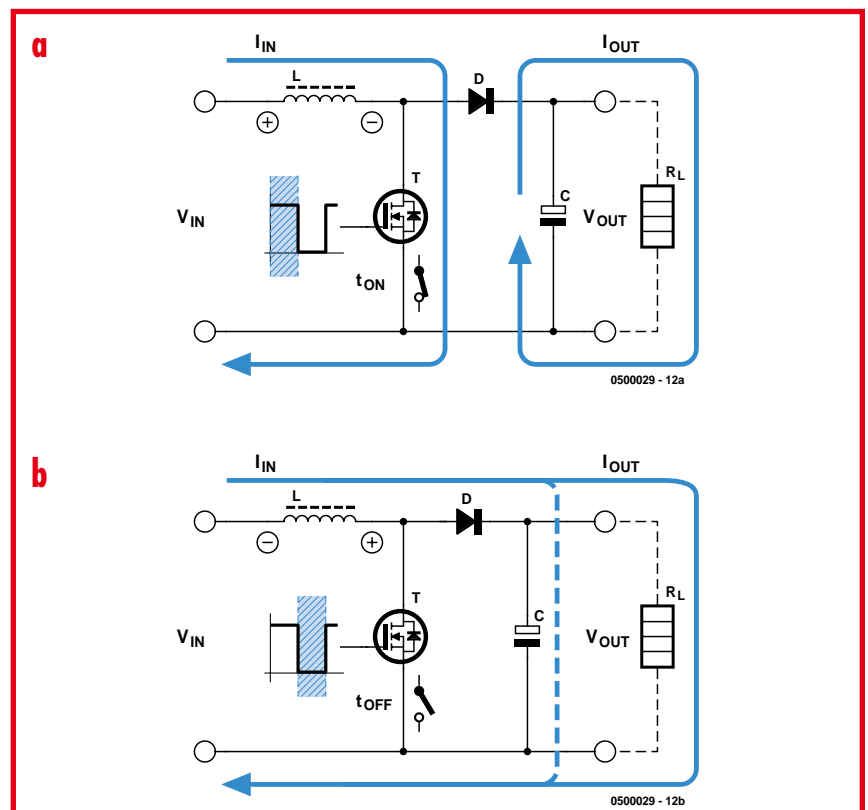

Figure 1. The step-up converter principle: Switch-on phase (a) and Switch-off phase (b).
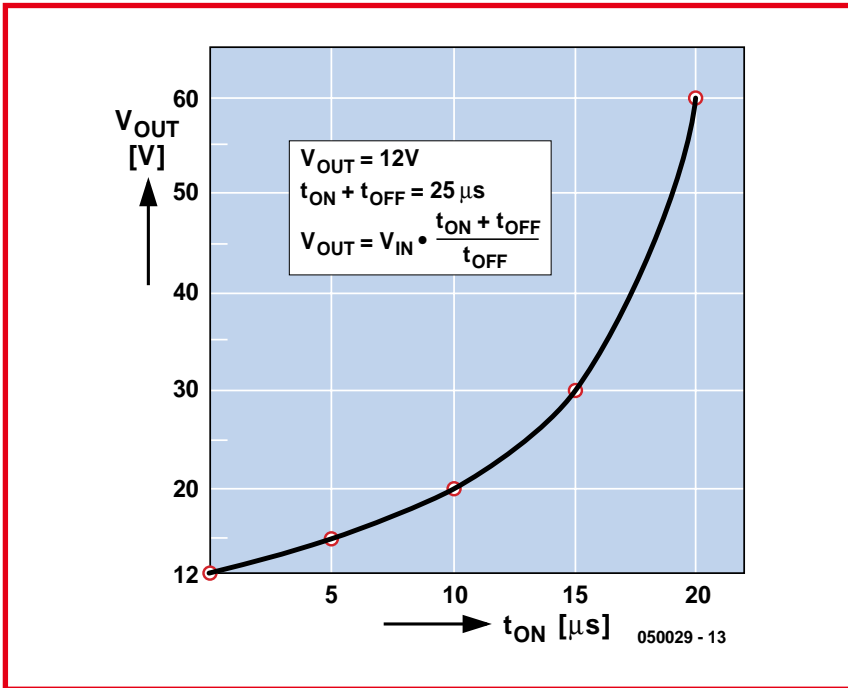
$$V_{OUT} = 12V$$
$$t_{ON} + t_{OFF} = 25\,\mu s$$
$$V_{OUT} = V_{IN} \bullet \frac{t_{ON} + t_{OFF}}{t_{OFF}}$$

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Figure 2. Output voltage control using PWM.

Figure 2 shows the correspondence between the output voltage V_{OUT} and the transistor switching time (t_{ON} and t_{OFF}). With short t_{OFF} times it is important to use low loss devices for the diode and capacitors to ensure they do not exceed their SOA (Safe Operating Area), otherwise the high energy transfer may lead to over heating and component failure. From a design point of view if you need an output more than about three to four times the input voltage it would be better to use a transformer in the design. This

would reduce the current ripple and lower the switching current peaks.

The step-up regulator current and voltage waveforms are shown in **Figure 3.** Waveform C shows the coil ripple current, increasing the coil size would reduce ripple but would also increase the physical size of the unit. It is important to ensure that the coil is not made so small that it cannot supply sufficient energy during the switch-off phase; this would produce an output voltage with very poor regulation. The $56\,\mu H$ coil used in this design produces
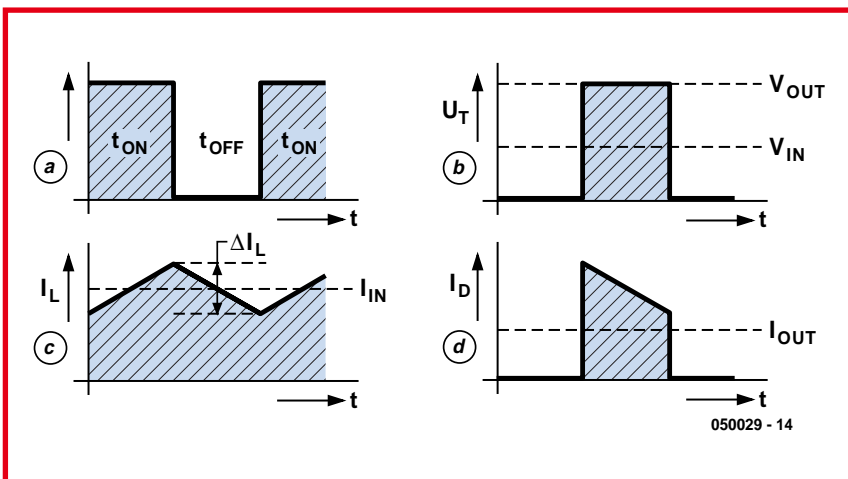
a ripple current of around 2 A which is approximately 40% of the maximum output.

Just one IC

The input voltage in the range from 10 to 15 V is connected to terminals K1 and K2 in the circuit diagram (**Figure 4**). A PCB mounted fuse is fitted in line with the positive supply and the specified fuse holder is equipped with two solder tags for each of the two fuse contact clips, these help to reduce the resistance of the fuse assembly which is particularly important because it passes a high current. Four electrolytic capacitors (C1 to C4) buffer the input voltage. The adapter circuit switches the supply current very quickly and requires special low-loss capacitors suitable for use in switched mode power supplies, the internal impedance of normal electrolytics is too high, they would overheat and may burst. C5 decouples any high frequency signals on the supply voltage.

The coil (L1) is made up from several lengths of enamel covered wire connected in parallel to reduce the skin effect which becomes a problem with high switching speed. The high power switching element is a HEXFET made by International Rectifier. This device has source/drain resistance of just 8 mΩ when it is conducting. The low resistance ensures very low power dissipation in the device and allows it to switch a hefty 104 A maximum which should ensure reliable operation in our application. Both the HEXFET and diode are fitted with finned heat sinks. Schottky diode D1 has a TO 220 package outline. It has a 45 V maximum operating voltage and a current of 16 A which gives a forward voltage drop of around 0.63 V, again for reliability the device is conservatively rated. Low ESR type electrolytic capacitors are specified again for output smoothing capacitors C6 to C9. Capacitor C10 is used for high frequency decoupling and the regulated 19 V is output from connectors K3 and K4.

A block diagram of the UC3843 (IC1) is shown in **Figure 5**. It contains a pulse width modulated (PWM) controller output signal and an internal voltage reference. The adapter output voltage is divided down by R1, R2, R3 and P1 and connected to the voltage feedback input (pin 2) of the controller IC (the error amplifier inverting input). C2 improves the amplifier stability as does R4, R5 and C12 connected between
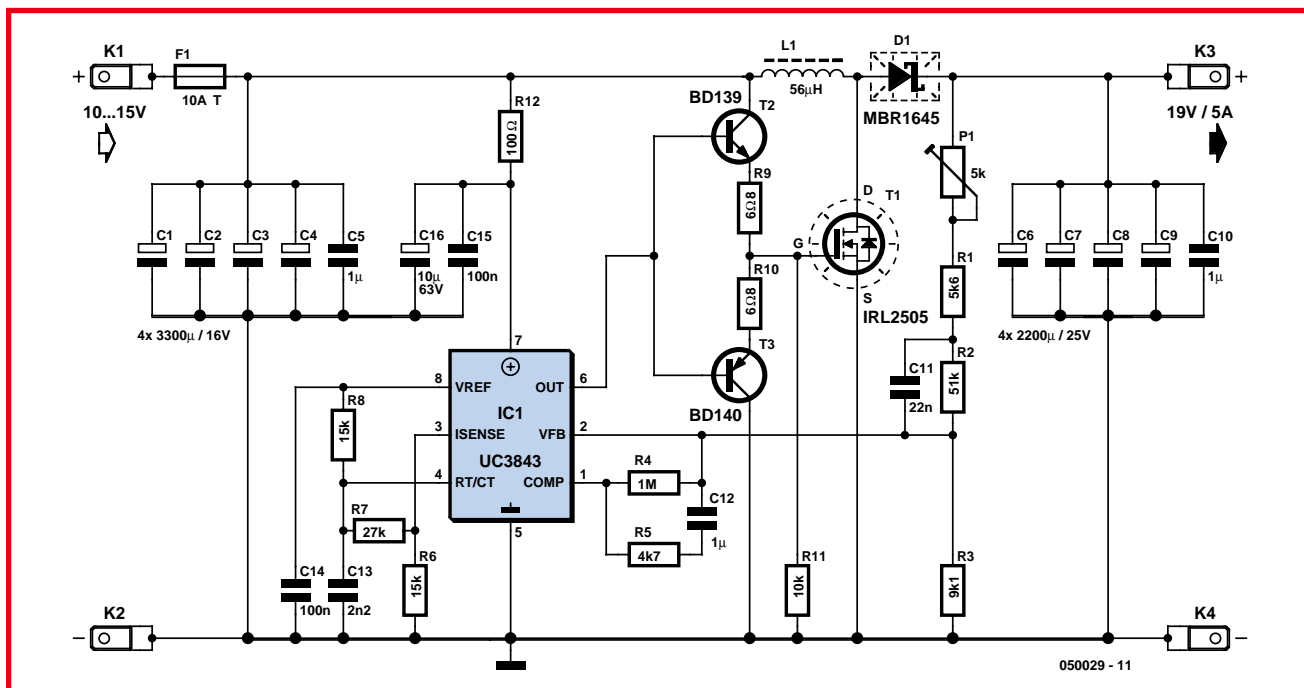

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Figure 3. Current and voltage waveforms with 50% on/off switching. (a) The PWM signal; (b) Voltage across the MOSFET (V_T); (c) Current through the coil (I_L); (d) Current through the diode (I_D).

Figure 4. The laptop PSU adaptor circuit diagram.

the output (Pin1) and non inverting input of the difference amplifier. The IC clock frequency is defined by the RC network formed by R8 and C13. The component values shown give an operating frequency of around 42 kHz. C14 provides decoupling of the internal reference voltage at pin 8. The supply decoupling network formed by R12, C15 and C16 on the supply pin 7 is important for reliable operation of IC1. The current sense input (pin 3) is not used in this application.

The power FET has a gate capacitance of around 5,000 pF which must be charged and discharged 42,000 times per second if the FET is to be switched successfully. It is important that the transition between on and off occurs as quickly as possible so that there is minimum dissipation in the FET. It is therefore necessary to use a low impedance driver (T2 and T3) between the PWM output of IC1 and the gate pin of the FET. The BD139 and BD140 complimentary pair can handle around 1.5 A limited by resistors R9 and R10. R11 will turn off T1 if for any reason both T2 and T3 become non-conducting or IC1 is defective.

Printed circuit board

The complete circuit fits on the single-sided PCB (**Figure 6**) without the need for any wire links. Before any of the

components are fitted it is best to construct the coil. The PCB layout also includes pads for an off-the-shelf 56 μH inductor but it must be able to handle the high switching currents. The prototype circuit used a coil with an ETD 29 core and was constructed as follows:

The coil has a total of urns but to make things a bit more interesting the wire consists of 10 strands of 0.5 mm diameter enamelled copper wire (ECW) connected in parallel. The effective cross sectional area of all the

strands is 1.96 mm^2. This method of construction produces a coil with much better properties at this switching speed than would be achieved with a single wire with a cross sectional area of 1.96 mm^2 (the skin effect has less influence).

The strands are first carefully twisted together before they are soldered to the coil termination posts, if the twisting is too tight the there will not be enough space to fit all the 21 turns. Each strand is 2 m long so overall 20 m of 0.5 mm enamel covered wire will be
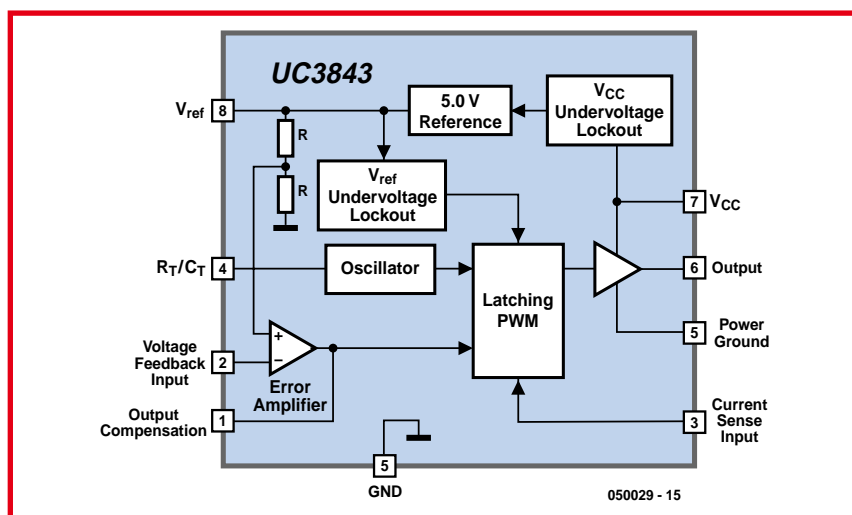

Figure 5. Block diagram of the PWM IC UC3843.

COMPONENTS LIST

Resistors:
R1 = 5kΩ6
R2 = 51kΩ (51kΩ1)
R3 = 9kΩ1 (9kΩ09)
R4 = 1MΩ
R5 = 4kΩ7
R6,R8 = 15kΩ
R7 = 27kΩ
R9,R10 = 6Ω8
R11 = 10kΩ
R12 = 100Ω
P1 = 5kΩ preset

Capacitors:
C1-C4 = 3300µF 16V, radial, low
    ESR, diam. 12.5 mm, e.g.
    Panasonic EEUFC1C332 (Farnell)
C5,C10 = 1µF MKT, lead pitch 5mm
    or 7.5mm (larger version preferred)
C12 = 1µF MKT, lead pitch 5 mm
C6-C9 = 2200µF 25V radial, low
    ESR, diam. 12.5mm, e.g.,
    EEUFC1E222 (Farnell)
C11 = 22nF, lead pitch 5mm
C13 = 2nF2, lead pitch 5mm
C14,C15 = 100nF ceramic, lead
    pitch 5mm
C16 = 10µF 63V radial

Inductors:
L1 = 56µH, 21 turns 10 x 0.5 mm
    ECW, parallel
1 x ETD 29 coil forner, vertical
    mounting, Epcos B66359X1014T1
    (Schuricht # 331622)
2 x ETD 29 clamp, Epcos B66359-
    A2000 (Schuricht # 333862)
2 x ETD 29 core half, material #
    N67, air gap 0.5mm, Epcos
    B66358-G500-X167 (Schuricht #
    333840)

Semiconductors:
D1 = MBR1645 (International
    Rectifier) (e.g. Reichelt, Segor)
T1 = IRL2505 (International Rectifier)
    TO-220AB case, (e.g., RS
    Components)
T2 = BD139
T3 = BD140
IC1 = UC3843N (Texas Instruments)
    (e.g. Reichelt, Segor)

Miscellaneous:
K1-K4 = 2-way spade terminal,
    vertical, PCB mount
F1 = fuse, 10A/T (slow) 6.3 x 32
    mm (¼ x 1¼ inch) + 2 fuse holders
    for 6.3 mm diameter and PCB
    mounting
2 x heatsink type SK104-STC (or STS)
    TO220 38.1mm, 11K/W (Fischer
    Electronic)Isolating washers for T1
    and D1 (TO-220AB) + isolating
    bushes
PCB, order code 050039-1 (see
    Elektor Shop pages or www.elektor-
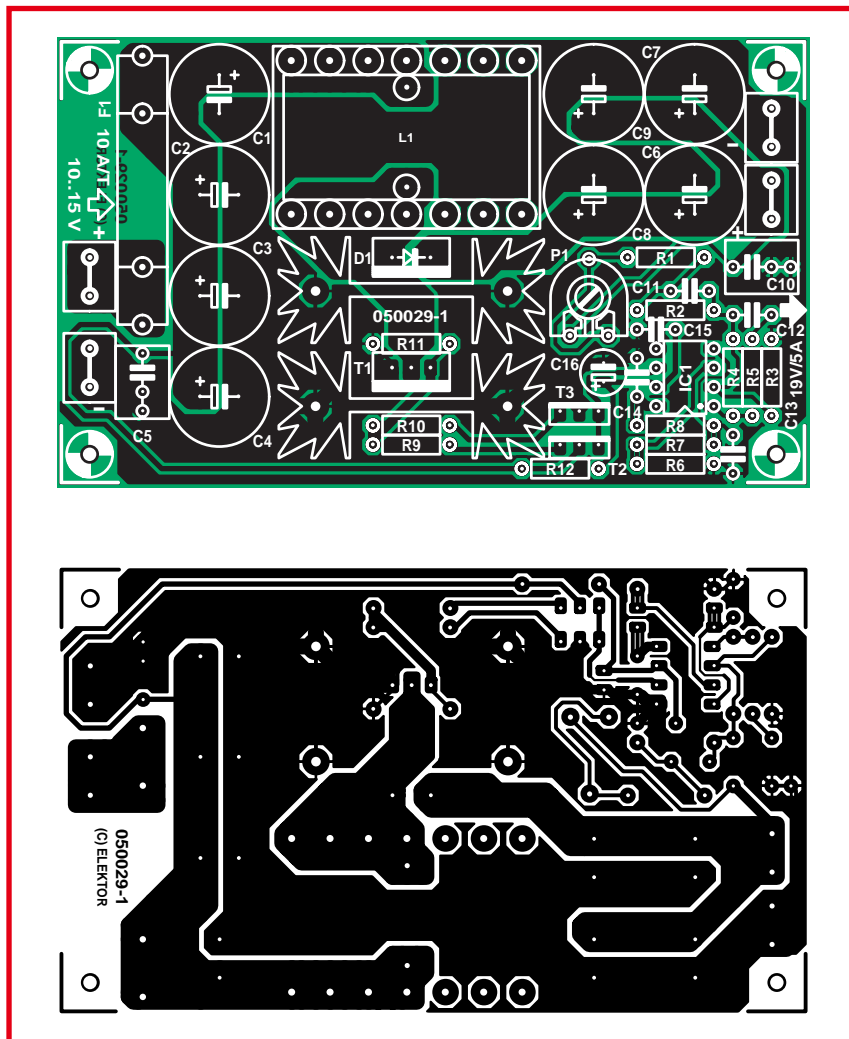   electronics.co.uk)

Figure 6. PCB Layout and component placement.

required. The start of the windings are soldered to the first four pins on one side of the coil former and after winding the ends are soldered to the first four pins on the other side of the former. It will be necessary to remove the enamel covering and tin the ends of the wire before they are soldered to the pins. Be careful here because the plastic coil former is not particularly tolerant to high temperatures and the pins may move out of position if the plastic is allowed to get too hot. The seven pins can be supported while soldering by fitting them into a spare strip of perforated prototyping board. For the prototype three layers were necessary for the 21 turns, the first and second layer both comprise of eight turns with five turns left for the last layer. Once the windings are finished and before the end of the windings are soldered in place try assembling the core pieces to make sure there is enough room. When

there is insufficient space you can leave off the final turn; 20 turns instead of 21 will not make a lot of difference to the unit's performance. Alternatively, you can remove one strand from the coil wire so that there are nine rather than ten strands. The coil can also be wound with 16 strands of 0.4 mm ECW (effective cross sectional area of 2.01 mm^2) or RF braid provided that the cross sectional area is around 2 mm^2.

When the winding is complete a layer of insulating tape is wound around the coil. Standard insulating tape is suitable here; the coil temperature never exceeds hand-warm during operation. The parts list specifies two identical core halves with a 0.5 mm gap, once the coil is assembled the total air gap is 1 mm. If you use core halves without any air gap it will be necessary to separate the two halves with some 0.5 mm thick non-conducting material

Test results and efficiency						
Input voltage (V)	Input current (A)	Input power (W)	Output voltage (V)	Output current (A)	Output power (W)	Efficiency η (%)
10.8	4.25	45.9	18.93	2.32	43.9	95.7
10.8	5.59	60.4	18.92	3.05	57.7	95.6
10.8	8.49	91.7	18.90	4.59	86.8	94.6
10.8	11.23	121.3	18.88	5.99	113.1	93.2
12.0	3.84	46.1	18.93	2.34	44.3	96.1
12.0	5.06	60.7	18.92	3.08	58.3	96.0
12.0	7.63	91.6	18.90	4.62	87.3	95.4
12.0	10.00	120.0	18.89	6.00	113.3	94.5
13.2	3.48	45.9	18.94	2.33	44.1	96.1
13.2	4.56	60.2	18.93	3.06	57.9	96.2
13.2	6.91	91.2	18.91	4.61	87.2	95.6
13.2	9.03	119.2	18.89	5.99	113.2	94.9
14.4	3.18	45.8	18.95	2.33	44.2	96.4
14.4	4.16	59.9	18.94	3.05	57.8	96.4
14.4	6.29	90.6	18.92	4.61	87.2	96.3
14.4	8.24	118.7	18.90	6.00	114.4	95.6

in order to achieve the 1 mm air gap. Larger outline capacitors were chosen for C5 and C10 with a lead spacing of 7.5 mm, these are better at handling high current and have lower losses. Begin assembly by fitting the resistors to the PCB then the fuse holder, next comes the spade connectors then the preset followed by the electrolytic capacitors (observe correct polarity) and the coil assembly.

Before the FET and diode are soldered into the PCB a bend should be introduced in the leads to help reduce the mechanical stresses on the soldered joints when the device heats up. Both semiconductors must be insulated from their heat sink using insulating washers and an insulated bush for the M3 mounting bolts and don't forget to apply a little thermal compound. Ensure that these devices are well soldered in place because the leads will be carrying several amps. The heatsink
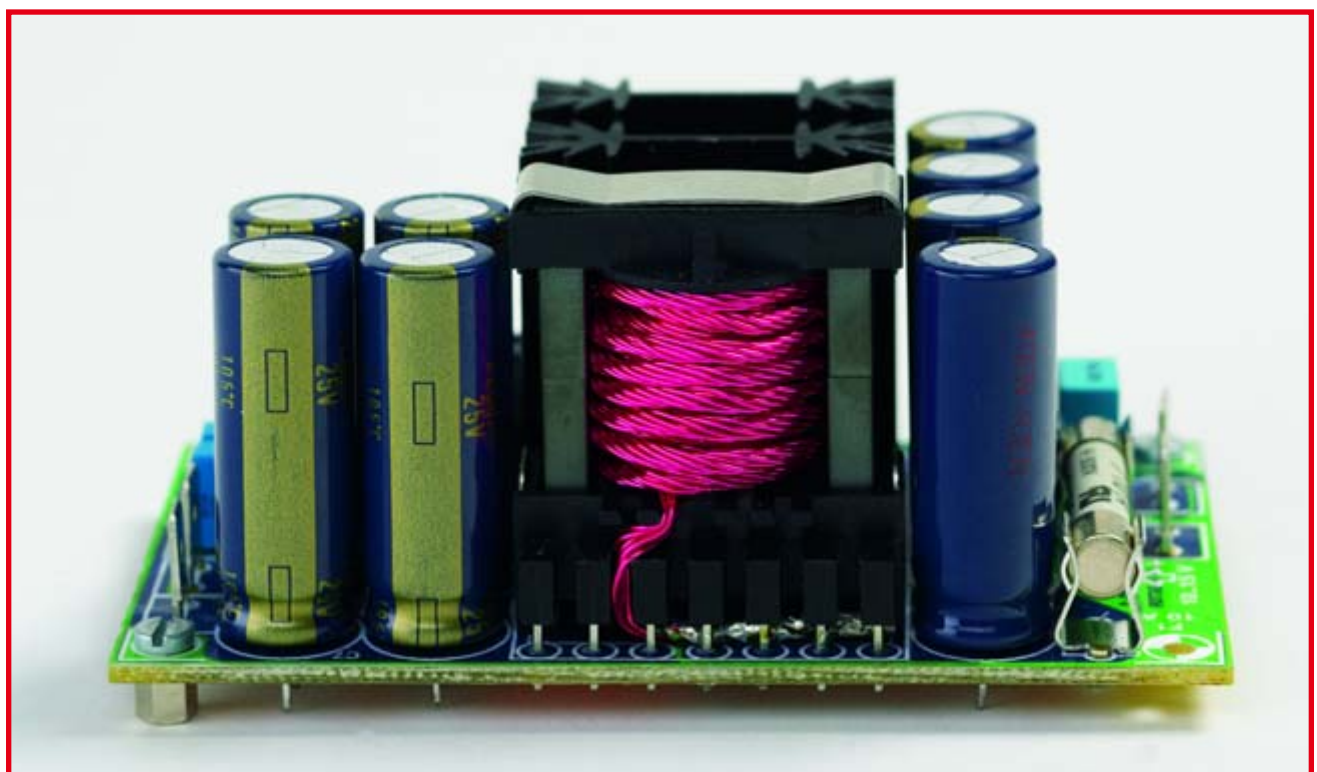

Figure 7. All components including the wound coil fitted to the prototype board.

can be taller, i.e., 50.8 or 63.5 mm with 9 K/W or 8 K/W respectively. The prototype is fitted with 38.1 mm high heat sink at 11 K/W. From the efficiency viewpoint it would be better if the diode had a smaller heat sink because the diode's forward conduction voltage decreases with increasing temperature. However a smaller heat sink may lead to overheating if the output is overloaded. A 20TQ045 diode from IRF can be substituted for D1; this device has a slightly smaller forward voltage drop. There is no advantage in letting the FET run warmer, its channel resistance (R_{DSon}) increases with increasing temperature. Finally fit transistors T2 and T3 along with IC1 and take the opportunity to double check all the components and soldering before you move on to the next phase and connect power to the adapter.

Power on

Before the unit is powered up for the first time turn the preset P1 fully clockwise to produce the minimum output voltage. For testing use either a power supply capable of supplying 12 V at 10 A or a 12 V vehicle battery. Initially adjust the power supply current limit to 200 mA or, if you are using a battery, connect a 5 W resistor (47 or 56 Ω) in series with the positive supply lead to the adapter. Double check that the positive lead of the power supply is connected to K1 and the negative lead to K2 (nearest to the PCB corner). When no obvious malfunction occurs with the power connected (no excess current drawn from the supply and no smoke signals…) the current limit can be increased (or the series resistor removed). Connect a multimeter to the adapter output connections K3 and K4 (the negative terminal is nearest the board corner again) and check that the output voltage lies in the range of 18 to 19 V. With no load connected to the adapter slowly adjust P1 to ensure that it can achieve an output voltage of 19.4 V. Now use either an electronic load or a combination of high power resistors (4.8 Ω at 100 W) and adjust P1 for 19 V output voltage at full load (5 A).

You may notice that when the adapter is operating under full load conditions the output voltage will bounce up briefly by 1 V whenever the load is disconnected. The output quickly returns to its regulated level and in practice this design 'feature' is not a problem for a laptop adapter application.

The finished unit can be mounted in an enclosure. The high efficiency achieved by this design means that very little heat is produced by the unit and there is no need for a fan. A few holes in the case will be sufficient just to allow a little air circulation. Before the unit is connected to the cigarette lighter socket make sure that it (and the plug) are capable of handling 10 A. Connect the adapter to the PC with a suitable lead and connector, double check that the plus and minus are connected to the correct input pin of the laptop or notebook PC — never assume that it is equipped with reverse voltage protection!

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Michael Schön
schoen.michael@inode.at