New design for long fence runs

High energy electric fence

For very long fence runs, say 1km or more, our previous electric fences are inadequate. This new design has a much lower output impedance so that it can drive long fence runs. It's our "industrial strength" model.

by COLIN DAWSON

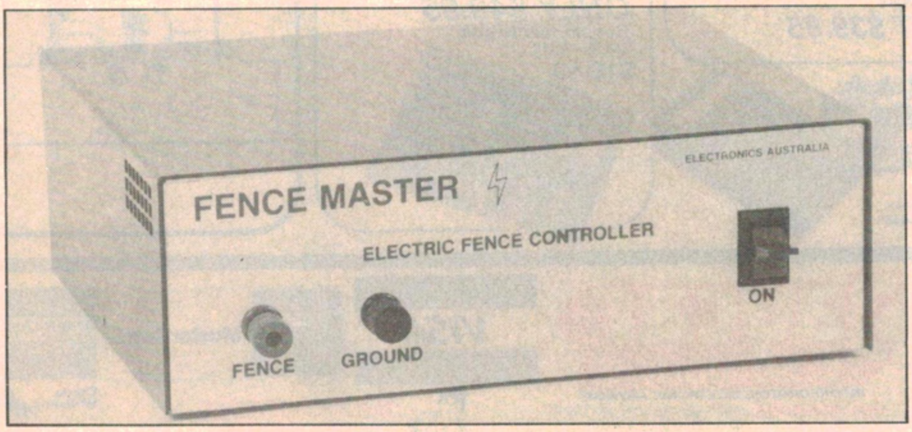
Our previous electric fences have been compact, inexpensive designs with low current drain — the sort of thing you might use to protect a vegetable patch or around an aviary to keep the cats away. And, of course, they were quite suitable for livestock control on farms, provided the fence run was kept short.

That was where the problem came in. From the spate of enquiries we received following publication of our Electric Fence Controller in the December 1985 issue, it was obvious that many farmers required something for use in the wide open spaces — in short, something that could power a fenceline several kilometres long.

This requires a circuit with substantially more "punch" than our previous designs. Our new Fence Master can deliver this punch — a high-energy open-circuit 5kV punch to be exact. These voltage punches are delivered at a nominal 1Hz rate and have an open-circuit pulse duration of about 0.4ms.

But perhaps the most important parameter in an electric fence is the output impedance. This must be kept low to stop the output voltage from drooping due to loading effects along the fenceline. This loading down of the output voltage can be caused by such things as wet grass or dirty insulators, and is one of the main factors affecting range.

Our new Fence Master has really low output impedance to minimise loading effects. So, if you want a really potent electric fence for long fence runs, this is the one to go for.



The Fence Master will require weather-proofing for field operations.

Special parts

The biggest obstacle in achieving a reasonably high power output is that it requires parts which are not normally available off the shelf from component retailers. The main problem was the output transformer — a suitable design simply didn't exist!

Rather than compromise with less than ideal components, we decided to round up all the special parts needed for the project. This mainly involved tracking down a special high-voltage capacitor. As for the transformer, we solved that problem by arranging to have a new design wound to our specifications.

In order to determine the ideal type of output transformer, we experimented with various 'customised' mains transformers (ie, with half the winding ripped out). And although we eventually achieved reasonable characteristics, the output voltage rating ruled out this approach for the final version. With an output in the order of kilovolts, the voltage gradient between adjacent windings had to be considered.

An electric fence output transformer requires a layer-wound secondary, with insulating leaves between layers. Fortunately, Jones Transformers came to the party and will be supplying the JT349 transformer especially for this project.

The high-voltage capacitor problem was solved by Plessey who manufacture a capacitor specifically for electric fences. It is rated at 900V and has a capacitance of 30μF — a brutish component if ever there was one. It should be handled with care — touching the terminals of a fully-charged capacitor could be fatal.

Having stored away nearly a Joule of energy, the next problem is to unleash it instantly. An SCR is the obvious choice, but no ordinary SCR will do. We eventually selected the Philips BTY91-800R to do the job, although the Marconi CR20-U08JY can be directly substituted. Both are rugged stud-mounted devices rated at 800V.

In addition to the stiff requirements imposed by the electrical nature of the circuit, the Australian Standards Association also have a say. The most important considerations are peak output voltage, pulse width and repetition rate. Our Fence Master conforms to the requirements laid down by the SAA.

Circuit description

Despite using some specialised components, the design of our electric fence is conventional. The battery voltage feeds into an inverter which steps it up to 250V. A capacitor is charged to this voltage and once every second is discharged into the primary of the output transformer which steps it up to 5kV.

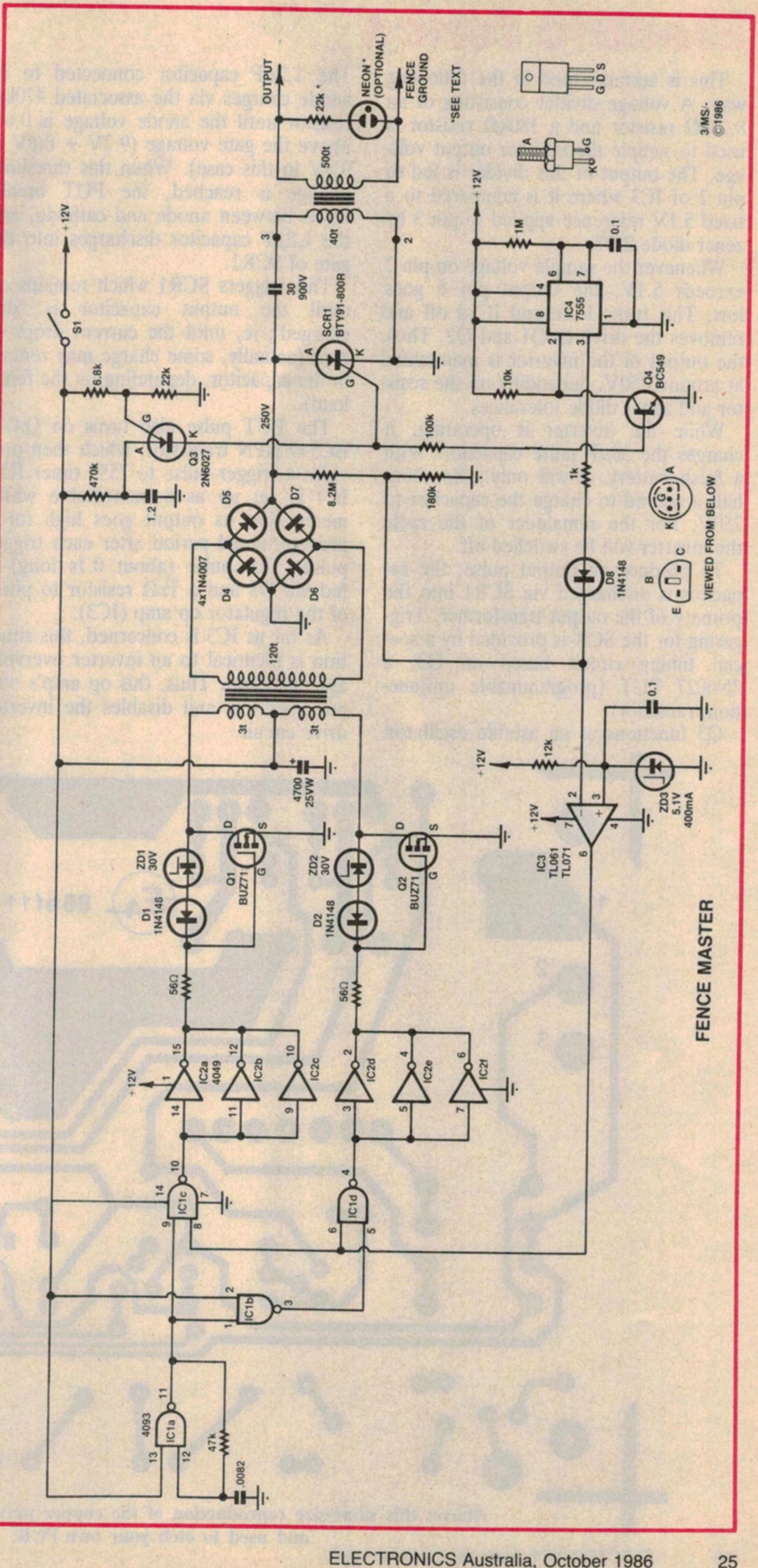
The inverter clock is formed by IC1a which is a 4093 CMOS Schmitt NAND gate. This is set up to oscillate at about 23kHz and its output is fed to pin 1 of IC1b and pin 9 of IC1c.

IC1b functions as an inverter, changing the phase of the signal by 180° before feeding it to pin 5 of IC1d. This means that IC1c and IC1d are fed with complementary drive signals and these signals switch transistors Q1 and Q2 in the inverter circuit via buffer stages IC2a-IC2d.

The remaining inputs of IC1c and IC1d, pins 5 and 8, are connected together and fed with a gating signal from the output of IC3. This gating signal provides output voltage regulation. When the gating signal is high, Q1 and Q2 are driven by complementary square wave signals at 23kHz. When the gating signal is low, both transistors are turned off.

Q1 and Q2 each drive one half of the split primary winding of the inverter transformer. Because the drive signals are 180° out of phase, 12V peak-to-peak is impressed across each half-primary winding and the primary voltage is 24V RMS. This voltage is stepped up by the transformer turns ratio (120:3) to give a nominal 960V peak-to-peak across the secondary.

This secondary voltage is now applied to bridge rectifier D4-D7 to give a nominal 960V output. But we don't want 960V. We only want 250V, so we turn the inverter off whenever the DC output voltage rises above 250V.



Electric fence

This is accomplished in the following way. A voltage divider consisting of an 8.2MΩ resistor and a 180kΩ resistor is used to sample the inverter output voltage. The output of this divider is fed to pin 2 of IC3 where it is compared to a fixed 5.1V reference applied to pin 3 by zener diode ZD3.

Whenever the sample voltage on pin 2 exceeds 5.1V, the output pin 6 goes low, This turns IC1c and IC1d off and removes the drive to Q1 and Q2. Thus, the output of the inverter is maintained at around 250V, depending on the resistor and zener diode tolerances.

While the inverter is operating, it charges the 30μF pulse capacitor. With a fresh battery, it will only take about half a second to charge the capacitor to 250V. For the remainder of the cycle the inverter will be switched off.

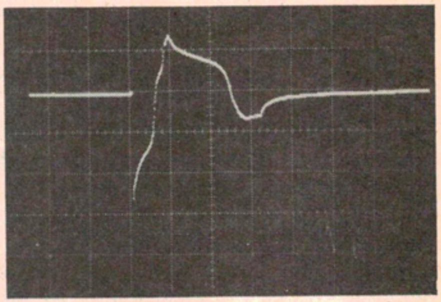
To produce an output pulse, the capacitor is discharged via SCR1 into the primary of the output transformer. Triggering for the SCR is provided by a special timing circuit based on Q3, a 2N6027 PUT (programmable unijunction transistor).

Q3 functions as an astable oscillator. The 1.2μF capacitor connected to its anode charges via the associated 470kΩ resistor until the anode voltage is 0.6V above the gate voltage (9.2V + 0.6V = 9.8V in this case). When this threshold voltage is reached, the PUT breaks down between anode and cathode, and the 1.2μF capacitor discharges into the gate of SCR1.

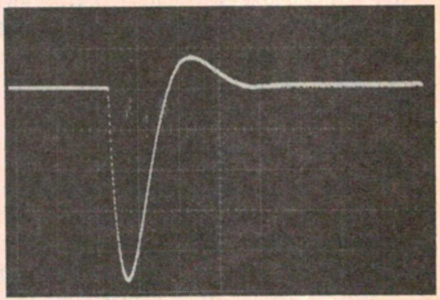
This triggers SCR1 which remains on until the output capacitor is 'discharged'; ie, until the current drops to zero (actually, some charge may remain in the capacitor, depending on the fence load).

The PUT pulse also turns on Q4, a BC549 NPN transistor, which then provides a trigger pulse to 7555 timer IC4. IC4 is set up as a monostable which means that its output goes high for a predetermined period after each trigger pulse. This pulse (about 0.1s long) is fed via D8 and a 1kΩ resistor to pin 2 of the regulator op amp (IC3).

As far as IC3 is concerned, this situation is identical to an inverter overvoltage condition. Thus, this op amp's output goes low and disables the inverter drive circuit.

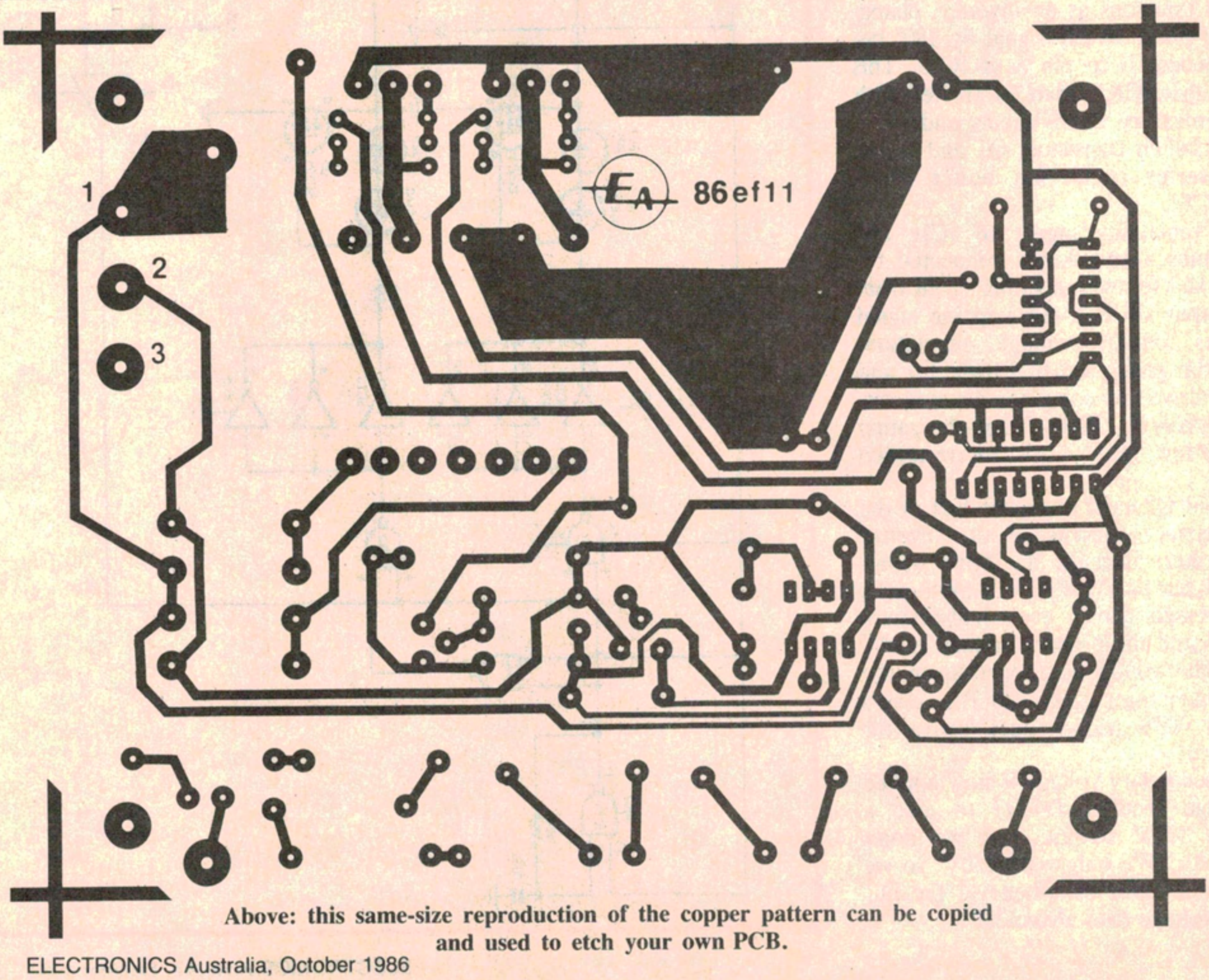


Above: open-circuit output waveform. (CRO settings — 2kV/div and 0.1ms).



Above: output waveform into a 500Ω load. (CRO settings — 400V/div and 0.1ms).

So why has this been done? The answer is that we need to turn the inverter off for a brief period after each output pulse to ensure that the SCR turns off (remember that the current through the



Above: this same-size reproduction of the copper pattern can be copied and used to etch your own PCB.

SCR must be reduced to zero before it will switch off). This technique also ensures that the inverter does not feed into the virtual short circuit when the SCR conducts.

With the output terminals open circuit, the output pulse from T2 lasts for about 0.4ms. This includes a substantial amount of ringing after the first half cycle.

Note that a damping network consisting of 10 2.2kΩ resistors wired in series has been connected across the output of T2. It may seem odd that we have connected such a load across the output of the fence controller, but there is a sound reason for it. Without this load, the output pulse will exhibit a very short (20μs) spike about 2kV above the nominal level. Thus, to conform to AS3129, the circuit would have had to be 'detuned' to reduce this spike.

Unfortunately, this would also reduce the remainder of the pulse to a much less formidable level.

Rather than detune the whole circuit, it makes more sense to get rid of any initial transient which is well above the nominal level. This, in turn, allows the transformer to be driven harder so that a substantial part of the pulse is at a high voltage.

Because the transformer is driven with such a solid pulse, it holds up well under load. Note that the damping network does not reduce the voltage appearing across an external 500Ω load. There would be no gain in omitting it.

Finally, a neon indicator can be connected in series with the damping network if required. This would verify that a high voltage pulse is present at the output of T2. It should not be regarded as a guide to power output.

Construction

Most of the parts are mounted on a printed circuit board (PCB) coded 86ef11 and measuring 145 x 114mm. This is housed in a standard metal cabinet measuring 269 x 222 x 90mm. A Scotchcal front panel was used to give the unit a professional appearance.

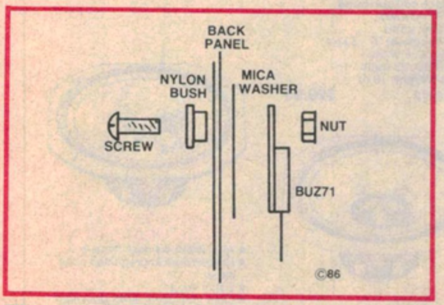


Fig 1: mounting details for mosfet transistors Q1 and Q2.

Before commencing assembly, make sure that the mounting holes for the SCR and the inverter transformer (T1) are large enough. The SCR needs a hole of 6.5mm, while the transformer mounting holes need to be about 1.7mm.

When the hole sizes are correct, use the PCB to mark out the standoff holes on the bottom of the cabinet. These holes should then be drilled to suit the plastic standoffs supplied.

Attention can now be turned to the PCB assembly. No particular procedure need be followed but we suggest that you mount the smaller components first, leaving T1 and the SCR until last. Note that there are four wire links (three if you include the neon indicator).

Make sure that you install the transistors, ICs, diodes and the electrolytic capacitor with the correct orientation. Also, mount transistors Q1 and Q2 at full lead length; this makes it easier to screw them to the back panel for heatsinking.

The SCR requires two insulated wire connections to the PCB in addition to its stud type anode. One of these is the cathode, which is connected to terminal 2 on the PCB, while the other is the gate, which is connected to a pad near the SCR at the back of the board.

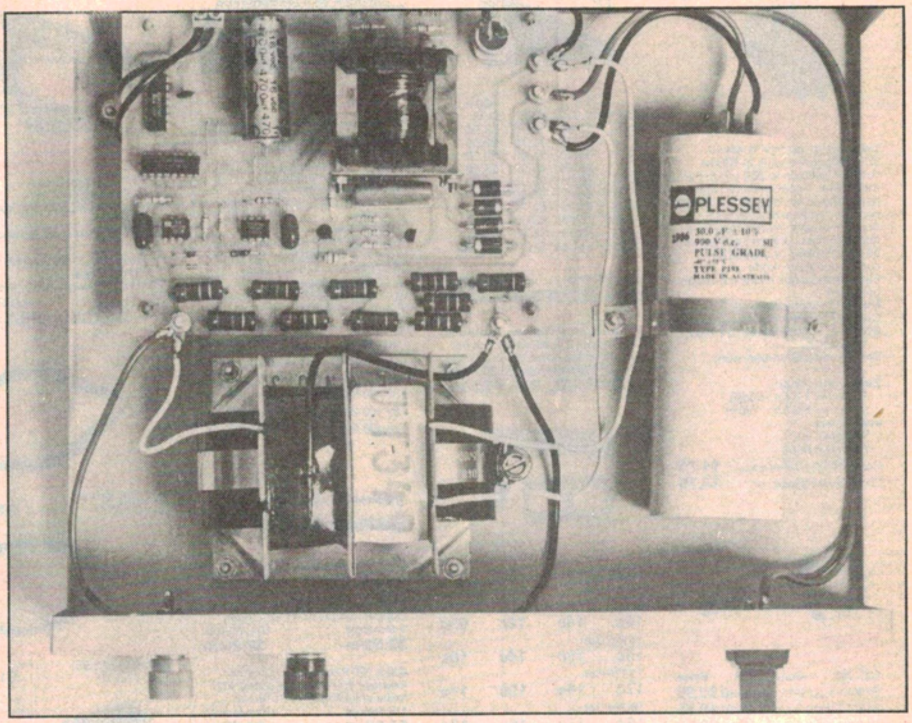
Note that terminals 1, 2 and 3 on our prototype do not correspond to those on the wiring diagram. The reason for this is that the PCB was subsequently rearranged slightly to improve the layout.

Terminals 1, 2 and 3 on the PCB, and the two high voltage connections, are all fitted with 3mm machine screws as terminal posts. These screws are passed upwards through the board and each locked in place with a single nut (this can be soldered if you want to ensure its security). Each terminal then has two leads connected to it via solder lugs and these are retained using additional nuts.

This was by far the cheapest method of obtaining high voltage, high current terminals.

Now for the inverter transformer. This is wound on a Siemens B66274-B1011-T1 former fitted with two B66339-G-X127 ferrite cores.

The primary is wound first, with each half wound separately using three turns of 1mm enamelled copper wire. The second half should be wound directly over the first at one end of the former and both windings should be in the same direction. One winding terminates on pins 1 and 2 (see wiring diagram),



This inside view shows the layout of the main components.

while the other terminates on pins 3 and 4.

The secondary winding occupies the remaining space on the former and consists of 120 turns of 0.6mm enamelled copper wire. Leave a 1mm gap between the secondary and the primary and wind on several layers, each slightly shorter than the preceding layer. Use adhesive tape to secure the windings and terminate the leads on terminals 6 and 12.

Once the PCB assembly has been completed, it can now be pushed onto its stand-offs, and the mounting holes marked for transistors Q1 and Q2. Remove the PCB before drilling the two holes to 3mm.

Four mounting holes must also be drilled for the JT349 transformer. Use the transformer itself as a template to mark out the holes. Similarly, carefully affix the Scotchcal artwork and use it as a template for the front panel holes. An additional hole will have to be drilled to accept the neon indicator if you elect to include this option.

Other holes which have to be drilled in the cabinet include: one for the power lead access; one for the power lead cord clamp; and two for the pulse capacitor retaining clamp. Each of these holes can be 3mm.

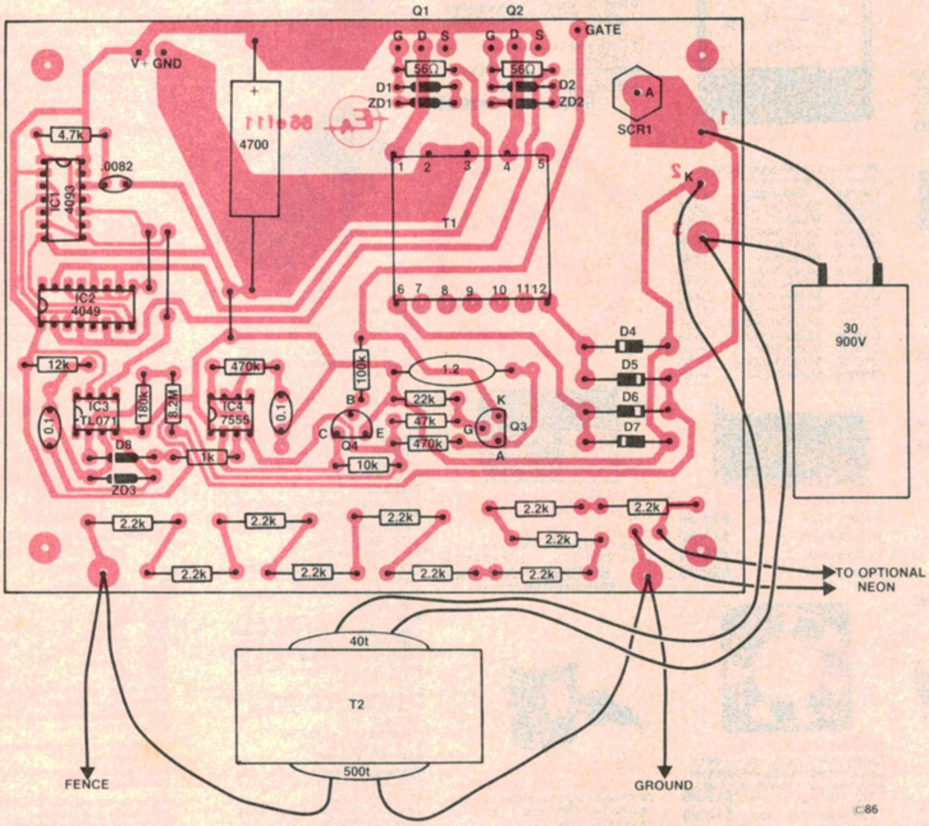
We fashioned a suitable capacitor clamp from a piece of scrap aluminium measuring 150 x 10mm. Wrap some plastic tape around the capacitor before installing the bracket. That way, the bracket can bite into the tape and hold the capacitor firmly in position.

You can now install the PCB and the remaining hardware items into the chassis. The two battery leads pass through a rubber grommet in the back panel and are retained by a small cord clamp. Use heavy-duty (32 x 0.2mm) wiring for the battery leads and for all internal wiring.

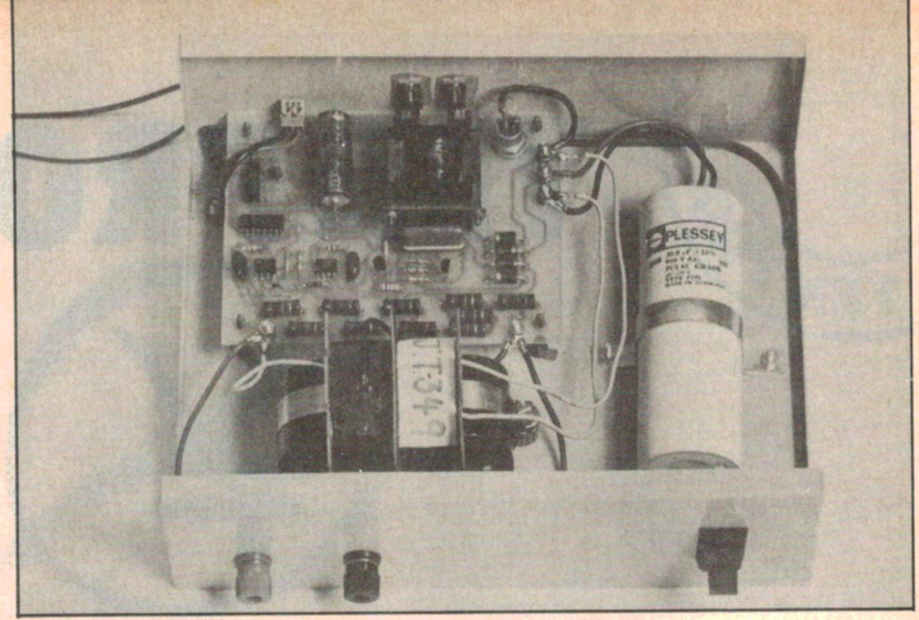
The two mosfet transistors (Q1 and Q2) must be insulated from the rear panel using mica washers and insulating bushes. Fig.1 shows the mounting details. Smear heatsink compound on all mounting surfaces before bolting the assemblies together.

Some readers may have an unused C-core transformer which they wish to modify for this project. Here are the details: primary — 40 turns 0.6mm wire, resistance 0.2Ω; secondary — 500 turns of 0.2mm wire, layer wound with polyester interleaving, resistance 75Ω. This gives a turns ratio of 12.5:1.

We can already see you racing for the calculator to prove that 250V x 12.5 does not add up to 5kV. No it doesn't, but we know. Pulse transformers are complicated creatures and do not abide by conventional transformer theory. If you refer to one of the accompanying oscilloscope photographs, you will notice a 'step' in the open circuit output waveform at around 3kV. This represents the transition from pulsed overvoltage to normal output voltage.



Here is the parts-placement diagram for the PCB. Note that the neon lamp must be replaced by a wire link if not used.



Be wary of the pulse capacitor — it can bite like an alligator.

Testing

An analog ammeter with a range of at least 0.5A can be used to test the circuit. This should be installed in series with one of the power supply leads to the battery.

At switch on, and immediately after each discharge, the meter should flick towards full scale. In fact, there is a transient of several amps but it is so short that the meter will not respond fully. The current should then quickly return to less than 100mA. If not, you have an error.

The circuit should discharge once every second. You will definitely know when it is discharging by a loud click from T2. Since the oscillator operates at 23kHz, you will not be able to hear the whistle from the inverter as the circuit builds up charge. However, you should be able to hear a faint 'frying' sound from T1 as the regulator cuts in and out.

If you prefer, the circuit can be tested in stages. To do this, disconnect all of the wires leading to terminals 1, 2 and 3. The first step is to check the inverter.

First, connect a load across the inverter output by installing a 10kΩ resistor between terminals 1 and 2. Next, replace the 4.7kΩ resistor between pins 11 and 12 of IC1a with a 22kΩ resistor. This will alter the oscillator frequency to 5kHz and allow you to hear the inverter working.

If you can't hear the new 5kHz inverter frequency, the inverter is not functioning correctly. Re-install the 4.7kΩ resistor at the end of this test procedure.

The next step is to verify that the trigger circuit is working. You can do this by connecting your multimeter (set to the 10V range) across the output of IC4 (pin 3). Pulses should be seen every second.

If all is well so far, only the discharge circuitry remains to be checked. To do this, restore the circuit to normal and switch on. As before, you should hear a loud click from the pulse transformer each time the 30μF capacitor discharges.

Finally, be very wary of the pulse capacitor. It can bite like an alligator as you will quickly discover if you are careless enough to get across the terminals when it is fully charged. You can make the circuit safe to work on by discharging the pulse capacitor through a 10kΩ resistor each time the unit is switched off.

PARTS LIST

1 JT349 C-core transformer
2 Siemens ferrite cores, B66339-G-X127 (100121)
1 Siemens former, B66274-B1011-T1 (100260)
1 Siemens mounting kit, B66274-B2002-X (100311)
1 Betacom metal cabinet, 269 x 222 x 90mm (or similar)
1 2-way PCB mounting terminal block
1 5A SPST toggle switch with all-plastic body (piano key type)
1 PCB, code 86ef11, 145 x 114mm
2 insulated panel-mounting jack sockets, 1 red, 1 black
1 neon lamp (optional)
4 20mm PCB stand-offs
13 3mm machine screws
18 nuts to suit screws
13 lock washers to suit
2 TO220 transistor mounting kits (insulating bushes plus mica washers)
1 rubber grommet to suit 4mm hole
2 metres heavy duty (32 x 0.2mm) hook-up wire (red)
2 metres heavy duty (32 x 0.2mm) hook-up wire (black)
1 500mm length of 1mm enamelled copper wire
1 cord clamp
1 capacitor bracket (see text)

Semiconductors

1 4093 quad Schmitt NAND gate
1 4049 hex inverter
1 Philips BTY91-800R or Marconi CR20-U08JY SCR
2 Siemens BUZ71 SIPMOS transistors
3 1N4148 diodes
4 1N4007 diodes
2 30V, 400mW zener diodes
1 5.1V, 400mW zener diode
1 2N6027 PUT
1 BC549 NPN transistor
1 7555 timer IC
1 TL071, TL061, LF351 op amp

Capacitors

1 4700μF 25VW electrolytic
1 30μF 900V pulse capacitor (Plessey)
1 1.2μF metallised polyester (greencap)
2 0.1μF greencaps
1 0.0082μF greencap

Resistors (0.25W, 5%)

1 x 8.2MΩ, 1 x 1MΩ, 1 x 470kΩ, 1 x 180kΩ, 1 x 100kΩ, 1 x 22kΩ, 1 x 12kΩ, 1 x 10kΩ, 1 x 6.8kΩ, 1 x 4.7kΩ, 1 x 1kΩ, 2 x 56Ω, 10 x 2.2kΩ 1W 500V (Philips MR52 or PR37).

Where to get the parts: complete kits for this project should be available from a number of retailers, including Jaycar Pty Ltd, Altronics and Rod Irving Electronics. All parts, including the PCB, are available separately from Geoff Wood Electronics. The PCB can also be purchased from RCS Radio or from Acetronics PCBs, while the Siemens ferrite cores and formers are available from Altronics and Jaycar Pty Ltd.