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WORLD LAMP

THOMAS SCARBOROUGH
and SURYA RAO MATURU

Low cost lighting when there's no mains supply available

THE quest for a battery-powered lamp for lighting in poorer areas has presented an interesting and important design challenge for many years. Such a lamp should ideally be cheap, simple, efficient, and flexible – all at the same time.

With this in mind, the authors have designed a lamp which is made from inexpensive stock parts throughout, runs off a nominal 12V d.c. supply, and will power any ordinary fluorescent lamp between 100mW and 15W. It will power the equivalent of a 60W incandescent lamp for about 80 hours off a standard 12V car battery.

CORE CONCEPT

Most d.c. powered fluorescent lamps use specialised components. While this may not pose a problem in major urban centres, it could pose serious supply problems in more remote areas of the world. The authors therefore searched for a means to unhook the World Lamp from the need for any uncommon or custom-made parts.

This is accomplished in the present design through a.c. pulse-width modulation (p.w.m.), which is the core concept of

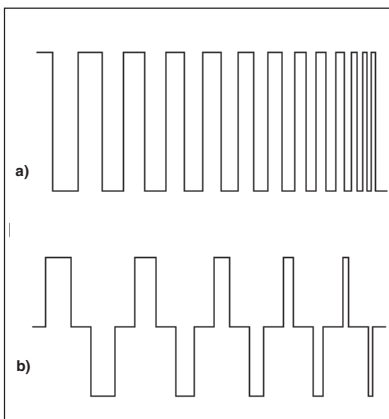


Fig. 1. A.C. pulse width modulation.

the design. In short, the faster a pulse passes through an inductor, the more the inductor resists it (called reactance).

The simple equation which applies to a pure sine wave is defined by X_L (reactance) = $2\pi fL$, where f is frequency, and L is inductance. If, for instance, an inductor of 1H is used on a 50Hz mains supply, its reactance is 314Ω. At 100Hz, its reactance rises to 628Ω. This fact is obviously useful in controlling a.c. power.

However, instead of simply changing the frequency which passes through the inductor (see Fig. 1a), the present design modulates the pulse-width (Fig. 1b), thus making the circuit very versatile, and also minimising problems associated with power dissipation.

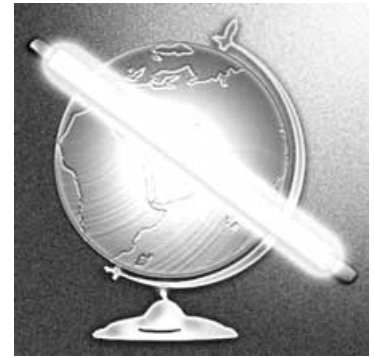
The practical implications of using a.c. p.w.m. are that a single circuit will power a very wide range of fluorescent lamps. Also, component tolerances may be fairly wide, since it is the pulse-width which is critical, not the components themselves. Supply voltage also becomes less critical, as p.w.m. compensates for voltage variations.

WORLD LAMP CIRCUIT

The complete circuit diagram for the World Lamp is shown in Fig. 2.

The circuit around Schmitt NAND gate IC1a is configured as an oscillator whose frequency is determined by the value of capacitor C3 and the total resistance across resistor R1 and preset VR1. The latter is used to set the square wave output frequency to between 60Hz and 70Hz.

From IC1a, the signal is routed in two directions, to IC1d and IC1b, the latter inverts the signal and sends it to IC1c. The circuits around IC1c and IC1d are identical and their input signals are the two complementary (opposite phase) signals from IC1a and IC1b. The two sub-circuits are configured as oscillators whose outputs can have their mark-space ratios simultaneously and identically changed. The



oscillators can only run when their control inputs are held high by the preceding gates.

To take the circuit around IC1c as the example, assume that the control input at pin 8 held high by IC1b. Capacitor C5 charges slowly via resistor R4 when the output of IC1c is high, until the voltage on input pin 9 crosses the Schmitt threshold, which causes the output to go low. Now the capacitor discharges at a faster rate via not only R4 but also resistor R5, diode D1 and potentiometer VR2a, which is used as a variable resistor. As a result, the time that the output of IC1c is low, can be varied in relation to the time that it is high.

Schmitt NAND gates IC2a and IC2b invert and buffer the twin pulse waveforms from IC1c/IC1d and their outputs are used to control the switching of power MOSFETs TR1 and TR2 in push-pull fashion. In turn, the MOSFETs drive the 6V-0V-6V dual winding of transformer T1, whose centre tap is connected to the +12V supply line.

The transformer is used in step-up mode and the resulting voltage across its output



winding is nominally about 230V peak-to-peak, but with the power available dependent on the width of the pulse that drives the transformer. Thus by varying the setting of dual-gang potentiometer VR2a/VR2b, the power which reaches the fluorescent tube can be varied.

SPECIFICATIONS . . .

- **Supply voltage.** 12V d.c. nominal, ± 20 per cent. This was the subject of keen debate between the authors, as 6V batteries are more freely available in certain parts of the world. However, 6V would likely have ruled out the use of more common stock parts.
- **All stock parts (off-the-shelf).** The boldest design decision – also keenly debated – which of necessity meant partially reduced light output, and less than the maximum quoted tube life. Nevertheless, the lamp surpasses various budget designs surveyed by the authors. This was considered necessary to make the difference between a more obscure design and one that could be built the world-over with ease.
- **Current consumption.** Approximately 120mA for a 100mW fluorescent “glow lamp”, rising to about 1.5A for a 15W fluorescent tube at full brightness. Tubes may also be dimmed, so that current consumption is much reduced.
- **Tube types.** Any fluorescent lamp rated 100mW to 15W, on condition that these *do not* contain an integral starter or ballast. This includes linear “strip lights”, four-pin (but not two-pin) compact fluorescent (c.f.l.s), 2-D lamps, “05 colour” (insect killer) lamps, ultra-violet “black lamps” (you must observe the necessary precautions to protect your eyes), and miniature glow lamps and neon indicators.
- **Light output.** Between one lumen for a sub-miniature fluorescent glow-lamp, up to about 900 lumens (the equivalent of 75W incandescent) for a four-pin 11W single c.f.l. at maximum brightness.
- **Starting method.** Single-filament warm-start. While cold-starting has advantages of simplicity and circuit economy in particular, this causes “sputtering” in the tube, which shortens the life of the tube. The alternative is warm-start, which first warms the filaments in the tube. In the present circuit, the warming of a *single* filament vastly improves starting.
- **Frequency.** 60Hz to 70Hz. This was a necessary result of the “all stock parts” decision, and minimises iron loss in the transformer in particular.

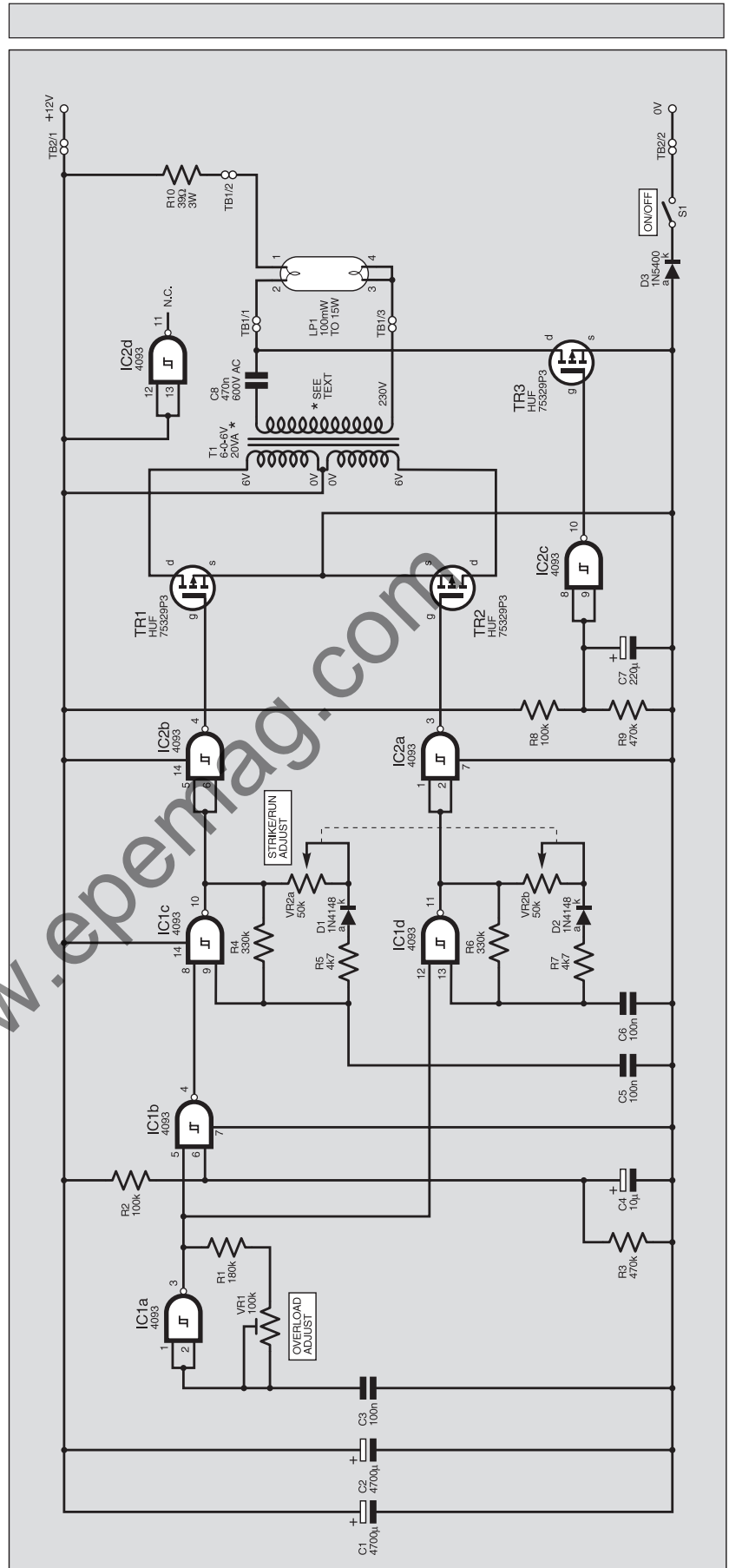


Fig.2. Complete circuit diagram for the World Lamp.

ON STRIKE

Capacitor C8 in series with the output winding of T1 provides current limiting – but not too much, otherwise more “stubborn” fluorescent lamps may not strike. If more stubborn fluorescent lamps are used (i.e. which will not strike easily), the value of C8 may be increased – with caution. The value of C8 may also be reduced, to prevent accidental abuse of smaller tubes.

“Pre-striking” of lamps when power is switched on is prevented by the R2, R3, C4 arrangement on one input of IC1b. This holds pin 6 low for a brief moment during switch-on, for the duration it takes capacitor C4 to charge up via resistor R2 before the gate’s threshold logic level is passed. During this time gate IC1c is disabled, so that only pulsed d.c. reaches the fluorescent lamp, as triggered via the IC1d path.

This greatly assists “striking” of the tube, since a unidirectional bombardment of ions first takes place, thus initiating conduction in the tube. A bidirectional bombardment can inhibit conduction.

It was found unnecessary to add any protection circuitry to the lamp. Only diode D3, in the 0V line, is added to prevent reversed polarity.

Transistor TR3 is switched on for half a minute at start-up to warm one of the filaments in the tube. While it is not entirely orthodox to strike a tube while warming a filament, this is common practice, and simplifies the start-up procedure. The warming of one filament can reduce the necessary start-up power by half, and thus greatly extends the life of the tube.

Although TR3 is directly connected to the high voltage section of the circuit, it does not close it, and is therefore unaffected by the high voltages present.

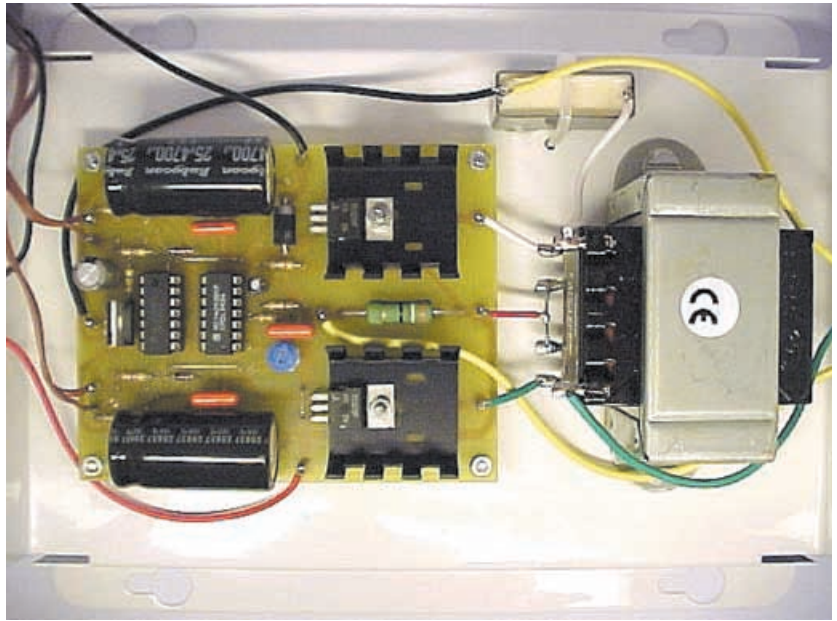
BENEFICIAL BLIPS

In order for the pulse width modulation to work smoothly, IC1a must oscillate either at or below the frequencies of oscillators IC1c and IC1d, otherwise these begin to fall out of sync with IC1a. If the frequency of IC1a rises above that of gates IC1c and IC1d, “blips” appear in the waveform across transformer T1’s windings, and the fluorescent lamp begins to “cycle”, or blink.

This, however, has a very useful function. With the correct setting of VR1, as soon as the lamp is turned up too high, it begins to blink. This provides a cheap and effective means of preventing any serious wastage of power, which can easily occur with fluorescent lighting. Preset VR1 needs to be adjusted with the aid of an ammeter (see later), or is disabled by turning it back (anti-clockwise).

The operation of this “Overload Adjust” function may best be understood visually. The two oscilloscope traces in Fig.3 show the voltage across the fluorescent tube when the World Lamp is: a) powering a 10W linear “strip light” at full brightness, and b) is turned up too high, so that a “blip” appears in the pulse width modulation.

Note that in some cases the lamp may need to be turned up “too high” momentarily in order to “strike” the tube (that is, to ionize the gas inside). Once this has been accomplished, it is turned down to its optimal level, and ceases to blink. In many



cases a correct setting of VR2a/VR2b will cause the tube to strike without the need for readjustment, as “run” current disables the higher “strike” voltage.

Note that since the output of the World Lamp is continuously variable, it is also possible on occasion to light up an otherwise “dead” fluorescent lamp. This could squeeze a few more evenings of light out of a lamp which would otherwise be a lost cause. Life may also be extended sometimes by reversing a tube.

Lastly, although transformer T1 may sometimes be pushed beyond its ratings, in practice this should not present a problem, so long as power dissipation, and thus heat, is kept within bounds. The authors pushed several standard transformers way beyond their voltage and power ratings, without any sign of failure. However, iron loss increases at higher power, which means reduced efficiency.

CONSTRUCTION

The World Lamp is built up on a single-sided printed circuit board (p.c.b.) measuring 100mm x 90mm. Details of the topside

component layout, together with the underside details, are shown in Fig.4. This board is available from the *EPE PCB Service*, code 340.

Begin construction by soldering the seven link-wires. Note that three of these are soldered underneath IC1 and IC2. Continue with the solder pins and 14-pin dual-in-line (d.i.l.) sockets. Then solder the resistors and diodes, continuing with the capacitors and transistor TR3.

Be careful to observe the correct polarity of the electrolytic capacitors, and the correct orientation of the transistors, diodes, and i.c.s. Note that C1 and C2 mirror each other on the board. The cathodes of the diodes are banded. Capacitor C8 may be strapped to the case with a cable-tie.

Bolt transistors TR1 and TR2 to their two heatsinks, using heatsink compound, then solder them in place, to achieve the correct stand-off from the p.c.b. Since the transistors are MOSFET devices, these should be treated with due care (ideally, short out the pins with a paper-clip while handling).

Attach switch S1, potentiometer VR2, and transformer T1 to the solder pins provided by means of suitable lengths of sheathed and stranded wire. If desired, use a panel mounting potentiometer in place of cermet preset VR1, and attach this to the p.c.b. as well. Insert IC1 and IC2 in their sockets, observing antistatic precautions (touching an earthed item before handling them).

BOXING UP

A metal enclosure is recommended, to help dissipate heat from the transformer in particular, and to minimise radio frequency interference (r.f.i.).

The p.c.b. and transformer are mounted securely inside with suitable nuts and bolts. If necessary, drill a few holes in the case to assist cooling. Fix S1 and VR2 (and VR1 if desired) to the front panel, adding a calibrated scale if preferred.

Ensure that all the circuitry surrounding the transformer’s 230V winding is enclosed. If available, connect this winding to proprietary fixtures to hold the tube, using suitably rated mains connecting

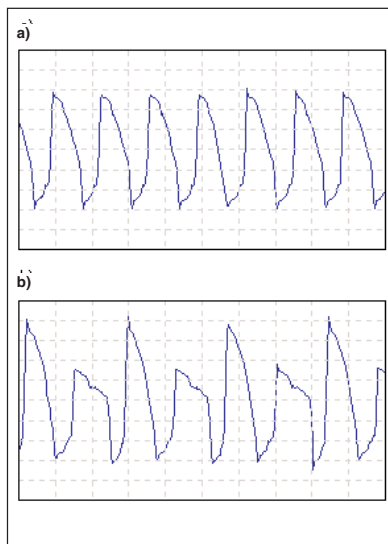


Fig.3. “Blips” across a 10W tube: (a) full brightness and (b) too high.

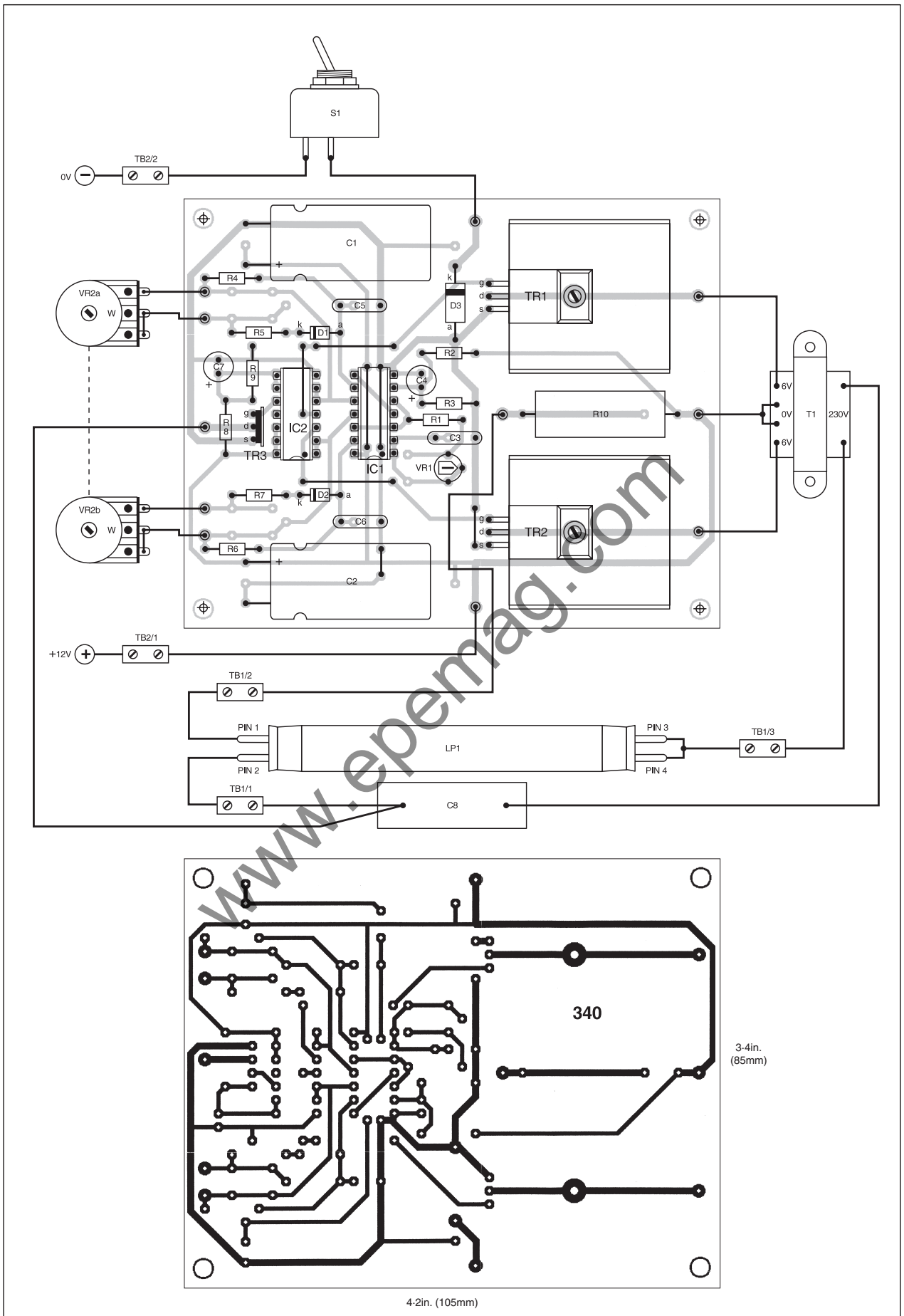


Fig.4. Printed circuit board component layout and off-board connection details, plus full size underside copper foil master track pattern.



Completed World Lamp in a robust well-ventilated metal case.

wire. Keep these wires relatively short, to minimise wiring capacitance. A 2-way and 3-way terminal block are used to connect wires to the battery and lamp, and in the prototype they were mounted on the outside of the case.

To prevent over-voltages in a tube through careless starting (thus causing sputtering from the filaments), optional presets may be wired in parallel with VR2a/VR2b to make up about 50kΩ in parallel – the equivalent of a rotation-limit stop. Provision is made for such presets on the p.c.b.

EQUIVALENTS

Generally speaking, any rough equivalent to the components specified may be

used. Where equivalent transistors are used, check the pinouts for correct placement on the p.c.b. Special note should be taken of the following:

- **Potentiometer VR2a/VR2b.** A dual potentiometer is ideal, but two single potentiometers may be used, with one or both of these being used to strike the tube. During normal running, both potentiometers are turned to the same position.
- **Capacitor C6.** A 600V a.c. rating is recommended, although slightly lower voltages may work without trouble.
- **Transistors TR1 and TR2.** Some care needs to be taken in the selection of these MOSFETs. They should be able to conduct at least 50W, and their “on” resistance should ideally be 0.02Ω. An “on” resistance of up to 0.05Ω may be used, but monitor heat dissipation carefully. Note that prices of equivalents may vary tremendously. Possible equivalents would include: IRFZ44N, IRL3202, IRFU3303, HUF75321P3 and (likely to run hotter) BUZ22, IRFZ34E, RFP25N06 and IRL2703.
- **Transistor TR3.** This may be the same as TR1 and TR2, or virtually any MOSFET which is rated about 0.5A or more.
- **Gate IC1.** The Motorola version of this Schmitt trigger NAND gate is recommended (MC14093BCP), although any make should suffice. Do not use the 4011 quad NAND gate as this is not a Schmitt trigger device.
- **Transformer T1.** The VA rating should be at least double that of the fluorescent lamp wattage to prevent overheating – e.g. an 11W c.f.l. tube should use at least a 22VA transformer (11VA or 1.8A per low voltage winding). Other close similar secondary voltage ratings may be used, particularly 5V-0V-5V. Secondaries having too high a voltage



The World Lamp can drive fluorescent tubes from 100mW to 15W.

rating, though, may not strike the fluorescent tubes, especially the larger ones.

COMPONENTS

Resistors

R1	180k
R2, R8	100k (2 off)
R3, R9	470k (2 off)
R4, R6	330k (2 off)
R5, R7	4k7 (2 off)
R10	39Ω 3W

All carbon film 0.25W 20% except R10

Potentiometers

VR1	100k cermet preset (see text)
VR2	50k dual-ganged rotary carbon, lin

Capacitors

C1, C2	4700μ radial elect. 25V (2 off)
C3, C5, C6	100n polyester (3 off)
C4	10μ radial elect. 16V
C7	220μ radial elect. 16V
C8	470n 600V a.c. rated (see text)

Semiconductors

D1, D2	1N4148 signal diode (2 off)
D3	1N5400 rectifier diode
TR1 to TR3	HUF75329P3 n-channel power MOSFET (3 off) (see text)
IC1, IC2	4093 quad Schmitt trigger NAND gate

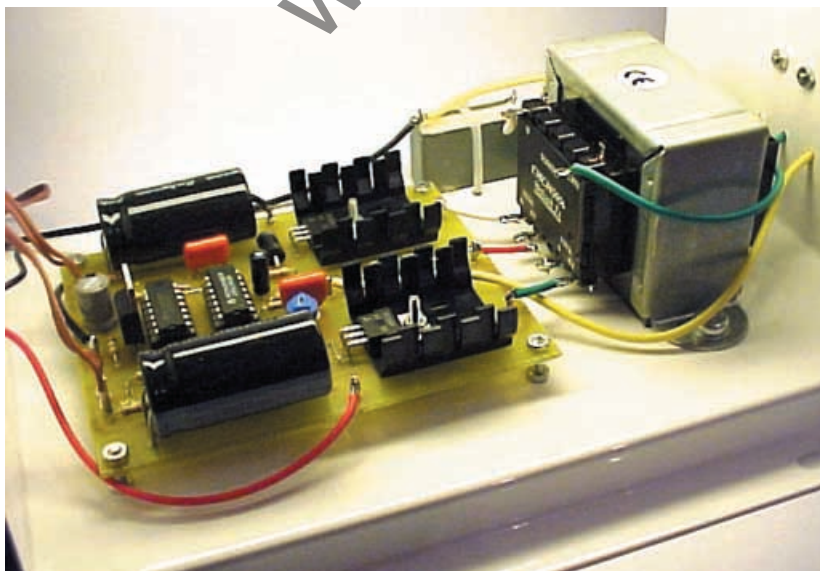
Miscellaneous

S1	s.p.s.t. toggle switch, 3A
T1	6V-0V-6V 20VA mains transformer, chassis mounting (see text)

Printed circuit board, available from the EPE PCB Service, code 340; heatsink, 20°C/W or less (2 off); terminal blocks PVC or ceramic, 500V a.c. 3-way and 2-way; fluorescent lamp and fittings (see text); metal case to suit; 14-pin d.i.l. socket (2 off), connecting wire; terminal pins; solder, etc.

Approx. Cost
Guidance Only

£20
excluding batts



Interior view of the World Lamp, showing the relative positions of the printed circuit board and transformer.

- **Heatsinks.** Any 0.5mm or greater thickness metal may be cut and drilled. Note that the two heatsinks should never touch each other.

SAFETY PRECAUTIONS

The World Lamp produces high voltage, up to and exceeding 400V a.c. This is hazardous, even though the current is limited, and is capable of giving a nasty, potentially fatal, shock.

Contact with all circuitry surrounding transformer T1's 230V winding should be carefully avoided when the unit is on. If you need to work on the World Lamp when it is on, use insulated tools, and work with one hand behind your back.

High voltage circuitry should be fully enclosed and, as far as possible, proprietary fittings should be used to hold the fluorescent tube. Failing this, suitable lengths of plastic tubing may be tightly fitted over the ends of a tube to prevent fingers from touching the terminals.

Fluorescent tubes contain a small amount of metallic mercury, so contact with any broken glass would best be avoided.

IN USE

Begin by turning back (anti-clockwise) VR1 and VR2 completely. Attach a fluorescent lamp to the circuit, exactly as shown in Fig.4, observing full safety precautions. Colour-coded wires were used in the prototype.

To calculate the circuit's likely power consumption, note the wattage of the tube on test. Add 20 per cent to this (e.g. 10W + 20% = 12W). Then divide by 12. This represents the approximate power which the circuit should be drawing while running normally (this might differ from tube to tube, and even drop as tube filaments warm).

Power up the circuit, using an ammeter in series with a d.c. power supply to monitor current consumption. If you have a

choice, set this to a 2A or higher output setting. Use an adequate power supply, otherwise the lamp may flicker. It is suggested that a modestly rated tube be used to begin with, say 6W.

On start-up, the fluorescent tube should briefly flicker, then gently glow. Current consumption should initially be between 200mA and 300mA. If not, switch off and recheck the circuit.

Now gently turn up (clockwise) VR2. At a certain point, the tube should "strike" – that is, its brightness should suddenly and dramatically increase. Then it may be necessary to turn VR2 back to find the normal running current. Note that one filament is warmed for half a minute at start-up. If the tube does not "strike", you may have exceeded this period. In this case, switch off the lamp for five seconds, then start again. The filament draws around 200mA current.

Once the lamp is running satisfactorily, gently turn VR1 (Overload Adjust) clockwise until the tube begins to blink or flicker. Then turn back slightly so that it just stops flickering. If VR2 is now turned up too high, the lamp will blink again. VR1 may be disabled by turning it back (anti-clockwise) – but not too far, otherwise the lamp may again flicker slightly due to reduced frequency.

For the first hour, carefully monitor heat dissipation in the circuit, since heat can slowly build up. The transformer may become warm, as well as transistors TR1 and TR2, and diode D3. The transformer in particular ought to run below 50°C.

If you are sure that there is no chance of reversed polarity, D3 may be omitted for improved efficiency (its absence will release seven per cent more power, and may help to strike tubes up to about 20W).

The circuit may buzz gently. This is normal for a fluorescent lighting circuit.

While the approximate cost is shown in the components list as £20, this represents a conservative first-world estimate.



Test clips on an 11W c.f.l. assembly.

The one-off cost in poorer regions of the world is likely to fall substantially below this.

The following Internet resources were found to be particularly helpful, and may be referred to:

Lights and electronics – www.epanorama.net/links/lights.html (links)

Sam's F-Lamp FAQ – www.misty.com/people/don/f-lamp.html

Fluorescent lamp inverters – www.misty.com/people/don/flvdc.html

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