Fluorescent light inverter for 12 V battery operation

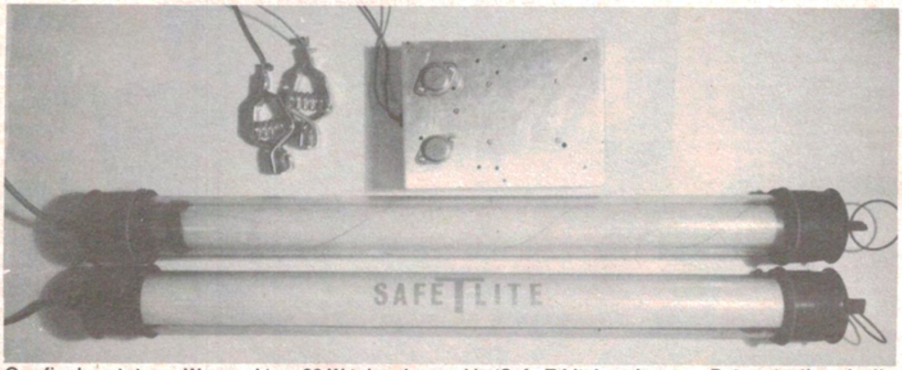
This inverter will drive two 20 W, one 40 W or one 20 W fluorescent tube from a 12 V battery. Light output is some three times that of an equivalent power incandescent globe and efficiency is very high.

David Tilbrook

WE FIRST published a fluorescent inverter in the November 1972 issue of ETI. It was a self-oscillating circuit, running at around 2 kHz, and was intended for use with a 20 W fluorescent tube and a 12 V battery. The circuit worked well, and countless numbers have been built over the years. The only disadvantage is the 2 kHz running frequency, which generates an audible tone that can be difficult to silence. Having decided to publish a new design, the main priority was to develop a circuit that would run above 20 kHz, making the inverter totally silent. However, this proved to be a much more difficult task than was first expected, and most of the initial prototypes failed miserably.

The main problems associated with running above 20 kHz are caused by losses in the cores and switching transistors, causing excessive heating and inefficiency. The circuit finally developed overcame these problems with the help of some cores from Philips that exhibit very low loss above 20 kHz. The problem with the switching loss was reduced by using BDY91 transistors, which have very low saturation voltages but fast switching speeds.

The circuit is a self-oscillating, saturating, push-pull inverter, similar in concept to the earlier design. The frequency of operation of these circuits depends on the number of turns on the primary of the transformer and on the properties of the core material. In general, if the primary turns are decreased the oscillation frequency is increased, since the magnetic field intensity necessary to cause core saturation occurs sooner, and core saturation causes the circuit to toggle to the opposite state. (A more detailed description of this is included in the How It Works section.)

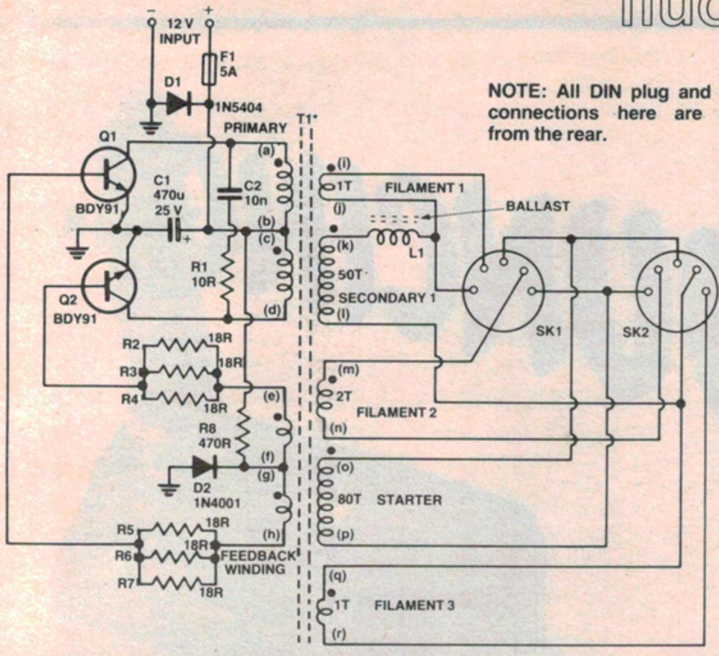


Our final prototype. We used two 20 W tubes housed in 'Safe-T-Lite' enclosures. Put protective plastic caps over the transistors to prevent shorts. One 'starter' wire (see circuit) can be seen wound around the top tube.

In the initial prototype designs we tried to use common potcores such as the FX2242 or FX2243. Unfortunately these have relatively large core loss above 20 kHz, and operation of the inverter for only 15 minutes caused core temperatures of well above 150°C. Furthermore, although it was possible to make the circuit oscillate above 20 kHz, this was achieved only by allowing the transistor to saturate in order to cause switching of the circuit. This was done by limiting the amount of base drive to the transistors so that when sufficient current flowed through the transistors a voltage drop would start to appear across them, causing switching. It was impossible to make the cores saturate before the transistors with a reasonable number of turns on the primary. The problem with this technique is that the increased voltage drop across the transistors causes an increase in the power dissipation in these devices, further decreasing the efficiency of the circuit.

The solution, as mentioned above, was to use a core capable of working above 20 kHz with negligible loss. We chose Philips EC52/24/14 cores as we had previously used them in the ETI-142 power supply (Feb. '79). They are commonly used in switch-mode applications and have been available for some years. See the 'Shoparound' page this issue for suppliers. The design uses four of these cores (they come in core halves), two for the main inverter transformer and two for the ballast inductor core.

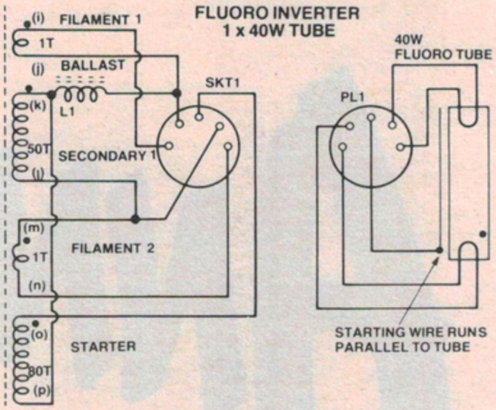
Fluorescent tubes, like most gas discharges, have a negative resistance and will pull extremely large currents if allowed to. To overcome this it is necessary to place an appropriate amount of impedance in series with the tube, limiting the current to a realistic value. A resistor of course cannot be used, since power dissipation would be enormous. Instead the ballast inductor is used, which has another advantage not immediately obvious. If the supply voltage to the inverter is decreased, by a slowly flattening battery for example, the frequency of oscillation and the output voltage will decrease. However, since the impedance of the ballast decreases at lower frequencies, the effect of decreased voltage is offset somewhat, and light output does not drop as much as expected. Similarly, if the voltage applied to the inverter is too



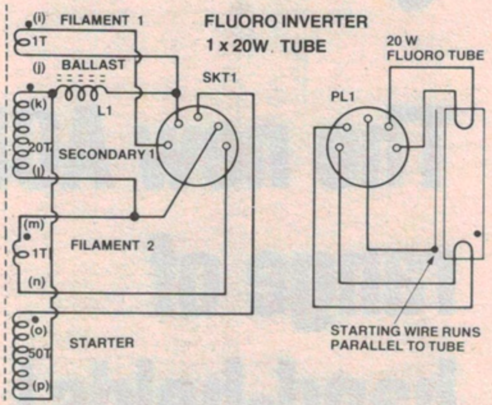
NOTE: All DIN plug and socket connections here are shown from the rear.

ABOVE: General circuit of the inverter, configured to drive two 20 W tubes, as in our final prototype.

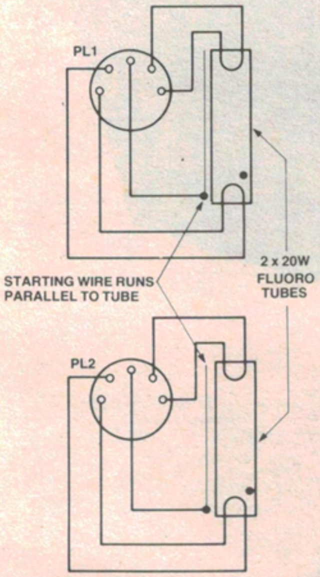
BELOW: Tube wiring details. Note that they are connected in 'series'. The 'starter' wire brings about initial ionisation of the tube. It may be laid parallel to the tube or wound around it once or twice.

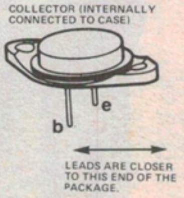


Arrangement for driving a single 40 W tube.

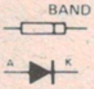


Arrangement for driving a single 20 W tube.





power transistors



DIODES

high, the oscillation frequency tends to increase, the impedance of the ballast increases, and once again the tube current is maintained closer to the optimum, ensuring good tube life.

This inverter can be configured to drive one 40 W tube, two 20 W tubes or one 20 W tube. However, the latter option is not recommended as actual power dissipation goes up! Battens for two 20 W tubes and for a single 40 W tube are readily obtainable from lighting suppliers and it is possible to build the inverter into these. We elected to have a pair of 'portable' 20 W tubes driven from the one inverter, constructed in a convenient aluminium box. ▶

HOW IT WORKS — ETI-1505

The circuit is a push-pull, self-oscillating inverter. The moment the supply voltage is connected, current flows through the 470 ohm resistor, R8, through the feedback winding and current limiting resistors to the bases of Q1 and Q2. One of these two transistors will turn on, as both devices are not exactly matched in characteristics, and force the other transistor to turn off. If, for example, Q1 turns on, current will flow through a-b of the primary winding. This causes a magnetic field to build up in the transformer core creating a positive voltage on d, h, j, l, n, p and r (i.e: the finish of each winding), the 'starts' being indicated by a ●). So, the base of Q2 is driven negative, forcing the transistor hard off. The base of Q1 is driven positive, driving the transistor hard on.

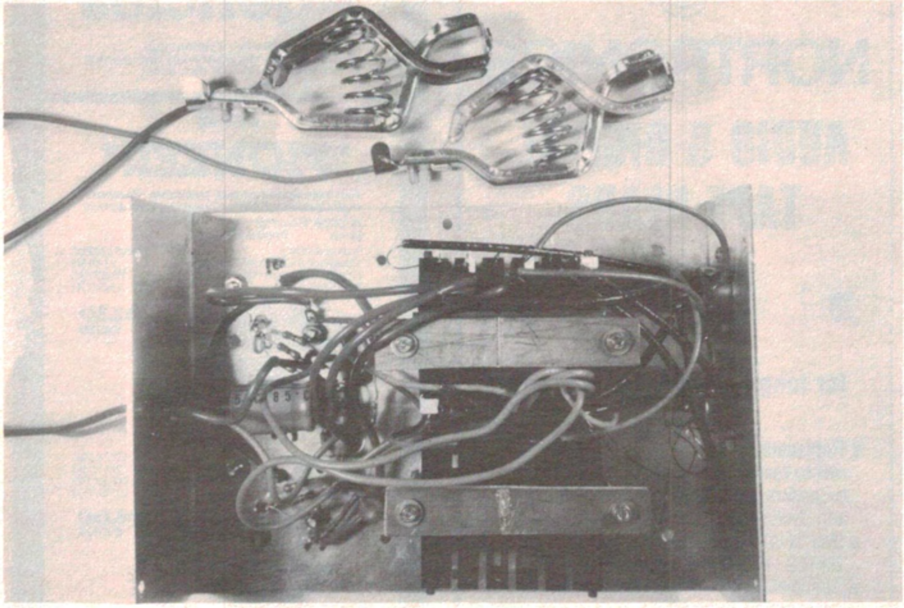
Since the primary of T1 acts as an inductor, the current flowing increases linearly for as long as the voltage is applied until finally the magnetic field intensity reaches a maximum, where the transformer core saturates. At this moment, the impedance of the core drops since the saturated core cannot maintain the relatively high inductance of the primary. The decreased impedance causes an increase in current flowing in the primary, driving the core even further into saturation until most of the coupling between coils on the transformer is lost. This causes the drive voltage to the transistor bases to disappear. Current stops flowing in the transformer and the magnetic field starts to collapse. This causes the voltage sense of each winding to reverse and the start (●) of each changes from negative to positive. This removes charge from the base of Q1, which turns off, and drives the base of Q2 hard on. The whole sequence of events then repeats itself, only Q2 is now hard on and Q1 is hard off.

In this way, the circuit oscillates at a frequency determined by the core material, the number of primary turns and the applied voltage.

Resistor R1 and capacitor C2 serve simply as a 'snubber' to remove flyback voltage spikes from the collectors of the transistors, preventing destruction of the devices by overvoltage. Diode D2 is incorporated to enable starting of the circuit but is 'transparent' during operation.

The transformer secondaries are wound to provide the necessary voltages for either 20 W or 40 W fluorescent tubes maintaining voltage and filament voltage. The 'starter' winding is necessary to ionise the gas in the tube to induce the tube to light. This could be done by increasing the secondary voltage but this causes an unnecessary current consumption in the primary. A separate starter winding is by far the better approach and the one we have used.

The ballast inductor L1 serves to limit the current flowing through the tube(s) which have a negative resistance characteristic and can draw very high currents once lit, if allowed.



Internal view of our final prototype inverter, showing general layout. The inverter transformer, T1, is at upper right, the ballast, L1, below it.

Construction

Best place to commence is with the hardware. We housed the unit in an aluminium case we had to hand that measured 170 mm long by 125 mm wide by 55 mm deep. This allowed plenty of room to mount everything. Any housing of a suitable size could be used, or the circuitry could be built into the base of a fluorescent light batten.

You'll need to drill TO-3 mounting hole patterns for the two power transistors (Q1 and Q2). Use an insulating washer as a template. The two transistors can be mounted adjacent to one another. We mounted ours 50 mm apart (between centre lines), toward one end of the box. The 7-lug tagstrip was mounted between them, toward the middle of the box, allowing plenty of room to mount the transformer and ballast in the area left. The two DIN sockets were mounted on the end panel, at the end of the box opposite the transistors. You'll need to drill suitable holes for the transformer mounting clamps. While the transformer assemblies are generally supplied with special mounting clamps, these may sometimes be unavailable. We didn't have any so fashioned some out of some 55 mm long bolts and a scrap of pc board for a top clamp (either remove the copper or cut it so that the bolts, chassis and clamp don't make a shorted turn around the core). When you're mounting transformer T1 later, its core should be separated from the chassis a little by a strip of cardboard or pc board. This reduces eddy current losses in the chassis and core and reduces chassis and core heating during operation.

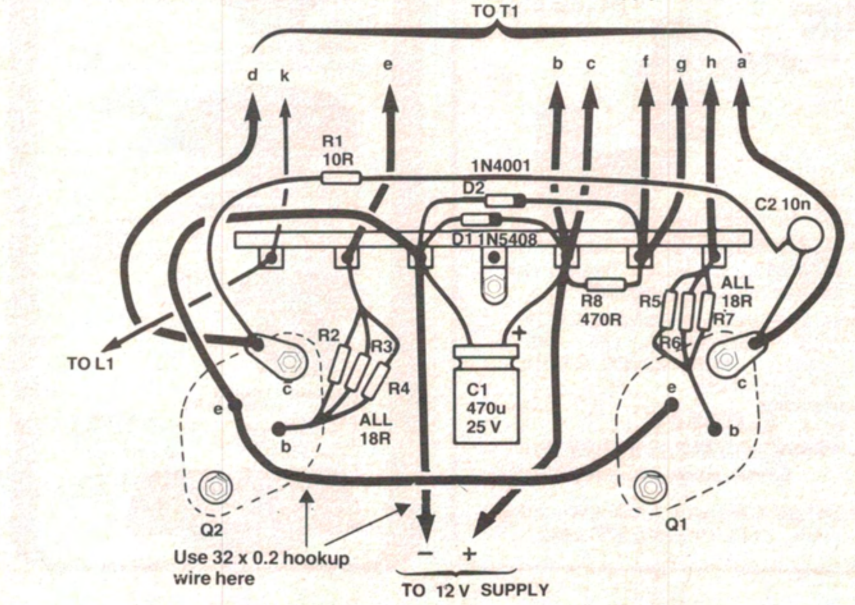
We leave the exact details to you as individual construction will likely vary considerably.

With the chassis drilled, mount the transistors first, using insulating washers, thermal compound and bushes for the mounting bolts. Put a solder lug under one mounting nut on each transistor (inside the chassis) for collector connections.

Next mount the tagstrip and solder in the resistors, capacitors, diodes and transistors, so far as possible. Refer to the wiring diagram.

Wind T1 and L1 next. Details are given in the accompanying panel. Having completed T1 and L1, assemble and mount T1 first. Sleeve all enamelled copper wire flying leads with spaghetti insulation. Make sure you can identify each lead. Wire up T1 according to the circuit and wiring diagram. Take particular care wiring up the DIN socket or sockets — depending on whether

General wiring diagram. Don't forget the line fuse in the positive 12 V supply lead.



PARTS LIST — ETI-1505

Resistors .... all ½W, 5%

R1	10R
R2, 3, 4, 5, 6, 7	18R
R8	470R

Capacitors

C1	470u/25 V RB electro.
C2	10n ceramic

Semiconductors

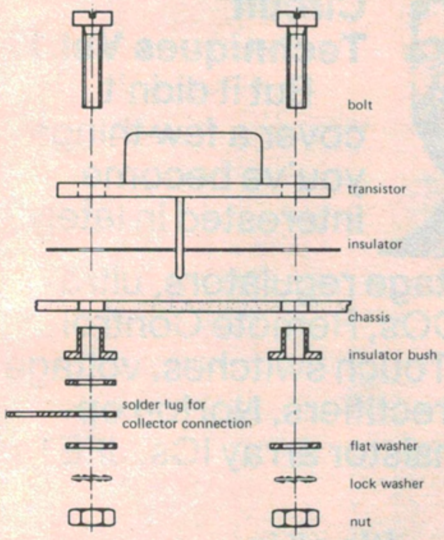
D1	1N5404 or similar
D2	1N4001 or similar
Q1, Q2	BDY91 or BDY92

Miscellaneous

F1	5 A fuse and in-line fuseholder
PL1, PL2	5-pin DIN plugs
SK1, SK2	5-pin DIN sockets (chassis-mount)
L1	Philips EC-core assembly (windings — see text) 2 x EC52/24/14 cores (4322-020-52520) 1 x former, no tags (4322-021-33020) clamp assembly: 1 x 52PLATE, 1 x 55UBOLT, 2 x 632NC2A.
T1	as per L1

One 20 W or one 40 W or two 20 W fluorescent tubes; housing(s) to suit tube(s); case for electronics; one 7-way tag strip; battery cable (pair of 32 x 0.2); battery connectors; nuts, bolts, wire etc.

Price estimate $35 — $40
not including fluoro tubes and tube housing(s)



Mounting Q1 and Q2

you're using one 20 W, one 40 W or two 20 W fluorescent tubes.

Mount the ballast inductor, L1, but don't secure it in place too permanently yet as you'll need to set up the inverter by 'gapping' the core. Put spaghetti on the flying leads of L1 also.

Now the tube or tubes can be wired up. We used two 20 W tubes mounted in 'Safe-T-Lite' plastic tubes with rubber ends which we obtained from Warburton Franki. Some kit suppliers may be able to supply these along with kits. Wiring to the fluorescent tubes may be done with ordinary hookup wire — the filament pins may be soldered to directly. The 'starting' wire is attached to the tube with glue or tape. We used hookup wire run the length of each tube. It is not connected to any part of the tube. For the lead from the tubes to the DIN plugs, we used five-core double-insulated cable, which should not be too difficult to obtain.

Setting-up procedure

Before powering up, make sure the ballast inductor core halves are in good contact with one another. Now, plug in your fluoro tube or tubes, connect the inverter to a 12 V battery or power supply (it should be capable of 4-5 A), and switch on. The tube should light smoothly and you should be able to hear the inverter oscillating at around 12-15 kHz (if your ears are OK). If the tube doesn't light or the inverter doesn't oscillate, switch off and check your wiring. If all seems OK, reverse connections 'e' and 'h' on the feedback winding and power up again. This time the inverter should spring to life — if not, you still have a problem. Sort it out before continuing.

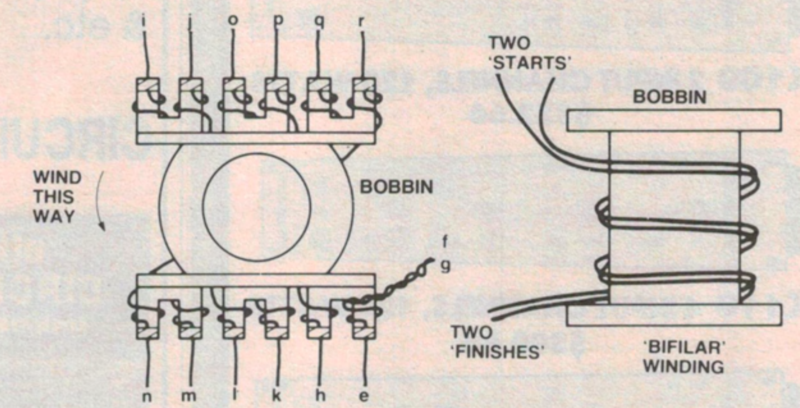
Assuming your inverter now works, you can proceed with adjusting the ballast inductor.

For correct operation, the inductance of L1 needs to be set by 'gapping' the core, limiting the maximum current through the fluorescent tube or tubes. To do this, insert an ammeter in series with one 12 Vdc supply lead, set to read 5 A (max.) if you have a 40 W load (one 40 W tube or two 20 W tubes), or 3 A (max.) if you have a 20 W tube.

We found the best gap was obtained by taking a small piece of paper, cut from a page of ETI, and inserting it between the faces of one 'leg' of the core halves! Clamp the assembly firmly. Then, apply power and measure the supply current. It should be within 100 mA of 4.5 A for correct operation on a 40 W load with a supply of between 12 and 14 volts. For a 20 W load, the current should be around 2.5 A.

That's it! May your little light shine brightly. ●

WINDING T1 AND L1



Components required:
Two Philips EC core assemblies, each consisting of:-
2 x EC52/24/14 cores — 4322-020-52520
1 x former, no tags — 4322-021-33020
1 x clamp assembly as follows;
1 x 52PLATE, 1 x 55UBOLT, 2 x 63NC2A

Wire required:
About 4 m of 0.4 mm dia. enamelled copper wire.
About 1 m of insulated hookup wire (10 x 0.2 mm).
About 1 m of heavy duty insulated hookup wire (32 x 0.2 mm).

L1: Wind 40 turns of 0.4 mm enamelled copper wire (about 1 m) on one bobbin, tieing off the ends to convenient posts on the bobbin end cheek. Spread the winding over the bobbin. Leave about 100 mm or so of lead length.

T1: Commence with the **'starter' winding** (o/p). For this you'll need about 120 cm of 0.4 mm enamelled copper wire. Referring to the accompanying drawing, tie off the start (o), leaving about 100 mm or so of lead. Wind on **80 turns,** spreading the winding over the bobbin. Tie off the end (p) adjacent to the start, as shown in the diagram, leaving another 100 mm or so of lead.

Do **secondary 1** next. This requires 0.4 mm enamelled copper wire. The number of turns required depends on which tube or tubes you intend to run. Consult the 'windings' table. As for the first winding, commence by tieing off the start (k) then wind on the required number of turns, spreading the wire over the former. Again, start and finish leads should be 100 mm or more.

Now wind the three filament windings. **Filament 1** and **filament 3** are each **one turn** of enamelled copper wire. **Filament 2** is **two turns.**

The feedback winding comes next. This is wound *bifilar* using the lighter duty insulated hookup wire (10 x 0.2 mm). Take a pair of wires, laid side by side, and wind **one turn** on the bobbin, tieing off the ends leaving long flying leads. Twist together one start and one finish for the centre tap (f & g).

An illustration of bifilar winding (showing three turns) is given in the accompanying diagram.

The **primary** winding comes last. This too is wound *bifilar,* using the heavy duty hookup wire (32 x 0.2 mm). Wind on **three turns,** tieing off the leads, leaving long flying leads as for the feedback winding. Twist together one start and one finish for the centre tap (b & c).

Windings
L1 40 turns, 0.4 mm enam. copper wire.
T1 **primary** (a-b, c-d)
3 turns, bifilar, 32 x 0.2 mm insul. hookup wire.
feedback (e-f, g-h)
1 turn, bifilar, 10 x 0.2 mm insul. hookup wire.
filament 1 (i-j)
1 turn, 0.4 mm enam. copper wire.
secondary 1 (k-l)
single 20 W tube: 20 turns, 0.4 mm enam. copper wire.
two 20 W tubes: 50 turns, 0.4 mm enam. copper wire.
one 40 W tube: 50 turns, 0.4 mm enam. copper wire.
filament 2 (m-n)
2 turns, 0.4 mm enam. copper wire.
starter (o-p)
80 turns, 0.4 mm enam. copper wire.
50 turns for 1 x 20 W tube
filament 3 (q-r)
1 turn, 0.4 mm enam. copper wire.