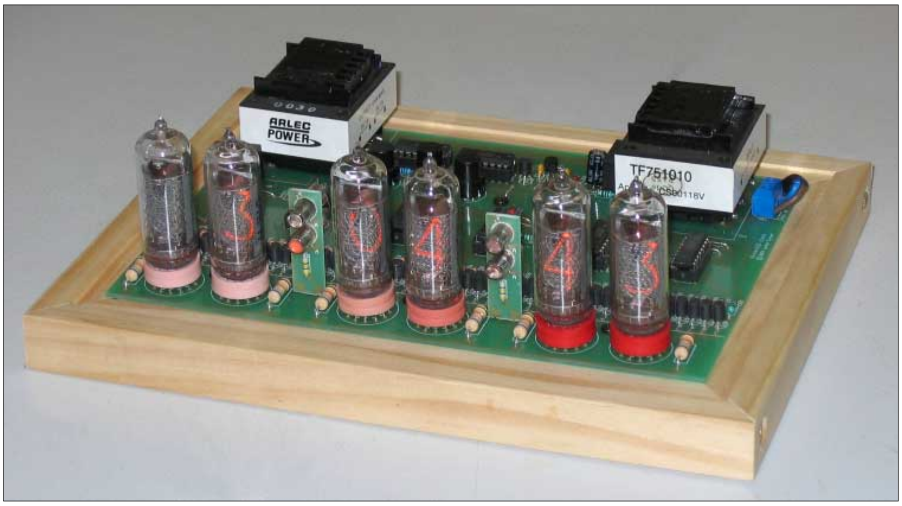
Build yourself a nixie clock!

You may have seen them in old sci-fi movies and wondered how they worked. Well, here is your chance to experiment with nixie tubes by building your own nixie clock.



Digital displays such as LEDs and LCDs are everywhere nowadays, but have you ever wondered what was used before these technologies came along?

There were several commonly used digital display—in fact, you may have even owned a digital clock with a mechanical display, where small tiles or cards were flipped over to show the number required.

However, there was another type of display quite common before LEDs and LCDs took over—nixie tubes. What is a nixie tube, you ask?

Well, nixies are a special type of neon bulb. You have most likely seen the small orange-glowing neon bulbs found in some powerpoints which are used as power-on indicators. These consist of a small glass bulb filled with neon gas. Inside the bulb are two wire electrodes, and when a high voltage is present across the electrodes, the neon gas between them glows a warm orange colour. Current through the bulb is limited by an external resistor, often over 100k when used on 240 volt AC systems.

A nixie tube works in the same way as a neon bulb, but instead of two similar electrodes using AC, they have specially-shaped electrodes and use DC. The anode is in the form of a fine mesh grid at the front of the viewing area of the tube, while the cathode is in the shape of the letter, symbol or digit you wish to display. So how can you display more than one symbol per tube? Simple—just stack a heap of differently shaped cathodes one behind the other with insulating spacers between them, and drive the cathode you want to light up.

While this sounds a bit messy, in fact it works rather well, and provides clear, sharp characters that can be driven by simply connecting the appropriate cathode to the negative of the high voltage supply. This arrangement is why you need DC to drive the nixie. If you used AC, both the character and the grid would illuminate, thus making the display rather hard to read!

Incidently, the name 'nixie' came about accidentally. A [Burroughs] draftsman making drawings of the device labeled it NIX I, for Numeric Indicator eXperimental No. 1. His colleagues began referring to it as 'Nixie', and the name stuck. (Scientific American, June 1973, pp. 66).

A warning

Like other neon tubes nixies use high voltage (well, they need around 100 volts or more to strike, and then maintain around 70 volts or so across the tube while running, but these figures vary a bit.

This project uses mains power, for two reasons. Firstly, to provide the voltage in a simple manner, and secondly, to provide a 50Hz signal to drive the clock electronics. The mains grid is quite accurately locked to 50Hz, so why not take advantage of this!

So, if you are not experienced at working with mains voltages, then make sure you get the help of someone who is. Despite having fairly simple circuitry, this project is not for the novice.

The circuit

Having a look at the circuit diagram, you can see that mains power comes straight into a 240 volt to 2 x 5 volt (or 2 x 6 volt, depending on availability) power transformer, TR1. Here it goes in two directions. Firstly, to a bridge rectifier and filter combination consisting of BR1, C1and C2, which supplies filtered DC to the electronics via a 78L05 five volt regulator, U1. C3 is the output filter for stable running of the regulator.

Secondly, you will notice that AC from the transformer goes to the secondary of an identical transformer at the other end of the board, TR2. It is stepped back up to something close to 240 volts and then rectified by BR2 to produce the high voltage supply for the nixies. No filtering is needed or used in this supply.

So why not use mains voltage through a bridge rectifier without using TR2? Simple—safety! The transformers isolate the mains from both the drive circuitry and the nixies, so even if you did touch the high voltage nixie supply you would not be likely to receive a shock, unless you were also touching the low-voltage side of the circuit—but don't go testing this out!

You may have also noticed resistor R1 comes from one end of the secondary of TR1. This is where we get our signal to drive the electronics. Using R1 in conjunction with ZD1, a 5.1 volt Zener diode, we end up with a series of positive-going pulses limited to the range of -0.7 to 5.1 volt. These pulses are fed into Q1, a BC547, to provide buffering to give the signal more oomph as it is also used for setting the clock, and to remove the negative going part of the pulse.

The drive circuitry

The signal from Q1 directly drives the clock input of U2, a 4017 decade counter/divider IC. This is a very common device and is ideal for use in nixie clocks as it has 10 high-going outputs, as well as a carry-out output. In fact, all of the dividing and driving circuitry is just a bunch of 4017 ICs—how simple is that!

U2 is connected so that it divides the incoming 50Hz pulses by five, down to 10Hz. You will notice that there is an option for both 50 and 60Hz mains frequencies on the board, for people living in the US or other countries using 60Hz mains. In this case, the signal is simply divided by six instead of five.

The Q0 output of U2 is fed into the clock input of U3, another 4017, which is set to divide the signal by 10, thus producing a 1Hz output—exactly what we want for a clock!

Switch SW1 and resistor R3 are there to provide a seconds-hold feature. R3 normally holds the master reset pin of U3 low. Pressing SW1 pulls it high, stopping the count and allowing the seconds count of the clock to be set accurately.

The carry-out output of U3 is connected to the clock input of the first of the nixie driver stages, U4. This causes U4 to send each of its 10 outputs high in turn at 1 second intervals, thus counting seconds. The carry-out of U4 goes to U5, which is wired to reset itself when its count reaches six—it counts zero to five and then resets. Thus, we get a seconds count of 00 to 59, resetting to 00 again.

The carry-out of U5 goes to the clock input pin of U6, the first of the two minutes counters, the carry-out output of which drive U7. This stage is a repeat of the seconds stage, with the exception of R4, R5 and C4. These allow the minutes stage to be fast forwarded by a signal from either the fast or slow advance buttons, SW2 and SW3, which provide either a 10Hz or 1Hz pulse to the clock input of U6. C4 just cleans up any switch bounce from SW2 and SW3. R58 prevents any damage to the circuitry should both SW2 and SW3 be pressed at the same time.

12 or 24 hour clock?

The output of the minutes stage drives the hours stage. The first section, U8, is the same as the first section of the minutes—it counts to 10 then resets, but only when the 10s of hours digit is not 1 or 2, depending on whether the clock is set to be a 12 or 24 hour clock.

The second section, controlled by U9, the 10s of hours, must be set to either count to 1 or 2 and then reset in conjunction with the outputs of U8.

The two ICs have their master reset pins wired together, but these are only reset when the appropriate pins on both ICs are high. For a 12 hour clock, the resets are triggered by the hour 'units' reaching 3 and the hour 'tens' reaching 1. In other words, the clock is fine until the hour tries to clock over to 13, then the hours reset.

For a 24 hour clock, the same thing happens, except that this time the hours reset when the hours get to 24.

Now, you might be thinking that the 12 hour system and the 24 hour system are different—and you would be right—the 12 hour system starts at 1 o'clock, while the 24 hour system starts at 0 o'clock.

So how can the clock be set up for either? Simple. When wiring the clock for 12 hour time, you must wire the pins of the 'units' nixie to one number lower than marked on the board. So, the '1' pin of the nixie goes to the '0' output of the driver stages, pin '2' of the nixie goes to output '1' of the drivers, etc. Pin '0' of the nixie goes to output '9' of the drivers.

But this is not the only change. There are three other changes that need to be made. The board has three sets of dual solder pads that must be bridged, depending on what type of clock you are making. One set, located just below U2, is labelled 'Fr' and allows you to set the clock for 50Hz or 60Hz mains frequencies. The other two pairs of pads set the clock up for 12 hour or 24 hour operation. You bridge either both 12 hour or both 24 hour sets of pads. Also, D1 must go in either the 12 hour or 24 hour position. The 12/24 hour pads are located just above R6 and C5, and underneath U8.

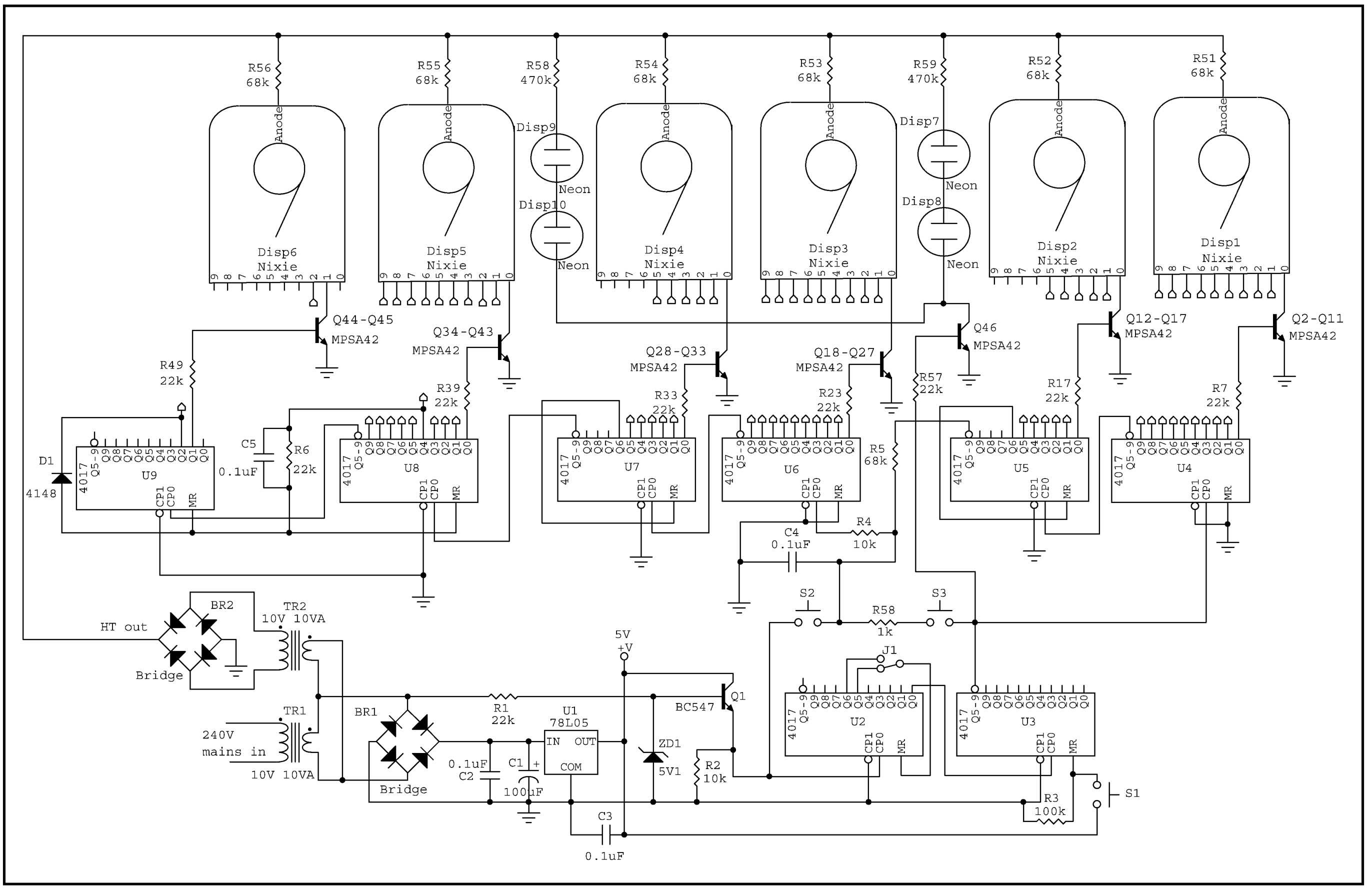


Figure 1. The circuit diagram.

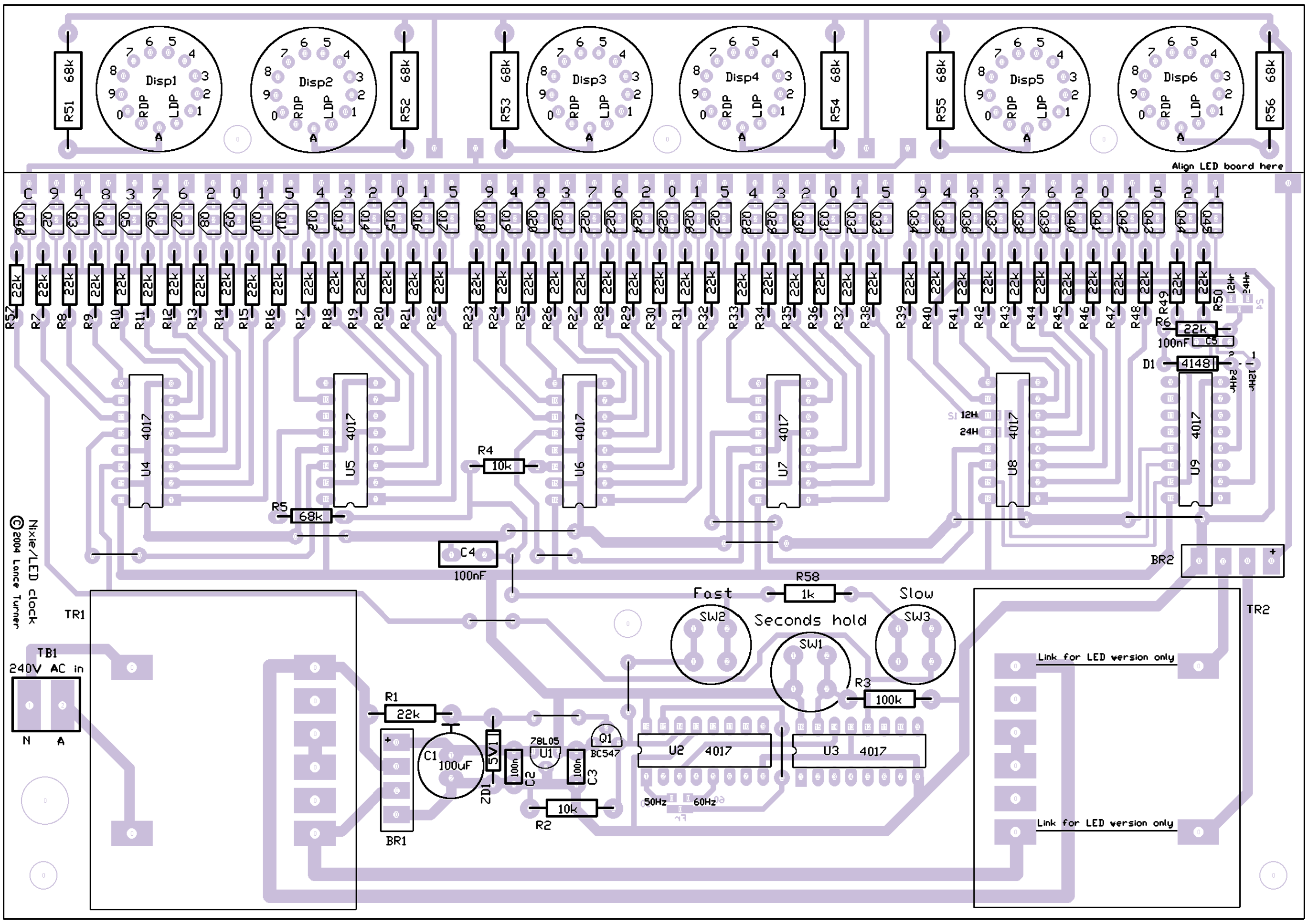


Figure 2. The PCB and overlay

Driving the nixies

The outputs of the 4017 counters obviously can't be used to drive the nixie tubes directly, for two reasons. Firstly, they are inverted—they are high when the cathode of the digit they are driving needs to be low. Secondly, the voltage from the nixies is way to high to be controlled by the IC—it may well damage or destroy the IC, and the few volts swing of the IC from low to high states is not enough to reliably switch a nixie.

These problems are easily solved using a high voltage NPN transistor (an MPSA42) and a suitable resistor to limit base current. There is one transistor for each nixie digit that needs to be driven, and a 22k resistor for each transistor. When the appropriate output from the 4017 goes high, it drives its associated MPSA42 into saturation via the 22k resistor—thus making the transistor act like a high voltage switch. This causes the cathode of the nixie segment which is connected to the transistor to effectively be connected to the negative supply rail, thus turning on that digit. These driver stages can be seen just below the nixie tubes themselves—they are quite well packed onto the board! Note that sometimes a 2N6517 or other similar high voltage transistor will be supplied instead of the MPSA42.

The current through each nixie segment is limited by the 68k, 1 watt resistor that is in series with the nixie tube's anode. Tube current will vary, but should not exceed 2.5mA, and will generally be around half this figure. For a brighter clock, reduce this resistor value for each tube, but don't go below 33k.

There are two pairs of nixie 'dots' between each pair of digits, mounted to their own tiny circuit boards which are attached perpendicularly to the main board on PC pins. The colons are driven on and off at a 1Hz rate by the seconds signal, which drives their associated transistor, Q46. If you don't want the colons to flash, then just leave out the 22k resistor, R57, and the MPSA42, Q46, and place a wire link from the collector to emitter holes (the two outer ones) of the transistor. This will make the colons stay permanently on.

Building the clock

Assembly is quite straightforward if you work methodically. Start with the wire links and resistors, then the diodes, capacitors and transistors, followed by the IC sockets and U1, the 78L05. Be sure not to mix up any of the transistors with U1. Also note that, due to several requests, an extra high voltage transistor and 22k resistor are supplied so that the 0 digit in the tens of hours tube can be lit for the 24 hour version of the clock. All you need to do is drill three small holes next to Q45 for the transistor, and use the 22k resistor to wire that transistor's base to pin 3 of U9, then connect the emitter of the transistor to the negative rail (use the emitter pad of Q45 as a convenient point) and wire the 0 digit of the nixie to the collector of the added transistor.

When soldering in D1 you will need to have decided which type of clock you are going to build—a 12 or 24 hour clock—and place the right-hand end (the cathode) of the diode into the appropriate hole. At this time it is also a good idea to join the three sets of solder pads mentioned earlier, including the 'Fr' pads below U2. In each set of pads, you must join either of the small pads to the larger pad, but make sure you don't join both small pads to the larger pad or the clock will not work and you may damage one of the ICs. There is no need to use wire to join the pads, just put a small blob of solder on each pad and then run them together with the soldering iron. If they separate before the solder solidifies, add a little more solder.

Next insert the bridges, the four PC pins (located in pairs between the pairs of nixie tubes) and the three pushbutton switches and solder into place. The flat side of the switches go towards U2 and U3. Then insert the two mains transformers, making sure they are sitting into place properly and solder them in. These last two items make the board a lot heavier, so be careful when handling it from now on as the weight of the transformers makes the board heavy enough to damage the nixies if you aren't careful. Don't install the ICs in their sockets yet—that comes at the testing stage.

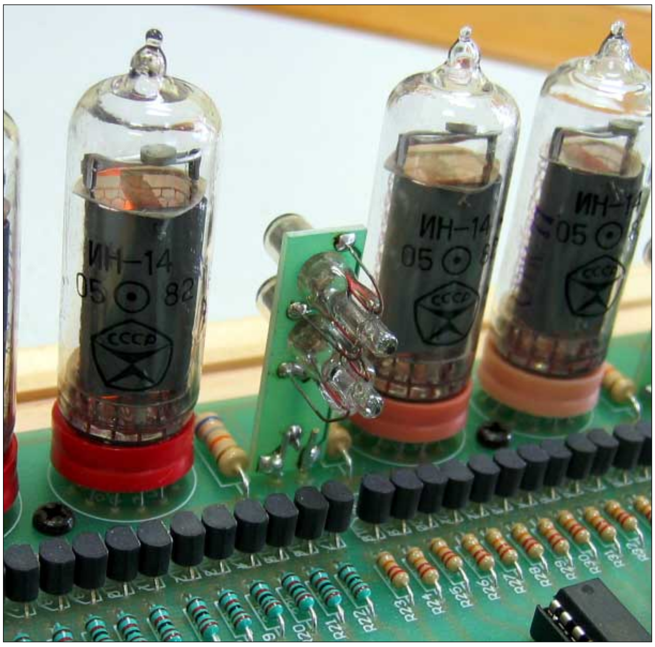
For those of you who live in a country with 100 to 120 volt mains power, you will need to source your own mains transformer. Use the nixie supply transformer (TR2) supplied in the kit, and find a new transformer with a 110 volt primary and two 5 volt (or 6 volt) secondaries with the same pinout as the original transformer TR1.

Now for the scary part—the nixies themselves.

Take a nixie tube and start by gently straightening the flying leads and bending them all slightly away from each other so they fan out slightly. This will make it easier to get them into the board. Now, starting with the anode lead (the lead furthest away from the anode grid, identified by the small insulating bead it has on it just inside the base of the tube), insert it into the hole in the board—don't push it through too far—5mm is enough for now. Work your way around the tube until all leads are partly inserted. The viewing area of the nixie tube should now face towards the front edge of the circuit board.

If you are happy that all leads are in the correct holes (make sure none have become crossed over!) then slowly work the tube into place until the plastic base is seated on the board and the tube is nicely seated in the base. Check that the tube it is perpendicular to the board in both directions, and then bend the leads on the solder side of the board to hold the tube in place. To make this task easier, you can clip the nixie's leads to about 12mm or so long, but this means you won't have any flying leads to do the final wiring with.

View showing the rear of the colon board. Note how the nixie dots pass through the board and the leads are bent back for soldering. Also note the Russian markings on the nixies!



Now, solder three leads that are evenly spaced around the tube, check that the tube is still aligned, and solder the rest.

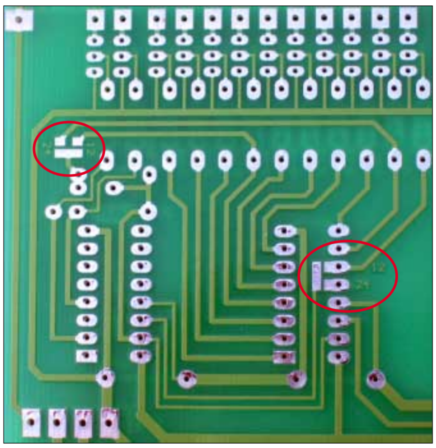
Repeat this for the other five tubes, being careful that all tubes line up when sighted from one end of the board and that they are all parallel to each other when looking from the front.

Final wiring

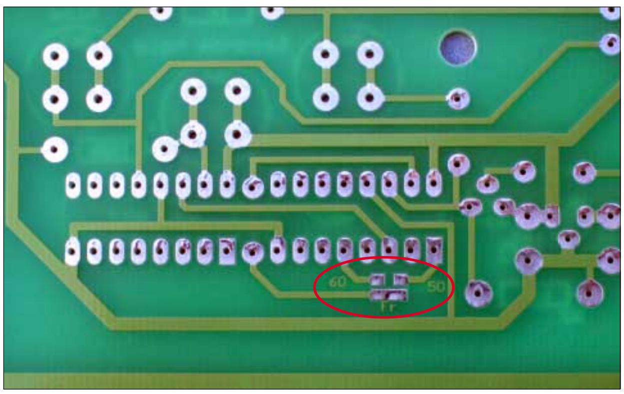
Once all the tubes are in place, you have to wire the leads from each of the 10 digits in each tube to the appropriate driver transistor. This sounds tedious, but can actually be achieved fairly quickly. Several of the segments can be wired simply by bending over the end of the flying leads (unless you trimmed them before inserting the tubes into the board) and soldering to the approriate pad, making sure that none of the leads touch each other. For the digits that have flying leads that are too short, trim these leads close to the board and use short lengths of thin hookup wire to connect the nixie tube pad to its associated driver transistor pad.

Also note that when you get to the hours nixies, the units nixie has to be wired in different ways, depending on whether it is going to be a 12 or 24 hour clock. For the 24 hour version, wire each segment to the corresponding pad, as you did with the minutes and seconds tubes. For a 12 hour clock, wire the pins of the 'units' nixie to one number lower than marked on the board. So, the '1' pin of the nixie goes to the '0' output of the driver stages, pin '2' of the nixie goes to output '1' of the drivers, etc. Pin '0' of the nixie goes to output '9' of the drivers.

Now, double check the wiring of the



The time setting pads can be seen at left, while the frequency setting pads can be seen at right. You must joint either of the small pads to the larger pad in each set of pads, but make sure you don't join both pads in any set!



tubes and snip off any spare flying leads. Also, make sure that none of the leads covers a board mounting hole—just bend them around the holes.

The last thing to do is to assemble the two small colon boards. These have only a single resistor and two nixie 'dots' or standard neon bulbs, depending on availability of the former. The dots are designed for this type of display and must be wired the correct way around. The anode and cathode wires must go to the corresponding A and K pads on the board. The cathode is the wire that goes to the formed metal plate at the viewing end of the tube.

Both the dots and tubes will probably be too long, so the boards are designed so that the tubes are inserted with part of their body sticking out of the rear of each board. The leads are then bent back to the board and soldered. This should be enough to hold them in place, but use a dot of hot-melt glue on the back of each one if you wish.

Once you have two colon boards, solder them to the PC pins between each pair of nixie tubes. Make sure you don't touch the tubes with the soldering iron, as they may not like it! You may have to trim the PC pins so that they are about 4mm long before soldering the boards in place. This is to ensure that the pin connected to the negative rail doesn't touch the positive end of the resistor on the colon board. And that's it, your clock is ready to test.

Wire a two-core mains lead to the terminal block, passing it up through the hole in the board before inserting each end into the correct place on the terminal block. The active (brown wire) of the lead goes closest to the transformer. This is to reduce the risk of you coming in contact with the active lead, but no matter what you do at this stage, be careful!

Not very exciting, but this is the underneath of the clock. Note the silver screws holding the base board to the wooden rail, and the six black screws that hold the clock PCB supports in place. Rubber feet stop the clock sliding around.

Testing

Now, place the clock on an insulated surface, making sure there are no bits of wire or other conductive crud rolling around underneath the board, plug the lead into a mains socket and switch on. Assuming nothing exploded, use a multimeter to check for +5 volts across pins 16 and 8 of each IC socket. Also check (being very careful) for high voltage at the top end (closest to the edge of the board) of one of the 68k, 1 watt resistors, measuring between the resistor and any convenient ground point, such as pin 8 in one of the IC sockets. This should measure around 200 volts or more if all is working correctly. If all is well, power down and unplug the lead from the powerpoint, wait a few minutes and insert the ICs, making sure that they are the correct way around.

Now, plug back in and power up. Hopefully you will get a display—most likely '11:11:11' or '12:11:11' or something similar—and the seconds should be counting and the colons flashing, if you have gone for that option.

If this is what you can see, then all is well. Check the various buttons and make sure they do what they should. Also make sure that the clock advances correctly and clocks over (resets) at the correct time. If all is well, you can either leave the clock running for a while to make sure nothing gets too hot (the transformers should run warm, not hot) or power down, unplug it and start building the case.

Do not be tempted to run the clock outside of a sealed case. While the high voltage nixie supply is effectively doubly-isolated from the mains, it is still dangerous if you connect yourself from the high voltage supply to the clock's ground rail. And, of course, there is the direct connection to the mains at TR1!

A case is simple to make using a few dollars worth of wood. The prototype was housed in a base made from some 20mm x 12mm strip to which was glued a 12mm x 12mm strip to form a 'hat section'. This was cut and mitred to form the frame. A piece of 3mm thick MDF was attached to the bottom and the board itself was fastened into the base using six 12mm long threaded nylon board supports and 5mm long screws each end. The use of screws less than half the length of the supports means it is impossible for the screws to compromise the insulation of the supports. If you are still concerned, use nylon screws as well.

To finish off, use a clear plastic or glass

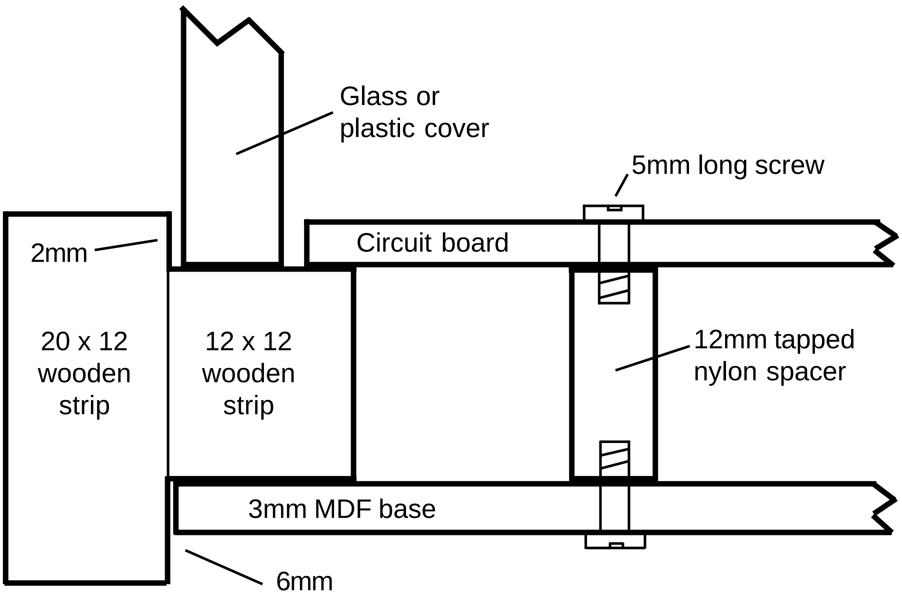


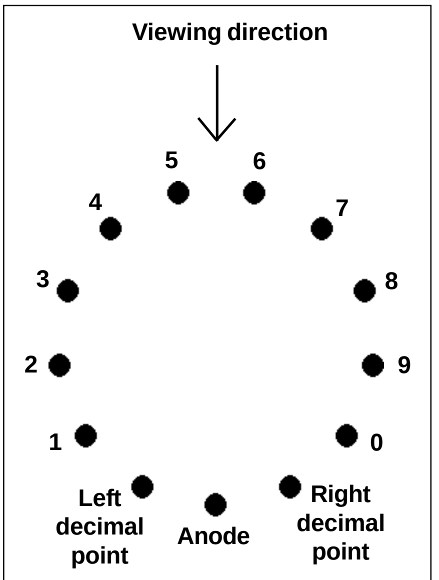
Figure 3. How to mount the board inside its case.

cover over the clock. Make it so that it just sits inside the lip of the base. See Figure 3 for a cross-section diagram. You might also want to make the cover so that it can be screwed down to prevent prying fingers coming in contact with mains voltages!

As a matter of interest, the prototype was tested with a real-power meter and was drawing 4.5 Watts from the mains. this equates to an energy consumption of around 39.4kWh per year, or about $5.50 per year to run (in Melbourne, at least) so the clock is not a huge energy user despite the bright display. ☼

Errata

- On the circuit board, there are two resistors marked R57. The one driving Q46 is R57, the resistor between the fast and slow set buttons is R58.
- C1 is marked on the circuit board as 100uF, but the unit supplied may range from 100 to 470uF.
- If the clock runs at twice the correct speed, fit the 0.01uF (10nF) capacitor (supplied in kit) across zener diode ZD1 to remove the problem, which is caused by an extra spike coming from the rectifier. For neatness you can mount this capacitor underneath the PCB.
- If the minutes count 1, 2, 3, 4, 6, 7, ie it skips the 5 count, this is caused by capacitor C4. The solution is to removing C4. However, C4 is there to debounce the setting switches and it can be difficult to set the time without it, so try reducing the value of this capacitor to 10nF or even 1nF and see if the problem disappears. I have had to reduce it to as low as 670pF with one brand of 4017 IC (made some dozen or so years ago, so newer chips should be less touchy).



As viewed from bottom of nixie tube.

Parts list

Part #	Value/description	Units per kit
U1	78L05	1
U2-U9	4017	8
Q1	BC547	1
Q2-Q46	MPSA42 or 2N6517	45
D1	1N4148	1
BR1, BR2	Inline bridge	2
ZD1	5V1 Zener	1
C1	100uF to 470uF 16V	1
C2-C5	0.1uF	4
R3	100k	1
R2, R4	10k	2
R5	68k	1
R1, R6-R50, R57	22k	47
R51-R56	68k 1W resistor	6
R58	1k	1
R59, R60	470k	2
TB1	2-way terminal block	1
SOC1-SOC8	16 pin IC sockets	8
S2-S4	Keyboard switch	3
TR1, TR2	10 volt, 10VA transformers	2
DISP1-DISP6	Nixie tubes	6
DISP7-DISP10	Nixie dots	4
PCB1	Circuit board	1
PCB2-3	Colon circuit boards	2
LEAD1	Mains lead	1
	PCB standoff	6
	3mm x 5mm screws	12
	Hookup and tinned wire	1
	PCB pins	4
	Rubber feet	4
	High voltage label	1