The Nixie Tube

The design and control of Nixie tubes

By Jens Boos (Germany)

There is no doubt Nixie tubes are once again trendy. No other display technology has quite the same character. The fact that we are unlikely ever to see these devices in consumer products (unless production restarts) makes their use in a one-off design special. If you are planning to add the Nixie coolness factor to your next home brew design we give details of their operating principle, power supplies and practical advice on driving the tubes. To inspire you a collection of fascinating reader's projects has been included.

To describe a Nixie tube as an electronic device for displaying numbers or characters is a reasonably good description of its basic function. It does not however give the full picture; a bit like describing a log fire as a type of room heater. Although Nixies are essentially cold-cathode devices many people find their orange glow very appealing, evoking nostalgia and memories of a bygone era. Back in the 1950s to the 1970s before the advent of LEDs, Nixie tubes displays were standard fare on frequency counters, bench timers and most other test equipment, Elektor even featured a project using them [1].
In more recent times we have responded to the revival of interest by publishing the 'Sputnik Clock' in January 2007 [2] and the 'Nixie Tube Thermometer' in January 2011 [3]. In this article we shed some light on their operating principles and give some historical background of the device.

A little history ...

During the course of the 20th century with the rise of digital electronics it became more important for equipment to deal with numeric values and to display values as numbers rather than the using the less precise analogue meter or crude indicator lamp. At the beginning of the 1950s the Nixie tube was developed to meet this need. It can display different types of symbols, is free of mechanical wear and consumes very little power. Interestingly a patent was granted for a Nixie-like indicator device back in the 1930s [4] but was never commercially exploited at the time.

There is a certain amount of confusion over which company was the first to produce a functioning 'Nixie-like' display tube. The typical Nixie tube familiar to collectors today was first introduced in 1955 by the Burroughs Corporation who one year later registered it as a trademark [5]. The name Nixie was originally only used internally in Burroughs to stand for 'Numeric Indicator

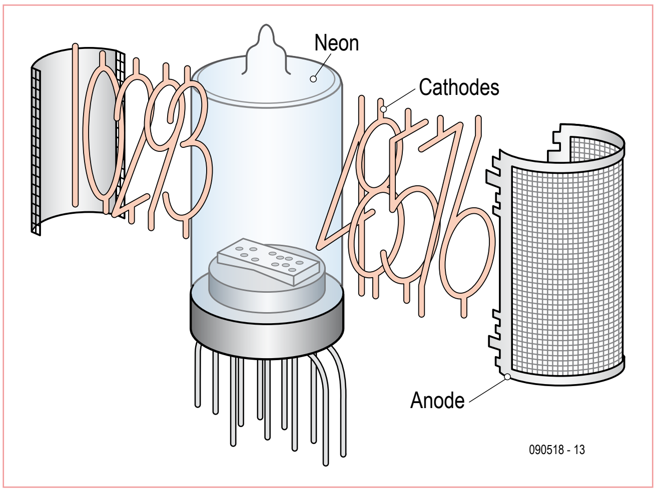


Figure 1. Construction of a typical Nixie tube.

Figure 2. Advertisement for a Nixie (ca 1955).

eXperimental no. 1' (**Figure 2**). One year earlier (1954) the company National Union had introduced its own design named the Inditron but this device remains something of a historical curiosity. The tube did not have an anode so required more complex driver electronics and it quickly lost ground to the Nixie when it was introduced.

In the following years the Nixie gained acceptance throughout the world and led to the production of the tubes in the UK, Germany, France, Poland, Russia, Japan and China, sometimes under licence to Burroughs.

The last Nixie tubes to be built rolled off the production line in Russia in the early 1990s. The company Richardson Electronics Ltd in the US reputedly still have all the necessary machines to begin production should the need arise [6].

The complete range of Nixie tubes produced is impressively large. The author has amassed a good selection of tubes over the years some of which are shown in the photo on the first page. A few of these examples are very rare and quite precious [7].

The structure and function

The Nixie tube consists of a sealed glass envelope filled with the noble gas neon or a mixture of neon and argon. Later models also included mercury vapour. Each of the display numbers has been punched from a very thin metal sheet. These are fixed in the glass envelope and wired to individual pins on the tube's base. Each number forms a cathode connection (**Figure 1**) and can be independently controlled. The anode typically consists of a fine wire mesh surrounding the numbers.

A small proportion of the neon-argon gas filling is already ionised due to the influence of the ever-present cosmic radiation. When a DC voltage is applied between the anode (plus) and cathode (minus) the electric field generated accelerates the available free charge carriers (electrons and gas ions) in the glass envelope. When this DC potential exceeds a certain value the speed of the particles (particularly electrons) is sufficient to ionise the neutral gas molecules. A charge-carrier avalanche occurs, causing significant current to flow through the tube. This 'strike voltage' is typically in the range 120 to 150 V.

A surplus of positive charge carriers (positive space charge region) builds up around the cathode while these gas ions have a much higher mass than the electrons. At this point the voltage gradient and therefore the field strength is increased so that the external voltage can now be reduced to some extent while still maintaining conduction. The lowest voltage necessary to sustain conduction is called the maintaining voltage; and is typically 5 to 10 V below the strike voltage.

When the Nixie is operating at a voltage somewhere between the strike and extinguish voltages (i.e. at the *maintaining voltage*), electrons form the majority of the flow through the tube. Shortly after leaving the cathode their speed is sufficient to excite emission from the noble gas (electrons in the outer shell of the noble gas atoms are moved to a higher energy level and then release a photon as they fall back to a lower energy level). On close inspection it can be seen that the illumination in the tube does not actually occur on the surface of the cathode but a little way out creating a 'glowing tube' effect around the shaped cathode. The electrons must first be accelerated to the necessary energy level.

The colour of the emission is orange with a gas filling of pure neon, adding some argon to the mix gives the orange a pale violet fringing. Blue effects can be attributed to the addition of mercury vapour.

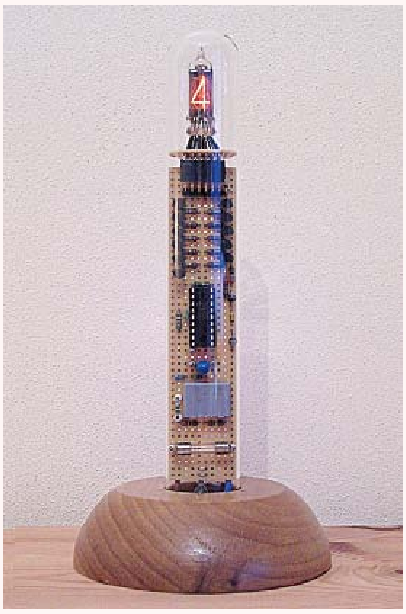
The series resistor

Current through the Nixie must be limited by using a resistor in series with the power supply. Without the resistor, arcing will occur causing the tube to overheat and be damaged. The series resistor value can be calculated (in the same way you would for an LED) using the formula:

$$R = V / I = (V_s - V_{maint.}) / I_{nom.}$$

A typical value lies in the range from 10 to 80 kΩ. The anode to cathode strike voltage and

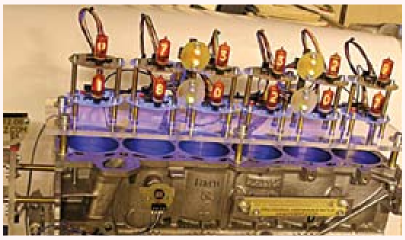
Figure 3. The Burroughs HB-106 along with the GI-10 from National Union.



Tube-In-A-Tube

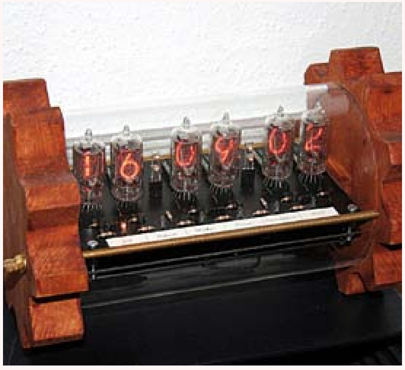
Ronald Dekker has a good selection of Nixie-based projects on his website. One of these is a Nixie clock powered directly from the mains mounted in an inverted test tube. The circuit doesn't require any high voltage transistors or special ICs (www.dos4ever.com/TiT/TiT.html).

An engine block clock



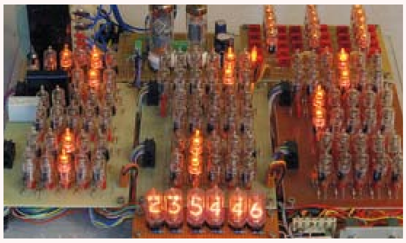
This is unusual, a DCF clock mounted in a BMW engine block! Steffen Möritz developed this idea in his spare time and has also designed a rev counter with Nixie tube display for his 1961 Mercedes-Benz.

Nixie clock meets Ethernet



Nixie tubes and clock designs belong together. Tobias Krista has designed his with an Ethernet interface. It can request the current time from an NTP server (Network Time Protocol) without the need for a PC. In addition all the functions (Alarm clock, Countdown etc.) can be accessed remotely using a web interface.

A silicon-free clock (display)



This Nixie clock by Michael Pape doesn't use any silicon devices at all. The circuit uses over 100 XC18 type valves. Several ring-counter circuits are used to derive a 1 Hz clock from the AC power frequency.

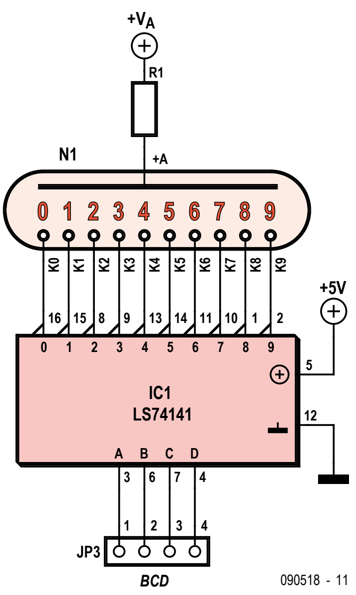


Figure 4. The LS74141 driver IC contains a BCD to decimal decoder and ten transistor drivers.

nominal maintaining current for a particular type of Nixie tube will be given in the corresponding data sheet. Where there is no data sheet available the series resistor value can be ascertained empirically. Using a supply voltage of 180 V identify the common anode pin and cathode pin connected to the displayed character with the minimum surface area (usually the number '1'). Take precautions to ensure that all connections are properly insulated. Connect a high value resistor (a 100 kΩ pot is a good choice here) in series with the supply and tube. Slowly reduce the resistance of the pot until the character starts to glow. When the whole area of the character is glowing uniformly and current through the tube is within spec (1 to 5 mA, or more for larger Nixies) turn off, remove the pot and measure its value. Now select the next highest fixed resistor from the E12 series to use as the series resistor. Larger characters require a smaller resistor (greater area of emission). Take care with the resistor power rating; 2 mA through 100 kΩ will fry a 0.25 W resistor.

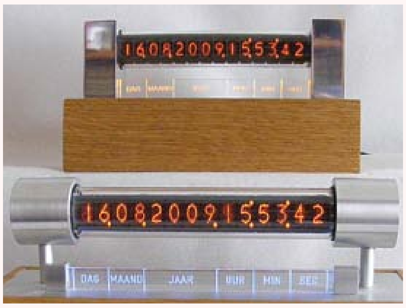
Driving the Nixie

The Nixie tube requires a relatively high supply voltage but not too much current. There have been many different systems to drive the device, some of the more common methods are shown here in chronological order.

Unfortunately it is not possible to use LED driver chips directly because they are not be able to handle the high voltage required for the tubes (although [8] is an exception).

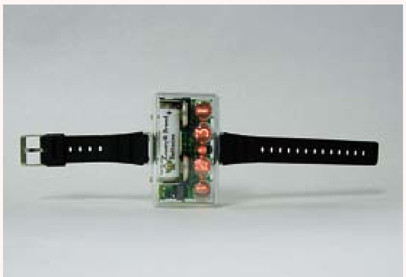
Beam switching tubes

Originally a Nixie would have been driven by a 'beam switching tube'; a vacuum tube decade counter which counts using the electromagnetic effect. The fastest versions could be clocked at speeds up to 10 MHz [9].
The tube can interface to a Nixie tube with very little additional circuitry directly. This method was originally used by Burroughs; these tubes are however more scarce nowadays than Nixies. In addition they are quite bulky [10].



Precisely two clocks!

These two clocks are the work of Loek Riemens. The first clock (at the bottom) receives time information via DCF while the second uses GPS satellite data to provide time information. The display of the GPS version changes colour from orange to red when it is receiving a signal from less than two satellites.



A remarkable watch

A wristwatch with Nixie tube displays? Reader Hugo Marien flagged up this project designed and built by Jeff Thomas. This watch measuring 7 x 4 x 3 cm uses miniature Nixie tubes and is sure to turn heads. Go to Jeff's website (www.amug.org/~jthomas/watch.html) for more information.

Nixie voltmeter

Nixies are seldom used in voltmeter designs but this project designed by the author of this article can be found on his website. It uses Russian tubes type IN-14 and IN-19B. (www.jb-electronics.de/html/elektronik/nixies/n_voltmeter.htm).

Illuminated room thermometer

This rather elegant room thermometer is the work of Simon Law and Alex Tsekenis. The temperature is displayed using an IN-13-Nixie tube. The current version has both Celsius and Fahrenheit scales and the backlight colour changes according to temperature — awesome!

Discrete Driver ICs

With the advent of digital technology came the driver IC type LS74141 (or the Russian equivalent K155ID1). It is a BCD to decimal decoder together with ten driver transistors in a 16-pin DIL outline [11]. The circuit is given in **Figure 4**. These chips are widely available (eBay or [12]) but their price is steadily rising, currently they cost 1 to 2 €. The advantage of this chip is the space saved on a PCB layout. One disadvantage is that only one output can be active at any time (the BCD to decimal decoder activates 1 of 10 outputs). In addition these chips cannot handle too much current; 7 mA (i.e. 80 mW) maximum.

Transistor drivers

Driving the tube using discrete transistors is also a possibility. The MPSA42 (NPN) and the MPSA92 (PNP) are the most common 'Nixie transistors'. Both of these are available in SMD and THT packages at reasonable cost. The disadvantage of this approach is that a transistor is required to drive the cathode of each displayed element so it consumes a relatively large area of the PCB layout (see **Figure 5**). Compared to the driver IC method described above discrete transistor drivers are more flexible and can be used to drive any bit pattern that may be required by the Nixie tube and not just one single element in the tube. Transistors can also drive more current (up to 100 mA), enough for all types of Nixie.

The Supertex HV series

The company Supertex [13] produce chips for high voltage applications for driving displays such as vacuum fluorescent (VFD) and plasma displays, some of these chips are also suitable for use with Nixies.

These devices are more sophisticated than the methods described above; not only can they drive high voltage outputs but they also contain shift registers to store the displayed bit pattern. They therefore have few input signals (Data input, Clock, Strobe and Blanking) but 20, 32 or up to 64 outputs. **Table 1** gives an overview of some of the more interesting ICs.

Some of the chips in the HV family of chips do not allow multiple outputs to be switched simultaneously so make sure you study the relevant data sheets. These chips are not stocked by the usual chip suppliers in the UK. It will be necessary to do some investigative work to track down a source [14].

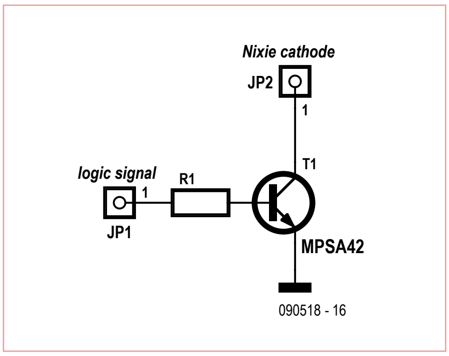


Figure 5. A circuit using discrete driver transistors.

Supplying the juice

We have already mentioned that these devices require a high voltage supply but

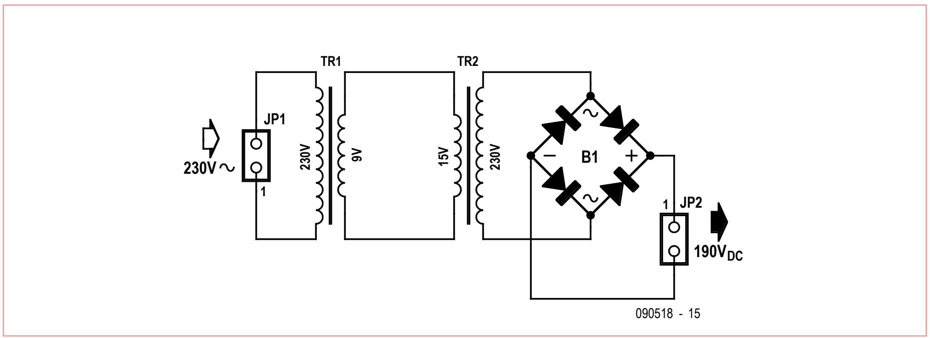


Figure 6. The high voltage is produced by reverse-connected TR2.

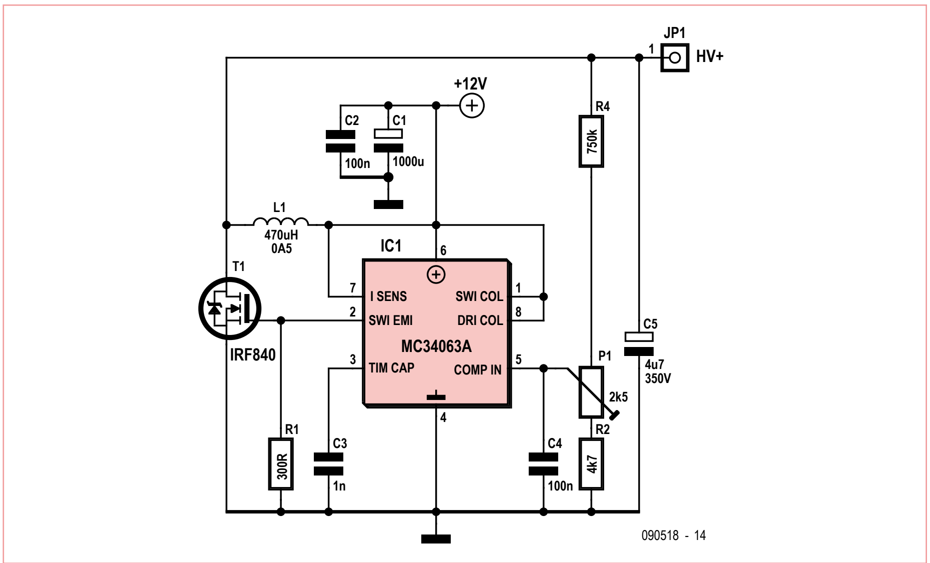


Figure 7. Boost converter using a (Standard) switch regulator type MC34063A [16].

not yet suggested how this can be achieved. A number of possibilities exist:

Direct from the AC outlet?
The simplest and least expensive option (as the author has sadly too often witnessed) is to rectify the AC outlet voltage. With this approach the complete circuit will be at AC grid potential and therefore hazardous. You have been warned!

Back to back
A power transformer with a 140 V secondary is a fairly rare beast. A better alternative is to use two low voltage transformers wired back to back. This achieves galvanic isolation for the entire circuit. The first PCB mounted 9 V transformer is wired to the AC as usual but its secondary is wired to the low voltage winding on the second transformer (see **Figure 6**). Choosing a 15 V transformer for T2 will give an output voltage of 138 VAC at its primary winding. After rectification and smoothing a DC voltage of 190 V is produced — good enough for the majority of Nixies. The maximum output current from this design is limited by the transformer ratings.

A Switch Mode Power Supply (SMPS)
Switch mode power supplies using the Boost-Converter (Step-up-Converter) principle can be used to generate the high voltage. The circuit relies on the principle of electromagnetic induction to generate high voltage. A current is passed through a coil and then abruptly interrupted. The voltage induced in the coil is proportional to the change of magnetic flux. A very fast step change will induce a voltage much higher than the supply voltage to the circuit. The induced voltage is then passed through a diode and smoothed with a high voltage capacitor. When this process is repeated it produces a stable high voltage supply.
In **Figure 7** shows the circuit for boost-converter supply using a standard switch regulator IC type MC34063A (thanks to Dieter Wächter for this circuit [15]).
Ready-made, fully assembled and tested switch mode supplies are also available for the less adventurous, designing a low-noise supply is not a trivial exercise. A good overview of some commercial designs can be found at [16].

Table 1. High voltage driver

Name	Output	Voltage	Current	Outline	Price [15]
HV5522	32 (open drain)	220 V max	100 mA *	44 PLCC, 44 PQFP	5.50 €
HV5630	32 (open drain)	300 V max	100 mA *	44 PLCC, 44 PQFP	6.17 €
HV9708	32 (push/pull)	80 V	20 mA, 5 mA	44 PLCC	4.16 €
HV5812	20 (push/pull)	80 V	3,5 mA	DIP28, 28 PLCC	2.27 €

* check max power dissipation!

The Author

Jens Boos studied physics at RWTH Aachen, Germany. He includes electronics and collecting Nixie tube as hobbies. He already has over 300 tubes in his collection gathered from all over the world including some rare and valuable examples. For more information visit the authors website www.jb-electronics.de.

Web links and Literature

[1] Elektor (German), January and February 1972, 'Digital Frequency Counter'

[2] www.elektor.com/050018

[3] www.elektor.com/090784

[4] US-Patent US2142106, issued on 3rd January 1939 to Hans Paul Boswau

[5] Serial number '72020699', applied for in 1955, view under http://tess2.uspto.gov/

[6] www.amug.org/~jthomas/clockwork.html

[7] www.jb-electronics.de/html/elektronik/nixies/index.htm

[8] http://dos4ever.com/QandA/QandA.html

[9] www.decadecounter.com/vta/tubepage.php?item=18

[10] www.radiomuseum.org/forum/nixie_and_trochotron_haydu_vs_burroughs.html

[11] www.tube-tester.com/sites/nixie/74141-NDT/74141-NDT.htm

[12] www.askjanfirst.de

[13] www.supertex.com/

[14] www.mouser.com/

[15] www.nixie.tube-tester.com

[16] www.tayloredge.com/storefront/SmartNixie/PSU/comparison.html

[17] www.nocrotec.com

[18] www.kosbo.com

A bright future for Nixies

There is no doubt that Nixies are of interest not just to collectors of electronic curiosities but also to home brewers worldwide. The following page shows some fascinating Nixie based designs. The enduring appeal of them is evident from their rising prices on the second-hand market. The tubes are now changing hands at four or five times the price they were fetching at the beginning of the year 2000. A good selection can usually be found on eBay or from specialist websites ([12] [17] [18]). Whether the existing stocks of Nixies will be sufficient to cater for the growing interest in this technology remains to be seen.

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