

# NIXIE CLOCK *REDUX*

IN-12 VARIANT (ИН-12Б)

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## Nixie Clock *Redux*

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# 1. Warnings

## 2. Pushbutton Interface

## 3. USB/Serial Interface

### A. Establishing a Connection

## 4. Project History

## 5. Nixie Tube Working Principle

### A. (Not) a Vacuum Tube

Despite appearing like a vacuum tube, Nixie tubes do not contain a vacuum. Sealed inside the tube is neon gas. This is what gives nixie tubes their orange glow when energized. Some more modern tubes also contain a mixture of mercury, which reduces sputtering - see below. This mercury creates a small blueish glow along the cathode in addition to the orange glow due to neon ionization.

### B. Ionization

Nixie tubes have anodes and cathodes, much like modern PN junction semiconductors. When a high voltage is applied from anode to cathode, electrons are stripped from the valence electron bands of the neon gas inside the tube. When a neon atom is stripped of an electron, it becomes a positive charged ion (ionization), which wants to flow towards the cathode - which is at a lower voltage potential. This is similar in principle to a neon tube sign. When these neon atoms hit the cathode, metal atoms are displaced from the cathode into the space within the tube (called sputtering). This is what forms an electric current, and allows charge to flow. This electric current is relatively small (~2.5mA). The light within a nixie tube is emitted through both ionization and sputtering.

### C. Common Anode

Much like some LED common-anode seven segment displays, most Nixie tubes have a single anode, constructed as a mesh, which has the high voltage applied to it through a single current limiting anode resistor. To illuminate a number within the tube, one of many cathodes is grounded, or driven to 0V. This creates the voltage potential needed for neon ionization. Most tubes have 10 cathodes and a single anode - the 10 cathodes correspond to the digits 0 to 9. The cathodes are physically arranged front to back within the tube, so that when any cathode is illuminated, they appear in the same location. Some tubes also have a decimal point cathode, which typically is rated to a much lower current. Other more rare tubes have common electrical symbols such as  $\Omega$  or  $\mu$ , since Nixie tubes were used within electrical measurement equipment. IN-12 tubes have their cathodes in the order 3 8 9 4 0 5 7 2 6 1. The digit 5 is an upside down 2 to reduce unique materials. The cathodes are arranged in this manner to minimize more forward cathodes from obscuring the rear cathodes.

### D. Cold Cathode

Nixie tubes do not heat up very much. There is no heating element within the tube, unlike most vacuum tubes electrical engineers would be familiar with. Other graphical tubes, such as VFDs, do require a heating element. A lack of a

heater does not mean they are efficient, though. IN-12 nixie tubes dissipate approximately 0.36W each when a single cathode is lit.

## E. Strike Voltage

To light a nixie tube, a high voltage must be applied. This first voltage application is known as the strike voltage. This clock design utilizes a strike voltage of +180V, which is the output of an internal boost converter on one of two internal printed circuit boards. This high DC voltage gives the neon atom valence electrons the motivation they need to be stripped from the neon atoms, turning the atoms into neon ions. The nixie tube sustains the strike voltage across its anode to the selected grounded cathode for about 100 $\mu$ s before the neon gas is sufficiently ionized to begin conduction. There is no current flow during this time.

## F. Sustain Voltage

After about 100 $\mu$ s of strike voltage application, the voltage across the tube drops to about 140V. This is called the sustain voltage. Conduction begins and the cathode begins to glow. The tube will hold the sustain voltage across it if the cathode is grounded and the anode voltage (pre-resistor) is sustained.

## G. Negative Resistance

The drop from strike voltage to sustain voltage, and how this corresponds to an increase in current draw (from 0mA to around 2.5mA when conduction begins) gives a nixie tube a *negative resistance* characteristic, since voltage drop is reducing while current draw is increasing.

## H. Multiplexing

Only one nixie tube within this clock is on at a time. This is because the circuitry required to have all tubes on at the same time would be much more complex and require a set of 10 or 11 high voltage bipolar transistors for each tube, which is not economical. In addition, nixie tubes have limited life. Having all the tubes on constantly would wear down the lifetime more quickly.

Instead, a multiplexing technique is used. Each tube has its own anode driven individually, and the cathodes for each tube are all tied together. To turn one number in one tube on, the anode for that tube has +180V applied to it with a PNP transistor, and the shared cathode signal for the number desired is grounded with an NPN transistor.

The timing for multiplexing is carefully controlled such that all 6 tubes (and two sets of neon bulb colons) are cycled through in 1/60<sup>th</sup> of a second, to give a display refresh rate of 60Hz. The changes are too fast for the human eye to



distinguish, the human brain blends the light for all tubes together, so that all digits appear to be on at the same time.

The timing is generated with hardware timers within the microcontroller (brains of the clock), and the code is interrupt based, meaning that the timing is deterministic, accurate and exact.

## I. Anti-Ghosting

Nixie tubes are highly capacitive. Because the anodes and cathodes are driven with either an NPN or PNP transistor (open-collector or open-emitter instead of a push-pull or totem pole circuit topology), when a tube is energized, it holds residual charge on the anodes and cathodes (instead of being discharged to ground). If this charge has nowhere to bleed to, it will move to the subsequent tube that is next in the multiplexing sequence. This would cause adjacent tubes to appear to have the same numbers falsely illuminated. This phenomenon is called ghosting. The cleanest approach to mitigating ghosting is to terminate the anode and cathode signals that are shared across all tubes together through a high value resistor. This “termination” connection is then tied to half of the strike voltage, or +90V. This is a low enough voltage to not energize the tube, but high enough to minimize switching losses when turning tubes on and off. The boost converter which generates the +180V strike voltage was also carefully designed to break out half of the output voltage magnitude for this termination level. This is a similar working principle to termination in DDR4 memory in modern computer design, just on a roughly ~100x voltage magnitude scale, and much, much slower in frequency.

## 6. Nixie Tube History

### A. From Wikipedia:

“Nixie tubes were invented by David Hagelbarger. The early Nixie displays were made by a small vacuum tube manufacturer called Haydu Brothers Laboratories, and introduced in 1955 by Burroughs Corporation, who purchased Haydu. The name Nixie was derived by Burroughs from "NIX I", an abbreviation of "Numeric Indicator eXperimental No. 1", although this may have been a backronym designed to justify the evocation of the mythical creature with this name. Hundreds of variations of this design were manufactured by many firms, from the 1950s until the 1990s. The Burroughs Corporation introduced "Nixie" and owned the name Nixie as a trademark. Nixie-like displays made by other firms had trademarked names including Digitron, Inditron and Numicator. A proper generic term is cold cathode neon readout tube, though the phrase Nixie tube quickly entered the vernacular as a generic name.”

### B. In Soviet Russia:

### C. IN-12A/B: