Vintage Nixie Timepiece with Modern Control

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***Abstract*- This paper presents the design of a Nixie tube clock as an educational tool for teaching key concepts in electronics, embedded systems, and programming. By combining vintage Nixie tube displays with modern microcontrollers, students gain practical experience in circuit design, voltage conversation, digital control, and timekeeping algorithms. The project enhances hands-on learning, encouraging active problem-solving while exploring the evolution of display technology. Additionally, the integration of retro components promotes sustainable engineering practices. Initial results suggest that this approach improves student engagement and understanding of electronics and computing fundamentals in engineering education.**

Keywords - Nixie tube, BCD decoder, glow discharge, RTC, real time clock, sustainability, resourcefulness

I. Introduction

Integrating vintage electronic components, such as Nixie (Numerical Indicator experimental No.1) tubes, with modern technology represents a compelling intersection of history and innovation. This paper examines the potential benefits and challenges of combining vintage and modern electronics, specifically through the creation of a Nixie tube clock, a popular device for demonstrating both fundamental electronics and microcontroller programming.

Nixie tubes, popular in the mid-20th century for displaying numerical data, have a distinctive visual appeal but require higher voltages and analog control circuits. In contrast, modern microcontrollers offer low-power, precise digital control. Combining these technologies requires bridging analog and digital domains, creating an educational opportunity to explore these different approaches.

The primary benefit of combining vintage and modern technologies is the enhanced learning experience. By utilizing a vintage component like the Nixie tube, students are exposed to older technology, which broadens their understanding of how modern electronics evolved. Building a Nixie tube clock requires knowledge of high-voltage circuitry to power the tubes while employing modern microcontrollers to drive them, thus combining analog and digital systems.

From a design perspective, this fusion offers a unique aesthetic that is visually engaging. Nixie tubes have a distinctive glow that modern displays cannot replicate, providing not only a functional timekeeping device but also an artistic, retro-style artifact.

Moreover, the integration encourages sustainability and resourcefulness. Repurposing vintage components like Nixie tubes reduces electronic waste, promoting the reuse of older technologies in novel ways. This concept aligns with the principles of sustainable engineering and can introduce students to eco-friendly design practices.

Despite the educational and aesthetic benefits, several challenges arise when integrating vintage technologies with modern electronics. Technical complexity is one of the primary drawbacks. Nixie tubes require high-voltage drivers, typically 170V, while modern microcontrollers operate at low voltages (3.3V or 5V). This requires careful design of power supplies and voltage conversion circuits, introducing additional layers of complexity that may be challenging for beginners.

There is also the issue of component scarcity. Nixie tubes are no longer in mass production, and finding reliable, functioning tubes can be difficult and costly. This limited availability can make long-term projects less sustainable and more expensive to maintain.

Finally, compatibility issues can arise. Vintage components are not designed to interface with modern microcontrollers directly, necessitating additional hardware like high-voltage transistors or specialized driver, converter ICs. This increases both the cost and the difficulty of the project.

II. Theoretical Background

The operation of Nixie tubes is based on the gas discharge phenomenon, which takes place in cold-cathode electron tubes filled with neon or other noble gases. The digits inside the tube are represented by individual cathodes, each of which is energized to produce a gas discharge and a bright orange glow around the respective cathode. The operating voltage is typically 170-200V, which is necessary to create the gas discharge [1-3].

During the discharge phenomenon, the gas field around the cathode is ionized, and the liberated electrons collide with the gas molecules and emit photons [4, 5]. This creates the characteristic light that makes the digits visible. The operating principle of Nixie tubes is based on analog technology, which makes the displayed numbers and signs visually different from modern digital displays, thus giving the devices a unique look.

In Fig. 1., the curve in blue shows the glow discharge section currently under discussion. At point E, the coronal discharge occurs, which can be observed, for example, in Tesla coils. At point F the glow discharge starts and stabilises at point G. In the ascending stage, an "abnormal" discharge occurs, and finally it turns into an arc discharge at point I [6]. It can be clearly seen that the glow discharge we use occurs in the milliampere range in the nx100 V range. Following in the footsteps of this physical phenomenon, a pair of Hungarian brothers, George and Zoltan Haydu in Haydu

Brothers Laboratories, developed the first Nixie tube in the 1930s and used it in the 1950s in different instruments [7].

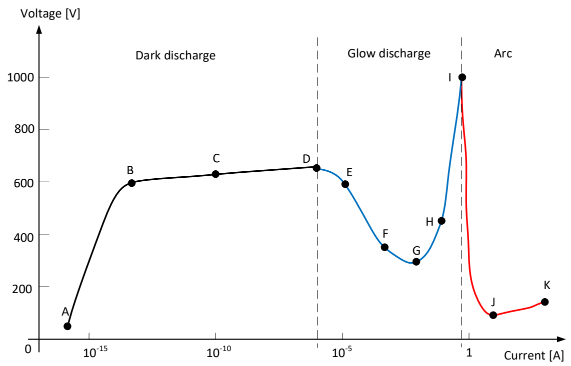

Figure 1: V-I curve of neon gas discharge in constant pressure

The tubes were maintained at pressures ranging from 0.1 to 10 Torr, utilizing a Penning gas mixture composed of neon and argon. The wire-formed elements serve as the cathode (-), while a wire mesh within the tube functions as the common anode (+). When a sufficiently high voltage, approximately 170 V, is applied between the anode and cathode, a yellowish glow is observed around the cathode, indicative of a discharge.

As illustrated in Figure 2, the color of the discharge is predominantly determined by the ionization of neon gas. However, the tube also contains mercury vapor, which emits a blue glow. This addition serves a critical role in preventing "cathode poisoning." Frequent use of the cathode can lead to the formation of oxide layers on adjacent, less-utilized electrodes, potentially impairing performance. The presence of mercury vapor mitigates this oxidation effect. Figure 3 presents the specific Nixie tube model utilized in this study, along with its corresponding pinout.

Figure 2: Fog discharge in Nixie tube

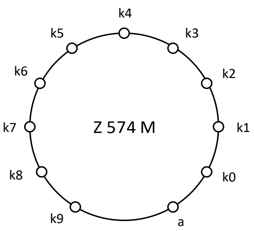

Figure 3: Pinout of the Nixie tube

A. Control of Nixie tubes

The control of Nixie tubes requires a relatively high voltage, which is realized with the help of a suitable power supply and transistors. One of the control solutions is the use of BCD (Binary-Coded Decimal) coded drivers, which receive the numbers in binary form, then decode them and activate the corresponding cathode. This form of control can be clearly integrated with modern microcontroller-based circuits.

To optimize space utilization and eliminate the need for high-voltage transistors (e.g., MPSA42), HVCMOS technology shift registers can be employed. These integrated circuits (e.g., HV509) house all necessary components in a DIL or SO package [8, 9]. Alternatively, general-purpose BCD decoders, such as the HCF4028, can be used in conjunction with transistor arrays. By supplying a low or high signal to a 4-bit input, the corresponding binary number is generated, which the IC uses to activate the output pin corresponding to the given decimal value. Since the anodes are connected to the control circuit, the output is pulled to ground potential.

In 1972, engineers at Texas Instruments developed a decoder specifically designed for controlling cold-cathode display devices, the SN74141. The outputs of this IC are equipped with NPN transistors for switching, and zener diodes are included to prevent negative voltage transitions (Figure 4). This integration reduces circuit complexity and space requirements, as all necessary components are enclosed in one package. Russian equivalents of these ICs, such as the K155ID1, are still available on the market. Given that controlling six ICs would require managing 24 inputs, multiplexing or using a GPIO expander (e.g., MCP23017) is recommended for such configurations.

Enhanced versions of the SN74141 also exist. The SN74142N, for example, includes both a 4-bit decoder and additional features such as a 4-bit latch and a counter. This IC is built using MSI technology and contains four 1-bit master-slave flip-flops. When the $\overline{\text{clear}}$ input is set low, both the counter and flip-flops are reset, resulting in low Q outputs and a high $\overline{Q}_d$ output. While the clear input remains high, the internal counter increments with the rising edge of the clock signal. The $\overline{Q}_d$ output, which is not latched, is routed externally to enable cascading of multiple ICs, thereby facilitating the creation of an n-bit counter. The counter's Q outputs are connected to the data inputs of the latch, and when the strobe input is low, the latch outputs track the counter outputs. If the strobe input is set high, the latch holds the last received value. $\overline{Q}_d$ output is specifically designed for synchronization with subsequent ICs in a cascaded configuration, meaning that the first stage counter can receive new values independent of the latch state [10].

B. Microcontroller program

Modern control of Nixie tube clocks is often solved using modern microcontrollers. Open source platforms are suitable for timing and control tasks. The control program is responsible for the correct operation of the clock, the display of the exact time, and the implementation of additional functions (e.g. temperature measurement, lighting control). The control algorithm typically uses a real-time clock Real-Time Clock, which ensures accurate time tracking even if the power supply is interrupted. The RTC communicates with the microcontroller via (in this case) I^2C or SPI serial interface, ensuring timing accuracy and easy integration into the system.

The microcontroller updates the time from the RTC, after every significant software event and from interrupt, in every 12-hour interval. When an alarm is set, the current time array is continuously compared to the predefined alarm time array. Upon a match, the alarm function is triggered. In addition to the deactivation function, a snooze feature is available; after five consecutive snooze activations, the alarm is automatically deactivated (see on Fig. 5.). Similar firmware implementations can be found in [11-12]. The microcontroller-based approaches outlined here are also applicable in advanced technical domains [13-14], and they align effectively with educational frameworks in higher education [15-17], particularly with a focus on contemporary cybersecurity education strategies [18-20].

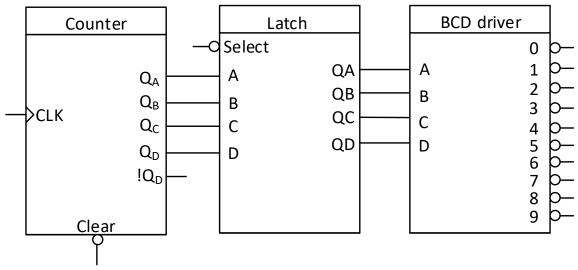

Figure 4: Internal block diagram of the driver IC [11]

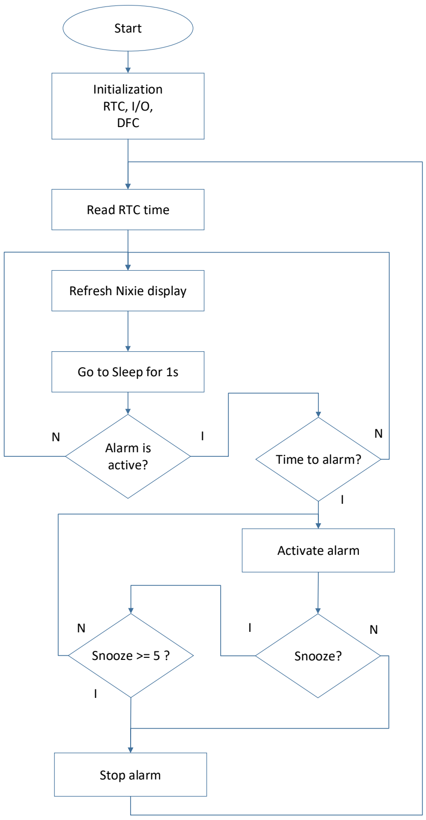

Figure 5: Main block diagram

C. Integration of additional functions

In addition to the time display, Nixie tube clocks can be expanded with other interesting functions that can serve both educational and practical purposes. Nixie tubes can also be used for temperature and humidity display with proper software support and the installation of the necessary sensors, such as DHT22 or DS18B20. With the help of modern microcontrollers, the lighting control of Nixie clocks can also be implemented using a light intensity sensor and, for example, PWM-controlled LEDs to change the intensity of the background lighting. The software control provides the possibility to set different lighting modes, for example the night mode implemented in the project, where the brightness of the display decreases. Furthermore, a Bluetooth or Wi-Fi module can be installed, which enables communication with smartphones, for example setting the time, alarm time or remote control of various lighting schemes.

In this way, students can learn about the integration of wireless communication protocols and embedded systems. Such projects help students understand the integration of vintage technology with modern solutions, which provides useful knowledge in terms of sustainability and upcycling. This approach can also be more sustainable, since the recycling of old technologies can reduce electronic waste by using the extra engineering hours required for implementation. This dual technology perspective allows students to apply the acquired knowledge in unique, tailored projects.

D. Power supply

12 V is supplied from the wall adapter, from which 170 V should be supplied to the tubes and 5 V to the ICs. I did this with a Buck and a Boost converter. The buck converter is homemade, the wiring diagram is shown in Figure 8.

The above equipment (Fig. 7.) is a possible implementation of the 170V circuit. The anodes of the tubes are connected to the output voltage through 15 kΩ protective resistors, the cathodes are connected to the corresponding outputs of the driver ICs. Here, the widely used ZVS step-up DC-DC converter has been used. The converter had been used can be operated from 12V. The buck converter is capable of 12V to 5V conversion, the converter, of which is an LM2576 DC-DC converter, see on Fig. 8.

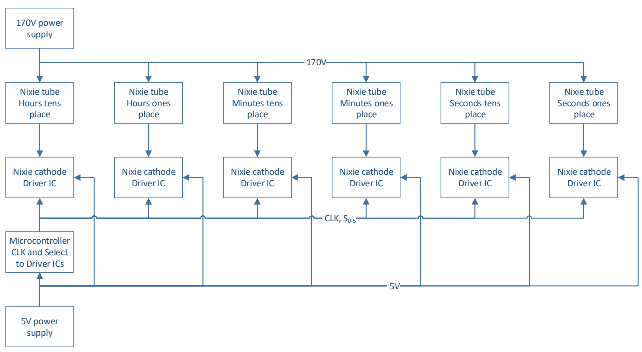

Figure 7: Nixie driver architecture

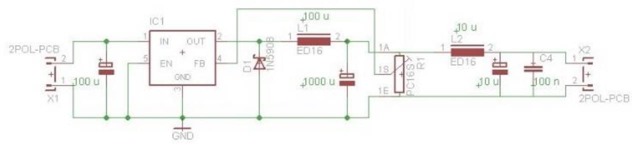

Figure 8: Buck converter circuit diagram

A common issue in switching power supplies is the presence of noise and voltage fluctuations on the output. These arise due to the high-frequency noise introduced by the switching process and the inherent nature of voltage conversion in such circuits. The "spikes" are brief but high-amplitude voltage surges. While these characteristics may not pose problems for some loads, they can negatively impact the performance of sensitive circuits. In this case, since a voltage-sensitive integrated circuit is being powered, it was necessary to address this issue. An effective solution is the use of an LC low-pass filter at the output. This configuration allows low-frequency and DC signals to pass while filtering out high-frequency components. To ensure proper filtering, the cutoff frequency of the Bode plot should be set to a fraction of the switching frequency. Given that the converter's internal oscillator operates at 50 kHz, selecting the cutoff frequency at this range ensures appropriate signal attenuation. In the implementation, a 10 µH inductor and two parallel capacitors, with values of 100 nF and 10 µF respectively, were used for the filter.

III. Practical realisation

The block diagram (Fig. 9) illustrates the microcontroller, with the ICs arranged in a row beneath it. The lower sections represent the 5 V, 170 V, and 12 V power sources. The RTC and DFC modules communicates with the controller via analog and digital inputs, while the other digital ports function as outputs. One clock signal, other six provide an enable signal, and one delivers a clear signal to the ICs. The ICs receive a 5 V supply, while a 12 V to 170 V boost converter generates sufficient voltage for the tubes. A common ground point has been established within the system using a stub, ensuring that the ICs apply the necessary 170 V ignition voltage to the appropriate tube cathode by pulling the corresponding output to ground.

When using K155ID type ICs, modifications to the microcontroller outputs are required, which involve adding an extra unit. Specifically, a GPIO expander array must be inserted between the microcontroller and the ICs. This allows for the expansion of two microcontroller ports into 16 ports through I^2C communication. By employing two expander lines, the CLK, STRB lines shown in the figure are replaced with SDA, SCL lines to interface with the GPIO. The expander setup provides sufficient connection points to transmit the appropriate binary numeric values to the 4-bit control inputs of the ICs, with each IC receiving four input lines. The ICs will then pass the output signals directly to the tubes. Although this requires more significant changes to the microcontroller's programming, there is library available for the expander that simplifies the integration process.

After the design and modeling of the clock components, the tubes are placed in custom-made sockets mounted on top of the PCB (Fig. 10). In the current configuration, the tubes are connected to the control system using pinheaders.

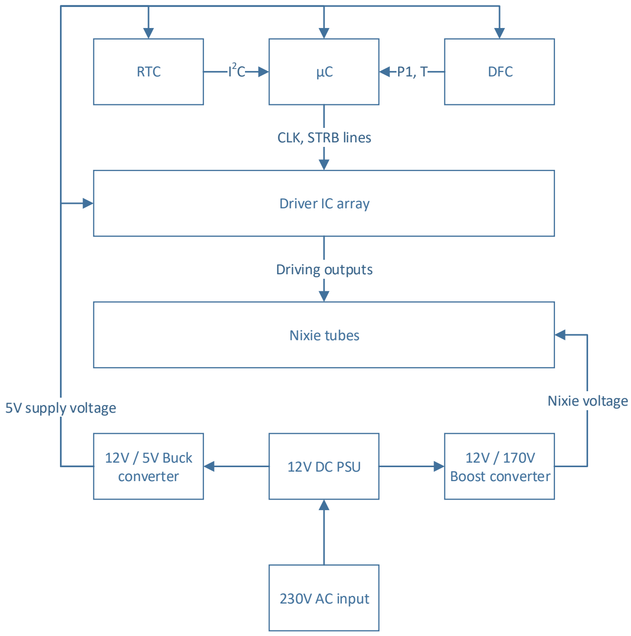

Figure 9: Block diagram of the device

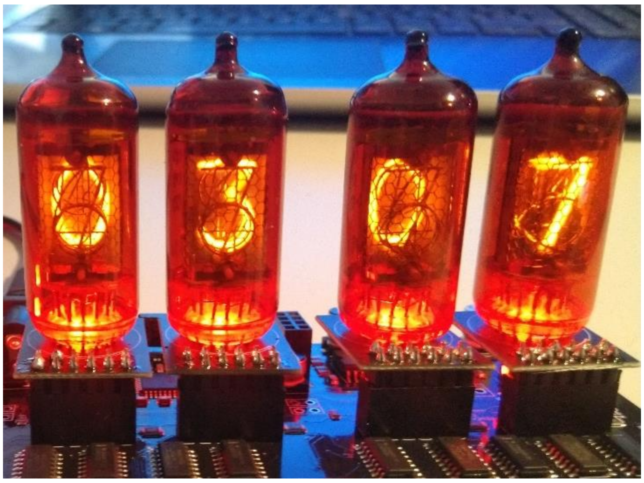

Figure 10: The completed timepiece

Conclusion

The combination of vintage Nixie tube technology with modern microcontroller systems offers both significant educational benefits and technical challenges. While the aesthetic appeal and learning opportunities in analog and digital electronics are substantial, the complexity of high-voltage circuits and the scarcity of vintage components present notable obstacles. Nevertheless, the creation of a Nixie tube clock represents a practical and rewarding project that demonstrates the fruitful intersection of historical and modern technologies in an educational setting. Combining electronic innovation with the intricacies of traditional analog circuits provides future engineers with a solid foundation in challenging industries.

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