NIXIE CLOCK *REDUX*
IN-12 VARIANT (ИН-12Б)

User Manual

Drew Maatman

IN-12 Variant

IN-12 Variant

1. Warnings

- This design contains high voltages that can be dangerous
- Ever effort has been made to keep this project safe, **but the user assumes all risk**
- The high voltage power supply has been designed with a low current limit to try to mitigate risk
- If any internal circuitry becomes exposed, do not touch it while the power cord is plugged in
- Do not use this project outside of its casing
- If the nixie tubes break, do not touch the metal elements inside. Remove power from the clock immediately
- The case is not waterproof
- The USB port is electrically isolated to mitigate risk of electrical stress to a host PC should a fault occur
- If the internal battery (CR1616 coin cell) needs to be replaced, do not leave the clock powered while changing the battery
- I am always willing to help troubleshoot issues, reach me at drewmaatman@gmail.com
- Nixie tubes age and degrade over time. Every effort has been made to maximize their lifetime within this design. The nixie tubes can be replaced if elements within them fail. Only do this when the clock is unpowered, and use care to not damage adjacent tubes

IN-12 Variant
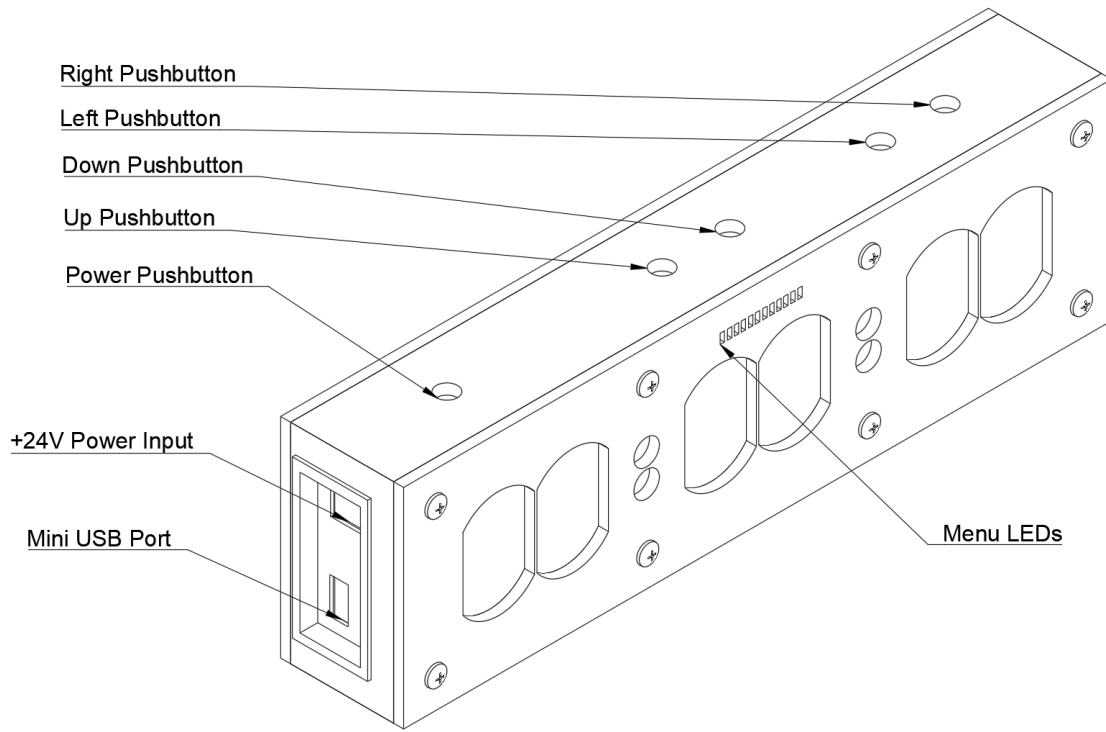
2. Clock Overview

FIGURE 1: OVERVIEW

- The clock requires a +24V DC power supply which can provide at least 12W of power
- The DC barrel jack for power input is center positive polarity
- The USB port is a USB 2.0 Mini B connector. This provides a serial interface and cannot power the clock (see USB/Serial Interface)
- The menu LEDs indicate the following menu settings, from left to right (see Pushbutton Interface)
    o Display Time
    o Set Time
    o Display Date
    o Set Date
    o Display Weekday
    o Set Weekday
    o Display Alarm
    o Set Alarm
    o Set Alarm Arm/Disarm
    o Set 24hr or AM/PM Format
    o Set Tube Brightness
    o Set RGB Backlight Color

IN-12 Variant

3. Clock Features

- The tubes can be configured to display:
    - Time (24 hour or AM/PM)
    - Date (MM/DD/YY)
    - Weekday (Numbered from 1 to 7)
    - Alarm Time (24 hour or AM/PM)
    - Alarm Arm (Armed or Disarmed), see Setting the Alarm, Arming/Disarming the Alarm (with pushbuttons) as well as Setting the Alarm and Arming the Alarm (with USB/Serial Interface).
    - Time/Date/Weekday and Alarm Setting Modes (set through pushbuttons or USB serial port)
    - Tube Brightness Setting (10% to 100%)
    - Tube RGB Backlight Color (build option)
- Additional Features:
    - USB Serial Port
    - Tube Elapsed Time Counter (build option, see Supported Serial Commands)
        - Nixie tubes age, this can track how long voltage has been applied, as well as how many times voltage has been cycled
    - Clock Elapsed Time Counter (build option, see Supported Serial Commands)
        - Tracks total time clock has input power applied, power cycles
    - Capacitive Touch Pushbuttons for Power On/Off and user interface
    - Battery Backed Real Time Clock (build option), battery backed time is updated whenever time is set on clock through pushbuttons or USB serial port
    - Internal Telemetry (build option, see Supported Serial Commands)
    - Input Power Protection
        - Reverse Polarity Protection
        - Input Under/Overvoltage Protection
        - Input Current Limit
    - Tube RGB Backlight Brightness (adjustable over USB, see Supported Serial Commands)

IN-12 Variant
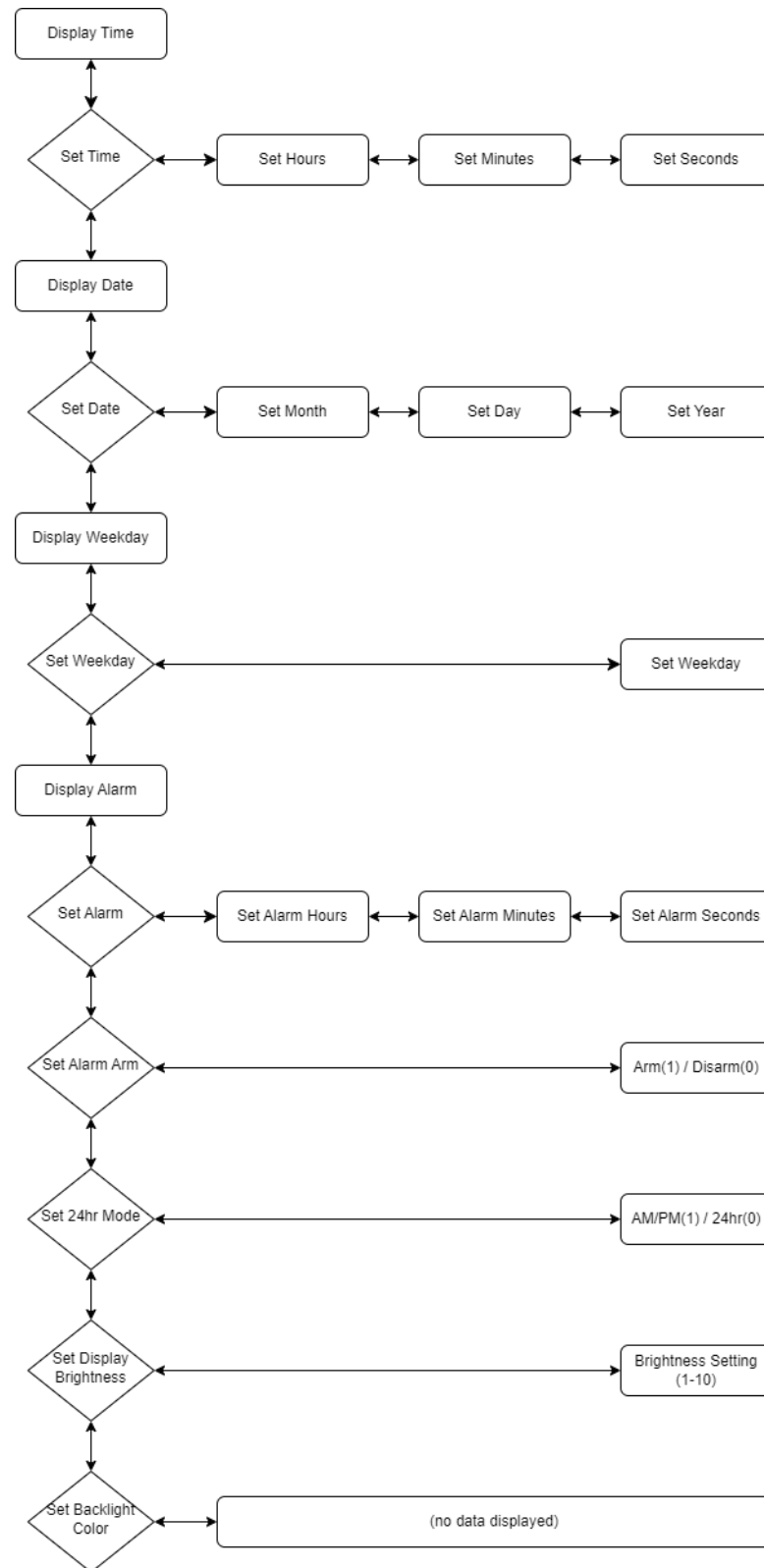
4. Pushbutton Interface

FIGURE 2: PUSHBUTTON MENUS

IN-12 Variant

A. Description

The pushbuttons allow setting time, date, weekday, alarm time, arming and disarming the alarm, the time hours format (AM/PM vs 24hr), tube brightness, and the tube RGB backlight color, if supported. The pushbuttons also allow for the selection of which data to be displayed on the clock, including time, date, weekday, and alarm time.

The up, down, left, and right pushbuttons allow for navigation through the menu displayed in Figure 2: Pushbutton Menus. The current menu item setting (leftmost column in Figure 2: Pushbutton Menus) is set using the up/down pushbuttons, and the menu item setting is displayed on the menu LEDs on the top edge of the clock. This is slightly counter-intuitive, as the menu items are visualized vertically and set using up/down pushbuttons, but the menu item LEDs are arranged left to right, for circuit layout reasons.

The top menu item (Display Time) is the left-most indicator when displayed on the menu LEDs, and the bottom menu item (Set Backlight Color) is the right-most indicator when displayed on the menu LEDs.

When navigating through the menu items using the up/down pushbuttons, the menu LEDs will update, and the data displayed on the tubes will change. The menu sub-items (the items further to the right within the menus described in Figure 2: Pushbutton Menus) can be navigated to using the left/right pushbuttons. The menu sub-item current selected for changing will blink on the tubes when it is selected. That data can then be changed using the up/down pushbuttons.

To finalize the change, the left/right pushbuttons should be used to move back to the menu item, such that no tubes are blinking. The sub-menus "wrap around," such that when the user selects the sub-menu furthest to the right, a single push of the right pushbutton will leave the sub-menu for the main menu item. Then, the up/down pushbuttons can be used to navigate back to the "display time" menu item, or any other menu item desired.

B. Setting the Time

a. The clock must be powered on
b. Start from the "Display Time" menu item (upper-most menu item in Figure 2, no tubes will be blinking). The left-most menu LED should be illuminated
c. Press the down pushbutton once. The "Set Time" menu LED (second from the left) will be the only menu LED illuminated. No tubes will blink, but all four colons will be solid, instead of blinking
d. Press the right pushbutton once. The "Set Hours" sub menu is now active. The left set of nixie tubes will be blinking, indicating the user is setting the hours
e. Use the up and down pushbuttons to increase or decrease the hour displayed on the clock

IN-12 Variant

f.   Press the right pushbutton again. The hour tubes will stop blinking, and the minute tubes will now blink, indicating that minutes are now what are being changed

g.   Use the up and down pushbuttons to increase or decrease the minutes displayed on the clock

h.   Press the right pushbutton again. The minute tubes will stop blinking, and now the second tubes will blink

i.   Use the up and down pushbuttons to set the seconds

j.   Finally, either press the right pushbutton once (to wrap around from the set-seconds sub-menu to the set time menu item), or press the left pushbutton three times. No tubes will be blinking, indicating the "Set Time" menu item is selected

k.   Press the up pushbutton once. This will change the menu item from "Set Time" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.

C. Setting the Date

a.   The clock must be powered on

b.   Start from the "Display Time" menu item (upper-most menu item in <u>Figure 2</u>). The left-most menu LED should be illuminated

c.   Press the down pushbutton three times. The "Set Date" menu LED (fourth from the left) will be the only menu LED illuminated. No tubes will blink, but the lower colons will be solid, instead of blinking

d.   Press the right pushbutton once. The "Set Month" sub menu is now active. The left set of nixie tubes will be blinking, indicating the user is setting the month

e.   Use the up and down pushbuttons to increase or decrease the month displayed on the clock

f.   Press the right pushbutton again. The month tubes will stop blinking, and the day tubes will now blink, indicating that day of the month is now what is being changed

g.   Use the up and down pushbuttons to increase or decrease the day of the month displayed on the clock

h.   Press the right pushbutton again. The day tubes will stop blinking, and now the year tubes will blink (furthest to right)

i.   Use the up and down pushbuttons to set the last two digits of the year (from 2000 to 2099)

j.   Finally, either press the right pushbutton once (to wrap around from the set-year sub-menu to the set date menu item), or press the left pushbutton three times. No tubes will blink

k.   Press the up pushbutton three times. This will change the menu item from "Set Date" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.

l.   Date can be displayed by pressing the down pushbutton twice when starting at the "Display Time" menu item. This will change the menu item from "Display Time" to "Display Date." The menu LED lit should be third from the left.

D. Setting the Weekday

a. The clock must be powered on
b. Start from the "Display Time" menu item (upper-most menu item in <u>Figure 2</u>). The left-most menu LED should be illuminated
c. Press the down pushbutton five times. The "Set Weekday" menu LED (sixth from the left) will be the only menu LED illuminated. No tubes will blink
d. Press the right pushbutton once. The "Set Weekday" sub menu is now active. The right set of nixie tubes will be blinking, indicating the user is setting the weekday (1-7, 1 being Sunday)
e. Use the up and down pushbuttons to increase or decrease the weekday displayed on the clock
f. Either press the right pushbutton once (to wrap around from the set-weekday sub-menu to the set weekday menu item), or press the left pushbutton once. No tubes will blink
g. Press the up pushbutton five times. This will change the menu item from "Set Weekday" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.
h. Weekday can be displayed by pressing the down pushbutton four times when starting at the "Display Time" menu item. This will change the menu item from "Display Time" to "Display Weekday." The menu LED lit should be fifth from the left.

E. Setting the Alarm

a. The clock must be powered on
b. Start from the "Display Time" menu item (upper-most menu item in <u>Figure 2</u>). The left-most menu LED should be illuminated
c. Press the down pushbutton seven times. The "Set Alarm" menu LED (fourth from the right) will be the only menu LED illuminated. No tubes will blink
d. Press the right pushbutton once. The "Set Alarm Hours" sub menu is now active. The left set of nixie tubes will be blinking, indicating the user is setting the alarm hours
e. Use the up and down pushbuttons to increase or decrease the alarm hour displayed on the clock
f. Press the right pushbutton again. The alarm hour tubes will stop blinking, and the alarm minute tubes will now blink, indicating that alarm minutes are now what are being changed
g. Use the up and down pushbuttons to increase or decrease the alarm minutes displayed on the clock
h. Press the right pushbutton again. The alarm minute tubes will stop blinking, and now the alarm seconds tubes will blink
i. Use the up and down pushbuttons to set the alarm seconds
j. Finally, either press the right pushbutton once (to wrap around from the set-alarm seconds sub-menu to the set alarm menu item), or press the left pushbutton three times. No tubes will blink

IN-12 Variant

k. Press the up pushbutton seven times. This will change the menu item from "Set Alarm" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.

l. The time that the alarm is set to can be displayed by pressing the down pushbutton six times when starting at the "Display Time" menu item. This will change the menu item from "Display Time" to "Display Alarm." The menu LED lit should be sixth from the right.

F. Arming/Disarming the Alarm

a. The clock must be powered on

b. Start from the "Display Time" menu item (upper-most menu item in Figure 2). The left-most menu LED should be illuminated

c. Press the down pushbutton eight times. The "Set Alarm Arm" menu LED (fourth from the right) will be the only menu LED illuminated. No tubes will blink

d. Press the right pushbutton once. The "Set Alarm Arm" sub menu is now active. The right set of nixie tubes will be blinking, indicating the user is setting if the alarm is armed or not. "1" corresponds to the alarm being armed, "0" corresponds to the alarm being disarmed.

e. Use the up and down pushbuttons to change the alarm arming setting, between 0 and 1.

f. Either press the right pushbutton once (to wrap around from the set-alarm-arm sub-menu to the set alarm arm menu item), or press the left pushbutton once. No tubes will blink

g. Press the up pushbutton eight times. This will change the menu item from "Set Alarm Arm" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink. The alarm will be armed if the set-alarm-arm sub-menu is set to 1.

h. Checking to see if the alarm is armed or disarmed is done by navigating to the same "Set Alarm Arm" menu item (by pushing the down pushbutton 8 times, from "Display Time"). There is no separate menu to view the alarm arming setting

i. ***When the alarm sounds, it can be disabled by pressing any pushbutton a single time. There is no snooze feature***

G. Setting the Time Format (24hr/ AM/PM)

a. The clock must be powered on

b. Start from the "Display Time" menu item (upper-most menu item in Figure 2). The left-most menu LED should be illuminated

c. Press the down pushbutton nine times, or press the up pushbutton three times. The "Set 24 Hour Mode" menu LED (third from the right) will be the only menu LED illuminated. No tubes will blink

d. Press the right pushbutton once. The "Set 24 Hour Mode" sub menu is now active. The right set of nixie tubes will be blinking, indicating the user is setting the time format. "1" corresponds to the hours being displayed in 24

hour format (0 to 23 hours), "0" corresponds to the time being displayed in AM/PM format.

e.   Use the up and down pushbuttons to change the time format setting, between 0 and 1.

f.   Either press the right pushbutton once (to wrap around from the set-24-hour mode sub-menu to the set 24 hour menu item), or press the left pushbutton once. No tubes will blink

g.   Press the up pushbutton nine times. This will change the menu item from "Set 24 hr mode" to "Display Time". The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.

h.   When in 24 hour mode, the time is reflected in 24 hour format. When in AM/PM mode, a small decimal point is illuminated on the hours tubes to indicate if the time is PM or AM (AM lacking decimal point, PM includes decimal point). All time modes are displayed based on this setting, including "Display Time," "Set Time," "Display Alarm," and "Set Alarm"

H. Setting the Display Brightness

a.   The clock must be powered on

b.   Start from the "Display Time" menu item (upper-most menu item in Figure 2). The left-most menu LED should be illuminated

c.   Press the down pushbutton ten times, or press the up pushbutton twice. The "Set Brightness" menu LED (second from the right) will be the only menu LED illuminated. No tubes will blink

d.   Press the right pushbutton once. The "Set Brightness" sub menu is now active. The right set of nixie tubes will be blinking, indicating the user is setting the display brightness. "10" corresponds to the brightness being set to 100%. "1" corresponds to the brightness being set to 10%. Increments of 10% are available.

e.   Use the up and down pushbuttons to change the display brightness setting, between 1 and 10. The tube brightness will be actively adjusted.

f.   Either press the right pushbutton once (to wrap around from the set brightness sub-menu to the set brightness menu item), or press the left pushbutton once. No tubes will blink

g.   Press the up pushbutton ten times. This will change the menu item from "Set Brightness" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.

I. Setting the RGB Backlight Color (if supported)

a.   The clock must be powered on

b.   Start from the "Display Time" menu item (upper-most menu item in Figure 2). The left-most menu LED should be illuminated

c.   Press the down pushbutton eleven times, or press the up pushbutton once. The "Set Color" menu LED (furthest to the right) will be the only menu LED illuminated. No tubes will blink, and no data will be displayed.

d. Unlike other menu items, there are no submenus, so pressing the right and left pushbuttons are what change the backlight color
e. Use the left and right pushbuttons to select the desired backlight color
f. Press the up pushbutton eleven times. This will change the menu item from "Set Color" to "Display Time." The menu LEDs update, and the left-most menu LED should now be illuminated. The colons will now blink.
g. The RGB backlight brightness cannot be adjusted using the pushbuttons, see Setting the Tube RGB Backlight

IN-12 Variant

5. USB/Serial Interface

A. Establishing a Connection

The Nixie Clock can be communicated with through its USB port. It enumerates as an FTDI virtual COM port on Windows, Macintosh, and Linux machines. The following serial settings should be used:

- 115.2kBaud
- 8-bit Data Length
- No Parity
- 1 stop bit
- No flow control

A serial client such as PuTTY or TeraTerm can be used on Windows machines. Macintosh and Linux machines allow serial communication through the command line using the `screen` command. If using PuTTY, ensure that `Implicit CR in every LF` is enabled, `Local Echo` is set to `Force on`, and `Local Line Editing` is set to `Force on`.

B. Beginning Communication

On reset (power on or software/hardware reset), the Nixie Clock will print startup messages and debug information about the startup code as it configures itself. This will not appear if the serial terminal is opened after boot is complete. An easy way to determine if a connection is established after boot-up is to call the `*IDN?` command. The clock will respond with an identification string used for automation scripts.

C. Serial Color Scheme

- Help messages and neutral responses appear in yellow
- System parameters and affirmative responses appear in green
- Measurement responses appear in cyan
- Urgent/interrupt messages appear in magenta
- Errors and negative responses appear in red
- User input appears in white

D. Help command

All supported serial commands, as well as arguments that can be passed with them, can be printed with the `Help` command. A one-line description of each supported command is also printed.

E. Setting the Time

The internal real-time clock and calendar (RTCC) can be set over the USB interface. The real-time clock and calendar tracks time, date, and weekday. All RTCC settings can be adjusted using the `Set RTCC` command, which requires an argument passed for what should be adjusted, along with the value that the RTCC should be adjusted to. For example:

`Set RTCC: Time: 09:30:25` would set the current time to 9:30 and 25 seconds, AM

`Set RTCC: Time: 21:30:25` would set the current time to 9:30 and 25 seconds, PM (regardless of time format displayed, RTCC time **must** be entered in a 24-hour format)

`Set RTCC: Date: 04/24/2023` would set the current date to April 24th, 2023 (only years between 2000 and 2099 are supported. All four digits of year must be entered)

`Set RTCC: Weekday: Friday` would set the current weekday as Friday. The RTCC weekday is set with a string, while it is displayed on the Nixie tubes as a number (1 to 7)

The Nixie Clock will respond to each of these commands indicating what RTCC settings have been adjusted to

F. Selecting what is Displayed

The clock can be configured to display information through the USB interface in a similar fashion to what the pushbuttons can select what to display.

`Set Display Mode: Time` would configure the clock to show the current time (most use cases)

`Set Display Mode: Date` would configure the clock to show the current date

`Set Display Mode: Weekday` would configure the clock to show the current weekday (numbered 1 through 7, 1 being Sunday)

`Set Display Mode: Alarm` would configure the clock to show the time that the alarm is set for

G. Setting the Alarm

`Set Alarm: 09:30:25` would set the alarm time for 9:30 AM and 25 seconds. This must be entered in 24-hour time format. This does not actually arm the alarm to sound.

H. Arming the Alarm

`Arm Alarm: Arm` would enable the alarm to sound at the time set by the `Set Alarm` command. Once the alarm sounds, it can be disarmed/silenced by pressing any pushbutton once, or by sending the `Arm Alarm: Disarm` command. There is no snooze function.

I. Setting the Tube RGB Backlight Settings

`Set Backlight Color: Red` would set the RGB tube backlight, if installed, to be a solid red color. Supported colors include Black (off, default), Red, Green, Blue, Cyan, Magenta, Yellow, and White. Any 24-bit RGB hex code can also be sent for custom colors (FFFFFF would correspond to white, for instance, while FF0000 would correspond to Red)

`Set Backlight Brightness: 90` would set the RGB tube backlight, if installed, to a brightness level of 90%.

J. Turning the clock On and Off

`Set Power: On` enables the clock. `Set Power: Off` disables the clock. Whenever the clock is turned on through either the power pushbutton or the USB interface, Time is always selected to be displayed, and the RGB backlight is disabled.

K. Supported Serial Commands

All supported serial commands and their help messages are listed below:

Help: Prints help message for all supported serial commands

Reset: Executes an MCU software reset

Clear Screen: Clears the serial port terminal

*IDN?: Prints identification string

Repository?: Prints project Git repo location

Host Status?: Prints status of MCU host device (IDs, WDT, DMT, Prefetch, Cause of Reset, up time)

Peripheral Status? <peripheral_name>: Prints status of passed host peripheral.

Available peripherals:

    Interrupts

    Clocks

    PMD

    WDT

    DMT

    Prefetch

    DMA

    ADC

```
ADC Channels

I2C Master

RTCC

Timer <x> (x = 1-9)
```

Error Status?: Prints the status of various error handler flags

Clear Errors: Clears all error handler flags

Platform Status?: Prints current state of surrounding circuitry, including PGOOD, clock elapsed time, I2C slaves

Live Telemetry: Toggles live updates of system level telemetry

Time and Date?: Prints the current system time and date

Set RTCC: <parameter>: <parameter args>: sets a time parameter within the Real Time Clock and Calendar. Available parameters:

Date: <mm>/<dd>/<yyyy>: Sets the RTCC date

Time: <hh>:<mm>:<ss>: Sets the RTCC time. (Must be 24 hr time format)

Weekday: <weekday>: Sets the RTCC weekday

Unix Time: <decimal unix time>, <hour offset from UTC to local time>: sets the RTCC to the supplied UNIX time with hour offset from UTC

Set Backlight Color: <color/hex>: Sets the tube backlight color. Colors include Red, Green, Blue, Yellow, Magenta, Cyan, White, and any 24 bit hex color (eg FFFFFF)

Set Backlight Brightness: <percentage>: Sets the brightness of the tube backlight

Set Power: <On/Off>: Turns the clock on or off

Set Display Mode: <Time, Date, Weekday, or Alarm>: Sets the display to show different clock functions

Display Lamp Test: Tests all IN12 display Elements. This should look like a giant blur on each digit

Set Display Brightness: <percent>: Sets the IN12 display to the entered brightness as a percentage

Set Time Format: <24/AM_PM>: Sets time display format. This only impacts tube display, not USB user interface

Alarm Status?: Prints clock alarm settings

Set Alarm: <hh>:<mm>:<ss>: Sets the alarm time. (Must be 24 hr time)

**Arm Alarm: <Arm/Disarm>:** Arms or disarms the clock alarm

IN-12 Status?: Prints status of devices on IN-12 Carrier Board, as well as carrier SPD data. This includes tube elapsed time counter.

IN-12 Variant

6. Project History

Git Repository: https://github.com/drewsum/Nixie_Clock

A. Rev A

The first incarnation of this project was completed in October of 2017. It ran on a PIC16LF1519 8-bit microcontroller, supporting IN-14 tubes. It featured a 1.65F supercapacitor stack backup circuit (charge pump, LDO) that allowed the PIC16 to continue timekeeping for up to a day after being unplugged without a battery. The PIC16 utilized extensive sleep modes and low power techniques to continue operation with this supercapacitor stack. This design was only able to display and track time, it could not track date or weekday, and did not have an alarm. Time was tracked directly in RAM as standard C variables. Due to the low pin count on the PIC16, binary coded decimal encoding (and hardware decoding) was used to control all the multiplexing signals. Like the rev B design, the rev A was constructed using two printed circuit boards. The top circuit board was entirely passive, only hosting the tubes. All power, processing and multiplexing was done on the lower PCB. There was no USB port, telemetry, or debug functionality. Also like the rev B design, the rev A featured an input protection circuit for under and overvoltage lockout, and reverse polarity protection. It sports a similar, yet less refined boost converter design to the rev B project. Due to the extreme step-up ratio required to boost the +24V input to the +180V strike voltage, the boost converter is a hybrid topology, with a standard non-synchronous boost design, but with a diode/capacitor voltage doubler added to the switch node. The regulator regulates to +90V, and the diode/capacitor double doubles this to the +180V strike voltage. Both voltages are needed to properly drive nixie tubes. The upper and lower PCBs are connected through three different connectors, which makes mating the two PCBs difficult within the enclosure.
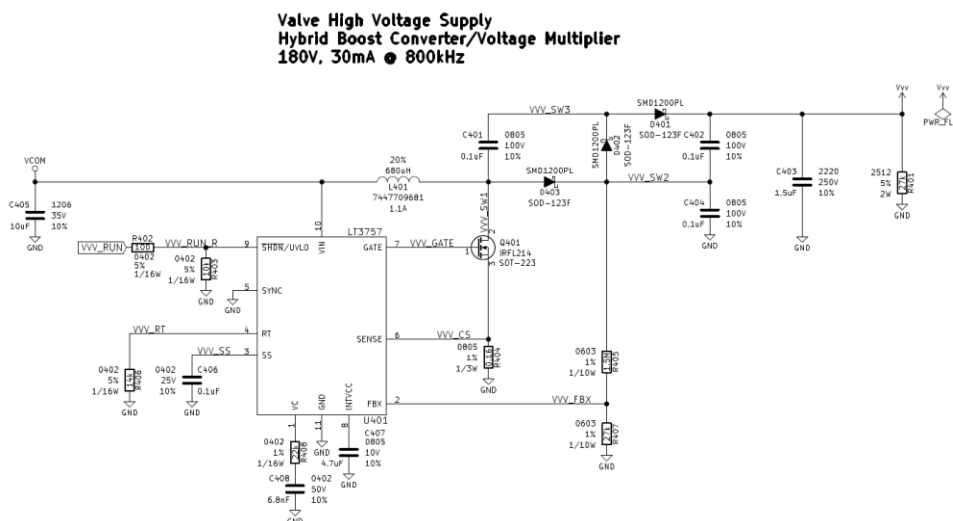
FIGURE 3: REV A BOOST CONVERTER

B. Rev B

The rev B design has many similar elements to rev A, but has been extensively redesigned. The original boost converter remains, although with more refined component selection. This design runs on a PIC32MZ EF 200MHz 32-bit microcontroller, which is extremely, extremely overkill. It is designed to be much more flexible from a user-interface and functionality standpoint, as well as from a configuration standpoint. Power and processing live on the lower PCB, but multiplexing and user interface support live on the upper PCB. This means that multiple tube types can be supported by swapping out the upper PCB. A single tall stacking height PMC connector bridges the two PCBs. The lower control PCB "core board" is able to detect which kinds of tubes and features are installed on the upper PCB "carrier board."
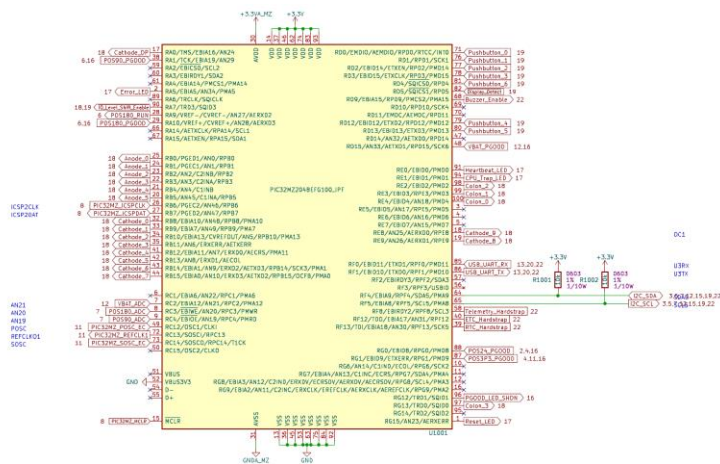

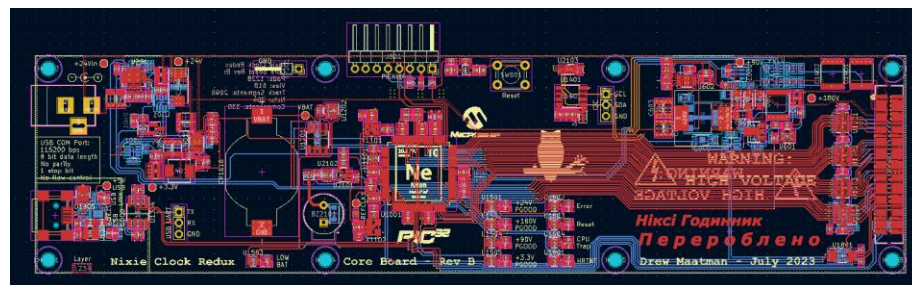**FIGURE 4: REV B MICROCONTROLLER**
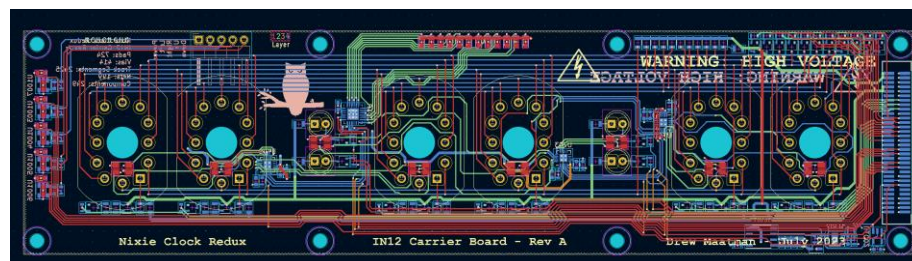

FIGURE 5: REV B LOWER/CORE PCB

FIGURE 6: REV B UPPER/CARRIER PCB (IN-12 VARIANT)

7. 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). Electrons are attracted to the positively charged anode. This movement of ions and electrons 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 Ω or μ, 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 cathodes are arranged in this manner to minimize more forward cathodes from obscuring the rear cathodes. The digit 5 is an upside down 2 to reduce unique materials, per the Soviet Union's cost saving design philosophy.

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.

IN-12 Variant

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, and the voltage drop developed across the tube, 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 100µs before the neon gas is sufficiently ionized to begin conduction. There is no current flow during this time.

F. Sustain Voltage

After about 100µs 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 decrease in anode to cathode voltage 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 occurs) gives a nixie tube a *negative resistance* characteristic, since voltage drop is reducing while current draw is increased.

H. Multiplexing

Only one nixie tube within this design 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 or efficient. In addition, nixie tubes have a limited lifespan. 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 numeral desired within that tube 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 1/60th 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 when voltage is applied. This would cause adjacent tubes to appear to have the same numerals 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.

IN-12 Variant

8. 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:

From "Medium.com":

Although the first mass-market nixie tubes were produced in the United States and created by the Hungarian Haydu Brothers, who were proudly outspoken of their hatred of the Soviet Union and their occupation of their home country: the Nixie tubes were most famously known as a Soviet technology. The Soviet Union produced more Nixie Tubes than any country in the world, they produced and used the technology up until their dissolution in 1991. As could be expected, the Soviet Union never paid any royalties to the Haydu brothers or Burroughs Corporation.
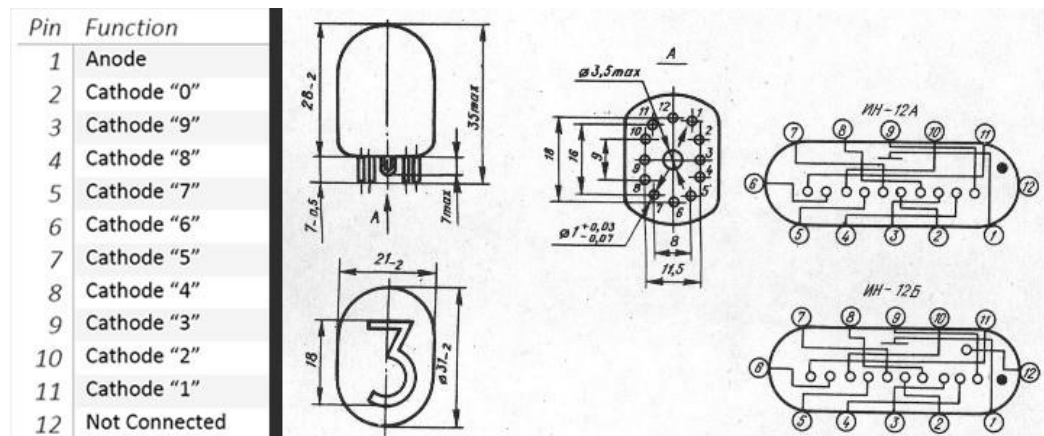
While the stealing of the Nixie Tube technology can be best described as a perfect example of copyright infringement, it is interesting to see how the Soviets modified the Nixie Tubes. As a perfect example of the Soviet school of thought, the "2" and "5" metal inserts were the exact same form — just flipped to their respective orientation. The Soviets valued simplicity and low production cost, opting for volume. The IN-18 nixie tube or biggie nixie, one of the most popular versions of the Soviet produced

Nixie Tube, made use of this cost saving measure and many others.

For more than 30 years the Soviets used nixie tubes as an alternative to the new American LEDs for military and industry concerns. While the United States was able to move on to more cost effective and new technologies, the Soviet Union was stuck in the early 1960s in digital number display technology. For this reason, Nixie Tubes are abundant in ex-Soviet states.

C. IN-12A/B:

The IN-12 tube design dates back to the 1980s in the USSR. The datasheets available online are dated 1988. The IN-12 is offered in an "A" variant, which does not include a decimal point cathode, as well as a "B" variant, which does include a decimal point cathode. They are otherwise interchangeable.

Pin	Function
1	Anode
2	Cathode "0"
3	Cathode "9"
4	Cathode "8"
5	Cathode "7"
6	Cathode "6"
7	Cathode "5"
8	Cathode "4"
9	Cathode "3"
10	Cathode "2"
11	Cathode "1"
12	Not Connected

FIGURE 7: IN-12A/B PINOUT