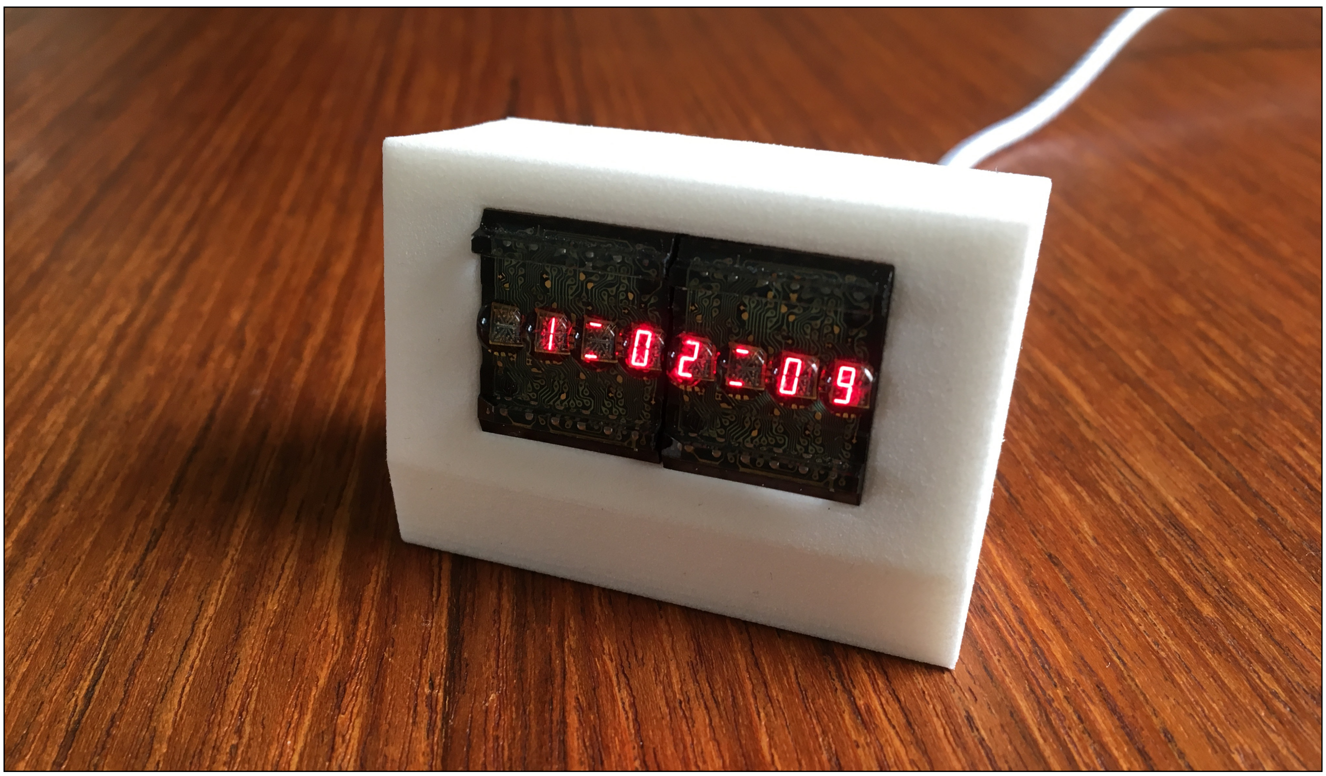
Digital Clock DC-002

User Guide

Software Version 1.1 - December 17, 2016



Warranty

Joey warrants that the product will be free of defects in materials and workmanship for the lifetime of the product. If the product proves defective during this warranty period, Joey, at his option, either will repair the defective product without charge for parts and labor, or will provide a replacement in exchange for the defective product. Batteries are excluded from this warranty. Parts, modules, and replacement products used by Joey for warranty work may be new or reconditioned to like new performance. All replaced parts, modules, and products become the property of Joey.

In order to obtain service under this warranty, Customer must notify Joey of the defect before the expiration of the warranty period and make suitable arrangements for the performance of service. Customer shall be responsible for packaging and shipping the defective product to the service center designated by Joey.

Contacting the Manufacturer

For product information, sales, service, and technical support:

- In North America, call: 1-XXX-XXX-XXXX
- Worldwide email: joey@joeyhagedorn.com
- On the web: `https://www.joeyhagedorn.com`

An electronic copy of this manual is available online at:

`https://www.joeyhagedorn.com/download/DC-002/UserGuide.pdf`

A project log, documenting the project construction, is available online at:

`https://www.joeyhagedorn.com/projects/DC-002/`

Features

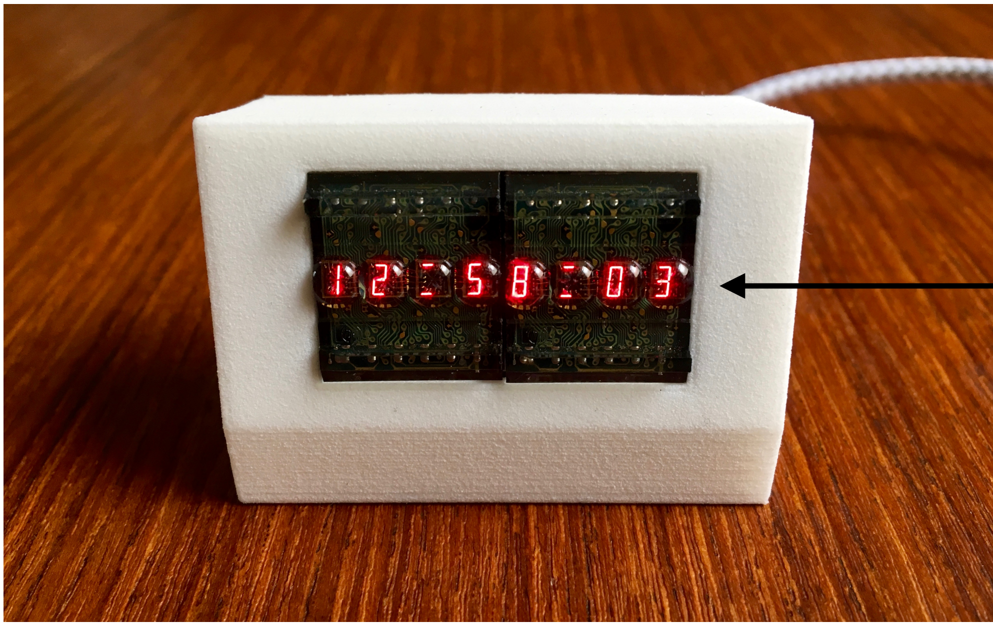
This Digital Clock DC-002 is a hand crafted device especially built for my dear friends and not available for sale. All features and clock design are bespoke and not derived from any existing commercial product. The primary features of this clock are:

- High-precision high-stability temperature compensated timekeeping
- Persistent settings and battery backup for timekeeping when unplugged
- Bright and clear retro-styled LED display
- Date Display and calendar function supporting fully supporting leap years
- Easy-to-use knob based menu UI
- Temperature Display
- Customizable time display with Seconds, AM/PM indicator, and 12/24h modes.
- Firmware upgradability
- USB interface for precision time synchronization
- Made in USA

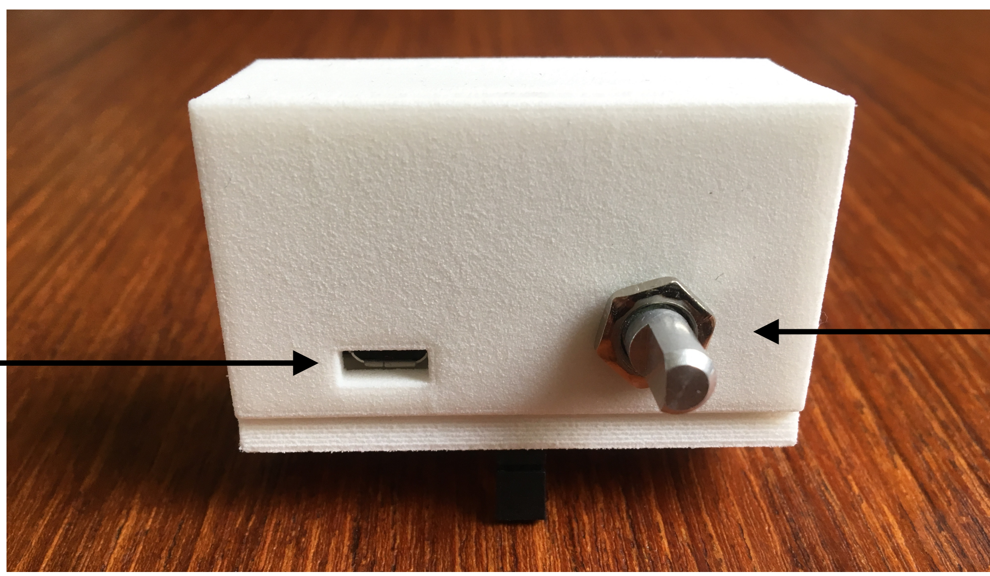
Specifications

- Teensy 2.0 based architecture/bootloader
  - 16 MHz ATMEGA32U4 MCU, 8 bit AVR
  - 32K Flash, 2.5K RAM, 1K EEPROM
- USB-Micro type B Connector for power and programming
- Time Synchronization offset of less than 10ms from USB sync source
- Time drift of less than one minute per year
- DS3231SN Temperature Compensated RTC
  - -40°C to <0°C ±3.5 ppm frequency stability
  - 0°C to +40°C ± 2 ppm frequency stability
  - >40°C to +85°C ± 3.5 ppm frequency stability
  - -40°C to +85°C ± 3°C temperature stability
- 2 module HPDL-1414 display assembly
  - 8 character 16-segment per character LED display
  - 2.85 mm character height
  - Integrated magnifying lenses
  - ± 40° off-axis viewing angle, Typical 1.0 mcd luminous intensity
  - 655nm peak wavelength, 640nm dominant wavelength
- EN11 Rotary Encoder with 20 Cycles per Rotation with Momentary Switch
- Custom 3D printed sintered plastic enclosure
  - Heat stable to 80°C/176°F

Interface and Hardware Overview

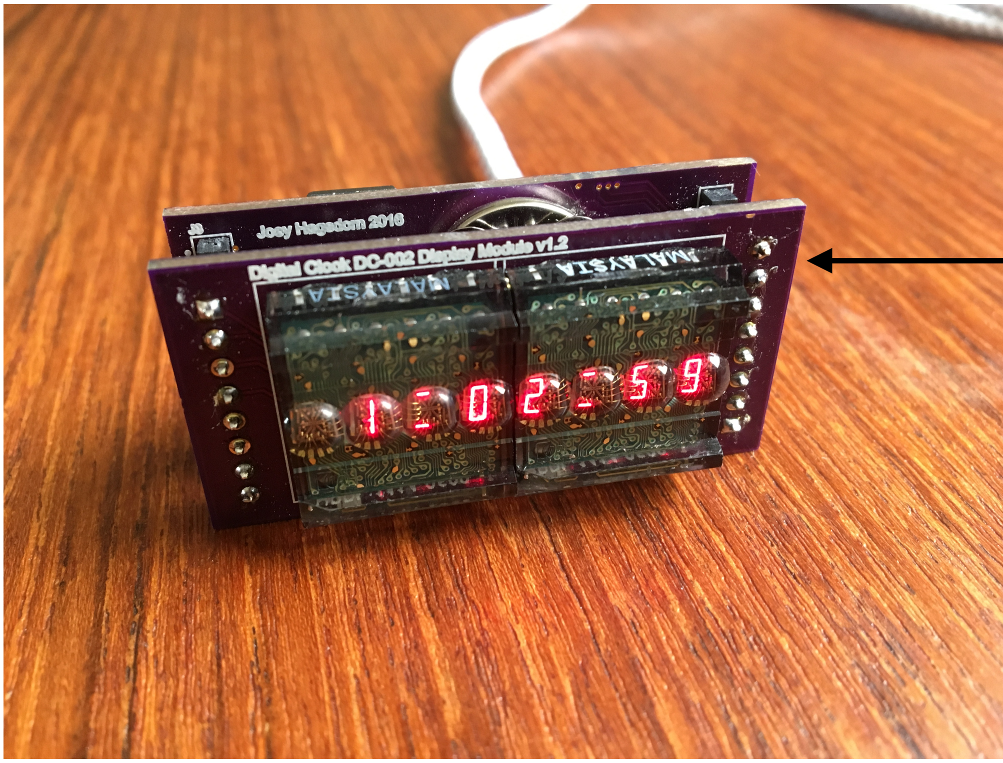


Time Display



Power &
Data USB
Connector

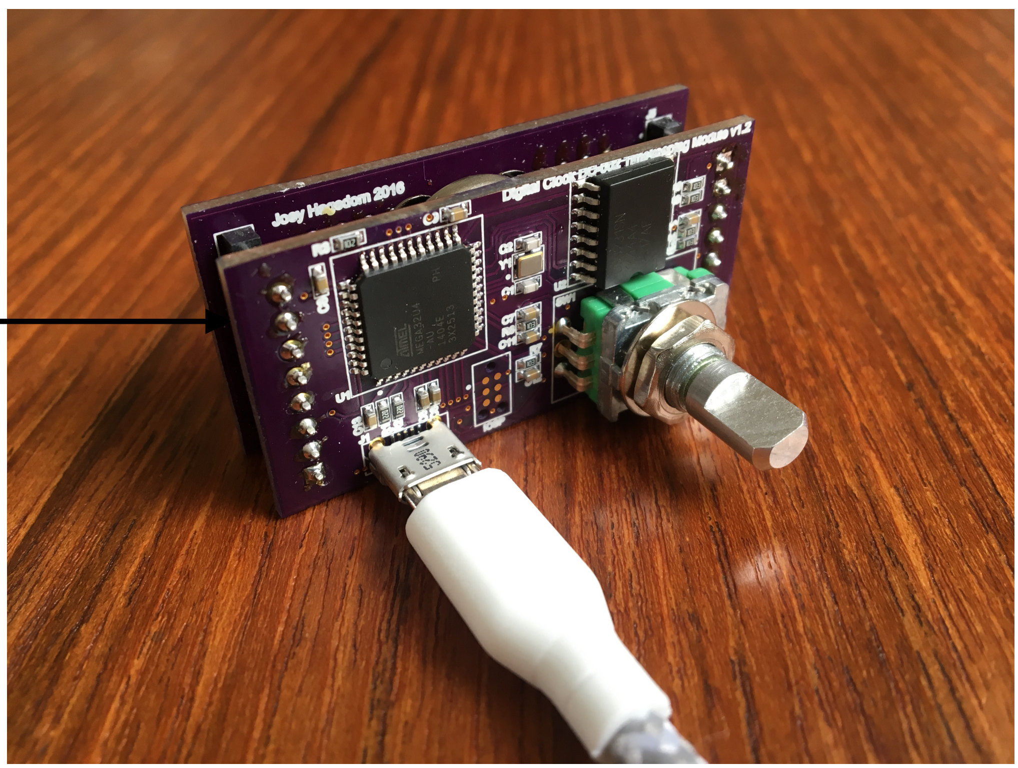
Adjustment
Knob



Display Board

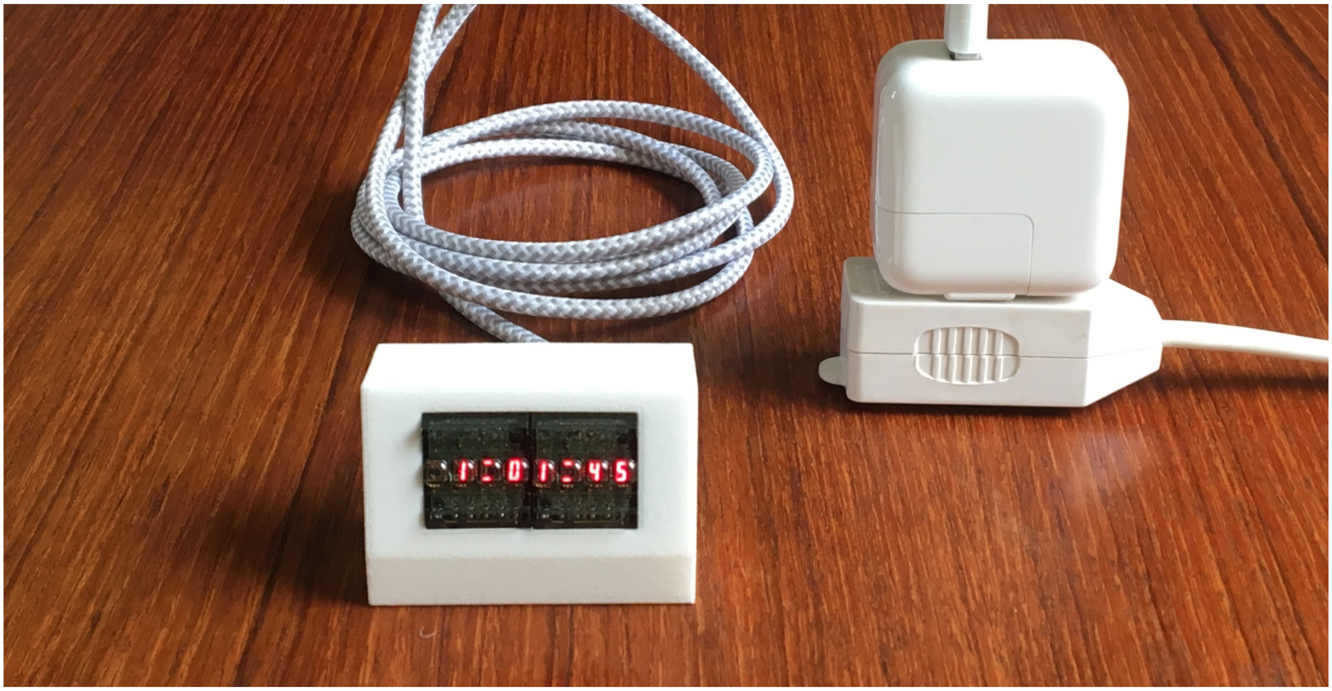
Enclosure Removed

Timekeeping and CPU Board



Enclosure Removed (rear)

Installation



The Digital Clock DC-002 can be installed on a desk or shelf with the included Micro-USB cable and USB power adapter. Simply plug the cable into the clock and USB power supply and plug into a standard household socket. The plug included works in the United States, but additional plugs are available to use worldwide from Apple as the “Apple World Travel Adapter Kit”, an optional accessory. More information available at: `https://support.apple.com/en-us/HT202114`

If you need to unplug the clock to move it, don’t hesitate; timekeeping is maintained through the backup battery.

Using your Clock

Displaying Time, Date, Temperature

The default mode for the clock when it is powered on is Display mode. Cycle through the different display modes; Time, Date, and Temperature, by rotating the knob. Each of the displays remains persistent until changed or power is removed from the clock.

```
[ 9:41:28] ⤸
[10/11/15] ⤸
[  67 F  ] ⤸
<  loop  >
```

Navigating the Menu[1] & Configuring Preferences

Menu Map

```
[ 9:41:28]    ⟶   [SET TIME]⤸    ⟶   <Time Set Mode>

                  [AUTO DST]⤸    ⟶   [ENABLED ]⤸   ⟶   <return>
                                     [DISABLED]    ⟶   <return>
                  [12/24 HR]⤸    ⟶   [12 HR   ]⤸   ⟶   <return>
                                     [24 HR   ]    ⟶   <return>
                  [SHOW SEC]⤸    ⟶   [SECONDS ]⤸   ⟶   <return>
                                     [AM/PM   ]    ⟶   <return>
                  [TEMP F/C]⤸    ⟶   [DEG F   ]⤸   ⟶   <return>
                                     [DEG C   ]    ⟶   <return>
                  [EXIT    ]     ⟶   <return>
```

Pressing the knob while in Display mode enters the Menu mode. Settings available include Set Time, Auto DST, 12/24 Hr, Show Sec, and Temp F/C. Selecting each of these options shows a submenu allowing for configuration of particular preferences. If left on the menu (excluding the Time Set Mode), the clock will automatically return to Display mode after 10 seconds of inactivity.

[1] The “⤸” symbol represents rotating the knob, “⟶” represents a click.

Set Time: See the “Setting the Time” section below.

Auto DST: This setting should be enabled for all localities observing Daylight Savings Time. Time will be adjusted automatically at the beginning and ending DST periods.

12/24 Hr: This display preference determines if the time readout will be shown in 12H format or 24H format. The Time Set interface is always displayed in 12H format.

Show Sec: This display preference determines if the clock shows seconds or the AM/PM indicator. If the clock has been configured for 24H format, the AM/PM choice simply hides the seconds instead of showing the day period indicator.

Temp F/C: This display preference determines if temperature is shown in Fahrenheit or Celsius scale.

Setting the Time

It is recommended to synchronize the time programmatically using a computer over the USB connection for the greatest accuracy. The time source of the computer should be synchronized correctly before beginning the process. On a Mac, it is often effective to open the “Date & Time” settings and toggle “Set Date & Time Automatically” off and back on again to encourage an accurate clock synchronization via NTP.

Setting Time via Computer (recommended)

1) The time and date of the computer should be verified to be accurate.
2) Install prerequisite pySerial library. On a Mac this can be accomplished by opening the Terminal program and running the following command:

```
sudo easy_install -U pyserial
```

3) Download the setTime.py program from the following URL and unzip it:

```
https://www.joeyhagedorn.com/download/DC-002/setTime.py.zip
```

4) Using Terminal, go to the directory in which the setTime.py file exists and ensure it has the correct permissions by running the following command:

```
chmod 755 setTime.py
```

5) Connect the Digital Clock DC-002 to the USB port of the computer. The clock need not display a specific screen, however it can be helpful to display the time with seconds while setting the time programmatically to verify it has been synchronized.

6) Run the following command:

```
./setTime.py
```

7) If the time has not been set, try running the command an additional time.

At this point the time should be accurately synchronized to the computer within a few milliseconds.

Setting Time via the Knob

Menu Map <Time Set Mode>

`[SET TIME]` ⟶ `[MM/DD/YY]` ⟶ `[HH:MM:XM]` ⟶ `<return>`

Time may be set directly using the knob as well. To set the time, begin by choosing the Set Time option from the main menu. Once in the Set Time interface, use the knob to select Month, Day, Year, Hour, Minute, and Day Period by rotating the knob then clicking to move to the next field. In order to set the time most accurately, it is best to choose the subsequent minute then wait on the AM/PM selection. Immediately as the clock ticks over to the next minute, click the button to commit the time. The seconds will start at zero upon selection of the AM/PM day period and return to the Display mode. The Digital Clock DC-002 is implemented to recognize button clicks on “button-up.”

Theory of Operation

The Digital Clock DC-002 is designed to be a maintenance free device. It is a fully digital product implemented on top of a realtime system to meet the high precision requirements accurate timekeeping demands.

Four main components dominate the design of the Digital Clock DC-002: the ATMEGA32U4 CPU, the DS3231 TXCO RTC, the rotary encoder, and the HPDL-1414 display modules. The 16 MHz ATMEGA32U4 CPU runs a custom monolithic timekeeping program that implements user interface as well as handles DST and other timekeeping features. The internal oscillator of the CPU is used to keep time between synchronizations with the RTC, which happen at startup and periodically every 5 minutes. The CPU communicates via a 400khz I2C Serial interface with a DS3231 TXCO RTC to re-sync CPU time to the master clock. This refresh rate provides excellent long term and short term drift characteristics. A specially developed algorithm has been employed to lock the CPUs internal time to that of the RTC with enhanced accuracy, beyond that provided in the more widely available TimeLib timekeeping library.

While not yet supported in software, a hardware square wave time synchronization PPS (Pulse Per Second) signal is routed from the DS3231 RTC to the CPU, so that even higher precision synchronization may be achieved in the future. This is one of the major architectural advancements of the DC-002 over the DC-001, in addition to construction techniques, SMT components, and an enclosure.

When in Temperature mode, the Teensy also queries the DS3231 for ambient Temperature, as the RTC module also includes a temperature sensor. The DS3231 has an internal crystal and a switched bank of tuning capacitors (TCXO). The temperature of the crystal is continuously monitored, and the capacitors are adjusted to maintain a stable frequency internal to the RTC.

In addition to communicating with the RTC, the CPU drives the two HPDL-1414 alphanumeric display units directly. The CPU monitors the rotary encoder for input using an interrupt based mechanism for rotation and a simple polling mechanism for button clicks. Bouncing of the pushbutton has been fully characterized and compensated for using software. The USB interface on the ATMEGA32U4 emulates a serial connection and is the most precise mechanism for synchronizing the RTC to an external time source. The protocol used is simply a text string prefixed with “T” and followed by a unix timestamp in local time representing the current time.

Maintenance

Replacing the Battery

The CR1632 battery supplied in your Digital Clock DC-002 is expected to last at least 8 years, but likely many more if the clock is left running. The battery is only used to keep time when the clock is not plugged in, and therefore only needs to be replaced to avoid resetting the time when it is not powered.

Procedure: Unplug the Digital Clock DC-002. Unscrew the nut securing the rotary encoder shaft on the back of the unit. Use a plastic spudger to pry the back case from the body of the clock. Slide out the clock module from the enclosure. Eject the old battery using a ballpoint pen or other blunt object, and slide in a replacement CR1632 in its place. Replace the clock module into the enclosure and press the back case into place, taking care to align the rotary encoder shaft and USB connectors with the holes in the back case. Screw the securing nut back onto the rotary encoder shaft.

Firmware Updates

The USB port that is normally used to power your clock may also be used for firmware updates. If in the future a firmware update is released by the manufacturer, it may be necessary to send the clock back to the manufacturer to upgrade the firmware. Alternatively, you may be able to perform a firmware upgrade in-the-field by installing the Arduino and Teensyduino software packages, as well as downloading dependent libraries. If you are interested in performing your own firmware upgrades, or developing your own software for your Digital Clock DC-002, contact the manufacturer for more specific instructions on getting started.

Software source code is available on GitHub:
`https://github.com/joeyhagedorn/DC-002/`

Appendix 1: Daylight Savings Time

International DST

Daylight Savings Time rules vary around the world. The Digital Clock DC-002 is programmed from the factory with DST rules for the United States, but has been architected to be easily reprogrammed through firmware update to fall back and spring ahead at different dates, and of different offsets. If you move to an international location and take your clock with you, please send it back to the factory or arrange for an in-the-field firmware update.

DST in the United States

According to the Uniform Time Act of 1966, the dates at which daylight savings time begins and ends, and the offset of DST is mandated by the federal government and uniform across the US. Some states, however, choose to exempt themselves from DST, such as Arizona and Hawaii, as of this writing. Support for this is built in to your clock and may be enabled by simply disabling the “Auto DST” option within the settings menu. Historically, the dates at which DST begins and ends have changed several times, most recently in 2005. If Congress makes a further change to the dates at which DST is observed, please send your clock back to the factory or arrange for an in-the-field firmware update.

Appendix 2: Bill Of Materials

For repair and replacement information:

Qty	Reference ID	Manufacturer	P/N	Package	Description
1	Y1	NDK	NX2520SA-16.000 M-STD-CSW-4	4-SMD	16MHz ±15ppm Crystal 8pF 80 Ohm -10°C ~ 75°C Surface Mount 4-SMD
1	U1	Atmel	ATmega32U4-AU	TQFP44	8-bit Microcontroller with 32K bytes of ISP Flash and USB Controller
1	U2	MAXIM	DS3231SN	16-SOIC	Extremely Accurate I2C-Integrated RTC/ TCXO/Crystal
1	BT1	KEYSTONE	3012		Battery Retainer 16mm Compact SMD
1	SW1	TT Electronics / BI Technologies	EN11-HSM1AF15		Rotary Encoder 11mm SW Top Adjust
2	DS0,DS1	HP	HPDL-1414	DIP	LED Display Module
1	J1	Molex	105133-0011		USB Micro-B Vertical Female
1	J2,J3,J4,J5	TE Connectivity	9-146458-0		Connector Header 40 Pos . 100" (2.54mm) Stacker
1		Panasonic	CR1632		Battery - 16mm 3V Lithium Coin Cell
1		OSH Park			PCB
2	R1, R2	Generic	22Ω resistor	0603	22Ω resistor
6	R4, R5, R6, R7, R8, R9	Generic	10K resistor	0603	10K resistor
1	R3	Generic	1K resistor	0603	1K resistor
7	C8, C11, C12, C10, C7, C13, C9	Generic	0.1 uF capacitor	0603	0.1uF capacitor
2	C5, C6	Generic	1 uF capacitor	0603	1uF capacitor
2	C1, C2	Generic	10pF capacitor	0603	10pF capacitor

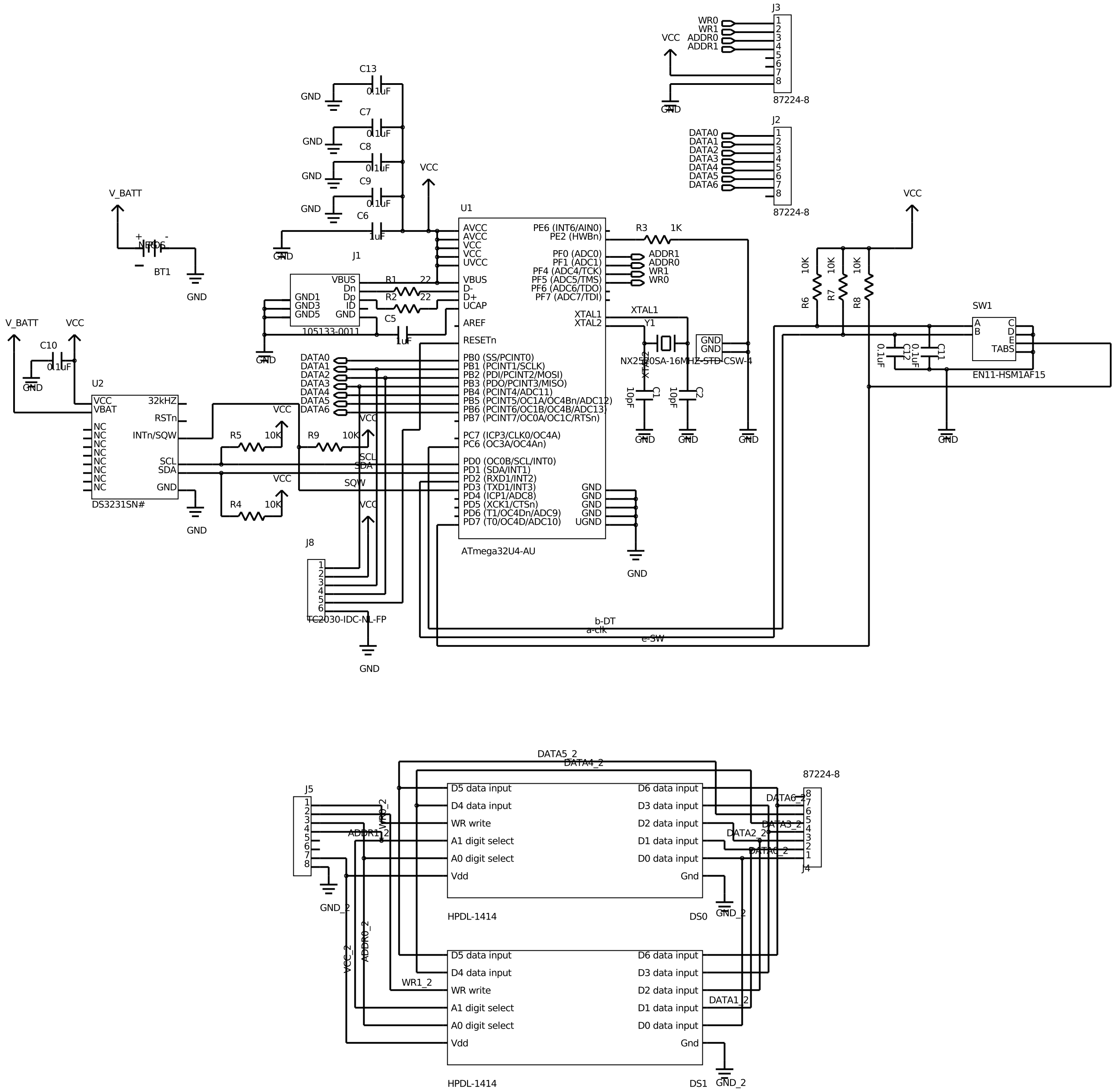
Enclosure is available from Shapeways:

`https://www.shapeways.com/designer/joeyhagedorn/creations`

PCB is available from OSH Park:

`https://oshpark.com/shared_projects/WSpndLJZ`

Appendix 3: Schematic



Schematic and board layout available at Upverter:

`http://tinyurl.com/DC002PCB`