

# μKenbak-1 Assembly & Operation Instructions



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Up-to-date instructions are always available at  
[www.adwaterandstir.com/kenbak](http://www.adwaterandstir.com/kenbak)

I would strongly suggest comparing the parts you received with the list on the next page. Let me know if you're missing anything and I will send a replacement.



# PARTS LIST

- 1 x PC Board
- 8 x 5mm White LED
- 4 x 5mm Yellow LED
- 1 x 470 $\Omega$  Resistor Array (10 pin)
- 2 x 2.2k $\Omega$  Resistor Arrays (10 pin)
- 3 x 10k $\Omega$  Resistor Arrays (6 pin)
- 15 x tactile push button
- 8 x black key caps
- 7 x white key caps
- 6 x 40mm F-F Hex Standoffs
- 6 x 12mm Pan Head Steel Screws
- 6 x 8mm Pan Head Steel Screws
- 6 x M3 Washers
- 4 x 14mm Flat Head Steel Screws
- 4 x M3 Knurled Nuts
- 3 x 16 Pin DIP Socket
- 1 x 28 Pin DIP Socket

- 1 x ATmega328p Microcontroller
- 2 x 74HC165 Shift Register
- 1 x 74HC595 Shift Register
- 1 x 16MHz Crystal
- 1 x USB Extension
- 1 x MTS-102 Micro Switch
- 1 x USB to UART TTL Module
- 1 x DS3231 Module
- 1 x 5 Pin Male Header
- 1 x 4 Pin Male Header (19mm)
- 1 x Front Panel
- 1 x Acrylic Laser Cut Spacer
- 1 x Project Case
- 2 x Aluminum Ends

## OTHER PARTS YOU MAY NEED

Soldering Iron with a nice fine tip

Good Solder (I recommend Alpha Fry Rosin Core 0.032")

De-soldering Iron (optional)

Phillips Screwdriver

Needle-nose Pliers

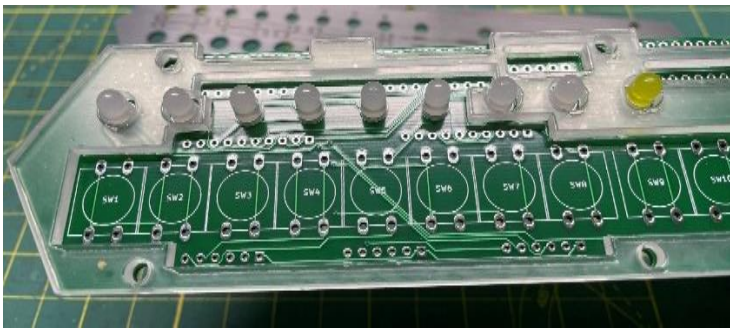
Side Cutters (Nippers)

A word about soldering: Don't underestimate the need for good solder and a good soldering iron. Most problems I've seen people have with this kit are caused by cold joints or insufficient wetting. That doesn't necessarily mean you have to spend a lot of money. I've had good luck with \$8 soldering kits from eBay. Just make sure it has an adjustable temperature and comes with an assortment of tips. Right now I'm using a \$55 soldering station and it works great. I strongly advise you to get quality 60/40 Rosin core .032" diameter solder (I use Alpha Fry). The spools I buy are only \$10 and well worth it. I set my iron to 400C degrees and use the fine point tip.

Since the alignment of the LEDs is fairly important to keep the front panel from bowing, we are going to put the LEDs in place (long leads facing to the right.)



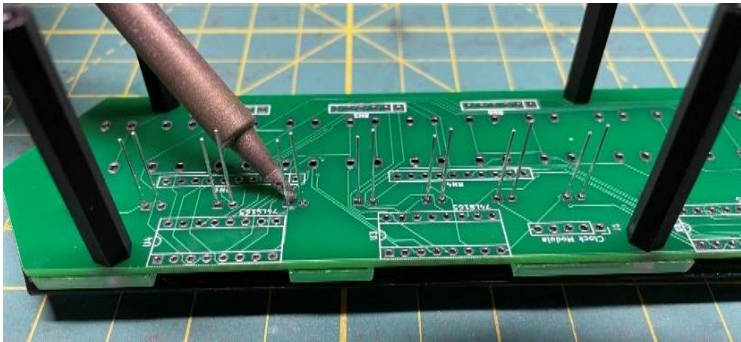
Next, place the laser-cut spacer in place.



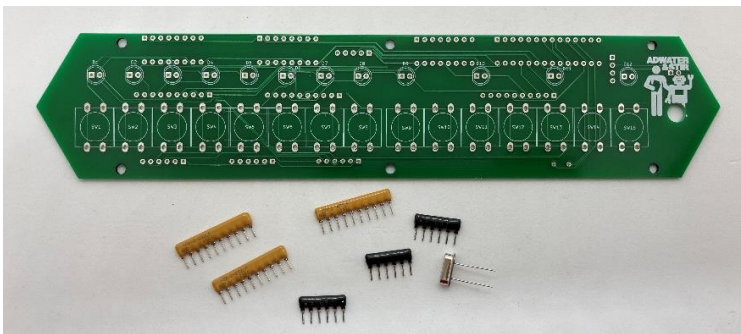
Put the front panel in place and secure it with six bolts and the nylon standoffs.



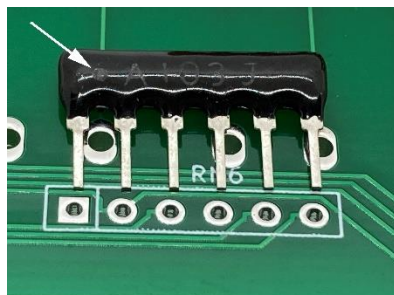
Now you can rest the LEDs on your work surface and the front panel will keep them in place while you solder them. Once all LEDs are soldered, you can remove the front panel and spacer and set aside for later.



Next we are going to install is the resistor arrays and crystal. These parts mount on the back of the printed circuit board (the side with the “Open Source Hardware” logo.)

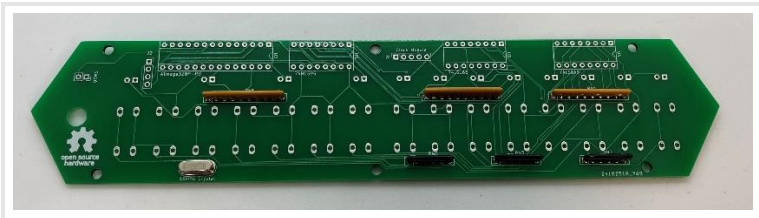


The 6-pin black resistor arrays are 10k $\Omega$  and the orientation is important. They are installed in RN2, RN3, and RN6. The end with the white dot should be installed in the square pad on the left side:

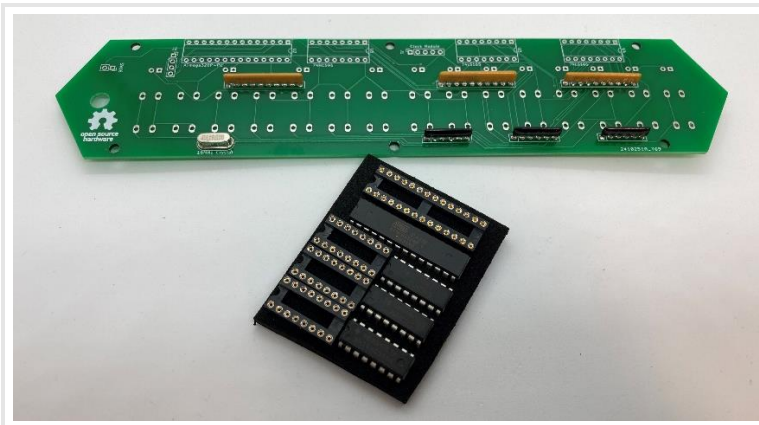


The two 2.2k $\Omega$  yellow resistor arrays are labeled “10X-2-222LF” and are installed in RN1 and RN4. The orientation is not important (they are independent, not bussed resistor arrays), but I like to install them with the dot to the left for consistency.

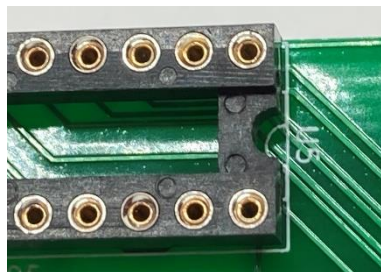
The yellow 470 $\Omega$  resistor array is labeled “10X-2-471LF” and is installed in RN5. Like the 2.2k resistor array, the orientation is not important. Finally, add the crystal to location Y1. The orientation is not important.



Add the DIP sockets to the back side of the printed circuit board (the side with the “Open Source Hardware” logo.)

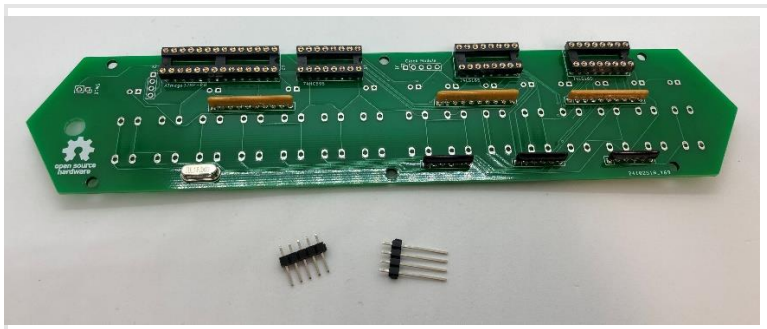


Make sure the DIP sockets are mounted with the notch facing right as indicated by the screen printing on the circuit board.





You'll find two male headers, a standard size five-pin, and a longer four-pin.

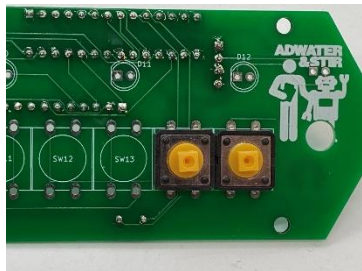


Add these to positions J1 and J2 on the back side of the board.

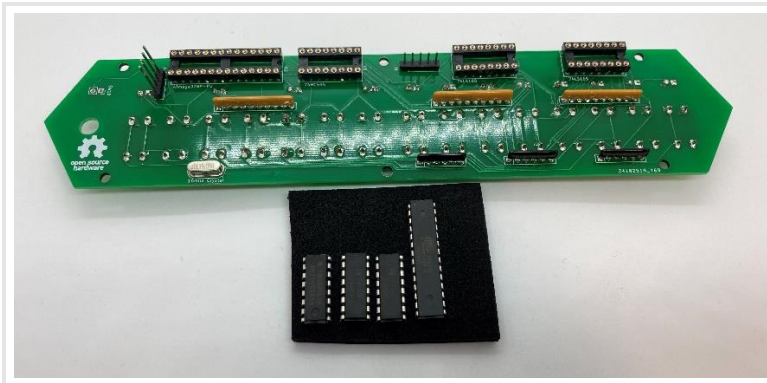
Find the bag of 15 tactile switches.



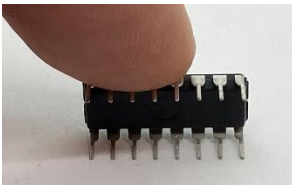
These will be placed on the front side of the circuit board (with the Adwater & Stir logo.) It is important that they are installed flat and aligned, so they will later align correctly with the front panel.



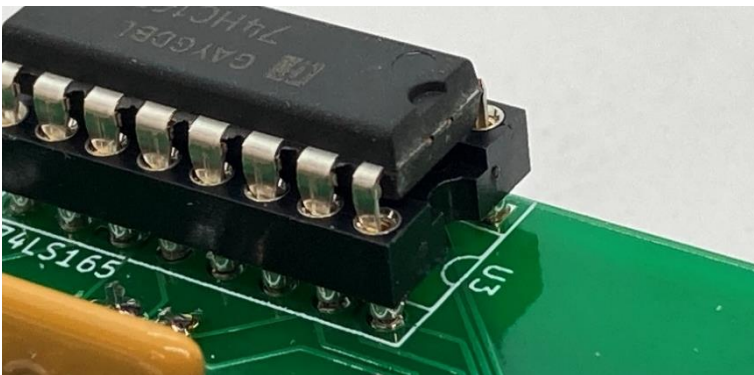
Install the integrated circuits.



You'll notice the legs on the ICs are typically bent outwards just a bit. You will need to make the legs perpendicular to the body. There are IC insertion tools that do that, but I like to simply push down on a flat surface to align them.



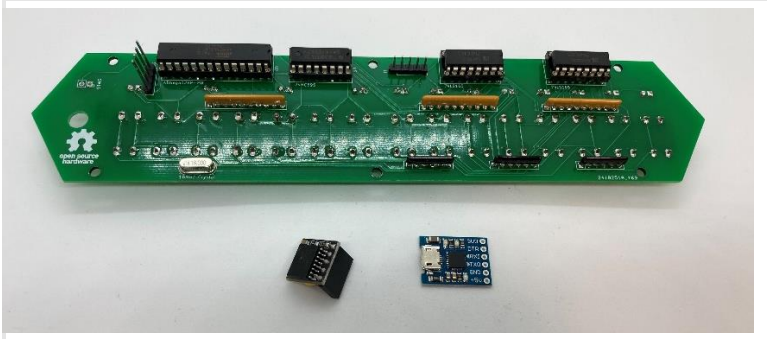
You will also want to make sure the notch at the top of each IC aligns with the DIP socket, and that the correct chip is placed where indicated on the silk screen.





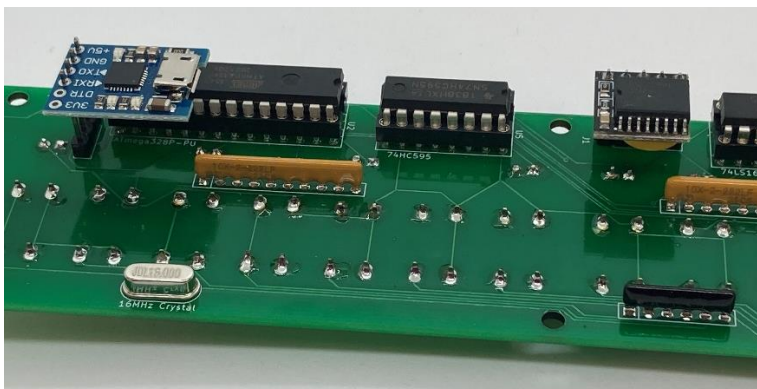
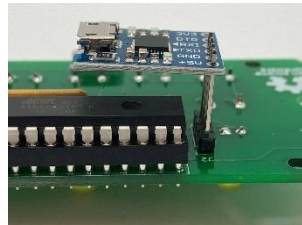
Note that there are two 74LS165, and one 74LS595. Make sure they are installed in the correct sockets as labeled on the circuit board.

Install the DS3231 (real time clock) module and the USB to UART module.

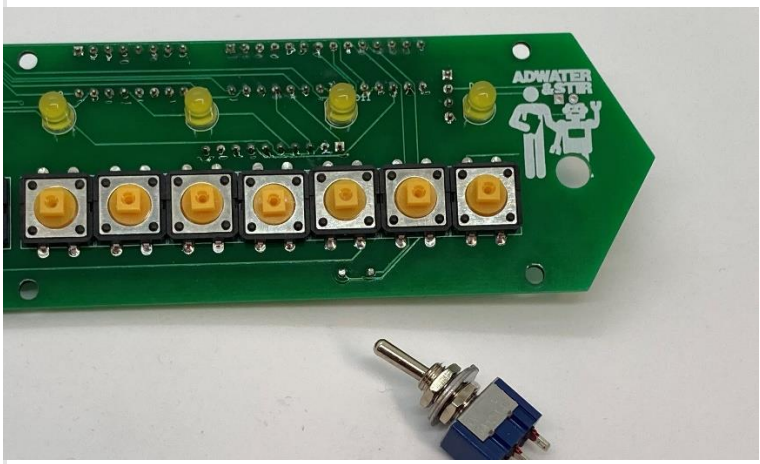


The DS3231 module simply mounts on the five-pin male header in the center, and the USB to UART module is soldered to the four-pin header (pins 5V, GND, RX, and TX as indicated in the photo.)

Leave clearance above the ATMEGA328p for the module.



Add the MTS-102 toggle switch.

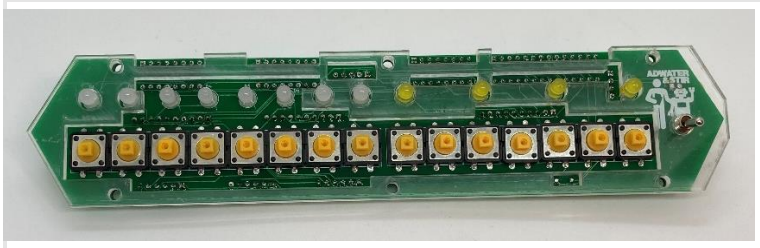


I like to temporarily secure it in place with a single nut, then turn the board over and solder a wire from SW16 to the center pin and bottom pin on the switch, as pictured.

This is a good time to check the function of your kit. You can plug a micro USB cable into the USB to UART module, flip the power switch up, and the  $\mu$ Kenbak-1 should be fully functional.



Remove the nut holding the power switch in place (if you used it) and place the acrylic cut spacer over the circuit board.



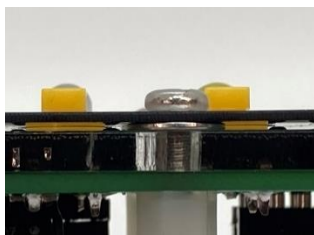
Put the front panel in place and get the bags with hardware and the 40mm nylon standoffs (they will be white or black.)



Add the 14mm pan head screws and standoffs as pictured:



There are six M3 washers included with the kit. You may want to use these to increase the spacing between the circuit board and the front panel. I find they work well. If you use these washers, you will also want to use the lock washer for the power switch under the front panel. Secure the switch with a nut.



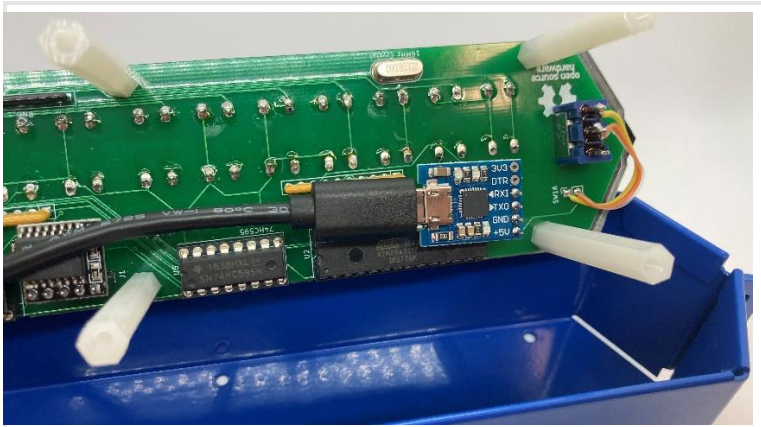
Get the metal case and USB extension.



Secure the extension to the case with the supplied M3 bolts.



You can now connect the USB extension to the USB to UART module:



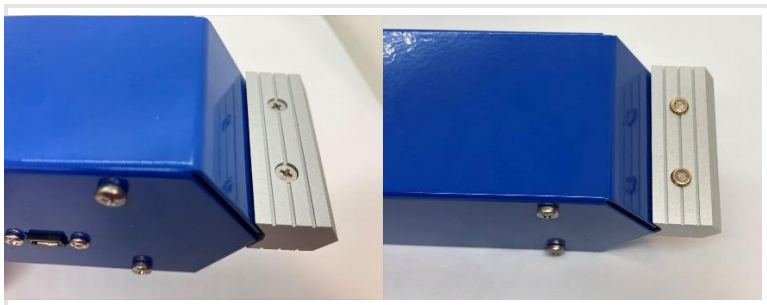
And secure the circuit board and front panel to the case with six 8mm bolts.



Next we'll add the aluminum side pieces.



The pieces are held in place by 14mm flat head bolts and brass knurled nuts.

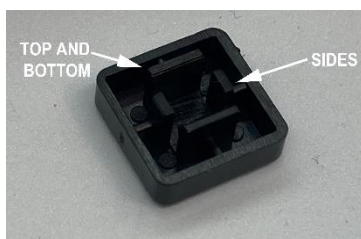




Finally, we'll add the button caps.



The button caps will fit in any orientation, but I have found that it's best to have the buttons mounted as pictured. It makes it easier to pry the buttons off (from the top and bottom) if necessary.



# CONGRATULATIONS! YOUR $\mu$ KENBAK-1 IS COMPLETE!

Read on to learn how to use a  $\mu$ Kenbak-1.



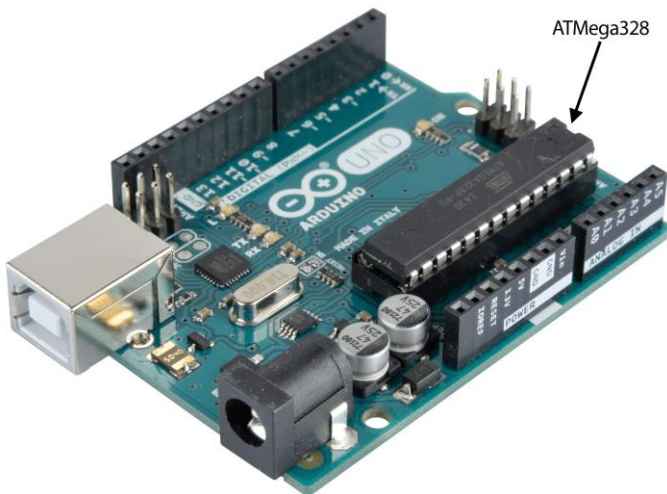


# Programming the ATMEL Microcontroller

Your ATmega328 microcontroller comes pre-programmed, but perhaps you'd like to dive into Mark Wilson's open-source code and do your own modifications.

First, you'll want to install the Arduino IDE (you probably already have this if you're actually thinking about modifying the code.) The source code is available at [www.adwaterandstir.com/kenbak](http://www.adwaterandstir.com/kenbak).

You're probably used to plugging into an Arduino and uploading the code, but there is no Arduino inside this project. There are other ways to upload the code using a programmer (I'll leave that up to you) but the easiest way is to simply remove the ATmega328 chip from the  $\mu$ KENBAK-1 and replace the ATmega328 chip in an Arduino Uno, then upload like usual.



Pop that chip out when done and put it back in the  $\mu$ Kenbak-1.

# History

John Blankenbaker first envisioned his creation in 1949, and quickly became convinced that it would be far too expensive to build at that time. But, he held onto his ideas until technology caught up (and prices came down.) In 1970 he realized he could actually build his computer. He worked out of his garage (which sounds like a familiar starting place for computer companies) and created a computer based on small and medium scale integrated circuits, as microprocessors had not been announced yet.

First advertised in the September 1971 issue of Scientific American (and later hailed as the “First Personal Computer” by the Boston Computer Museum), the Kenbak-1 experienced sluggish sales. Only about 40 units were sold at \$750 each. But it remains a remarkable achievement!

## Using the $\mu$ KENBAK-1

Much of this text is from Mark Wilson’s original documentation for his “Kenbak-uino” project from 2011.

## Introduction

Not long after discovering the Arduino it seemed to me it could be a fun project to re-create an early computer, one with just LEDs and switches. I looked at things like the Altair 8800 (1975) but it has 30+ LEDs and 20+ switches and seemed like too much work.

Then I stumbled on the KENBAK-1 (1971). Perfect! Only a dozen LEDs and 17 switches. As a bonus it was the 40th anniversary of its introduction. I found a reasonable amount of information online, starting at the Wikipedia article: <http://en.wikipedia.org/wiki/Kenbak-1>.

This is a software emulation of the KENBAK-1's CPU, and method of operation, together with a basic recreation of the hardware.

## Operation

The basic operation is to enter values with the 8-bit switches on the left (0 through 7). CLEAR clears them all. The bits toggle on/off when a button is pressed. Pressing SET sets the address register to the displayed value. Pressing STORE writes the displayed value into the memory at the address and increments the address.

In this way programs can be entered. Like the original, the nanoKenbak-1 has only 256 bytes of memory and no registers, however some memory locations act like registers:

<i>Register</i>	<i>Address</i>
A	000
B	001
X	002
Program Counter	003
Output Register	200
Input Register	377

Also, memory locations 201, 202, and 203 were assigned to hold the overflow and carry bits from the A, B, and X registers, respectively.

START starts the program running.

STOP halts it.

STOP+RUN single-steps.

DISP displays the current address.

READ reads the memory at the address.

For more details - refer to the online information. For examples - see the scans of the original manuals available at [www.adwaterandstir.com/operation-kenbak](http://www.adwaterandstir.com/operation-kenbak). These manuals include:

- Theory of Operation Manual
- Programming Reference Manual
- Programming Worksheets
- Laboratory Exercises Manual

## Extensions

Mark added a few extensions to the basic KENBAK-1 behavior.

### Extension: SysInfo Instructions

The KENBAK-1 instruction set includes 3 NOOP (no-operation) op-codes: 02Q0, 03Q0 and 031R+[Second Byte] (Q=0..7, R=3..7). I've chosen a particular value of the latter, 0360, to implement an "operating system" SysInfo extension rather than no-operation. (I use 0300 when a real NOOP is required.) The execution of any of the NOOPs is handled by the virtual method

*virtual bool OnNOOPExtension(byte Op);*

on the CPU class. On the base class it does nothing (just returns true to indicate execution can continue). On the Sketch's derived ExtendedCPU class it traps the 0360 NOOP and execute the SysInfo function as follows:

The value in the A register sets the operation: if the high bit is set, the operation is a "write" otherwise it is a "read". The remaining 7 bits provide the Index of the item. The argument for a write comes from the B register.

The result of a read is placed in the B register.

Note that some writes actually perform an \*action\* and the corresponding reads do nothing. Executing the SysInfo instruction resets the CPU speed.

The first 8 values for the Index read/write the DS3231 RTC registers. Numbers are BCD (Binary Coded Decimal).

000: Seconds (00..59)

001: Minutes (00..59)

002: Hours (00..23) (always 24-hr, no matter how the RTC is configured)

003: Day (01..07)

004: Date (01..31)

005: Month (01..12)

006: Year (00..99)

007: Control

No validation is performed.

The next 8 values read/write bytes to the subsequent 8 bytes of "user" RAM in the DS2321:

010: Flags controlling the Kenbak-uino.

Currently only 1, if b0 is set, pressing one of the Data switches \*toggles\* the bit, otherwise it only sets it (as per the KENBAK-1).

#### *011: EEPROM Page Map*

See EEPROM Extension. The value of this byte defines how the 1k of EEPROM is partitioned into 8 pages starting with #0 of 256 bytes. Bits in the Map indicate if subsequent pages should be half the size, a 1 means halve, a 0 leaves the size as-is. The least significant bit applies to page #1 -- if it should be half the size of #0 (i.e. 128 bytes). Thus for example, a Map of 012 creates the following page sizes: 256, 256, 128, 128, 64, 64, 64

000 creates 4 full-size pages (higher pages are ignored): 256, 256, 256, 256

012: User #1

013: User #2

014: User #3

015: User #4

016: User #5

017: User #6

These 6 bytes are available for reading and writing non-volatile values.

The final 6 Index values act as follows:

### *020: Control LEDs*

Reading does nothing. Writing sets the control LEDs as follows:

b0:INP

b1:ADDR

b2:MEM

b3:RUN

The upper 4 bits control the intensity of the RUN LED, 0000 = max brightness (PWM=255), 1111 = min (PWM=16).

### *021: Random*

A read returns a random byte, 0..255 in B. Writing a 0 seeds the random number generator using the time etc. Writing a non-0 value uses that as the seed.

### *022: Program delay milliseconds*

Reading does nothing. Writing delays execution for the given duration.

This is separate from the "CPU Speed" (Extension #7 below.)

### *023: Serial*

Reads or writes a byte from the Serial port (@38400baud)

0177: Reading this special value simply returns 0 in Register A, indicating that extensions are enabled. Writing does nothing.

### **Extension: Blank**

Pressing STOP+CLR (i.e. Press STOP and without releasing it press CLR) turns off all LEDs.

### **Extension: Erase**

Pressing CLR+STOR sets all memory to 0 \*except\* 03 (P register) which is set to 04. The address register is set to 04, ready to enter a program. The CPU speed (BitN-STOP, Extension below) is set to 0.

### **Extension: Library**

Pressing STOP+BitN loads one of eight pre-defined programs:



<i>N</i>	<i>Description</i>
0:	Simple counter
1:	Pattern
2:	Counting Clock
3:	BCD Clock
4:	Binary Clock
5:	Das Blinken Lights (random pattern)
6:	Sieve of Eratosthenes
7:	Set Clock

### **Extension: EEPROM**

Pressing BitN+STOR writes program memory to EEPROM at "page N". Pressing BitN+READ reads program memory from EEPROM at page N. The ATmega328 has 1k of EEPROM, by default this is divided into 8 "pages" of various sizes:

<i>N</i>	<i>Size</i>
0:	256
1:	256
2:	128
3:	128
4:	64
5:	64
6:	64
7:	64

Program memory is always read from or written to starting at address 000.

Thus Bit7+STOR writes the *\*first\** 64 bytes (addresses 000 through to 077) of program memory to EEPROM address 960. Bit0+READ reads all 256 bytes of program space (addresses 000 through to 0377) from EEPROM address 0. Note that EEPROM memory which has not been written to will be read as 0377 (Unconditional JUMP AND MARK INDIRECT).

### **Extension: SystemInfo**

Pressing STOP+READ executes a SysInfo read. The Index is taken from the Address register; the result is placed in the Output register (0200).

Pressing STOP+STOR executes a SysInfo write. The Index is taken from the Address register (there is no need to set b7), the argument is taken from the Input register (0377).

All SysInfo calls are available programmatically and from the front panel but some make more sense than others (for example Delay from the front panel).

### **Extension: CPU Speed**

Pressing BitN+STOP sets the "CPU speed". It sets the delay in milliseconds added after each CPU cycle, equal to  $2^N$  ms. Thus b0+STOP sets the delay to 1ms. b7+STOP sets it to 128ms. The delay is set to 1 at power on and on CLR+STOR (Extension: Erase above) of if a program executes the SysInfo instruction, 0360.

### **Programs**

--Count (STOP+Bit0):

Simply increments the OUTPUT register. Will be a blur unless slowed-down with BitN+STOP.

---Pattern (STOP+Bit1):

Cylon-style single LED moving left-right-left etc. Will be a blur unless slowed-down with BitN+STOP.

---Counting Clock (STOP+Bit2):

Alternates between showing the hours and the minutes. Minutes display in five minute increments (blinking LED = add five minutes).

---BCD Clock (STOP+Bit3):

Scrolls back and forth between showing the hours and the minutes in BCD. The minutes display has the left most (b7) LED blinking.

--Binary Clock (STOP+Bit4):

Shows the time in binary. The minutes are shown on the Data LEDs with the left most (b7) LED blinking. The hours are shown on the Control LEDs.

--Das Blinken Lights (STOP+Bit5):

Just blinks all the LEDs, old-school.

---Sieve (STOP+Bit6):

Builds a table of the odd numbers up to 255 and applies the Sieve of Eratosthenes to them. Then display the primes, HALTING after each one (hit START to proceed to the next one).

---Set Clock (STOP+Bit7):

Follow this procedure to set the time:

1. STOP+Bit7 to load the set clock program
2. CLEAR
3. SET (sets the address to 000)
4. Enter hours (24 hour format) in BCD
  - example: 0001 1000 (018 BCD = 6PM)
5. STORE (saves to A register)
6. Enter minutes in BCD
  - example: 0101 0100 (054 BCD = 54 minutes)
7. STORE (saves to B register)
8. RUN (runs the program, sets time to 18:54)

## Programming Example

Try entering this program into your µKenbak-1:

```
003 {Set}{Clear}
004 {Store}{Clear}
103 {Store}{Clear}
001 {Store}{Clear}
134 {Store}{Clear}
200 {Store}{Clear}
```

003 {Store}{Clear}  
001 {Store}{Clear}  
043 {Store}{Clear}  
010 {Store}{Clear}  
344 {Store}{Clear}  
004 {Store}{Start}

The numbers are octal, and each octal digit is entered as a three-bit binary number. That's what the numbers under the LEDs are for. For example, the octal number 134 would be entered in the Kenbak-1 as



Yeah, programming was hard back then!

## Serial Communications

The original Kenbak-1 did not have a serial port or any I/O method other than the incandescent lamps and push buttons. Because it was simple to implement, the  $\mu$ Kenbak-1 does include a method to save and load data via the USB serial port.

Most computers will recognize the serial port when the  $\mu$ Kenbak-1 is connected. If your computer doesn't, download and install the CH-340 serial drivers. You can use a free utility like PuTTY, Tera Term, or CoolTerm to view/send the data.

**Write out memory to USB serial port:**

Press BitN+DISPLAY writes program memory as 16 lines of 16 bytes of octal data to the serial port. BitN sets the baud rate as shown below.

### **Read memory from USB serial port:**

Press BitN+SET reads program memory from the serial port. BitN sets the baud rate as shown below.

By default the program expects octal constants, delimited by almost anything (comma, newline etc).

Prefix hexadecimal constants with 0x. Use uppercase A through F.

Each number is treated as a single byte and written to program memory, starting from address 000.

The operation halts when:

- the 256th byte is written to memory
- either an 'e' or an 's' (lowercase) is read from Serial (i.e. end/stop).
- STOP is pressed

When running, the program displays the most significant nibble of the current address (hex).

When finished it displays the length and checksum (sum modulo 256) in hex:

[0123456789ABCDEF] len=0x100 chk=0x9E

### **Examples**

A file containing this:

```
0000,0000,0000,0004,0023,0220,0123,0000,0360,0023,
0221,0123,0000,0360,0023,0021,0360,0134,0002,0023,
0021,0360,0134,0001,0134,0000,0323,0017,0034,0001,
0023,0220,0360,0023,0222,0123,0024,0360,0024,0001,
0001,0034,0001,0023,0220,0360,0234,0200,0023,0222,
0123,0050,0360,0343,0016,s
```

or this:

```
0x00 0x00 0x00 0x04 0x13 0x90 0x53 0x00 0xF0 0x13 0x91
0x53 0x00 0xF0 0x13 0x11 0xF0 0x5C 0x02 0x13 0x11 0xF0
0x5C 0x01 0x5C 0x00 0xD3 0x0F 0x1C 0x01 0x13 0x90 0xF0
0x13 0x92 0x53 0x14 0xF0 0x14 0x01 0x01 0x1C 0x01 0x13
0x90 0xF0 0x9C 0x80 0x13 0x92 0x53 0x28 0xF0 0xE3 0xE
e
```

will upload Das Blinken Lights.

Higher baud rates may be less reliable, although setting a transmit delay may help.

#### **BitN baud rates:**

- 0 = 4800 baud
- 1 = 9600 baud
- 2 = 19200 baud
- 3 = 38400 baud

## Run Program at Power-On

You can set a stored program to launch at power-up.

#### **To load a pre-defined program:**

With the power off, press STOP+BitN, where N = the button representing the pre-loaded program (eg. STOP+3 for the BCD real-time clock.) While holding the buttons, turn the power on. Release buttons after the power-on "animation".

#### **To load a user-saved program:**

With the power off, press READ+BitN, where N = the "page" of memory you would like loaded. While holding the buttons, turn the power on. Release buttons after the power-on "animation".



**To prevent any program from loading (default condition):**

With the power off, press STOP. While holding the button, turn the power on. Release button after the power-on "animation".

**To return all settings to defaults:**

With the power off, press STOP+CLEAR. While holding the buttons, turn the power on. Release buttons after the power-on "animation".

**K E N B A K u i n o**

Mark Wilson 2011

Software emulation of a KENBAK-1.

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