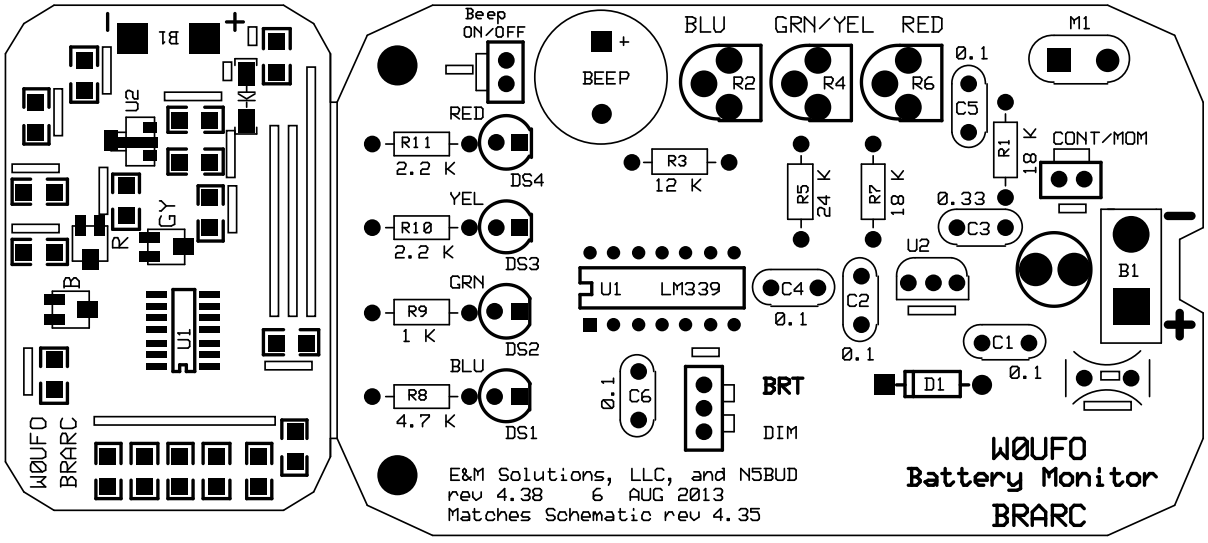
Baton Rouge Amateur Radio Club
Builders Circle

WØUFO
Battery Monitor
QST, June 2013



Designed by
Mert Nellis, WØUFO

Modified by
Buddy Brown, N5BUD
Jim Giammanco, N5IB

Introduction

Mert Nellis, WØUFO, recently published an article describing a simple monitoring device to help keep tabs on the health and welfare of rechargeable batteries (*QST*, June 2013, pp43-44). Members of the Baton Rouge Amateur Radio Club build several of the monitors, and they proved very useful during 2013 Field Day activities. Several club members expressed interest in building their own and inquired whether a kit could be provided. Mert graciously gave his permission to use his design for the kits.

Here is the result of that request. BRARC members Buddy Brown, N5BUD, and Jim Giammanco, N5IB, undertook to tweak the circuit just a bit, generate a comprehensive bill of materials, and produce a commercial quality printed circuit board. Two versions of the monitor were created – one using only through-hole parts, and the second exclusively employing surface mount components.

Circuit Description

If you look over the schematic diagrams of the two versions you'll notice that they are very nearly the same. The difference is a few convenience options that are available on the through-hole version. Both provide four LED lamps that can be set to illuminate at specific voltage that are indicators of the state of discharge of a battery.

The battery voltage is applied though a resettable protective fuse, F1, before being connected to the remainder of the circuit. This device will open the circuit if excessive current is drawn, but will return to a conducting state if the fault is removed.

Next is a voltage divider consisting of resistors R1 and R3, and potentiometer R2. Notice that this divider is positioned downstream of the fuse, but ahead of the polarity protection diode D1. The reason is to monitor the actual battery voltage without the few tenths of a volt drop across the diode. But this means *you had better still be careful not to connect your battery backwards!*

The output of this first voltage divider is delivered to all four analog comparators that comprise U1, an LM339A quad comparator circuit. Thus all four comparators receive a signal telling them the current state of the batter's terminal voltage.

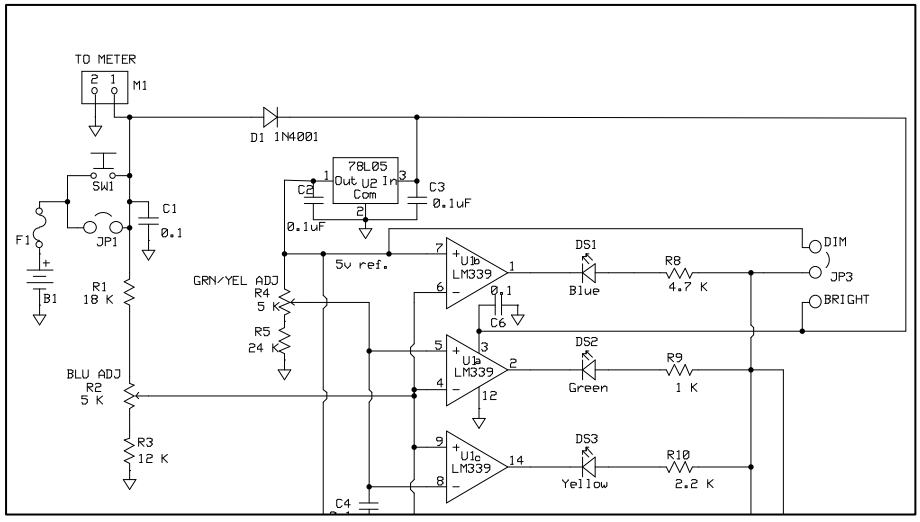
Analog comparators work be *comparing* the voltages presented to their two inputs. The comparator outputs are what are termed open collector outputs. That means the output is simply the collector terminal of an NPN transistor. When the transistor is turned **ON** current will flow to ground through whatever is connected to the output. When the output transistor is turned **OFF** no current will flow.

The comparators operate in this fashion: if the voltage at the non-inverting (+) input is **greater than** the voltage at the inverting (-) input, the output transistor of the comparator will be turned **OFF** and no current flows into the output pin. If the opposite, V(+) is less than V(-), the output transistor will be turned **ON** allowing current to flow to ground.

Notice in the schematic that each comparator output is connected through a resistor and an LED to a positive voltage supply. When the comparator outputs are turned **ON**, the LEDs light up. The resistors determine the amount of current through, and hence the brightness of, the LEDs. You'll see that the resistors are not all the same value. That is to balance the brightness of the different color LEDs.

To provide a stable reference voltage to the four comparators U2, a 78L05 three terminal voltage regulator device is used. Its output is a constant +5 volts independent of the state of the battery. Voltage dividers R4/R5 and R6/R7 divide the reference voltage into two separate adjustable levels that control the voltage levels at which the LEDs turn on and off.

Let's study the operation of just one of the comparators (U1b) as an example. The reference voltage (+5 V) is connected to its non-inverting input (pin 7). The divided battery voltage is connected to the inverting input (pin 6). Potentiometer R2 is adjusted so that the voltage at pin 6 is equal to +5V when the battery voltage is, for example, +13 V. Then, if the battery rises above +13 V the voltage at pin 6 will be greater than the voltage at pin 7 and the BLUE LED will turn on, indicating a fully charged condition.



For a lead-acid battery (which includes flooded, or wet, cells; gell cells; and AGM batteries) a fully charged condition is a terminal voltage around 13.4V. That voltage rapidly drops when cureent is drawn from the battery, but will remain above 12 V for most of the available capacity of the battery. When the voltage drops below 12 V the battery has delivered perhaps 50% of its available capacity and is a candidate for recharging. When the voltage has fallen to between 11 and 11.5 V the battery is nearly completely discharged. Allowing a battery to discharge much more than 50% will ultimately shorten its life.

For the reasons mentioned above, the indicators of this battery monitor should be adjusted to approximately the following set points for use with 12V lead-acid batteries.

BLUE LED – turn on when V_{BATT} > 13.4 V (adjust R2)
GREEN LED – turn on when V_{BATT} > 12.0 V (adjust R4)
YELLOW LED – turn on when V_{BATT} < 12.0 V (adjust R4)
RED LED – turn on when V_{BATT} < 11.3 V (adjust R6)

Note that a single adjustment of R4 determines both the GREEN and YELLOW set points.

Optional Features

The through-hole version of the monitor offers a few extra features that can optionally be added:

Audible alarm*: A piezo-electric beeper can be added that will sound an alarm whenever the RED (severe discharge) LED illuminates. If the beeper is added, jumper JP2 can be used to disable/enable that annoying sound.*

LED brightness*: Jumper JP3 connects the LEDs to either the full battery voltage, or the +5 volt reference voltage, and serves as a bright/dim control.*

Always ON vs Push-to-Measure*: If a shorting jumper is placed on JP1 the monitor will be operating whenever it is connected to the battery under test. If the jumper is removed, switch S1 must be pressed to obtain a measurement.*

Digital voltmeter*: There are very small three or four digit digital LED voltmeter modules available from offshore chip vendors for prices under five dollars. A connection point is provided on the through-hole circuit board to connect one of these meter modules if desired. They will draw an addition 8 mA or so from the battery.*

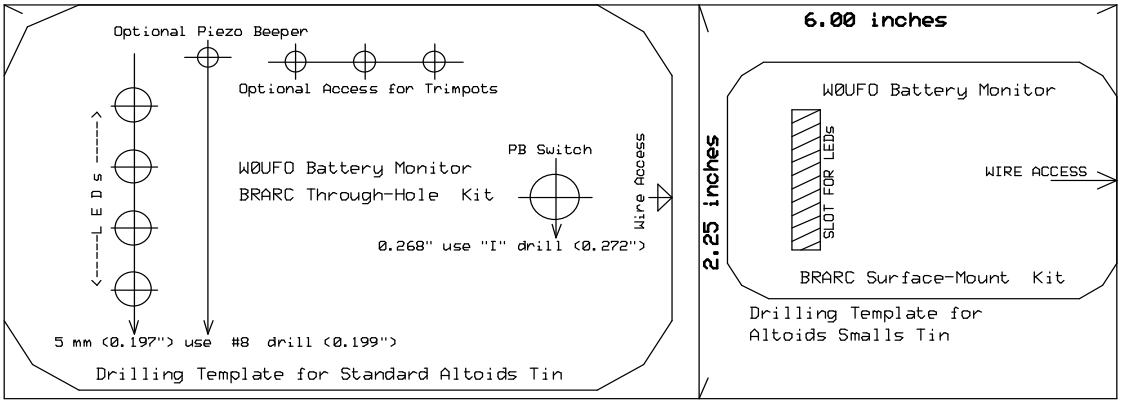
The monitor draws less than 20 mA when operating, so it is not a serious drain on any battery of more than a few ampere-hours capacity. But over a long time it will discharge the battery, so the monitor should be disconnected when the battery is not in active use or recharge.

Assembly Procedure: Through-Hole Version

Enclosure: The printed circuit board is sized to fit a standard ***Altoids*** tin, or alternatively, the *medium hinged rectangular tin can* from PaperMart.com:

http://www.papermart.com/hinged-rectangular-tin-cans/id=23271#23271

A drilling template has been provided. Measure the template outline carefully, it should be 6 x 2¼ inches if it is printed to correct scale. For the though-hole version, we recommend that you drill and prepare the enclosure before beginning circuit board assembly. The drilled enclosure will be an essential aid in positioning components on the circuit board. Cut out the template and tape it to the tin, then center punch each hole location before drilling.



Drill the mounting hole for the pushbutton switch and four holes for the LEDs. You need drill the hole for the beeper only if you intend to add that option. Also drill the hole in the side of the tin to receive the grommet. The Surface mount version needs only a slot and a single hole for the grommet.

Note that the currently styled Altoids tins have an embossed lid, making it less desirable as a "front panel." The older Altoids tins, and the PaperMart tins, have smooth lids. If you have a smooth-lidded tin, drill the lid for use as the panel. If your tin has an embossed lid, drill the bottom of the tin and use that as the panel.

Parts Inventory: Refer to the bill of materials and do a complete inventory of parts, making sure that you have the correct quantity and correct type of component. Be careful to note that the fuse looks very similar to the ceramic capacitors, but has a different shape and marking. If in doubt about the resistor color codes, use an ohmmeter to verify.

Populating the circuit board: Notice that most components are identified on the silk screen lettering on the circuit board with their actual component value, as well as part ID.

The resistors and the diode should have their leads formed with 0.4" spacing between leads to fit their mounting holes. The capacitors and fuse already have their leads formed to the proper spacing. A plastic lead bending jig is a useful and recommended tool:

http://www.jameco.com/webapp/wcs/stores/servlet/Product_10001_10001_106884_-1

The following components will be installed on the **BOTTOM** (no white silk screened markings) side of the circuit board***. Set them aside for now:***

Pushbutton switch and all four LEDs, and (optionally) piezo beeper

Top side component installation: We recommend you install components on the top (silk screened) side of the board in the following order:

1. Four ¼ watt resistors (R1, R3, R5, R7). Be sure to match the color coded value with the value printed on the circuit board. Insert the resistor leads from the top and solder on the bottom side. After soldering, trim the excess lead length flush with the bottom of the board.

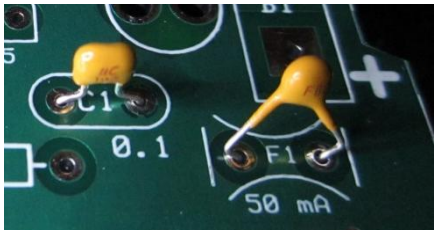
   DO NOT INSTALL THE FOUR RESISTORS NEAREST THE LEDS (R8, R9, R10, R11)

   If mounted, those resistors' leads would interfere with use of a spacing jig to mount the LEDS. Save these four parts for later.

2. Three 5K trimmer potentiometers: R2, R4, R6. Press them firmly onto the board until the shoulders of the leads are flush against the board. Solder on the bottom side and trim excess lead length.

3. Diode D1. May be a 1N4001, 1N5818, or some other common rectifier diode. Be sure that the banded end of the diode is oriented to match the banded end of the silk-screened outline.

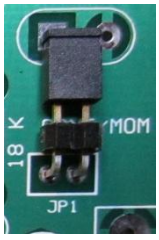
4. Fuse F1. Insert the fuse as far as it will go without bending the preformed leads from their original shape. Solder on the bottom and trim excess.

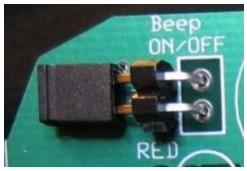


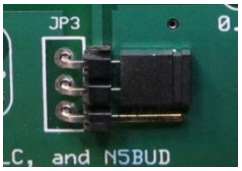
5. Five 0.1 µF ceramic capacitors (marked 104).
   One 0.33 µF capacitor (marked 334).
   Some kits may have a 0.47 µF (474) instead of 0.33 µF.

   As above, insert the capacitors as far as they will go without bending the preformed leads from their original shapes. Note that the value is marked on the silk-screened outline. Solder on the bottom and trim excess.

6. Right angled male headers at JP1, JP2, and JP3. Note that JP3 is a three-pin header. Before installing the headers, slip a shorting jumper onto each one. This will help maintain the alignment of the pins during soldering. The short ends of the pins are inserted into the circuit board, and the long pins will extend parallel to the board in the directions pictured. If you want to nip off a little bit of the long pins so that the jumper will fit flush, that's OK.







   Solder one pin first and re-check the alignment. Reheat and adjust if necessary before soldering the remaining pin(s).

7. Integrated circuits U1 (LM339A) and U2 (78L05). Be sure to orient the integrated circuits correctly. For the LM339A there will be a notch or dimple identifying the pin 1 end of the chip, be sure this aligns with the notched end of the silk-screened outline. No socket is provided, though you may provide one on your own if you wish. Insert the chip's leads into all fourteen holes and be sure the chip is fully seated against the board. Solder one pin and recheck alignment before soldering the remaining pins.

   For the 78L05 be sure that the flatted side of the plastic case aligned with the long flatted side of the silk-screened outline. The part need not be flush against the board, a standoff of 1/8" or so is fine. Solder the middle pin, and check alignment before soldering the other two.

   This (almost) completes the top side assembly

Bottom side component installation: We recommend you install components on the bottom (non silk screened) side of the board in the following order:

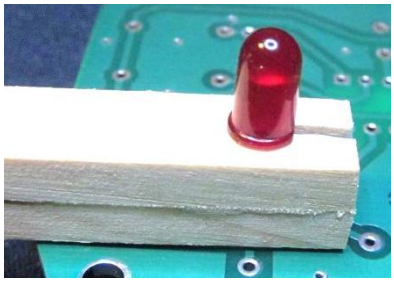
8. Pushbutton switch. The switch should be inserted from the bottom of the board. Its leads will project through to the top side. It is important that the switch be seated fully so that the bottom of its plastic case is in contact with the board. It may be necessary to gently file the pins right near the case to remove some excess metal.

   Be sure that the switch is seated properly and is perpendicular with the board. Solder one pin and recheck alignment before soldering the other pin. You do not need to completely fill the holes with solder, just be sure the pin and surrounding pad are joined.

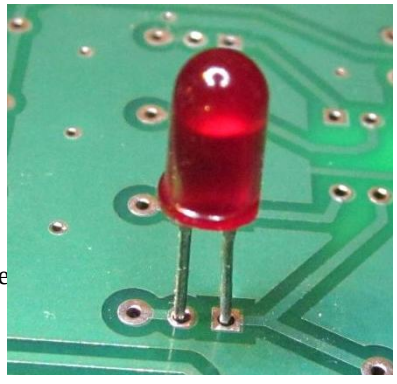
9. All four LEDs. Be sure to put the right colors in the right places. The LEDs will be inserted from the bottom side of the board and their leads will be soldered on the top side.

   THE LEDS WILL NOT BE PRESSED FLUSH AGAINST THE BOARD

   You'll notice that at the bottom of the plastic case of the LED there is a slight shoulder. The LED should be positioned so that shoulder is the same height above the board as the mounting surface of the pushbutton switch. Refer to the photos. It's possible to make a spacing guide like the one pictured to help in the alignment.



   The LEDs must be oriented with correct polarity. One lead is longer than the other. The longer lead should be inserted into the round pad inside the silk-screened LED outline. The short lead goes into the square pad.



   Solder one lead. Check that it's the right color LED and it is spaced and aligned correctly.

At this point you can dry fit the board into the drilled case. The LEDs should project through the holes in the case up to their shoulders and the when the switch's mounting nut is tightened the board should be held firmly in place. If everything fits, leave the board mounted onto the case and solder the remaining LED pins, then trim the excess on the top side. Now you can remove the board from the case to complete the board assembly.

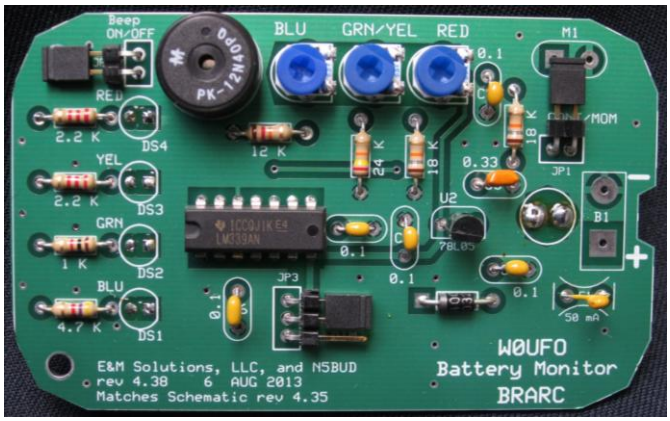
10. Optional piezo beeper.

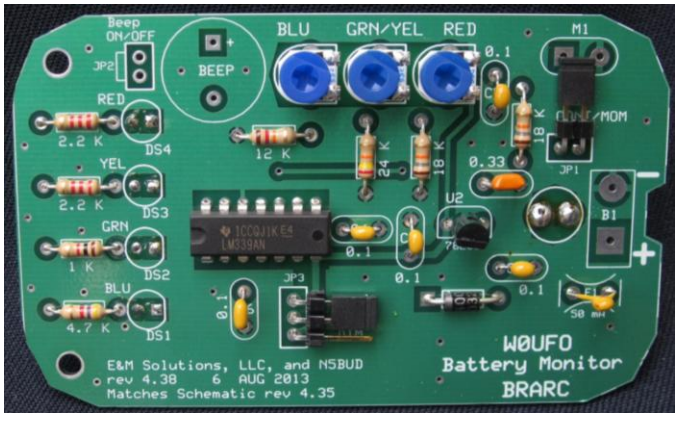
NOW, TURN BACK OVER TO THE TOP SIDE

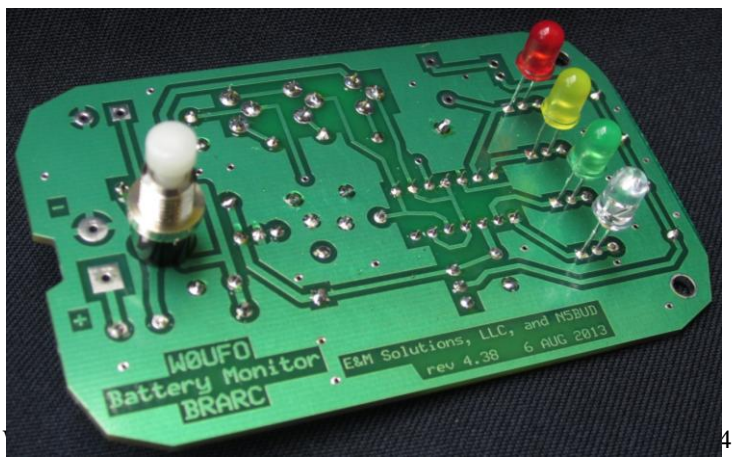
11. The remaining four ¼ watt resistors, R8 R9 R10 & R11, just to the right of the LEDs. Install these on the top side, solder on the bottom, and trim excess. Be sure that the correct value, as indicated on the silk-screened outline, is installed.

12. Solder lead wires to the pads marked B1. Be sure to choose wires that can fir through the grommet in the side of the case. Terminate the wires with your choice of connections. Alligator clips or Anderson PowerPoles are good choices.

The photos below show a completed board. On the left is a board that includes the optional piezo electric beeper.







Assembly Procedure: Surface-Mount Version

You are going to be working with some very small components. A magnifying glass will probably be very useful. Your soldering iron must have a very fine pointed tip, no more than 1/16" or so. The solder you use should be very fine gauge, either 0.020" or 0.015" diameter. You may find it useful to construct a positioning aid, such *the funny looking goose shaped surface mount holder downer doofus* that you can find at *http://www.qsl.net/n5ib/surface_mount/Smk30.jpg* .

We recommend you install the components in the following order:

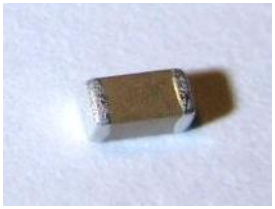
Six 2 K resistors. They look like the photo at left, and are to be installed on the top (silk-screened) side of the board along the left edge, just under the **BRARC** label.

Three 2 K potentiometers. Notice that they have three terminals. In the photo, two terminals to the left and one to the right. Install them at the outlines marked **GY**, **R**, **B**. ***Do them in that order***, for convenience of room to work. A useful technique is to very lightly tin the single pad on the circuit board, hold the pot in place, re-heat and re-flow the tinned pad, then solder the remaining pair of pads. At the **B** and **GY** positions they are mounted with the two-terminal side towards the top edge of the board. At the **R** position the two terminals are towards the right edge.

Now install the remaining four resistors. They look just like the ones you've already placed, but are different values:

4.3 K marked "432"
6.8 K marked "682" there are two of these
9.1 K marked "912"

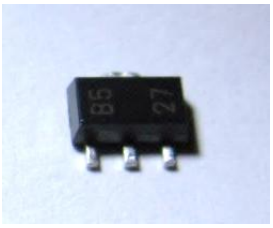
The silk-screened outline shows the value of the resistor to be mounted at each position.



Capacitors. There are five 0.1 µF capacitors and one 0.33 µF cap.
Surface mount capacitors HAVE NO MARKINGS. There carrier card is marked with the value, so don't remove them until you are ready to install. Again the silk-screened outline indicated the value to be installed at each location.

Rectifier diode, D1. Notice in the photo that there is a faint vertical line near the left edge of the part. That marks the cathode (banded) end of the diode. Be sure to install it on the board matching the orientation of the banded end of the silk-screened symbol.

Resettable fuse, F1. Polarity is not a concern. It may be installed in either orientation.



5 volt regulator, U2. Match the terminal configuration (one on top, three on the bottom) with the copper pads and silk-screened outline. Solder one lead, check positioning, reheat and adjust if necessary, then solder the remaining leads.

Quad analog comparator, U1, LM339A. Notice the faint writing on the chip. The "ST" logo at the left end should be positioned over the notch on the left side of the silk-screened outline of this chip. Position the chip over the outline, line up the leads with the pads, and solder one corner lead. Check positioning, reheat and adjust if necessary, then solder the remaining leads.

Now its time to install the four LEDs. One each – BLUE, GREEN, YELLOW, RED.

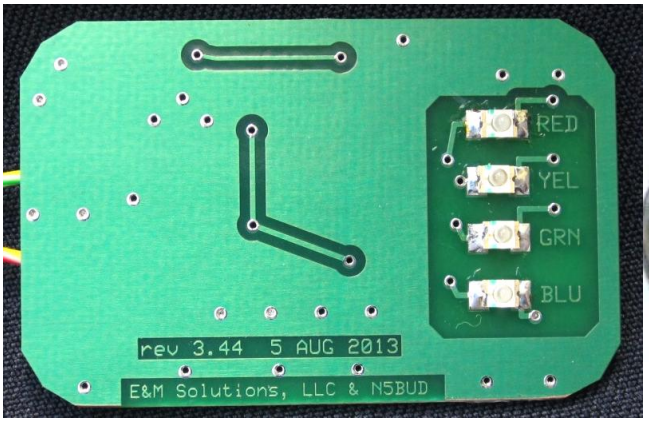
They will be mounted on the **bottom** (non silk-screened) side of the board. A legend had been etched next to each LED position to tell which color goes in which position.

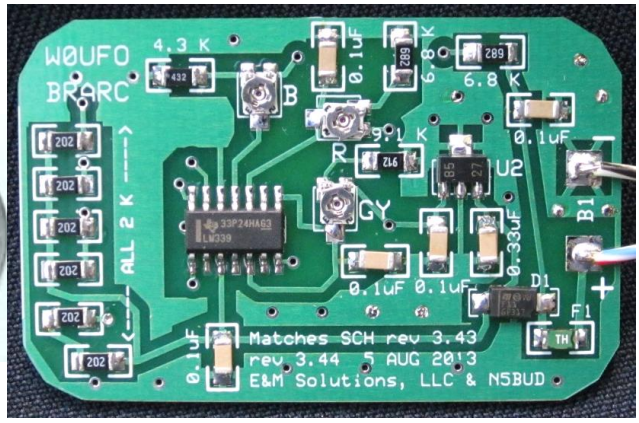
The LEDs look identical, so do not remove one from its carrier card until you are ready to install it.

Examine the LED in the photo very carefully. You will notice a faint green band at the left of the plastic dome. That band ***DOES NOT*** mean it is a green LED! The green band on each LED marks the cathode (banded, or negative) end of the diode.

The banded end of each LED must be oriented to face ***AWAY*** from the label on the board that indicates the color. The banded end will be farthest from the edge of the board.

Congratulations! You've completed assembling a surface mount circuit board. Add a couple of wire leads, adjust the calibration, put it in an Altoids Smalls and you're done!





Final Assembly and Adjustments

Solder lead wires of any convenient length to the pads marked B1. Choose wires that will fit through the grommet in the end of the case. Terminate the far end as you choose. Alligator clips, or Anderson PowerPole connectors are good choices.

The only calibration needed is the set the voltage levels at which the LEDs will light up/turn off. You'll need an adjustable voltage source and an fairly accurate voltmeter that can read tenths of a volt in the range 10 to 15 Volts. If you're using the through-hole version, it will be convenient to install the jumper at JP1 so that the monitor is always on while you perform these tests.

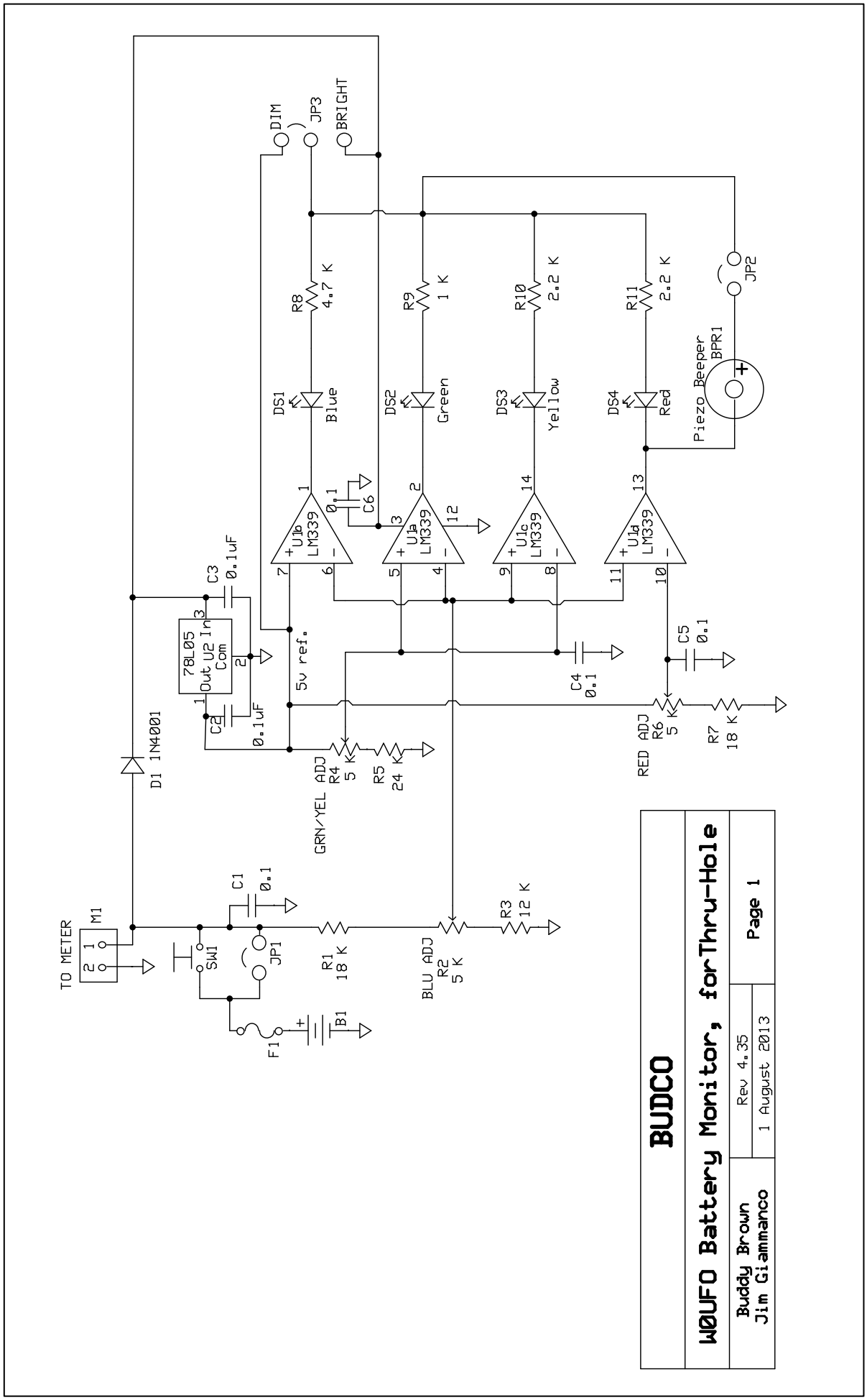
Do the adjustments in the following order:

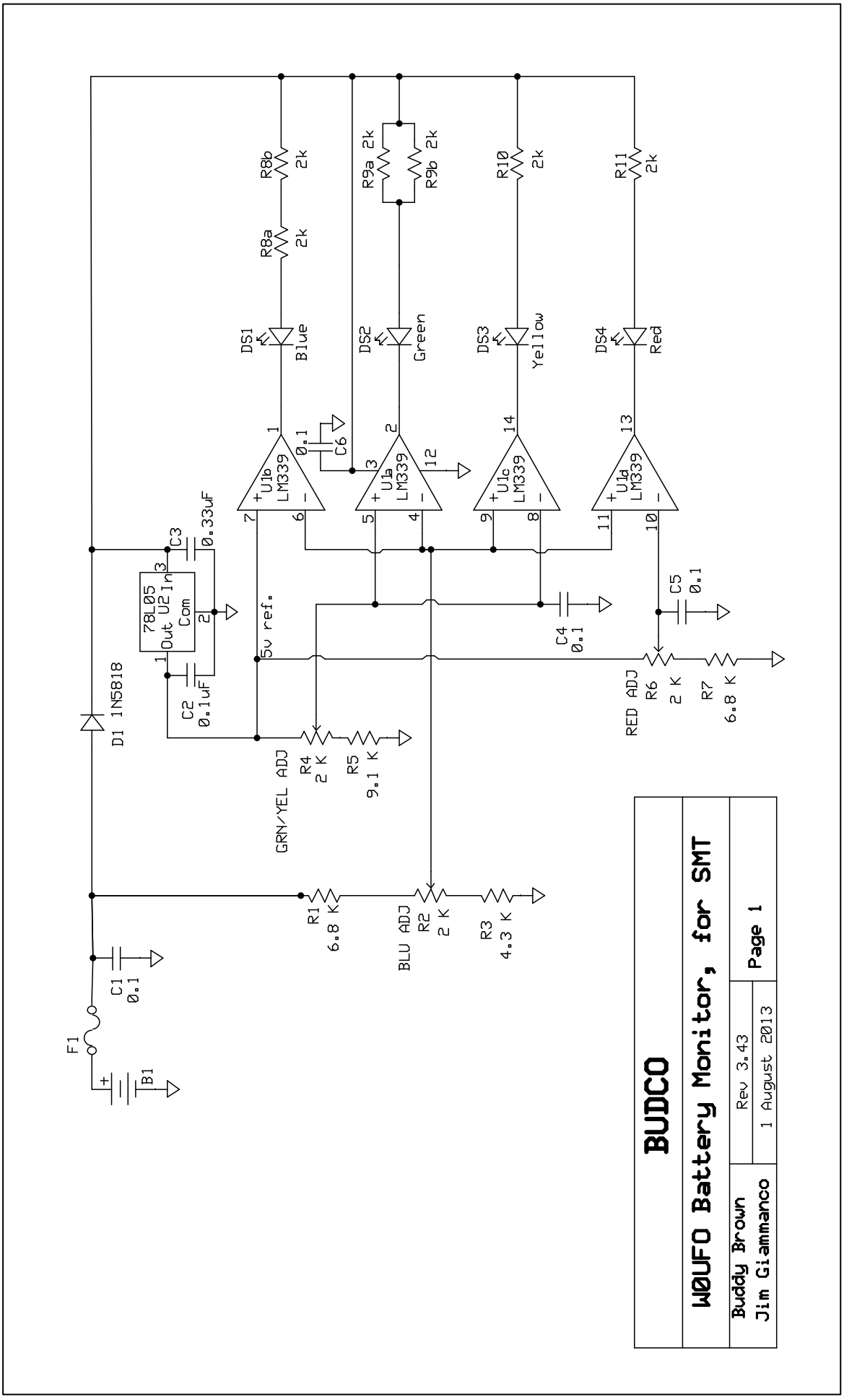
1. BLUE LED setting. Connect the monitor to a voltage source set for the voltage at which you would like the BLUE LED to just turn on. Adjust trimmer R2 (BLU) until the BLUE LED is off, then turn the control back until the LED just turns on. You must make this adjustment first, since it affects the next two settings. If you later decide to change the setting for the BLUE LED you'll have to readjust the other two setpoints.

2. GREEN/YELLOW LED setting. One adjustment serves for both of these LEDs. Reset your voltage source to the voltage at which you would like the GREEN LED to light up, and the YELLOW LED to go off. Adjust trimmer R4 (GRN/YEL) until the YELLOW LED is lit, then turn back until the GREEN LED just come on (the YELLOW one should go off at this point).

3. RED LED setting. Reset your voltage source to the voltage at which you would like the RED LED to light up. Adjust trimmer R6 (RED) until the RED LED is off, then turn back until it just lights up.

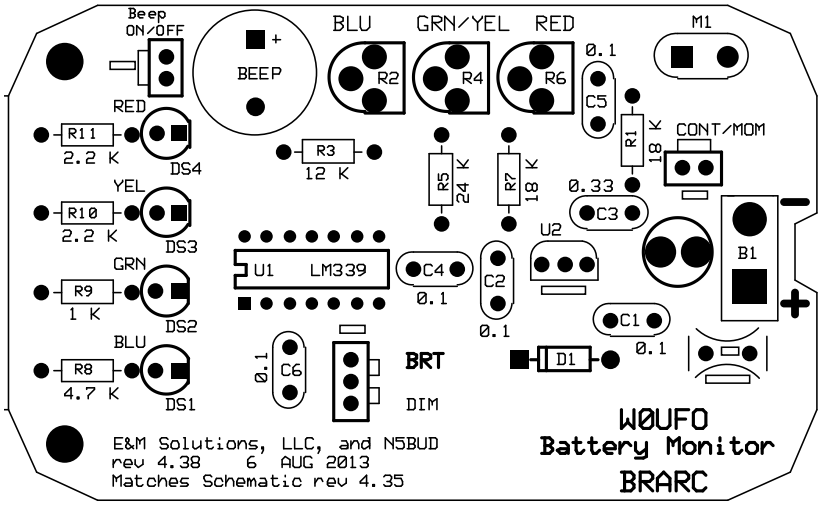
This completes the calibration and testing of your battery monitor.


DIM
JP3
BRIGHT
R8
4.7 K
R9
1 K
R10
2.2 K
R11
2.2 K
JP2
DS1
Blue
DS2
Green
DS3
Yellow
DS4
Red
Piezo Beeper
BPR1
C6
0.1
U1b
LM339
U1a
LM339
U1c
LM339
U1d
LM339
C3
0.1uF
78L05
Out U2 In
Com
C2
0.1uF
5v ref.
C4
0.1
C5
0.1
D1 1N4001
GRN/YEL ADJ
R4
5 K
R5
24 K
RED ADJ
R6
5 K
R7
18 K
TO METER
M1
C1
0.1
SW1
JP1
R1
18 K
BLU ADJ
R2
5 K
R3
12 K
F1
B1
BUDCO
W0UFO Battery Monitor, forThru-Hole
Buddy Brown
Jim Giammanco
Rev 4.35
1 August 2013
Page 1


BUDCO
WØUFO Battery Monitor, for SMT
Buddy Brown
Jim Giammanco
Rev 3.43
1 August 2013
Page 1
F1
B1
C1 0.1
D1 1N5818
C2 0.1uF
C3 0.33uF
78L05
Out
In
Com
5v ref.
R1 6.8 K
R2 2 K
R3 4.3 K
BLU ADJ
R4 2 K
R5 9.1 K
GRN/YEL ADJ
R6 2 K
R7 6.8 K
RED ADJ
C4 0.1
C5 0.1
C6 0.1
U1b LM339
U1a LM339
U1c LM339
U1d LM339
R8a 2k
R8b 2k
R9a 2k
R9b 2k
R10 2k
R11 2k
DS1 Blue
DS2 Green
DS3 Yellow
DS4 Red

BRARC WØUFO Battery Monitor, Through-Hole Version, Bill of Materials

C1, C2, C4, C5, C6	0.1 uF, 50V 0.2" LS ceramic capacitor	(marked 104)	Mouser# 81-RDEF51H104Z0K103B
C3	0.33 uF, 50V 0.2" LS ceramic capacitor Note: 0.1 uF or 0.47 uF may be substituted	(marked 334)	Mouser# 81-RDEF51H334Z0K103B
D1	Rectifier diode, 1 A, 1N4001, 1N5819, etc		Mouser# 512-1N4001
DS1	Blue LED, 5 mm diameter		Mouser# 941-C566CBFNCS0W0352
DS2	Green LED, 5 mm diameter		Mouser# 941-C566CGFNCV0Z0792
DS3	Yellow or Amber LED, 5 mm diameter		Mouser# 941-C566CAFNCU0W025
DS4	Red LED, mm diameter		Mouser# 941-C566CRFNCT0W0BB2
F1	Resettable fuse, 50 mA	(marked F60)	Mouser# 650-RXEF005-2
JP1, JP2	2-pin male right angle header		JAMECO# 2076869 (strip of 26)
JP3	3-pin male right-angle header		JAMECO# 2076869 (strip of 26)
JUMPER 1, 2, 3	shorting jumpers (shunts)		JAMECO# 19141
R2, R4, R6	5 K linear potentiometer	(marked 502)	Mouser# 652-3306F-1-502
R1, R7	18 K 1/4 W 5% carbon film resistor	(BRN GREY ORG)	Mouser# 291-18K-RC
R3	12 K 1/4 W 5% carbon film resistor	(BRN RED ORG)	Mouser# 291-12K-RC
R5	24 K 1/4 W 5% carbon film resistor	(RED YEL ORG)	Mouser# 291-24K-RC
R8	4.7K 1/4 W 5% carbon film resistor	(YEL VIO RED)	Mouser# 291-4.7K-RC
R9	1.0 K 1/4 W 5% carbon film resistor	(BRN BLK RED)	Mouser# 291-1K-RC
R10, R11	2.2 K 1/4 W 5% carbon film resistor	(RED RED RED)	Mouser# 291-2.2K-RC
SW1	SPST NO momentary Pushbutton, panel mount		JAMECO# 26623
U1	LM339 Quad analog comparator, DIP-14		Mouser# 512-LM339AN
U2	78L05 5V Positive linear regulator, TO-92		Mouser# 512-KA78L05AZTA
PCB-1	Printed circuit board		BRARC custom
Case-1	Standard Altoids tin		Grocery item
Grommet	3/16" ID thin panel grommet		Mouser# 534-730
Decal-1	Panel label overlay		BRARC custom
BPR1	Piezo beeper (optional)		Mouser# 539-PK-12N40PQ Radio Shack #273-0074



BRARC WØUFO Battery Monitor, Surface-Mount Version, Bill of Materials

U1	LM339 quad comparator SOIC		Mouser# 595-LM339ADR
U2	LM78L05 +5V regulator SMT		Mouser# 595-UA78L05CPK
F1	50 mA resettable fuse SMT 1206		Mouser# 504-PTS120660V005
D1	diode SMT		Mouser# 771-BAS21J115
R2, R4, R6	2K trimmer surface mount		Mouser# 652-TC33X-2-202E
R1, R7	6.8 K 1/8W resistor, SMT 1206	(marked 682)	Mouser# 71-CRCW12066.8K00JNEB
R3	4.3 K 1/8W resistor, SMT 1206	(marked 432)	Mouser# 71-CRCW12064.3K00JNEB
R5	9.1 K 1/8W resistor, SMT 1206	(marked 912)	Mouser# 71-CRCW12069.1K00JNEB
R8a, R8b, R9a, R9b, R10, R11	2K 1/8W resistor, SMT 1206	(marked 202)	Mouser# 71-CRCW12062K00JNEB
C1, C2, C4, C5, C6	0.1 uF SMT capacitor 1206	(unmarked)	Mouser# 77-VJ1206V104ZXAPBC
C3	0.33 uF SMT capacitor 1206	(unmarked)	Mouser# 77-VJ1206V334ZXAPBC
DS4	Red 1209 SMT LED		Mouser# 859-LTST-C930KRKT
DS2	Green 1209 SMT LED		Mouser# 859-LTST-C930KGKT
DS3	Yellow 1209 SMT LED		Mouser# 859-LTST-C930KSKT
DS1	Blue 1209 SMT LED		Mouser# 859-LTST-C930TBKT
PCB-2	Printed circuit board		BRARC custom
Grommet	3/16" ID thin panel grommet		Mouser# 534-730
Case-2	Mini Altoids tin		Grocery Item
Decal-2	Panel label overlay - mini		BRARC custom