An Arduino NANO based Battery Monitor

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http://qsl.net/n5ib/

Here is a device to help manage the care and feeding of rechargeable batteries. It is not a charger or charge controller, but it monitors and displays several important battery performance parameters.

Using an Arduino NANO microcontroller, an LCD display panel, and a Hall-effect current sensor, the device is programmed to provide the following information:

1. Battery terminal voltage numeric display, range is 0 – 20 V
2. Terminal voltage bar graph display covering the range 11.5 – 14.5 V
3. Current out of (negative values) or into (positive values) the battery, numeric display
4. Net milli-ampere-hours (mA-hr) delivered (plus) or drawn (minus) from the battery, numeric display
5. An elapsed time display hh:mm:ss of the battery's time in service.
6. Morse annunciated audible alarm for high or low voltage conditions

Microcontroller

An Arduino NANO microcontroller module handles all of the measurements, calculations, and data output required. The firmware program (included within this documentation package) is loaded via a USB connection to a host computer. The IDE (Integrated Development Environment) that runs on the host computer is available as a free download.

Figure 1. Arduino NANO microcontroller

Display

The Nokia 5510 LCD display was manufactured for use in some of the early cell phones. It has a monochrome graphics-capable screen 84 pixels wide by 48 pixels high. Up to 6 lines of up to 14 ASCII characters, can be displayed, or a mix of character and graphic elements. It is readily available from Adafruit, Sparkfun, and many other eBay and Amazon vendors, usually in the price range of $3 to $5.

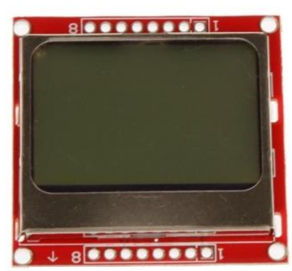


Figure 2. Nokia 5110 graphic LCD display

The display communicates with the microcontroller via a serial data bus (the ***master-out-slave-in*** or ***MOSI*** half of an SPI bus protocol). It is powered from the 3.3V regulated output provided by the NANO microcontroller module.

While the display and its on-board controller chip are powered by a 3.3 V supply, and normally require connection to 3.3 V logic level signals, it's been found that a simple series resistor connection is adequate protection to allow connection to the 5 V logic level signals sent by the NANO. The chip apparently includes clamping diodes connected to the 3.3 V supply. A resistor in series with a 5 V logic signal will limit the current into the controller input pins to safe levels. Experiments have shown that anything from 1 K to over 10 K is satisfactory.

Voltage Monitor

The Arduino NANO includes several ADC (analog to digital conversion) channels with 10 bit resolution. The NANO's 5 V supply is used as the ADC reference voltage, and a voltage divider is employed to allow measurements over the range of 0 V to 20 V, with a resolution of about 20 mV. A trimmer potentiometer in the voltage divider allows the voltage display to be calibrated against an external meter. The firmware program accounts for the voltage drop across a polarity protection diode included in the circuit.

The numerical display shows the battery terminal voltage, to two decimal places, over the whole range from 0 V to 20 V. But to aid in monitoring battery health, a bar graph is provided that zooms in on just the range from 11.5 V to 14.5 V. This "safe range" display can be easily modified in the program code if necessary to match up with different battery chemistries.

In addition, and audible alarm sounds if the voltage strays outside of the pre-set "safe range." The alarm is in Morse code, sounding "HIGH V" or "LOW V" as appropriate. A small ½" diameter piezoelectric transducer is used as the speaker. The code speed and audio pitch can be adjusted within the firmware program.

Current Monitor

An inexpensive bi-directional Hall-effect current sensor is used to measure the current flowing into or out of the battery. Using the Allegro Microsystems ACS-712 chip, there are sensor modules available for 5 A, 20 A, and 30 A maximum current. The sensor's output is a DC voltage in the range from about 1.5 V to 4.0 volts. Since the sensor is bi-directional, it's possible to tell if the battery is being charged or discharged, and at what rate. The resolution is fairly coarse, the step size being about 25 mA for the 5 A sensor, and 50 mA for the 20 version. But since the usual operating charge/discharge currents are several times larger than that, useful information is still possible.

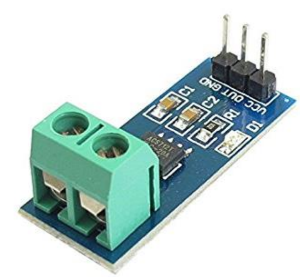


Figure 3. Hall-effect current sensor

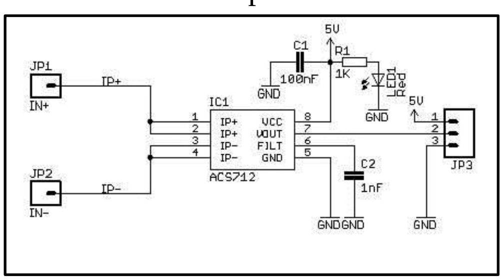


Figure 4. Current sensor module schematic

It seems incredible that currents of up to tens of amperes can pass through such a tiny device without vaporizing it. But the manufacturer claims that the series resistance of the device is less than a mill-ohm, so it would dissipate less than 400 mW at 20 amps, 25 mW at 5 amps. Search for ***ACS-712 current sensor*** on YouTube for some remarkable video demonstrations.

Like the LCD display, fully assembled sensor modules are also available from Sparkfun, Adafruit, and Amazon and eBay vendors, usually in the $4 to $6 range.

Milliampere-hour Monitor

The NANO includes on-board timers with millisecond to microsecond resolution. That makes it simple to accurately measure time intervals. By measuring the elapsed time between successive current measurements it's a simple matter to calculate the mA-hr. Since the current measurement is by-directional, it's also easy to determine if the battery is in a charge or discharge state.

There is an inherent inefficiency in battery charging. A rule-of-thumb is that about 140% of the capacity drawn from the battery must be replaced in the charging cycle. For example, if 1 amp were drawn from a battery steadily for 5 hours, that would be 5000 mA-hr of capacity used. The charging system would have to provide about 1.4 x 5000 ma-hr (about 7000 mA-hr) to replace that capacity. The firmware program includes a provision to account for the charging inefficiency by calculating the effective charging mA-hr as only 70% of the actually measured value.

When the mA-hr display is negative, that means the battery has undergone a net discharge during the elapsed time shown. A positive mA-hr report means that the battery has gained charge during the interval.

Elapsed Time Display

The same NANO timers that are used to calculate ma-hr can be used to provide an elapsed time clock that shows the time since the monitor device was started. By starting up the monitor from zero at the same time that the battery is placed in service, it becomes a convenient check of battery running time.

Power Supply

The monitor is powered from the battery system to which it is connected. A +9 V regulator provides a steady supply to the NANO microcontroller, and the NANO provides regulated +5 V and +3.3 V to the current sensor and to the LCD display. The monitor draws about 35 mA from the battery. That can be reduced by a few mA by turning off the display's LED backlight. If desired, the monitor could be powered by a separate supply or battery. A 9 V battery is not recommended, as it would probably give less than 8 hours of continuous service.

The LM7809 regulator requires an input voltage of at least 10.5 to 11.0 V in order to give a well-regulated 9 V output. Ordinarily a nominal 12 V battery would not be allowed to drop below 11 volts, to avoid shortening its life. If it is anticipated that battery voltage may fall below that level, an 8 V regulator (LM7808) may be substituted. There are *low-dropout* regulators that also would be good candidates.

Construction Notes

The project is certainly a candidate for perf-board construction, since there only a couple of dozen connections that must be made. And the board size can be trimmed to fit whatever enclosure may be on hand. Printed circuit construction will make things quicker and easier, though. An image of a suggested PCB layout (approximately actual size) is included below the Bill of Materials. The board is sized to fit an inexpensive plastic project box.

Most of the resistors and capacitors used on the PC board version are surface mount devices, the larger 1206 sized parts. The rest of the components are ordinary through-hole parts.

The LM7809 voltage regulator only has to supply about 35 mA, so does not need a heat sink. It can be held in place simply by its soldered leads, or secured to the board with a #4 machine screw and nut. The tab of the device is a grounded terminal, so insulation beneath the body of the device isn't needed.

A DIP switch is used to set/clear several input bits that are read by the micro controller to determine calibration settings and operating features. Optionally, the DIP switch can be omitted and wire jumpers used instead.

The component values are marked on the silkscreen legend of the PC board. Be sure to observe the polarity of the diode, the two electrolytic capacitors, and the piezo speaker.

Connectors

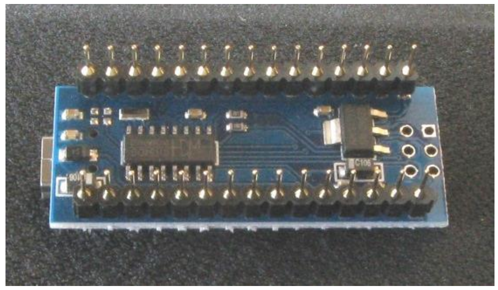


Figure 5. NANO with round pin strips

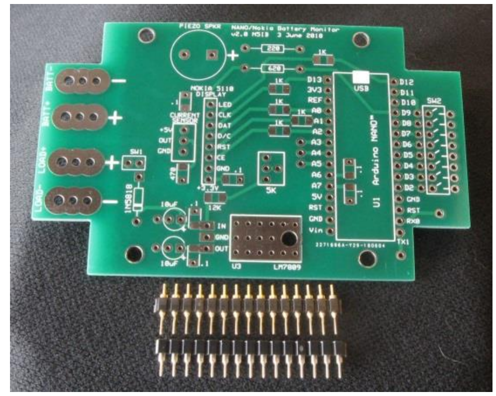


Figure 6. Monitor PC board and male/female pin strips

While all the parts could be directly soldered to the board – even the NANO - sockets for the NANO, DIP switch, current sensor, and display connections are a good idea. The round, machined-pin, break-away pin and socket strips work very well for the NANO, providing a lower profile mounting. NANOs can be purchased with or without the pins installed. But if they are already installed they will be the 0.025” square posts on the bottom of the module. Regular 0.025” square post pins/sockets are suitable for the connection to the display, current sensor, and piezo speaker.

Preparing the current sensor

The current sensor most commonly available from eBay vendors usually comes with pins and wire terminals installed. The pins may be straight or right angled. The wire terminals are usually compression type screw terminals which are usually rated for about 15 amps, and accept wire sizes from 22 to 14 AWG.

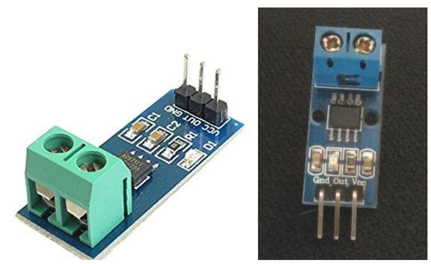


Figure 7. Current sensors as received, with pins and terminals

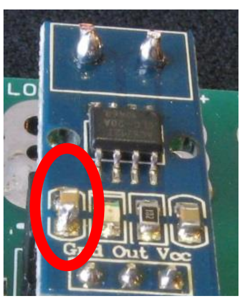


Figure 9. Filter capacitor on current sensor module

In the unit shown in Figure 8 at right, the original pins and terminals have been removed. Vertical pins were installed on the bottom so that the module can be plugged into a 3-pin female header socket. For the 5 amp version, the screw terminal wire connection block on the sensor module can be retained. For the 20 amp version, it would be better to remove the connector block and make direct solder connections to the sensor module as has been done in Figure 8.

Figure 8. Modified current sensor with vertical header pins and direct soldered connection

Refer to the current sensor schematic in Figure 4. A 0.001 µF capacitor (position circled in Figure 10) is installed on the module as a low pass filter for noise reduction. Testing reveals that a larger capacitance is called for. The quickest fix is to stack another 0805 sized SMD capacitor on top of the original one, as shown , where a 0.1 µF cap has been tacked on top.

Figure 10. Vias joining top and bottom side traces

The traces that carry the current being measured are duplicated on the top and bottom sides of the sensor module circuit board. Four ***vias*** (circled in Figure 10) connect the top and bottom traces. It’s a good idea to make sure that these vias are filled with solder to provide as low a resistance path as possible. Re-heat and re-flow with a bit more solder if necessary.

Preparing the LCD display panel

The LCD display panels usually are sold with one set of vertical header pins already installed. A second set of eight circuit board pads is also provided. Connection to the display can be made at either pad set, or even a combination of the two. The pads are wired in parallel.

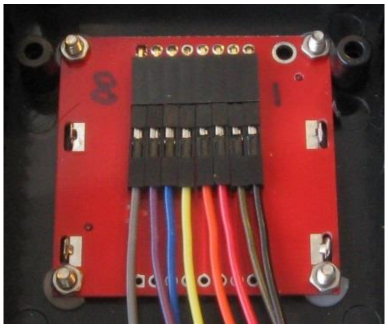


Figure 11. LCD display with substituted right angled header

Depending on how the display will be mounted in an enclosure, it is possible that the vertical pins may interfere with components below the display. This was the case in the unit pictured. The vertical header pins were removed and a right angled female header substituted.

DuPont type wire connectors can be used to connect the display to the header on the main circuit board.

ON/OFF Switch

If a switch is to be installed, its wire leads can be soldered directly to the pads at the SW1 position. Or a 2-pin header can be installed at that position to accept a plug-in connection.

Note: the SW1 pads are placed a little too close to the position of the current sensor module. If a header/socket arrangement is to be used, the header pins should be slightly angled out towards the diode so that the plug assembly will clear the edge of the sensor module.

Piezo speaker

In order to make the Morse annunciation audible, the small piezo speaker should be mounted beneath a small hole drilled in the enclosure. Glue or double sided tape can be used to fix it in place. The speaker is polarized. One of its pins is marked "+" so be sure to observe the polarity when connecting it to the PC board.

Assembly sequence

A suggested sequence for populating the circuit board is:

1. Install the surface mount resistors (7) and capacitors (6)

2. Install the sockets and pins for the NANO microcontroller. It's best to dry fit the pins and sockets to the NANO module and the PC board. Leave everything mated together and solder diagonal pins on the NANO and on the PC board. Check alignment. If everything is in order, solder the remaining pins.

3. Install the headers for the current sensor (3-cond female), LCD display (8-cond female).
If desired, header pins can be installed for the on/off switch and piezo speaker connections.

4. Install the through-hole components: resistors (2), polarized capacitors (2), diode (1), and potentiometer (1)

5. Either solder the DIP switch directly to the PC board, or install a DIP socket to receive the switch.

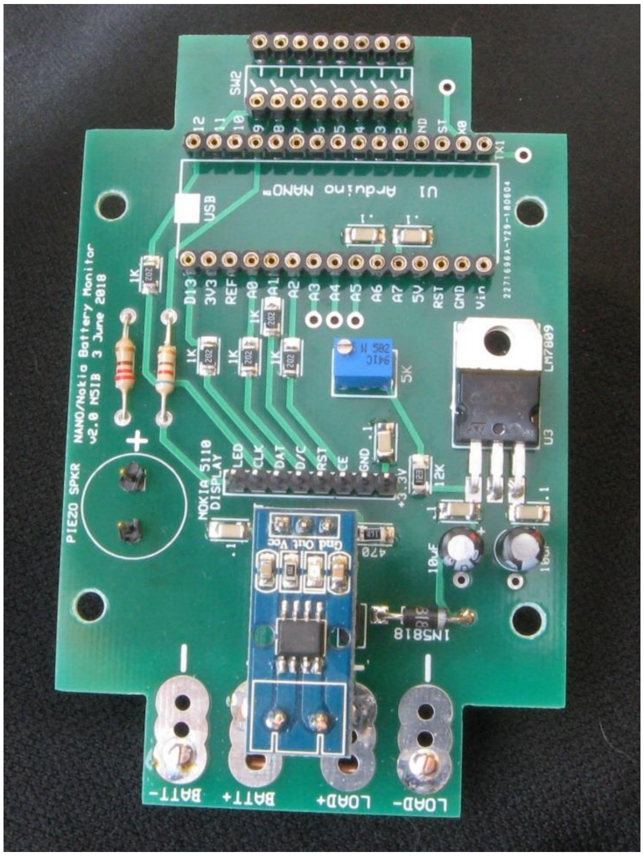


Figure 12. Populated PC board

6. The negative terminals from the battery and load/charging source are connected together by a heavy copper wire on the bottom of the PC board. Input and output wire leads are also soldered to the pads on the underside of the board.

7. Install the LM7809 voltage regulator. It may be secured to the PC board with a #4 screw and nut, but that is optional. No heat sink is needed.

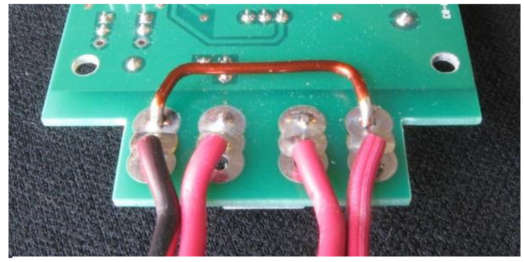


Figure 13. Negative battery and load leads jumpered

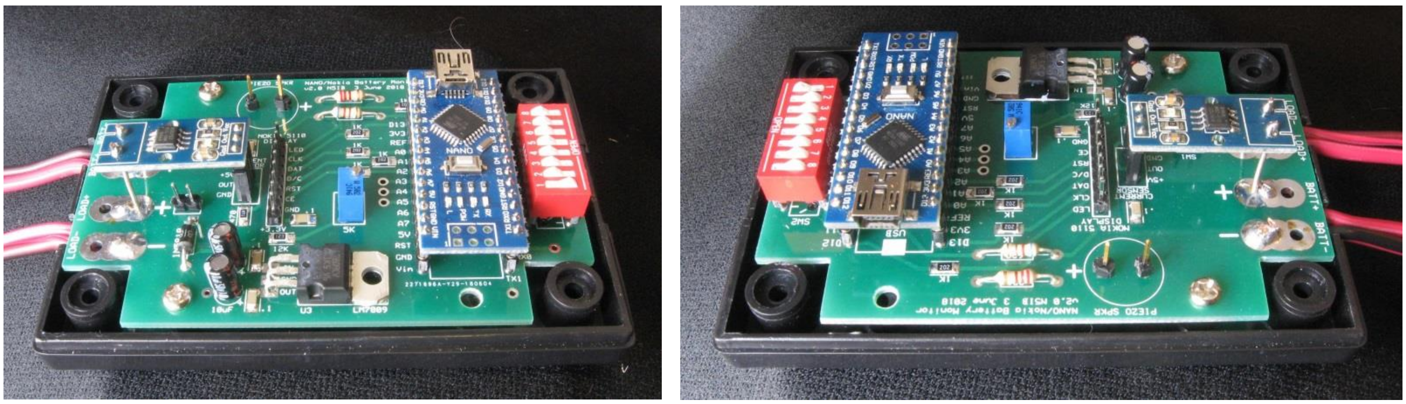


Figure 14. Side views of populated PC board, mounted into the bottom section of the plastic enclosure

Figure 15. Additional views of populated PC board, including piezo speaker connected

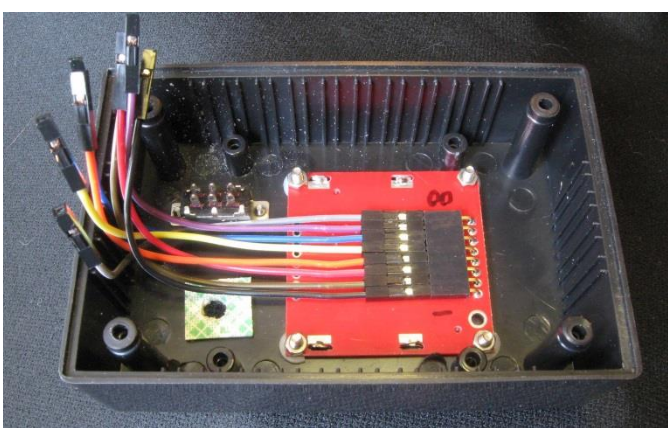


Figure 16. LCD display and ON/OFF switch mounted into the top section of the enclosure. Note the use of washers at the four corners of the display. Also note the double sided tape in place to secure the piezo speaker

Enclosure

The PC board is sized to fit the PB-03 project box sold by Tayda Electronics. The rubber feet are on the shallow section of the box, so that becomes the bottom, and the circuit board is mounted there. One end of the bottom section is notched to allow the input and output wire leads to exit the box, as shown in Figure 15.

The LCD display, ON/OFF switch, and piezo speaker are mounted in the deeper, upper section of the box.

There are solder fillets along the header pads on the top side of the LCD board. These would prevent the board from lying flat when mounted, so washers are used at the four corners to space the board slightly.

Program Loading

There are two ways to load the firmware program into the Arduino NANO. One is to use the Arduino Integrated Development Environment (IDE) to compile the source code and then upload it via a USB connection from a host computer. The other is to use the USB connection to upload the already compiled program from a .HEX file.

The program is saved as a compressed (zip) folder at: http://qsl.net/n5ib/BatMon_Morse.zip
that contains several files:

BatMon_Morse.ino	the main source code file
BatMon_Morse_Defs.h	variable declarations, definitions, and initial settings
BatMon_Morse.hex	the compiled code ready for direct upload
BatMon_Morse.pdf	this document
Nokia 5110 Datasheet.pdf	Nokia 5110 LCD display controller datasheet
ACS712-Datasheet.pdf	ACS-712 Hall-effect current sensor data sheet
Tayda PB-03 Plastic Project box A-2383.pdf	dimensioned drawing of PB-03 enclosure

All of these files should be extracted from the compressed folder into a folder named "BatMon_Morse"
Only the first two are needed if the builder wishes to compile the code and then upload.
Only the third file is needed for direct upload. The rest are reference documents.

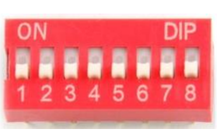
The source code is fairly well commented to assist the builder in customizing the operation of the monitor or for adding new features.

Operation of the Arduino IDE and/or the hex loader is beyond the scope of this document. But there are lots of tutorials and guidance available in the on-line Arduino community.

Initial Checkout

Refer to the table below and initially set the DIP switches to:

Enable CW annunciation
Enable backlight
Offset bits 000
Offset sign positive
Current sensor max set for the sensor that is installed



The DIP switches are connected between the NANO's digital input pins and ground. The inputs are pulled up to +5V by internal resistors. So a switch in the "OFF" or "OPEN" position will be read as a logic "1" while a switch in the "ON" or "CLOSED" position will be read as a logic "0."

Position	OFF - OPEN circuit – Logic Level "1"	ON - CLOSED Circuit – Logic Level "0"
1	Enable CW annunciation	Disable CW annunciation
2	Enable LED backlight	Disable LED backlight
3	Bit 0 (LSB) of offset = 1	Bit 0 of offset = 0
4	Bit 1 of offset = 1	Bit 1 of offset = 0
5	Bit 2 (MSB) of offset = 1	Bit 2 of offset = 0
6	Sign of current sensor offset = NEGATIVE	Sign of current sensor offset = positive
7	Current sensor maximum = 20 A	Current sensor maximum = 5 A
8 (spare)		

If the optional power ON/OFF switch is used, set it to OFF.
Connect the BATT+ and BATT- leads to a 12 volt battery
The LOAD+ and LOAD- leads may be left unconnected at this time
Turn the power switch ON

Within a couple of seconds the backlight should illuminate and the Morse sign-on message should play.
Shortly after that the full display should appear as below

The elapsed time should begin counting up from 00:00:00
The voltage and current reading are as yet uncalibrated, so may not be correct
The mA-hr reading should begin at 0
If the 20 A sensor was selected via the DIP switch, an "H" should appear to the right of the mA display
Depending on the voltage calibration, the bar graph may or may not be visible at this time.

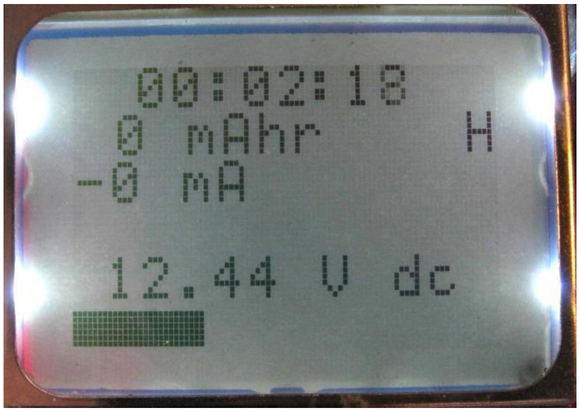


Figure 18. Screen display while operating

Voltage display calibration
Use a separate voltmeter to measure the battery voltage
Adjust the trimmer potentiometer until the unit's displayed voltage is as near as possible to the voltmeter

> *An exact match is generally not possible, but the readings should agree within a few tens of mV*
> *The programming includes a compensation for the voltage drop across the polarity protection diode, which is assumed to be a Schottky diode with a forward drop of about 320 mV. If the builder has substituted an ordinary silicon rectifier, that compensation will have to be changed in the source code to about 600 mV.*

Once the voltage display has been calibrated, the bar graph should be visible as long as the battery voltage is between about 11.5 V and about 14.5 V

Current display calibration
Refer to the DIP switch table
Disable the CW annunciation for the time being.
Set the four offset bits are set to "0" (ON or CLOSED) to zero the offset

Pos 3	Pos 4	Pos 5	Pos 6	Offset
ON	ON	ON	ON	0
OFF	ON	ON	ON	+1
ON	OFF	ON	ON	+2
OFF	OFF	ON	ON	+3
ON	ON	OFF	ON	+4
OFF	ON	OFF	ON	+5
ON	OFF	OFF	ON	+6
OFF	OFF	OFF	ON	+7
OFF	ON	ON	OFF	-1
ON	OFF	ON	OFF	-2
OFF	OFF	ON	OFF	-3
ON	ON	OFF	OFF	-4
OFF	ON	OFF	OFF	-5
ON	OFF	OFF	OFF	-6
OFF	OFF	OFF	OFF	-7

Disconnect the BATT and LOAD leads and connect the monitor to a host computer using the USB connection. It is not necessary to have the IDE running. The USB port will be used only to supply power to the monitor. Under this condition, the current through the sensor will be zero. This can be used to set the calibration for the sensor.

The current being displayed will probably be flickering among several values, but should be near zero, within the sensor resolution step size (25 mA for 5 A sensor, 50 mA for 20 A sensor)

If the current displayed is more than one step away from zero, use the DIP switch offset bits to move the zero point as needed. The adjustment range is +/- 7 steps with respect to zero. The display will still jump up and down a bit, but the program employs a trailing average to help smooth out the jitter.

Normal operation

Enable the CW annunciation if audible alarms are desired
Connect a 12 V battery to the BATT+ and BATT- leads
The monitor should start up with the time and mA-hrs zeroed

> *Be sure to always connect the battery first. The battery serves as a voltage stabilizer in case a charging source can supply an excessively high voltage while under very light load.*
>
> *For example, a solar panel that might only be able to supply a few hundred mA might still have a voltage above 20 V under open circuit or light load conditions. If the battery is already connected it will supply a load and pull the voltage down.*

Connect the load and/or charging source to the LOAD+ and LOAD- leads

The display should begin to show the net current into (+) or out of (-) the battery, and the mA-hr display will begin to accumulate. Time and mA-hr will reset to zero each time power is cycled.

Ideas for modifications and enhancements

It's easy to change the source code to do things such as

- Change the high and low voltage alarm points
- Change the CW sign-on, and alarm messages
- Change the backlight brightness
- Change the forward diode voltage drop compensation
- Change the number of samples in the trailing average for current

Since this is a programmable platform there is a nearly endless variety of things that can be done. There are three multipurpose I/O pins, presently unused (A3, A4, A5), which can function as analog inputs, or digital inputs/outputs. Here are just a few thoughts…

Instead of the DIP switches, use momentary contact pushbuttons and program a menu to select operating modes and features. This will also free up more I/O pins for other features

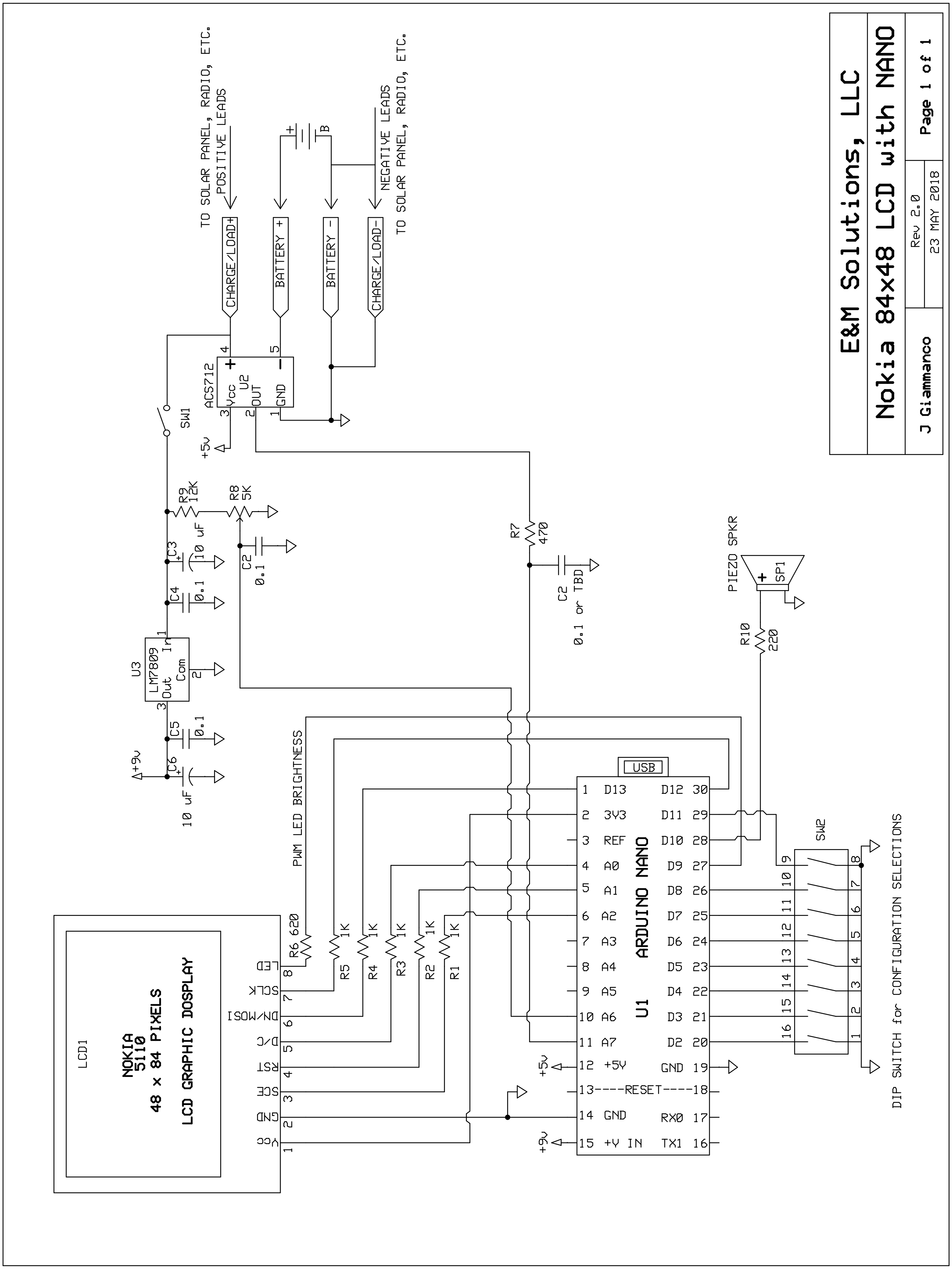
Use a power MOSFET as a switch to control the charging of the battery

Connect a BlueTooth serial module so that the monitor data can be read remotely (iOS or Android devices?)

Utilize the NANO's EEPROM non-volatile storage to save/restore the state of the battery instead of resetting to zero at each power up.

Change the current sensor to one that gives greater precision at low current

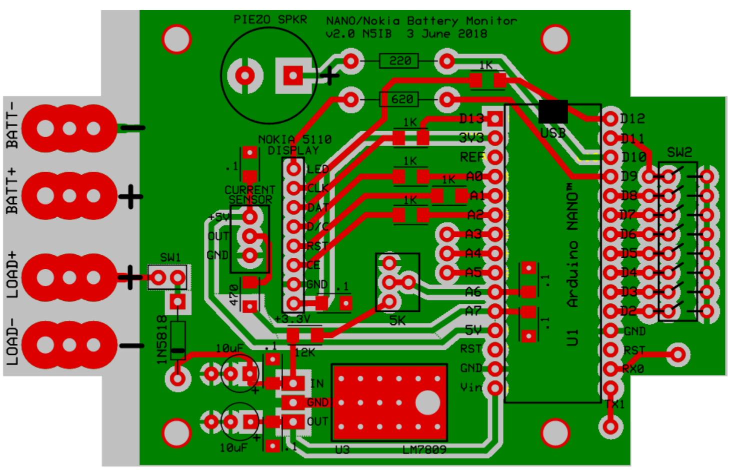
Figure 19. Complete Schematic Diagram:



Bill of Materials (*denotes surface mount components):

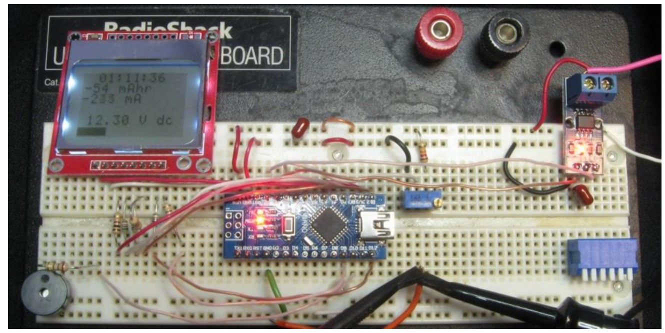
C1*	0.1 uF 10% 50V SMD MLCC capacitor, size 1206, or value TBD
C2, C4, C5, C7, C8*	0.1 uF 10% 50V SMD MLCC capacitor, size 1206
C3, C6	10 uF 25V or 50V electrolytic, radial leads spaced 0.1” or 0.2”
LCD1	Nokia 5110 48 x 84 pixel LCD display *Search for “Nokia 5110” on Amazon or eBay*
R1, R2, R3, R4, R5*	1K 5% 1/8 W resistor SMD size 1206
R6	620 ohm, 5%, ¼ W carbon film resistor, axial leads
R7*	470 ohm, 5% 1/8 W resistor SMD size 1206
R8	5K multi-turn trimmer potentiometer, side adjust preferred
R9*	12K 5% 1/8 W resistor SMD size 1206
R10	220 ohm, 5%, ¼ W carbon film resistor, axial leads
SP1	Piezo Speaker, ½” diameter, can be passive type, or self-contained oscillator
SW1	optional SPST On/OFF switch
SW2	DIP switch, TBD - up to 8 positions, single throw
U1	Arduino NANO microcontroller
U2	Hall effect current sensor using ACS712 *Search for “ASC-712 current sensor” on Amazon or eBay*
U3	LM7809 9 volts linear regulator, TO-220
Enclosure	Plastic project box, TAYDA Future Box PB-03 https://www.taydaelectronics.com/hardware/enclosures/plastic-project-boxes/project-plastic-box-03.html
Hardware	header pins and sockets to suit builder
Firmware	Arduino program files

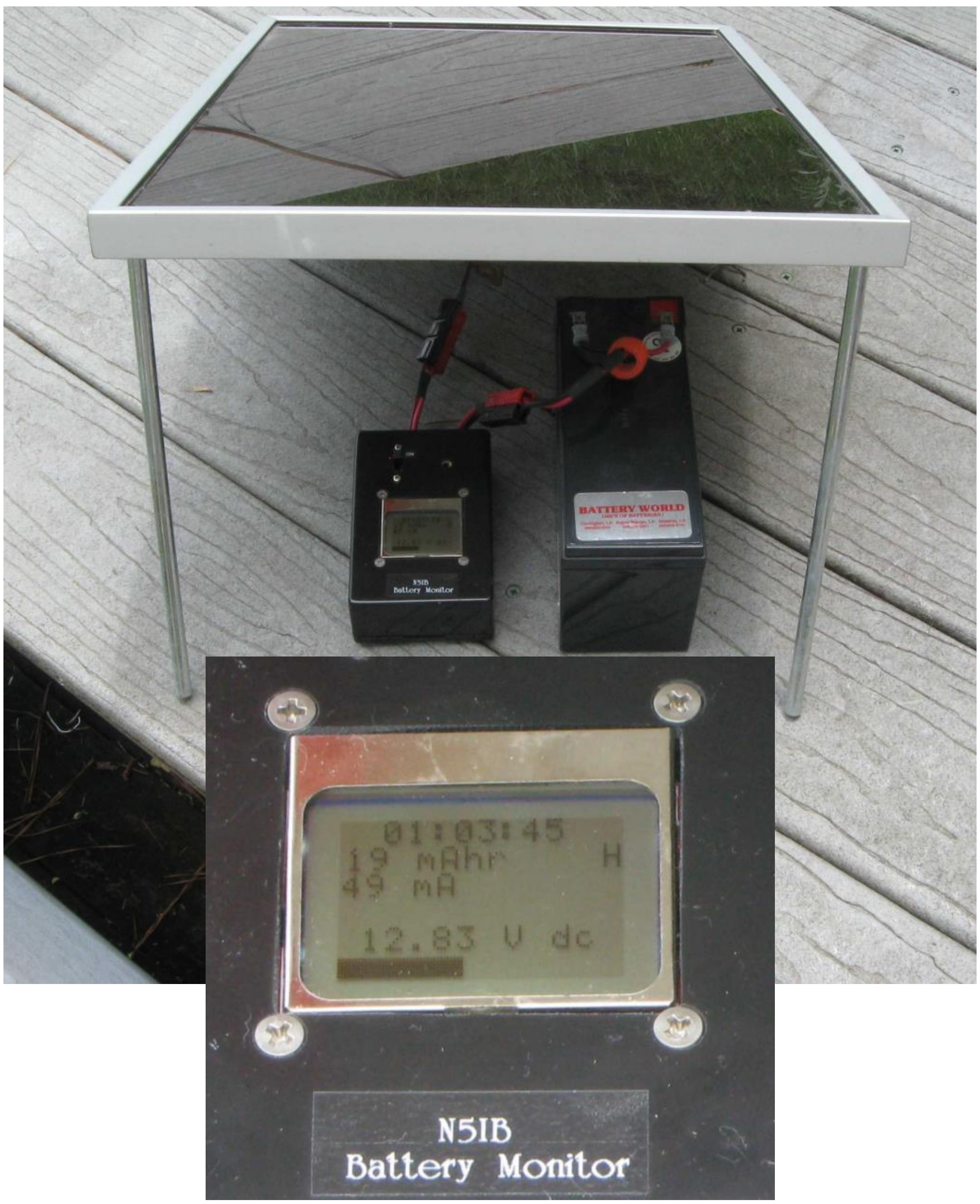
Circuit Board Pattern, shown approximately actual size:



Photos:


BP SOLAR


BOARD


BATTERY WORLD
01:03:45
19 mAhr H
49 mA
12.83 V dc
N5IB
Battery Monitor