PowerSwitch/SmartCharger
Construction / Operation Manual

KX4Z

Version 2.001

May 11 2020
Updated: August 26, 2020 – concurrent with software 2.004
Updated Sept 6 2020, improved construction steps & tests, concurrent with software 2.007

Introduction.

Amateur radio operators involved in emergency communication and others often need to have backup battery power for their station. It is advantageous if that backup power comes on-line immediately if there is a loss of AC power. There are excellent commercial solutions that accomplish this goal using P-channel power MOSFETs and associated circuitry. Some also provide for background charging of the battery; there is also a commercial solution based on high power Shottky diodes with current-controllable battery charging --- but these systems come at hefty prices.

This batteryswitcher/smart charger can be built for below $50 and the builder will likely learn a lot in the process.

There were multiple purposes to this project:

- Create an immediate-backup battery switching system (with such a fast switchover that digital or other connections would not be lost)
- Provide for charging of the backup battery-- not just “trickle charging” REAL charging
- Possibly provide for multiple types of backup batteries, both lead-acid and LIFEPO4
- Provide learning opportunities for amateur radio operators in construction
- Provide learning opportunities for amateur radio operators in Arduino programming

I recommend that you read this entire manual before attempting to construct this device. Building this device and setting it up for proper operation requires some level of skill and knowledge

SPECIFICATIONS

Current handling capacity	Depends solely on the size of the heatsink—can extend to 40 Amps @ 13.8VDC with a suitable heatsink.
Switch-over time	Approx. 50 milliseconds (software adjustable)
Maximum AC power supply voltage	15.0 VDC max recommended. Beyond 20V, damage is likely to occur to the MOSFET gate insulation.
Battery charging	User-setting of battery chemistry and amp-hours at startup: • Lead acid • Sealed lead acid • Absorbed glass Mat lead acid • LiFePO4, Bioenno type, with or without their special

	15VDC charger Ahr from 5-50+
Display	Inexpensive 2-line 16 character display
Current Monitoring	Both battery charging current, and radio usage current. Measured every 10 seconds (software adjustable)
Power Source:	13.8-14.5 VDC typical amateur radio DC power supply. The higher voltage is more important if LiFePO4 battery is utilized

<u>OBTAINING MAXIMUM BATTERY BACKUP LIFE</u>:

Lead Acid: Keeping a lead-acid type battery in a charged state while providing radio power from a standard power source may make batteries last longer (potentially up to 6 years[1]) than our previous Alachua County technique of using the battery to power the radio and continuously recharge with a smart battery maintainer.

LIFEPO4: *Avoiding* continuous maintenance at full charge improves lifespan of these batteries. It's best to charge it to a value somewhat below full charge and let it discharge somewhat before recharging back up. The exact optimum spot is a trade-off between desired backup storage and longevity; some advise only storing at 50-60% state of charge.

1 https://www.mastervolt.com/determining-the-lifespan-of-a-battery/ Suggesting up to 6 year life span for lead acid batteries, down to 80% capacity.

TYPICAL OPERATION

This information is provided here because understanding the usage of this device helps one when constructing and setting it up.

Be certain to connect AC-based supply, battery, and radio to the proper connections and avoid incorrect polarity. (Power pole connectors are strongly suggested.)

As soon as either power source is connected, the Arduino will automatically turn on. It goes through several setup steps:

<table>
<tr><th>Step</th><th>Description</th><th>User Actions Required</th></tr>
<tr><td>1</td><td>Presentation of GNU GPL license information and software version</td><td>None</td></tr>
<tr><td>2</td><td>Checking quiescent bias on op amp measurement of battery and radio current.</td><td>None. A few millivolts above 0.000 is desirable. Software remembers the tare value and appropriately adjusts.</td></tr>
<tr><td>3</td><td>Countdown to set battery chemistry, 5-4-3-2-1-0</td><td>During this time, you can adjust the battery chemistry trimmer potentiometer with an insulated screwdriver; the reading is immediately presented. Multiple “zones” in the angular rotation of the trimmer are defined to allow you to set the type of battery chemistry
<table>
<tr><th>ZONE</th><th>Type of Battery</th><th>Software Moniker</th></tr>
<tr><td>0 (fully counterclockwise)</td><td>Undefined</td><td><code>BATTUNDEFINED</code></td></tr>
<tr><td>1</td><td>Flooded type lead acid battery (with battery caps to allow you to check and add water)</td><td><code>FLOODED</code></td></tr>
<tr><td>2</td><td>Sealed type lead acid battery, no way to add water</td><td><code>SEALED</code></td></tr>
<tr><td>3</td><td>Absorbed Glass Mat lead-acid battery</td><td><code>AGM</code></td></tr>
<tr><td>4</td><td>Bioenno LIFEPO4 battery using its own charger</td><td><code>LIFEPO_W_CHGR</code></td></tr>
<tr><td>5</td><td>Bioenno LIFEPO4</td><td><code>LIFEPO_ALONE</code></td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td></td><td><table><tr><td></td><td>battery without its own charger; must be charged by this device</td><td></td></tr><tr><td>6
(fully clockwise)</td><td></td><td>NOBATT</td></tr></table>
You must be settled on the correct battery type by the time 0 arrives. If any question, power down the unit and start over.</td></tr>
<tr><td>4</td><td>Countdown to set battery amp-hr capacity 5-4-3-2-1-0</td><td>During this time, you can adjust the battery amp-hour from 5 to 50 Ahr. For any battery above 50 A-hr, choose the 50 value. This does NOT have to be exact, just within about 10% of the correct value is fine. If you do not get it set by the 0 presentation, power down the unit and begin anew</td></tr>
<tr><td>5</td><td>Initial measurement of battery status, voltage and equivalent series resistance (except LIFEPO4 using external charger)</td><td>No required user effort</td></tr>
<tr><td>6</td><td>Proceeds to continuously running normal programming</td><td>No required user effort.</td></tr>
</table>

After the setup, the endless loop of normal operation begins.

As long as AC power based supply voltage appears useful, the system will utilize the AC supply.

When the radio current is less than 10Amps (software adjustable) the system will attempt to charge a discharged battery. If the radio current is above the preset value, the system will temporarily discontinue charging a discharged battery so as not to place any excessive load on the AC based power supply.

If the AC power based supply appears to be significantly lower voltage than the battery, the system will shift to the battery for power; this measurement is made, in general, every 0.050 seconds (50 milliseconds) and changeover takes only a few milliseconds.

During CHARGING from the internal system, the charging current and accumulated charge are presented. Charging protocol is dependent on battery type and battery capacity. Accumulated charge is reset to zero anytime the system goes back to AC-based supply from battery usage.

During battery usage, the system will measure the radio current being consumed every 10 seconds (software adjustable) and present this value, and use it to estimate the total charge removed from the battery; this assumes that the current was constant during the previous 10 seconds (unlikely to be true for a single-sideband or CW station).

There is no ON-OFF switch for the system.

The system includes a crude measurement of ambient temperature and adjusts voltage points for lead-acid chemistry batteries using this; this is only important at very extreme temperatures.

Optimal AC power supply voltage (if adjustable) depends on the type battery being used for battery backup:

- Lead Acid of any type: 13.8 VDC-14.5 VDC is fine.
- LIFEPO4 using this system as charger 14.5VDC is recommended.

LED Indicators: Understanding their function.

The LED lights provide a visible indication of the voltage present at two points – the +PWR input and the +BAT input. However, it is important to realize that there are three MOSFETS in series between these points and that each MOSFET includes a body diode that will definitely carry current from its anode to the cathode. Further, the system is designed to move current from the +PWR input to the +BAT terminal in order to charge the battery. Thus….just because an LED is lit does not necessarily mean that there is a power source at that terminal!

- When the device is powered up for the first time, during setup all MOSFETS are turned OFF and at this point, the LEDs do indicate whether a power source is present at the input terminal.
- When operating from battery supply, the body diode of the MOSFET connected to the +PWR terminal will allow current from the battery to light the AC PWR led, regardless of the actual state of the AC-based power supply.
- When operating from the AC-based power supply, any time there is a charging or testing current directed at the battery, it will light the battery LED.

SCHEMATIC DIAGRAM

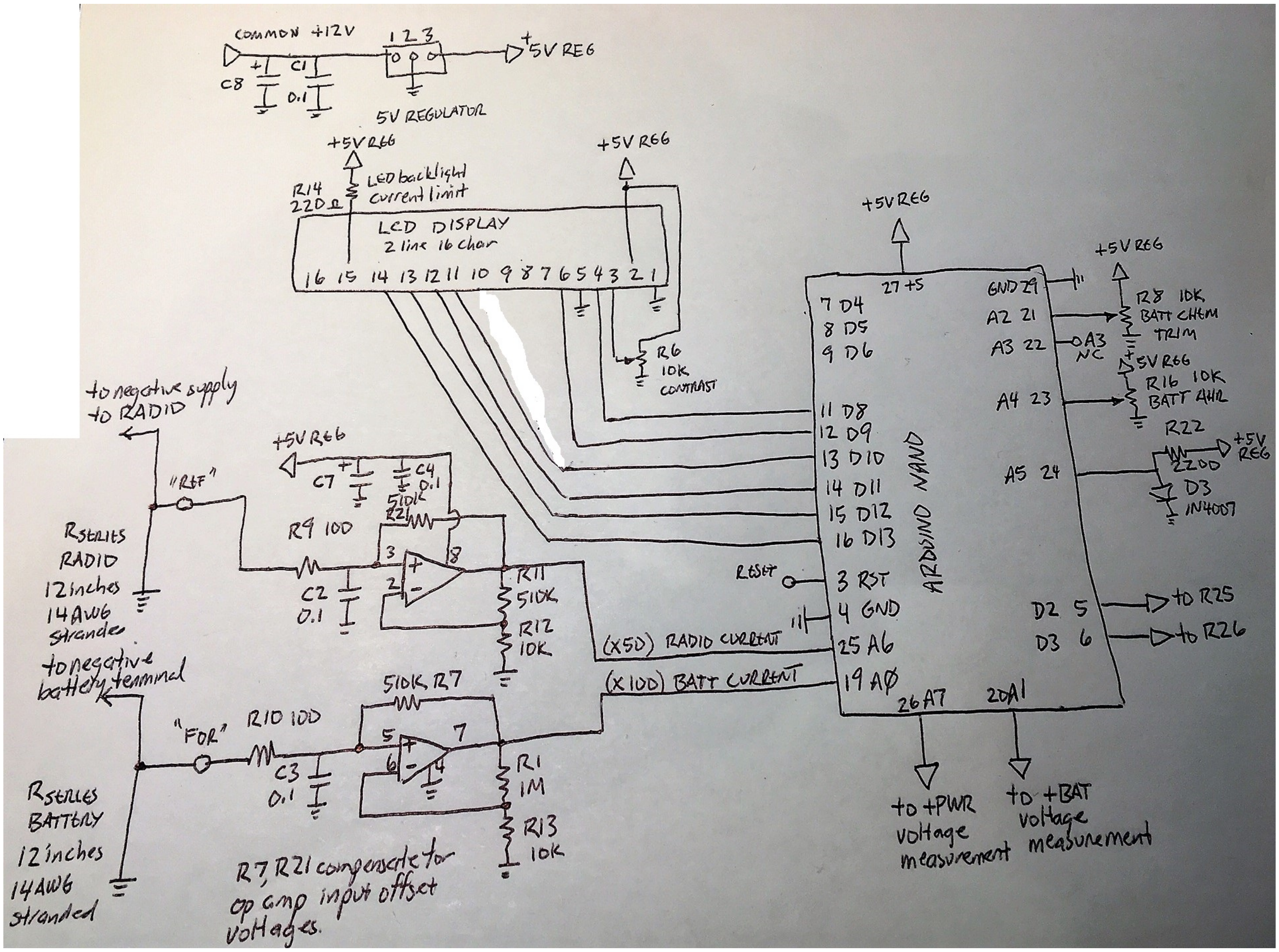


Figure 1: Schematic of the logic/measurement portions of the project.

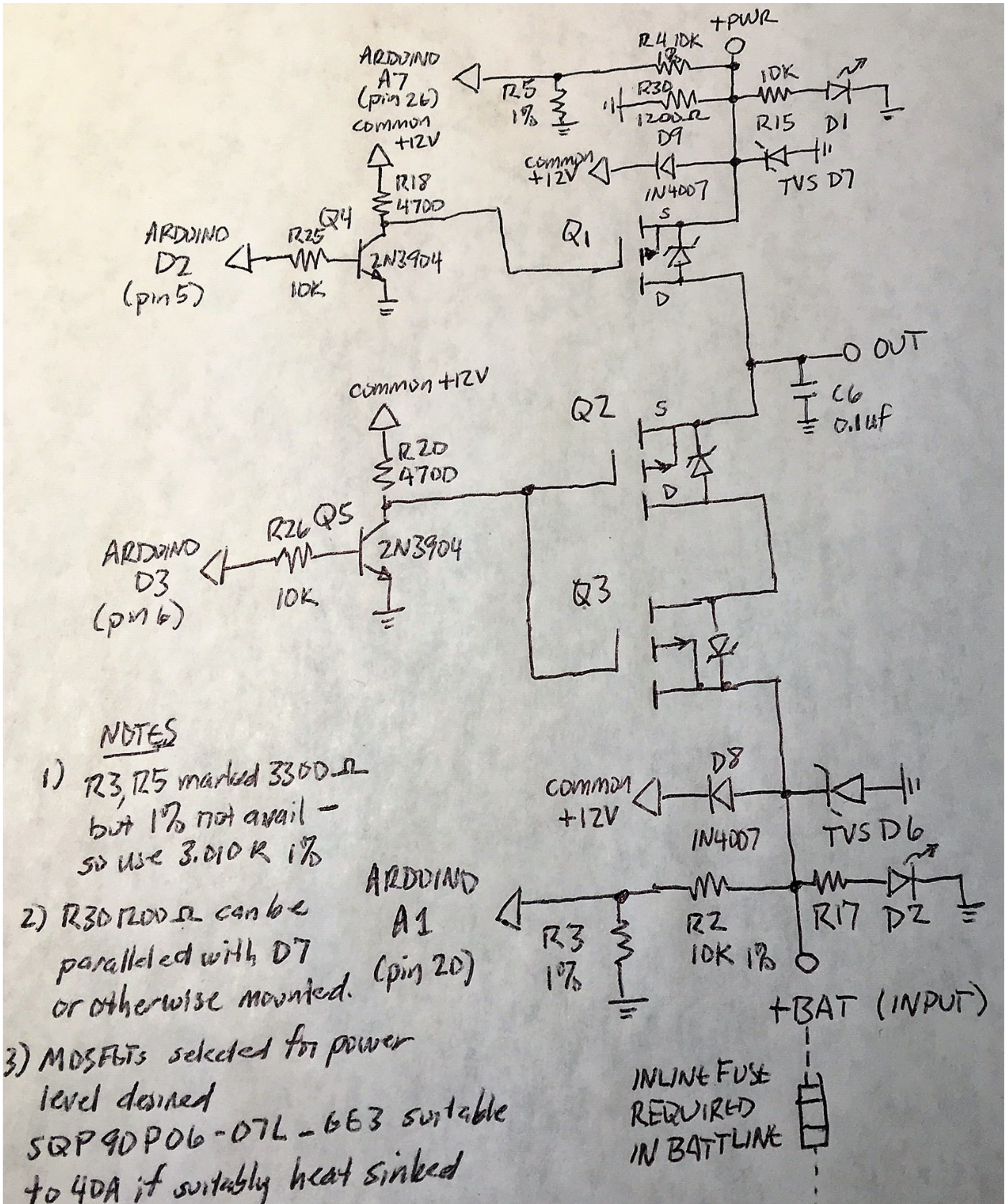


Figure 2. Schematic of the output control portion of the project.

CONSTRUCTION INFORMATION

HEAKSINK NOTES

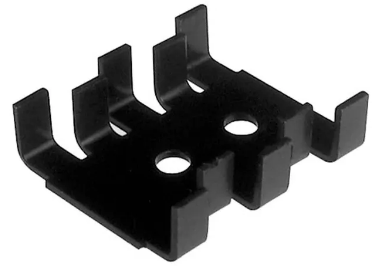
The choice of the MOSFET heatsink is key to having adequate current capacity for the individual desired application. Low power radio assets may need only a few amperes capacity; while higher powered asserts or multiple assets running simultaneously may require up to 40A

> The MOSFETs have an "on" resistance of 0.0067 ohms and will likely drop a lot less voltage than even a power Shottky diode. Nevertheless, for high currents (>5A) and CONTINUOUS operation (e.g., FM) they require a heatsink. The three power mosfets that would handle this level of current are at one end of the board, allowing the easy positioning of some heatsinking.

The power dissipated within each MOSFET is I^2R.

This table gives an approximation of the power dissipated by each MOSFET at various levels of current. During AC operation, a single MOSFET dissipates this power; during Battery backup operation, TWO MOSFETS are both dissipating this amount, so the total amount is TWICE. While the junction MUST be kept below 175 degrees, <u>it is advisable to keep the heat sink below 60 degrees C for operator safety</u>. The thermal resistance between junction and case is approximately 0.5 deg C/watt, and that of the insulated silicone spacer may be on the order of 0.2 deg C/W – a total of 0.7 deg C/W. With a heat sink temp of 60 degrees C, and a junction temp of a conservative 150 degrees C, this allows a dissipation of (150-60) (deg C) / 0.7 deg C/W = 128W

Amperes	Individual MOSFET dissipation = I*I*(0.007)	**Junction temp if NO heatsink** (25 deg C ambient) Junction – ambient = 40 deg C/W	Max thermal resistance of heatsink to keep its temperature below 60 (on an individual MOSFET) (30 deg C amb)	Typical suitable heatsink
5	0.175 W	32	171 deg C/W	No heatsink required
10	0.7 W	53	42 deg C/W	Heatsink optional
15	1.58 W	88	19 deg C/W	https://www.digikey.com/product-detail/en/assmann-wsw-components/

				V5236B-T/AE10802-ND/3511523 
20	2.8 W	(not safe)	11 deg C/W	https://www.digikey.com/product-detail/en/assmann-wsw-components/V5220W/AE10798-ND/3511401 
30	6.3 W	(not safe)	4.7 deg C/W	https://www.digikey.com/product-detail/en/aavid-thermal-division-of-boyd-corporation/6398BG/6398BG-ND/1624804

				
40	11.2 W	(not safe)	2.5 deg C/W	Larger heatsink

MAJOR FUNCTIONS OF BOARD	
Measure output voltage of AC-based power supply	Accuracy of approximately 0.1 Volt (calibrated by user)
Measure output voltage of Battery	Accuracy of approximately 0.1 Volt (calibrated by user)
Measure charging current to battery	Gross measurement of charging current, approximate measurement resolution 50 mA; based on tapping into a 12” 14-gauge WIRE on the negative side of the battery so that we don’t waste battery voltage.
Measure current usage by radio	Gross measurement of radio current usage; approximate measurement resolution 100 mA; based on tapping into a 12” 14-gauge WIRE on the negative side of the battery so that we don’t waste battery voltage.
Electronically connect/disconnect the AC-based power supply to the output terminal	
Electronically connect/disconnect the DC battery to the output terminal	We can choose when the battery is feeding the load.
Electronically control charging of the DC battery by the AC -based power supply	
Polarity protection	Because of the way the MOSFETs are wired for this system we can’t use them for the polarity protection (otherwise because of their inherent diode, we wouldn’t be able to use them to turn the supplies on and off…) but do provide a reverse-connected DIODE across the line to blow a series fuse if a power supply is reverse connected
I2C Connection	Available, but not used in this current base design. This offers immense additional functions. For example, an I2C based display could be controlled. A frequency synthesizer chip Si5351 can provide three digitally controlled synthesized frequencies from this board. I2C based temperature/humidity/pressure sensors can act as altimeters, thermostats,, and even explosive gas detectors.

Soldering & Construction

GENERAL WARNINGS

SOLDERING TECHNIQUE
Soldering Iron: Low wattage 25-watt or lower soldering iron with pointed tip and relatively thin solder is recommended.

If your soldering skills aren't quite up to soldering the close terminals of the Arduino Nano, work on simpler portions of the circuit beforehand. Be very careful when soldering the 2N3904 transistors not to short out their terminals.

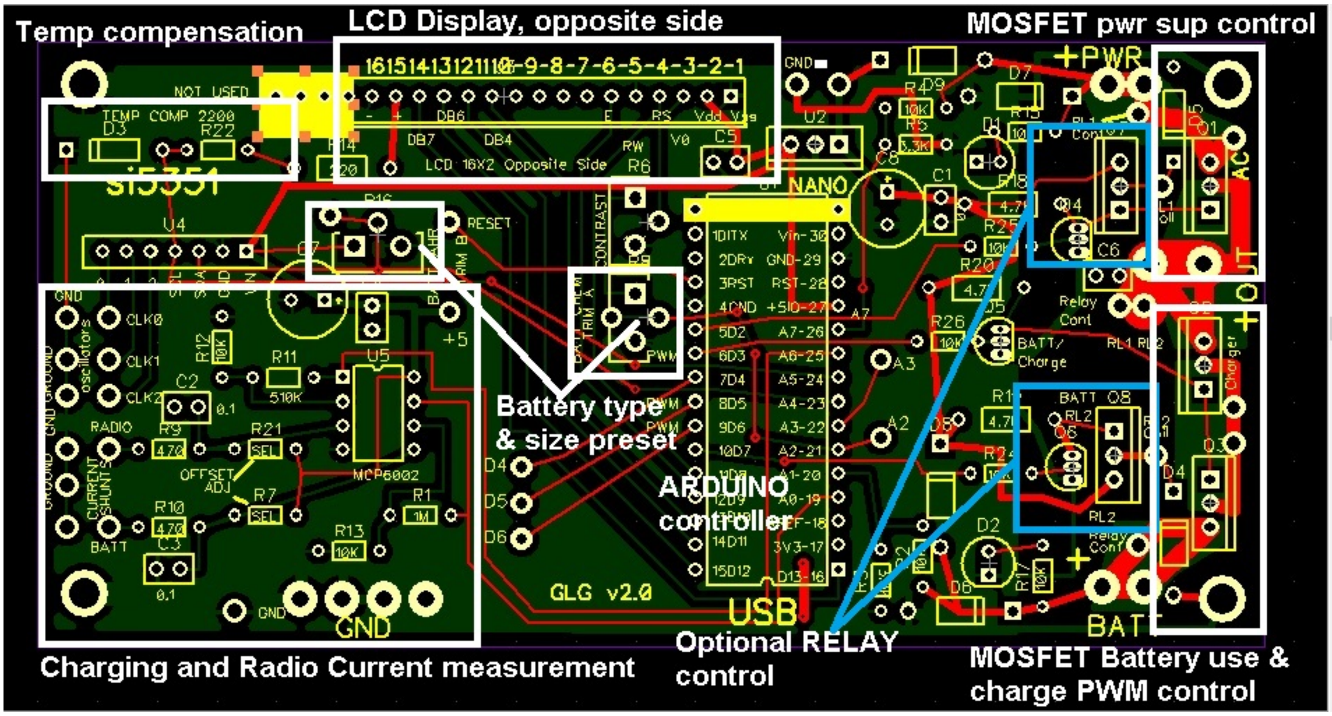
STATIC PROTECTION
The MOSFETS specified have a maximum gate-source voltage of only 20VDC and do not have any zener diode protection built in. They should be considered static sensitive and very carefully handled.

Note that if you are using heatsinks to the side of the printed circuit board, you will mechanically prefer to have the metal tabs of the MOSFETS pointing AWAY from the board. Q1 and Q2 if mounted on the top of the board, will face the wrong direction. You can mount them on the underside of the board which will work properly with their metal tabs now pointing away from the board. Carefully think through the effect of this to understand the correctness of the pin positions as a result.

Suggested extremely conservative static-sensitive MOSFET -technique:

Place a conductive surface (aluminum foil is useful) below the soldering area. Touch your hands to it to discharge yourself and then don't move in your chair or get up. Place the static-protective delivery packager of the MOSFETS right onto the aluminum foil. Also place the printed circuit board on the foil – you should only install the MOSFETS after you have already installed their driving transistors, resistors, and all the protective diodes in the circuit. Do not install the MOSFETS "first". They depend on the remainder of the circuitry to help protect their gates.
I suggest having a few fine strands from stranded hookup wire available, approximately 3" in length. Remove the MOSFETS from their protective holder directly onto the aluminum foil, with your hands in contact with it, and quickly wrap a strand of thin wire around the three terminals from the MOSFET, leaving the ends so that you can remove it later; and snug the strand up to the plastic body. This strand of wire keeps the gate shorted to the channel and prevents damage. Now solder the MOSFET into position, considering physical positing to the heatsink – you will want to AVOID putting significant torque or stress on the wiring when you physically mount the MOSFET to the heatsinks to avoid possibly delaminating the MOSFET die internally from the TO-220 tab. Once soldered, remove the wiring strand.

Soldering is conventional but requires skill, a sufficiently pointed tip and low-temperature solder. I prefer lead/tin 60/40 for this purpose but others will prefer lead free despite higher temperatures required. The secret to not damaging semiconductors is to get enough temperature to the joint QUICKLY, flow solder, and then WITHDRAW.



Expensive Complicated Semiconductors That Might be Faulty

You may wish to use a socket for the LCD display or the Arduino. Otherwise, I suggest that you TEST those components before soldering into the printed circuit board. Note the yellow-marked pin areas where the components are NOT positioned (the PCB has more holes than the devices have pins, so position them carefully, avoiding the pins that are marked out as non-used).

> You can purchase standard sockets easily and carefully cut them off at the appropriate number of socket holes. But you can't really abutt two such sockets next to each other in order to "add them together" as you will have an extra plastic wall where they abut and the spacing will be wrong right there.

Components that go on the BACK of the printed circuit board

- Remember that the LCD display goes on the BACK side (NOT the side with the silk screen printing) of the board.
- You probably wish to position the LEDs on the back side also.

Unusual Resistors or Corrections

R7/R21 are for the purpose of slightly biasing the op-amp current measurements such that the op-amp inputs are not near enough to zero volts such that the imperfect "offset voltage" of the op-amp would create a dead band. The software measures the offset and takes it into account. R7/R21 can be 510K resistors to create a small positive offset. The MPS6002 op amps have an offset voltage of up to 4 millivolts. The small positive offset created in this circuit will be enough for most but not all of them, but the remaining error in current measurement should be relatively small.

R9 and R10 should be 100 ohm resistors, not the 470 that is marked on the board.

POLARITY CONCERNS
Semiconductors (diodes, LED diodes, chips, voltage regulator and transistors) have to be inserted the proper way to operate!

The voltage regulator and the three MOSFET transistors' screen print shows the direction their heatsink tab should be *when mounted on the top side* in order to position them properly. BE CERTAIN YOU KEEP THE HEATSINK ON THE PROPER SIDE. I blew out several devices once by accidentally putting the voltage regulator in backwards. You may choose to solder some of the MOSFETS on the bottom side of the board to physically mount your heatsink --- pay attention to their pin alignment – the heatsink tab will switch to the opposite side if they are mounted on the bottom side of the board.

Pay careful attention to polarity of electrolytic capacitors. These usually have the NEGATIVE side marked – which obviously is the opposite of the side that goes to the + mark on the board.
Pay careful attention to the banded cathode of all diodes. The TVS transient suppression diodes specified for this design are zener-like and DO have a polarity (cathode) that must be observed.
Pay careful attention to the cathode end of Light Emitting Diodes (squared off side of their plastic case) Almost ANY light-emitting diode will work, so choose those that fit with your preferred mounting. In my case, I mounted the LED's on the BACK side of the printed circuit board so that they can be seen from the front panel along with the LCD display.

U4 is not utilized in this design. The Si5351 is from a previous use of the basic design of this board for a software controlled VFO.

The largest wire that can be easily soldered for power wiring to the board is #16 stranded. If you plan to use this for currents above 20 Amps, transition from there to 14gauge as soon as possible.

PLACE A FUSE IN YOUR BATTERY POSITIVE WIRING. This is for safety as most batteries can produce very large currents if there is a short.

The 5V regulator does NOT need a heatsink. It should NOT get warm. If it does, you have something wrong.

I suggest to build the base system without any of components for the relays, as those are optional and involve additional complexity. You might wish later to add the battery-sided relay if necessary.

Be VERY careful not to have solder bridges or shorts particularly at the +PWR or BATT or RADIO OUTPUT.

Add an additional ground wire (simple stranded hookup wire) from the ground point near pin 1 of the LCD, over to the ground connections beneath the OP-AMP. This is to improve the ground plane of the design.

Construct your two #14 12-inch current shunts and carefully connect them to the single point ground beneath the op amp, and use smaller wire to connect to their tap ends over to the inputs left of the op amp. I suggest that you add an external bit of wire to well-connect ALL of the ground wires that go to the ground connection below the op amp.

SUGGESTED BUILDING SEQUENCE

+12VDC Systems/ +5VDC Voltage Regulator

In this section you'll install the basic power supply systems for the circuitry and test the resulting regulated power.

- ❐ Install the 5V regulator, paying attention to the correct direction for its heat sink tab.
- ❐ Install C8 electrolytic capacitor
- ❐ Install C1 rf bypass capacitor

- ❐ Install R2 10K 1%
- ❐ Install R3 3.010K 1%
- ❐ Install R17 10K dropping resistor for D2
- ❐ Install LED D2 – note the flat side of the plastic case and match to the silk screening You may wish to install this diode on the bottom side of the board, which will face the user along with the LCD display. The flat side still needs to be properly aligned.

- ❐ Install D8 1N4007 – paying attention that the band on the diode matches the band on the silk screening
- ❐ Install TVS diode D6, again being sure that the band on the TVS diode matches that on the silk screening

- ❐ Install R11 10K 1%
- ❐ Install R5 3.010 K 1%
- ❐ Install R15 dropping resistor the LED Diode D1
- ❐ Install D1 LED, paying attention that the flat on the diode matches the flat on the silk screening. You may wish to install this diode on the bottom side of the board, which will face the user along with the LCD display. The flat side still needs to be properly aligned.

- ❐ Install D9 1N4007, paying attention that the band on the diode matches the band on the silk screening
- ❐ Solder a 1200 ohm resistor R30 in parallel with the leads of the TVS Diode D7, with the leads close to the body of the diode, but don't overheat the diode when soldering. After it has cooled, install on the board in the proper spot, against paying attention that the band on the diode matches the band on the silk screening.

- ❒ Arrange #16 (or for currents higher than 20A, #14) wiring for battery and AC-based supply. The ground wires will go to the ground wiring holes near the op amp. Be certain to have an inline fuse in the battery plus lead, near the battery if possible. I strongly suggested polarity protected connections, typically POWER POLE connectors.

Once all the above steps have been completed,

- ❒ Power the circuit briefly from the AC-based power supply and verify that the LED D1 lights up and that +5V (within 0.1 VDC) shows up at the +5 VDC marked point near the op amp.

- ❒ Power the circuit briefly from the Battery input (you can use the AC based supply for this purpose) and verify that the LED D2 lightss and that +5VDC (within 0.1 VDC) shows up at the +5VDC makred point near the op amp.

- ❒ Correct any errors in the power supply wiring before proceeding any farther in the construction.

Next install the op amp current measurement section and verify its proper operation

Next install the LCD and temperature measurement diode

Next install the Arduino Microcontroller and verify its proper operation

Finally install the output circuitry – without any of the relay components for now.

POWER-OFF TESTS AFTER ASSEMBLY

Before applying any power use a digital multi meter to verify:

- No short from +PWR input to ground.
- No short from +BAT input to ground
- No short from +OUT to ground.
- Very low resistance from the GROUND point near the op-amp, to the grounded (anode) side of D7 and D6.

CAREFULLY VERIFY

Voltage regulator properly positioned with heatsink tab on the proper side (assuming device mounted on the top side of the board)

LCD is mounted on the BOTTOM side of the board.

Check every single diode to be certain you have soldered them in the correct direction.

Check every mosfet to be certain you have properly soldered them so that their pins are in the right spots.

SOFTWARE PREPARATION

Current software as of the time of this writing is version 2.007.
This software does not yet include support for relays.
Software can be downloaded here: http://qsl.net/nf4rc/2020/BatteryBackupVer2.0.zip

In the source code, adjust the value of the resistors (either 3010 or 3300 ohms) depending on which ones you used for R3 and R5. In my prototype I used 3300 ohm resistors that were only 5%, but in the Bill of materials I specified inexpensive 1% 3010 ohms:

Adjust the **bolded resistor values** in the subroutines below to match the resistors that you actually installed. The publicly released software will be set for the recommended 3010 ohm 1% resistors after August 28 2020

```
void Read_Battery_Voltage()
{
battery_voltage = (float) BATTERYVOLTAGEFUDGE *  ( 5* ((float)
(analogRead(BATTSUPPLYVOLTAGEPIN)) )*  (10000 + 3300)/(3300))/1023 ;
#ifdef VOLTAGEOUTPUTS
Serial.print(F("\nBattery Voltage = "));
Serial.println(battery_voltage);
```

```
#endif
return;
}

void Read_AC_Supply_Voltage()
{
AC_supply_voltage = (float) ACSUPPLYVOLTAGEFUDGE  *   ( 5* ((float)
(analogRead(ACSUPPLYVOLTAGEPIN))) * (10000+3300)/3300 )/1023;
#ifdef VOLTAGEOUTPUTS
Serial.print(F("AC pin reads: "));
Serial.println((float)analogRead(ACSUPPLYVOLTAGEPIN));
Serial.print(F("\nAC-based Supply Voltage = "));
Serial.println(AC_supply_voltage);
#endif
return;
}
```

- Compile the software, which should have no errors.
- Using standard Arduino techniques, load the software onto the Arduino.   Using a suitable small screwdriver, adjust the contrast potentiometer so that you can read the LCD.
- You will probably wish to monitor the Arduino output using the Arduino IDE serial monitor during your original checkout and setup.   Set for 115kbaud, 8N1.

INITIAL POWER-UP

The Arduino can be powered from its USB port and the software loaded up without applying any 12VDC power.   However the LCD will not light up because it has to get its power from the voltage regulator.

Apply power only for a second or so, from the +PWR input, and observe the current draw which should be small (<1 Amp).   If there is smoke or spark, stop and discover the error before proceeding further.

When the power can be applied for several seconds without obvious overheating, adjust the LCD contrast so that the display appears properly.

Measure the +5VDC pad near the op amp and verify that it is +5VDC indicating that the voltage regulator is working and that current loads are not excessive.

Verify that the software that you have loaded on the Arduino Nano comes up and works in some appropriate fashion.

Figure. Example of Screen Display.

ON AC = radio is powered by AC-based supply
B13.78 = current battery voltage is 13.78VDC
Note: On 10 second intervals this automatically reports the AC based supply output voltage in the same position
A=0.56 = battery is being charged with 0.56 Amps
0.13AH = battery has so far absorbed 0.13AH since charging began
32 = current pulse width modulation is 32/255 duty cycle

CHECK VOLTAGE MEASUREMENT CALIBRATION

Using a sensitive digital voltmeter carefully measure the DC quiescent output of the two op amps, which should be slightly positive by a few millivolts (not all the way to +5V), with the current shunts correctly installed.

Once you have the software up and running, experiment with power applied to the +BATT connector. The system will measure the voltage of both +PWR and +BAT inputs and display on both the serial output and the LCD Display. It should be fairly accurate. **Using simple ratios, if it is not within 0.1 volt make the necessary corrections to the "fudgefactors"**

After August 28, 2020, the publicly released software will be set for 1.000 factors

```
#define BATTERYVOLTAGEFUDGE       0.976        // correction factor for battery voltage
measurement
#define ACSUPPLYVOLTAGEFUDGE      1.010        // correction factor for ac supply voltage
measurement
```

These should be within a few percent of 1.000.
Adjust the trimmer potentiometers to properly set your battery type and ampere-hour rating.

The setup routine gives you about10 seconds in which to see what it see you as having selected. You may need a few startup-tries to get these set to your preference. If you are using an external LIFEPO4 charger, be sure to select the option that includes the charger; if you wish for the board to charge the LIFEPO4, then select the option that indicates LIFEPO4 ALONE

These settings are used to pick the proper charging voltages and currents.

MOUNTING

Chosen heatsinks can be mounted to the MOSFETS using insulated silicone insulators and insulated bushings and 3mm screws/nuts.   The heatsinks if heavy can be further secured to the mounting box after the system is positioned.

I chose to use a double thickness of thin aluminum roof flashing as the front panel.   Holes were easily drilled into the soft metal, and edges and cutouts made with tin-snips or heavy toenail scissors.   Brass standoffs (3mm) of approximately 1.5 cm allowed the display to fit within a cutout.   I placed a cardboard shield over the LCD display to guarantee that it did not short out its terminals to the front panel.

With the printed circuit board attached to the front panel, the assembly was lowered into the ganged electrical boxes, and the wiring routed through a knockout with a cable securement to avoid any damage to the wiring insulation by the sharp edges.   The 12” current shunts were within the mounting box.

SOFTWARE commentary

SETUP()
Turn OFF all the outputs so no current flows until the software is ready to go.
Initialize the Serial connection
Initialize the LCD display
Initialize the global variables
sets up a “watchdog timer” (an available function from a library) that if not called within every two seconds….will restart the code.

LOOP()
(Note that in the Arduino environment, the LOOP function is repetitively executed; you don’t need to write it into a loop as it will loop on its own.)

Software actions are carried out on time intervals.

- A call to `wdt_reset()` is made so that this timer gets reset. If the code hangs, this call will fail to be made, causing the watchdog timer to reset the processor.
- If the time has advanced to the next_millisecond_time, the AC-based supply voltage, and the battery voltage are both measured; if the AC-based supply voltage has declined unacceptably, the MOSFETS are switched to connect the battery to the output terminal, and a message is sent to the LCD and the serial monitor. `using_battery` is set to 1 if powering from the battery; 0 if using the AC powered supply.

- If the time has advanced to the (slower) time interval at which the charging system should be checked, the battery voltage (which may be in charging mode) is measured, and displayed on the top line of the display.
- Then, if we are using the AC-based power supply, it is appropriate to consider charging and thus the following is carried out:

  Based on the measured battery voltage, the desired_battery_charge_ma is chosen.

  The current charging current is then measured by making a number of measurements of the voltage from the current shunt in the negative lead of the battery.

  Changes are then made to the pulse-width-command to be sent to the PWM output pin driving the charging MOSFET; this number can vary between 0 (0% duty cycle) and 255 (100% duty cycle).

  A series of rules are used to slowly advance the actual charging toward the desired number; note that the effects of these choices will be evaluated only on the SECONDs intervals

```
if(instant_current_reading>desired_battery_charge_ma + 100)
battery_charge_pwm = battery_charge_pwm/2; // cut it way down
```

  If we are more than 100 mA above the desired charging current, the duty cycle is cut in half.

```
if(instant_current_reading>desired_battery_charge_ma)battery_charge_pwm
=battery_charge_pwm-3;   // decrease by 1% of our range
```

  If we are above the desired charge level, but by less than 100 mA, the charging duty cycle is reduced by 1%

```
if(instant_current_reading<desired_battery_charge_ma)battery_charge_pwm
=battery_charge_pwm+3;  // increase by 1% of our range
```

  If the charging current is below the desired charging current, the duty cycle is increased by 1%. It may take several cycles of this hunting algorithm, but within a few minutes the charging should be very close to the desired charging.

A couple of sanity checks finish out the control

```
    if(battery_charge_pwm <0) battery_charge_pwm = 0;
    if(battery_charge_pwm >255) battery_charge_pwm = 255;  // can't go
beyond these limits!
```

This desired PWM modulation is then sent to the CHARGER pin control using

```
analogWrite(CHARGER  ,battery_charge_pwm);
```

The next moment in time at which the battery needs to be measured and charging possibly adjusted is then set.

The loop is now done and repeats.   Recognize that the Arduino moves through this loop at FULL SPEED, hundreds of thousands of times per second, but only stops to carry out our orders at the appointed discrete time intervals, which are adjustable.   Why? Because we wish to minimize radio frequency interference created by this switching system, and by using slower decision making intervals, we can reduce the repetitive base frequency of the interference, thus reducing the strength of harmonics that make it to our radio.

FACTORS TO INCREASE BATTERY BACKUP LIFESPAN

Battery Type	Desirable factors
Lead-Acid (flooded, sealed, or AGM)	Avoid discharging the battery below 50%; strictly avoid leaving the battery in a discharged state for days or weeks (forms large sheets of sulfate crystals on plate); strictly avoid overcharging such that the liquid declines with air access to the tops of the plates. Store in a fully charged state and maintain a float voltage. The software maintains a small trickle charge on all lead-acid type batteries The voltage chosen is lower for batteries that are not open to air (that is, flooded cells).
LithiumFePhosphate	Avoid storing at full charge due to damage to Lithium plate; instead store at 50-80% As of 2.007 the setting is designed to stop charging once the battery reaches 13.90 volts, and to begin to recharge if it declines to 13.70 volts – a bit of hysteresis.

TROUBLESHOOTING

Problem	Possible Causes
Display cannot be read	Contrast setting is not appropriate; re-adjust
Very low battery charging current	Battery may already be charged Lead Acid battery may be sulfated (variable success by leaving it to charge for several days—software is set to try this; equivalent series resistance calculations printed out on the serial port will demonstrate series resistances >> 100 milliohms.)
Audible hum heard	Normal to hear the 500 Hz pulse width modulation carrier sound.

Battery or AC-supply voltage readings are erroneous	Incorrect values for chosen resistors in subroutines; or lack of calibration when originally constructed.
Both Battery and AC leds light up	Normal. See above discussion of operation of the LEDs and the impact of the inherent body diode of the MOSFETs