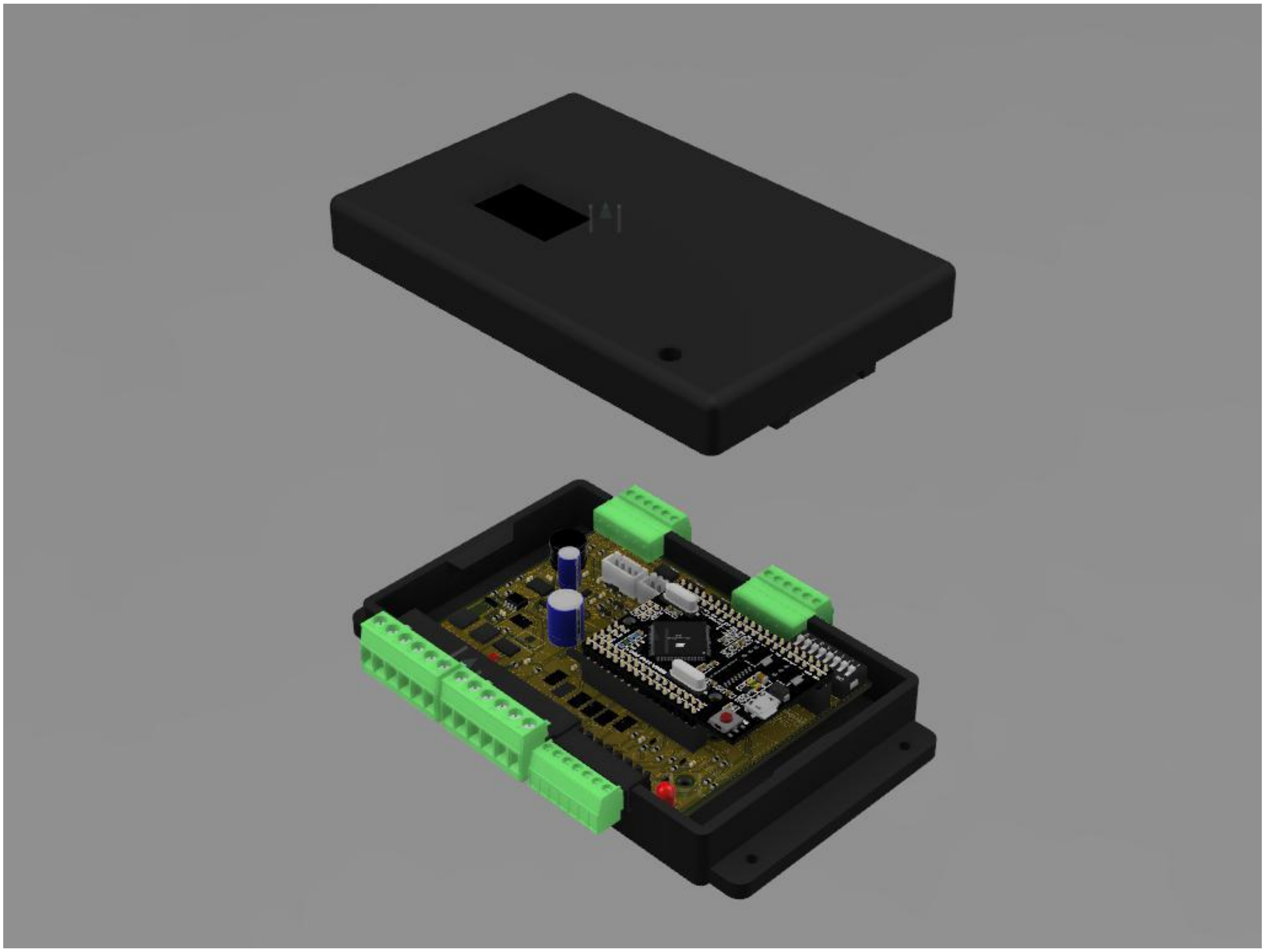
ALTERNATOR REGULATOR
VSR Mini Mega 2650

With optional remote TFT LCD display

AN OPEN-SOURCE INTELLIGENT ALTERNATOR REGULATOR - *Redesigned*



Reference Manual

https://github.com/peteDDD/VSR-Mini-Mega-Alternator-Regulator

Rev 11/1/2021 – Work in Process.

Adopted from the outstanding work of William A. Thomason on several generations of VSR Alternator Regulators

ACKNOWLEDGMENTS

The source code and hardware described here are derived directly from the tireless work of William “Al” Thomason on several generations of Arduino-based alternator regulators.

Al’s work took a core of software forward over several hardware sets. The software carried forward support of all of that hardware though extensive #ifdef and #define statements as well as a portability.h file and other code considerations. This derivative attempts refactor that code to a new hardware base, with no support of other hardware, thus attempting to simplify the new code base while adding additional features and extensibility for future expansions.

At the real core of this alternator controller’s functionality is Al’s PID control software. That code is left, somewhat as a shrine of engineering exceptionalism, untouched.

There were many artifacts of the long history of the original code remaining in the original code from the many generations of functionality and different boards developed by Al. It was my objective to remove thet unused code carefully so as to not damage any data structures with unanticipated effects.

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THE VSR MINI MEGA ALTERNATOR REGULATOR: OVERVIEW

What the heck does "VSR" mean? Not entirely sure but one possibility is "Voltage Sensitive Regulator" is a possibility. Sure, this regulator senses voltage from the alternator and the battery but that is just a small part of the full regulation and functionality story of which you will read more about below. "Voltage Sensing Relay" is another possibility. A VSR in that context can be used to connect a starter battery bank and house battery bank together once one exceeds a set voltage such that one bank cannot draw down the other when cross charging. Yes, this regulator can also provide that function with the addition of an external relay or contactor. But that too is not all…

"House Batteries" are common on RVs, boats, remote cabin / houses. These battery banks often represent investments in the hundreds if not thousands of dollars, so it is well worth the effort to take care of them.

The use of an external alternator regulator is a well-known way to improve over standard 'auto' internal regulators. With accurate measurement of battery voltage, and then control of the alternators field to adjust its output, these often provide several important features such as soft starting to save wear on belts, multi-stage charging to assure faster and more complete recharging, and temperature sampling of the battery to precisely adjust target voltages. But with almost universal exception, almost all currently available external chargers are lacking one key ability: the ability to monitor current as well as voltage.

Sampling the specific gravity of the battery acid is often the preferred way to determine the true SOC of a battery. Another approach recommended by many battery manufacturers is to monitor the amount of current a battery is accepting[1] while recharging. By continuing to hold a battery in the acceptance phase until these manufacturer's recommended thresholds are meet, we can assure a battery is indeed fully recharged. Without the ability to measure current, most common regulators revert to another approach for determining if a battery is fully recharged: they guess.

The VSR Mini Mega Alternator Regulator ("VSMMAR"), as did the many generations of VSR Alternator Regulators ("VSRAR"), includes the ability to monitor current in addition to voltage and temperatures. It also provides the ability to limit alternator output to protect the alternator, battery and/or engine (depending on how it is configured). The Mini Mega version has support for 12V and 24V systems, whereas the earlier VSR versions also supported 48V systems. The Shield version drops support of the relatively rare N-type alternators in favor of simplicity and only supports P-type alternators.

The VSMMAR may be used in many applications but understanding the design focus provides some insight into the feature choices (both additions and subtractions) as compared to the VSRAR. The design focus of the VSMMAR has been, without in any way reducing its optimization for larger engines, to support a 6-HP diesel DC genset sporting a 200-amp large-frame alternator and a SCUBA compressor engaged by an electric clutch. This focus intends to maintain maximum output of the alternator by directly measuring amps generated at a level that does not bog down the engine. A feature-in port option allows the switch which engages the SCUBA compressor clutch to signal the VSMMAR to reduce the alternator field signal and thus the alternator's engine load to a pre-designated level, leaving the rest of the engine horsepower available for the SCUBA compressor.

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[1] Example, see: "Exide Battery Charging & Storage Guidelines 5_9_13" -- www.exide.com/Media/files/Downloads/TransAmer/Battery Care and Maintenance/Battery Charging & Storage Guidelines 05_9_13.pdf

The VSMMAR, as compared to the VSRAR, adds a **second INA226** to measure voltage and current. As such, the VSMMAR directly supports and is intended to be used with two amp shunts, one at the alternator and one at the battery bank for maximum benefit. The VSMMAR software can be configured for only one shunt as well.

The VSMMAR has **three feature-in and three feature-out ports**, whereas the VSRAR had only one of each. These ports can be activated to each perform a variety of features and feature-in or feature-out functionality can be assigned to any of the feature-in or feature-out (respectively) ports. The feature-in and feature-out ports can each be assigned to a variety of optional functions. These options and the assignment of the ports is easily accomplished in the Config.h header file where #defines are uncommented to activate the functionality or edited to select the port number. Feature-out functionality in the code includes: echoing of the red and green on-board LEDs to feature-out ports, mimicking an old-fashioned "alternator lamp" on a feature-out port, providing an engine stop pulse, providing a LiFePO4 BMS alarm, and/or providing a battery combiner signal to tie starter and house battery banks together while the alternator is actively charging. Feature-in function options include the previously mentioned "SCUBA" compressor input, an input to initiate battery equalization, an input, which, in combination with dipswitch setting, resets the system to the "factory" settings, and a disable (aka "force-to-float") input which keeps the charging state in float charging mode.

The VSMMAR also adds headers for two separate **serial ports**, which do not interfere with the serial port used by the USB for programming of the Arduino Mini Mega processor board. Of the two serial ports, either one can be used to optionally support a remote TFT LCD display which displays all of the same data which the OLED can plus any fault codes encountered and a historical graph of voltage and (alternator) current over the current charge cycle. This display uses an Arduino Uno with a TFT LCD shield. (A bezel for panel mounting this display has also been designed for 3-D printing. The materials for this display may be found in the github for this project. The second serial port, could be used to monitor a LiFePO4 battery management system to detect impending shutdown events and to turn of the PWM output of the regulator before the battery is disconnected by the BMS, thus protecting the alternator from being fried by a voltage dump. Presently there is a stub in the firmware to support this function and it will be coded in the near future. This port could be used for any other function the user might care to code. For example it could be used to provide NMEA-0183 output with addition programing.

There are also two **I2C**/5V/GND 4-pin headers on the VSMMAR. One can be used for adding a small SSD1306-based OLED to display dynamic data. As coded, when this option is enabled the following can be/is displayed on the OLE: boot-time information including software rev, battery type, battery bank size, small alternator mode, and tach output mode. After boot, the following is displayed on the OLED: battery and alternator voltage, amps, and temperature, field PWM, charging state (in words, not as a number), countdown of time remaining in warm-up and ramp-up phases, time in current charging state, error messages, and a flag for indicating that the SCUBA compressor is engaged, if that feature is enabled.

During installation, an amp shunt is placed on the house battery to monitor current into and out of the battery. You may already have such a shunt already installed, for example if you use a battery monitor along the lines of the Link-10. In this case, simply reuse the same amp shunt, though do make sure the regulator is correctly configured to match the shunt properties (typically stamped on the shunt but also can be derived by measuring the resistance of the disconnected shunt and doing the math) (the default shunt value expected for the VSMMAR is 300A / 75mV, i.e. 200A / 50mV).

Another way to utilize the alternator regulator is to place the amp shunt on the alternator, as opposed to, or in conjunction with, locating one at the battery. With this configuration, the amps monitored can more closely focus on the alternator and one is able to configure the VSMMAR to limit the amount of amps produced, and hence the load the alternator places on the engine. This can be *VERY IMPORTANT* when switching from traditional batteries to LiFePO4 batteries and the ability of LiFePO4 batteries to accept high charging currents could easily exceed the alternator's design capabilities. This can also be useful in cases of building a DC generator where the alternator is much larger than the engine is able to support. By capping the amount of power the alternator is allowed to produce, you can match its demands to the capability of the engine. A shunt on each the battery and the alternator provides the most rapid charging of the batteries as it considers both the output of the alternator as well as the current actually flowing to the batteries. The VSMMAR was designed to have the user implement two shunts without having to add any other hardware.

Although it would be a waste of hardware and software, the VSMMAR may also be used in conventional voltage-only mode[2] by simply not connecting the Amp Shunt (place a small wire across the Amp Shunt terminals to remove the chance of any electrical noise fooling the regulator). The Regulator will fall back to time-only charge profiles, though with very accurate measurement of voltages. In addition, acceptance phase will utilize an 'adaptive' time-based formula; it will remain in acceptance phase for 5x the duration the regulator was in bulk mode, or the configured maximum amount of time contained in the CPE (charging profile) – whichever is less. In this way, the battery gains more protection from over charging when the regulator is unable to measure the amps.

WHAT IS A "SYSTEMS-BASED APPROACH"?

Even the most basic DC battery and an associated charger is a `system', it is only a question of how well the system works. Voltage-only regulators have only one channel of communications: voltage. Though very important, it leaves no ability to communicate any other information, hence the addition of additional sensors: temperature probes, current shunts, etc. But even with added sensors there is still only one channel of communications: voltage. And having only one channel of communication can be restrictive and starts to introduce compromises.

The 3rd generation of the VSR Alternator Regulator added a CAN (Control Area Network) port to provide for a robust proven communications path between devices connected to and surrounding the battery. It attempts to provide the most extensive systems control however its promise has yet to be realized since low-cost CAN battery monitors and coordinating solar and wind charging controllers are not yet available commercially or from the open-source ecosystem. For more on this, refer to the VSRAR manuals.

Lacking economical CAN-based accessories, and adding a second INA226 to the VSMMAR, CAN was not included on the VSMMAR. If CAN functionality is critical to your implementation, consider the WS500 commercial product or consider coding your own CAN drivers into the VSMMAR, perhaps leveraging the VSRAR open-source code which included such functionality.

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[2] Voltage-only mode is detected when the alternator regulator is unable to measure current in excess of +5A at any point in time. Under this case the code will ASSUME the amp shunt is either not connected, or damaged and will fall back to time-only exit criteria. (i.e., all the charge profile (CPE) values will be assumed set = 0 (disabled). See source code "#define USE_AMPS_THRESHOLD" to control this capability.

CONNECTIONS

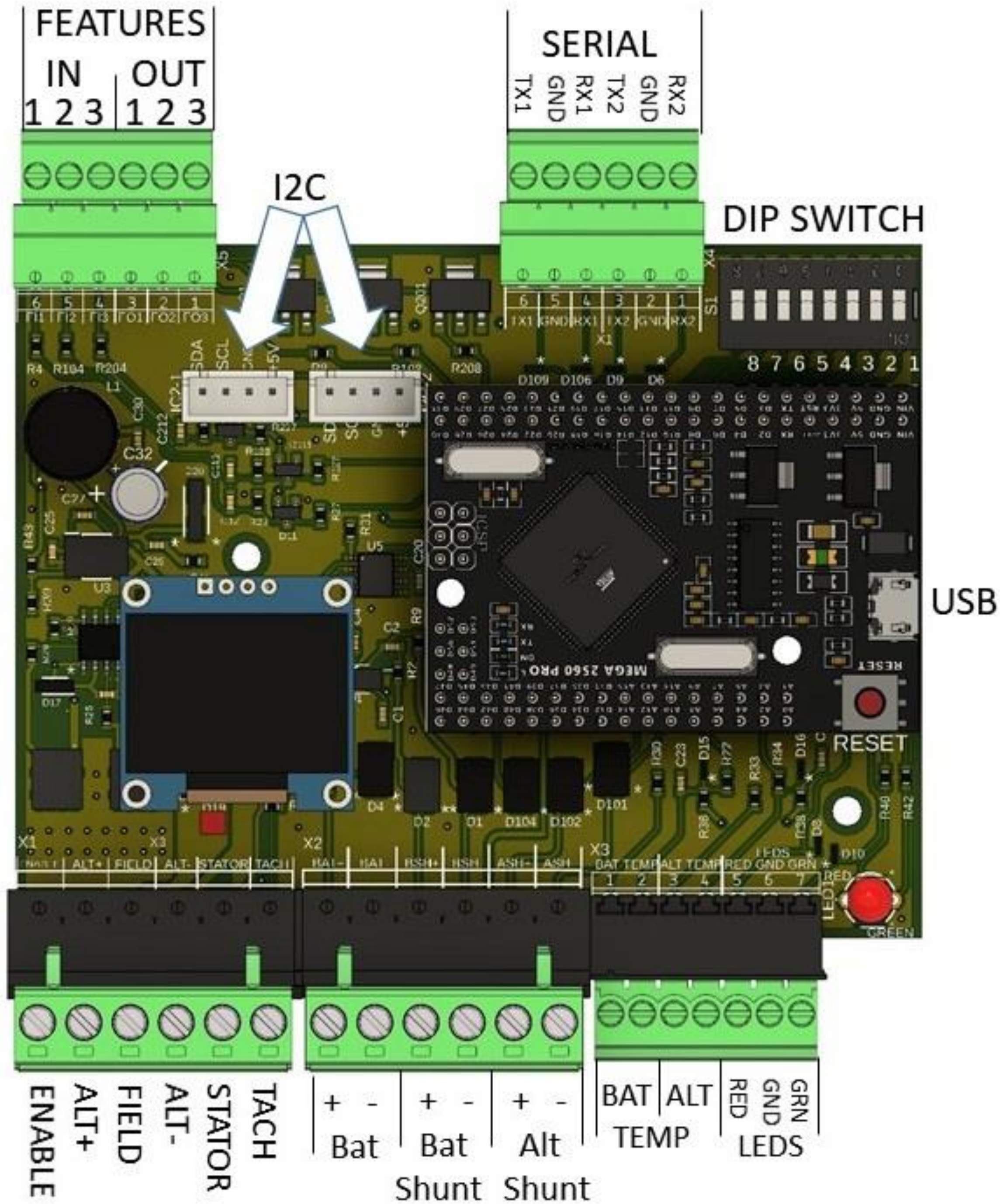


Figure 1: Board Connections

ENABLE	Connect to VBat+ to 'turn on' the regulator. This could be the key switch of an engine or switched through an oil pressure switch on an engine. Use min 14AWG wire and a 2A fuse.
ALT+	Connect to + (Bat) terminal of Alternator. Use wire sized to match your expected maximum Field current draw and protected by an appropriate fuse. (typically 4-12A, depending on alternator size) (Min 14AWG – use 12AWG or 10AWG for large frame alternators)
FIELD	Connect to the field of the alternator. VSMMAR supports only the common P-type alternator field input. Use wire of sufficient gauge to carry the expected current, up to 32A (connector limit) (Min 14AWG).
ALT-	Connect to the – (gnd) terminal of Alternator using appropriate wire. (Min 14g)
STATOR	(optional) Connect to an Alternator Stator pole via 2A fuse and 16AWG wire. Used to increase battery voltage measurement accuracy, as well as enable several battery and alternator protection features in the regulator.
TACH	(optional) Output to drive a tachometer when TachMode is enabled. Requires Stator input
BAT+	Connect ***directly*** to the battery via 14AWG wire protected with a 2A fuse located at the battery. (Do not connect after any busses, shunts, etc.)
BAT-	Connect ***directly*** to the battery via 14AWG wire protected with a 2A fuse located at the battery. (Do not connect after any busses, shunts, etc.)
BAT SHUNT +/- ALT SHUNT +/-	(technically optional but highly recommended) Connect to current shunts using twisted pair 16AWG or larger wire. The current shunt maybe installed in either a ground wire (low shunt), or in the + voltage wire (high shunt). Do not exceed 80mV difference between + and - inputs, nor exceed connect to a shunt more than 32v above ground. If the current shunts are not being used, it is suggested to place a wire between these two terminals to avoid any electrical noise confusing the regulator. "+" and "-" refer to the higher and lower voltage side of each shunt. For example, if the shunt is on the positive terminal of the alternator, the "+" side of the shunt is the one closest to the alternator.
BAT and ALT TEMP	Connect 10Kohm 3950 beta NTC temperature sensors from battery and alternator. This connections are not polarized. See more on temperature sensors later in this manual.
LEDS Red Gnd Grn	The status and error on-board bi-color LED output is echoed to these pins using two LEDs; red and green. Connect LEDs directly to these terminals. The Gnd terminal is shared between the two LEDs. 22awg or larger wire. These LED could for example be added to the engine gauge panel for remote monitoring of the VSMMAR.
FEATURE-IN 1, 2, 3	See details later in this manual
FEATURE-OUT 1, 2, 3	See details later in this manual
SERIAL TX1, GND, RX1 TX2, GND, RX2	See details later in this manual

Figure 2: Connection Table

CONNECTIONS AND FEATURES ENABLED

The VSMMAR minimal installation needs only 6 wires to be connected (See “Example 1: Minimal (Voltage Only) Installation” on page 21) and will operate as a highly capable multi-step voltage regulator, where charging decisions are based on time. Adding sensing wires unlocks additional features. The following table highlights a few of these capabilities and connections needed.

	Minimal Required Connections BAT+, BAT-, ALT+, ALT, PWM, ENABLE	**Additional Connections** (can be used individually or in combination)		
Highly accurate voltage-based charge regulation	✓			
Battery temperature compensation		✓		
Alternator overheating protection			✓	
Battery measurement-based charging				✓

Figure 3: Features enabled by connections
(Capabilities of the VSMMAR. not exhaustive, only illustrates some of the main features)

WHY DO WE NEED A STATOR WIRE?

The MMAR includes a wire to be connected to one of the stator terminals on your alternator. Though optional, attaching this wire will improve the accuracy of voltage measurements, and enable several protection features.

- Improved voltage measurement by synchronizing the sampling of battery voltage with the stator. This is a ‘best Practice’ for measuring battery voltage as it allows us to see the true ‘high point’ of the alternators output each time we measure battery voltage. It also reduces external noise and other issues versus sampling alternator voltage at random times. Battery voltage is measured to a resolution of 1.25mV (a bit more than 0.001 volt. By using the stator wire we are able to maximize the accuracy of the voltage measurements.
- Connecting the stator wire is also needed to facilitate TachMode.

- Stator Sample also enables a few protection features. For example, if at some time we see *some* stator pulses, and then they disappear, we assume the engine has stopped. In this condition we reduce the field PWM drive greatly. Without the stator wire we have no idea this has happened (remember, other sources might be charging the same battery, so looking for a drop in VBat is no use). This prevents the regulator from continuing to apply field current and heating up the alternator.

Special note: If your existing installation has additional lamps, resistors, diodes etc. connected to the Stator field, or perhaps a Diode Trio (part of the dash lamp) or 'exciter' connection on the alternator, it is advisable to remove these. You can reconnect the dash lamp to one of the feature-out connectors. Leaving existing resistors, diodes, or other connections from the old installation have been known to cause issues with RPM measurements and other features of the VSRAR and presumably will do the same to the VAMMAR.

WHY DO WE NEED A CURRENT SHUNT?

The VSR Alternator Regulator is fully capable of operating using only battery voltage sensing, and in fact this is a fail-over mode in the case of a missing or broken current sensing probe. In voltage-only mode charging decisions are based on times values, either pre-determined, or at times calculated based on prior phase changes. However, with very few exceptions, battery manufactures preferred charging guidelines call for the monitoring of charge acceptance current as a critical factor in making charger mode decisions, specifically when to end the acceptance phase. As a battery is held in acceptance phase the amount of current being accepted by the battery has a direct correlation to a batteries SOC (state of charge). Monitoring acceptance current allows the regulator to make better decisions and safer charge profiles: using a lower acceptance voltage set point while still allowing for the complete recharging of the battery. LiFeP04 and related battery technologies greatly benefit by this 'lower stress' charging approach of a proper acceptance phase vs. being held long enough to assure a fully charged battery, and no more, thus reducing battery stress as a result of overcharging.

Contrast this to time-based decision criteria which uses fixed or perhaps a calculated time basis for determining the batteries needs; perhaps adding a bit of extra time just to make sure. While time-based decisions can be estimated in the lab, they are often confounded by real world imitations. Battery age, temperature, model, and other factors all impact the amount of time needed to properly complete an acceptance phase. Adding extra time may potentially result in a more complete battery SOC recharge, however care must be taken with this approach as some battery are less forgiving to overcharging then others. FLA (Flooded Lead-Acid) batteries might just use more water, while some GEL/AGM and any lithium-based battery technologies could be damaged. The alternative of a short acceptance phase has it own issues: chronic under charging has a very detrimental impact on the lifespan of many battery technologies, not to mentioned the underutilization of the full (and paid for) capacity in the battery bank. Another mitigating approach is to monitor the field drive and use that to help augment charging decisions. However field drive decisions have no idea where the alternator output is actually being consumed and can be tricked to either over or under charge. One example is by simply running a concurrent load while charging. If a washer/dryer is being powered via an inverter, field drive decisions will never see a reduced field drive and can easily overcharge the battery.

MAXIMUM LIMITATIONS

The following table documents maximum allowed values during the operation. Exceeding any of these values may cause unpredictable operation and/or damage. All voltages are referenced to VBat- unless otherwise noted.

Item	Min	Max	Symbol
VBat+		32	Volts
Enable	8.5	32	Volts
Alt or Bat Shunt -	-0.5	32	Volts
Alt or Bat Shunt -	-0.5	32	Volts
Alt or Bat Shunt – to +	-80	80	mVolts
Feature-In	-0.5	32	Volts
Feature-out		32	Volts
		0.5	Amps
Alt+		32	Volts
Field (B or C) current		32	Amps
Ambient Temperature	-40	100	Celsius

Figure 4: Maximum Values for Connections

Note: Special care should be noted of the current shunt lower voltage limitations. If a current shunt is located in the ground line of the battery or alternator and there is too small of a ground wire between the shunt and the battery ground terminal. A ground-loop may be created and the voltage limits for the current shunt input could be exceeded. Increasing the size of the ground cable, and/or relocating the amp shunt(s) to the positive side of the alternator or battery are potential solutions. Of course, having too small a ground cable on either the battery or the alternator has other implications. When in doubt, oversize the battery and alternator cables.

Accessories – probes, cases, shunts, etc.

To install your regulator you may need some or all of the following. There are many ways to purchase these, and the examples given are only one option.

TEMPERATURE PROBES

The VSMMAR uses NTC temperature probes to optionally monitor battery and/or alternator temperature. The NTC temperature probe is a very common one which is easy to source. There are several sources for NTC probes, do make sure to get ones with these specifications:

- Resistance: 10K Ohms
- Beta: 3950

(Note: It is possible to alter these values (to some extent) by making changes to the Source Code)

Searching Ebay or Amazon for “NTC 10K waterproof 3950” will quickly bring up a wide range of suppliers, with cable lengths from 0.5m to 5m. Aliexpress: https://www.aliexpress.com/item/32800546643.html Be sure to purchase a temperature probe with a metal sensor end (not plastic).   The metal sensor end can then be pressed into an 8awg (6mm diameter or 10mm^2) 1/4”, 5/16”, or 3/8” non-insulated ring terminal so it can be easily attached to the battery or alternator. Aliexpress: https://aliexpress.com/item/33057214186.html Heat the terminal to expand it then the probe will slide in easily and fit tightly when it cools.

Littelfuse 01530002H   Powerwerz CrimpFuse

ALTERNATOR TEMPERATURE PROBE LOCATION

In most cases the diode pack is the critical limitation in alternators and the best point of reference for measurement, however it is best to consult your alternator manufacturer for recommended placement - as well as for allowable operational limits.   Figure 5 below shows the recommended location for the alternator temperature probe from Leece Neville / Prestotolite -- on the diode pack.

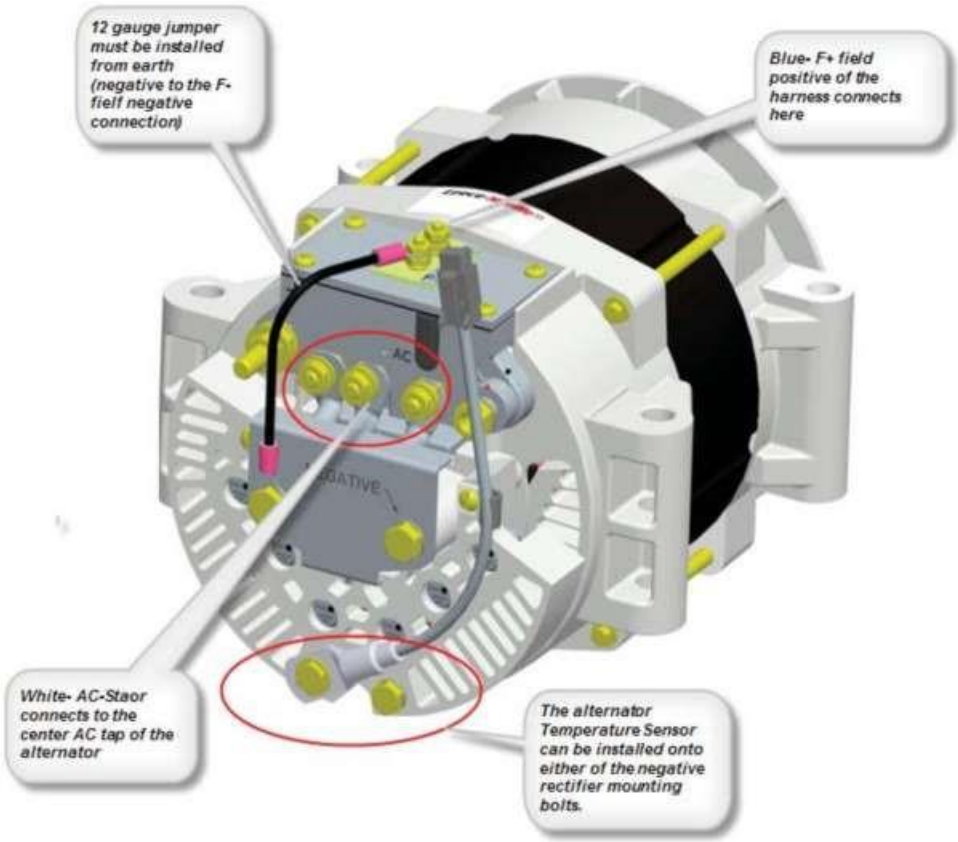


Figure 5 - Example Alt Temperature probe location

FUSE HOLDERS

It is recommended to install fuses in the locations indicated in the Example Installations. Chose a fuse of appropriate rating (See `Connections' above) I recommend the Littelfuse 01530002H for wires up to 16awg and 20 amp which uses mini fuses and is crimped to your wire, making for a very neat installation. For 10 and 12 AWG wire, consider the Powerwerz crimpable ATO fuse holder (and some heat shrink tubing). Remember, Fuses are primarily intended to protect wires, not the device – with one exception: the field fuse will also help protect the Alternators Regulators field drive circuit – choose a fuse about 50% higher than you expected maximum field draw. For smaller alternators, a 10A fuse should be sufficient, while larger units may need a 15A fuse. If you are driving multiple alternators in parallel from one VSR Alternator Regulator, adjust the fuse size accordingly, but do not exceed 32A as that is the terminal strips maximum rating.

CURRENT SHUNTS

Many installations already have a battery current shunt installed, often as part of an existing battery meter. If so, simply attach the Current Shunt leads to that existing shunt. The battery shunt may be located in the + or the – wire with no adjustments needed for your regulator. The VSMMAR shunt wires can be placed in parallel with the existing shunt wires. The shunt negative wire should be on the side of the shunt closest to ground and the positive wire, on the side of the shunt furthest from ground or closest to the positive terminal of the battery.

Similarly for the alternator shunt, the negative terminal should be closest to ground and the positive terminal furthest from ground. See Figure 6.

For the wires running to the shunt, twist a pair of 16awg wires using an electric drill. (Pro tip: don't cut the wire to length until after it is twisted and routed. The pair of wires will be substantially shorter after twisting.) The twisted pair will reduce the likelihood of induced currents causing errant readings.

If the current shunt wires are connected in reverse, the current indicated on the OLED will reflect negative numbers. You can either reverse the wires for the respective current shunt or change the systemConfig.REVERSED.BAT.SHUNT or system.Config.REVERSED>ALT>SHUNT flag(s) in the System.cpp.

By default the regulator is configured for a 300A/75mV shunt (common on many battery monitors). If you are using different shunts, you can either use the $SCA: command to inform the regulator of the shunt values or edit the values in the System.cpp file. For example to change the battery shunt calibration to a 500A/50mV shunt,

```
(int)((300 / 0.075) * 1.00), // .BAT_AMP_SHUNT_RATIO
```

Would be changed to:

```
(int)((500 / 0.050) * 1.00), // .BAT_AMP_SHUNT_RATIO
```

CAUTION: Do not use a shunt whose voltage exceeds 80mV, or inaccurate results will occur as well as a potential for damage.

Shunts are known for being less than accurate, and if you find the calibration of the VSR Alternator Regulator is off, you may use the $SCA: command to adjust for any error or by editing the System.cpp file as noted above.

ENCLOSURE

A 3-D printable custom case can be found in the github files:

https://github.com/peteDDD/VSR-Mini-Mega-Alternator-Regulator

There are two versions of the lid, one with a hole for the USB connector and one without. There is also a file for a removable plug for the USB connector hole.

WATERPROOFING

It is recommended that the PCBs be sprayed with a silicone conformal coating.

REGULATOR INSTALLATION OPTIONS

The VSMMAR is a very versatile device with several installation options depending on your goals and objectives. In its simplest form, the Enable, Alt+, Alt- and Field wires are all that need be connect, and in this mode the regulator will behave as many voltage-only regulators, albeit with a high level of precision. Adding additional sensing capabilities will unlock additional capabilities of the VSMMAR.

The following will give an overview of how to connect and configure the regulator in different situations. The recommended dual amp shunt installation is covered first. Next, some “simpler” but less efficient and less ‘feature-rich’ implementations are shown. Finally, some more complex or specific situations are covered.

REGULATOR PLACEMENT

Place the near the alternator – keeping the Alt+, Alt- and Field wires as short as reasonably practical. Take into consideration ambient temperature as well as any potential for water splashing and consider augmenting the case as needed. The regulator is very efficient and does not need much cooling beyond what is typically found in engine room compartments, but that is not to say one should test its limits!

CAUTIONARY NOTE: OVERSTRESSING SMALL-FRAME ALTERNATORS

The most common alternator found will be a small frame unit, especially if it is the OEM alternator on an engine. These alternators are good reliable units, but may not be up to the demands of delivering large amounts of current over a long period of time. Overstressing alternators can result in damage from burnt-out diodes and/or internal heat stress-related damage and failures. Such stress conditions are exacerbated by high-acceptance battery banks (eg, Lithium, AGM/GEL, or even large-capacity standard wet-cell FLA batteries).

The best way to protect a small-frame alternator is to install an alternator temperature sensor, ideally located near or on the alternator’s diode pack. This will allow the VSMMAR to monitor the alternator and reduce output as its safe temperature limit is approached. (It is not unknown to see an ‘80A’ alternator restrained to as low as 30A in order to prevent alternator overheating…). In addition, it is recommended to select ‘Small-Alt Mode’ via DIP switch 6 to provide an overall capping of alternator loading. After some run-time experience has been had, you can consider turning off Small-Alt mode and see if the alternator is able to handle your specific installation.

OTHER IMPORTANT CONSIDERATIONS

DIODE BASED BATTERY ISOLATORS

These are often installed when one alternator is asked to charge two or more batteries. The isolator prevents any loads on one battery from discharging the other battery when the engine is turned off. These present a problem for the VSMMAR, as it is attempting to decide when the battery is full: which battery does it look at? If you have a battery diode battery isolator it is might be better to replace it with an automatic battery switch/combiner (following). However, if you do install the regulator in a system with a diode battery isolator, it is suggested you pick the battery you with to focus on – place the battery amp shunt on that battery, and attach the battery voltage sensing wires to that same battery. The regulator will then control the alternator to meet the needs of *that* battery. There is a risk of overcharging the 2nd battery, but that risk existed well before installing the VSMMAR.

AUTOMATIC BATTERY COMBINER

Another way to connect a 2nd battery to the main one is to use an automatic battery switch or [digital voltage sensing relay (DVSR)](). These will sense the voltage of both batteries, and when the time is right, connect them together. If you install in a system with one of these, connect the VSMMAR to the primary (largest) battery bank, placing the battery shunt on that main battery and connecting the Battery + and Battery – sensing wires to that battery. The VSMMAR will focus on that main battery and let the automatic battery combiner deal with the needs of the 2nd battery. A couple of notes:

- Make sure to connect the 2nd battery on the alternator side of the battery amp shunt – it is important that the amp shunt *only* measure the current needs of the battery we are focusing on.
- There is a #define FEATURE_OUT_COMBINER option in the source code that can be enabled to allow a simple external high-current relay or continuous-duty contactor to be used for a battery combiner. See the section on feature-out options.

CROSS-CHARGING DIFFERENT BATTERY TYPES

As LiFePO4 batteries become larger and more affordable, it is very enticing to switch a boat's house battery bank to LiFePO4 while keeping the engine starter battery an AGM or other type of battery which works well for engine starting. In this case, the two battery types require different charging regimes. In this case it is best to have the VSMMAR focus on the LiFePO4 bank and use [a DC to DC charger]() to maintain the starter battery.

VOLTAGE-SENSING WIRES

Install the battery and alternator voltage-sensing wires (Bat+ and Bat -, Alt+ and Alt-) *directly* to the battery and alternator respectively (with recommended fuses). Do not attach the wires after a battery switch, dual-alternator diode separator, the battery Amp Shunt, or a common 'bus bar'. Instead connect directly to the batteries and alternator for best results.

RECOMMENDED TWO-SHUNT INSTALLATION

To take advantage of all of the best charging features of the VSMMAR, the connections illustrated below should be made. The shunts may be on either the high or low side of the battery and alternator but placing shunts on the negative side is a more widely accepted practice.

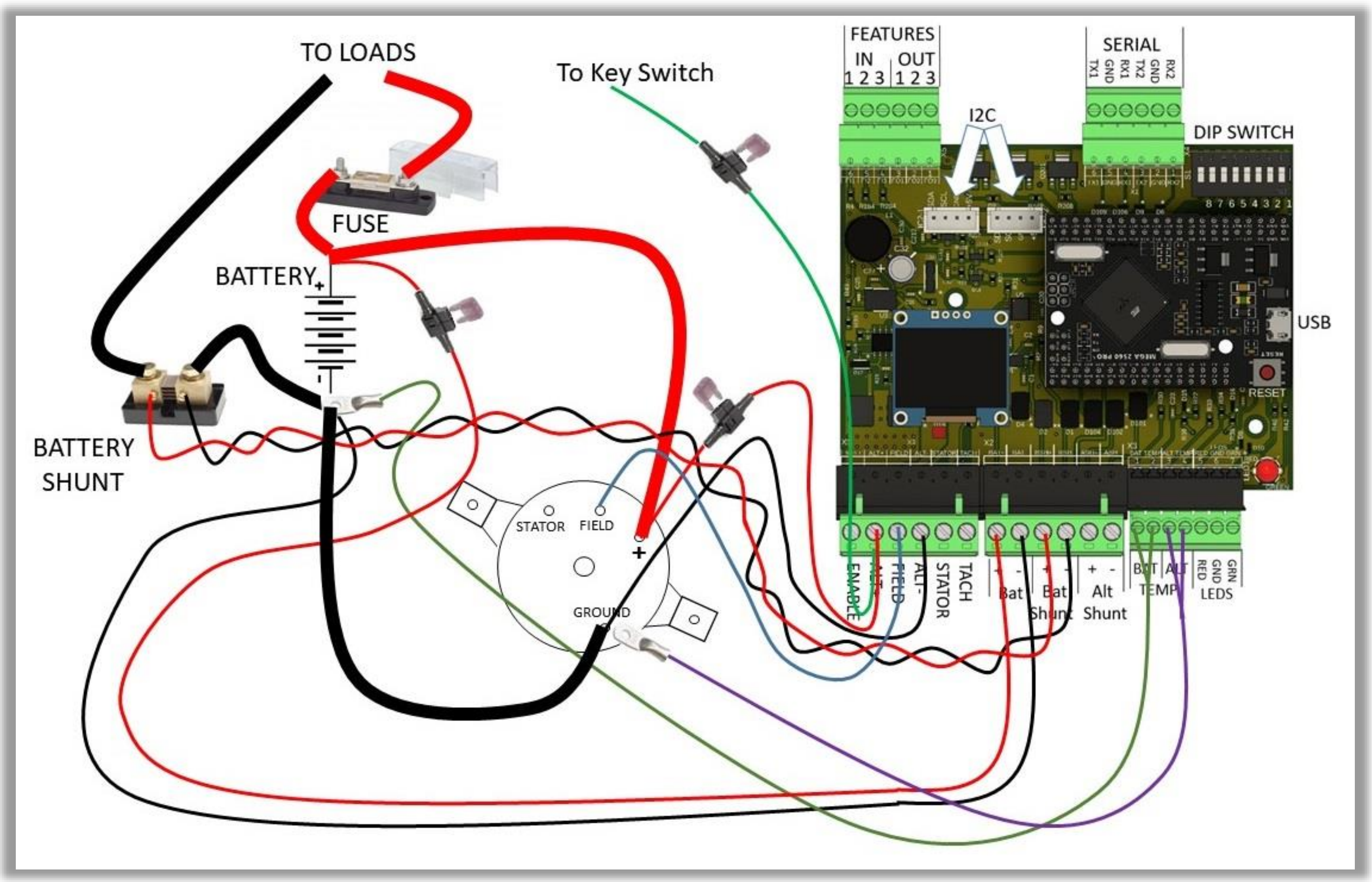


Figure 6 – Recommended Two-Shunt Installation Connections

SINGLE-SHUNT INSTALLATIONS:
BATTERY-CENTRIC VS. ALTERNATOR-CENTRIC INSTALLATIONS

Throughout the examples it is helpful to keep in mind there are two distinct ways the VSMMAR may be configured and installed in a system, depending on where the amp shunt is placed, if only one shunt is used. If the shunt is placed at the battery the installation is known as a 'Battery Centric' installation, allowing for accurately monitor the SOC (state of charge) of the battery and use that to determine when it should change charging phases. (e.g., from acceptance to float).

Though simple to install, it is not suggested to use this configuration as many of the capabilities of the VSMMAR will be disabled. If you do select this installation option take great care with the configuration options (alternator output capping / limitations, CPE selection of voltages and transition times among a few) to best match your typical operations and assure limited risks due to incomplete battery charging and/or alternator overstress situations.

Even with these risks it is helpful to understand this simplest installation as if any of the regulators sensors fail, the VSMMAR will `fallback' to simpler modes of operation, thereby allowing continued operation, though perhaps in a less efficient manner.

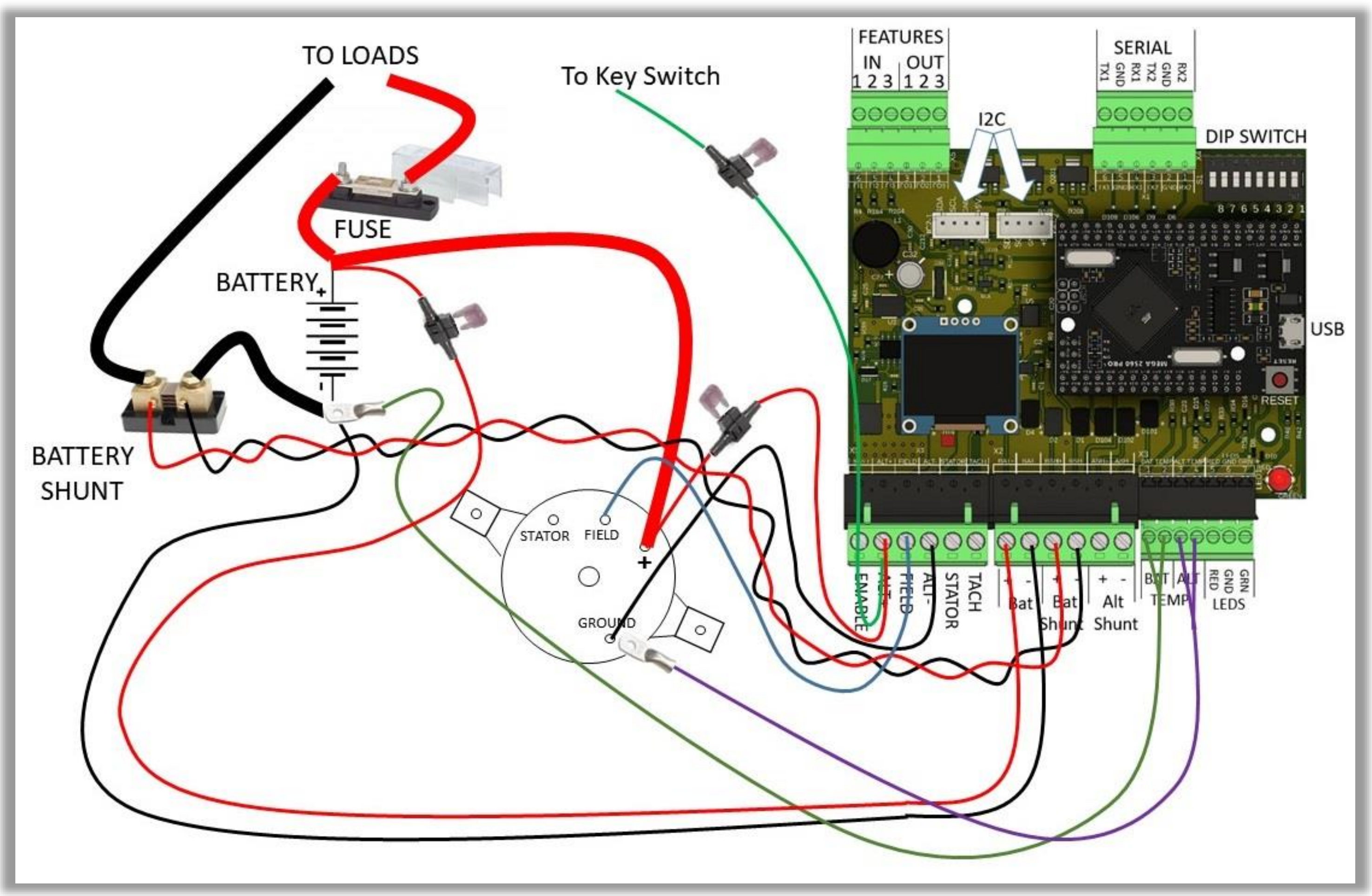


Figure 7: Battery-centric, Single-shunt Installation

Figure 8: Alternatively, the amp shunt can be placed at the alternator in what is referred to as an 'alternator-centric' configuration. This is useful to either further protect a smaller alternator, or perhaps to allow a very large alternator to be placed on a small engine (for example in a DC generator) but this also does not offer the full benefits of a dual-shunt installation.

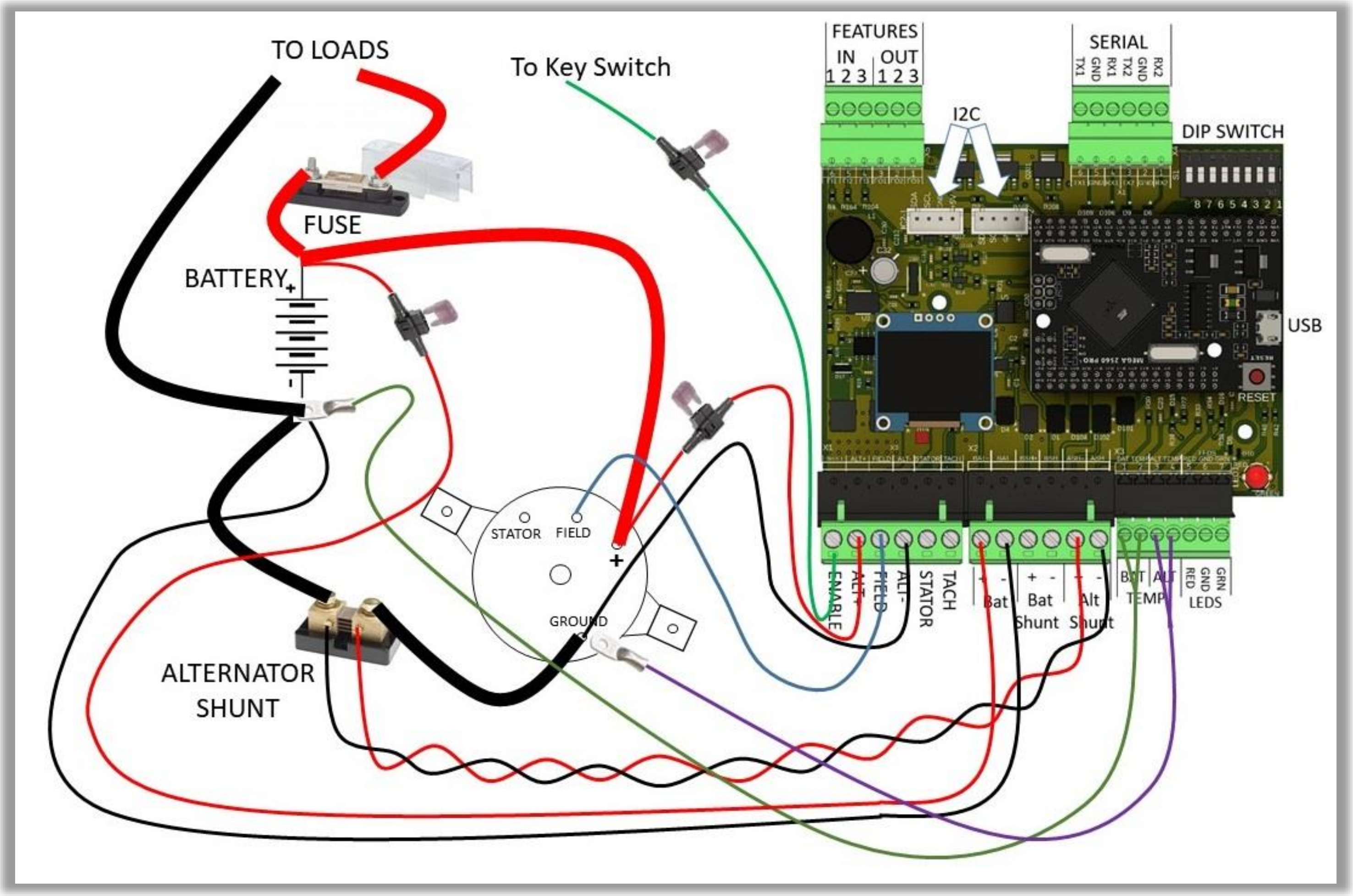


Figure 8: Alternator-centric, Single-shunt Installation

CONFIGURING THE VSR MINI MEGA ALTERNATOR REGULATOR

The simplest way to configure your VSMMAR is via the DIP switches. With these you can select one of the default Charge Profile Entries (CPE), as well as tell the regulator the size of the battery bank you have (needed to more accurately decide when the battery is full).

USING THE DIP SWITCHES

Many of the basic features of the VSMMAR can be configured using the DIP switches. Advanced changes may be made via edits to the source code files or by using the ASCII serial commands (See: **Error! Reference source not found.**). The following table defines how the DIP switches are used:

Position	**Meaning (Regulator Version 3)**
1..3 <1> <2> <3> Off, Off, Off On, Off, Off Off, On, Off On, On, Off Off, Off, On On, Off, On Off, On, On On, On, On	Select Charge profile 1..8 1 = Default (Safe) Lifeline AGM (also known as Concord AGM) 2 = Flooded Lead Acid #1 (Starter type , etc.) 3 = Flooded Lead Acid #2 (HD - Storage type) 4 = AGM #2 (Higher charge voltages) 5 = GEL 6 = Carbon Foam (Firefly) 7 = Custom (Changeable – Preconfigured HD Storage with Overcharge) 8 = LiFeP04) *(See* Table 6 *for more details)*
4,5 <4> <5> Off, Off On, Off Off, On On, On	Define Battery Capacity as: ** 1x, – 250Ah 2x, 250Ah – 500Ah 3x, 500Ah – 750Ah 4x. 750Ah and above
6	On – Use Small Alternator Mode Off – Use Large Alternator Mode Small Alternator Mode will restrict the maximum alternator output to 75% of its amperage capability. Large Alt mode limits output to 100%.
7	On - Enable Tach Mode Off – Disable Tach Mode
8	Factory Reset (with FEATURE_IN_RESTORE asserted at startup)

Figure 9: DIP Switch Settings

USING ASCII COMMANDS

In addition to the DIP switches, many parameters of the VSMMAR can be customized by sending in a series of ASCII commands via a USB cable attached to the Mini Mega 2650 processor daughter card.

Changes sent to the VSMMAR are saved in flash memory on the CPU for use next time the regulator starts up. (See Sequence of Operation section below for more details). *Because of this you will need to restart the regulator after you have finished sending it ASCII change commands before those changes will take effect.* There are some exceptions, such as the $FRM Force Regulator Mode command, $EBA – External Battery Amps, and a few more. See details of each command below.

Communicating with the Arduino Shield Alternator Regulator

The VSMMAR supports external communication of status and more advanced configuration changes than the DIP switches allow. Communications is primarily via serial ASCII strings, the formats of which are documented in the *"VSMMAR Systems – Communications and Programming Guide*, via the USB connector on the Mini Mega processor daughter board.

At this time, the VSMMAR is not compatible with the WS500 Configuration Tool available from Off Grid Software Solutions who also sell a commercial version of the VSR Alternator Regulator: https://offgridsoftwaresolutions.com/product-category/software/

TUNING USING SOURCE CODE

As a final configuration method, the source code may be directly modified, recompiled and then flashed into the VSMMAR. This gives the ultimate flexibility, as well as the ultimate responsibility.

It is best to conduct this editing with Microsoft Visual Studio Code and PlatformIO. The Github files include the appropriate development environment configurations include the variant files needed to support the Mini Mega Pro daughter card and the Platformio.ini files necessary for configuring the environment and libraries.

The first place to start for basic configuration and turning is the Config.h file. Next, study the System.cpp file. Take care to completely understand the code and the implications of each setting before making any changes. To put things into perspective, I spent several years working with this code in order to create the refactored code while not breaking any of Al's great work on the underlying operation of the regulator. Step slowly and carefully.

Figure 10: Default Charge Profiles

FEATURE-IN AND FEATURE-OUT PORTS

FEATURE-IN PORTS

Feature-in ports are enabled by connecting the feature-in pins to a voltage greater than 6v. Voltages as high as 72v are allowed. Feature-in ports can serve several purposes. The function of each feature-in port can be altered using various #define compile options in the source.

OPTIONS FOR FEATURE-IN PORTS

In the source code there are several optional uses of the feature-in ports. These are enabled in the source file Config.h via first selecting different #define statements (uncommenting them) to active the feature, then editing, as desired, the immediately following FEATURE_IN_PORT(number) entry, and finally recompiling the source, and re-flashing the firmware. The following options are included in the source; each is explained in more detail below:

- #define FEATURE_IN_RESTORE - Restore settings to “factory defaults” *see special instructions below
- #define FEATURE_IN_EQUALIZE - Initiate equalization charge
- #define FEATURE_IN_SCUBA - Enable reduction of PWM field drive
- #define FEATURE_IN_FORCE_TO_FLOAT - Keeps regulator in float charge mode

FEATURE_IN_RESTORE

This feature is only checked at start-up of the VSMMAR, that is, when ENABLE is powered or after the reset button on the processor board is pressed (or the system conducts a reset due to a fault condition). To force such a restore, three conditions must be true at this time:

1- DIP switch 8 must be in the ON position
2- The assigned Feature-in port must be held high (at battery voltage)
3- The systemConfig.CONFIG_LOCKOUT in System.cpp must not be set to 2.

After conducting such a restore, reset DIP switch 8 to the OFF position and remove the power from the assigned Feature-in port.

Note: The Feature-in port assigned to the restore feature can also be assigned to another Feature-in function. This is because this port is checked both at start-up and in the main loop of the program. Of course, if one is intending to use this port for another function, and not intending to initiate a restore at boot time, DIP switch 8 should be set to OFF.

FEATURE_IN_EQUALIZE

If CPE #1 through 7 is selected, when this Feature-in port is held high and the alternator running, equalize mode will be enabled provided the charge profile (CPE) includes an equalization voltage setting. Once this feature is activated, the equalization will continue until any of the following is true:

1- the assigned Feature-in port is no longer held high;
2- defined exit Amps have been met; or
3- defined timeout has been met.

Note: Equalize is considered a high-monitoring mode and there is a potential for damage to the batteries. As such, the Feature-in port must be in an inactive state (low) and then transition to high in order for equalize to be recognized. This is to prevent the possibility of someone accidentally leaving the equalize Feature-in switch turned on. Once equalize mode has been entered, the Feature-in port must remain connected to VBat and the status LED(s) will blink-out the equalize status pattern. This Feature-in function is ignored if the charge profile (CPE) is #8.

FEATURE_IN_SCUBA

This feature exists to force the field PWM output to a lower level while not changing the charge mode. It is useful for small engines when a SCUBA compressor, water maker, or other substantial load can be switched on, loading down the engine. When this Feature-in port is held high, the PWM field drive will be set to a pre-set lower level, defined by FIELD_PWM_SCUBA in Config.h. The range of this value is 0 to 255. To calculate this number, starting with the percentage of maximum PWM, the calculation would be: (Percentage * 255)/100 … rounded to an integer.

FEATURE_IN_FORCE_TO_FLOAT

This feature exists to allow an external input (a switch or a signal) to override the charge mode and activate float mode until the assigned Feature-in port is returned to a low state. This is useful for reducing engine load or to protect LiFePO4 batteries (if the LiFePO4 battery management system (BMS) has a digital shutdown (or alarm state) output. (Also see FEATURE_OUT_LIFEPO_SHUTDOWN_ALARM below).

FEATURE-OUT PORTS

Each of the three Feature-out ports of the VSMMAR provide an open-collector driver and can used for any of several functions. Open-collector means that when the Feature-out port is active, the port provides a ground and when the Feature-out port is inactive, the port is a high-impedance point, neither high nor low. Feature-out ports are <u>active Low</u> and are limited to 0.5 amp on each of the feature-out connectors, but ideally would be limited to that maximum total amongst the three Feature-out ports. This is not only due to the thermal limits of the output transistors, but also because the return line (battery -) is shared by the Feature-out and the VBat voltage sensing. Placing too much return current via the feature-out connectors can impact the accuracy of measured battery voltages.

OPTIONS FOR FEATURE-OUT PORTS

In the source code there are several optional uses of the Feature-out ports. These are enabled in the source file Config.h via first selecting different #define statements (uncommenting them) to active the feature, then editing, as desired, the immediately following FEATURE_IN_PORT(number) entry, and finally recompiling the source, and re-flashing the firmware. The following options are included in the source; each is explained in more detail below:

- #define FEATURE_OUT_LAMP - Enable LAMP / Fault driver
- #define FEATURE_OUT_RED_LED - Echo the on-board red LED to the designated feature-out port

- #define FEATURE_OUT_GREEN_LED - Echo the on-board green LED to the designated feature-out port
- #define FEATURE_OUT_ENGINE_STOP - Active when we enter FLOAT mode.
- #define FEATURE_OUT_LIFEPO_SHUTDOWN_ALARM - An output for an alarm buzzer, light, etc.
- #define FEATURE_OUT_COMBINER - Allows sharing of charging source(s) between two batteries.

Example of code:

```
#define FEATURE_OUT_RED_LED                          // Enable feature to echo the green LED to the feature out por
t
#ifdef FEATURE_OUT_RED_LED
  #define RED_LED_FO_PORT  FEATURE_OUT_PORT2      // Set the feature_out_port to use for the Green LED output fe
ature
#endif

//#define FEATURE_OUT_ALT_LAMP                       // Enable FEATURE_OUT port as an ALTERNATOR LAMP driver, to sh
ow rough
                                                     // alternator status as well as blink out the FAULT code
#ifdef FEATURE_OUT_ALT_LAMP
  #define ALT_LAMP_FO_PORT  FEATURE_OUT_PORT3     // This sets the feature_out_port of the Alternator Lamp featu
re
#endif
```

REGARDING LEDS AND "LAMP"

The on-board LED(s), LEDs ports, FEATURE_OUT_LAMP, FEATURE_OUT_RED_LED, and FATURE_OUT_GREEN_LED, these may at first glance seem to be duplicate features. In fact though, there are some important and useful differences between these options.

On-board Led: The on-board LED can either be a bi-color 5mm LED or one each red and green SMD LEDs. Red flashing patterns of this LED indicate fault codes. Green flashing patterns of this LED indicate charge modes.

LED ports: The three-pin LED port (Red, Gnd, Grn) can be used to *directly* drive an LEDs which duplicate the on-board LED(s). A series resistor is not necessary, unless a dimmer LED is desired.

FEATURE_OUT_LAMP

With this feature enabled, a Feature-out port can be set to drive a dash mounted 'Alt' lamp. The port will be disabled (lamp off, port high), unless in one of the following conditions:

- Indication of no-charging status – lamp will be full on during this time. (e.g., during engine warm-up period)
- Fault status – lamp will blink-out fault codes if OUT_LAMP_MIRROR_FAULT is defined to true
- Controller resetting – lamp will blink-out resetting LED pattern if OUT_LAMP_MIRROR_RESETTING is defined to true

- Regulator is in EQUALIZE mode – Lamp will blink-out Equalize LED pattern, if OUT_LAMP_MIRROR_EQUALIZE is defined to true

So for those of us who are old enough to remember the single red alternator light on the dash of their VW or other car… if all of the OUT_LAMP_MIRROR options are set to false, the lamp output will somewhat mimic those old alternator lamps and be on when the alternator is not outputting current. (It will not dim. It will only be either on or off).

With all or some of the OUT_LAMP_MIRROR options set to true (in Config.h), the FEATURE_OUT_LAMP will provide a combination of the old "alt lamp" and a digital report of key status or fault conditions.

FEATURE_OUT_RED_LED, FEATURE_OUT_GREEN_LED

With either of these options enabled, the designated Feature-out ports will follow the respective on-board status LED(s). This option is provided in addition to the LED ports so lights other than LEDs can be used (for example incandescent lamps already existing in an engine gauge panel).

FEATURE_OUT_LIFEPO_SHUTDOWN_ALARM

With this this option enabled, a designated Feature-out port will become active if the FEATURE_IN_FORCE_TO_FLOAT port is defined and active. This could be useful to provide a separate alarm (buzzer or light) if the FEATURE_IN_FORCE_TO_FLOAT port was being driven by a digital alert from a BMS.

FEATURE_OUT_ENGINE_STOP

With this option enabled, a designated Feature-out port will become active for a designated number of milliseconds, the ENGINE_STOP_PULSE_DURATION, once the alternator enters float, forced-float, or post-float mode. This can be used to stop a generator or to provide a "done" alert.

FEATURE_OUT_ENGINE_COMBINER

With this option enabled, the VSMMAR can provide a battery combiner function via a designated Feature-out port. The following is a detailed explanation of the rationale and settings for using this option.

Many situations have more than one battery bank, such as a starter battery and a "house" bank, but only one alternator. Or there might have two batteries, each with its own alternator. An example might be a boat that has a large battery bank for the house battery, and a smaller battery used for the starter, or a bow thruster, or for a windlass. Using the one of the Feature-out ports to drive a high-current, continuous-duty relay or contactor is an inexpensive way to get a 'smart' battery combiner. There are perhaps two common reasons for using a battery combiner:

1. Allow a second charging source to 'help' recharge the large house battery during its bulk phase
2. Recharging a second battery which has no charging source of its own.

Because the VSMMAR is designed to focus on the attached battery, and not the 'combined in' battery, some assumptions must be made and care taken. We want to make sure we do not overload a second alternator, or overcharge a second battery. Some additional considerations which must be taken into account:

- Do not exceed the current limit of the Feature-out port (0.5 amp) with the coil draw of the external large relay. (Using an intermediate low-current relay to drive the coil or a higher coil current combiner relay might be necessary).
- Use a length of medium size wire (e.g., 10' of 10g wire) to ensure a low level of resistance between the two batteries. A minimum resistance of 5-10mΩ (milli-ohm) appears to be common.

<u>Situation #1: Recharging a second battery which has no charging source of its own (most common situation)</u>

In this example, there are still two independent batteries, but only one charging source. A representative example would be a house battery / alternator being controlled by VSMMAR, and a second battery used for engine starting or to power a bow-thruster. Unlike the case below where we are looking to gain assistance from the other battery/alternator, in this case the one alternator is being asked to be the charging source for the second battery.

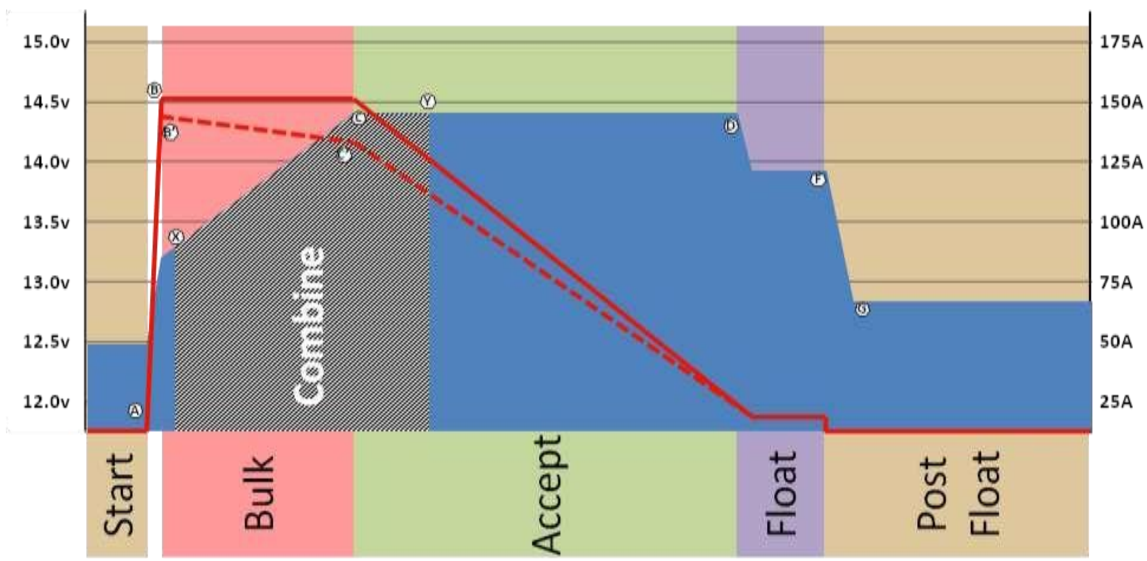


Figure 10: Charging second battery combiner profile

Figure 11 illustrates the conditions when we want the combiner enabled. The idea is the second battery parallels the charge profile of the main battery, and because we are not actively managing the second battery we cut off the acceptance phase after a relatively short time (Points 'C' to 'Y' above) to reduce the risk of overcharging the second battery, in effect boiling it off.

Care must be taken in each of these situations to protect the second battery and/or second charging system. Remember the VSMMAR will focus on its battery and adjust things to that battery's needs with no regard to the other battery's needs, outside of the limited combiner configuration options.

<u>Situation #2: Using second battery/alternator to 'help' the house battery during bulk charging phase.</u>

In this example, there are two fully independent batteries and associated charging systems, perhaps the factory alternator and starter battery, and a house battery with its own alternator using the VSMMAR. The starter battery will likely be quickly recharged after the engine starts, leaving a significant amount of unused capacity in the starter battery's alternator (or visa versa).

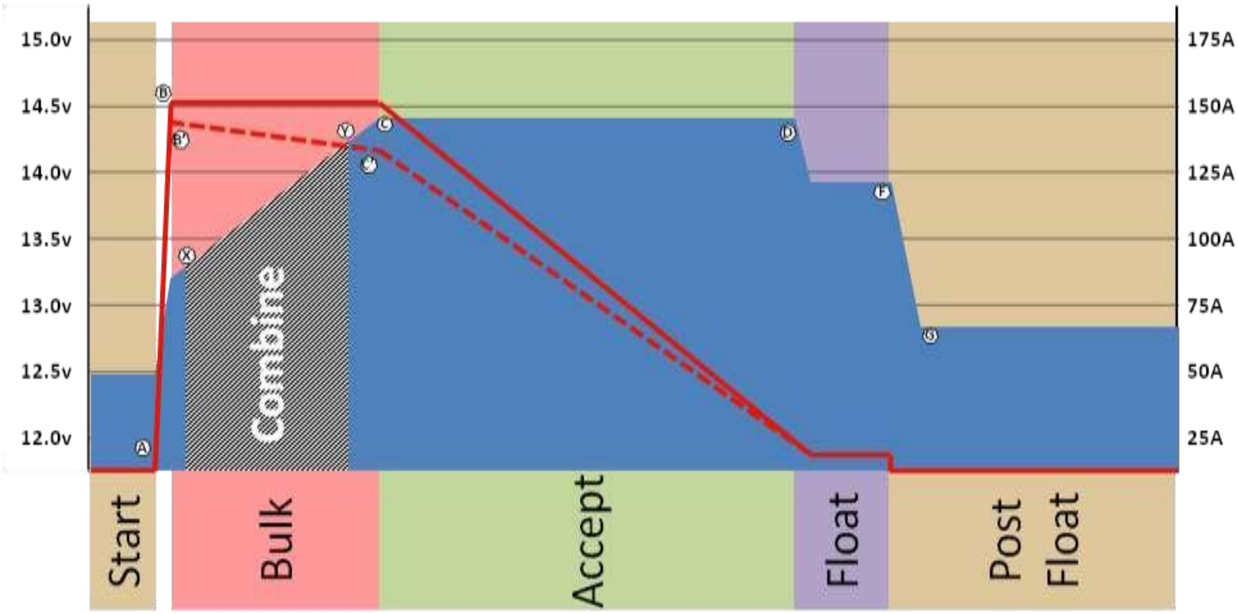


Figure 11: Receiving Help combiner profile

In this mode, Figure 12 above illustrates when we want to combine the two systems (between points 'X' and 'Y').

Specifically during Bulk, we want to:

- Wait until the house battery reaches 13.2v before enabling the combiner. If we combined sooner there is a risk of pulling energy from the second battery, as opposed to only asking the second alternator to share its capacity. 13.2v will also reduce the voltage difference between the two batteries thereby minimizing initial surge current.
- Break the connection of the two batteries after 14.2v. With the assumption the second battery has its own charging source that will handle all the recharging needs of that battery, we do not want to 'override' those decisions. 14.2v was selected under the assumption that many 'starter' batteries are connected to a default internally regulator fixed voltage alternator; those are often in the 13.8 to 14.2v range.

COMBINER CONFIGURATION OPTIONS

All options for configuring the Feature-out port as a combiner are made in the source code file Config.h, there are no ASCII commands to modify these. In Config.sys, there are two combiner profiles: COMBINER_PROFILE_LIFEPO and COMBINER_PROFILE_OTHER. Only one should be defined and the other #define statement commented out.

The following variables in the source code for COMBINER_PROFILE_OTHER:

```
#define     COMBINE_CUTIN_VOLTS           13.2
#define     COMBINE_HOLD_VOLTS            13.0
#define     COMBINE_CUTOUT_VOLTS          14.2
#define     COMBINE_ACCEPT_CARRYOVER    0.75*3600000UL  // ¾ an hour, 45 minutes.
```

Once voltage raises to the COMBINE_CUTIN_VOLTS level (13.2 by default) – point 'X' in the figures above - the combiner will be enabled (via a Feature-out port), and will stay enabled even if the battery voltage temporarily dips – as long as it remains at or above the COMBINE_HOLD_VOLTS level (13.0v by default). However, if it drops too much and goes below the HOLD level, the combiner will be disabled.

As battery voltage rises, the combiner will be disabled by either the voltage rising above the COMBINE_DROPOUT_VOLTS level – point 'C' shown in the figures above (14.2v by default), or after being in the acceptance phase for the COMBINE_ACCEPT_CARRYOVER duration – point 'Y' shown in t. Either point (along with low voltage) will cause the combiner to open.

Note that as with all charge profile entries (CPEs), voltages shown above are 'normalized' to a 12v battery and will automatically scale by the system voltage multiplier. (e.g., in a 24v system, the multiplier is 2, so the combine voltage becomes 2 * 13.2v, or 26.4v).

OPERATION OVERVIEW

The Arduino Shield Alternator Regulator has a wide range of flexibility and can be configured in three ways, ranging from simple to anything-goes.

- Select among built-in (default) parameters via the DIP switches
- Modify many of the built-in parameters via sending ASCII commands over the USB port
- Modifying any or all built-in parameters in the source code, recompiling, and re-flashing to the processor board.
  (requires use of USB port and Arduino (www.arduino.cc) or other compatible IDE such as PlatformIO on Visual Studio Code, the IDE used for the refactoring of the VSMMAR code)

START-UP SEQUENCE

When the VSMMAR is first powered up it loads the default setting from the firmware and then looks to the DIP switches to see what the user has selected. It will then samples the system voltage to decide if it is installed in a 12v or 24v environment (and thereby setting the SysVolt multiplier, see SST: / System Status below for more details about this and how it is used). If the VSMMAR is installed in higher voltage battery system that a nominally 24V system, the boot process will abort and the processor will be rebooted. Finally, it will look at the saved flash memory in the CPU to see if any of the parameters have been modified or any of the DIP switches have been overridden by the user using ASCII commands.

Note that parameters saved to flash are *only* checked during startup; this is why after changing any parameters via an ASCII string command you need to reset the regulator (via the $RBT – ReBooT command) in order for any of those parameters to take effect. This is done this way so that the regulator does not start acting on changes part way through you making configuration changes. For example, if you are updating the CPE entry, you want to update and verify all parts of it before the regulator starts using the new values.

RAMP-UP SEQUENCE

Next, the regulator will enter the ramp-up phase. It first waits 15 seconds before doing anything (configurable: systemConfig.ENGINE_WARMUP_DURATON in System.cpp) to give the engine time to start. Finally it will begin to slowly ramp up the alternator field over a period of about a minute(configuarable: PWM_RAMP_RATE in SmartRegulator.h) before entering bulk phase.

CHARGING THE BATTERY

Once the regulator has completed its startup and ramping sequence it enters the 'charging' phases. Each phase has limits (e.g., voltage, amps, etc.) as well as 'exit' criteria based on voltage, amps and/or time. A high degree of configurability allows each phase to be used, or bypassed as needed to meet the battery manufacturer's recommended charging profile. While in each of these phases the regulator will also monitor battery and alternator temperature, making adjustments as required. It will also look to see if the regulator has been configured with system limits and make sure none of those are exceeded.

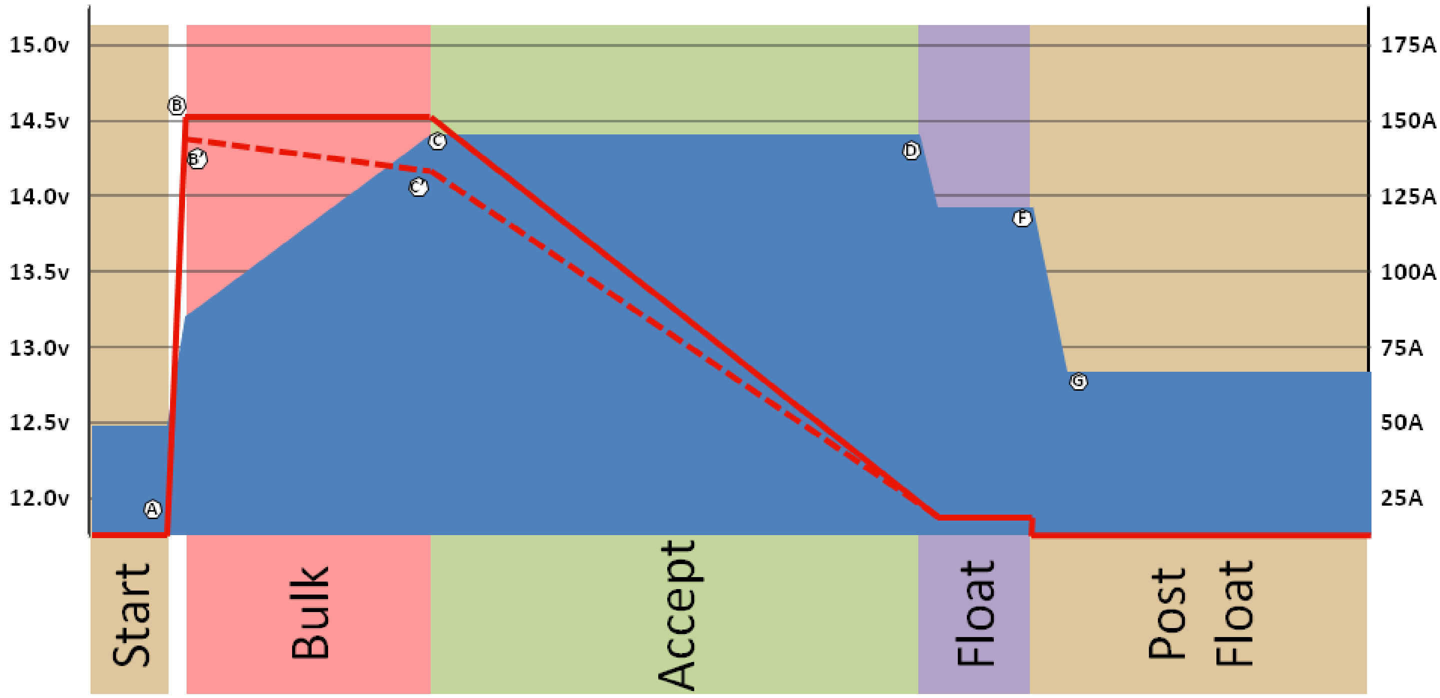


Figure 12: Example 3-stage Charge profile

Figure 13, above, shows a typical 3-phase charge profile, consisting of the Bulk, Acceptance, and Float state. The red lines correspond to amps and the right axis. The shaded bars correspond to volts and the left axis. This is one of the simplest charge profiles, and very commonly seen in external regulators. The following table details each phase as well as the parameters in the source which can impact them.

Phase	Ref	Limiting Factor	Exit Criteria	Discussion	Key Source Variables
Bulk	B-C	Alternator Capacity	Battery Voltage Time(optional)	Using default configuration (Battery Focused). During this phase, the majority of energy is returned to the battery, often touted as up to the 80% SOC point. The Alternator is run full out producing as much power is it is capable of producing. As the battery recharges voltage will raise until the set point is reached, which will trigger the exiting of Bulk. If Small-Alt mode is selected via the DIP switches, then the output of the Alternator will be managed to a lower level, to prevent overheating of small alternators that are unable to sustain continuous max amp output. Likewise, if Half-power mode is selected (via shorting the Alt Temp probes together), a more aggressive scale back will occur. This can be useful in installations where extra engine power is needed, perhaps to drive an additional pump, or perhaps allow for high speed / power mode (passing).	ACPT_BAT_V_SETPOINT ALT_AMP_DERATE_NORMAL ALT_AMP_DERATE_SMALL_MODE ALT_AMP_DERATE_HALF_POWER
Bulk'	B'-C'	System Capacity	Battery Voltage Time(optional)	An alternative configuration (Alternator Focused) to manage the system load at a lower level than the full capability of the Alternator. This is useful when powering a large alternator with a small engine, such as in a DC generator. All items discussed in Bulk above are still applicable in this configuration, with the additional system limit added. Notice in Figure 22 above: as the battery voltage increases – amps delivered are reduced, resulting in a constant wattage. Which translates to a constant load placed on the driving engine.	ALT_WATTS_LIMIT ALT_AMPS_LIMIT
Accept	C-D	Battery Acceptance Rate	Battery Acceptance Current Time – Fixed Time - Adaptive	Acceptance carries recharging from 80% to 100% of the battery's capability. The preferred way to exit this phase is via measuring the current the battery is accepting; indicating its state of charge. Other ways to exiting include a fixed Max time, as well as a time ratio based on a multiplier of how long the battery was in the Bulk phase. Both of these can be useful for installations where the Amp shunt has not been installed, or it has failed.	ACPT_BAT_V_SETPOINT EXIT_ACPT_AMPS EXIT_ACPT_DURATION ADPT_ACPT_TIME_FACTOR
Float *Forced Float*	D-F	--	Pull back to Bulk Time(optional)	Float is a 'parking place' intended to maintain a fully charged battery. A slightly higher than rest voltage is maintained to overcome the batteries internal self-discharge. Further, the Alternator is maintained in a ready mode to supply current to any external load that might be requested. If the Alternator is unable to support this load and current is requested from the battery, we are pulled out of Float and back into a recharge cycle (back to Bulk). Another indication of this is if the battery volts start to drop. This can be helpful in situations where the Amp shunt is not installed, or has failed. Finally, the accumulated Amp Hours may be monitored and once a given amount has been removed from the battery – the regulator will revert to Bulk mode. Note: If CPE #8 is enabled, the FEATURE_IN pin may be used to force the regulator into Float mode. As such, none of the above exit criteria will be checked while FEATURE_IN is active.	FLOAT_BAT_V_SETPOINT EXIT_FLOAT_DURATION FLOAT_TO_BULK_AMPS FLOAT_TO_BULK_VOLTS FLOAT_TO_BULK_AHS <NONE – All exits bypassed>

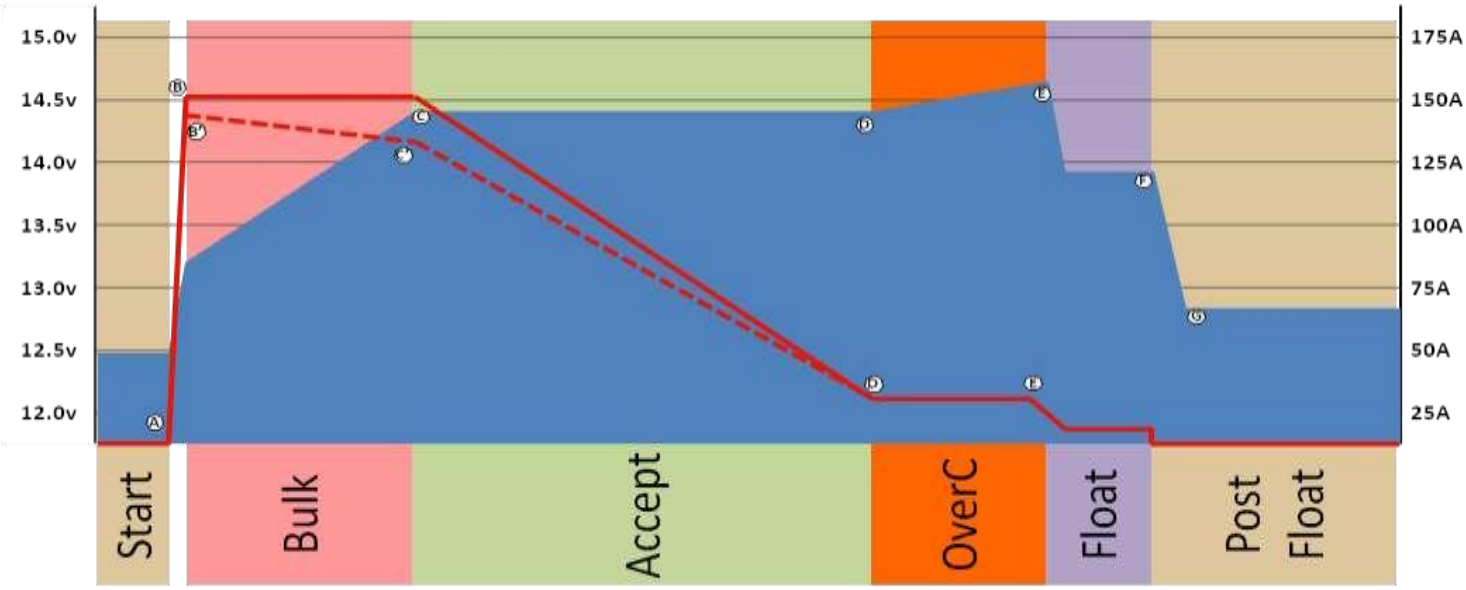


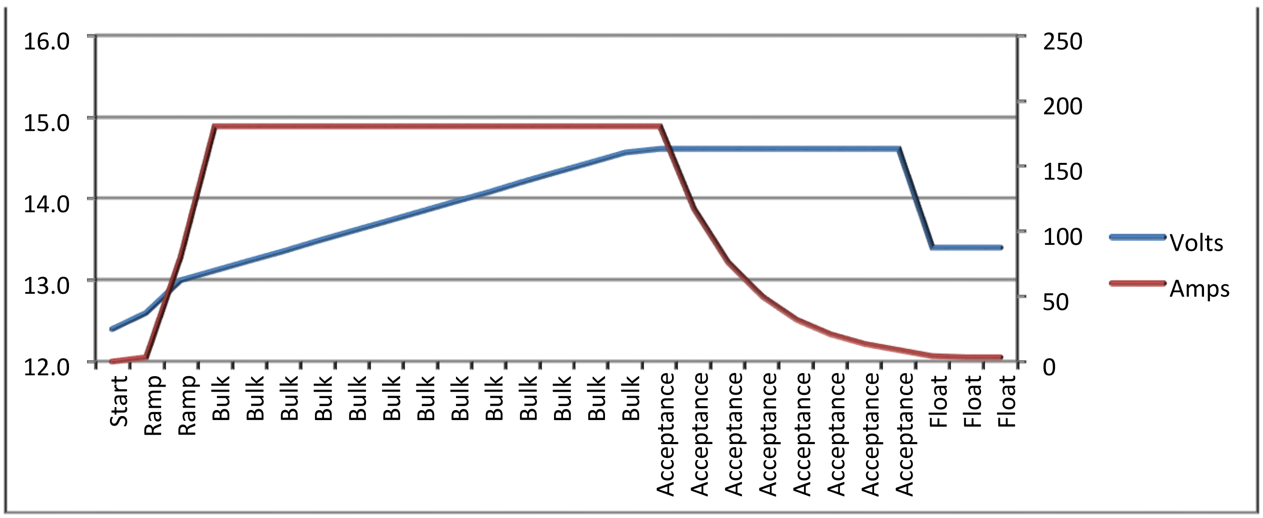
Figure 13: 4-Stage Charge Profile

Some batteries ask for an additional charging phase after the acceptance phase, one that provides a small constant current and allowed the voltage to raise. Referred to as a "finish charge" or an "over charge", the purpose is to assure even chemical action has occurred throughout the entire battery. For batteries which specify this fourth charge step, the above charge profile is used. Refer to the above table for stages other than over charge.

Phase	Ref	Limiting Factor	Exit Criteria	Discussion	Key Source Variables
Post Float	F-G	--	Pull back to Bulk Time(optional)	Post Float is much like Float, except the alternator is turned off allowing the battery to sit on its own. Post Float will return to Float mode based on a timed exit value. Once this has been exceeded, the regulator will revert to FLOAT mode. Another way to exit Post Float is through the appearance of a large load which has been placed on the system. This can either be determined by battery voltage, or by monitoring the accumulated Amp Hours removed from the battery – much like Float above. Note however that when exiting via these conditions these two methods will cause the regulator to move back into Bulk mode - just like Float above.	EXIT_PF_DURATION PF_TO_BULK_VOLTS PF_TO_BULK_AHS

Note how the VSMMAR will move directly to acceptance phase if the battery voltage quickly rises. This, combined with the measurement of the acceptance current to determine if a battery is fully charged, handles the all too common situation of being plugged into shore power and subsequently getting under way with the battery already fully charged. Traditional time-only based regulators might be stuck in the acceptance phase for several hours until the fixed-time limit is reached, overcharging the battery. With the VSMMAR, the regulator will recognize quickly that the battery is fully charged and move into float mode within seconds of the engine starting. This eliminates one of the major ways a less intelligent regulator can damage your batteries.

Each of the charge steps are fully configurable, and many can be bypassed (e.g., most charge profiles do not use



the overcharge step). As way of an example, the following two diagrams show two different approaches for charging a heavy duty 12v / 500Ah battery (e.g., two L-16 batteries). Both profiles are included in the default VSMMAR CPEs as profiles #3 and #6. Figure 14 shows the traditional 3-step charge profile (bulk, accept, and float), while Figure 15 illustrates the flexibility to accommodate a 4-step charge profile (bulk, accept, over-charge, and float). The diagrams provide an overview of each phase and represent an 180A alternator charging a 12v 500Ah battery.

Figure 14 – Example – 3-Stage Profile - Charge profile #3 (HD FLA)

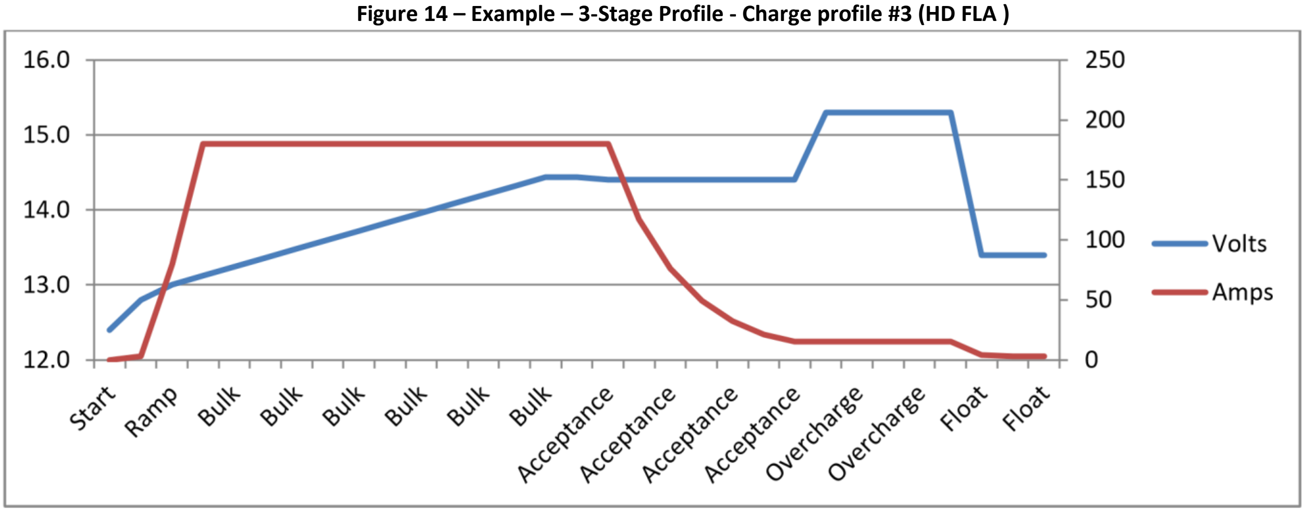


Figure 15 – Example – 4-Stage Profile -CPE #6 (HD FLA - Alternative Charge Profile)

CHARGING LiFePO4 BATTERIES

To be written

RESTORE TO AS-COMPILED (DEFAULT) STATUS

Configurations (system and Charge parameters) which have been changed from the as-compiled default values may be restore in one of three ways:

- Individually by the $CPR:n , $SCR: and $CCR: commands.
- Collectively via the $MSR: command.
- Total system restore is accomplished by:
  1: Connecting a Feature-in port which has be configured for the FEATURE_IN_RESTORE function in Config.h to Vbat (battery positive voltage) before applying power to the regulator, AND
  2: setting DIP switch 8 to ON, AND
  3: then applying power.
  This will restore *all* configurations to the default condition.

If the regulator has been locked out via the $SCO command the only way to restore to the default configuration is via using the Feature-in restore procedure, because none of the ASCII change commands will function once the regulator has been locked. You may also clear the locked flag by recompiling the firmware and reloading it. If you do this, you will need to make a change to the following defines in the Flash.h file of the source code to some other random value:

```
#define         SCS_ID1_K   0xFC3A
#define         SCS_ID2_K   0x69D3
```

These provide a validation token at the beginning of each saved block of data in the flash memory. If you do not change these values the CPU will read the existing FLASH and finding a match to the above keys will assume the saved parameters are valid. (Including the locked-out bit). So, in order to 'clear' the flash memory, you must change the tokens.   … So avoid the hassle and don't lock out changes with the $SCO command.

BENCH TESTING AND DIAGNOSTICS

Limited testing can be performed on the VSMMAR using a simple test mockup, a voltage meter, power supply and the built-in OLED display. If you suspect the regulator has been damaged, these steps can help you confirm basic functionality.

Simple Go / No-Go testing

The 1st test is to simply confirm the regulator is able to wake up and begin processing. This may be done with the regulator installed or removed on the bench.

Just connect either connect the USB cable to your PC or connect power to the Enable connector and ground to the Bat- connector and observe the normal start-up screens on the OLED. This means the basic CPU is operational. Please note that for bench testing the VSMMAR is able to self-power from the USB port, so no other connection is needed – though this simple Go / No-Go test may also be performed with the regulator installed.

You should also observe the on-board LED (and the external LEDs if you installed them) should start flashing, about once a second. Both the flashing LEDs and the display of the OLED will continue for approximately 30 seconds at which time if the regulator is not installed (specifically, the Vbat sensing wires are not connected) it will fault-out with a low-voltage error. This is normal, as if the regulator cannot see a battery voltage that is reasonable it assumes something is wrong.

If none of his happens, the best next step would be re-flash the processor with the current firmware.

BENCH-TEST BOARD

A full-function external bench testing board was also designed to support the VSMMAR. The schematic, PCB design file, bill-of-materials, and Gerber files are found at the Github site:

https://github.com/peteDDD/VSR-Mini-Mega-Alternator-Regulator

This tool is intended for makers and engineers who want to delve deeper into the VSMMAR and its firmware while operating in a bench-top environment as opposed to testing in a live environment with a real alternator and engine. For most users, the built-in OLED will provide adequate feedback for testing as discussed above and for most real-world operation and testing.

The bench testing board provides potentiometers for input of battery and alternator voltage, current, and temperature. Small meters can be added to the board to display the voltages and currents. There are also connectors for the output of field PWM and Tach. The field PWM should be measured with a quality (high-sample-rate) voltmeter or an oscilloscope. The Tach output should be observed with either a frequency meter or an oscilloscope.

Feature-in port simulation and Feature-out port state monitoring are also provided on the bench-test board via switches and LEDs, respectively.

Lastly, the bench-testing board provides a switch for turning the Enable input on and off. Note that if the processor on the VSMMAR is connected to a live USB PC port (or power via the USB cable), the VSMMAR will not reboot when the bench-testing board power switch is turned off since the VSMMAR will still be receiving power through the USB port.

APPENDIX A: CHARGE PROFILE ENTRIES - CPE

The following table provides a summary of the charge profiles.

Profile #	Battery Type	Bulk / Absorption Target Voltage	Exit Absorption when either:		Overcharge (Finish Charge)			Float		Equalize		Temperature Compensation (mV / 1c from 25c)
			Amps drop to	or Time exceeds	Target Amps	Exit Voltage	Max Time	Regulated Voltage	Regulated Amps	Target Voltage	Max Time	
#1	**Safe / AGM-1 (Lifeline)**	14.3v	15A	6 Hrs				13.4v				23.4mV
#2	**Flooded Acid STD** (Start)	14.8v	5A	3 Hrs				13.5v				30mV
#3	**Flooded Acid HD** (GC, L16+)	14.6v	5A	4.5 Hrs				13.2v		15.3v	3 Hrs	30mV
#4	**AGM-2**	14.7v	3A	4.5 Hrs				13.4v				24mv
#5	**Gel**	14.1v	5A	6 Hrs				13.5v				30mV
#5	**Firefly**	14.4v	7A	6 Hrs				13.4v		14.4v	3 Hrs	24mV
#7**	**Custom**	14.4v	15A	6.0 Hrs	15A	15.3v	3 Hrs	13.1v		15.3v	3 Hrs	30mV
#8**	**LiFePO4**	13.8v	15A	1.0 Hrs				13.6v	0A			0 (n/a)

Actual content of the CPE table from CPE.h. Remember, all references are against a ‘normalized’ 12v / 500Ah battery.

const tCPS PROGMEM defaultCPS[MAX_CPES] = {

// eliminated decimal places to fix conversion narrowing problem. Note that, for example, 6 hours uses 60 here and 4.5 hours uses 45

// Name	BULK/ACCEPTANCE			OVERCHARGE			FLOAT						POST-FLOAT TO BULK			EQUALIZATION					Min Temp	Bat Min	Bat Max	
	Target Volts	Exit Accpt Duration	Exit Accpt Amps	Limit Amps	Exit Volts	Exit Duration	Volts	Limit Amps	Exit Duration	FLOAT TO BULK Amps	FLOAT TO BULK Ahrs	FLOAT TO BULK Volts	Duration	Volts	Ahrs	Equal Volts	Limit Amps	Exit Duration	Exit Amps	Min Temp Comp	Temp Limit	Chrg Temp	Chrg Temp	
{"LIFELINE"	14.3	60 * 360000UL	15	0	0	0 * 360000UL	13.3	-1	0 * 360000UL	-10	0	12.8	0 * 360000UL	0	0	0	0	0 * 360000UL	0	0.0234	-9	-45	45}	// LIFELINE BATTERY #1 Default (safe) profile & AGM #1 (Low Voltage AGM).
{"STD FLA"	14.8	30 * 360000UL	5	0	0	0 * 360000UL	13.5	-1	0 * 360000UL	-10	0	12.8	0 * 360000UL	0	0	0	0	0 * 360000UL	0	0.005 * 6	-9	-45	45}	// #2 Standard FLA (e.g. Starter Battery small storage)
{"HD FLA"	14.6	45 * 360000UL	5	0	0	0 * 360000UL	13.2	-1	0 * 360000UL	-10	0	12.8	0 * 360000UL	0	0	15.3	25	30 * 360000UL	0	0.005 * 6	-9	-45	45}	// #3 HD FLA (GC, L16, larger)
{"AGM #2"	14.7	45 * 360000UL	3	0	0	0 * 360000UL	13.4	-1	0 * 360000UL	-10	0	12.8	0 * 360000UL	0	0	0	0	0 * 360000UL	0	0.004 * 6	-9	-45	45}	// #4 AGM #2 (Higher Voltage AGM)
{"GEL"	14.1	60 * 360000UL	5	0	0	0 * 360000UL	13.5	-1	0 * 360000UL	-10	0	12.8	0 * 360000UL	0	0	0	0	0 * 360000UL	0	0.005 * 6	-9	-45	45}	// #5 GEL
{"FIREFLY"	14.4	60 * 360000UL	7	0	0	0 * 360000UL	13.4	-1	0 * 360000UL	-20	0	12.0	0 * 360000UL	0	0	14.4	0	30 * 360000UL	3	0.024	-20	-20	50}	// #6 Firefly (Carbon Foam)
{"CUSTOM "	14.4	60 * 360000UL	15	15	5.3	30 * 360000UL	13.1	-1	0 * 360000UL	-10	0	12.8	0 * 360000UL	0	0	15.3	25	30 * 360000UL	0	0.005 * 6	-9	-45	45}	// #7 4-stage HD FLA (& Custom #1 changeable profile)
{"LiFePO4 "	13.8	10 * 360000UL	15	0	0	0 * 360000UL	13.6	0	0 * 360000UL	0	-50	13.3	0 * 360000UL	0	0	0	0	0 * 360000UL	0	0.000 * 6	0	0	40}	// #8 LiFeP04 (& Custom #2 changeable profile

All values are normalized for 12v / 500Ah battery and assume an amp shunt is installed at the battery. If the shunt is mounted at the alternator, adjust the exit amp values to account for house loads. (A suggestion is to add 5A to the values shown in the above table.)   All amperage exit values will automatically scale up by the battery capacity DIP switch and likely match larger batteries with larger ‘house loads’.

Blank sections indicate that feature is disabled.

** Profile #7 and 8 may be modified via the Change Profile ASCII commands: *$CP_:n*   or   by editing the CPE.cpp file.

APPENDIX B: DEFAULT SYSTEM CONFIGURATION

The following documents default “system” values (as compiled) for the VSMMAR’s system configuration. It is configured assuming both and alternator and battery shunts are installed. Note that a 300A / 75mV shunt is being used on the alternator and a 500A / 50mV shunt is being used on the battery. (The latter is the shunt used in the Link-10 battery meter as well as others).

Settings in System.cpp:

```
tSCS systemConfig = {
    false, // .REVERSED_BAT_SHUNT          --> Assume shunt is not reversed.
    false, // .REVERSED_ALT_SHUNT          --> Assume shunt is not reversed.
    90,    // .ALT_TEMP_SETPOINT           --> Default Alternator temp - 90c  (Approx 195f)
    1.00,  // .ALT_AMP_DERATE_NORMAL       --> Normal cap Alternator at 100% of demonstrated max Amp capability,
    0.75,  // .ALT_AMP_DERATE_SMALL_MODE   --> Unless user has selected Small Alt Mode via DIP switch, then do 75% of its
capability
    0.50,  // .ALT_AMP_DERATE_HALF_POWER   --> User has shorted out the Alternator Temp NTC probe, indicating they want
           //                                  to do 1/2 power mode.
    -1,    // .ALT_PULLBACK_FACTOR         --> Used to pull-back Field Drive as we move towards Idle.
    0,     // .ALT_IDLE_RPM                --> Used to pull-back Field Drive as we move towards idle.
    //                                         Set = 0 causes RPMs to be determined automatically during operation.
   //!! NOTE THAT I SET THIS TO 125 AMPS instead of 0 for my genset
    125,   // .ALT_AMPS_LIMIT --> The regulator may OPTIONALLY be configured to limit the size of the alternator output
    //                                  Set = 0 to disable Amps capping.
    //                                  Set = -1 to auto-size Alternator during Ramp. (required Shunt on Alt, not Bat)
    0,     // .ALT_WATTS_LIMIT  --> The regulator may OPTIONALLY be configured to limit the load placed on the engine via the
Alternator.
    //                                    Set = 0 to disable, -1 to use auto-calc based on Alternator size. (Required Shunt on Alt)
    12,    // .ALTERNATOR_POLES            --> # of poles on alternator (Leece Neville 4800/4900 series are 12 pole alts)
    ((6.7 / 2.8) * 1.00),        // .ENGINE_ALT_DRIVE_RATIO      --> Engine pulley diameter / alternator diameter &  fine tuning
calibration ratio
    (int)((500 / 0.050) * 1.00), // .BAT_AMP_SHUNT_RATIO **Spec of amp shunt,  500A / 50mV shunt (Link10 default) and %
calibrating error
    //                                    CAUTION:  Do NOT exceed 80mV on the AMP Shunt input
    (int)((300 / 0.075) * 1.00), // .ALT_AMP_SHUNT_RATIO  -->
```

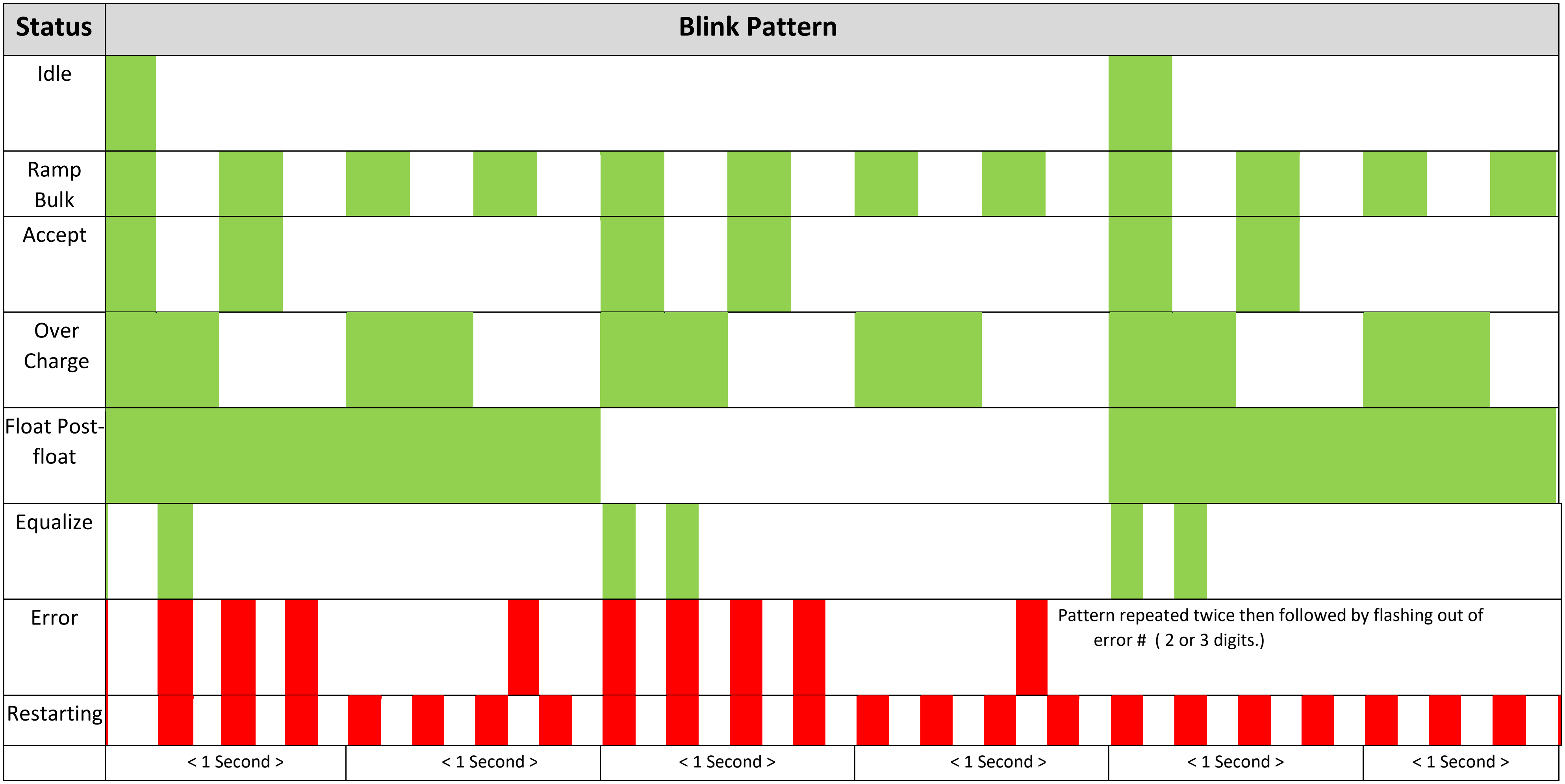
```
//                                  DUBLER 061720 CHANGED TO 300A/75mV for alternator shunt
//                                  CAUTION:  Do NOT exceed 80mV on the AMP Shunt input


-1, // .FIELD_TACH_PWM  --> If user has selected Tach Mode, use this for MIN Field PWM.
//                      Set = -1 to 'auto determine' the this value during RAMP phase
//                      Set =  0 to in effect 'disable' tach mode, independent of the DIP switch.
0, // .FORCED_TM   --> User can FORCE tach mode independent of DIP switch using $SCT command.
//                      0=DIP/off, 1=Force-on

0,   // .CP_INDEX_OVERRIDE  --> Use the DIP switch selected indexes
0.0, // .BC_MULT_OVERRIDE   --> Use the DIP switch selected multiplier
0.0, // .SV_OVERRIDE        --> Enable Auto System voltage detection
0,   // .CONFIG_LOCKOUT     --> No lockouts at this time.
#ifdef BENCHTEST
2,   // .ENGINE_WARMUP_DURATION  **Shortened for bench testing**
#else
15,  // .ENGINE_WARMUP_DURATION  --> Allow engine X seconds to start and 'warm up' before placing a load on it.
//                                    DUBLER MOD 080320 changed from 60
#endif
0}; // .REQURED_SENSORS  --> Force check and fault if some sensors are not present (eg alt temp sensor)
```

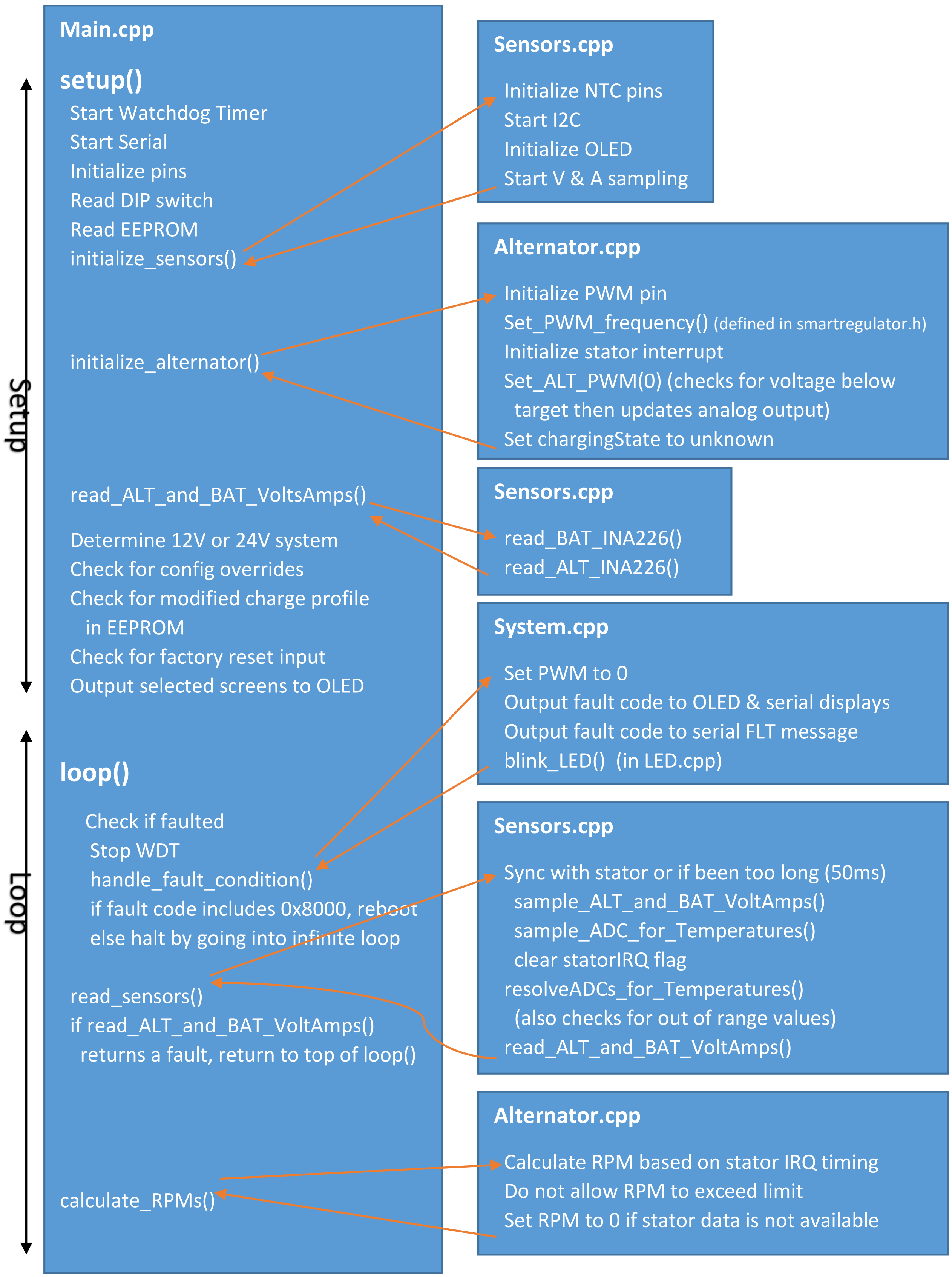
APPENDIX C: LED BLINK PATTERNS

The on-board LED will blink out patterns to inform the user of its current status, errors, and pending actions (e.g., about to restart). Patterns are made up by a combination of blink patterns, and the speed at which they blink. The following table describes the patterns.



APPENDIX D: FIRMWARE FLOW CHART

The following three pages provide insight into the actual flow of the VSMMAR firmware. After years of working with the original VSR firmware, I found it necessary to hand trace the code and create earlier generations of this flow chart in order to wrap my head around the logic of the code… and to keep my head from exploding multiple times per day. This version does not provide line-by-line detail but rather functional flow. I have taken a great deal of care and time to comment the firmware in plain English and to create variable names and definitions which are self-explanatory, including renaming many of the original variables and definitions where I found them confusing or not self-explanatory. Nonetheless, there are still plenty of variables and definitions from the original firmware which remain, largely in places where I did not touch the code because I could not add value to that code, such as the PID algorithms for alternator management (the real heart of the regulation function… most of the rest is just bells and whistles… but useful bells and whistles.) Also, as noted in the design objectives in the introduction to this manual, I removed large blocks of functionality which I did not feel the majority of users would take advantage of (if you need those, such as CAN, the Wakespeed commercial products will serve you well).


Main.cpp
setup()
Start Watchdog Timer
Start Serial
Initialize pins
Read DIP switch
Read EEPROM
initialize_sensors()
initialize_alternator()
read_ALT_and_BAT_VoltsAmps()
Determine 12V or 24V system
Check for config overrides
Check for modified charge profile in EEPROM
Check for factory reset input
Output selected screens to OLED
loop()
Check if faulted
Stop WDT
handle_fault_condition()
if fault code includes 0x8000, reboot
else halt by going into infinite loop
read_sensors()
if read_ALT_and_BAT_VoltAmps() returns a fault, return to top of loop()
calculate_RPMs()
Setup
Loop
Sensors.cpp
Initialize NTC pins
Start I2C
Initialize OLED
Start V & A sampling
Alternator.cpp
Initialize PWM pin
Set_PWM_frequency() (defined in smartregulator.h)
Initialize stator interrupt
Set_ALT_PWM(0) (checks for voltage below target then updates analog output)
Set chargingState to unknown
Sensors.cpp
read_BAT_INA226()
read_ALT_INA226()
System.cpp
Set PWM to 0
Output fault code to OLED & serial displays
Output fault code to serial FLT message
blink_LED() (in LED.cpp)
Sensors.cpp
Sync with stator or if been too long (50ms)
sample_ALT_and_BAT_VoltAmps()
sample_ADC_for_Temperatures()
clear statorIRQ flag
resolveADCs_for_Temperatures()
(also checks for out of range values)
read_ALT_and_BAT_VoltAmps()
Alternator.cpp
Calculate RPM based on stator IRQ timing
Do not allow RPM to exceed limit
Set RPM to 0 if stator data is not available

Loop

Main.cpp (continued from page 1)

Calculate_ALT_targets()

Check for faults,
if any, return to top of loop()

manage_ALT()

manage_system_state()
if chargingState is unknown or
disabled, transition to warm-up

handle_feature_in()

(Continued on page 3)

Alternator.cpp

Validate cpIndex – if invalid, fault
if measuredBatTemp is out of range,
set chargemode to float_charge
switch(chargingState) to find BAT_V_SETPOINT,
targetAltAmps, and targetAltWatts based on
current chargingState. Calls set_VAWL()

Set_VAWL()
sets targetBatVolts, scaled to systems voltage
if alt temp sensor shorted, targetAltAmps are
set to ALT_AMP_DERATE_HALF_POWER
elseif smallAltMode, scale targetAltAmps and
fieldPWMLimit by
ALT_AMP_DERATE_SMALL_MODE
else scale by ALT_AMP_DERATE_NORMAL

if RPMs != 0, protect slow spinning alternator

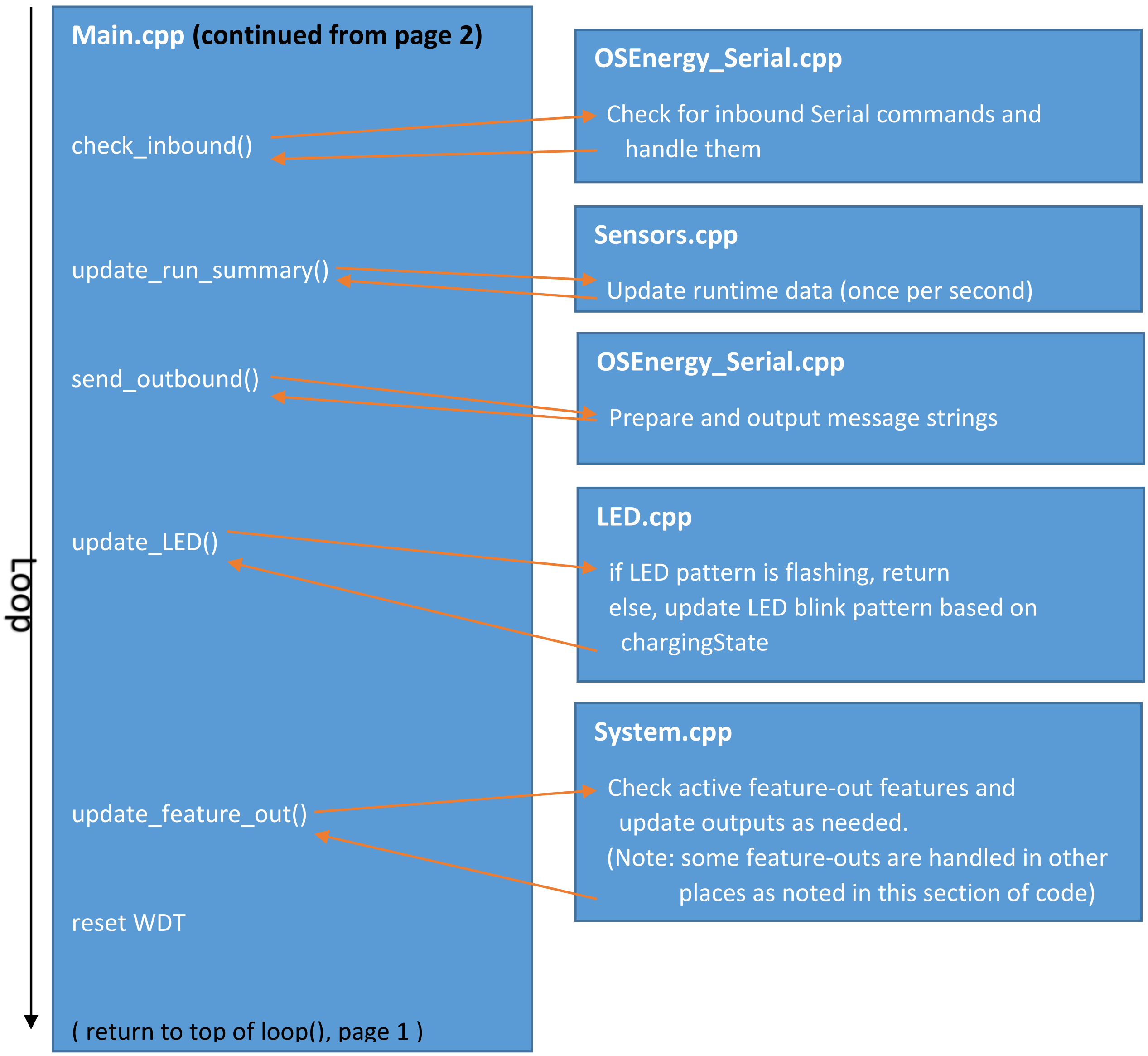
if chargingState == determine_Alt_CAP, set
values way high
else set targetALtWatts to ALT_WATT_LIMIT

Alternator.cpp

if updatingBatVAs or updatingAltVAs, return
if not time to update PWM, return
Conduct PID magic to adjust fieldPWM
Switch(chargingState) to manage transitions
between charging states
Check for fieldPWM limits
set_ALT_PWM()
if sendDebugString == true,
build and write debug string and
set SDMCounter to SDM_SENSITIVITY

System.cpp

Scan and handle feature-in pins


Main.cpp (continued from page 2)
check_inbound()
update_run_summary()
send_outbound()
update_LED()
update_feature_out()
reset WDT
(return to top of loop(), page 1)
Loop
OSEnergy_Serial.cpp
Check for inbound Serial commands and handle them
Sensors.cpp
Update runtime data (once per second)
OSEnergy_Serial.cpp
Prepare and output message strings
LED.cpp
if LED pattern is flashing, return
else, update LED blink pattern based on chargingState
System.cpp
Check active feature-out features and update outputs as needed.
(Note: some feature-outs are handled in other places as noted in this section of code)