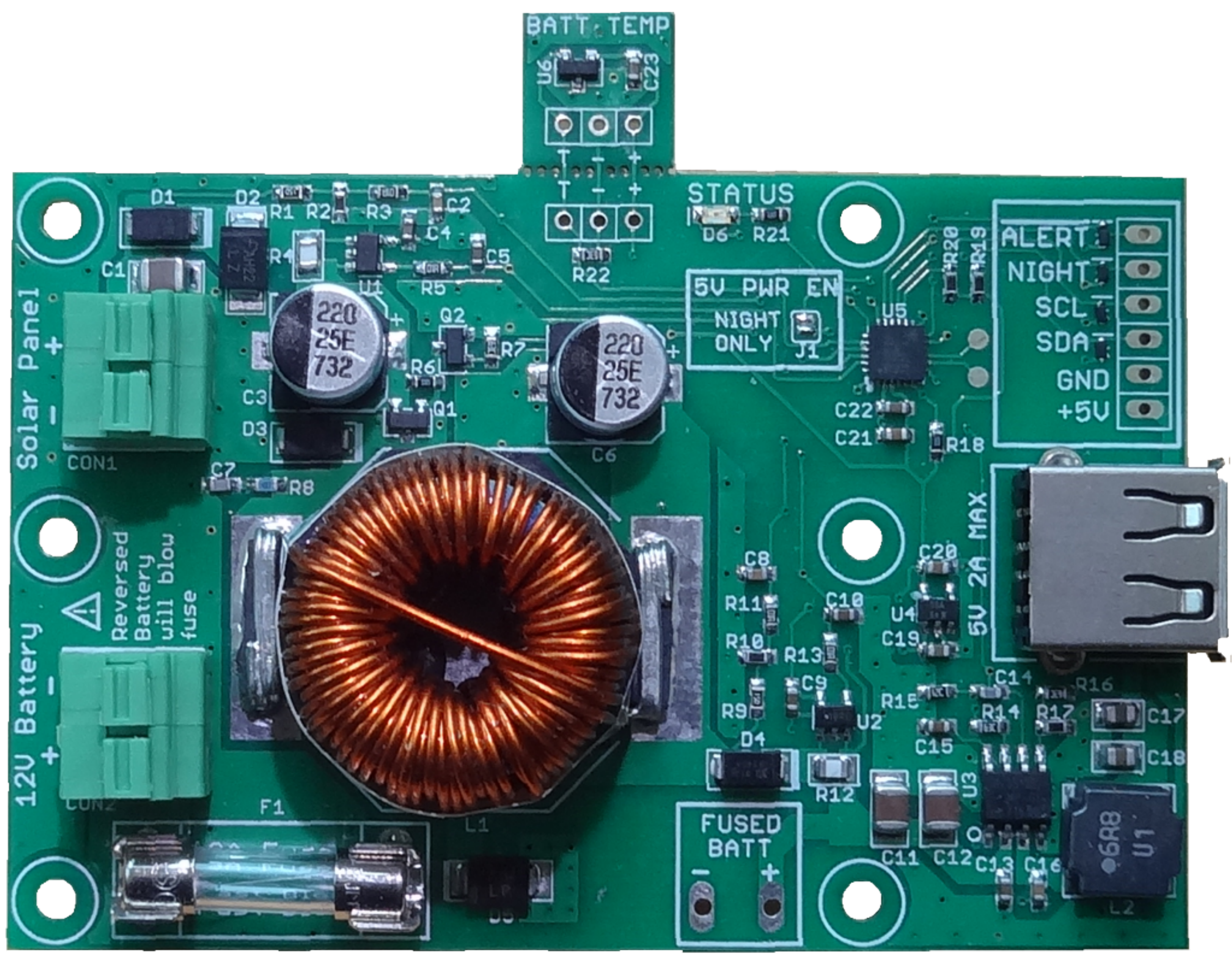
MPPT Solar Charger User Manual



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MPPT Solar Charger

Description

The MPPT Solar Charger is an intelligent solar charging system and power supply designed to provide power to IOT-class devices (Arduino type through Raspberry Pi 3 type) in remote, solar-powered environments. It manages charging a 12V AGM lead acid battery from common 36-cell 12V solar panels. It provides 5V power output at up to 2A for systems that include sensors or communication radios. Optimal charging is provided through a dynamic perturb-and-observe maximum power-point transfer converter (MPPT) and a 3-stage (BULK, ABSORPTION, FLOAT) charging algorithm. A removable temperature sensor provides temperature compensation. Operation is plug&play although additional information and configuration may be obtained through a digital interface making it an ideal companion to intelligent or internet-connected devices.

Features

- Reverse Polarity protected solar panel input with press-to-open terminal block
- Fused battery input with press-to-open terminal block
- Maximum 2A at 5V output on USB Type A power output jack and solder header
- Automatic low-battery disconnect and auto-restart on recharged battery
- Temperature compensation sensor with internal sensor fallback
- Status LED indicating charge and power conditions, fault information
- I2C interface for detailed operation condition readout and configuration parameter access
- Configurable battery charge parameters
- Status signals for night detection and pre-power-down alert
- Night-only operating mode (switch 5V output on only at night)
- Watchdog functionality to power-cycle connected device if it crashes

Applications

- Remote control and sense applications
- Solar powered web cam
- Night-time “critter” cam
- Solar powered LED night lighting controller
- Power supply with battery backup for Raspberry Pi Server or Router

Version Information

Datasheet Revision	Firmware Version	Comments
1.0	1.0	Initial Release for Assembly 35-00082-02

Disclaimer

This product and its documentation are supplied on an as-is basis and no warranty as to their suitability for any particular purpose is either made or implied.

danjuliodesigns, LLC. will not accept any claim for damages howsoever arising as a result of use or failure of this product. Your statutory rights are not affected.

This document and the functionality of the product may be subject to change without notice.

Contact

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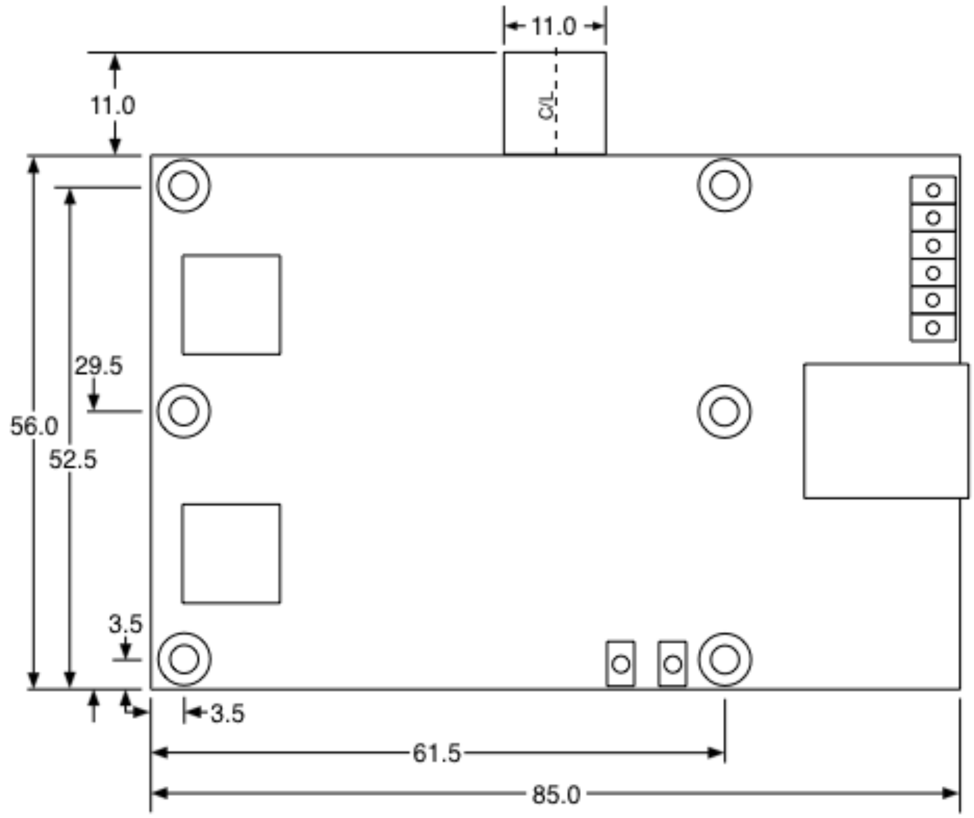
Website: http://www.danjuliodesigns.com

Github:https://github.com/danjulio/MPPT-Solar-Charger

Electrical Specifications

Parameter	Min	Typ	Max	Unit	Conditions/Notes
Battery Supply Range	11.0	12.7	16	V	Six-cell sealed lead acid
Designed-for Battery Capacity	7	9	18	A/hr	Ideal range for max charge current
Battery Charge Current			2.75	A	
Battery Discharge Current			1	A	Maximum 5V 2A load at low Vbatt
Solar Power Input Operating Voltage Range	Battery Voltage + 1.5V		23	V	Designed for 36-cell, 18V nominal (22V open-circuit) solar panels
Solar Power Input Maximum Voltage			25	V	
Solar Power Input Current	0		2	A	
Maximum Battery Discharge Current			3	A	Protected by a 5x20 mm 3A Fast Blow Fuse (Bel 5MF-3-R or equivalent)
Maximum 5V output current			2	A	
5V Supply Range	4.9	5.04	5.1	V	
Charger Burden Current		7	9	mA	Charger power required from battery
Control Signal High Voltage Level	2.5			V	
Control Signal Low Voltage Level			0.6	V	
Control Signal Maximum VOH Drive Current			20	mA	
Control Signal Maximum VOL Sink Current			-20	mA	
I2C Pull-up reference voltage			3.4	V	I2C signals pulled-up to internal 3.3V rail with built-in 10 k-ohm resistors
I2C Operating Frequency	10		100	kHz	
VS, VB Measurement Accuracy	-2		2	%	
IS, IB Measurement Accuracy	-2.5		2.5	%	
External Temperature Sensor Measurement Accuracy	-5		5	°C	
Charge Temperature Range	-20		50	°C	Charge is suspended outside this temperature range
Operating Temperature Range	-30	20	60	°C	
Storage Temperature Range	-40	20	80	°C	

Mechanical Specifications

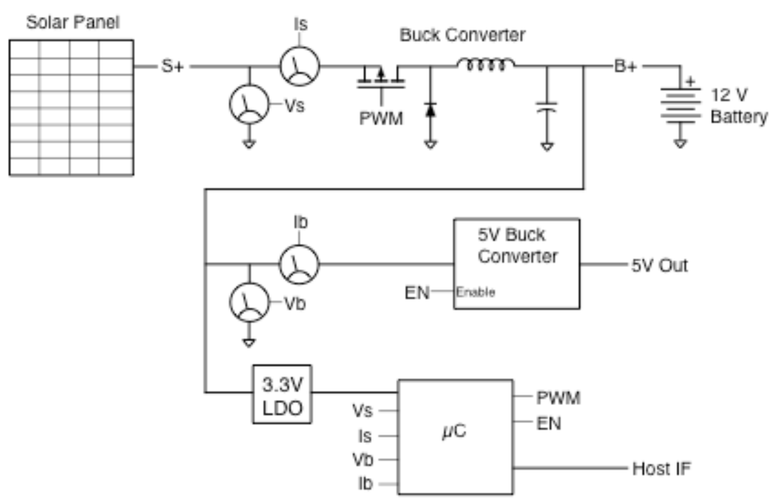


Board Dimensions (mm)

Mounting holes match those of the Raspberry Pi family.

Description

Block Diagram



MPPT Solar Charger Block Diagram

Circuit Description

The MPPT Solar Charger is both a 12V lead acid battery charger and a 5V power supply. It is comprised of two major subsystems controlled by a micro-controller. The first subsystem is a modified Perturb and Observe MPPT charger built around a buck converter used to maintain the solar panel at maximum-power point by controlling the charge current to match the optimal solar panel voltage. The second is a dedicated buck converter with a 5V output at up to 2 A (10W) for the system. The 5V output is automatically disabled when the battery is discharged and re-enabled when the battery recharged. The micro-controller measures voltage and current from the solar panel and from the battery as inputs for its control algorithms.

The system can operate in a completely stand-alone fashion. It also provides a digital interface allowing an external controller to query and configure operating values and status.

The MPPT Solar charger is configured by default to charge 6-cell AGM-style (Absorbent Glass Matt) batteries (e.g. UPS back-up battery). It is designed for “traditional” 12V solar panels. These panels have 36 solar cells with a typical maximum power point under good light of 18V and a maximum open-circuit voltage of 22-23V.

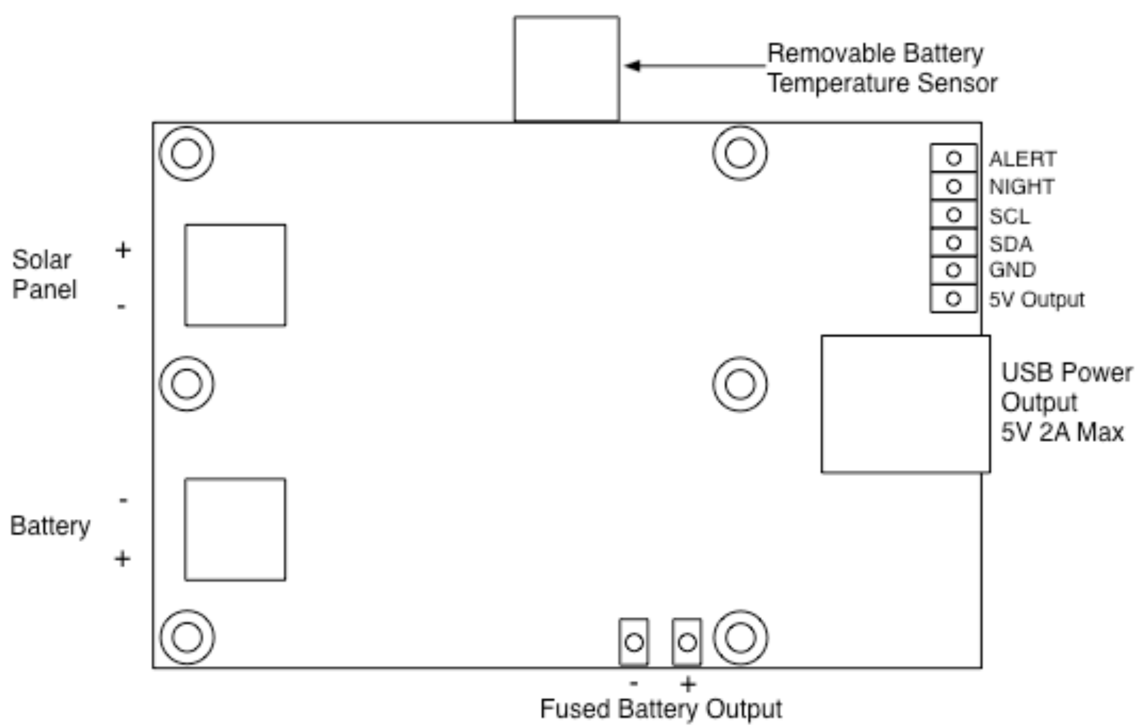
Connections

Connections to the MPPT Solar Charger are made using a variety of standard connectors and with through-hole connectors on 0.1 inch (2.54 mm) centers. The core power connections may be accessed via the standard connectors. The through-hole connectors expose additional functionality and are designed to connect wires directly to single-board power and data connectors.

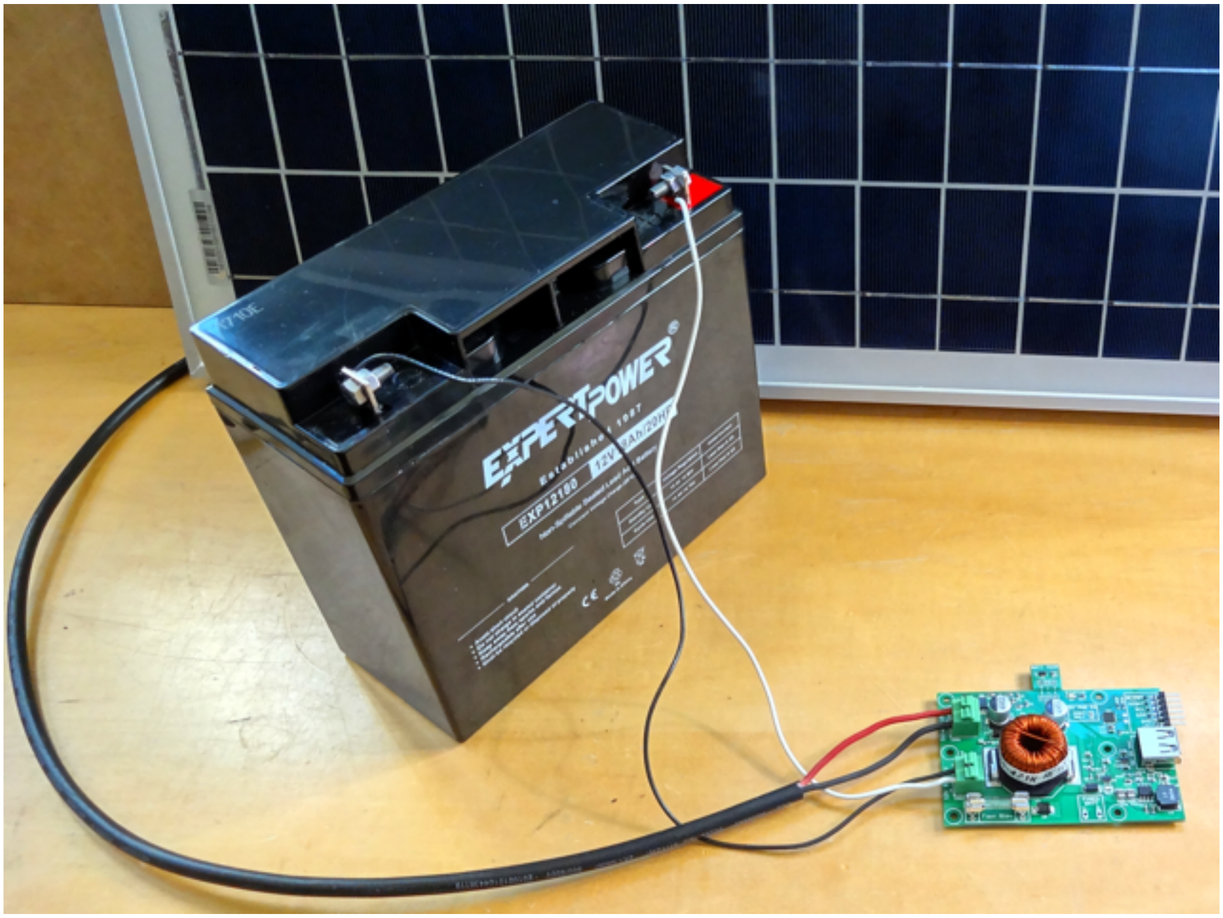
One jumper, described later, allows configuring the charger into a special Night mode.

Important Notes:

1. **Take extreme caution when connecting the 12V lead acid battery to the charger. Although the charger includes a fuse on the battery connection, lead acid batteries are capable of delivering huge amounts of current when shorted that may cause severe injury or fire. Connect wires to the charger before connecting them to the battery.**
2. **Care should be taken when soldering or de-soldering leads to the MPPT Solar Charger through-hole connectors or adding or removing a jumper. Too much heat or pressure may tear the pad or jumper location off the PCB. Use a fine-tip soldering iron and a minimum amount of solder.**



Board Connectors (Top View)



Connected to Solar Panel and Battery

Battery Connection

The MPPT Solar Charger provides a two-terminal press-to-open connector block for the battery connection. Use adequate gauge wire to support at least 3A of current (AWG 20-24). Connect the wires to the MPPT Solar Charger before connecting to the battery to prevent an accidental short. Connect the negative battery terminal before connecting the positive terminal. Wire length should be 100 cm or less.

The MPPT Solar Charger is designed to charge batteries in the 7Ah - 18Ah range. It may be possible to exceed these limitations under certain conditions. The charger can deliver up to 2.75A of current to the battery with a 35W solar panel. This current may exceed the maximum charge current for 7Ah and smaller batteries so these batteries should be used with smaller panels. A 7 Ah battery should be used with a 25W solar panel. Larger batteries may exceed the capabilities of the system to charge fully. However under good lighting conditions with a larger panel, larger batteries may be used.

Typical AGM-style 12V 9Ah battery

Note that reversing the battery connection will cause the fuse to blow. Replace with a 3A Fast Blow 5x20mm fuse (Bel 5MF 3 -R or equivalent).

Solar Panel Connection

The Solar Panel two-terminal press-to-open connector block is designed to connect to commonly available 36-cell "12V" panels. These panels were originally designed to connect directly to 12V lead-acid batteries with reduced efficiency. The MPPT Solar Charger allows these panels to operate at their maximum power-point, typically 17.5-18.5 volts. Panel open-circuit voltage must be under 23V.

Connect the panel's negative wire first, followed by the positive wire. The panel should be shaded during connection. Cable length should be less than 3m.

Typical 35W Panel (cut off the Alligator clips)

The MPPT Solar Charger limits panel current to 2 A for a maximum power transfer of about 35 W making it ideally suited for 35W solar panels. Smaller panels should be used for battery with capacities less than 9 Ah. Larger panels may be used to improve performance in low-light conditions or during winter when solar production is naturally lower.

The following table provides a guideline for sizing solar panels and batteries depending on application. Specific environments may require different sizing.

Panel Size	Battery Capacity	Application
15-20W	4 Ah	Arduino-class device. Constant current consumption from battery < 50 mA.
25W	7 Ah	Wifi-enabled embedded controller like ESP32 or Particle or Raspberry Pi Zero. Constant current consumption from battery < 100 mA.
35W	9-18 Ah	Raspberry Pi 3 type device. Constant current consumption from battery < 200 mA.
50W +	18-25 Ah	Devices with higher current consumption or environments with less light.

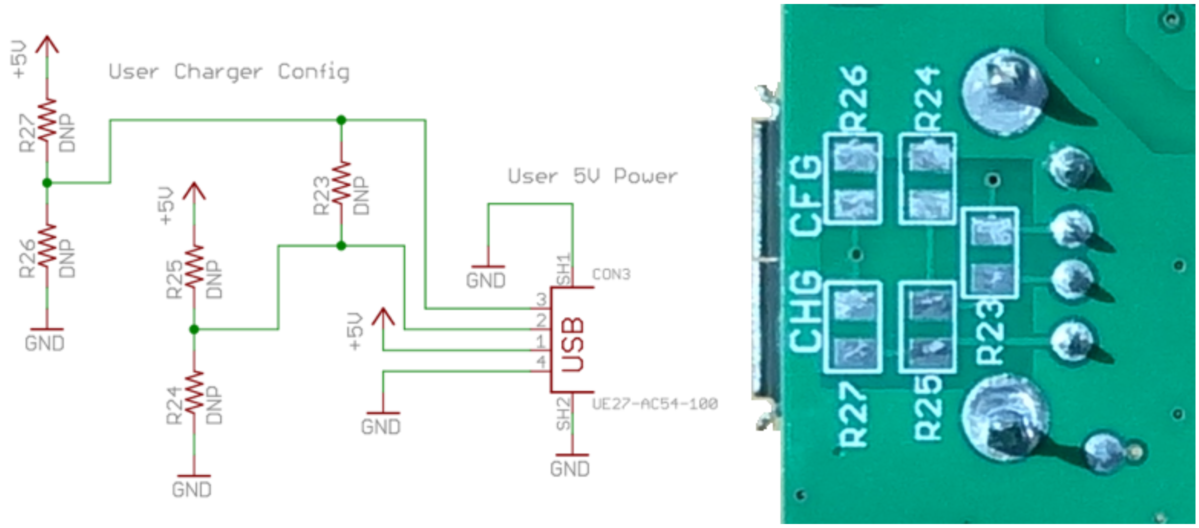
Sizing Guide

USB Port

The USB Port is a power-only port providing up to 2A at 5V. As described later, the charger will disable power under certain conditions such as low-battery or during daylight when the charger is configured for night-only operation.

The USB Port is designed for plug&play operation when powering devices that do not need to communicate with the charger or for using it as a solar power supply (e.g. cellular phone charging).

A user-available expansion capability is provided with five unpopulated 0805 sized SMD resistor locations on the rear of the PCB under the USB connector. These resistors allow connecting the data lines to different voltages for legacy charge current configuration.



Charge Configuration Circuitry

Populating these resistor locations with different resistor values allows configuring several different type of legacy charging current configurations. Values in the following table were taken from the online discussion:

https://electronics.stackexchange.com/questions/123172/what-is-the-ideal-way-to-handle-data-pins-d-and-d-on-a-usb-power-adapter-to-be

Legacy Charge Description	Resistor Configuration
Dedicated Charging Port	R23 <= 200 ohms
Apple 500 mA Charger	R27 = 75.0 k-ohm R26 = 49.9 k-ohm R25 = 75.0 k-ohm R24 = 49.9 k-ohm
Apple 1 A Charger	R27 = 75.0 k-ohm R26 = 49.9 k-ohm R25 = 43.2 k-ohm R24 = 49.9 k-ohm
Sony Charger	R27 = 5.1 k-ohm R26 = 10.0 k-ohm R25 = 5.1 k-ohm R24 = 10.0 k-ohm
Dedicated Charger	R27 >= 2 M-ohm R23 = 0 ohm (short) R24 >= 2 M-ohm

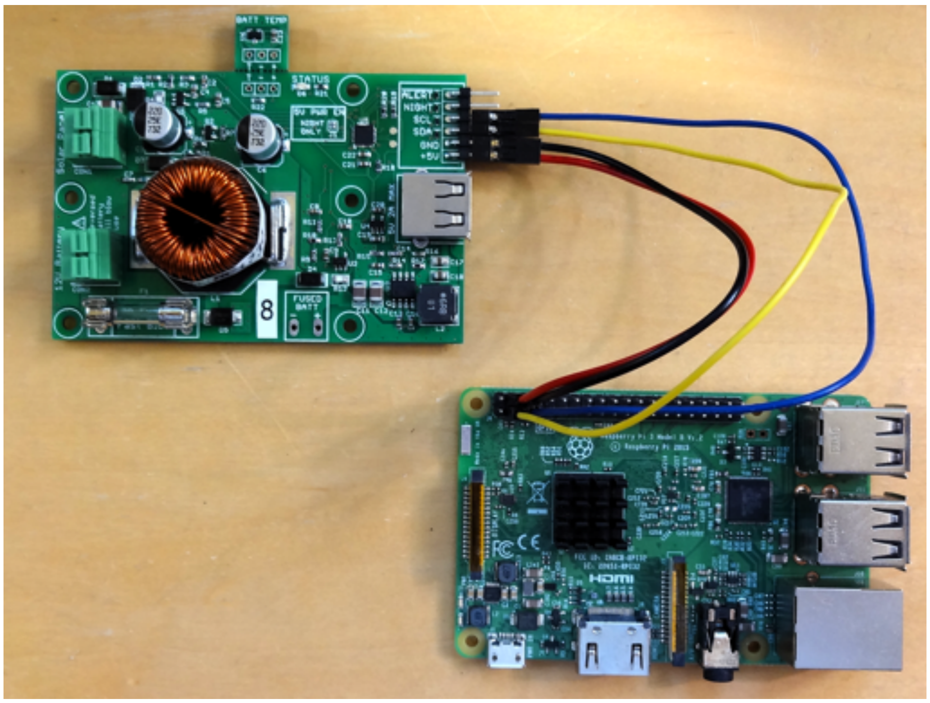
Charge Configuration

Fused Battery Header

The MPPT Solar Charger provides a fused connection to the battery. This connection, and current consumed by the 5V Buck Converter, is limited to less than 3A. This connection passes through the charger's battery current monitoring circuit and is useful for user applications that require unregulated 12V but want to monitor its current consumption.

Expansion Header

The MPPT Solar Charger provides a set of expansion signals and auxiliary power output on a header. These are designed to be connected directly to wires interfacing to the user's circuits or connected to using the provided right-angle header assembly.



Expansion Header connected to Raspberry Pi

Power

Five volt power and the reference ground are available on the header. Total current on both this connector and the USB connector is limited to 2A.

Care must be taken. Shorting the 5V output may result in damage to the charger circuitry.

ALERT

The ALERT signal is an active-low 3.3V logic signal indicating an impending shut-down of the 5V Buck Converter. It is high while power is enabled. It is driven low 60 seconds before power is disabled. It is designed to allow the user's application time for a controlled shutdown or final communication before power is disabled.

NIGHT

The NIGHT signal is an active-high 3.3V logic signal indicating solar panel voltage is below 3.5V and the charger is in the NIGHT state. It may be used by the user's application to enable or disable activities at night.

I2C (SDA and SCL)

The I2C interface allows the user's application to query measured data and status from the charger as well as configure some parameters and manage the watchdog function. The charger includes built-in 10 k-ohm pull-up resistors to a 3.3V power supply. The I2C interface supports 100 kHz data rate and 7-bit addressing. It does not support the General Call function. The I2C interface will inter-operate with 5V powered devices, however these devices should not include pull-up resistors to 5V.

The MPPT Solar Charger 7-bit I2C address is 0x12.

The I2C interface requires support for a small period of clock stretching during read operations. Note that there is a bug in all current Raspberry Pi computers that cause I2C to fail when a slave device stretches the clock. The work around is to run the Raspberry Pi I2C bus at 50 kHz. This may be done by include the following line in the `/boot/config.txt` file.

```
dtparam=i2c_arm_baudrate=50000
```

The I2C Interface is described in detail in the I2C Interface section.

Removable Battery Temperature Sensor

The MPPT Solar Charger provides temperature compensation function on the two charge voltage levels used by the BULK/ABSORPTION and FLOAT charge states. The charger contains two temperature sensors. The external temperature sensor is a small chip (U6) located on the break-off portion of the PCB. The internal temperature sensor is built into the charger's micro-controller (U5). The charger will use the external temperature sensor to adjust (compensate) the battery charge voltage levels based on temperature. It will use the internal temperature sensor if it detects that the external sensor is missing (disconnected).

The temperature sensors should be positioned to measure the approximate battery temperature. Typically it is adequate for the PCB to be adjacent to the battery. However if conditions cause the battery temperature to vary differently than the charger PCB, the external temperature sensor may be "cut-away" from the main PCB by using a fine saw to saw along the perforated lines (take a lot of care not to damage any other part of the PCB). It is then reconnected using three small gauge wires soldered between the header on the separate temperature sensor portion and the main charger PCB ("T" to "T," "-" to "-", and "+" to "+"). In this case the temperature sensor should be mounted near one of the battery terminals (but electrically isolated from it). The wire length should be 60 cm or less and braided together if possible to prevent picking up electrical noise.

Status LED

The Status LED indicates both operating status and fault conditions. Fault conditions take priority over status.

Fault conditions are indicated by a series of blinks repeated every five seconds.

2 blinks : Bad Battery connected. Battery voltage is less than 10.5 volts. Charging and power are disabled.
3 blinks : External temperature sensor is disconnected.
4 blinks : Temperature exceeds charge range (-20°C - 50°C). Charging is disabled.

Operating status is shown as follows.

1. One short blink every 10 seconds : Output power disabled because of low-battery and the system is not currently charging.
2. One short blink every 5 seconds: Output power is enabled and the system is not currently charging.
3. Pulsing : Charging. Pulse brightness indicates charging power level.

Operation

The battery must be connected for the MPPT Solar Charger to operate. It starts up with charging disabled. Five volt power is enabled if the battery voltage exceeds the Low Battery Threshold (11.5V by default). Power and charging are disabled, and a fault indicated on the Status LED, if battery voltage is below the Bad Battery Threshold (10.5V).

Battery Charger

The charger implements the BULK/ABSORPTION/FLOAT charge model using a state machine. It uses solar panel voltage, two temperature compensated battery voltage thresholds and an estimate of battery charge current to transition between states. A scan function is used to initially, and periodically, set or reset the maximum power point solar panel voltage. The charger ramps the solar panel voltage between its open-circuit voltage and 1.5 volts above the battery voltage during the scan function and records the point of maximum power as the starting point for the MPPT algorithm.

Night Charge State

The charger enters NIGHT state whenever the solar panel voltage is below 3.5 volts. When transitioning from day to night the charger will move from IDLE to NIGHT state five minutes after the voltage is first detected below 3.5 volts. When transitioning from night to day the charger will move from NIGHT to IDLE one minute after the voltage is first detected above 3.5 volts. These timeouts provide a hysteresis function to prevent errant or multiple transitions.

The charger asserts the NIGHT signal during this state.

Idle Charge State

The charger enters IDLE state when the solar panel voltage is above 3.5 volts (not nighttime) but there is not enough energy to commence charging. The charger will transition from one of the charge states (BULK, ABSORPTION or FLOAT) to IDLE after 15 seconds of power production from the solar panel of less than 100 mW. The charger transitions from IDLE to one of the charge states through the scan function, initially starting in the VS Recover Charge STATE (VSRCV) when the solar panel voltage exceeds 18 volts.

VS Recover Charge State

The charger enters VSRCV state from IDLE when charging is initiated. It also enters VSRCV periodically (every 10 minutes) from one of the charge states while the MPPT algorithm is running. The VSRCV state is used to setup the scan function. It disables power consumption from the solar panel for three seconds in order to allow the panel voltage to increase to its open-circuit value. The charger transitions to the Scan Charge State from VSRCV.

Scan Charge State

The charger enters SCAN state from VSRCV when the scan function is initiated. During the scan function the charger enables charging and measures the output power of the solar panel (watts) while it reduces the panel voltage to within

1.5 volts of the battery voltage by modifying the charger buck converter parameters. It records the panel voltage at the maximum power for use as the initial maximum power point setting.

The charger transitions to the Bulk Charge state at the end of the scan function if the battery voltage is less than 12.7 volts. It transitions to the Float Charge state at the end of the scan function if the battery voltage is 12.7 volts or higher.

The charger suppresses the scan function when the MPPT algorithm is not running. The MPPT algorithm doesn't run when the solar panel is capable of putting out more current than the battery is consuming (a condition that may occur while it is ABSORPTION or FLOAT charge states).

Bulk Charge State

The BULK state is used to provide the maximum charge current to the battery. The charger will supply the battery with as much power as it can until the battery voltage is equal to the BULK/ABSORPTION Charge Threshold (14.7V by default). Then it transitions to the Absorption Charge State.

The charger will spend a maximum of 10 hours in Bulk and Absorption Charge states during any one charge cycle.

Absorption Charge State

The ABSORPTION state is used to complete charging of the battery. The charger attempts to maintain the battery voltage at the BULK/ABSORPTION Charge Threshold until the battery charge current is less than 300 mA for 30 seconds. Then it transitions to the Float Charge State.

The battery voltage may naturally decline from the BULK/ABSORPTION Charge Threshold when solar production falls off and the charger cannot supply the current the battery is capable of sinking.

Float Charge State

The FLOAT state is used to maintain a battery charge. The charger attempts to maintain the battery voltage at the FLOAT Charge Threshold (13.65V by default) as long as the solar panel is producing adequate power.

The battery voltage may naturally decline from the FLOAT Charge Threshold when solar production falls off.

MPPT Algorithm

The MPPT Solar Charger implements a Perturb and Observe (P&O) algorithm for determining maximum power point. It uses the buck converter to set the panel voltage and measurements of panel voltage and current to determine solar production in watts. It then adjusts the panel voltage slightly based on past history to try to increase production. The algorithm is initialized, and occasionally re-initialized, with the current maximum power point by the scan function.

The algorithm uses a dynamic solar panel voltage step size based on the solar panel current. It uses a larger step size when the current is low in order to more accurately predict which way to adjust the panel voltage during the perturb. It uses a smaller step size when the current increases to reduce the power variability that is the hallmark of the P&O algorithm.

The algorithm is suspended while the panel is capable of putting out more power than the battery charging (and system load) requires.

Temperature Compensation

The MPPT Solar Charger contains two temperature sensors. The external temperature sensor is a small chip (U6) located on the break-off portion of the PCB. The internal temperature sensor is on-board the charger's micro-controller (U5). The charger will use the external temperature sensor to adjust (compensate) the battery charge threshold levels. It will use the internal temperature sensor if it detects that the external sensor is missing (disconnected).

The charger uses the following temperature compensation values from the default at 25°C.

1. -30 mV/°C during Bulk/Absorption charging (adjusts BULK/ABSORPTION Charge Threshold from the default)
2. -18.8 mV/°C during Float charging (adjusts FLOAT Charge Threshold from the default)

Battery Configuration

The MPPT Solar Charger is designed to charge AGM-style batteries by default. It provides access to the BULK/ABSORPTION and FLOAT Charge threshold values that may be adjusted through the I2C interface from the default at 25°C to support other lead-acid battery chemistries. Refer to the battery spec sheet for the appropriate values. These values must be updated every time the charger is connected to a battery (volatile).

1. BULK/ABSORPTION Parameter: Default 14.7 volts. May be adjusted between 14.0 and 15.0 volts.
2. FLOAT Threshold Parameter: Default 13.65 volts. May be adjusted between 13.0 and 14.0 volts.

Low Battery Handling

The MPPT Solar Charger detects two low-voltage conditions.

1. Bad Battery: The battery is discharged to a level (below 10.5V) that indicates it is no longer capable of being charged. The charger indicates this as a fault on the Status LED and disables both charging and 5V power.

2. Low Battery: The battery is almost completely discharged (below the Low Battery Threshold of 11.5V by default) and power must be disabled to prevent damage to it.

Battery status is available via the I2C interface.

The battery must be replaced if the charger indicates it is bad.

When the battery voltage falls below the Low Battery Threshold for more than 60 seconds the charger will initiate a power shutdown by first asserting the ALERT signal and then switching off the 5V Buck converter 60 seconds after that. A power shutdown, once initiated, cannot be stopped by a recovering battery voltage.

After the charger disables power due to a low battery, it will keep power disabled until the battery has been charged to a voltage above the Restart Battery Threshold (default 12.5V). It then de-asserts the ALERT signal and re-enables the 5V power output. It must see at least one hour of charging before it will re-enable power to prevent a nearly dead battery from recovering without being charged.

Night Only Operation

Jumping the J1 jumper with a blob of solder enables Night Only operation. Night Only operation only enables 5V power while the charger is in the NIGHT state (the Night signal is asserted). When the charger transitions out of NIGHT state, it will first assert the ALERT signal and then switch off the 5V Buck converter 60 seconds after that. When it transitions into NIGHT state, it will de-assert the ALERT signal and re-enable the 5V power output.

Night Only Jumper

The solder jumper can be bridged using a soldering iron to deposit a small blob of solder across the two pads. It can be un-bridged by using solder-wick to remove the solder or dragging a fine tip between the two pads after applying flux to cause the solder to separate into two blobs. Take care to use a fine soldering iron tip and not rip up the jumper pads.

Night Only operation is useful for applications like night lighting or devices like “critter cams” that should only function at night. It allows power saving during the day while the battery charges.

Watchdog Operation

A watchdog function may be enabled that requires the user application to write an I2C register within a specified period. Failure to write the control register causes the 5V power to be cycled for 10 seconds. The watchdog function may be used to assure the user application doesn’t hang.

By default the watchdog function is disabled. Two I2C registers control the watchdog function.

1. Watchdog Enable (WDEN) : An 8-bit register than enables the watchdog function. Writing 0xEA to this register enables the function. Writing any other value disables the function.
2. Watchdog Count (WDCNT) : An 8-bit register that contains the watchdog timeout in seconds. Writing a value of 1 - 255 sets the watchdog timeout. This register must be re-written with a new non-zero timeout value before the current value counts down to zero or the power will be cycled. Writing a 0 to this register disables the function.

Both registers must be written with valid values for the function to be enabled. After power has been cycled due to a watchdog timeout, the function is reset and must be re-enabled by the user application.

I2C Interface

Description

The MPPT Solar Charger implements a slave I2C interface providing access to a set of internal 8- and 16-bit registers. These registers are split into three categories described in this section.

1. Read-only 16-bit charger state and measurement values
2. Read-write 16-bit charger configuration parameters
3. Read-write 8-bit watchdog control registers

The charger operates at up to 100 kHz I2C clock rate with a 7-bit I2C address of 0x12. It supports repeated starts but does not support General Call.

Important Notes regarding I2C on the Raspberry Pi

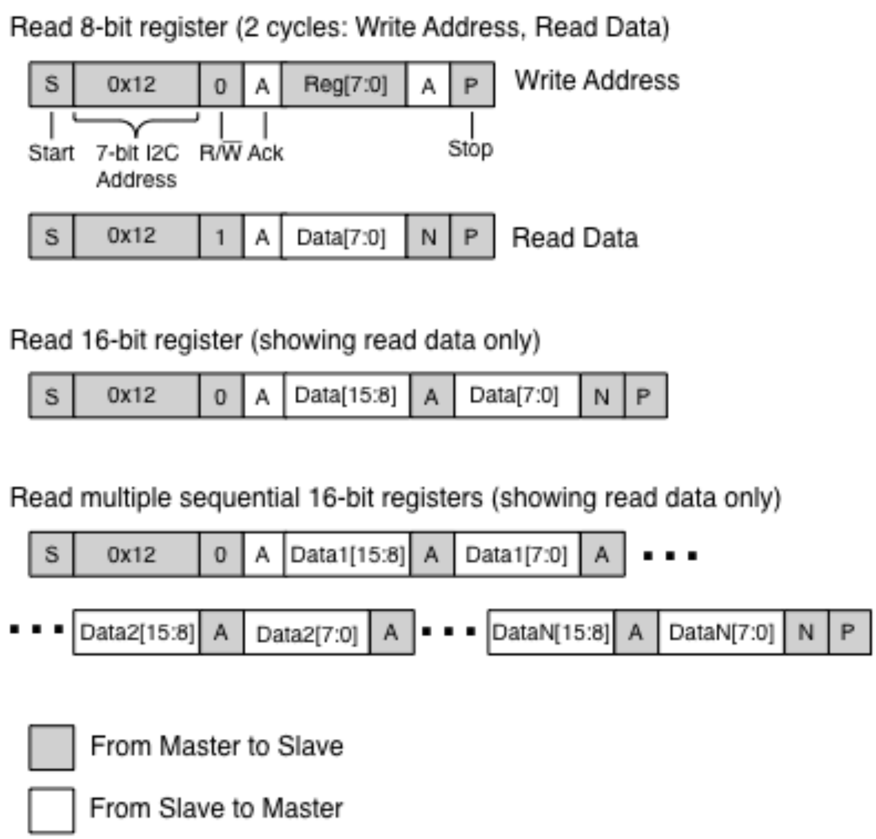
There is a hardware bug in the microprocessors used by all current Raspberry Pi computers that causes a malfunction with any I2C slave, like the charger, that can extend the I2C clock. The charger has been designed to minimize I2C clock extension but the Raspberry Pi I2C clock must be configured to 50 kHz or less in order for the hardware bug to be avoided. This can be done by adding the following line to the /boot/config.txt file.

```
dtparam=i2c_arm_baudrate=50000
```

I2C Cycles

Registers are accessed using an indirect register-address scheme. They may be read or written individually or sequentially in a burst. The 8-bit register address must be written first. The high-half (bits 15:8) of 16-bit registers are presented on the bus before the low half.

I2C Write Cycles



I2C Read Cycles

Charger Registers

Register Address	Type	Size	Description
0	RO	16-bit unsigned	ID : Board ID and firmware version
2	RO	16-bit unsigned	STATUS : Board Status
4	RO	16-bit unsigned	BUCK STATUS : MPPT Buck converter status
6	RO	16-bit unsigned	VS : Solar Panel Voltage in mV
8	RO	16-bit unsigned	IS : Solar Panel Current in mA
10	RO	16-bit unsigned	VB : Battery Voltage in mV
12	RO	16-bit unsigned	IB : Battery load current in mA (current taken by load)
14	RO	16-bit signed	IC : Estimated battery charge current in mA
16	RO	16-bit signed	IT : Internal (U5) temperature sensor value in °C x 10 (25°C = 250)
18	RO	16-bit signed	ET : External (U6) temperature sensor value in °C x 10
20	RO	16-bit unsigned	VM : Current MPPT solar panel set voltage in mV
22	RO	16-bit unsigned	TH : Current battery charge set voltage in mV. This is the temperature compensated version of either BULKV or FLOATV depending on the charge state.
24	RW	16-bit unsigned	BULKV : Adjustable parameter for BULK/ABSORPTION charge state battery voltage in mV at 25°C. Default 14700 mV. Must be a value between 14000 - 15000.
26	RW	16-bit unsigned	FLOATV : Adjustable parameter for FLOAT charge state battery voltage in mV at 25°C. Default 13650 mV. Must be a value between 13000 - 14000.
28	RW	16-bit unsigned	PWROFFV : Adjustable parameter for low-battery power-off threshold in mV. Default 11500 mV. Must be a value between 11000 - PWRONV. PWRONV should be updated before PWROFFV.
30	RW	16-bit unsigned	PWRONV : Adjustable parameter for battery recharged power restart threshold in mV. Default 12500 mV. Must be a value between 12000 - 1300. PWRONV should be updated before PWROFFV.
33	RW	8-bit unsigned	WDEN : Watchdog enable register. Write a value of 0xEA to this register to enable the watchdog function (WDCNT must also be written with a non-zero value to enable the watchdog function). This register will read 0x01 if the watchdog has been enabled and 0x00 if the watchdog is disabled.

Register Address	Type	Size	Description
35	RW	8-bit unsigned	WDCNT : Watchdog count register. Write a value between 1 - 255 seconds to this register to set the watchdog timeout. Write a value of 0 to disable the watchdog function. Reading this register returns the number of seconds remaining before a watchdog reset. WDEN must also be enabled to start the watchdog timer counting down.

Board ID Register

Bit(s)	Type	Description
15:12	RO	Board ID : This hardware version reads 1 for Board ID
11:8	RO	Reserved. Returns 0
7:4	RO	Firmware Version Major Value (0 - 15)
3:0	RO	Firmware Version Minor Value (0 - 15)

STATUS Register

Bit(s)	Type	Description
15	RO - clear when read	Internal Watchdog Detected : The firmware detected an internal watchdog timeout and reset. This is separate from the Watchdog function which can be used to power cycle the user's application. It may be set by transient conditions such as bouncing supply voltages upon connecting the battery. This bit will be cleared the first time it is read.
14	RO - clear when read	Power Watchdog Executed : The Watchdog function triggered a power-cycle of the load. This bit will be cleared the first time it is read.
13	RO	Bad Battery Status : A bad battery condition has been detected. Note that the charger power will not be enabled so the user's device must have another power supply to read this status bit set.
12	RO	External Temperature Sensor Missing : The external temperature sensor value reads less than -40°C and it is assumed to be disconnected. Compensated battery charge thresholds are being computed based on the internal temperature sensor.
11:9	RO	Reserved. Returns 0.
8	RO	Watchdog Running. Set when the Watchdog function is enabled and running. Clear when the watchdog
7	RO	Power Enable : 5V power is enabled. Note that the user's device must have another power supply to read this status bit if power is disabled.

Bit(s)	Type	Description
6	RO	Alert Asserted : The ALERT output is being driven indicating that 5V power will be disabled due to a low-battery or night condition (if the jumper is bridged) within 60 seconds or is currently disabled.
5	RO	5V PWR EN Jumper : Indicates the state of the jumper. Set when the jumper is bridged, clear when the jumper is open.
4	RO	Charger Temperature Limit : Set when charging in inhibited because the temperature measured by the active temperature sensor is below -20°C or above 50°C.
3	RO	Night Detected : Set when the night condition has been detected, clear otherwise.
2:0	RO	Charger State: 0 : NIGHT - Not charging; VS < 3.5V 1 : IDLE - Not charging; 3.5V < VS < 18V 2 : VSRCV - Charger disabled for 3 seconds to let the solar panel voltage float upward to open-circuit voltage prior to a scan function. 3 : SCAN - Scan function in progress. Charger enabled and MPPT solar panel set voltage scanned through the range starting with the solar panel open-circuit voltage down to 1.5V above the current battery voltage to determine the solar panel's current maximum power point. Typically requires 4-7 seconds. 4 : BULK - Charger in Bulk Charge State. 5 : ABSORPTION - Charger in Absorption Charge State. 6 : FLOAT - Charger in Float Charge State.

BUCK STATUS Register

Bit(s)	Type	Description
15:6	RO	Charger buck converter PWM value (0-1023) indicating duty cycle (0-100%).
5:2	RO	Reserved. Returns 0.
1	RO	Buck Limit 2 : Set when the buck converter is limiting due to solar over-current or battery over-voltage limit.
0	RO	Buck Limit 1 : Set when the buck converter is limiting to keep the battery voltage at the specified threshold.

Charger Configuration Parameters

BULKV and FLOATV allow the user to change the battery charge voltage thresholds to account for different lead acid battery types. These values may only be changed within the specified range. The charger will limit values outside the range.

PWROFFV and PWRONV allow the user to change the low-battery shutdown and power-restart voltage thresholds respectively. The default values are industry standards but the user may wish to adjust them for specific situations.

These registers may be changed at any time and are usually written to by the user's application when it starts operating. They may also be maintained by the `mpptChgD` daemon on linux single-board computers.

Watchdog Function

The watchdog function may be enabled to allow the charger to power-cycle the user's application if it fails to update the charger's WDCNT register periodically. This may be helpful to handle cases where the user's application has locked-up or crashed.

Both the WDEN and WDCNT registers must be written to enable the watchdog function. The WDEN register must be written with the special value 0xEA and the WDCNT written with a non-zero value. This is a safety feature to minimize the possibility that an errant write accidently enables the watchdog function without the user application knowing this has happened. Writing any other value to WDEN or 0 to WDCNT will disable the watchdog function.

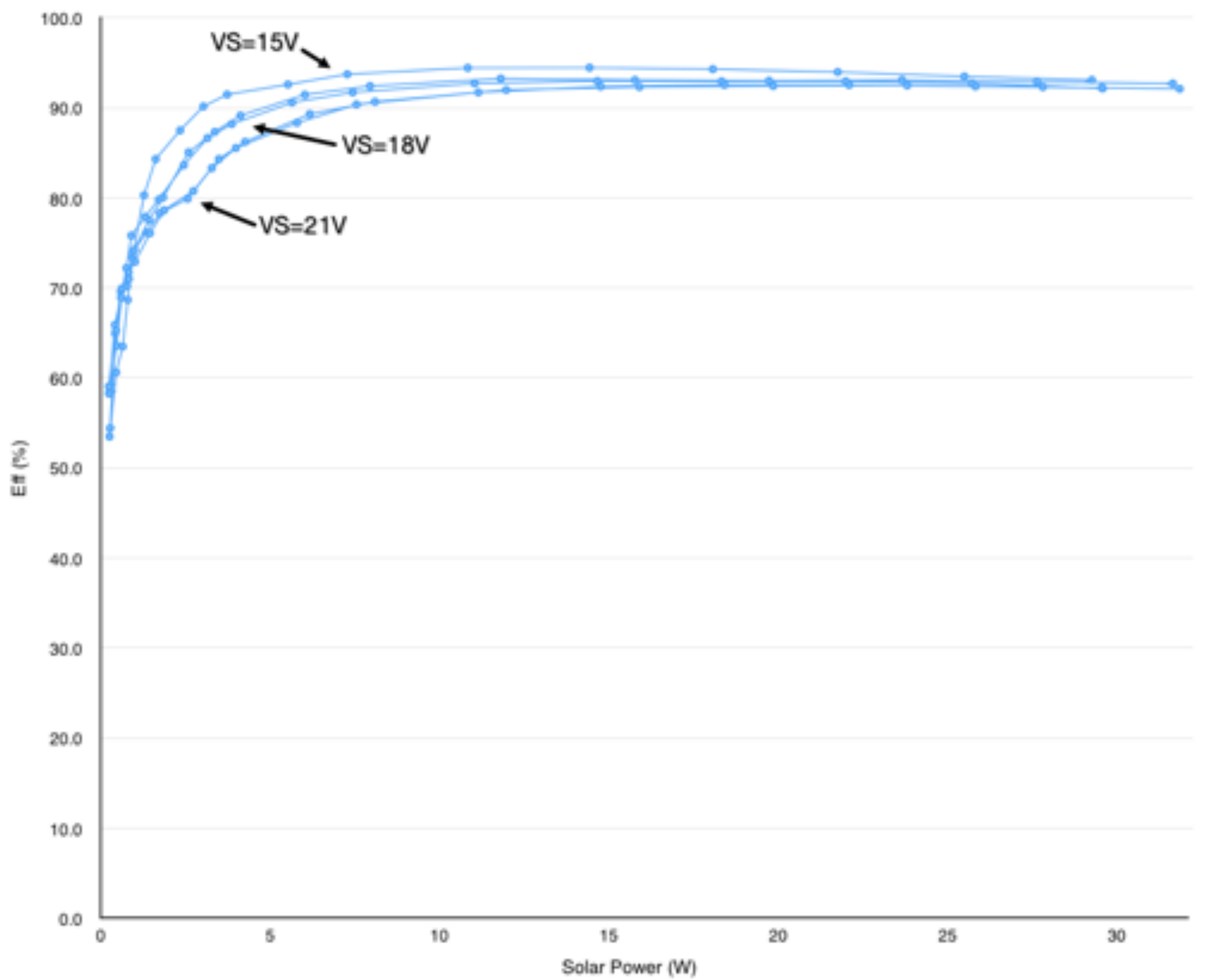
When enabled the WDCNT register is decremented once per second. When it reaches zero the Alert signal is asserted and then 5V power is switched off for 10 seconds and then switched back on and Alert de-asserted. The user application must repeatedly write a new non-zero value to WDCNT before it counts down to zero in order to keep the watchdog function from cycling power. For example it could set WDCNT to 60 and then at an interval of less than 60 seconds update the WDNT register to 60 again to prevent the watchdog function from executing.

The Power Watchdog Executed bit in the STATUS register is set when power is cycled by the watchdog function so the user application can identify cases where it was reset. The watchdog function is disabled after it cycles power and must be explicitly re-enabled by the user's application.

Appendix A : Buck converter efficiency charts

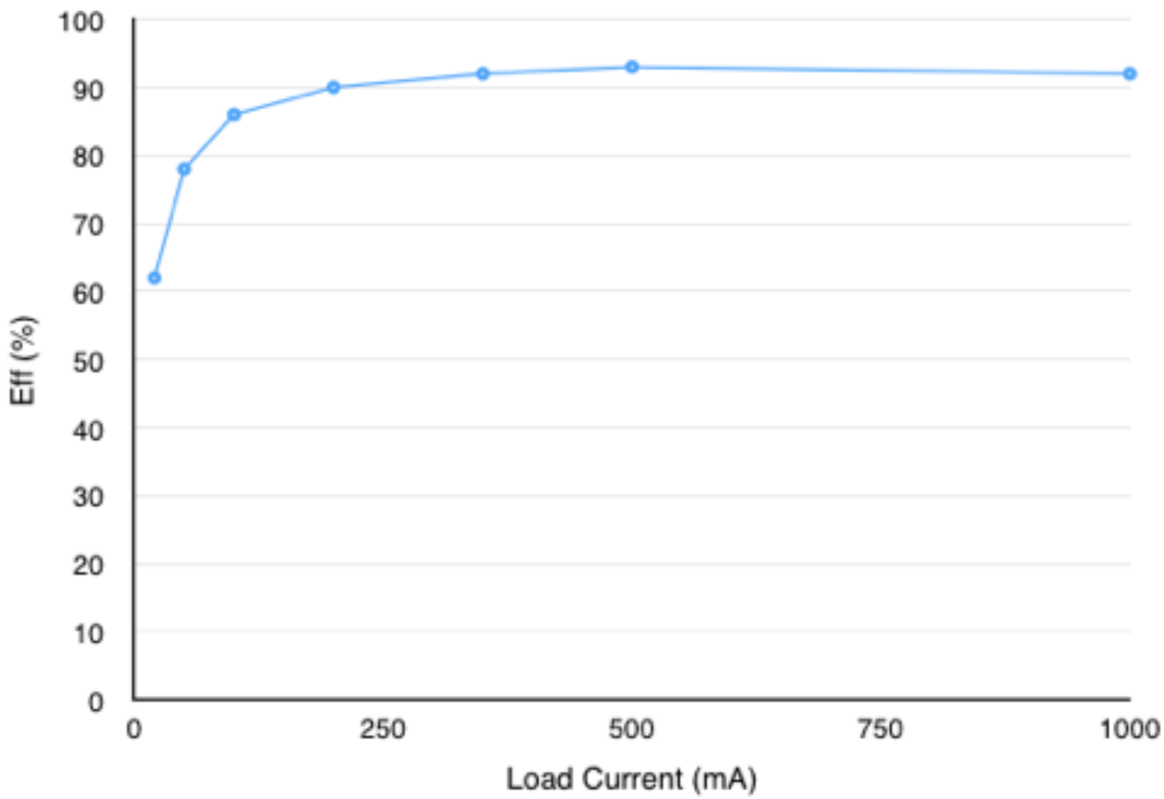
MPPT Buck Converter

Measured data for a variety of charge conditions.



5V Buck Converter

Data taken from the Diodes Inc AP3512E datasheet.



Appendix B : Calculating required charge power

Generating power using solar energy is a complex topic. This appendix describes one method for sizing the solar panel and battery for a user's specific application. The method has four steps.

1. Determine daily application power requirement
2. Determine maximum daily battery discharge
3. Determine required solar power
4. Size panel

This method is based on a 24-hour charge/discharge cycle with the goal of keeping the daily battery discharge to a specified percent given average assumptions about daily sunlight levels. Daily sunlight levels vary considerably, due to weather and season of the year, and accounting for all variability is beyond the scope of this guide. The user should take their specific environmental conditions into account, for example calculating Panel Size using conditions in the season with the least sunlight or choosing a smaller daily battery discharge level to accommodate conditions where solar production might be minimal on some days.

Daily Application Power Requirement

The Daily Application Power Requirement is the amount of power, in watts, that the user's application requires in a 24-hour period.

For an application powered by the 5V output this is as simple as multiplying the current consumption by 5V and by 24 hours. For example if the user application requires an average of 200 mA during the entire day, the Daily Application Power Requirement is

0.2 x 5.0 x 24 = 24 Watts

Since the 5V Buck Converter is not 100% efficient power consumed at the 5V output must be derated by the buck converter efficiency at the load current that can be taken from the 5V Buck Converter graph in Appendix A. The efficiency of the converter with a load current of 200 mA is about 90% so the Daily Application Power Requirement from the 5V output is

24 Watts / 0.90 = 26.7 Watts

The equation is more complex if the user application also uses power from the Fused 12V output since the battery voltage decreases as it is discharged and increases as it is recharged. An estimate of 12.5V may be used assuming the user application maintains the battery at least 67% charged. The Daily Application Power Requirement from the Fused 12V output is simply the current multiplied by the average voltage multiplied by 24 hours.

Current (A) x 12.5 x 24

The MPPT Solar Charger itself presents an approximate 7 mA load to the battery. Assuming a partially charged battery voltage of 12.5V this is an additional daily power requirement of 2.1 Watts that must be added to the average from the user's application. For our example

Total Daily Application Power Requirement = 26.7 + 2.1 = 28.8 Watts

Daily Battery Discharge

Many factors impact the functional lifetime of a lead acid battery.

- The natural degradation mechanism of oxidation of the grid and plate materials is a common failure mode for batteries maintained on a float charge (the MPPT Solar Charger may maintain a battery for part of a day, after bulk charging, with a float charge).
- Loss and changes to materials on the positive plate result in loss of capacity over time.
- Design life. Manufacturers provide batteries with a range of design life typically ranging from 3 to 10 years at different price points.
- Temperature. Battery life is degraded at increased temperature levels.
- Cycle Service. Battery life is reduced with deep discharge cycles. A battery consistently discharged to a 70% capacity may allow double the number of discharge cycles as a battery consistently discharged to 50% capacity.

All of these considerations should be taken into account when selecting a battery. For the purposes of this guide, we will consider Cycle Service and a goal of maximum 30% discharge per day (70% capacity). Total battery capacity in watts may be roughly estimated by multiplying the Ah rating by 12V. The amount of power available daily for the user's application is then 30% of that number. A battery should be selected that can provide that power or more daily. The table below shows these values for common battery sizes.

Battery Rating	Total Capacity	30% Capacity
7 Ah	84 W	25 W
9 Ah	108 W	32 W
12 Ah	144 W	43 W
15 Ah	180 W	54 W
18 Ah	216 W	65 W

Estimating Battery Capacity

This example application, as can be seen from the table, requires at least a 9 Ah battery to maintain a maximum 30% discharge level per day (assuming the solar panel can provide enough current to recharge it each day).

An occasional deep discharge will not significantly harm the battery.

Required Solar Power

The Required Solar Power is the amount, accounting for charging inefficiencies, that is required to prevent the battery from being discharged past the desired amount each day. There are two primary sources of inefficiency in the charging system.

1. MPPT Buck Converter Efficiency. Power is lost during the power conversion from solar panel voltage to battery charging voltage by the MPPT Buck Converter. Its efficiency is a function of both the power being transferred and the difference in voltages as shown in the MPPT Buck Converter efficiency table in Appendix A.
2. Lead Acid Battery Charging Efficiency. Lead acid batteries are not 100% efficient at storing energy. A typical industry figure is 85%.

An estimate of the Required Solar Power may be made by taking the Total Daily Application Power Requirement and dividing by both the MPPT Buck Converter Efficiency and the Lead Acid Battery Charging Efficiency. Since most of the charging will be done when the solar panel is producing significant power, an reasonably conservative estimate of 90% is used for the MPPT Buck Converter Efficiency.

Required Solar Power = 28.8 / (0.90 x 0.85) = 37.6 Watts

Panel Sizing

Solar Panels are typically specified by testing the panels using Standard Test Conditions (STC). The STC measures the panel's output using common conditions of light exposure, orientation and panel temperature. Under direct exposure to full sunlight the panels can produce even more than the STC although most of the time they will produce less (often much less) power. The MPPT Solar Charger is capable of obtaining the full power output of a solar panel because it can operate the panel at its optimal point (as indicated by the panel specifications created from the STC).

The total amount of power produced by the panel, at a given orientation, during the entire year, must exceed the Required Solar Power almost every day. Typically this is ensured by selecting a panel that can produce this much power during peak sun-hours during the lowest energy producing time of year (for example, winter in North America).

Panels should always be aligned to try to maximize the sunlight falling on them. This orientation is generally selected for the sun's position during the lowest energy producing time of the year. Solar panel production falls off dramatically when the sun is not shining directly on the panel or when the panel is partially shaded.

There are many on-line resources for determining how much power a solar panel can produce at specific locations around the world. An example is shown below. Generally these resources are geared at sizing large-scale solar systems.

https://www.solarpowerauthority.com/how-to-calculate-your-peak-sun-hours/

Since there are many conditions that reduce the solar panel's production of power, it is reasonable to add an additional derating factor.

For our example a 25 watt panel under full sun can supply our hypothetical application's Required Solar Power in

37.6 / 25 = 1.5 Hours

A 50% derating factor to allow for inefficiencies due to panel orientation, dust on the panel and sun variability (e.g. occasional cloud cover) increases the time to

1.5 / 0.5 = 3 Hours

Note that this is time in a good light. It shows that a 25 watt panel is reasonable for many parts of the world for this application.

As a general rule, 25 W panels are probably adequate for small power consumption systems like this. Thirty-five or forty watt panels should be used for larger power consumption systems.

Final Note

This guide describes the steps to calculate the minimum sized solar panel and battery necessary for a specific user application. Often these components are over-sized to account for other conditions. Over sizing slightly is recommended. However some limitations should be noted that may limit gains from large increases in solar panel or battery sizes.

1. The MPPT Solar Charger limits solar current to 2A (resulting in a maximum charge current of up to 2.75A for high panel voltages). Capacity beyond this will be wasted by larger solar panels during full sunlight. However larger panels will be able to produce more useful current in low-light conditions.
2. The charge current limits of the MPPT Solar Charger may be too low to fully charge or maintain large capacity batteries.