
Single Chip MPPT with Backup Battery and LED Light

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INTRODUCTION

Price reductions for batteries, solar panels and high efficiency LEDs in the last decade have made solar-powered lights a very attractive alternative for places where utility power is not available or cables are not convenient to install. A small solar panel with a battery and an LED lamp can provide light without any kind of electrical mains connection or maintenance.

Using a charge controller that can perform Maximum Power Point Tracking (MPPT) can result in considerably less wasted power, which makes the design more efficient and ultimately more cost-effective. If using Li-Ion batteries, it is recommended that the charge controller state machine properly test for end-of-charge conditions to prevent premature battery failure. A charge controller that can perform MPPT can be expected to store more than 90% of a solar panel's available power into the battery, and a proper charging procedure will ensure hundreds of charge cycles before the loss of capacity becomes significant.

OVERVIEW

Microchip's MCP19215 Digitally Enhanced Power Analog (DEPA) controller [1] can perform all these tasks as a single-chip solution and is ideal for robust applications with added intelligence from the microcontroller core.

The chip is dual-channel, meaning in this particular application, it can charge the battery while the LED lamp is on. Essentially, the application controls two SEPIC converters that function independently, one charges the battery while the other one drives a string of LEDs. Each channel can control both voltage and current. For the LED string, both the current and maximum voltage are controlled on the output side of the converter. For the battery charging part, things are more complicated because MPPT mechanisms must be incorporated.

To perform the Perturb & Observe (PO) MPPT [2], the panel voltage and current must be sampled, and at least one parameter must be controlled by the converter.

For the battery charging, ideally, both voltage and current are controlled, but voltage is critical (high voltage will damage the battery). The implementation uses the current loop for the panel input and the voltage loop for the output to the battery. Consequently, the battery voltage is tightly controlled by hardware and the panel power (delivered into the battery) is controlled by limiting the panel current.

PO MPPT works by modulating and measuring the panel power, and the best way to do this is to change the panel voltage setpoint. However, this is not possible in this case because the voltage control loop is used for the battery, so the current control loop is used instead. While controlling the panel voltage inherently protects the charger from collapsing the input voltage, this problem becomes evident when controlling the current and is solved by setting a minimum operating voltage as a percentage of the panel operating voltage.

On the battery side, current is not controlled or sampled; instead, the input power is limited and the battery current is estimated compared to the charging voltage (in constant voltage mode). This is a good strategy to extract as much power as possible from the panel while protecting the battery in the later stages of charging when the voltage rises (end of charge conditions).

The MPPT charger also controls a 2 x 16 alphanumeric LCD, which communicates on the I²C interface and displays relevant information, such as panel input power, battery voltage and LED power. For added functionality, the device can communicate with a PC GUI using the UART interface. Users can read telemetry and modify the type of panel and battery used or charging parameters. The settings can be saved back to the charger and stored in FLASH as the default configuration.

HARDWARE DESCRIPTION

The MCP19215 SEPIC MPPT board has two SEPIC converters. The first SEPIC converter is used to charge a battery from a solar panel. The second SEPIC converter is used to power a string of LEDs from a battery. Both converters are controlled by the MCP19215 DEPA Controller, a peak current mode, dual-channel low-side PWM controller. The part includes a fully programmable microcontroller, a 10-bit multi-channel ADC and four 8-bit DACs used to set the current and voltage references for each PWM channel, making this application a highly integrated single-chip solution that can be

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used with any solar panel and battery combination, as well as power any type of LEDs. This also has the benefit of fitting on a small PCB (62 mm by 35 mm).

The SEPIC converter was chosen due to its minimally necessary active components, low-noise operation, and the ability to work as both buck and boost converter.

Shunt resistors are used to accurately measure the current. These were chosen to have as few losses as possible without compromising accuracy and performance.

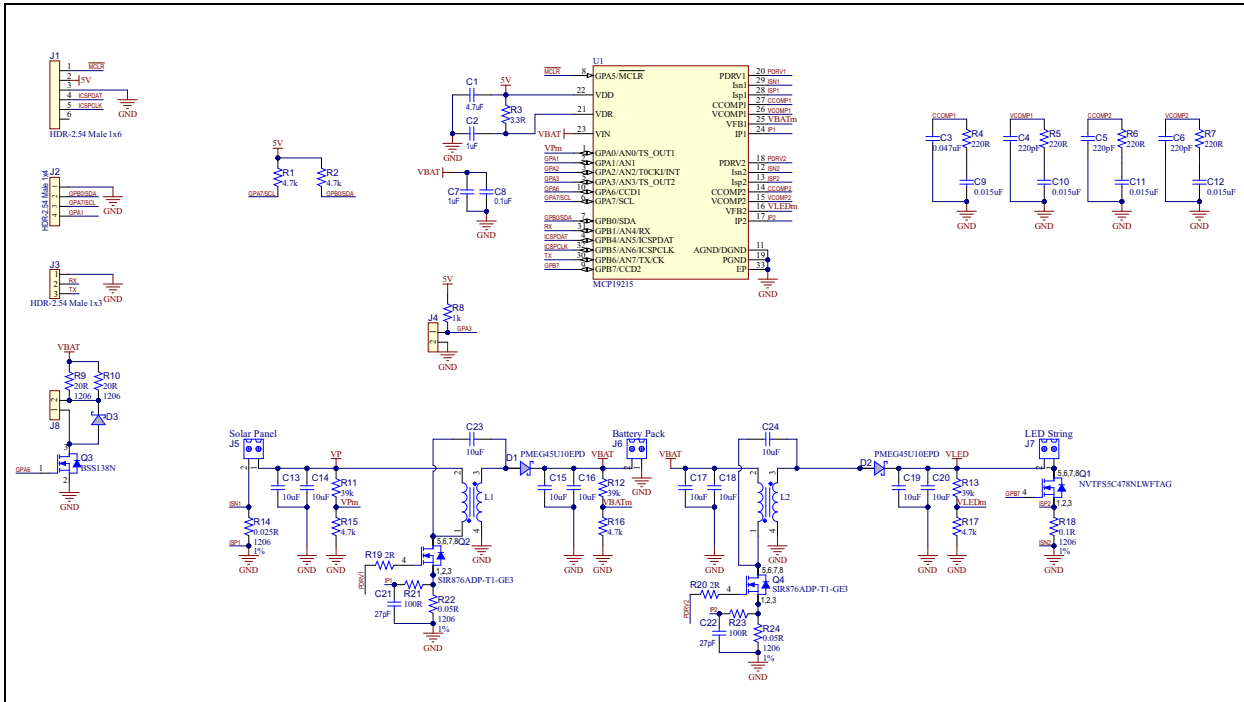


FIGURE 1: MCP19215 Dual SEPIC Schematic.

The chosen solar panel connects to J5 (Solar Panel), which is the input for the first SEPIC converter. The battery connects to J6 (Battery), which is the output to the first SEPIC converter and the input of the second SEPIC converter. The LED string connects to J7 (LED), which is the output for the second SEPIC converter.

J1 (ICSP™) is utilized to connect a programming device (PICKit™ 4/5) for programming purposes. J2 (I²C) and J3 (AUSART) are used for communication purposes with the board through I²C or UART protocols. The I²C is employed for a 2x16 LCD to display critical information about the current state of operation of the board, such as solar panel power drawn and battery level. For example, the LCD used in this project is the MCCOG21605B6W-SPTLY1 from Midas Displays. The UART interface is used to connect to a Graphical User Interface (GUI) installed on a Windows PC.

J4 can accommodate a button or a passive infrared sensor (PIR). When using a button, the LED output can be controlled with dimming options (available through the GUI) and ON/OFF commands. The use of a PIR sensor to control the LED output can be activated through the GUI.

J8 (FAN) can accommodate a cooling fan. The cooling fan needs to be selected according to the battery used. If using a higher voltage battery, R9 and R10 may require adjusting to reduce fan driving voltage.

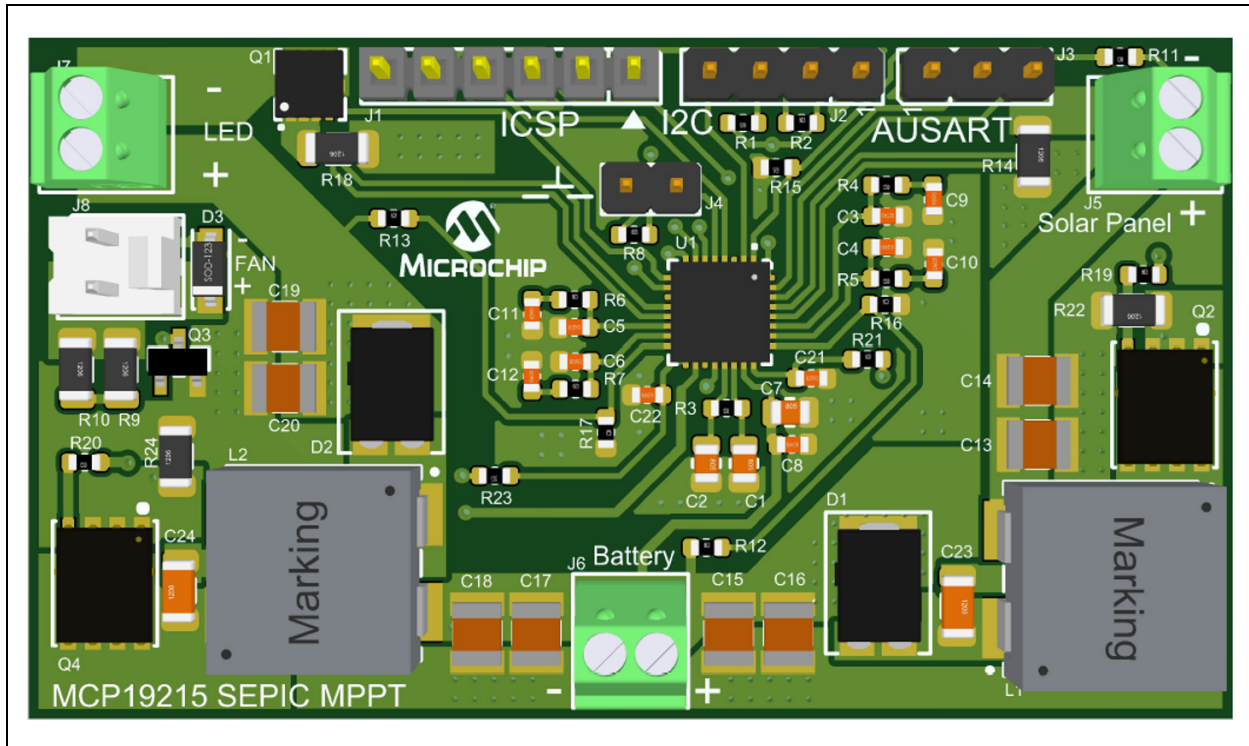


FIGURE 2: MCP19215 Dual SEPIC PCB.

In this configuration, the connected solar panel can have a maximum of 60 cells (30V MPP) with a maximum power of 20W. Selecting a battery with a maximum charging voltage of 30V is recommended. Choosing an LED/LED string with a voltage of up to 30V with a maximum power of 10W is recommended.

While operating the device, always powering it using the battery connector is recommended. There are certain cases where keeping the UART connector plugged before powering the board will inject voltage through the ESD diodes and will result in erroneous current offset readings.

FIRMWARE DESCRIPTION

The application uses a main loop with a timer running at approximately 1 kHz. To accommodate all the functions, such as ADC channel sampling, MPPT, I²C and UART communication running in parallel, it was necessary to use non-blocking programming and to break the non-essential tasks into smaller bits executed sequentially.

The main tasks implemented in firmware are:

- ADC sampling
- MPPT
- Button handling/LED dimming
- Battery charging state machine
- I²C communication (for 2x16 LCD)
- UART communication (for PC GUI)

ADC Sampling

ADC sampling is performed at 1 kHz in the main loop, sequentially on 5 parameters: the panel input voltage and current, battery voltage and the LED string voltage and current.

LED string parameters are controlled by hardware, so the ADC samples are only used to calculate power. The value is displayed on the LCD and sent to the PC GUI.

Battery voltage is used in telemetry and is displayed on the LCD. More importantly, it is used in the battery charging state machine. Low battery voltage (below the configured cutoff voltage) will also shut down the LED lamp.

Panel voltage and current are used to calculate panel power for the MPPT function, telemetry, in some decisions related to Sleep mode and for the battery end of charge conditions. If the panel voltage drops below a certain threshold (the panel cannot provide power), the peripherals are disabled and the part is put to sleep with the watchdog timer active. The part becomes active again only if the panel voltage is above approximately 80% of the MPP voltage or if the LED lamp is turned on using the button. The part is always powered by the battery, so Sleep mode is mandatory to reduce power consumption when idle.

MPPT

The panel power input is continuously calculated and filtered, and the MPPT algorithm runs at about 20 Hz. In each MPPT interval, the first samples are ignored to let the panel parameters stabilize after perturbing the current, and the rest are accumulated and used to decide if the perturbation was in the right direction.

One of the critical issues with MPPT is controlling the input parameters in such a way that the collapse of the panel voltage is prevented. This happens naturally when the perturbation is applied to the panel voltage, but in this case, it is not possible because the voltage control loop is used for the battery. On the other hand, perturbing the panel current requires some extra conditions. The panel voltage is not controlled, just sampled using the ADC, and it can be used to limit the extracted current if the voltage gets too low. This threshold is calculated as a fraction of the MPP voltage for a certain type of panel.

The PO MPPT algorithm starts by increasing the current in fixed steps and saves the last calculated power value. If the previous power value is higher than the new one, the algorithm changes direction, meaning that it will switch from increasing to decreasing current and vice versa. If the previous power value is lower than the new one, it will keep going in the same direction. The current value is capped at zero and a maximum value depending on panel voltage (this can change based on irradiance and temperature).

Button & Dimming

The button routine reads the corresponding pin at about 16 Hz. There is no need for capacitors or other debouncing routines because the update period is significantly longer than the switch's mechanical chatter.

When the button is pressed, the LED string is turned on at maximum current/brightness. Subsequent presses will subtract fixed current steps from the reference, practically dimming the lamp. At zero current, the output driver is turned off to minimize consumption.

Battery voltage is monitored, and if the voltage drops below the cutoff voltage, the LED string is turned off automatically.

Battery Charging State Machine

This device implements a fully customizable CC/CV battery state machine with fault detection and multiple end-of-charge strategies. It supports charging of lead-acid and lithium chemistry batteries [3].

The battery starts in PRECHARGE state with limited charging current and will move to the CHARGE state when the voltage is over the cutoff voltage. The charging state will test both constant current and constant voltage conditions.

In constant current, the battery voltage is monitored. If the voltage rise fault is enabled and the voltage has not risen in a set number of seconds, it will set the battery state to FAULT and stop charging.

In constant voltage, the battery current is monitored. If the current sinks below the end-of-charge current, the state changes to either DONE (for lithium chemistries) or to FLOAT (for lead-acid batteries). Similarly, if the battery current does not sink for a set number of seconds, the battery state changes (second end-of-charge condition).

In FLOAT charge mode, the charging voltage is reduced to the defined floating voltage, and it will change state to DONE only when the current drops near zero.

From either FLOAT (lead-acid) or CHARGE state (for lithium chemistry), the battery state will change to DONE when charging is completed. In this state, it will monitor the battery voltage until it drops below the topping voltage and switches back to CHARGE mode.

Note that the default values are configured for a 6-cell lead-acid battery (12V nominal), and they can be changed anytime using the graphical user interface.

I²C Communication & LCD Display

For easy access to the panel and battery status, the device uses a 2x16 alphanumeric LCD connected to the I²C interface. The LCD uses an ST7032 [4] compatible controller. It has the same command set as the classic HD44780, but it needs an address byte and a command select byte before the actual data/command byte(s).

The display shows the charging state, the panel input power, the battery voltage, the LED power, and it is updated every second. Power and voltage calculations, plus the fixed point binary to binary coded decimal (BCD) conversions, are broken down into small operations and calculated between screen updates to minimize the impact on time-sensitive tasks.

I²C communication is also non-blocking; all operations are initiated after polling the interrupt flag. This allows the LCD to be turned off completely during device sleep. On wake-up, LCD initialization routines can run in the background while the other tasks are undisturbed, then resume displaying the relevant information.

UART Communication

The application uses UART communication to send telemetry data to the PC GUI. Some important values, like battery charging parameters and the MPP voltage for the panel, can also be modified and saved to the non-volatile memory as defaults.

Signals on the UART pins are TTL and an adapter (like the MCP2221 breakout board) is required to connect to the PC and the GUI. The connector on the board is not pin-compatible with the MCP2221 breakout board for space-saving reasons, and suitable wiring is necessary (see the board schematic in [Figure 1](#)).

Note: Without a minimum voltage on the panel input, the board will go into Sleep mode in 5 seconds but not if it is connected to the GUI nor if the LED lamp is on. One must either provide voltage on the input side or turn on the LED lamp until the GUI connects.

GRAPHICAL USER INTERFACE

The application is designed for the **Windows® 10/11 Operating System** and requires **.NET Framework 4.7.2 x64** to function properly.

To install the application, two files are required: "setup.exe" and "MCP19215_single_chip_MPPT_installer.msi" (as illustrated in [Figure 3](#)).

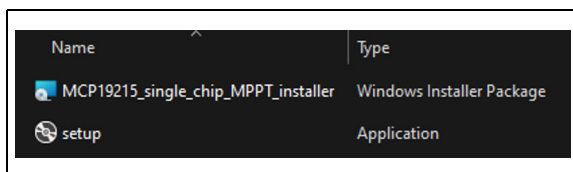


FIGURE 3: *Installation Files Required.*

The "setup.exe" file must be run first. The setup file will install the specified framework if it is not already installed. In this case, connection to the Internet is required. A shortcut will be created in the Programs menu and on the Desktop.

Communication Description

As previously mentioned, the application uses the UART protocol to communicate with the MCP19215 board. The data between the two is exchanged via transactions initiated by the application. The application sends a command along with the data, and the board must respond with the corresponding command in the response header and the required data.

Any data sent by the application or the MCP19215 board is followed by a checksum byte. The receiver recalculates the checksum byte over the received data and checks the values to see if they match. If they do not match, it indicates a problem with the connection.

The application can reset the serial communication if different conditions (described in [Table 1](#)) are met.

TABLE 1: RESET CONDITIONS

| Error | Description |
|-----------------------|--|
| Checksum error | The calculated and received checksum bytes (over the same data) are different. |
| Wrong response header | The MCP19215 board did not respond with the expected package header. |
| Timeout | The application does not receive a response for a given time (~330 ms) (Note). |
| IO operation failed | This error can occur when the serial port encounters an error (for example, the serial port cannot be accessed anymore). |
| Invalid configuration | The application reads an invalid configuration. |

Note: The timing described is for reference only and is not guaranteed.

If the board is in Sleep mode and the UART serial port is disabled, attempting to start a connection will likely result in a timeout error because the application will not receive a response. Additionally, improper wiring of the UART connection might cause a timeout, checksum or an incorrect response header error.

Interface Description

The application's default display is shown in [Figure 4](#).

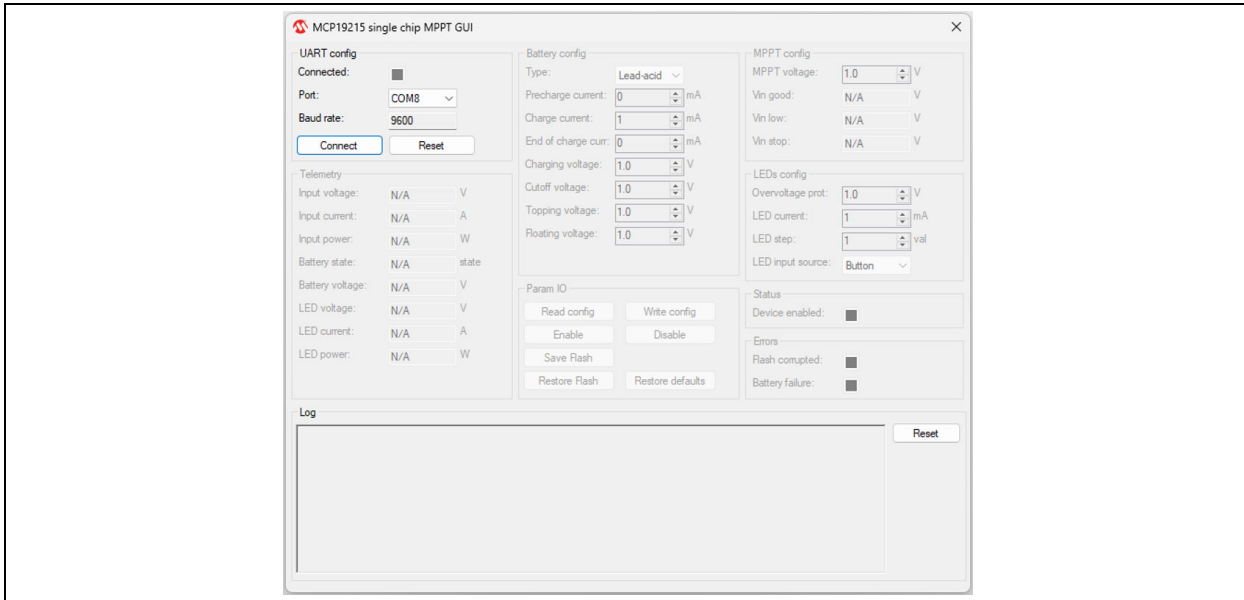


FIGURE 4: Default Display.

The application provides a log interface ([Figure 5](#)) where different messages and updates display for the user to view (see [Table 2](#)).

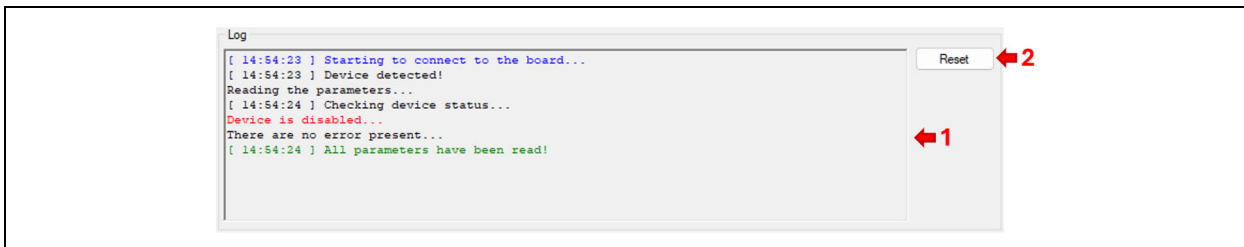


FIGURE 5: Log Panel.

TABLE 2: LOG PANEL ITEMS

| Item | Description |
|------|---|
| 1 | Displays messages and updates to the user |
| 2 | Clears the content displayed in item 1 |

The serial port can be configured using the "UART config" panel ([Figure 6](#) and [Table 3](#)), where the port can be chosen and the serial communications can be initiated or stopped. An important aspect is that the application cannot connect to the board if the chip is in Sleep state.

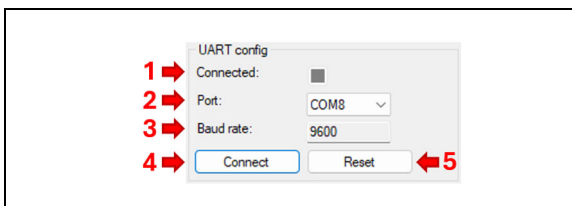


FIGURE 6: UART Config Panel.

TABLE 3: UART CONFIG PANEL ITEMS

| Item | Description |
|------|--|
| 1 | Displays the status of the serial port; green means connected, while gray means not connected |
| 2 | Selects the serial COM port |
| 3 | Displays the default baud rate |
| 4 | Starts the serial communication with the items previously selected; the chip must not be in Sleep state to respond |
| 5 | Resets the serial communication and the application |

After the board is detected and the connection is established, the application will read the configuration parameters. Initially, the board is enabled and the parameters cannot be modified ([Figure 7](#)). The board can be disabled by pressing the "Disable" button.

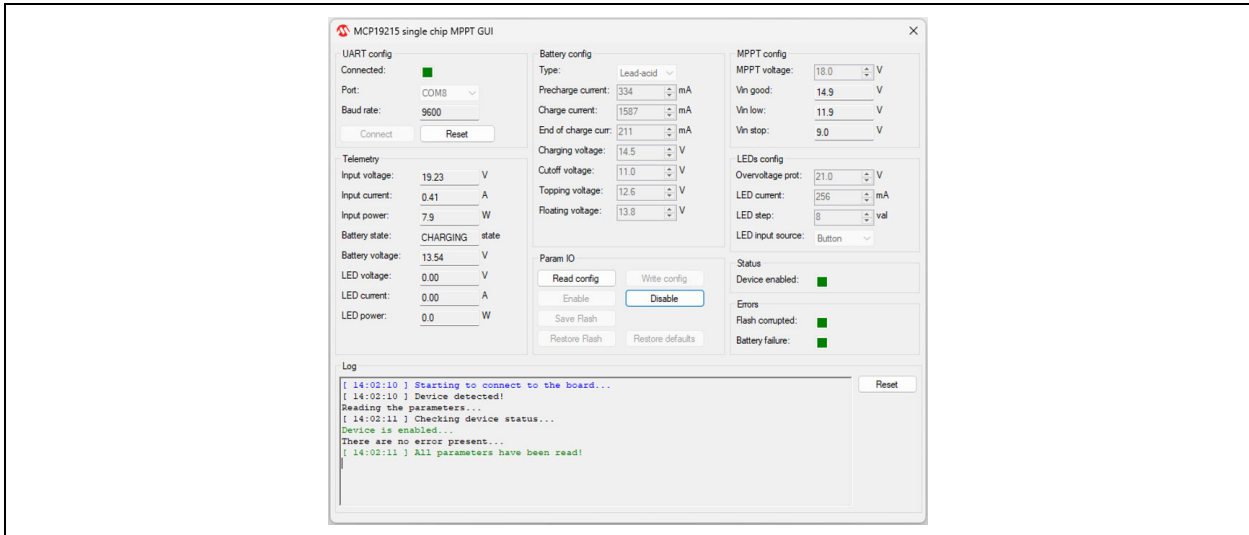


FIGURE 7: Application Connected; Device Enabled.

After the board is disabled, all parameters are available for modification (Figure 8).

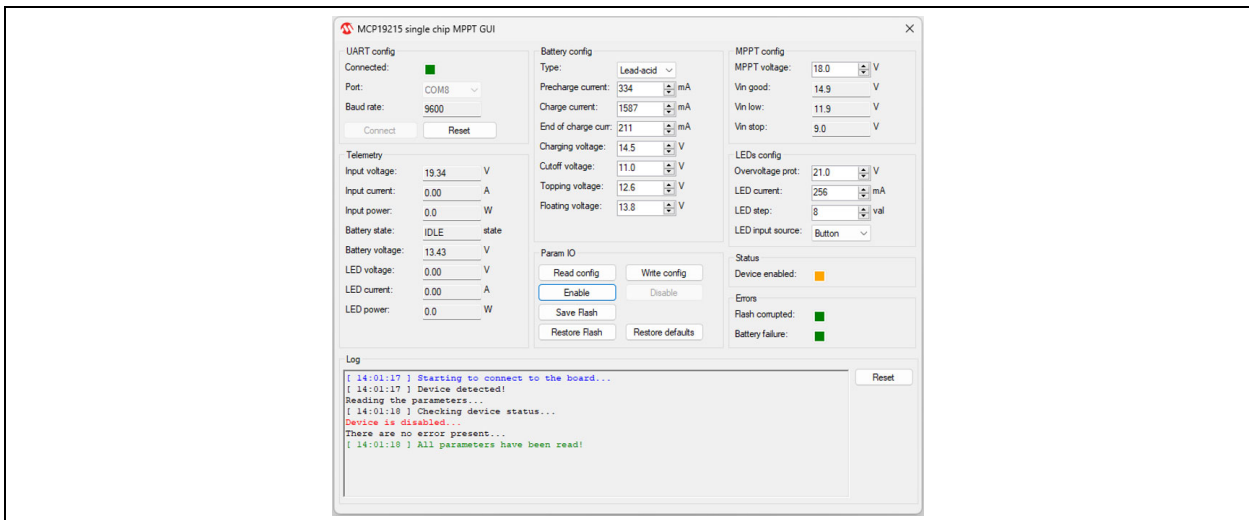


FIGURE 8: Application Connected; Device Disabled.

The telemetry parameters (Figure 9 and Table 4) are periodically read at approximately 240 ms. The precise timing, however, is not guaranteed. The input power and LED power are calculated by the graphical application using their respective voltage and current values.

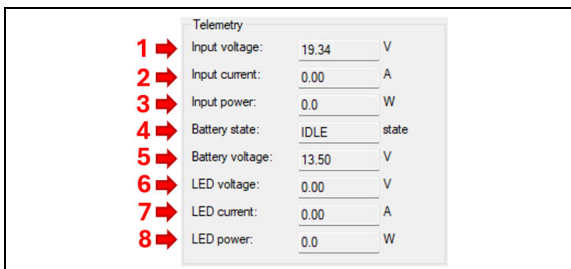


FIGURE 9: Telemetry Panel.

TABLE 4: TELEMETRY PANEL ITEMS

| Item | Description |
|------|---|
| 1 | Displays the input voltage in V |
| 2 | Displays the input current in A |
| 3 | Displays the input power in W; calculated using the item 1 and 2 values |
| 4 | Displays the battery state |
| 5 | Displays the battery voltage in V |
| 6 | Displays the LED voltage in V |
| 7 | Displays the LED current in A |
| 8 | Displays the LED power in W; calculated using the item 6 and 7 values. |

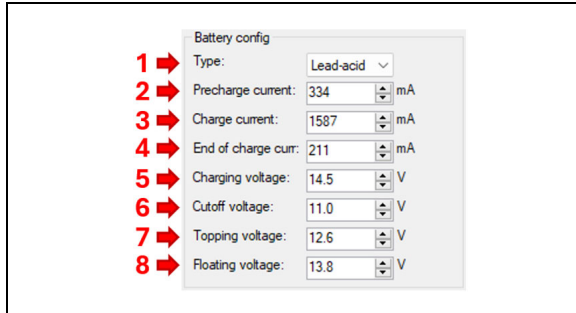


FIGURE 10: Battery Config Panel.

TABLE 5: BATTERY CONFIG PANEL ITEMS

| Item | Description |
|------|---|
| 1 | Displays the battery type selected; two options are available, lead-acid and Li-ion |
| 2 | Displays the pre-charge current in mA |
| 3 | Displays the charge current in mA |
| 4 | Displays the end of charge current in mA |
| 5 | Displays the charging voltage in V |
| 6 | Displays the cutoff voltage in V |
| 7 | Displays the topping voltage in V |
| 8 | Displays the floating voltage in V; available if the lead-acid battery type is selected |

The configuration values may be constrained by their maximum possible limits, which can differ from the values set by the user. In such cases, the interface will update and display the adjusted values accordingly.

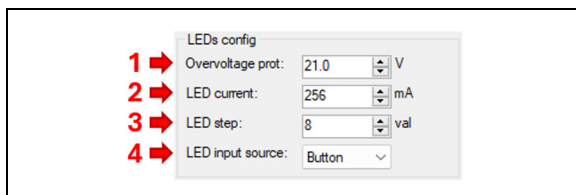


FIGURE 11: LEDs Config Panel.

TABLE 6: LEDS CONFIG PANEL ITEMS

| Item | Description |
|------|--|
| 1 | Displays the overvoltage protection in V |
| 2 | Displays the LED current in mA |
| 3 | Displays the LED step value |
| 4 | Displays the LED input source; the LED input source can be selected from the "Button" and "PIR" options. |

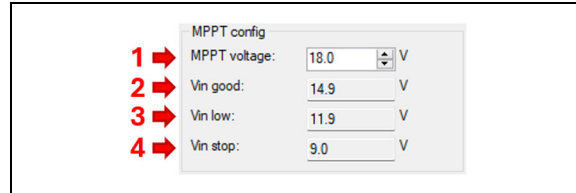


FIGURE 12: MPPT Config Panel.

TABLE 7: MPPT CONFIG PANEL ITEMS

| Item | Description |
|------|--|
| 1 | Displays the MPPT voltage in V |
| 2 | Displays the Vin good in V (Note) |
| 3 | Displays the Vin low in V (Note) |
| 4 | Displays the Vin stop in V (Note) |

Note: The value is read-only and is calculated as a percentage of MPPT voltage.

The status and errors (Figure 13 and Table 8) are periodically read at approximately 240 ms. As mentioned previously, the precise timing is not guaranteed.

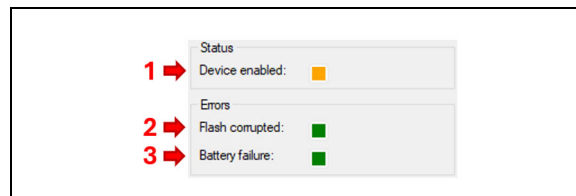


FIGURE 13: Status and Errors Panels.

TABLE 8: STATUS AND ERRORS PANELS ITEMS

| Item | Description |
|------|--|
| 1 | Displays the status of the MCP19215 board (green: board enabled, orange: disabled) |
| 2 | Displays if the Flash data is corrupted (green: error is not set, red: error set) |
| 3 | Displays if a battery failure is encountered (green: error is not set, red: error set) |

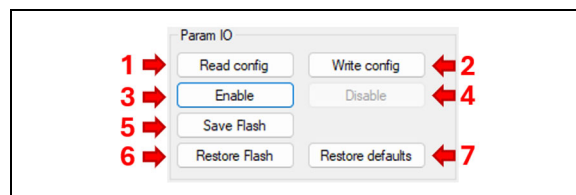


FIGURE 14: Param IO panel.

TABLE 9: PARAMETER IO PANEL ITEMS

| Item | Description |
|------|---|
| 1 | Reads the current configuration parameters |
| 2 | Writes the current configuration parameters |
| 3 | Disables the inputs, reads the current configuration and enables the device |
| 4 | Disables the device, reads the current configuration and enables the inputs |
| 5 | Saves the current configuration to the Flash memory and reads it |
| 6 | Restores the Flash values and reads configuration parameters |
| 7 | Restores the default values and reads configuration parameters |

Write, save to Flash and restore operations are available only when the device is disabled.

CONCLUSION

A single-chip MPPT battery charger combined with a LED light is a very attractive solution for maintenance-free illumination that can be placed anywhere. The MPPT part ensures that most of the panel power is extracted and stored into the battery, and it allows the use of smaller wattage panels with the same result. The complete CC/CV type charging state machine can be used with both lead-acid and Li-ion batteries and will prevent the premature degradation of the battery, thus prolonging the product life.

The solution shows that a single chip containing a microcontroller core combined with a high-performance analog controller can handle a feature-rich application (I²C LCD, UART communication and battery charging state machine) while managing time sensitive ADC data sampling on multiple channels and performing the calculations necessary for MPPT. The PC GUI adds extra flexibility, as most of the panel and battery charging parameters can be modified and saved, and the board telemetry can be viewed in real time during the device customization.

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