

### Description

In an era characterized by the internet of things (IoT), more connectivity means more outdoor devices are now battery-powered and constantly communicating. In particular, an increasing number of outdoor devices are being powered through solar panels. The charger should be suitable for maximum power point tracking (MPPT) in outdoor designs with a solar panel. This article illustrates design tips for a solar panel charger with a Lithium-ion battery, suitable for applications such as outdoor solar surveillance cameras or outdoor lighting (see Figure 1).



Figure 1: Solar Panel Application for Outdoor Security Camera and Outdoor Lighting

### System Overview

This reference design is developed based on the MP2731 IC from MPS with an MC96F1206 controller (a low-cost 8051 MCU). It is suitable for small and medium solar-powered charging solutions. Compared to a conventional MPPT system, the MP2731-based system integrates a  $V_{IN}$  connection switch, ADC, and voltage/current-sensing circuitry, which significantly reduces the system cost. The system design uses the perturb-and-observe (P&O) algorithm for MPPT to achieve 98% or greater tracking accuracy.

Figure 2 shows the system diagram of the reference design. The major blocks of the system include the MP2731, MC96F1206 MCU, battery, and system load.

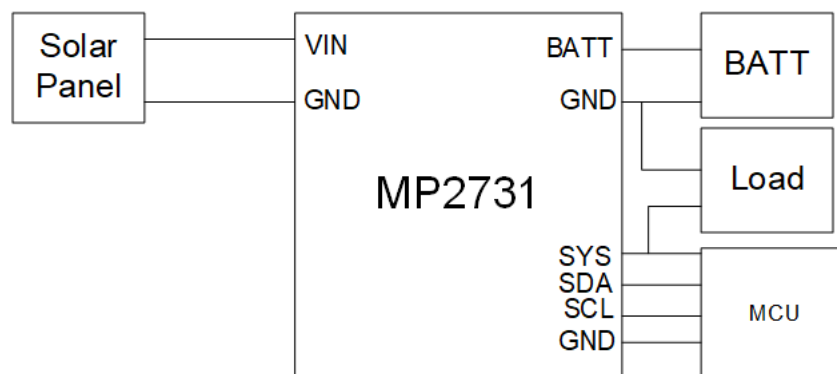


Figure 2: MPPT System Block Diagram

Features of the MP2731 include up to 93% efficiency in a 9V input 5W system, 98% MPPT accuracy, a small 25mmx25mm core circuit area, fully integrated power switches with built-in robust charging protection including JEITA and programmable safety timer, and an I2C interface for flexible system parameter setting and status reporting (see Figure 3).

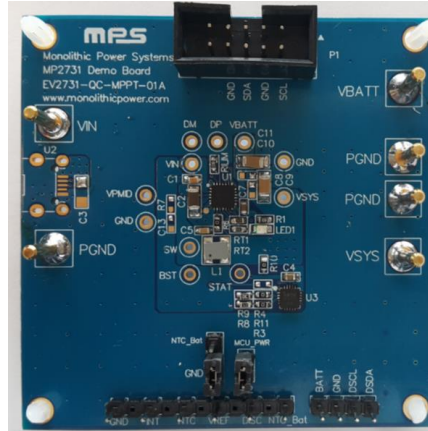


Figure 3: PCB of the MPPT Control System

### System Design

#### MPPT Theory

The output power from a solar panel is determined by several factors: the irradiance level, the operating voltage and current of the panel, and the load. There exists a maximum power point where solar panel is outputting optimal power to the system (see Figure 4). Maximum power point tracking techniques like P&O or incremental conductance methods are used to actively keep the solar panels operating at MPPT during changing irradiance conditions.

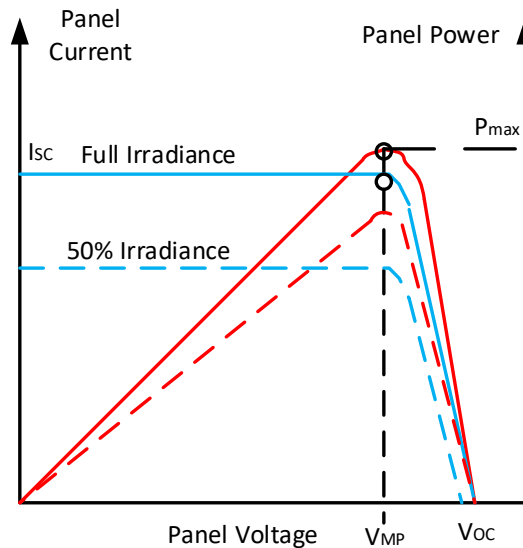


Figure 4: Solar Panel P-V and I-V Curve

In the power-based P&O MPPT algorithm, the derivative of power to voltage  $dP/dV$  of a PV panel is used as a tracking parameter. Calculate when MPP is reached using Equation (1):

$$\frac{dP_{in}}{dV_{in}} = 0 \tag{1}$$

#### Hardware Implementation

A DC/DC converter is generally used to ensure MPP optimization inside the system. A highly integrated switching charger (the MP2731 from MPS in this reference design) is connected between the PV panel and battery load.

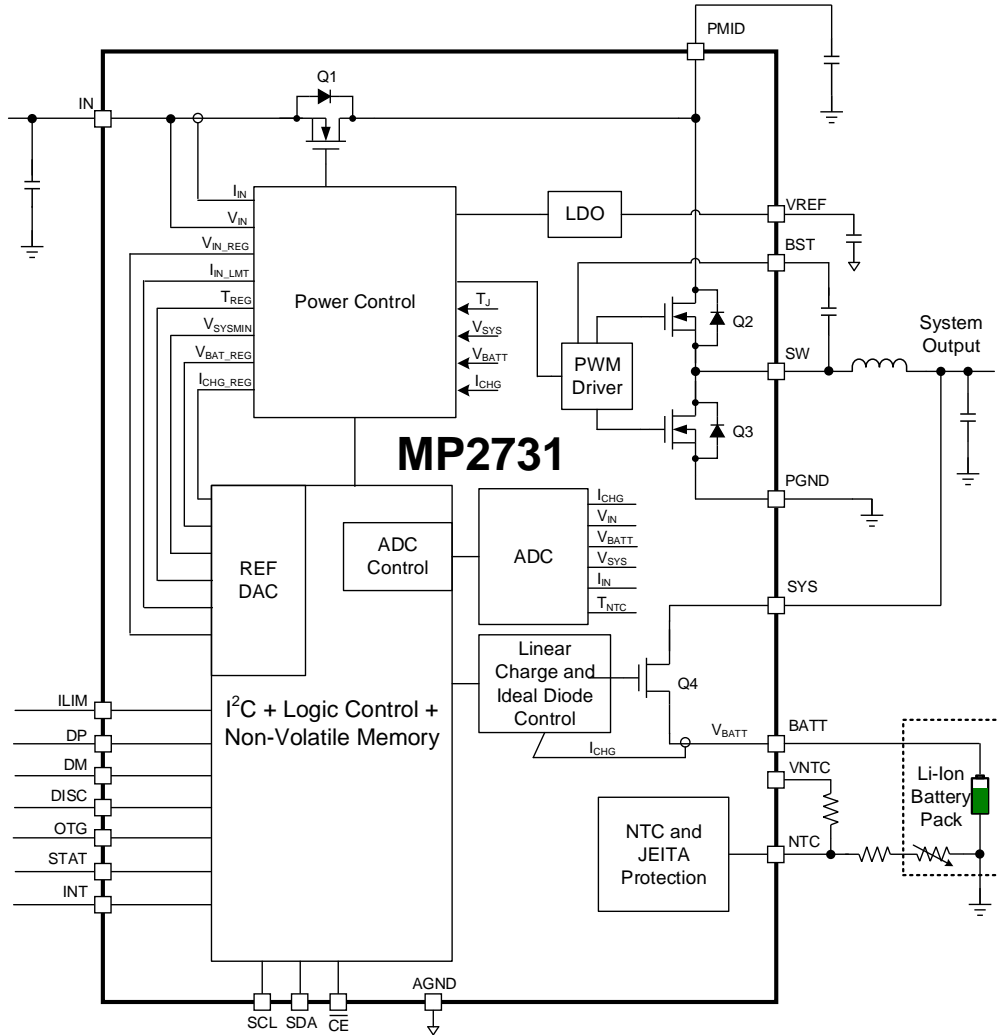
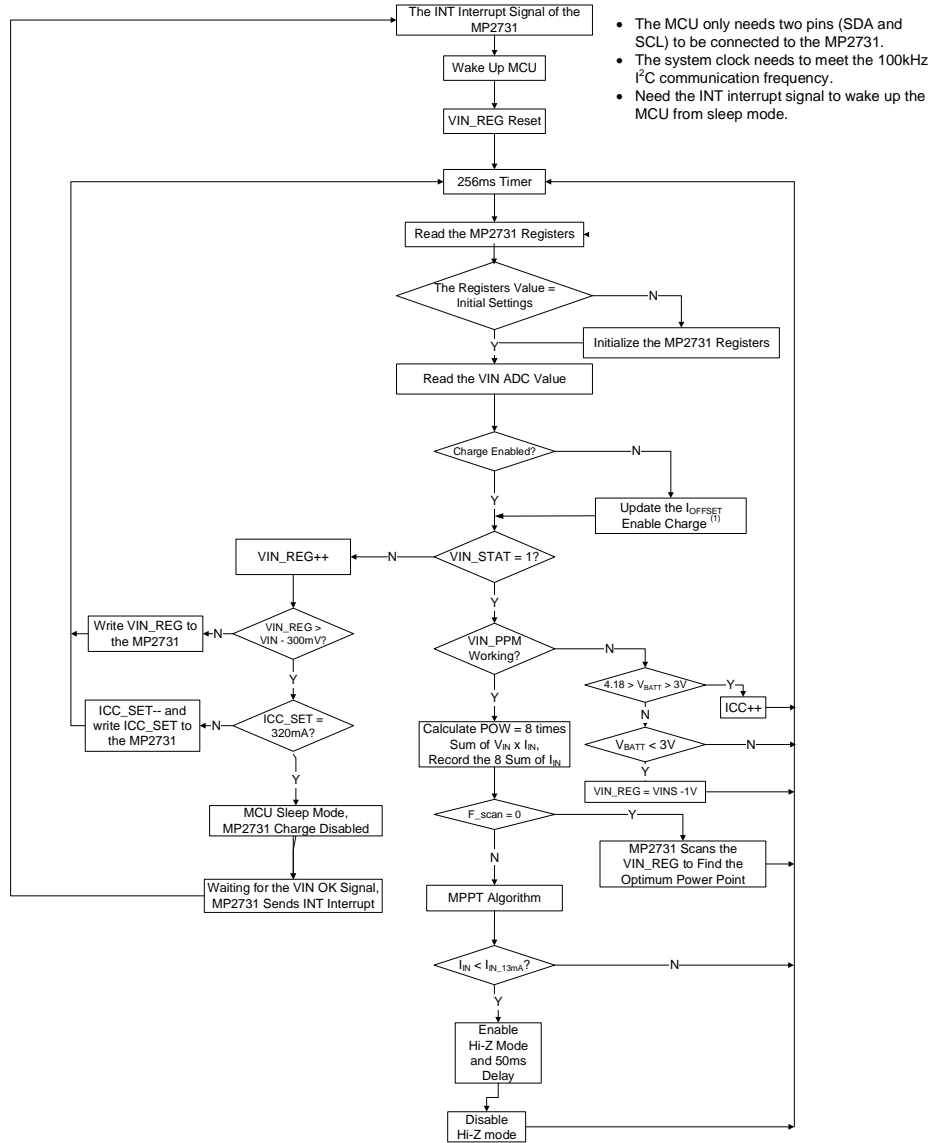


Figure 5: Functional Block for the MP2731

A reverse-blocking FET Q1 is used to block the path from the battery load to the PV panel when the panel is under low irradiance. The input voltage/current and output voltage/current of the IC are sampled through an 8-bit ADC. The IC supports I<sup>2</sup>C communication, so the digitized current and voltage information can be easily communicated to the external MCU.

### Software Implementation

The P&O MPPT algorithm is implemented in a 20-pin, 8-bit MC96F1206 MCU from ABOV Semiconductor. To communicate with the MP2731, the I<sup>2</sup>C peripherals in the MCU are activated.



**Figure 6: System-Level Software Flowchart**

**Note:** Before updating  $I_{OFFSET}$ , turn off other devices connected at the MP2731's SYS pin to ensure  $I_{OFFSET}$  is calibrated correctly.

Figure 6 shows the system-level software flow. The MCU is in sleep mode when  $V_{IN}$  drops below the under-voltage threshold. When  $V_{IN}$  recovers, it sends an interrupt (INT) to wake the MCU. Then the MCU reads the MP2731 registers and initiates those registers (see Table 1).

**Table 1: Operation Registers**

REG Address	Value (HEX)	Value (BIN)	Description
0x00	0x7F	0111 1111	Set the input current limit to 3.25A (max)
0x02	0xDC	1101 1100	Auto input current optimize is disabled
0x03	0x50	0101 0000	ADC continuous conversion is enabled
0x08	0x84	1000 0100	Termination is enabled, WTD and safety time are disabled
0x0B	0xC0	1100 0000	USB detection is disabled

By setting the input current limit to its maximum value, the panel voltage is controlled only by the input voltage limit loop. By adjusting the input voltage limit loop reference, the PV panel's voltage can be adjusted. After initializing the MP2731, read the ADC initial value, then enable charging.

Check if VIN\_STAT is equal to 1. If it is not equal to 1, increase VIN\_REG by one unit, and then go back to the previous value for VIN\_STAT. When VIN\_REG reaches its maximum limit, VIN\_STAT is still not equal to 1. The charging current gradually decreases, and returns to the previous value set by VIN\_STAT.

When VIN\_REG set has reached its limit, the ICC is set to a minimum. If VIN\_STAT is still not equal to 1, the MCU enters sleep mode, and the MP2731's charging functionality is disabled until the INT interrupt function wakes the MCU.

**Dealing with Local MPP During Partial Shading**

In case the PV panel is partially covered and a local MPP can be tracked using a conventional P&O MPPT algorithm, the MCU initiates a scan every time the input voltage flag changes. The MCU adjusts the input regulation voltage reference of the MP2731 with a 100mV step from 50% of the panel open-circuit voltage (V<sub>oc</sub>) to 80% V<sub>oc</sub> to scan the optimum power point.

After the initial scan, the PV panel is set to operate at the maximum power point. To continue tracking the optimum point under varying load and irradiance conditions, the P&O algorithm runs in every 256ms on the MCU (see Figure 7).

**MPPT Algorithm**

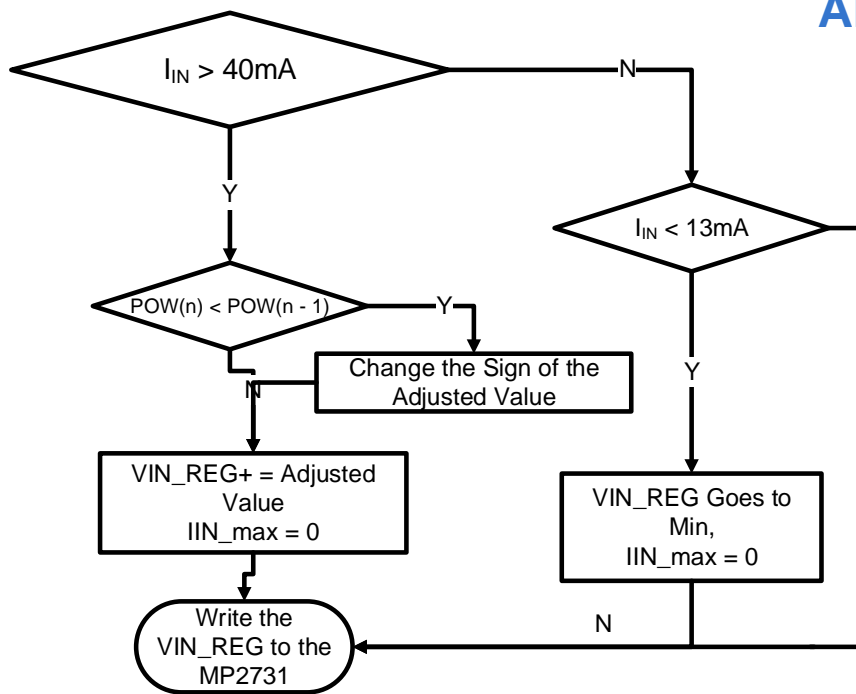


Figure 7: P&O MPPT Algorithm

**Experiment Results**

Figure 8 shows the MPPT process for a PV panel with (8V, 500mA) MPP. Before t<sub>0</sub>, with no load, the PV panel outputs 12V at open-circuit voltage. After the MP2731 IC and MCU power up, the PV panel runs at the preset 6V input voltage, configured by the MCU. From t<sub>0</sub> to t<sub>2</sub>, the MCU scans for MPP.

At t<sub>1</sub>, the MPP is located but the scan algorithm keeps sweeping the input voltage until the power falls to 85% of the recorded peak power at t<sub>2</sub>. After t<sub>2</sub>, the MCU sets the panel voltage to the scanned peak power voltage, then activates the real-time P&O algorithm.

Figure 9 shows the complete charging behavior for a Lithium-ion battery. From  $t_0$  to  $t_1$ , the system powers up and scans MPP. From  $t_1$  to  $t_2$ , the battery goes through the CC and CV stages as the battery charge current changes from constant current to lower values. When the battery is close to fully charged, the PV panel voltage starts ramping up to the open-panel voltage again. There is a light-load condition because the battery consumes a lower load current when fully charged.

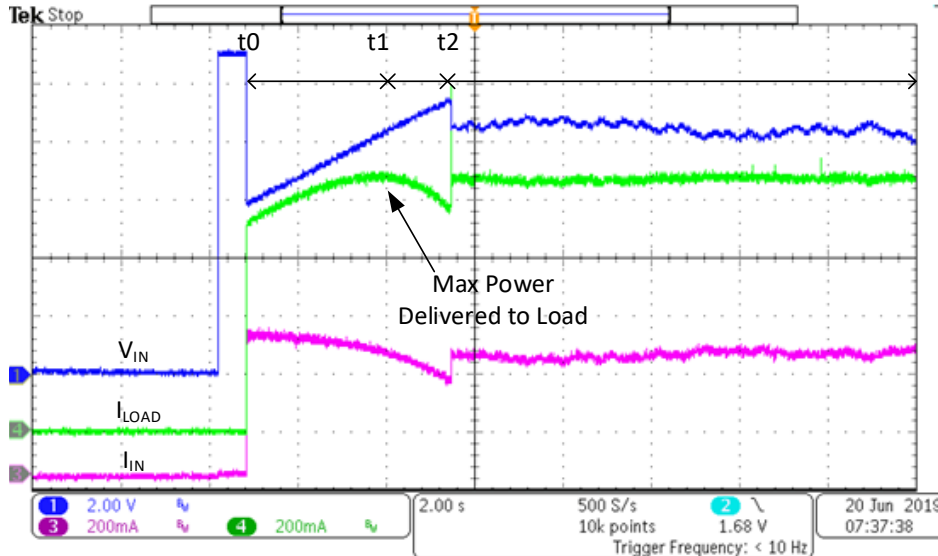


Figure 8: MPPT Process for PV Panel from Power-Up to Steady State

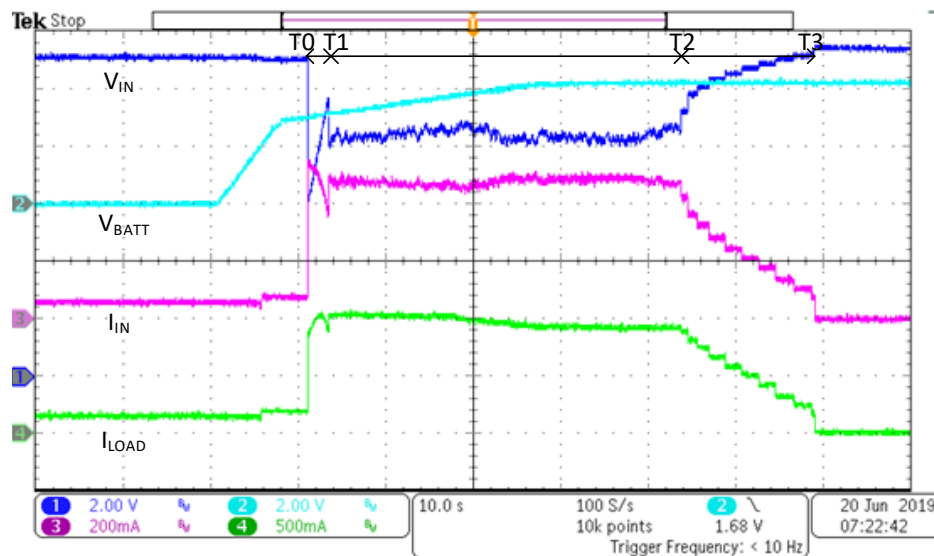


Figure 9: MPPT Behavior During Charging Cycle

With low-resistance, integrated MOSFETs, the MP2731-based MPPT system also achieves high efficiency under various conditions (see Figure 10).

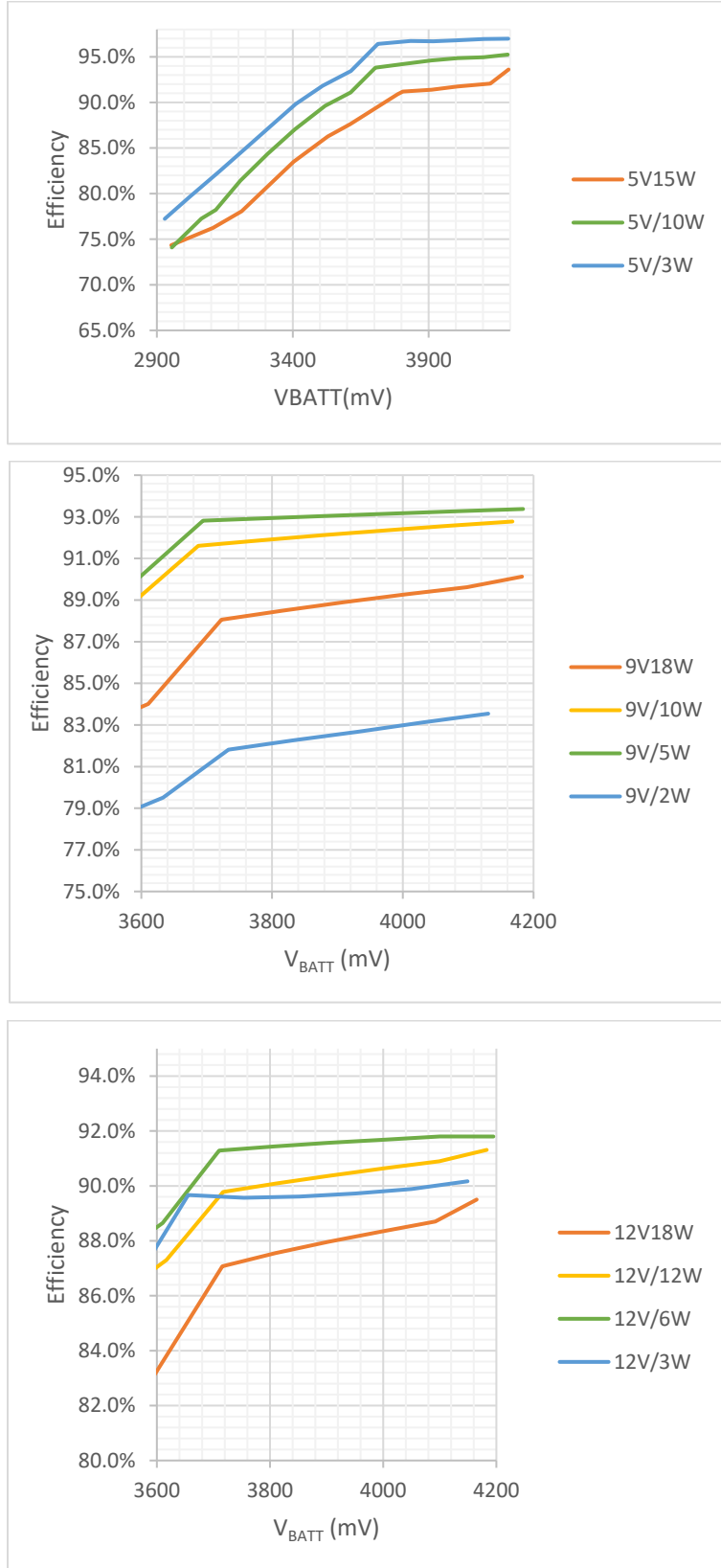
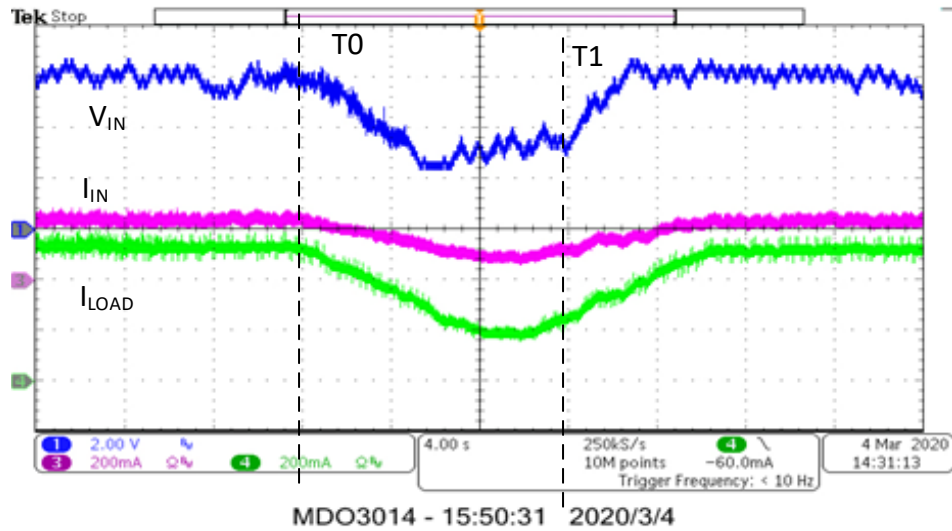
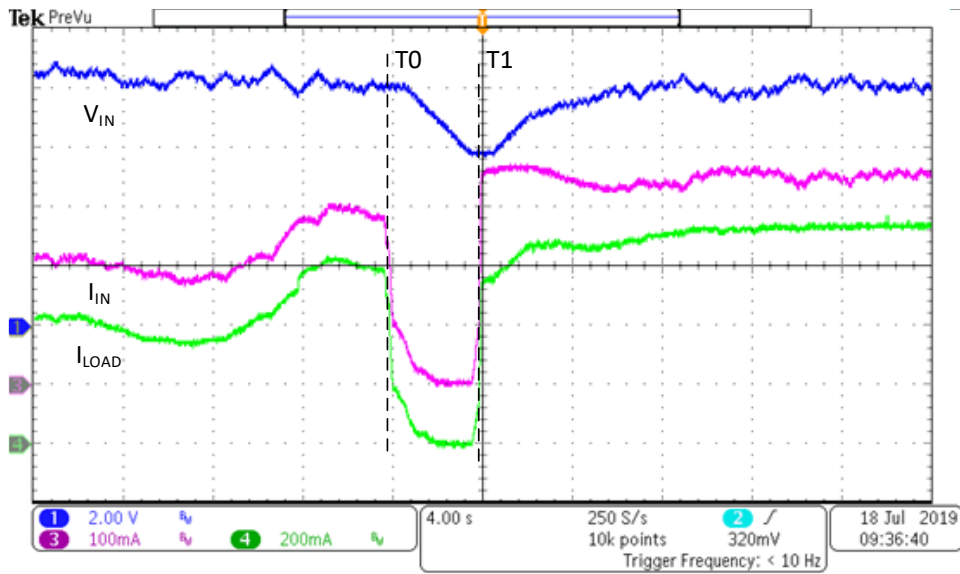


Figure 10: Efficiency Data for Panels (5V, 9V, 12V)



(PV Panel is about 5V)

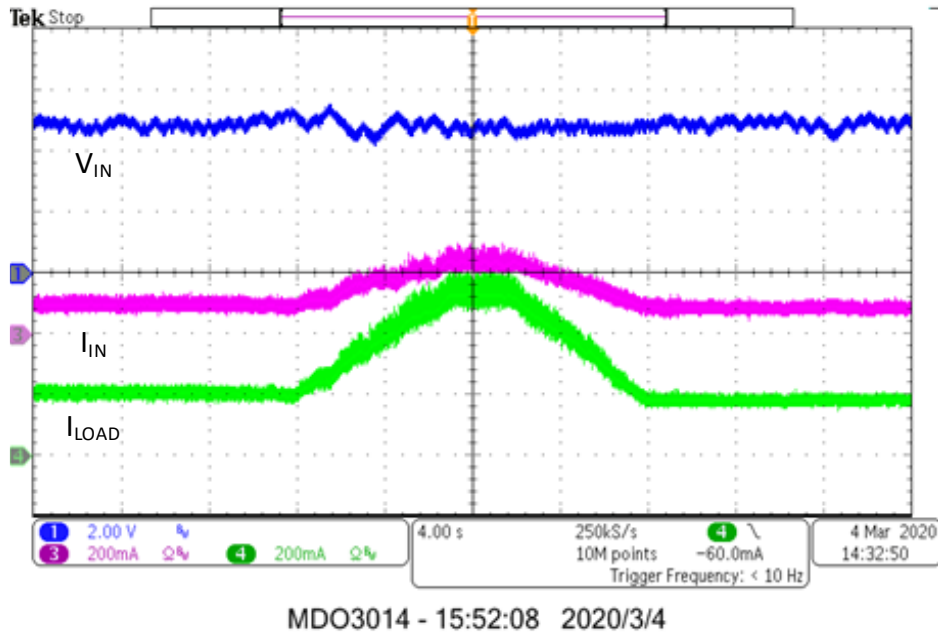


(PV Panel is about 8V)

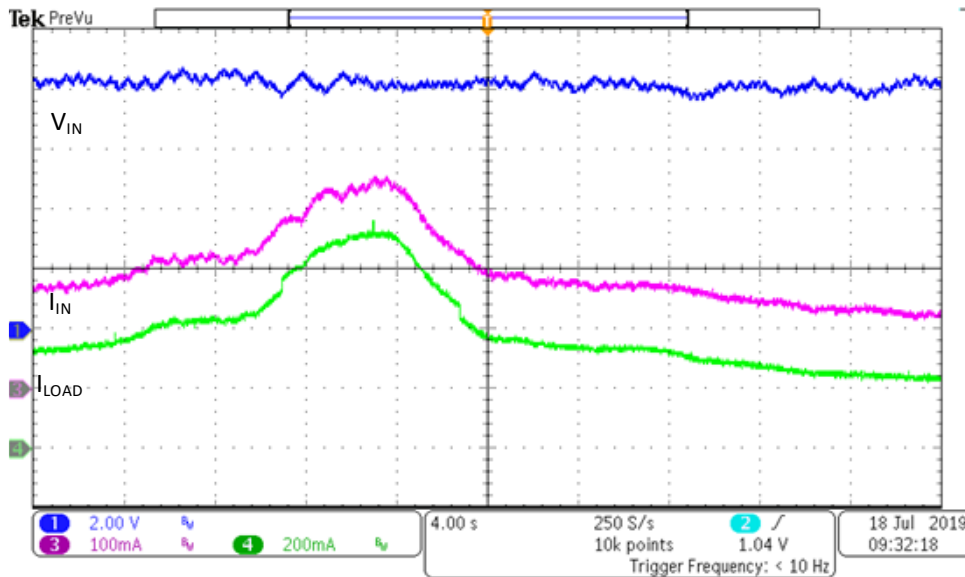
**Figure 11: Tracking Performance for Partial Shading**

Figure 11 shows the tracking performance for a PV panel under partial shading. When partial shading conditions occur at  $t_0$ , the PV panel voltage and current reduce. At  $t_1$ , when the partial shading is removed, the MPPT adjusts the PV panel voltage back to the MPP level.





(PV Panel is about 5V)



(PV Panel is about 8V)

**Figure 12: Tracking Performance under Natural Lighting Environment**

Figure 12 shows the tracking performance for a PV panel under natural outdoor sunlight. The sun irradiance fluctuates higher and lower, which affects PV panel output current. However, the MPP panel voltage is generally not affected by irradiance level (about 8V in this example). Figure 12 shows that the effective MPPT algorithm is able to keep the MPP tracked at 8V under changing irradiance.

## Conclusion

The MP2731 lithium-ion battery charger IC effectively reduces the cost for outdoor IoT systems by eliminating discrete voltage and current-sensing circuitry from the BOM. Highly integrated low  $R_{DS(ON)}$  allows for a high-efficiency system with a compact PCB area. Future product development projections include accommodating design in higher power, higher voltage applications, further reduction in system quiescent power consumption, and developing solutions for multi-panel systems.