Application Report
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# bq25504 Optimization of MPPT Algorithm

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**ABSTRACT**

The bq25504 is an ultra-low-power charger IC intended for interfacing DC sources like solar cells, thermal harvesters and high-impedance batteries. The bq25504's industry-leading low-quiescent current and high charger efficiency make it an ideal choice for charging batteries and super-capacitors τ from a variety of energy-harvesting sources. This application note details how to optimize the bq25504 maximum power point tracking (MPPT) network to accurately regulate different types of solar cells to their maximum power point (MPP). For details, see the bq25504 data sheet (SLUSAH0).

## Introduction

The Texas Instrument's bq25504 uses the open-circuit voltage (OCV) technique to regulate the solar cell to its maximum power point (MPP). This technique relies on the fact that for most solar cells, the MPP is achieved at some fraction of the OCV, typically 80%. A resistor divider ($R_1$ and $R_2$) is used to obtain the appropriate percentage of the solar panel's OCV. During normal operation, the bq25504 periodically turns off the charger so the solar panel can return to its OCV. During this time, the fractional voltage generated from the divider network is sampled and held by the capacitor, $C_{REF}$. The voltage on $C_{REF}$ is used as a reference voltage to regulate the panel's operating voltage.

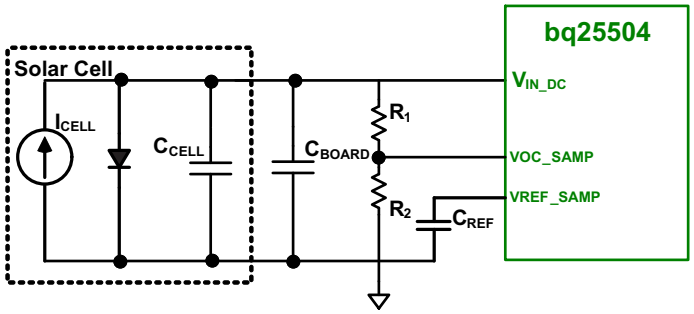


**Figure 1. bq25504 MPPT System Diagram**

The bq25504 has a preset 256-ms OCV sampling period that is refreshed every 16 s. For most commercially available solar cells, the 256-ms time interval is adequate for $I_{CELL}$ to charge the solar cell's internal capacitance ($C_{CELL}$) and the board capacitance ($C_{BOARD}$) to settle the voltage at $V_{IN_DC}$ to the OCV of the solar cell, even under low light conditions. This is true for most solar cells because the capacitance at $V_{IN_DC}$ is approximated as $C_{BOARD}$, because $C_{CELL}$ is usually small and $I_{CELL}$ is usually greater then 20 µA. However, some solar cells have a very large $C_{CELL}$ and/or a very small $I_{CELL}$ such that the voltage at $V_{IN_DC}$ no longer settles to OCV in the 256-ms sampling window. Under these conditions, the sampled voltage will actually show up as something less than the target fraction of OCV that $R_1$ and $R_2$ are normally set to achieve. To better understand how this phenomenon affects the selection of the MPPT resistor divider network the solar cell is approximated as a simple RC settling network.


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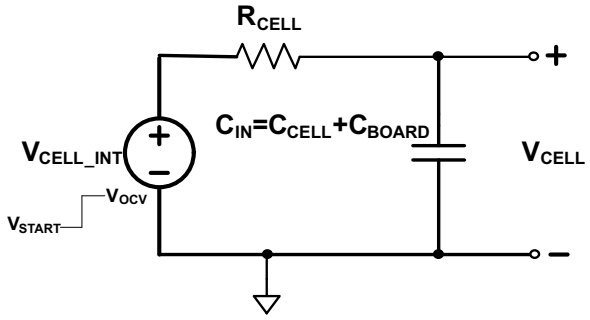


**Figure 2. Model for Analyzing Settling Time of Solar Panel**

The voltage at the cell is initially regulated to $V_{cell_start}$, at the beginning of an MPPT sampling period. The voltage at the cell at the end of a sampling period ($V_{cell_end}$) is given by

$$V_{cell_end} = V_{cell_start} + (V_{OCV} - V_{cell_start}) \times (1 - e^{-256ms/\tau}) \quad (1)$$

Where $\tau$ is the settling-time constant of the solar panel with the additional input board capacitance.

$$\tau = R_{CELL} \times C_{IN} \quad (2)$$

Assuming the settling time of the MPPT sampling network is negligible, the sampling network $R_1$, $R_2$, and $C_{REF}$ store the voltage given by

$$V_{cell_start} = \left( \frac{R_2}{R_1 + R_2} \right) \times V_{cell_end} \quad (3)$$

The condition (Equation 4) must hold true for the panel to regulate the input to MPP when the cell voltage has reached its steady-state value.

$$V_{cell_start} = V_{MPP} \quad (4)$$

Combining Equation 1, Equation 3, and Equation 4 gives

$$R_2 = \frac{V_{MPP} \times R_{total}}{V_{MPP} + \underbrace{(V_{OCV} - V_{MPP}) \times (1 - e^{-0.256/\tau})}_{\Delta V_{256ms}}} \quad (5)$$

$$R_1 = R_{total} - R_2 \quad (6)$$

Where $R_{TOTAL}$ is a user-specified value; the bq25504 specification recommends 20 MΩ.

## Procedure to Calculate MPPT Resistor Values

Solve for $R_1$ and $R_2$ using Equation 5 and Equation 6, to set the appropriate ratio for operation at the panel's MPP. The quantities $V_{MPP}$, $V_{OCV}$, $R_{TOTAL}$ and $\tau$ are required to solve these equations. Obtain the values for $V_{MPP}$ and $V_{OCV}$ from the panel manufacturer's data sheet or by requesting them. The data sheet will include the settling point of the panel. The value of $\tau$ is both a function of the panel's settling time and the board's input capacitance (4.7 µF).

The values for $V_{MPP}$, $V_{OCV}$, and $\tau$ vary with operating point and change with voltage, temperature, irradiance, age, and dimensions of the panel. Solving for $R_1$ and $R_2$ with the values provided by the manufacturer may provide a good approximation but might not yield the most accurate solution for every situation. For the most accurate value, understand that the underlined quantity ($\Delta V_{256ms}$) in Equation 5 is the voltage difference seen at the panel between the beginning of the MPPT sampling period and the end of the period, 256 ms later. The following procedure is the most accurate way of determining $R_1$ and $R_2$ values, ensuring the bq25504 operates the solar panel at its MPP.

1. At room temperature, place the panel in a light box on the LUX setting expected for a typical application.
2. Connect the panel terminals to a Keithley 2400 SourceMeter or similar device.
3. Set the SourceMeter source voltage to 0 V. Begin increasing the voltage while observing meter power


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measurement. The power will increase with increasing voltage until it reaches its maximum after which it will begin decreasing as the voltage is taken higher. Record the voltage at which power reaches its maximum ($V_{MPP}$).

4. Set the SourceMeter to the voltage setting that achieves MPP. Connect a scope probe to the positive terminal of the solar panel. Open circuit the solar panel by disconnecting the SourceMeter. Record the voltage difference seen on the scope probe 256 ms later ($\Delta V_{256ms}$)
5. Using $V_{MPP}$, $\Delta V_{256ms}$, and user-selected $R_{TOTAL}$ solve Equation 5 and Equation 6 for the resistor values.

## Example Calculation of MPPT Resistors

The following example illustrates how to calculate the proper resistor values using the procedure described above. A 3-cell solar panel with OCV measured at 1.66 V is used in this experiment. Using steps 1-3 described above, the $V_{MPP}$ is measured as 1.36 V. The panel was then connected to the source meter with the voltage set to 1.36 V ($V_{MPP}$). The OCV settling waveform in Figure 3 was obtained by removing the SourceMeter from the panel.

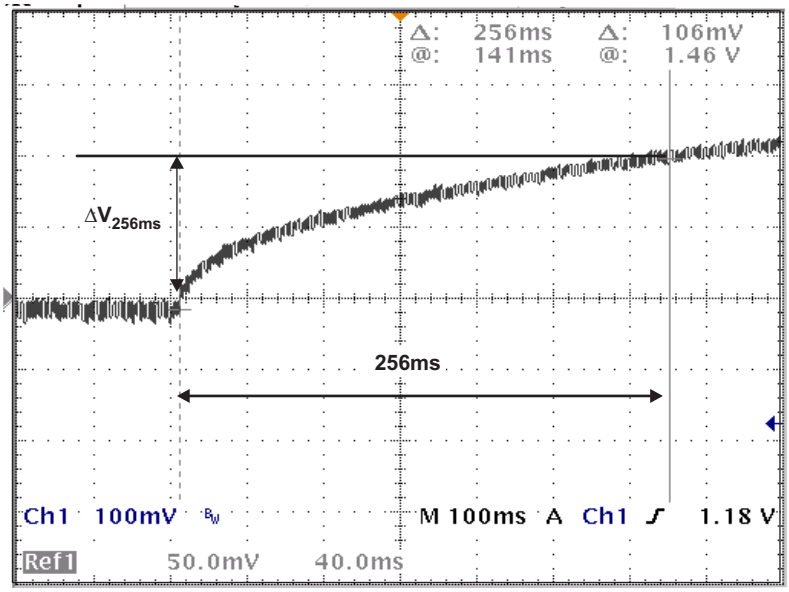


**Figure 3. Panel Voltage Settling from $V_{MPP}$ to VOC ($\Delta V_{256ms}$ measured is 106 mV).**

The waveform shows that this panel is unable to settle completely to OCV within the 256 ms sampling time. The final voltage at the end of the 256 ms sampling period was measured to be 1.466 V ($\Delta V_{256ms}$ = 106 mV). Using this data and Equation 5 and Equation 6, the resistor values were found to be $R_1$ = 1.45 MΩ and $R_2$ = 18.5 MΩ ($R_{total}$ = 20 MΩ). The panel was connected to the bq25504 IC with these calculated MPPT resistor values and allowed to settle to steady state, see Figure 4.


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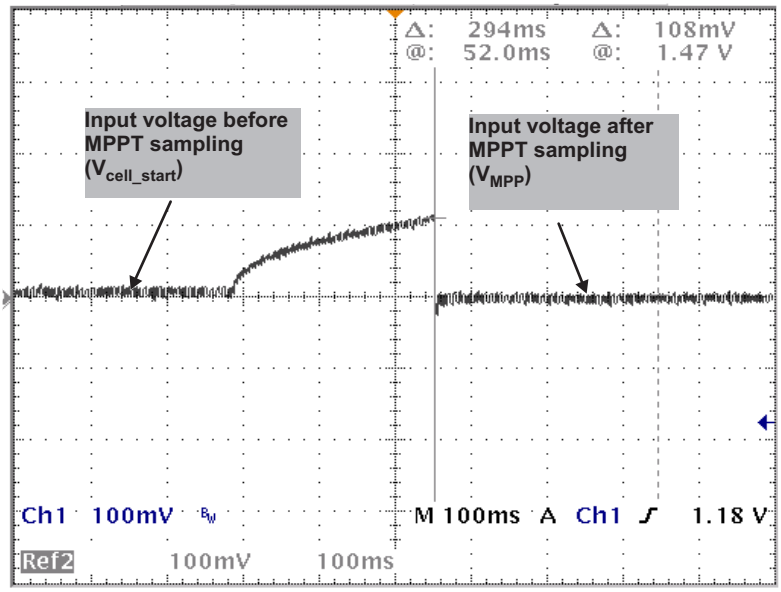


**Figure 4. Panel Voltage During Charging and MPPT Sampling, Voltage of the Panel Before and After Sampling are Equal - Steady State**

The $V_{MPP}$ of 1.36 V is approximately 80% of $V_{OC}$ (1.66 V); however, rather than setting the resistor divide ratio to 80%, the calculated resistor values set the divide ratio to 92.5%. The final result shows that with the resistor ratio set to 92.5% the input voltage regulates to approximately 1.37 V which is very close to the panel's actual MPP voltage. This shows that even if the panel does not settle in the allotted 256 ms window that Equation 5 and Equation 6 can be used to regulate the input to $V_{MPP}$.

For panels that are unable to settle to OCV under typical environmental conditions, set the ratio in the range of 80%–90% to ensure operation near MPP. If the conditions change such that the panel is able to settle within the sampling period, the panel will be regulated to the actual ratio and not near MPP unless the resistor values are changed. It is recommended the ratio is not set above 90%, ensuring the bq25504 continues to harvest energy under these changing conditions.


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