Solar Powered LED Street Lighting
Solar Powered LED Street Lighting

Courtesy of BetaLighting
Agenda

• Trends for solar powered LED street lighting

• Regulating voltage out of a solar panel
  – Application overview
  – Maximum Peak Power Tracking (MPPT)
  – Reference design

• Driving High-Brightness LED (HB-LED)
  – Selecting a design approach
  – Reference design
The Application of Solar Powered LED Street Lighting

- LED lighting offers high efficiency, long operating life and low voltage operation which is ideal for solar.

- Solar street lights were initially used in remote locations and disaster prone areas.

- As LED efficacy and light output have improved, they are becoming mainstream.
Tipping Point is Close on All the Major Apps…

Number of 1W LEDs Needed

Expected Lumens per 1W LED

- 150 W Roadway
- 400 W HID Met
- 4x T5 FL Troffer
- Lumens/1W LED

Regulating Voltage out of a Solar Panel
Solar Power – Block Diagram

Solar Panel → ~24 V → Charge Controller → ~12 V → Battery → 350 mA → LED

Solar Panel produces approximately 24V, which is then regulated by a charge controller to 12V before charging a 12V battery. The battery supplies power to a LED, which operates at 350 mA.
### Comparison of Different Types of Charge Controllers

<table>
<thead>
<tr>
<th>Basic</th>
<th>PWM</th>
<th>MPPT</th>
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<tbody>
<tr>
<td>• Designed to protect the battery from overcharge or undercharge</td>
<td>• Controls the amount of current charging the battery</td>
<td>• Optimize the power output from the cell</td>
</tr>
<tr>
<td>• Prevents reverse current</td>
<td>• Trickle charge</td>
<td>• Battery charge to optimal capacity</td>
</tr>
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</table>
Maximum Peak Power Tracking (MPPT)

- Solar panels in general are inefficient
  - ~30% efficient
  - Most expensive component in the system

- Charge controllers and other electronics need to be as efficient as possible to maximize the benefits
  - Typically implemented with a micro-controller

- MPPT compensates for the changing Voltage versus Current characteristic of the solar cell to increase the efficiency
Solar Panel Characteristics

Extracting the maximum amount of power from the solar panel is difficult due to the nonlinearity and variability of the Voltage-Current (V-I) characteristic.

MPPT fools the panels into outputting a different voltage and current allowing more power to go into the battery by making the solar cell think the load is changing when you really are unable to change the load.
Power and Voltage for a Solar Panel

Voltage Current and Max Power of a Solar Panel

Noon Sun

Max power = 24.3 w @ 14.3v

Afternoon Sun

Max power = 17.3 w @ 15.4v

Evening Sun

Max power = 6.1 w @ 15.99v
Solar Panel Charge Controller

- **Solution**: CS51221
- **Target Application**: Solar Panel LED Street Lighting, Solar Panel Battery Charger
- **Specification**:
  - Input: 12 V – 24 V
  - Output: 12 V @ 2 A
  - Protection: Adj Current Limit, Input UVLO, Input OVLO
  - Maximum peak power tracking required
  - Efficiency: Target >80%
  - Isolation Required: YES – Prevent discharging the batteries
Component/Topology Justification

- The topology was chosen as it can buck down to 12 V from the solar panel in the case of one battery.
- The topology can also boost to 24 V in the case of 2 batteries or more and can be easily changed.
- Aux rail available for remote transmission and monitoring.
- Can accommodate panels as large as 90 W.
- Implement maximum peak power tracking to improve efficiency.
- Need to meet good efficiency, target costs and easy to implement.

- CS51221 offers:
  - Isolated and non-isolated topology
  - Adjustable pulse-by-pulse current limit
  - External voltage reference
The CS51221 fixed frequency feed forward voltage mode PWM controller contains all of the features necessary for basic voltage mode operation. This PWM controller has been optimized for high frequency primary side control operation.

### Unique Features
- 1 A sink/source gate drive
- Up to 1MHz Fsw
- External voltage reference

### Benefits
- High efficiency operation
- Optimize for size or efficiency
- Reduced component count

### Others Features
- Programmable Max Duty Cycle Limit
- Programmable Pulse–By–Pulse Overcurrent Protection
- Overvoltage Protection with Programmable Hysteresis
- Bidirectional Synchronization

### Market & Applications
- **Consumer Electronics**: PoE PD, ...
- **Automotive**: Body electronics, Navigation, ...
- **Computing**: Power supply, ...
- **Industrial**: Power supplies, Process control, PoE PD, Solar Power Charger...

### Application Data

### Ordering & Package Information
- **SOIC-16**
- **CS51221**: -40 to +125°C Tj
Circuit and Block Diagram

Programmable OVLO, UVLO, Vff

Adjustable Max Duty Cycle & Fsw

Maximum Peak Power Tracking
Implementing MPPT With the CS51221

- MPPT is implemented by dynamically adjusting the current limit with the Iset pin.
- Once the Input voltage drops, the pulse by pulse current limit is lowered until the input voltage returns.

Eliminates the need for an expensive microcontroller.
Peak Power Tracking

Controller will find the peak power point and adjust dynamically to meet changing source characteristics.

Controller tracks the maximum power the panel can produce within -5% error.
MPPT – Dynamic Reaction to Full and Partial Sun

Sun Returns and Current Limit Adjusted

Solar Panel in Partial Shade

Full Sun

Panel in Full Shade

Panel Fails to Provide Minimum Power

Fast Moving Shade and Full Sun

Panel in 50% Shade

Input Voltage

Current Limit Voltage

Measure value status

P1: rms(V2)
77.3 mV

P2: f(V2)
109.27321 ms

P3: f(V2)
10.47415 ms

P4: --
P5: --
P6: --

Input Voltage

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ON Semiconductor
MPPT Enables Lower System Cost

- MPPT enables a smaller size solar panel to be used
- ~$4/W for the panel x 30 W = $120 system savings

90 W Panel w/ Basic Charge Controller

60 W Panel w/ MPPT

~30% more charge transferred from the panel to the battery
# Reference Design

<table>
<thead>
<tr>
<th>Device</th>
<th>Application</th>
<th>Input Voltage</th>
<th>Output Voltage</th>
<th>Output Current</th>
<th>Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS51221</td>
<td>Solar Panel Battery Charger</td>
<td>12 V – 24 V</td>
<td>12 V – 14.4 V</td>
<td>2 A</td>
<td>Flyback</td>
</tr>
</tbody>
</table>

## CS51221

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>12</td>
<td>14.4</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Output Current</td>
<td>2</td>
<td></td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Oscillator Frequency</td>
<td>100</td>
<td></td>
<td>kHz</td>
<td></td>
</tr>
</tbody>
</table>

Note: Easily scalable to larger solar panels & multiple batteries
Driving HB-LED for Street Lighting Applications
Solar Power – Block Diagram

Solar Panel → ~24 V → Charge Controller → ~12 V → Battery → 350 mA → LED
## Metal Halide Source Replacement

### Number of LEDs Required

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Average Delivered Lumens*</th>
<th>Number of LEDs Req’d 2007**</th>
<th>Number of LEDs Req’d 2012***</th>
</tr>
</thead>
<tbody>
<tr>
<td>70 W Metal Halide</td>
<td>2,100</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>100 W Metal Halide</td>
<td>3,500</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>150 W Metal Halide</td>
<td>5,450</td>
<td>46</td>
<td>31</td>
</tr>
<tr>
<td>175 W Metal Halide</td>
<td>7,700</td>
<td>66</td>
<td>44</td>
</tr>
<tr>
<td>250 W Metal Halide</td>
<td>10,600</td>
<td>90</td>
<td>60</td>
</tr>
<tr>
<td>320 W Metal Halide</td>
<td>15,200</td>
<td>130</td>
<td>86</td>
</tr>
<tr>
<td>400 W Metal Halide</td>
<td>16,500</td>
<td>141</td>
<td>94</td>
</tr>
</tbody>
</table>

* From HID bulb data sheets, includes 60% typical fixture CU
** Current best-in-class LED technology (Cree XLamp Q4 bin @ 6000K, 700 mA), includes 80% typical fixture CU. Assumes thermal equilibrium of LEDs (65°C Tj)
*** Based on DOE projections of LED performance improvement, 80% CU. Assumes thermal equilibrium of LEDs (65°C Tj)

- LEDs make clear economic sense in lower wattage applications now, all MH applications in the near future
- Tradeoff on lifetime versus operating current should be considered based on ambient conditions
Strategy #1 for Coping with Rapid Change in LED Performance

Modular Approach to MH Source Replacement

A modular design approach can yield constant photometric output while facilitating ongoing cost reductions each time LED brightness is improved.
Strategy #2 for Coping with Rapid Change in LED Performance

Lifetime Analysis - Aim Ahead of the Duck…

Prototyping with the highest performance LEDs currently available is more expensive, but can yield a more competitive and longer life product over the long term.
Strategy #3 for Coping with Rapid Change in LED Performance

Plan for BOM savings

Generation 1

Generation 2

25% brighter LEDs can also mean 25% fewer LEDs. Need to plan flexibility in your driver design to accomplish this
LED Street Light Design

What’s important?

• Type III street lighting pattern
• 4200 initial lumens on target
• 12 V Battery Source
• Reasonable optical efficiency; “single layer optics”
• Manage junction temperature for lifetime

What’s less important…

• Uniformity (seeing spots is OK…)
• Size
LED Assumptions

1. Output: 100 lm Typical at 350 mA @ Tj = 25 deg C
2. Drive current = 350 mA
3. Optical losses of 12% due to single layer, well coupled optics
4. Max ambient = 40 deg C
5. Driver losses = 10% (90% efficiency target)

Many LED Options Available
Sizing the # of LEDs for the Application

First order estimate:
- Number of emitters
- Total wattage

Emitter output = 100 lm @ Tj 25.
Derate for elevated Tj; assume Tj = 90 deg C.

At 90 deg C, emitter output is down 20% = 80 lumens per emitter.
Optical losses – 12% → 71 Lumens per emitter.
4200 lumens required/71 lm per emitter = 60 emitters
Vf= 3.6 volts * .350 A = 1.26 W (60 emitters x 1.26 W = 76 W)

Worst Case driver losses: = 15% => Total fixture wattage is ~89 W
LED Street Light

• Solution:
  – NCP3066
  – Configured as a Boost Controller

• Target Application:
  – Solar Panel LED Street Lighting
  – LED Light Bar

• Specification:
  – Input: 12 V battery
  – Output: 350 mA
  – Protection: Current Limit, Under Voltage Lockout (UVLO)
  – Efficiency: Target >90%
  – Isolation Required: NO
Component/Topology Justification

- Supports modular Constant current architecture
- Configurable output LED current from 350 mA to 1 A
- Able to drive 5-10 LEDs in series
- Cost effective system approach
- Easy to implement

- NCP3066 offers:
  - Dedicated ENABLE pin for low standby power
  - Average current sense (current accuracy independent of LED Vf)
  - 0.2 V reference for small / low cost sense resistor
  - User adjustable peak current limit to maximize battery lifetime
  - No loop compensation required
NCP3066 – Constant Current Multi-mode Regulator

**Value Proposition**
The NCP3066 is a switching regulator designed to deliver constant current to high power LEDs. The device has a very low feedback voltage of 235 mV (nominal) which is used to regulate the average current of the LED string.

**Unique Features**
- **F\text{sw}** from 52 to 250 kHz
- Wide **V\text{in}** from 3 to 40 V
- Multi-topology
- ENABLE pin

**Benefits**
- Optimize component size and efficiency
- Allows use in many versatile applications
- <100 uA standby

**Others Features**
- 1.5 A peak current
- Ability to add external transistor to increase output current in buck mode or increase voltage in boost mode
- 2% accurate internal reference over temperature

**Market & Applications**
- **Consumer Electronics**: CRT, LCD TVs, STB, DVD, ...
- **Automotive**: Airbag, Body electronics, Brake systems, Infotainment, Navigation, ...
- **Computing**: Power supply, Peripherals (Printer, Scanner, Graphic card, …)
- **Industrial**: Power supplies, Process control, Home energy and control, Security systems, …

**Typical Application diagram & Package info**

**Ordering info & Support**
PDIP-8, SOIC-8, DFN-8
NCP3066: -40 to +125°C Tj
NCP3066 as a Controller

- Boost: Higher output voltage and/or current is desired
- Buck and SEPIC topologies also supported
- Controller efficiency can be optimized for highest performance
- Simple drive circuit to support external MOSFET or Bipolar

Boost example with 100 V External N-FET From a 24 V Source
Boost Controller Schematic

- Supports a variety of different applications from 4-30 W
- Options for different MOSFETS (Gate Clamp)

Programmable Current Limit

Programmable Maximum Duty Cycle Limit

Optional:
Ramp Injection
For enhanced performance
With high line and load variation

Open LED Clamp
Iout vs. Vin of NCP3066 Boost Driving 8 CREE XRE

Accurate Current Regulation

Efficiency > 90%

Automatic LED dimming under Low battery conditions
# Reference Design LED Street Light

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<td>+12 V Battery</td>
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Conclusion

• Highly efficient solutions like the CS51221 with MPPT are needed to maximize the efficiency from solar panels

• The NCP3066 provides a flexible/expandable solution for driving LEDs from a battery source

• Expectations are increasing for solar-powered LED lighting to become the environmentally friendly outdoor lighting solution for the 21st century
Backup
Guangzhou, China

Hybrid Solar/ Grid Powered Street Lamps

Courtesy of Multi-Cell Semiconductor Lighting Technology Co., Ltd.
Split, Croatia

Warm White Street Lamps

Courtesy of Schréder
For More Information

- View the extensive portfolio of power management products from ON Semiconductor at www.onsemi.com

- View reference designs, design notes, and other material supporting the design of highly efficient power supplies at www.onsemi.com/powersupplies