Solid State LED Driver Application Note
Global Solid State LED Lighting Market forecast to Grow 30.9% to nearly $1.3bn in 2013
**Light Emitting Diodes (LED)**

- A LED is a semiconductor diode.
- Its semiconducting materials create a P-N (positive-negative) junction.
- When connected to a DC power source current flows from the P side (anode) to the N side (cathode) but not in the reverse direction.
- At the P-N junction a photon of Light is emitted for every electron that falls into a lower energy level.
- The color (wavelength) of the light is dependent on the semiconductor material.
- **RED LEDs** are Aluminum Gallium Arsenide (AlGaAs).
- **BLUE LEDs** are Indium Gallium Nitride (InGaN).
- **GREEN LEDS** are Aluminum Gallium Phosphide (AlGap).
- **WHITE Light** is created with a combination of Red Blue Green (RGB) LEDs or a Blue LED covered with yellow phosphor.
Light Emitting Diodes (LED)

Charge carriers (electrons and electron holes) flow into the junction from the positive and negative electrodes. When an electron meets a hole it falls into a lower energy level which releases the equivalent energy in the form of light (photons).
The diodes are called light emitting because the energy given up by the electron as it relaxes is emitted as a photon.

Above the threshold voltage (1.8V for Red to 3.3V blue LEDs), the current and light output increases exponentially with the bias voltage across the diode.
Powering Light Emitting Diodes

- The basic LED circuit consists of a DC voltage source powering two components connected in series. A current limiting resistor (sometimes called the ballast resistor), and the LED. The current limit can range from 20mA to 3A depending on the power of the LED used.
- \[ R \text{ Ohms} = \frac{\text{Power Supply Voltage} \ V - \text{(Voltage drop across LED)}}{\text{LED current} \ I} \]
- Example \( R = \frac{(6V - 1.8V)}{0.02} = 210 \text{ Ohm} \)
- LED power = 0.02*1.8=36mW
- However wasted power \( W \) watts =\( I^2 \times R \)
- Example \( W = (0.02 \times 0.02 \times 210) = 84\text{mW} \) which is 2.3 times the LED power!
- Therefore the need for Efficient Power supply Designs
Powering LED s

- LED electronic driver design is an area of emerging importance in LED product development. Implementation of simple voltage control LED driver circuitry is disappearing in favor of current control, pulse width modulation, and energy efficient switching power supply designs. In many applications, temperature sensing and feedback are essential. In advanced lighting and display system applications, LED flux and color control feedback circuitry have become essential.

The high performance Cool, Neutral and Warm white LED arrays from Bridgelux in Star and Square package formats
LED Driver Topologies

The driver topology will depend upon the factors shown in above flow chart. However the function of the driver is convert the 115-230 V 50/60Hz mains power into a controlled dc current to light the LED lamps and at same time complying to Harmonic and efficiency standards.
A Typical high Power LED Driver can deliver power to 30 LEDs with Power factor correction and filtering to meet international harmonic standards. **FIRST STAGE: PFC**

Many basic ac-dc power supplies generate harmonic distortion in the input line and have poor power factor, making it difficult to meet the European standard EN-61000-3-2. The solution is to use a PFC circuit to make the input current waveform appear sinusoidal, like the input voltage waveform.
Adding Control systems will have the effect of reducing the overall driver efficiency.
LED Brightness Control—Why Pulse Width Modulation?

From the driver IC perspective, analog dimming presents a serious challenge to the output current accuracy. Almost every LED driver uses a resistor of some type in series with the output to sense current. The current-sense voltage, VSNS, is selected as a compromise to maintain low power dissipation while keeping a high signal-to-noise ratio (SNR). Tolerances, offsets, and delays in the driver introduce an error that remains relatively fixed. To reduce output current in a closed-loop system, VSNS, must be reduced. That in turn reduces the output current accuracy and ultimately the output current cannot be specified, controlled, or guaranteed. In general, dimming with PWM (Pulse Width Modulation) allows more accurate, linear control over the light output down to much lower levels than analog dimming.
The pulse width modulation (CH2) will produce an AC ripple current through the LED string at the switching frequency (CH4). In general, higher switching frequencies improve driver efficiency.
LED Driver Output Measurements

The driver output will have high frequency (30kHz) voltage transients produced by the PWM as seen on the Tektronix scope.

These can be seen as ripple on the DC output current wave form as shown on the Voltech PM6000 Power analyzer which has a 5MHz sampling rate, thereby measuring accurately the total output power of the LED driver.
LED Driver Testing

Some LED Drivers use electrolytic capacitors on their outputs to reduce the AC ripple. However, electrolytic capacitors have a defined life. It has shown that by measuring the percentage of ripple on this output is a good indication of the life of the product.
LED Driver Measurements

Typical Output measurements
Using a Voltech PM1000+
DC Volts  9.913 RMS
DC current  372.8 mA
Watts  3.695 W

Typical Input measurements
Watts  5.024 W
Frequency 60.00Hz
Power factor 0.885
Current distortion 38.89% ATHD

Calculated Efficiency of this Driver =  3.695/5.024 = 73.55%
The Mains Input current Harmonics can be measured individually as an absolute value or as a percentage of fundamental as shown here on the Voltech PM1000+Power Analyzer.

Note the harmonic spread of this driver is typical.

Also Input measurements of Watts, Current, Voltage, Frequency and “scope” waveforms of Voltage, Current and Power can be displayed in real time on the PM1000+

Note the non linear current waveform (Green) is the cause of the Harmonics.
Evolving Standards for LEDs

## European LED Standards

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<th>Description</th>
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<td>Lamps - Self-ballasted LED-lamps for general lighting services by voltage &gt; 50 V - Safety specifications 34A/1354/CDV</td>
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<td>Method of measurement of centre beam intensity and beam angle(s) of reflector lamps</td>
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<td>IEC/EN 60061</td>
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<td>IEC/EN 60838-2-2</td>
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<td>IEC/EN 61347-1</td>
<td>Lamp control gear - Part 1: General and safety requirements</td>
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<td>IEC/EN 61347-2-13</td>
<td>Lamp control gear - Part 2-13: Particular requirements for d.c. or a.c. supplied electronic control gear for LED modules</td>
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<tr>
<td>IEC/EN 62384 + A1</td>
<td>DC or AC supplied electronic control gear for LED modules - Performance requirements</td>
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<td>Digital addressable lighting interface - Part 207: Particular requirements for control gears; led modules (device type 6)</td>
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<td>IEC/EN 60825-1</td>
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<td>IEC/EN 61000-3-2:</td>
<td>EMC - Limits for harmonic current emissions</td>
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<tr>
<td>IEC TR 62471-2</td>
<td>Photobiological safety of lamps and lamp systems - Part 2: guidance on manufacturing requirements relating to non-laser optical radiation safety (see Annex A to the Guide)</td>
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</table>
Harmonic Standards

- IEC61000-3-2  Class C  Mains Current Harmonic Limits. For European Markets
- ANSI C82.77-2002 Harmonic Emission Limits
- ANSI C82.XXX – LED Drivers For American Markets
  - Provides specifications/operating characteristics of electronic drivers (power supplies) for LED devices, arrays, or systems
  - Applies to drivers operating up to 600V and frequencies of 50 or 60 hertz as well as above 20 kHz
Harmonic Standards

- EN61000-3-2  Class C

Shown here, a 17 Watt LED Driver with Power Factor corrected current waveform, but has still has current harmonic content.
Harmonic Standards

- **EN61000-3-2** Class C
- Mains Current Harmonic Limits are % of Fundamental.
- LED Drivers are Rich in Harmonics.

Limits are set for all 40 current harmonics. The setting of the dimming device is varied in 5 equidistant steps between the minimum and the maximum power in order to obtain comprehensive results.
Harmonic Standards

EN61000-3-2  Class C Mains Current Harmonic Limits are % of Fundamental.

Table 2. Limits for Class C Equipment

<table>
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<tr>
<th>Harmonic order (n)</th>
<th>Maximum permissible harmonic current expressed as a percent of the input current at the fundamental frequency (%)</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>30 \cdot \lambda^*</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>11 \leq n \leq 39 (odd harmonics only)</td>
<td>3</td>
</tr>
</tbody>
</table>

\* \lambda is the circuit power factor.

As said before Limits are set for all 40 current harmonics. Note the third Harmonic limit is altered by the Power factor measured, so having a “good” PF of 1.00 is an advantage.
Harmonic Standards

EN61000-3-2  Class C  Waveform check.

Rules: The value of the current reaches 5 % of the max value latest at 60º and value of the current reaches its maximum latest at 65º. The value of the current is decreased to 5 % of its maximum value not before 90º: Applies to Active input power ≤25 W. The third harmonic current, expressed as a percentage of the fundamental current, shall not exceed 86 % and the fifth harmonic current shall not exceed 61 %.
ANSI C82.77,

Most recently revised in 2002, it recommends that all commercial indoor, hard wired ballasts meet a minimum power factor of 0.9 with a maximum of 32% THD. (21 Harmonics measured) Note at the time of the ANSI standard publication most discharge lighting hard wired ballasts were 28 Watts or greater. The cost of correcting the power factor at this wattage level to ANSI commercial limits was considered acceptable for hard wired electronic ballasts. ANSI C82.77 requires residential hard wired luminaries below 120 Watts meet a minimum power factor of 0.5 with a maximum of 200% THD.

The ANSI standard acknowledges that low density installations do not have same impact on the VA load and require less power factor and harmonic content control.

ANSI C82.77 has special allocations for specific applications such as task, down lighting and modular office furniture.

For these applications ANSI recommends a minimum power factor of 0.5 with maximum THD of 32% for products below 50 Watts. This gives an allowance for ballasts that have an increased displacement factor. By granting this allowance ANSI has permitted lower cost power factor appropriate solutions to be used.
European LED Efficiency Standards

- Light output is measured in Lumens (lm)
- Electrical power input is measured in Watts
- ELC and CELMA are providing input on quality requirements to the Commission as it prepares part 2 of the EcoDesign Regulations. The current EU Regulation 244/2009 (EcoDesign part 1) is restricted to non-directional lamps.

The recommendation is to include LED modules in part 2, and to require efficacy >50 lm/W in 2012, increasing to >60 lm/W by 2015.
Title 24 is a local Californian US Standard for Promoting Lower Power consumption in lighting systems.

The Efficiency of the LED Driver System will improve as the total power increases because the power lost in the driver circuit remains nearly constant and independent of the power supplied the LEDs.

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<th>Luminaire Power Rating for LED Lighting</th>
<th>Minimum Luminaire Efficacy for LED Lighting</th>
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<tr>
<td>15 watts or less</td>
<td>40 lumens per watt</td>
</tr>
<tr>
<td>15 watts to 40 watts</td>
<td>50 lumens per watt</td>
</tr>
<tr>
<td>Over 40 watts</td>
<td>60 lumens per watt</td>
</tr>
</tbody>
</table>
Safety Standards

- IEC SC 34C 62384 - DC or AC supplied electronic control gear for LED modules
- • IEC SC 34A - Performance Standard for LED Lamps
- • NEMA Premium SSL Standard (SSL-5)Tabled for the moment
- NEMA SSL-1 Power Supply
- IEC SC 34A 62031:2008 LED modules – Safety

- IEC SC 34A IEC 62560 Self-Ballasted LED Lamps
- IEC SC 34A <tbd> LED lamps > 50 V - Safety specs
- UL 8750 Standard for LED Equipment for Use in Lighting Products
Recommended Voltech Solutions

- LED IEC61000-3-2/3 Class C Full Compliance Testing
  - Solution: PM6000 Power Analyzer & IEC Network with Voltech IEC Software

- LED IEC61000-3-2/3 class C Pre-Compliance Testing
  - Solution PM1000+ and Pre-Compliance IEC Software.
Recommended Voltech Solutions

- Efficiency Measurements for 1 phase Input
- Solution (A) :- 2 channel PM6000 Power Analyzer with on board math Function or VPAS software
- Solution (B):- PM1000+ Power Analyzer.

For Steady state conditions; measure input power and then the output power and calculate the efficiency.
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