Welcome to this Web seminar on Controlling High Brightness LEDs Using the dsPIC “GS” Series of Switch Mode Power Supply Digital Signal Controllers.

I am Michael Curran, an applications engineer with Microchip Technology.
We will start by going over some of the basic characteristics of LEDs including their advantages, and then talk about a technique to digitally control their brightness.

Next, we will look at how low-power LEDs are driven and why other methods are needed for High Brightness LEDs and the advantages of using a dsPIC “GS” series Digital Signal Controller.

Finally, we will look at Buck and Boost converters for controlling High Brightness LEDs, and review a list of supporting documents which provide more details on the topics covered in this seminar.
LED Basics

Let’s start by looking at the advantages of using LEDs.
LED Basics

● LED Advantages
  – Higher efficiency
  – Longer life
  – Size
  – Single color emitted
  – Dimming for RGB applications
  – Produce less heat

LEDs have many advantages compared to incandescent lighting. Some of them include higher efficiency, longer life, and smaller size for the same amount of light emitted.

In addition, LEDs emit light of a single color without the need for color filters, are well suited for RGB applications, and produce less heat for the light emitted.
LED Basics

- **Low Power**
  - Used for signalling (on/off, alarms, ...)
  - Forward current of a few mA

- **Mid Power**
  - Used for indoor lighting
  - Forward current in wide range from 20 mA to 150 mA

- **High Power (High Brightness)**
  - Used for outdoor lighting and automotive
  - Forward current is 350 mA and above

There are 3 main types of LEDs. Most of us are familiar with low power LEDs, which are typically used as indicators and only require a few milliamps of forward current.

Mid power LEDs are often used for indoor lighting and have a range from 20 milliamps up to 150 milliamps.

High power or High Brightness LEDs are any LEDs that have a forward current of 350 milliamps or above and are typically used for outdoor and automotive applications.

The High Brightness LED is the type that we will be focusing on in this seminar.
LED Basics

- **Light Emitting Diode**
- An LED consists of semiconducting material doped with impurities to create a p-n junction
- As in normal diodes, current flows from the p-side (anode) to the n-side (cathode) and emit light when current passes through them
- An LED’s light output is determined by the forward current ($I_F$) through the LED

  Forward Voltage ($V_F$)

  ![Diagram of LED with forward current](image)

  Forward Current ($I_F$)

The term LED is an acronym for Light Emitting Diode

An LED consists of a semiconducting material doped with impurities to create a p-n junction similar to normal diodes and emit light when current passes through them.

As in normal diodes, the current flows from the anode (p-side) to the cathode (n-side), this current is referred to as the forward current.

The light output of an LED is dependent on the forward current of the LED.
LED Basics

- Light output is measured by luminous flux, which is the perceived power of light emitted and has the unit lumen (lm)

- The color of the LED is measured on the Correlated Color Temperature (CCT) scale and is measured in kelvin (K)

<table>
<thead>
<tr>
<th>Color Temperature</th>
<th>CCT Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High color temperature</td>
<td>≥ 5000 K</td>
<td>Cool colors (blueish white)</td>
</tr>
<tr>
<td>Low color temperature</td>
<td>2700-5000 K</td>
<td>Warm colors (yellowish white through red)</td>
</tr>
</tbody>
</table>

An LED’s light output is measured by luminous flux, which is the perceived power of light emitted and has the unit lumen.

The color of LEDs is measured on the Correlated Color Temperature scale and is measured in degrees kelvin.

Cooler colors such as blueish white are greater than 5000°K, while warmer colors such as red and yellowish white are between 2700-3000°K.
We will now take a closer look at some of the specifications of a High Brightness LED.

This graph shows the relationship between luminous flux and forward current for a Luxeon Rebel High Brightness LED. You can see that for 350 milliamps of forward current the luminous flux is 1 Lumen.
This graph shows the relationship between the forward voltage and the forward current of the same LED. For a forward current of 350 milliamps the forward voltage is approximately 2.9 volts.

One important factor to note with LEDs is that the forward voltage will drift with both temperature and age, causing the trace on this graph to shift left and right. For this reason it is important that the forward current and not the forward voltage of the LED be regulated so that the lumen output of the LED is consistent.
Digitally Controlling Brightness

We will now take a look at how to control the brightness of the LED
There are two ways to control the brightness of an LED. The first method is using Analog dimming, which involves varying the forward current through the LED to adjust the brightness. Shown here is an example of analog dimming where the forward current is reduced to obtain 50% brightness.

The major disadvantage of analog dimming is that when adjusting the forward current, the color temperature of the LED will vary. This is not desirable for most applications.
Digitally Controlling Brightness

- Digital Dimming
  - Switch the LED current on and off for short periods of time
  - Provides constant current while maintaining brightness control
  - Switching must be fast enough to avoid noticeable flicker
    - 400 Hz – 1.2 kHz are typical frequencies

The second method uses a digital dimming technique involving switching the forward current on and off for short periods of time. The human eye averages these on and off times together for a perceived brightness. This example also shows a 50% reduction in brightness indicated by the red dashed line. With this method you are effectively reducing the average forward current, while maintaining consistent color of the LED.

One important thing to note with digital dimming is that the switching frequency of the current must be fast enough to avoid noticeable flicker, 400 Hertz to 1.2 kilohertz is a typical switching frequency.

We will be using 400 Hertz for the upcoming examples.
To digitally control the brightness of the LED we first need create a 400 Hertz dimming frequency. The dsPIC “GS” series of Digital Signal Controllers has a PWM override feature, which when active, disconnects the PWM module from the pin. This feature, along with an 8-bit counter, is used to achieve the 400 Hertz dimming frequency.
Here we can see one period of the 400 Hertz dimming frequency. The 500 kilohertz PWM indicated is used to regulate and maintain the constant forward current of the LED during the ON time, this will be explained later in the seminar. At the start of the dimming period, the PWM override is inactive and the PWM is connected to the pin of the device. During the OFF time the override is active, the PWM is disconnected from the pin, and the forward current of the LED will be zero. This process will restart at the beginning of the next Dimming period.
Digitally Controlling Brightness

Let’s take a closer look as to how the dimming frequency is created and how the override point is determined for controlling the brightness. The 500 kilohertz PWM has been removed for easier viewing.

The gold diagonal line represents an 8-bit dimming counter, which increments during the dimming period. Once the dimming counter reaches 255 it is reset to zero for the start of the next period.

The variable Dimming time is shown here to equal 128, and is compared against the dimming counter to activate the PWM override. Because Dimming Time equals 128, which is half of the dimming counter, the brightness of the LED is 50 percent.
Here is a similar example except with the variable dimming time changed to 64. And, because the Dimming time is 25 percent of the dimming counter’s full range of 255, the brightness of the LED is 25 percent of its full intensity.
Driving an LED

Now let us look at how to drive a High Brightness LED
Driving an LED

- \( V_{IN} = 3.3V \)
- \( V_F = 1.7V \)
- \( I_F = 5mA \)
- \( R = (V_{IN}-V_F)/ I_F \)
- \( R = (3.3V-1.7)/ 5mA \)
- \( R = 320\Omega \)

Here is an example of how a typical low power signal LED is driven. The I/O pin on the microcontroller can easily handle the 5 milliamps of forward current to operate the LED. The forward current is determined by the value of the resistor.
The High Brightness LED requires a much higher forward current of 350 milliamps, more than a Microcontroller I/O can provide. One solution is to power the LED directly from the main supply and add a MOSFET in series with the LED as shown here to control the brightness. However, there are drawbacks to this method. The resistor would be required to dissipate about 2 watts of power, which is inefficient and would require a physically large resistor. There is also no regulation of the input voltage. For example, if this was a battery powered system, when the battery voltage drops the forward current will also decrease because of the fixed resistor.
Advantage of the dsPIC “GS” DSC

A better solution is needed to control the current of a high brightness LED.
The dsPIC “GS” series of Digital Signal Controllers provides several features which allow for precise control of high brightness LEDs. These features include a High-Speed 10-bit Analog-to-Digital converter with up to 4 million samples per second, a flexible high-speed PWM, a high-speed analog comparator with a fast 20 nanosecond response time, and a flexible clock scheme with 40 MIPS operation speed.
Let’s take look at how a dsPIC “GS” series Digital Signal Controller can control a High Brightness LED with a Buck converter.
This is an example of a Buck converter circuit. The Buck converter converts a higher input voltage to a lower output voltage. Because of this, the input voltage must always remain higher than the forward voltage of the LED.

The sense resistor, Rsns, is used to monitor the forward current of the LED using the built-in analog comparator. Now let us look at how the current feedback with the sense resistor functions in the dsPIC.
Buck Converter

- The built-in analog comparator is used to monitor the current through the LED using cycle-by-cycle Fault mode.
- The reference for the comparator is determined in software with the CMREF register bits.
- When a Fault is detected, the PWM drives the pin low for the rest of the PWM period.
- At the start of the new period the PWM will continue at the set duty cycle.
- This method requires no CPU time to regulate the current through the LED.

This diagram is a general representation of the analog comparator and how it interacts with the PWM module in the dsPIC.

The current from the sense resistor, which is effectively the forward current of the LED, is fed into the non-inverting input pin of the comparator. The CMREF register is used to set the current reference for the comparator with a 10-bit DAC. If the input from the sense resistor is equal to or greater than the current reference, the comparator generates a fault, which causes the PWM output to be driven low for the remainder of the PWM period. If the fault is not present at the start of the next PWM period, the PWM will restart.

Along with its fast response time of 20 nano seconds, a significant advantage with using the analog comparator is that no CPU time is needed to regulate the forward current because the fault is directly connected to the PWM module. This allows the CPU to perform other functions and still be able to maintain the forward current of the LED.
Now we will take a closer look at the ON time of the dimming period with the Buck converter. We will see how the 500 kilohertz PWM regulates the forward current during the first few cycles.
Let’s follow the current path with the start of a new Dimming period with all currents beginning at zero.

At the start of the ON time, the PWM is active and will have a duty cycle of 100 percent. The diode D is reverse-biased and the current will take the path indicated by the red arrow through the LED, inductor, MOSFET, and the sense resistor. The PWM continues to be active past the first period until the MOSFET current reaches the current reference. At this point the analog comparator recognizes that there is a fault and drives the PWM low for the remainder of the PWM period.
Because MOSFET Q is now open, the diode D is forward-biased and the inductor supplies the current for the LED as shown by the blue arrow.
Now that a new PWM period has begun, the PWM restarts and the MOSFET current will again rise to the current reference. At this point a fault will occur and the PWM module will again be driven low.
This process is continuous during the ON time of the dimming period.
Here we will look at a Boost converter for driving multiple High Brightness LEDs
A Boost converter converts a lower input voltage to a higher output voltage, as a result the input voltage must always be lower than the forward voltage of the LED string.

The average forward current is monitored using the sense resistor Rsns using the 10-bit ADC module in the dsPIC.
The average current through the LED is monitored using the ADC module.

A PI control loop is used to regulate the forward current (IF) of the LED.

This diagram is a general representation of how the ADC and PWM modules interact in the Digital Signal Controller.

The current from the sense resistor is fed into the ADC module, a PI control loop is then processed in software and the duty cycle of the PWM is then updated.

Because the dsPIC “GS” series of Digital Signal Controllers has a 40 MIPS CPU speed it can handle managing multiple high brightness LED strings with this method.
Now we will take a closer look at the ON time of the dimming period with the Boost converter. We will see how the 500 kilohertz regulates the forward current.
At the start of the PWM period the input current takes the path represented by the red arrow through the inductor and MOSFET. During this time the capacitor supplies the current for the LEDs as shown by the gold arrow.

The forward current of the LEDs is measured at the midpoint of the PWM ON time so that the average current of 1 PWM cycle can be determined. The current measurement can now be used in the PI control loop to adjust the PWM duty cycle as needed. To simplify this example we will assume that the duty cycle will not need to be adjusted and will remain at 50%.
We have now reached the midpoint of the PWM period. The PWM is low, the MOSFET is open, and the current follows the path indicated by the blue arrow through the inductor, diode, LEDs, and the sense resistor.
This process is continuous during the ON time of the dimming period.
Here is a list of application notes on LED applications as well as general Switch Mode Power Supply design.

Application notes AN1114 and AN1207 describe in detail both the Buck and Boost converters.

All of these documents can be downloaded from the Microchip website.

This concludes the Web seminar on Controlling High Brightness LEDs Using the dsPIC “GS” Series of Switch Mode Power Supply Digital Signal Controllers. Thank you for your interest in the dsPIC Digital Signal Controller.