DOMINANT™ Opto Technologies *Innovating Illumination*

APPLICATION NOTES:

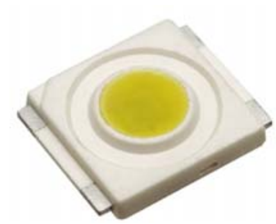
Dimming InGaN LED

Introduction:

Indium gallium nitride (InGaN, $In_xGa_{1-x}N$) is a semiconductor material made of a mixture of gallium nitride (GaN) and indium nitride (InN). Indium gallium nitride is the light-emitting layer in modern blue, green and white LEDs and often grown on a transparent substrate such as sapphire or silicon carbide.

Characteristic Of InGaN LED

While the InGaN produces the brightest light output across blue, true green and white, it shows a dependency of wavelength shift across varying forward current. The typical relationship between the forward current change versus the wavelength or CxCy shift are depicted in Fig 1 - Fig 5 below :



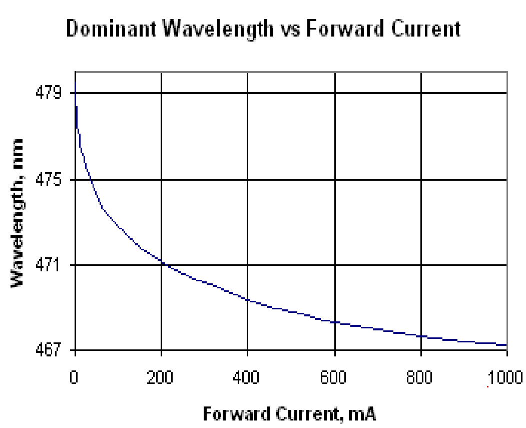


Figure 1 – SPNova InGaN Blue

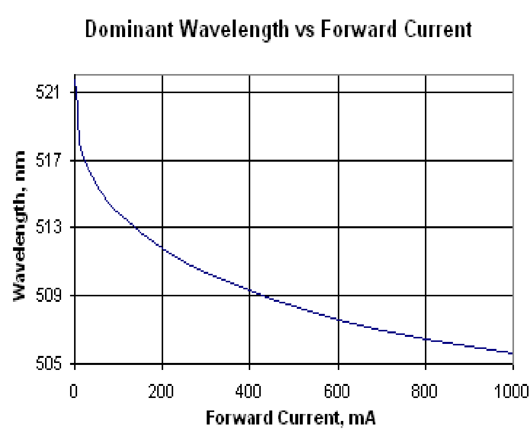


Figure 2 – SPNova InGaN Cyan

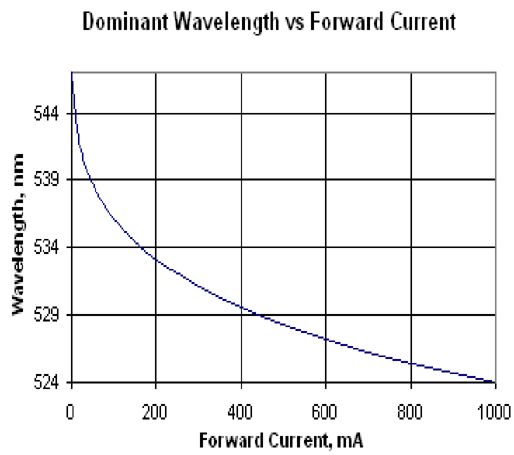


Figure 3 – SPNova InGaN True Green

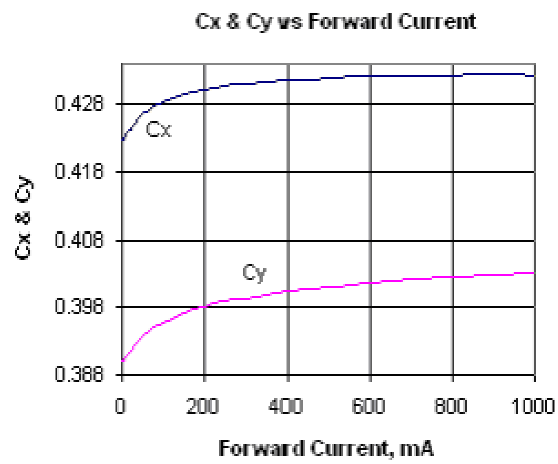


Figure 4 – SPNova InGaN Warm White

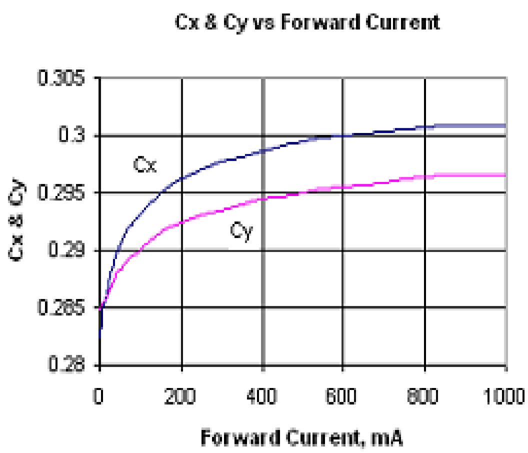


Figure 5 – SPNova InGaN White

The magnitude of shift for InGaN LED is proportional to the wavelength, longer wavelength (eg. True green) will shift more compared to shorter wavelength (eg. Blue). Due to wafer process variation, the exact magnitude of shift might vary from one LED chip to another.

As comparison, Aluminum Indium Gallium Phosphate (AlInGaP) technology LED exhibits only little changes in wavelength with varying forward current (Fig 6 – Fig 7). AlInGaP technology is to produce LED with color from hyper red to pure green.

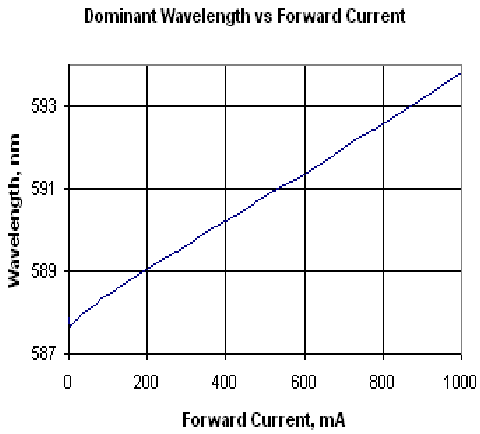


Figure 6 – SPNova AlInGaP Yellow

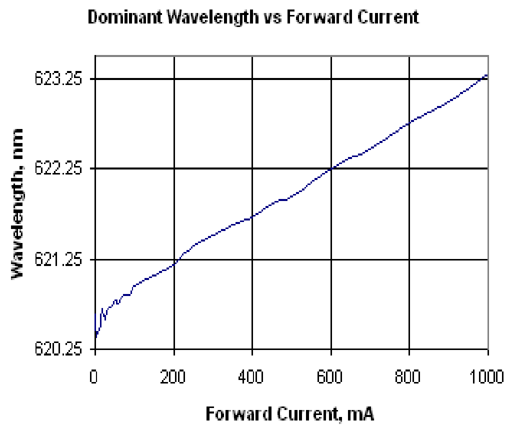
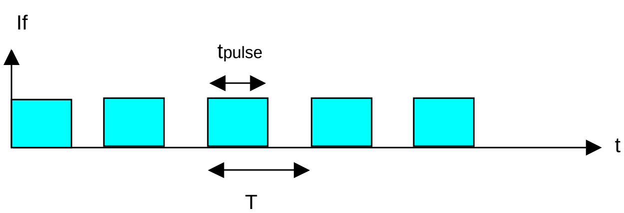


Figure 7 – SPNova AlInGaP Red

Dimming InGaN LED Using PWM

Due to this unique characteristic of InGaN, dimming an LED by the common method of varying forward voltage or forward current will effectively shift the dominant wavelength and thus shifting the color. In application where this shift of dominant wavelength cannot be tolerated, Pulse Width Modulation (PWM) should be used to control the dimming of an LED. In PWM operation, the forward current, I_f is kept constant, thus the wavelength will not shift. Brightness perceived by human eyes is directly proportional to the duty cycle (D) of the PWM signal (Figure 9). For general application, the frequency of PWM should be greater than 200Hz, so that the human eyes would not be able to differentiate each on/off pulse, but integrating all the pulses as perceived brightness. The color (dominant wavelength) shift can be avoided by using PWM dimming.



Duty cycle $D = \frac{tpulse}{T}\%$

Figure 8 – Typical PWM signal

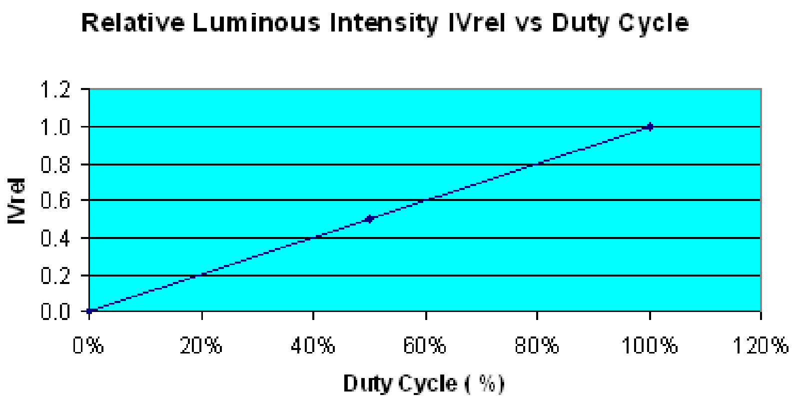


Figure 9 – LED dimming can be accomplished by adjusting the duty cycle of PWM signal

Example: Dominant SPNova True Green LED, NPT-USS with luminous intensity grouping AE has a typical IV of 20cd at 350mA. If a customer need 10cd in their final application, they could do so by driving the LED with 5ms pulse on and 5ms pulse off with biased current stay at 350mA. This 50% duty cycle configuration will ensure the light output is 50% of the same DC current level without causing any wavelength shift.

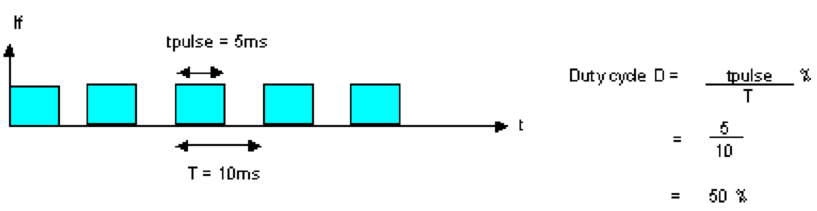


Figure 10 – Typical PWM signal for duty cycle = 50%

If the 50% dimming is achieved by reducing the forward current from 350mA to 175mA, the dominant wavelength will increase by approximate 4nm from 530nm to 534nm (Fig. 11). This might cause visual detectable color shift.

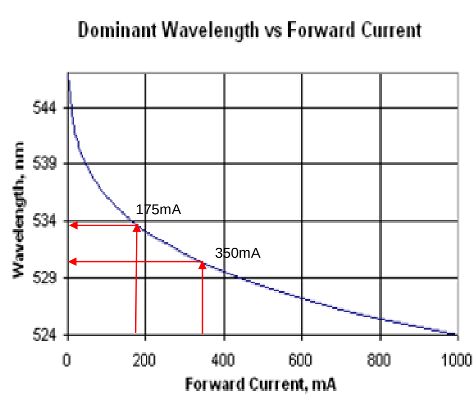


Figure 11 – Dominant wavelength shift with forward current bias from 350mA to 175mA

For application that requires full spectrum dimming, that is to adjust the light intensity from zero light output to maximum illumination, PWM dimming is the only design option. When using linear current dimming, and the LED forward current level falls below the minimum current density threshold of the LED chip, the LED might light up intermittently or on a multiple LEDs design, some LEDs might light up while the rest remain off. This will cause non-uniformity illumination on the application. The minimum current density threshold is depends on the chip size and the chip technology.

PWM Dimming Circuit Design

Most of the constant current LED drivers available in the market now are with built in function to allow PWM input. This simplifies the LED circuit design and allows a wide range of dimming ratio without impacting the color performance of the LED.

Several example of PWM dimming circuit implementations are depicted in the figures below:

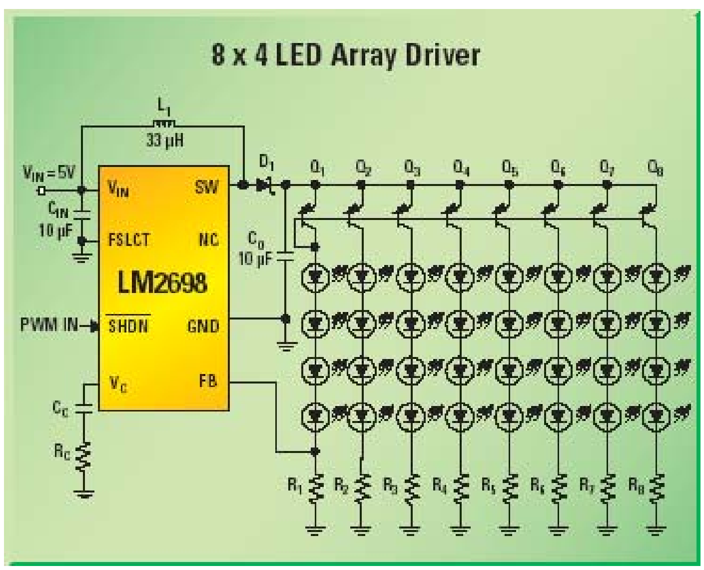


Figure 12 – A typical LED driving circuit using National Semiconductor LM2698 Boost regulator. The PWM signal is directly supply to the SHDN Pin of LM2698 to control dimming operation.

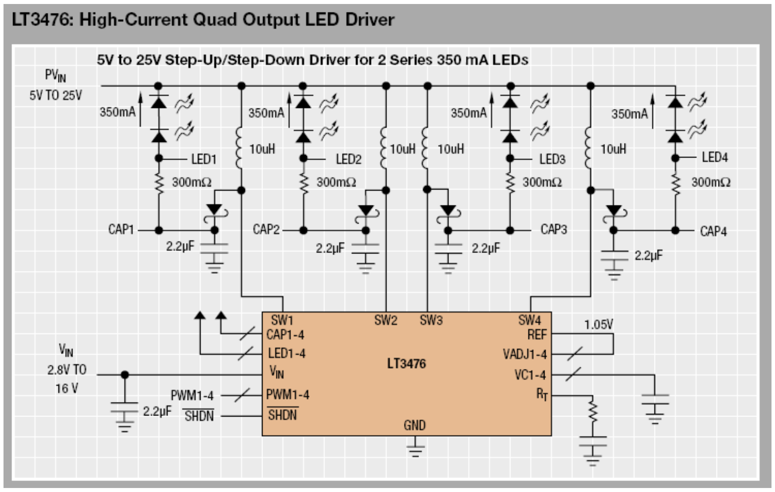


Figure 13 – LED circuit design suitable to drive Dominant 1W SPNova using Linear Technology LT3476. This LED driver is capable to drive 4 strings of LED and perform separate PWM dimming on each string.

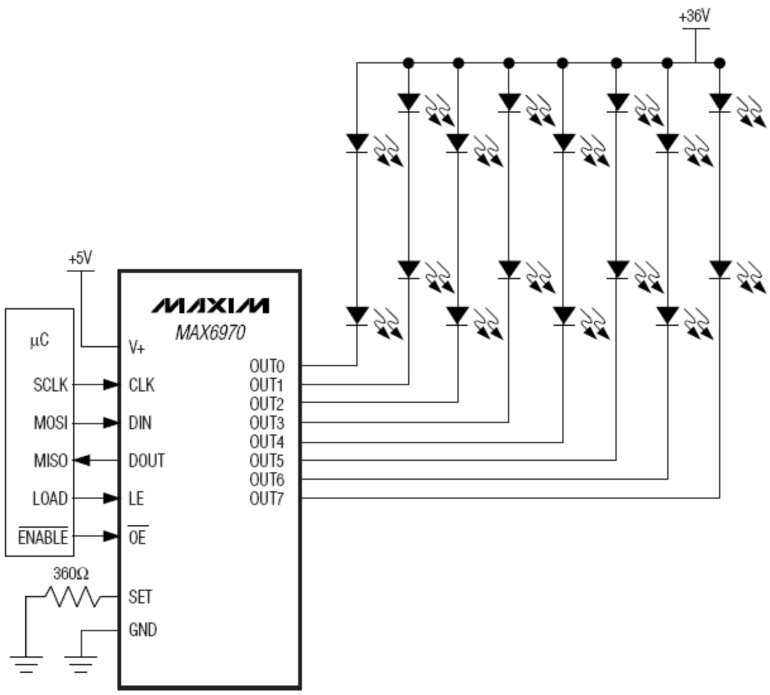


Figure 14 – Another LED circuit design using Maxim MAX6970, 36V, 8 Channel Constant Current LED Driver. The PWM signal to perform LED dimming can be applied through the OE pin or direct input from a microcontroller.

PWM Signal Generation

There are 3 typical ways to generate PWM signal:

1. Microcontroller
2. 555 timer
3. LED driver with inbuilt PWM generator such as Maxim MAX16805

Out of the 3 above, the 555 timer solution provides the simplest and cost effective solution for PWM signal generation.

PWM Signal Generation Using 555 Timer

A simple circuit design to generate PWM signal is as depicted in Figure 15 below. This circuit design requires only a low cost, widely available 555 timer and 5 passive components.

PWM signal pulse width is defined by the charging of capacitor C2 through resistor R1. While the duty cycle of PWM signal can be adjusted by the ratio of R1 and R2. The CV pin of 555 timer should be bypassed with a capacitor for noise reduction and false triggering prevention.

The pulse width signal can be approximated by the equation below :

Pulse on time = 0.69 X (R1 X C2) = Pulse Width

Pulse off time = 0.69 X (R2 X C2)

And thus the duty cycle can be calculated by the equation below :

$$\text{PWM duty cycle} = \frac{R1}{R1 + R2}$$

By replacing R2 with a 15K Ohm potential meter, the duty cycle for the circuit below can be adjusted from ~5% up to 95%. This would provide sufficient dimming range for typical LED application.

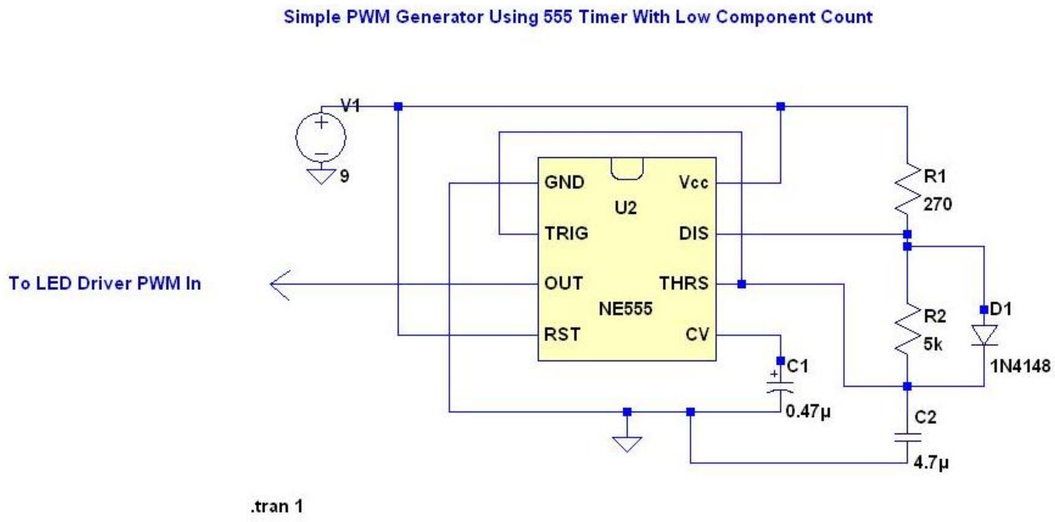
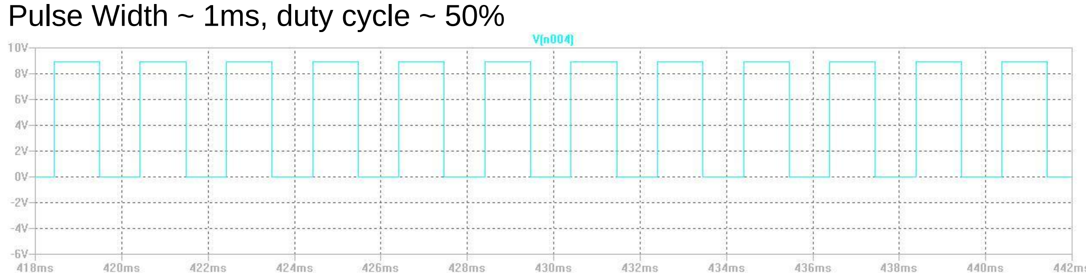


Figure 15 – A typical PWM signal generation using NE555

Configuration: R1 = 270 Ohm, R2 = 5K Ohm, C2= 4.7uF
Pulse Width ~ 1ms, duty cycle ~ 5%

Configuration: R1 = 270 Ohm, R2 = 270 Ohm, C2= 4.7uF
Pulse Width ~ 1ms, duty cycle ~ 50%



Configuration: R1 = 270 Ohm, R2 = 27 Ohm, C2= 4.7uF
Pulse Width ~ 1ms, duty cycle ~ 90%

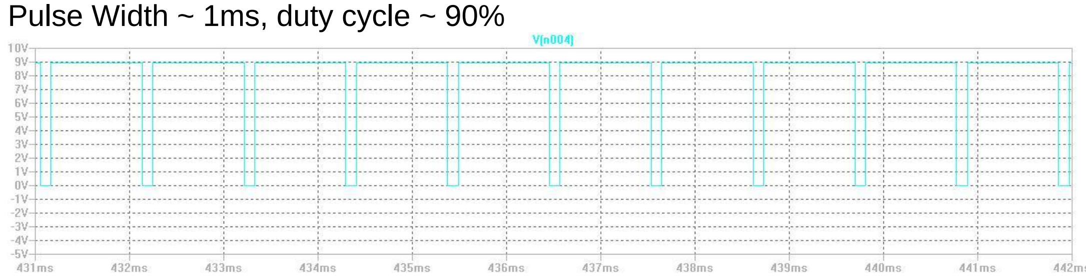


Figure 16 – By adjusting the value of resistor R2, various duty cycle can be obtained

Summary

PWM is a better approach for dimming InGaN technology LED instead of linear current dimming. PWM dimming prevents unwanted color shift on LED while maintaining the required light intensity. With most of the LED driver ICs have inbuilt function for PWM input signal, the implementation of PWM dimming becomes very simple and do not require any extensive circuit design or extra circuit components.