App Note 11: An overview of the electronic drive techniques for intensity control and colour mixing of low voltage light sources such as LEDs and LEPs.

There are a number of techniques that can be used for intensity control of devices such as LEDs.

This white paper provides an overview of the available options and a brief analysis of the relative benefits of each.

It should be understood that intensity control and colour mixing control are terms that can be used interchangeably. Colour mixing simply involves the intensity control of more than one colour.

Amplitude Modulation

Amplitude Modulation is the simple technique of varying the voltage across the LED. It is assumed that the LED circuit is equipped with the relevant current limiting resistor.

As the voltage (V) is increased from 0V, the LED starts to illuminate when the voltage exceeds the forward conduction voltage (V_F) of the LED. From this point, an increase in voltage will increase the intensity of the LED.

Benefits:

1. Amplitude Modulation is probably the simplest control technique.

Drawbacks:

1. The forward voltage limit of the LED, means that there is a 'black' area at the low end of the voltage range over which there is no light.
2. The manufacturing tolerance of LEDs gives a wide range of variation in LED V_F. The result is that there is no guarantee that two 'identical' LEDs will provide the same output of light for a given voltage.

The term Amplitude Modulation can be applied to varying the voltage, current or resistance of the circuit. The relationship between these is given by Ohm's Law:

$$V - V_F = IR$$

V	Applied Voltage
V_F	Forward Voltage of LED
I	Current passing through LED
R	Load Resistor

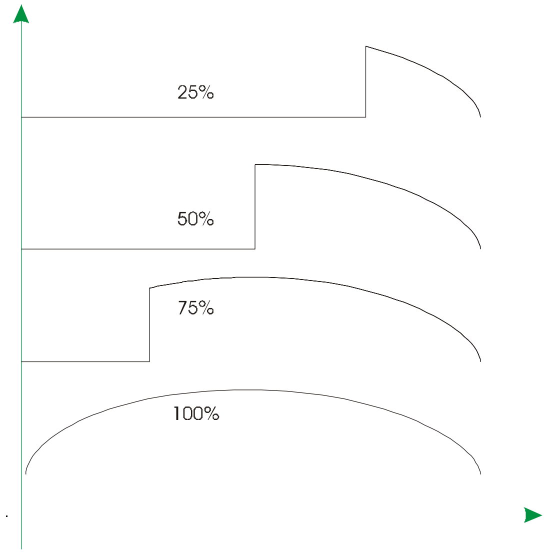
Pulsed Amplitude Modulation

The technique of Amplitude Modulation can be combined with pulse drive techniques. This can be beneficial in multiplexed LED systems such as video walls.

AC Drive – Phase Angle Modulation

The AC drive concept simply involves powering LEDs with a full wave rectified AC waveform.

The following diagram shows the concept for a half cycle. The phase angle at which the AC waveform is switched, sets the average power in the load and so intensity:



Benefits:

1. Obviates the need for a DC power supply, allowing an inexpensive transformer drive to be used.
2. Allows conventional phase angle modulation techniques to be used. Phase Angle Modulation (PAM) is the technique used in mains powered lighting dimmers to dim conventional lamps. The system works by switching on the power at a specific point in the AC waveform using a semiconductor device. Power is then switched off at the end of the half cycle and the process then repeats. The intensity of the light is then proportional to the duty cycle of the waveform. In effect this is pulse width modulated AC.

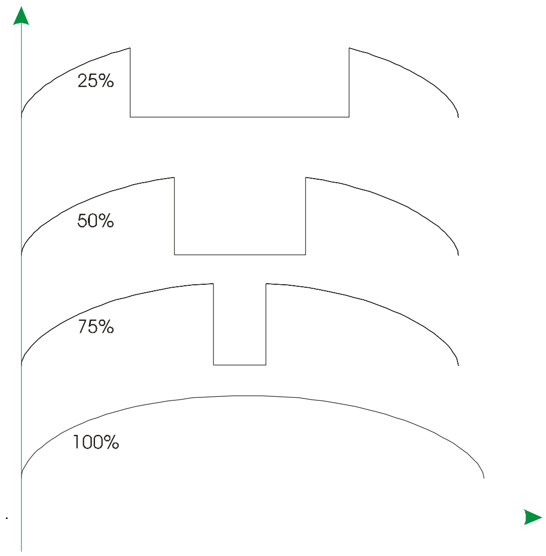
Drawbacks:

1. Dissipates a higher level of RMS power in the LED compared to DC drive.
2. Applies a higher peak current to the LEDs compared to DC drive. It should be noted that it is the LED peak current that affects the life of an LED.

AC Drive – Bi-Phase Angle Modulation

Bi-Phase Angle Modulation is a variant of Phase Angle Modulation.

The key difference is that the drive signal is symmetric around the peak voltage as shown in the following diagram:



Benefits compared to Phase Angle Modulation:

1. Peak voltage and peak current is lower for most of the response curve.
2. The drive waveform operates at twice the data modulation frequency, reducing potential flicker.

Drawbacks:

1. Requires higher processing power for a given resolution.

Mains Power

It is possible to power LEDs by direct connection to rectified mains power, although significant caution is required in the use of the approach. Active current limiting must be used instead of resistive current limiting.

Benefits:

1. Very simple to implement with no electronics.

Drawbacks:

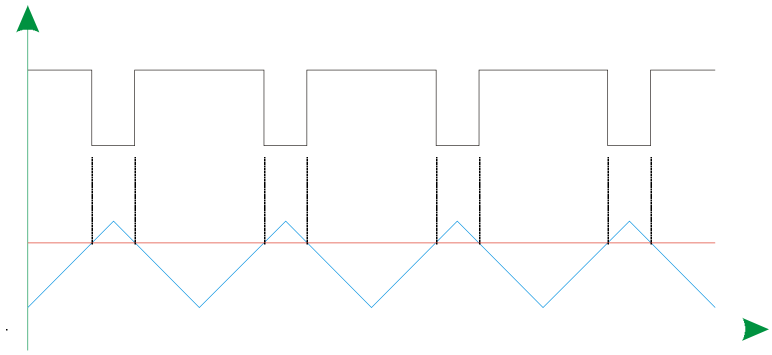
1. As large numbers of LEDs are connected in series the potential variation in the cumulative V_F value increases. This can lead to significant variation in average current and therefore brightness when two apparently identical light sources are compared.

2. It is also important to consider the potential failure mode of this type of circuit. In resistive current limiting, if one of the LEDs fails short circuit, the voltage across all other LEDs increases. This in turn increases the average current and therefore the potential for a second failure.

Pulse Width Modulation

Pulse Width Modulation (PWM) is the best known technique for controlling the intensity of LEDs. The technique uses a fixed frequency signal with a repeating drive pulse. The width of the pulse is varied between zero and full as shown in the drawing below. The ratio of on time to the maximum possible on time (Duty Cycle) defines the intensity of the LED.

PWM is generated by comparing a voltage with a triangle wave form as shown in the following drawing. The procedure for generating PWM in software is identical, the triangle waveform becoming a software counter.



The blue curve represents the triangle wave or counter. The Red line shows the required intensity. When the red line is above the blue curve, the PWM output switches on.

Benefits:

1. Simple to implement in hardware or software.

Drawbacks:

1. Can produce unwanted flicker if the modulation frequency is too low.
2. Requires significantly more processing power than Bit Angle Modulation.
3. Generates a drive signal that has the same frequency as the modulation frequency.

Frequency Modulation

Frequency Modulation is a technique invented by Artistic Licence and is covered in a separate document – Application Note 009.

Bit Angle Modulation

Bit Angle Modulation (BAM) is a new LED drive technique invented by Artistic Licence. It is a variation of Pulse Code Modulation.

The technique can be used with fixed or variable frequency modulation and is also applicable to multiplexed systems.

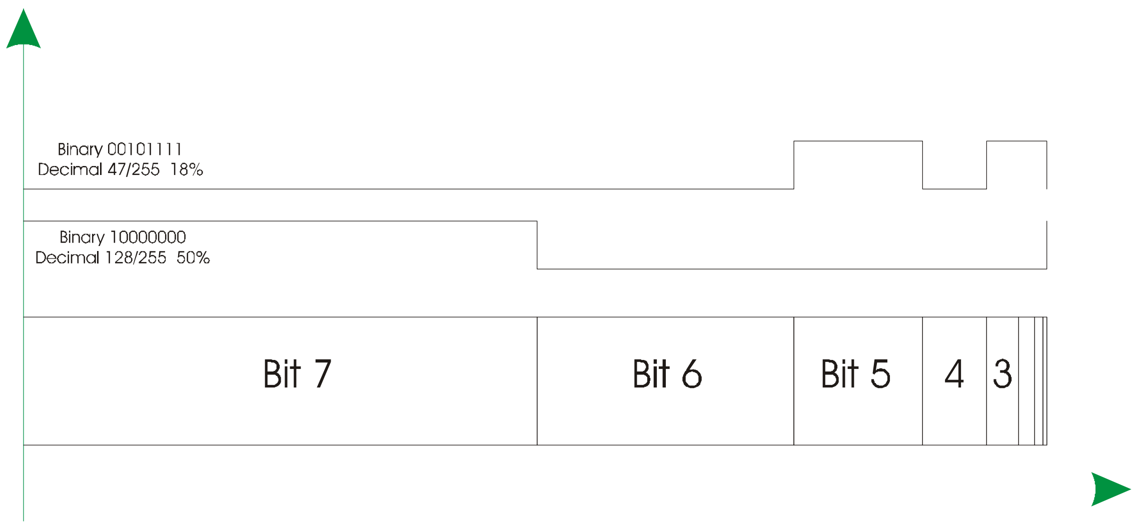
In essence, the LED is driven by a pulse train that is the binary word defining the value of required intensity. Each bit of the pulse train is stretched by a ratio defined by the binary significance of each bit.

Each bit of the binary word is effectively allocated a fixed range of phase angles within the drive cycle.

The following table shows the ratio by which each bit is stretched:

Bit Position	Stretched by:
7	128
6	64
5	32
4	16
3	8
2	4
1	2
0	1

The following diagram shows an example (not to scale):



Benefits:

1. Simple to implement in hardware of software.
2. The drive signal is a multiple of the modulation frequency, thus reducing potential flicker.
3. Required significantly less processing power compared to PWM. A microprocessor generating an eight bit resolution PWM signal at 100Hz will need to process the output every 39uS, a total of 256 times per output cycle. By comparison a microprocessor generating an eight bit resolution BFM signal at 100Hz will need to process the output only 8 times at 5000us, 2500us, 1250uS, 625uS, 312uS, 156uS, 78uS, 39uS intervals from the cycle start. This represents an 800% reduction in required processing power compared to PWM.
4. The LED drive signal contains a digital code of the intensity value allowing other devices to recover the data.

Drawbacks:

1. None – this is the most efficient drive technique developed thus far.

Bit Voltage Modulation

Bit Voltage Modulation is the AC version of Bit Angle Modulation. In this variant, the drive signal is used to switch a full wave rectified AC waveform.

The pulse stretching used in BAM is modified to allow for the varying peak voltage of the AC waveform in such a way as to ensure that the time averaged drive current represents the binary ratios of 128 : 64 : 32 etc.

Benefits:

1. Simple to implement in hardware of software.
2. The drive signal is a multiple of the modulation frequency, thus reducing potential flicker.
3. Reduced processing power

Drawbacks:

1. Can suffer from the same peak current limitations of standard AC drive.

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