Thermal Considerations for High Brightness LEDs

Much attention is being focused on the dimming strategies used for controlling high brightness LEDs in a rapidly increasing number of applications. The nature of these devices demands, however, that even more attention be paid to thermal control. **Colin Davies, Zetex Semiconductors, Oldham, UK**

While LED manufacturers are pushing back the technological boundaries by dramatically increasing the Lumens per Watt, there is still more electrical power converted to conducted heat than to light output. An overall strategy of thermal management is required to ensure that the power into the LED is controlled as a function of temperature.

Figure 1 shows typical derating characteristics for a 1W LED. As expected, this clearly shows that the LED is driven with constant current up to a point at which the current then needs to be reduced linearly to 0 at 150°C. The point at which this derating occurs and the slope of the decrease is dependent on the mechanical/ thermal heatsinking arrangement.

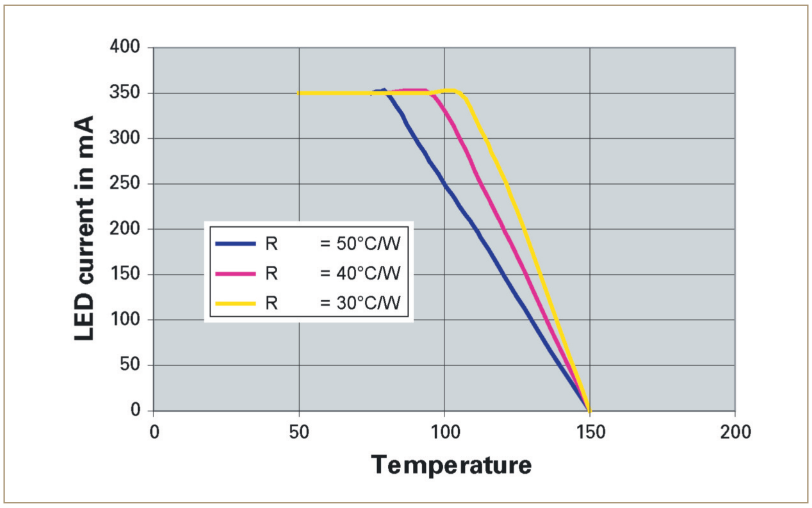

Figure 1: Typical derating characteristics for a 1W LED

The control electronics must therefore be able to cope with a trip point setting and a gain setting. It is also important to remember that the LED needs to be able to cope, in fact, with three potential contributors to the heating effect: self-heating, ambient temperature and the LED electronic control. If the electronic control is remote from the LED illumination, then this will not be an issue – EMC, however, may be a concern.

Linear control of the LED

The first and most obvious way of controlling a LED is with a resistor. Although a low cost method, it inevitably results in power loss which negates or diminishes the LED's key efficiency attribute. Using a variable resistor as the dimming element is also impractical for high brightness LEDs, since the power in the resistor will be too large and a dedicated wire-wound device would be required. For a single 1W LED taking 350mA from a 12V supply, around 2.5W would be wasted in the dimming resistor at full brightness. And if the resistor is in close proximity to the LED, then the extra heating it produces will only add to the problem.

The pass element could, of course, be a transistor, which would mean the power dissipation resides in the transistor and not the variable resistor. This approach provides more flexibility by enabling logarithmic response, negative (NTC) or positive (PTC) temperature coefficient thermistors to be used for thermal control and brightness definition. A bit of imagination then easily leads to the use of optical feedback for automatic brightness control.

The transistor could be of any type: MOSFET, NPN bipolar or PNP bipolar. Amazingly, some engineers of a more digital persuasion still believe that MOSFETs are better for this application because of their low on resistance! It simply has to be understood that linear power dissipation is the same, regardless of silicon choice. It is still wasted power in the form of heat which needs to be managed.

Use of thermistors in LED thermal control

The simplest implementation of LED thermal control using a thermistor employs a PTC device. This is a thermal resettable fuse that can be used as either an overcurrent or a thermal protection device if mounted close to the LED. Safety considerations need to be taken into account here. The PTC increases its nominal low resistance with temperature to a high not open circuit condition at its trip point. So it does not isolate. The PTC is a non-linear device with an effective switch action at around 125°C. But up to that point, the temperature is not being reduced in a controlled way in accordance with the LED current de-rating graph. Also, does the lighting strategy want a zero light output due to over temperature conditions? The primary purpose of the LED is illumination, not self-protection. Overheating and cooling down can cause a thermal cycling, resulting in low frequency flashing of the LED.

NTC thermistors exhibit continuous, but non-linear, variation of resistance over temperature. The amount of variation with temperature is dependent on the b value of the particular NTC device, with typical figures being 2700, 3590 and 4400. The nominal resistance value is usually quoted at 25°C and devices are available from 10's of Ohms to mega Ohms. These are usually used as a control element in conjunction with a linear or switching regulator. The variation of the resistance with temperature can be calculated from a formula, but is usually presented as a table of resistance values over the range -40 to 150°C. Table 1 shows the resistance values of a typical 10kΩ nominal thermistor with three different ß values.

As is often the case in life, the non-linear

Temp C	-40	-20	0	20	25	40	60	80	100	120	140	150
10k ß = 2700	131500	51930	23400	11720	10000	6400	3752	2234	1527	1042	738	628
10k ß = 4400	213900	72660	28090	12100	10000	5790	2978	1645	957	588	379	309
10k ß = 4400	632900	148700	40660	13030	10000	4704	1878	825	393.1	200.9	108.9	81.7

Table 1: Resistance values of a typical 10kΩ nominal thermistor with three different ß values

response of the thermistor has the least sensitivity in the area you wish it to be most responsive. The change in resistance is more dramatic at lower temperatures than the higher temperatures. As a guide, the higher the ß value, the faster is the roll off of resistance with increasing temperature. This is illustrated in Figure 2. The response can be made more linear by paralleling a suitable resistor with the thermistor. Positioning of the temperature sensor is also very important, as it needs to be as close as possible to the die of the LED to avoid thermal gradients and response delay as the LED heats up.

Referring back to Figure 1, it is evident that consideration must be given to lower temperatures. If the thermistor is used in a control circuit that reduces the current as temperature increases, it may also increase the current when temperature decreases. This may cause transient overheating of the LED and take the junction temperature beyond its rated value. Self-heating will self-correct, but the implied thermal stress is undesirable. It is better to include a clamping configuration to ensure the current does not continue to increase as temperature decreases.

Thermistor control with a switching regulator

Figure 3 shows a typical example of a step-down (buck) regulator using simple thermal control. Here, advantage is taken of the ADJ pin of Zetex's ZXLD1350. By overdriving the pin using a PNP transistor as an emitter follower and using the pin's internal 250kΩ resistor as a load, the LED current falls in proportion to the thermistor resistance. As the temperature drops, the resistance of the thermistor increases, but as the base voltage increases beyond the ADJ reference voltage, the transistor turns off and the LED receives only its maximum set current, thereby clamping the low temperature response.

Matching the thermal derating curve for a given LED will depend on many factors as discussed earlier. Good thermal modelling will help get this right first time, but it is likely that some experimentation is required to match the trip point and gain coefficient. Figure 4 shows the results of several tests using the circuit in Figure 3.

It should be noted that if the thermal control circuit of Figure 3 is used near the LEDs the transistor will be affected by the self-heating of the LEDs. This will increase the dimming effect by approximately -2.2mV/°C.

PWM thermal control

Thermistor or other temperature sensors can also be used in conjunction with PWM thermal control. A simple block diagram is shown in Figure 5. PWM control of brightness is the preferred method of many high brightness LED manufacturers. This is because the LED maintains its colour signature over the complete dimming range. This is particularly important in RGB

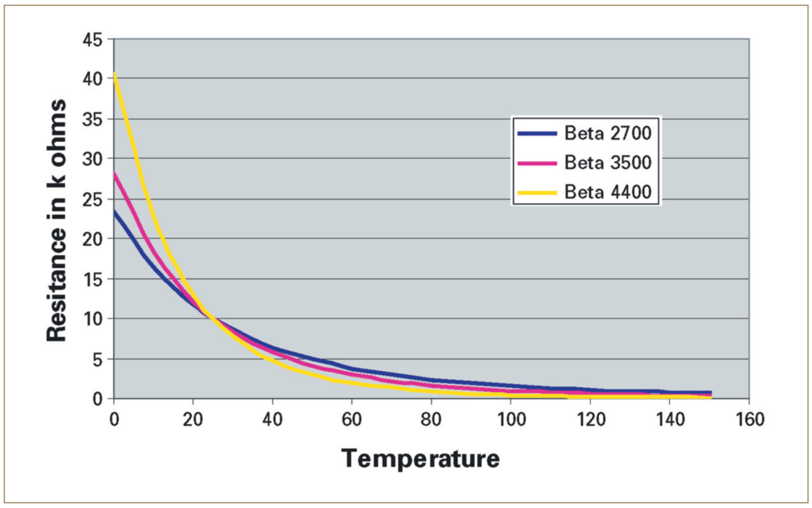

Figure 2: Typical change in thermistor resistance with temperature

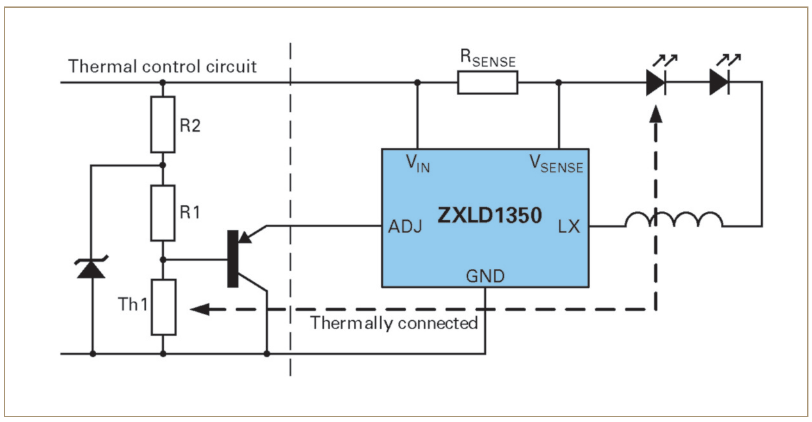

Figure 3: A step-down (buck) regulator using simple thermal control

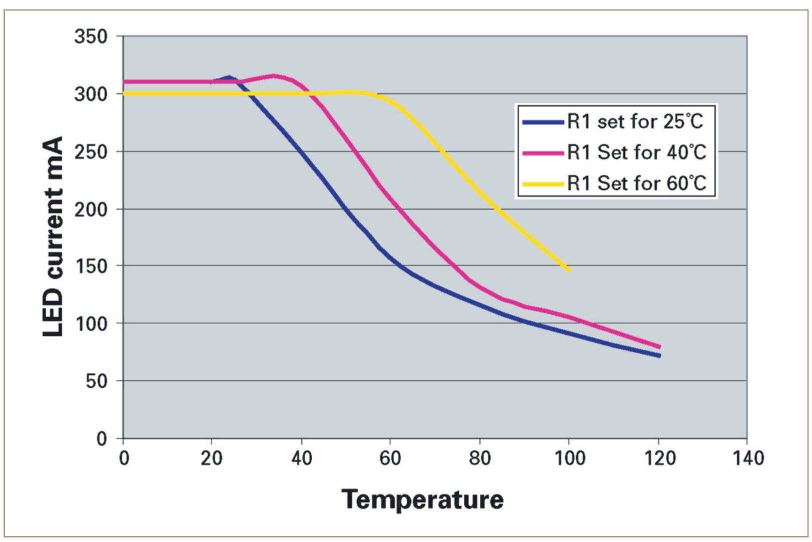

Figure 4: Test results using the circuit shown in Figure 3

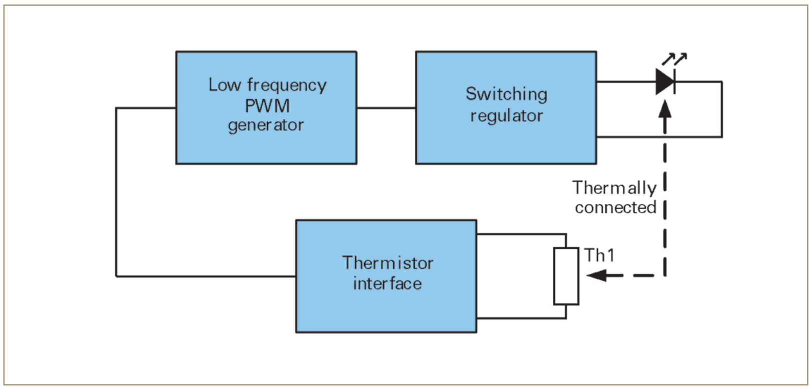

Figure 5: Thermistors used in conjunction with PWM control

colour mixing applications. It is more difficult to implement, but generally the dimming is more pleasing and the technique lends itself to microcontroller interfacing.

PWM dimming is generally applied at low frequencies that are above eye-flicker perception of 100Hz. The designer must consider though, whether the illumination is going to be subject to movement, as stroboscopic effects may occur, requiring a faster PWM frequency to be used. This is a consideration for moving vehicle illumination or even flashlights. If the PWM dimming is used in conjunction with a switching regulator, the technique generally is used to chop the LED current. This will put a further modulation on the EMI signature, which may make the EMI worse. It may also make it better, as it is effectively doing the same as dithering the switching frequency - thus, reducing the quasi peak EMI signal.

There is an audible consideration too. The higher the PWM frequency, the higher is the possibility of switching regulator inductor ringing at the PWM dimming frequency. This would be more noticeable at 1kHz than 100Hz, partly due to the poor base response of the inductor and the frequency response of the ear.

Despite all this, PWM dimming still offers a better brightness control. Linear control is simpler to implement from an analogue point of view, but not from a digital standpoint. You may need to consider the logarithmic response of the eye to brightness change. This may require the use of logarithmic potentiometers to produce apparent linear brightness control.

Conclusion

Thermal control is a very important aspect of high brightness LED control. The correct application of thermistors offers a simple and versatile method of LED temperature control. This can be done linearly, or via switching techniques. PWM control offers the best overall method, but care must be taken to consider all the lighting system requirements and not just the optical needs.