Optimal operating point of an LED

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Analog Field Applications

Achieving optimal performance of an LED luminaire or LED backlight design requires numerous trade-offs. Understanding an LED's power transfer characteristics empowers intelligent choices regarding cost, power consumption, and weight. While most LED datasheets publish pertinent data that can be used to make these decisions, data may not be formatted in a way that is readily applicable to the chosen application. Optimal performance requires finding pertinent information from manufacturer's LED datasheets and utilizing methods to capture, reformat and analyze the data.

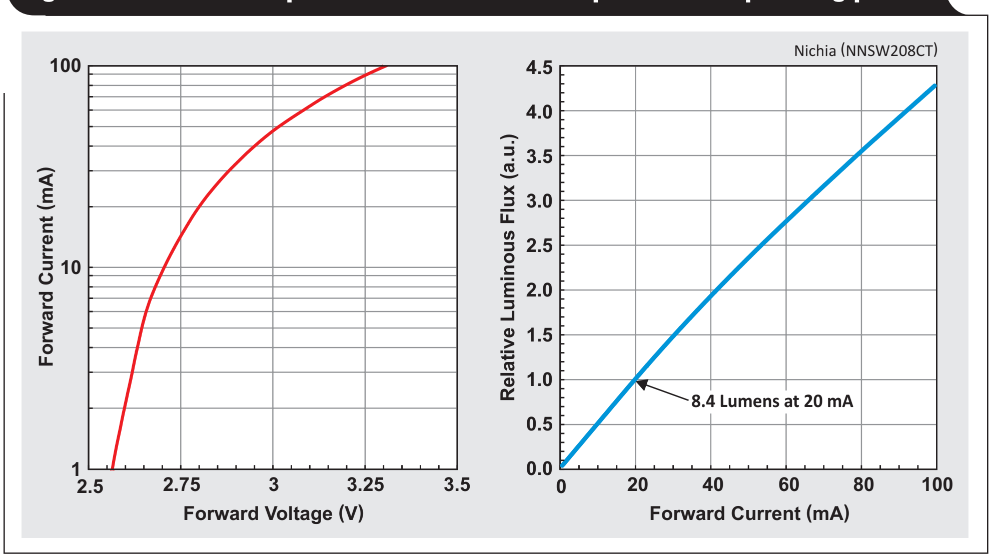
A relevant case study involves a typical tablet LCD backlight application that drives a 10-inch display with a 16:9 aspect ratio. Driving the backlight, the LED chosen for our example is the Nichia NNSW208CT[1]. Typical displays in modern mobile devices emit approximately 650 nits of light when driven at maximum brightness. Most of the LED light produced is lost as it passes through the physical elements integrated into the display (light diffuser, polarizers, RGB color filter, touch-panel ITO, and so on). Modern display stack-ups loose approximately 95% of the light produced by the LED. This device in this case study emits 10.398 lumens when driven at the recommended continuous drive current of 25 mA. Calculate the minimum number of LEDs using Equation 1.

$$\#\text{LED}_{min} > \underbrace{\overbrace{\frac{L_S^{\,2}}{K}}^{\frac{\text{Screen Size (inches)}}{\text{Conversion Constant (inches}^2\text{ to m}^2)}}\left(\overbrace{\frac{A_X \times A_Y}{A_X^{\,2}+A_Y^{\,2}}}^{\text{Aspect Ratio 16:9}}\right)}_{\text{Screen Area (m}^2)} \times \underbrace{M_{V(disp)}}_{\text{Max Brightness (nits)}} \times \underbrace{\frac{1}{1-V_{disp}}}_{\text{Lumped Stackup Losses}} \times \underbrace{\frac{1}{\varphi_V}}_{\text{Lumen Output of Single LED}} \qquad (1)$$

Using a conversion constant of K = 1550.0031 and the design requirements listed above, the calculated minimum number of LEDs is 35. While seven strings of five LEDs satisfies the design requirements, most LED driver ICs in this market are tailored to drive only six strings of LEDs. Adjusting the LED count to 36 enables an off-the-shelf LED driver. Assuming 100% driver efficiency, driving 36 LEDs at maximum brightness consumes 2.56 W of power.

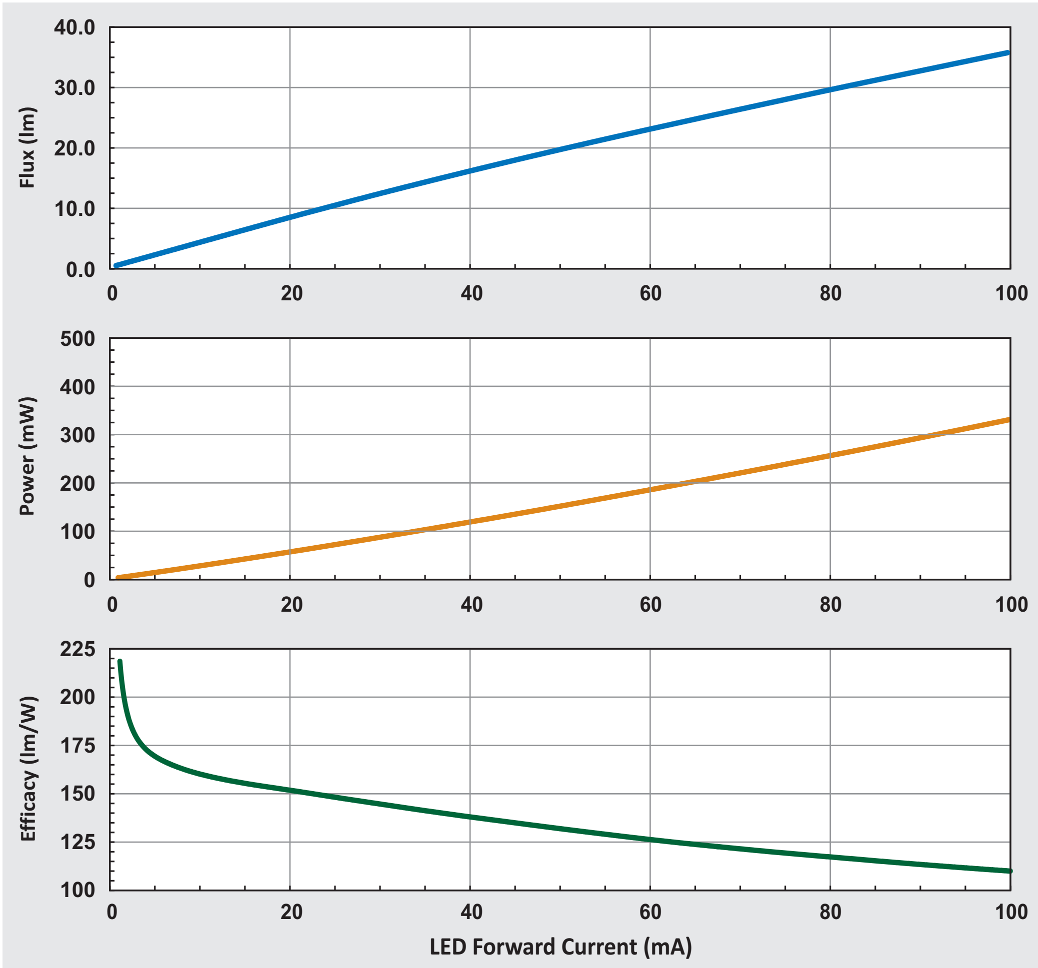
LED efficacy, color shift, and thermal properties are key data metrics. Efficacy versus forward current is rarely provided in an LED datasheet. Tabulated efficacy data is also difficult to find in specifications. Calculating this key metric is relatively easy using available I_F versus V_F and luminosity versus I_F curves. Also required is a typical lumen output at a given I_F (8.4 lumens at I_F = 20 mA). All required data is readily available in the manufacturers' datasheets.

Figure 1. Cornerstone plots used to derive the optimal LED operating point



Start by importing/digitizing the datasheet graphs (Figure 1) into a spreadsheet using predefined increments of LED current. Free software tools speed the process and digitize Y data on pre-determined X increments[2], enabling the calculations required to derive efficacy.

Figure 2. LED flux output, power consumption and efficacy can be calculated and plotted



Once digitized and tabulated, LED flux output (ΦV), LED power consumption (P_{LED}) and efficacy (η) are calculated versus LED forward current (I_F) (Figure 2). Peak efficacy is reached at a relatively low forward current and drops off steadily as forward current approaches the maximum rated amount.

Battery-powered applications greatly benefit by reducing these power requirements. Operating more LEDs at a lower forward current results in a net reduction of power for a given fixed-light output. Table 1 summarizes the original application requirements while comparing three alternative LED configurations.

Cost and mechanical volume requirements may limit the final configuration; however, doubling the number of LEDs yields a power savings of 160 mW. This equates to a 6.3% net power reduction. Additionally, the backlight can be operated at a much higher brightness (with increased power consumption) when ambient light conditions (outdoors/daylight) dictate a brighter image.

Table 1. A comparative backlight design study

Number of LEDs	LED Operating Point (mA)	Total Light Output (lm)	Total Power Consumption of LED Array (W)	Net Reduction in Operating Power (%)
Decreasing Number of LEDs				
24	32.6	373.2	2.65	–3.5
Control				
36	25	374.2	2.56	0
Increasing Number of LEDs				
42 (16%)	21.2	373.2	2.50	2.2
54 (50%)	16.4	374.1	2.45	4.1
72 (100%)	12.2	374.1	2.40	6.3

Figure 3 highlights the increasing power savings trend over a number of LED data points. Note that the LED knob turns both ways. Overdriving each LED decreases the total number required, yielding a less expensive display module; which is particularly beneficial when cost is crucial.

Operating the LEDs at a reduced brightness requires 100% duty cycle and a reduced current. Driving the LEDs using a traditional pulse-width modulation (PWM) architecture at maximum LED current yields no performance improvements.

White-point shift at lower currents is a perceived complication for backlight applications. Modern LEDs exhibit minimal to negligible color shift. Digitizing the LED's color-shift parametrics (Figure 4) and superimposing a MacAdam ellipse over the center of the operating range highlights this point. A one-step MacAdam ellipse encompasses all LED colors when operating between forward currents of 5 mA and 25 mA. Colors inside a one-step MacAdam ellipse are perceived as the same to the average observer.

Figure 3. LED power analysis shows lower power with greater number of LEDs

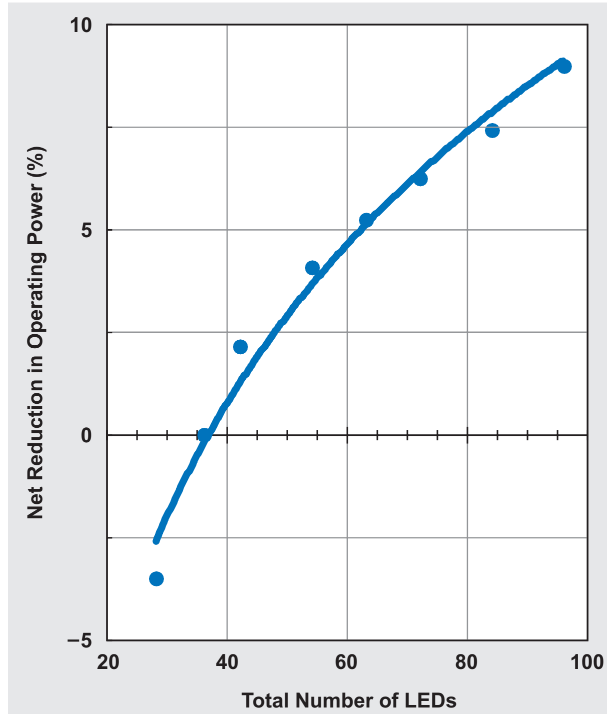


Figure 4. White point shift versus LED current

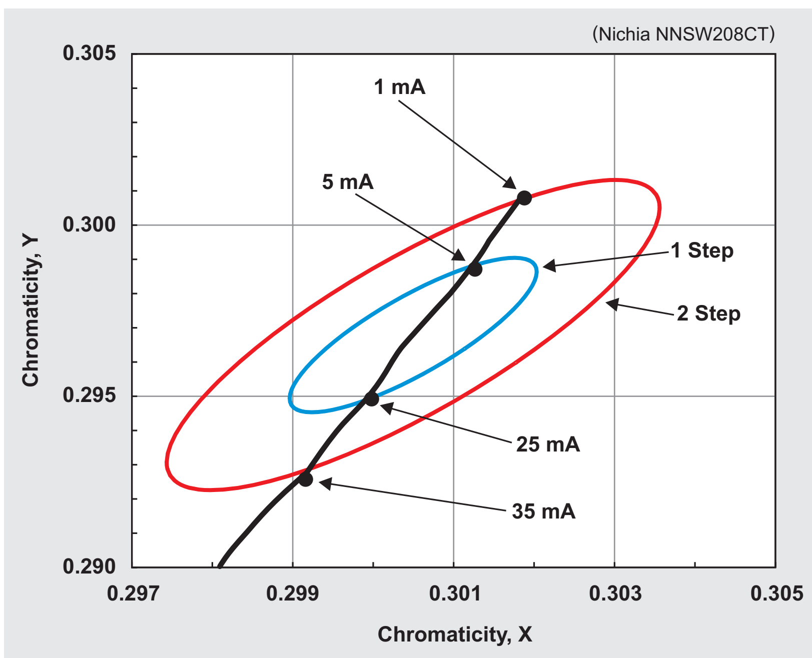
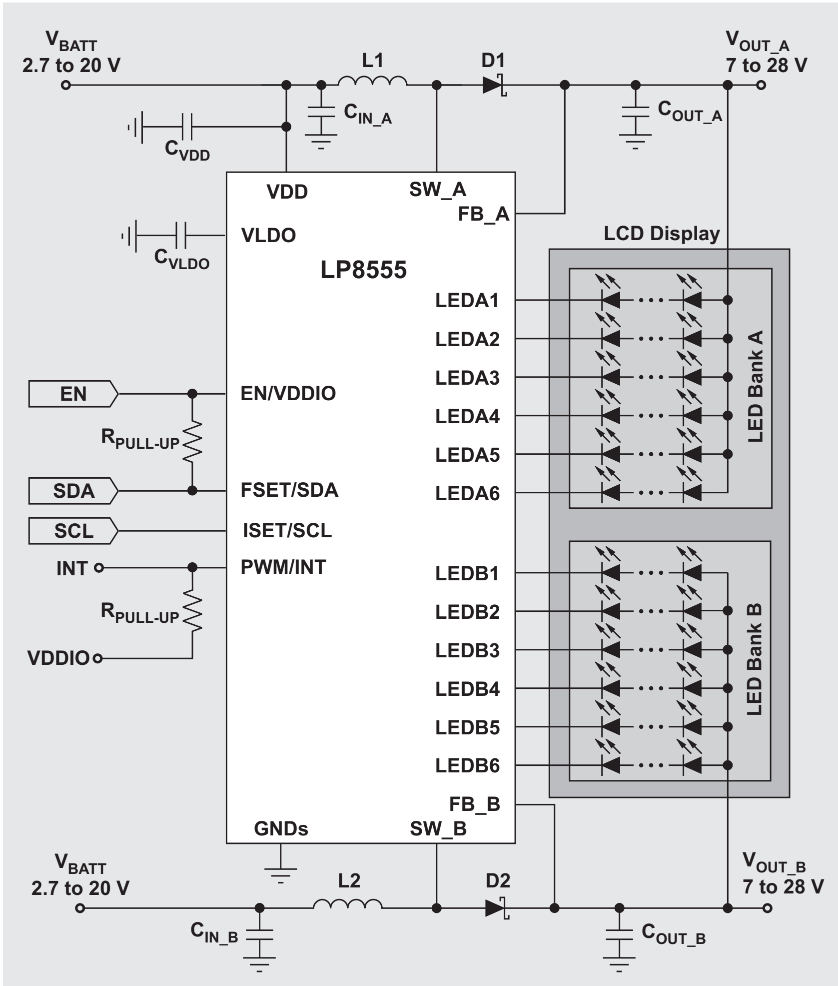


Figure 5. The LP8555 can power large matrices of LEDs



Powering a large array of LEDs is relatively easy using an LED driver such as the LP8555 (Figure 5). This device drives up to 96 LEDs, which is suitable for the largest of mobile displays and capable of driving all the configurations mentioned above. Two-percent string-to-string matching is a key metric to maintain a uniform image quality. A dual-boost architecture maximizes electrical efficiency while minimizing the physical height of the associated inductors. Additionally, this device features 12 current-sink inputs, enabling shorter series-LED strings. This allows the boost converters to power the LEDs at a more efficient electrical operating point. Key features such as adaptive dimming and content-adjustable backlight control (CABC) yield further electrical efficiency gains over all operating modes.

Conclusion

For maximum power savings, the key objective is to tailor the operating point of the LED to the most typical operating mode of the application. While LCD backlight applications have been the main focus, the concepts presented here can be easily applied to any LED lighting application that requires efficiency as a key performance metric.

References

1. Nichia NNSW208CT datasheet. Available : **www.nichia.co.jp/en/**
2. Donald Schelle, Mark Brouwer, "Digitize graphical data easily and accurately," *EDN*, March 2013. Available: **www.edn.com/**

Related Web sites

www.ti.com/1q15-LP8555