

Optimal operating point of an LED

By Donald Schelle
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 lose 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.

$$\#LED_{min} > \frac{L_S^2}{K} \left(\frac{A_X \times A_Y}{A_X^2 + A_Y^2} \right) \times M_{V(dis)} \times \frac{1}{1 - V_{disp}} \times \frac{1}{\Phi_V} \quad (1)$$

Screen Size (inches)
Aspect Ratio
16:9

Conversion Constant
(inches² to m²)

Screen Area (m²)
Max
Brightness
(nits)
Lumped
Stackup
Losses
Lumen
Output of
Single LED

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.

Start by importing/digitizing the datasheet graphs (Figure 1) into a spreadsheet using pre-defined 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 1. Cornerstone plots used to derive the optimal LED operating point

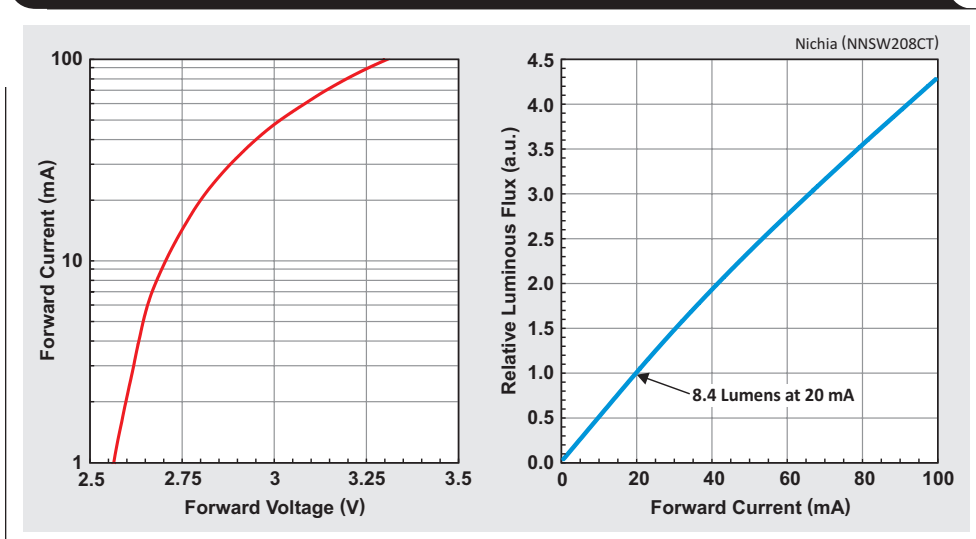
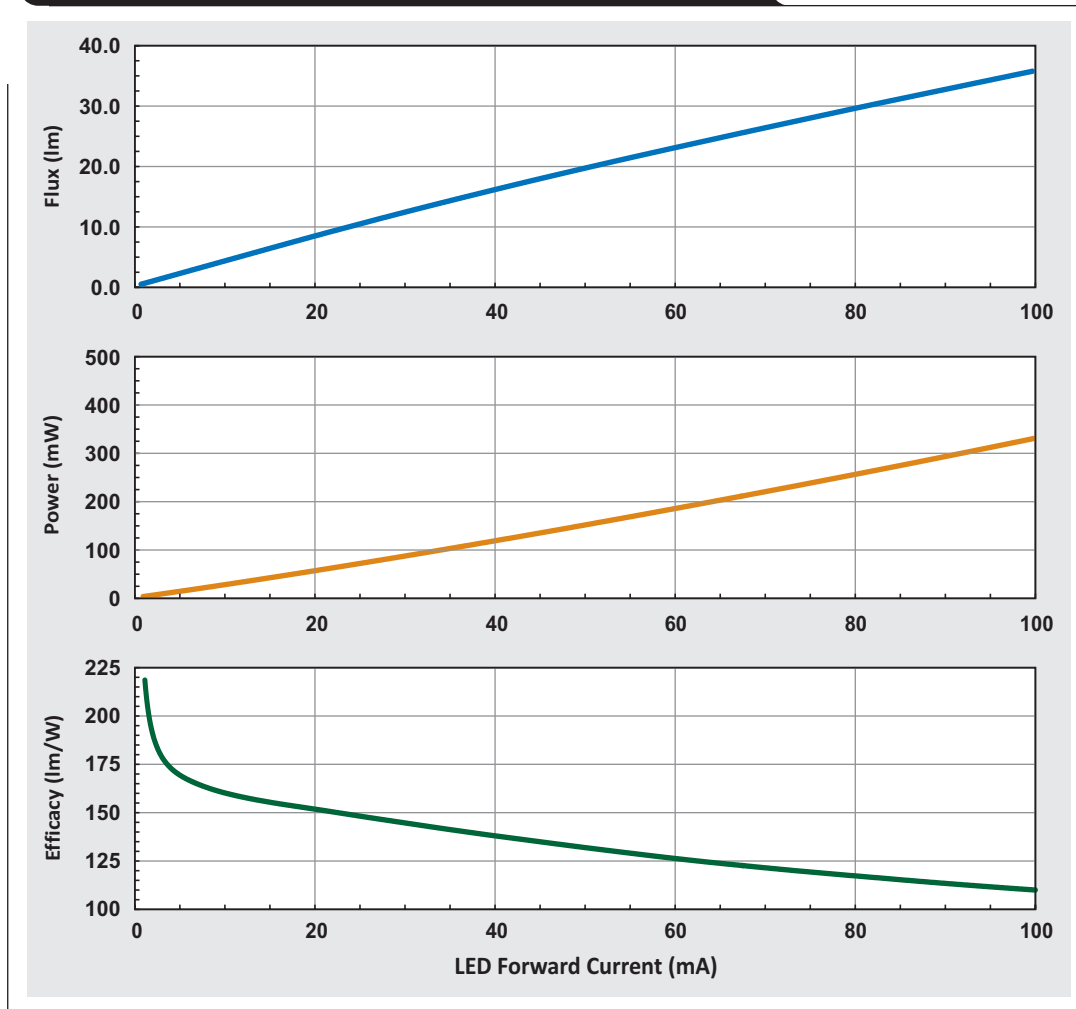


Figure 2. LED flux output, power consumption and efficacy can be calculated and plotted



Once digitized and tabulated, LED flux output (Φ_V), 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

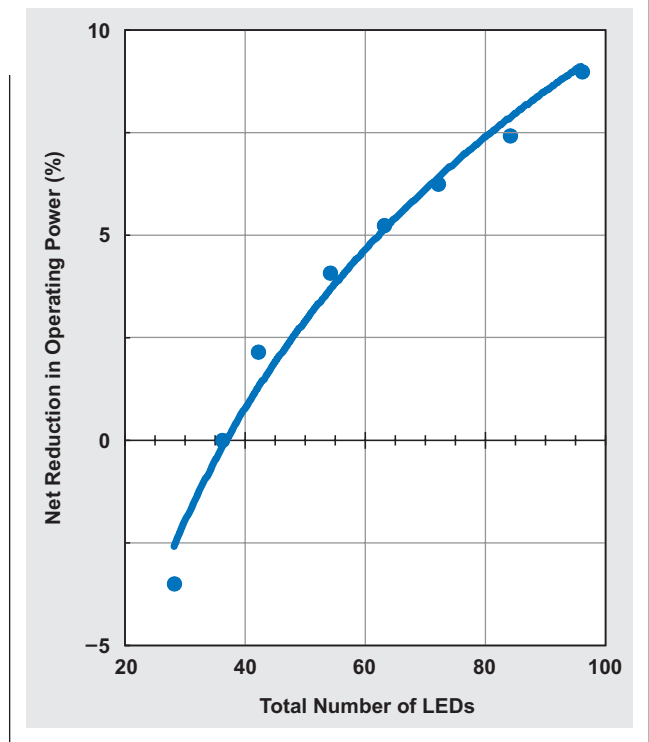


Figure 4. White point shift versus LED current

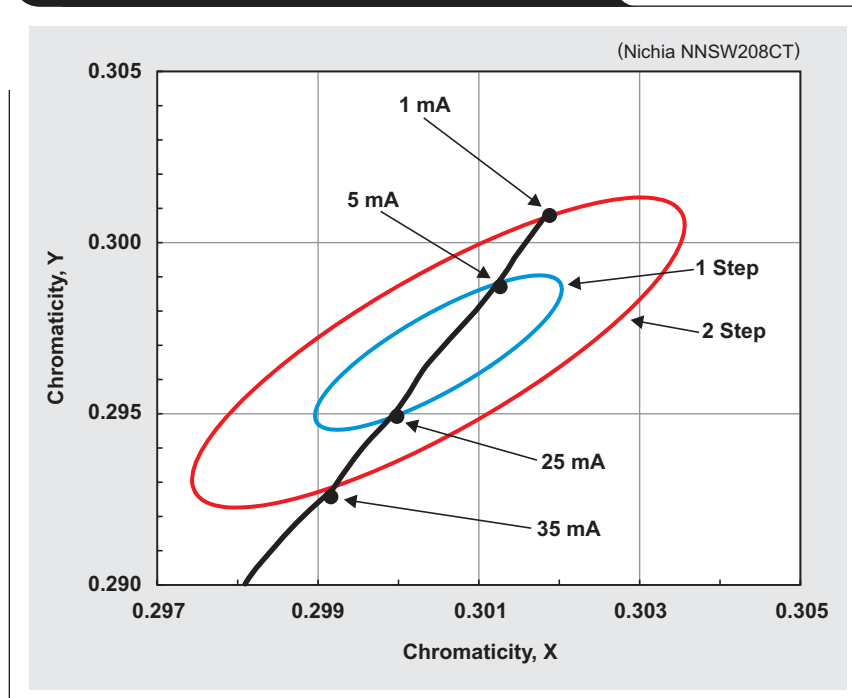
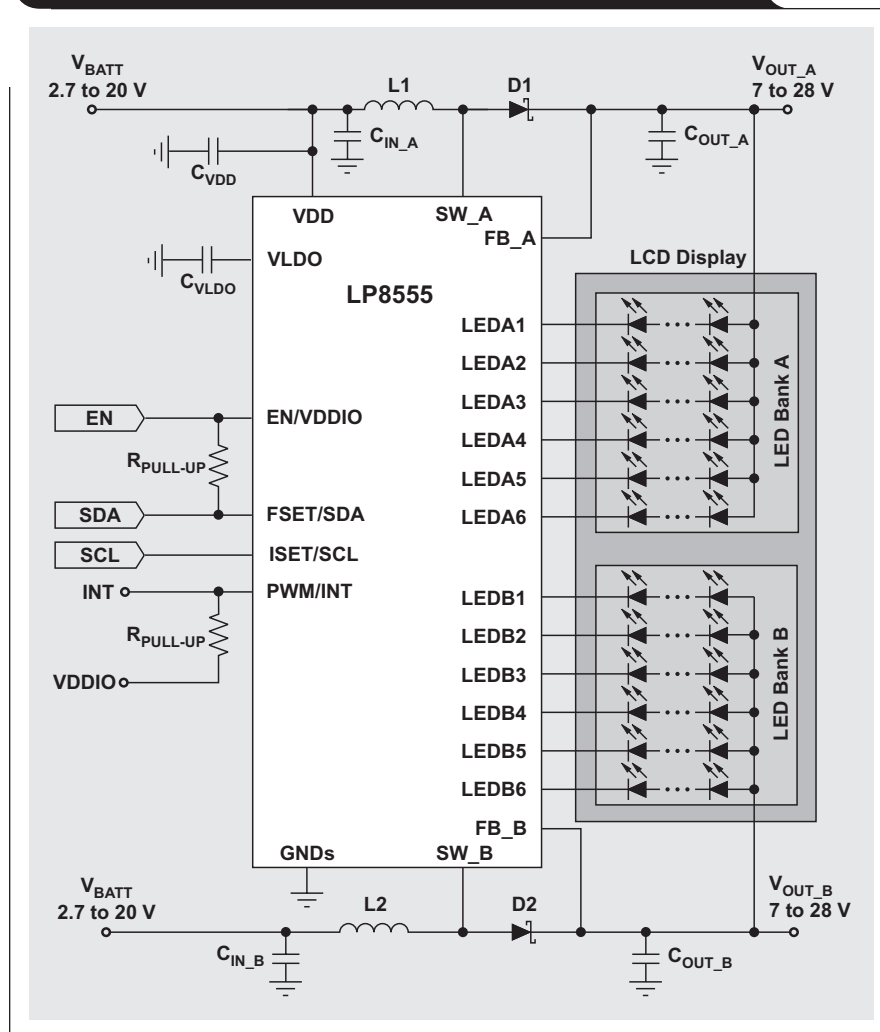


Figure 5. The LP8555 can power large matrices of LEDs



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

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com