ECE 492

Computer Design Project

Final Report

Poor Man's Light Show

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Poor man's light show consists of a real-time audio input 'Line In' and will output an accompanying electrified light show.

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Abstract

Our implementation of a Poor Man's Light Show consists of an input into our system from any audio source through the 'Line In' port on the Altera DE2 board. With this audio signal we separate the signal into its various frequency components using a Fast Fourier Transform and use specific frequency ranges to turn on corresponding Light Emitting Diodes in a visually intense fashion. This can then be scaled up at a later time to include actual stage lighting equipment. Our algorithm is one that tries to mimic the visually intense lighting sequences, which typically would be designed by a sound engineer, which you would normally see at a concert. The Light Show was designed to be fully portable as for one to be able to take the Altera DE2 and the LED external circuit to any environment that could supply a 'Line Out' from their audio source.

Functionality

Our functionality of the project has not changed and was entirely met since our proposal report, which was to read in an audio signal and generate a visually intense light show based off this signal. Our system is designed to accept an audio signal through the Line In port, analyze this audio signal by splitting it into its frequency components and output an accompanying lightshow all in real-time.

Originally we wanted to design our project to acquire the ambient audio in any environment with the use of a microphone. We did most of the design and implementation with this is in mind, but as we tried to fine tune our system to pick up accurate and specific frequencies, we just couldn't get consistent and accurate functionality with the noise that a microphone introduced. This is the point where we switched our design algorithm to use the "Line In" port instead of the "Mic In" port. Also, another main factor in switching from the microphone to the Line In port, was that in a real scenario of a concert if the music ever fell below a certain level, a microphone would start to pick up noise from the outside interference, and would trigger the lights at unexpected times. This is where Line In supersedes the Mic In port. Line In is more of a direct audio input, which eliminates almost all or close to all of the noise you would regularly acquire between the audio source and a microphone.

Once the audio has been converted to a digital signal through the on board Analog to Digital Converter, we have designed our hardware to pull this data from the ADC and input this into our 1024-point Fast Fourier Transform supplied by Altera's Megacore. Our FFT is setup to input data at a sampling rate of 44100 kHz, a width of 24 bits and to compute a 1024-point transform. We chose to use the Avalon Streaming Interface, which simplifies the importing and exporting of data into and out of the FFT. The streaming interface gives certain control signals to ease this

process even further. Our system runs on a universal clock, whose frequency is 50 MHz. Since our FFT expects new data to be available on each clock pulse, we had to generate a secondary clock that matched the audio sampling frequency.
Once the FFT has completed its calculation, we're able to pull this data and input it into our algorithm for generating our lighting sequence. The data comes out of the FFT as a complex number and so a vector magnitude calculation was required. The FFT core also outputs an exponent value which both the real and imaginary parts of the output need to be adjusted by. To take the magnitude we took the sum of the squares of the adjusted real and complex outputs. We decided the square root was unnecessary and would introduce delays due to the iterative nature of square root calculation. Our algorithm takes magnitude, stores the maximum magnitude of all frequency bins, and then normalizes the sensitivity levels of each LED by this maximum. This adjustment provides the system with automatic gain control so that the system works independent of input volume. We then send this normalized signal though our threshold logic which controls each individual light. The simple algorithm checks whether the corresponding bin magnitude is greater than the sensitivity value and if it is, turn on that LED. Because a bass note is usually the more dominant sound in any song, and for our system to pick up the low sound level of say a high hat, or tom, we must set the sensitivity of the bass bins lower so the bass light will not be on constantly.

We also have a mode, where if any LED does not exceed its threshold sensitivity level for 5 seconds, we turn on silent mode. The silent mode uses pulse width modulation on all 4 LEDs to fade them in and out. The fade-in and out times for each LED is slightly different, giving the silence mode a more random feel.

Design Description and Operation

Our project consists of three major design components. Reading an audio source, analyzing this raw audio data, and producing an algorithm for generating a lighting sequence based off this audio input.

Audio Input Integration:

We read the audio signal through the on-board Line In port. The analog audio signal is sampled and digitized via the on board Wolfson WM8731 audio codec chip. Hardware drivers provided by Altera's University IP program were then used to de-serialize the data from the chip into 24-bit samples.

Fast Fourier Integration:

After the driver provides each sample, we send this signal directly into our FFT with help from our control signals from our audio codec and FFT's streaming interface. It should be noted here that we chose, arbitrarily, to use the left channel of the stereo input as the FFT can only handle one 24-bit input. After the sample is passed to the FFT, we inform the audio codec, via a control signal, that the value was read. We then send this 24-bit audio signal into our FFT if the FFT indicates it is ready for data (another control signal), otherwise we wait until the next clock cycle and our FFT is ready to accept new data. To synchronize the audio source and the streaming FFT, we had to generate a clock that matches our sampling frequency: 44.1 kHz. We generate this clock in a process that counts clock cycles of the main 50 MHz clock. To calculate how many clock cycles of the 50 MHz would be able to fit into the 44.1 kHz clock, we divided 50 MHz by 44.1 kHz and received a value of 1134. In this process we count 1134 rising edges of the 50 MHz clock before generating a rising edge of the generated clock. At a count of 567 (1134/2), we drive the generated clock low to complete the cycle.

The FFT transforms the digital audio signal and outputs 1024, 24-bit bins of corresponding frequencies. In each bin, the FFT generates the real and imaginary parts of the signal in that specific bin. To acquire this data, we must wait until the next clock cycle and with help from our control signals for knowing when the FFT is done processing our data sample, we can then grab this result and use it in our algorithm. This is done by waiting for the FFT to set the "start-of-packet" signal which indicates that the current output is the 0^{th} bin.

We chose which bins to map to each LED by analyzing the typical frequencies of 4 different drum kit pieces. We found that a typical kick drum has a very low frequency range from around 40 to 200 Hz. We therefore mapped the red LED to a range of 60 Hz to 100 Hz to pick up the kick drum sounds. We also found that the "hiss" sound of a high hat has a fairly high frequency range around 300 Hz to 2k Hz. So we mapped the blue LED to center around 500 Hz. We found that a typical tom was around 200-800 Hz and mapped the frequencies surrounding 300 Hz to our yellow LED. A snare drum has many frequency components but we found that a primary range is between 200 Hz and 500 Hz so we centered the green LED around 400 Hz. These values roughly represented bins 4-6 for the red, bins 7-9 for yellow, bins 10-12 for green and bins 13-15 for blue. Through experimentation we realized that using these bin values for each LED was not ideal. With such a large range of frequencies corresponding to an LED, the LED was on far too often. Using bins 4, 9, 11, and 14 for red, yellow, green, and blue respectively, gave us the best results for our use of the system. This is where our system diverges if we wanted to use our system for a straight plug in of a drum kit or other piece of music equipment as opposed to a mix of many instruments. More on this in the Future Work section.

Output Algorithm:

Our algorithm for turning on each LED is as follows. We have a process that waits until our FFT source_valid control signal goes high, which indicates there is new processed data ready to be pulled from the FFT. Then on the next rising clock edge of our generated FFT clock, we repeat the following. Again, we do this every time we pull a new 24-bit sample out of our FFT. We first adjust both the real and imaginary parts of the FFT output by the exponent value output by the FFT. Then, by taking the sum of the squares of the real and imaginary parts, we acquire the magnitude of the current bin. We store the magnitude of each bin we are interested in, as well as the maximum magnitude of any bin. This maximum is the key to our automatic gain control. After grabbing the overall maximum magnitude we adjust two sensitivity levels based off this value. The red LED bin sensitivity level is special because a bass note is more dominant in a song and has a larger magnitude than our other three bins. To accommodate this we set the lowest frequency bin sensitivity level to the highest power of two that is less than the maximum. We then set the sensitivity level for the other 3 bins to a quarter of the first bin.

To complete our processing, we then simply check the stored bin values against the sensitivity level for that bin. If the current magnitude of the bin is greater than the sensitivity, we turn on the corresponding LED. If not, we turn it off.

With a 1024-point/bin and our sampling frequency of 44100 kHz, this gives us a bin width of approximately 43 Hz per bin. We found in practice that the lower frequency bins do not hold perfectly to this rule but we were able to find bins that worked in the end.

Silence Mode:

The other feature of our project is the silence mode. If no LED's are activated in a 5 second span, the system enters silence mode. This mode uses pulse-width modulation to fade the LED's in and out in a visually pleasing way. This works by using a different process for each LED. This process uses 3 counters to perform the pulse-width modulation. The first counter counts every clock pulse. This gives us our current count. Then we have our limit counters, one for the up state and one for the down state. Basically, the output signal stays high until the current count exceeds the up limit. Then the output is driven low, the current count is reset and the output holds low until the down limit is met. Once a full cycle is complete, the up limit is incremented and the down limit decremented. This will cause the LED to fade in. For fade out the vice-versa occurs where the up limit is decremented and the down limit is incremented. A control signal indicates whether the process is currently fading in or out. When the decrementing limit reaches zero, the control signal is flipped and the LED fades in the opposite direction.

External Circuit:

Our Altera DE2 board supplies two banks of GPIO pins. We chose to use GPIO bank 0 and to use pin 0,1,2,3 to control each LED circuit. The DE2 board can only source 3.3V at .03 A. This is obviously insufficient for our high power LED's which require .7 A at that voltage. We decided to use a Darlington transistor to perform this current amplification. The Darlington TIP 120 transistor we chose had a 1000 gain from the input current at the base, to the collector current. With this information, and the fact that we need 0.7A to be supplied to our LEDs, which are attached to collector of our transistors, we needed a base input current of 0.7mA. Now, with our known 3.3V source from our GPIO pins, and only needing 0.7mA off each pin, we were within the power constraints of the board. At 3.3V and needing 0.7mA, we would require a 4.7k-ohm resistor connected between our GPIO pin and the input into our transistor base.

This concludes our design of our hardware, and external LED power circuit.

Software Design

In the final design of our project, no software component is present. Finding that we could do the project completely in hardware allowed us to cut out potential delays that may have been introduced in software. At one point in the design process, we did attempt a version of the project in software which we will detail here. In the end it was decided that too many problems arose by using software.

The software design began with choosing and flashing a NIOS II processor to the board. We created a µC/OS project and began coding. The project consisted of two software tasks, one to retrieve the data from the audio input, and one to perform the FFT and calculations. An interrupt was also needed to notify the first task that new data was available. The basic data path was as follows:

1. An interrupt is raised and the ISR posts to semaphore 1.
2. Task 1 pends semaphore 1.
3. Task 1 reads data and adds it to the buffer.
4. Task 1 posts to semaphore 2 when the buffer is filled.
5. Task 2 pends semaphore 2.
6. Task 2 calculates the FFT of the buffer.
7. Task 2 calculates magnitude information for each of the necessary bins.
8. Task 2 performs sensitivity comparisons.
9. Task 2 outputs results to the LED's.

Originally we tried to run a 1024 point FFT on the 44.1 kHz input. We found that the software could not handle this high of sampling frequency and so we down-sampled the input until the system could keep up. This was at 4 kHz. We also had to cut the FFT down to 32 points. At this point the system worked as expected, however other problems arose from this down-sampling. The higher frequency components of the audio signal were being aliased onto the lower frequencies, which caused the outputs to behave unexpectedly. In response to this, low pass filters, both digital and analog, were used to cut out the high frequency components. However, in the end we could not get it to a point we were happy with so at this point we decided to use a complete hardware solution.

Bill of Materials

~ 2 feet of 22 gauge wire:- ~$0.10
4 – High powered LEDs:- $45.28
4 – TP120 Darlington Transistors:- $4.00
4 – Trimpot Resistors :- $4.00
3.3V 0.7A power supply required – not included in bill.
Multi-bank Bread Board:- $40 for a 4 bank, or ~$10 per bank.
40-pin ribbon cable:- $10
Altera/Terasic DE2 development board:- $517.72
Total Cost:- $621.10

Reusable Design Units

We used the supplied Altera FFT Megacore Function.

Datasheet

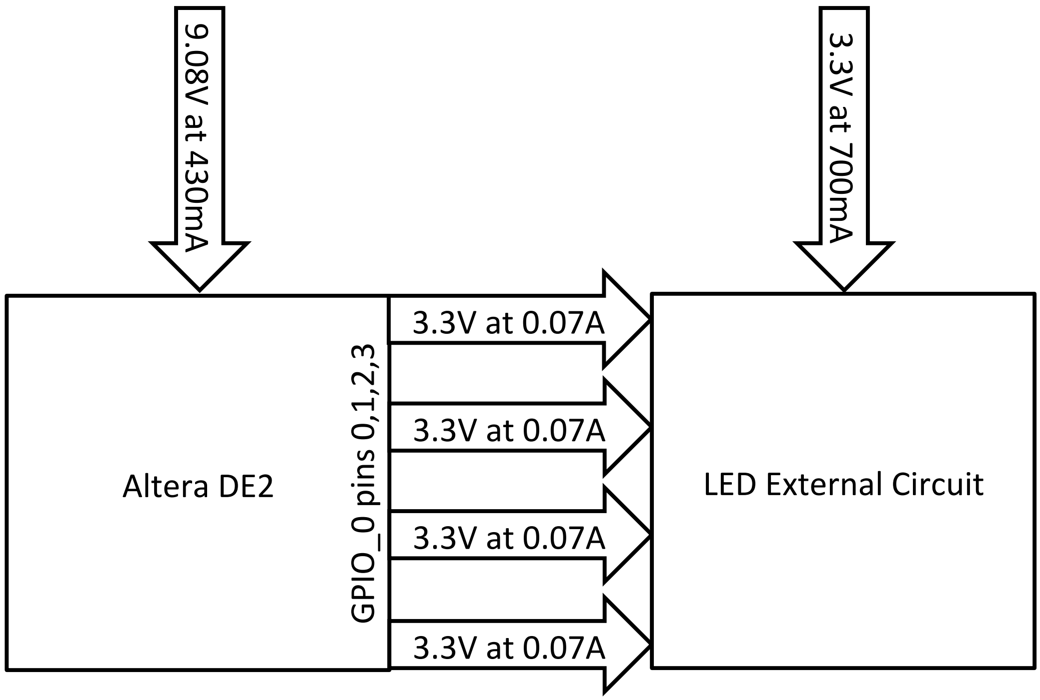
Since our system operates only in hardware the delay in our FFT processing is the only delay we experience. Based on our 1024-point streaming FFT, the delay is therefore 1024 clock cycles of our generated FFT clock. The FFT clock is based on the sampling frequency of the audio codec. In our case this frequency is 44100 Hz and provides a delay of approximately 23.2 milliseconds.

Both of the following voltage and current ratings are calculated using our DE2 power measurement wiring harness, which measures the voltage and draw current that the board uses.

9.08V with 390mA at standby, just the DE2 board running, no LEDs.

9.08V with 430mA at idle; this is when our LEDs are on standby and are turning on and off at random, which occurs after 5 seconds of inactivity.

9.08V with 430mA at peak, while a song is playing and LEDs running.



Background Reading

Real-Time Digital Signal Processing : Implementations and Applications 2nd Edition By: Sen. M Kuo, Bob H. Lee, Wenshun Tian.
http://books.google.ca/books?hl=en&lr=&id=QIj9Pthp_T8C&oi=fnd&pg=PR5&dq=real-time+streaming+fft&ots=kzFezGlrv0&sig=2TYQmDwXoFQ-4BjFCY8Aw98EtGM#v=onepage&q&f=false, Accessed April 9th 2013.

We found some useful information in this reading, mainly the functionality and how to go about implementing Digital Signal Processing algorithms.

Real-time Frequency-Domain Digital Signal Processing on the Desktop by Zack Settel & Cort Lippe
http://www.music.buffalo.edu/sites/www.music.buffalo.edu/files/pdfs/Lippe-AnnArbor.pdf, **Accessed April 3rd 2013**

This article showed us an overview of the insides of a FFT implementation in high-level coding. This helped us when trying to get our KISS_FFT working in C++.

Test Plan

Our test plan was separated into three main groups of testing. First was to test the functionality of our audio codec. Second was to test that our Fast Fourier transform was separating our audio input into its respective 1024-bins like it was designed to. Third was for testing that our LEDs were lighting up predictably based on the respective frequency bins we mapped out.

Our test plan for our audio codec was very simple. We merely just took in an audio source from "Line In" and re routed the data to the "Line Out" port and with this, we were able to listen to the audio source via speakers. This part wasn't very complicated because we didn't have to deal with any timing issues as opposed to the next part of testing, the Fast Fourier Transform.

The functionality of the FFT was the main design challenge we faced, and was more difficult than we expected. We dealt with timing issues in regard to when the bits are streaming in and out of the FFT and how to properly access the frequency bins. To test this functionality, we used the on-board red LED bank. This was done by sending a known frequency from our in-lab frequency generator into our Line In port via a stereo cable. After the digital audio signal (which is just a constant frequency signal) was passed through the FFT we showed the bin number with the greatest magnitude on the on-board red LED's. Confirming that this number matched the corresponding bin number for the known frequency, we were able to successfully and reliably show full functionality of the FFT. We used various different frequency ranges, to test the accuracy of our FFT and noticed that this approach worked very well.

The last section of our test plan was to test our external LED circuit to prove that our circuit design was accurate and could maintain our design specifications for an extended period of time. We tested this by outputting all 1's on the GPIO pins and monitoring the state of the circuit over time. We also took measurements with a voltmeter to confirm we were getting the expected values.

Results of Experimentation and Characterization

Since we only have 4 LEDs to map to our 1024-bin frequency range, we ultimately thought experimentation was the course to go. We did the calculations to figure out the width of each bin, which was 43 Hz each. We knew from before what the typical frequencies of standard drum kits were, but to optimize the lights to generate a lighting sequence from a song was a whole different story. When testing with just isolated drum sounds, we were able to isolate each drum sound to a different LED, however, when a song was played, the additional instruments and sounds caused to the LED's to be on almost continuously.

We realized that while humans are quite good at being able to pick out parts of a song as the drum part or the guitar part or the vocals part, from a signal perspective these sounds are all quite similar. We also realized that many types of music are not drum-centric and we wanted the system to work for those genres as well. In the end we decided that while the frequencies we were mapping were ok, the sensitivities required to pick up the drum sounds were too low. This was when we added the automatic gain control and were pleased with the results. In the end our system works well with almost any type of music.

References

Altera's University IP Laboratory Exercises

http://www.altera.com/education/univ/materials/digital_logic/labs/unv-labs.html, Accessed April 6th 2013.

Appendix 3:

TIP 120 – Darlington Transistor

http://www.adafruit.com/datasheets/TIP120.pdf, **Accessed April 8th 2013**

Luxeon Star Rebel Star/O High Powered LEDs

http://www.luxeonstar.com/Luxeon-Rebel-Star-O-s/372.htm, **Accessed April 9th 2013.**

Quick Start Manual

1. Program the FPGA with nios_lightshow.sof or nios_lightshow.pof
2. Connect the 40-pin ribbon cable to GPIO_0

3. Connect the other side of the ribbon cable to the external circuit, pin 0 is indicated
4. Connect the external circuit to a power supply which supplies 3.3 V at 1.5 A
5. Plug a 3.5 mm audio cable into Line-In
6. Play music through the audio cable

Future Work

Future implementations of this project would include designing the LED circuit to not just work with LEDs but to control various types of actual stage lighting equipment.

With the above, we would also like to include functionality for the use of both of the on-board GPIO banks, which have a total of 72 usable pins, and then we would be able to include a max of 72 different controllable pieces of stage equipment. With this we would like to map groupings of GPIO pins to be used with specific pieces of equipment. Explained below:

- Say, 40 pins out of 72 for up to 40 multi-coloured pot lights, could also colour code groupings of 1, 2, 4, 5 or 10 pins depending on the need.
- Say, 8 pins for up to, 8 different coloured lasers if desired. Could do colour groupings also.
- Say, 4 pins for up to 4 different fog machines that would go off periodically throughout the show.
-Say 20 pins reserved for any other equipment a band might want to include in their concert.

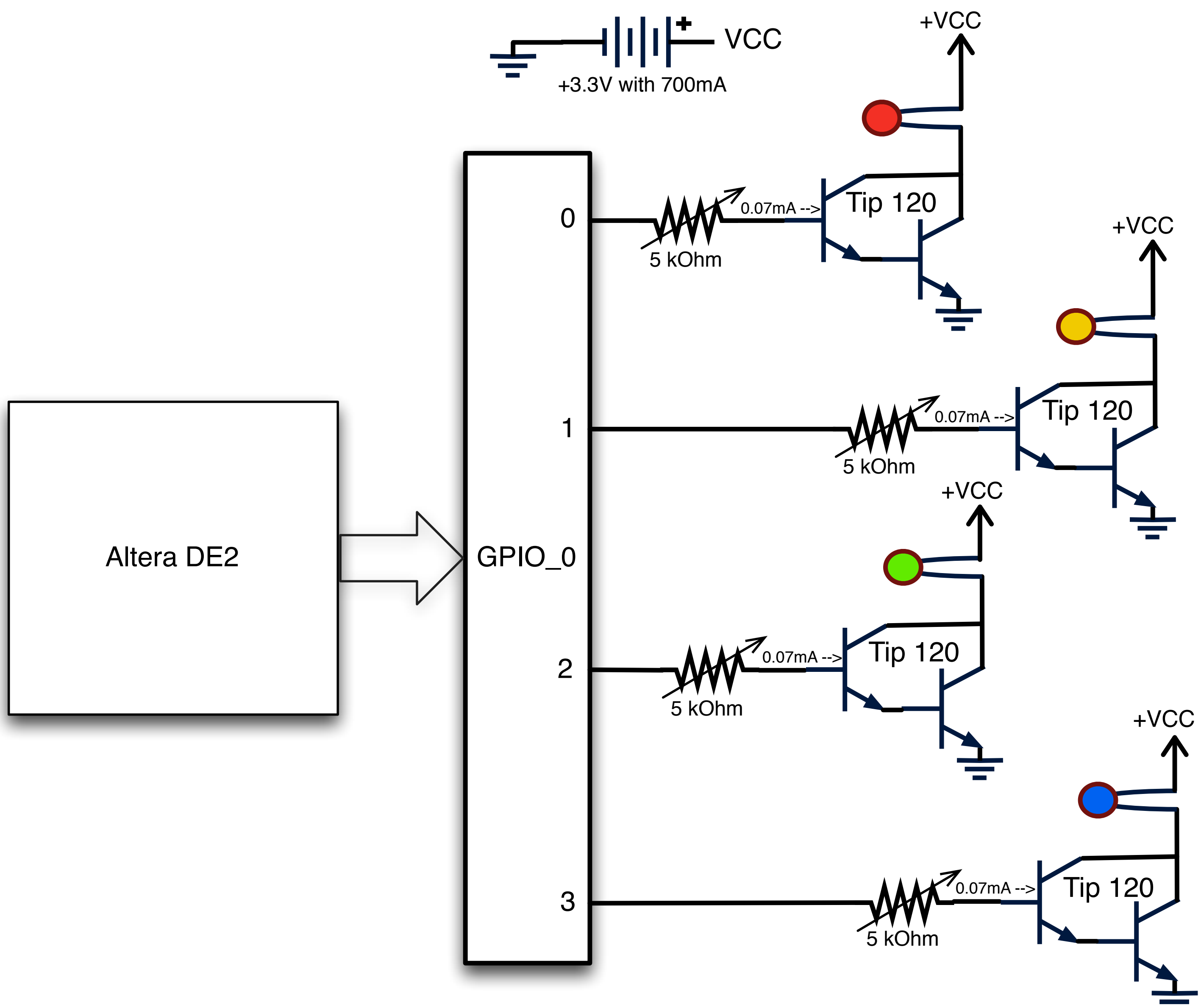
The design is entirely customizable for any clients needs if need be and the above is just a suggestion. This merely shows you how scalable this product can be.

Designing the external circuit for the appropriate power supply, and drive current would be left up to the specifications of each piece of stage equipment. Our system would only provide a mechanism for the control of these pieces. But with our knowledge, designing this external circuit would come with great ease, and would not be a problem.

From our discussion above in the Design Section of how to appropriately map what bin numbers to which LED light. If we had multiples of this system, or multiple “Line In” ports, we could have separate Line-Ins for each instrument in a band, we could then tailor each LED to that instrument. (i.e have a line in from all the drum kit microphones, so we could tailor each LED to go off on the beat of the drummer, rather then say try and differentiate between a bass note that a drummer hits and bass player plays). This type of a system would give more accurate and predictable results as seen by the human eye.

Hardware Documentation

Diagram of our external hardware circuit showing all components. Altera DE2 FPGA board shown as one component.



Appendices

Appendix 1 - Source Code

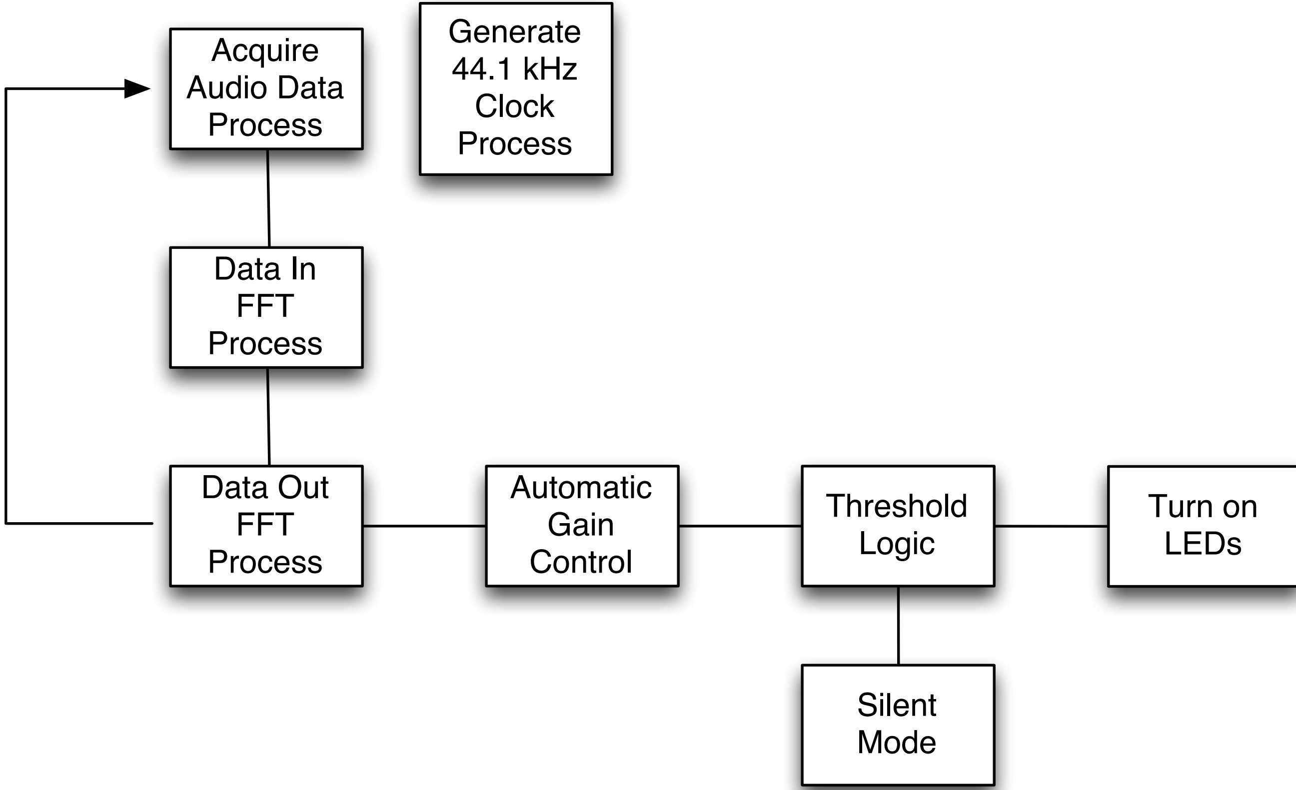
niosII_lightshow.vhd

- Toplevel file, all hardware design included.
- Compiled

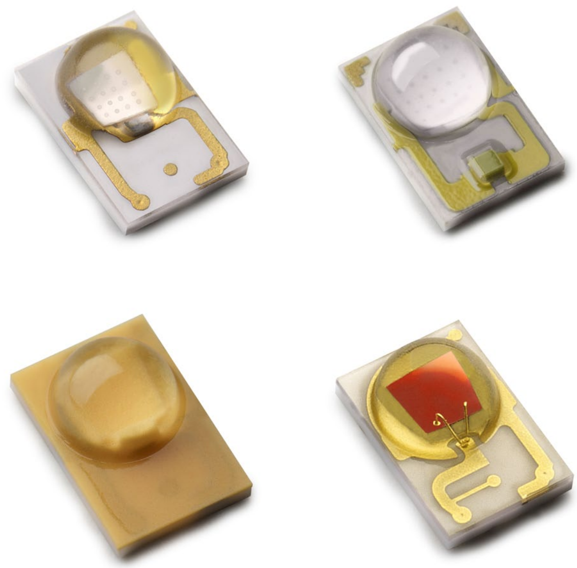
Appendix 2 - Process Flow Diagram

Appendix 3 - Hardware Datasheets

- Luxeon Star Rebel Star/O
- TIP 120 Darlington Transistors


Acquire Audio Data Process
Generate 44.1 kHz Clock Process
Data In FFT Process
Data Out FFT Process
Automatic Gain Control
Threshold Logic
Turn on LEDs
Silent Mode

Appendix 3a.



LUXEON Rebel and
LUXEON Rebel ES
Color Portfolio

Illuminating
your creativity

Technical Datasheet DS68

LUXEON
NEVER BEFORE POSSIBLE

RoHS Compliant

LUXEON® Rebel and LUXEON® Rebel ES

Color Portfolio

Introduction

With leading light output, color stability, flux density, and clear saturated colors, the LUXEON® Rebel Color Portfolio of emitters is ideal for a wide variety of lighting, signaling, signage and entertainment applications. Every LUXEON Rebel Color Portfolio emitter has built-in quality, reliability, lumen maintenance and the ease of manufacturing needed to create a superior high quality light.

Using the information in this document you can begin designing applications to your unique specifications.

Use LUXEON Rebel Color Portfolio to

- deliver more usable light and higher flux density
- optimize applications to reduce size and cost
- tightly pack the LEDs for color mixing
- engineer more robust applications
- utilize standard FR4 PCB technology
- simplify manufacturing through the use of surface mount technology
- recognized under the Component Recognition Program of Underwriters Laboratories Inc. UL listing E327436.

PHILIPS
LUMILEDS

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General Product Information

Product Nomenclature

LUXEON Rebel color emitters are tested and binned at 350 mA with the exception of LUXEON Rebel ES color emitters which are tested and binned at 700 mA.

The part number designation is explained as follows:

L X M L - A B C D - E F G H
L X M 2 - A B C D - E F G H
L X M 3 - A B C D - E F G H

Where:

A — designates radiation pattern (value P for lambertian)
B — designates color (see LUXEON Rebel color binning and labeling section)
C — designates color variant (0 for color variants)
D — designates test current (value 1 for 350 mA; 2 for 700 mA.)
E — open slot to accommodate additional requirements per product and part number
FGH — minimum luminous flux (lm) or radiometric power (mW) performance

Therefore products tested and binned at 350 mA or 700 mA follow the part numbering scheme:

L X M L - P x 0 1 - x x x x
L X M L - P x 0 2 - x x x x
L X M 2 - P x 0 1 - x x x x
L X M 3 - P x 0 1 - x x x x

Average Lumen Maintenance Characteristics

LUXEON Rebel color emitters are tested and binned at 350 mA and LUXEON Rebel ES color emitters at 700 mA, with current pulse duration of 20 ms. All characteristic charts where the thermal pad is kept at constant temperature (25°C typically) are measured with current pulse duration of 20 ms. Under these conditions, junction temperature and thermal pad temperature are the same.

Philips Lumileds projects that green, cyan, blue and all royal blue LUXEON Rebel color products will deliver, on average, 70% lumen maintenance (B50, L70) at 50,000 hours of operation at a forward current of 700 mA. This projection is based on constant current operation with junction temperature maintained at or below 135°C. Red, red-orange and amber LUXEON Rebel color products will also deliver, on average, 70% lumen maintenance (B50, L70) at 50,000 hours of operation at a forward current of 350 mA and is based on constant current operation with junction temperature maintained at or below 110°C. LUXEON Rebel PC amber delivers, on average, 70% lumen maintenance (L70) at 50,000 hours of operation at a forward current of up to 700 mA. This projection is based on constant current operation with junction temperature maintained at or below 130°C.

This performance is based on independent test data, Philips Lumileds historical data from tests run on similar material systems, and internal LUXEON Rebel reliability testing. Observation of design limits included in this data sheet is required in order to achieve this projected lumen maintenance.

Environmental Compliance

Philips Lumileds is committed to providing environmentally friendly products to the solid-state lighting market. LUXEON Rebel and LUXEON Rebel ES color products are compliant to the European Union directives on the restriction of hazardous substances in electronic equipment, namely REACH and the RoHS directive. Philips Lumileds will not intentionally add the following restricted materials to the LUXEON Rebel Color Portfolio: lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE).

Flux and Efficacy Performance Characteristics

Luminous Flux Characteristics for LUXEON Rebel Color Portfolio, Thermal Pad Temperature =25°C

Table 1.

Color	Part Number	Min Luminous Flux (lm) or Radiometric Power (mW)	Typ Flux	Typ Efficacy (lm/W) or Radiant Efficacy for Royal Blue and Deep Red	Min Luminous Flux (lm) or Radiometric Power (mW)	Typ Luminous Flux (lm) or Radiometric Power (mW)	Typ Efficacy (lm/W) or Radiant Efficacy for Royal Blue and Deep Red
		Performance @ 350 mA			Performance @ 700 mA		
Green	LXML-PM01-0100	100	102	100		161	68
	LXML-PM01-0090	90	95	93		150	63
	LXML-PM01-0080	80	88	86		139	58
	LXML-PM01-0070	70	79	78		125	52
Cyan	LXML-PE01-0080	80	83	81		133	56
	LXML-PE01-0070	70	76	75		122	51
	LXML-PE01-0060	60	67	66		110	46
Blue	LXML-PB01-0040	40.0	41	38		70	29
	LXML-PB01-0030	30.0	35	33		58	24
	LXML-PB01-0023	23.5	28	26		48	20
	LXML-PB01-0018	18.1	22	21		38	16
	LXML-PB02-0050				50	58	28
	LXML-PB02-0060				60	67	32
	LXML-PB02-0070				70	75	36
	LXML-PB02-0080				80	83	40
Royal Blue	LXML-PR01-0500	500 mW	520 mW	48%		910 mW	40%
	LXML-PR01-0425	425 mW	480 mW	44%		840 mW	37%
	LXML-PR02-1100				1100 mW	1120 mW	53%
	LXML-PR02-1050				1050 mW	1070 mW	51%
	LXML-PR02-1000				1000 mW	1030 mW	49%
	LXML-PR02-0950				950 mW	970 mW	46%
	LXML-PR02-0900				900 mW	940 mW	44%
	LXML-PR02-0800				800 mW	890 mW	42%
	LXML-PR02-A900*				900 mW	1030 mW	49%

* LXML-PR02-A900 is a selection of color Bins 4,5 only.

Flux and Efficacy Performance Characteristics, Continued

Luminous Flux Characteristics for LUXEON Rebel Color Portfolio, Thermal Pad Temperature =25°C

Table 1, Continued

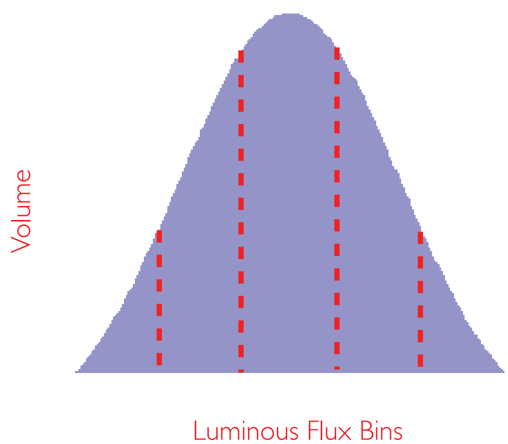
Color	Part Number	Min Luminous Flux (lm) or Radiometric Power (mW)	Typ Flux	Typ Efficacy (lm/W) or Radiant Efficacy for Royal-Blue and Deep Red	Min Luminous Flux (lm) or Radiometric Power (mW)	Typ Luminous Flux (lm) or Radiometric Power (mW)	Typ Efficacy (lm/W) or Radiant Efficacy for Royal-Blue and Deep Red
		Performance @ 350 mA			Performance @ 700 mA		
Deep Red	LXM3-PD01-0350	350 mW	360 mW	46%		720 mW	42%
	LXM3-PD01-0300	300 mW	320 mW	41%		640 mW	38%
	LXM3-PD01-0260	260 mW	290 mW	37%		580 mW	34%
Red	LXM2-PD01-0060	60	62	83		119	74
	LXM2-PD01-0050	50	53	75		106	65
	LXM2-PD01-0040	40	48	65		90	56
	LXML-PD01-0050	50	52	53		85	35
	LXML-PD01-0040	40	46	47		75	30
	LXML-PD01-0030	30	38	37		62	24
Red-Orange	LXM2-PH01-0070	70	72	98		134	83
	LXM2-PH01-0060	60	67	91		122	76
	LXML-PH01-0060	60	62	63		100	40
	LXML-PH01-0050	50	56	57		90	35
PC Amber	LXM2-PL01-0100	100	102	96		184	83
	LXM2-PL01-0090	90	95	89		171	76
	LXM2-PL01-0080	80	86	80		155	70
	LXM2-PL01-0070	70	78	73		140	63
Amber	LXML-PL01-0060	60	61	60		98	39
	LXML-PL01-0050	50	54	51		84	33
	LXML-PL01-0040	40	48	46		77	30
	LXML-PL01-0030	30	38	37		61	24

Notes for Table 1:

1. Minimum luminous flux or radiometric power performance guaranteed within published operating conditions. Philips Lumileds maintains a tolerance of ± 6.5% on flux and power measurements.
2. Typical luminous flux or radiometric power performance when device is operated within published operating conditions.

Flux Performance, Binning, and Supportability

LEDs are produced with semiconductor technology that is subject to process variation, yielding a range of flux performance that is approximately Gaussian in nature. In order to provide customers with fine granularity within the overall flux distribution, Philips Lumileds separates LEDs into fixed, easy to design with, minimum luminous flux bins. To verify supportability of parts chosen for your application design, please consult your Philips Lumileds sales representative.



Optical Characteristics

LUXEON Rebel Color Portfolio at Test Current [1] Thermal Pad Temperature = 25°C

Table 2.

Color	Dominant Wavelength [2] λ_D, or Peak Wavelength [3] λ_P Min.	Typ.	Max.	Typical Spectral Half-width[4] (nm) $\Delta\lambda_{1/2}$	Typical Temperature Coefficient of Dominant or Peak Wavelength (nm/°C) $\Delta\lambda_D / \Delta T_J$	Typical Total Included Angle [5] (degrees) $\theta_{0.90V}$	Typical Viewing Angle [6] (degrees) 2θ 1/2
Green [7]	520.0 nm	530.0 nm	540.0 nm	30	0.05	160	125
Cyan [7]	490.0 nm	505.0 nm	510.0 nm	30	0.04	160	125
Blue [7]	460.0 nm	470.0 nm	480.0 nm	20	0.05	160	125
Royal-Blue [3] [7]	440.0 nm	447.5 nm	460.0 nm	20	0.04	160	125
Red [8]	620.0 nm	627.0 nm	645.0 nm	20	0.05	160	125
Deep Red [3, 8]	650.0 nm	655.0 nm	670.0 nm	20	0.05	160	125
Red-Orange [8]	610.0 nm	617.0 nm	620.0 nm	20	0.08	160	125
Amber [8]	584.5 nm	590.0 nm	594.5 nm	20	0.10	160	125
PC Amber [7]	588.0 nm	591.0 nm	592.0 nm	80	0.10	160	120

Notes for Table 2:

1. LXML-PR01-XXXX, LXM2-PL01-XXXX and LXM3-PD01-XXXX emitters are tested at 350 mA, LXML-PR02-XXXX emitters are tested at 700 mA.
2. Dominant wavelength is derived from the CIE 1931 Chromaticity diagram and represents the perceived color. Philips Lumileds maintains a tolerance of ± 0.5 nm for dominant wavelength measurements.
3. Royal-blue and Deep Red LEDs are binned by radiometric power and peak wavelength rather than photometric lumens. Philips Lumileds maintains a tolerance of ± 2nm for peak wavelength measurements.
4. Spectral width at ½ of the peak intensity.
5. Total angle at which 90% of total luminous flux is captured.
6. Viewing angle is the off axis angle from lamp centerline where the luminous intensity is ½ of the peak value.
7. PC amber, green, cyan, blue and royal-blue products are built with Indium Gallium Nitride (InGaN).
8. All red, deep red, red-orange, and amber are built with Aluminum Indium Gallium Phosphide (AlInGaP).

Electrical Characteristics

Electrical Characteristics at 350 mA for LUXEON Rebel color, Thermal Pad Temperature = 25°C

Table 3.

Color	Part Number	Forward Voltage V_f [1] (V) Min.	Typ.	Max.	Typical Temperature Coefficient of Forward Voltage [2] (mV/°C) $\Delta V_f / \Delta T_J$	Typical Thermal Resistance Junction to Thermal Pad (°C/W) $R\theta_{J-C}$
Green	LXML-PM01	2.55	2.90	3.51	- 2.0 to - 4.0	10
Cyan	LXML-PE01	2.55	2.90	3.51	- 2.0 to - 4.0	10
Blue	LXML-PB01	2.55	2.95	3.51	- 2.0 to - 4.0	10
Royal-Blue	LXML-PR01	2.55	2.95	3.51	- 2.0 to - 4.0	10
Red	LXML-PD01	2.31	2.90	3.51	- 2.0 to - 4.0	12
Red	LXM2-PD01	1.80	2.10	2.80	- 2.0 to - 4.0	8
Deep Red	LXM3-PD01	1.80	2.10	2.80	- 2.0 to - 4.0	8
Red-Orange	LXML-PH01	2.31	2.90	3.51	- 2.0 to - 4.0	12
Red-Orange	LXM2-PH01	1.80	2.10	2.80	- 2.0 to - 4.0	8
PC Amber	LXM2-PL01	2.55	3.05	3.51	- 2.0 to - 4.0	10
Amber	LXML-PL01	2.31	2.90	3.51	- 2.0 to - 4.0	12
Electrical Characteristics at 700 mA for LUXEON Rebel ES Color, Thermal Pad Temperature = 25°C						
Royal-Blue	LXML-PR02	2.50	3.00	3.50	- 2.0 to - 4.0	6
Blue	LXML-PB02	2.50	2.95	3.50	-2.0 to -4.0	

Notes for Table 3:

1. LUXEON Rebel ES colors measured between 25°C = Tj = 110°C and If = 700 mA.
2. Measured between 25°C = T_J = 110°C at I_f = 350 mA.
3. Philips Lumileds maintains a tolerance of ±0.06V on forward voltage measurements.

Typical Electrical Characteristics at 700 mA for LUXEON Rebel color, Thermal Pad Temperature = 25°C

Table 4.

Color	Part Number	Typical Forward Voltage V_f (V)
Green	LXML-PM01	3.25
Cyan	LXML-PE01	3.25
Blue	LXML-PB02	2.95
Blue	LXML-PB01	3.30
Royal-Blue	LXML-PR02	3.00
Royal-Blue	LXML-PR01	3.25
Red	LXML-PD01	3.60
Red	LXM2-PD01	2.30
Deep Red	LXM3-PD01	2.40
Red-Orange	LXML-PH01	3.60
Red-Orange	LXM2-PH01	2.30
PC Amber	LXM2-PL01	3.20
Amber	LXML-PL01	3.60

Absolute Maximum Ratings

Table 5.

Parameter	Green/Cyan/ Blue/Royal Blue	LUXEON Rebel ES Royal Blue/ES Blue	Red/Deep-Red Red-Orange/Amber	PC Amber
DC Forward Current (mA)	1000	1000	700	700
Peak Pulsed Forward Current (mA)	1000	1200	700	700
Average Forward Current (mA)	1000	1000	700	700
ESD Sensitivity	< 8000V Human Body Model (HBM) Class 3A JESD22-A114-B			
LED Junction Temperature [1]	150°C	150°C	135°C	130°C
Operating Case Temperature at 350 mA	-40°C - 135°C	-40°C - 135°C	-40°C - 120°C	-40°C - 110°C
Storage Temperature	-40°C - 135°C	-40°C - 135°C	-40°C - 135°C	-40°C - 135°C
Soldering Temperature	JEDEC 020c 260°C	JEDEC 020c 260°C	JEDEC 020c 260°C	JEDEC 020c 260°C
Allowable Reflow Cycles	3	3	3	3
	Autoclave Conditions 121°C at 2 ATM 100% Relative Humidity for 96 Hours Maximum			
Reverse Voltage (Vr)	LUXEON Rebel Color Portfolio LEDs are not designed to be driven in reverse bias.			

Notes for Table 5:

1. Proper current derating must be observed to maintain junction temperature below the maximum.
2. The maximum rating for LUXEON Rebel ES Royal Blue is 1200 mA with peak pulsed forward current not to exceed 60 seconds.

JEDEC Moisture Sensitivity

Table 6.

Level	Floor Life		Soak Requirements Standard	
	Time	Conditions	Time (hours)	Conditions
1	unlimited	≤ 30°C / 85% RH	168 + 5 / -0	85°C / 85% RH

Reflow Soldering Characteristics

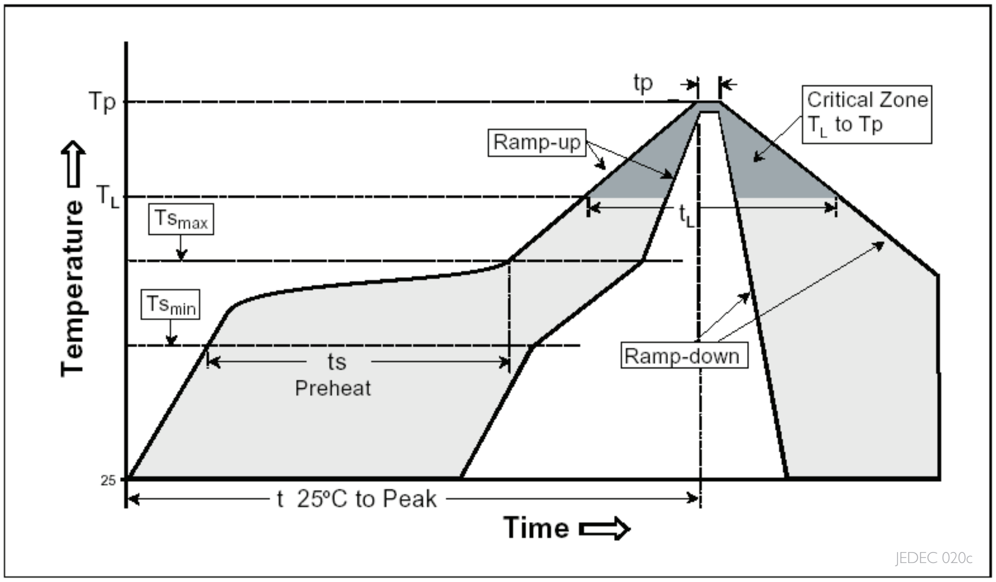


Table 7.

Profile Feature	Lead Free Assembly
Average Ramp-Up Rate (Ts_{max} to T_p)	3°C / second max
Preheat Temperature Min (Ts_{min})	150°C
Preheat Temperature Max (Ts_{max})	200°C
Preheat Time (ts_{min} to ts_{max})	60 - 180 seconds
Temperature T_L (t_L)	217°C
Time Maintained Above Temperature T_L (t_L)	60 - 150 seconds
Peak / Classification Temperature (T_P)	260°C
Time Within 5°C of Actual Peak Temperature (t_P)	20 - 40 seconds
Ramp-Down Rate	6°C / second max
Time 25°C to Peak Temperature	8 minutes max

Note for Table 7:

- All temperatures refer to the application Printed Circuit Board (PCB), measured on the surface adjacent to the package body.

Mechanical Dimensions: LUXEON Rebel Color Emitter

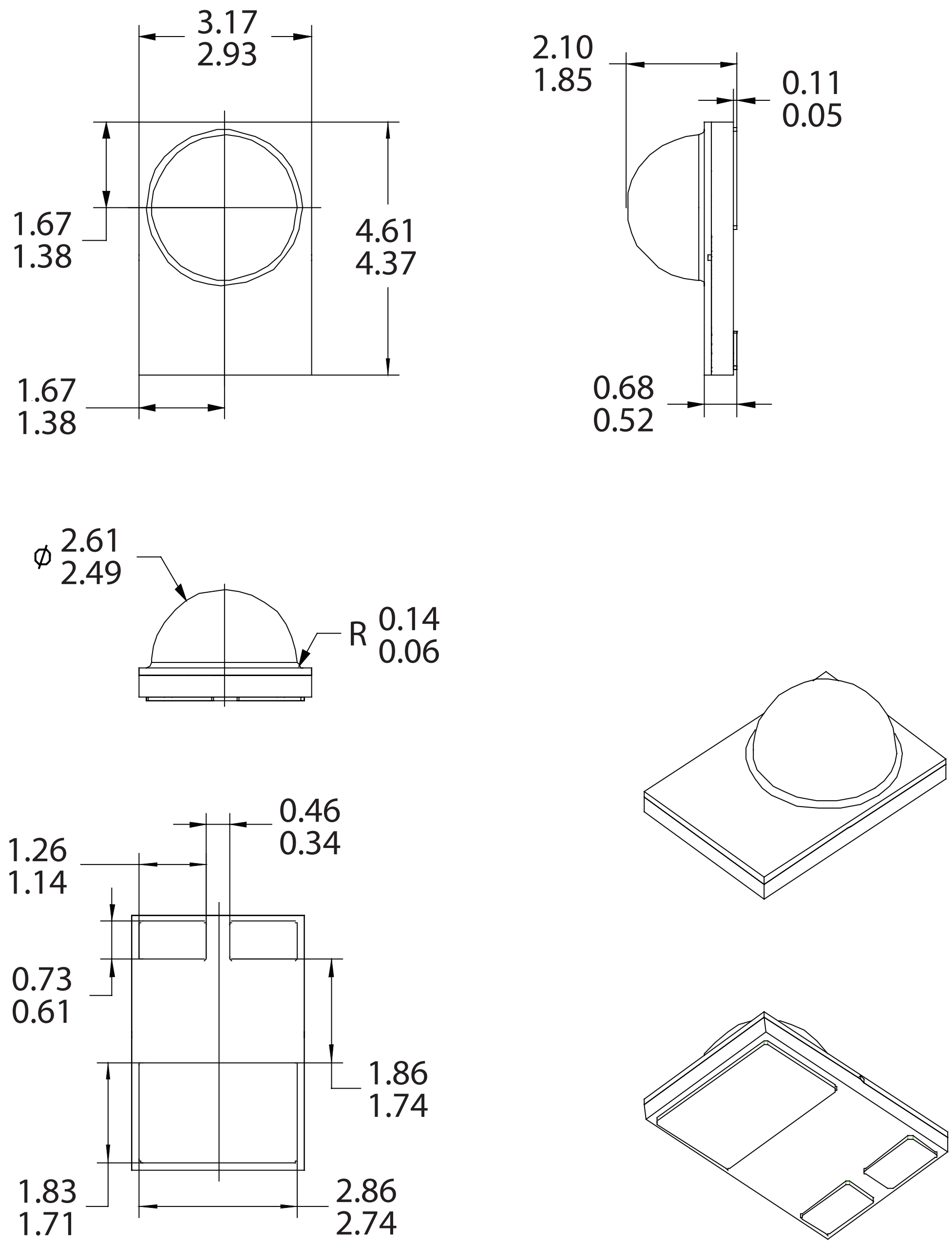


Figure 1. Package outline drawing.

Notes for Figure 1:

- To avoid damage, do not handle the device by the emitter lens.
- Drawings not to scale.
- All dimensions are in millimeters.
- The thermal pad is electrically isolated from the anode and cathode contact pads.

Mechanical Dimensions: LUXEON Rebel ES Color Emitter

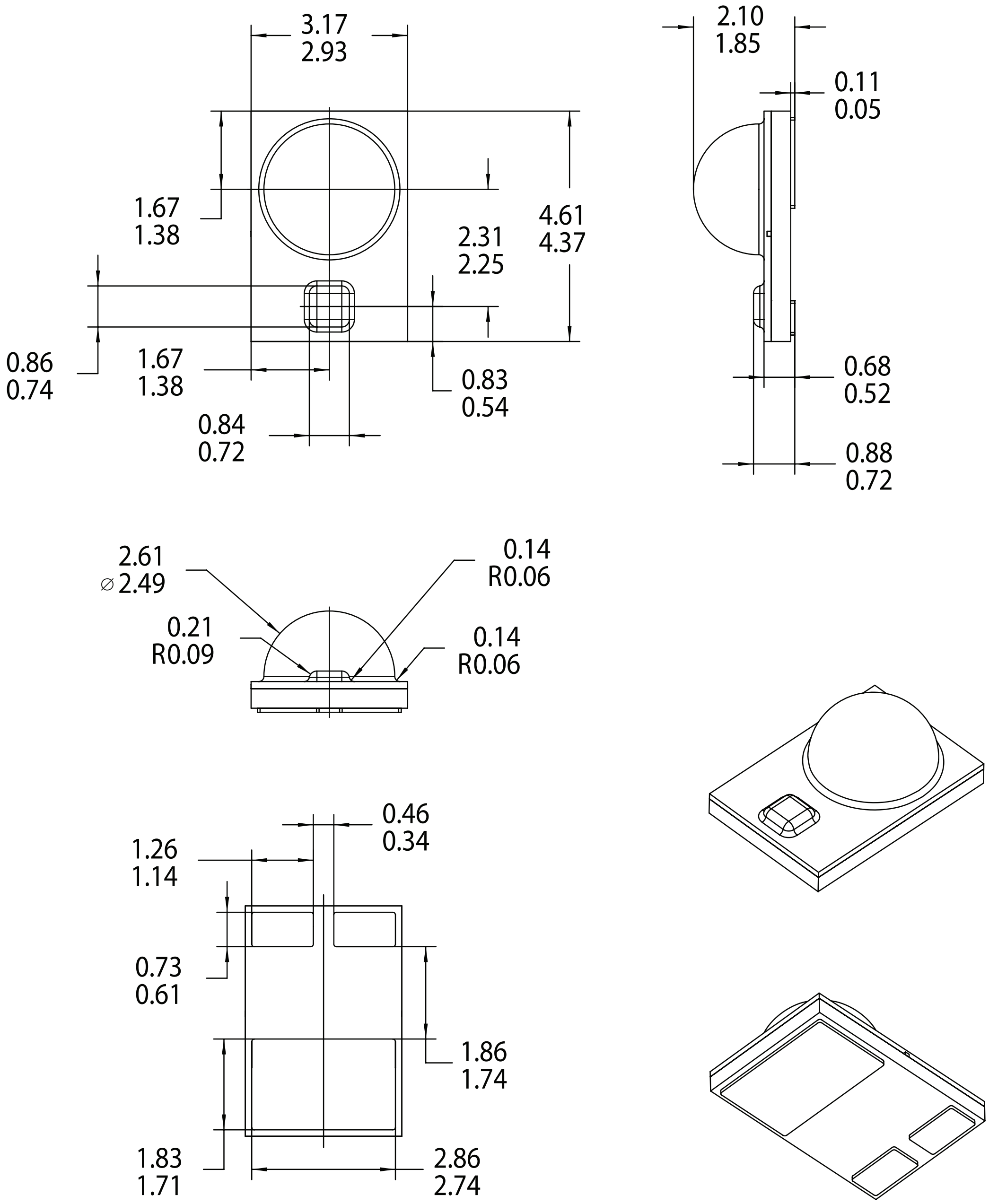
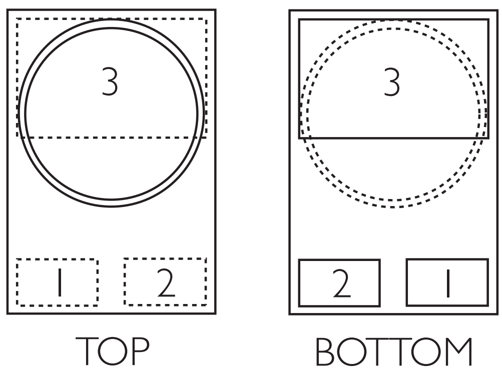


Figure 2. Package outline drawing.

Notes for Figure 2:

- To avoid damage, do not handle the device by the emitter lens.
- Drawings not to scale.
- All dimensions are in millimeters.
- The thermal pad is electrically isolated from the anode and cathode contact pads.

Pad Configuration



PAD	FUNCTION
1	CATHODE
2	ANODE
3	THERMAL

Figure 3. Pad configuration.

Note for Figure 3:

- The thermal pad is electrically isolated from the anode and cathode contact pads.

Solder Pad Design

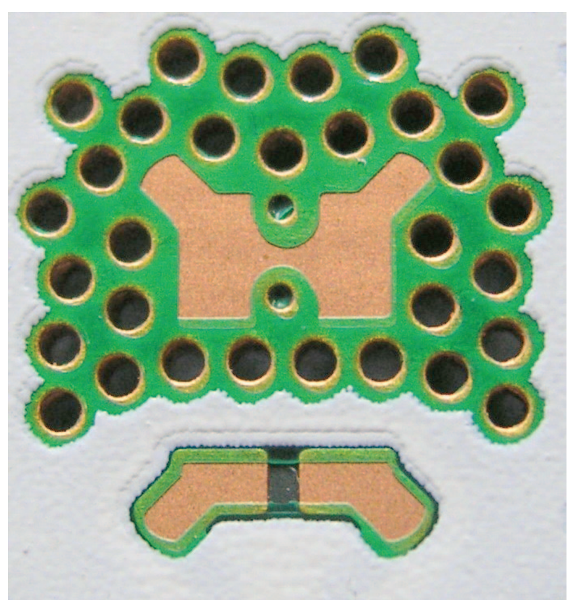


Figure 4. Solder pad layout.

Notes for Figure 4:

- The photograph shows the recommended LUXEON Rebel Color Portfolio layout on printed circuit board (PCB). This design easily achieves a thermal resistance of 7K/W.
- Application Brief AB32 provides extensive details for this layout. The .dwg files are available at www.philipslumileds.com and www.philipslumileds.cn.com.

Wavelength Characteristics

Green, Cyan, Blue, all Royal Blue, Red, Red-Orange and Amber at Test Current, Thermal Pad Temperature = 25°C

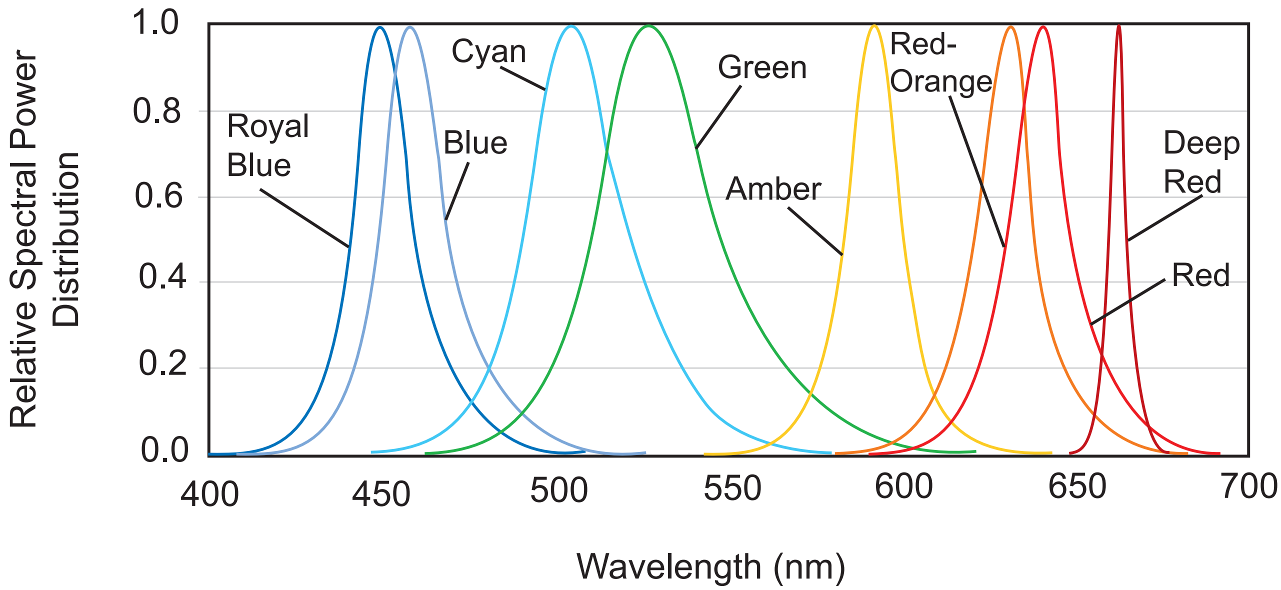


Figure 5. Relative intensity vs. wavelength.

PC Amber at Test Current, Thermal Pad Temperature = 25°C

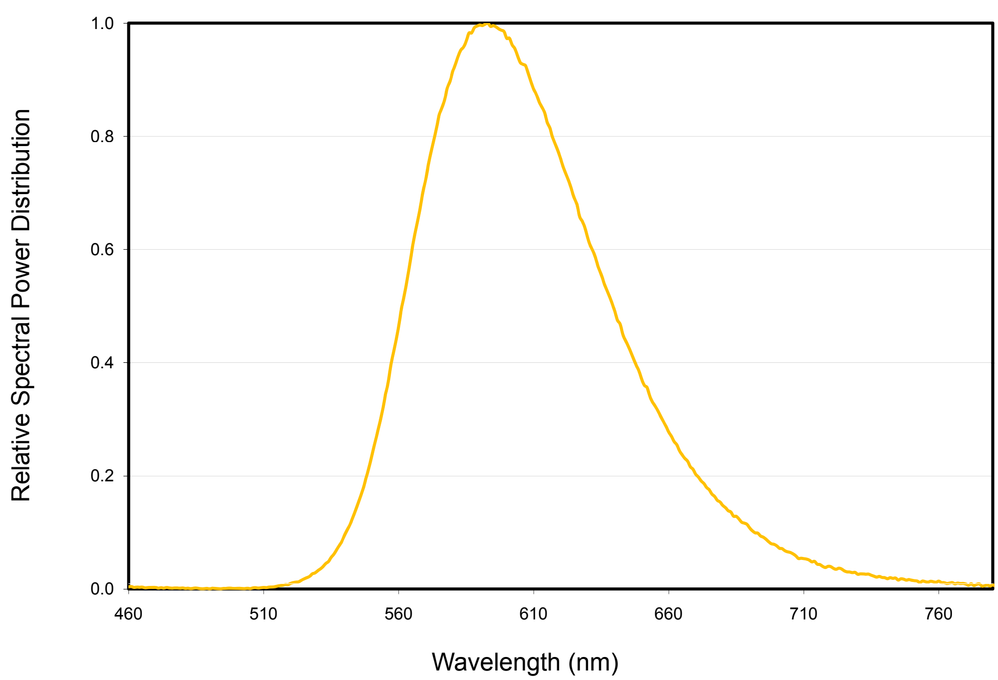
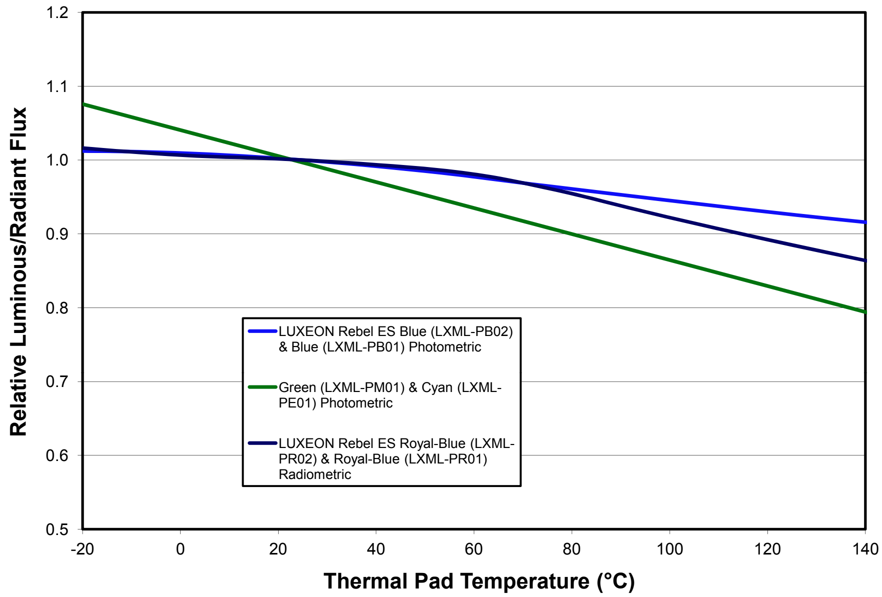


Figure 6. Relative intensity vs. wavelength.

Typical Light Output Characteristics over Temperature

Cyan, Blue, Royal Blue and LUXEON Rebel ES Royal Blue at Test Current



*LXML-PR02 and LXML-PB02 values are based on 700 mA drive current.

Figure 7. Relative light output vs. thermal pad temperature for green, cyan, blue, royal blue, LUXEON Rebel ES Royal Blue and ES Blue.

Red, Deep Red, Red-Orange and Amber at Test Current

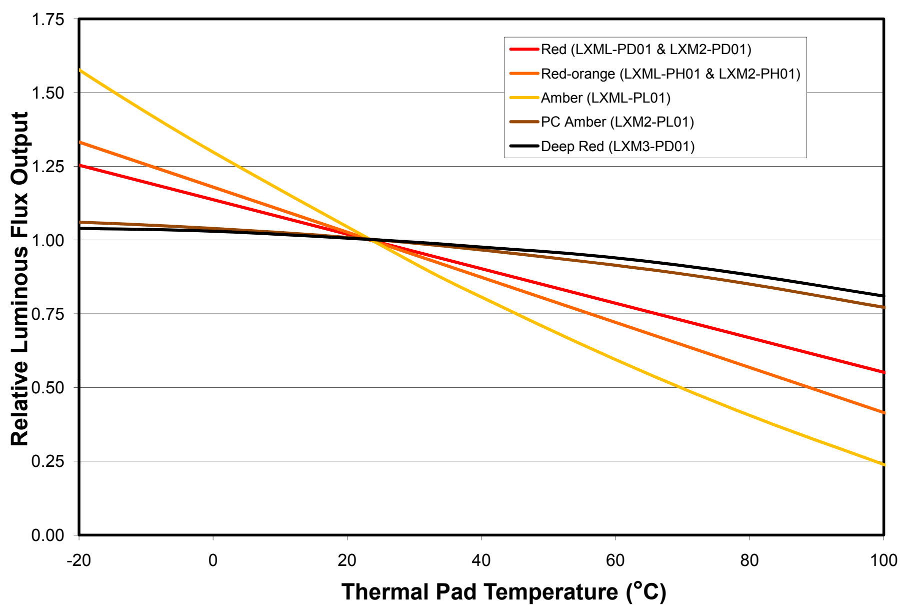


Figure 8. Relative light output vs. thermal pad temperature for red, deep red, red-orange and amber.

Typical Forward Current Characterisics

Green, Cyan, Blue, Royal Blue, LUXEON Rebel ES Royal Blue and ES Blue
Thermal Pad Temperature = 25°C

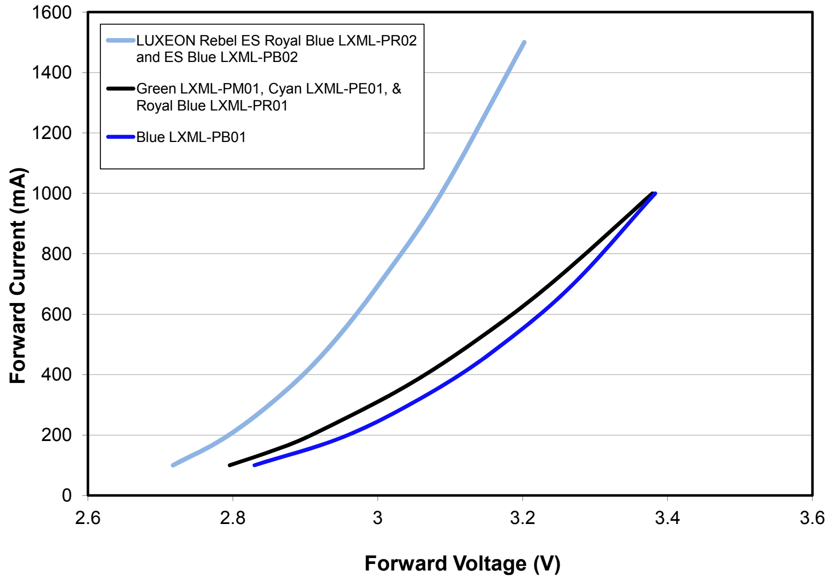


Figure 9. Forward current vs. forward voltage for green, blue, royal blue, LUXEON Rebel ES Royal Blue and ES Blue.

Red, Deep Red, Red-Orange, Amber and PC Amber
Thermal Pad Temperature = 25°C

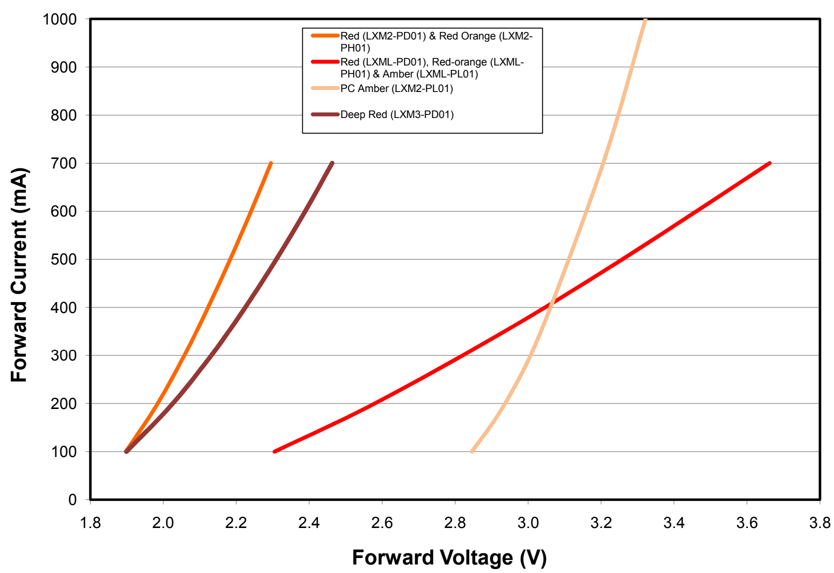


Figure 10. Forward current vs. forward voltage for red, deep red, red-orange, amber, and PC amber.

Typical Relative Luminous Flux

Typical Relative Luminous Flux vs. Forward Current for LUXEON Rebel ES Royal Blue and ES Blue, Thermal Pad Temperature = 25°C

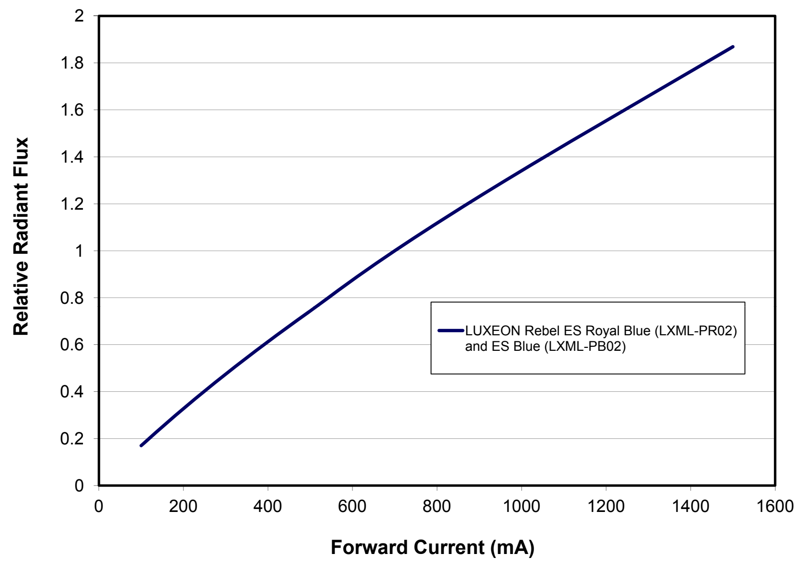


Figure 11. Relative luminous flux or radiometric power vs. forward current for LUXEON Rebel ES Colors at Thermal Pad = 25°C maintained.

Typical Relative Luminous Flux vs. Forward Current for Green, Cyan, Blue and Royal Blue, Thermal Pad Temperature = 25°C

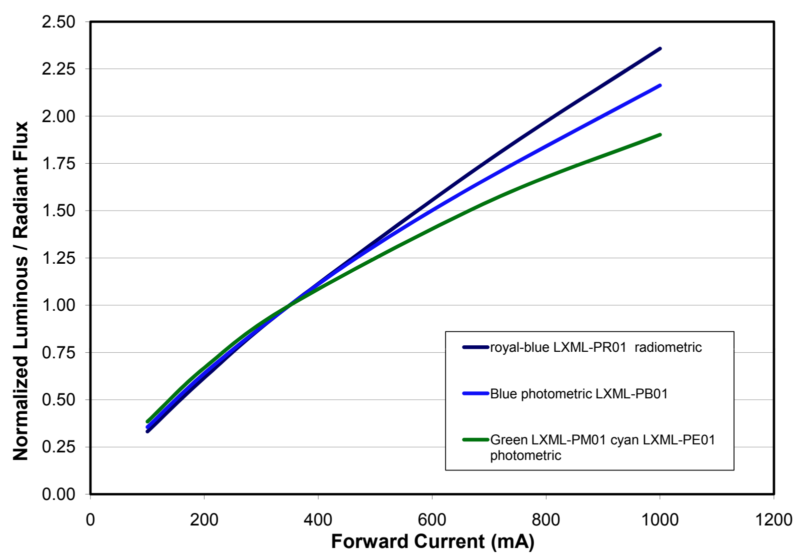


Figure 12. Relative luminous flux or radiometric power vs. forward current for green, cyan, blue and royal blue at Thermal Pad = 25°C maintained.

Typical Relative Luminous Flux vs. Forward Current for Red, Deep Red, Red-Orange, Amber, Thermal Pad Temperature = 25°C

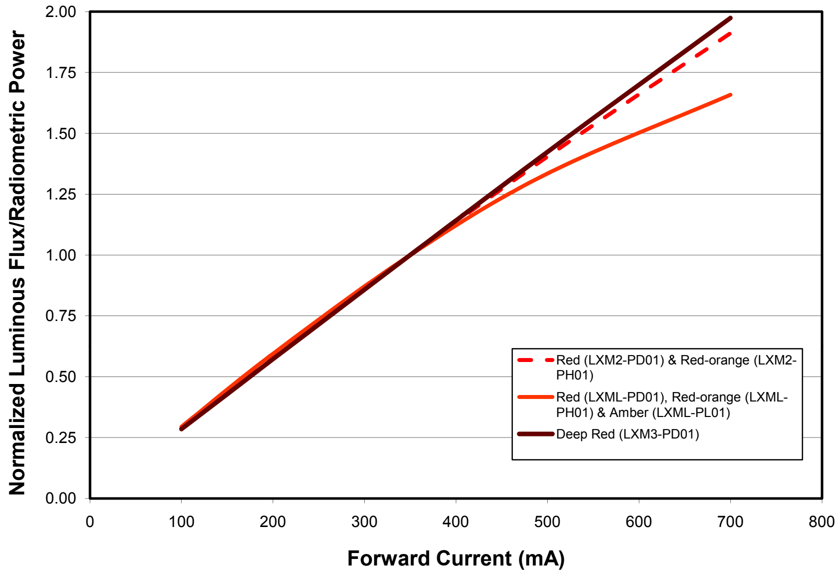


Figure 13. Relative luminous flux vs. forward current for red, deep red, red-orange and amber at Thermal Pad = 25°C maintained.

Typical Relative Luminous Flux, PC Amber Thermal Pad Temperature = 25°C

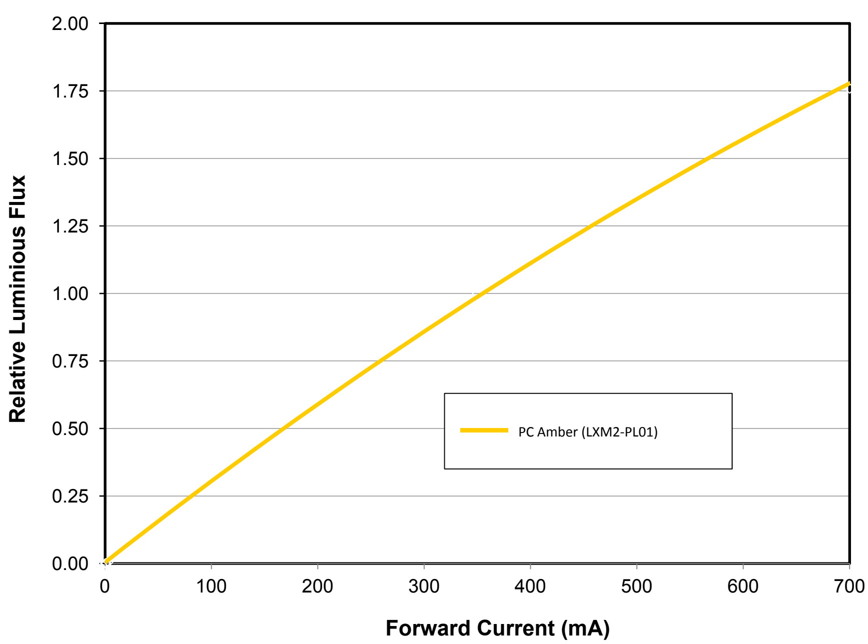


Figure 14. Relative luminous flux vs. forward current for PC amber LXM2-PL01 emitters.

Current Derating Curves

Current Derating Curve for 350 mA Drive Current for Green, Cyan, Blue and Royal Blue

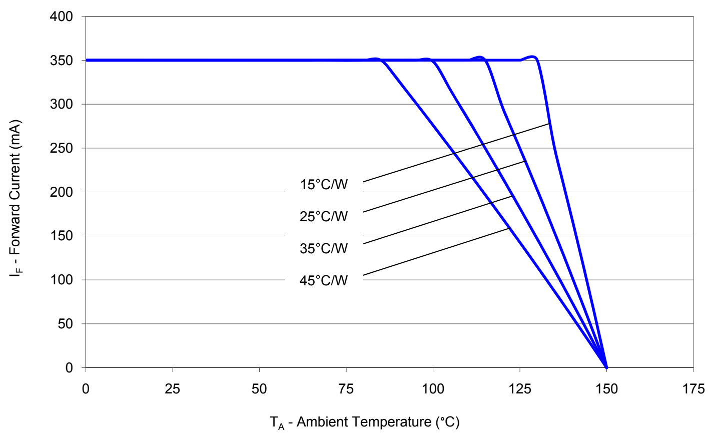


Figure 15. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 150°C, green LXML-PM01, cyan LXML-PE01, blue LXML-PB01 & royal blue LXML-PR01 emitters.

Current Derating Curve for 350 mA Drive Current for Red, Red-Orange, Amber

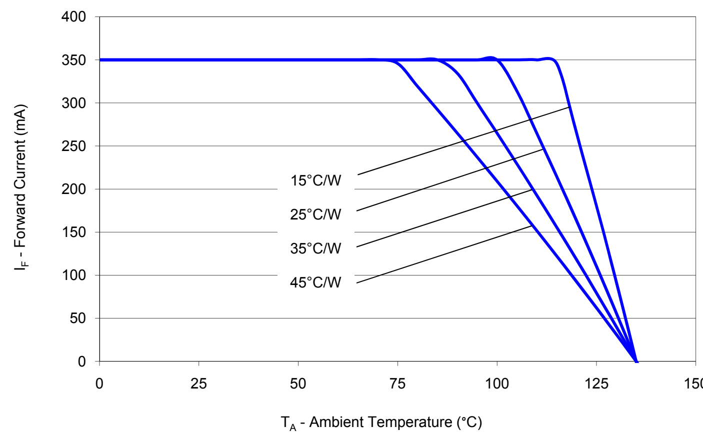


Figure 16. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 135°C, red LXML-PD01, red-orange LXML-PH01 & amber LXML-PL01 emitters.

Current Derating Curve for 350 mA Drive Current for Red, Deep-Red and Red-Orange

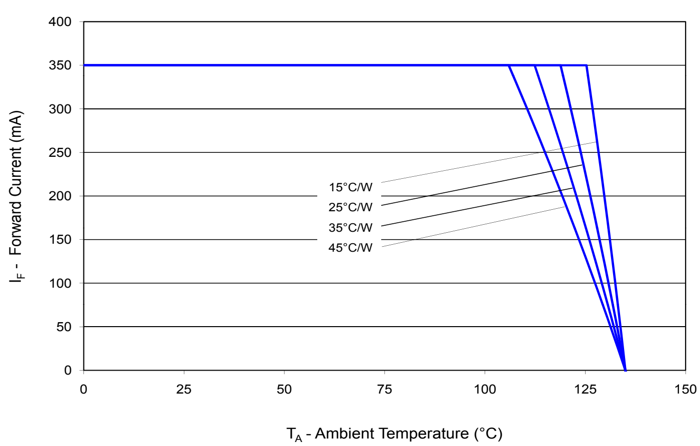


Figure 17. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 135°C, red LXM2-PD01, deep red LXM3-PD01 & red-orange LXM2-PH01 emitters.

Current Derating Curve for 350 mA Drive Current for PC Amber

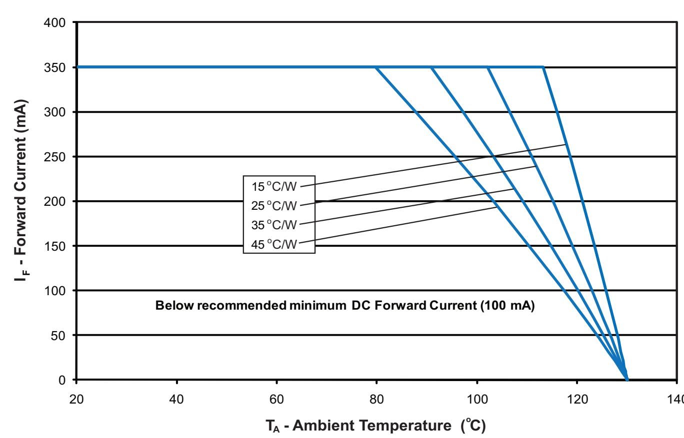


Figure 18. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 130°C, PC amber LXM2-PL01 emitters.

Current Derating Curves

Current Derating Curve for 700 mA Drive Current for Green, Cyan, Blue and Royal Blue

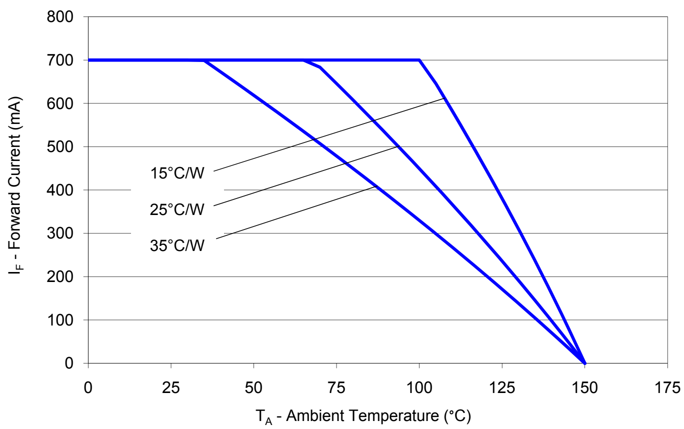


Figure 19. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 150°C, green LXML-PM01, cyan LXML-PE01, blue LXML-PB01 & royal blue LXML-PR01 emitters..

Current Derating Curve for 700 mA Drive Current for LUXEON Rebel ES Royal Blue and ES Blue.

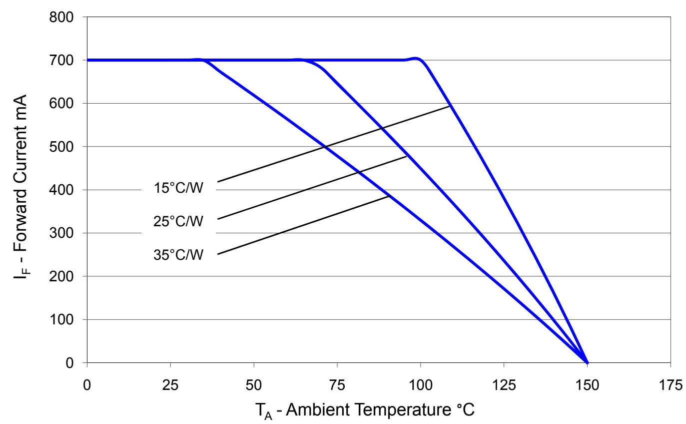


Figure 20. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 150°C, royal blue LXML-PR02 emitters.

Current Derating Curve for 700 mA Drive Current for Red, Red-Orange, Amber

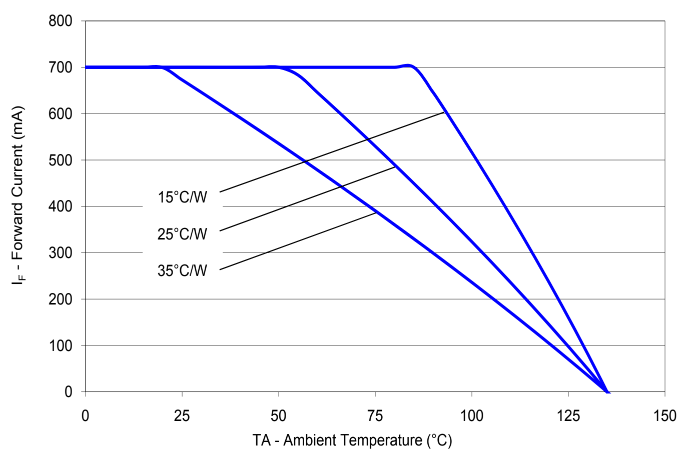


Figure 21. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 135°C, red LXML-PD01, red-orange LXML-PH01 & amber LXML-PL01 emitters.

Current Derating Curve for 700 mA Drive Current for Red, Deep Red and Red-Orange

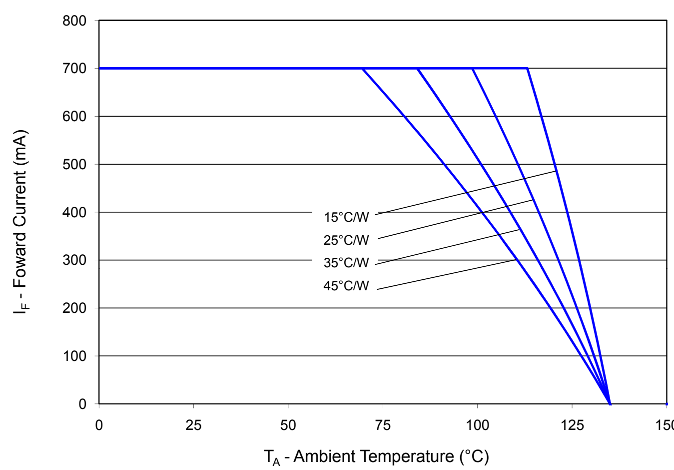


Figure 22. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 135°C, red LXM2-PD01, deep red LXM3-PD01 & red-orange LXM2-PH01 emitters.

Current Derating Curves

Current Derating Curve for 700 mA Drive Current for PC Amber

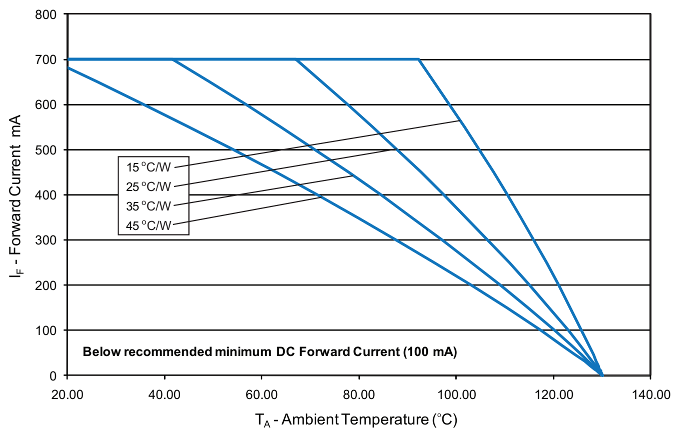


Figure 23. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 130°C, PC amber LXM2-PL01 emitters.

Current Derating Curve for 1000 mA Drive Current for Green, Cyan, Blue and Royal Blue

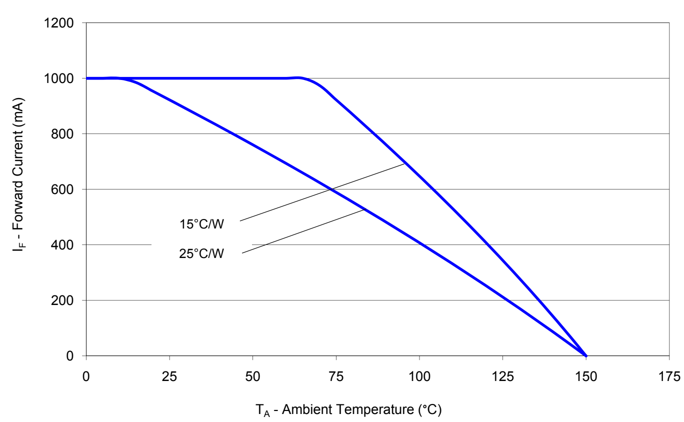


Figure 24. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 150°C, green LXML-PM01, cyan LXML-PE01, blue LXML-PB01 & royal blue LXML-PR01.

Current Derating Curve for 1000 mA Drive Current for LUXEON Rebel ES Royal Blue and ES Blue

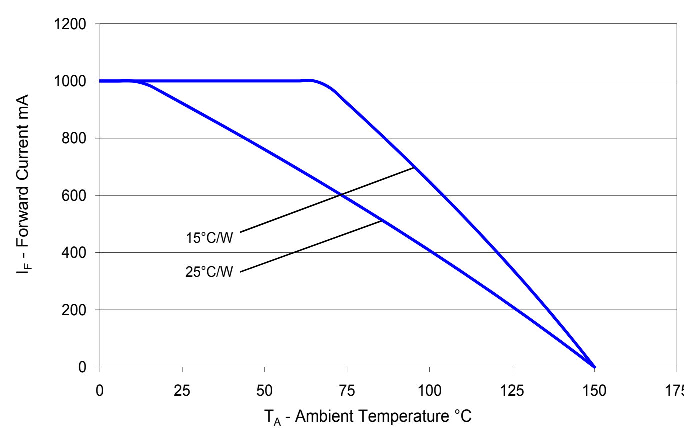


Figure 25. Maximum forward current vs. ambient temperature, based on T_{JMAX} = 150°C, royal blue LXML-PR02 emitters.

Typical Radiation Patterns

Typical Spatial Radiation Pattern for Green, Cyan, Blue, Royal Blue, LUXEON Rebel ES Royal Blue and ES Blue Lambertian

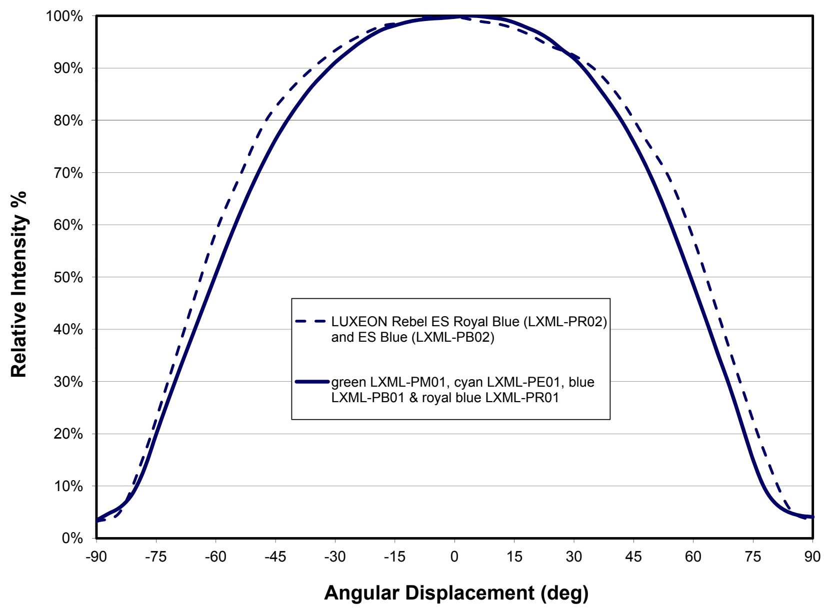


Figure 26. Typical spatial radiation pattern for green, cyan, blue, royal blue, LUXEON Rebel ES Royal Blue and ES blue lambertian.

Typical Polar Radiation Pattern for Green, Cyan, Blue, Royal Blue, LUXEON Rebel ES Royal Blue and ES Blue Lambertian

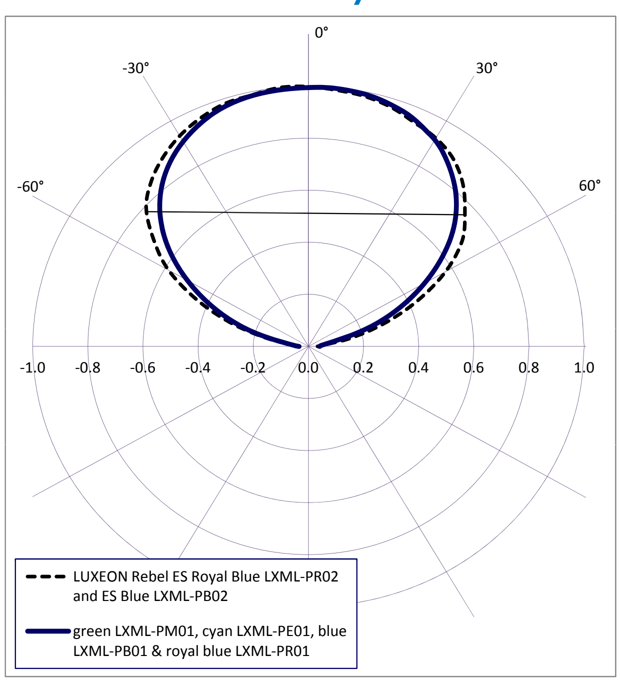


Figure 27. Typical polar radiation pattern for green, cyan, blue, royal blue and LUXEON Rebel ES royal blue lambertian.

Typical Spatial Radiation Pattern for Red, Red-Orange and Amber Lambertian

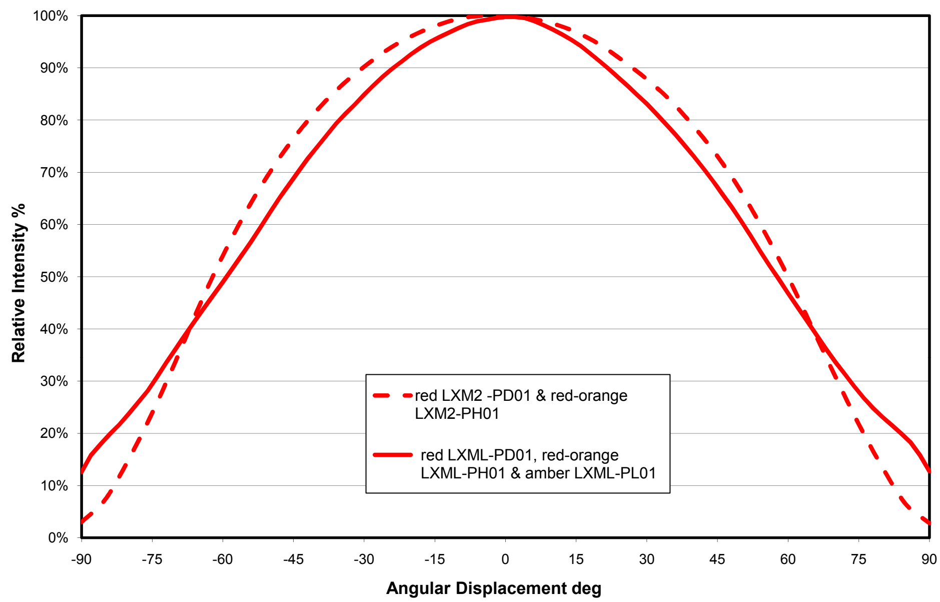


Figure 28. Typical spatial radiation pattern for red, red-orange and amber lambertian.

Typical Polar Radiation Pattern for Red, Red-Orange and Amber Lambertian

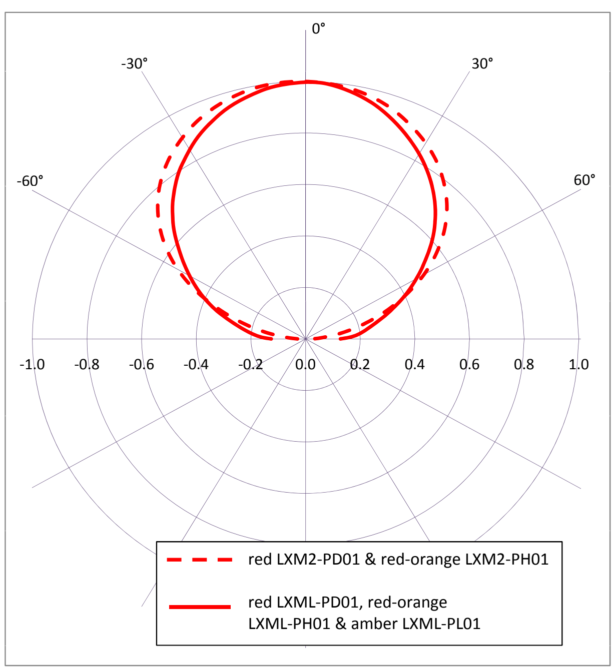


Figure 29. Typical polar radiation pattern for red, red-orange and amber lambertian.

Typical Spatial Radiation Pattern for Deep Red Lambertian

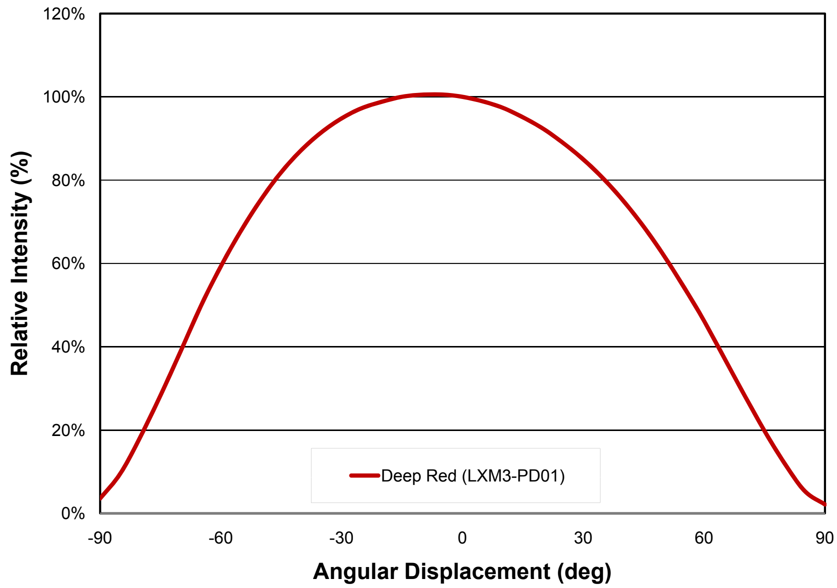


Figure 30. Typical spatial radiation pattern for deep red lambertian.

Typical Polar Radiation Pattern for Deep Red Lambertian

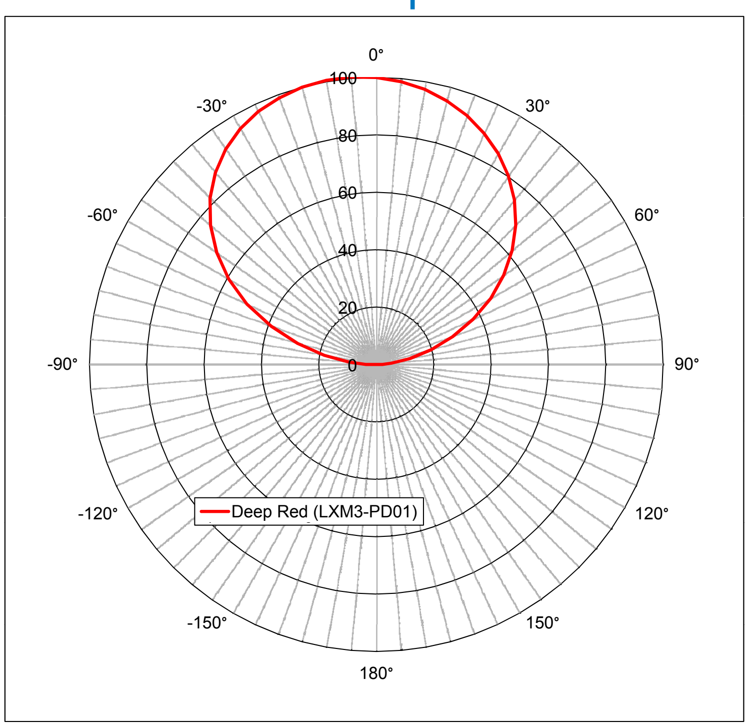


Figure 31. Typical polar radiation pattern for deep red lambertian.

Typical Radiation Patterns

Typical Spatial Radiation Pattern PC Amber

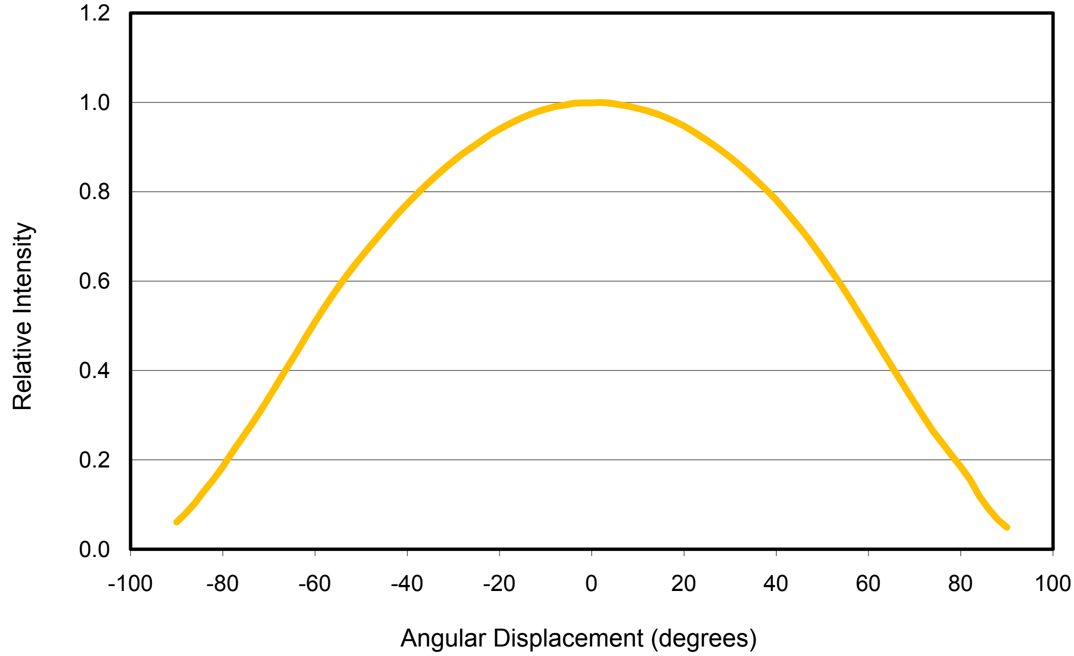


Figure 32. Typical representative spatial radiation pattern, PC amber LXM2-PL01 emitters.

Typical Polar Radiation Pattern PC Amber

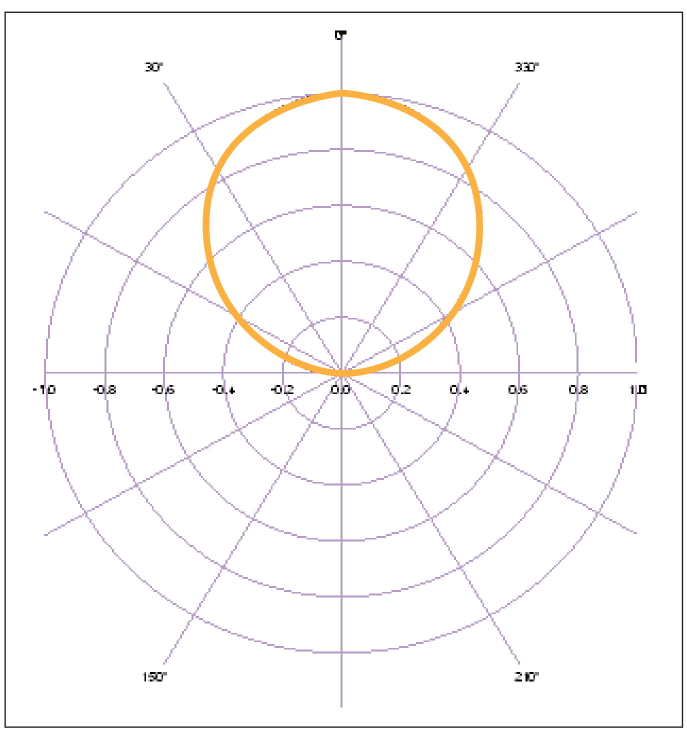


Figure 33. Typical polar radiation pattern, PC amber LXM2-PL01 emitters.

Typical Chromaticity Characteristics PC Amber

Typical Chromaticity Characteristics over Temperature

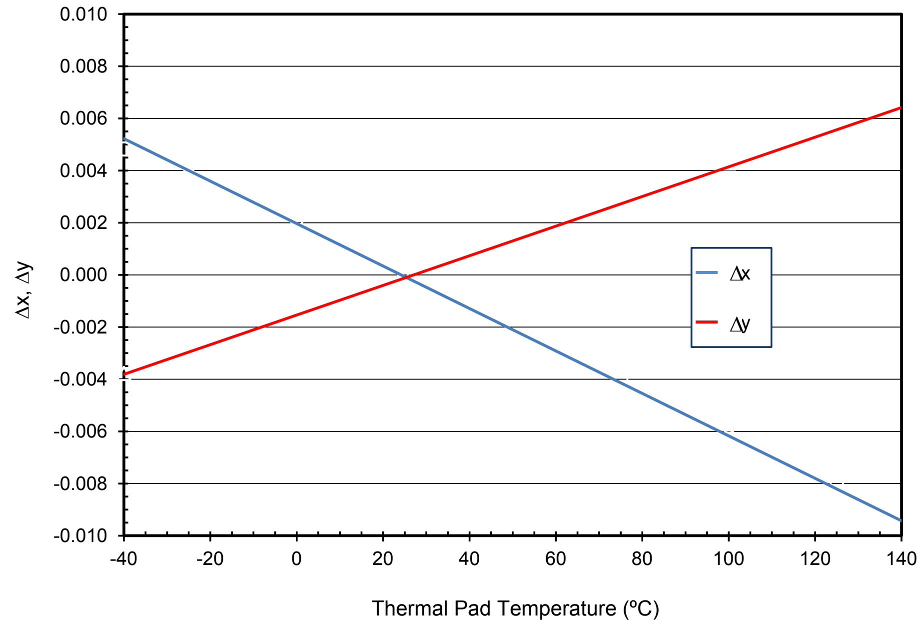


Figure 34. Chromaticity coordinate vs. thermal pad temperature. Test current: 350 mA.

Typical Chromaticity Characteristics over Forward Current Thermal Pad Temperature = 25 °C

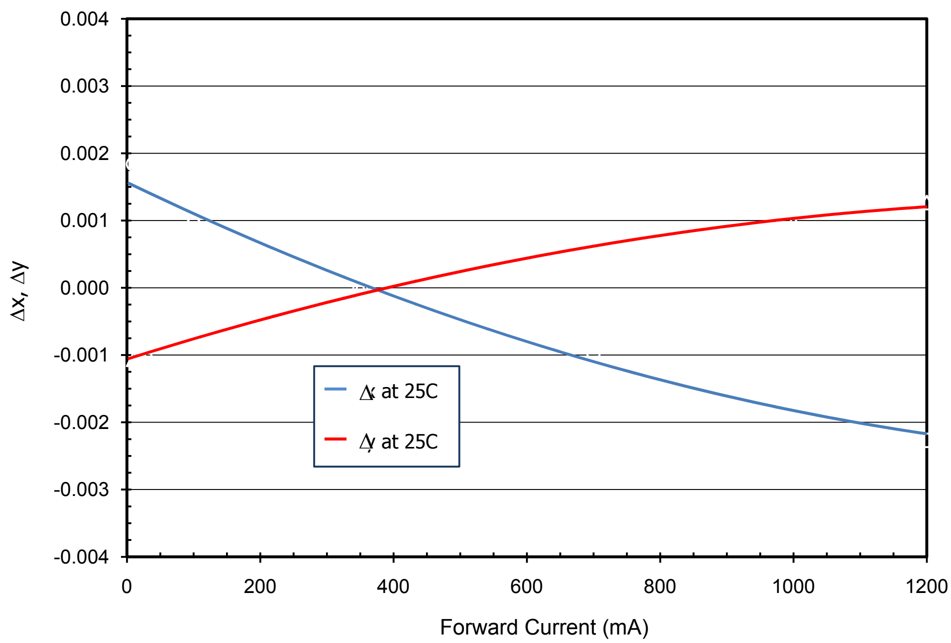


Figure 35. Chromaticity coordinate vs. forward current.

Emitter Pocket Tape Packaging

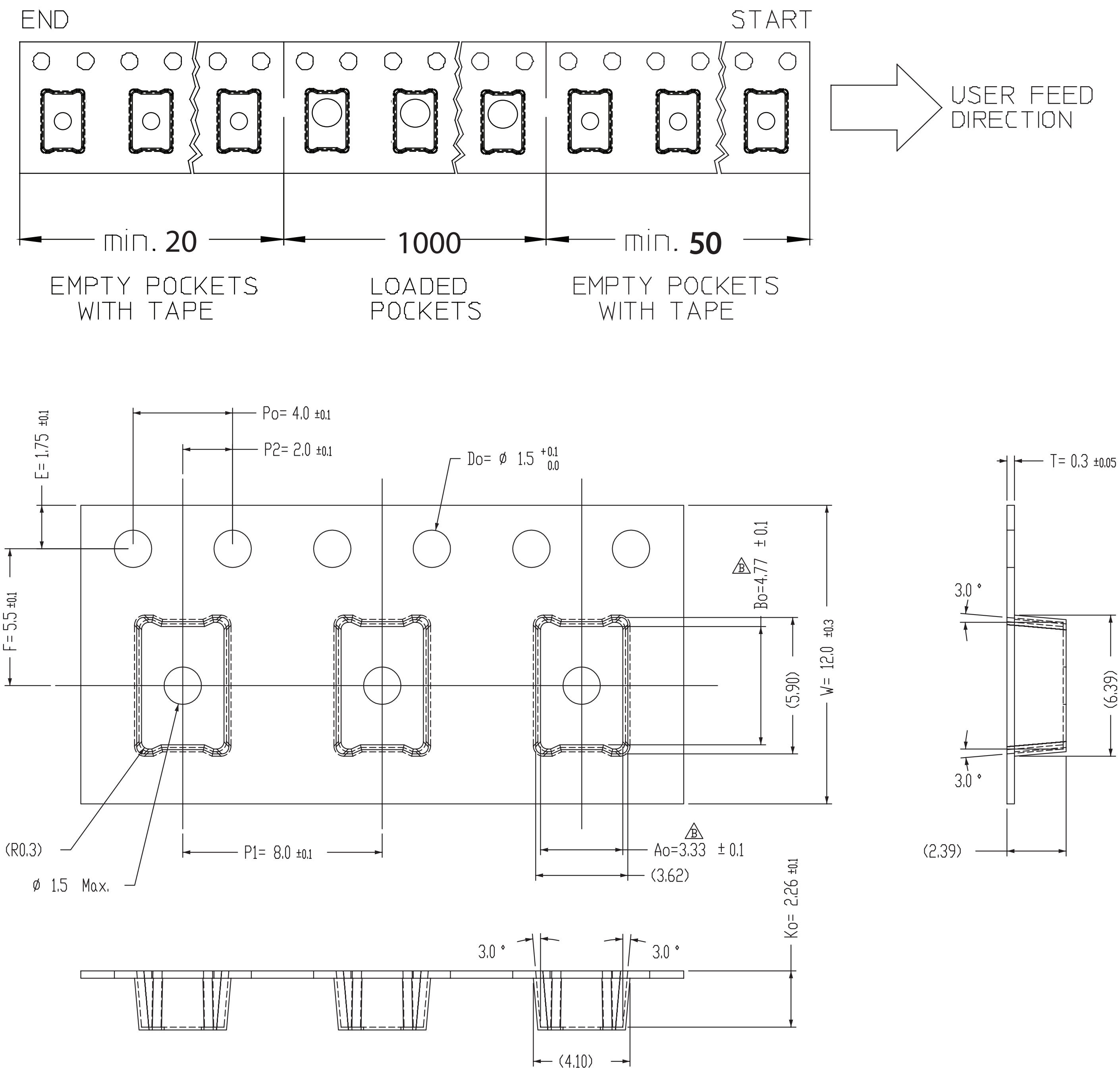


Figure 36. Emitter pocket tape packaging.

Emitter Reel Packaging

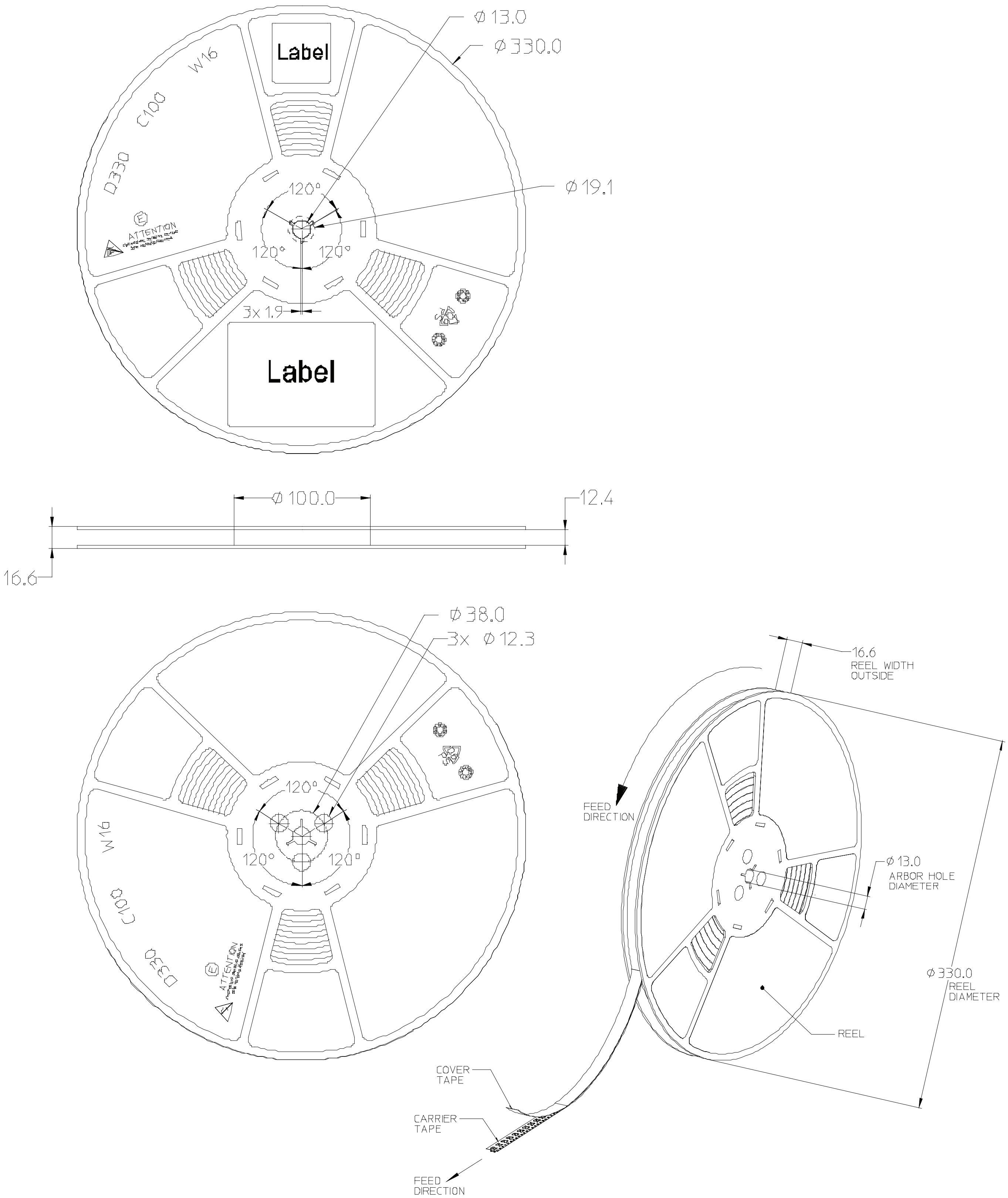


Figure 37. Emitter reel packaging.

Product Binning and Labeling

Purpose of Product Binning

In the manufacturing of semiconductor products, there is a variation of performance around the average values given in the technical data sheets. For this reason, Philips Lumileds bins the LED components for luminous flux, color and forward voltage (V_f).

Decoding Product Bin Labeling

LUXEON Rebel Color Portfolio emitters are labeled using a three or four digit alphanumeric code (CAT code) depicting the bin values for emitters packaged on a single reel. All emitters packaged within a reel are of the same 3-variable bin combination. Using these codes, it is possible to determine optimum mixing and matching of products for consistency in a given application.

Format of Labeling for Emitters

Reels of green, cyan, blue, royal blue, red, red-orange, amber and PC amber emitters are labeled with a three digit alphanumeric CAT code following the format below.

ABC

A = Flux bin (J, K, L, M etc.)
B = Color bin (2, 4, 6 etc.)
C = V_f bin (D, E, F, G etc.)

Luminous Flux Bins

Tables 8, 9 and 10 list the standard photometric luminous flux/radiometric power bins for LUXEON Rebel and LUXEON Rebel ES color emitters (tested and binned at 350 mA and 700 mA respectively). Although several bins are outlined, product availability in a particular bin varies by production run and by product performance. Not all bins are available in all colors.

Table 8.

Flux Bins All Colors (except Royal Blue and Deep Red)		
Bin Code	Minimum Flux (lm)	Maximum Flux (lm)
D	18.1	23.5
E	23.5	30
F	30	40
G	40	50
H	50	60
J	60	70
K	70	80
L	80	90
M	90	100
N	100	110
X	110	120

Table 9.

LUXEON Rebel Royal-Blue and LUXEON Rebel ES Royal Blue		
Bin Code	Minimum Radiometric Flux (mW)	Maximum Radiometric Flux (mW)
D	350	425
E	425	500
F	500	600
G	600	700
H	700	800
J	800	900
K	900	950
Y	950	1000
A	1000	1050
B	1050	1100
M	1100	1200

Table 10.

LUXEON Rebel Deep Red		
Bin Code	Minimum Radiometric Flux (mW)	Maximum Radiometric Flux (mW)
C	260	300
D	300	350
E	350	400

Forward Voltage Bins

The following forward voltage bins include the minimum and maximum V_f bin values for the emitter. Although several bins are outlined, product availability in a particular bin varies by production run and by product performance.

Table 11. Applicable for LXML-PXX1 and LXM2-PL01 (PC Amber) emitters.

V_f Bins		
Bin Code	Minimum Forward Voltage (V)	Maximum Forward Voltage (V)
A	2.31	2.55
B	2.55	2.79
C	2.79	3.03
D	3.03	3.27
E	3.27	3.51

Table 12. Applicable for LXML-PR02-XXXX (ES Royal Blue) and LXML-PB02-XXXX (ES Blue) emitters tested at 700 mA.

Bin Code	Minimum Forward Voltage (V)	Maximum Forward Voltage (V)
P	2.50	2.75
R	2.75	3.00
S	3.00	3.25
T	3.25	3.50

Table 13. Applicable for LXM2-PXX1 (Red and Red Orange) and LXM3-PD01 (Deep Red) emitters tested at 350 mA.

Bin Code	Minimum Forward Voltage (V)	Maximum Forward Voltage (V)
V	1.80	2.00
W	2.00	2.20
X	2.20	2.40
Y	2.40	2.60
Z	2.60	2.80

Color Bins

Green, cyan and blue LUXEON Rebel color emitters are tested and binned for dominant wavelength.

Dominant Wavelength Bin Structure for Green Emitters

Table 14.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
1	520	525
2	525	530
3	530	535
4	535	540

Dominant Wavelength Bin Structure for Cyan Emitters

Table 15.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
1	490	495
2	495	500
3	500	505
4	505	510

Dominant Wavelength Bin Structure for Blue and LUXEON Rebel ES Blue Emitters

Table 16.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
1	460	465
2	465	470
3	470	475
4	475	480

Royal blue LUXEON Rebel and LUXEON Rebel ES emitters are tested and binned for peak wavelength.

Peak Wavelength Bin Structure for Royal Blue and LUXEON Rebel ES Royal Blue Emitters

Table 17.

Bin Code	Minimum Peak Wavelength (nm)	Maximum Peak Wavelength (nm)
3	440	445
4	445	450
5	450	455
6	455	460

Red, red-orange and amber LUXEON Rebel color emitters are tested and binned for dominant wavelength.

Dominant Wavelength Bin Structure for Red Emitters

Table 18.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
4	620.0	630.0
5	630.0	645.0

Dominant Wavelength Bin Structure for Red-Orange Emitters

Table 19.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
2	610.0	620.0

Dominant Wavelength Bin Structure for Amber Emitters

Table 20.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
1	584.5	587.0
2	587.0	589.5
4	589.5	592.0
6	592.0	594.5

Peak Wavelength Bin Structure for Deep Red Emitters

Table 21.

Bin Code	Minimum Dominant Wavelength (nm)	Maximum Dominant Wavelength (nm)
6	650	660
7	660	670

Table 22.

PC Amber Bin Coordinates		
Bin Code	x	y
2	0.5622	0.4372
	0.5576	0.4326
	0.5775	0.4132
	0.5843	0.4151
4	0.5705	0.4111
	0.5775	0.4132
	0.5576	0.4326
	0.5499	0.4249

Note for Table 22:

- LUXEON Rebel PC amber emitters are tested and binned by x,y coordinates.

Color Bins PC Amber

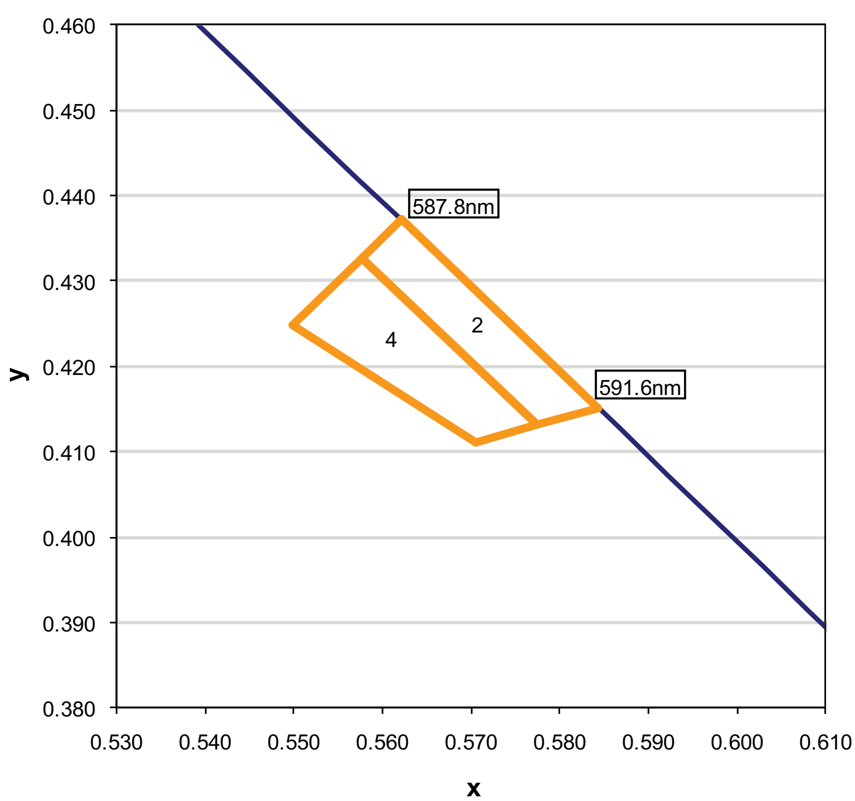


Figure 38. Color bin structure.

Company Information

Philips Lumileds is a leading provider of LEDs for everyday lighting applications. The company's records for light output, efficacy and thermal management are direct results of the ongoing commitment to advancing solid-state lighting technology and enabling lighting solutions that are more environmentally friendly, help reduce CO_2 emissions and reduce the need for power plant expansion. Philips Lumileds LUXEON® LEDs are enabling never before possible applications in outdoor lighting, shop lighting, home lighting, consumer electronics, and automotive lighting.

Philips Lumileds is a fully integrated supplier, producing core LED material in all three base colors, (Red, Green, Blue) and white. Philips Lumileds has R&D centers in San Jose, California and in the Netherlands, and production capabilities in San Jose, Singapore and Penang, Malaysia. Founded in 1999, Philips Lumileds is the high flux LED technology leader and is dedicated to bridging the gap between solid-state technology and the lighting world. More information about the company's LUXEON LED products and solid-state lighting technologies can be found at www.philipslumileds.com.

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Appendix 3b.

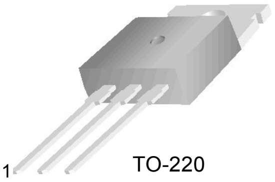
FAIRCHILD SEMICONDUCTOR®

October 2008

TIP120/TIP121/TIP122

NPN Epitaxial Darlington Transistor

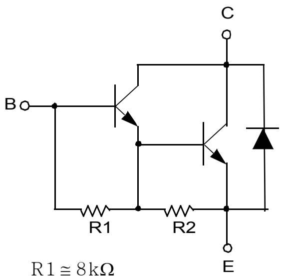
- Medium Power Linear Switching Applications
- Complementary to TIP125/126/127



1 TO-220

1.Base 2.Collector 3.Emitter

Equivalent Circuit



R1 ≅ 8kΩ
R2 ≅ 0.12kΩ

Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Ratings	Units
V_{CBO}	Collector-Base Voltage : TIP120 : TIP121 : TIP122	60 80 100	V V V
V_{CEO}	Collector-Emitter Voltage : TIP120 : TIP121 : TIP122	60 80 100	V V V
V_{EBO}	Emitter-Base Voltage	5	V
I_C	Collector Current (DC)	5	A
I_{CP}	Collector Current (Pulse)	8	A
I_B	Base Current (DC)	120	mA
P_C	Collector Dissipation (T_a=25°C)	2	W
	Collector Dissipation (T_C=25°C)	65	W
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	- 65 ~ 150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Electrical Characteristics* T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
V_{CEO}(sus)	Collector-Emitter Sustaining Voltage : TIP120 : TIP121 : TIP122	I_C = 100mA, I_B = 0	 60 80 100			 V V V
I_{CEO}	Collector Cut-off Current : TIP120 : TIP121 : TIP122	 V_{CE} = 30V, I_B = 0 V_{CE} = 40V, I_B = 0 V_{CE} = 50V, I_B = 0			 0.5 0.5 0.5	 mA mA mA
I_{CBO}	Collector Cut-off Current : TIP120 : TIP121 : TIP122	 V_{CB} = 60V, I_E = 0 V_{CB} = 80V, I_E = 0 V_{CB} = 100V, I_E = 0			 0.2 0.2 0.2	 mA mA mA
I_{EBO}	Emitter Cut-off Current	V_{BE} = 5V, I_C = 0			2	mA
h_{FE}	* DC Current Gain	V_{CE} = 3V,I_C = 0.5A V_{CE} = 3V, I_C = 3A	1000 1000			
V_{CE}(sat)	* Collector-Emitter Saturation Voltage	I_C = 3A, I_B = 12mA I_C = 5A, I_B = 20mA			2.0 4.0	V V
V_{BE}(on)	* Base-Emitter On Voltage	V_{CE} = 3V, I_C = 3A			2.5	V
C_{ob}	Output Capacitance	V_{CB} = 10V, I_E = 0, f = 0.1MHz			200	pF

* Pulse Test: Pulse Width≤300µs, Duty Cycle≤2%

Typical characteristics

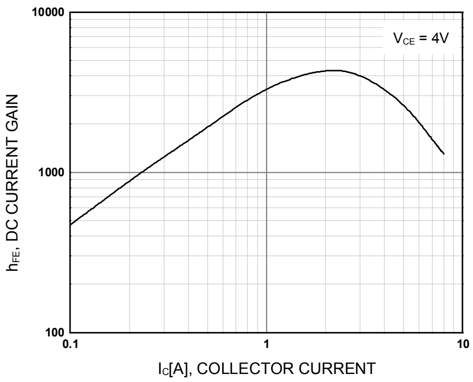


Figure 1. DC current Gain

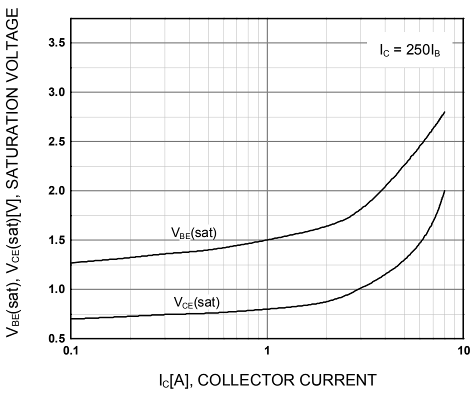


Figure 2. Base-Emitter Saturation Voltage
Collector-Emitter Saturation Voltage

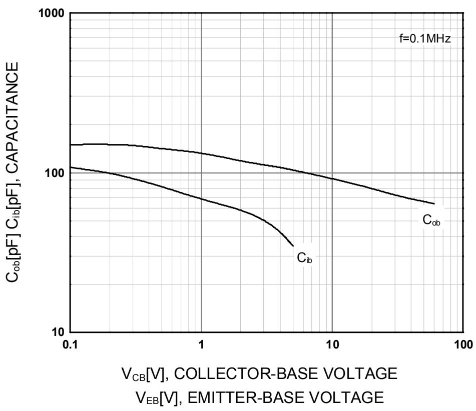


Figure 3. Output and Input Capacitance
vs. Reverse Voltage

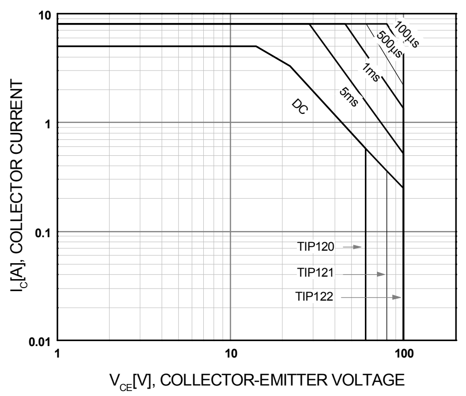


Figure 4. Safe Operating Area

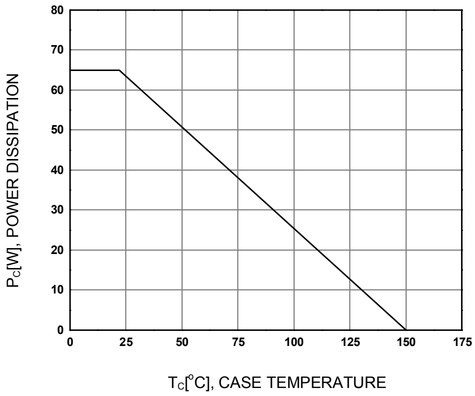
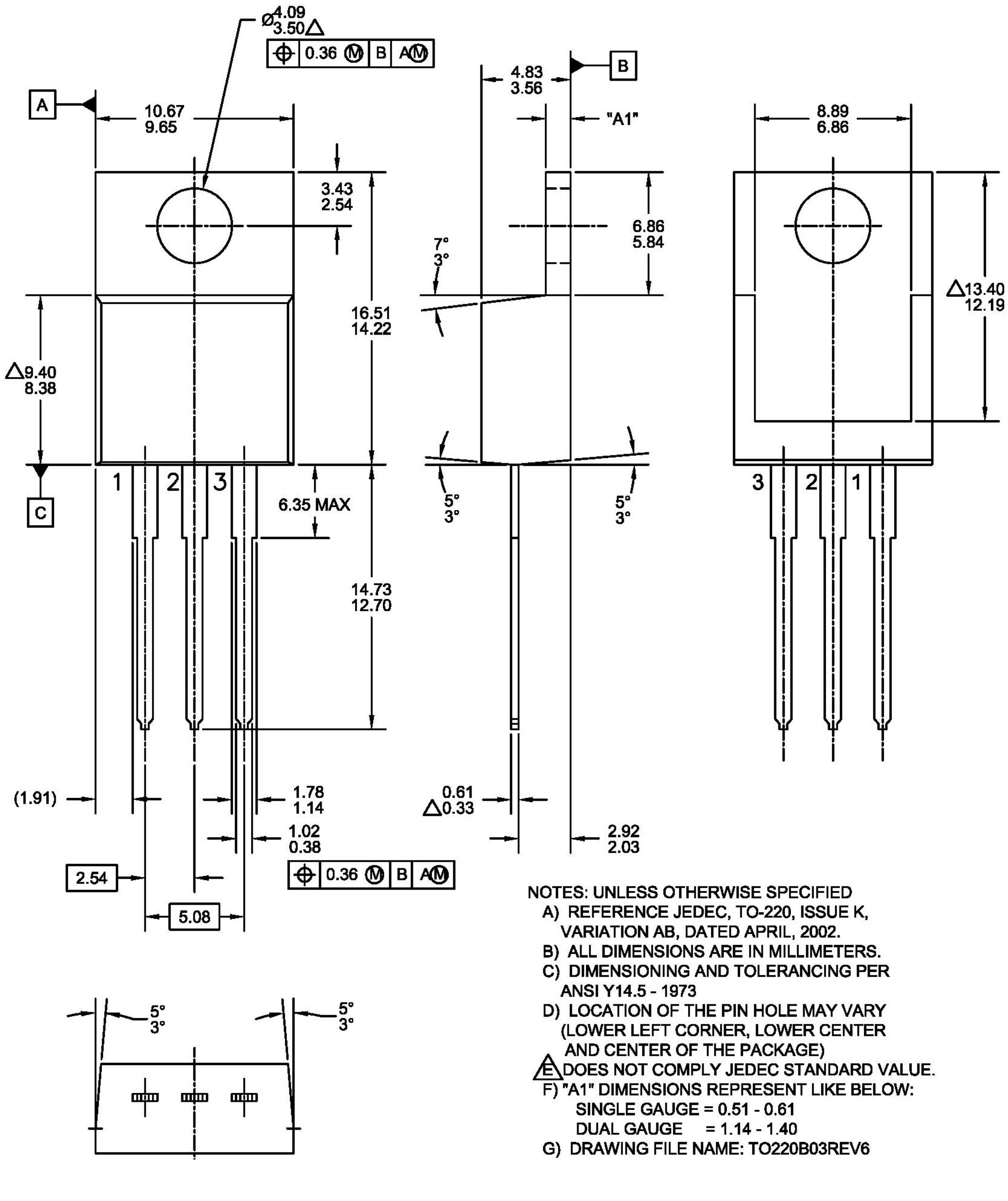


Figure 5. Power Derating

Mechanical Dimensions

TO220



NOTES: UNLESS OTHERWISE SPECIFIED

A) REFERENCE JEDEC, TO-220, ISSUE K, VARIATION AB, DATED APRIL, 2002.

B) ALL DIMENSIONS ARE IN MILLIMETERS.

C) DIMENSIONING AND TOLERANCING PER ANSI Y14.5 - 1973

D) LOCATION OF THE PIN HOLE MAY VARY (LOWER LEFT CORNER, LOWER CENTER AND CENTER OF THE PACKAGE)

E) DOES NOT COMPLY JEDEC STANDARD VALUE.

F) "A1" DIMENSIONS REPRESENT LIKE BELOW:
SINGLE GAUGE = 0.51 - 0.61
DUAL GAUGE = 1.14 - 1.40

G) DRAWING FILE NAME: TO220B03REV6

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GTO™
i-Lo™
IntelliMAX™
ISOPLANAR™
MegaBuck™
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MicroFET™
MicroPak™
MillerDrive™
Motion-SPM™
OPTOLOGIC®
OPTOPLANAR®
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PDP-SPM™
Power220®
Power247®
POWEREDGE®
Power-SPM™
PowerTrench®
Programmable Active Droop™
QFET®
QS™
QT Optoelectronics™
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SuperFET™
SuperSOT™-3
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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

PRODUCT STATUS DEFINITIONS

Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data; supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

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