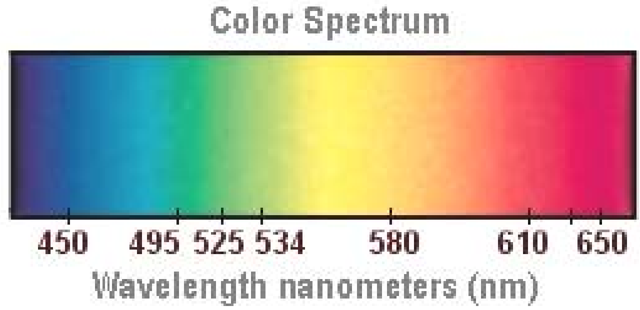
# Red and Green Light-Emitting-Diode Position Lights! **Rev. D 08Dec04**

**Eric M. Jones** 

It would be ideal to use LEDs for position lights. The argument is long and we won't make it here. I have e-mailed many builders with this subject on their minds and it is important to get this right.




Here's the situation--Now this is a bit difficult to figure since the FAA has chosen to use a lighting specification system so complicated that nobody reads it. The proof is that it has errors and typos that nobody fixes. How's this example?

> Sec. 23.1395 No position light intensity may exceed the applicable values in the following equal or exceed the applicable values in §23.1389(b)(3):

Surely nobody reads this stuff! But take heart; it all has a well-thought-out purpose. Let's take a few industrial strength No-Dozes, a triple espresso and try to do our best.

See FAR Sec. 23.1397 Color Specifications (same as MIL-C-25050A Aviation Colors).

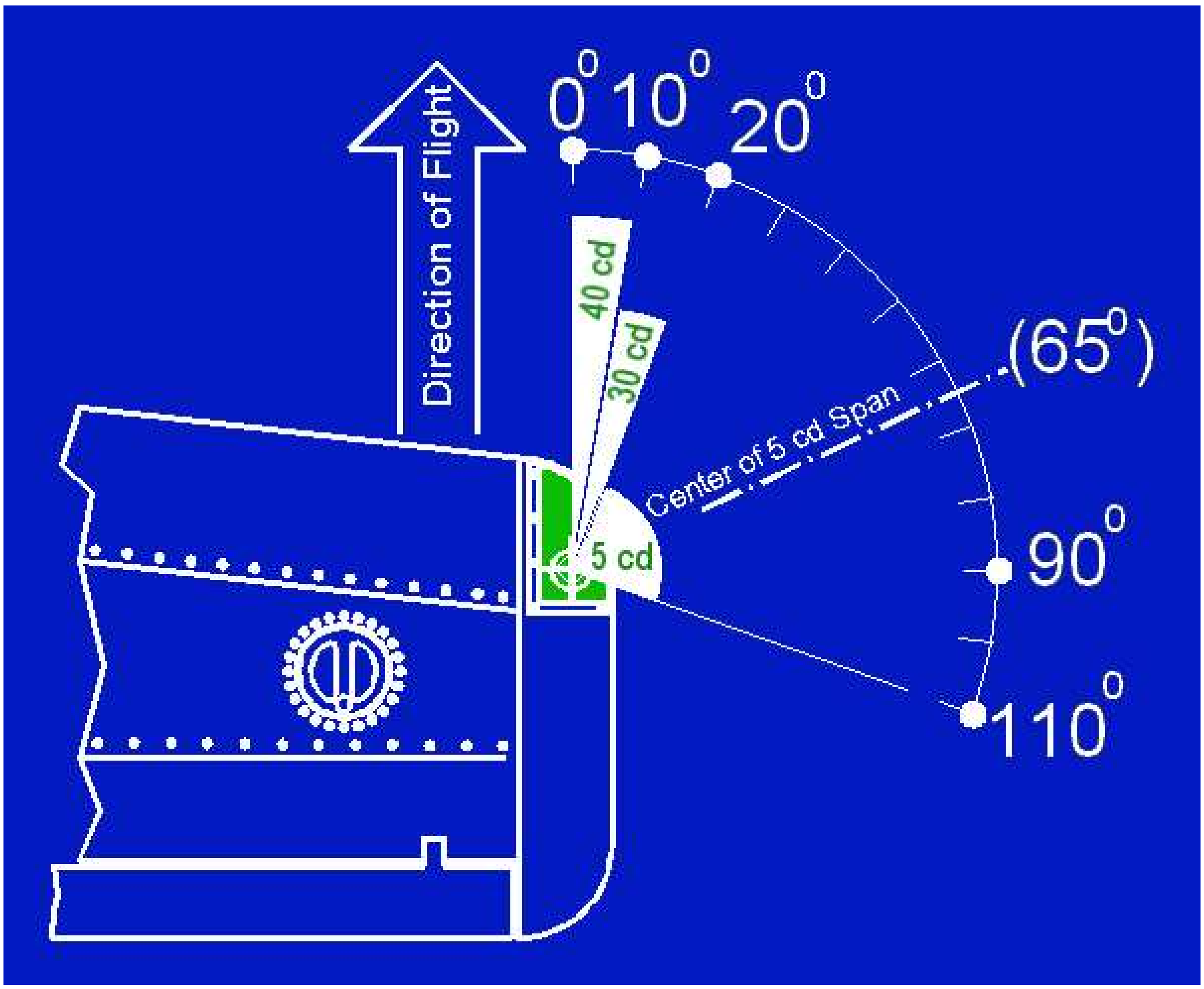
First a couple words about the colors: Until recently all aviation colors were generated by tungsten-filament lamps behind colored glass filters, so some warmth prevails in the choice of color, but you could get almost any color you wanted. Unfortunately LEDs emit just wherever in the spectrum their strange crystalline cookie recipes demand--and no place else. So you can't get every color you might need.

**Aviation Red** is orange-red to deep red, and for LEDs the CIE numbers equate to 610 nm and longer wavelengths. Although it is legal to make the red 650-680 nm or so, lot's of people are almost blind to 650 nm and above (including this writer). Scotopic (dark adapted) Luminous Efficacy (how well you can see it) at 610 nm is 23X what it is at 650 nm--for people who aren't red-green colorblind! Unfortunately 640 nm and 660 nm LEDs are real boomers so it's a toss up.

**Aviation Green** is 495-534 nm. LED "true green" is 525 nm and they are very efficient and a good choice.  But be careful, advertising gimmickry is everywhere. There are "greens" at 555 nm, and "greens" at 565 nm, but are not FAA legal. As of this writing there is ONE single FAA-legal green led color—525 nm. What gives? Well, green leds are simply not as evolved as red leds. The selection is poor and the prices are higher. You can get the right ones but they are very expensive—at least 5X as much as similarly constructed red LEDs.

**Aviation White** is not really on any spectrum. Aviation white is based on the allowable colors provided by tungsten filament lamps that approach what are called blackbody radiators (so we refer to them in Kelvin temperatures like very hot little iron stoves). The FAA allows white from very orange 1800K to 5000K but oddly, no higher! By the rules, xenon-white and some HIDs cannot legally be used as a tail-light color, but may be used as a landing light. The ICAO and SAE are much more generous with the white specs. This writer believes that the FAA is due to revise this to reflect the reality of new light sources, and it will probably accept the ICAO colors as their own.

The FAA wants the red-green position lights to make the aircraft visible when it is approaching head-on or off the wing of other aircraft. Let's take an imaginary journey around your aircraft at night with the position lights on---




Standing in front of your aircraft, the FAA specifies that the position lights must emit 40 candelas horizontally (with respect to the flight path!) pointing directly forward (0°) parallel to the flight path, to a 10° swing away from the aircraft. This is a good time for a pause.

> **(Here's the physics class on photometry you probably skipped: Just as you can use a voltmeter to measure current, you can use a lux meter that measures illuminance in lux (power per unit area) to measure candelas. This measurement must be done at one meter distance from the position light. A piece of string taped to the underside of the lamp will help keep this distance honest. A means of measuring the angle would be nice but**

**you can eyeball most of it. And it should be dark. One candela causes an illuminance of one lux at a distance of 1 meter. So if you have your lux meter pointed at the position light and it reads 40 lux when it is one meter away, it means that the position light is shining 40 candelas [power per unit solid angle] in your direction. Get it? There'll be a test next Tuesday; you have all weekend to study. Lux meters are available on eBay, many old photographic meters have a lux scale, and if you are hard-up you can use a foot-candle meter and convert it to lux. Remember, 1 footcandle = 10.76 lux. For extra credit explain why*).**

Now back to our imaginary trip around the position light--The FAA wants a variety of conditions met. They want 40 candelas from straight ahead to 10° outboard. From 10° to 20° they allow a fall-off to 30 candelas. This makes the aircraft easy to see when it is approaching. Since another airplane is less likely to collide with the side of your airplane, only 5 candelas are required from 20° off the nose to 20° behind the wing (actually 110° away from the flight path). Only 5 candelas are required but a 90° sweep is illuminated so the power is still significant. At 20° behind the wing, the white taillight becomes visible and takes over the job.)

So what did the FAA have in mind? Well, they obviously were measuring a bare tungsten lamp with a reflector behind it, but with LEDs you need different sets of LEDs to do the job cost effectively.

So let’s design this thing--There are some things we need to state -Uh-Oh-!

1) We use only clear or transparent-color (no diffused or frosted) LEDs. Diffused LEDs can have a very wide angle but only at the expense of their peak intensity. It could be done, but is much harder.
2) In every case we err on the side of brighter and broader than the FAA specifies. The FAA usually specifies MINIMUM light intensities. LED makers like to specify MAXIMUMS, so be conservative.
3) Lighting design is difficult. It seems easy to just throw in a very bright LED and think the job is done. Not so fast! If you use a bright laser for a position light, your airplane will be invisible no matter how bright the laser is, unless it points directly at someone’s pupil, and even then they won’t be able to gauge the distance to your airplane.
4) This is a safety issue. If your best friend uses some cheapo LEDs—remember *his aircraft’s visibility is a big problem* <u>*for you*</u>. Lot’s of people will die because someone neglects to say, “This is wrong bubela!”
5) The standard legal stuff--This device is not FAA approved and you cannot put it in a certificated aircraft. This paper and the information contained herein are copyrighted and may only be used for personal use and at the user’s risk.

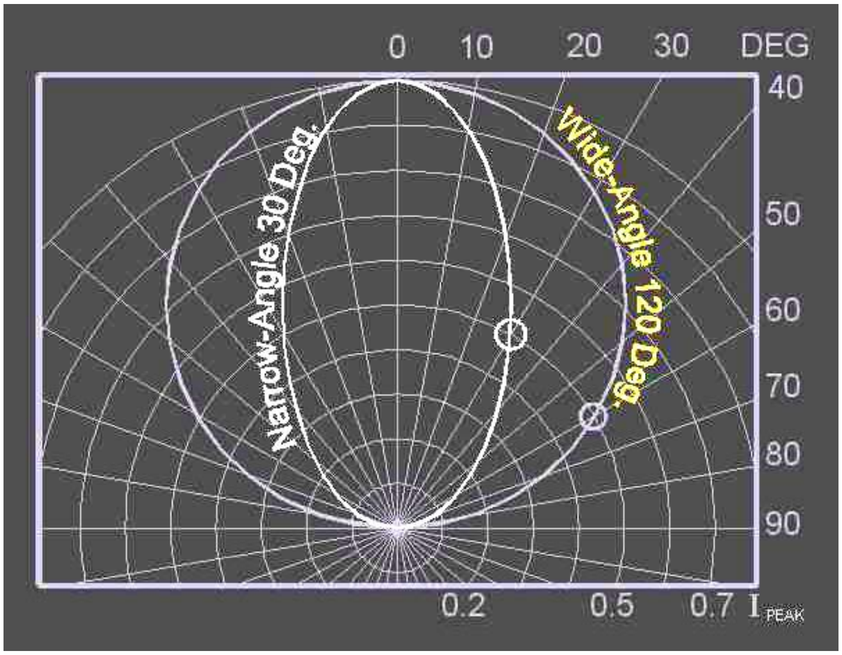
The first set of LEDs provides the forward lighting. They must project 40 candelas (40000 millicandelas) over at least 10° and we might as well make those 30° for reasons we will see. We can get 6 red Indium Gallium Aluminum Phosphide (InGaAlP),10000 (minimum!) millicandelas with a 630 nm wavelength for short money. That would do. They have to be pointed 10° horizontally out from straight ahead and slightly (and precisely) splayed as described later.

Now the green LEDs. Uh-Oh…! Well, there are not many green LEDs but there are some green monster 10000 (minimum) millicandelas at 525 nm. There are so many narrow green LEDs going into traffic signals that getting the 30° coverage ones is difficult.

The second set provides the side lighting. And it is a bit easier; we need to project at least 5 candelas over at least 90°. Imagine we have 40 surface mount leds in a 4 X 10 grid. For the thing to exhibit 5 candelas over a 90° solid angle we need 5000 millicandelas (mcd) divided by 40 LEDs = 125 mcd each. For red we can get 120°, 200 mcd surface mount parts. Sweet...

Are we done? This is the FAA remember? It turns out that the FAA wants your aircraft to be seen at other angles than head-on and to the side. They also want your aircraft to be visible from below and above and other "dihedral angles".

**(Back to class for more terminology—Filament lamps usually put out the same amount of light in almost all directions, called "isotropic" which is Latin for "*the same in all directions*" and the FAA designed the position-light standard for this characteristic plus a reflector for the forward lighting. LEDs have to be made to do this type of distribution. How the light is distributed around the light source is called the "spatial distribution" a phrase that real optical physicists throw around a lot, so be sure to use it when the FAA asks.)**



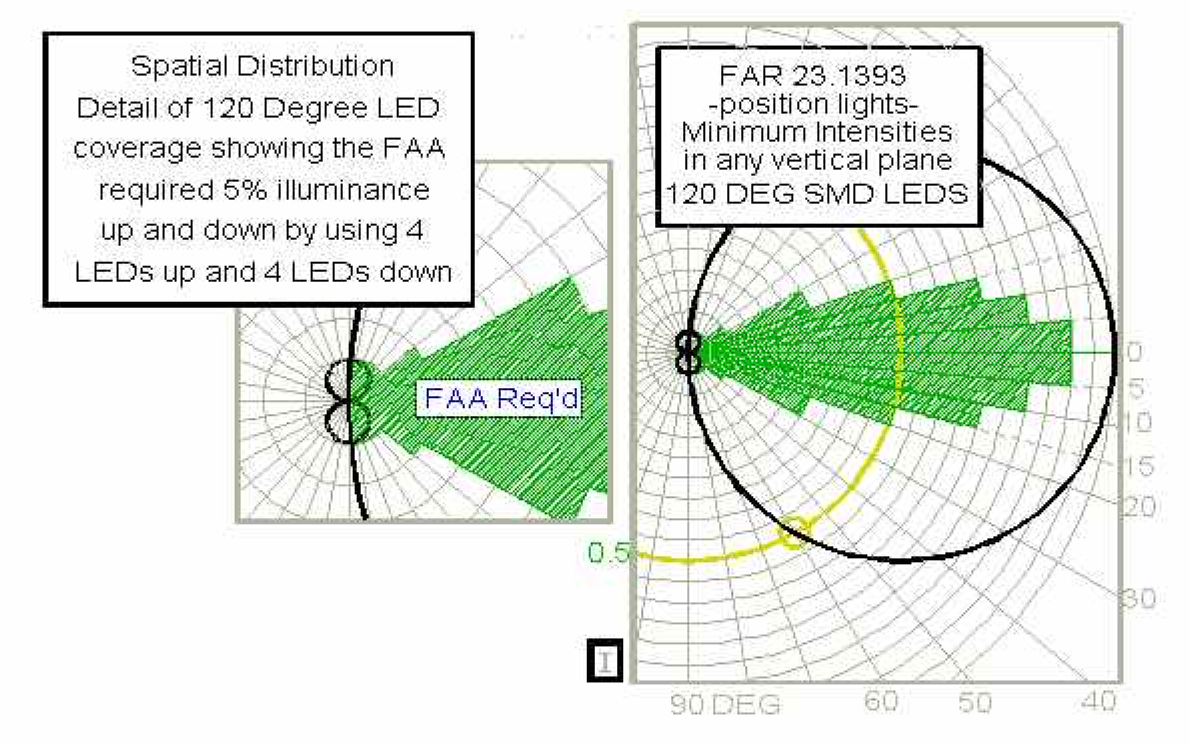

**But let's look at a diagram of one narrow and one wide LED. The LED is at the center of the chart pointed toward the top of the page. The radial distance indicates how bright it is AT THAT ANGLE. The small circles indicate where the LED is 50% as bright as it's maximum $I_{peak}$. This is important because this is how the LEDs "viewing angle" is defined (that is—the LED spread angle is where the beam brightness is 50% of maximum). The numbers on the bottom are just to indicate which circle indicates what. The 0.5 distance circle is 50%.**

**Now-- there is a problem if a specification requires a certain illuminance over a certain angle because the light is only 50% brightness at the margins of its beam by definition. So be careful.**

**For our purposes I have calculated all the photometric stuff using 20 mA LEDs but you can do this with any leds of the proper color and angle.**

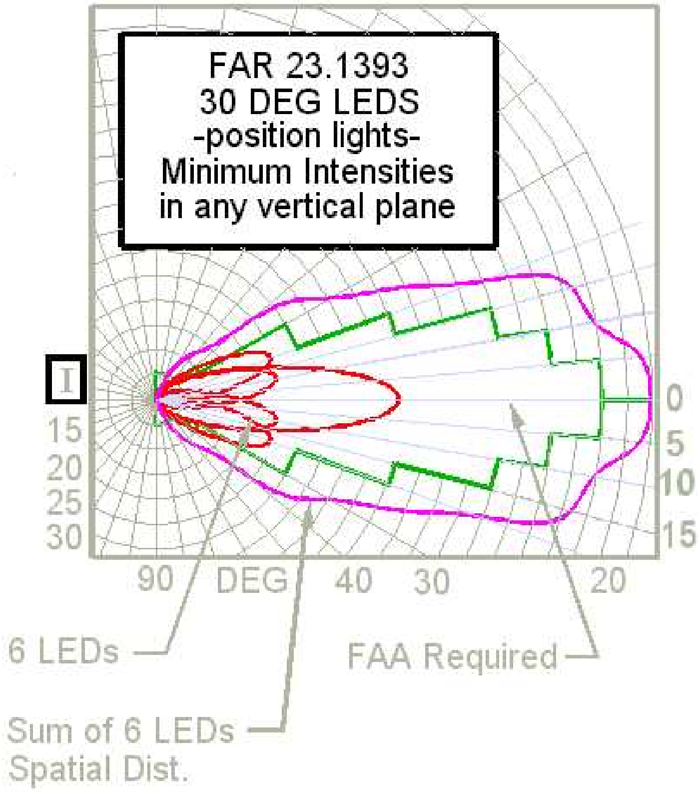
So the FAA wants a minimum of 5% of the peak illuminance (that the FAA confusingly calls "**I**" in one place and "**L**" in another-- but worse yet this is the "minimum peak" so to speak.) to show straight down and straight up with FAA-defined progressively greater amounts of light as the angle approaches the horizontal, where we started this thing. Notice also that the FAA requires 100% of $I_{peak}$ horizontally *but* only 80% from 0° to 5°. This is a logical problem, but we'll comply with the harder interpretation. This is not too hard, but we have to add a few more LEDs and bend some others—

That pesky 5% of $\mathbf{I}_{peak}$ must be directed up and down. You might believe that we can ignore a mere tiny little 5%, but since the eye has a dynamic ratio of a billion-to-one, 5% is a whole dump truck full of visibility. It's very easy to notice and must be complied with!



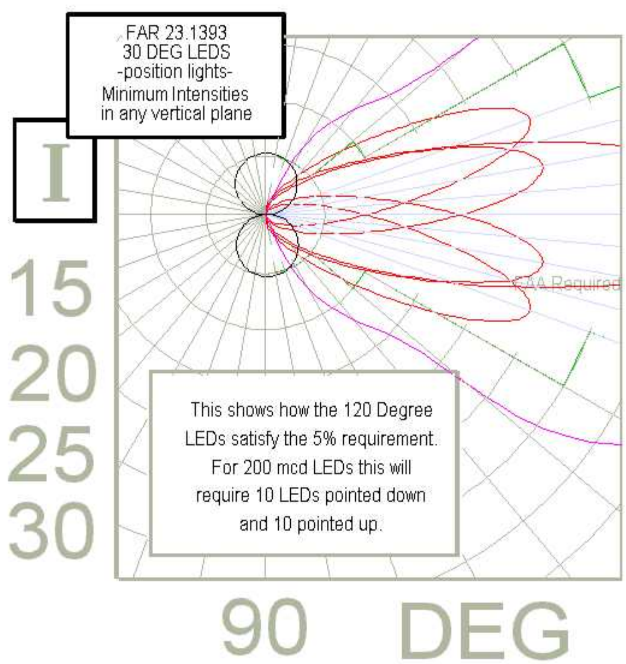

For the 120° side lighting all that's necessary is to have 4 LEDs facing downward and 4 facing upward. *BUT* we don't need them at all as you will see later. Life is easy!

For the front beams, $\mathbf{I}_{peak}$ is 40000 millicandelas. And 5% of that is 2000 millicandelas up and 2000 millicandelas down. We can do that with 120° right-angle LEDs. For 120° 630 nm red there are plenty of choices, but here we go again…for 120° 525 nm green the pickings are very slim. For 200 millicandelas (minimum) we need 10 LEDs. For each direction--but we can include the LEDs we specified previously, so 10 each way is enough.




Here is a graph of the FAA requirement for vertical plane minimum intensity, showing how it is achieved with 6, 30°, 10000 mcd LEDs splayed 2 at 0°, 2 at + and – 10°, and 2 at + and – 20°.

And here is the final graph of how the pesky 5% is covered with the 10-up and 10-down LEDs:



So are we done with the FAA? Not quite….

Let's review the FAA Regulations on Aircraft lighting—
23.1381 Instrument lights. You need them, but not applicable here.
23.1383 Taxi and landing lights. You need them, but not applicable here
23.1385 Position light system installation. DONE
23.1387 Position light system dihedral angles. DONE.
23.1389 Position light distribution and intensities. DONE.
23.1391 Minimum intensities in the horiz. plane of position lights. DONE.
23.1393 Minimum intensities in any vertical plane of position lights. DONE
23.1395 Maximum intensities in overlapping beams of position lights. This is important but it is a function of the aircraft shape and light-housing construction, etc. Basically the FAA does not want the various position lights to visually interfere with one another. Specific limits are called out. The builder should review this.
23.1397 Color specifications. DONE.
23.1399 Riding light -- For Floatplanes. Easy to do with a few LEDs
23.1401 Anticollision light system— Hey--We could make an Anticollision lighting system with LEDs!

Regards,
Eric M. Jones

- *—Because one square-meter equals 10.76 square-feet. Easy, huh?

Revision Notes: Previously I offered the PCBs and the mounting bracket. Now I offer the whole set of red and green and white tail light complete and assembled. Please see my website.