ZTF flat field screen: reference design

Dan Reiley

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**Background**

 We recently met to discuss the flat field screen and to generate a requirements document. Eric did a fine job of refining Roger’s placeholder document; however, when I began to add my own edits, it seemed that some of the values that belong in such a specification would be meaningless without a proof of principle.

**Broad goals of a flat field screen**

 A flat field screen must illuminate the telescope entrance pupil uniformly in space, angle, and wavelength, without allowing stray light onto the sensors. Project constraints force the screen to be easily designed, inexpensively built, and reasonably adjustable. Operational constraints force the screen to be easily installed, unobtrusive, and stable.

 ZTF spatial constraints will force the screen to be about 1.5m in diameter, about 1m from the end of the telescope. Mechanical modeling is necessary to refine these values.

**LEDs - spectral uniformity**

 An ideal illumination source would be spectrally flat across the bulk of the ZTF filters, but have no power near the edge of the ZTF filters. Figure 1 shows the measured transmission of the ZTF filters, plus the notional transmission of the I-band filter, as defined in Rich’s DIQ budget. (I’m not aware of any quantitative discussion of the bandpass of the I-band filter). The measured quantum efficiency of nine of the ZTF CCDs is also shown.



*Figure 1: Measured transmission bands for ZTF’s G-filter and R filter, plus a notional bandpass for a possible I-band filter. The measured CCD Quantum efficiency is shown for reference.*

 Selecting LEDs to match these transmission bands requires several additional goals. First, the LEDs must be commercially available; many catalogs and websites list LEDs that are obsolete and not procurable in the small quantities we’ll need. Second, the LEDs must have a reasonably smooth spatial distribution; the importance of this is nicely described in “Primary Optics for LEDs,” IODC 2010. Many LED package types have angular distribution that is entirely incompatible with the need for a spatially uniform screen. Third, the LEDs should have a fairly wide angular distribution so they can provide some spatial uniformity over a screen with a diameter that’s larger than the distance to the screen. Finally, all of the colors should have similar spatial distribution, minimizing the need for optics that are external to the LEDs.

 I spent some time looking into LEDs that meet these needs. Table 1 shows my results. Note that all LEDs have a “viewing angle” of about 125 deg. Also note that the visible LEDs are from the manufacturer; they are also have identical packaging, which would simplify the design and fabrication of the circuit board. Also note that the colored LEDs should be specified with a wavelength bin to narrow the variation in the delivered spectrum.

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| --- | --- | --- | --- | --- |
| Description | Manufacturer | part # | notes | viewing angle |
| Deep blue | Lumileds | LXML-PR01-0500 | WL bin 4 | 125 |
| Blue | Lumileds | LXML-PB01-0040 | WL bin 3 | 125 |
| Amber | Lumileds | LXML-PL01-0050 | WL bin 2 | 125 |
| Cyan | Lumileds |  LXML-PE01-0070 | WL bin 4 | 125 |
| Red-Orange | Lumileds | LXM2-PH01-0070 | WL bin 2 | 125 |
| Red | Lumileds | LXM2-PD01-0040 | WL bin 4 | 125 |
| Deep red | Lumileds | LXM3-PD01 | WL bin 7 | 125 |
| IR1 | Vishay | VSMG2700-GS08 |  | 120 |
| IR3 | Vishay | VSMF4720-GS08  |  | 120 |

*Table 1: A candidate set of LEDs that seems reasonable for the ZTF flat field system*

 Figure 2 adds the spectra of these LEDs to the plots in Figure 1. The spectral coverage in the G band looks as good as we could expect from LEDs. The spectral coverage in the R-band shows a little lumpiness within the covered region, as well as a gap in coverage at the long end. I belivee that both of these shortcomings are fundamental to the material properties of LED chips. Wider and spectra are available, but these wide spectra encroach on the band edges. The spectral coverage in the I-band misses the short end of the spectrum; LEDs that have these wavelengths encroach on the band edges.



*Figure 2: Measured transmission bands for ZTF’s filters, with nominal LED spectra.*

 If we wanted to capture this performance in a requirement for the flat field screen, I suggest defining the requirement as an overlap integral.

**LEDs - Spatial uniformity**

 I used Zemax to investigate the possible spatial uniformity that LEDs can provide.

 The first step is to ensure that the Zemax model of each LED is appropriate. I assumed the LED would have a 2-SMD package, which matches the packages of the LEDs listed in Table 1. One manufacturer, Osram, shares measured data in a way that Zemax can import directly. Figure 3 shows how this imported data matches the device specifications and the Zemax model I used. Several characteristics of the curves are worth noting:

- The measured data shows oscillations at small angles that aren’t evident in any LED I’ve even seen. I suspect measurement error

- The plots from the datasheet show a slight asymmetry in angular space; this isn’t modeled.

- The simplified model, a Zemax “Source Ellipse” with a Cosine exponent=1, shows more light at large angles than the datasheet, but less than the measurements.

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| --- | --- |
| a)  | *Figure 3: Angular distribution for an OSRAM LED in a 2-SMD package. Figure 3 a shows measured data, captured in Zemax. Figure 3 shows the same plots from the LED’s datasheet. Figure 3 c shows the same plot for the simplified model I used in the simulations.* |
| b)  |
| c)  |

 The next step is to put this Zemax LED model into a Zemax model that can give guidance on the number and pointing of LEDs necessary to get excellent uniformity. Eric’s literature search suggests 10%. Figure 4 shows the model at its simplest: one LED pointing straight down; Figure 4 also shows the resultant irradiance pattern, which, unsurprisingly, has terrible uniformity.

|  |  |
| --- | --- |
| a | b |
| *Figure 4: Zemax plots of the simplest model: a single LED with a rectangular screen. Figure 4 a shows the schematic; Figure 4 b shows the irradiance pattern.* |

 Figure 5 shows how uniformity of the illumination can be improved by adding more LEDs. For ach plot, the pointing of the LEDs was adjusted to improve uniformity. Unsurprisingly, for small numbers of LEDs, uniformity is optimized by pointing the LEDs towards the center of the circle. For more than four LEDs, the uniformity is optimized by pointing the LEDs away from each other; this result seems like an artifact of the model’s simplifications. Six LEDs are sufficient to reach the desired uniformity, but more LEDs do better. I suggest using far more LEDs, a number that should be determined by ease of mounting and driving, not by the minimum uniformity requirements.

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| --- | --- |
| a | *Figure 5: Illumination uniformity for a) two, b) three, c) four, and d) six LEDs. Six LEDs meet the requirement of 10% uniformity, if the LEDs are pointed 10 deg towards the center. More LEDs do better.* |
| b |
| c |
| d |

 If we wanted to capture this knowledge into a requirement for the flat screen, I suggest leaving the 10% requirement that Eric found in the literature.

**Screen material**

 The diffuse material of choice is Barium Sulfate (BaSO4) because its reflectance is spectrally flat across our wavelength range. The brand-name standard for diffuse materials is Spetralon; it’s BaSO4 suspended in PTFE. I suggest that we \*not\* try to use Spectralon or other brand names of BaSO4  in PTFE. The material has been shown to have instabilities of about 1-2% around room temperature. (Appl. Opt. 52:20 pp. 4806-4812) These instabilities are thought to be the result of known phase transitions in PTFE near room temperature.

 I suggest that we use BaSO4 suspended in paint. (It’s a common paint pigment) We shouldn’t use some random paint, though; other materials might disrupt BaSO4‘s beautiful scattering spectrum. Instead, we should use BaSO4 in a paint from a manufacturer that controls the paint’s optical properties. Brand name BaSO4 paints include:

- Spectraflect from Labsphere

- Permaflect from Labsphere (slightly lower reflectivity, but better adhesion)

- White Reflectance Coating from Sphere Optics

- Barium Sulphate Coating from Pro-Lite

- OPRC from OptoPolymer

 If we wanted to capture this knowledge into a requirement for the flat screen, I suggest calling out the spectral reflectance of BaSO4, plus some requirements on durability and stability.