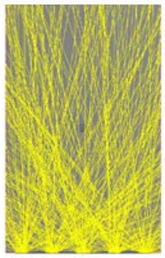
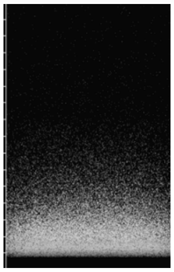
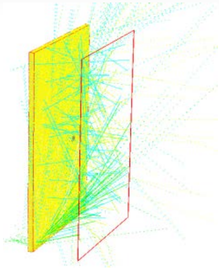





Application Note: Mobile Displays

Introduction

Mobile devices such as smartphones, e-readers, and watches are becoming ubiquitous in today's world. Precise optical engineering is required to optimize the performance of mobile features such as the camera system, sensors, and the display.

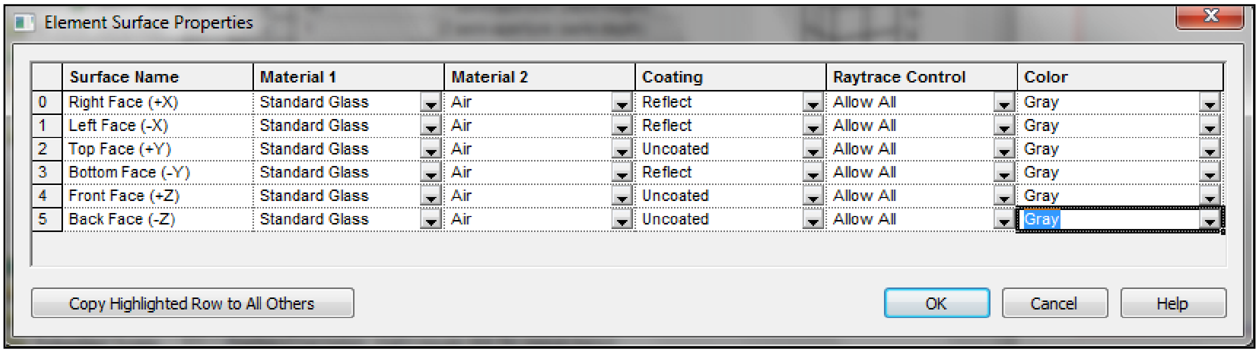
A key design objective for a mobile display is uniform illumination over its area and range of viewing angles. In addition, it should have high optical efficiency to reduce power consumption and increase battery life. Edge-lit LED screens accomplish this by using compact and efficient LED lights coupled into a transparent waveguide. Elements such as reflective back surfaces, microstructure patterns, brightness-enhancing films, and diffusers can be incorporated into the display to increase efficiency and uniformity. In this FRED model, an edge-lit LED smartphone display is virtually prototyped. Uniform illumination is achieved by incorporating a gradient diffuser along the waveguide.

Edge-Lit LED Screen with Diffuser

Setting up the model:

Waveguide

The first component in the system is a rectangular waveguide. Create a block with dimensions [25 x 40 x 1 mm] semi-width, semi-height, and semi-depth. Choose the following properties for the block:



Element Surface Properties

	Surface Name	Material 1	Material 2	Coating	Raytrace Control	Color
0	Right Face (+X)	Standard Glass	Air	Reflect	Allow All	Gray
1	Left Face (-X)	Standard Glass	Air	Reflect	Allow All	Gray
2	Top Face (+Y)	Standard Glass	Air	Uncoated	Allow All	Gray
3	Bottom Face (-Y)	Standard Glass	Air	Reflect	Allow All	Gray
4	Front Face (+Z)	Standard Glass	Air	Uncoated	Allow All	Gray
5	Back Face (-Z)	Standard Glass	Air	Uncoated	Allow All	Gray

Copy Highlighted Row to All Others | OK | Cancel | Help

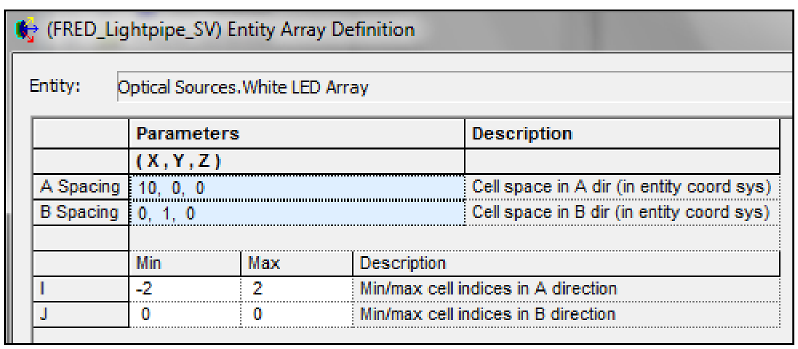
Figure 1. Waveguide block material, coating, and raytrace control properties.

LED Array

Create a New Detailed Optical Source. The LED array will be embedded within the edge of the waveguide to maximize optical efficiency: Under the Source tab, pick *Standard Glass* as the Immersion Material. Under the Location/Orientation tab, place the LED just inside of the Top Face of the block.

The LED will be modeled as a small rectangular Lambertian emitter. Navigate to the Positions/Directions tab. Select *Ray Positions→Random Plane*. Choose dimensions of [1.8 x 0.7 mm] x-semi-aperture and y-semi-aperture. Select *Ray Directions→Random Directions into an angular range* with 90 degree semi-angle spread in x and y directions. Be sure to also specify a Lambertian angular distribution type.

Finally, create an array of identical LEDs along the top face of the waveguide by right-clicking the completed LED source and selecting "Edit/View Array Parameters..." Chose "A spacing" of 10 mm and index I ranging from -2 to 2. The array now consists of 5 identical side-by-side LEDs.



(FRED_Lightpipe_SV) Entity Array Definition

Entity: Optical Sources.White LED Array

	Parameters	Description
	(X , Y , Z)	
A Spacing	10, 0, 0	Cell space in A dir (in entity coord sys)
B Spacing	0, 1, 0	Cell space in B dir (in entity coord sys)

	Min	Max	Description
I	-2	2	Min/max cell indices in A direction
J	0	0	Min/max cell indices in B direction

Figure 2. LED array settings.

Reflectors

A back-reflector will increase optical efficiency of the display by recycling light that would have exited its backside. Model the back-reflector by creating a [25 x 39 mm] semi-width and semi-height reflective surface. Place it just behind the back face of the waveguide and translate it 1 mm vertically (away from LED array). Model a small front-reflector just in front of the embedded LEDs: Create a [25 x 1 mm] semi-width and semi-height reflective surface and place it just in front of the front face of the waveguide on the LED end. The front-reflector and truncated back-reflector also reduce excess light that refracts directly out of the bottom of the display, increasing uniformity.

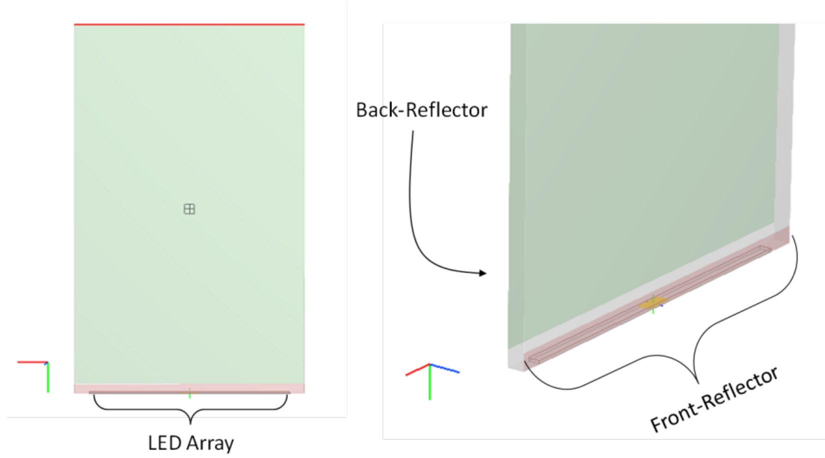


Figure 3. Display geometry, including LED array (central LED shown in yellow), front-reflector (red), and back-reflector (green).

Diffuser with Scripted Scatter

Without a diffuser, light will either refract out of the waveguide or get guided to the end via total internal reflection. The purpose of the diffuser is to gradually scatter trapped light out of the waveguide for uniform illumination. To counteract an exponentially decreasing irradiance gradient from the LEDs, the diffuser needs to have an equal and opposite effect. An exponential diffuser with maximum scatter at the end of the waveguide achieves this.

Create a new scatter function (Scatterers→Create a New Scatterer…), and choose "Scripted" from the drop-down menu. Assuming that local y-position along the diffuser (g_Ypos) ranges from -40-40 mm, we create a variable "p" (probability of scatter) based on the following exponential function:

```
p = a*Exp(b*(-g_Ypos+40))-1
```

The parameters "a" and "b" are constants that can be adjusted. In this model, a=4 and b=0.04. Additionally, scatter occurs only for rays with y-positions sufficiently above the LED array (y>25 mm from bottom). This abrupt scatter "cut-on" counteracts the high-irradiance region near the light source.

Assign the custom scatter script to one side of the waveguide:

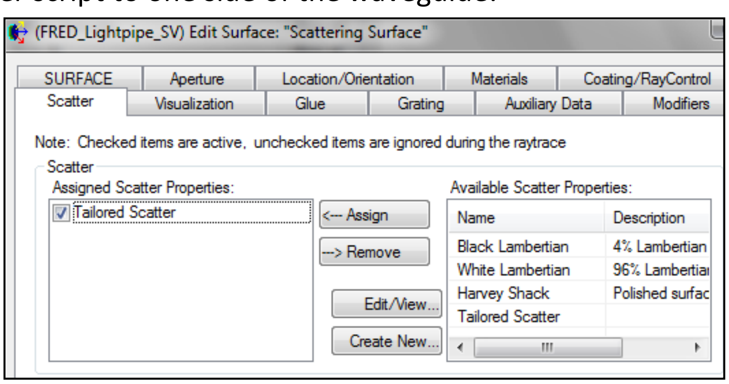


Figure 4. Assign the scripted scatter function ("Tailored Scatter" in this case) to the front or back of the waveguide under the Scatter tab of the surface.

To make the simulation more efficient, a Monte Carlo raytrace control can be applied to the scattering surface. This feature ensures that rays do not split at each scattering event. Under the Coating/Ray Control tab of the scattering surface, click Edit/View in the Raytrace Control section. Create the following control and assign it to the surface:

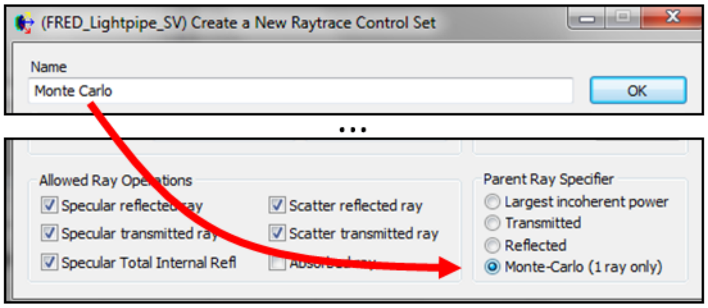


Figure 5. New Raytrace Control: Select "Monte-Carlo" as the Parent Ray Specifier to prevent ray splitting at scattering events.

Evaluating the display:

The irradiance exiting the mobile display before and after the scripted gradient diffuser is shown:

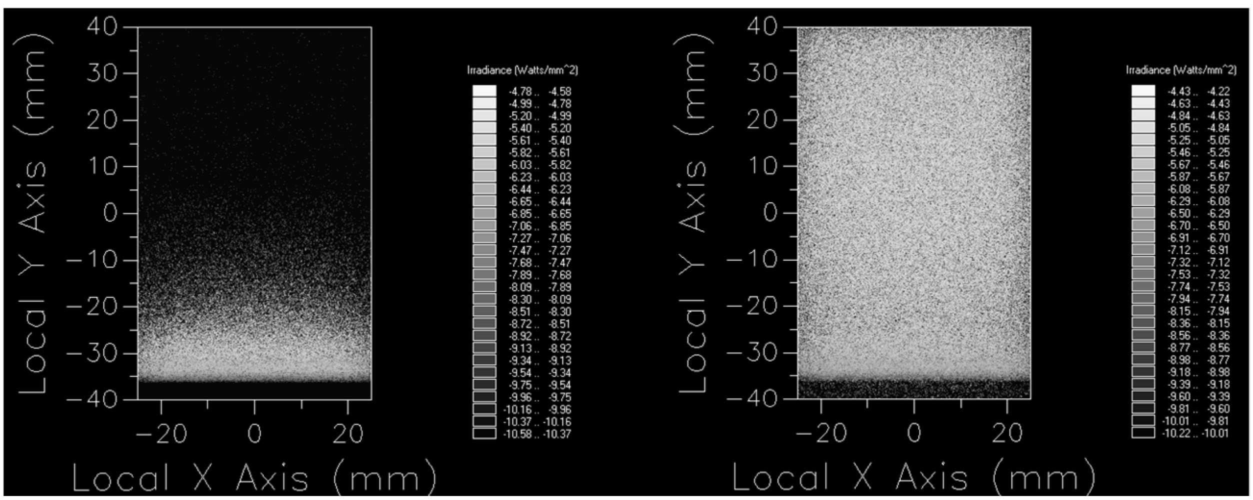


Figure 6. Log(10) of irradiance distribution from mobile display without diffuser (left) and with exponential diffuser (right). Logarithmic scaling gives a better idea of what the human eye perceives. 250,000 rays were traced in this simulation.

Photon ENGINEERING
Illuminating Ideas

310 South Williams Blvd., Suite # 222
Tucson, Arizona 85711
Tel: +1-520-733-9557
Fax +1-520-733-9609
http://www.photonengr.com