powerphotonic
enhancing beam performance

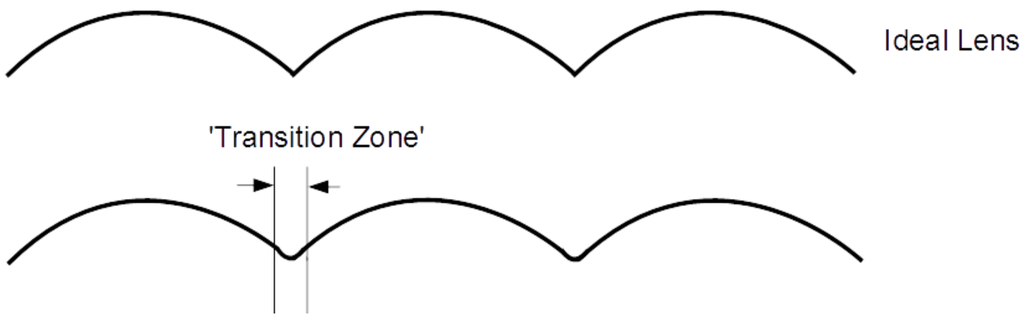
Application Note AN002

Homogeniser Performance

Revision 1v1, 9 October 2013

SUMMARY

This application note analyses the behaviour of refractive transition zones on the performance of imaging homogenisers. A homogeniser can be constructed from two lens arrays in a fly's eye configuration. A lens array consists a series of lenslets. Ideally, there should be a sharp transition from one lens to the next with no degradation in the clear aperture. However, due to manufacturing tolerances and other imperfections, there is always a transition zone between one lenslet and the next, which ultimately compromises the clear aperture of the lens.



The unique nature of the PowerPhotonic production process means that instead of a 'dead' zone, there is a smooth refractive concave 'transition' zone from one lenslet to the next that allows light through.

For a PowerPhotonic two lens fly's eye homogeniser, the impact of this transition zone is shown to be negligible with power losses of less than 0.6% with an 800um pitch lens array with 40um transition zone.

THE IDEAL 1D HOMOGENISER

A 1D homogeniser comprises two cylinder lens arrays of pitch p at focal length separation f. The ray transfer matrix M is given by:

$$M = \begin{bmatrix} 0 & f \\ -\frac{1}{f} & 0 \end{bmatrix} \qquad \textbf{Equation 1}$$

So that

$$x_o = f\theta_i \qquad \textbf{Equation 2}$$
$$\theta_o = -x_i/f$$

Hence ray position is transformed into angle and vice versa. The output far-field distribution is therefore the input near-field distribution averaged modulo one lens pitch. When the input near-field distribution averaged modulo one lens pitch is uniform, then the output far-field distribution is uniform over angular range $-\phi_o$ to $+\phi_o$ i.e. a full width of Φ_o where $\Phi_o = p/f = 2\phi_o$.

The above holds only for input rays within the input acceptance angular range of $-\phi_i$ to $+\phi_i$ i.e. a full width of Φ_i where $\Phi_i = p/f = \Phi_o$, and ignores effects due to diffraction.

Function of the two lenses

The imaging homogeniser can be thought of in terms of the function of the two lenses, as follows:

- The job of the first lens is to direct all rays within the input acceptance onto the second lens
- The job of the second lens is to image the intensity distribution at the first lens onto the far field

This is shown in the diagram below:

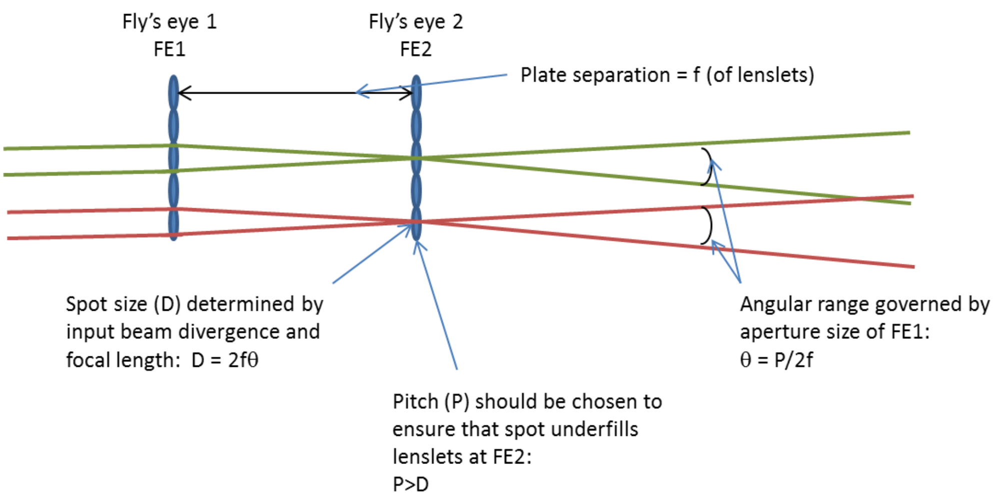


Figure 1: Schematic showing properties of Fly's eye homogeniser

EFFECTS AT LENS BOUNDARIES: IDEAL PHASE-SPACE MODEL

Dead zones and transition zones

In practise, lens shape will not be maintained all the way to a line boundary between lenses, and there is a region usually called the *dead zone* where either form error may depart significantly from the ideal shape or where scatter loss is large. Where the dead zone is a smooth refractive surface, it can be considered as a *transition zone*. The effect of dead zone/transition zone on input and output surfaces is different.

Exit lens dead zone/transition zone

The effect of an exit surface dead zone or transition zone of width $A_o = 2a_o$ is to reduce the input acceptance (angular range) by A_o/f, as shown in Figure 2. There is no impact on the output divergence profile as long as the input is underfilled i.e. $\theta_i < (p - A_0)/2f$. This is the case regardless of whether the dead zone is smooth (transition zone) or rough (dead zone).

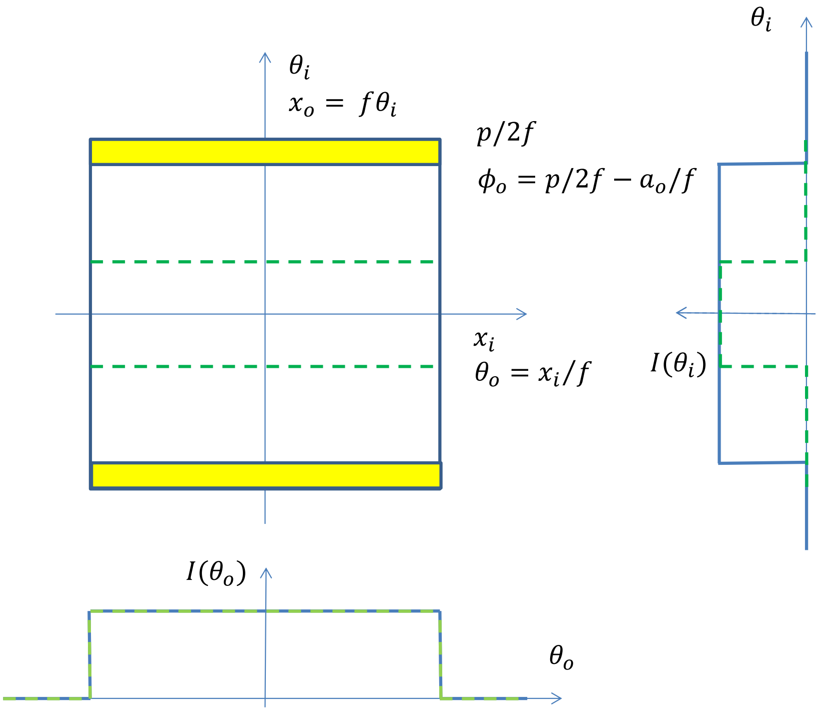


Figure 2 Effect of output dead zone
Blue: input acceptance fully filled
Green: input acceptance underfilled
Yellow region is input angular range affected by output dead zone

Input lens dead zone

The effect of the input lens dead zone/transition zone is illustrated in the schematic below:

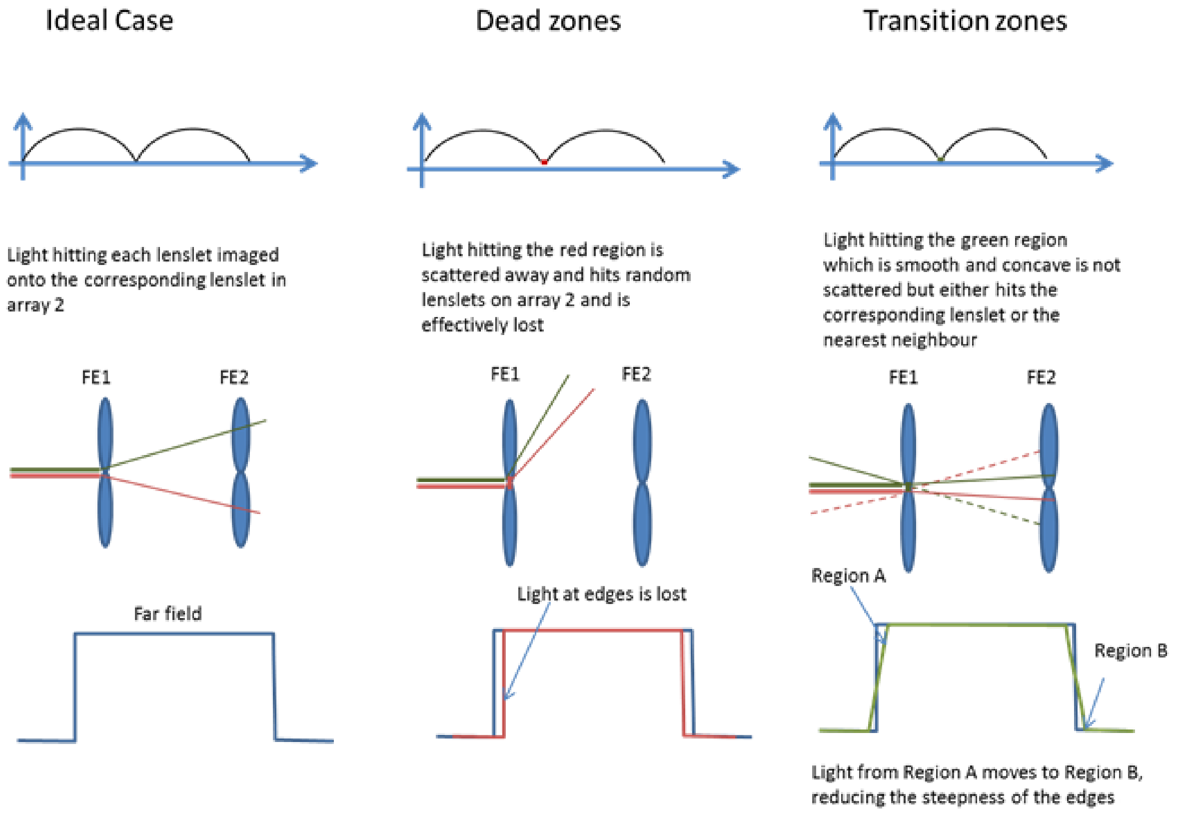


Figure 3: Schematic illustrating the effect of dead zones and transition zones on performance of Fly's eye homogeniser

Where the input lens has a dead zone that is lossy or highly scattering, this reduces efficiency by an amount corresponding to the area fraction of the input dead zone i.e., Loss $= A_i/p = D$. This also reduces the output divergence accordingly.

When the input lens dead zone is concave and smooth, then the refracted light can still find its way to the second lens. The phase space diagram and output far-field for this (for uniform input illumination) are shown in Figure 4.

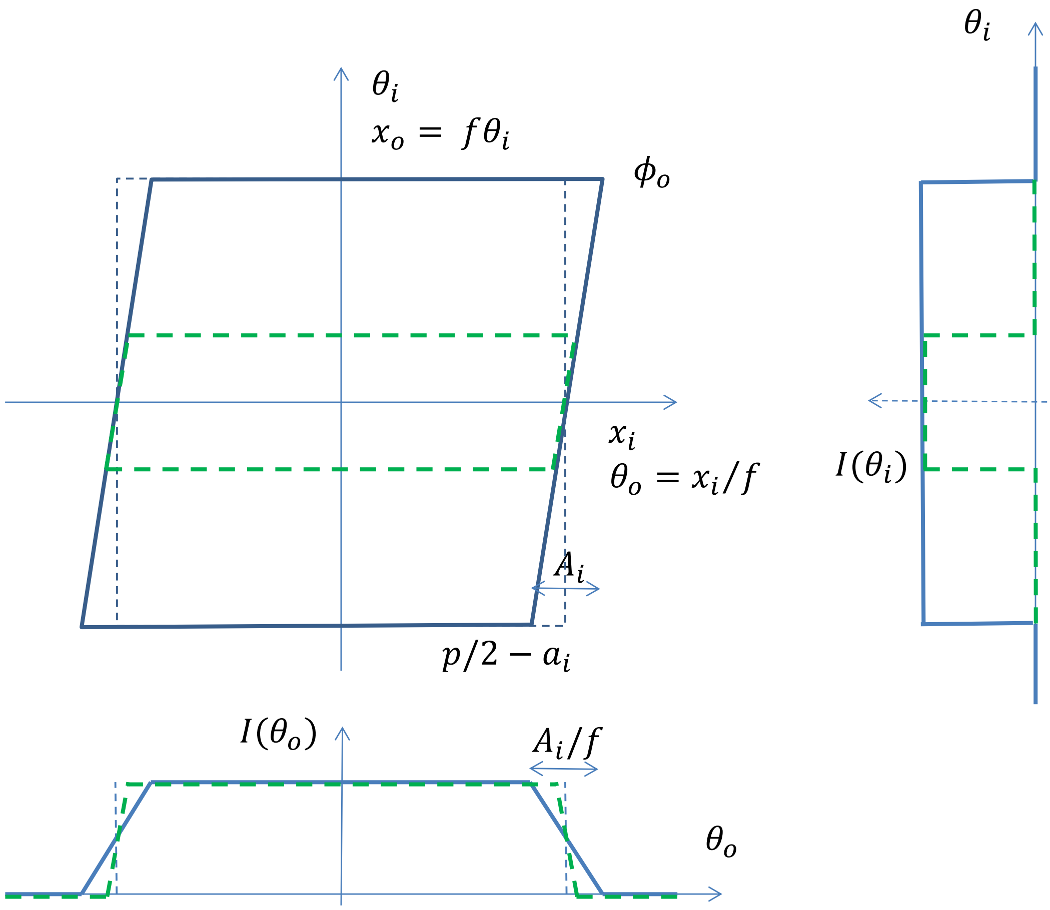


Figure 4 Effect of smooth concave input dead zone
Blue: input acceptance fully filled
Green: input acceptance underfilled

The effect of a smooth concave dead zone is therefore to soften the edges of the beam by an amount that depends on how well-filled the input acceptance is. In the extreme case, where the input acceptance is fully filled, the power lost from the output angle of full width Φ_o is four times smaller than in the case of a lossy or scattering dead zone, and this power is shifted to just outside Φ_o.

In the more general case, when the input acceptance is underfilled, the power shifted outside of Φ_o is reduced in proportion to the input divergence, and the overall divergence broadening is also reduced. If all the power in the trapezoid is considered useful power, then the effective loss is reduced to $L = (A_i/p)^2 = D^2$, which is typically small or negligible.

2D HOMOGENISER

The ideal 2D homogeniser

The 2D imaging homogeniser comprises a pair of spherical lens arrays at focal length separation, where each lens array is identical and is tessellated, typically in a square, rectangular or hexagonal array.

When the input near-field distribution averaged modulo one lens cell is uniform, then the output far-field distribution is uniform over an angular range defined by the unit cell dimensions divided by the focal length. This holds only for input rays within the input acceptance angular range, which is the same as the output angular range, when both input and output lens arrays are identical.

Effect of dead zone/transition zone

The effects of dead zone/transition zone on input acceptance and output divergence profile for a 2D homogeniser are analogous to the 1D case.

In a 2D homogeniser, where the transition zones occupy area fractions D_x and D_y in the x and y directions, and occupy only a small fraction of the overall area, then behaviour is approximately separable into the product of the 1D case x and y dependences, and loss is approximately:

- Dead zone (scattering): Loss ≈ $D_x + D_y$
- Transition zone (refracting): Loss ≈ $D_x^2 + D_y^2$

Effects at lens boundaries: Raytrace modelling

The prediction of the phase-space model can be verified by ray tracing. The optical system that was used for the modelling analysis is shown in the schematic below:

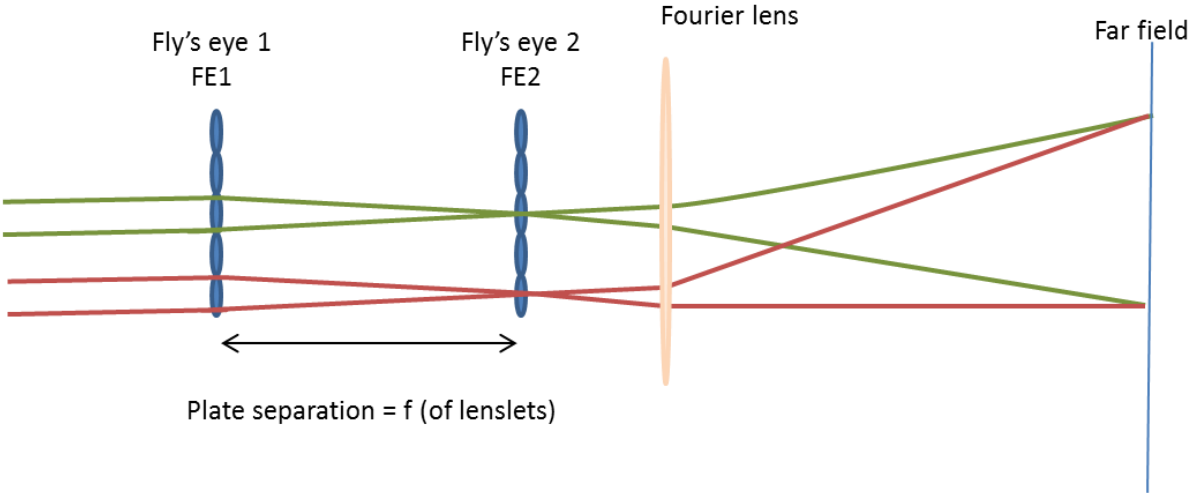


Figure 5: Schematic of optical model used in ray tracing

The source used was a diode source with a Gaussian distribution in both position and angle. The size and divergence were adjusted so that it extended over 3 lenslets in each direction and so that it filled the central portion of each lenslet in the second array (FE2).

The modelling of the arrays is discussed in the next section. A paraxial lens was used for the Fourier lens to generate the far field distribution in the end plane. Detectors were placed at each element so that the evolution of the beam and light distribution could be traced. To separate the effects of the central portion of the beam which should perform close to the ideal case from the edge effects, apertures were used to pick out the sections of the beam which were of interest.

The surface shape of the lens array, including the effects of smooth transition regions, was generated in Matlab as a grid sag file and then imported into Zemax. Identical data is used for each array and the 2 arrays are spaced by the focal length of the array.

Typical case with square array

The pictures below show the expected performance with the following characteristics:

- Fused silica, radius of curvature = 8.7mm, f = 19.29mm @ 940nm
- Pitch = 800um
- Typical smooth transition zones, width approximately 40µm

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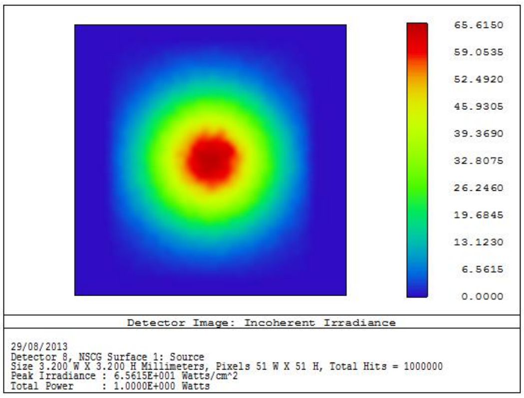
<tr><td>Source</td><td>
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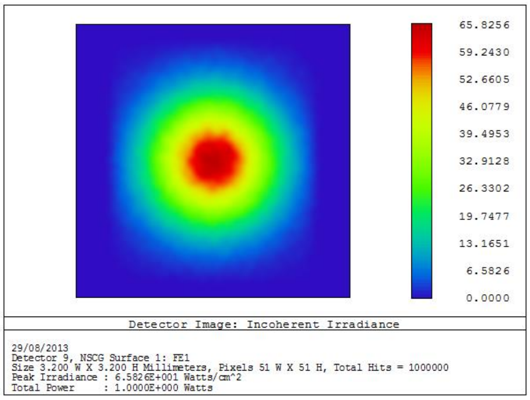
<tr><td>FE1</td><td>
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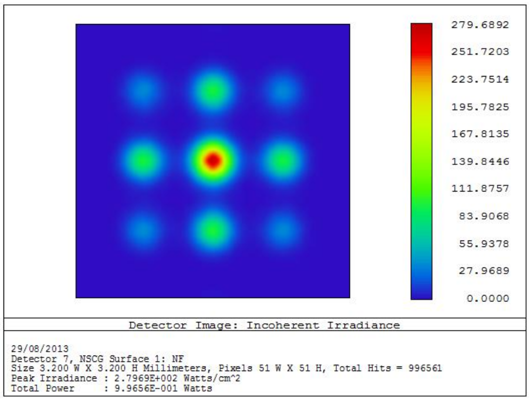
<tr><td>FE2</td><td>
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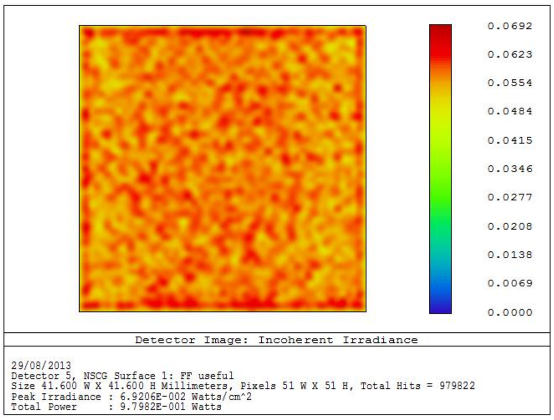
<tr><td>Far field centre</td><td>
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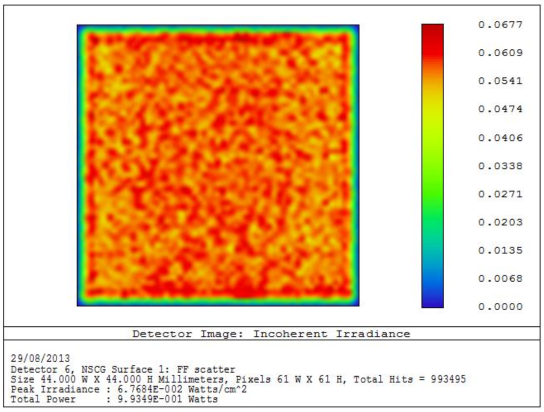
Far field all



Far field Cross-section

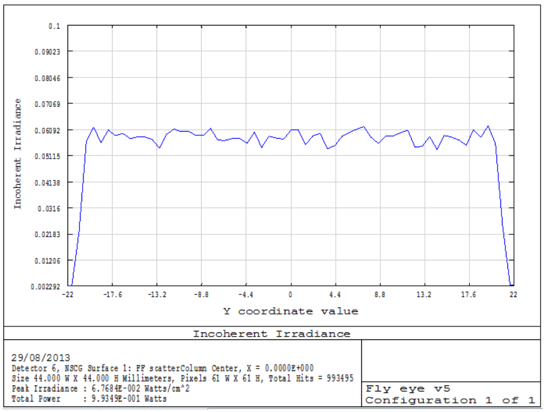


Table 7: Performance of square lens array in a typical case

In this case, the paraxial limit of the beam size was calculated to be a diameter of 41.4mradm in the far field. 98% of the light falls within this region. Increasing the region looked at to a diameter of 44mm to include the whole of the step down from the top hat increased the amount of transmitted light to 99.4%. This indicates that only 0.6% of the light is scattered away by the 2D fly's eye array. The quality of the top hat is good and close to the ideal case illustrated earlier.

The phase-space model indicates an expected loss of $2 \times (40/800)^2 = 0.5\%$ for a 40µm transition zone. This compares will with the value of 0.6 obtained from raytrace analysis.