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Physical optics

3rd Class Optoelectronics Branch

Chapter -2

Image Quality Analysis

Point Spread Function(PSF)

The image of a point source object formed by an optical system is known as "point spread function (PSF). Other names for PSF include "impulse response, Green function, and Fraunhofer diffraction pattern". It is one of the most complete function for describing the performance of an optical system an can be extended to include the effects of an obstructed aperture, apodization and any factor external to the optical system.

The most fundamental type of object to use in the testing of optical components is a point source of light which is effectively of negligibly small dimensions. The PSF is characteristic of the system under test.

The normalized complex amplitude is given by,

$$\boldsymbol{U'_p(u,v) = N \iint_{-\infty}^{\infty} f(x,y) e^{i2\pi(ux+vy)} dxdy}$$

Where f(x,y) is the complex pupil fuction which consist of two parts, (ι(x,y) is the amplitude transmittance pupil function and W(x,y) is the aberrations function).

$f(x,y$

=0 for $x^2+y^2>1$

$\tau(x,y)$=1 for uniform pupil function, f(x,y) =1 is for aberration free system W(x,y)=0 and uniform pupil function.

In polar coordinates, u=p sinψ ; v=pcosψ ; x=rsinφ :y =cosφ

$$\boldsymbol{U'_p(p,\psi) = N \iint_0^{1,2\pi} e^{i2\pi pr\cos(\varphi-\psi)} r dr d\varphi}$$

Which gives,

Where J1( ) is the Bessel function of the first kind.

The intensity distribution for in-focus aberration free system is,

<u>Aberration free system with focus error i.e. W=$W_{20}r^2$</u>

For optical system with circular aperture of unit area(area =π), The amplitude distribution is given by.

$U(p,$

For intensity along the optical axis, i.e. p=0 one get,

Which gives

So the axial intensity is,

The axial intensity is seen to be zero at $W_{20}=1\lambda$,2λ ,…

Encircled Energy EE(z)

The encircled energy function measures the fraction of the total energy in the PSF which lies within the radius z. For rotationally systematic PSF ,the encircled energy function is centered on the real principle ray. For non-rotationally symmetric PSF,EE(z) may shift laterally to coincide with the irradiance centered,

Excluded Energy XE(z)

If the energy in the outer ring structure is to be examined in detail ,it is some time convenient to replace the encircled energy with excluded energy, where,

$$XE(z)=1-EE(z)$$

XE(z) is used in evaluating apodization technique for suppressing the ring structures.

Displaced Energy DE(z)

EE(z),XE(z) describes the particular PSF.If we wish to compare the energy distribution in a real optical system to its perfect counter , one method would subtract the encircled energy function of one from the other, this is called displaced energy DE(z)

$$DE(z)= EE_p(z)-EE(z)$$

Where EEp(z) is the encircled energy function for perfect lens. Positive value of DE(z) represent an outer displacement of energy and indicate image quality degradation.DE(z) ia more sensitive measure of image degradation than strhel definition for factors such as aperture obstruction

Zonal Energy Increment ZEI

ZEI is useful in examine details of the redistribution of energy in a degraded PSF. The ZEI measure the amount of energy added to or subtracted from the perfect PSF in the zone between radii z_1 and z_2.

$$ZEI(z)= \{EE(z_2)-EE(z_1)\}-(EEp(z_2)-EEp(z_1)$$

$$= DE(z_1)-DE(z_2)$$

Negative value of ZEI indicate energy scattered out of the zone and positive values indicate energy scattered into the zone. ZEI is used to compare the manner in which different factors such as wave front error and aperture obstruction affect PSF.

Half Width

The diameter of PSF at 50% of its peak intensity is used a measure of image quality. The half width is not useful in comparing diffraction limited and near diffraction limited optical system. The shape of the central maximum varies little with increasing wavefront error at these level of performance. A central obstruction in fact reduces the half-power diameter. The half power diameter is most useful when large amount of aberrations are present.