Chapter 7
Gaussian Optics

Mey Chern Loh
Universiti Tunku Abdul Rahman, Malaysia

ABSTRACT

Analysis of Terahertz waves comes in three main forms, physical optics, geometrical optics, and Gaussian optics. Physical optics has the highest accuracy but it is time consuming when it is applied in the design of large radio telescopes. Also, it is only capable of computing radiation characteristics. Geometrical optics, on the other hand, reduces computational time significantly. But it does not give accurate results when designing telescopes which are to operate at Terahertz frequencies. Gaussian optics is a good trade-off between these two methods and it is a popular approach used in the design of large radio telescopes — particularly those which operate near/in the Terahertz band. Since it accounts for the effects of diffraction, this method produces reasonably accurate results. This chapter describes Gaussian optics, with emphasis given on its application in the design of radio telescopes.

GAUSSIAN OPTICS

Waves in the THz band are rich with spectral and spatial information in the field of astrophysics and is one of the few regions of the electromagnetic spectrum yet to be fully available to astronomy. THz systems are typically analyzed using physical optics, geometrical optics or Gaussian beam techniques.

Physical optics is very time consuming while offering high accuracy but the trade-off becomes apparent in the analysis of multiple reflector antennas. Another limitation of physical optics is that it is only capable of computing radiation characteristics, such as beam patterns and field contours, of the reflector antenna based on a set of predetermined antenna design parameters and it could not be applied to calculate optimum antenna design parameters which would give the highest aperture efficiency. To overcome the limitations of physical optics, the antenna design parameters are usually calculated first before applying the physical optics approach to determine radiation characteristics.

Geometrical optics approach on the other hand, ignores diffraction and polarization effects entirely to reduce computational time which in turn, reduces its accuracy. As cross polarization, distortion, and diffraction cannot be ignored in the THz region, the analysis of THz band is unable to utilize both tech-

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niques for analysis in the optical and microwave bands directly. Therefore, an intermediate approach is required to accelerate the analysis process and to provide sufficient accuracy in THz optical system designs.

A popular approach is the Gaussian beam modes. The Gaussian beam modes include the effects of diffraction within reasonable limit and are reasonably accurate for most applications. As performing accurate calculations for real systems can be very time consuming (Chou & Pathak, 2004), approximations are necessary to speed up the analysis process especially when speed is particularly important when a large number of optical elements are involved or when optimization techniques are required.Derived based on paraxial wave equations (Goldsmith, 1998), the simplicity of the Gaussian beam modes can also provide a starting point for more diffraction calculations when necessary and can also be used to calculate the parameters of the reflector (Tham, Yassin & Carter, 2007; Yeap &T ham, 2018). On average, the Gaussian beam technique requires 4.84s to find the radiation pattern at 626 field points as opposed to 164.3s required by conventional numerical physical optics approach using the same computer (Tham, Yassin & Carter, 2007).This means that the Gaussian beam analysis is approximately 40 times faster than the conventional numerical physical optics approach. A study showed that Gaussian beam analysis is able to shorten solution time significantly compared to that performed using physical optics (Chou & Pathak, 2004). However, inaccuracies can be observed due to inabilities to account for distortion and polarization (Yeap & Tham, 2018) and hence, could only provide approximation for the design parameters.

As the Gaussian beam propagation is based on the paraxial wave equation, it has limited transverse variation compared to a plane wave. It originates from a region of finite extent which is different from a beam originating from a source in geometrical optics which is from an infinitesimal point source.

FUNDAMENTAL QUASIOPTICAL GAUSSIAN BEAM PROPAGATION

Quasioptical propogation is important for millimeter and submillimeter wavelength systems. To obtain the paraxial wave equation that is of use for millimeter and submillimeter wavelength systems, the Helmholtz wave equation is needed (Goldsmith, 1998). A single component, ψ, of an electromagnetic wave propagating in a uniform medium satisfies the Helmholtz wave equatin

$$\left(\nabla^2 + k^2\right)\psi = 0\,. \tag{1}$$

where,

$$\nabla^2 = \text{Laplacian} = \frac{1}{h_x h_y h_z}\left[\frac{\partial^2}{\partial x^2}\left(\frac{h_y h_z}{h_x}\right) + \frac{\partial^2}{\partial y^2}\left(\frac{h_x h_z}{h_y}\right) + \frac{\partial^2}{\partial z^2}\left(\frac{h_x h_y}{h_z}\right)\right]$$

k = wave number

ψ = amplitude ofany component of E (electric field) or H (magnetic field).

Time variation at angular frequency is assumed to be exp(jωt). The wave number, k, is equal to $2\pi/\lambda$ so that

$k = \omega(\epsilon_r \mu_r)^{0.5}/c$

where,