Application of the diffracted gaussian beam analysis method in terahertz

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Abstract: The use of millimeter and sub-millimeter wave antenna systems for the studies of space is of great significance to astronomy. This paper presents the application of Diffracted Gaussian Beam Analysis method (DGBA) in Terahertz. And a three dimensional visual software based on DGBA is used for the simulation of a single-channel quasi-optical system at 325*GHz*. The simulation results and comparison analysis between Simatrix and GRASP, which proves the accuracy of DGBA and the simulation by Simatrix in Terahertz are also presented.

Keywords: Terahertz, DGBA, Quasi-optical system

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1. Introduction

In the last decades, advances in astronomy technology have made it possible for people to use millimeter and sub-millimeter wave antenna systems for the studies of space remote sensing and the Earth's atmosphere from the space-platform. For example， in 2009, ECA launched two space telescopes, the Plank and the Herschel, with their antennas being 3.5 *m* and 1.5 *m* in diameter, covering frequency ranges from 30 to 857 *GHz* and 448 *GHz* to 5 *THz* respectively[1]. Therefore, it gives a big challenge to the analysis and measurement.

The quasi-optical system has open architecture design of the optical components to overcome the shortcomings of the traditional metal waveguide in the millimeter wavelength such as high attenuation, small power capacity and strait manufacture and so on. While taking into account the coupling and diffraction of the beam, it is a combination of optical theory and electromagnetic calculations [2].

2. Basic idea of diffracted gaussian beam analysis method

A. The foundation of the Gaussian beam propagation theory

The basic concept of quasi-optical system is based on Gaussian beam propagation, whose characteristics are determined by the finite-size beam diffraction. In certain conditions, the Gaussian optics formula can be simplified to the formula of geometrical optics [3].

Based on the assumption of the paraxial approximation, the propagation of Gaussian beam can be induced. In a homogeneous medium, the propagation of electromagnetic waves can be written by the Helmholtz equation

$$\nabla^2\psi + k^2\psi = 0 \tag{1}$$

where ψ is the component of E or H. Considering Gaussian beam propagation direction as the positive direction, electric field can be represented by

$$E(x, y, z) = u(x, y, z)e^{-jkz} \tag{2}$$

In Cartesian coordinates, the above equation can be expressed by the simple wave equation.

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} - 2jk\frac{\partial u}{\partial z} = 0 \tag{3}$$

Finally we can get the expression of the fundamental Gaussian beam mode in cylindrical coordinates, under the conditions of paraxial approximation

$$E(r,z) = \left(\frac{2}{\pi w^2}\right)^{0.5} \exp\left(\frac{-r^2}{w^2} - jkz - \frac{j\pi r^2}{\lambda R} + j\phi_0\right) \tag{4}$$

where $R = z + \frac{1}{z}\left(\frac{\pi w_0^2}{\lambda}\right)$ is Gaussian beam radius of curvature,and $w = w_0\left[1 + \left(\frac{\lambda z}{\pi w_0^2}\right)^2\right]^{0.5}$ is Gaussian beam radius.

B. The approach of DGBA

Methods for the design verification of quasi-optical systems are very limited. Geometrical Optics (GO) does not account for the effects of edge diffraction, which is very important in some compact quasi-optical systems. Physical Optics (PO) is an accurate and modular method for analyzing reflector antennas. But it will need giant servers for computation and data storage.

Both Geometric Optic (GO) and Physic Optic (PO) are efficient methods to analyze optic problems. However, neither is suitable for quasi-optic system, especially large multi-reflector systems in the millimeter or sub-millimeter band because of time consuming or computation accuracy. To overcome the defects of GO and PO, this paper adopts the Diffracted Gaussian Beam Analysis Method (DGBA) and gives verification of DGBA in Terahertz, which combines the accuracy of PO and the efficiency of GO, furthermore, can be modularized[4-6]. Fig. 1 shows the illustration of a single reflector in multi-reflector system analyzed by DGBA. As shown in Fig. 2, the incident electric fields are expanded and sampled with fundamental Gaussian beam modes.

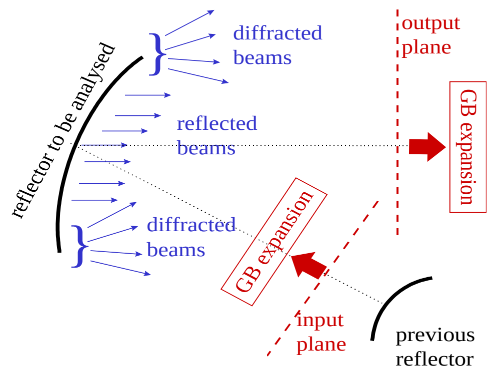

Fig. 1 DGBA Schematic diagram

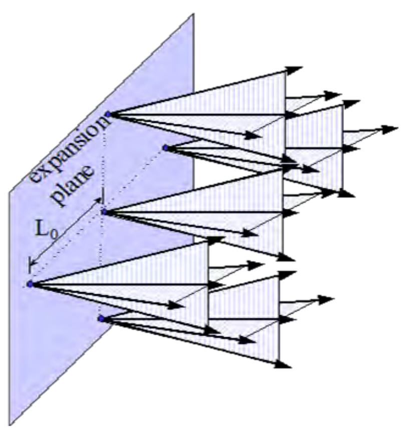

Fig. 2 Gaussian beam expansion

The operating flow follows fours steps[7]:(1)The incident electric fields are first expanded to Gaussian Beam Modes by windowed Fourier transform on the input plane.(2)These Gaussian beams will be projected to the reflector to be analyzed according to Gaussian beam propagation theory.(3)The reflected Gaussian beams can be processed by GO, and the diffraction coefficients of Gaussian beams to an equivalent Kirchhoff half plane and calculating the canonical solutions.(4)The reflected and diffracted Gaussian beams will be superposed on the output plane, which serves as the input plane to the next reflector. If this reflector is the last one in the system, far fields can be calculated by superposing the far field of each Gaussian beam.

3. Simulationverification

A three dimensional visual software SiMatrix_3.0 Based on DGBA has been developed at Beijing University of Posts and Telecommunications. Shown in Fig. 3, the quasi-optical system is simulated by this software. The single-channel quasi-optical system is designed around 325 *GHz* and the simulation results are acquired with a rapid speed, less than two minutes. Then a single-channel quasi-optical system at a much higher frequency (3 *THz*) is simulated by SiMatrix and the compared simulation results by GRASP, which is developed by TICRA Company and has complex procedures and heavy computation. It shows the accuracy and similarity of the results by SiMatrix.

Ellipsoidal reflectors can be used to carry out beam forming. The single-channel quasi-optical system consists of an ellipsoidal reflector and other sub-reflectors. Parameters of the ellipsoidal reflector are listed in the table below.

Tab. 1 Parameters of the ellipsoidal reflector (*mm*)

d_{in}	ω_{0in}	d_{out}	$\omega_{0_{out}}$	f
56.8	1.5890	168.057	9.2384	53.496
R_1	R_2	a	b	c
58.1	660	359.05	169.60	316.47

Fig. 4 and Fig. 5 show the three dimensional near field of the ellipsoidal reflector at 325 *GHz*. Fig. 6 shows the two dimensional far field of the ellipsoidal reflector at 325*GHz*. The simulated results reasonably satisfy the requirements of the system that the divergence angle of outgoing beam is less than 10 degrees. Considering the higher frequency, an ellipsoidal reflector is simulated at 3*THz* and the model is the same as the one in Fig.3. Fig.7 shows frequency sweep simulation results between 1 *THz* and 5 *THz*, which proves the good simulation performance of Simatrix in the Terahertz.

GRASP uses PO method to analyze multi-reflector antenna systems. It needs large data storage and giant computing servers to carry out complex procedures for high accuracy, which takes longer computing time as well. However, Simatrix based on DGBA does not limit the harsh conditions. Fig. 8 offers the simulation results and comparison analysis between Simatrix and GRASP, which proves the accuracy of the simulation by Simatrix.

Fig. 3 Model of quasi-optical system in SiMatrix_3.0

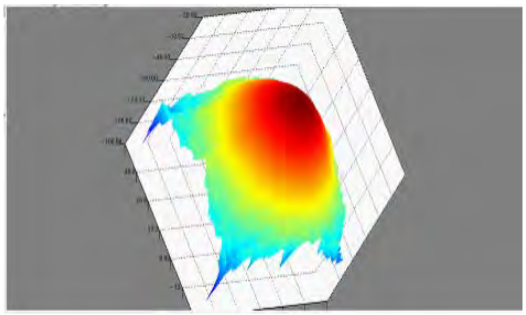

Fig. 4 Three dimensional near field co-polarization amplitude distribution at 325 *GHz*

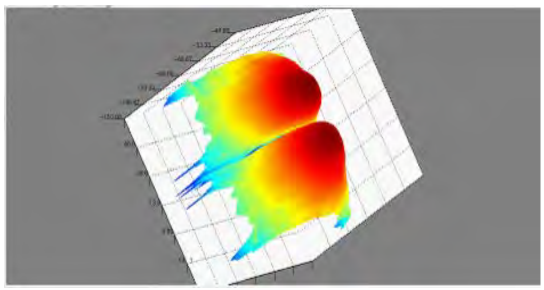

Fig. 5 Three dimensional near field cross-polarization amplitude distribution at 325 *GHz*

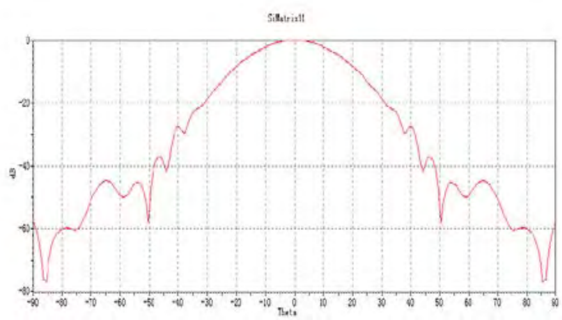

Fig. 6 Two dimensional far field distribution at 325 *GHz*

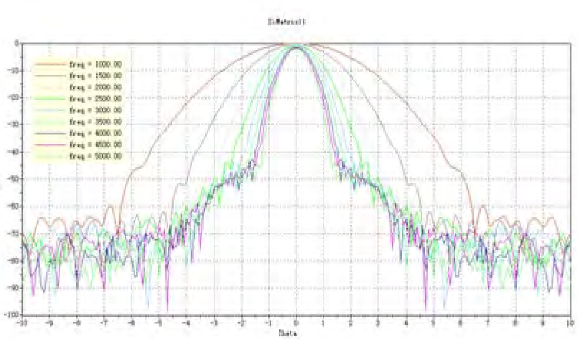

Fig. 7 Frequency sweep simulation results by Simatrix (Range between 1 *THz* and 5 *THz*, the step 500*GHz*)

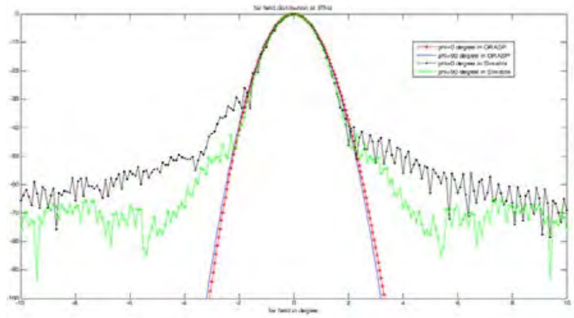

Fig. 8 Simulation and comparison between Simatrix and GRASP at 3 *THz*

4. Conclusions

This paper presents the application of Diffracted Gaussian Beam Analysis Method (DGBA), which is a modular method for quasi-optical system analysis, with the accuracy of PO and numerical efficiency of GO [4, 5]. A single-channel quasi-optical system is designed at 325 *GHz* and simulated by a three dimensional visual software SiMatrix based on DGBA. The paper also gives the comparison analysis between Simatrix and GRASP to provide effectiveness of DGBA in Terahertz.

Furthermore, the design of a multi-channel quasi-optical system by using DGBA to meet the demand of system in Terahertz band is in progress.

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