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A GO/FO Tool for Analyzing Quasi-Optical Systems in Reception

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***Abstract*—In this work, a free accessible MATLAB interface is presented to analyze antenna-coupled Quasi-Optical (QO) systems in reception. This goal is achieved by using Fourier Optics (FO) and Geometrical Optics (GO) based methods. Specifically, the FO method represents the field focalized by a QO component on its focal plane as a plane wave spectrum when the component is illuminated by an incident field. This spectrum is related to the field scattered by the QO component which is calculated here using a GO method. By using this spectrum, the tool estimates the power received by an antenna placed at the focal plane of the QO component. Moreover, the performance in reception is evaluated.**

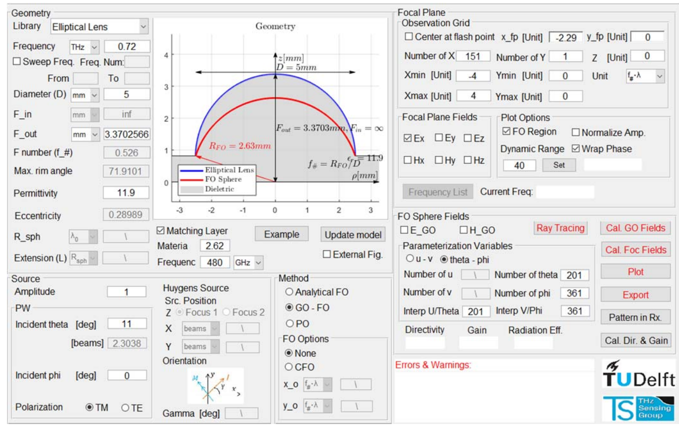
I. Introduction

Quasi-optical (QO) systems are widely used in applications such as stand-off security monitoring and astronomical observations, in order to increase the directivity of the systems to achieve better performance. QO systems can be analyzed either in transmission or reception. In this work, we focus on representing an analysis in reception since it is easier to design and optimize antenna-coupled QO systems in reception. In order to analyze the coupling between antennas and QO components, a Fourier Optics (FO) based analysis is proposed in [1, 2]. When a QO component is illuminated by a plane wave, the field focalized by the QO component on its focal plane can be expressed as a summation of plane waves, referred to as plane wave spectrum (PWS). One can use this spectrum to analyze antenna-coupled QO systems, by resorting to antenna in reception formulation [3]. It is discussed in [1] that PWS is proportional to the scattered field on an equivalent sphere, referred to as the FO sphere, centered at the focus of a QO component. Therefore, once this scattered field is known, the performance in reception can be obtained.

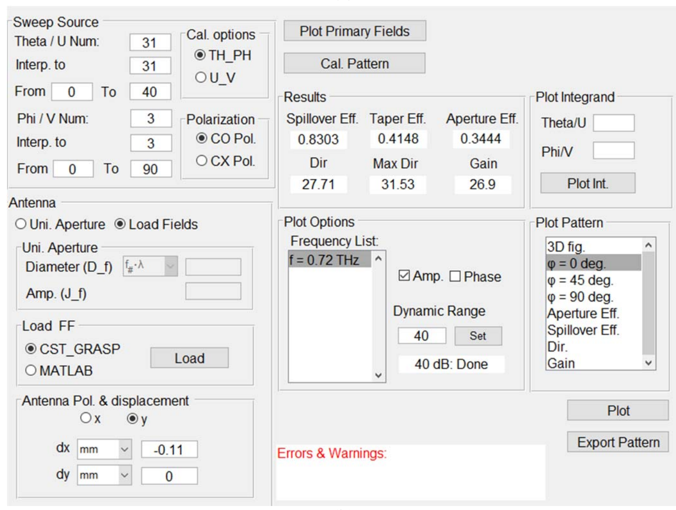
In this work, the scattered fields on a FO sphere are calculated by using Geometrical Optics (GO). A MATLAB Graphical User Interface[1] (GUI), in Fig. 1a and 1b, based on the GO/FO analysis, is built to analyze antenna-coupled QO systems in reception. In order to enlarge the design possibilities with this tool, five widely used QO components are considered, namely parabolic reflectors, elliptical lenses, hemispherical lenses, hyperbolic lenses, and elliptical mirrors.

II. GO Fields on FO Spheres

Let us consider a case that a QO component is illuminated by a plane wave, as depicted in Fig. 2a. An incident field $\vec{E}_i$ impinges on a QO surface S with the skew angle θ_s. It is scattered by the surface and propagates to the FO sphere, S_{FO}. During the propagation, the scattered field has an amplitude spreading and a phase variation. By implementing the GO technique discussed in [4], one can evaluate the GO ray field on the FO sphere, $\vec{E}_{GO}$. It is found that for broadside incidence, the spreading, S_{pread}, can be simplified as a function of the polar



(a)



(b)

Fig. 1. (a) Main interface. (b) Interface for analyzing reception performance.

angle θ, which is derived in [5] for all QO components in the tool. Moreover, for slightly off-broadside incidence ($\theta_s \leq 11°$), the GO ray field can be approximated as the product among the GO field in broadside case, i.e. $\vec{E}_{GO}(\theta_s = 0°)$, a linear phase term, $e^{-j\vec{k}_\rho \cdot \vec{\rho}_{fp}}$, and a coma phase term, $e^{-j\vec{k}_\rho \cdot \vec{\rho}_{fp} \Phi_{coma}}$, which is discussed in [2] and can be expressed as:

$$\vec{E}_{GO}(\theta_s) \simeq S_{pread}\left[\vec{E}_i \cdot \bar{R}/\bar{T}\right] e^{-j\vec{k}_\rho \cdot \vec{\rho}_{fp}} e^{-j\vec{k}_\rho \cdot \vec{\rho}_{fp} \Phi_{coma}} \quad (1)$$

where $\bar{R}$ and $\bar{T}$ are reflection and transmission dyads, respectively; $\vec{\rho}_{fp}$ is the flash point that indicates the position of the field focalized on the focal plane; and Φ_{coma} is the coma phase that represents the phase error. The explicit expressions of Φ_{coma} for all QO components are discussed in [5].

[1] The GUI can be freely downloaded at http://terahertz.tudelft.nl.

III. Antenna-coupled QO systems

An important application of this tool is to analyze antenna-coupled QO systems in reception. Once the inward GO field is evaluated, the power pattern in reception can be calculated by using antenna in reception formulation derived in [3] as:

$$P_L = \frac{|V_{oc}|^2}{16P_{rad}} = \frac{\left|\int_0^{2\pi}\int_0^{\theta_0} \vec{E}_a^{Tx}\cdot\vec{E}_{GO}\sin\theta d\theta d\phi\right|^2}{2\zeta\int_0^{2\pi}\int_0^{\pi}\left|\vec{E}_a^{Tx}\right|^2\sin\theta\, d\theta d\phi} \qquad (2)$$

where θ_0 is the maximum rim angle of a QO component, $\vec{E}_a^{Tx}$ is the field radiated by the antenna in transmission, and $\vec{E}_{GO}$ is the inward GO field. It is worth mentioning that we take the phase of the open-circuit voltage V_{oc} as the phase pattern. Besides patterns, the tool also calculates spillover efficiency, taper efficiency, aperture efficiency, directivity, and gain, as shown in Fig. 1b.

IV. Numerical examples

The designed tool has two interfaces. The main interface (Fig. 1a) is used to define a QO component and calculate the GO field on its FO sphere. In this work, we derived analytical expressions for GO fields when the incident skew angle is less than 11 degree; while for larger skew angles, the GO ray fields are calculated. In Fig. 2b, an elliptical silicon lens operating at 720 GHz is defined. This lens is illuminated by a TM plane wave with the skew angle of 11 degree (Fig. 2b). Here a quarter-wavelength matching layer is applied. In this case, the GO field over the FO sphere is calculated and shown in Fig. 3a. To validate the GO field, we indirectly validate the focal plane field. If the focal plane field is validated by PO, we can assume the GO field is also validated. The amplitude of the x-component of the focalized field calculated by using GO-FO ($|E_x|$) is shown in Fig. 3b, and we validated it within the FO validity region discussed in [1]. Here the x-cut of E_x calculated by GO-FO is compared to PO results. As can be seen in Fig. 3c, the agreement between GO-FO and PO is very good within the FO validity region, for both the amplitude and the phase.

The user interface shown in Fig. 1b is used to evaluate the performance of antenna-coupled QO systems in reception. It calculates the power received by an antenna placed at the focal plane of a QO component, by using the antenna in reception formulation [3]. Here we consider a leaky wave slot coupled to the above-mentioned lens (Fig. 2b). The antenna is placed and shifted within the focal plane of the lens. The power pattern calculated in reception is compared to CST simulation, as shown in Fig. 4. It can be seen that the agreement is quite good for both the Co-Pol. ($\phi = 0°$) and the Cx-Pol. ($\phi = 45°$). Moreover, we checked the aperture efficiency, directivity and gain in reception. The agreement is also very good.

For other QO components, we also validated their GO fields and performance in reception calculated by our tool. Therefore, this tool fulfills the need for a universal tool which implements the GO/FO analysis for variety of QO components.

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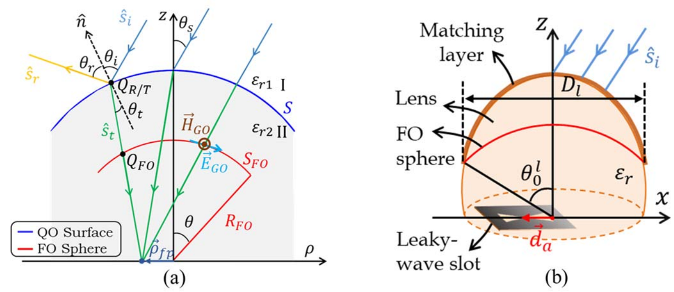

Fig. 2. (a) GO ray propagation for a QO surface. (b) A leaky lens antenna.

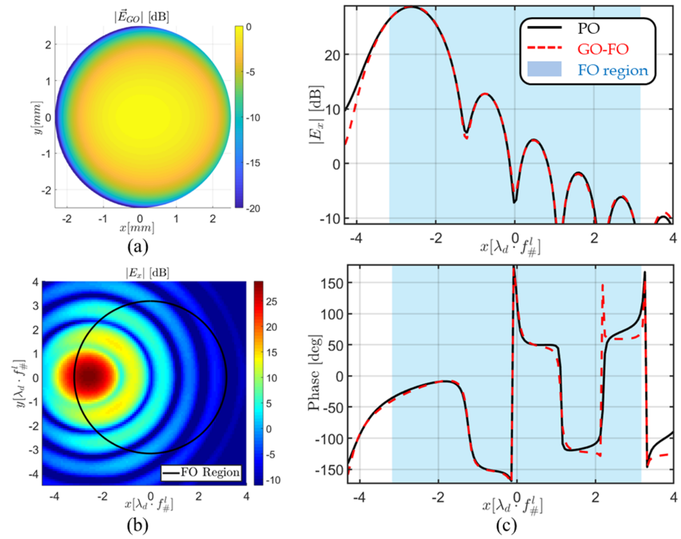

Fig. 3. (a) GO field on the FO sphere. (b) $|E_x|$ calculated by using GO-FO. (c) x-cut of E_x validated by PO for both the amplitude and the phase.

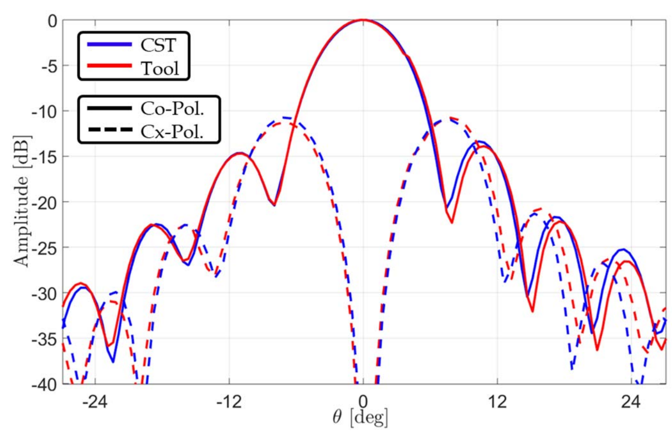

Fig. 4. Co-Pol. ($\phi = 0°$) and Cx-Pol. ($\phi = 45°$) patterns in reception compared to CST simulation.

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