Terahertz Cassegrain Reflector Antenna

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***Abstract-* In this report, we present our recent work on terahertz Cassegrain reflector antenna with compact configuration and directive radiation pattern. The geometrical parameters and electrical performance of the Cassegrain reflector system are calculated and analyzed through folded optics approach, combined with feeding horn design through numerical package simulations. Analytic results of the antenna show high directivity over 50dB, side lobe less than -20dB and beam width of 0.5° from the far field radiation pattern, making the antenna an interesting candidate for high resolution imaging applications as surveillance equipment.**

I. INTRODUCTION

Very recently, terahertz (THz) technology has attracted much attention due to the unique characteristics [1-3]. THz wave could transmit opaque material as clothing or heavy smoke, and thus provides a powerful tool for concealed object detection and imaging underneath [1-3]. Besides, for a diffraction-limited image application, very high image resolution could also be achieved with a compact and effective terahertz antenna aperture [4-5]. In this presentation a compact and directive reflector antenna for these application cases is discussed. The antenna is with high directivity to radiate and receive wave in 0.33THz frequency band.

In the following parts, we will first introduce the design approach of folded geometry optics method [5-6], and then investigate the antenna system, with results and analysis predicted through the method. Analysis shows that the antenna directivity is very sensitive to the surface smoothness of the reflector, which could be controlled and minimized by finish machining and techniques.

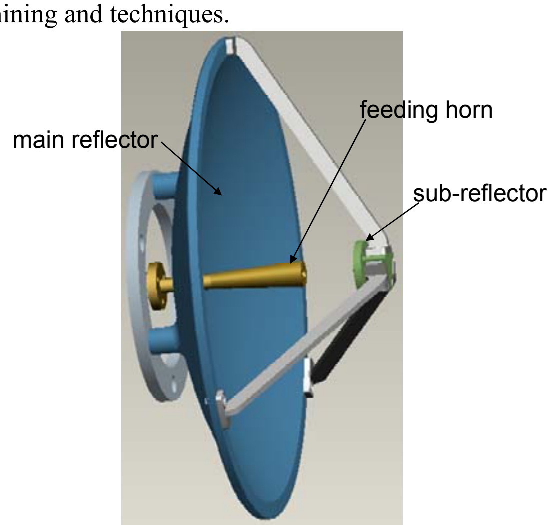
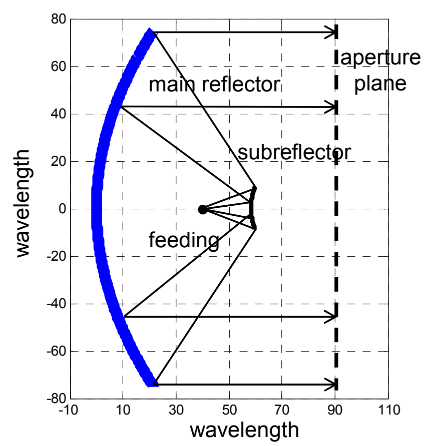


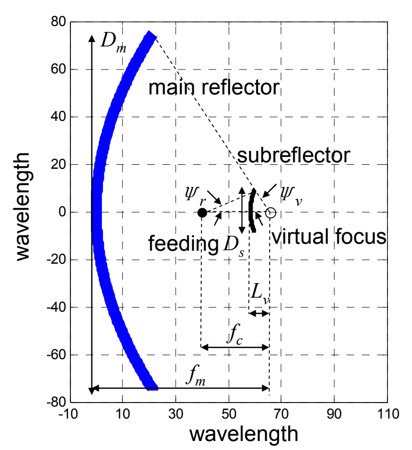
Figure 1. Configuration of the terahertz Cassegrain reflector antenna.

II. DESIGN APPROACH

Maxwell's equations are generally acknowledged to describe and predict radiation and transmission properties of electromagnetic (EM) waves. However, for electrically large objects, it is time-consuming work to solve the EM fields over the objects with analytical expressions of the equations or their numerical resolutions with convergent accuracy. For these cases as electrically large antenna aperture, one special approximation method of classical folded geometry optics is introduced to facilitate design [5-6]. Fig.1 portrays the large aperture reflector antenna of Cassegrain type with compact configuration as a promising candidate. Two reflectors, one hyperbolic subreflector and parabolic main reflector combined with the feeding horn compose the antenna.



(a)



(b)

Figure 2. Scheme for the terahertz Cassegrain antenna

Terahertz wave from the feeding as the focus of the hyperbolical subreflector is folded to radiate onto the aperture plane, with ray path portrayed in Fig.2 (a). With equivalent geometry path theory, the multi reflector system could be regarded as a single parabolic reflector with feeding at the virtual focus. The aperture for the main reflector is about 150 wavelengths, while the dimension in the radiation direction for the antenna is about 60 wavelengths. Detailed description of the aperture sizes, the positions, and characteristic focal lengths are presented with parameters in Fig.2 (b). These parameters are related as following [5-6],

$$\begin{cases} \tan(\psi_v/2) = D_m/(4f_m) \\ 1/\tan\psi_r + 1/\tan\psi_v = 2f_c/D_s \\ 1-\sin((\psi_v-\psi_r)/2)/\sin((\psi_v+\psi_r)/2) = 2L_v/f_c \end{cases} \quad . \tag{1}$$

The relationship in (1) restricts terahertz ray trajectory of the reflector systems in Fig. 2(a). For large apertures, this geometry method provides rather accurate and effective approach to predict antenna performance [5-6].

III. Results and Analysis

With the folded geometry optics method described in the above literature, results and qualitative analysis of the reflector antenna will be shown in this section, together with the introduction of feeding antenna with satisfactory primary radiation patterns.

In reflector antenna system, conical hybrid mode horns as feedings are widely used for the desirable radiation properties as good pattern symmetry and low cross-polar sidelobe levels. In terahertz band, dual-mode Potter horns are preferable to corrugated horns for fabrication facility. The dual-mode Potter horn antenna with steps could converts the incident dominant TE11 mode to hybrid TE11 and TM11 modes. With proper length compensation, the hybrid two modes will be in phase on the radiation plane. Fig.3 gives the simulated radiation pattern with co-polar and cross polar levels of the dual-mode horn. We could see that good pattern symmetry is achieved in the subreflector coverage range. And the cross-polar radiation field is about 40dB level lower than the copolar field, which provides expected primary patterns for the reflector systems.

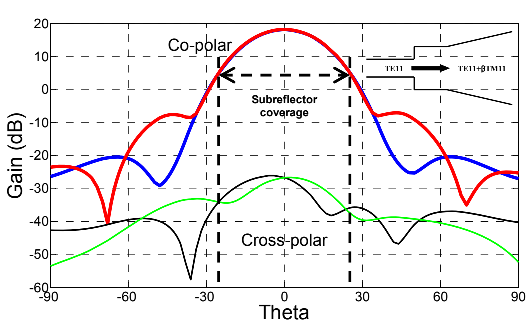
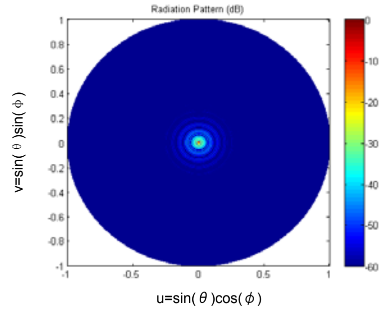
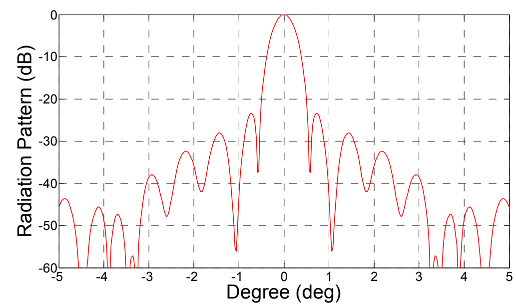


Figure 3. Farfield radiation pattern for dual-mode feeding horn.



(a)



(b)

Figure 4. Farfield radiation pattern of the reflector antenna

The near field distribution for the reflector aperture is obtained from geometry optics method, which is then extrapolated to the farfield radiation pattern shown in Fig.4. The extrapolation procedure follows the equations as

$$\vec{E}(u,v) \propto \iint \vec{E}_a(x,y)\exp(jk_0(ux+vy))dxdy \quad , \tag{2}$$

where $u=\sin(\theta)\cos(\varphi)$, $v=\sin(\theta)\sin(\varphi)$, and $\vec{E}(u,v)$ and $\vec{E}_a(x,y)$ denote vector farfield and aperture field separately. It should be noted that the aperture field $\vec{E}_a(x,y)$ in (2) includes the blockage effect of subreflector and mechanical support.

We could estimate the beamwidth and near-in sidelobe of the antenna as 0.5° and -23dB from the patterns in Fig.4. The directivity of the antenna could be further processed with the farfield data with the following equation

$$D = \frac{|E_{\max}|^2}{\frac{1}{4\pi}\iint |E(\theta,\varphi)|^2 \sin\theta d\theta d\varphi} = \frac{|E_{\max}|^2}{\frac{1}{4\pi}\iint \frac{|E(u,v)|^2}{\sqrt{1-u^2-v^2}}dudv} \quad . \tag{3}$$

And the efficiency of the antenna excluding the loss and spillover energy is calculated by $\eta = D\lambda^2/(4\pi A)$. Through these expressions, we could calculate the directivity as 51.1 dB and the efficiency as 57%.

Perturbations deriving from the manner the terahertz reflector antenna fabricated, assembled and installed, might occur in the radiation pattern. Generally, these errors departure from the theoretical design might reduce directivity; raise the sidelobe and cross-polar level. The RMS error associated with surface random fabrication has been analyzed in [6-7], while a quantitative effect on directivity performance due to small correlation interval deviation is given by

$$D / D_0 = \exp(-(4\pi\varepsilon / \lambda)^2)\,, \qquad (4)$$

where D and D_0 are antenna directivity with and without errors, λ is the wavelength and ε is the RMS surface error. A detailed illustration could be found in Fig.5. Fabrication error should be controlled in 0.01mm as the loss might be less than 0.1dB. Assembly and installations errors should also be controlled with the same order, provided careful checkout procedure used.

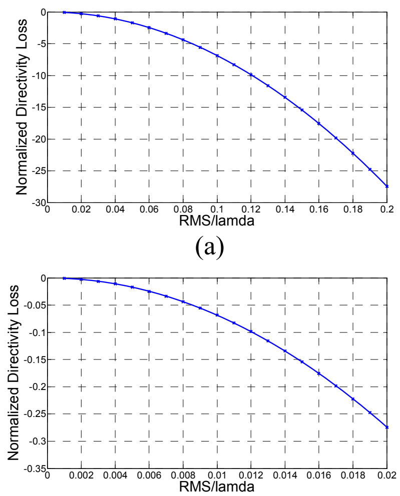


Figure 5. Normalized D/D0 with RMS errors

IV. Conclusion

In conclusion, we present one compact Cassegrain type antenna system for terahertz band applications with high directivity. The reflector antenna system is designed with classical folded optics method, validated by desired geometry parameters and positions of the reflectors system, while the primary illumination for the reflectors from a dual-mode horn feeding is predicted with accurate numerical simulated radiation performance. Near aperture fields from the geometry optics are further extrapolated to obtain the far field distribution. Radiation performance is also investigated to obtain antenna beamwidth, sidelobe and directivity with surface error analysis.

References

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