Multi-moded horns in reflector antenna systems
Exemplified by the Planck telescope

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Abstract

In this paper bolometric detectors applied in conjunction with reflector antenna feed horns that support multiple modes are studied. As an example, the preliminary design of the Planck telescope is used to calculate both the receiving pattern of the feed element as well as the receiving pattern of the telescope.

Introduction

In astronomy bolometric detectors used in conjunction with horns are useful since they combine the efficient power conversion of a bolometer with the high-resolution and stray-light-rejecting properties of a horn.

The bolometric detector is placed at the bottom of the waveguide and replaces the standard waveguide adaptor. In some cases, where high power detection is preferred to high resolution, the waveguide section of the horn is enlarged to support multiple modes.

In [1] and [3] the multi-mode patterns of a smooth conical horn are calculated. The individual modes are excited in a circular waveguide and propagated through the horn. The propagation through the horn is done in an approximate way by multiplying a quadratic phase factor to the field of the mode. In the far-field the power of the individual modes are added, as explained in the next section. Hereby the combined receiving patterns for an arbitrary number of modes can be found.

In the present work, this method is employed to compute the multi-mode receiving pattern for a simplified horn with the same physical dimensions as the proposed high frequency horns for the Planck telescope, see Figure 1 and [5]. The horns of the Planck telescope will be corrugated and designed to support a specific number of hybrid modes. Most likely this number will be just below thirty. To simulate this situation, GRASP8 [6] is used to conduct an analysis of the first 30 hybrid modes. The horn is operated at 857 GHz, which will be the highest frequency for the Planck telescope.

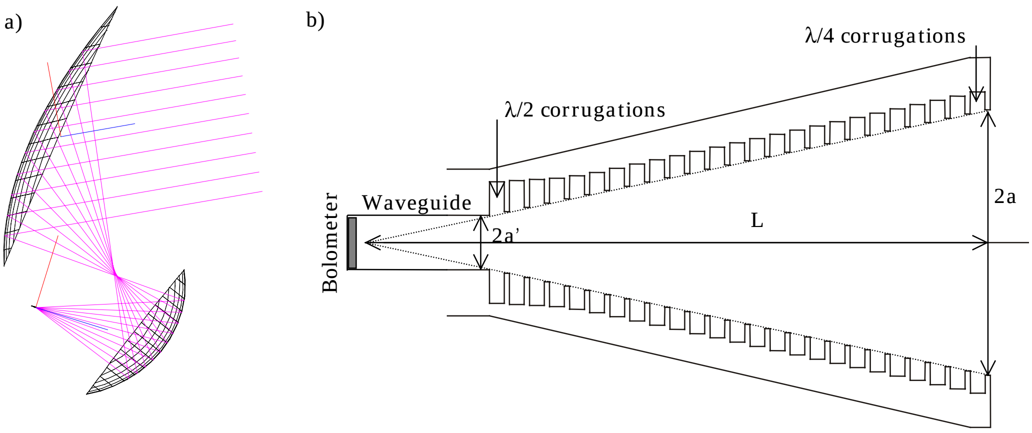

Figure 1 In a) the Planck telescope is illustrated. The telescope is an aplanatic system consisting of two ellipsoidal reflectors, the main reflector having a diameter of 1.5 m. Operating at 857 GHz the feed horns are placed slightly out of focus. In b) a drawing of a standard corrugated horn that employs a bolometric detector is shown.

Theory

For a single-mode microwave horn the receiving area A_e is given by the usual formula

$$A_e = \frac{\lambda^2}{4\pi} G \text{ ,} \tag{1}$$

where G is the gain of the horn when it is used as a transmitting antenna. Both A_e and G are functions of the direction of incidence.

It may be shown by the reciprocity theorem [3] that the receiving area of a multi-mode horn with a bolometric detector becomes

$$A_e = \frac{1}{2} \frac{\lambda^2}{4\pi} \sum_{r=1}^{m} G_r \text{ ,} \tag{2}$$

where G_r is the gain of mode No. r for the transmitting horn and m is the total number of modes. The sum in (2) contains modes with both polarisations which is compensated by the additional factor 1/2. Furthermore, it is assumed that all directions of polarisation are equally likely to occur in the incident field.

Hence the received pattern of a bolometric system is given by *the sum of the normalised power patterns of all individual modes.*

It is convenient to normalise A_e with the physical horn aperture area A_p. The resulting ratio A_e / A_p is a number between 0 and 1 with $A_e / A_p = 1$ for an ideal case in the axial direction. The equation (2) is also valid for a total reflector antenna system in which case G_r is the gain pattern of the main reflector far field and A_p is the main reflector aperture area.

Far-field patterns from the Planck feed horns

The Planck telescope will map the background radiation in 8 frequency bands, from 30 GHz to 857 GHz [5]. At the two highest frequencies the currently proposed horns are oversized and hence multi-moded. The horns have the dimensions: *L=25 mm, a=4.1 mm and a'=0.49 mm* (see Figure 1).

Hybrid modes in corrugated horns can be low-frequency as well as high-frequency cut-off. Whereas low-frequency cut-off is determined by the inner waveguide diameter, high frequency cut-off occurs in a non-trivial manner ([2], [4]). The 30 modes that may exist both in the aperture and in the waveguide are (the azimuthal index is the first number listed):

the non-degenerate modes:

- TE01
- TE02
- TM02
- TM03

the double-degenerate hybrid modes:

- HE11, HE12, HE13, EH12, EH12, EH13
- HE21, HE22, EH22
- HE32, EH32
- HE41
- HE51

The aperture fields of the hybrid modes can be derived from [4] and the far-fields of the individual modes are calculated by integration over the aperture based on standard techniques. The total pattern for all 30 hybrid modes is then obtained by adding the power of the individual modes. In Figure 2 the total feed pattern is shown and compared to the feed pattern of the HE11 mode.

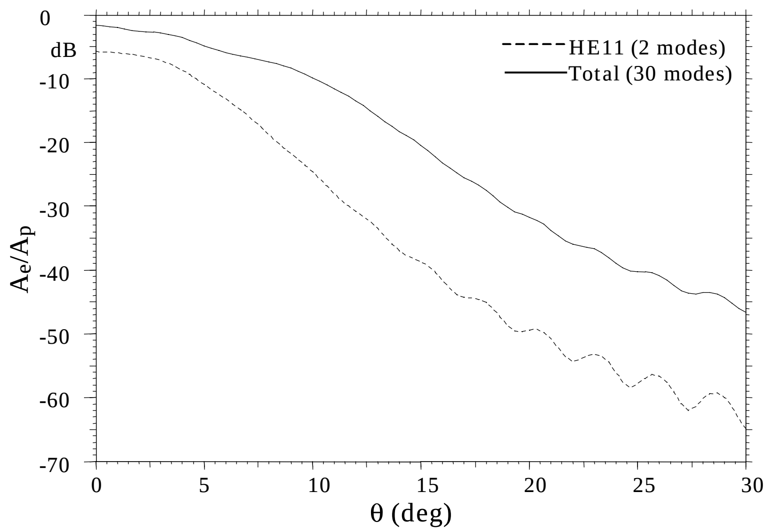

Figure 2
Radiation patterns from the Planck telescope feed horns for 857 GHz. The total power pattern is the sum of the power patterns from each of 30 hybrid modes. The power pattern of the two orthogonal HE11 modes is shown for comparison.

Far-field patterns from the Planck telescope

The Planck telescope consists of two reflectors, a subreflector and a main reflector, see Figure 1 a). The reflector geometry is used to investigate how the feed radiation propagate through the telescope.

Each mode is propagated through the telescope applying GO (geometrical optics) on the subreflector and PO (physical optics) on the main reflector. From the PO currents induced on the main reflector the far-field pattern of each mode is calculated. The total radiated far-field pattern is again calculated by addition of the individual power patterns and the result is shown in Figure 3.

A Gaussian beam in the Planck geometry can obtain a resolution at the 3 dB beam width of ~0.03°. However, various limitations of the Planck system result in a resolution of ~0.083°. It is therefore not possible to use the information stored in a 0.03° resolution and it is more desirable to use a multi-moded horn where the total power envelope is broader and contains more power.

This effect is illustrated in Figure 3 where the total radiated beam of all 30 hybrid modes is compared to a Gaussian beam emanating from an optimum feed position.

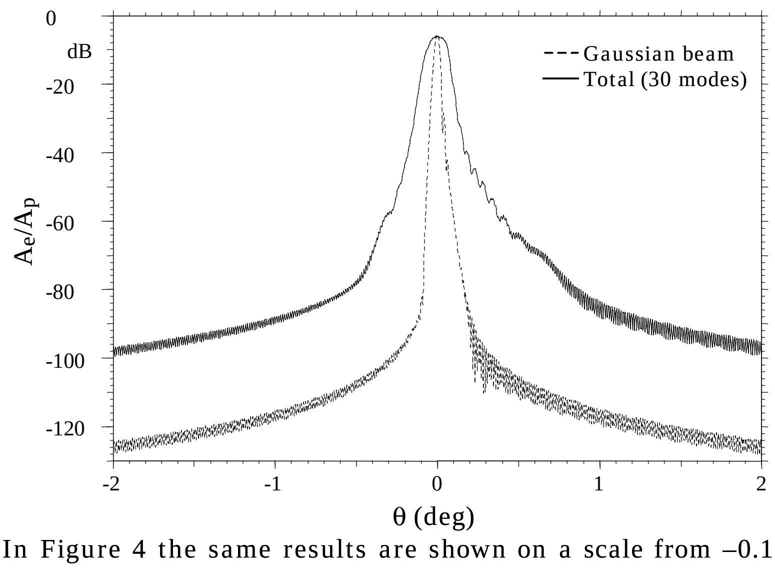

Figure 3
Telescope radiation patterns from the Planck telescope at 857 GHz. The total power pattern is the sum of the power patterns from each of 30 hybrid modes. A conventional Gaussian beam radiating with a taper of -30 dB at 19.4° is shown to illustrate how it is possible to increase the received power by using a bolometric detector**.**

In Figure 4 the same results are shown on a scale from –0.1° to 0.1°. The 3 dB beam width of the total radiated pattern is ~0.12°.

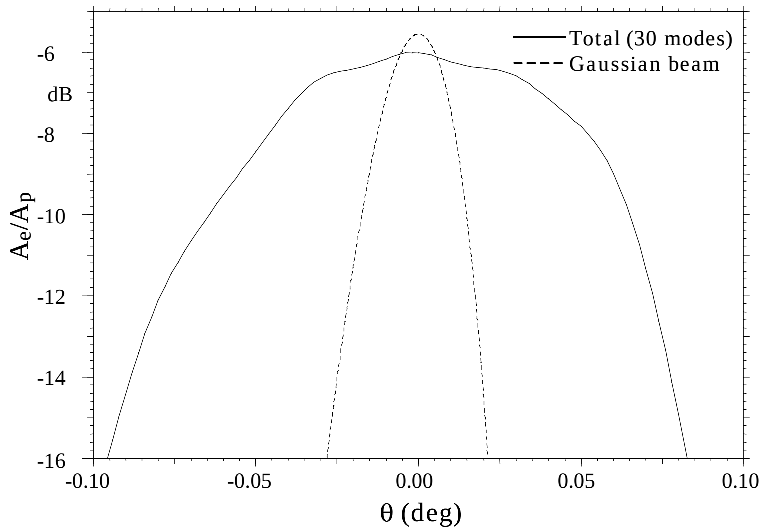

Figure 4
The results of Figure 3 shown on a scale from –0.1° to 0.1°. A 3 dB beam width of ~0.12° is observed for the total 30 modes pattern.

Conclusions

The results presented in this paper show that it is possible to calculate the receive pattern of a multi-moded horn coupled to a bolometric detector. In particular, the receive pattern of the horn is found by adding the power of the individual modes in the far field. The Planck telescope feed horn at 857 GHz that support 30 hybrid modes was used to illustrate this calculation method.

References

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