Optimization of axially-corrugated horns for symmetrical or offset parabolic reflectors

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ABSTRACT

A new technique to optimize axially-corrugated horns for symmetrical or offset parabolic reflectors is described. The technique is fast, accurate and permits optimizing a horn to suit a given reflector geometry. Multi-frequency and multi-band optimizations are possible to cater for transmit/receive applications. The technique is illustrated by the design of a Ku-band transmit/receive horn for a reflector with a F/D of 0.575.

INTRODUCTION

Parabolic reflector antennas, both symmetrical or offset, are commonly used for communication or VSAT applications. These antennas are cheap to manufacture (usually pressed by a hydraulic press for the smaller size or spun for sizes up to 2.4m in diameter) and can be bought off-the-shelf with a variety of F/D characteristics (where F is the focal length of the reflector and D the diameter of the projected aperture). However, the importance of high performance feeds to feed these reflectors tends to be underrated or even forgotten. Many feeds on the market are based on the same empirical design and have been around for many years. They may not even have been designed for the particular reflector geometry they are currently used with. There should be no good reason for this nowadays, as with the advance in computer speed and electromagetic methods, one can easily optimize a smooth-walled or a corrugated horn [1] to feed a given reflector geometry.

The geometry of a symmetrical parabolic reflector is quite simple, being defined by its diameter D and its focal length F (see Fig. 1), but there is usually some blockage by the feed and the supporting struts where the maximum level of energy is located. The offset parabolic reflector geometry is slightly more complex [2] [3], but the advantage is that it is possible to design the antenna to avoid blockage by the feed or to move this blockage towards a region on the aperture where the field is weak. Many companies use elliptical apertures for their offset parabolic antennas, and a generic drawing of such antennas is shown in Fig. 2. Explanations about the various parameters can be found in [2] and [3].

For a given F/D ratio, the half-subtended angle at the feed (see Fig. 1) can be calculated using the following formula:

$$Half-subtended\ angle = ArcTan\left[\frac{8\frac{F}{D}}{16\left(\frac{F}{D}\right)^2-1}\right] \qquad (1)$$

Typically, F/D varies from 0.3 to 0.6, which corresponds to half-subtended angles from about 80º to 45º. In this paper, we will concentrate on the design of small, prime-focus, axially-corrugated horns that can be optimized for various F/D values, i.e., various half-subtended angles in the 45º to 80º angular range.

Particular applications require different illuminations for the reflector, e.g., for maximum gain, for sidelobe levels or beamwidth [4]. In this paper, however, we will try to provide a –12 dB taper at the edge of the reflector [5] as it is deemed to be a good compromise between the efficiency of the reflector and the spillover efficiency (energy from the feed spilling over the edge of the reflector, i.e., lost energy).

CHOKED-HORN OPTIMIZATION PROCEDURE

There are many different feed types available to illuminate a reflector [6]. However, in recent years, horns with axial corrugations have been widely used because they provide good performance over a useful frequency range that could encompass both receive and transmit frequencies for typical satellite applications.

Let us consider the geometry of an axially-corrugated horn with N corrugations, as in Fig. 3 (for simplicity, N=4 in this general geometry). The required parameters are the input radius “ai”, the pitch “p”, the width “w” and tooth-width “t” of each corrugation (i.e., a pitch-to-width ratio of w/p), the output radius (ao=ai+Np), the flange-width and the depths and length making the corrugations (d1 to dN and L1 to LN). For a given horn, we specify the input radius, the number of axial-corrugations and the pitch (therefore fixing the output radius), width, tooth-width and the flange-width. We are then left with the depth (di) and length (Li) of each axial-corrugation “No i” (with i=1-N), and these are the parameters that we will optimize to shape the radiation pattern of the horn.

A computer program has been written to optimize the parameters of the horn to meet a specified radiation pattern. The horn synthesis is based on minimization of a penalty function representing a measure of the extent to which the pattern constraints are violated. The approach is similar to that which has been applied to the synthesis of array feeds for reflectors with gain pattern constraints [7], the only difference in this case being that corrugation-parameters rather than feed-parameters are the variables to be optimized. The penalty function is of the least p^{th} index form with p set equal to 2. The minimization is done via a quasi-Newton method in which the derivatives are approximated by finite difference. The program can handle multi-frequency optimization for wide band or multi-band applications. The desired pattern-envelope for each frequency is supplied by the user as a list of angular points that specify weighted upper- and lower- bounds for the co-polarized pattern and a weighted upper bound for the cross-polarized pattern (see Fig. 4, but note that a specification in dBi is also included in the program). The program uses the mode-matching technique to calculate accurately the radiation pattern of any given geometry [8][9]. Also included is the effect of a finite flange on the radiation pattern of the horn. As the reflector can sometime be in the near-field of the horn, the program can handle the radiation pattern optimization at any given distance in front of the horn’s aperture.

EXAMPLE

We take as an example a transmit/receive Ku-band horn (receive band: 10.70-12.75 GHz, transmit band: 13.75-14.50 GHz) designed to feed a prime-focus parabolic reflector with a F/D of 0.575 (i.e, a half subtended angle of 47º). For this type of application, a horn with four axial corrugations (N=4) was selected as a compromise between the physical size required for the horn and the performance over the required frequency band.

We specify the radiation envelope to be a Gaussian taper with a –12 dB level at 47º and set a cross-polarization target of –35 dB. Ideally, we would like the radiation pattern of the horn to be constant over both bands to make as much use of the reflector as possible. In many low-cost feeds, the radiation pattern degrades substantially between the bottom and top of the band and this is another reason why optimization of the feed is critical for some applications.

The geometry of the horn after optimization is shown in Fig. 5 while the radiation pattern over the 10.70-12.75 GHz and 13.75-14.50 GHz frequency bands is shown in Fig. 7. It can be seen in Fig. 6 that the radiation pattern in both bands has been optimized to be almost identical. As mentioned earlier, this is very important to ensure optimum performance of the overall antenna.

This optimization technique has already been applied to a number of projects at CSIRO. It is fast and is applicable to any F/D ratio required by a specific application.

CONCLUSIONS

A new optimization technique has been applied to the design of axially-corrugated horn for symmetrical or offset parabolic reflectors.

This technique permits the quick optimization of a horn for any given reflector geometry, allowing each feed/reflector combination to be optimum for the given application. The method is fast, accurate and the feed geometry is simple enough to be easily manufactured on CNC machines for low-volume productions or by die-casting for high-volume production.

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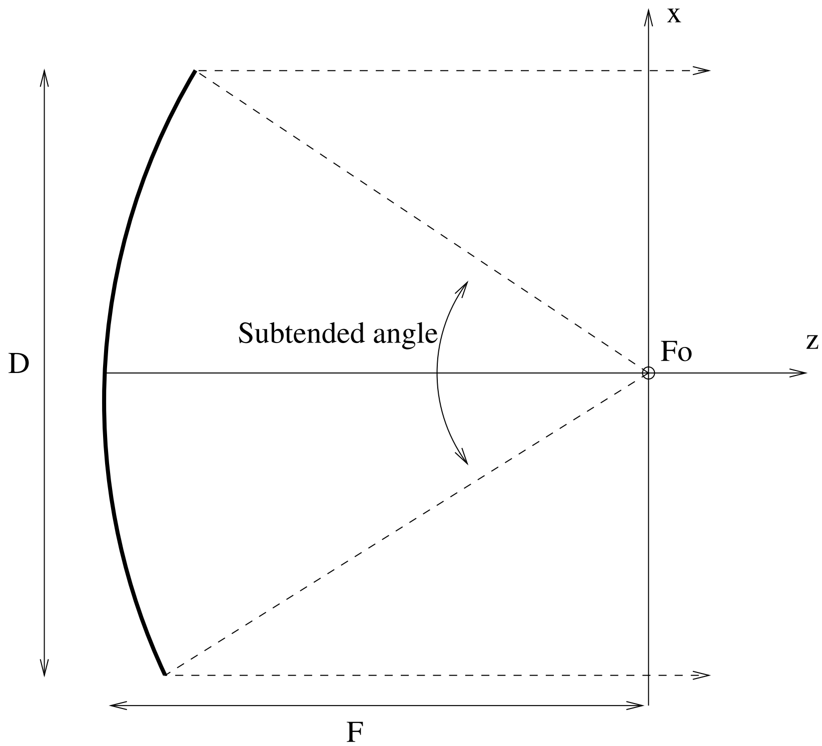

Figure 1: Geometry of a symmetrical parabolic reflector.

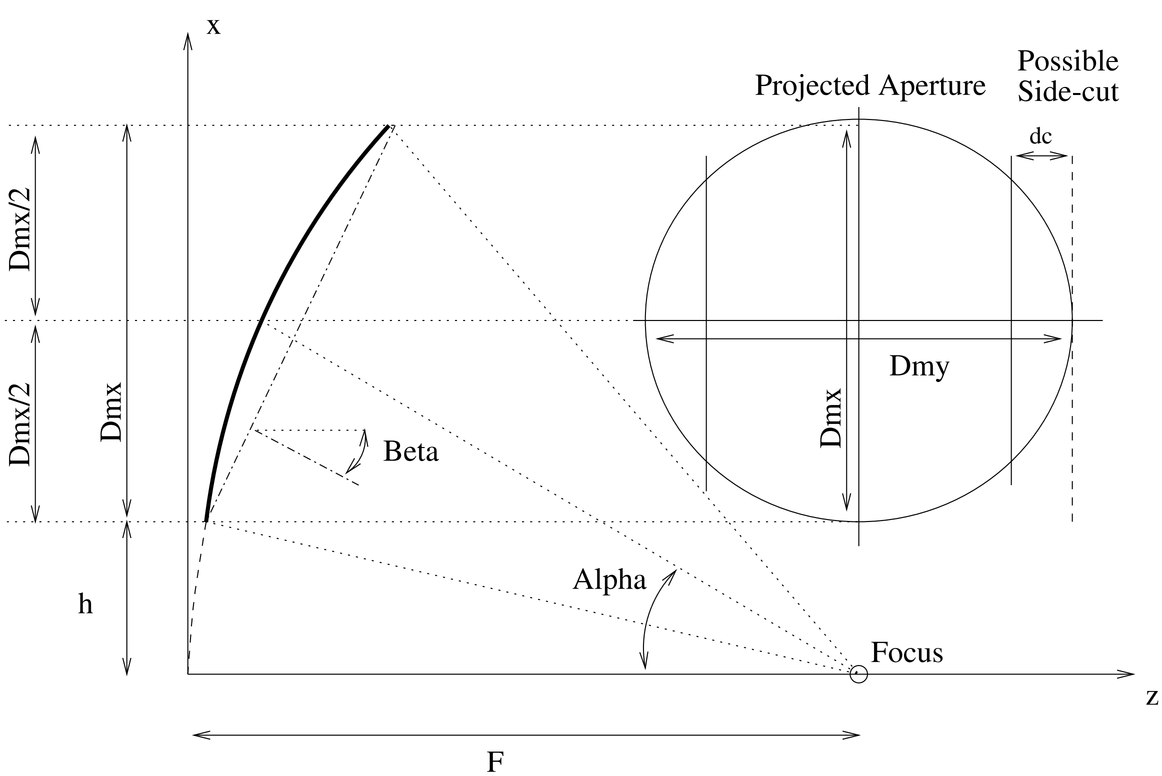

Figure 2: Generic geometry of an offset parabolic reflector.

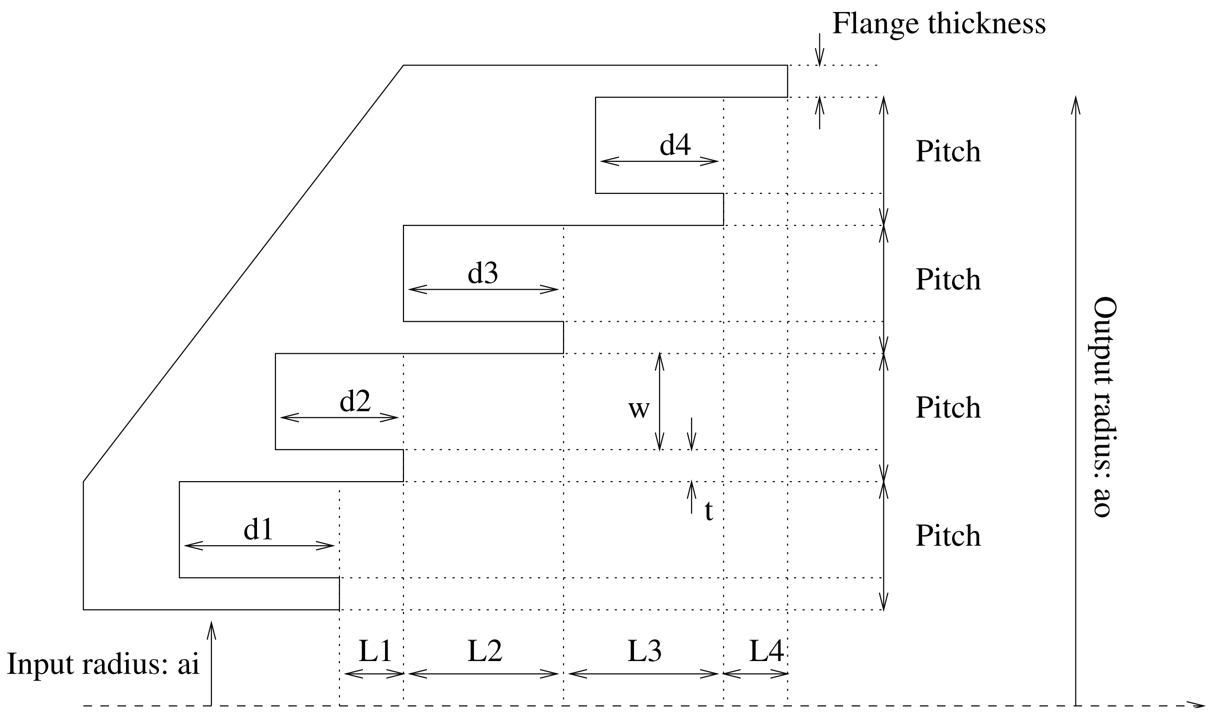

Figure 3: Example of a choked-horn containing 4 corrugations.

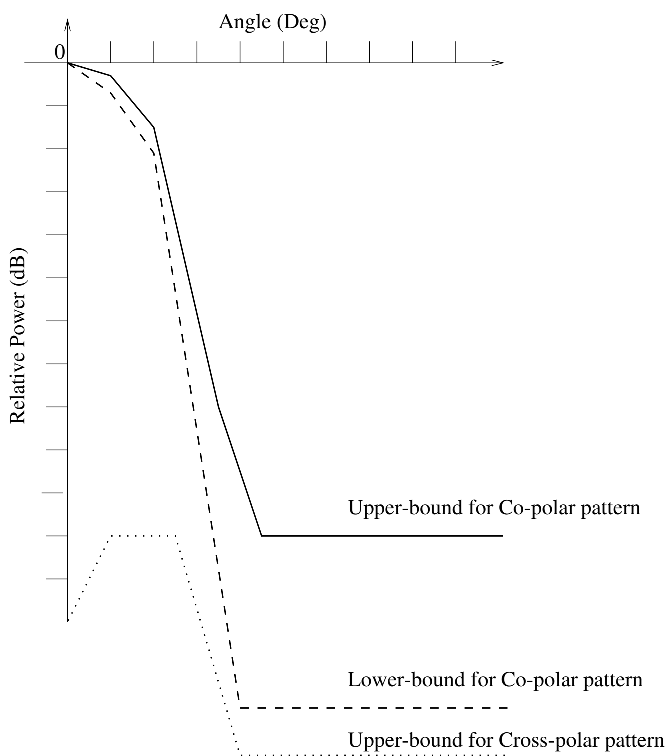

Figure 4: Envelope pattern used for the optimization.

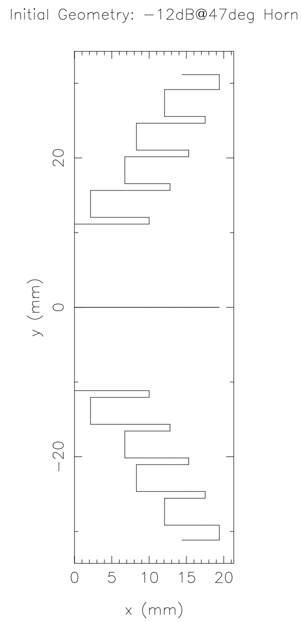

Figure 5: Geometry of the Ku-band receive/transmit horn after optimization.

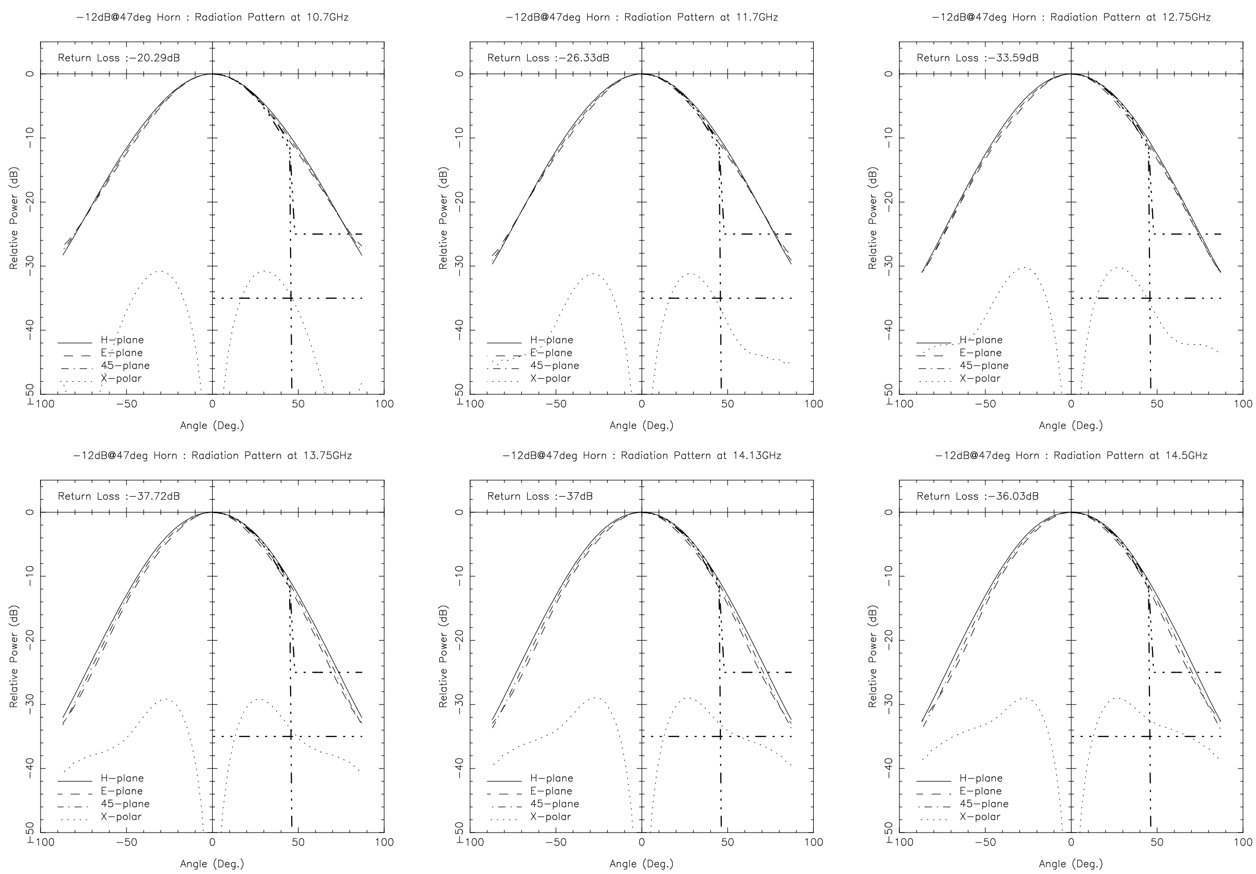

Figure 6: Radiation pattern of the Ku-band horn over the 10.70-12.75 GHz and 13.75-14.50 GHz frequency bands.