A Pickett Potter Horn-Reflector Antenna for Submillimetre-Wave Applications

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ABSTRACT

In this paper, we present a new type of horn-reflector antenna. The design employs an offset parabolic reflector fed by a Pickett-Potter horn. The horn is essentially a smooth-wall conical horn with a single step at its throat. This arrangement is a simplified version of the conventional Potter horn and is much easier to manufacture than the corrugated horn. We designed a Pickett-Potter horn-reflector antenna for a 700 GHz SIS mixer. We also developed and tested a 15 GHz scale model. We found that the Pickett-Potter horn and horn-reflector antenna has good beam circularity and a return loss value better than –25 dB over a bandwidth of about 15%.

INTRODUCTION

Astronomical interest in submillimetre wavelengths has increased considerably in recent years. High quality SIS heterodyne detectors led to new discoveries in the area of spectroscopic submillimetre astronomy. Conventionally, a high-quality mixer feed consisted of a corrugated horn corrected by a dielectric lens. This is because a collimated circular beam (near equal E-plane and H-plane radiation patterns) with low sidelobes is required for many astronomical applications.

At short wavelengths, however, machining of scalar horns is difficult, expensive, and time consuming, in particular for large format imaging arrays where many detectors are needed. In addition, dielectric lenses introduce considerable problems such as multiple reflections and diffraction which, if not carefully considered, could result in high sidelobe levels.

In this paper, we present an alternative design which retains the beam circularity of the corrugated horn and yet is much easier to fabricate. The proposed design is horn-reflector antenna [1], which comprises a 90° offset parabolic reflector fed by a Potter horn [2]. The feed is a dual-mode horn of the type developed by Potter which is essentially a smooth-wall conical horn with a single step at its throat. It is a simplified version of the classical Potter horn and is clearly much easier to manufacture than the corrugated horn.

As we shall see later, this horn has many of the desirable properties of the scalar horn, namely, low sidelobes and cross polarisation. The parabolic reflector is located very close to the horn aperture (the case in the conventional horn-reflector design) and corrects the phase error at the horn aperture, resulting in a high efficiency antenna with a collimated beam without the use of dielectric lenses.

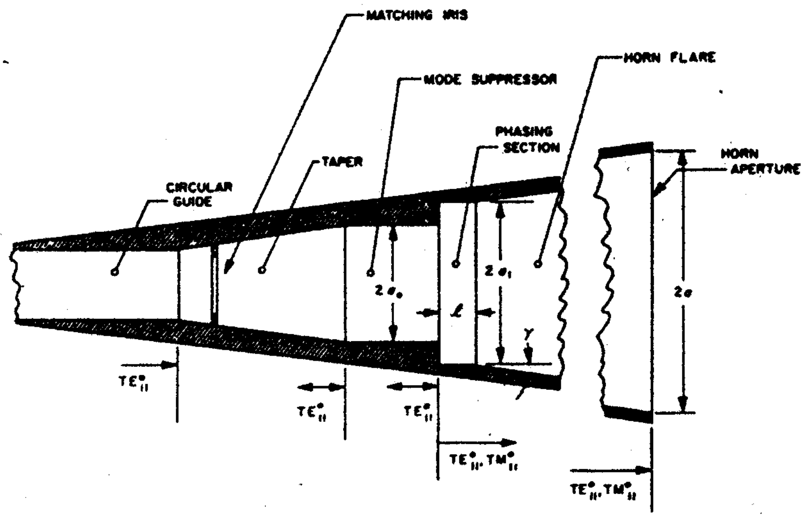
We have conducted extensive theoretical investigation of the Potter horn-reflector antenna at 700 GHz in view of its application in submillimetre receivers. In particular, we developed software packages to calculate the parameters which determine the bandwidth of the antenna such as the return loss, the cross polarisation and the sidelobe levels. The Software calculates the scattering matrix of the horn using a modal matching method and then conformally maps the horn aperture field onto the projected aperture plane.

Based on our theoretical model we designed and fabricated a 700 GHz Potter horn reflector antenna machined into an aluminum split-block. The block has already been loaded with a 700 GHz finline chip and beam pattern tests of the antenna is in progress. In addition we constructed a 15 GHz scale model antenna and carried out extensive out-door radiation pattern tests of this antenna. We obtained excellent agreement between the computed and measured results. In particular, we demonstrated that the bandwidth of the antenna can approach 15% which exceeds 100 GHz at a central frequency of 700 GHz. Our work also suggests that Potter horn reflector antennae could be fabricated at frequencies well above 1 THz.

1. The Pickett-Potter Horn

A dual mode of the type developed by Potter [2] is shown in Fig 1. It has a tapered section connecting two circular wave guides, a step transition to a larger circular waveguide, a phasing section and a conical horn section.

Figure 1. Potter Horn



The step transition generates a small fraction of TM_{11} mode as well as the propagating TE_{11} mode. The phasing section and the conical horn combine to create a phase difference between the two modes at the aperture relative to the phase generated at the step. The dimension of the phasing section and the horn length are chosen so that the TM_{11} and TE_{11} reach the horn aperture in phase. Consequently, the effect of the TM_{11} mode is to make the E plane aperture distribution more tapered than it would be for a standard single-mode conical horn. The E-plane and the H-plane aperture distributions therefore become similar to those in a corrugated horn.

A simplified version of the conventional Potter horn was first introduced by Pickett [3] in 1984. Here, the phasing section is removed, leaving a single step discontinuity at the throat of the horn, as shown Fig. 2.

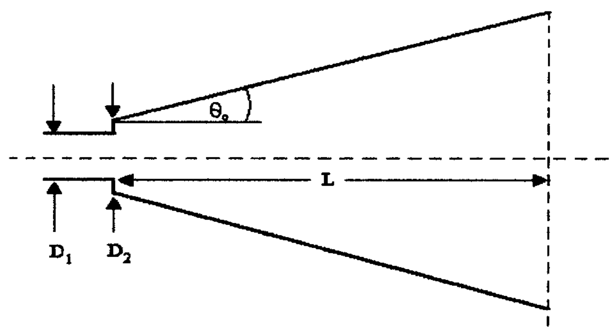


Figure 2: Pickett Potter Horn Design for semi-flare angle 15°.
$D_1 = 1.036\lambda_0$, $D_2 = 1.295\lambda_0$, $L=13.53\lambda_0$ and $\theta_0 = 15^0$

The modification simplifies greatly the horn fabrication; however, the relative phases between modes can now only change as the modes propagate along the horn itself. Consequently, the horn dimensions, normally chosen to obtain a predetermined beam shape, are now constrained by the requirements of minimum phase difference between the two modes. In all other respects, the electrical properties of this simplified horn are identical to the original Potter horn.

1.1 Calculations of the electrical properties of the Pickett-Potter horn

We have developed software that allows us to predict the performance of the Pickett-Potter horn-reflector antenna. This is done by calculating the scattering matrix and the aperture field distribution of the horn using a modal matching technique, In this method, the horn is divided into discrete sections with a minimum of 20 sections per wavelength. At each junction, a scattering matrix is calculated by matching the coefficients of the modal fields. The overall scattering matrix of the horn is calculated by cascading the matrices of the individual sections. The transmitted and reflected coefficients are extracted from the resulting scattering matrix.

Calculations of radiation patterns are done using Kirchhoff's aperture diffraction theory. The co-polar and cross-polar patterns are defined using Ludwig's third definition of cross polarization as:

$$\begin{pmatrix} E_{cp} \\ E_{xp} \end{pmatrix} = \begin{pmatrix} \sin\theta & \cos\phi \\ \cos\theta & -\sin\phi \end{pmatrix} \begin{pmatrix} E_{\theta} \\ E_{\phi} \end{pmatrix}$$

where θ and ϕ are respectively the polar and azimuthal angles on the observational plane. The following parameters were used to design the horn: a centre frequency of 700 GHz, a semi-flare angle at 15^0, an aperture diameter of 3.8 millimetres and the two radii of the step discontinuity at the throat are 0.222 and 0.775 mm.

1.2 Measurements of Pickett-Potter horn

To verify the integrity of our theoretical method under ideal conditions, we designed a scale model at 15 GHz. The horn was fabricated in two sections and has the dimensions as in Fig 2. The horn was placed on a turntable at 10 m from a transmitter. We measured the E and H planes and the cross-polar pattern at 45^o. The measured patterns agree very well with the calculated values, as can be seen in Fig 3. The dynamic range of our receiver was about 27 dB.

In Fig 3, we also compare the measured patterns of the scale modal with those predicted at the high frequency range. It can be seen that the pattern quality at the design frequency (700 GHz) is comparable to that of a corrugated horn. The sidelobe levels are low and the maximum cross-polarization is –27 dB. At 770 GHz, however, the cross polarization level has increased to –18 dB. The return loss of the antenna was better than –25 dB across the bandwidth, as shown in Fig. 4. The best indicator of the bandwidth of the Pickett horn is the cross-polarization level, as given in Fig 5, and is used to define the useful bandwidth of the antenna. For example, a –20 dB cross-polarization level can be maintained over a fractional bandwidth of 15%.

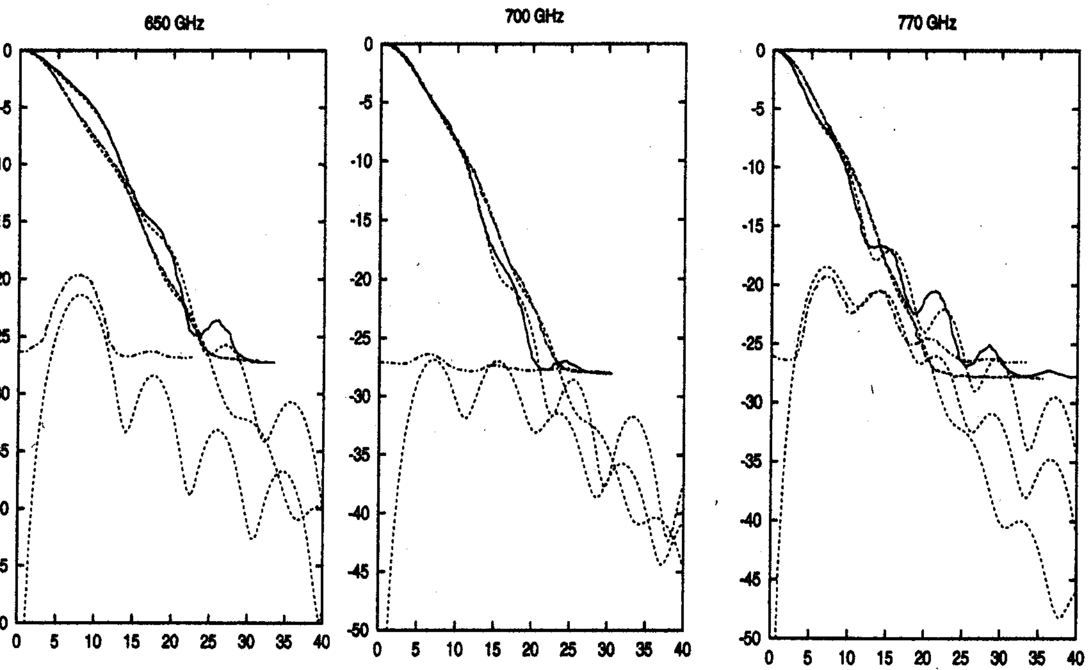


Figure 3a. 14.0 GHz **Figure 3b.** 15.0 GHz **Figure 3c.**16.5 GHz

Radiation patters of Pickett horn. Solid lines are measured E planes. Dashed lines are measure H planes. Dash-dotted lines are measured cross-polar. Dotted lines are calculated values.

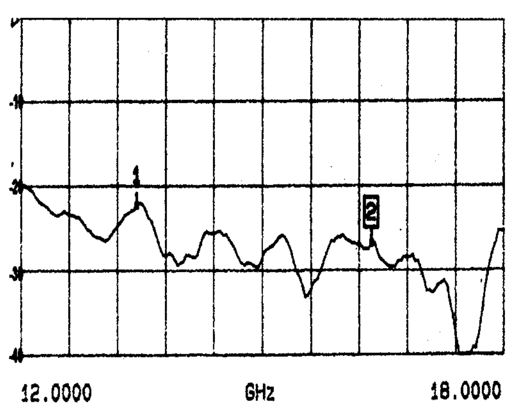


Figure 4. measured return loss

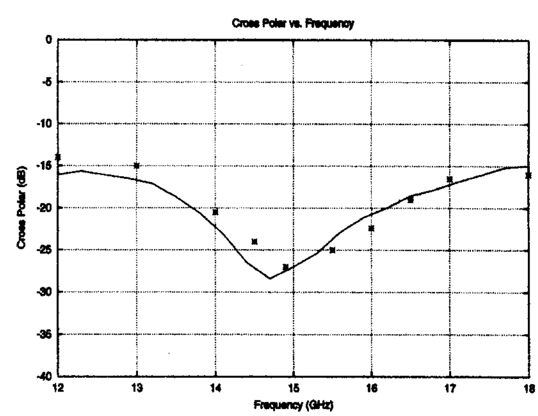


Figure 5. Cross polarization
Points are measured values

2. THE PICKETT-POTTER HORN-REFLECTOR ANTENNA

We calculated the horn-reflector antenna radiation patterns by assuming that the field at the horn aperture is given by that of a cylindrical waveguide at the step junction, multiplied by the spherical phase error factor, $\exp(-jkr^2/2L)$, where $\boldsymbol{r}$ is the radial distance in the horn aperture, $\boldsymbol{k}$ is the free space wavenumber and $\boldsymbol{L}$ is the distance from the aperture to the apex. We compared this method with a full modal-matching technique and found that the two methods agree very well for semi flare angle under 15^0. The field distribution of the horn aperture was then mapped onto the project aperture using conformal mapping [5].

We would like to emphasis at this stage that designing Potter horn-reflector antenna is not a straight forward extension of the design of the corrugated horn-reflector antennas. This is because in the latter case, the mode propagating in the horn is a single HE_{11} hybrid mode. For a given horn aperture, and assuming that the apex of the horn is located at the focal point of the reflector, the radiation pattern of the antennas is almost be independent on the length of the horn. This fact is no longer valid in case of the Pickett-Potter horn feed since the length of the horn determines the relative phase between the TE_{11} and TM_{11} modes. Our analysis nevertheless shows that it is indeed feasible to realize a horn-reflector fed by a Pickett-Potter horn with performance comparable to that of a corrugated horn-reflector.

We measured the radiation patterns of the antenna for two orthogonal polarisation, one in the plane of symmetry (longitudinal plane, L), and the other in the plane of asymmetry (Transverse plane, T). For each polarisation, the far field patterns was also observed in both the longitudinal (L) and transverse (T) planes. From Fig. 6 we notice that that the main beam shapes resemble that of a corrugated horn. Fig.7 shows measured values of half beam-width and Fig 8 shows the measured and calculated maximum cross polarization level of the Pickett horn-reflector antenna. The discrepancy between the measured and computed values of the cross polarisation levels in Fig. 8 is caused by the fact that the side plates which supported the reflector have very slightly clipped the beam.

It can be seen that the agreement between the measured and computed results at the design frequency is excellent down to –25 dB level. We would like to emphasis that the beam circularity of the Pickett horn-reflector antenna is significantly better than that of the horn alone.

14.9 GHZ (695 GHZ) Longitudinal Plane

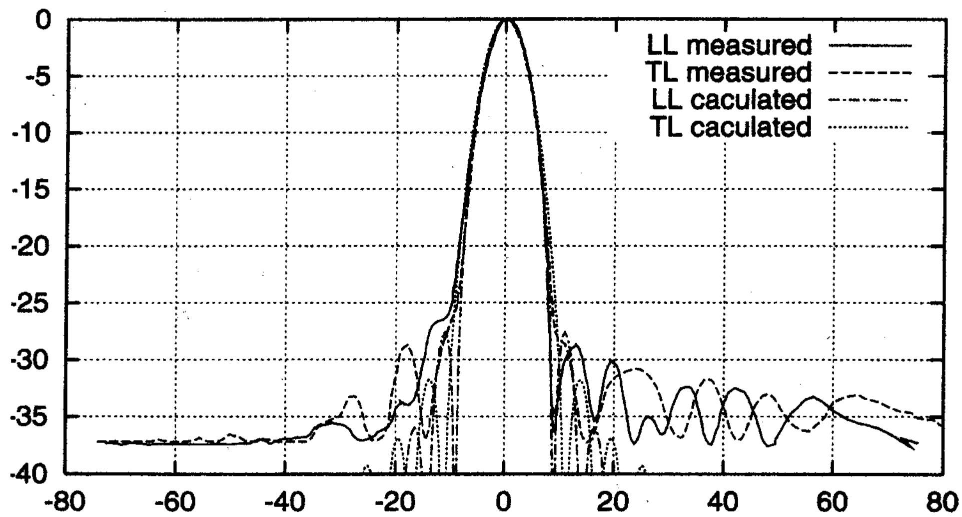


Figure 6a. Measured beam patterns at 14.9 GHz
(Longitudinal Plane of Observation)

14.9 GHZ (695 GHZ) Transverse Plane

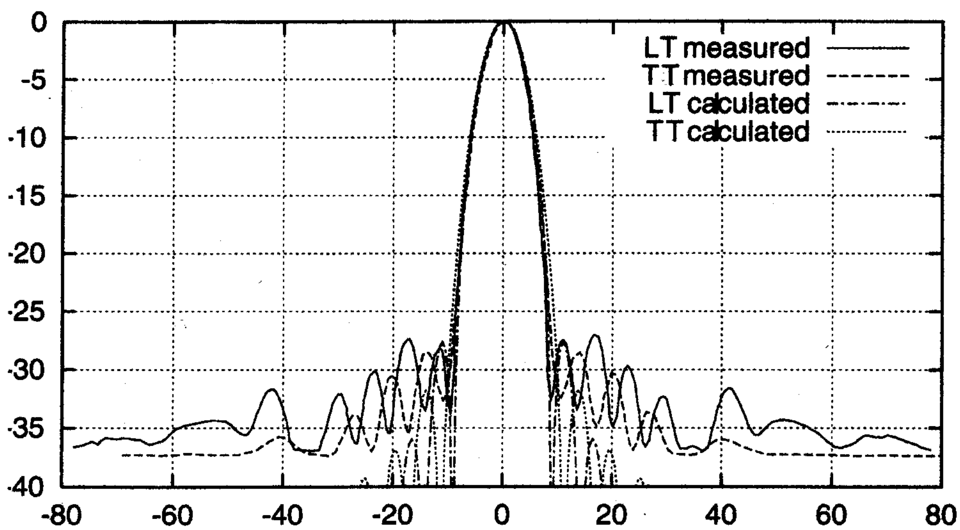


Figure 6a. Measured beam patterns at 14.9 GHz
(Transverse Plane of Observation)

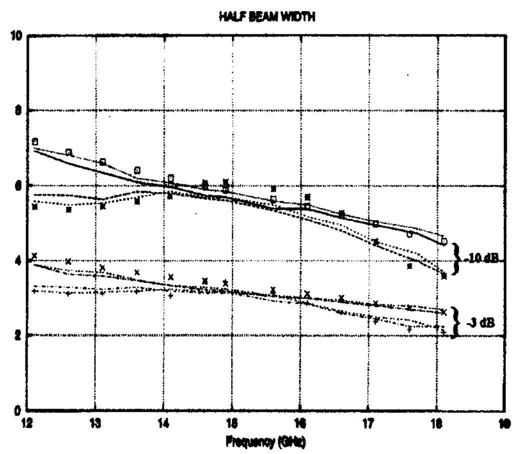


Figure 7. Calculated and measured half width at –beam width 3dB and –10 dB

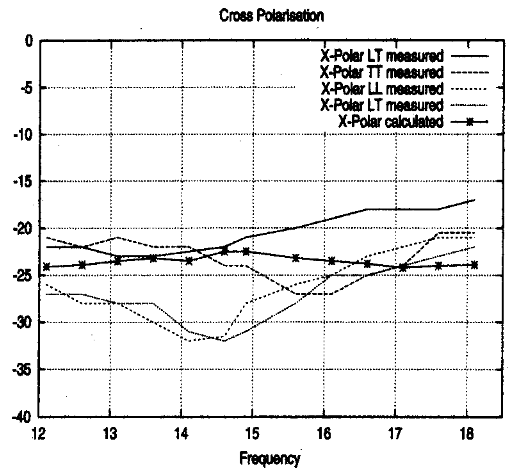


Figure 8. Measured maximum cross polarization level of Pickett-Potter Horn-Reflector Antenna.

CONCLUSION

We have shown that the Pickett-Potter horn can be employed in conjunction with horn-reflector antennas, provided that TE11 and TM11 modes reach the projected aperture in phase. Although the absence of a phasing section in the Pickett-Potter horn restricts the horn design flexibility, out study showed that practical horn-reflector antenna dimensions suitable for submillimetre wave array receivers can still be found. We designed and tested a Pickett-Potter horn-reflector antenna. We found that a –20 dB cross-polarization level can be maintained over a fractional bandwidth of 15%. Testing of a 700 GHz Pickett-Potter horn-reflector antenna is in progress.

ACKNOWLEDGEMENTS

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Reference:

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