A NOVEL COMPACT CORRUGATED HORN

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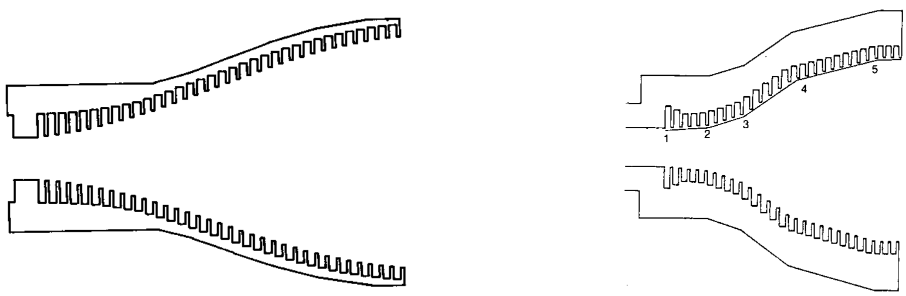
ABSTRACT

The paper describes a novel compact corrugated horn with a wide bandwidth over which both the sidelobe level and crosspolarisation are low. The horn comprises three sections, an initial flare from the horn throat followed by two straight sections whose flare angles are chosen so that the final section leads to a plane aperture. By making an appropriate choice of the change in flare angle and the position of the change, the adverse influence of the higher order HE12 mode can be greatly reduced, when it is excited at a change in flare angle.

INTRODUCTION

The corrugated horn is widely used both as a feed for a high efficiency reflector antenna, in quasi-optic feeds and as a direct radiator in, e.g., radiometer applications. Horns have been manufactured for use at frequencies between 1 GHz- 2 THz. At low microwave frequencies the size and mass of a conventional corrugated horn is excessive which renders them unsuitable for many applications including spacecraft. As an alternative [1,2], compact corrugated horns were proposed in the 1970s and a number of design studies have been reported; a typical profiled corrugated horn is shown in Fig. 1a). The principal adverse influence on performance by virtue of the profile arises because mode conversion occurs due to the change in flare angle along the horn length. The dominant mode of the corrugated horn is HE_{11} mode whose co-polar radiation pattern is symmetrical with low sidelobes and there is low off-axis crosspolarisation. However, this mode converts to higher order modes and in particular to the HE_{12} mode when the flare angle changes. That mode gives rise to a high first sidelobe and increased crosspolarisation. Olver and Xiang [3] have examined the characteristics of profiled horns and have also examined a horn divided into a number of segments as in Fig. 1b). At each discrete change in flare angle, higher mode excitation occurs but the use of optimisation enables a reduction in the adverse effect of the HE_{12} mode to be achieved over a modest bandwidth. Because they utilise a number of steps the cancellation of the HE_{12} mode in the aperture is never complete. In the new horn which we describe herein, we use only two changes in flare angle and thus achieve almost complete cancellation of the HE_{12} mode at mid-band. We can also achieve an improved performance over a 30% bandwidth.



a) b)

Fig.1. Profiled corrugated horns

METHOD OF ANALYSIS

Two methods of analysis of corrugated horns have been described in the literature. In one method the horn is represented by means of a very large number of cylindrical waveguide sections in which the normal modes are TE_{1n} and TM_{1m} [4]. Modal matching is then used to characterise the propagation behaviour and the fields in the aperture. Because the hybrid modes are synthesised from TE and TM modes, a large number are required especially in and near the aperture. The alternative method [1], [2], [5], which we have used, employs spherical hybrid modes which are the true normal modes of a conical hybrid mode horn. Thus only a few modes are required which is computationally more efficient. Our main approximation is to utilise the surface impedance to represent the fields at the slot boundary. Elsewhere this approximation has been shown to be very accurate [1]. We also employ the E-field approximation to compute the radiation pattern from the aperture field and again modal matching is used to evaluate the fields at each junction [2]. Although the method of analysis appears straight forward there are several issues which give rise to complexity.

Near the throat of the horn for the HE_{11} mode and at all points along the horn where a higher order mode begins to propagate, the propagation coefficient and the mode functions are complex as are the higher mode excitation coefficients when the flare angle changes. To achieve cancellation of the HE_{12} mode excited at the two flare angle discontinuities, account must be taken of the difference in propagation coefficient between the HE_{11} and HE_{12} modes over the second flare section as well as the phase changes at both flare angle discontinuities. All of these issues have been investigated in detail and an account is contained in reference 6.

THEORETICAL RESULTS

The propagation coefficients of the hybrid modes are obtained from the equations below [1]

$$p_n^m(q_1)(p_n^m(q_1) - \overline{Y}n(n+1)) = m^2\, \overline{b}^2 \big/ \sin^2 q_1$$
$$\overline{L} - 1\big/\overline{L} = \overline{Y}n(n+1))\sin q_1 \big/ m\overline{b}$$

As an example, Fig. 2 shows the real part of the propagation coefficient for the HE_{11} and HE_{12} modes in a horn of flare angle $q = 10°$, where kR is normalized slant distance. Also shown is the differential phase change between the above modes. At a change in flare angle the HE_{12} mode is excited and Fig. 3 shows the excitation coefficients for a number of flare angle changes and at the different radii. From an accurate analytical study, we have observed that the following empirical relations are obtained which can be very useful in an initial design study

$$\left|S_{21}\right|^{HE_{11}\rightarrow HE_{12}} \propto 0.1Dq\ kr\,,$$
$$Dj^{\ HE_{11}\rightarrow HE_{11}} \propto 0.4\,Dq\ kr\,,$$
$$Dj^{\ HE_{11}\rightarrow HE_{12}} \propto 90^\circ + 0.3\,Dq\ kr\,,$$

where Dq – flare angle change, kr – normalized junction radius.

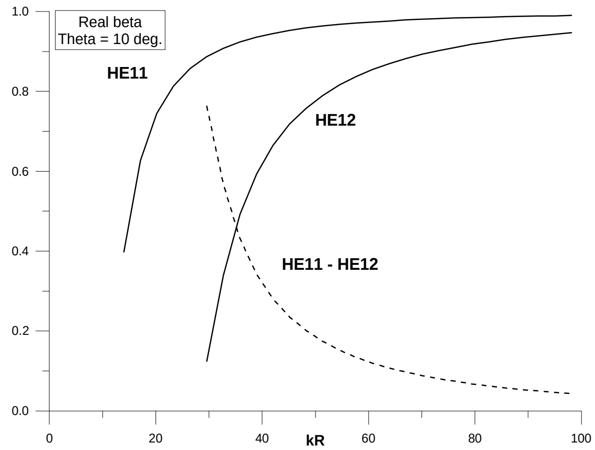


Fig.2. Propagation coefficients and differential phase change for the HE11 and HE12 modes

At the second flare angle change, cancellation of the HE_{12} mode requires that the amplitude of the incident and excited modes are equal and are of opposite phase. However we should recall that the HE_{11} mode which is converted to the HE_{12} mode at the second junction has also accumulated a phase change along the length of the second section and it is the difference in phase between the HE_{11} and HE_{12} modes which is important together with the phase of the excitation coefficients at the two junctions. Because the excitation amplitude depends on the transverse radius of the horn at the point where the flare angle changes, as well as the actual change in angle, the optimum design requires the information in both Figs 2 and 3, to obtain cancellation at mid-band.

In Fig.4 we show how the amplitude of the HE12 mode varies with frequency for a typical horn with just two changes of flare angle. The radiation pattern at mid-band is shown in Fig. 5, while in Fig.6 the level of first sidelobe and the maximum level of cross-polarization is also shown as a function of frequency.

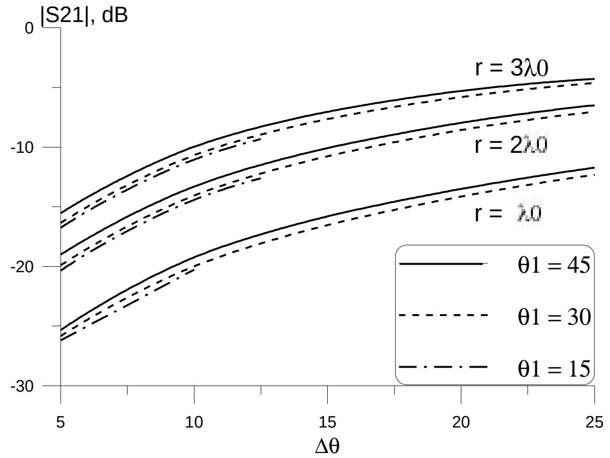


Fig.3. Normalized excitation coefficients as a function of flare angle change. Parameters – q_1 and r

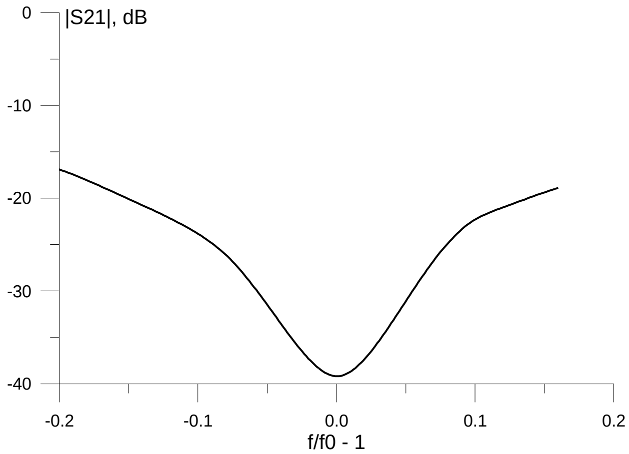


Fig.4. Normalized excitation coefficient as a function of frequency

CONCLUSIONS

We have compared our results with those obtained previously by Olver and Xiang and observe a significant reduction in the level of the HE_{12} mode at mid-band and an increase in bandwidth over which the first sidelobe level below –18 dB.

The new horn offers other benefits: because only two control sections are deployed in which the flare angle is changed, fewer parameters characterise the horn. Thus if optimisation is required to achieve a particular aspect of performance, the optimisation is computationally less demanding. From a mechanical standpoint, the new horn is simpler to construct and, for example, if a horn with constant flare angle exists it is a simple matter to attach two additional sections.

Experimental studies are in progress but as excellent agreement between experiment and theory has been obtained in the past [3], we are confident of the outcome which will be published later.

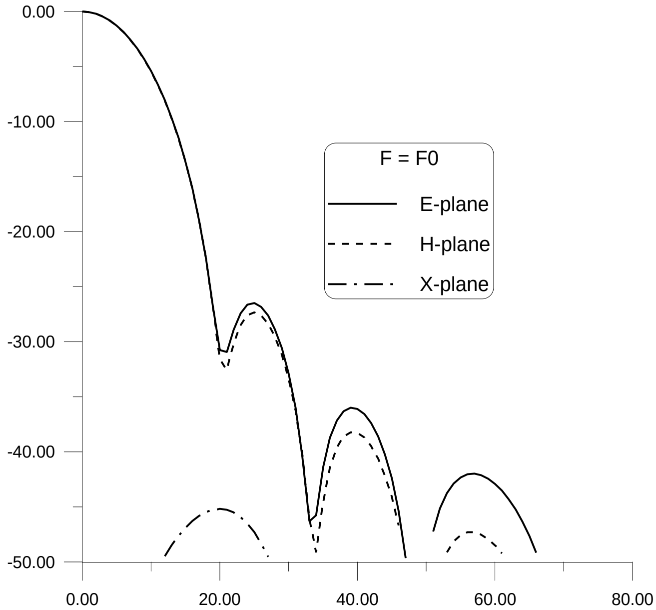


Fig. 5. Mid-band radiation pattern of a profiled corrugated horn with two flare angle changes.
Axial length - $7l_0$, aperture diameter - $5l_0$, flare angle of sections: $q_1 = 38°$, $q_2 = 15°$, $q_3 = 2.5°$.

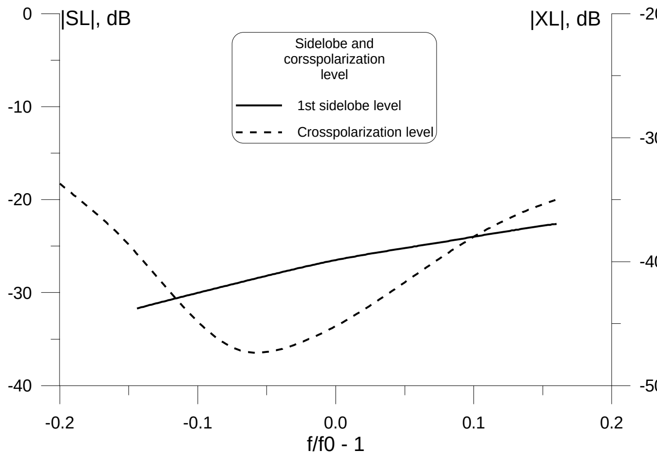


Fig.6. Sidelobe and crosspolarization level as a function of frequency

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