PROTOTYPING OF RADIAL SLOT ANTENNAS FOR THE DIRECT TO HOME SATELLITE TV IN AUSTRALIA

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ABSTRACT

A cost-effective prototyping method for low profile radial slot antennas suitable for receiving Direct to Home Satellite TV programs is described. Using this method, a 0.4m and a 0.6m diameter linearly polarised Ku-band prototype antennas were constructed and tested. Preliminary measurements show high radiation efficiency for this form of radial slot antenna, and its suitability for the DTH-TV application.

1. Introduction

The recent launch (in 1992 and in 1995) in Australia the Optus B series satellites has made possible Direct to Home (DTH) broadcasting of television. This has been achieved due to a special antenna system on the Optus B series satellites which incorporates a beam called the High Performance beam. This beam covers over 80% of the Australian population at an EIRP level in excess of 50dBW. The use of High Performance beam together with the series B 50W transponders means that more than 80% of the Australian population requires only a 60cm diameter parabolic antenna together with other equipment such as a down converter and an integrated receiver/decoder to receive Satellite Broadcast television programs. However, the use of a standard parabolic dish has some disadvantages. In a primary fed design, there is a considerable aperture blockage. An offset design which eliminates the blockage is on the other hand susceptible to physical damage as its feed is significantly exposed from the body of the reflector. Also in the latter design, the alignment procedure is quite involved. A more beneficial design is that of the Radial Line Slot Array (RLSA) type antenna as proposed in [1]. Advantages of this antenna include its low profile, the ease of installation, and possibilities of unexposed mounting on roofs or vertical walls (if suitable beam steering techniques are applied). Aspects of the design of this type of antenna, with linear polarisation and gain in the range of 30dBi are discussed in this paper.

2. The Radial Line Slot Array Antenna Design

The configuration of the investigated single layer, linearly polarised RLSA for use in Australia is shown in Figure 1. The structure consists of two plates, spaced a distance d apart, with the upper plate bearing a radiating slot pattern. The radial cavity formed between these plates is filled with a dielectric material of relative permittivity $\varepsilon_g > 1$. The purpose of this dielectric is to form a slow-wave structure to ensure that the guided wavelength λ_g is less than the free space wavelength λ_0. This is to avoid grating lobes in the radiation pattern.

A plane wave incident on the upper antenna structure is coupled inside the cavity via a sequence of slots. The orientation of slots is such that only waves of proper polarisation (linear, circular or elliptical) are coupled inside the cavity. This coupling results in the formation of an axially symmetric wave which travels in the radially inward direction in the cavity. Any residual wave which travels in the outward direction in the cavity is dissipated in the match termination (absorbing material). The feed probe receives an inward travelling wave and couples it to the coaxial transmission line which in turn feeds a low noise amplifier. In order to obtain a good impedance match between the radial cavity and the coaxial line, an area of radius ρ_m is left without slots on the upper cavity surface, allowing the field to stabilise.

Much research into RLSA antennas has been performed in Japan, with a lot of success reported for circularly polarised antennas. However, the design of a linearly polarised RLSA which would be required for reception of DTH Satellite TV in Australia is still not fully established [2]. Because of this, further investigation of linearly polarised RLSA are required. As a full wave analysis of the complete RLSA is very complicated, a hybrid theoretical/experimental approach is proposed by the authors. In this approach, the design of the feed and the radiating surface is divided into separate tasks. The feed design is aided with the software which has already been developed in [3]. On the other hand, the optimisation of the radiating surface which produces a linearly polarised wave is achieved in an iterative experimental manner.

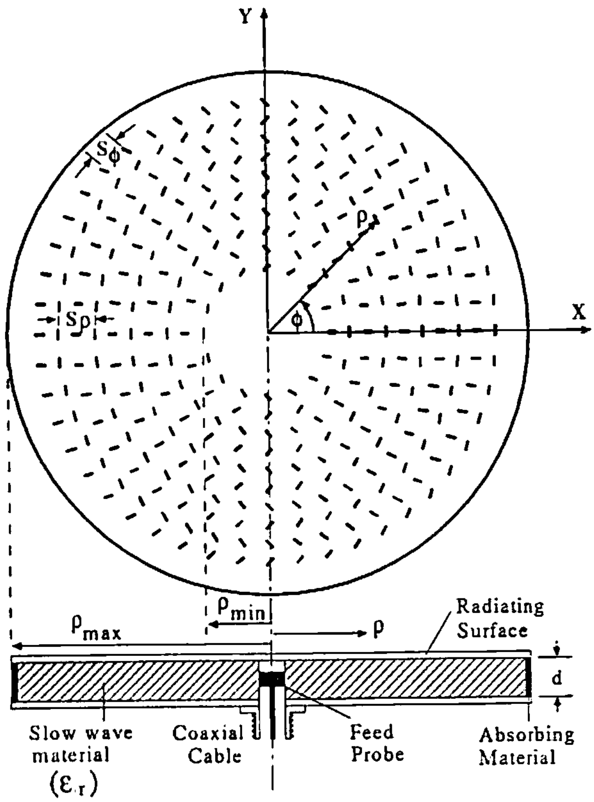

Figure 1 Single Layer RLSA Structure

3. Prototype Development

The design of the coax-to-waveguide transition was approached from a standpoint that for a properly designed slot pattern, the radial cavity should operate as a match terminated radial guide. Under such conditions, the design of the feed is regarded as the design of the transition from the coaxial line to the matched radial guide (or vice versa). The task is to obtain high return loss of this transition at least over the frequency range of interest, being the frequency band allocated for reception of the satellite TV signal. In Australia, the design band is 12.25 to 12.75 GHz. The other bands, if required, can be covered in a similar way. A disc-ended coaxial probe (as shown in Figure 1) was assumed to be a good candidate for the coaxial-to-radial guide transition. In order to obtain the dimensions of this probe for high return loss, the software described in [3] was applied.

The radiating surface was developed using a combined theoretical and experimental approach. For a centrally excited, linearly polarised antenna as shown in Figure 1, the requirement for linear polarisation (in the +x direction) results in simple, closed form mathematical equations for the slot inclinations with respect to the current flow line (ρ , ϕ=constant). Based on these equations, PC based software was developed to generate the required slot coordinates. In the next step, a relatively inexpensive method must be found to create the slot pattern in a conducting surface. This is a non-trivial task, as the number of slots to be produced is in the order of 1,200 for the 400mm prototype and 4,700 for the 600mm case, which includes reflection cancelling slots. The option chosen in this work was to use a Computer Aided Manufacturing (CAM) technique to make slots in a metallic foil which was then adhered to the dielectric material forming the antenna's slow wave structure. The construction of a single radiating surface using this method was found to be very cost-effective, coming in at less than $50 for a single radiating surface, including labour and machine time costs.

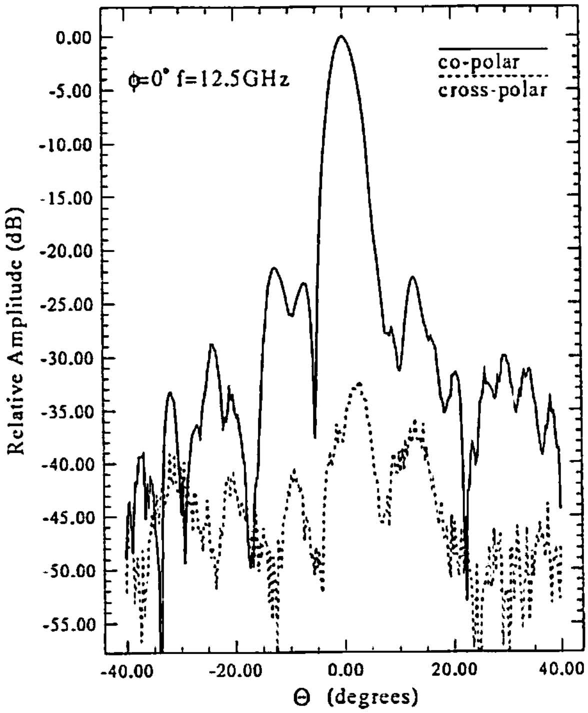

Figure 2 400mm Prototype Radiation Pattern

4. Results

Using the development procedures for the feed and the radiating surface outlined above, 400mm and 600mm diameter prototypes were constructed. The 400mm prototype was a standard design without reflection cancelling slots. On the other hand the 600mm diameter prototype featured extra reflection cancelling slots. In keeping with the low cost approach, commercially available polypropylene of thickness d=6mm was chosen for the slow wave material in both cases. Measurements on this material indicated a dielectric constant of ε_r=2.33, and low loss performance with ε_r''<0.096 over the frequency band of interest. The height of the slow wave structure, d=6mm, being 0.38λ_g is consistent with the requirement for exciting only the dominant mode of operation within the parallel plate guide (d<½λ_g). The other design parameter for the two prototypes was ρ_m=50mm. The feed included a standard SMA probe modified by adding a terminating disk according to the following specifications: air gap under disk=1.6mm, disk height=3.6mm, disk radius=1.415mm. The radiating surface had slot lengths ranging from 5.2 to 7.1mm, slot width=1mm, $S_\rho=\lambda_g/2$=7.85mm, S_ϕ=13.35mm. The number of radiating slots was 1,200 for the 400mm prototype and 2,350 for the 600mm prototype.

Figure 2 shows the measured radiation pattern for the 400mm prototype in the Fresnel zone obtained at 12.5 GHz. From the measured 3dB beamwidth of 4.5°, an estimated antenna directivity of 32dBi has been obtained. This is equivalent to an aperture efficiency of 58%. The main factor bringing this efficiency figure down would be due to the non-uniform aperture amplitude taper and phase distribution. Also, with measurements being taken in the Fresnel Zone, higher gain is expected in the Far Field Zone. In order to estimate the antenna's gain, the return loss of the feed also needs to be included. Although the measured return loss for the constructed prototype feed transition was approximately 20dB over the 12 to 13 GHz band for the case of the matched parallel plate radial guide with no slots, it dropped to approximately 6dB across 12.25 to 12.75 GHz band with the slot surface in place, reducing the total antenna gain by approximately 1dB.

To combat the low return loss which was present in the 400mm diameter prototype, a 600mm diameter prototype with extra reflection cancelling slots was constructed. The sequence of extra slots was introduced following the postulates in [4]. For obtaining the radiating surface, the same CAM procedure as for the 400mm diameter prototype was used.

The return loss of the constructed 600mm prototype was then tested, and found to offer an excellent improvement over the prototype surface with no reflection cancelling slots present. The return loss for both the 400mm and 600mm prototypes are shown in Figure 3 for comparison. Initial tests of

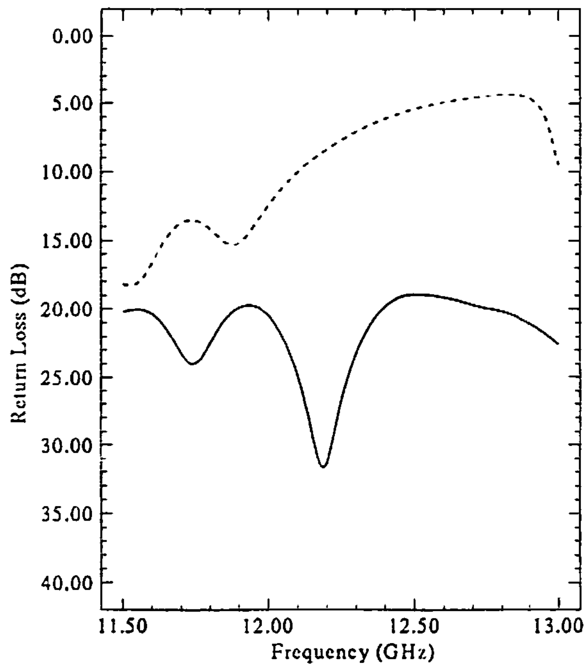

Figure 3 Prototype Return loss:
- - - - 400mm, ——— 600mm

the 600mm radiation pattern in the Fresnel Zone indicate a satisfactory pattern shape, but more extensive tests are currently being performed to ascertain the Gain/Directivity performance of this antenna. Full results will be available for presentation at the conference.

5. Conclusions

A cost-effective prototyping method of low profile radial slot antennas suitable for receiving Direct Broadcast Satellite TV programs in Australia has been described. Two prototypes, one 400mm diameter without reflection cancelling slots and the other 600mm with reflection cancelling slots were constructed. The design of the feed has been aided with a field matching method based on computer software. The radiating slot pattern with or without extra reflection cancelling slots has been determined using the approach postulated elsewhere. The prototypes of the radiating surfaces have been developed using a Computer Aided Manufacturing (CAM) technique. Although both prototypes have shown highly directive radiation patterns, the 400mm prototype suffered from slot reflections which resulted in low return loss of the feed. This problem has been overcome in the 600mm diameter prototype by incorporating extra reflection cancelling slots. The results obtained for the 600mm diameter RLSA have shown great promise to achieve a final prototype suitable for the DTH Satellite TV in Australia.

ACKNOWLEDGMENTS

Financial support for the work presented in this paper from DEET, ATERB and the Australian Research Council is gratefully acknowledged.

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