SYNTHESIS OF CIRCULARLY POLARISED MULTIPROBE FEED RADIAL LINE SLOT ARRAY

Manuel Sierra P. , J.M. Salamanca. , María Vera Isasa , Manuel S. Castañer

ABSTRACT

In previous articles, we presented an easy way to analyse a slot array fed through a radial line and the design of an array of slots placed in an Archimedes Spiral. The analysis was based on a circuit approach where circuit parameters have been estimated using the first propagation mode in the radial line and the far field theory. The Archimedes Spiral design, obtained with only one probe, has an eficiency problem due to the reflected field, that can be solved with this multiprobe design.

1. INTRODUCTION

Antennas based on narrow slots directly coupled to a radial line have been used previously in Direct Broadcast Satellite (DBS) receivers [1] and mobile communications [2]. One of the most important features for such antennas is their low cost and low loss feeding line. This paper shows a synthesis method to define the length, position and orientation of slots on the antenna surface. The basic model is based on the assumption that fundamental TEM mode keeps is original structure over the radial line, except for the attenuation due to the slot power coupling. Four probes are used to generate a mode with circular symmetry in amplitude and linear variation in phase. Changes in phase in the coupled field due to the slot resonance must be taken into account to obtain an uniform phase aperture field. Finally second order effects like the change in the field phase or field reflections must be included in the design process. The antenna final analysis using the equivalent circuit analysis method developed by the authors [3], [4] give a good behaviour of the antenna.

2. ANTENNA BASIC STRUCTURE

The antenna structure is a radial line, formed by two parallel plates, fed at its centre by the four monopole probes. The space between the plates (h) is less than half wavelength, so only the TEM mode can propagate between them. The slots are placed on the upper plate of the radial line. Figure 1 shows the antenna structure and Figure 2 an scheme of the design variables for each slot: slot length (L_i), tilt angle between the slot and the radial line (α_i) and slot position referred to the feeding point (ρ_i, ϕ_i). Other parameters like slot width (w), metal thickness (t) or dielectric inside the waveguide (ε) are kept constant for every slot. The original field inside the radial line can be considered as an ideal TEM mode with symmetry of revolution in amplitude and linear variation in phase, and far from the coaxial probe can be written like :

$$\overline{E}(\rho) = \sqrt{\frac{2}{\pi k\rho}}\left[E_1 e^{-\left(k\rho-\frac{\pi}{4}\pm\phi\right)}\right]\hat{z} \qquad (1) \qquad \overline{H}(\rho) = -\frac{1}{\eta}\sqrt{\frac{2}{\pi k\rho}}\left[E_1 e^{-\left(k\rho-\frac{\pi}{4}\pm\phi\right)}\right]\hat{\phi} \qquad (2)$$

Twin Slots for circularly polarised far field:

The slots are narrow and close to resonance, so we can assume uniform field in the narrow dimension and cosine in the resonant dimension, giving a linearly polarised radiated field. To obtain the circular polarisation we must combine at least two slots as shown in figure 2. The relative field in the slots must satisfy the condition :

$$R = \left|\frac{E_1 \cdot L_1}{E_2 \cdot L_2}\right| = 1 \qquad (3) \qquad Arg\left(\frac{E_1}{E_2}\right) = -k_g\Delta r = \pm\theta \qquad (4)$$

The field phase can be obtained moving the slots along the radial direction. The sign of previous equation depends on the desired polarisation. The parameter 's', in figure 2, is a final free parameter defining the relative position of the slots, and has been adjusted to minimize the coupling effect on the radiated field polarisation.

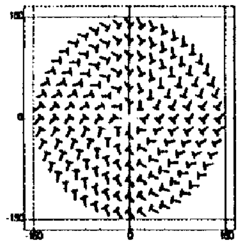

Figure 1: Position of the slots

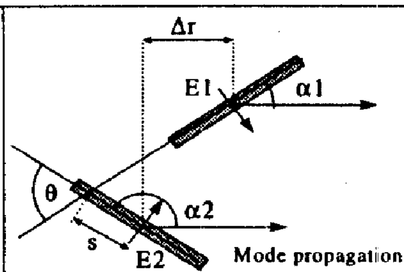

Figure 2: Twin Slots Angles

Aperture phase: slot position.

Assuming we generate a wave whose phase front is a spiral, if we want to get a circular polarised antenna we do not have to modify that phase with the different position of the slots. That means we can place the couple of slots in concentric rings, where each ring is separated λ_g of the previous one, in order to add in phase the radiated field of each slot.

The position of the short circuit at the end of the antenna has to be placed $\lambda_g/4$ from the centre of the last slot.. The reflected field on that short-circuit will not depend on the angle, so the design will be easy to optimise. An scheme of the array is shown in figure 1.

Aperture magnitude: slot length

The coupled field to slots depends on the slot position, tilt angle and length. Keeping constant the angle, the field inside the guide spreads and attenuates in previous slots and the slot length must grow from the centre to the antenna border. Assuming each slots turn as a coupling element and the field attenuation is uniform (keeping the circular symmetry), a closed formula for the slot coupling can be developed as :

$$\eta_p(\rho_k)=\frac{2\rho_k}{\frac{\rho_{max}^2-\rho_{min}^2}{1-t}-(\rho_k-\rho_{min}-0.5\lambda_g)\frac{(\rho_k+\rho_{min}-0.5\lambda_g)}{\lambda_g}} \qquad (5)$$

where ρ_{max} and ρ_{min} are the maximum and minimum distances from the centre, and t is the power fraction over the final load. Figure 4 shows the coupling versus distance from the centre for a 6λ antenna radius. The slot coupling depends on the slot length like a resonant cavity and can be computed from an equivalent circuit like shown in figure 3. Not always is possible to reach the estimated coupling and the maximum is assumed for the last slots.

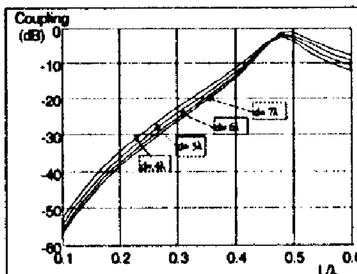

Figure 3. Coupling vs. Slot length

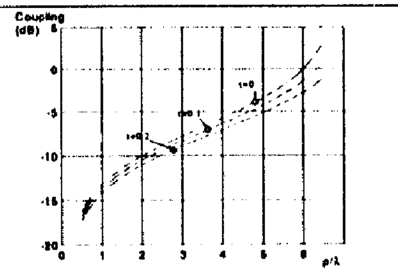

Figure 4. Theoretical coupling vs. Radius

3. DESIGN OF THE COAXIAL PROBES

The incident wave, whose phase front is an Archimedes Spiral, is generated feeding the radial guide with four monopole probes, and exciting each one with a relative phase of 90° respect the next one. The purity of the spiral wave front depends on the separation of the four probes: the mode is better when the probes are closer, but the impedance bandwidth is perturbed when the probes are very close. We got an optimum value for a separation of 4 mm from the centre of the antenna to each probe. An scheme of the coaxial probes is shown in figure 5.

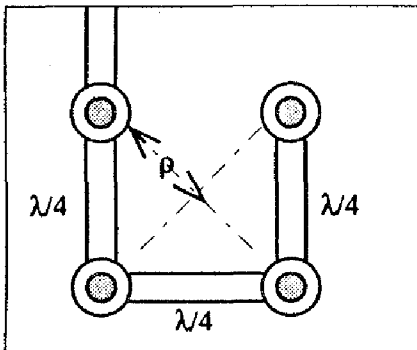

Figure 5: Position of the coaxial probes

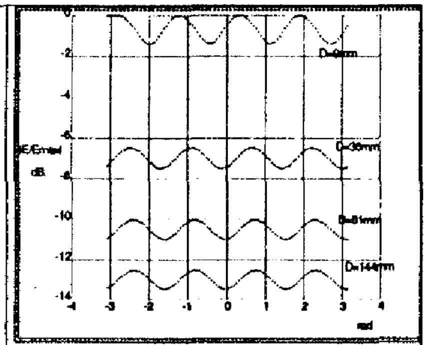

Figure 6: Electric field in the radial guide

The equivalent circuit of the four probes is calculated as a four ports multipole where the mutual impedance follow the next formula:

$$z_{ij} = \frac{-\eta \cdot k}{4 \cdot h} \cdot G_i \cdot G_j \cdot \frac{\sqrt{2}}{k \cdot \pi \cdot \rho_{ij}} \cdot e^{-j\left(k\rho_{ij} - \frac{\pi}{4}\right)} \quad (6) \qquad G_i = \frac{\cos(k\delta L_i) - \cos(k(L_i + \delta L_i))}{\mathrm{sen}(k(L_i + \delta L_i))} \quad (7)$$

The excitation circuit must be very simple in order to minimise the final cost of the product. We designed a serial circuit, where we adapt each probe varying the width of the microstrip lines. The circuit is composed by three $\lambda_g/4$ microstrip lines. In figure 6 we present the purity of the wave for several distances in the radial guide, for a separation of each probe to the centre of the antenna of 4 mm.

4. SECONDARY EFFECTS

Phase change due to the slot resonance:

The slot field phase changes from the ideal field inside de guide due first to the slot resonance and second to field phase changes when coupled to previous slots. In general these changes are lower than $\pi/4$ but add with the same sign and can lower the antenna efficiency as much as 3dB. To compensate them, the slots are moved toward the centre of the antenna. This change in slot position allows reducing the wavelength in the guide keeping the grating lobes under control, without using any dielectric. The phase change due to the slot resonance in the radiation field is shown in figure 7. In figure 8 we present the change in phase and amplitude of the wave after a ring of several slots in the transmitted wave inside the radial guide. Both graphics can be written depending on the parameters of the circuit approach. These changes of phase are compensated moving the slots towards the centre of the antenna.

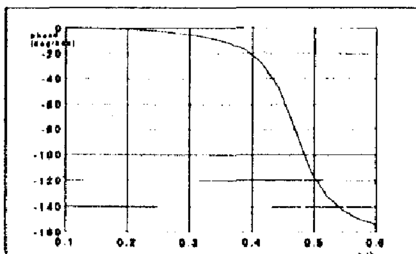

Figure 7: Change of phase in radiation field

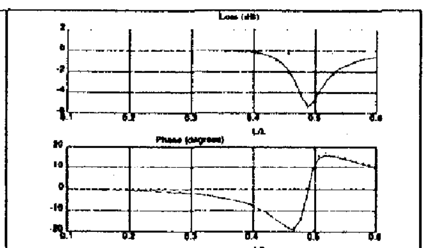

Figure 8: Change of phase after a ring of slots

Field Reflection

When we place the slots in concentric rings the reflected field does not depend on the angle, so we are going to have an uniform field. Optimising the position of the first ring we can increase the gain of the antenna.

5. ANALYSIS

We designed an antenna based on this philosophy to be used for the reception of DBS with the Spanish Satellite HISPASAT. The frequency band was 12.1 – 12.5 GHz, left circular polarisation. We imposed a maximum diameter of 300 mm. The best design we could get with these limits were:

- Slot width: 1,5 mm
- Metal plate thickness: 0,1 mm
- Distance between metal plates: 8 mm
- The radial guide is finished in a short-circuit.
- Dielectric material: $\varepsilon = 1,3$
- Coaxial probes: SMA (50 ohm and 0,65 mm)
- Distance from coaxial probe to the centre : 4 mm.
- Distance between two pair of slots in a ring: $0.7\lambda g$
- Number of slots: 396.

With this design we get a directivity of 29.5 - 30 dBi in the frequency band, side lobe levels better than 15 dB, and a very good symmetry in the radiation pattern. The copolar-crosspolar ratio is better than 20 dB.

6. CONCLUSIONS

The paper describes the way to do the antenna design, giving the slot position and angle to get a radial line slot antenna having circular polarisation and broadside main beam. The design is based in a multiprobe feed array of slots. With this design we get better uniformity of the field in each slot than we got with the one coaxial probe feed array. This uniformity improve the gain of the antenna.

REFERENCES

[1] Ando M. "New DBS Receiver Antennas ", 1993, Proc. 23rd EuMC, pp. 84-92.

[2] Takada J., Tanisho A., Ito K, Ando M., "Circularly polarised conical beam radial line slot antenna", 1994, Electronics Letters, vol. 30, n°21, pp.1729-1730.

[3] M. Sierra, J. Redoli, M. Vera, A.G. Pino, "Design and analysis of slot array antennas on a radial feed line", 1995, Proc. IEEE AP-S, vol. 1, pp. 362-365.

[4] M.P.Sierra, M.Vera, A.G.Pino, M.S.Castañer, Analysis of slot antennas on a radial transmission line, International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering. vol.6, n°2, pp.115-127, Feb. 1996.

[5] Vera M. "Diseño de Antenas de Ranuras sobre Guía Radial". Doctoral disertation. Universidad de Vigo (1996)

[6] Ando M. Sakurai K., Arimura K., Ito Y. "A Radial Line Slot Antenna for 12 GHz Satellite TV Reception". IEEE Trans. Antennas and Prop. Vol AP-33, pp. 1347-1353 (1985)

[7] SasazawaH., Oshima Y., Sakurai K., Ando M., Goto N., "Slot Coupling in a radial line slot antenna for 12 GHz Band Satellite TV Reception".IEEE Trans. On Antennas and Propagation. Vol. 36, n.9, (1988)

[8] Natori M., Ando M., Goto N. "A Design of Coaxial-to Radial Line Adaptors in Radial Line Slot Antennas". The Transactions of the IECE" Vol. E 73, n° 11. Nov. (1990).

[9] M. Sierra P., M. Vera, A.G. Pino, M. S. Castañer, "Synthesis of circularly polarised radial line slot array". Proc. EuMC 1997.