Radial Line Slot Antennas with an Elliptical Beam

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Abstract

This paper aims to design a radial line slot antenna (RLSA) with rotational asymmetry for realizing an elliptical beam. The characteristics of quasi-elliptical aperture RLSA are predicted by method of moments (MoM). An elliptical beam with 3 dB beam widths of 2.6 and 4.9 degrees agrees well with targeted values.

Keywords: Radial Line Slot Antennas, Elliptical Beam

1. Introduction

The conventional radial line slot antennas (RLSAs) are well-known as high-gain, high-efficiency planar antennas which generate the circular polarization. In RLSA, the oversized radial waveguide consists of two circular metal plates that sandwich the dielectric spacer disk. A RLSA is fed from the centre of the bottom plate and generated an outward cylindrical wave flows inside the radial waveguide. This wave excited a spirally arranged slots array on the top plate.

A unique and fundamental difficulty in RLSA is that it is oversized and the angularly higher order modes generally deteriorate the stable operation of the antenna; only the rotationally symmetric operation as well as the beam has been realized. In order to dispense with this constraint, all the modes in whole RLSA should be analysed and controlled. Notwithstanding these dangers, RLSA with elliptical beam (EB-RLSA) seems very attractive for its wider application. The MoM capable of full structural analysis of RLSA is providing the fundamental tool for this design of asymmetrical beam RLSA [2]. In this paper, slot design as well as the aperture shape is numerically varied for shaping the beam and enhancing the efficiency of EB-RLSA. It is confirmed that RLSA can realize the beam shaping with the eccentricity of up to 1:2.

2. RLSAs for Elliptical Beam (EB-RLSA)

Analogous to the conventional RLSAs, the EB-RLSA also needs to have a uniform aperture illumination, which would give the high antenna gain. In order to achieve that, there are two key points that need to be discussed.

- The design of a slot array for realizing a uniform aperture in both ϕ- and ρ -directions.
- The feeding structure which distributes the power non-uniformly to individual direction, with respect to the non-circular aperture shape $R(\phi)$.

Figure 2 shows a structure of the EB-RLSA. The design frequency is 22.0 GHz; the foaming material with a relative permittivity of $\varepsilon_r = 1.06$ was used to fill the spacer with thickness of 3mm. For checking the design, the large ellipse with ratio 2:1 is adopted. The design of feeding structure for appropriate angular power distribution (power ratio) will be discussed latter on.

3. Design of EB-RLSA

3.1 Design of Feeding Structure

The design of feeding structure to realize uniform illumination for a quasi-elliptical aperture was proposed by the authors [1] and is shown in Figure 3; a pair of parasitic pins is added around SMA conductor [1]. Theoretically, with the ellipticity of 2:1, the power divide ratio with respect to the major and minor axis should then be 4:1. However, with the efforts to optimize the EB-RLSA, the authors figured out that the divide ratios 8:1 might be giving better uniform aperture illumination or the aperture efficiency as in Figure 4, where the antenna aperture efficiency is predicted as the function of the divide ratio.

This feeding structure is designed by HFSS. The distance of parasitic pins is 1mm and the sinusoidal amplitude deviation of 9dB (=1/8) is realized as in Figure 5. Meanwhile, the phase deviation less than 4 deg is small enough.

3.2 Aperture Shape

The electromagnetic cylindrical field $F(\rho,\phi)$ excited by the feeder in 3.1 is well approximated by the Eq. in Eq (1) $F(\rho,\phi) \propto (1+C\cos 2\phi) H_0^{(2)}(k\rho)$ (1)

The power distribution should be proportional to $(1+C\cos 2\phi)^2$. Considering two sectors with the same small angle located along the major and minor axes, these two areas need to receive the same power distribution. Therefore the power distribution will also be proportional to the area of the two sectors. From that assumption, we can derive the factor C as follow:

$$\frac{(1+C)^2}{(1-C)^2} = \frac{a^2}{b^2} \Rightarrow C = \frac{a-b}{a+b} \simeq 0.33 \qquad (2)$$

The termination distance $R(\phi)$ now has to be proportional to the excited cylindrical field indicated in Eq. (1), but is zoomed out by the factor D to fit the given radius of the antenna.

$$R(\phi) = D*(1+\cos 2\phi) \qquad (3)$$

Factor D could be easily calculated by considering $R(0)=a$. Specifically, for a equals 150mm we derived $D = \frac{a}{1+C} \simeq 112.5mm$ (4)

3.3 Design of Slots Array

The slot array of the proposed EB-RLSA is designed by applying the procedure for conventional RLSA design [2], but some revisions are necessary to adapt with the non-circular aperture shape. Slot array of EB-RLSAs is designed by the following procedures.

a) A unit element composed of a pair of orthogonal slots is designed by using the approximate model considering the periodicity in the ρ- and ϕ-directions [2]. This model then is analyzed by MoM [3] in order to find out the optimum parameter for reflection canceling.

b) A continuous coupling factor distribution $\alpha(\rho,R(\phi))$ is determined as a function of ρ and the termination distance $R(\phi)$ depending on ϕ.

c) The slot array is arranged spirally to satisfy the derived coupling factor distribution $\alpha(\rho,R(\phi))$ in a circular area with a diameter of a. Slots length distribution is shown in Figure 6. The slot array is designed from the inside to the outside for the in-phase excitation.

g) The elements outside of $R(\phi)$ will be removed.

It is worth noting that in the EB-RLSA design the starting angle of the first slot also needs to be considered. The reason is the slots were designed from inside to outside and the radiating phase of each single slot is sequentially adjusted with respect to that of the first slot. Therefore, by changing the position of the first slot, the in-phase radiation can be realized more beautifully. Figure 7 shows the effect of the first slot position to the antenna’s aperture efficiency. They indicate that about 0.5 dB of directivity can be increased by just changing the position of the first slot.

4. Antenna Performance

The numerically improved design of EB-RLSA is conducted by using the full slots MoM code [3], with the initial design given in Section 3. The first slot position of $\phi = 135\deg$ is chosen. The feeding structure mentioned in section 3.1 is assigned. The aperture illumination in Figure 8.a and 8.b shows quite uniform in ρ direction for both amplitude and phase. In the ϕ direction, slightly non-uniform but the deviations smaller than 3dB in amplitude and 50deg in phase are observed. The radiation pattern in Figure 9 indicates that the 3dB beam-widths are 2.5 and 4.7 deg in 0 and 90 deg cut plains. Figure 10 shows the variation of 3dB-beamwidth predicted by MoM, in the bandwidth of 1GHz. This result agrees well with the calculated radiation pattern by assuming a uniform continuous RHCP source over the aperture $R(\phi)$. Finally, the antenna gain and aperture efficiency are estimated in Figure 11. The predicted directivity at the design frequency of 22GHz is 32.99 dB; correspond to 72.2% of aperture efficiency.

5. Conclusion

The RLSA for realizing elliptical beam shape was proposed. By using MoM for design and analysis, we were able to achieve the target of 3dB beam width. The uniformity in aperture illumination was also acceptable, that gave the directivity of 32.99 dB, efficiency of more than 72% at the design frequency. Those results show the possibility of using RLSA to realize axially asymmetric beam.

References

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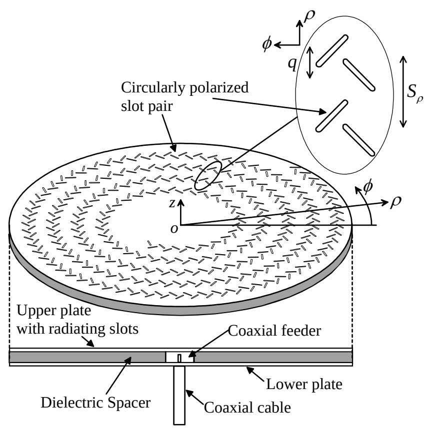

Figure 1: Structure of conventional RLSA

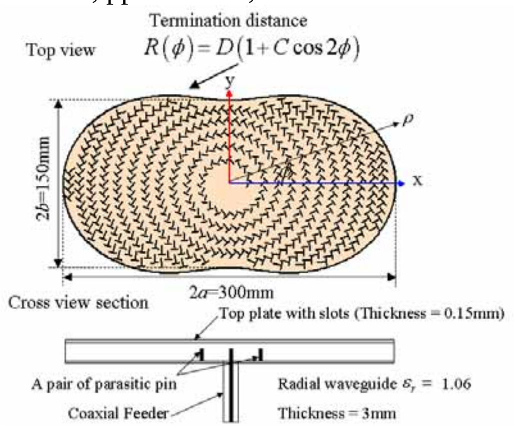

Figure 2: Structure of proposed EB-RLSA

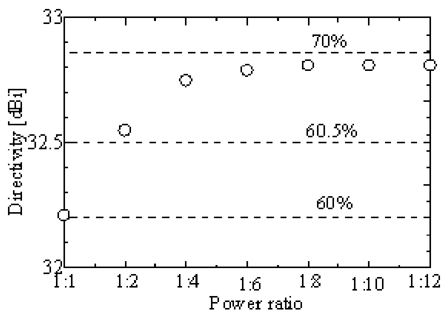

Figure 3: Effect of power divide ratio to the aperture efficiency

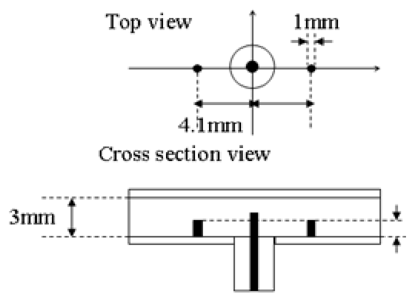

Figure 4: Proposed feeding structure to generate 8:1 power dividing

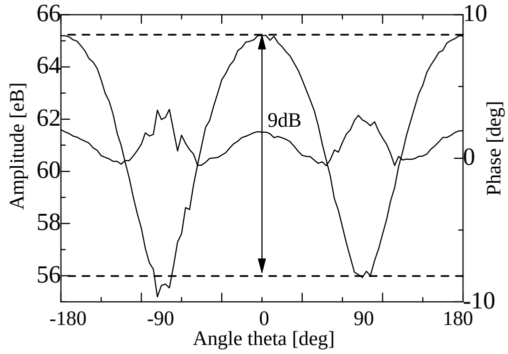

Figure 5: HFSS analyzed circumferential dependence of cylindrical wave generated by a proposed feeding structure

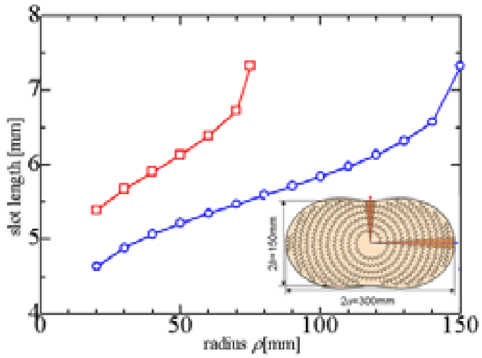

Figure 6: Slots length distribution on aperture

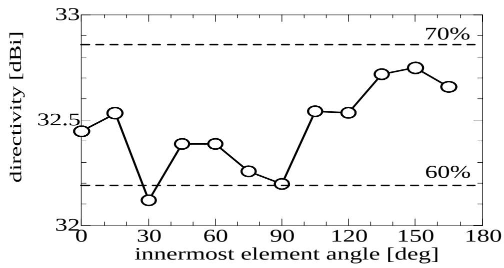

Figure 7: Effect of the first slot position on aperture efficiency

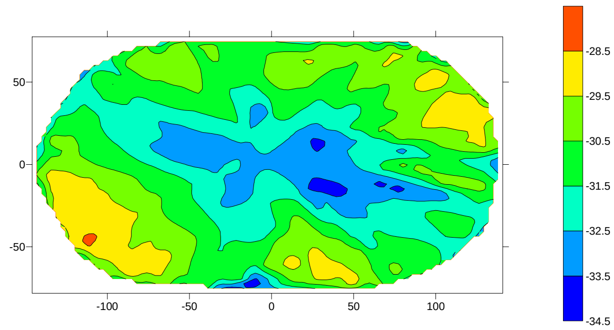

Figure 8.a: Aperture Illumination (Amplitude)

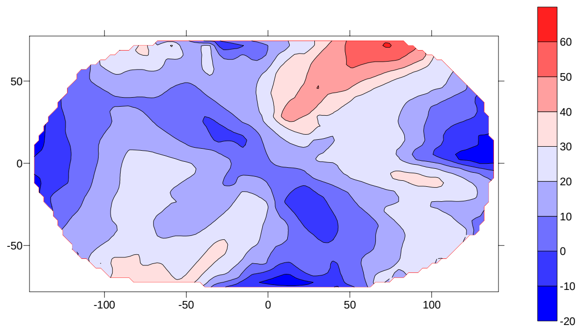

Figure 8.b: Aperture Illumination (Phase)

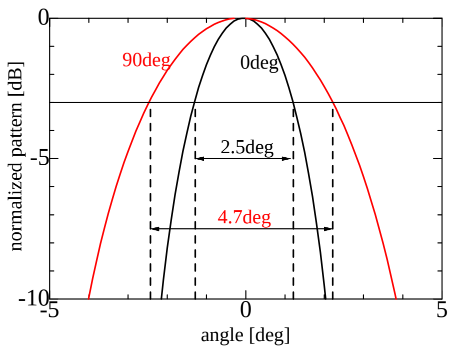

Figure 9: Radiation pattern on major and minor axes cut plain

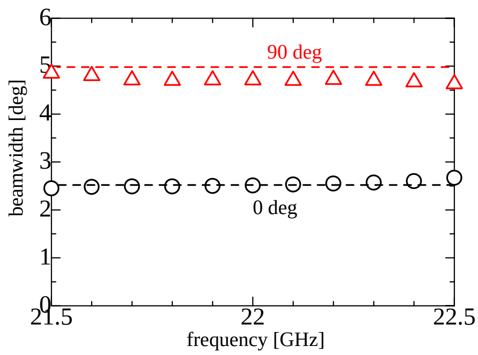

Figure 10: Frequency dependence of 3dB beam widths on major and minor axes

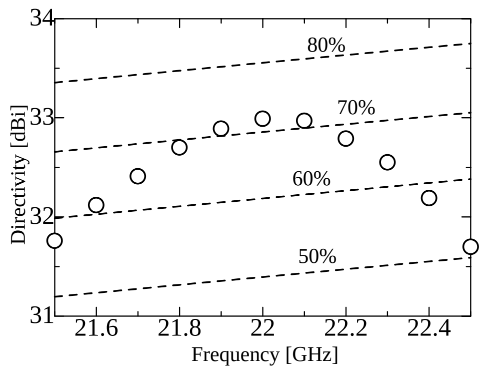

Figure 11: Frequency dependence of directivity