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***Abstract*— In this work, the two-sided frequency beam scanning property of a millimeter-wave leaky wave Bull's-Eye antenna is numerically, analytically and experimentally demonstrated. The pointing angle for n = −1 and n = −2 space harmonics in terms of frequency is first extracted and the operation at different frequencies is analyzed. Finally, the gain and beamwidth as a function of frequency is studied, showing the latter one interesting low values in a fractional bandwidth of 4% around the operation frequency.**

Keywords— leaky wave antenna, Bull's-Eye, millimeter wave, corrugation, sinusoidal.

I. Introduction

Leaky wave antennas have been known for a long time and are characterized by their ability to achieve high gain and narrow beams. A new class of leaky-wave antennas has been proposed in the last years [1–4] inspired by the enhanced transmission phenomenon [5–9]. Recently, a thorough analysis of a metallic Bull's-Eye antenna has been presented [10]. This kind of antennas are of great interest, as they present even better radiation characteristics than those displayed by larger volume horn antennas.

Here, we extend the previously reported analysis of a Bull's-Eye antenna with period d = 3.89 mm working at 77 GHz (λ~3.89mm) [10], to understand better the angular response of this structure as a function of frequency.

II. Analysis of Analytical, Numerical and Experimental Results

The scan-angle behavior displayed by leaky wave antennas is discussed in [11], from which we obtain:

$$\beta_n = k\sin(\theta_n) \qquad (1)$$

where β_n is the phase constant of the n-th space harmonic, $k = 2\pi/\lambda$ is the free-space wavenumber and θ_n is the beam direction.

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Due to the fact that the wave propagates along an aluminium-air interface, and aluminium at millimeter-waves can be considered a good conductor, its phase constant β_0 (corresponding to the slow wave supported by a non-corrugated metallic plane, with index n = 0) can be approximated as the free-space wavenumber k. Thus, from (1):

$$\sin(\theta_n) \approx 1 + \frac{\lambda n}{d} \qquad (2)$$

By means of (2), the beaming direction is calculated for each space harmonic as frequency is swept. The values obtained analytically are plotted (blue line) in Fig. 1 together with the numerical results (black crosses), showing good agreement.

The gain of the antenna was experimentally obtained in the E-plane in terms of frequency (70-90 GHz) and angle (from -90 to 90 deg). From these results, the beam direction can be extracted and displayed as a function of the frequency for n = -1 and n = -2, see Fig. 1 (a) and (b) respectively. Due to the symmetry of the structure, the upper and lower halves of the antenna radiate in opposite directions. The pointing angle values represented in Fig. 1 correspond to the beam radiated by the lower half. Experimental results (green dots) show good agreement with values obtained from simulations.

The simulated and experimental maximum realized gain at each beaming angle as a function of frequency is shown in the insets of Fig. 1. Given that the antenna was optimized for operation at the n = -1 space harmonic, the mean gain for the first radiating mode is larger than for the second harmonic. The n = -2 space harmonic, meanwhile, shows a slowly increasing tendency as a function of frequency.

The half-power beamwidth (θ_{-3dB}) for each radiated beam varies as frequency is swept, as shown in Fig. 2. A minimum in the range corresponding to the second regime of operation and part of the first regime (from 74.2 GHz to 77.3 GHz, approximately) is observed, which coincides with the region where the n = -1 space harmonic radiated by each half apparently merge in a single beam. The largest beamwidth values are found at f = 73.5 GHz (red arrow) and f = 77.6 GHz (blue arrow), where θ_{-3dB} = 5.6 deg and θ_{-3dB} = 4.4 deg respectively. At these frequencies, the radiated $n = -1$ beams are not close enough and they appear as a wide single beam. Within the range of f = 74.2 GHz to f = 77.3 GHz (4% fractional bandwidth), the measured beamwidth values are below 1.5 deg, with a minimum at f = 77 GHz (1.2 deg).

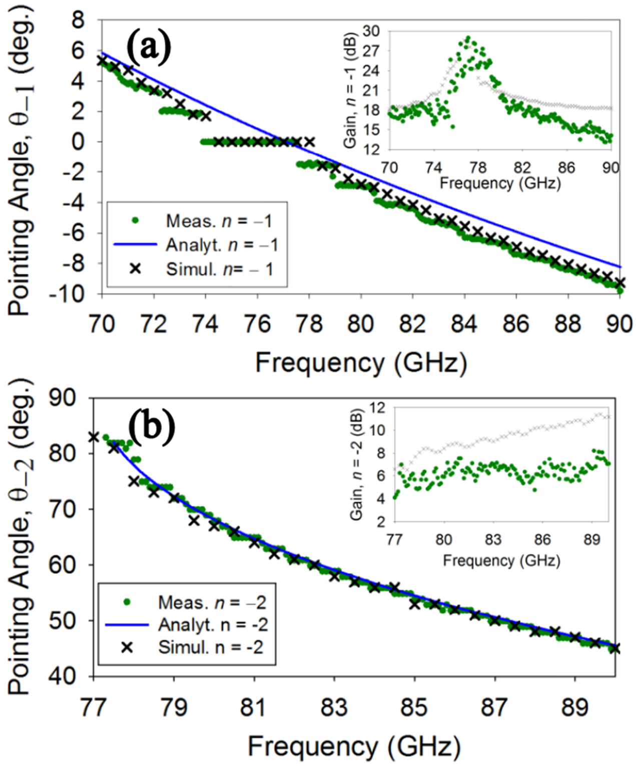

Fig. 1. Measured (green dot), simulated (black cross) and calculated (blue line) beam direction for n = -1 (a) and n = -2 (b) space harmonics. Inset: Measured and simulated maximum realized gain for n = -1 (a) and n = -2 (b)

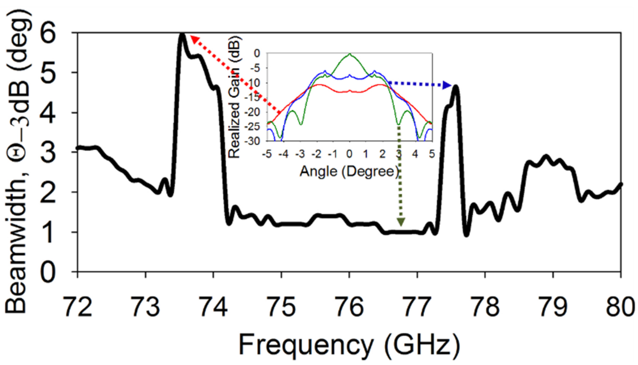

Fig. 2. Experimental beamwidth as a function of frequency. Inset: Detail of beamwidths at f= 73.5 GHz (red curve), f= 77 GHz (green curve) and f= 77.6 GHz (blue curve).

III. Conclusion

In this work a thorough study of the beam scanning behavior of a metallic Bull's Eye antenna, previously reported in [10], has been presented. The variation of the beaming angle as the operating frequency is swept has been experimentally proven and confirmed by theoretically predicted and numerically obtained values. The antenna behavior has been analyzed at three different radiation regions. When $\beta_0 \sim 0$, it is observed that the beams radiated by each half of the antenna merge into a single broadside high gain beam. The largest beamwidths are located in the extremes of the range of frequencies for which broadside radiation is obtained, as merging beams are not close enough, appearing as a wider single beam..

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