Multiple-Beam mmW-Slotted-Waveguide Leaky Wave Antenna with Control on Polarization

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Abstract—By performing the Floquet-mode analysis of a periodic slotted waveguide, a multiple-beam leaky wave antenna is proposed in the millimetre-wave (mmW) band. Considering the direction of surface current lines on the broad/side-walls of the waveguide, the polarization of constructed beams are also controlled. The simulation results are well matched with the initial mathematical analysis.

I. INTRODUCTION

A Leaky Wave Antenna (LWA) is realized by forming an EM-aperture on a guided-wave structure. Based on the aperture distribution, LWAs are split into two main groups of “uniform”, “periodic”, and “quasi-uniform” [1], [2]. The periodic structures consist of a geometry repeated locally and can be analyzed mainly based on the theory of space harmonics [3]. The objective of this paper is to use these harmonics to propose a multiple-beam slotted-waveguide LWA. The polarization of constructed beams are also controlled by utilizing the inherent characteristics of TE_{10} mode in the waveguide.

II. FLOQUET MODE ANALYSIS AND ANTENNA DESIGN

A. Floquet Mode

The air-filled closed-structures support fast waves for all propagating modes. This means that any slot on the waveguide's walls that cuts the surface currents will result in leaking of the guided waves and a beam will be shaped. By applying periodic slots, infinite number of spatial harmonics will be generated that can be analysed by the Floquet theorem [3]. For a waveguide lay in y -axis with guided wave number of $k_{y0} = \beta_y - j\alpha$ and slot's repeating period of d , the harmonic wavenumbers are as follows;

$$k_{yn} = k_{y0} + \frac{2\pi n}{d}, n = 0, \pm 1, \pm 2, \dots \quad (1)$$

The schematic view of the corresponding dispersion diagram is presented in Fig. 1. By adjusting d in Eq. 1, for every n^{th} harmonic located in the fast wave region the radiation condition is met, therefore additional beams can be built. Considering the standard right-hand coordinate system, the tilt angle θ_m of the radiated beams with wavenumbers of k_0 from the 1-D aperture are estimated as follows;

$$\theta_m \approx \sin^{-1} \frac{\beta_n}{k_0}. \quad (2)$$

Fig. 1. Dispersion diagram of 1D periodic slotted waveguide LWA.

B. Antenna Design

The design frequency of operation is chosen to be $f = 30$ GHz, therefore WR-28 is selected as the standard waveguide of this band. The phase constant of the TE₁₀ mode, which also is the fundamental mode ($n = 0$) in Eq. 1 is:

$$\beta_{n=0} = \sqrt{k_0^2 - \left(\frac{\pi}{a}\right)^2}, \quad (3)$$

with $a = 7.11$ mm as the waveguide's broad-wall width. As it is clear from Fig. 1, the related fundamental mode $n = 0$ is always located in the fast-wave region, steering from almost broadside to the endfire as β_y increases. This means that the structure is actually characterised as a “quasi-uniform” LWA [2]. Considering Eq. 2 and 3, $\theta_m \approx +45$ deg at the operating band, regardless the values of d . The tilt angle of fundamental mode is regulated by k_{y0} . The simplest approach to alter θ_m when $n = 0$ is to employ the dielectric-filled waveguides, therefore by changing the dielectric properties, k_{y0} would be varied. However, for this design, we use the fundamental mode as it already is to generate the “Beam 1” towards the mentioned forward direction.

Those spatial harmonics that are capable of locating in the radiation region, i.e. $n = -1, -2, \dots$ can be managed by altering d . Considering both Eq. 1 and 2, the possible tilt angle of constructed beams at $f = 30$ GHz are presented in Fig. 2.

To achieve a multiple-beam LWA, let us define two additional beams (Beam 2 and Beam 3) with the specifications listed in Table. I. The defined tilt angles can be any angle within the range of θ_m in Fig. 2. It can be concluded from this figure that the tilt angles of Beam 2 and Beam 3 are

Fig. 2. Possible tilt angle of constructed beams at $f = 30$ GHz.

TABLE I
BEAM SPECIFICATIONS

	Beam 1	Beam 2	Beam 3
Tilt angle θ_m	+45 deg	-7 deg	-45 deg
Polarization	composite	x	y

approximately related to $n = -1$ harmonic with $d = 12$ mm and $d = 7$ mm respectively. Utilizing higher negative harmonics (for example $n = -2$) is not recommended since the constant relative motion of harmonics (see Fig. 1) will restrict the designers to define independent tilt angles.

In order to control the polarization of constructed beams, the innate property of TE_{10} guided wave mode is used. Considering the surface current lines on the waveguide's walls, slots on the broad-wall and side-wall result in orthogonal polarizations. With the polarization specifications of Table. I, the proposed structure is shown in Fig. 3 consisting of Arm1 and 2 for Beam 2 and 3 respectively. The Arm1 is axially-rotated, granting the aperture with a relatively orthogonal polarization in comparison with that of Arm2. Both arms also result in shaping the Beam 1 (since the $n = 0$ harmonic is radiating for both); therefore the polarization of "Beam 1" is composite. The orthogonal polarization of beams 2 and 3 helps to decrease the distortion effect of constructed beams to each other and make it possible to put the arms relatively close to each other.

III. RESULTS AND DISCUSSIONS

The constructed radiation pattern of the designed antenna is presented in Fig. 4 (a), indicating the tilt angle of beams. The polarization property is presented in Fig. 4 (b) and (c) as the normalized Ludwig 3 diagrams, traditionally used for studying the co/ cross polarization of an antenna. The result shown in this figure are well matched with the predefined objectives

Fig. 3. The proposed structure (dimensions are in millimetre).

Fig. 4. Polarimetric plot of the proposed LWA's directivity pattern at 30 GHz. (a) absolute value, (b) normalized Ludwig 3 horizontal, and (c) normalized Ludwig 3 vertical.

Fig. 5. S_{11} of the designed antenna.

presented in Table. I. Last but not least, Fig. 5 shows the antenna is matched well at the operating frequency.

IV. CONCLUSION

A multiple-beam leaky wave antenna with control on both beam's direction and the polarization is proposed at 30 GHz. The antenna consists of two arms and is embodied by periodic slotted waveguide. Three directional beams are obtained at different angles of interest. The design method is based on space-harmonics analysis.

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