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Analysis of E- Plane Radiation Patterns of a Simulated Scalar Feed Horn Antenna

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Abstract: *Simulated scalar feed horn antennas are found to be exhibiting identical radiation characteristics of metallic corrugated feed horn antennas of same dimensions. Hence, in this paper, the E-plane radiation characteristics of a simulated scalar feed horn antenna is analysed theoretically by extending the theory of metallic corrugated horn antennas. The theoretical E-plane radiation patterns at different frequencies in X-band are compared with that of experimentally obtained E-plane radiation patterns. Even though the nulls of of the radiation patterns are not fully realised by the theory, the main beam characteristics are well explained. Losses that may occur in the dielectric substrate of the E-plane walls are not considered in the theoretical explanation. This may be the reason for slight discrepancies observed in the experimental and theoretical 3-dB and 10 dB beam widths.*
Key words: *Antennas, Feed horns, Microwaves, Scalar feeds, Theoretical analysis*

I. Introduction

The E-plane walls of the Simulated Scalar Feed (SSF) horn antenna are fabricated with dielectric substrate of appropriate thickness whose inner surface is periodically loaded with thin conducting strips which is called simulated corrugated surface [1, 2, 3, 4, 5].It is well known that the E-plane aperture electric field distribution of a metallic corrugated antenna whose corrugation depth is judiciously selected for the balanced hybrid mode of operation is cosine in nature. The SSF horn antenna is also exhibiting a cosine nature for its E-plane aperture electric field distribution [3, 4]. Hence, the present theoretical analysis of the E-plane radiation characteristics of the SSF horn antenna is based on the theory of metallic corrugated horn antennas [6].

I I. Analysis of E- Field Distribution of E-Plane Aperture

In order to calculate the radiation pattern, first the E- plane aperture electric field distribution of a square waveguide fabricated with simulated corrugated surface as its E-plane boundary walls is calculated. For this the theory of metallic corrugated horns [6] is used. Once the aperture electric field is obtained, the flaring of the horn in the two principal planes is accounted and the E-plane far field radiation patterns are calculated on the basis of vector diffraction formula.

The sketch of the square waveguide with strip grating structure on its E-plane boundary walls is shown in figure 1. The waveguide is directed along z- axis and ν and τ are the unit vectors which are respectively directed normally and tangentially to the boundary surface such that $\tau = I_z \times \nu$, where I_z is the unit vector along z- axis.

The surface impedance Z_τ and Z_z are defined by the longitudinal field components E_τ and H_τ and are given by,

$$Z_\tau = E_\tau / H_z \qquad \text{and} \qquad Z_z = E_z / H_\tau \qquad \text{-----} \qquad (1)$$

Since at the boundary surface $E_\tau = 0$, only the impedance Z_z exists. However, as Z_z is imaginary, a real parameter Y is introduced and it is defined as,

$$J\,Y = Z / Z_z \qquad \text{-----} \qquad (2)$$

Where $Z = \mu / \varepsilon$ is the free space impedance.

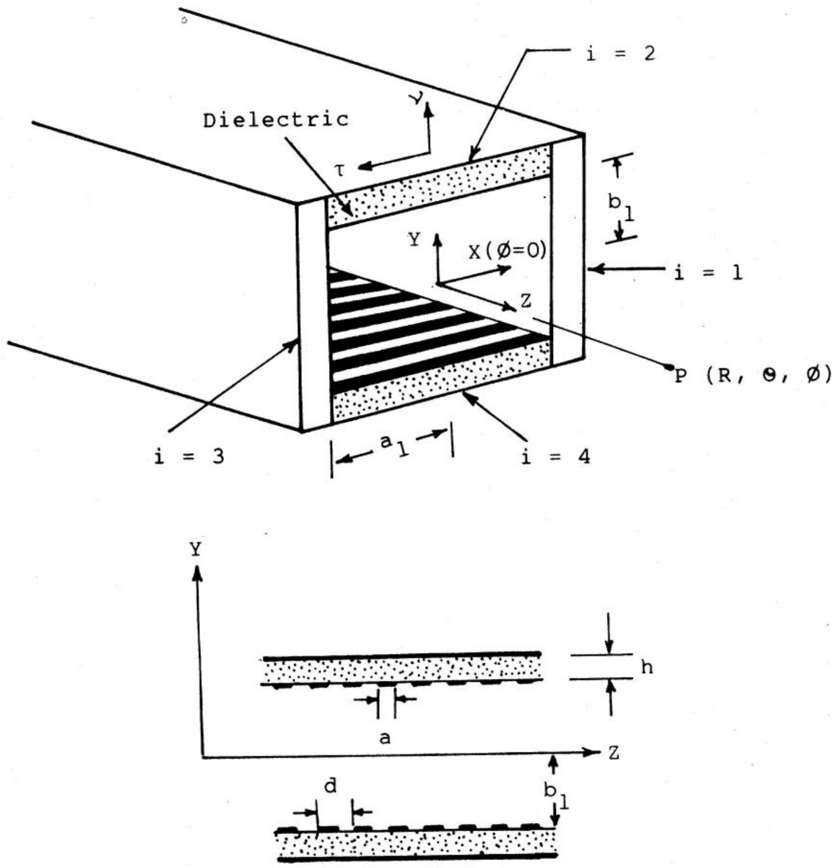

Fig.1. Sketch of the waveguide with strip grating structure on its dielectric E-plane walls

As per the indices given to the four walls of the waveguide in figure 1, Y_n denotes Y of the n Th wall. Since the opposite walls are identical in nature, $Y_1 = Y_3$ and $Y_2 = Y_4$. Now for a wave polarised in the y direction, $Y_1 = \infty$. Then the transverse components of the electric field are given by,

$$E_x = 0; \qquad E_y = \cos\alpha x . \ \cos\gamma y \ e^{-j\beta z} \qquad \text{-------} \qquad (3)$$

Where α, β and γ are the propagation constants.

Other field components can be determined using Maxwell's equations:

$$E_z = j\,\omega\,\mu/\beta . \ \cos\alpha x . \ \cos\gamma y \ \ e^{-j\beta z}$$

$$H_x = -1/\beta . \ (\mathcal{E}\,\psi + \alpha^2/\omega) \cos\alpha x \cos\gamma y \, e^{-j\beta z}$$

$$H_y = \alpha\gamma/\omega\beta . \ \sin\alpha x \ \ \sin\gamma y \ \ e^{-j\beta z}$$

$$H_z = j\,\alpha/\omega \ . \ \sin\alpha x \ \ \cos\gamma y \ \ e^{-j\beta z} \qquad \text{-------} \qquad (4)$$

For the dominant HE_{11} mode,

$$\alpha a_1 = \pi/2$$

As E_z varies with x as $\cos\alpha x$, we get

$$Y_2 = -1 \ / \ (1 - a/d) \ . \ \ \gamma_c / \ k \tan(\gamma_{ch}) \qquad \text{--------} \qquad (5)$$

Where $\gamma_c^2 = k^2 - \alpha^2$

k is the free space propagation constant. As stated earlier, for dominant HE11 mode, for large ka_1 and kb_1

$$\alpha a_1 = \pi / 2 \quad \text{and} \quad \gamma b_1 = \pi /2 (1- Y_2 /kb_1 \qquad \text{-------} \qquad (6)$$

In the case of a square waveguide, $a_1 = b_1$.

Hence the aperture electric field of the waveguide under consideration is given by the equation,

$$E_y = \cos \alpha x. \cos \gamma y \; e^{-j \beta z} \qquad \text{-------} \qquad (7)$$

III. Analysis of Far- Field E- Plane Radiation Patterns

Equation (7) is the E-plane aperture electric field distribution of the waveguide fabricated with strip loaded dielectric substrate as its E-plne boundary walls. In the case of a horn antenna, due to the flaring, a quadratic phase shift for the aperture field along the aperture is accounted by the factor $e^{-j 4\pi y2/\lambda L}$. Incorporating this quadratic phase variation, the E- plane aperture electric field of the horn antenna is given by,

$$E'_y = \cos \alpha x. \cos \gamma y \; e^{-j \beta z} \; e^{-j 4\pi y2/\lambda L.} \qquad \text{-------} \qquad (8)$$

In the above expression, L is the distance from the phase centre to the aperture of the horn. As a rectangular to square waveguide transition is used to feed the SSF horn antenna, the effective phase centre of the SSF horn antenna along with the transition is experimentally determined by plotting its phase pattern for different axes of rotation. The E-plane radiation pattern of the SSF horn antenna along with its phase pattern plotted for at an axis of rotation of L = 18 cm at 10 GHz is given in figure 2.

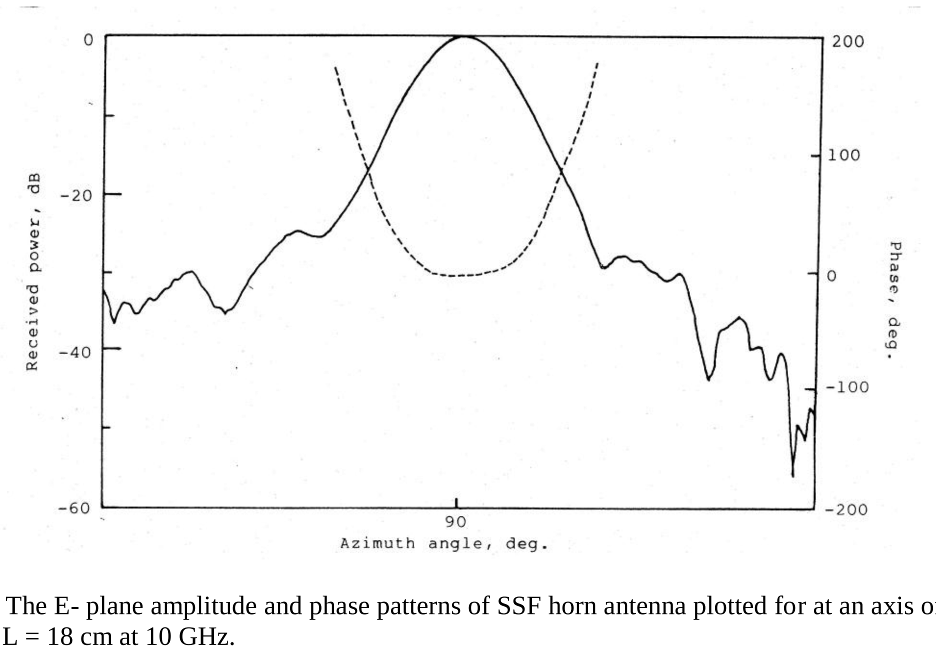

Fig. 2. The E- plane amplitude and phase patterns of SSF horn antenna plotted for at an axis of rotation of L = 18 cm at 10 GHz.

———— Amplitude ----------------- Phase

The far-field radiation pattern in the E-plane ($\varphi = \pi / 2$) of the simulated scalar feed horn antenna, based on the vector diffraction formula [7, 8, 9] is given by,

$$E_\theta = jk \exp(-JkR) / \pi R \; (1 + k_r \cos\theta / k) \iint E'_y \exp(j k y \sin\theta) \, dx \, dy \qquad \text{--------} \qquad (9)$$

Where $k_r = (k^2 - \pi^2 / 4 a_1^2)^{1/2}$

IV. Results

The theoretically calculated E- plane radiation patterns compared with the experimental ones at different frequencies in X- band are presented in figures 3 and 4. The theoretically obtained 3-dB and 10- dB beamwidths of the SSF horn antenna compared with that of the experimental ones are given in table 1. From the table it is clear that the theoretical beamwidths are almost agreeing with the experimental values. In the theoretical calculations, the fields within the dielectric substrate are neglected. This may be the reason for the small discrepancies between the theoretical and experimental radiation patterns. Even though the theoretical calculations cannot predict the nulls of the radiation patterns exactly, the main beams are well predicted with a good accuracy.

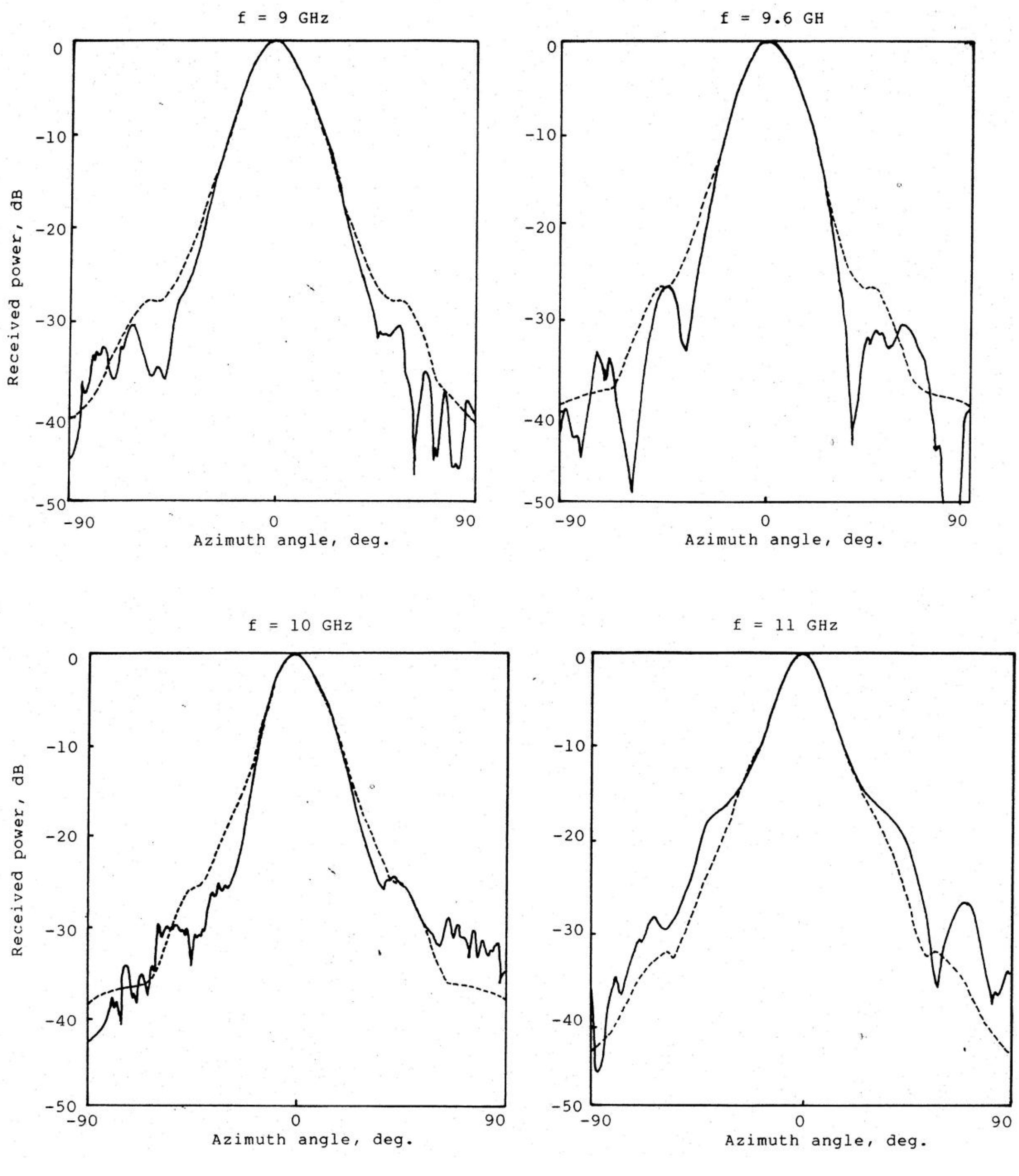

Fig.3. E-plane patterns of SSF horn antenna at different frequencies in X- band

——————— Experiment ---------------- Theory

Table 1. Comparison of theoretical and experimental 3-dB and 10-dB beamwidths of the SSF horn antenna

Frequency (GHz)	3 dB BEAMWIDTH (DEG.)		10 dB BEAMWIDTH (DEG.)	
	Theory	Experiment	Theory	Experiment
8.4	23.6	21.6	42.2	41.7
9.0	22.1	22.8	39.9	42.2
9.4	20.6	20.9	38.0	39.2
10.0	18.8	20.0	36.0	34.9
10.4	17.5	17.4	36.0	33.0
10.8	18.1	16.6	36.5	32.6
11.2	16.2	16.5	37.0	34.9
11.6	15.4	15.7	36.5	40.0
12.0	15.4	15.5	37.0	50.0

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