Periodic Leaky-Wave Array Antenna on Substrate Integrated Waveguide for Gain Enhancement

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***Abstract*—In this paper, 2-elements and 4-elements substrate integrated waveguide (SIW) based leaky-wave array antennas are presented and their performances are compared. The enhanced gain and scan angles for 2-elements are 15.4 dBi and 45^o respectively and for 4-elements the same is 18.4 dBi and 30^o respectively. In the final design of 4-elements array antenna, sinusoidal variation of slot length is used to reduce the side lobe level (SLL). A 1x4 cascaded SIW power divider with effective matching port is used to feed the antenna. Simulations of the antennas are carried out using HFSS software and presented here.**

Keywords—Frequency scanning; gain enhancement; leaky-wave array antenna; substrate integrated waveguide; power divider.

I. Introduction

Leaky-wave antennas (LWAs) belong to the class of travelling wave antenna family with high gain and are popularly used for space scanning applications. In the early stage, the LWAs are designed using conventional rectangular waveguide. However, waveguide LWAs suffer from bulky structure and higher fabrication cost. Recently, substrate integrated waveguide (SIW) has been used [1], [2] to realize LWAs that transforms the bulky and non-planar waveguide into planar form. Several types of LWAs based on SIW have been reported recently [3], [4]. In this paper, a SIW based leaky-wave array antenna is presented for high gain and low side lobe level.

II. Antenna Array Design Procedure

The top view of the design is shown in Fig. 1. and Fig. 2. Fig. 1 shows leaky-wave antenna layout with periodic transverse slots using 1x2 Y-type SIW power divider (antenna1). Design dimensions for the realized antenna are given in figure caption. To enhance the gain further with low side lobe level, the antenna configuration is modified with sinusoidal variation of slot length. A 1x4 cascaded SIW power divider is then used to feed the array antenna as shown in Fig. 2. Both the antennas are excited in equal amplitude and equi-phase.

1x2 Y-type and 1x4 cascaded SIW power dividers reported in [5] are used to feed leaky wave array antenna for better performance. Procedure adapted to design the proposed antenna is discussed next.

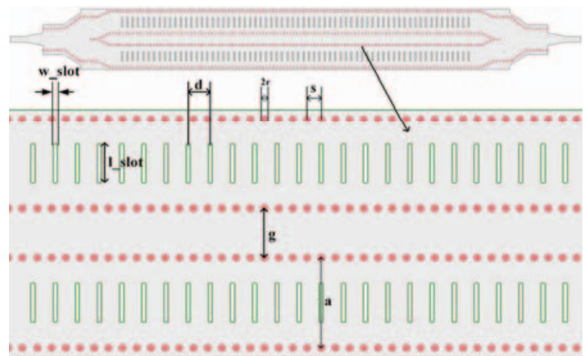

Fig. 1. Layout of Y-type SIW power divider based leaky-wave antenna (antenna1). (a = 10.5 mm, l_slot = 4.55mm, d = 2.5mm, w_slot = 0.45mm, s=1.6mm, r=0.4mm, g=5.71mm, $\mathcal{E}_r$ = 2.25, tanδ= 0.001, h=1mm.)

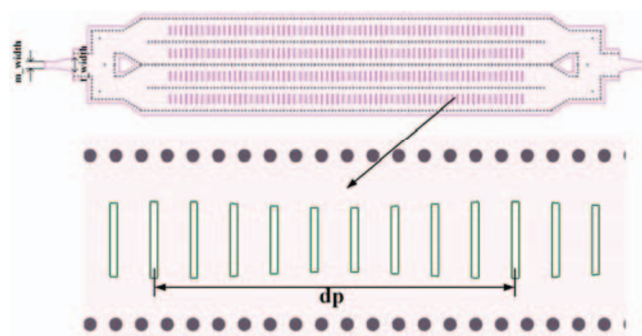

Fig. 2. Layout of cascaded SIW power divider based LWA (antenna2). (dp = 22.5mm, lm = 4.78mm, ln = 4mm,m_width = 2.97mm, t_width = 6.2mm; remaining dimensions are same as that of Fig. 1.)

From the theory of LWAs, we must maintain the necessary condition for the radiation that is nth space harmonic phase constant should be less than free space wave number (β_n<k_0). For the practical design purpose single beam radiation is needed thus space harmonic β_{-1} is selected which radiates in first quadrant. The beam direction of periodic leaky-wave antennas can be calculated as

$$\sin \theta_m \approx \frac{\beta_{-1}}{k_0} \quad (1)$$

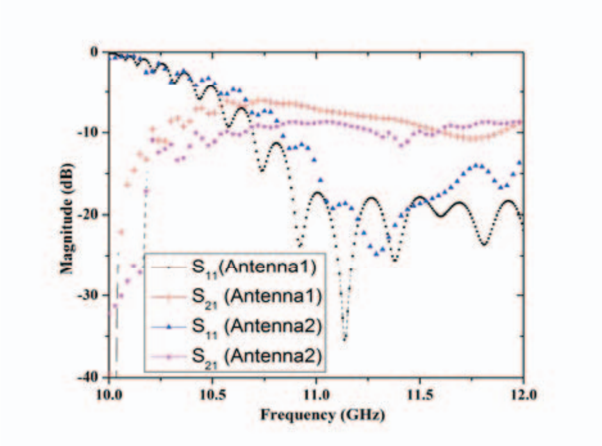

Fig. 3. Simulated S-parameters of antenna1 and antenna2.

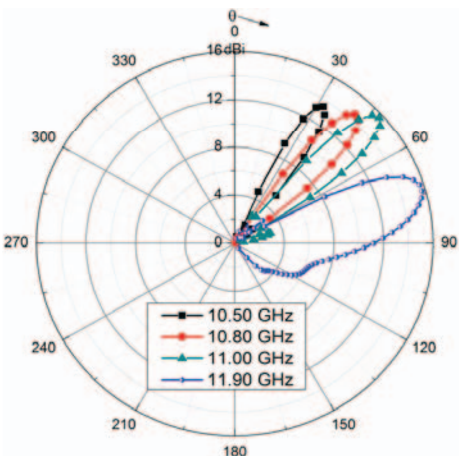

Fig. 4. Simulated radiation patterns for the antenna shown in Fig. 1.

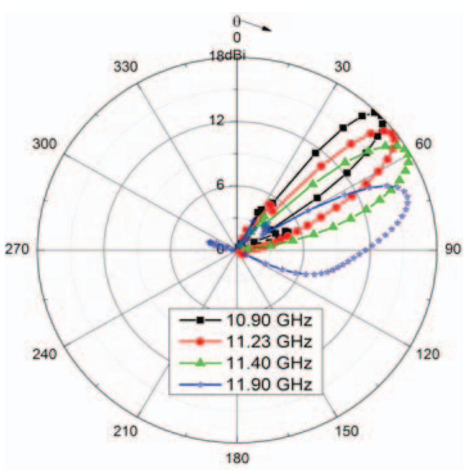

Fig. 5. Simulated radiation patterns for the antenna shown in Fig. 2.

where θ_m is the angle of maximum beam direction measured from broadside to end fire and β_{-1} is the space harmonic at n = -1. The phase constant for TE_{10} mode which can be approximated as

$$\beta_{-1} = \frac{2\pi}{\lambda}\sqrt{1-\left(\frac{\lambda}{2a}\right)^2} - \frac{2\pi}{d} \tag{2}$$

where a is the width of the SIW and d is the periodicity of the slots. Periodicity of the slots is chosen as about 1/13 of the guided wavelength to avoid multi-beam operation. By choosing the proper value of slot length, slot width and periodicity of the slots, the working range of leaky-wave antenna is set in the fast wave region i.e. $\beta_{-1} < k_0$ [6].

III. Results and Discussions

Fig. 3 shows the simulated response of both the antennas. For antenna1, the fast wave region falls under 10.5-11.9 GHz and for antenna2, it falls under 10.9-11.9 GHz. After 11.9 GHz, leaky mode is in slow wave region and loses its physical significance that reflects in deterioration of the radiation pattern. The length (278 mm) of the radiator is chosen nearly about 10 wavelengths in free space. Radiation pattern for antenna1 and antenna2 is shown in Fig. 4 and Fig. 5 respectively. Using antenna1, a maximum gain of 15.40 dBi with frequency scan range of 45^o is achieved. Using antenna2, maximum gain of 18.4 dBi is achieved but the design limits the frequency scan range to 30^o due to the mutual coupling between the two adjacent elements with periodic slots having undesired side lobe level (SLL). To overcome this issue of undesired SLL, the sinusoidal variation of slots amplitude with aperture field distribution is studied and implemented.

IV. Conclusion

In this proposed design a 1x4 cascaded SIW power divider fed leaky-wave antenna is introduced. By transforming the design from 1x2 to 1x4, 3dB gain is enhanced with acceptable SLL. The proposed design is low profile, low cost and can be easily integrated into microwave and mm-wave circuits.

References

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