Continuous Backward-to-Forward Beam-Scanning Conformal Leaky-Wave Antenna

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***Abstract*—A periodic substrate integrated waveguide (SIW) structure based conformal leaky-wave antenna (LWA) is presented. The LWA is capable of scanning its beam from near backfire, backward endfire, through the broadside to the forward direction. The −10-dB reflection coefficient bandwidth of the antenna is 7.428 - 10.47 GHz. The gain of the antenna is greater than 10 dBi throughout the beam scan range from −84° to +19° with a variation of source frequency from 7.3 to 10.3 GHz.**

Keywords—Beam scanning; backward; conformal; forward; substrate integrated waveguide (SIW); leaky-wave antenna (LWA)

I. Introduction

Leaky-wave antennas (LWAs) are promising for advanced communication and surveillance systems because of their unique beam-scanning property [1]. Beam-scanning antennas can also be very useful for unmanned aerial vehicle (UAV) applications [2]. The configuration of a frequency-dependent beam-scanning LWA is simple and does not require a special feed network, instead, the antenna can be operated using a simple feed line [3]. The propagation constant of an LWA is complex, given by $\beta - j\alpha$, where α and β are the attenuation and phase constants, respectively, as the energy radiates from the structure as it travels along it [3]. The main beam of an LWA shifts with frequency, and for the $n = -1$ spatial harmonic radiation it is given by

$$\theta = \sin^{-1}\left(\frac{\beta_{-1}}{k_0}\right) \tag{1}$$

where the direction of the beam (θ) is measured from the broadside, β_{-1} and k_0 are the phase constant for the $n = -1$ spatial harmonic and the free-space wave number, respectively [4]. A method for suppression of the open stopband (OSB) of a substrate integrated waveguide (SIW)-based periodic LWA and to realize a continuous beam scan from backward passing through the broadside is discussed in [4].

Various types of LWAs have been reported including an SIW-based LWA [4], half-mode SIW based LWAs [5], [6], composite right/left-handed LWA [7] etc. Most of the LWAs reported so far are designed on a planar platform. On the other hand, conformal LWAs are gaining significant research interest because many applications require integration of an antenna radiator on a conformal surface, e.g. missiles, cars, trains, aircraft etc. [8]. However, research on conformal LWAs is rather limited.

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In this paper, a conformal LWA is presented. The antenna is designed using periodic SIW structure. Each unit cell has a partially radiating edge and a slot on the top metal. The beam-scanning range of the LWA covers most of the backward region and then through the broadside to the forward direction.

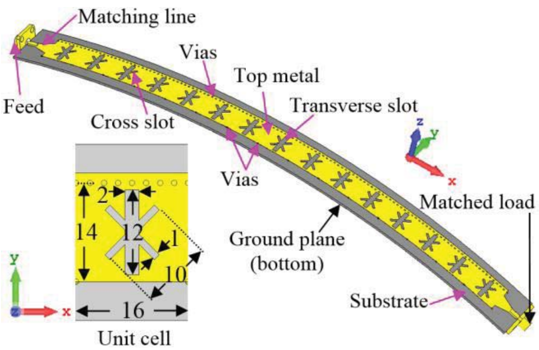

Fig. 1. Perspective view of the SIW-based conformal LWA with unit cell (top view). The dimensions are in mm.

II. Antenna Configuration

The perspective view of the conformal LWA configuration is shown in Fig. 1. The antenna is designed using an SIW structure. One edge of the top metal is shorted to the ground plane (bottom) by densely placed metallic vias and another edge, also shorted, using widely spaced vias. The LWA is designed on a Rogers RT5870 substrate with loss tangent (tanδ) and dielectric constant (ε_r) of 0.0012 and 2.33, respectively. The width and thickness of the substrate are 30 mm and 1 mm, respectively. A total of 15 unit cells, each 16 mm long, is used in the antenna design. The width of the top metal, measured as the distance (center-to-center) between the vias at two edges, is 14 mm. The slot in each unit cell (as mentioned before) itself is composed of a cross-shaped and a transverse slot, and their centers are aligned. The dimension of each of the cross-shaped slot branch is 10 mm × 1 mm, and the dimension of the transverse slot is 12 mm × 2 mm.

As indicated in Fig. 1, the LWA is fed from one end, upper end in Fig. 1, and hence the signal travels along the structure, and the other end, lower end, is terminated in a matched load. The matched load is used to absorb any remaining energy so that the reflected wave is suppressed. A tapered matching line is used to feed the antenna and also for the termination. The length of the matching line is 6.5 mm, and its width at the SMA connector end and the SIW end (output end) are 3.2 and 8.5 mm, respectively. The SMA connector is connected to the matching line through a pad and its length is 4.5 mm. The radius of the curved surface, the surface where the antenna is to be integrated, is 400 mm.

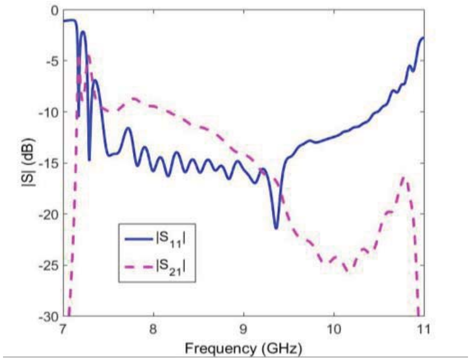

Fig. 2. Simulated scattering parameters of the conformal LWA in Fig. 1.

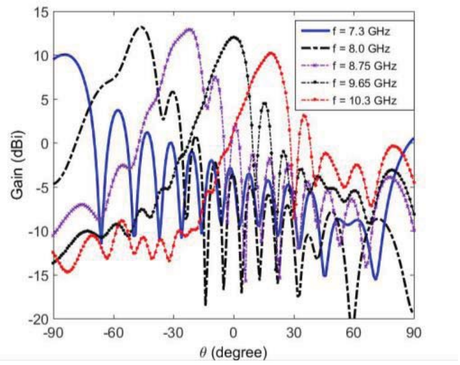

Fig. 3. Simulated radiation patterns of the conformal LWA in Fig. 1 at various frequency points.

III. Results and Discussion

The simulated reflection and transmission coefficients of the conformal LWA are shown in Fig. 2. The transmission coefficient is computed using ports at both ends of the antenna. The −10 dB reflection coefficient bandwidth of the conformal LWA is 7.428-10.47 GHz. The simulated $|S_{11}|$ is larger than −10 dB at frequencies below 7.428 GHz but remains lower than −6.96 dB for frequencies down to 7.3 GHz. At lower frequencies, the transmission coefficient is high and gradually decreases with frequency. As an example, the transmission coefficients of the antenna at 7.3 and 10 GHz are −5.35 and −23.59 dB, respectively, this indicates a good radiation performance.

The simulated radiation patterns of the antenna at five frequency points are shown in Fig. 3. The beam points at −84° at 7.3 GHz and scans gradually towards the broadside direction with increasing frequency. For instance, the main beam directions at 8 and 8.75 GHz are −46° and −22°, respectively. With further increase of the source frequency, the beam moves closer to the broadside direction and then scans through the broadside (0° at 9.65 GHz) into the forward direction. For example, the beam points at +19° at 10.3 GHz. If the frequency increases further the main beam scans further away from the broadside, but the gain decreases gradually. It was found that when the antenna is designed for a conformal surface, the backward beam scanning improves compared to the planar structure. However, the forward beam scanning range reduces.

The simulated directivity and gain of the antenna at 7.3 GHz are 12.92 and 10.06 dBi, respectively. The antenna gain increases with frequency. For instance, the gain of the antenna at 8 GHz is 13.2 dBi, and the directivity is 14.13 dBi. The directivity and gain then decrease as the beam approaches closer to broadside. The gain at 8.75 GHz is 12.93 dBi and the directivity is 13.5 dBi. The gain of the antenna at 9.65 GHz is 12.02 dBi when the antenna beam directed at 0° (broadside). The antenna gain decreases as the main beam moves away from the broadside in the forward direction. At 10.3 GHz the gain of the antenna is 10.2 dBi.

The simulated radiation efficiency remains greater than 88% between 7.34 and 10.3 GHz, and the total efficiency of the antenna is more than 80% for frequencies above 8 GHz. However, at some lower frequencies the total efficiency is low.

IV. Conclusion

An SIW based conformal LWA is presented here for wide-angle beam scan from backward through the broadside into the forward direction. The LWA can scan its beam from −84° to +19° when the frequency sweeps from 7.3 to 10.3 GHz. Furthermore, the simulated gain of the LWA is over 10 dBi within the beam scan range. This type of conformal LWA can be very useful for different beam-scanning applications, such as frequency scanning radars, with reduced system complexity and ease of mounting on a conformal surface.

References

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