Reconfigurable Leaky Wave Antenna Based On Embedded Liquid Crystal

Elahehsadat Torabi, Pai-Yen Chen, Danilo Erricolo
Electrical and Computer Engineering Department
University of Illinois at Chicago
Chicago, Illinois, USA
etorab2@uic.edu, pychen@uic.edu, derric1@uic.edu

***Abstract*—A liquid crystal (LC)-based leaky wave antenna (LWA) capable of wide beam steering is proposed and numerically studied. The wide-angle beam-scanning (56°) is obtained at 13.6 GHz by biasing the LC with a simple uniform bias mechanism. The unique advantages of this LWA are high realized gain, low side lobes, simple mechanism for beam steering, frequency-fixed reconfiguration, non-complex design with much reduced bias lines and control circuits, low cost, low profile, compactness, and mature of LC technology.**

I. INTRODUCTION

Beam forming and Reconfigurable antennas have applications in hot research areas like automotive radar, remote monitoring in medical applications and 5G wireless communications. The most well known and applied characteristic of LWAs is their capability for beam steering. LWAs are waveguides that leak power into free space. LWAs provide a much simpler feeding mechanism compared to phased arrays, especially in the microwave and millimeter regions. These antennas can also achieve high directivities and they are usually low profile planar structures[1].

LWAs can scan their beam when the phase constant of the traveling wave in the waveguide changes. This can happen in two ways. One way is to change the operational frequency and the other is to tune the electromagnetic characteristics of the media where the wave is traveling. Each technique suits different applications. Fixed frequency scan is a must for spectrally-efficient applications. Fixed frequency scan also reduces the complexity of front-end-design in terms of matching compared to frequency scan [2]. Tunable materials can be applied to change the electromagnetic characteristics of the media in the waveguide. LCs are tunable materials well characterized in microwave and higher frequency bands [3]. The permittivity of LCs could be tuned easily by applying electric field bias. This is due to the change of LC molecules' orientation under the field's influence. LCs have low permittivities with modest losses and low dispersion. They also provide continuous tuning with relatively low cost [3], [4].

Research has been conducted on LC-based LWAs to improve their beam scanning performance. Ref. [5] proposes a composite right/left-handed (CRLH) LWA with 20 degrees beam steering. The antenna scan includes backward ($-10°$), broadside and forward ($10°$) at 7.6 GHz. A larger beam scan of 32 degrees in backward direction ($-15°$ to $-47°$) at 12 GHz is obtained in [6]. Their LC-based LWA uses a microstrip-waveguide conversion mechanism. [7] focuses on increasing the beam scan range from 30 degrees to 47 degrees by meander line. Their inverted microstrip LWA with CRLH elements scans in forward from $0°$ to $47°$ at 12.4 GHz.The article has only reported results for the maximum and minimum states of LC permittivities. So, there is no information on the antenna performance during other scan angles and the main lobe level of the antenna is largely missed. On the other hand, the proposed design will offer continuous wide beam steering from -22° (backward) to 34° (forward) including broadside. The proposed antenna design and the uniform bias mechanism for tuning LC are simple and feasible. In addition, the antenna offers high main lobe level for realized gain with low side lobes during the whole scan. In our design, we use a substrate integrated waveguide (SIW) which benefits from higher power handling, high gain, low-profile and light-weight planar structure [8].

II. THEORY AND DESIGN

The guiding structure is a SIW designed to support a slow wave (phase constant β larger than free space wave number k_0). In LWAs, the traveling wave will not leak (radiate) unless it is a fast wave($-k_0 < \beta < k_0$). By introducing periodic discontinuities (here complimentary electric-LC (cELC) resonator) to the SIW, there will be infinite space harmonics (Floquet waves) with phase constants $\beta_n = \beta_0 + \frac{2n\pi}{p}$ where p is the period of the slots (here 11 mm) and β_0 is the main harmonic phase constant (slow wave) [1]. We would like to have β_{-1} as the leaky mode (fast wave) and change the beam angle (θ_0) by changing β_{-1} [1]

$$\sin\theta_0 = \frac{\beta_{-1}}{k_0} \tag{1}$$

In order to change β_{-1}, an LC rod covered on top with a strip line for uniform bias is installed in the SIW. By biasing the LC, the relative permittivity of LC changes and so will the phase constant of the traveling wave. The schematic of the proposed antenna is shown in Fig. 1. The PVA layer, shown in the schematic, is used to align the LC molecules in the absence of bias voltage. The substrate is Rogers RT/duroid 5880 with permittivity equal to 2.2 and loss tangent equal to 0.0009. The LC is w-1825 [3] with relative permittivity range from 2.78 to 3.82. The total length of the antenna is 66 mm, including 5 periodic slots. The through vias are replaced with PEC walls in the simulations to reduce simulation time. The width of the simulated waveguide is 25 mm. The other design parameters are listed in Table I.

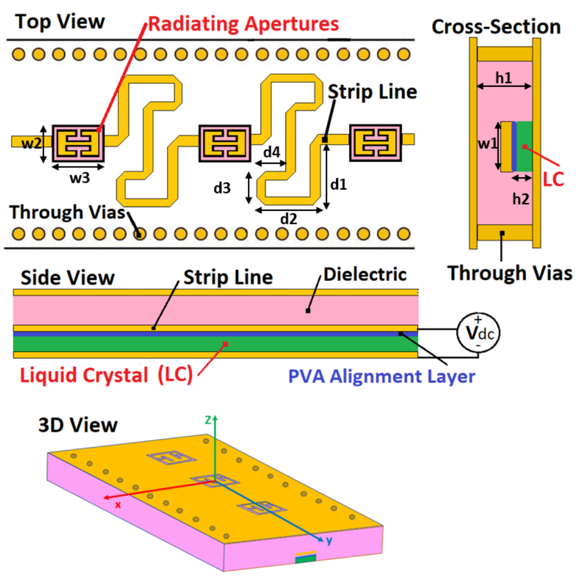

Fig. 1. Schematic of the LC based LWA.

TABLE I
DESIGN PARAMETERS IN MILLIMETERS.

h1	h2	w1	w2	w3	d1	d2	d3	d4
1	0.3	1	3.5	6	11	6.5	7	5

III. Results

The beam scan performance and side lobes are depicted in Fig. 2. A continuous beam scan angle of 56° from -22° (backward) to 34° (forward), including broadside, at 13.6 GHz is achieved with low side lobes (more than 10 dB difference compared to the main lobe). S parameters and realized gains at each scan are reported in Fig. 3. Even at broadside, the realized gain maintains high (7.5 dBi compared to the maximum of 10 dBi), while S_{11} increases due to in phase excitation of slots.

IV. Conclusion

An LC-based LWA with wide beam steering of 56° is presented. By biasing the LC, the propagation characteristics of the traveling wave in the LWA changes. Due to the correlation of beam angle and the propagation constant, tuning the LC permittivity will steer the beam of the antenna. In addition to continuous 56° beam steering from backward to forward, this simple low cost and low profile LWA offers high realized gain, low side lobes and frequency-fixed reconfiguration.

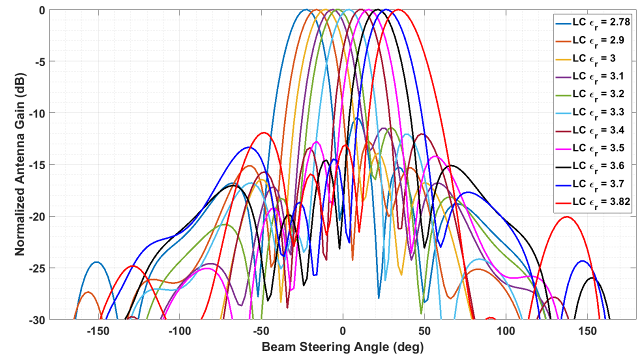

Fig. 2. The beam scanning angle of 56° with side lobes less than -10 dB is obtained.

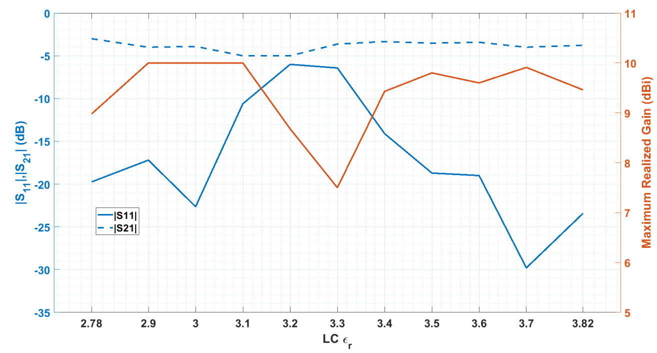

Fig. 3. S parameters and maximum realized gain at each scan (LC relative permittivity) for the proposed LC-based LWA.

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