Tunable LC MTM SIW LWA for continuous scanning at fixed frequency

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***Abstract*— In this study, a novel tunable LC CRLH leaky wave antenna is designed using both substrate integrated waveguide and meta-materials technologies. This structure is loading by 25 CRLH meta-materials unit cells and fed by a tapered microstrip line transition. This antenna is simulated and analyzed by the CST Microwave Studio software. The simulated results indicating that by tuning the permittivity tensor of the LC materials, it is possible to obtain a wide scanning range from backward to forward direction including broadside at the fixed frequency 14.2 GHz.**

Keywords—Leaky wave antenna (LWA), Substrate integrated waveguide (SIW), fixed frequency, Crystal Liquid (CL), tunable.

I. INTRODUCTION (*HEADING 1*)

Substrate integrated waveguide has become one of the most popular and developed technology so far because it is very easy to integrate with conventional rectangular waveguide in the standard PCB. This technology exhibits the same advantages of the conventional rectangular waveguides (high quality factor, high power capacity and self-consistent electric shielding) but with low losses, low cost and compact size [1-3].

In particular, the CRLH SIW LAW have recently become a very important research interest for their attractive properties, mainly continuous scanning by frequency beams. [4-6]. However, some modern communication systems, such as in broadcast applications where a frequency band containing the information must be used, require fixed frequency operation with sweeping of the main beam for efficient channelization. To obtain this performance, many techniques have been proposed. In reference [7], the varactor diodes have been employed to control the radiation angle by varying the applied voltage. In [8], an electronic switches consisting of microstrip multiport line have been added to the antenna structure. In [9], PIN diodes have been used to control the period of the structure and therefore the direction of the LWA. However, these tuning elements exhibit poor performance and high losses at high frequencies, resulting in a low radiation efficiency.

Recently, another technique has been suggested for designing tunable fixed frequency LWAs which utilize an adjustable permittivity liquid crystal (LC) material [10-11]. This material is ideally suited for use in microwave circuits and millimeter wave devices, as it deals with some important features because of its dielectric anisotropy and the possibility of controlling this anisotropy by magnetic or electric fields. LC offers the following advantages: low cost, light weight, low losses, compatibility with microwave circuits and ease of integration into future wireless communication devices.

This paper presents a new type of tunable LC LWA by using a CRLH MTM on the upper face of the SIW. The antenna is composed of 25 tunable unit cells. By adjusting the permittivity of the crystal liquid material, it is possible to obtain beam orientation from the back to the front at a fixed frequency of 14.2 GHz.

This communication is organized as follows, Section II reviews the design procedures of the proposed structure, in Section III, the simulated results are presented, and Section IV, concluding the proposed work.

II. ANTENNA STRUCTURE

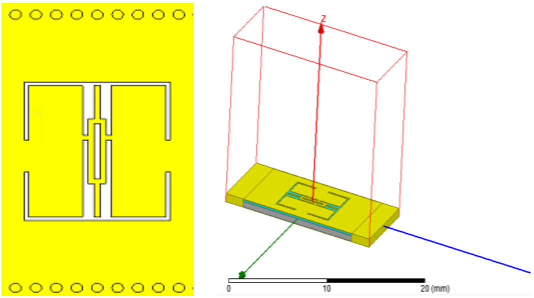
A. Unit cell design

Fig. 1 shows the CRLH unit cell of SIW meta-materials. The unit consists of two symmetrical C-shaped bands, divided in two, oriented back-to-back and coupled by a combination of a gap-and-strip and engraved on the upper side of the waveguide. Table I summarizes the geometric parameters of the proposed unit cell. To obtain the tunability, a layer of polymer liquid crystals (GT3-23001) is injected between the substrate and the upper face of the SIW. This material was chosen for its quick adjustment and good long-term stability [12].

TABLE I. GEOMETRIC PARAMETERS OF THE PROPOSED UNIT CELL

Parameters of the unit cell	Wsiw	w1	w2	w3	w4	d	s
Values (mm)	11.62	5	1.4	0.15	1	0.4	0.7

As shown in Table II, the LC permittivity εr can be adjusted from 2.47 to 3.16 when a bias voltage is applied, the loss tangent is 0143 and the thickness is equal to 0.2 mm. In simulation, the LC is modeled as an anisotropic material with ε|| and ε⊥ , respectively, so that the maximum tuning is usuagly overvalued. Besides, the position of the LC is chosen to obtain the widest range of the main beam scanning at the fixed frequency 14.2 GHz. In the measurement, it is possible to align the polarization of the LC molecules by applying a magnetic or an electric biasing in the structure.



(a) (b)

Fig. 1. Configuration of the proposed complimentary MMT SIW unit cell (a) top face, (b) explosed view

TABLE II. THE CHARACTERISTICS OF THE LC POLYMER

LC Name	$\varepsilon_{\parallel}$	tan $_{\delta\parallel}$	$\varepsilon_{\perp}$	tan $_{\delta\perp}$
GT3-23001	3.16	3.3 * 10 -3	2.47	15.1 * 10-3

Fig. 2 presents the corresponding dispersion characteristics of the tunable unit cell under different bias voltage of the crystal liquid, and therefore different permittivity values, simulated using Ansoft HFSS simulator. It can be noted that, by adjusting the permittivity ε of the LC, the dispersion curve is shifted downwards, and therefore, forward and backward scanning can be obtained between 12.5 and 13.39 GHz and 13.9-17.85 GHz, while the transition frequency changes from 13.8 to 14.84 GHz. In addition, both equilibrium conditions and operating bands are well conserved when tuning the LC permittivity, indicating that the proposed design is a very promising candidate for fixed frequency beam steering LWAs. Thus, we observe that the β_p graph is shifted toward low frequency as the voltage decreases (and ε increases). The fixed frequency is assumed to be at 14.2 GHz since it covers both positive and negative regions as well as the broadside region and a large scanning range from forward and backward directions can be achieved.

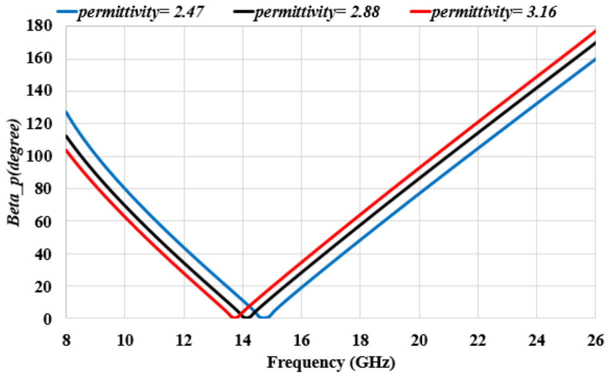


Fig. 2. Dispersion diagram of the proposed unit cell with for different LC states

B. *Antenna geometry*

The geometrical configuration of the tunable LWA is illustrated in Fig. 3. As shown, the structure is constituted by 25 complementary MTM unit cells which are periodically etched on the upper face of the SIW. A 50 Ω microstrip line section combined with a tapered line for impedance matching is located at the ends of the to allow the external connection. The tunable antenna is designed on a substrate of Rogers 5870 with a thickness of 0.508 mm a relative permittivity of 2.33. A 0.2 mm thick LC polymer layer is injected between the substrate and the SIW top surface to ensure the agility of the frequency and the radiation patterns at a fixed frequency.

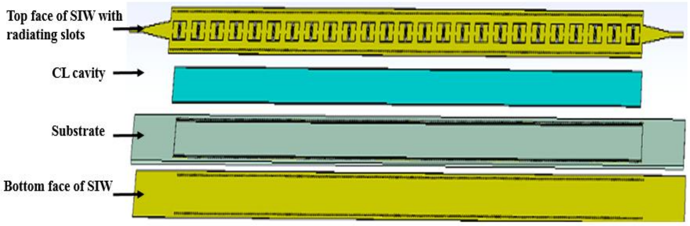


Fig. 3. Structure of a tunable MTM CRLH SIW LWA based on LC.

III. SIMULATED ANTENNA PERFORMANCE

The S- parameters of the tunable SIW MTM leaky wave antenna proposed in all the cases studied are presented in Fig. 4. S_{11} is keeping below -10 dB on the LH and RH operating bands. In addition, it should be noted that the broadside frequency decreases when the LC permittivity tensor increases from 2.47 to 3.3 and a balanced condition is obtained in all states.

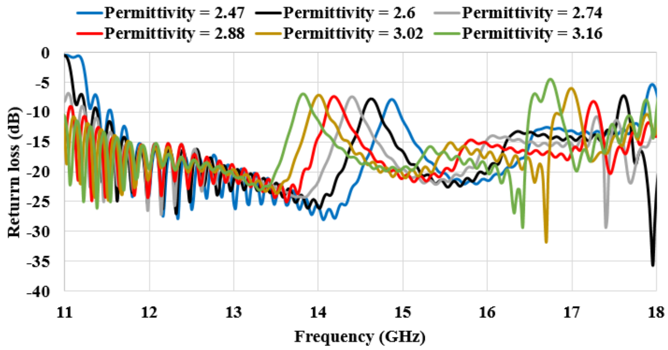


Fig. 4. S11 vs. frequency at different tuning permittivity states

Table III labeled the operating band of the proposed tunable antenna in all the cases studied. Therefore, at the fixed frequency 14. 2 GHz, a LH, RH and broadside frequency bands can be displayed, which leads to a wide sweeping range from backward to the forward direction, including the broadside one.

The E-plane radiation patterns are calculated for different states at four different fixed operating frequencies in order to validate the electrical control capability of the beam steering as shown in Fig. 5. At the fixed frequency 14.2 GHz, the main beam points at -24 ° which corresponds to the LH band when the permittivity is 2.47 while it points at 15° when the permittivity is tuned to 3.16, corresponds to the RH band. On the other hand, it can be observed that a large scanning angle of the beam that reaches 38°, 39° and 38° at 14 GHz, 14.5 GHz and 17.7 GHz is obtained by varying the permittivity tensor of 2.47 to 3.16, respectively.

TABLE III. SUMMARY OF OPERATING FREQUENCY BANDS EXHIBITED FROM S-PARAMETER RESULTS

Permittivity	Backward frequency region (GHz)	Broadside frequency (GHz)	Forward frequency region (GHz)
2.47	13.39 -13.7	13.8	13.9-17.85
2.6	13.3- 13.9	14	14.1-17.54
2.74	13.18-14.09	14.2	14.3-17.3
2.88	12.91- 14.31	14.4	14.5-17.9
3.02	12.72-14.52	14.6	14.72-16.8
3.16	12.5-14.78	14.84	14.95-16.5

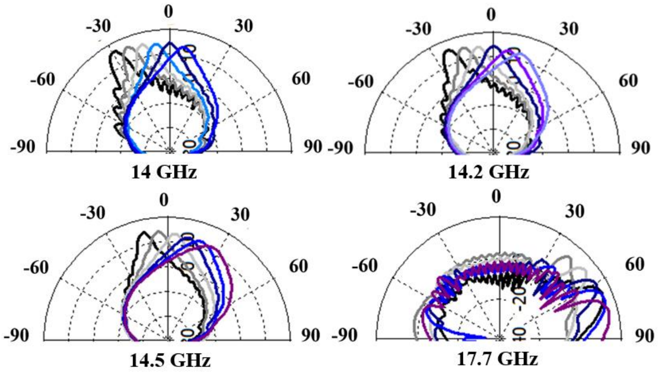


Fig. 5. Simulated Far-Field radiation patterns with different permittivity tuning states

Fig. 6 shows the simulated beam angle of the main over the bias voltage at different frequencies, which shows that the main beam can be controlled to move from quadrant backward to quadrant forward continuously at the fixed frequency 14.2 GHz. Therefore, it is also observed that, in all cases studied, the adjustment of the permittivity tensor from 2.47 to 3.16 leads to a progressive increase in the point angle of the antenna.

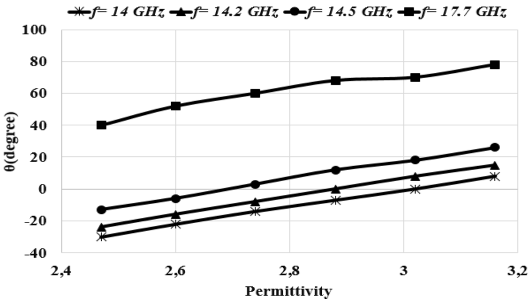


Fig. 6. Simulated scanning angle versus the permittivity tuning states

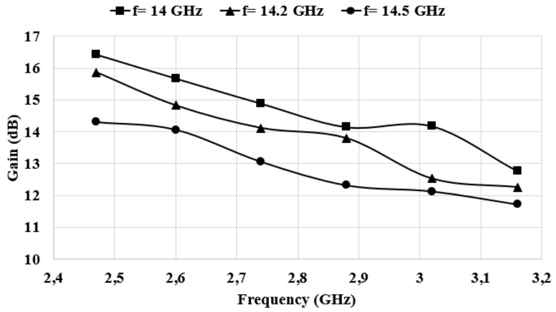


Fig. 7. Maximum gain versus the permittivity tuning states at f= 14 GHz, f= 14.2 GHz and f= 14.5 GHz.

Since we are interested to the scanning behavior of the tunable antenna at a fixed frequency, the maximum gain results over the adjustment of the permittivity tensor at three fixed frequencies, namely 14 GHz, 14.2 GHz and 14.5 GHz is discussed as presented in Fig. 7. It can be noticed that a high gain is achieved in all studied cases. It is obvious that the gain is gradually decreases as the LC permittivity tensor is increases, but remains important (more than 11 dB).

IV. CONCLUSION

In this communication, an electrically tunable MTM SIW LWA operating at a fixed frequency of 14.2 GHz is designed and investigated. In order to perform beam scanning from backward to forward directions without varying the frequency, Polymer liquid crystal material which allows a continuous tunability of it anisotropic permittivity is used. This antenna is a promising candidate for Ku- band applications.

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