EMSICC Based CRLH Compact Leaky-wave Antenna with Enhanced Broadside Efficiency

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***Abstract*—In this paper, composite right/left handed (CRLH) compact high gain leaky-wave antenna (LWA) is designed based on eighth-mode substrate integrated circular cavity (EMSICC). Utilizing the longitudinal asymmetry, frequency as well as Q-balancing condition are achieved which result in the enhancement of overall radiation efficiency. The broadside efficiency of the proposed antenna is 93.79% with the off-broadside radiation efficiency variation of $\pm1.4\%$. The proposed antenna covers a frequency beam scanning range of $\sim 98°$ $(-45°$ to $53°)$ and maximum gain of 14dBi is obtained. The proposed prototype could be suitable for land, airborne and naval radars. Full-wave simulations are carried out in Ansys HFSS.**

I. Introduction

CRLH transmission-lines (TLs) represent an artificially structured media having unique properties which have been used extensively in several applications over the past few decades. Besides this, with the rapid advancement of wireless technology, the demand of improved antenna performances such as high gain, high efficiency, larger scanning range etc. are highly desirable in various surveillance systems and many scanning applications. LWA appears to be an appropriate choice for such applications [1]. Recently, several compact LWAs based on SIW technology open a new avenue for frequency scanning antenna design [2]. SIW technology has become popular for integrated microwave and millimeter-wave circuits due to their high-density integration with subsystems, low fabrication cost, low loss and being less bulky compared with a rectangular waveguide with similar performances. By bisecting the SIW along fictitious magnetic wall, EMSIW has been realized [3]. The major requirements of designing scanning antennas are to achieve a constant high gain and higher radiation efficiency throughout the operating frequency range. Also, it is required to be an efficient radiator along broadside which generally degrades while scanning.

In this paper, an eighth-mode substrate integrated circular cavity (EMSICC) incorporated with interdigital slot is utilized to design a full-space scanning leaky-wave antenna. Using its longitudinal asymmetry feature, broadside efficiency is improved and is equalized with off-broadside efficiency. Optimization for the proposed design is done using High Frequency Structure Simulator (HFSS). The proposed LWA is able to scan within the frequency range of 8.3-10.8 GHz with a beam scanning range of 98°.

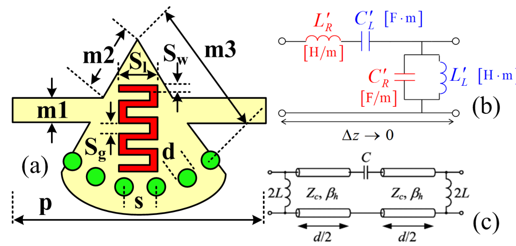

Fig. 1. (a) CRLH unit cell, (b) Distributed TL model, (c) Equivalent π- model. Optimized dimensions are: d=0.8mm, s=1.25mm, m1=2.32mm, m2=4.43mm, m3=7.7mm, S_g=0.3mm, S_l=2.2mm, S_w=0.33mm

II. CRLH based EMSICC Longitudinal Asymmetry Unit Cell Design

The EMSICC, shown in Fig. 1(a) has two radiating edges and one bounded via edge. Tip of the EMSICC has the maximum magnitude of electric field which implies larger accumulation of electric charges which causes radiation [3]. Interdigital slot is etched on the top of EMSICC to design composite right/left handed (CRLH) unit cell as shown in Fig. 1(a). Shunt capacitance and series inductance corresponding to each unit cell are distributed along the line, which correspond to an equivalent model of ground plane and top wall of the EMSICC. Slot provides series capacitance and the metallic vias of the bounded via wall are realized as distributed shunt inductance as shown in Fig. 1(b). The unit cell shows transversal symmetry and longitudinal asymmetry (LA) [4]. For the double symmetry (DA) unit cells like Full mode SIW or quarter mode SIW, the overall efficiency particularly in broadside direction has become very poor due to the non-radiating nature of the shunt resonances. Basically LA primarily affects the shunt resonances of the CRLH unit cell without affecting the series resonances which ultimately enhances the overall radiation efficiency. The equivalent π-model of the unit cell is shown in Fig. 1(c). In order to balance the unit cell, series (ω_{se}) and shunt (ω_{sh}) resonance frequencies are made equal. Simultaneously, the equalization of series (Q_{se}) and shunt (Q_{sh}) Q-factors are achieved. Firstly, ω_{se} and ω_{sh} are obtained from the series impedance (Z_{se}) and shunt admittance (Y_{sh}) using the circuit analysis [4] as well as from full wave simulation by considering the appropriate boundary condition as shown in Fig. 2 and mentioned in (1).

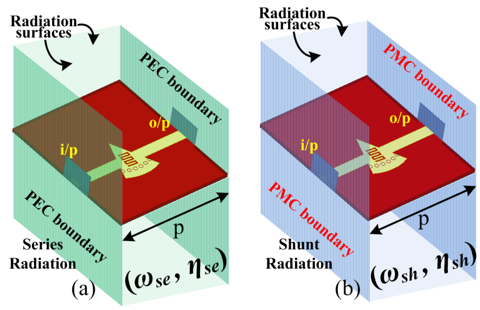

Fig. 2. Boundary condition for (a) Series (b) Shunt radiation from the CRLH unit cell.

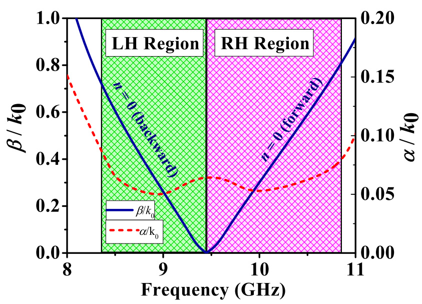

Fig. 3. Dispersion diagram of the frequency balanced unit cell.

$$\Im\{Z_{se}\}|_{\omega_{se}} = 0 \Rightarrow \omega_{se} = 9.48GHz \qquad (1)$$
$$\Im\{Y_{sh}\}|_{\omega_{sh}} = 0 \Rightarrow \omega_{sh} = 9.57GHz$$

By tuning the physical parameter of the interdigital slot, the balance condition is achieved where ω_{se}=ω_{sh}. Then Q_{se} and Q_{sh} are calculated using (2).

$$Q_{se} = \frac{\omega_{se} L}{R} \quad \text{and} \quad Q_{sh} = \frac{\omega_{sh} C}{G} \qquad (2)$$

The dispersion diagram at frequency balanced condition is depicted in Fig. 3 where, the behavior of the radiating space harmonic ($n = 0$) is showing. In Fig. 4, after equalization of Q-factor, the variation of Bloch impedance is depicted. The range of overall efficiency is obtained as min(η_{sh},η_{se}) $< \eta_{bs} <$ max(η_{sh},η_{se}).

III. Leaky-wave Antenna Design and Analysis

The unit cell shown in Fig. 1(a) is placed periodically with a periodicity of p such that fundamental space harmonic belongs to the fast wave region (8.3-10.8 GHz) and radiates. The proposed leaky-wave antenna is able to scan within the above mentioned frequency range where $-k_0 < |\beta_n| < k_0$ ($n = 0$ is chosen for radiation). The antenna layout is shown in Fig. 5. By changing the geometrical parameters of the CRLH unit cell, balanced condition is achieved which is validated numerically. Then by tuning the LA one can tune the Z_{se} and Y_{sh} which further optimize R, L, G and C for Q-balancing. At this point broadside efficiency is improved significantly and almost equal to the series and shunt radiation efficiency. We have considered 10 unit cells to design the LWA. The proposed LA LWA shows a radiation coverage of $\sim 98°$ ($-45°$ to $53°$) as shown in Fig. 6(a) and a gain variation from 9.8-14 dBi. Due to the participation of shunt resonator in antenna

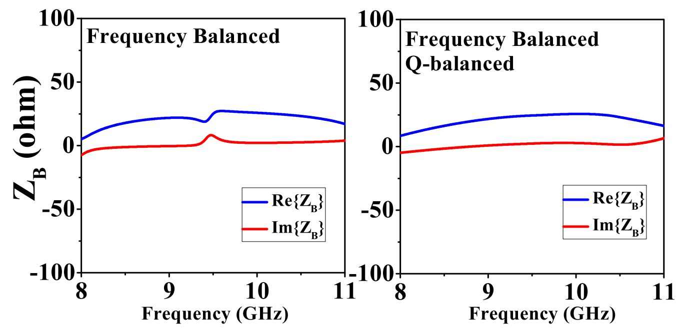

Fig. 4. Variation of Bloch impedance with frequency and Q-balancing

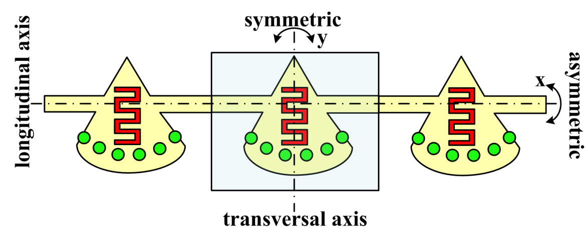

Fig. 5. Layout of the proposed LA LWA

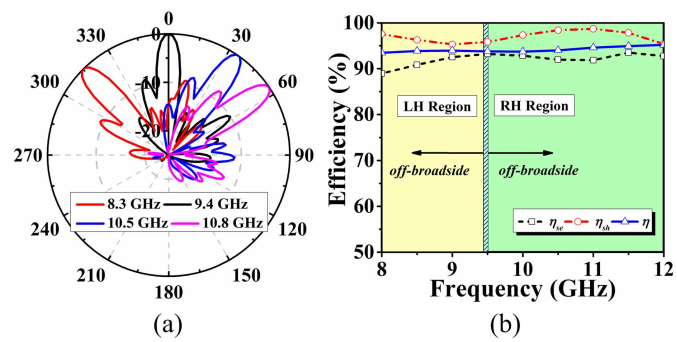

Fig. 6. (a) Radiation pattern in xz-plane, (b) efficiency variation with frequency

radiation the overall efficiency is enhanced and is varied within $93\% - 95.5\%$ as shown in Fig. 6(b).

IV. Conclusion

A CRLH based LWA has been presented for enhanced overall radiation efficiency and larger radiation coverage. EMSICC incorporating with interdigital slot is utilized to realize CRLH media where as LA is used for efficiency enhancement.

References

[1] D. R. Jackson, A. A. Oliner '*Leaky-wave antennas*', *in Modern Antenna Handbook*. C. A. Balanis, Ed. Hoboken, NJ, USA: Wiley, blue.

[2] A. Sarkar, M. Adhikary, A. Sharma, A. Biswas, and M. J. Akhtar and Z. Hu, "Composite right/left-handed based compact and high gain leaky-wave antenna using complementary spiral resonator on HMSIW for Ku band applications," *IET Microw. Antennas Propag.*, DOI: 10.1049/iet-map.2017.0478.

[3] S. Sam and S. Lim, "Electrically small eighth-mode substrate-integrated waveguide (EMSIW) antenna with different resonant frequencies depending on rotation of complementary split ring resonator," *IEEE Trans. Antennas and Propag.*, vol. 61, no. 10, pp. 4933-4939, 2013.

[4] S. Otto and C. Caloz, "Importance of transversal and longitudinal symmetry/asymmetry in the fundamental properties of periodic leaky-wave antennas," *2013 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, Orlando, FL, 2013, pp. 240-241.