Novel Single/Dual Beam Scanning Provided by an Array Composed of Two CRLH SIW LWAs

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***Abstract* — A novel single/dual beam switchable steering of dual different elements CRLH LWAs has been introduced in this communication. This structure with two phased feeding ports is designed on a SIW technology with only one via walls that associates both structures. The fabricated prototype features a complex beam scanning from -72° to 73° by sweeping the frequency from 6.9 to 13.4 GHz. Radiation performances are obtained by measuring the antenna in an anechoic chamber, results show a pick gain of 15.4 dB and high radiation efficiency with an average 90 %. This design suitable for tracking applications and smart monitoring systems.**

***Keywords* — SIW, single beam/dual beams steering, CRLH, LWA.**

I. INTRODUCTION

Leaky wave antennas (LWA) have been used in a variety of research since they can reduce complexity in many applications like multipoint communications and surveillance systems and [1-3]. With features of low cost, low-profile, and easy integration with circuits despite the fact of keeping the advantages of conventional rectangular waveguide, SIW technology has been widely used recently in the design of LWA [4-5].

Recently, a variety of research has been conducted on dual beam LWA antenna due to their low profiles and low costs [6-8]. Different designs based on dual-beam scanning LWA were reported in the past decades. [8] Presents a microstrip leaky wave antenna based on one-dimensional triple periodic structure which is able to provide symmetrical dual beam steering. A dual beam steering could be also realized by exciting the second higher order mode of a microstrip LWA as has been proposed in [6]. A wideband microstrip LWA with simultaneous side beams radiation from the edges of the line has been reported in [7].

This communication discusses an array composed of two SIW CRLH leaky wave antennas with high gain high radiation efficiency proprieties. The design exhibits a single / dual beam scanning over the wide frequency band from two different 25 cell CRLH LWA elements located in parallel on a single substrate. The paper is organized as follows: section II presents a theoretical analysis of the proposed design and discuss the dispersion characteristics. Simulation and experimental results are presented in section III. Finally, section IV concludes the paper.

II. DESIGN AND CONFIGURATION

The far-field behaviour of the proposed an array of two LWAs can be figured out by using the following theory where ideal case not considering coupling between the two parallel elements is chosen [9]:

$$E_{\theta totale} = E_{\theta 1} + E_{\theta 2}\, e^{j\varphi} \tag{1}$$

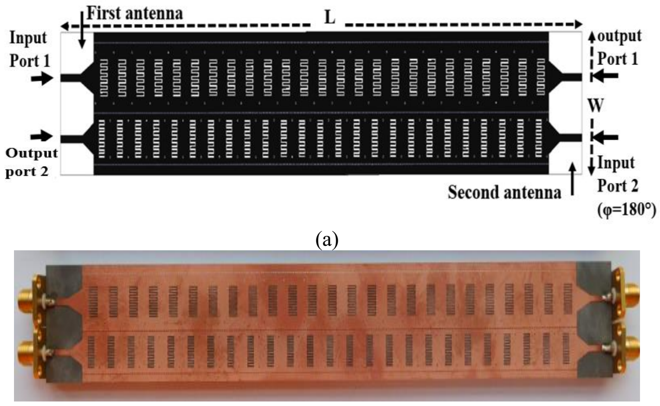
with

$$E_{\theta 1} \approx I_0 \frac{j\omega\mu_0}{4\pi r} e^{-jk_0 r} \sin\theta \int_0^L e^{-jk_{z1}\cos\theta\, z'} dz' \tag{2}$$

$$E_{\theta 2} \approx I_0 \frac{j\omega\mu_0}{4\pi r} e^{-jk_0 r} \sin\theta \int_0^L e^{-jk_{z2}\cos\theta\, z''} dz'' \tag{3}$$

where Eθ1 and Eθ2 are the radiated field; kz1 and kz2 are complex propagation constants of the first and the second antenna, respectively. φ determines the phase shift between the two feeding ports.

The proposed structure has been designed and fabricated on Rogers RT5880 (εr= 2.2 and tanδ = 0.0009) with dimensions 205×29.3×0.508 mm3. Fig. 1 presents the layout and the fabricated top views of the array fed with tapered microstrip transmission lines. Two input ports are excited simultaneously and each LWA element is terminated by a 50 Ω loads.



(b)

Fig. 1. Top view of the dual LWA elements (a) configuration of the designed structure (b) Fabricated structure

Fig. 2 shows the configuration of the two proposed unit cells used in the design. Each one is building with one interdigital capacitors graved at the upper face of the SIW and two inductor pins loaded in the right side. The geometric parameters are well optimized in order to achieve two equilibrium unit cells. Dimensions are summarized in Table 1. Fig. 3 plot the dispersion characteristics. It is obvious that the balanced conditions when (β=0) are obtained at the frequencies 7.8 GHz and 10.2 GHz aimed at the first and the second CRLH SIW unit cells, respectively. The first cell exhibits a LH behaviour with (β < 0) in the band [6.9 - 7.7 GHz] and a RH properties with (β > 0) in the frequency band [7.9 - 11 GHz]. The LH region of the second cell is given from 8.9 to 10.1 GHz while the RH one is obtained from 10.3 to 13.5 GHz.

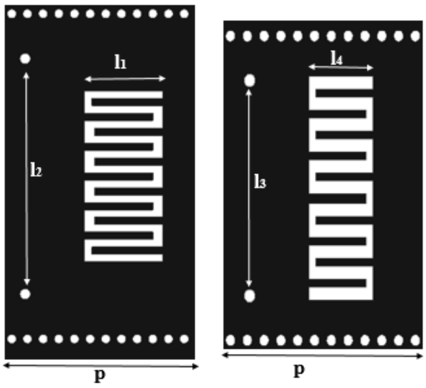


Fig. 2. Top view of the proposed unit cells used in the design

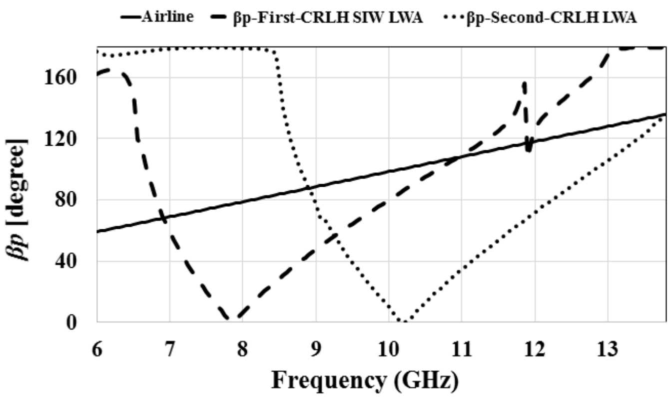


Fig. 3. Dispersion diagram of proposed unit cells

Table 1. Geometric parameters of the proposed unit cells

Parameters	l1	l2	l3	l4	w1	w2	w3	p
Dimension (mm)	4	6.4	7.7	2.7	0.45	0.33	0.45	8.2

III. EXPERIMENTS

The implemented array of two LWAs radiating with complex beam steering is created by cascading 25 SIW CRLH unit cells for each antenna as shown in Fig. 1. The structure was fabricated by a professional company using the standard printed circuit board technology with metalized vias Simulation results were carried out by CST simulator and a prototype has been fabricated for verification purposes.

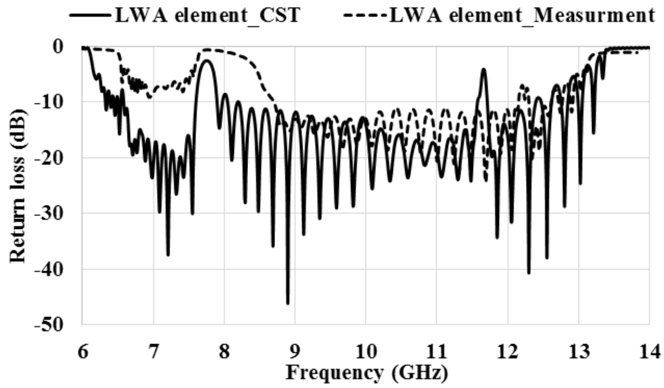


Fig. 4. Measured and simulated S11 of the first CRLH SIW leaky wave antenna

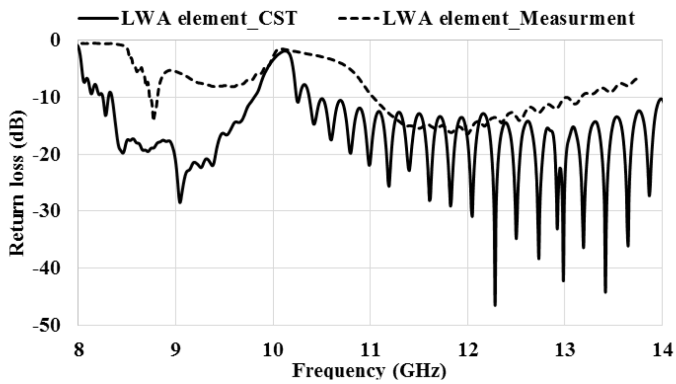


Fig. 5. Measured and simulated S11 of the second CRLH SIW leaky wave antenna

The measured S11 of the first CRLH SIW leakage wave antenna is compared with the simulation of Fig. 4. CST result shows that good impedance matching below -10 dB is achieved in the LH and RH regions. These regions are covering an impedance bandwidth given from 6.9 - 7.7 GHz and 7.9 - 11 GHz, respectively. In addition, an increase in impedance matching is achieved at the 7.8 GHz resonance frequency. The LH radiating band of the second antenna is given from 8.9 to 10.1 GHz and the RH one is founded from 10.3 to 13.5 GHz. the broadside radiation frequency is given at 10.2 GHz.

Measured results of S11 presented in Fig. 4 and Fig. 5 are obtained by Rohde & Schwarz ZVA67 vector network analyser. It is obvious that the backward- forward radiating bands of the first antenna are given from 6.9 to 11 GHz. Unluckily, a disagreement between measured and simulated results is shown around the broadside area where a gap band is obtained from 7.95 to 8.5 GHz. The same is shown in Fig.5 where the antenna radiates from 8.9 to 13.5 GHz but with a stop band given from 10.3 to 10.8 GHz. Many factors can explain the discrepancy between measurement and simulated results such as: the material manufacturing tolerance, the SMA connector mismatch with the circuit and their losses and mainly the sensitivity in the unit cell design where a small modification in the position of the inductor pins can widely effect the balance of the design.

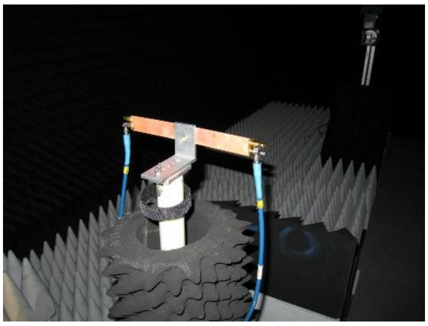


Fig. 6. Measurement of the radiation patterns of the fabricated antenna in the anechoic chamber.

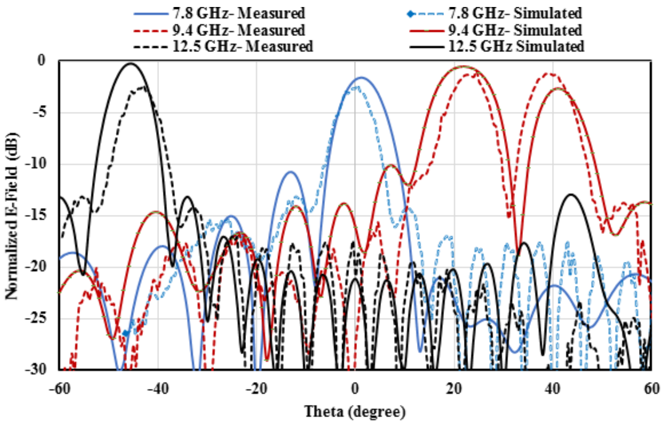


Fig. 7. Comparison of measured and simulated radiation patterns results in different frequencies.

Fig. 6 shows the photograph of the proposed antenna in the anechoic chamber. The measured and simulated E-plane radiation patterns at different frequencies are displayed in Fig. 7. Measured results agree well with simulation and the theoretical analysis. The beam steering comportment of the proposed array composed by two CRLH SIW LWAs is described with more details in Table 2.

Table 2. Complex beam steering behaviour of the proposed dual elements

Frequency (GHz)	**β_1 of first LWA**	**β_2 of second LWA**	**Number of main beams**
6.9 to 7.7	β_1<0	-(no radiation)	One beam
at 7.8	β_1=0 (θ=0)	-(no radiation)	One beam
f7.9 to 8.9	β_1> 0	-(no radiation)	One beam
8.9 to 9.3	β_1>0	β_2<0	Two beams
At 9.3	β_1= - β_2		One beam
9.3 to 10.1	β_1>0	β_2<0	Two beams
at 10.2	β_1>0	β_2=0 (θ=0)	Two beams
10.3 to 11	β_1>0	β_2>0	Two beams
11 to 13.5	-(no radiation)	β_2>0	One beam

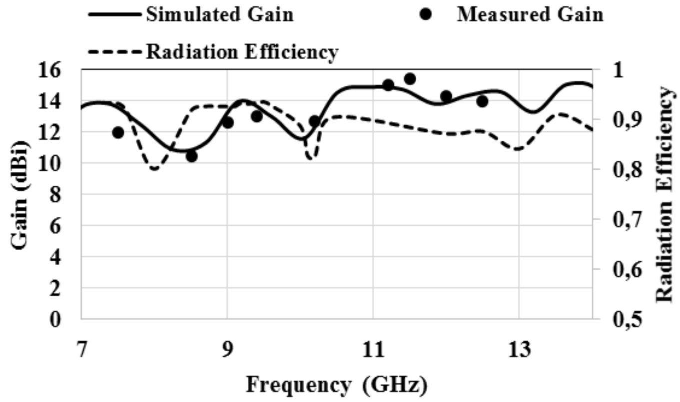


Fig. 8. Simulated and measured gain and radiation efficiency of the proposed dual elements CRLH SIW LWA.

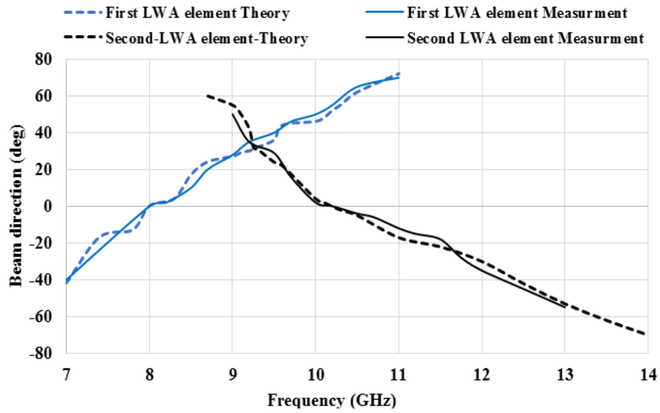


Fig. 9. Comparison of measured and analytical analysis results of main beams direction of the proposed dual elements LWA.

Measured and simulated gain over the frequency is presented in Fig. 8. Maximum of gain is between 11 and 11.4 GHz for both simulation and measurement, respectively. The degradation of the gain around 7.8 and 10.2 GHz is attributed to bad matching at the broadside radiation frequencies. Radiation efficiency is also plotted in Fig. 8 where a maximum value of 93 % is obtained at 9.5 GHz. The proposed LWA has a high radiation efficiency with an average of 90 %. This structure can be a potential candidate for monitoring system with coverage of complex areas.

The measurement results of the scanning angles of the beams radiating from the dual elements CRLH LWA are compared with the analytical analysis results picked from equations (1), (2) and (3) as shown in Fig. 9. It can be noticed that the results are in good agreement where the first elements scans from -40° to 71° in the band (6.9 -11 GHz) and the second scans from -73° to 60° in the band (8.9- 13.5 GHz).

IV. Conclusion

In this communication, novel complex beam steering CRLH LWA system based on SIW technology is designed, fabricated and tested. The proposed prototype is able to scans a single and dual main beam over a wide frequency band with keeping a good radiation efficiency and a significant gain value. The antenna is a good candidate for monitoring and tracking application used in the X-band.

ACKNOWLEDGMENT

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