Comparison of Uniform and Non-Uniform SIW CRLH LW antennas

Rihem Noumi[1], Jan Machac[2], Ali Gharsallah[3]
[1,3] Department of physics, Laboratory for Research on Microwave Electronics, Faculty of Sciences of Tunis, University of Tunis El Manar 2092, Tunis, Tunisia
[2] Department of Electromagnetic Field, Faculty of Electrical Engineering, Czech Technical University in Prague, Technická 2, 16627 Prague 6, Czech Republic
noumii.rihem@gmail.com, machac@fel.cvut.cz, ali.gharsallah@gmail.com

***Abstract* - This paper presents the results and investigation of substrate integrated waveguide (SIW) leaky-wave antenna (LWA) based on the composite right/left-handed (CRLH) structure designed for X band applications. The interest is given to two antenna types: uniform CRLH antenna, non-uniform CRLH antenna where three balanced CRLH unit cells are used in the design. Results of both structures show that a wide scanning range over the frequency bandwidth from 9 to 13.4 GHz is obtained. The side lobe level is remarkably decreased in the non-uniform structure especially around the broadside area which is suitable for many scanning applications.**

Index Terms – Side Lobe Level (SLL); composite right-left transmission line (CRLH); substrate integrated waveguide (SIW), Leaky wave antenna (LWA)

I. INTRODUCTION

Since their invention by W.W. Hanson in 1940 and up to now, the LWA still arouse a strong interest in the fields of wireless communication, surveillance systems and modern radars since they have many important features such as beam steering capability, a straightforward feeding arrangement, broad bandwidth, narrow beamwidth, and low cost [1-4].

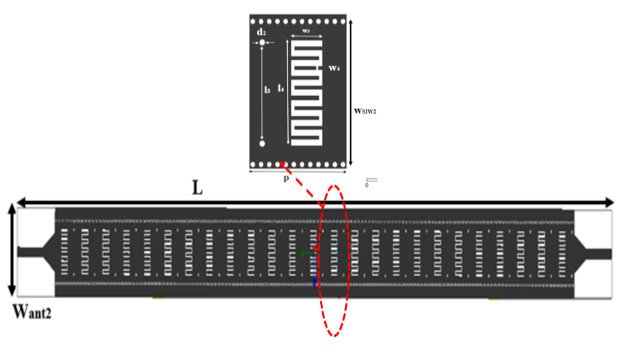
In particular, SIW CRLH leaky-wave antennas have received much interest due to their outstanding advantages of simple structure, low profile and easy of fabrication. They usually have the ability of beam scanning over the frequency, so they can be used in radar systems and wireless locations [5-8].

This article is intended to design and comparison the results of a uniform and a non-uniform CRLH SIW LWA antennas in order to show the efficiency of using a non-uniform structure to minimize the secondary lobe level. Besides, the aim of this work consist in designing wide scan range antennas with high radiation performances. These structures can be manufactured at low cost using standard technology for printed circuit board technology.

II. UNIFORM CRLH SIW LWA

A. *Design of uniform structure*

The layout of the uniform antenna structure is shown in Fig. 1. The Rogers 5880 substrate with thickness h = 0.508 mm, and with relative permittivity ε_r = 2.33 is used. The antenna is composed of twenty-five-unit cells. In addition, two feeding ports are used which is very usual for this type of antenna. The second port is typically a 50 Ω load charged to absorb the non- radiated energy. The input and output SMA ports are connected to a tapered microstrip feeding line. The dimensions are obtained through the design conditions calculated using the equation [9]. Also, we found that if the number of cells increased more than 25 cells, its influence on the radiation efficiency and the gain of the antennas is negligible. The prototype of the fabricated SIW CRLH leaky-wave antenna is presented in Fig. 1(b). Tab. 1 recapitulates the final geometrical parameters of the proposed unit cell.



(a)

(b)

Fig. 1. Uniform SIW-CRLH leaky wave antenna: (a) Layout, (b) Fabricated structure

Tab.1. Geometric parameters of the second proposed unit cell

Parameters of CRLH SIW unit cell	**Values (mm)**
l3	7.7
l4	7.6
W3	2.7
W4	0.33
p	8.2
d2	0.7
Wsiw2	12.45
Weq2	11.2
N	11

B. Design of non-uniform structure

As it is known, the design of the periodic leaky wave antenna always begins with the configuration of a balanced unit cell. On the other hand, it is possible to control the leakage rate of the CRLH-TL LWA by using different sizes of the unit-cell as indicated in [10]. In this section, we decide to use three different unit cells that operate in the same frequency band. Each cell has a different number of interdigital fingers. They are designed to have the origin of the phase at the same transition frequency. Although, the radiation resistance of the seven fingers antenna is always higher than that of the eleven fingers structure, resulting in fast deterioration of power (more leakage) along the structure. Hence, for the applications that necessitate higher gain and narrow beam antenna, the LWA with reduced unit cell size is recommended.

Once optimizing the unit cells, the final configuration of the proposed antenna is constituted. The geometry of the proposed antenna is composed by three sections as shown in Fig. 2. The first section is composed of nine cascading unit cells with eleven fingers along the y-axis, the second section consists of six unit cells with nine fingers divided three by three on each sides of section one and finally six seven fingers unit cells are connecting three by three on the edges of the second section. This configuration is chosen after several parametric studies giving the optimal results. The proposed antenna is also excited by means of a tapered microstrip line at port 1 and terminated by a 50 Ω load at port 2. The geometric dimensions of the proposed unit cells are summarized in Tab.2.

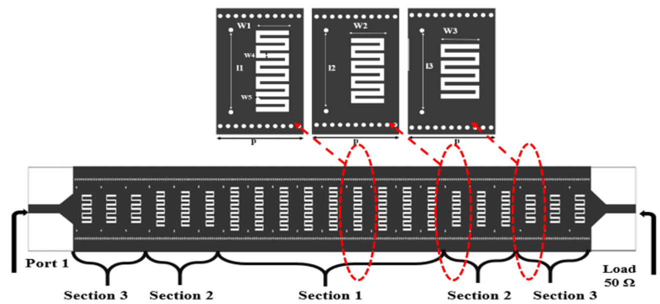


Fig.2. Geometry of the proposed non-uniform SIW leaky wave antenna and the three used unit cells.

Tab. 2. Dimensions of the three proposed CRLH unit cells

Parameters of three CRLH SIW unit cells	**Values (mm)**
l1	7.97
l2	7.9
l3	7.7
W1	2.94
W2	3.34
W3	3.7
W4	0.45
W5	0.33
p	8.2

III. RESULTS DISCUSSION

Simulations were performed using the CST simulator. Fig. 3 displays the predicted S_{11} of the non-uniform CRLH SIW leaky wave antenna compared with results of the uniform antenna design. It can be noted that the obtained results are very close, which designates that the use of different unit cells with close dispersion diagrams does not disturb the performance of the antenna. The LH impedance bandwidth (S11 < -10 dB) is 800 MHz covers the frequency band 9.2 - 9.95 GHz, whereas the RH one is around 3.1 GHz covering the band 10.4 - 13.5 GHz. The broadside frequency is assigned at around 10 GHz.

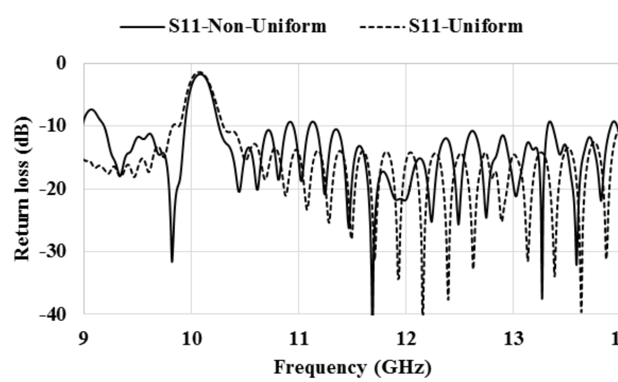


Fig. 3. S11 results of the uniform and non-uniform CRLH SIW LWAs

The 2D radiation patterns results of the uniform and non-uniform CRLH SIW LWA are displayed in Fig. 4 and Fig. 5, respectively. The results are obtained in both LH and RH regions and at the broadside area at some particular frequencies. As depicted, a continuous beam steering is reached in an angular region in both structures, starting from -44° till 52° in the case of the uniform structure and from -52° till 64° in the non-uniform design when the operating frequency increases from 9 to 13.5 GHz. It can be noted that the scanning range is increased in the non-uniform antenna from 96° to 116° although the desired low side lobe is attained.

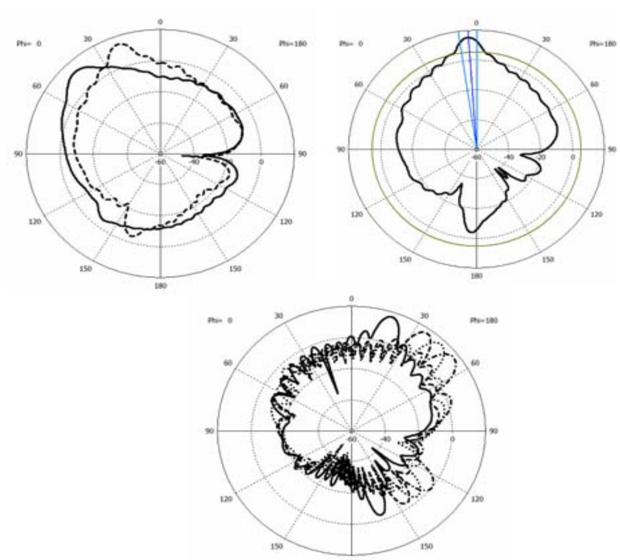


Fig. 4. 2-D radiation patterns of the uniform CRLH SIW LWA in the frequencies: LH band (*f* = 9 GHz; *f* = 9.5 GHz), transition frequency (*f* = 10 GHz), RH band (*f* = 11 GHz; *f* = 11.5 GHz, *f* = 12 GHz, *f* = 13 GHz).

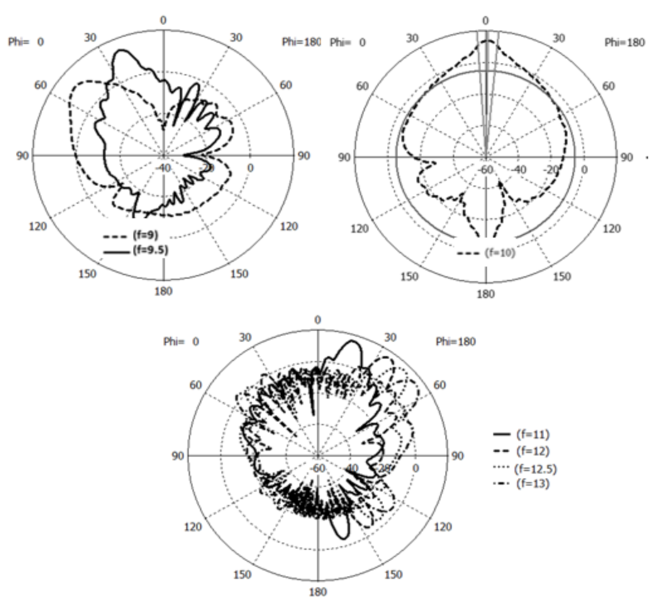


Fig. 5. 2-D radiation patterns of the non-uniform CRLH SIW LWA in the frequencies: LH band (*f* = 9 GHz; *f* = 9.5 GHz), transition frequency (f=10 GHz), RH band (*f* = 11 GHz; *f* = 11.5 GHz, *f* = 12 GHz, *f* = 13 GHz).

The absolute value of the side lobe level (ASLL) of the proposed design is shown in Fig. 6. The results are compared with those of the uniform CRLH antenna. It can be depicted, from the results that, an attractive increasing on the ASLL value is achieved by the non - uniform design, mainly at the transition frequency 10.2 GHz where the ASLL increased from 9.9 dB to 19.9 dB.

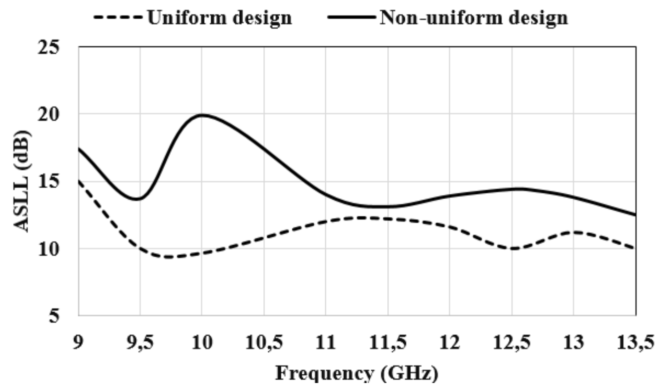


Fig. 6. Results of ASLL over the frequency of the uniform and non-uniform CRLH SIW LWA structures

The non-uniform LWA CRLH SIW results were compared to other LWA antennas published in the literature. Regarding bandwidth, scanning band, radiation and side lobe level on the broad side. The results indicate that the proposed antenna outperforms the chosen designs and can be considered a good candidate for scanning system applications.

Tab. 3. Comparison of the obtained results with works in the literature

References	**Antenna type**	**Beam scanning range**	**Impedance bandwidth (%)**	**Broadside ASLL (dB)**
[11]	microstrip	60	83	16
[12]	HMSIW	86	34	12
[13]	Microstrip CRLH	47	61	10
This work	SIW CRLH	116	44	19.9

IV. Conclusion

In this communication, two CRLH SIW leaky wave antennas were studied. The first one is composed of twenty-five uniform CRLH SIW periodic uniform unit cells while the second proposed antenna is a non-uniform twenty-one CRLH SIW LWA designed to reduce the side lobe levels of the uniform structure. Results of the non-uniform structure are more suitable in terms of SLL and scanning range. Both antennas radiate in the frequency band starting from 6.9 to 11

GHz. Nonetheless, these two antennas offer many prospects for use, in particular in radars and telecommunication systems.

ACKNOWLEDGMENT

This work has been supported by the Grant Agency of the Czech Republic under project No. 17-00607S.

REFERENCES

[1] W. W. Hansen. "Radiating electromagnetic waveguide". U.S. Patent No. 2,402,622, 1940.

[2] J. Machac, P. Lorenz, M. Saglam, C.-T. Bui, and W. Kraemer, “Substrate Integrated Waveguide Leaky Wave Antenna Radiating from a Slot in the Broad Wall,” 2010 IEEE MTT-S Int. Microw. Symp. Digest, TU1A-2, May 2010.

[3] Y. Mohtashami, J-R- Mohasee, “A butterfly substrate integrated leaky wave antenna”, IEEE Trans. AntennasPropag., 2013

[4] K. D. Karmokar, K. P. Esselle, T. S. Bird and S. G. Hay. "Fixed-frequency beam steering of microstrip leaky-wave antennas using binary switches." IEEE Transactions on Antennas and Propagation, pp: 2146-2154, 2016.

[5] J. Machac; M. Polivka; K. Zemlyakov, “A Dual Band Leaky Wave Antenna on a CRLH Substrate Integrated Waveguide,” IEEE Transactions on Antennas and Propagation, vol. 61, No. 7, pp 3876 – 3879, 2013.

[6] M. M . Sabahi ; A. A. Heidari and M. Movahhedi. “A Compact CRLH Circularly Polarized Leaky-Wave Antenna Based on Substrate-Integrated Waveguide”, IEEE Transactions on Antennas and Propagation, Vol: 66 , Issue: 9, pp. 4407 – 4414, 2018

[7] Yuandan Dong ; Tatsuo Itoh, “Substrate Integrated Composite Right-/Left-Handed Leaky-Wave Structure for Polarization-Flexible Antenna Application”, IEEE Transactions on Antennas and Propagation, Vol: 60 , Issue: 2, pp: 760 – 771, 2012

[8] S. S. Haghighi ; A. A. Heidari and M. Movahhedi,”A Three-Band Substrate Integrated Waveguide Leaky-Wave Antenna Based on Composite Right/Left-Handed Structure”, IEEE Transactions on Antennas and Propagation, Vol: 63 , Issue: 10, pp: 4578 – 4582, 2015.

[9] D. Deslandes, 'Design equations for tapered microstrip-to-substrate integrated waveguide transitions'. IEEE MTT-S Int. Microwave Symp. Digest, Anaheim, CA, USA, 23-28, pp. 704-707, 2010.

[10] A. Rahman, Y. Hao, Y. Lee and C.G. Parini, “Effect of unit-cell size on performance of composite right/left-handed transmission line based leaky-wave antenna”, Electronics Letters, 19th Vol. 44 No. 13, 2018.

[11] R. Henry and M. Okoniewski, “A broadside scanning substrate integrated waveguide periodic phase-reversal leaky-wave antenna,” *IEEE Antennas Wireless Propag. Lett.*, vol. 15, pp. 602–605, 2015.

[12] N. Yang, C. Caloz, and K. Wu, “Full-space scanning periodic phasereversal leaky-wave antenna,” IEEE Trans. Microw. Theory Techn., vol. 58, no. 10, pp. 2619–2632, Oct. 2010.

[13] A. P. Saghati, M. M. Mirsalehi, and M. H. Neshati, “A HMSIW circularly polarized leaky-wave antenna with backward, broadside, and forward radiation,” *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 451–454, 2014.