Step by step designing of Composite right left handed leaky wave antenna on Substrate integrated waveguide using S Slots

Nitin Kumar
ECE Dept.
UTU
Dehradun, India
nitin.vnit@gmail.com

*Rahul Agrawal & S C Gupta
ECE Dept.
DITU
Dehradun, India
*rahul16389@gmail.com

Abstract **: A step by step designing of Composite right left handed transmission line Substrate integrated waveguide Leaky wave antenna with novel S shaped slots is presented. The S slots etched on the upper plate of the Substrate Integrated Waveguide provides the series capacitance necessary for the realization of composite right left handed transmission line unit cell. A 1 D periodic array of the proposed unit cell is designed showing contionous beam scanning in a wide range of -33 deg to 25 deg for the frequency scan of 32 GHz to 42 GHz. Simulated results show that the antenna radiates with almost constant & high gain values of approximately 15 dBi max and a first sidelobe level of around 3 dBi.**

Keywords: Composite right/left-handed transmission line, Substrate integrated waveguide, Leaky wave Antenna

I. INTRODUCTION

Composite right left handed (CRLH) transmission line (TL) is an artificial engineered material with unsual properties and this metamaterial concept of TL, paved the way for practical applications. Backfire to endfire leky wave antennas (LWA) are generally realized from the open CRLH TL[1]. The backfire-to-end fire capability of LWA was first demonstrated experimentally in [2] is a very unique feature for a LWA, which cannot be obtained in conventional (uniform or periodic) leaky wave structures. This is due to this feature, field of LWA has regained interest with the advancement of concept of CRLH TL. Various CRLH LWA structures are reviewed in [3].

Substrate Integrated Waveguide (SIW), which is synthesized on planar platform proved itself to be an excellent candidate for the realization of CRLH LWAs. SIW is typically a waveguide structure consisting of two rows of cylinder in the transverse direction connecting the upper and lower metal plate (ground plane) through the dielectric and acts like the side walls. The only element required to realize a CRLH TL on SIW is the series capacitance. SIWs implemented as CRLH TL that can be used as LWA which are capable of steering the main beam from backward to forward direction whenever frequency is varied in the operating range [4]. The effective width of SIW, diameter of via holes and the pitch is chosen according to frequency range of interest in which antenna is desired to radiate, using the equations available in [5].

In this paper, step by step designing of CRLH SIW LWA is presented using novel S shaped slots etched on the upper plate of the SIW, the proposed unit cell is shown in fig.1. It is designed on RT Duroid 5880 substrate with ϵ_r= 2.2 and thickness of 0.508mm.

II. THEORY & DESIGN

A. Theory

CRLH TL is a candidate for realizing LWA in the microwave and millimeter wave region. LWA is a direct application of open CRLH transmission line structure. The equivalent circuit of typical CRLH transmission line is shown in fig.1.

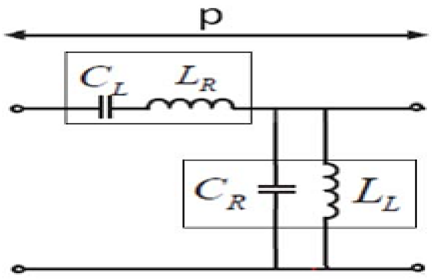

Fig.1 Typical representation of CRLH equivalent circuit [6]

The CRLH circuit consists of two basic parameter of circuit theory i.e. inductance and capacitance. (Resistance is not taken into account). The series impedance (Z_{se}) is a combination of Series Inductance (L_R) and capacitance (C_L) whereas shunt admittance is a combination of parallel inductance (L_L) and capacitance (C_R).

On comparing the equivalent circuit of SIW and CRLH circuit, the only thing requires to complete the circuit of CRLH using SIW is the series capacitance which can be inferred from the fig.1 and fig.2.

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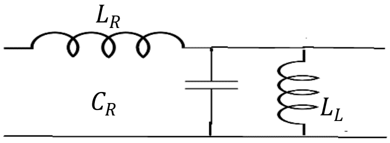


Fig.2 Equivalent circuit of SIW

In the design, the slot etched on the top surface of SIW provides the series capacitance (C_L) and vias provides the shunt inductance (L_L). Voltage gradient that develops between the two metal layer of SIW provides the parallel capacitance (C_R) whereas the current flowing in the upper metal provides the series inductance (L_R).

III. Antenna Design

A. Design steps

The steps used for the design of a CRLH SIW LWA are as follows:

A. Design of a SIW in desired frequency range using the effective design equations presented in [5]
B. Design of series capacitance in range of interest and then combined with the SIW structure to realize CRLH TL.
C. The capacitance of slot depends upon size, shape, position and angle between the slots [6]. Parametric analysis can be done on these factors for effective design.

B. Designed Structure

The structure is designed on RT Duriod 5880 substrate with ϵ_r= 2.2 and thickness of 0.508mm. The unit cell shown in fig.3, showing different parameters, their values are shown in Table 1. The width of the microstrip feed line with characteristic impedance of 50Ω is found to be 2.42mm. The dimensions of the SIW are chosen such that the proposed structure operates between 32GHz to 42GHz. In this design, we provide a tapered microstrip transition because of its capacity to cover the entire bandwidth [7]. In the unit cell design, slot length L_1 is taken approximately as $\lambda/12$ and L_2 is taken as $\lambda/5$. The dimensions of pitch and diameter of SIW are chosen as per available fabrication facilities.

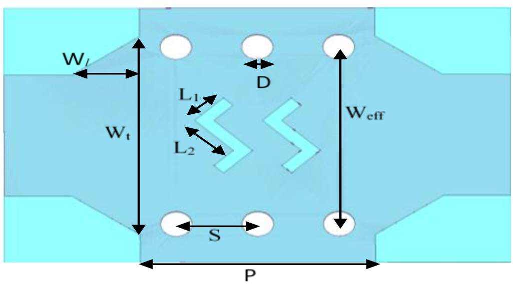


Fig.3 Proposed Unit cell

TABLE 1 UNIT CELL PARAMETERS

Parameters	*Values*
D	0.7mm
S	1.75mm
W_t	5.6mm
W_{eff}	5mm
P	5.2 mm
L_1	0.75mm
L_2	1.5mm
W_l	1.5mm

Using the unit cell, a periodic array (1x8) is designed in Ansys HFSS and is shown in fig.4.

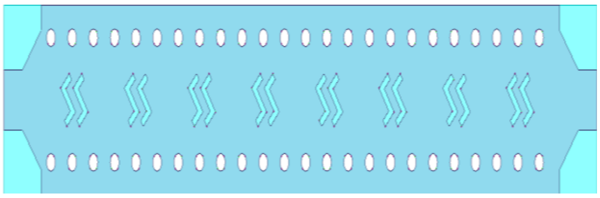


Fig.4. CRLH SIW LWA with S slots (1x8)

The single S slot is a combination of inclined slots and the angle between these slots is taken as 90° for the maximum radiated power which is proportional to $\sin^2 \emptyset$ where $\emptyset$ is the angle between the adjacent slots [6].

IV. Results and Discussions

The simulated results of the proposed antenna is presented in fig.3 to fig.6. It can be seen from fig.5 that S_{11} shows a bandwidth of 10GHz starting from frequency 32 GHz to 42 GHz.

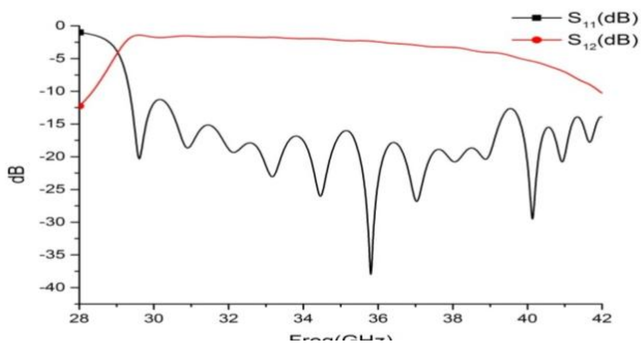


Fig.5 Simulated return loss S_{11} (dB) and transmission loss S_{12} (dB)

The dispersion characteristics shown in fig.6 is based on the simulated S parameters and calculated as per eq. (1)

$$\cosh(\gamma) = \frac{1}{p}\Big[(1 - |S_{11}|^2 + |S_{21}|^2) + \frac{Z_{01}}{Z_{02}}(1 - |S_{11}|^2 + |S_{21}|^2)\Big] \qquad (1)$$

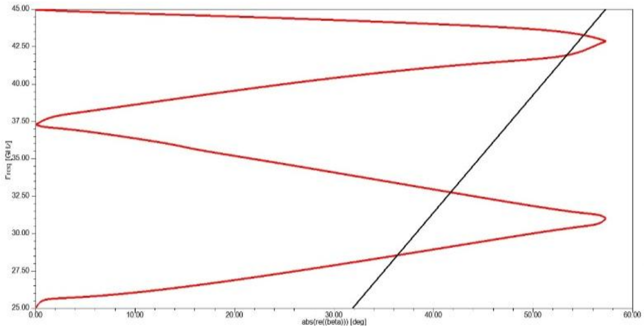
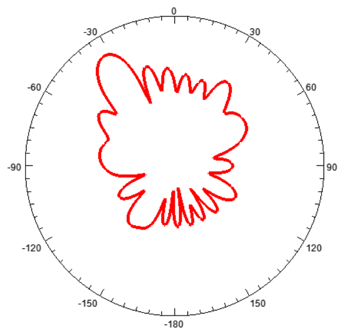
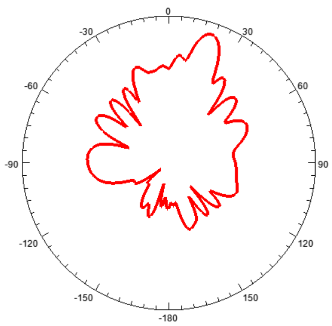


Fig.6 Dispersion characteristics

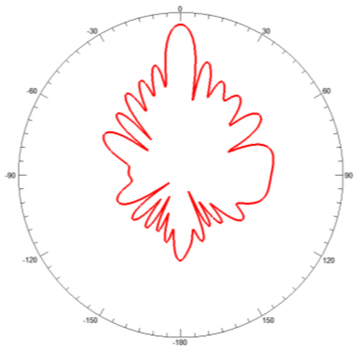
The dispersion shows that it is behaving as a CRLH LWA with range from 32 GHz to 42 GHz. The far field radiation pattern of the proposed LWA is simulated at different frequencies. The antenna radiates in backward direction from 32 GHz to around 40 GHz, and forward from 40 GHz to around 42 GHz. The frequency dependence of the beam can be viewed clearly from the fig 7. It can be observed that as the frequency increases, the beam is scanning from the backfire to endfire direction with radiation at broadside obtained at the transition frequency i.e. 40.14GHz.



(a) At 32.15 GHz



(b) At 42.07GHz



(c) At 40.14 GHz

Fig.7 Simulated radiation patterns with main lobe in (a) left (b) right (c) broadside direction

The simulated gain values for frequencies in left hand, right hand and broadside region are shown in fig 8. The realized gain values are almost constant with a maximum gain of ~15dBi max. The side lobe level of the S slot CRLH SIW LWA is shown in fig.9. The first side lobe level is ~13 dBi below the maximum value.

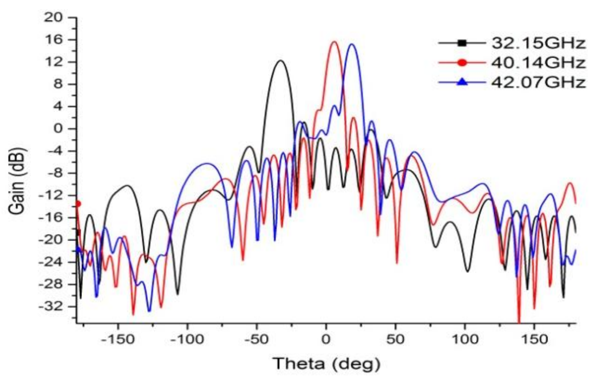


Fig .8 Simulated antenna gain of the structure in left hand(32.155GHz), right hand(42.07GHz) and broadside (40.14GHz) region

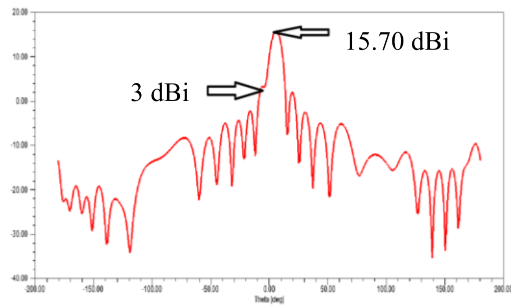


Fig.9 Sidelobe level comparision

V. CONCLUSION

Steps involved in designing a CRLH SIW LWA are presented, a CRLH SIW with S slots etched on the upper plate of the SIW is designed. A 1-D periodic array of the antenna is designed showing the contionous beam scanning from -33° to 25° for the frequency scan of 32 GHz to around 42 GHz is illustrated. This unique planar scanning capabilities with various applications like MIMO with pattern diversity or radar system.

ACKNOWLEDGEMENT

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