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A Novel Transversal, Longitudinal Slots with Monopole Leaky Wave Antenna to Enhanced Scanning

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ABSTRACT: Antenna design plays a crucial part in radio engineering to establish transmission and reception of radio waves effectively. The effectiveness of antenna is defined through its improved gain and reduction of losses. Many antennas are designed in a way that enhances its performance. However, there is need for further improvement in its performance. In order to provide good scanning capability, a Substrate Integrated Waveguide based Leaky Wave Antenna (SIW-LWA) is designed in this research study. ROGERS 4350 Substrate is taken as the design material. In this design, straight transverse slots are kept by performing phase delay analysis, and longitudinal slots are placed as parallel components. Furthermore, monopoles are added to the design. Two structures are proposed in this research; the first structure of the antenna includes a monopole in the middle, and the second structure of antenna introduces monopole to the side. The performance analysis of the proposed antenna designed is conducted through simulations and measurements. The results show a reduction in the return loss, increase in the gain value, and a consistent gain level in dB in the radiation pattern of the proposed SIW-LWA.

Keywords: Substrate Integrated Waveguide, Leaky Wave Antenna, Radiation, Stop-band, Scanning**.**

Abbreviations: SIW, Substrate integrated waveguide; LWA, Leaky wave antenna; PRS Partially Reflecting Surface; OSB, open stop band

I. INTRODUCTION

Leaky Wave Antenna (LWA) is known as a kind of traveling-wave arrangement established on a transmission line consisting of radiating components. These antennas were initially developed with the help of a rectangular waveguide comprising of slots. The placement of these slots defines the direction of radiation and the polarization of the LWA [1].

Loading similar elements periodically on each segment of the cell of LWA, results in good frequency-dependent ability of scanning the beam and provides high directivity. Such distinctive characteristics of LWA, make it eye-catching in several applications, namely, real-time spectrum analysis [2], field pattern synthesis [3], and frequency modulated continuous wave radar [4].

LWAs are being used widely to adapt the pattern of radiation for sources with low directivity. These antennas can be modeled by keeping a Partially Reflecting Surface (PRS) on top of a waveguide to form a sort of half-wavelength Fabry-Perot cavity. This cavity is triggered using an embedded source, and has the capacity to concentrate the radiated power into a high directive fan beams with dispersive frequencies [5].

Three different shaped monopole *antennas are* presented for UWB application. The hexagonal antenna has the bandwidth of 1GHz to 2.6 GHz. The band width for circular antenna is about 1-13 GHZ and for elliptical antenna it is about 1-14 GHz. The future direction of the work is to increase the gain and directivity [14]. A rectangular micro-patch antenna was proposed with defected grounded structure and CSSR loading for UWB application. The radiation characteristics of antenna is regulated by the CSSR loading. The bandwidth for the proposed design is 3.5 -15 GHz [15].

Different approaches have been adopted to improve the scanning capability, increase the gain of antenna and to reduce return loss [8-12]. Several small antennas have recently been developed by several researchers. However, with reduced sensitivity for the environment, the gains, bandwidth and pattern characteristics presented tough challenge. Furthermore, there could be greater degree of independence for the small antenna. For managing those problem, the proposed approach introduces the combination of both transverse and longitudinal slots in the LWA design. Two monopoles are included in the designing of the Proposed LWA, and hence two structures are designed. In the first structure design, the monopole is placed in the middle. And in the second structure design, the monopole is placed in the sideways. The proposed design of antenna increases the gain level and minimize the return loss. The obtained gain level is found to be more effective than the gain attained in other approaches [13]. The main contributions of the research work are,

– The integration of Monopoles to the LWA design.
– The return loss of the proposed LWA is reduced effectively.
– The proposed LWA design increase the gain level

II. PROPOSED ANTENNA MODEL

Present section discusses about the design of proposed antenna, model and their fabricated parameters. First, the design was a model simulated in Ansoft HFSS simulation software and then fabricated and tested.

A. Antenna configuration

The proposed antenna is configured as displayed in the Fig. 1 (a). In this design, the substrate used in the model is ROGERS 4350 laminates with thickness h= 0.61mm, ε_r = 2.2, tan δ = 0.0009. Plated metals present on both the sides of the substrate are laminated. One plate is used as ground, and another is used for the patch. The perfect plane of ground has been reduced to the defected plane of ground. The transverse slots and longitudinal slots along with the monopole is proposed in the paper. The position of the monopole is changed in model 1 and 2. Monopoles are added by elongating a metal, in shape of a rectangle, transversely at the side of the LWA and middle of the LWA in model 1 and 2 respectively.

Table 1: Parameters with dimensions.

Parameters	Values (mm)
d	0.61
p	0.91
W_{eff}	9.9947
L_s	4.6136
L_p	9.994
W_p	1.5
L_{mon}	8.9
W_{mon}	1.34

In table1 depict the parameters and dimension values used in the design of antenna. The Fig. 1(b) shows the dimension of diagram with parameter which is implemented. The transverse and longitudinal slots are arranged symmetrically like "T". Current study selects the width and the length of monopole of the rectangle metal as 1.34 mm and 8.52 mm, respectively for both models. The layers of the metals around the corners of the substrates are linked by metalized holes. The width and the length of the transverse slots are 0.4 5 mm and 4 mm, respectively. The dimension of a longitudinal slot and width of longitudinal slot the total length of the LWA is L = 150mm and width of the LWA is W = 19.5mm with monopole and 10.99m without monopole.

Fig. 2(a) displays the parameters considered and the configurations fabricated for the suggested LWA with the monopole at the end and Fig. 2(b) shows the monopole in the middle of the LWA. For feeding this structure, two microstrip lines are utilized. The coaxial cable feeds the antenna through an SMA connector. Finally, the proposed LWA is stopped for a matched load condition.

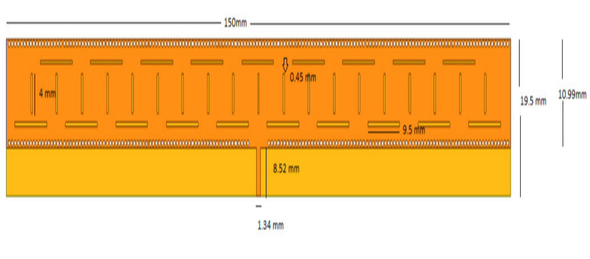

Fig. 1 (a) Simulation of middle monopole LWA.

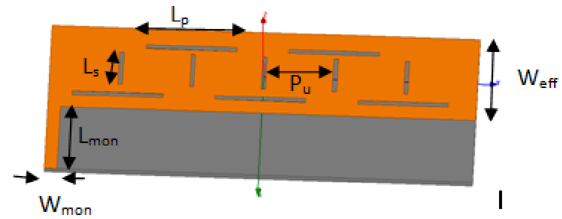

Fig. 1 (b) Simulation of side monopole LWA.

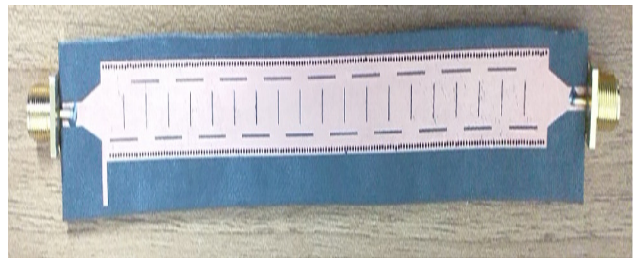

Fig. 2 (a) Fabricated of side monopole LWA.

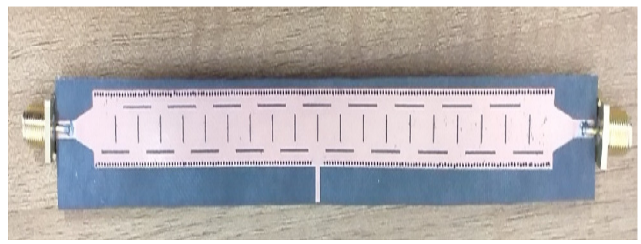

Fig. 2 (b) Fabricated of middle monopole LWA.

In addition to this, for establishing a better impedance matching at the output and the input, each microstrip line is tapered, so that the width of every microstrip line modifies constantly.

B. Principle of operation of the proposed LWA

(i) ***Transverse and longitudinal slot with vias*****:** To make the antenna radiate, the slots must be removed from the current distribution over the surface of the Substrate Integrated Waveguide (SIW). It means that, the field distribution must be different on both the sides of the slots. If the SIW is operated on dominant mode, the current distribution is not cut off that is open-stop band (OSB). In this mode, the field distribution is symmetrical on both the sides of the slots and the slots are placed in the middle of the top most plane of the antenna. This does not allow the slots to radiate.

In this section, the OSB is suppressed by attaining an impedance-matched structure of a unit cell. Since the transverse slot-loaded onto the SIW presents only the series type impedance Z, a shunt type admittance Y in series with the Z must be included in the unit cell's equivalent circuit for the purpose of accomplishing impedance matching with the monopole. The S parameters of the equivalent circuit can be calculated according to the microwave network theory as,

$$S_{unit} = \begin{pmatrix} S_{11} & S_{21} \\ S_{21} & -S_{11} \end{pmatrix}$$

$$S_{11} = \frac{\frac{Z}{Z_0} - YZ_0 + ZY}{2 + \frac{Z}{Z_0} - YZ_0 + ZY} e^{-j\beta\rho} \quad (1)$$

$$S_{21} = \frac{2}{2 + \frac{Z}{Z_0} - YZ_0 + ZY} e^{-j\beta\rho}$$

According to (1), to achieve impedance matching, i.e., $S_{11} = 0$, Z and Y should follow the relationship described as

$$Y = Z/Z_0(Z_0 - Z) \quad (2)$$

Furthermore, (2), the imaginary and real parts of the complex shunt admittance denoted as Y can be stated as

$$\begin{cases} Re[Y] = \frac{1}{AZ_0}\left(\frac{Re[Z]}{Z_0}\left(1 - \frac{Re[Z]}{Z_0}\right) + \left(\frac{Im[Z]}{Z_0}\right)^2\right) \\ Im[Y] = \frac{Im[Z]}{AZ_0^2}\left(1 - \frac{Re[Z]}{Z_0}\right) \\ A = \left(1 - \frac{Re[z]}{Z_0}\right)^2 + \left(\frac{Im[Z]}{Z_0}\right)^2 \end{cases} \quad (3)$$

It is worth noting that the band of frequency is lower than the slot's resonant frequency, and therefore, the imaginary and real parts in the band of interest are positive, as shown in the Eqn. (3).

Loading a comparatively long longitudinal slots over the waveguide's wall in a periodical manner, is an efficient method for accomplishing the loading of the capacitor in a parallel way in the LWA's equivalent circuit. As the transverse current in the waveguide is disturbed by the longitudinal slots, the slots function like parallel components, and the length of these slots are adjusted properly, the resonant frequency reduces to a level lower than the threshold frequency, as anticipated for capacitive loading. The arrangement of the proper transverse and longitudinal slots is vital for realizing the model approximately.

For efficiently suppressing the OSB, a group of shorting vias is introduced in LWA of the SIW periodic structure. If in case, the unit cell comprises of a single slot without any shorting vias, then the slot can be taken as a π equivalent model. The equivalent rectangular waveguide of the SIW is represented by the equivalent transmission line, as shown in Fig. (1).

(ii) ***Added monopole*****:** The LWA with the added monopole of length 17mm. The back lobe and the main beam are found in the Radiation coming during the leaky mode of operation of the conventional MLWA; on including the monopole to the LWA, the radiation from the monopole decreases the reflecting power at the terminal and the back lobe subdues. However, the defective ground plane generates the remaining side lobes. The downward facing side lobes are found lower than the main lobes (Z < 0 region) mainly because of the radiation caused by the monopole being included. In addition to this, the back lobe of the proposed LWA is suppressed. The monopole in the middle is more efficient suppresses the back lobe when compared to the monopole added to end of the structured. In the next section, we discuss the monopole position that change the simulation for better results.

III. RESULTS AND DISCUSSION

For verification purposes, we have fabricated a prototype of the designs. SMA connectors of the microstrip to SIW transitions feed this archetype as the archetype that is developed to permit sufficient matching of the characteristic impedance of the host SIW. The measurement process of the S-parameters is carried out with the help of Agilent N5227A Microwave Vector Network Analyzer (VNA), and the outcomes of side monopole LWA and middle monopole LWA are depicted in Fig. 3 (a) and (b) respectively, along with the results of the simulation (from Ansoft HFSS). Both the measurement and the simulation of the magnitude of S11 show same shapes and tendencies in the response of the spectrum. Owing to the surplus reflections produced by the SMA connectors, variations are seen in the potential production process.

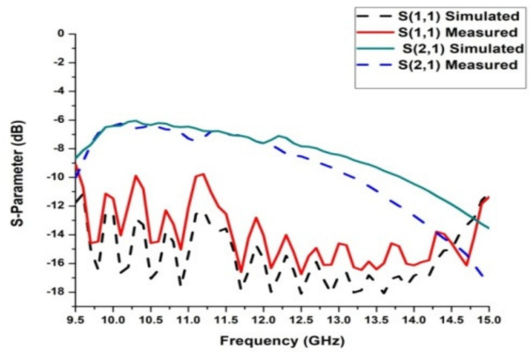

Fig. 3 (a) side monopole LWA.

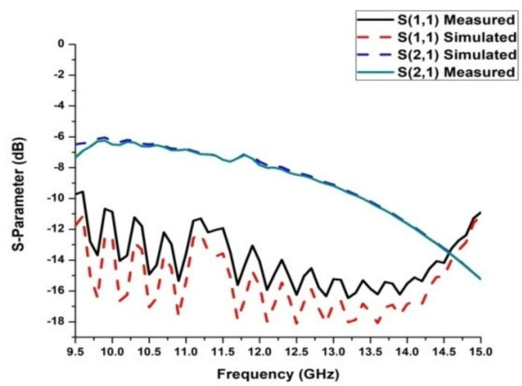

Fig. 3 (b) Middle monopole LWA.

In a band from 9.5 to 15 GHz, the coefficient of transmission is found lesser than −10 dB, which is less than 10% of the total residual power at the terminal of the antenna and an adequate impedance matching happens at the input of the prototype. The gain obtained from the simulation is about 14 dB, with a deviation seen around 4 dB. Around the broadside frequency, the gain stays almost constant. The simulation and measured insertion loss (S21) is similar in middle monopole LWA when compared to the side LWA. In return loss (S11) is a difference of 2 dB in simulation and measured results for both LWA.

Fig. 4(a) and (b) also shows the simulated and measured normalized radiation pattern for the proposed side monopole LWA and middle monopole LWA, respectively.

The measured and simulated outcomes infer that the proposed LWA continuously scans from -30 degrees to 30 degrees as the frequency rises from 9.8 GHz to 14.5

GHz. The side lobe is lower than the main lobe by -15dB. The proposed LWA renders a probability of uninterrupted beam scanning through the broadside

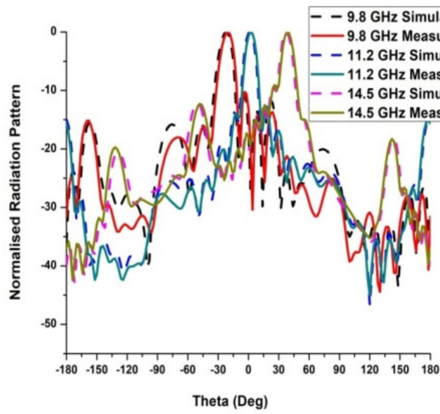

Fig. 4(a) Radiation patterns (-30 degree to +30 degree).

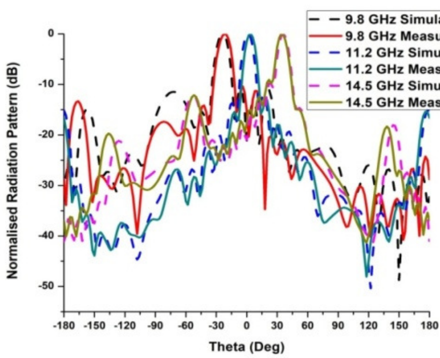

Fig. 4 (b) Radiation patterns (-30 degree to +30 degree).

Fig. 5 summarizes the measured and the simulated the efficiency and the peak gain of the beam generated by the SIW LWA array at various frequencies with the comparison of Gain with monopole and without monopole LWA [7]. Because of the differences between the measured and the simulated outcomes of the *S*-parameters, as mentioned above, the gain of the measured result is lesser than that of the simulation.

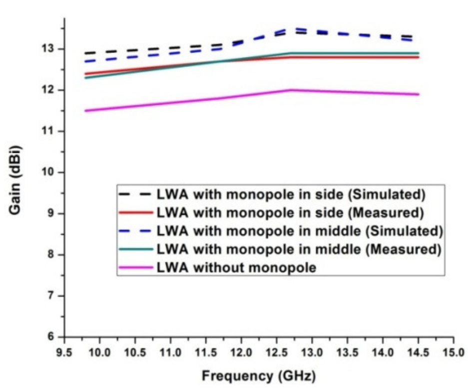

Fig. 5. Comparison of gain.

with a gain staying almost constant throughout, without any suppression in the performance of the radiation in the broadside frequency band.

The graphs clearly show the gain is efficiently improved in the proposed antenna by 2 dB. It is evident that the gains can attain a nominal level of 12.5 dB for the measured results and 13.5dB for the simulation of the proposed LWA. The gain of the proposed LWA is relatively high and stable.

IV. CONCLUSION

In this research, a Substrate Integrated Waveguide based Leaky Wave Antenna (SIW-LWA) is designed to improve the gain and reduce the loss. The measurements are taken in Agilent N5227A Microwave Vector Network Analyzer (VNA). Furthermore, the simulations are conducted in Ansoft HFSS software tool. ROGERS 4350 is the substrate considered for the design. The proposed LWA combines both transverse and longitudinal slots. The straight transverse slots are kept by performing phase delay analysis, and longitudinal slots are placed as parallel components. Furthermore, monopoles are added to the design. Two structures are proposed in this research; the first structure of the antenna includes a monopole in the middle, and the second structure of antenna introduces monopole to the side. The simulation and measurement results show a reduction in the return loss, increase in the gain value of up to 12.5dB in measured and 13.5dB in simulation, and the radiation pattern of the proposed SIW-LWA maintains the gain value throughout. It can be thus said that, the proposed SIW-LWA has good scanning capability and provides better gain.

V. FUTURE SCOPE

The inclusion of monopole clearly shows the enhancement in gain. Therefore the proposed structure may be used in application where high gain is desirable with leaky wave antenna. Further the added monopole could be optimized in size to achieve more gain.

Conflict of Interest. No.

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