Transverse Bow-Tie Slotted Substrate Integrated Waveguide Leaky-Wave Antenna

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***Abstract*—A novel bow-tie slotted substrate integrated waveguide (SIW), leaky wave antenna is proposed and investigated. This antenna works in the TE_{10} mode. Proposed antenna leads to more intense electric field and better coupling of E-field in adjacent slots, which results in more uniform spectral behavior in comparison with transverse slot leaky wave antenna. In addition to this proposed antenna gives improved broad side behavior and can scan larger angular range with in lesser frequency change.**

***Index Terms*—Leaky wave antenna (LWA), bow-tie antenna, SIW and microstrip fed lines.**

I. INTRODUCTION

Substrate integrated waveguide (SIW) has attracted great attention in recent years [1], [2] and [3] for its excellent advantage of low profile, low cost and easy in integration with microstrip circuits. It has a complex propagation wave number $\gamma = \beta - j\alpha$ where β is the phase constant and α is the attenuation constant.In such waveguides, EM waves are confined within the two rows of metallic rods (vias). The distance between vias are of the order of wavelength. Scanning of leaky wave antenna (LWA) from broadside to end-fire is governed by

$$\sin(\theta) = \beta(\omega)/k_o \tag{1}$$

where $\beta(\omega)$ is the phase constant and k_o is free-space wave number. When the structure operates in the fast wave region ($\beta < k_0$), the energy constantly leaks out from the guiding structure. Although this technique is highly efficient for high gain millimeter-wave antennas but requires a large surface on the substrate and hence it is bulky and costly. As a result more compact design is sorely required for advanced application. To overcome these disadvantages a number of SIW antennas are proposed in recent years [4], [5], and [6].

In this paper, we propose bow-tie shaped slot in order to get better spectral behavior of antenna. The proposed structure is shown in Fig.1. This antenna works in TE_{10} mode. In this antenna leakage is obtained by periodic bow-tie shaped slot on the top of the SIW which interrupts the current flow gradually on the top of the wall. Proposed leaky wave antenna also gives radiation much closer to broadside. We propose the bow-tie slot which improves frequency response. It is known that bow tie antenna [7] is used in ultra wide band to improve the bandwidth of an antenna.

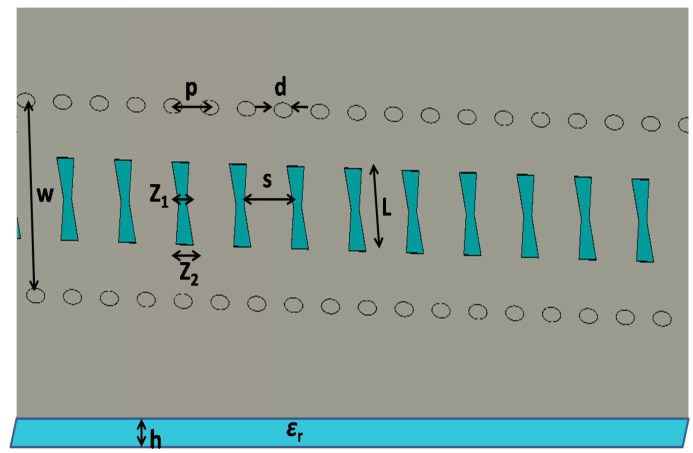

Fig. 1. Geometry of the bow-tie slot leaky-wave antenna.The SIW has $w = 10.5mm$, $\epsilon_r = 2.25$, $h = 1mm$, $d = 0.8mm$ and $p = 1.6mm$. The slots have $L = 4.45mm$, $Z_1 = 0.35mm$, $Z_2 = 0.75mm$ and $s = 2.5mm$

The paper is organized into five sections. In section II, details of antenna design is discussed. Section III, deals with the antenna geometry, S-parameters, spectral behavior comparison, dispersion relation and radiation pattern of proposed antenna and have been discuss in details. In section IV, the results have been discussed in brief. Finally, some concluding remarks and discussion are provided in Section V.

II. ANTENNA DESIGN

The SIW is designed by a wide microstrip which is shorted by conducting pins, in order to create a rectangular waveguide structure. Bow-tie shaped slots are etched at the top of the structure. The leakage is obtained by these periodic slots. The height and width of SIW are h and w. The dielectric constant is ε_r .The diameter and the period of shorted pin is d and p. The slot on the top surface has length L. The width of slot is linearly varying from Z_1 to Z_2. The period between the bow-tie slots is along the z-axis.

III. EXPERIMENTS

Here transverse bow-tie slotted LWA is designed using the substrate of $\varepsilon_r = 2.25$ with the thickness of $1mm$. Later the paper will show the optimized value of Z_2 in order to get better spectral behavior of the bow-tie slotted structure.

A. Geometry

The geometry of transverse bow-tie slot leaky wave antenna is shown in Fig.2. A series of bow-tie slots are the important parts of this structure. This section has the length $220mm$ and then we taper the slots linearly at both ends to a distance of $22.5mm$. This will suppress the reflection S_{11} from the ports. The details of the dimensions are shown in Fig. 2.

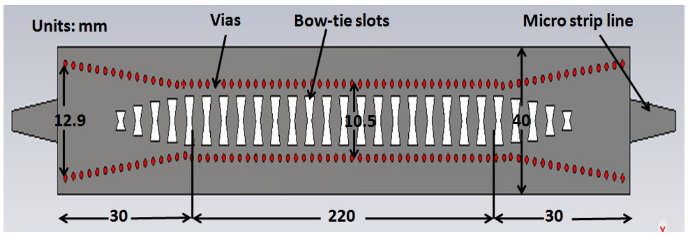

Fig. 2. Geometry of Transverse bow-tie slot LWA. The structure is shown in Fig.1 is the part of this figure.

The width of SIW is $10.5mm$. We also flare this width to $12.9mm$ in order to obtain better impedance matching between SIW and microstrip fed line. The antenna is fed with a microstrip line of length $15mm$. The width of feed line is linearly varying from $4.7mm$ to $3.1mm$. The device is fed by microstrip line.

B. S-Parameters

We use CST Microwave Studio to simulate the structure shown in Fig 2. The transmission coefficient S_{21} and reflection coefficient S_{11} are shown in Fig. 3. S_{11} lies below $-10dB$ and slightly improved than Transverse slot LWA in the band of interest. This reduction is a result of uniform leakage through the bow-tie slots. The lower cut-off frequency is approximately 10.2 GHz. Figure shows comparison of S-parameters between transverse slot LWA and transverse bow-tie slotted LWA. The reflection coefficient of bow-tie slot LWA is less than transverse slot LWA.

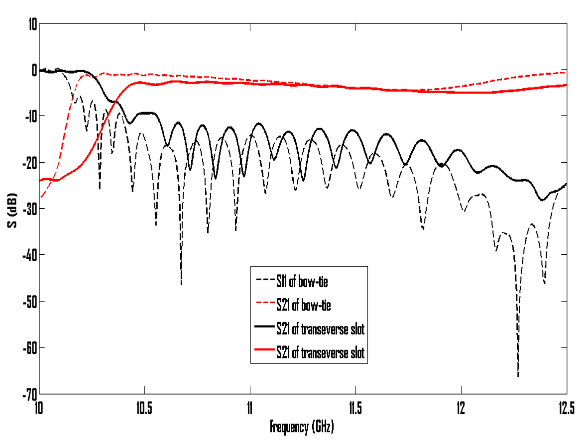

Fig. 3. S-parameters of transverse slot LWA and transverse bow-tie slotted LWA

C. Spectral Behavior

The spectral behavior of transverse slot SIW [1] is not constant. The spectral behavior (Magnitude vs. Frequency plot) becomes constant if we use bow-tie slot in SIW leaky wave antenna. Here the magnitude (directivity) of the spectrum is taken on linear scale. The spectral response is shown in Fig. 4. The spectral response is more uniform due to gradual impedance matching of individual slot antenna. Directivity and gain of the proposed antenna are also enhanced in desired frequency range. In proposed device, coupling of E-field between the adjacent slots is found better due to the use of bow-tie slots. Slot excitation is more uniform in case of bow-tie slot LWA while in transverse slot there is abrupt fall in E-field. Because of this the spectrum is not uniform in case of transverse slot leaky wave antenna.

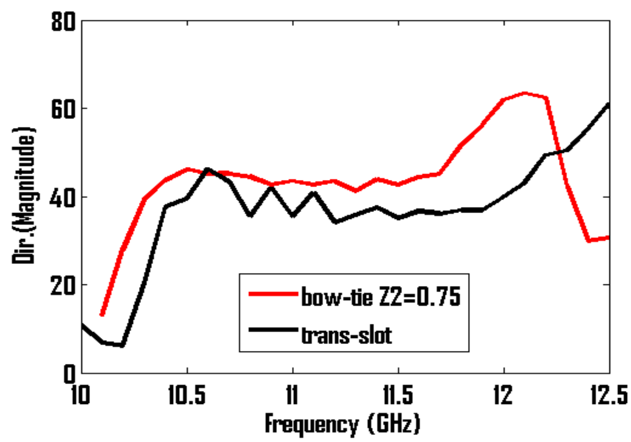

Fig. 4. Comparison of transverse slots and proposed bow-tie slot leaky wave antenna. The magnitude is taken at linear scale.

The results are optimised by varying Z_2, taking mid thickness of the slot i.e. Z_1 is constant. In Fig. 4, the spectral behaviour of transverse slot and bow-tie slot SIW leaky wave antenna has been compared. It is also verified on matlab that while scanning the spectral behavior of bow-tie slot LWA is more unifom in desired frequency range. The comparision by scanning is shown in Fig.5. Figure clearly shows that there is spectral behaviour is not constant in Fig. $5(a)$ and while spectral behaviour is more uniform in Fig. $5(b)$.

D. Dispersion Relation

We have calculated the normalized dispersion relation shown in Fig. 6 in order to calculate the fast wave region. We find that when the frequency is less than 11.8 GHz, the phase constant of the leaky mode is less than k_o, which is a fast wave region. When the frequency increases above to 11.8 GHz, the phase constant is greater than k_o, so it comes under the slow wave region. This is not leaky mode and most of its power is stored in waveguide. We have calculated the dispersion relation (β vs. frequency) from CST Microwave Studio. In order to find the fast wave and slow wave regions, we have calculated the normalized (β/k_o vs. frequency) by

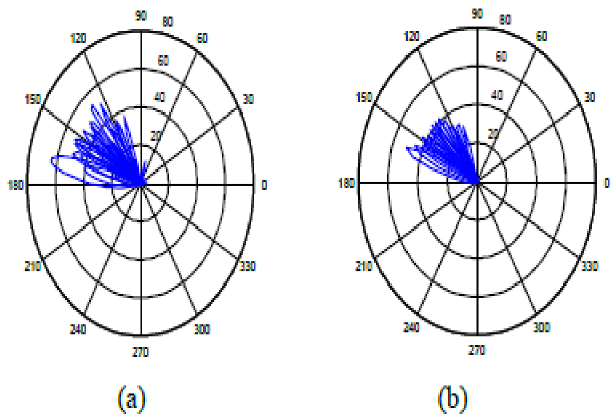

Fig. 5. Beam scanning of- (a) transverse slot LWA (b) bow tie slot LWA

fitting two traveling waves in Matlab. In Fig.6 Normalized dispersion relation is shown which clearly demarks the fast wave (leaky wave) and slow wave regions.

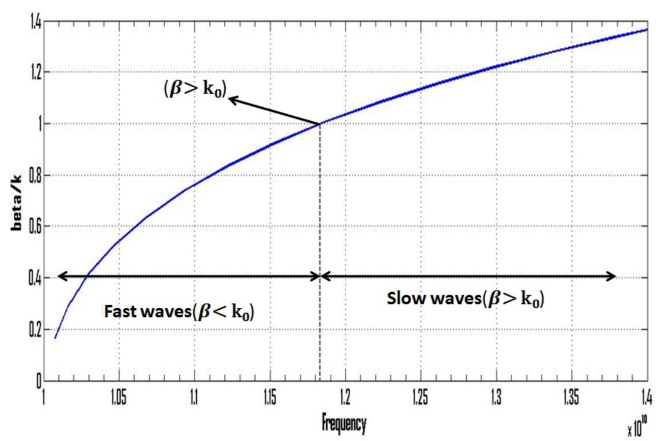

Fig. 6. Normalized dispersion relation of Bow-tie slot leaky wave antenna

E. Optimized Results

It is found in transverse slot leaky wave antenna, the spectral response is not constant. The spectral response is improved by bow-tie slot which is shown in Fig.4. The dimension Z_2 is varied in order to achieve optimum spectral response. In Fig.7 the variation of spectral response is shown at different values of Z_2. The dimension shown in figure are taken as follows: $Z_2 = 0.65mm$, $Z_2 = 0.75mm$, $Z_2 = 0.85mm$. The best result comes at $Z_2 = 0.75mm$. This is due to gradual impedance matching of individual slot antenna. We also investigated about the directivity for transverse bow-tie slotted LWA. We observed that the directivity for the antenna resembles with their spectral behavior and hence highest directivity is obtained in case of Z_2=0.75mm as shown in Fig.7. The simulated result shows that antenna has high gain in the band of 10.2 GHz to 11.8 GHz. The directivity is almost constant in the desired frequency range which clearly shows the improvement in spectral response.

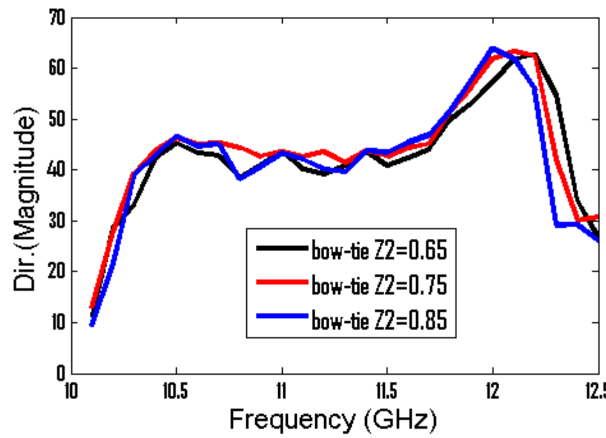

Fig. 7. Optimization of Z_2 is shown in order to achieve better spectral response which is at (a) Z_2=0.75mm (b) Z_1=0.35mm.

F. Coupling Of Electric Field

The near field pattern for the bow tie and transverse slot antennas are analyzed in this section. E-field coupling along the direction of propagation are compared at a distance of 4mm from the centre of substrate and at a frequency of 11GHz. The comparison of E-fields is shown in Fig.8, 9. It clearly indicates that using proposed bow-tie slot E-field is more intense and better coupling of E-field are achieved in adjacent slots so that leakage becomes more uniform. Hence spectral response become more uniform in the range of interest.

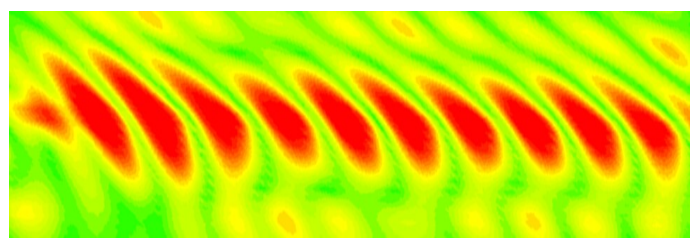

Fig. 8. Electric Field Coupling in Bow-Tie LWA

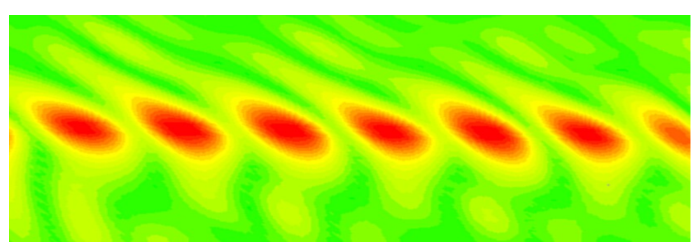

Fig. 9. Electric Field Coupling in Transverse Slot LWA

G. Radiation Patterns

Fig. 10(a)-(d) demonstrate the radiation pattern. The main beam can scan near broadside to end-fire as the frequency increases. Fig. 10(a) shows that at 10.2 GHz beam scans much closer to broadside in comparison to transverse slot LWA [1]. As frequency increases beam scans in the same quadrant reaches up to nearly 45^o. When frequency increases up to 11.8 GHz, this gives near end-fire scan. This structure also scans large range of angle with less frequency change.

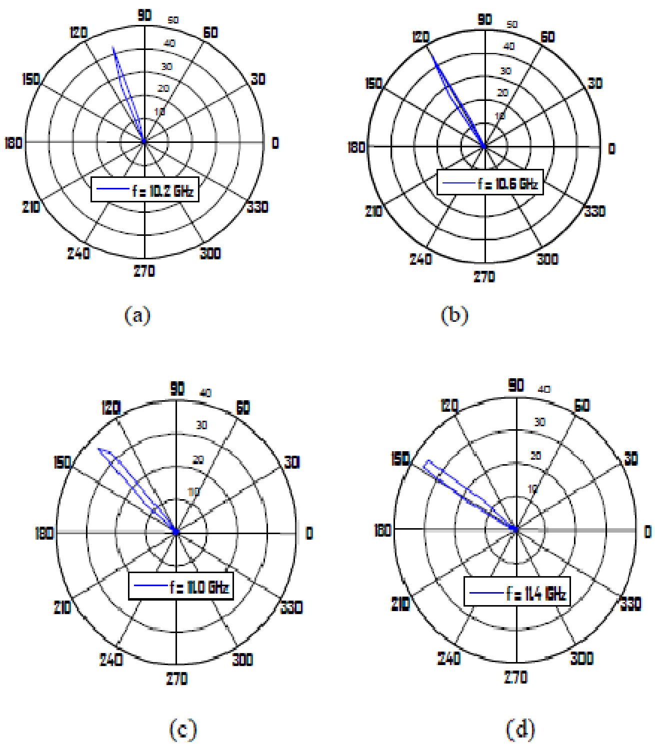

Fig. 10. Simulated Radiation patterns- (a) 10.2 GHz (b) 10.6 GHz (c) $11.0GHz$ and (d) $11.4GHz$

IV. Results

This novel bow-tie SIW antenna leads to more uniform spectral response as a result of enhanced electric fields of the bow-tie slots. These dimensions lead to better impedance matching of individual slot antenna. This can also be considered that the bandwidth is improved. The improved spectral response is shown in Fig.4. The proposed structure also gives same scanning range in less frequency change; this can be verified by Fig.6. By using this structure the broadside performance has also been improved.

V. Conclusion

A novel leaky wave antenna based on SIW with bow-tie shaped slot has been proposed and investigated in this paper. This gives the better uniform spectral response in desired frequency range by optimizing the antenna slot dimension parameters. The proposed leaky wave antenna scans from near broad side to end-fire as frequency increases. This gives closer scan to broadside in comparison to transverse slot LWA. The key feature of bow-tie slot is its better spectral behavior, which is achieved because enhanced E-fields of bow-tie slots and better E-field coupling in required frequency range. The proposed antenna scans larger angle for lesser frequency change.

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