

Design of Substrate-Integrated Waveguide Slot Antenna with AZIM Coating

Pomal Dhara Anantray ¹, Prof. Satish Ramdasji Bhojar ²

¹ Student, Electronics and Telecommunication, Rajiv Gandhi Institute of Technology, Mumbai, India

² Assistant Professor, Electronics and Telecommunication, Rajiv Gandhi Institute of Technology, Mumbai, India

Abstract - A Periodic an End-Loaded Dipole Array (ELDR) behaves as a metamaterial which posses zero refractive index when placed on substrate-integrated waveguide (SIW). In this paper a design of a low profile, high bandwidth antenna has been proposed using both Metamaterial (MM) and substrate-integrated waveguide techniques and the same work has described here. To achieve the proposed concept, ELDR is used to realize that the required anisotropic zero-index property and is applied to a SIW fed slot antenna, that confines the waves along the axis perpendicular to the radiating patch hence increasing the gain. To enhance the bandwidth, in SIW radiating patch an L-shaped slot and a rectangular slit are cut off, of appropriate size. Also an air gap between the patch and MM has been used to further enhance the bandwidth. An ELDR array with an air gap is used to enhance the gain for the 5.8 GHz. Proposed antenna, which is suitable for application in Wireless Local Area Network (WLAN). An ELDR is also used to remove beam squinting. The fabricated and simulated results have a great deal common among them. From the simulation and measured results, it is observed that the slit, air gap and L shaped slot has improved the bandwidth performance and the air gap has improved the gain of the slot antenna. The resulting antenna is only 0.12λ thick. The proposed AZIM-coated antenna achieves a -10 dB impedance bandwidth of more than 16%. Notably, with the presence of the AZIM coating and an air gap, the broadside gain is significantly increased to ~ 5 dBi, which indicates an improvement of about 4 dB and by using an air gap and slits, bandwidth is increased from 6.75 % to 16.15%. The proposed design represents a promising candidate for constructing low-profile and compact unidirectional radiating antennas with high gain, relatively broad impedance and radiation bandwidth. The bandwidth and gain of proposed antenna are investigated using full-wave analysis (HFSS).

Key Words: Bandwidth Enhancement, Low profile, Slot antenna, Substrate-Integrated Waveguide, Zero-Index Metamaterials.

1. Introduction

Till date, metamaterial technologies have been used in a variety of different antennas resulting in a lot of functionality improvements, including reducing the thickness of Fabry-Perot (FP) cavity antennas, low beam squinting [1], broadening the impedance bandwidth of microstrip [2], enhancing the directivity of antenna, and a lot more.

Conventional approaches frequently employ FP cavities [3] to obtain high directivity within a narrow bandwidth. When they are constructed with a ground plane, the device thickness is usually on the order of one half of the operating wavelength. Recent advanced FP cavity designs employing artificial magnetic conducting surfaces allow the total device thickness to be reduced to around one quarter of the wavelength [4]. Further reduction in the antenna profile can be achieved, e.g., down to $\lambda/9$, by using metamaterial surfaces designed with customized reflection phases for both the top and bottom covers of the cavity [5]. However, most of these FP cavity antennas exhibit an enhanced directivity and matched input impedance only over a very narrow bandwidth, which considerably limits their utility. Apart from the FP cavity related technique, another MM approach for increasing the directivity has recently been proposed by using a volumetric zero/low-index metamaterial (ZIM/LIM) lens [6], with one of the permittivity and/or permeability tensor parameters approaching zero, can give rise to directive radiation [7]. Such AZIMs can be used as a volumetric AMC antenna backing to confine the radiation energy into a narrower angular range.

The main objective of this paper is to design microstrip antenna using metamaterial with larger bandwidth. Microstrip lines (MSL) are widely used in microwave systems because of its low cost, light weight, and easy

integration with other components. Here, we have used FR4 as a substrate material as it gives best results regarding utilization of bandwidth, resonating frequency and return loss. FR4 has a good fabrication process, good electrical insulation as its features. Our chief aim is to increase the operating bandwidth. To increase the bandwidth of an antenna one effective technique is to cut a slit in a proper position on a microstrip patch. Thus the paper deals with the modifications in the structure of [8] by changing the shape of the slot and by optimizing the distance between slot and SIW to enhance the bandwidth.

Section II gives the design of a SIW fed slot antenna with metamaterial to operate at around 5.8 GHz. In Section III, simulation and experimental results are presented.

2. DESIGN OF SIW SLOT ANTENNA WITH METAMATERIAL

The proposed antenna has dimensions of 133 mm x 92.5 mm for 5.8 GHz. The 'L' slot is cut off from the rectangular microstrip patch. Two slits are used in this design. The FR4 is used as a dielectric substrate material and copper is used as patch and ground plane material. A Lumped port is used as a feeding technique in this design. The proposed antenna gives optimal result for dimensions as shown in Table -1. It is prototyped on FR4 substrate with dielectric constant, $\epsilon_r = 4.4$ and fed by microstrip taper line. A tapered microstrip is used for impedance matching between the 50Ω feedline and the SIW. The design of the presented antenna is shown in Fig -1. If we apply an L shaped slot, slits and air gap to the same design instead of simple slot design, bandwidth has been enhanced. For achieving good bandwidth I have tried for different values of L and W. The optimum design parameters of the L slot, slit and air gap were set respectively: $L_1 = 17$ mm and $W_1 = 1$ mm, $L_2 = 0.7$ mm and $W_2 = 1.8$ mm, $L_3 = 11$ mm and $W_3 = 1$ mm, air gap = 0.575 mm, $a_{ELDR} = 0.2$ mm, $b_{ELDR} = 0.3$ mm. An SIW is integrated waveguide-like structures fabricated by using two periodic rows of metallic vias or slots connecting the top and bottom ground planes of a dielectric substrate. To increase the performance of antenna in terms of impedance bandwidth slit is used and to increase the gain an Anisotropic Zero-Index Metamaterial (AZIM) is used. An AZIM has been employed to offer unidirectional radiation in the broadside direction with low beam squinting. As from [8], to realize the anisotropic zero/low index property for the 5.8 GHz band, periodic ELDRs are employed. The side view of SIW Slot Antenna with AZIM is

as shown in Fig -2. A prototype of the proposed antenna has been fabricated and shown in Fig -3. The simulation has been carried out by HFSS software. The design parameters of Rectangular Microstrip Patch Antenna are given in Table -1.

Table -1: Dimensions of the antenna

Parameters	Dimensions	Unit
Thickness of FR-4 (h)	1.6	mm
Loss Tangent ($\tan \delta$)	0.02	-
Substrate Length- L_s	133	mm
Substrate Width- W_s	92.5	mm
Patch Length- L_p	90.5	mm
Patch Width- W_p	92.5	mm
Slot Length- L_1, L_2	17,0.7	mm
Slot Width- W_1, W_2	1,1.8	mm
Slit Length L_3	11	mm
Slit Width W_3	1	mm
Air gap h_1	0.575	mm

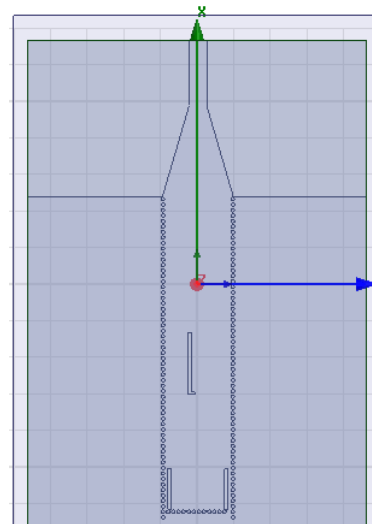


Fig -1: Top view of SIW Slot Antenna

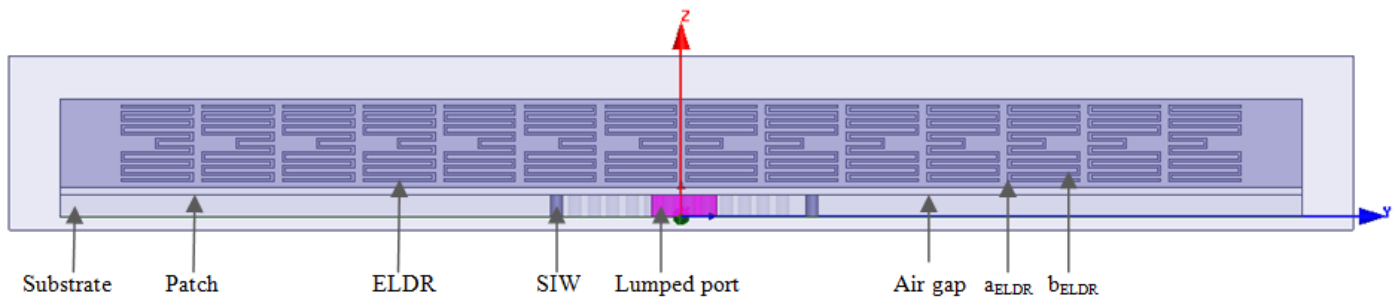


Fig -2: Side view of SIW Slot Antenna with AZIM

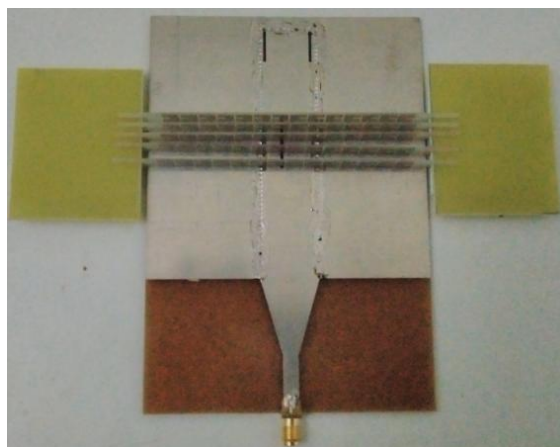


Fig -3: Photograph of fabricated SIW Slot Antenna with AZIM

3. RESULTS AND DISCUSSIONS

The antenna resonates at 5.8 GHz frequency. This frequency comes under the Wireless Local Area Network (WLAN) band and can be used for wireless applications.

- Bandwidth of SIW Slot Antenna with AZIM

Bandwidth of SIW Slot Antenna with AZIM above 16% has been achieved. The design is optimized using the High Frequency Structure Simulator (HFSS) software. As shown in Fig -4 using air gap and slits, bandwidth is increased. Using air gap bandwidth is increased from 6.75 % to 16.15%. Various results are given in Table -2.

- Radiation pattern of SIW Slot Antenna with and without AZIM

The Radiation pattern of SIW Slot Antenna without AZIM antenna is as shown in Fig -6. It shows the beam squinting in the pattern. The Radiation pattern of SIW Slot Antenna with AZIM antenna is as shown in Fig -7. As

shown in Fig -7 the beam squinting has been removed by using AZIM.

- Gain of SIW Slot Antenna with AZIM

The Gain output of SIW Slot Antenna with AZIM antenna is as shown in Fig -8. It shows the gain of the antenna at resonant frequency 5.8 GHz is more than 5dBi.

- Bandwidth of SIW Slot Antenna without air gap

The bandwidth of SIW Slot Antenna without air gap is as shown in Fig -9. Here bandwidth is decreased without air gap. It shows resonant frequency 5.6 GHz which is shifted towards lower frequency component. Without air gap bandwidth is decreased to 6.75 %.

- Bandwidth of SIW Slot Antenna without slits

The bandwidth of SIW Slot Antenna without slits is as shown in Fig -10. Here bandwidth will be decreased without slits. It shows resonant frequency is shifted towards lower frequency component.

With aid of the High Frequency Structure Simulator and Vector Network Analyzer, the simulated and measured return losses of the slot antenna are shown in Fig.4 and Fig.5 respectively.

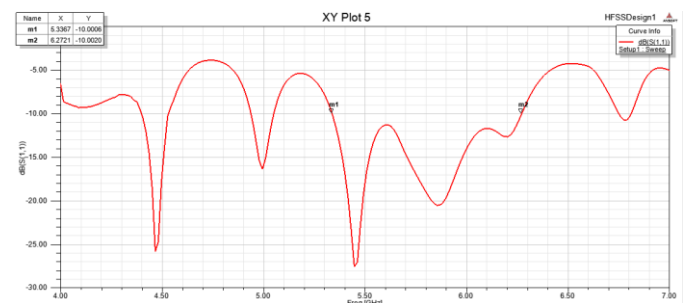


Fig -4: Return loss output of SIW Slot Antenna with AZIM

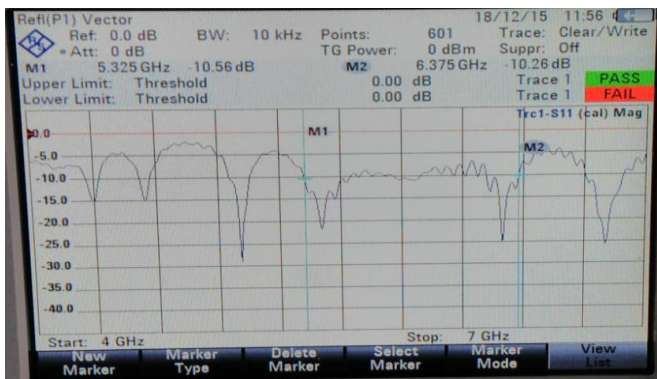


Fig -5: Photograph of Return loss output in VNA of SIW Slot Antenna with AZIM

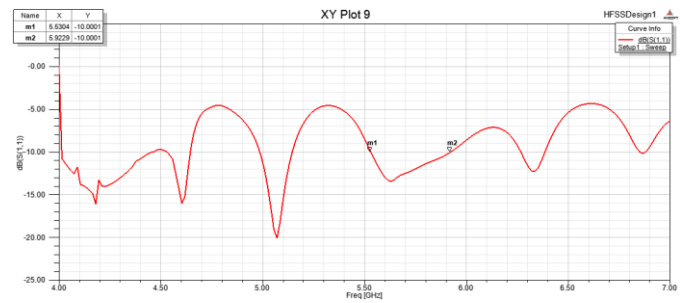


Fig -9: Return loss output of SIW Slot Antenna without air gap

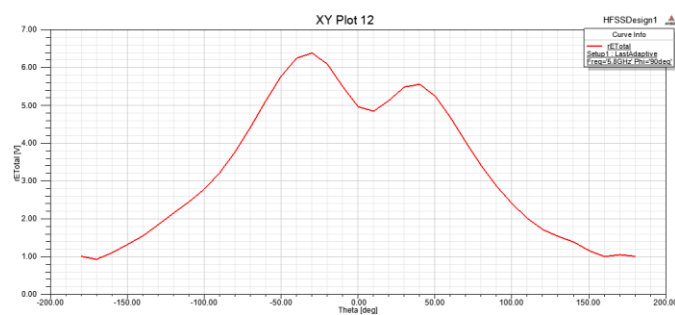


Fig -6: 2D radiation pattern of SIW Slot Antenna without AZIM

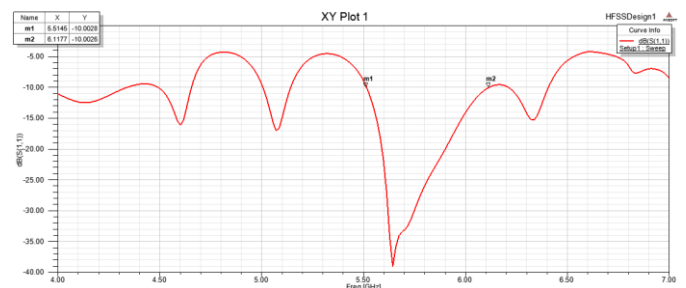


Fig -10: Return loss output of SIW Slot Antenna without slit

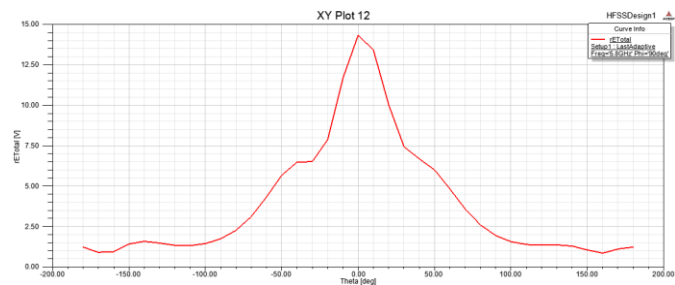


Fig -7: 2D radiation pattern of SIW Slot Antenna with AZIM

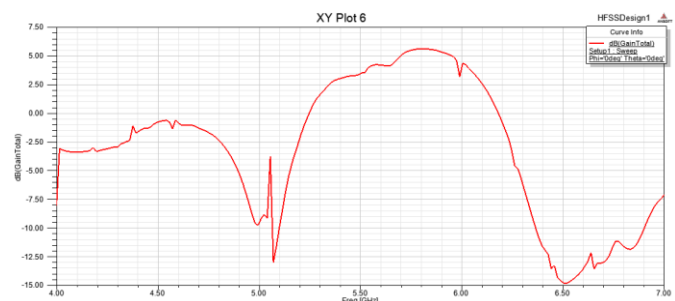


Fig -8: Gain of SIW Slot Antenna with AZIM

From the simulated and measured results, it is observed that the slit and air gap has improved the bandwidth performance of the slot antenna. The bandwidth of the slot antenna with the slit is approximately 16.15% from 5.33 to 6.30 GHz and overall gain of the antenna is 5 dBi, while the antenna without a slit is approximately 10% from 6.11 to 5.51 GHz. Simulation and experimental results comparison is shown in Table -2.

4. CONCLUSIONS

The Proposed antenna with low profile and high bandwidth that comprises a SIW fed slot covered by an AZIM coating. The Air gap has improved gain and bandwidth of the slot antenna. By introducing slits with a proper size on the rectangular radiating patch, the bandwidth of the slot antenna broadened. This antenna achieves a more than 16% impedance bandwidth of 5.33-6.27 GHz, a broadside gain around 5 dBi. The proposed antenna has a strong application in WLAN devices.

Table -2: Simulation and experimental results comparison

Antenna Structure	Simulation Results of SIW Slot Antenna with AZIM		Experimental Results of SIW Slot Antenna with AZIM	
	Bandwidth (GHz)	Bandwidth (%)	Bandwidth (GHz)	Bandwidth (%)
Proposed work with $\epsilon_r = 4.4$	5.33-6.27	16.15	5.325-6.375	18

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