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Traveling Wave Slotted Waveguide Antenna For Ku Band Applications Using SIW

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ABSTRACT

The design and optimization of broadband, beam steering and high gain traveling wave slotted waveguide array antenna using substrate integrated waveguide (SIW) is discussed in this paper. The antenna has been designed on Rogers 5880 with a dielectric constant of 2.2 and height of 0.762 mm. The functional frequency range is from 13.5 GHz - 15.5 GHz and the gain is about 14 dB at 15.5 GHz. The proposed antenna radiation beam steers from -33^0 at 13.5 GHz to 5^0 at 15.5 GHz in elevation plane. This antenna possesses the benefits of low profile, low weight, low cost and it can be used for Ku band applications.

I. Introduction

Slotted waveguide arrays (SWA) were first studied by Watson and Stevenson and came into existence during World War-II [1]. SWA are most well liked in several applications instead of microstrip antennas because of its advantages such as low loss, good isolation, and rich in power handling. On the other side, microstrip antennas possess less production charge, compact in size and can be easily mounted on single or multifaceted surface [2, 3]. How-ever, they have complex feeding systems like probe feeding which makes fabrication difficult, series feed has radiation loss and strip line feed has cross coupling problems. Whereas in SWA, feeding mecha-nism in waveguide networks do not have radiation and coupling problems but feeding problem arises while integrating with planar circuits.

Presently, a planar wave guiding media, named as Substrate Integrated Waveguide (SIW), is developed [4, 5]. Even though dielectric loss came into existence since it is filled with substrate which does not exist in air filled waveguides, SIW holds most of the benefits of waveguides and also of microstrip technology. Furthermore, SIW can be freely fabricated and incorporated with RF ICs and different planar components by employing modest PCB process. These benefits empowered the usage of slotted SIW array antennas. Characteristics and properties of Travelling-wave slot antennas were discussed [6]. In [7], a compact single layer SIW monopulse slot array antenna is reported. Traveling wave SIW slot array antenna is optimized on the basis of method of least squares [8].

This work presents a slotted SIW array antenna design based on traveling-wave to achieve broadband, high gain and beam steering using frequency hopping. In section II, design procedure and dimensions are discussed. In section III, simulation and results are analyzed followed by conclusion in section IV.

II. Design

A. SIW structure

In the design process, initially the SIW structure is designed that is equivalent to air filled waveguide for required cut off frequency.

The structure is designed on Rogers 5880 substrate with dielectric constant ε_r = 2.2 and height of 0.762 mm which is considerably lower compared to rectangular wave-guide. SIW structure design formulae

SIW is operated in TE_{10} mode. Cut frequency of TE_{10} in air filled waveguide is:

$$f_c = \frac{c}{2W} \quad (1)$$

Where W refers width of air-filled waveguide.

Width of dielectric filled waveguide (W_d) is:

$$W_d = \frac{W}{\sqrt{\varepsilon_r}} \quad (2)$$

Width of SIW (W_{SIW}) is:

$$W_{SIW} = W_d + \frac{d^2}{0.95 * p} \quad (3)$$

where

$$d < \frac{\lambda_g}{10} \quad (4)$$

$$p < 2 * d \quad (5)$$

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\varepsilon_r w^2}{c^2} - \frac{\pi^2}{a^2}}} \quad (6)$$

Where λ_g refers guided wavelength, d refers diameter of via and p refers inter via spacing. The above equations from (1) to (6) are taken from [9, 10].

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B. Transition from strip line to SIW

Microstrip operates in quasi TEM mode whereas SIW operates in TE_{10}. To join these two different modes a tapered section is used which is capable of converting quasi TEM mode to TE_{10} mode.

Width of the tapered section in one end is same as width of microstrip line and width of other end (W_{tap}) is evaluated using following analytics.

The impedance of the waveguide modal of microstrip line is given by

$$Z_e = \sqrt{\frac{\mu}{\varepsilon_0 \varepsilon_e}} \frac{h}{W_{tap}} \tag{7}$$

$$Z_e = \begin{cases} \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8h}{W} + \frac{0.25h}{W}\right) & for \frac{w}{h} < 1 \\ \frac{120\pi}{\sqrt{\varepsilon_e}\left(\frac{w}{h}+1.393+0.667\ln\left(\frac{w}{h}+1.444\right)\right)} & for \frac{w}{h} > 1 \end{cases} \tag{8}$$

$$\frac{W_{SIW}}{W_{tap}} = 4.38 e^{\frac{-0.627\varepsilon_r}{\varepsilon_e}} \tag{9}$$

Rewriting and combining above equations:

$$\frac{1}{W_{tap}} = \frac{4.38}{W_{SIW}} e^{\frac{-0.627\varepsilon_r}{\frac{\varepsilon_r+1}{2}+\left(\frac{\varepsilon_r-1}{2}\right)\left(1+\frac{12h}{W}\right)^{-0.5}}} \tag{10}$$

The equations (7) to (11) referred from [11, 12]. The SIW structure including transition is presented in Fig. 1.

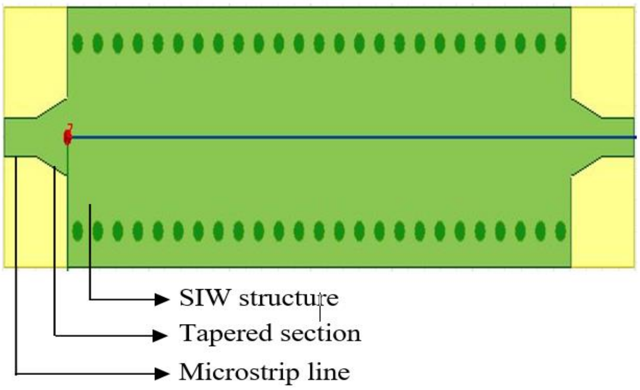

Fig. 1. SIW structure including transition.

C. SIW structure to Antenna

In SWA antennas, the slots are placed by analysing the modal fields for proper radiation. SWA antennas are classified as standing wave and traveling wave depending on whether the waveguide end is short circuited or matched termination. The standing wave SWA antennas are preferred where broad-side radiation beam and narrow band are main concern. The traveling wave SWA antennas are preferred where non-broad-side radiation beam and beam steering are main concern [13].

The authors objective is to design SWA antenna for beam steering applications. Therefore, traveling wave type SWA is opted. The antenna is composed of 8 element traveling wave longitudinal slots on the wide wall of SIW. Longitudinal slots are designed using Elliot's formulas for 14.25 GHz

To maximize frequency-bandwidth performance, resonant slots are used in traveling wave arrays. One end is terminated with matched load to prevent the occurrence of a secondary beam due to reflected waves. Spacing between adjacent slots is selected to be approximately one-half guided wavelength.

TABLE I. Design Dimensions

Name	Value
W	16.67 mm
d	1.3071 mm
p	2.48349 mm
h	0.762 mm
Wsiw	10 mm
sp	15.6862 mm
ws	2.35 mm
ls	3.8475 mm
ltap	3.92155 mm
Wtap	5 mm
du	1.68 mm
sw	0.826 mm
lo	14.2 mm
l	62.47938 mm

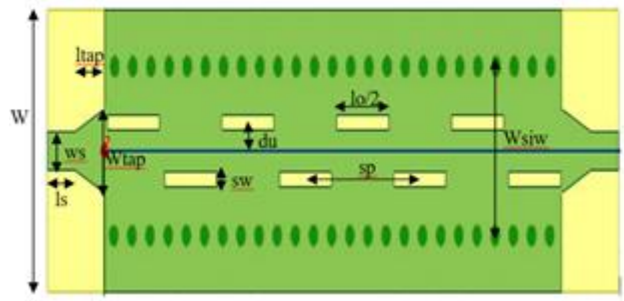

Fig. 2. Geometry of the designed antenna

The SIW is connected to a microstrip line transition at $\Phi = 90^0$ on both ends and port 1 is employed to activate traveling-wave slots while port 2 is terminated with a matched load. The progressive phase shift between slots, which modifies with frequency, causes beam to shift. As power excite the SIW, the first slot couples some power, leaving the remaining power to travel to the next slot, and so on. Some power be absorbed by the matched load. The geometry of complete antenna design is exhibited in Fig. 2.

In the following sections, simulations and results are analysed.

III. Simulations and Results

The proposed model is designed using Ansys HFSS an EM simulation software. The reflection coefficient (S_{11}) and transmission loss (S_{21}) plot of the basic SIW structure including microstrip transition is shown in Fig. 3.

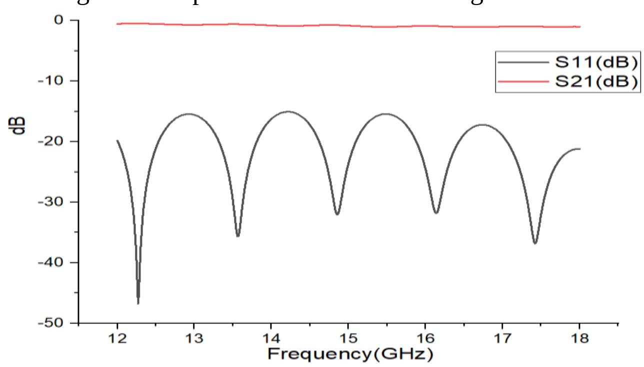

Fig. 3. S_{11} and S_{21} plot of the basic SIW structure.

Converting the basic structure into an antenna using traveling-wave longitudinal slots on broad wall, the gain patterns are analysed by sweeping frequency from 13.5-15.5 GHz.

The reflection coefficient of the designed antenna provides better than 10 dB between 13.5-15.5 GHz is displayed in Fig. 4. Comparison of gain rectangular plot and main beam position are analysed at 13.5 GHz, 14.5 GHz and 15.5 GHz frequencies seen in Fig. 5.

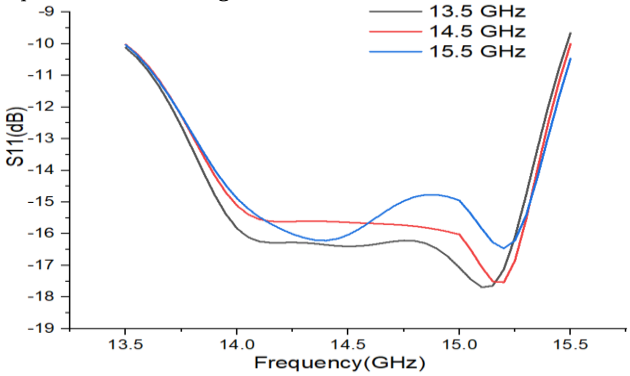

Fig. 4. S_{11} at 13.5, 14.5 and 15.5 GHz.

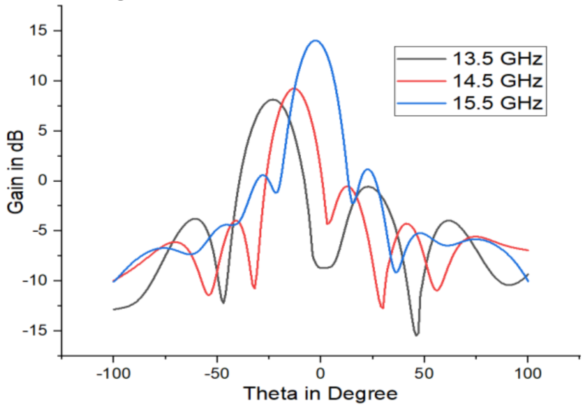

Fig. 5. Gain rectangular plot at 13.5, 14.5 and 15.5 GHz with respect to theta at phi = 90^0.

TABLE II. COMPARISON OF SIMULATED RESULTS AT DIFFERENT FREQUENCIES

Freq. (GHz)	Max. Gain (dB) @ θ (degree)	Half Power Beamwidth (degree)
13.5	08.154 @ θ = -23	19.83 (-33.43 to -13.6)
14.5	09.276 @ θ = -13	16.40 (-21.13 to -4.73)
15.5	14.041 @ θ = -02	15.99 (-10.71 to 5.28)

By observing the Table II, it is evident that beam steering is achieved by changing the frequency. This type of beam steering can be used in RADAR applications where both scanning and multiple pulse repetition frequency is needed.

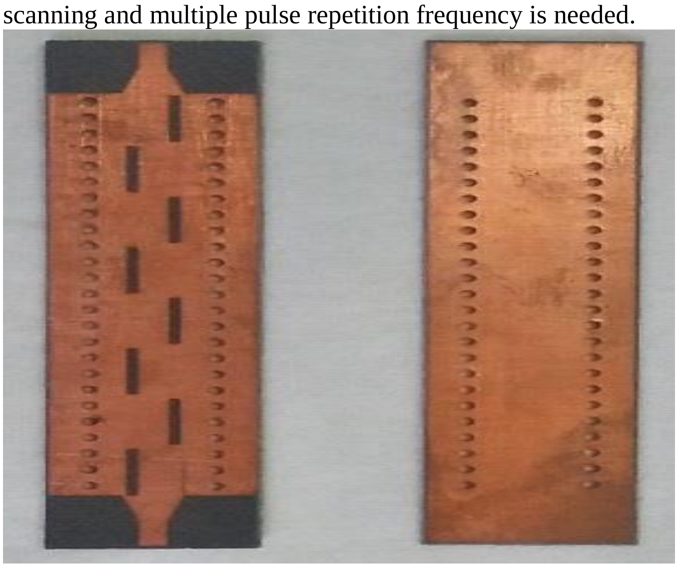

Fig. 6. Fabricated Antenna

The antenna is fabricated on Rogers 5880 substrate with dielectric constant εr = 2.2 and height of 0.762 mm shown in Fig. 6.

IV. Conclusion

SIW dependent antenna is opted to get benefits of both microstrip and waveguide technology. This paper explained the design and optimization of compact broadband, beam steering and high gain traveling wave antenna using substrate integrated waveguide (SIW). The foremost measurements of the SIW and of the slot were attained from mathematical equations for equivalent hollow waveguide and from dispersal properties. The simulated S-parameters and antenna characteristics are presented. The operating frequency band is from 13.5 - 15.5 GHz and the gain is utmost 14 dB at 15.5 GHz. The antenna radiation beam steers from -33^0 at 13.5 GHz to 5^0 at 15.5 GHz in elevation. The antenna array is competent for the beam steering operations employing frequency scanning.

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