A Dual-frequency Antenna Based on Substrate Integrated Waveguide (SIW) in Millimeter-Wave Range

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***Abstract-* This paper presents a novel way to design dual-frequency slot antenna based on substrate integrated waveguide (SIW) in millimeter wave range. The existing of first two modes in SIW resonator, TE_{101} and TE_{102} modes, ensure that slot cuts the current of two modes at the same time which leads to a dual-frequency performance of the slot antenna. The proposed antenna resonates at 25.8 GHz and 31.5 GHz with gain of 6.3 dB and 6.9 dB, respectively.**

I. Introduction

Nowadays, millimeter wave range wireless communication systems draws great attention in industry and academia [1]-[3]. Slot antennas are one of the brilliant candidates in application of wireless communication systems due to their low profile, good radiation efficiency, and simple structure [4]-[6]. Substrate Integrated Waveguide (SIW) structures have the advantages of low loss, easy integration, high power capacity. With lower energy leakage and profile than microstrip line and rectangular waveguide (RWG), SIW has substantive applications in slot antennas within millimeter wave range especially in K-band frequency range. However, traditional slot antennas based on SIW structure can realize dual-frequency or dual-band only by utilize more than one slot [7]-[8].

In this paper, we demonstrate a novel technique to design dual-frequency slot antenna based on SIW structure. Considering the first two modes in SIW resonator, TE_{101} and TE_{102}, the slot cuts the current of both modes to radiate energy into free space which has good performance on two resonance frequencies. The proposed antenna has central frequencies at 25.8 GHz and 31.5 GHz with gain of 6.3 dB and 6.9 dB, respectively.

II. Antenna Design

SIW is a structure with a dielectric substrate separating two metal plates which are shorted by two rows of metallic via holes. The performance of SIW structure is similar to conventional RWG which replace the vertical metal walls by metallic via holes.

According to the parameters of SIW, the equivalent width a_{equ} of conventional RWG can be defined [10],

$$a_{equ} = a - \frac{d^2}{0.95p} \tag{1}$$

TABLE I
SIW Parameters And Calculated Resonant Frequency

SIW Width (a)	4.4 mm	SIW Length (l)	11.2 mm
Via Diameter (d)	0.5 mm	Via Distance (p)	0.7 mm
Equivalent Width (a_{equ})	4.024 mm	Equivalent Length (l_{equ})	10.824 mm
Resonance Frequency I (TE_{101})	26.9 GHz	Resonance Frequency II (TE_{102})	31.35 GHz

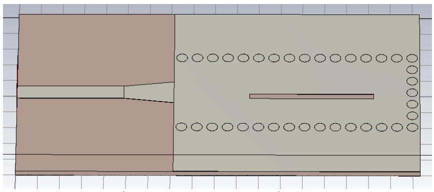

Fig. 1. Antenna structure in CST

$$l_{equ} = l - \frac{d^2}{0.95p} \tag{2}$$

where a is the distance between two rows of metallic via holes in SIW and l is the length of SIW.

To realize dual-frequency resonance within single slot, SIW resonator is introduced in the antenna design. The resonance frequency of conventional rectangular resonator is given by,

$$f_{mnq} = \frac{c_0}{2\pi\sqrt{\varepsilon_r \mu_r}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{q\pi}{l}\right)^2} \tag{3}$$

The resonance frequency of SIW resonator is,

$$f\left(TE_{m0q}\right) = \frac{c_0}{2\sqrt{\varepsilon_r}} \sqrt{\left(\frac{m}{a_{equ}}\right)^2 + \left(\frac{q}{l_{eqy}}\right)^2} \tag{4}$$

With equations mentioned above, resonance frequency of TE_{101} and TE_{102} SIW resonator is obtained. The simulation of resonator is performed in Rogers RT Duroid 5880 with the

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substrate thickness of 0.254 mm and dielectric constant of 2.2. The parameters of SIW and the theoretical calculated resonance frequency of TE_{101} and TE_{102} are depicted in Table I.

Based on the theoretical calculation of resonance frequency of TE_{101} and TE_{102} of SIW resonator, the dual-frequency slot antenna is presented in Fig. 1. Tapered microtrip line transition is applied in antenna design due to its wide bandwidth. The length of the slot *L* is larger than $\lambda_g / 2$ to ensure disturbing the current progress of both modes. All the simulation have been done in CST. Fig. 2 presents the input reflection coefficient (S_{11}) of dual-frequency SIW slot antenna which resonances at both 25.8 GHz and 31.5 GHz. Fig. 3 and Fig. 4 shows the radiation pattern on 25.8 GHz and 31.5 GHz, respectively. The gain of each resonance frequency is 6.3 dB and 6.9 dB, respectively.

IV. Conclusion

A detailed analysis of a novel K-band dual-frequency single slot antenna based on SIW structure is demonstrated in this paper. The proposed design starts from the view of SIW resonator to obtain the performance of dual-frequency in single SIW slot antenna. With short SIW structure which can be regarded as a SIW resonator, a slot larger than $\lambda_g / 2$ disturbs current distribution of TE_{101} and TE_{102} modes at same time then radiate the energy. The antenna resonates at 25.8 GHz and 31.5 GHz with gain of 6.3 dB and 6.9 dB, respectively. As such, realizing dual-frequency characteristic in single slot antenna have a bright application in minimizing of antenna in millimeter wave range.

Acknowledgment

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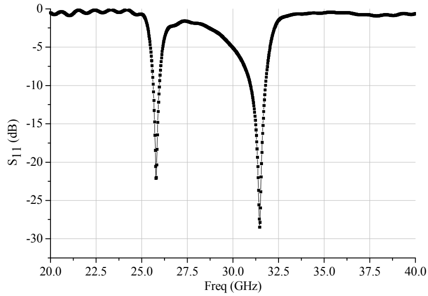

Fig. 2. Input reflection coefficient

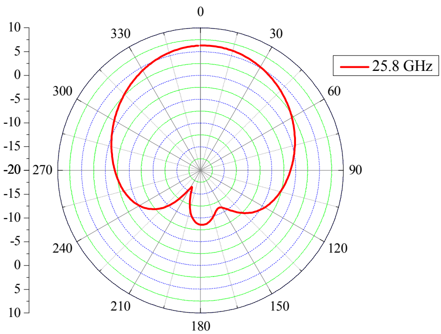

Fig. 3. Radiation pattern of 25.8 GHz

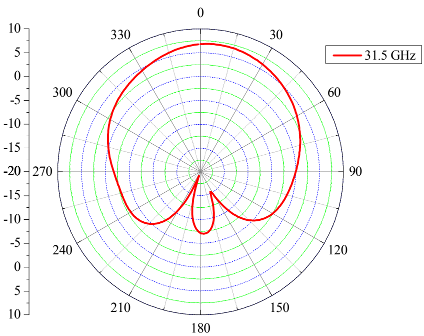

Fig. 4 Radiation pattern of 31.5 GHz