Improvement in Planar Array Antenna Performance by Using Center-fed Coaxial-to-SIW Transition and UC-EBG Structure for 60 GHz Wireless Communication

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Abstract— Improving antenna performance is an important topic in antenna design. This paper proposes an improved planar array antenna to achieve proper input impedance matching and suppress the undesired surface waves by utilizing a new center-fed coaxial-to-SIW transition and a uniplanar electromagnetic band-gap (UC-EBG) structure. A proposed center coaxial feed is used in substrate integrated waveguide (SIW) transition line in order to employ millimeter wave (MMW) 2×2 planar microstrip patch antenna (MPA) array in 60 GHz center frequency and about 900 MHz impedance bandwidth with return loss less than -10 dB. The results are obtained by applying FDTD numerical electromagnetic method in CST simulation software. Also, according to these results, also the gain and side lob level are slightly better than conventional one because of surface waves suppression properties in UC-EBG structures.

1. INTRODUCTION

Microstrip patch antennas are widely used in modern communication systems because of low profile, conformability to planar or curved surface, low cost and light weight. Therefore they are good candidates for low cost MMW applications. But these antennas have low efficiency and low gain because of having small size and high conduction losses. To overcome these problems, the waveguide resonance slot antennas are employed. These antennas have high gain, high cross-polarization and low side lobe level. But there are some disadvantages with them such as heavy weight and high price. By using substrate integrated waveguide (SIW), these problems can be solved [1]. Automotive radar [2], imaging sensors [3] and medical laboratory equipment are some applications of MMW band. In this band, the elements dimensions of the telecommunication system are smaller than other systems in lower frequencies, thus it is quite suitable for mobile and portable applications. In recent years, Electromagnetic band-gap structures have become more interesting because of having desirable properties [4] such as suppressing undesired surface waves to increase the gain and reduce mutual coupling between antenna radiation elements [5, 6].

In this paper, first, process of substrate integrated waveguide (SIW) transition line designing is discussed and then a novel coaxial to SIW transition structure is introduced due to the fact that employing microstrip line for feeding millimeter wave antenna in commercial use is not appropriate because of internal losses. Finally, the gain and side lobe level of proposed antenna are improved by using surface waves suppression properties of EBG structure in antenna. These purposes are achieved by employing UC-EBG structure. If antenna center frequency is within the UC-EBG band-gap areas, mutual coupling, antenna gain and side lob level will be improved effectively. The proposed antenna is simulated using CST Microwave Studio [7].

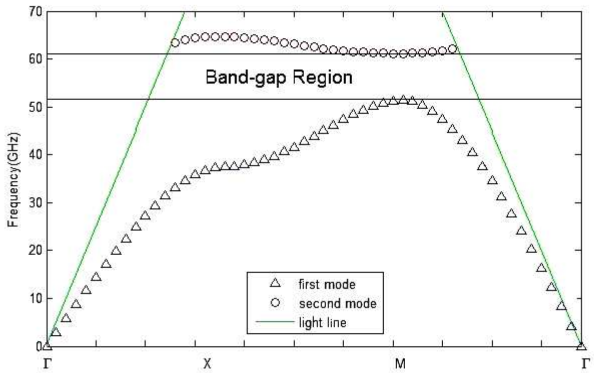
2. EBG DESIGN

The electromagnetic properties of UC-EBG structure can be specified by physical dimensions of each unit cell [8]. In comparison with conventional design, its vertical vias has been removed. Thus its fabrication is simpler and compatible with MMIC designs [9–11]. Dispersion diagram and UC-EBG unit cell dimensions that have been shown in Fig. 1 are defined by using FDTD/PBC (periodic boundary conditions) method in CST simulation software [10, 12]:

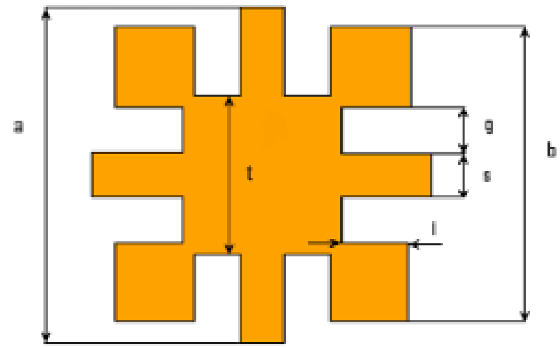
$$a = 0.3\lambda,\ s = g = 0.04\lambda,\ t = 0.14\lambda,\ \varepsilon_r = 2.20 \tag{1}$$

λ (about 5 mm) is free space wavelength in center frequency.

To obtain a stop band at 60 GHz, the parameters of UC-EBG structure according to (1) are designed as: $a = 1.49$ mm, $b = 1.3$ mm, $s = g = 0.19$ mm, and $t = 0.71$ mm. Fig. 1(a) shows the unit cell UC-EBG dispersion diagram with a band-gap frequency range between 53 GHz and 61 GHz. It shows the dispersion relation of surface waves between wave numbers and frequency [13]. The UC-EBG has been designed on Rogers RT/Duroid 5880 substrate with a thickness of 0.254 mm and a relative permittivity of 2.2.



(a)



(b)

Figure 1: (a) Dispersion diagram and (b) unit cell of UC-EBG structure.

3. CENTER-FED COAXIAL-TO-SIW TRANSITION

Low loss coaxial cables are widely used as a direct connection between signal generator devices and MMICs up to MMW frequencies. According to Fig. 2, the presented center-fed coaxial-to-SIW transition is designed based on cylindrical waveguide structure and step matching due to better matching of TEM mode for a coaxial line with TE_{10} mode in SIW. As depicted in Fig. 3, same as mode converting unit in waveguide rotary joint, increasing the guide width in transition section results improvement in impedance transformation. Furthermore, larger bandwidth can be achieved by varying the step discontinuities [14].

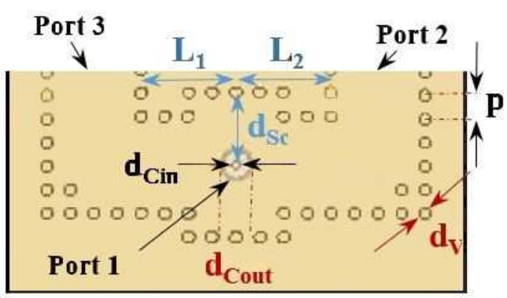


Figure 2: The center-fed coaxial-to-SIW transition.

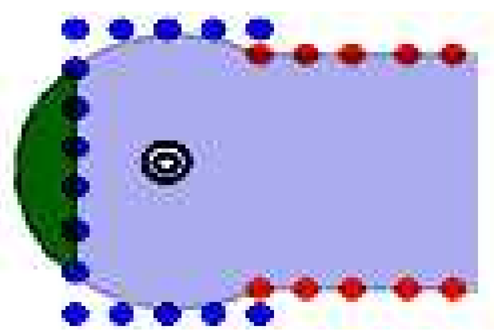
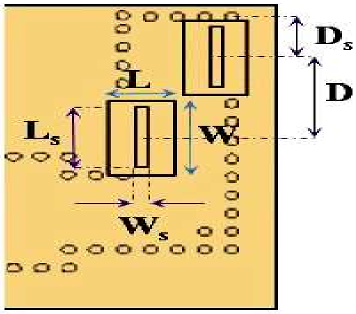


Figure 3: Top viewed of the waveguide rotary joint's schematic.

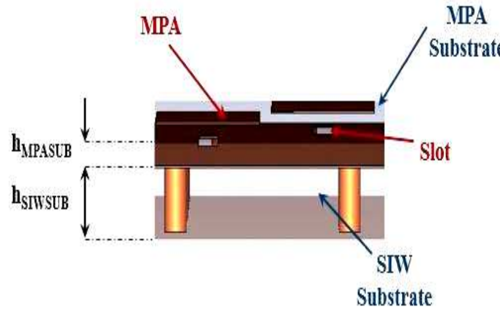
4. SIMULATION AND RESULTS

In this paper, performance of the conventional SIW-fed two layers 2×2 MMW planar array antenna [15] has been improved by adding a center-fed coaxial-to-SIW transition and a UC-EBG structure. Fig. 4 proposes geometry of an antenna that contains two layers. The SIW is placed in bottom layer and MPAs is on the top of upper one. The MPAs are excited by the slots on the SIW substrate. The parameters of RT/Duroid 5870 SIW substrate are height $h_{\mathrm{SIWSUB}} = 0.7874\,\mathrm{mm}$ and relative permittivity of 2.33. Also, MPA substrate is same as UC-EBG one. The proposed antenna has been designed using the CST MWS. Its dimensions (shown in Figs. 2 and 4(a)) have been given in Table 1.

The main disadvantage of proposed antenna in [15] is using rectangular waveguide port as feed. This port is only used at simulation, so applying this structure is practically impossible. There are different methods that increase microstrip antennas bandwidth [16]. In this paper, the SIW feed converter that has been proposed in Fig. 2 is added to antenna structure in [15] to connect this structure to the source of electromagnetic waves by coaxial transmission line. Increasing antenna impedance bandwidth and decreasing cross polarization are achieved by employing this structure due to step matching and mode matching that have been used in it. In addition, antenna performance is improved by using surface wave suppression properties of EBG structure. Fig. 5



(a)



(b)

Figure 4: Dimension of the SIW-fed MMW MPA array. (a) Top view and (b) side view.

Table 1: Dimensions of the proposed antenna.

Dimensions	
Parameters	Size (mm)
$L_T(L_1 + L_2)$	2.24
d_{Sc}	1.7
d_{Cin}	0.2
d_{Cout}	0.66
d_v	0.28
p	0.56
L	1.35
L_s	2.0
W	2.29
W_s	0.25
D	2.5
D_s	1.25

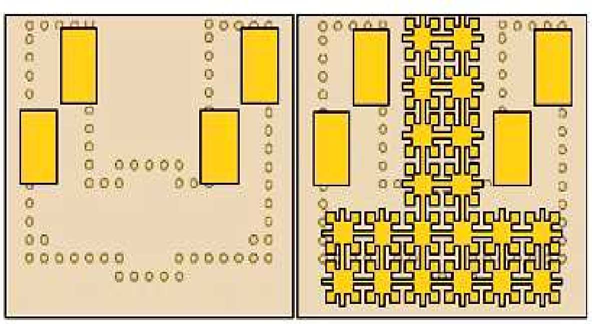

(a) (b)

Figure 5: Slot array antenna. (a) Without UC-EBG and (b) with UC-EBG structure.

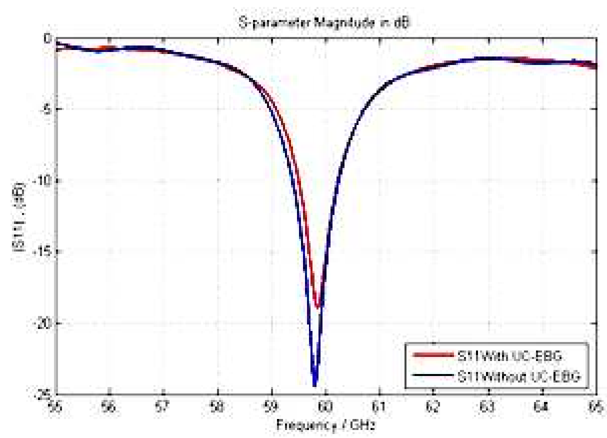


Figure 6: Simulated impedance bandwidth (S_{11}) with and without UC-EBG structure.

shows the proposed antenna with UC-EBG structure and without it. Antenna is composed of 20 UC-EBG cells.

The reflection coefficient (shown in Fig. 6) is better than -10 dB within the band from 59.6 GHz to 60.4 GHz. It shows that there is 60% enhancement compared to conventional one in [14].

Figure 7 shows the comparison between radiation pattern of SIW slot antenna with and with-

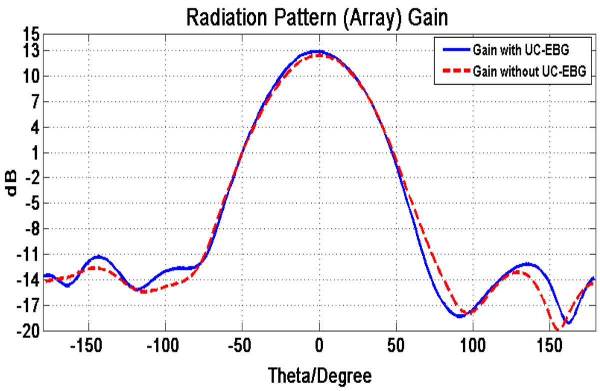


Figure 7: Comparison of the simulated radiation patterns of SIW slot array antenna.

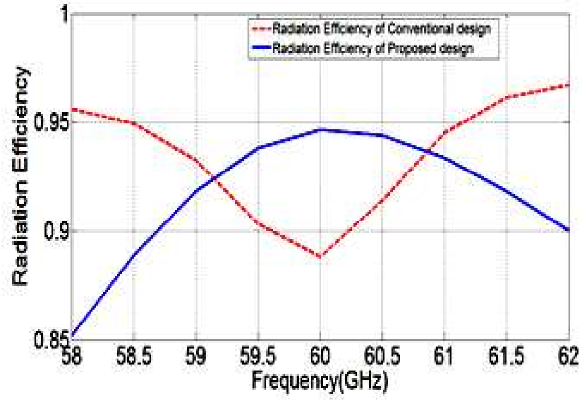


Figure 8: Radiation efficiency at different frequency points for the conventional and proposed antennas.

out UC-EBG structure at the center frequency. As shown in Fig. 7, the presented configuration has improved the antenna gain (about 1.5 dB) by applying feed converter and UC-EBG structure compared to [15]. The both designed antenna in [15] and proposed antenna radiation efficiency variation with frequency is also shown in Fig. 8. It is apparent that in the antenna operating impedance bandwidth (< -10 dB) the proposed antenna gives better results (Eff $> 90\%$).

5. CONCLUSION

In this paper, a SIW-fed 2×2 MMW MPA planar array antenna performance is improved by using new center-fed coaxial-to-SIW transition and UC-EBG structure. The simulation results show that the UC-EBG structure that has been added to the proposed antenna can effectively suppress the side radiation and increase the gain of a center-fed SIW slot array antenna, when the antenna operating frequency is situated in band-gap frequency range. Moreover, this EBG structure has a little effect on the resonant frequency of slots, which is helpful to keep the optimum design. The proposed antenna has 60% impedance bandwidth enhancement and radiation efficiency more than 90%. Its validity has been confirmed full-wave results with CST MWS.

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