Research Article

BCB-Si Based Wide Band Millimeter Wave Antenna Fed by Substrate Integrated Waveguide

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A benzocyclobutene (BCB) silicon (Si) based wideband antenna for millimeter wave applications is presented. The antenna consists of multilayer with one layer of BCB and the remaining three layers of Si. A patch is etched on the Si substrate above the air gap, which is excited through a slot. This architecture of slot, air gap, and patch will produce wide bandwidth by merging each one of resonances. The simulated results show that the antenna provides an $S_{11} < -10$ dB bandwidth of 9.7 GHz (17%) starting from 51.5 GHz to 61.2 GHz around 57 GHz central frequency. The antenna provides a maximum gain of 8.9 dBi with an efficiency of 70%.

1. Introduction

The trend towards wireless communication and demand for large bandwidth in wireless local area networks (WLAN)/wireless personal area networks (WPAN) environment is increasing rapidly, for example, wireless high definition multimedia interface (HDMI) devices, streaming and content download, peer-to-peer device communication, and high-speed internet access. For this purpose, 60 GHz is the natural candidate [1]. This continuous 7 GHz unlicensed band, around 60 GHz, has emerged as a worldwide opportunity for a range of short-range wireless applications. Oxygen absorption phenomenon is maximum at 60 GHz, which makes it the most suitable choice for WLAN, WPAN indoor secure communication [2]. Antenna is the fundamental element in all wireless communications. Currently, researchers all over the world are trying to produce some efficient small antennas/array system for deploying in 60 GHz applications. At this frequency band, different antenna designs have been proposed. Previously, many papers have been published in designing microstrip patch antennas/array. These antennas are lossy and have high level of back radiations pattern due to traditional planar feeding, such as microstrip lines [3], and coplanar waveguides [4]. The conduction and radiation losses problems are even more dominant at millimeter wave

V-band communication. Due to these problems, the antenna efficiency is degraded, especially in antenna array scenario, because of high level of back radiations. In microwave engineering, rectangular waveguides are widely used, because of their merits such as low losses, high power handling, and high isolation [4]. However, applications of these waveguides at millimeter wave frequencies are still very limited by high manufacturing cost, relatively large volumes, and difficulty of integration with other components.

The classical design techniques are not appropriate for millimeter wave frequency band as microstrip line designs exhibit large ohmic losses and spurious radiation. On the other hand, bulky waveguides designs are incompatible to deploy on such a compact circuitry. At this frequency band, we need to design a highly efficient antenna system, having optimum radiation characteristics (gain, radiation efficiency, and operating bandwidth), along with technology reliability, low cost, and compatibility with other RF modules. The current research challenges are not only to achieve large bandwidth around 60 GHz but also to design an efficient feeding network that does not affect the antenna array performance. Recently substrate integrated waveguide (SIW) technology is introduced for designs at millimeter wave frequency bands [5]. SIW technique is a transition between microstrip and dielectric filled waveguide (DFW) which

TABLE 1: Design parameters.

Parameter	W_{siw}	D_{via}	S_{via}	W_{trans}	L_{trans}	W_s	L_s	W_p	L_p	X_s	Y_s
Numerical value (mm)	2.35	0.156	0.50	1.98	2.61	0.34	2.20	1.5	3.80	-0.10	3.12

FIGURE 1: 3D exploded model view.

uses top and bottom metallization of the substrate and the metalized via-holes to create an artificial waveguide. It has been used and preferred in many millimeter wave circuits as a new type of transmission line for guiding the electromagnetic energy to excite the antenna structure [6, 7]. SIW has the qualities of low loss, high power handling capabilities, and being easy to integrate within millimeter wave circuits and components. On-chip antenna designs are preferred in terms of cost and compatibility with millimeter wave circuits. BCB based system-on-package (SOP) technology can be a good candidate for antenna packaging trends, because BCB has a low relative dielectric constant and a low tangent loss. Si layers with the rectangular cavities are created for bandwidth and gain enhancement of the antenna [8, 9].

The need for a low-volume and high-performance radiofrequency (RF) front-end module makes the RF packaging issues more important with increase in millimeter-wave applications. Here authors are presenting SIW based, multilayer antenna design technology using BCB-Si substrate. The fundamental design consists of an aperture antenna on the BCB layer excited by SIW, which acts as source antenna. Multiple layers of Si are used above the BCB layer. Our purpose is to design an efficient antenna with high gain and wide bandwidth.

2. Antenna Design

The 3D view of the antenna structure is shown in Figure 1. It consists of six layers. From top, the upper three silicon layers, layer 1, layer 2, and layer 3, have the thickness (t_{si}), 0.1 mm, 0.05 mm, and 0.23 mm, respectively with permittivity $\epsilon_r = 11.9$ and loss tangent $\tan \delta = 0.003$. A $5 \times 5 \text{ mm}^2$ cavity is created in layer 1 and layer 3, which helps to enhance the bandwidth. There is a patch etched at the upper face of the layer 2, with optimized dimensions of $1.5 \times 3.8 \text{ mm}^2$. SIW is designed at the last three layers (layer 4, layer 5, and layer 6). Layer 4 and layer 6 are copper metal with thickness (t_{clad}) of 0.003 mm having conductivity $\sigma = 58 \times$

10^6 s/m . Layer 5 is BCB with thickness (t_{BCB}) of 0.03 mm having permittivity $\epsilon_r = 2.3$ and loss tangent $\tan \delta = 0.003$. The SIW parameters, calculated from the guidelines given in [10], are shown in Figure 2. SIW width (W_{siw}) is the inner separation between the sidewalls created by via-holes, D_{via} is the diameter, and S_{via} is the center-to-center distance between two consecutive via-holes. The length and wall-to-wall width of SIW antenna element are 5.13 mm and 2.35 mm, respectively. A 50Ω microstrip line with a transition from microstrip to SIW having width W_{trans} and length L_{trans} [11] is designed on the bottom of the structure at layer 6, which excites the slot. A longitudinal slot is engraved at the ground layer (layer 4), having width W_s and length L_s and displacement from the symmetry axis is X_s . One end of the SIW is made short circuit to produce standing waves inside; Y_s is the distance from the short circuit end to the middle of the slot. A patch is etched on the upper face of the layer 2 and L_p and W_p are the length and width of the patch, which helps to enhance the gain. The standing waves will be radiated through the aperture created in the form of a longitudinal slot on the ground layer 4. The optimized numerical values of the design parameters are given in Table 1. The antenna is designed and simulated using both CST Microwave Studio and HFSS.

3. Results and Discussion

3.1. Return Loss, Gain, and Directivity. The simulated return losses (S_{11}) both in CST and HFSS are shown in Figure 3. We have taken into effect all the losses in simulations. The impedance bandwidth ($S_{11} < -10 \text{ dB}$) is 9.7 GHz, from 51.50 GHz to 61.20 GHz in CST and more in HFSS. The large bandwidth is due to the merging of three resonances as shown in CST results, which are due to the resonance from slot, air cavity, and the upper patch. There are three resonances in HFSS results too, but the third one comes after 62 GHz. The maximum gain and directivity are found to be 8.9 dBi and 10 dBi at 59 GHz with 70% radiation efficiency.

FIGURE 2: 2D top view, SIW parameters.

FIGURE 3: Simulated return loss.

FIGURE 4: E-plane radiation patterns.

3.2. Radiation Characteristics. The E-plane and H-plane radiation characteristics using CST and HFSS simulations are shown in Figures 4 and 5, respectively. Both the simulation results are in good agreement. The simulated results for three frequencies (52 GHz, 56 GHz, and 59 GHz) are presented. The co-polar and cross-polar levels can be seen in each plane. Efficient radiation characteristics are achieved in terms of co-polar and cross-polar levels. The 3 dB beam width is 69 degree for the E-plane and 71 degree for the H-plane at 56 GHz. The bore sight to back radiation level difference is more than 17 dB in both the cases. The side lobe levels are almost 15 dB in both the planes. All the radiation patterns are good within the bandwidth in both the planes.

4. Conclusion

A BCB-Si based wide band millimeter wave antenna is designed. The antenna provides a wide bandwidth with good gain and efficiency. This antenna finds application in millimeter wave high speed communication systems.

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FIGURE 5: H-plane radiation patterns.

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