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Enhanced Bandwidth of Microstrip Patch Antenna using Defected Ground Plane for 5G Application

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A B S T R A C T

An antenna is used in an RF system to receive or transmit radio wave signals. Without a properly designed antenna, the signal created by the RF system will not be transferred and no signal will be recognised at the receiver. Many different types of antennas have been developed to meet the demands of various applications. Antennas come in the form of microstrip patches. A microstrip antenna is basically a two side printed circuit board (PCB), one side known as patch and second side is ground. Communication systems have been driven towards the fifth generation (5G) due to the demands of compact, high-speed, and large bandwidth systems. A wideband defected ground surface (DGS) microstrip antenna at 60 GHz designed. Here two antenna rectangular microstrip as a reference antenna and DGS microstrip as propose antenna are design and simulate using ANSYS HFSS 2019R1 at 60 GHz. An Aperture coupled feed technique is used in this work. The proposed antenna resonates from f_L= 56.8630 GHz to f_H= 62.0550 GHz with a return loss $\leq$ -10 dB. The proposed antenna having 5.192 GHz bandwidth which is ≈ 8.66% wider as compared to reference antenna bandwidth 4.511 GHz. Gain of proposed antenna 7.5 dB and efficiency of 94.25%. In this design, two substrate Roger RT/Duroid 6006 and Roger RT/ Duroid5880 which has dielectric constant of 6.15 and 2.2 with loss tangent 0.0009 with a height of substrate are 0.635 mm and 1.6 mm was used. Finally conclude the performance of proposed antenna in terms of bandwidth its good agreement for 5G applications.

Keywords:Aperture coupled feed microstrip antenna, DGS, 5G.

1. Introduction

An antenna is a device used to send and receive electromagnetic waves in free space. Antennas are classified into two types: passive antennas and active antennas. The reciprocal device is the passive antenna. The reciprocal device is not an active antenna. Further Antennas are classified into nine categories. Active antennas, antenna arrays, dielectric antennas, microstrip antennas, lens antennas, wire antennas, aperture antenna reflector antennas, and leaky wave antennas are examples of these antennas.

Above all, these antennas differ in terms of feeding techniques and layouts. Deschamps initially introduced the notion of microstrip radiators in 1953. Printed circuit technology may be used to create a microstrip antenna. A technology called as photolithographic process may be used to print out exact dimensions on PCB.

The microstrip antenna can be made with low cost. In the photolithographic process, fabrication can be done the same as a photocopy machine because the mask of the design can be reused as many times as possible. Microstrip antenna has narrow bandwidth. Usually for rectangular microstrip antenna, the bandwidth is below 5%. It is also has low gain.

1.1 Aperture Coupling

This is the most difficult to fabricate and it also has high bandwidth. In this coupling method use a feed line on ground on one side of PCB and other side creates a slot as shown in Figure 1.

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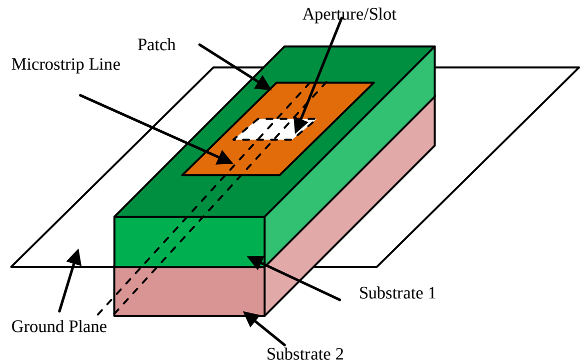

Figure Error! No text of specified style in document. **Aperture coupling**

2. Design and Analysis of Antenna

Transmission line model used for analysis. It is very simple and easy to understanding. In this method two slots represent a patch and work as line resonator that occur fringing field by variation of radiating field. Since the microstrip patch antenna consist of two slit first slot known as radiating patch and second is represent ground patch, therefore in this model width of antenna and length of antenna separated as transmission line with the thickness of antenna is h. The microstrip has no homogenous line of two dielectrics, typically the substrate and air. Figure shows the most of electric field lines reside in the substrate and some parts of lines in air. Therefore, the result of this transmission line cannot support pure TEM mode of transmission because the phase velocities would be different in the air and the substrate.The width of microstrip patch calculated by using following equations (Eqn-1-6). Where W is width of microstrip patch, C is the velocity of light, ε_r is the dielectric constant of the antenna substrate and f_0 is design frequency of the microstrip patch antenna.

$$W = \frac{C}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \qquad \text{Eqn. 1}$$

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r + 1)}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad \text{Eqn. 2}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff} + 0.300)\left(\frac{W}{h} + 0.262\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.813\right)} \qquad \text{Eqn. 3}$$

$$L = \frac{c}{2 f \sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad \text{Eqn. 4}$$

$$L_g = L + 6h \qquad \text{Eqn.5}$$

$$W_g = W + 6h \qquad \text{Eqn. 6}$$

$W_g$and L_g represent the finite ground plane width and length.

Table 1Optimized dimension of the patch antenna

Parameter	Dimension(mm)
Ground Plane & Substrate Length (G_x)	12
Ground Plane& Substrate Width (G_y)	12
Patch Length (L_p)	0.55
Patch Width (W_p)	1.98
Height of substrate(h_1)	0.635
Height of substrate(h_2)	1.6
Width of feedline (W_f)	0.9563
Length of Stub(ΔL_S)	0.15
Length of slot L_a	0.9646
Width of slot W_a	0.0986

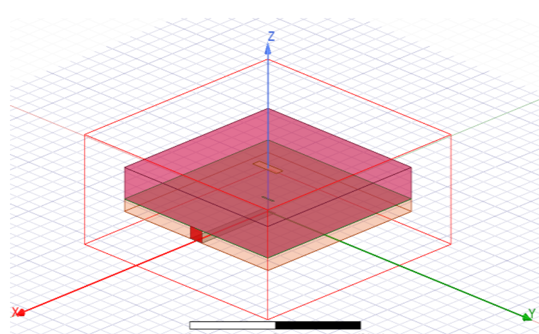

Figure 2 an aperture coupled microstrip antenna

2.1 Aperture coupled patch antenna as test antenna

In this section, antennas designed at resonance frequency 60 GHz with help of previous section parameter explain and considered in previous section. ANSYS HFSS 2019R1 full wave EM software is used for all simulation work. All simulated result compare and analyzed for bandwidth, gain, directivity and efficiency of antenna point of view

Draw Ground Substrate

Draw the box and rename as ground substrate with the dimension of G_x = 12 mm and G_y = 14 mm. Height of box is h_1= 0.635 mm with dielectric constant (ε_{r1}) = 6.15 RT/duroid 6006 and set position as centre.

Draw Feed Line and Position of Stub

Draw a rectangular and rename as feedline with W_f= 0.9563 mm. Now add the fringing stub length ΔL_S = 0.15 mm at the centre axis that is $G_x/2+\Delta L_S$ =6.15 mm. Now set the color and transparency of element up 70%. Feed line and stub position of antenna.

Draw Ground Slot

For structure of ground slot is combination of two planes. First draw a rectangular with size 12 mm x 12 mm and second with size 2.2 mm x 0.23 mm. Then subtract the second element with first element. Now set the color and transparency of element up 70%.

Draw Patch Element

Draw the box and rename as ground substrate with the dimension of G_x = 12 mm and G_y = 12 mm. Height of box is h_2= 1.6 mm with dielectric constant (ε_{r1}) = 2.2 RT/Duroid 5880 and set position as centre. Now draw a rectangular with size of L_P = 0.55 mm and width W_P = 1.98 mm. Now set the color and transparency of element up 70%.

Draw Source Element

Change the position of axis from xy plan to xz plane and draw a rectangular with size 0.9563 mm x 0.635 mm.

Assign Boundary Condition and Excitation of Source

Check the position of axis as xy plain. Now assign the boundary condition for all conductor plain as perfect E. Assign the radiating surface as vacuum and solution type considers as terminal. Now assigns excitation with lump port.

2.2 Analysis and Simulation Setup

Assign the analysis at frequency 60 GHz, maximum number of passes 20 and maximum delta s = 0.02. Now assign the sweep as fast and distribution for linear step start from 55 GHz to 65 GHz with step size 0.001 GHz.

Check validation and click analyze all. After the completion of simulation work plot some parameters like as, S11, VSWR, Smith chart, radiation patterns as well as radiation efficiency.

2.3 Defected Ground Surface Aperture Coupled Microstrip Antenna

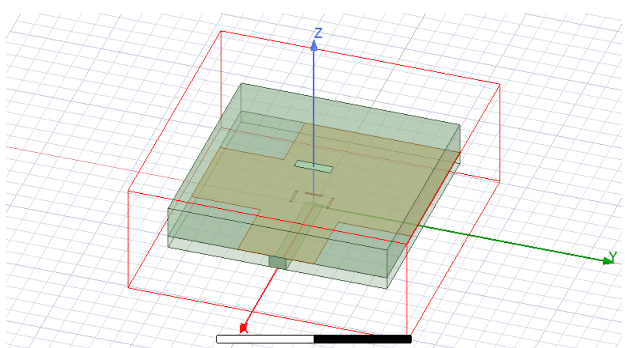

Figure 3 Aperture coupled DGS microstrip antenna

Taking a second patch of substrate RT/Duroid 5880 (ε_{r3}) = 2.2, height (h_3) =1.6 mm and copper thickness t_c= 0.0175 mm. Further ground surface defect as two sides of source section with dimensions of 3.5 mm. Now the opposite one side of source section cut the ground surface with the dimension of 4 mm as shown in Figure. Now two more slot cut near in the feed line with the dimension of 0.9646 x 0.0986 mm as shown in Figure.3. Size and parameters related to proposed antenna consider from previous section. Drawing procedure repeat as described in design section in the test antenna.

3. RESULT

This section present the simulation result of the antenna and summary of the result between test and proposed antenna.

Return Loss, Smith Chart and VSWR

The reference antenna resonates at 60 GHz with a return loss ≤ -10 dB from of -20.4438 dB, impedance bandwidth obtained 4.511 GHz from f_L= 56.467 GHz to f_H= 60.978 GHz while proposed antenna resonate at 60 GHz from with reflection coefficient -35.60 dB, the f_L= 56.8630 GHz to f_H= 62.0550 GHz having 5.192 GHz are shown in Figure 4. Smith chart of the test antenna and proposed antenna shown in Figure 6 and Figure 7.

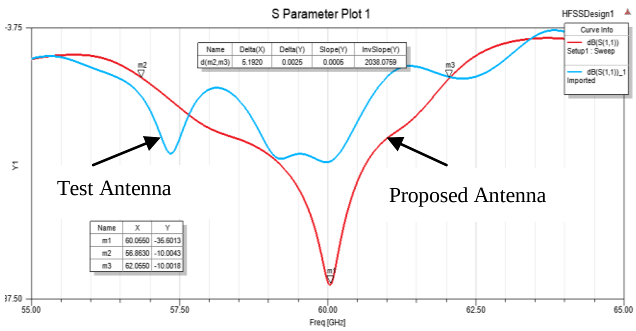

Figure 4Return loss of the antenna

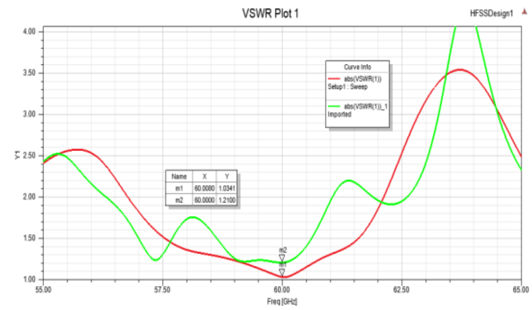

Figure 5 VSWR of antenna

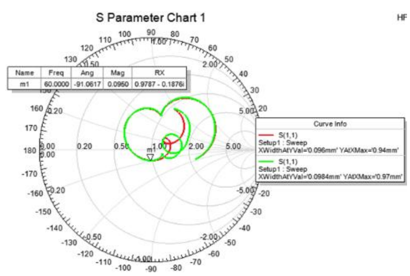

Figure 6 Smith chart of the test antenna

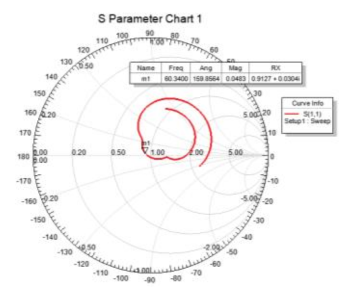

Figure 7 Smith chart of the proposed antenna

For a microstrip antenna, the VSWR should be between 1 and 2 along the bandwidth of efficiency. The proposed antenna voltage standing wave ratio (VSWR) can be observing 1.03 at 60 GHz. VSWR value of DGS antenna while reference antenna having VSWR is 1.21 at 60 GHz are shown in Figure.5.

The maximum gain of DGS antenna is 7.5 dB whereas the maximum gain of the reference antenna is 3.5 dB 2D and 3D plot of the gain of proposed antenna shown in Figure 8 and Figure 9 respectively. Figure 10 and Figure 11 shown the directivity of the test antenna and proposed antenna respectively. The summary of the result of the test antenna and proposed antenna shown in Table 2.

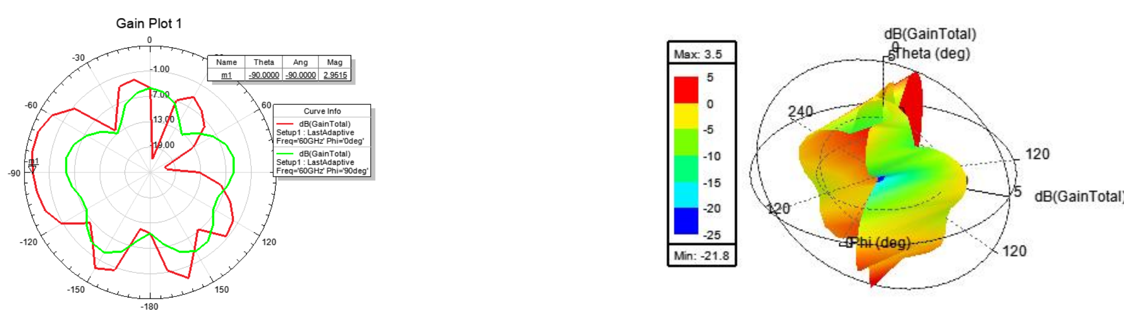

Figure 82D and 3D Gain plot of antenna

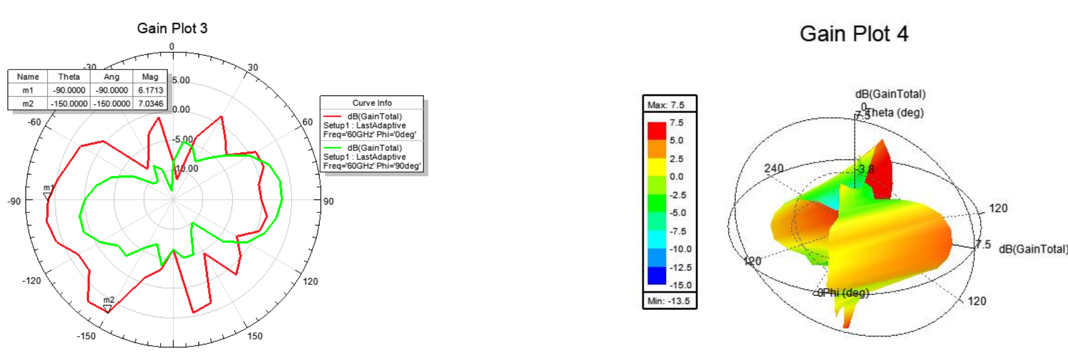

Figure 92D and 3D Gain plot of antenna

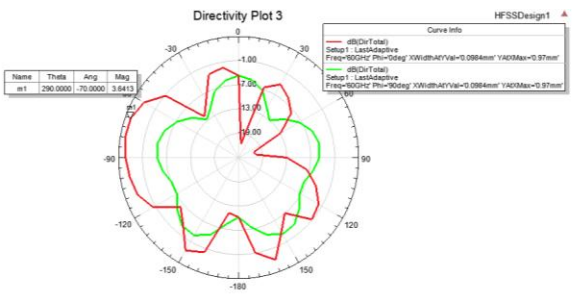

Figure 10 VSWR of antenna

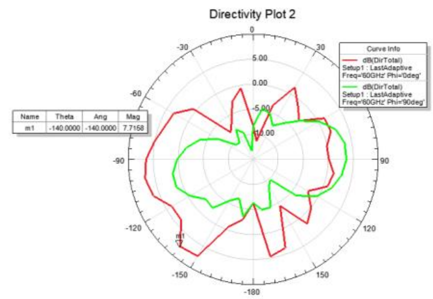

Figure 11 Directivity of antenna

Table 2 Summary of the simulated result between the proposed and test antenna

Antenna Parameter	Values(Test Antenna)	Proposed Antenna
S_{11}	-20.4438 dB	-35.60 dB
VSWR	1.21	1.034
Bandwidth	4.511 GHz	5.192 GHz
Gain	3.5 dB	7.5 dB
Directivity	3.55dB	7.72 dB
Efficiency	93.27%	94.25 %

Conclusion

Two antennas patch antenna as test antenna and DGS antenna as proposed antenna designed at resonance frequency 60 GHz. ANSYS HFSS 2019R1 full wave EM software is used for all simulation work. An aperture coupled DGS rectangular microstrip antenna has been proposed for 5G application. The antenna has bandwidth of 5.192 GHz, which is ≈ 8.66% wider as compared to test antenna bandwidth 4.511 GHz. The Gain of proposed antenna is 7.5 dB and test or reference antenna gain 3.5 dB. Here, it can be observed that the proposed antenna having wide band more than 681 MHz and gain is also high more than 4 dB which are requirements of 5 G applications. Therefore, proposed antenna as a good option for 5G applications.

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