Defected Grounded Rectangular Patch Antenna with Rhombic-Shaped Slots for Early Phase 5G Applications

URSI GASS 2020

29 AUGUST - 5 SEPTEMBER

SAPIENZA UNIVERSITY CAMPUS, ROME

B.G. Hakanoglu, O. Sen, B. Koc, S.E. Hayber, M. Turkmen

Rome, 2020

bghakanoglu@ahievran.edu.tr

Outline

- Introduction
- Theory
- Aim
- Design
- Simulation
- Results
- Conclusion

bghakanoglu@ahievran.edu.tr

The Near Future of Mobile Communication

- According to the Cisco Visual Networking Index (VNI) there will be 12.3 billion mobile-connected devices by 2022, including M2M (Machine-to-Machine) modules- exceeding the world's projected population at that time (8 billion) by one and a half times.

- In addition, by 2022, a 5G (fifth generation) connection will generate 2.6 times more data traffic than the average 4G (fourth generation) connection [1].

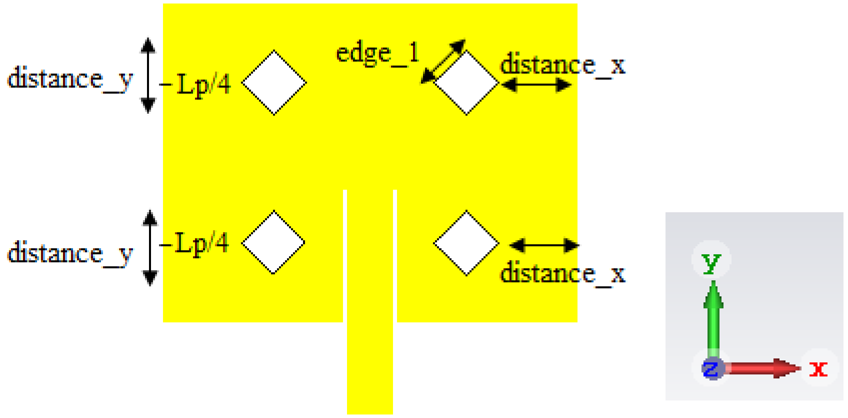
5G Frequency Spectrum

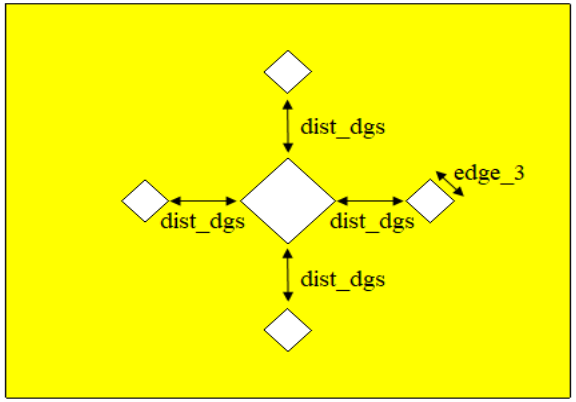
- The frequency spectrum for 5G is divided mainly in three regions,
- millimeter wave (mm-wave) band,
- mid-band also called sub 6 GHz band or early phase 5G band,
- low-band covering 600 MHz - 800 MHz [2].

- For the sub 6 GHz bands different countries plan to use different bands, for example in Europe many countries have defined 3400-3800 MHz range as the primary band and 4400-5000 MHz band is planned to be assigned for 5G by China and Japan [3].

Proposed Design

- There are few studies about patch antennas with defected ground structure (DGS) operating at early phase 5G bands compared to the ones operate at mm-wave bands.
- This study proposes a new design of a rectangular patch antenna with rhombic shaped slots (RSS) and defected ground operating at 3.5 GHz band.





bghakanoglu@ahievran.edu.tr

The Design Steps

- The design consists of four steps;
- Step one is to design the reference antenna according to the design equations (Antenna#1),
- Step two is etching of four RSS on the radiating part for improved radiation (Antenna#2),
- Step three is etching a RSS in the center of the ground plane (Antenna#3),
- Step four is etching of four additional slots with equal distances from the corners of the slot in the center of the ground plane (Antenna#4).

Rectangular Patch Antenna Design Procedure

Step 1 : Define the operating frequency (fr), the substrate material(ε_r) and the height (h) of the substrate,

Step 2 : Calculate the width of the patch,

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

Step 3 : Calculate the effective dielectric constant, for (W/h >1),

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

Reference : Antenna Theory, Balanis [4]

Rectangular Patch Antenna Design Procedure

Step 4 : Calculate the length correction due to fringing effects,

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

Step 5 : Calculate the length,

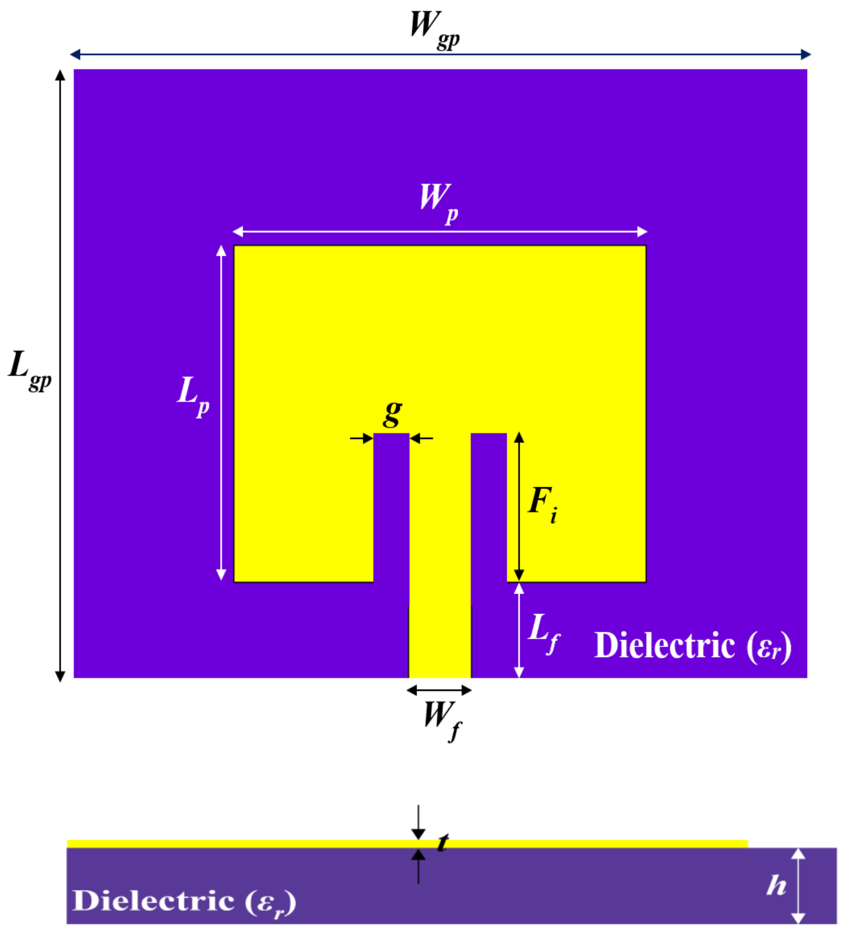
$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$

bghakanoglu@ahievran.edu.tr

Reference : Antenna Theory, Balanis [4]

Inset Fed Rectangular Patch Antenna Design

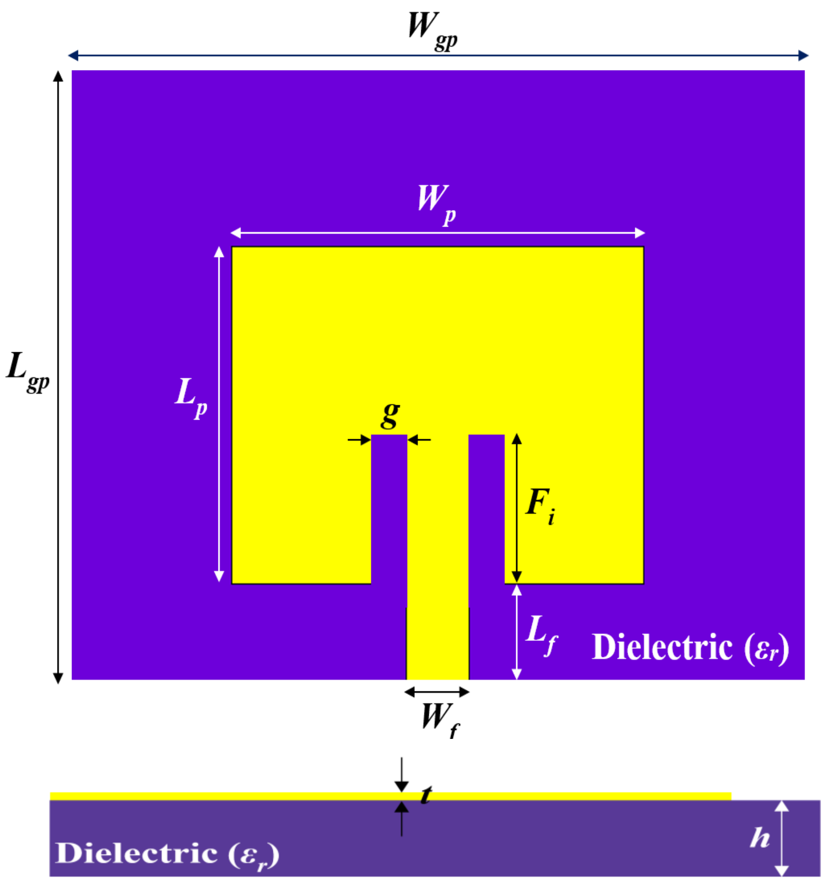
W_p : The width of the antenna
L_p : The length of the antenna
W_{gp} : The width of the ground plane
L_{gp} : The length of the ground plane
ε_r : The dielectric constant of the substrate
h : The height of the substrate
t : The height of the copper
W_f : The width of the feed line
L_f : The length of the feed line
g : The width of the inset feed
F_i : The length of the inset feed



Antenna #1

bghakanoglu@ahievran.edu.tr

Optimised Antenna Dimensions

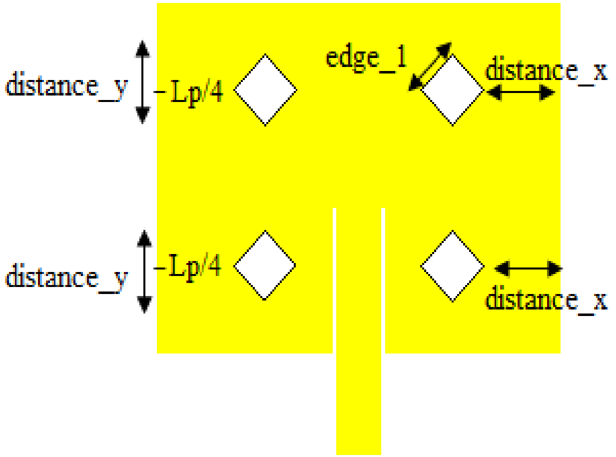


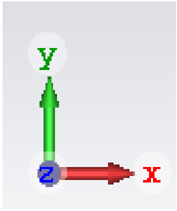
W_p	L_p	W_{gp}	L_{gp}
26.06 mm	20.02 mm	47.46 mm	36.57 mm
g	F_i	W_f	L_f
0.14 mm	8.2 mm	3 mm	5.86 mm

Dielectric Substrate : FR 4

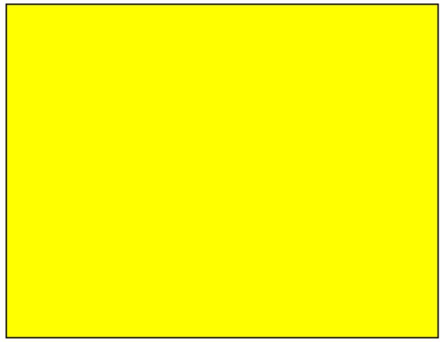
Antenna #1

Proposed Patch Antenna With Diamond Shaped Slots





Radiating part



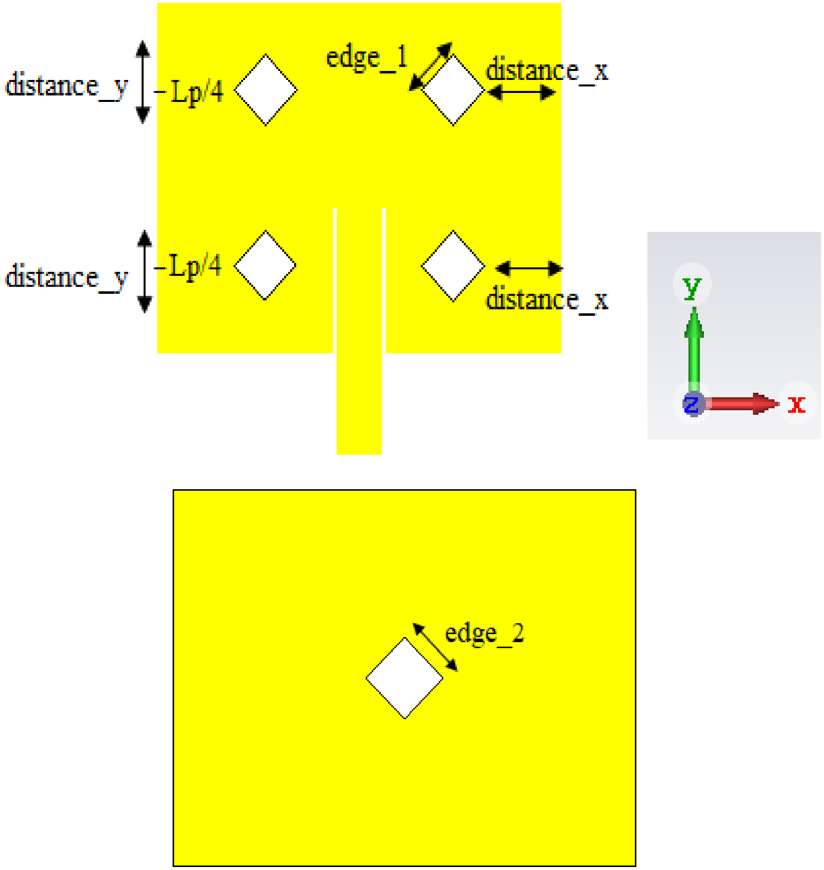
Groundplane

Antenna #2

The slot edge dimensions are shown with parameter edge_1, the spacing between the slots and the antenna edge on x-direction is shown with parameter distance_x and parameter distance_y shows the location of the slot compared to the reference point of $L_p/4$ on y-direction, e.g. -2 mm means 2 mm in -y direction and 2 mm means 2 mm in +y direction. These parameters have effects on the resonant frequency and other radiation characteristics of the antenna. So, we have performed a detailed parametric analysis to obtain the effects and find the best values for the antenna to radiate.

bghakanoglu@ahievran.edu.tr

Proposed Patch Antenna With Diamond Shaped Slots on the Ground

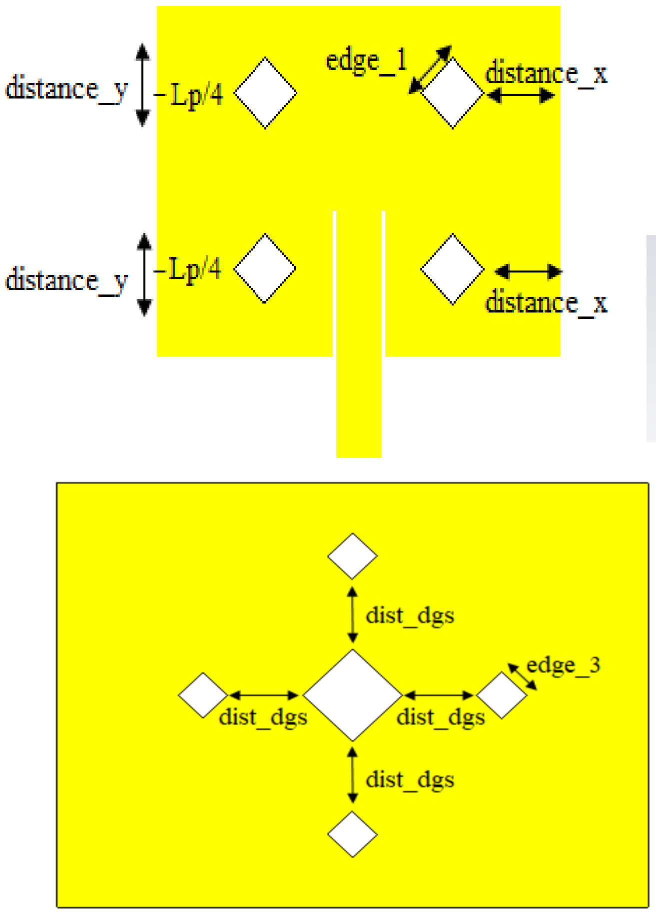


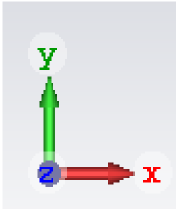
Antenna #3

- To obtain the effects of DGS we etch another RSS at the centre point of the ground plane with an edge dimension of parameter edge_2.

- We have performed an optimisation for the best results and also to see further effects, we change the value of parameter edge_2 having other parameters on the patch fixed with their best results.

Proposed Patch Antenna With Diamond Shaped Slots on the Ground



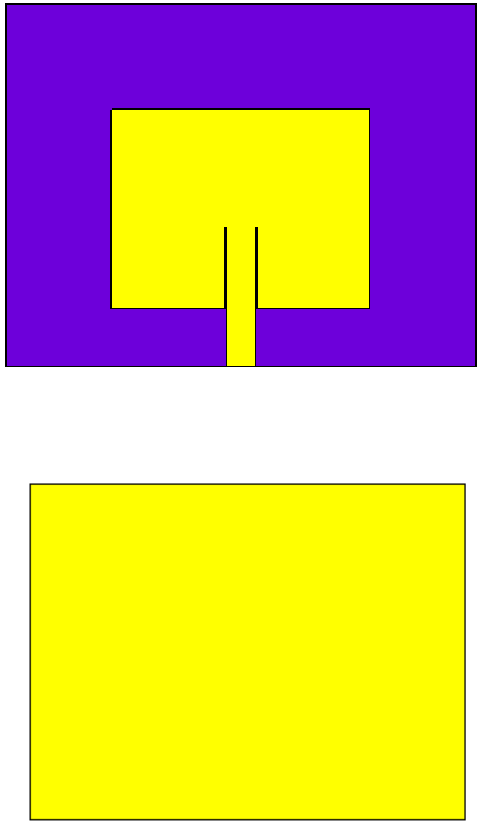


Antenna #4

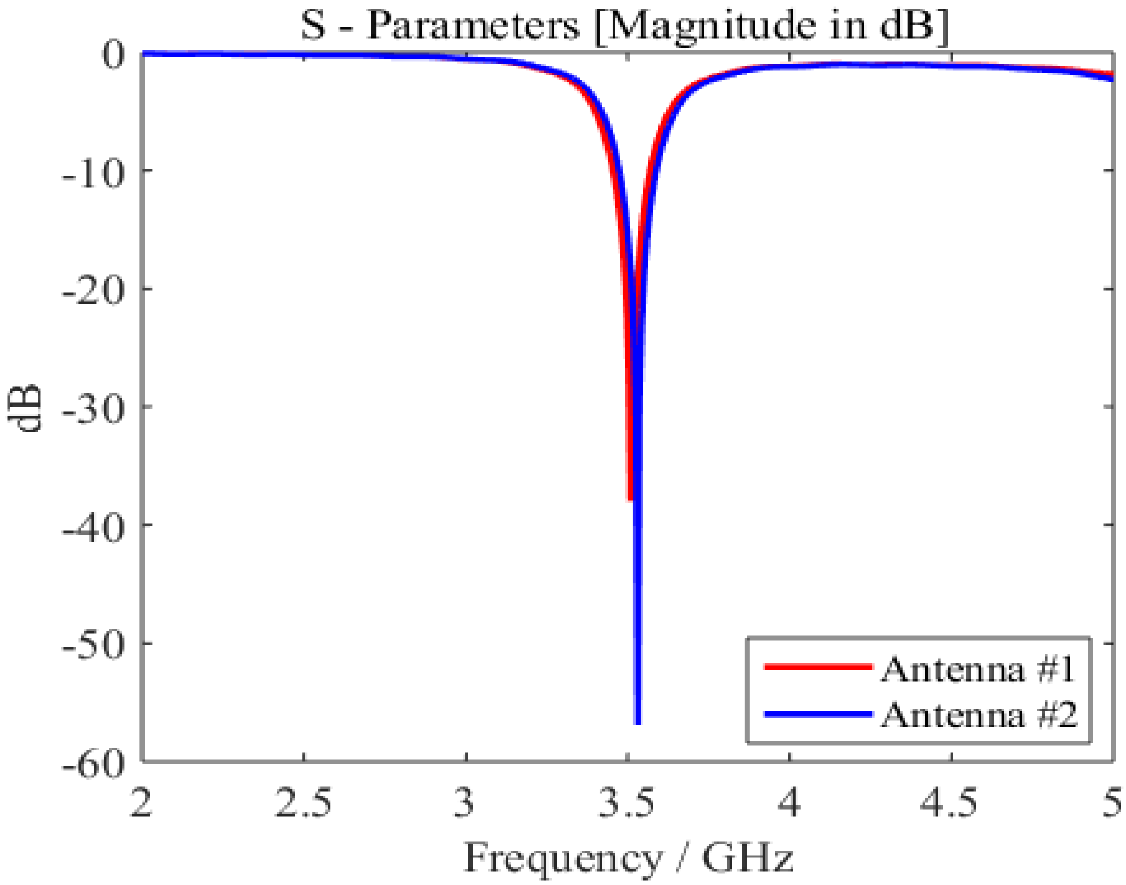
- For additional bandwidth and improved return loss levels we etch four more slots on the ground plane with the edge dimension of parameter edge_3.
- The spacing from the corners of the first slot on the ground plane is shown with the parameter dist_dgs.
- To obtain the effects we have performed a detailed parametric analysis about these parameters having all the other parameters fixed. The final optimised parameters for the Antenna #4 are given in the following table.

edge_1	edge_2	edge_3
2 mm	0.9 mm	0.6 mm
distance_x	distance_y	distance_dgs
5 mm	-2 mm	15 mm

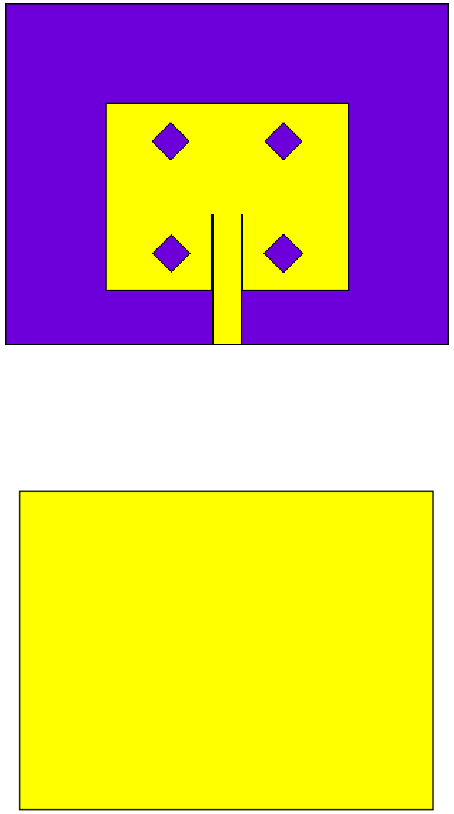
Simulation Results of Antenna#1 & Antenna#2



Antenna #1



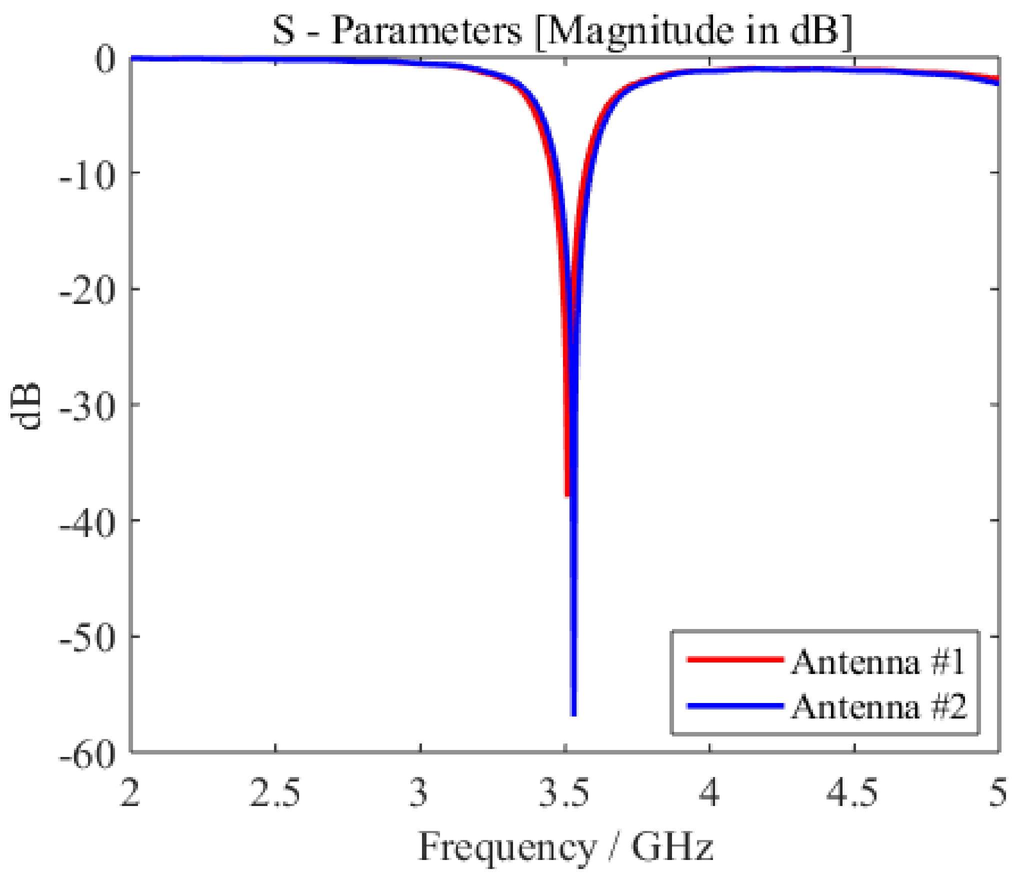
S11 vs Frequency Plot of the Antennas #1 and #2



Antenna #2

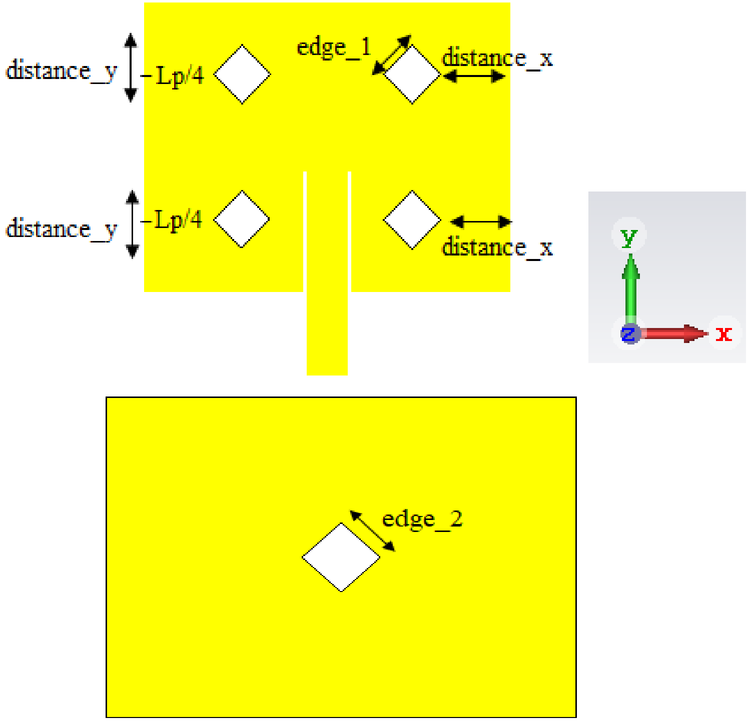
Comparison of Simulation Results of Antenna#1 & Antenna#2

- The reference antenna, Antenna #1, resonates at 3.50 GHz with a return loss level of -37.97 dB and a bandwidth of 114.8 MHz. After the slots are etched, -56.89 dB return loss level with a bandwidth of 115.1 MHz at 3.53 GHz are obtained.

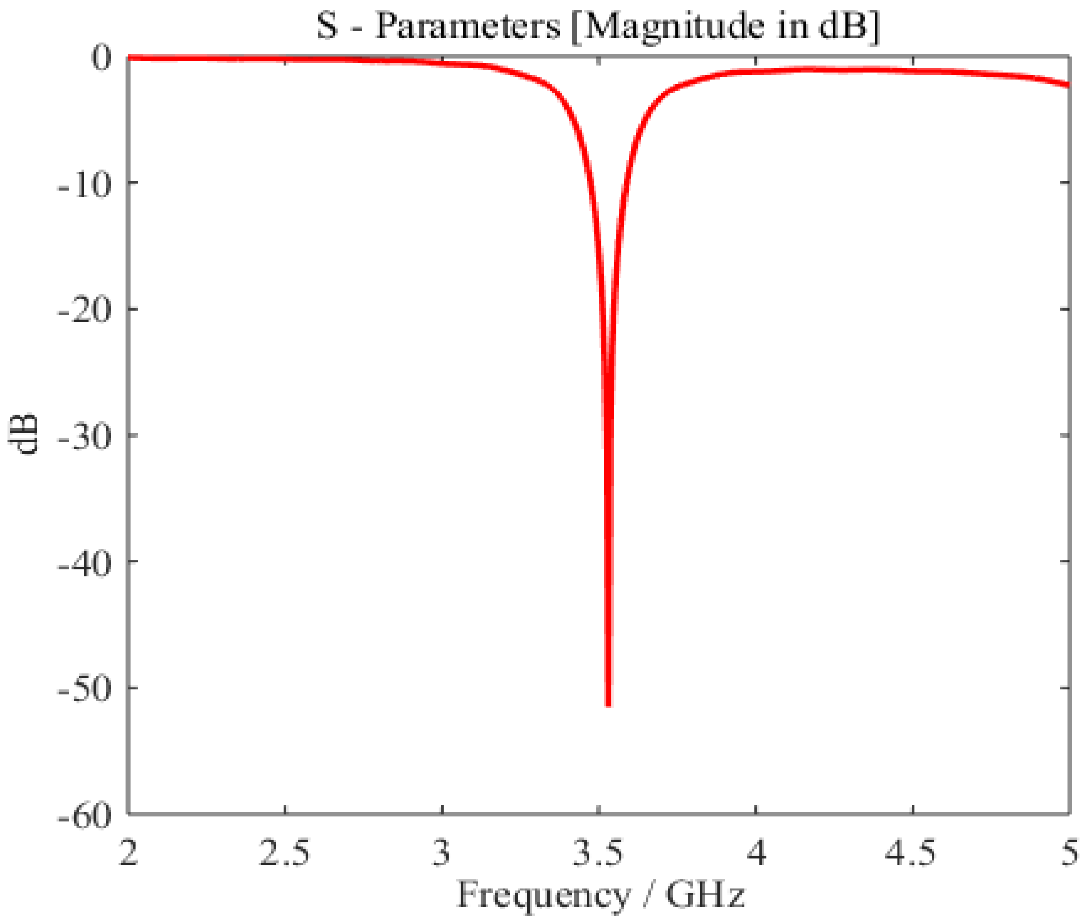


Design and Simulation Results of Antenna #3

- Antenna #3 has attained 200 Hz bandwidths increase with 115.3 MHz at the same resonant frequency of 3.53 GHz with a return loss level of -51.48 dB.

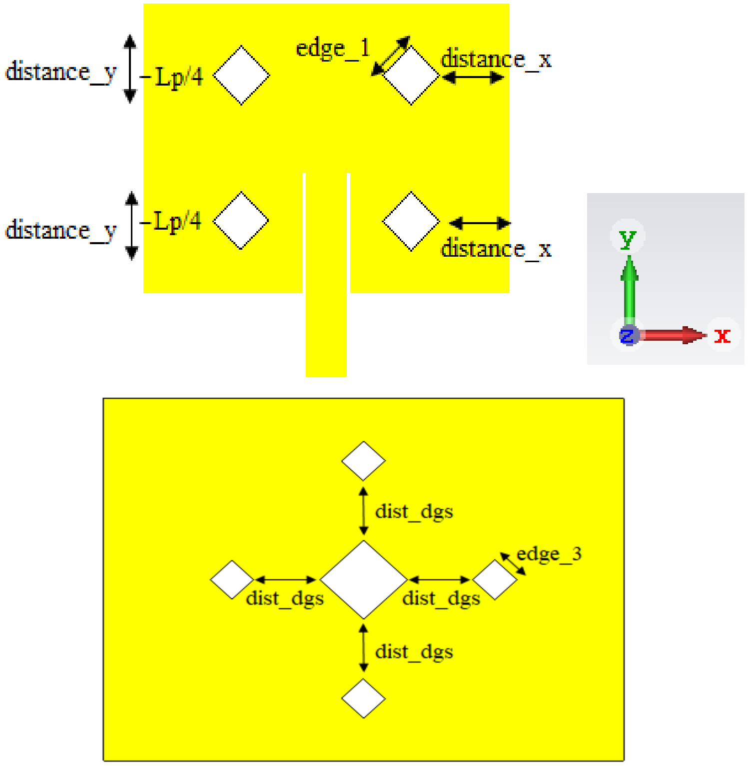


Antenna #3

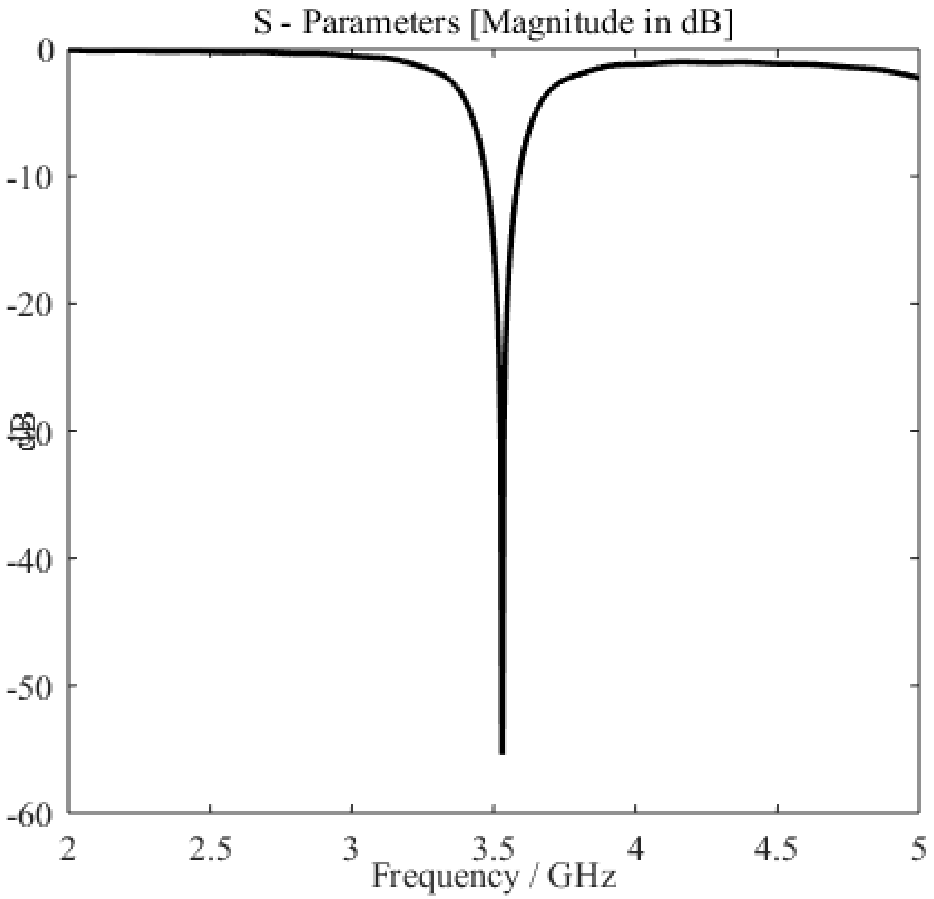


Design and Simulation Results of Antenna#4

- With this modification, we reach at -55.42 dB in return loss level and 116.4 MHz bandwidth which result in additional decrease of 3.94 dB in return loss and 1100 Hz increase in bandwidth compared to the Antenna #3.



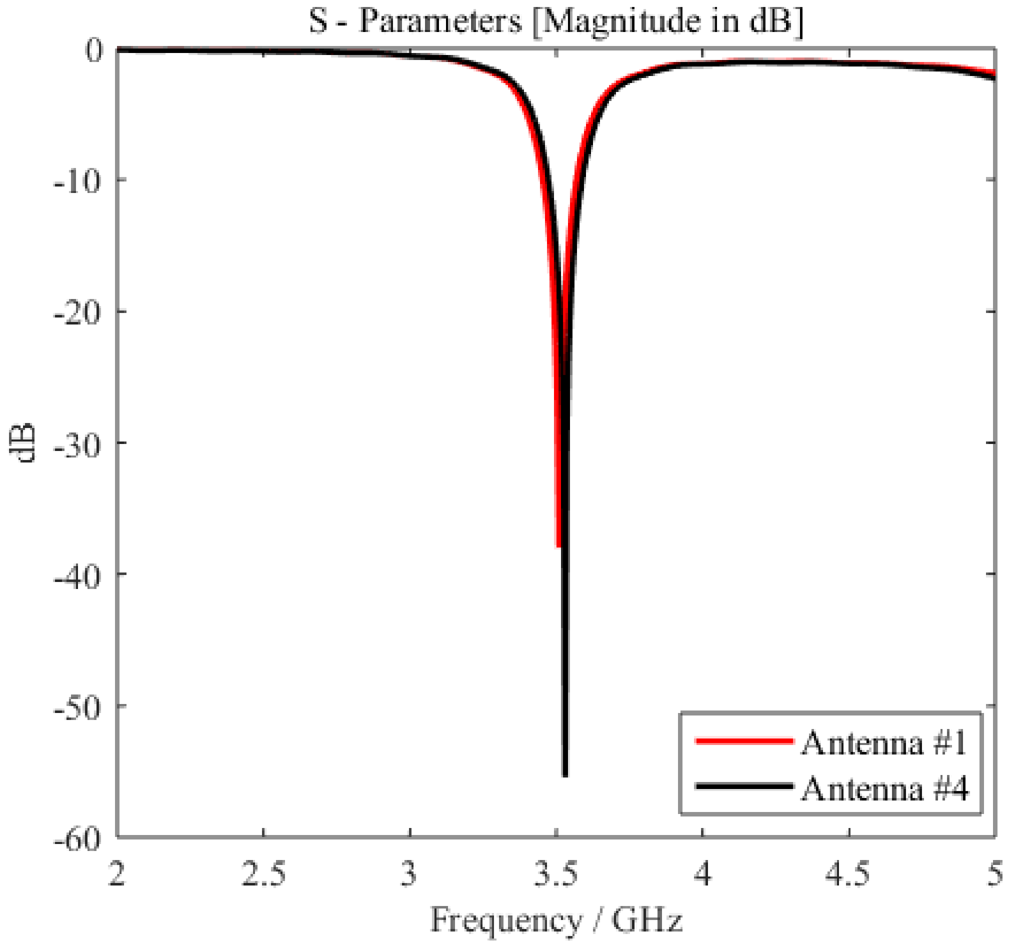
Antenna #4



bghakanoglu@ahievran.edu.tr

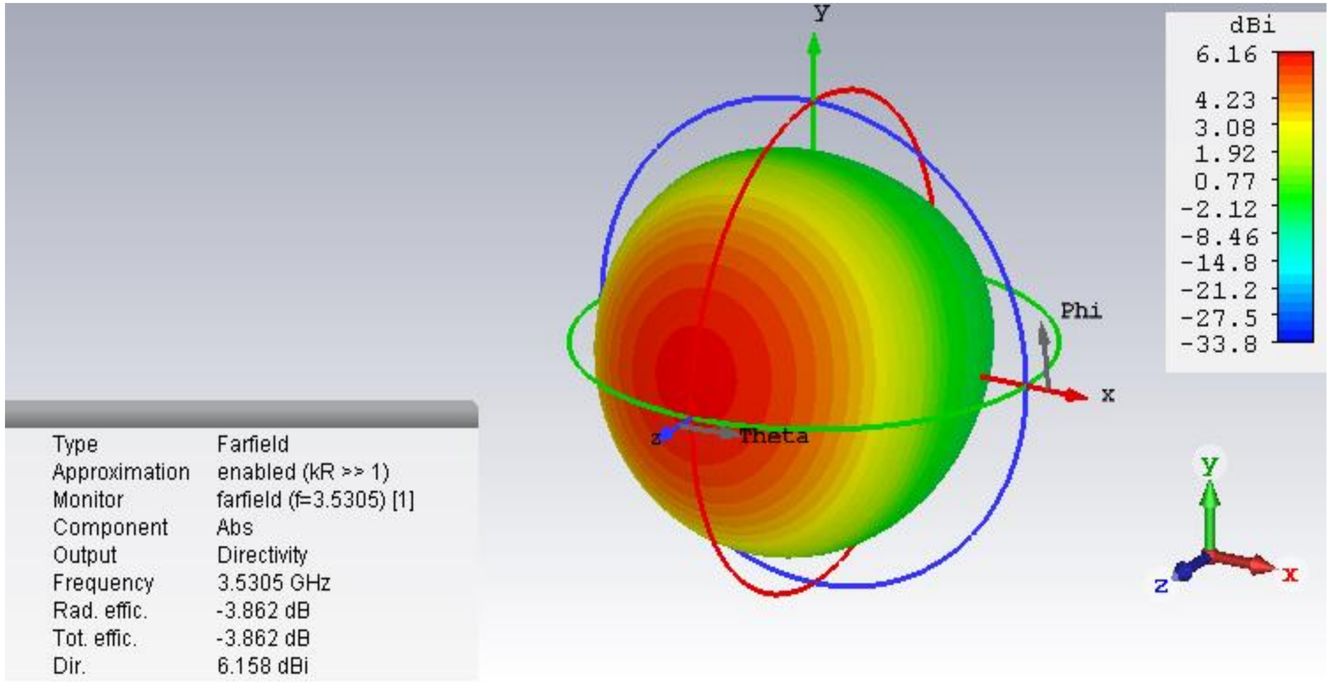
Comparison of Simulation Results of Antenna#1 & Antenna#4

- With this final structure the 10 dB bandwidth has increased by 1600 Hz from 114.8 MHz to 116.4 MHz and the return loss level has decreased by 17.45 dB from -37.97 dB to -55.42 dB.



Radiation Pattern of the Proposed Antenna

- Three dimensional radiation pattern at 3.53 GHz is shown. The antenna has a directivity of 6.16 dBi.



Conclusion

- In this study a rectangular microstrip patch antenna is designed and simulated at 3.5 GHz.
- For improved radiation characteristics, RSS and defected ground with five additional slots are proposed.
- This novel design has increased the 10 dB bandwidth by 1600 Hz from 114.8 MHz to 116.4 MHz and the return loss level has decreased by 17.45 dB from -37.97 dB to -55.42 dB.
- The final design is a promising candidate for the early phase 5G wireless applications due to having good radiation characteristics and compact design.

References

[1] Cisco, Visual Networking Index, White Paper, Available: www.cisco.com, February 2019.

[2] S. R. M. Gonzales, R. T. R. Marquez, "Microstrip Antenna Design for 3.1-4.2 GHz Frequency Band Applied to 5G Mobile Devices," *European Journal of Engineering Research and Science*, Vol. 4, No. 10, October 2019, doi: 10.24018/EJERS.

[3] J. Lee, E. Tejedor, K. Ranta-aho, H. Wang, K. T. Lee, E. Semaan, E. Mohyeldin, J. Song, C. Berglijung, S. Jung, "Spectrum for 5G:Global Status, Challenges and Enabling Technologies," *IEEE Communications Magazine,* March 2018, doi: 10.1109/MCOM.2018.1700818.

Thank you…

bghakanoglu@ahievran.edu.tr