Design of Enhanced Gain Multiband Minuaturized Antenna for Mobile Communications

G. Guru Prasad[1], Dr. G. Senthil Kumar[2]

[1]Research Scholar, Dept of ECE ,SCSVMV, Kanchipuram
[2]Associate Professor, Dept of ECE, SCSVMV, Kanchipuram

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Abstract - Antennas are the heart of modern communication systems. The response of communication system depends on Antenna. Amongst all the antennas, microstrip antennas are broadly used due to their small size and minimal cost. To function microstrip antenna in various chosen frequencies, slots were being made on patch of different shapes and positions. Including Metamaterial technology in antenna design, reduces the actual dimensions of antenna. In this paper a rectangular shaped patch antenna is designed at 2.4GHz frequency and a rectangular slot of 2.5mmx3.5mm is made on the patch, to operate the antenna at 8 different frequency bands 2.4GHz-2.6GHz, 3.4GHz-3.55GHz, 4.2GHz-4.75GHz, 5.2GHz-5.8GHz, 6.1GHz-6.8GHz, 7GHz-7.3GHz, 7.8GHz-8.2GHz, 9.1GHz-10GHz. Square shaped slots were made on the edges of the patch in three iterations and observed the Gain improvement as the increase in number of iterations. In the first iteration, four slots were made on the edges of the patch and observed the Gain increased from 1.78 dB to 1.82dB. In second iteration 12 slots were made on the edges of patch and observed the enhancement of Gain to 1.92dB. In third iteration 18 slots were made on edges of patch and observed the Gain improved to 2.04dB. In all the iterations, it was observed that electrical length of patch is gradually reduced, resulting in reduction of size of Antenna. The novelty of the antenna design in this paper is as electrical length of patch is decreased, Gain of the Antenna is increased, exhibiting same operating frequency bands at all the iterations. The proposed multiband miniaturized Antenna can be used for mobile communications covering Bluetooth, Wi-Fi, WIMAX, VOLTE and 5G bands.

Keywords- Multiband, Miniaturized, Slot, Mobile Communication

1. Introduction

Future mobile phones are habitually necessary to operate at various frequency bands to enable the application for different communication needs. Size of Smart phones are demanded to be small. In view of these emerging developments in mobile communication, innovative antenna designs are required. Various techniques have been utilized in design to fulfill multiband requirement. Hong Yun Wen et.al.,[1] proposed A Multiband Dual Polarized Omnidirectional Antenna for 2G,3G,LTE Applications. Antenna consists of 3 polygonal radiating patches with 3 equally spaced legs shorted to ground plane, triangle shaped slots are made on patch to operate antenna at 2G/3G/LTE frequency bands. Advantage is simple to design and fabricate. Drawback of this antenna is its bulky size and occupies more space. Mohamed F et.al.,[2]. Proposed Design and Implementation of Multiband Metamaterial Antennas. The antenna consists of two U shaped slots on patch. Fr4 substrate is used with metamaterial consisting of unit cells. Proposed antenna is operated at two frequencies. Position and separation between the slots can be adjusted to operate antenna at 4G/5G frequency bands. Advantage is its multiband and miniaturized. Disadvantage is it is operated at two frequencies only.

RASHID SALEEM et.al.,[3] proposed An FSS Based Multi band MIMO Incorporating 3D Antennas for WLAN, WiMAX & 5G Cellular and 5G Wi-Fi Applications. T shape and E shape slots are made on the frequency selective surface of patch. The proposed antenna is operated at multiband providing WLAN, WiMAX and 5G frequency bands. Advantages is it can be used for MIMO. Disadvantage is it has poor Isolation. Xicheng Wang et.al.,[4] proposed A Multi-Broad band Antenna for LTE, GSM& UMTS and WLAN, WiMAX and Mobile Applications. It consists of a C shaped and U shaped monopoles on one side of the dielectric substrate paired to an F-shaped strip on the other side without any lumped elements. The proposed antenna covers multiple broad frequency bands including LTE700, LTE2300/2500, GSM850, GSM900, DCS/PCS/UMTS, WLAN/WiMAX. The size of antenna is 15mm × 68mm × 0.8mm, which is a limitation for the proposed antenna But, it might be better if the size of the antenna is reduced.

Abdelheq Boukarkar et.al.,[5] proposed Miniaturized Single-Fed Multi band Antenna. The size cut of antenna is obtained by inserting shorting metalized vias on one edge of radiating patch and while multi band is achieved by etching inverted many U-shapes. The proposed antenna covers multiple broad frequency bands and size of the antenna also reduced. Proposed antenna might be better if it provides better Isolation between frequency bands. Daiwei Huang et.al.,[6] proposed A Quad band Antenna for 4G, 5G, GPS enabled Metal Frame Phones. It is a quad-antenna system, achieved under the condition of metal frame (PCB) and without using any decoupling structure. The antenna is operated at LTE700,2300,2500, GSM850,900,1800,1900, and

3.5GHz bands. Proposed antenna is operated at multiband frequencies and covering all 4G, 5G and GPS bands, providing better Isolation. The only drawback of the Antenna is its size 14x7 cm. Ridha Salhi et.al.,[7] proposed A design of multiband antenna built on active metamaterials. Split ring resonators are used in substrate to make substrate as metamaterial. Rectangular slots are made on patch to operate at multiband frequencies. Operated at 3.14-3.35, 5.67-6.3, 7.58- 9.5 GHz bands. Surendra Kumar Painam et.al.,[8] proposed Miniaturizing a patch Antenna Employing Metamaterials and Metasurfaces. Circular patch Antenna is designed, and complementary split ring resonators are embedded on substrate. The Antenna is operated at 6.22 GHz. Size of the antenna is reduced to 75%.

2. Design calculations

Design calculations of rectangular patch antenna is done using Transmission line model. The antenna is designed at 2.4GHz resonant frequency, height of substrate is considered as 1.6mm and substrate material used is FR4.

$f_r = 2.4GHz$

$h = 1.6mm$

$\varepsilon_r = 4.4$

Rectangular Patch

Width of the Patch is calculated using the below formula

$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$ = 0.038m = 38mm =0.304λ

Effective Dielectric Constant is calculated using the below formula.

$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{2h}{W}}}\right)$ = 2.7+1.7*0.96=4.33

Effective Length is calculated using the below formula.

$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$ = 0.0625/2.08 = 0.030m = 30mm=0.24λ

Length to compensate fringing fields.

$\Delta L = h \times 0.412 \times \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$ = 0.6592 * (4.63*24.014)/(4.072*24.55) = 0.733

Patch Length is calculated using the below formula.

$L = L_{eff} - (2 \times \Delta L)$ = 30-1.466=28.54mm = 0.22832λ

Ground Plane length is calculated using the below formula.

$L_g = 6h + L$ = 38.14mm =0.30512λ

Ground Plane Width is calculated using the below formula.

$W_g = 6h + W$ = 47.6mm=0.3808λ

Slot Dimensions:

Dimensions of Rectangular Slot is considered as Length x Width = 2.5mm x 3.1mm (0.02λ x 0.0248λ)

3. Design of multiband minuaturized antenna using hfss

By using the design calculations, rectangular patch antenna is designed, and a rectangular slot is made on the patch using HFSS simulation software. Designed slotted patch antenna is shown in below figure 1.

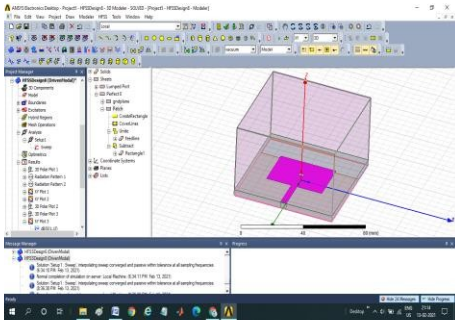

FIGURE 1: Designed slotted patch antenna

In the first iteration, four edges of the patch is slotted with slot dimensions and it is fed with strip feeding technique is shown in below figure 2.

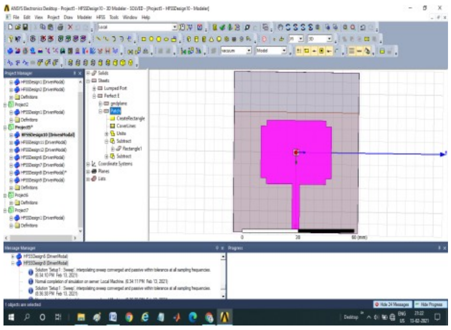

FIGURE 2: Designed antenna after first iteration

In the second iteration,12 slots were made on four edges of the patch. These slots reduce the electrical length of the patch and result in minuaturization of antenna. The designed antenna is shown in below figure 3.

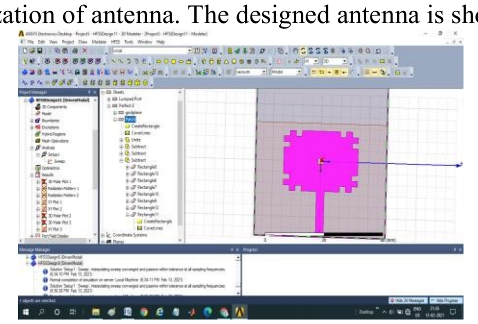

FIGURE 3: Designed antenna after second iteration

In the third iteration,18 slots were made on four edges of the patch. These slots still reduce the electrical length of the patch and result in furthur minuaturization of antenna. The designed antenna is shown in below figure 4.

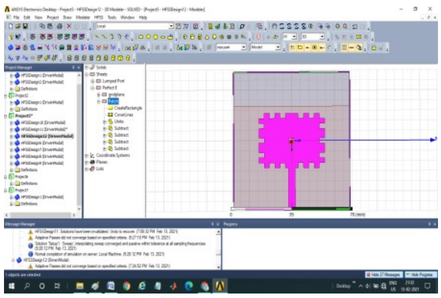

FIGURE 4: Designed antenna after third iteration

4. Simulated results and discussion

The designed Antennas are simulated from 1 to 10 GHz using HFSS V.13. Different antenna parameters like Return loss, VSWR, Radiation pattern, Gain and Directivity were measured and plotted.

(i) Simulated results for Slotted antenna:

Return loss: After simulation, Return loss of slotted antenna is illustrated in figure 5. From return loss, it was observed that antenna is operated at 8 different frequency bands 2.4GHz-2.6GHz, 3.4GHz-3.55GHz, 4.2GHz-4.8GHz, 5.2GHz-6GHz, 6.1GHz-6.4GHz, 6.9GHz-7.6GHz, 7.8GHz-8.8GHz, 9.1GHz-10GHz.

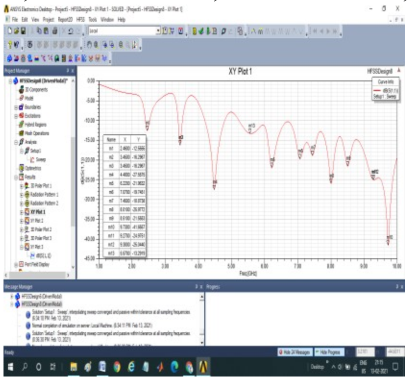

FIGURE 5: Return Loss plot for slotted antenna

VSWR: After simulation, the VSWR plot of slotted antenna is shown in figure 6. It was observed that at 2.4GHz band obtained VSWR is 1.9, at 3.4GHz band obtained VSWR is 1.3, at 4.5GHz band obtained VSWR is 1.9, at 6.2GHz band obtained VSWR is 1.1, at 7GHz band obtained VSWR is 1.2, at 8GHz band obtained VSWR is 1.1, at 8.5GHz band obtained VSWR is 1.1 and at 9.7GHz band obtained VSWR is 1.03.

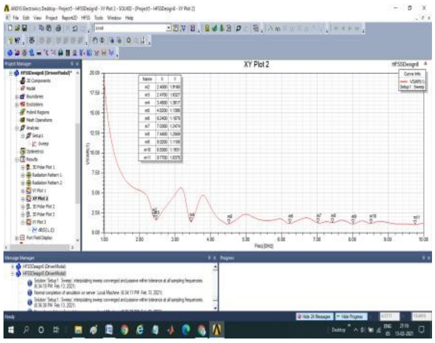

FIGURE 6: VSWR plot

Radiation Pattern: Three-dimensional and Two-dimensional radiation patterns are shown in below figure 7.

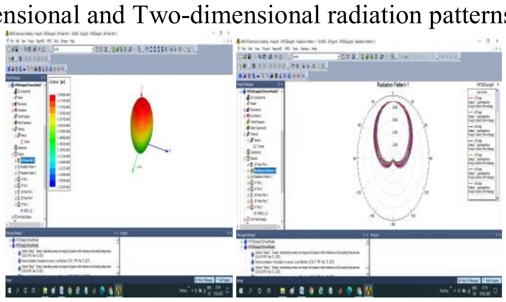

FIGURE 7: 2D, 3D radiation pattern

Gain: The simulated Gain of slotted antenna is as shown in the figure 8. From simulated plot it was observed that Gain of the slotted antenna is about 1.78dB.

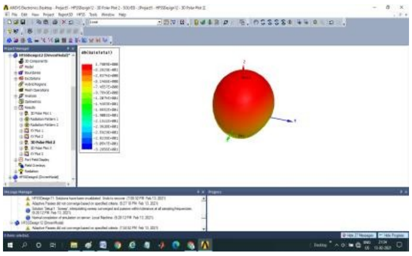

FIGURE 8: Gain of slotted antenna

Directivity: The simulated Directivity of slotted antenna is as shown in the figure 9. From simulated plot it was observed that Directivity of the slotted antenna is about 3.7dB.

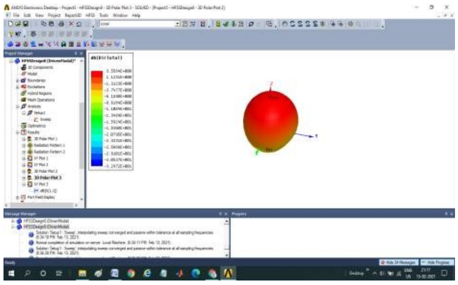

FIGURE 9: Directivity of slotted antenna

(ii) Simulated Results of antenna after first Iteration:

Return loss: After simulation, the return loss of slotted antenna after first iteration is shown in figure 10. From return loss, it was observed that antenna is operated at 8 different frequency bands 2.4GHz-2.6GHz, 3.4GHz-3.6GHz, 4.2GHz-4.8GHz, 5.3GHz-6.1GHz, 6.3GHz-6.5GHz, 6.9GHz-7.6GHz, 7.4GHz-7.8GHz, 9GHz-9.4GHz.

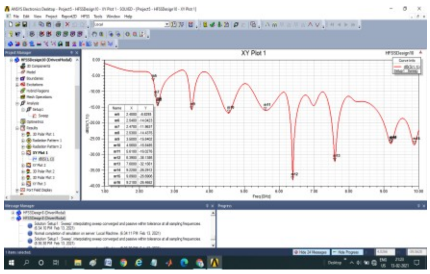

FIGURE 10: Return Loss plot of slotted antenna after first iteration

VSWR: After simulation, the VSWR plot of slotted antenna after first iteration is shown in figure 11. It was observed that at 2.5GHz band obtained VSWR is 1.4, at 3.5GHz band obtained VSWR is 1.3, at 4.5GHz band obtained VSWR is 1.3, at 5.5GHz band obtained VSWR is 1.3, at 6.5GHz band obtained VSWR is 1.2, at 7GHz band obtained VSWR is 1.4, at 8.2GHz band obtained VSWR is 1.5 and at 9.2GHz band obtained VSWR is 1.1.

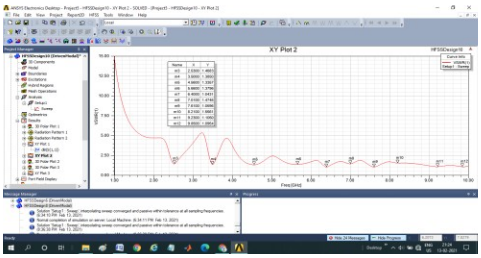

FIGURE 11: VSWR plot of slotted antenna after first iteration

Radiation Pattern: Radiation Pattern: Three-dimensional and Two-dimensional radiation patterns of slotted antenna after first iteration are shown in below figure 12.

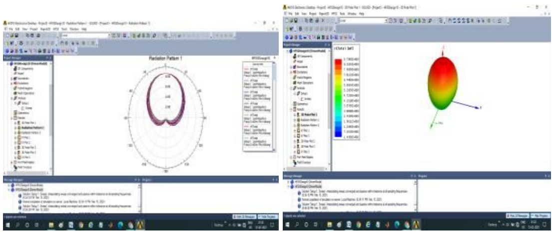

FIGURE 12: 2D, 3D radiation pattern of slotted antenna after first iteration

Gain: The simulated Gain of slotted antenna of slotted antenna after first iteration is shown in the figure 13. From simulated plot it was observed that Gain of the antenna is about 1.82dB.

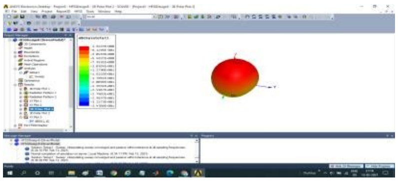

FIGURE 13: Gain of slotted antenna after first iteration

Directivity: The simulated Directivity of slotted antenna of slotted antenna after first iteration is shown in the figure 14. From simulated plot it was observed that Directivity of the antenna is about=3.9dB.

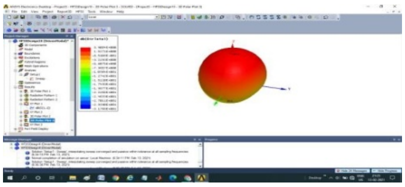

FIGURE 14: Directivity of slotted antenna after first iteration

(iii) Simulated Results of antenna after Second Iteration:

Return loss: from simulation, the return loss of slotted antenna after second iteration is exhibited in figure 15. From return loss, it was observed that antenna is operated at 8 different frequency bands 2.45GHz-2.55GHz, 3.4GHz-3.5GHz, 4.2GHz-4.7GHz, 5.2GHz-6.6GHz, 6.9GHz-7.1GHz, 7.6GHz-8.6GHz, 8GHz-8.6GHz, 9.1GHz-9.8GHz.

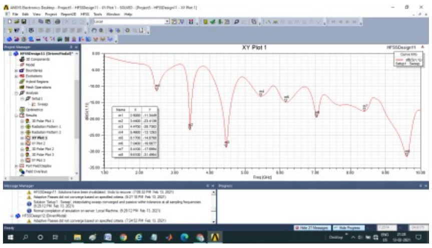

FIGURE 15: Return Loss plot of slotted antenna after second iteration

VSWR: After simulation, the VSWR plot of slotted antenna after second iteration is shown in figure 16. It was observed that at 2.4GHz band obtained VSWR is 1.7, at 3.4GHz band obtained VSWR is 1.1, at 4.4GHz band obtained VSWR is 1.09, at 5.3GHz band obtained VSWR is 1.5, at 6GHz band obtained VSWR is 1.5, at 7GHz band obtained VSWR is 1.2, at 8.4GHz band obtained VSWR is 1.3 and at 9.2GHz band obtained VSWR is 1.2.

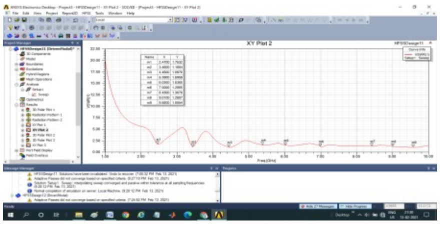

FIGURE 16: VSWR plot of slotted antenna after second iteration

Radiation Pattern: Three-dimensional and Two-dimensional radiation patterns of slotted antenna after second iteration are shown in below figure 17.

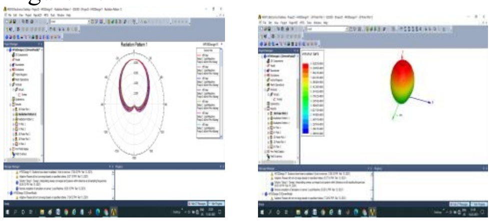

FIGURE 17: 2D, 3D radiation pattern of slotted antenna after second iteration

Gain: Simulated Gain of the slotted antenna is as shown in the figure 18. From simulated plot, it was observed that Gain of the slotted antenna after second iteration is about 1.92dB.

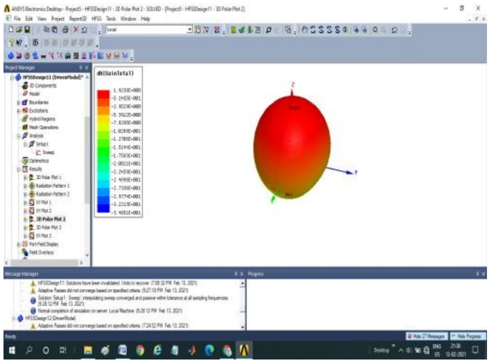

FIGURE 18: Gain of slotted antenna after second iteration

Directivity: The simulated Directivity of slotted antenna after second iteration is as shown in the figure 19. From simulated plot, it was observed that Directivity of the antenna is about=3.6dB.

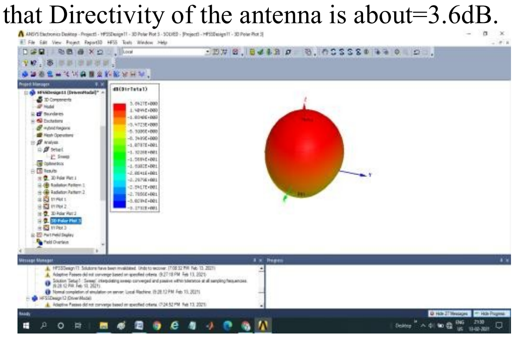

FIGURE 19: Directivity of slotted antenna after second iteration

(iv) Simulated Results of antenna after Third Iteration:

Return loss: After simulation, the return loss of slotted antenna after third iteration is shown in figure 20. From return loss, it was observed that antenna is operated at 8 different frequency bands 2.4GHz-2.6GHz, 3.4GHz-3.6GHz, 4.2GHz-4.8GHz, 5.2GHz-6.1GHz, 6.3GHz-6.9GHz, 7.2GHz-7.8GHz, 6.9GHz-7.6GHz, 9GHz-9.4GHz.

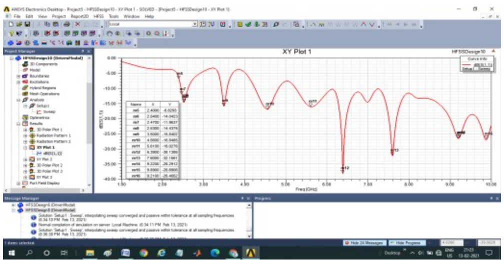

FIGURE 20: Return Loss plot for slotted antenna after third iteration

VSWR: After simulation, the VSWR plot of slotted antenna after third iteration is shown in figure 21. It was observed that at 2.5GHz band obtained VSWR is 1.4, at 3.5GHz band obtained VSWR is 1.3, at 4.5GHz band obtained VSWR is 1.3, at 5.5GHz band obtained VSWR is 1.3, at 6.4GHz band obtained VSWR is 1.03, at

7GHz band obtained VSWR is 1.4, at 8.2GHz band obtained VSWR is 1.5 and at 9.2GHz band obtained VSWR is 1.1.

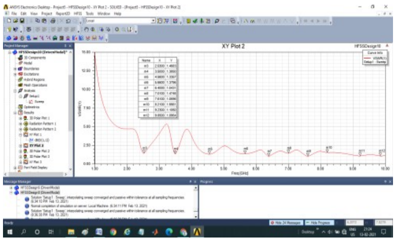

FIGURE 21: VSWR plot of slotted antenna after third iteration

Radiation Pattern: Three-dimensional and Two-dimensional radiation patterns of slotted antenna after third iteration are shown in below figure 22.

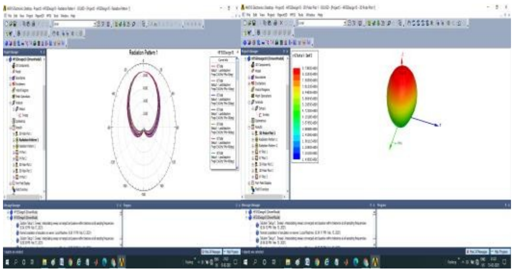

FIGURE 22: 2D, 3D radiation pattern of slotted antenna after third iteration

Gain: The simulated Gain of slotted antenna after third iteration is as shown in the figure 23. From simulated plot it was observed that Gain of the antenna is about 2.04dB.

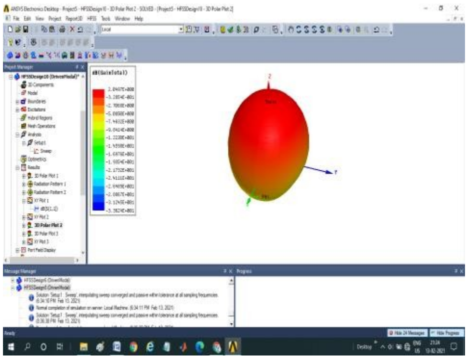

FIGURE 23: Gain of slotted antenna after third iteration

Directivity: The simulated Directivity of slotted antenna after third iteration is as shown in the figure 24. From simulated plot it was observed that Directivity of the antenna is about=3.9dB.

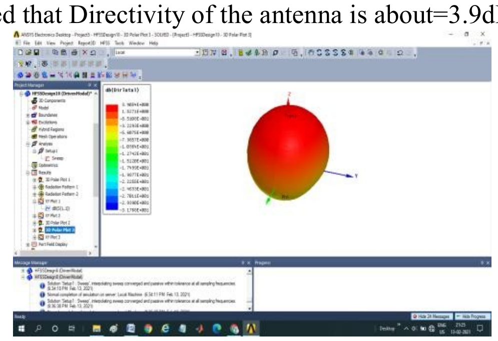

FIGURE 24: Directivity of slotted antenna after third iteration

(v) Comparison of Simulated Results:

Antenna Type	**No. of Slots present on Antenna**	**Operating Frequency Bands**	**VSWR at Operating Frequency**	**Gain**	**Directivity**
Slotted Antenna	1	2.4GHz-2.6GHz, 3.4GHz-3.55GHz, 4.2GHz-4.8GHz, 5.2GHz-6GHz, 6.1GHz-6.4GHz, 6.9GHz-7.6GHz, 7.8GHz-8.8GHz, 9.1GHz-10GHz.	2.4GHz - 1.9, 3.4GHz - 1.3, 4.5GHz - 1.9, 6.2GHz - 1.1, 7GHz - 1.2, 8GHz - 1.1, 8.5GHz - 1.1, 9.7GHz 1.03	1.78dBi	3.6dBi
Slotted Antenna after First Iteration	9	2.4GHz-2.6GHz, 3.4GHz-3.6GHz, 4.2GHz-4.8GHz, 5.3GHz-6.1GHz, 6.3GHz-6.5GHz, 6.9GHz-7.6GHz, 7.4GHz-7.8GHz, 9GHz-9.4GHz.	2.5GHz - 1.4, 3.5GHz - 1.3, 4.5GHz - 1.3, 5.5GHz 1.3, 6.5GHz 1.2, 7GHz - 1.4, 8.2GHz - 1.5, 9.2GHz - 1.1.	1.82dBi	3.7dBi
Slotted Antenna after Second Iteration	13	2.45GHz-2.55GHz, GHz- GHz, 4.2GHz-4.7GHz, 5.2GHz-6.6GHz, 6.9GHz-7.1GHz, 7.6GHz-8.6GHz, 8GHz-8.6GHz, 9.1GHz-9.8GHz.	2.4GHz - 1.7, 3.4GHz -1.1, 4.4GHz - 1.09, 5.3GHz - 1.5, 6GHz - 1.5, 7GHz - 1.2, 8.4GHz - 1.3, 9.2GHz - 1.2.	1.92dBi	3.9dBi

Slotted Antenna after Third Iteration	19	2.4GHz-2.6GHz, 3.4GHz-3.6GHz, 4.2GHz-4.8GHz, 5.2GHz-6.1GHz, 6.3GHz-6.9GHz, 7.2GHz-7.8GHz, 6.9GHz-7.6GHz, 9GHz-9.4GHz.	2.5GHz - 1.4, 3.5GHz - 1.3, 4.5GHz - 1.3, 5.5GHz - 1.3, 6.4GHz - 1.03, 7GHz - 1.4, 8.2GHz - 1.5, 9.2GHz - 1.1.	2.04dBi	3.9dBi

5. Conclusion and future scope

Conclusion

Multiband Miniaturized antenna has been designed and simulated using HFSS software and various parameters like return loss, gain, directivity, radiation pattern is measured for four different designs of antenna i.e., Slotted antenna, slotted antenna after first iteration, slotted antenna after second iteration, slotted antenna after third iteration. Square shaped slots were made on the edges of the patch in three iterations and observed the Gain improvement as the increase in number of iterations. The projected antenna has achieved great impedance matching, stable radiation pattern and assured return loss. The simulated results show that the obtained frequency bands are 2.4GHz-2.6GHz, 3.4GHz-3.55GHz, 4.2GHz-4.75GHz, 5.2GHz-5.8GHz, 6.1GHz-6.8GHz, 7GHz-7.3GHz, 7.8GHz-8.2GHz, 9.1GHz-10GHz respectively, good enough for Bluetooth, Wi-Fi, WIMAX, VOLTE and 5G bands. In supplement, the proposed antenna has very good radiation characteristics and gains in the eight operating bands, hence it can emerge as an excellent candidate for multiband generation for mobile communication.

6. Future Scope

Using different shaped slots may increase the parameters like return loss, gain, radiation pattern and directivity. In current work, Microstrip Patch antenna is designed using FR4 substrate. Gain of the antenna can be further than increased by designing slot antenna array. In future work, different materials with different dielectric constants can be used for different applications.

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