Novel Design of Highly Directive Mictrostrip Patch Antenna with Air Substrate

Skanda H
Department of Electronics and Communication
B.M.S College Of Engineering
Bangalore, India.
skandah151@gmail.com

Abstract: **This paper presents a novel design and analysis of inset fed microstrip patch antenna with an air substrate operating at 2.4 Ghz. The proposed antenna has a high directivity and high radiation efficiency which are 2 important parameters in antennas for communications, radars, wireless power transmission and other applications. The S parameters, VSWR, Directivity, gain, beamwidth, radiation efficiency, electric field intensity and size of the design are presented. Ansys HFSS was used for the study. Small amounts of FR4 material was also used.**

Index Terms: Microstrip Patch antennas, Wireless communication, Radars, Air substrates.

I. INTRODUCTION:

Antennas in general are an integral part of our lives. They are crucial parts of all communication systems, radars, biomedical applications, etc.. Among the broad array of antennas, microstrip antennas have gained immense popularity as they can be easily manufactured and can be easily integrated with modern electronic systems. But their low directivity and gain act as a limiting factor. [1] has a study on gain enhancement methods. [2] presents cylindrical electromagnetic bandgap (EBG) substrate to enhance the performance of the patch antennas. [3 - 4] present various techniques for gain enhancement of microstrip antennas. [5] presents the design of a 2x2 microstrip patch array with air substrates at 28Ghz. [11] has a detailed analysis of coaxial fed patch antennas with air substrates. [12-17] have presented various high gain antenna designs, whose characteristics have been compared with this work in the later sections. Air substrates for microstrip antennas have always been an ideal choice. This paper presents a novel, simple and ideal solution for gain enhancement of a microstrip patch antenna resonating at 2.4Ghz and using air as substrate.

II. ANTENNA DESIGN:

Microstrip patch antennas are basically two conducting plates designed in some fashion and separated by a dielectric material. These dielectric are usually materials like FR-4, RT Duroid, etc. Since the radiation in a patch antenna primarily happens due to the fringing effect, the dielectric constant, loss tangent and other material properties of the dielectric is a crucial parameter which dictates most of the antenna parameters. The fringing effect is shown in Fig. 1. [6].

Fig 1: Electric field lines

As presented in [7], the directivity of an antenna increases with decrease in dielectric constant. This can be explained by solving Maxwell's equations at the boundaries of different substrates. On an approximated view, using lenz law;

$$\eta = \sqrt{\varepsilon_r \, \mu_r} \tag{1}$$

We can say that decrease in permittivity decreases refractive index. This increases the angle of refraction at the air - substrate boundary, therefore increasing the horizontal component of the electric field. It is known that in microstrip patch antennas, the horizontal component is what causes radiation.

The dielectric constant and loss tangent of air at STP is nearly 1 and 0 respectively, which is an ideal set of substrate properties for the patch antenna unless of course metamaterials are used whose dielectric constant can be less than 1 or even negative.

Antenna designing involves a crucial management of various parameters like length of the patch, width of the patch, height of the substrate, dielectric constant of the substrate(as previously discussed), etc. In the presented design Inset feed is used to feed the patch. 1mm thick copper plates are used for the patch, since they have greater stability. Small pieces of FR-4 Dielectric are used as it is cheap and easily available. For any other dielectric, only the thickness of the part of the feed line lying over the substrate(refer Fig.) will change but the same design methods depicted below can be followed. The design equations [8 - 9]used are depicted below. The formulas mentioned are just approximations. There is a requirement of tuning, once the design is complete.

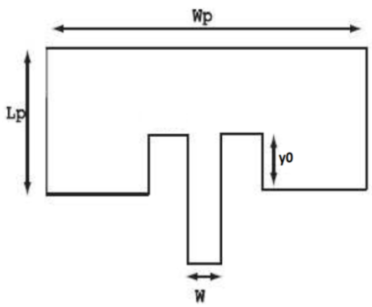

Fig 2: Microstrip patch [7]

A. Effective permittivity:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_p}\right]^{-1/2} \quad \text{for } W_p / h > 1 \tag{2}$$

B. Width(Wp):

$$W_p = \frac{v_o}{2 f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{3}$$

C. Length(Lp):

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

$$L_p = \frac{v_o}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

D. Inset Feed Depth(y0):

$$y_0 = 10^{-4}\{0.016922\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + 2.561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697\}\frac{L}{2} \tag{5}$$

E. Inset Feed Width:

$$\frac{W}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2} & \text{for } W/h < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right] & \text{for } W/h > 2 \end{cases}$$

$$\text{where} \quad A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{6}$$

In (6), Z_0 is the characteristic impedance. In (2), (3), (4), (5) and (6) ε_r is the relative permittivity of the used substrate.

The width of the inset feed is taken such that it accounts to 50 ohm on the substrate and frequency chosen. The impedance of a microstrip line was calculated using online calculator (Microstrip Line Calculator | em: talk, 2022)[10].

The initial part of the inset feed mictrostrip line is designed to be 50ohm at 2.4 Ghz for an FR-4 Substrate. Since the dielectric constant of FR-4 (4.4) is much larger than the dielectric constant of air, that part of the microstrip line is much smaller than the rest of the inset feed line which is designed for an impedance of 50 ohm at 2.4 Ghz for air. FR-4 is used for supporting the antenna structure.

The designed patch antenna is depicted in Fig. 2 ; The electric field distribution at the center is very minimal as can be seen in Fig. 5. From simple ohm's law, the impedance at the center of the patch is zero as the voltage at that portion is zero. Thus, small strips of FR-4 substrates are added at the center as shown in Fig 4. This addition of FR-4 substrates at the center has very minimal to no effect on characteristics of the antenna. These FR-4 materials with standard 1.6mm thickness are placed on a copper ground plane. Then the 1mm thick copper plate cut in the shape of the antenna using some standard machinery can just be placed over these dielectric supports.

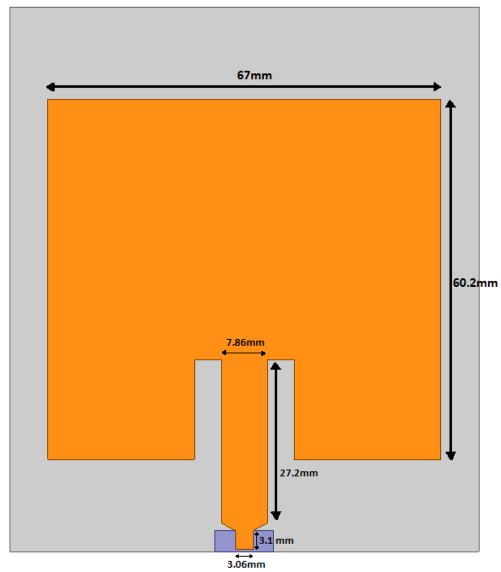

Fig 3: Designed Microstrip patch

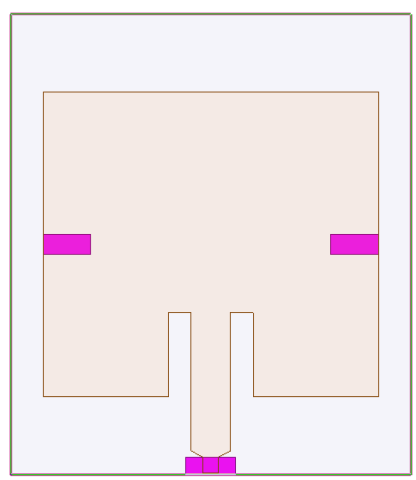

Fig 4: Dielectric support structures

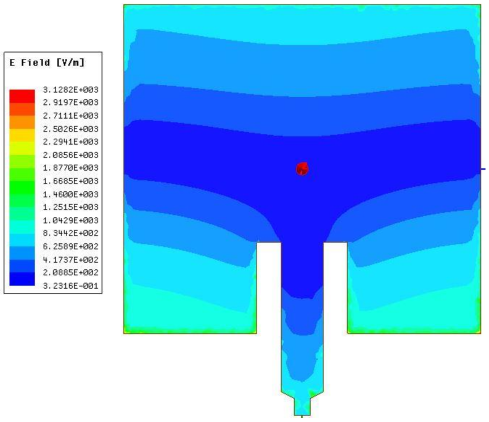

Fig 5: Electric field distribution of the designed antenna

III. RESULTS

The antennas designed above were analyzed using a FEM based EM simulator, Ansys HFSS. All the measured parameters are depicted below.

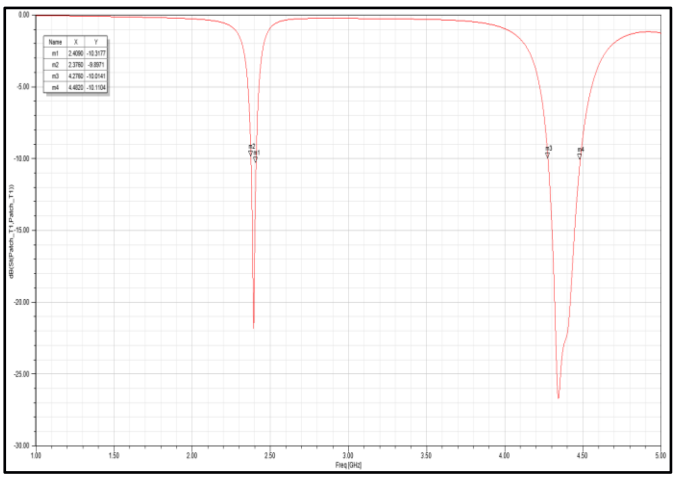

Fig 6: S11 of the designed antenna

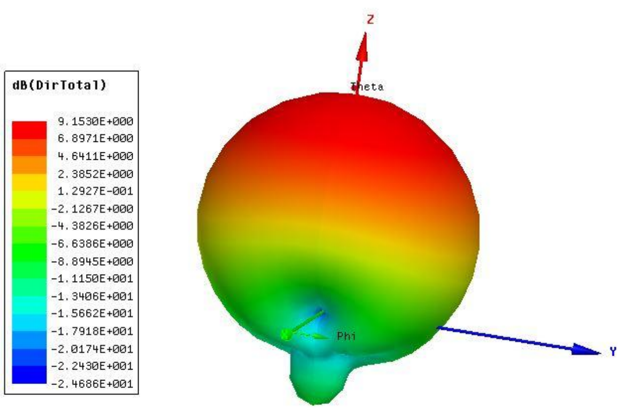

Fig 7: Directivity of the designed antenna

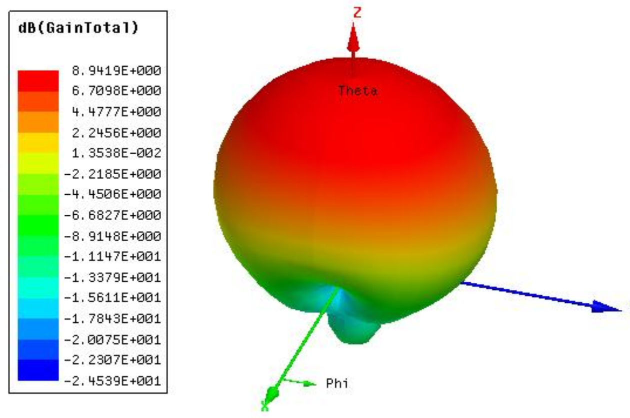

Fig 8: Gain of the designed antenna

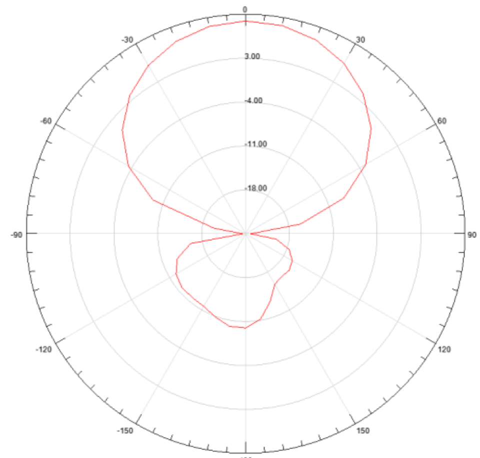

Fig 9: 2D Radiation pattern of the antenna

The antenna is delivering a S11 of around -20dB at 2.4Ghz with another wide band in the 4.2 to 4.4 Ghz range. A high Directivity of 9.15dB is obtained. The gain is at 8.94dB. The gain has been reduced due to dip in the radiation efficiency which is because of the use of 1mm thick Cu plates for patch. The radiation efficiency is 96.73% which is also significantly higher compared with other substrate antennas. The Half power beam width is around 62 degrees.

TABLE I. COMPARISON OF PROPOSED ANTENNA CHARACTERISTICS WITH OTHER PUBLISHED ANTENNAS.

Ref.	Freq.	Gain	Rad. Effic.	Substrate, Complexity
[12]	2.4Ghz	7.7dB	95%	RT/duroid 5880, Low to medium
[13]	2.4Ghz	8.27dB	69%	FR4 with meta structure, High
[14]	5.8Ghz	8.4dB	96.4%	Air substrate, Medium

[15]	10Ghz, 28Ghz	6.8dB, 9.29dB	-	RT/duroid 5880, Low
[16]	1.26Ghz	9.05dB	94.6%	FR4-Air substrate, Medium
[17]	3.52Ghz	6.68dB	25.33%	Air substrate, -
This work	**2.4Ghz**	**8.94dB**	**96.73%**	**Air substrate, Low**

In the above table, complexity is decided based on the amount of work required to design those systems, i.e complexity involved in the design and the complexity involved in manufacturing the microstrip structures.

IV. CONCLUSION

A simple narrow multi band antenna with high directivity and gain made with an air substrate is presented. These antennas can be used in wireless communication, sub-6 Ghz radars, wireless power, satellite communications or other applications where high gain is necessary. It can be easily fabricated using 3D printing or separately integrating the patch with the ground plane. These can further be used to make antenna arrays with air substrates, which can be used for radar and communication applications. The only disadvantage of the antenna presented in this paper is its relatively large form factor. Our future work includes using metamaterials to reduce the form factor and further increase the gain of the antenna.

REFERENCES

[1] Xiao-Hai Shen, G. A. E. Vandenbosch and A. Van de Capelle, "Study of gain enhancement method for microstrip antennas using moment method," in IEEE Transactions on Antennas and Propagation, vol. 43, no. 3, pp. 227-231, March 1995, doi: 0.1109/8.371990.

[2] H. Boutayeb and T. A. Denidni, "Gain Enhancement of a Microstrip Patch Antenna Using a Cylindrical Electromagnetic Crystal Substrate," in IEEE Transactions on Antennas and Propagation, vol. 55, no. 11, pp. 3140-3145, Nov. 2007, doi: 10.1109/TAP.2007.908818.

[3] Kumar, Arun & Khandelwal, Raghav & Singh, Samarth & Kumar, Ambuj & Makhdumi, Arsh. (2021). A review on gain enhancement techniques of microstrip antenna. 476-479. 10.1109/ICIEM51511.2021.9445306.

[4] S. Akinola, I. Hashimu and G. Singh, "Gain and Bandwidth Enhancement Techniques of Microstrip Antenna: A Technical Review," 2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE), 2019, pp. 175-180, doi: 10.1109/ICCIKE47802.2019.9004278.

[5] A. SB Mohammed, S. Kamal, M F. Bin Ain, F. Najmi, Z A. Ahmad, Z. Zahar, R. Hussin, I A. Zubir and MF. Ab Rahman, “Improving the Gain Performance of Air Substrate Patch Antenna Array Using the Effect of Conductive Material Thickness Study for 5G Applications” in 2020 J. Phys.: Conf. Ser. 1529 052020, doi:10.1088/1742-6596/1529/5/052020

[6] Elrashidi, Ali & Elleithy, Khaled & Bajwa, Hassan. (2011). The fringing and resonance frequency of cylindrical microstrip printed antenna as a function of curvature. EURASIP Journal on Wireless Communications and Networking. 3.

[7] Tilanthe, Dr. Pramendra & Sharma, P.C.. (2009). An equilateral triangular patch antenna with T - Shaped notch for enhanced gain. Proceedings of the 4th International Conference on Wireless Communication and Sensor Networks, WCSN 2008. 179 - 180. 10.1109/WCSN.2008.4772706.

[8] U. Venkateshkumar, S. Kiruthiga, H. Mihitha, K. Maheswari and M. Nithiyasri, "Multiband Patch Antenna Design for 5G Applications," 2020 Fourth International Conference on Computing Methodologies and Communication (ICCMC), 2020, pp. 528-534, doi: 10.1109/ICCMC48092.2020.ICCMC-00098.

[9] Matin, Mohammad & Sayeed, A. (2010). A design rule for inset-fed rectangular microstrip patch antenna. WSEAS TRANSACTIONS on COMMUNICATIONS. 9.

[10] Emtalk.com. 2022. *Microstrip Line Calculator | em: talk*. [online] Available at: <https://www.emtalk.com/mscalc.php> [Accessed 8 February 2022].

[11] A. F. A. Ayoub (2003) ANALYSIS OF RECTANGULAR MICROSTRIP ANTENNAS WITH AIR SUBSTRATES , Journal of Electromagnetic Waves and Applications,17:12, 1755-1766, DOI: 10.1163/156939303322760335

[12] El Alami, Ali & Bennani, Saad & Bekkali, Moulhime & Benbassou, Ali. (2013). Optimization and High Gain of a Microstrip Patch Antenna Excited by Coaxial Probe for RFID reader Applications at 2.4 GHz. European Journal of Scientific Research. 104. 377-391.

[13] Tian, H. ., Wang, J. ., Han, D. ., & Wang, X. . (2022). A Gain-enhanced Dual-band Microstrip Antenna using Metasurface as Superstrate Configuration. The Applied Computational Electromagnetics Society Journal (ACES), 36(12), 1586–1593.

[14] J. Ou, A. S. Andrenko, C. Fu, Z. Xie and H. Tan, "High-gain microstrip antenna for microwave power transmission," 2016 International Symposium on Antennas and Propagation (ISAP), 2016, pp. 740-741.

[15] Abdalaziz, Ahmed & Hamad, Ehab. (2019). Design of a Compact High Gain Microstrip Patch Antenna for Tri-Band 5 G Wireless Communication. Frequenz -Berlin-. 73. 45-52. 10.1515/freq-2018-0058.

[16] K. Ozenc, M. E. Aydemir and A. Öncü, "Design of a 1.26 GHz high gain microstrip patch antenna using double layer with air gap for satellite reconnaissance," 2013 6th International Conference on Recent Advances in Space Technologies (RAST), 2013, pp. 499-504, doi: 10.1109/RAST.2013.6581259.

[17] Gupta, M. , Sachdeva, S. , Swamy, N. and Singh, I. (2014) Rectangular Microstrip Patch Antenna Using Air as Substrate for S-Band Communication. *Journal of Electromagnetic Analysis and Applications*, **6**, 38-41. doi: 10.4236/jemaa.2014.63006.