Design, Analysis and Gain Enhancement of a Series-Feed Microstrip Patch Antenna Array for Wireless Applications

M. Sathish*, V. Vignesh, S. Sivasubramanian and G. Vijaya Sripada
Department of Electronics and Communication Engineering, Rajalakshmi Engineering College, Thandalam, Chennai, India.
***Corresponding author: E-Mail: sathish.m@rajalakshmi.edu.in**

ABSTRACT

This paper presents the parametrical analysis of lone patch microstrip radiator radiating at a resonant frequency of 2.4GHz and analysis of patch array with the series-feed configuration. The proposed radiator has been constructed using flame retardant glass epoxy FR_4 substrate having a value of 4.4 as dielectric constant (ε_r) and loss tangent ($\tan\delta$) of 0.02, while the thickness of the substrate (h) being kept at 1.6mm. The gain, field pattern and RL (return loss) are obtained through the simulated results, which have been analyzed and compared with fabricated radiator using network analyzer. It has observed that the array axis along the radiating slot with series-feed has increased gain in comparison with the single patch antenna.

KEY WORDS: Dielectric Constant, Loss Tangent, Microstrip, Patch, Radiating Slots, Substrate, Series feed and Corporate feed.

1. INTRODUCTION

The commercial demand for the microstrip patch radiator has been enormously increasing for over the preceding few eras. This is due to the utilization of the microstrip patch radiators in almost all the compact hand held devices, it's very low cost and the easiness to fabricate on a planar printed circuit boards (PCB's). These radiators can be constructed to operate at multiple frequencies especially in the band of radio frequencies. The internationally reserved band according to the Federal Communications Commission (FCC) is 2.4GHz for wireless applications in the IEEE 802.11 standards. The substrate (dielectric material), patch and ground are the most vital aspects of designing the microstrip patch radiator. The dielectric medium is sandwiched between the patch (on the top) and the ground (etched under the bottom of the substrate). In our antenna model the FR_4 epoxy glass substrate that has been made into use. The patch act as main radiating element that uses series-feed method. Here, we have made use of the inset feed, to match an impedance of 50Ohms. The shape of the patch chosen for the design is the rectangular patch with dimension LxW, where 'L' is the length of the patch and 'W' is the width of the patch. Like patch, the ground surface is also a conducting one. The most important analysis parameters are gain, field pattern and return loss of the radiator. A parametrical analysis is performed on the patch radiator to enhance the gain and RL (return loss) of our antenna model. In addition an array of two numbers of optimized single patch radiator are kept close to one another. These array elements can be fed either through a common feed or through the individual feeds, the former being called as the series-feed network (array axis along the radiating slot) and the latter being called as the corporate-feed network (array axis along the non-radiating slot). The main purpose of the radiator array is, its ability to increase the gain while making it highly efficient. The various radiating parameters are generally difficult to enhance using single radiating element and hence an attempt is made by cascading two elements in a series manner. It is noteworthy that length of the feed element should be maintained at an optimum value since any slight variations made will affect the results. Therefore in this design, it is key to take account of these parameters and various other effects like coupling and reflections that occur internally.

Design of series-feed antenna arrays: The proposed radiator is designed for two array elements in a series-fed manner. The dimensions of the radiator are computed for a resonant frequency of 2.4GHz. Let the space between the patches be 'd'. The Fig. 1 shows the rectangular microstrip patch antenna and the Fig. 2 shows the design of the series-feed antenna array.

Geometrical Specifications of a single patch radiator: Let W is the width of the patch, L is the length, ε_{reff} is the effective dielectric constant and Δ_l is the incremental length.

It is given as follows.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_{reff}+1}} \quad (1)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \quad (2)$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta_l \quad (3)$$

$$\frac{\Delta_l}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

On the basis of the above stated formula, the various antenna parameters are tabulated as shown in the Table.1.

Table.1. Specifications of the single patch antenna

Symbol	Quantity	Values (in mm)
W	Width	38.02
L	Length	29.46
h	Thickness of the Substrate	1.6
g	Gap between feed line and patch	0.3
Lf	Length of the feed	20.93
y	Inset Depth	10.32
Wf	Width of the feed	2.57
a,b	Effective Length and Width	5

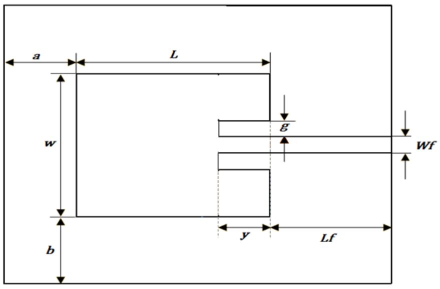

Figure.1. Rectangular microstrip patch antenna

The thickness 'Wf' of the feed is considered to be 2.57mm and the inset depth 'y' as 10.32mm to match the input impedance. The gap 'g' between inset feed line and the patch is optimized to 0.3mm for achieving the better results.

Geometrical Specifications of radiator array using series-feed: The Fig.2, shows the proposed radiator array using the series-feed configuration. Let 'd' be the distance between the two radiators parallel along the axis of the feed line.

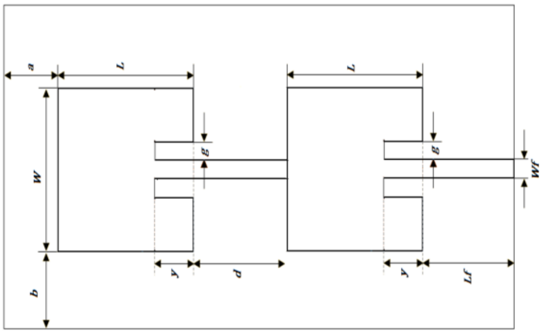

Fig. 2. Series-feed microstrip patch antenna array or microstrip patch antenna array in radiating slot

Simulation and analysis:

Simulated result analysis: The simulation is done using HFSS (High Frequency Structure Simulator) and the various parameters like gain, field Pattern, return loss and impedance matching are analyzed.

The variation in the distance 'd' between the two patches is done and found that the optimum distance between the two patches is maintained at 14.5mm. By varying the distance 'd' the gain and RL (return loss) are tabulated as shown in the Table. 2. From the tabulation and the plot, we can interpret that the gain attains peak values at a distance of every multiples of 'Lf'. The Fig. 3 shows the gain plot for the variation of 'd'.

i.e, Gain (in dB) attains peak value for every n times of Lf, where n=1,2,3…so on.

Table.2. Parametric vaiation of 'd'

d (in mm)	Gain (in dB)	Return Loss (dB) (At 2.4GHz)
0.1	0.004	-23
0.5	1.92	-19
1	3	-26
5	3.87	-18
10	4.38	-17
14.5	4.48	-12
20.93	4.11	-11

25	3.41	-11.5
30	3.54	-13.5
41.86	4.28	-12.5
50	3.54	-12
62.79	4.45	-10.5

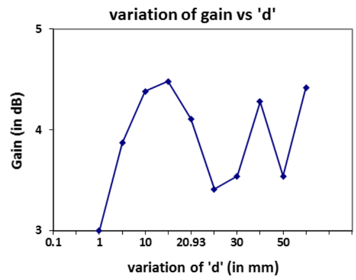

Figure.3. Gain Vs 'd'

The single patch radiator resonates at a frequency of 2.4GHz as shown in the Fig. 6 with a lower gain than that of the series-feed antenna. The array antenna resonates at two different frequencies making it a multi-band radiator with a higher gain. The Fig.7, shows that the series-feed antenna array resonating at 2.35GHz and at 2.45GHz respectively with RL of -16dB and -10.5dB. The Fig. 8 and Fig. 9 illustrate the field pattern of the single patch and antenna array network respectively. The Fig. 10 and Fig. 11 show the impedance matching property of the two antennas respectively using the Smith chart. Further, it may be proven that by adjusting the distance between the elements in the array under the effect of mutual coupling, the multi-band can be converted to single band with increased bandwidth.

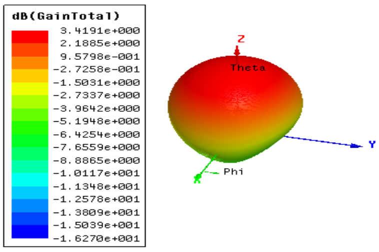

Figure.4. Gain of the single patch antenna

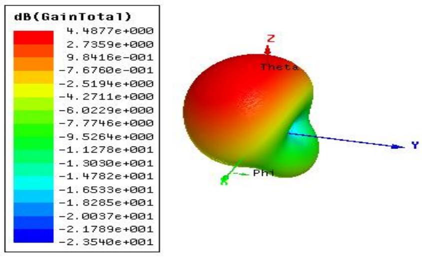

Figure.5. Gain of the series-feed microstrip patch antenna array

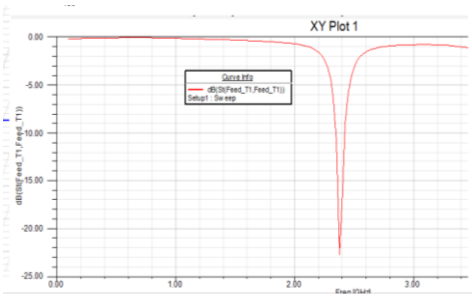

Figure.6. Return loss of the single patch antenna

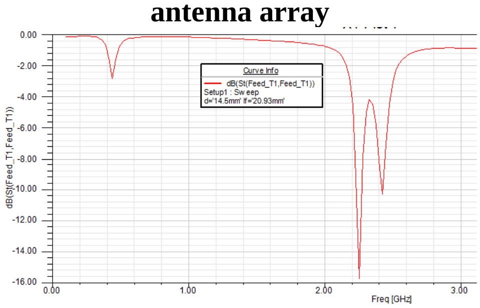

Figure.7. Return loss of the series-feed microstrip patch antenna array

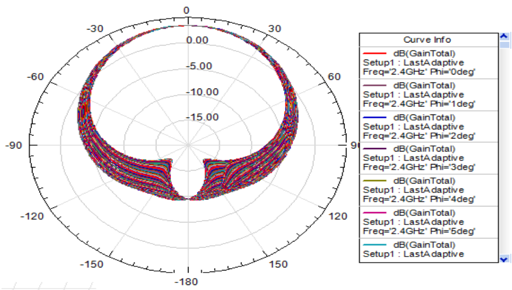

Figure.8. Radiation pattern of the single patch antenna

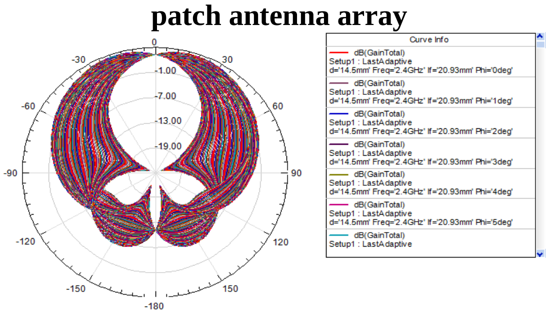

Figure.9. Radiation pattern of the series-feed microstrip patch antenna array

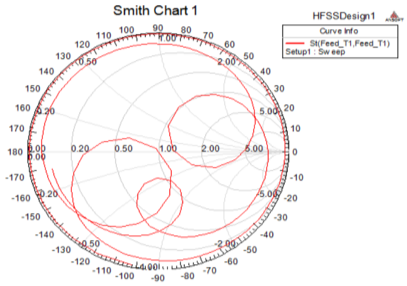

Figure.10. Smith chart of the single patch antenna

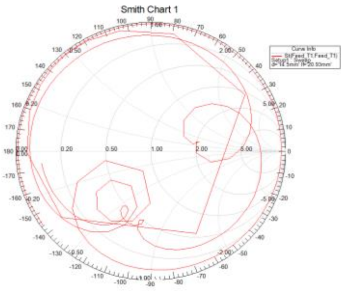

Figure.11. Smith chart of the series-feed microstrip patch antenna array

The Table.3, shows the tabulation of the gain and RL for the two proposed antennas. It is found that gain of the single patch radiator is 3.41dB whereas the gain of the series-feed array is nearly 4.5dB.

Table.3. Comparison between the single patch antenna and series-feed array

Parameter	Single Patch Antenna	Antenna Array (Series-Feed)
Gain	3.41dB	4.48dB
Return Loss	-23dB at a frequency of 2.4GHz	-16dB at a frequency of 2.5GHz and .-10.5 at a frequency of 2.45GHz

Measurement and inferences: The best optimized simulated antenna: one for single patch and one for series-feed array are fabricated and they are tested using vector network analyzer. The analyzer is well calibrated using calibration kit which includes short, open and matched loads. The measurement is done for both the single patch radiator and the series-fed antenna. A good correlation between the simulated results and the measured results is obtained for the return loss. The slight variations in the results are attributed for the fabrication. The Fig.12 and Fig.13, show the testing of the single patch radiator and the series-feed radiator array using the analyzer. The responses are recorded as illustrated in the Fig.14 and Fig.15, for the single patch and the series-feed antenna array respectively.

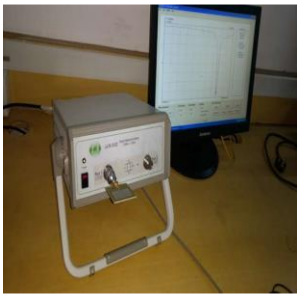

Fig. 12 Testing of the Single Patch Antenna using Network Analyzer

Fig. 13. Testing of the microstrip Patch Antenna array in series-feed configuration using Network Analyzer

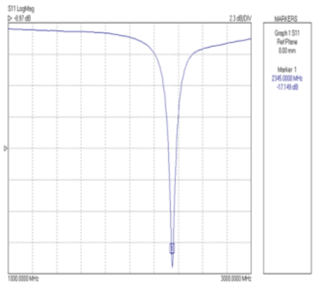

Figure.14. Response of the Single Patch Antenna using Network Analyzer

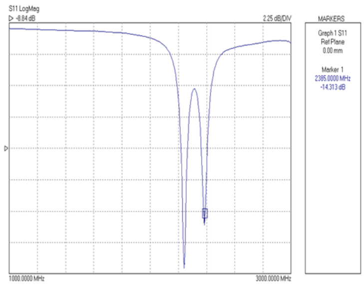

Figure.15. Response of the microstrip patch Antenna array in series-feed configuration using Network Analyzer

2. CONCLUSION

An experimental study and simulation has been done for the proposed radiators which has been constructed with the dimensions 55.33x48.02x1.60mm^3 for the single patch radiator and with the dimensions 99.35x48.02x1.60mm^3 for the array antenna in the radiating slot. It has been observed that this series-feed antenna operates at dual frequencies making it very suitable for the 4G (LTE-band 3, VoLTE), 5G and other wireless applications. Thus the designed radiator array has shown an increment in gain which is nearly 4.5dB in this case in comparison with the 3.4dB for the single patch antenna. Thus this enhancement of gain is obtained in compensation with the return loss.

3. ACKNOWLEDGEMENT

Authors are grateful to the University Grant Commission, New Delhi for sanctioning grant and supporting this research work under UGC minor research project.

REFERENCES

Bikash Ranjan Behera and Priyadarshi Suraj, Rectangular Microstrip Patch Antenna for Wireless Fidelity Application, Design of a Wi-Fi Antenna using the concept of Metamaterials, IEEE International Conference on Recent Trends in Electronics Information Communication Technology, 2016, 20-21.

Boutheina Tlili and Hadef ahmed Alshansum, Multiple bands stacked microstrip patch antenna for satellite communications, the 5th international conference on electronic devices, systems and applications, 2016.

Chakraborty U, Kundu A, Chawdhury S.K and Bhattacharjee A.K, Compact dual-band microstrip antenna for IEEE 802.11a WLAN application, IEEE Antenna wireless propogation letter, 13, 2014, 407-410.

Constantine Balanis A, Microstrip Antannas, in Antenna Theory, 3rd ed, John wiley & sons, Inc. New York, NY, 1964, 811–817.

David Pozar M, Microwave Engineering, 4th ed, Jhon Wiley & Sons Inc, 2012.

Lee C.J, Huang W, Gummalla A and Achour M, Small Antennas Based on Composite Right/Left Handed Structures, Concept, Design, and Applications, IEEE Antennas and Propagation Magazine, 53 (2), 2011, 34-50.

Mazhar W, Tarar M.A, Tahir F.A, Shan Ullah and Bhatti F.A, Compact Microstrip Patch Antenna for Ultra-wideband Applications, PIERS Proceedings, Stockholm, Sweden, 2013, 12-15.

Ramesh Garg, Prakash Bhartia, Inder Bahl, Apisak Ittipiboon, Microstrip Antenna Design HandBook, Boston, Artech House, 8, 2001,252.

Yahya Khraisat S.H, Design of 4 elements rectangular microstrip patch antenna with high gain for 2.4 GHz applications, Modern Applied Science, 6 (1), 2012.