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Design and Implementation of a Broadband Equilateral Triangular Parasitic Patch Microstrip Antenna Array for Wireless Applications

Prasanna L. Zade
Associate Professor
Y.C.College of Engineering Nagpur

Dr. N. K. Choudhary
Principal
S.B.C. College Engineering, Nagpur

ABSTRACT
This paper presents design and fabrication equilateral triangular parasitic patch microstrip antenna array with operating frequency at 2.42 GHz, for wireless communication systems. The Industry, Scientific and Medical (ISM) Band, unlicensed with the range 2.40 - 2.4835 GHz is used as the operation band. The maximum bandwidth can be achieved by controlling the distance between the patch antennas and by adjusting the probe feed position. Return loss of -33.23 dB with VSWR 1.10 at 2.42 GHz. The results shows that the proposed antenna has the impedance bandwidth of 120MHz for the array without triangular slot and 140MHz with triangular slot loaded ETMA planar array. The antenna parameters are investigated and optimization is performed by varying the feed position and substrate dielectric constant. The input and radiation characteristics are examined and compared. The various parameters are measured and practical results are presented and discussed.

General Terms
Microstrip antenna, dielectric constant, resonant frequency.

Keywords
Array, parasitic patch, multi-resonator, ETMA, VSWR,VNA

1. INTRODUCTION
Microstrip patch antennas are widely implemented in many applications in wireless communication due to their attractive features. Therefore they are extremely compatible for embedded antennas in handheld wireless devices. Some of their principal advantages are light weight, low volume, low fabrication cost, easy to mount, low profile, conformal, linear and circular polarization possible, easy to implement by position of feed, dual frequency use possible, solid state devices easily integrated. The patch using a simple coaxial probe feed is advantages due to ease of matching and fabrication. However in array applications a microstrip line feed may often be more appropriate. In general, the impedance bandwidth of the traditional microstrip antenna is only a few percent (2% - 5%) [1]. Therefore, it becomes very important to develop broadband technique to increase the bandwidth of the microstrip antenna.

The bandwidth of the MSA increases with an increase in the substrate thickness *h* or with a decrease in the dielectric constant εr. However, there is a practical limit on increasing the *h*, and if increased beyond $0.1\lambda_0$, surface-wave propagation takes place, resulting in degradation in antenna performance. Also, with an increase in *h*, the probe inductance increases and probe compensation techniques have to be employed to obtain impedance matching.

There are several ways to overcome this problem such as use modified patch shape [2] and use array technique [3]. Although rectangular and circular geometries are most commonly used, other geometries having greater size reduction find wide applications in wireless communication systems, where the prime concern is compactness. The triangular patch antenna configuration is chosen because it has the advantage of occupying less metalized area on substrate than other existing configurations [4,5].

This paper presents the planar multiple-resonator technique using microstrip parasitic patches for broadband operation. Only a single patch is fed, and the other patches are parasitically coupled. The coupling between the multiple resonators has been realized by using all gaps between the patches smaller than 2h.

2. ANTENNA DESIGNS
2.1. Design a Single Element Equilateral Triangular Patch Microstrip Antenna
A probe-feed single patch ETMA are designed, simulated and fabricated for resonant frequency 2.42 GHz on a finite ground plane. The probe feed technique has been used, since; the feed can be placed at any place on the patch to match with its input impedance (usually 50 ohm).

The Figure 1.shows the ETMA patch and finite ground plane.

(a) Top side **(b) Bottom side**
Figure 1 A photograph of probe fed Triangular Microstrip patch antenna

2.2. Resonant Frequency

The equilateral triangular patch has a side length ‘a’ and printed on a substrate of thickness ‘h’ with relative dielectric constant ‘εr’ [6,7,8].

The resonant frequency of ETMA is given as

$$f_r = \frac{cK_{mn}}{2\pi\sqrt{\varepsilon_r}} = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{m^2+mn+n^2} \qquad ....1$$

Where c is the velocity of light in free space and

K_{nm} = wave number, given by

$$K_{nm} = \frac{4\pi}{3a}\sqrt{m^2+mn+n^2}$$

The fundamental mode resonant frequency of antenna is given by

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}} \qquad ....2$$

In this relation effects of fringing fields are not considered. The resonant frequency may be determined with better accuracy, if ‘ε_r’ and ‘a’ in the above equation are replaced by effective dielectric constant ‘ε_{eff}’ and ‘a_{eff}’ which is given by

$$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r+1)+\frac{1}{4}\frac{(\varepsilon_r-1)}{\sqrt{1+\frac{12h}{a}}} \qquad .....3$$

and

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}} \qquad ......4$$

Respectively, Hence

$$f_r = \frac{2c}{3a_{eff}\sqrt{\varepsilon_{eff}}} \qquad ......5$$

It is clear from Equs (3) and (4) that for high dielectric constant substrate such as alumina, ‘ε_r’ and ‘a’ should be used in place of ‘ε_{eff}’ and ‘a_{eff}’ respectively.

2.3. Antenna parameters

Let ‘a’ be the side length of the equilateral triangular patch is fabricated on a FR-4 substrate of height 1.6 mm with relative dielectric constant whose loss tangent (*tan* δ) of 0.002. The patch side length is calculated for the 2.42 GHz resonant frequency with considering parameters mentioned.

At first the feed position is varied and its effect on the input impedance, S11 and V.S.W.R. are measured. The coaxial cable impedance in general 50 Ω. Here a feed location point is to be finding out on the conducting patch where patch impedance is 50 Ω. This feed point gives maximum radiation because of proper matching. The ETMA antenna characteristics were analyzed using HFSS EM software simulation package.

The simulated and measured input characteristics, like return loss and VSWR for single ETMA patch antenna are shown in Figure 2 and 3.

Both curves have similar behaviors of one deep at frequency 2.42GHz. The return loss is below -10 dB and obtained bandwidth 40 MHz of single ETMA patch.

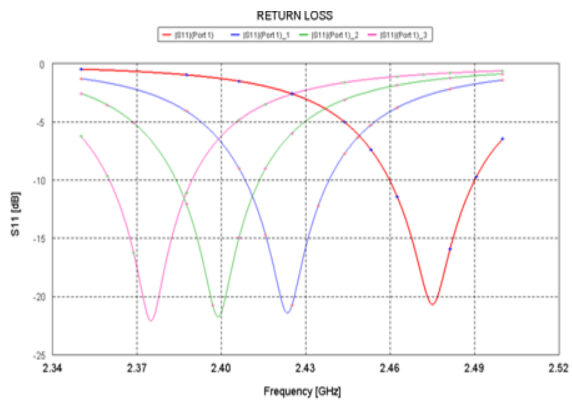


Figure 2 Simulation Result of Single element of ETMA Return Loss Vs Frequency

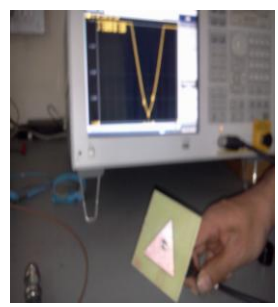


Figure 3 Single ETMA Measured Results of VSWR and Return Loss on VNA

3. PLANAR ARRAY ANTENNA DESIGN

3.1. Design of a Three Element parasitic ETMA Antenna Array

A patch antenna with parasitic elements is one of the best candidates among those antennas because of its simple design and implementation for array element antennas. The three element gap-coupled microstrip antennas are designed, simulated and fabricated. By using the concept of gap-coupling the bandwidth of microstrip antenna has been increased [3, 4].

In this paper, single patch is fed and the two parasitic patches are excited by the gap-coupling. Figure 3 shows the ETMA geometry of the three elements gap-coupled microstrip proposed antennas with the patches are of the same size.

A patch placed close to the fed patch gets excited through the electromagnetic coupling between the two patches. Such a patch is known as a parasitic patch. If the resonance frequencies f_1 and f_2 of these two patches are close to each other, then broad BW is obtained. The overall VSWR will be the super position of the responses of the two resonators resulting in a wide bandwidth. The parasitic patches are chosen to be identical for symmetrical pattern; and its base length has been optimized to further enhance the bandwidth [9,10].

4. SIMULATION AND FABRICATION RESULTS

4.1. The single and three element parasitic microstrips patch array simulations

The simulated and measured return losses for three element ETMA parasitic patch without triangular slot, showing the curves of one deep at operating frequency 2.42 GHz. The return loss is below -10 dB and obtained bandwidth is three times greater than single patch is 120 MHz

The bandwidth will be further enhancing by introducing the triangular slot at the centre of each individual patch as shown below in Figure 4. The simulated return loss and VSWR for three elements with inserting triangular slot ETMA parasitic patch antenna are given in Figure 5 and 6.

Both curves have similar behaviors of one deep at frequency 2.42 GHz. The return loss is -33.23 dB with obtained bandwidth is three times greater than single patch is 140 MHz, which is greater than three parasitic patches without slot and corresponding VSWR is 1.10.

Figure 7 shows the smith chart of 3-element ETMA parasitic patch array. The side length of the parasitic patch determines the position of the loop on the Smith chart. As side length increases, the resonance frequency of the parasitic patch decreases and the position of the loop moves in the anti-clockwise direction on the Smith chart. The size of the loop depends upon the gap between the two patches [2,5, 6].

The radiation pattern near the resonant band frequencies are shown in Figure 8. With an increase in frequency, the radiation pattern varies and the cross-polar level increases significantly to the extent that the radiation becomes maximum along θ =30° at 2.42 GHz. At a higher frequency, the parasitic patches are resonant, and therefore experience a large phase delay with respect to the fed patch; hence, the beam maxima shifts away from broadside.

Here for a given resonant frequency, the height of the substrate is varied to decide the different antenna parameters such as S_{11}, V.S.W.R., and band-width.

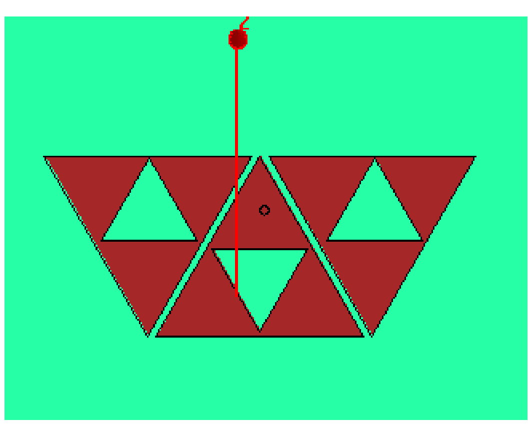


Figure 4. View of 3-element parasitic patch array geometry

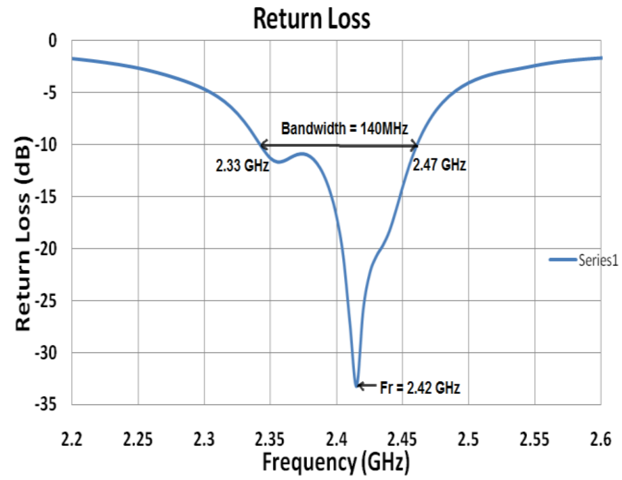


Figure 5 Return Losses vs. Frequency Curve Simulation Result of S_{11} is -33.23 dB, with bandwidth is 140MHz 3-element slot loaded ETMA parasitic patch array

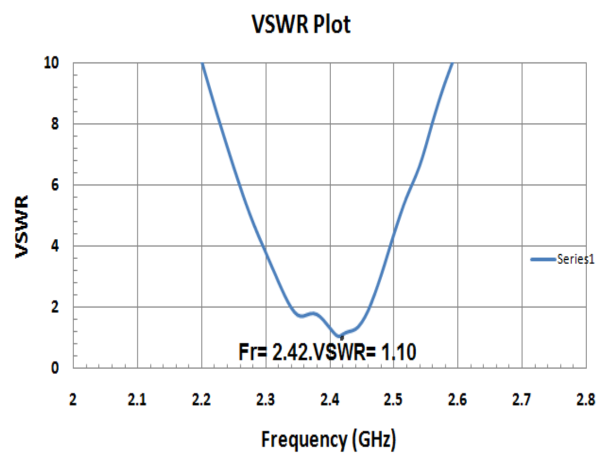


Figure 6 VSWR vs. Frequency Curve Simulation Result of VSWR is 1.10 at 2.42GHz 3-element slot loaded ETMA parasitic patch array

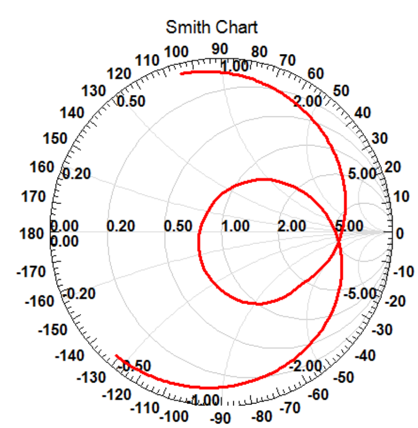


Figure 7 Simulation Result of 3-element parasitic patch array. Input Impedance Loci using Smith Chart

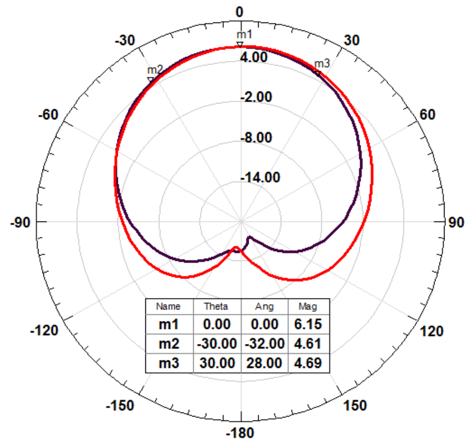


Figure 8 Radiation pattern of 3-element parasitic patch array with $\Phi = 0^0, 90^0$
Total Directivity is 6.16 dB at $\theta = 0^0$.

As the smith chart curve passing very close to value 1, means there is good impedance matching between patch and feed networks mostly 50 ohm as shown in Fig7. The total directivity is 6.15 dB with $\Phi = 0^0, 90^{0,}$ as indicated in figure 8.

4.2. Fabrication results

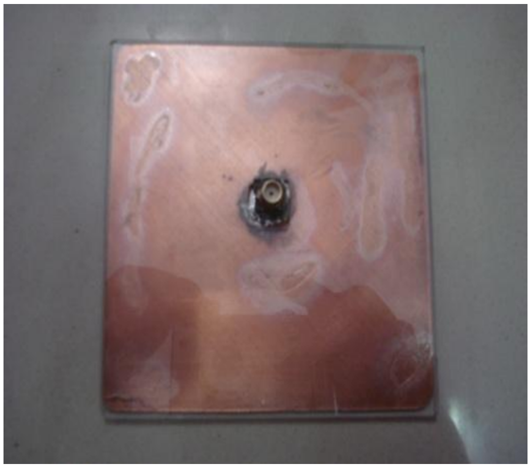
A 3 - element parasitic equilateral triangular microstrip patch antenna is fabricated and tested experimentally using vector network analyzer.

The Figure 9 and Figure 10 show the top side and bottom side of fabricated antenna array. The return loss characteristics of this antenna is measured using Agilent vector network analyzer and is shown in the Fig. 11and 12.

The measured bandwidth (S11< –10dB) ranges from 2.33GHz to 2.43 GHz, with the centre frequency 2.47 GHz.

The experimental results appear to be slightly different from the simulated results. This may be attributed to fabrication issues such as dielectric material, loss tangents, and soldering, slight curvature of substrate due to its flexible nature, and the minor changes in the air gap height [10, 11, and 12].

(a) Top View of Radiating patch
Figure 9 A photograph of probe fed Triangular Microstrip patch antenna array with triangular slot.



(b) Bottom View of Radiating patch

Figure 10. A photograph ground plane of probe fed Triangular Microstrip patch antenna array .

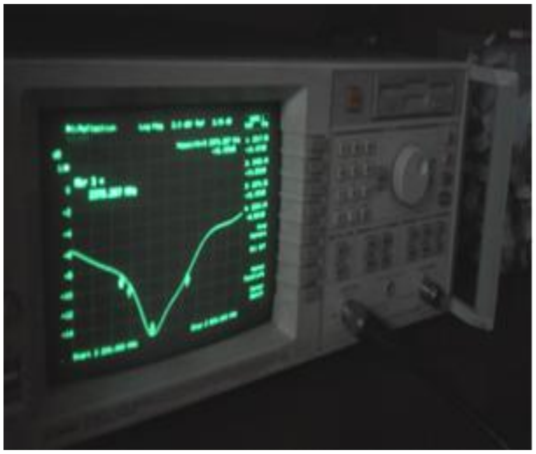


Figure 11 A photograph of practical measurement of Return Loss S_{11}= - 35 dB with bandwidth of 100MHz using Vector Network Analyzer.

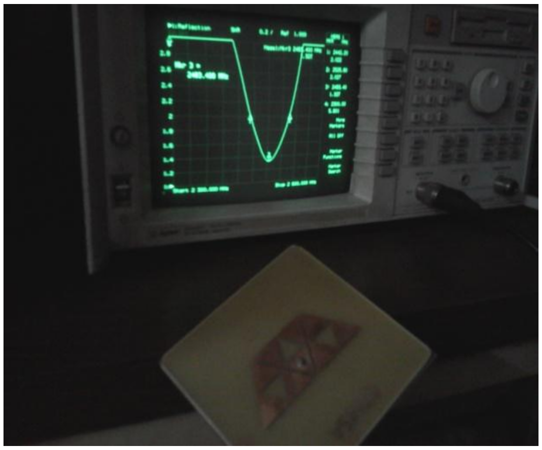


Figure 12 A photograph of practical measurement of VSWR =1.34 at 2.47GHz using Vector Network Analyzer

Figure 12. Fabrication Result of 3-element parasitic patch array on smith chart using VNA

Above fabrication measurement results graph shown the return loss of -35dB at frequency 2.47 GHz which is actually the good, ideally return loss should be RL ≥ -10dB and the VSWR of 1.34 which is also good, ideally VSWR should be < 2. The root cause of the shift is could be due to the FR4 material has Ɛ r that varies from 4.0 to 4.8 with moderately high value of loss tangent (tan δ) of 0.02. In practical world, a material which has varying εr along a length/width/height, will affect resonant frequency to shift. The other factors affecting etching accuracy such as chemical used, surface finish and metallization thickness also could be the reason for the resonant frequency shifting.

5. CONCLUSIONS

In conclusion, design and fabrication of probe feed single element and three element planar ETMA array with good matching, input and radiation characteristics with varying feed position is presented. It is clear from the both the simulated and practical result, that as the number of patch element increases, the band-width increases four times compared with single patch antenna..The results demonstrated that the bandwidth and radiation properties of the antenna with triangular slot have better performance than the antenna without triangular slot.

The antenna was designed to have a good return loss and radiation pattern. The corresponding return loss obtained from simulation is -33.23 dB and VSWR is 1.10 and from measurement is -35 dB and VSWR is 1.34, while the resulted directivity of array antenna is 6.16 dB .The value of impedance is passing through 1 on both the smith chart ,it shows perfect matching of probe impedance and patch impedance. It is also shown that the geometry with triangular slot has an influence towards the performance of the antenna characteristics.

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