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# Microstrip patch antenna arrays for wireless communication

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**ABSTRACT**

This paper focuses on the design of multi-element micro strip patch antenna array applicable to WLAN/MIMO at 2.4 GHz. Obviously, the performance of multi-element antenna system depends critically on the proper design of the arrays. In this paper design and simulation of 4x1 micro strip patch array with software IE3D is discussed. The performance of array have been compared with that of a single element micro strip patch antenna .Also the effect of mutual coupling of array elements on its performance is discussed .To reduce surface wave propagation, implementation of EBG substrate is discussed.



## Introduction

Micro strip patch antennas became very popular in mobile and radio wireless communication. This is because of ease of analysis and fabrication, and their attractive radiation characteristics. However, they have some drawbacks of low efficiency, narrow bandwidth and surface wave losses[2]. In order to overcome the limitations of micro strip antennas such as narrow bandwidth , lower gain , excitation of surface waves etc, different array configurations are worked out which gives high gain [8], wide bandwidth and improved efficiency. To minimize surface wave excitation, a new solution using electromagnetic band gap (EBG) structure, as substrates has attracted increasing attention. Unlike other methods, this method utilizes the inherent properties of dielectric materials to enhance micro strip antenna performance. These periodic structures have the unique property of preventing the propagation of electromagnetic waves for specific frequencies and directions which are defined by the shape, size, symmetry, and the material used in their construction[4]. In this paper, design, simulation and performance study of single patch antenna and 4x1 micro strip array with and without EBG structure operating at 2.4 GHz frequency are discussed. Simulations are made by simulation software Zeeland's IE3D 12.0.

## Design of Single micro strip patch

For a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\ \lambda o$, where $\lambda o$ is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ ,where t is the patch thickness. The height h of the dielectric substrate is usually $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate ($\varepsilon r$) is typically in the range $2.2 \leq \varepsilon r \leq 12$. [3]

## Feed Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch [2]. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).[3] Microstrip line feed with Inset cut is used since this is an easy feeding scheme, it provides ease of fabrication and simplicity in modeling as well as impedance matching.

## Method of Analysis

Transmission line model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non-homogeneous line of two dielectrics, typically the substrate and air. The figure 1.1 shows the microstrip diagram of rectangular shape of micro strip patch antenna and the equivalent circuit. It is seen from Figure that most of the electric field lines reside in the substrate and parts of some lines in air[3]. As a result, this transmission line cannot support pure transverse-electromagnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant ($\varepsilon_{reff}$) must be obtained in order to account for the fringing and the wave propagation in the line. The value of $\varepsilon_{reff}$ is slightly less then $\varepsilon_r$ because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air.

Following are the design equations for single element micro strip patch antenna[3].

$$\varepsilon_{reff} = (\varepsilon_{reff} + 1)/2 + (\varepsilon_{reff} - 1)/2\,[1+12h/W]^{-1/2}$$

Where $\varepsilon_{reff}$ = Effective dielectric constant

$\varepsilon_r$ = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

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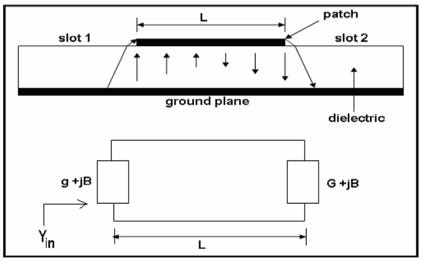


**Fig. 1.1 : Microstrip patch and equivalent circuit**

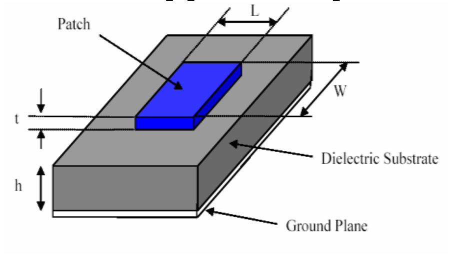


**Fig. 1.2 : Microstrip patch Antenna**

**For a given resonance frequency $f_o$, the effective length is given by as:**

$$L_{eff} = L + 2\Delta L$$

$$L_{eff} = c/(2f_o\sqrt{\varepsilon_{reff}})$$

**For a rectangular Micro strip patch antenna, the resonance frequency for any TM mode is given as:**

$$f = c/(2\sqrt{\varepsilon_r})[(m/L)^2 + (n/W)^2]^{1/2}$$

**Where m and n are modes along L and W respectively. For efficient radiation, the width W is given as:**

$$W = c/(2f_o\sqrt{(\varepsilon_r+1)/2})$$

The input admittance at the radiating edge is given by;

$$Y_{in} = Y_{slot} + Y_o \frac{Y_{slot} + jY_O \tan\beta(L+\Delta l)}{Y_o + jY_{slot}\tan\beta(L+2\Delta l)}$$

At resonance .Yin = 2G

Based on Harrington, the conductance, G for parallel radiator is given by;

$$G = \frac{\pi W}{\eta\lambda_o}\left[1 - \frac{(kh)^2}{24}\right]$$

Where,

$$\eta = 120\pi \qquad k = \frac{2\pi f}{c}$$

**Inset feed Impedance**

The type of feeding technique that will be used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna.. The resonant input resistance for the microstrip patch is given by

$$R_{in} = \frac{1}{2(G1 \pm G12)}\cos^2\left(\frac{\pi}{L}y_0\right)$$

L is the length of the patch, $y_0$ is the length of the inset, $G_1$ is the conductance of the microstrip radiator and $G_{12}$ is the mutual conductance between the two slots.. $I_1$ is the current excited into the microstrip patch.

$$G_1 = \frac{I_1}{120\pi^2}$$

$$I_1 = \int_0^\pi \left[\frac{\sin\left(\frac{k_0 w}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta \quad d\theta$$

The mutual conductance of the two slots can be calculated using equation

$$G_{12} = \frac{1}{120\pi^2}\int_0^\pi \left[\frac{\sin\left(\frac{k_0 w}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_0(k_0 L\sin\theta)\sin^3\theta \quad d\theta$$

The equations above need tedious effort to calculate. The calculations for finding the inset length can be simplified by the equation below. This equation is valid for εr from 2 to 10 [5].

$$\ell = 10^{-4}\left(\begin{matrix}0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - \\ 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697\end{matrix}\right)\frac{L}{2}$$

Where

$\varepsilon_r$ = Permittivity of the dielectric

L = Length of the microstrip patch

**Design of Microstrip patch**

**The three essential parameters for the design of a rectangular Micro strip Patch Antenna:**

- fo = 2.4 GHz
- εr = 4.4
- h = 1.59 mm

Using the above parameters and the equations of the transmission line model we obtain

- W = 38.0 mm
- $\varepsilon_{reff}$= 4.08
- $L_{eff}$= 30.9 mm
- ΔL = 0.7349 mm
- L = 29.4 mm
- Yo=9.47mm

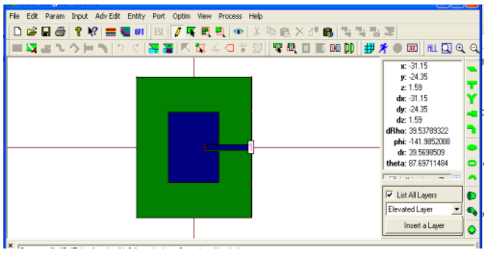

**Fig 2.1 Geometry of Microstrip Patch**

**Return Loss**

The inset feed used is designed to have an inset depth of 9.47mm, feed-line width of 2.99 mm and feed path length of 24 mm. A frequency range of 2-3 GHz is selected and 101 frequency points are selected over this range to obtain accurate results. The center frequency is selected as the one at which the return loss is minimum. The bandwidth can be calculated from the return loss (RL) plot. The bandwidth of the antenna can be said to be those range of frequencies over which the RL is greater than -9.5 dB (-9.5 dB corresponds to a VSWR of 2 which is an acceptable figure). The optimum feed depth is found to be at Yo = 8mm where a RL of -20dB is obtained. The bandwidth of the antenna is calculated to be 80 MHz and a center frequency of 2.40 GHz is obtained .

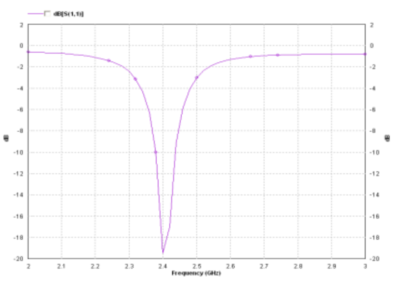

**Fig 2.2 Return loss curve for Microstrip Patch**

**Voltage Standing Wave Ratio**

The most common case for measuring and examining VSWR is when installing and tuning transmitting antennas. When a transmitter is connected to an antenna by a feed line, the impedance of the antenna and feed line must match exactly for maximum energy transfer from the feed line to the antenna to be possible. When an antenna and feed line do not have matching impedances, some of the electrical energy cannot be transferred from the feed line to the antenna. Energy not transferred to the antenna is reflected back towards the transmitter. It is the interaction of these reflected waves with forward waves which causes standing wave patterns. Ideally, VSWR must lie in the range of 1-2 which is achieved in the design.

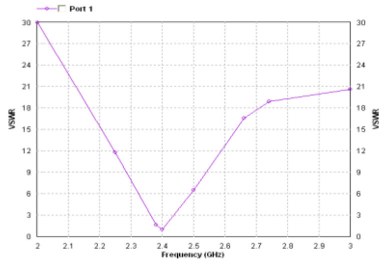


**Fig 2.3 VSWR vs Freq curve for Microstrip Patch**

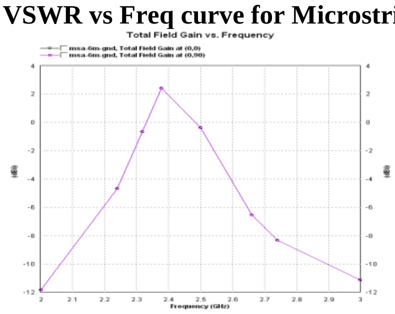


**Fig. 2.4 Gain of Microstrip patch**

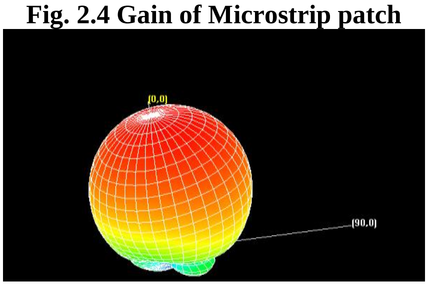


**Fig 2.5 Radiation pattern of single patch antenna**

**Design of microstrip patch array**

The wireless local area network uses the frequency range from 2.40-2.48 GHz and 5.15-5.35 GHz. The designed antenna must be able to operate in the frequency range of first kind. The resonant frequency selected for the design is 2.4 GHz.The dielectric constant $\varepsilon r$ =4.4 and height of the dielectric substance h=1.59. The substance with high dielectric constant has been selected since it reduces the dimension of the patch. The width (W) of the microstrip patch by using the essential parameters for the design is 38.0 mm and length (L) is 29.40 mm. The geometry of the proposed patch antenna (4x1) array is illustrated in Figure 3.1. The distance between the antenna elements is set at 0.5 $\lambda o$ to avoid the effect of mutual coupling and correlation between the elements. The elements of the array are connected by transmission line. The calculation of the transmission lines are based on transmission line model [3]. Setting 50 Ω feed line Z1 = 50 Ω, which splits into two 100Ω ones, Z2 = 100 Ω. we found the width of the microstrip line at Z1 = 50 Ω and Z2 = 100 Ω are W1 = 2.96mm and W2 = 0.62 mm, respectively. Then solved for impedance of quarter-wave transformer, Zc. Setting Z c =√ Z 1 Z 2 , impedance of quarter-wave transformer, and solve for the width, Wc of quarter- wave transformer as shown in the Figure 3.0. This yields Zc = 70 Ω. After that, we found the width of the microstrip line at Zc = 70 Ω is, Wc = 1.56 mm. Solving for the length of quarter-wave transformer by dividing the effective wavelength λreff, by four. λreff = 68.98mm. The Length of quarter-wave transformer is, λreff/4 = 17.2571 mm. The inset feed length is optimized to have the value 8.2 mm for impedance matching of 50 Ω.

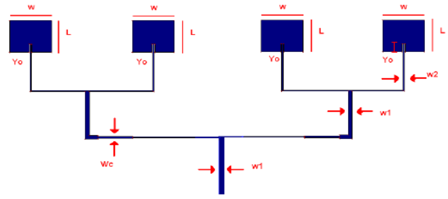


**Fig.3.1 Feed network for antenna array**

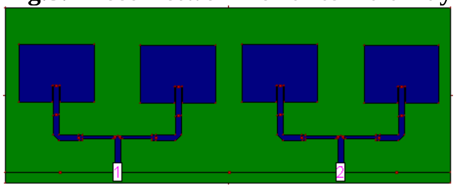

**Fig. 3.2 Geometry of 4x1 antenna array**

**Results and Discussion:.**

Fig. 3.2 shows that 4x1 array of micro strip antenna is designed according to the design parameters given above. However the spacing between antenna elements should be equal to or more than λ/2 [6], for this design the distance between two elements is kept 23.5 mm (which is less than λ/2) and distance between two 2x1 arrays is kept 14mm still it gives proper impedance matching at 50 Ω and gain not less than 8 dB. Comparison of single patch antenna and 4x1 array of patch antenna is given in table 4.1

| Type of antenna | Gain(dB) | Directivity(dB) | Efficiency |
|---|---|---|---|
| Single Patch | 2.5 | 7.24 | 37% |
| 4x1 Array | 8.0. | 11.5 | 47% |

**Table N0. 4.1 Comparison between single patch and 4x1 array**

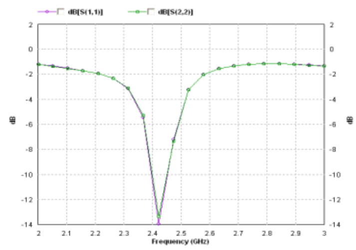

**Fig .4.1 Return loss for 4x1 Patch Array**

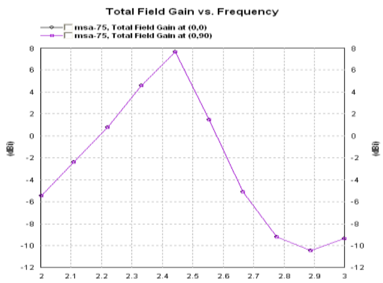


**Fig. 4.2 Gain vs Freq for 4x1 Patch Array**

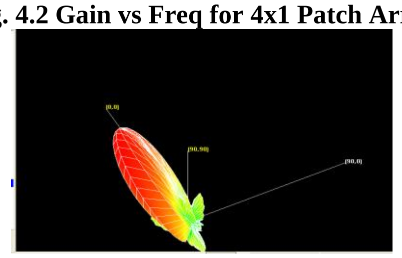

**Fig .4.3 Radiation Pattern for 4x1 Patch Array**

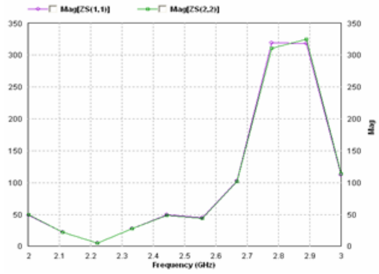

**Fig .4.4 Magnitude of Impedance for 4x1 Patch Array**

**Surface Wave Propagation and Mutual Coupling**

Surface wave propagation is a serious problem in micro strip antennas. Surface waves reduce antenna efficiency and gain, limit bandwidth, increase end-fire radiation, increase cross polarization levels, and limit the applicable frequency range of micro strip antennas Besides end fire radiation, surface wave give rise to coupling between various elements of an array. To overcome the problem of surface wave propagation now use of EBG (electromagnetic band gap material ) is made. In this case, the substrate is periodically loaded so that the surface wave dispersion diagram presents a forbidden frequency range (stop band or band gap) about the antenna operating frequency. Because the surface waves cannot propagate along the substrate, an increase amount of radiating power couples to the space waves and mutual coupling between array elements does not occur. The basic design of EBG structure is shown in figure 5.1 known as mushroom like EBG structure. This structure has certain frequency range where the surface impedance is very high. The equivalent LC circuit acts as a two dimensional electric filter in this range of frequency to block the flow of the surface waves.

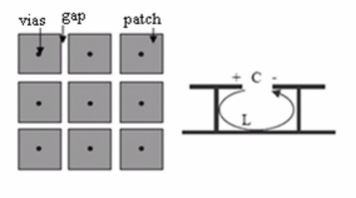


**Fig:5.1 EBG Structure**

**Micostrip Patch Antenna with EBG substrate**

The EBG structure is designed to operate at frequency 2.4GHz. For this design, the FR4 dielectric material ($\varepsilon r = 4.4$) with dielectric loss tangent ($\tan\delta$) of 0.019 and height of substrate (h) 1.59mm were used. The EBG structure analyzed in this section roughly has the following parameters.

$W = 0.12\lambda o$ GHz, $g = 0.02\ \lambda o$ GHz

$h = 0.04\lambda o$ GHz, $\varepsilon r = 4.4$

Because there is no specific formula created to calculate the size of the EBG structure to get the band gap characteristic at certain operational frequency, the parametric study will be used. For this EBG of 6mmX6mm has tried. The gap between EBG elements is 1mm and vias radious is 0.5 mm.

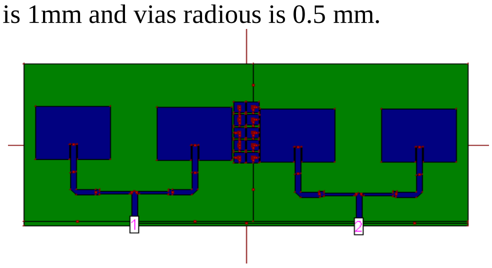


**Fig 6.1 4X1 Microstrip Antenna Array with EBG**

**Results & Dissussion**

The mutual coupling of microstrip antennas is parametrically investigated, including both the E- and H- coupling directions, different substrate thickness, and various dielectric constants. In both coupling directions, increasing the substrate thickness will increase the mutual coupling. For 4x1 patch antenna transmission coefficient s21 shows decrease in its value by 22dB with the implementation of EBG indicating that mutual coupling reduces.

**Table 6.1 Comparison of Simulated Results & Measurement Results of Antenna Parameters with EBG and without EBG**

| | Simulated Results | | Measurement Results | |
|---|---|---|---|---|
| Type of Antenna | S11(dB) | S21(dB) | S11(dB) | S21(dB) |
| 4X1 array without EBG | -14 | -28 | -19.4 | -38.35 |
| 4X1 array with EBG | -14 | -30 | -19.4 | -60.50 |

**Conclusion**

The design of single patch array and 4X1 patch antenna array has been presented and both structures are tested using Network Analyzer The antenna array shows higher gain & good radiation efficiency at WLAN band. The peak gain for the single element is 3.0 dBi and that of array is 8.0 dBi. The impedance characteristics of the array shows 50 ohms at 2.40 GHz. There is no effect observed with EBG on return loss of antenna but mutual coupling between antennas reduces by inserting EBG structure on the sunstrate of array. It is observed from the graph that the resonant frequency of 4X1 antenna with EBG lies in the band gap of EBG structure. Hence at 2.44 GHz, S21 shows decrease in its value. Before implementation of EBG the S21 was -38.35 whereas after implementation of EBG , it decreases to about -60.50. The improvement in reduction of mutual coupling is about 22.15 dB. . Hence there is improvement in performance of the antenna.

**References**

[1] Girish kumar & K P Ray "Broadband Microstrip antnna" (Artech House antennas and propagation library)2003

[2] James, J. R., and P. S. Hall (Eds), Handbook of Microstrip Antennas, Peter Pereginus, London, UK 1989.

[3]. Balanis, C.A. Antenna Theory: Analysis and Design. 2nd Ed. New York: John Wiley and Sons.

[4] F. Yang, and Y. Rahmat-Samii, "Microstrip Antennas integrated with electromagnetic band-gap structure: a low mutual coupling design for array application," IEEE Trans. Antennas and Propagation., vol. 51,pp. 2936-2946, Oct. 2003.

[5] Xiaowen XU Xiuping LI Yi AN, "Design of a stacked broadband microstrip antenna array Department of Electronic Engineering Bejing University, China

[6] M. T. I. Huque, "Design and Simulation of a Low-cost and High Gain Microstrip Patch Antenna Arrays for the X-band Applications," in International Conference on Network Communication and Computer – ICNCC 2011, New Delhi, India., March 21-23, 2011

[7] Yahya S. H. Khraisat Design of 4 Elements Rectangular Microstrip Patch Antenna with High Gain for 2.4 GHz Applications Modern Applied Science Vol. 6, No. 1; January 2012

68 ISSN 1913-1844 E-ISSN 1913-1852

[8] Zeland Software Inc., "IE3D electromagnetic Simulation and Optimization Package, Version 12".