Impact of Geometry and Feed Point on Radiation Pattern of a Patch Antenna and Its Linear Array as a Substitute of Multi-hop Link

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Abstract— **Rao-Wilton-Glisson (RWG) edge elements are widely used to determine the performance of an antenna specially the distribution of elemental dipole on the antenna surface, surface current distribution, profile of input impedance and radiation pattern. In this paper the impact of geometry and position of feed point of a patch antenna is analyzed in terms of variation of input impedance against frequency to get the bandwidth of the antenna and radiation pattern on both two dimensional surface and three dimensional space. Finally an array of such antenna is placed on a line to observe the end fire and broad side radiation pattern to get intense and heavily directed beam, can be used as substitute of multi hop ad-hoc link.**

Index Terms— **Security, In-polar and cross polar component, Green function, incident EM signal, impedance matrix and array antenna**.

I. Introduction

DISTRIBUTION of surface current on the body of an antenna in receiving mode and the radiation pattern EM wave in transmitting mode is considered as the most important parameter in selection of antenna. In this paper we emphasis on patch antenna in context of above where the analysis is done based on RWG elements. The microstrip or patch antenna is widely used in in-door wireless communication for several reasons[1-3]: (a) the microstrip antenna is simple and inexpensive to manufacture (b) small in size therefore is compatible to be embedded inside handhold wireless communication devices (c) it can be mounted on rigid surfaces because of its stiffness in construction (d) supports both linear and circular polarization of EM wave. Although the directivity of a single antenna is poor but array of such antenna provides better directivity and gain.

The microstrip antenna can be considered as a segment of a planar transmission line usually used for indoor communications. The geometry of such antenna is shown in fig.1 where a metallic strip called patch and a ground plate are separated by a dielectric sheet of relative permittivity ε_r called substrate. The region above the upper plate of the antenna is air of dielectric ε_0 but the region below the upper plate is filled with medium of dielectric $\varepsilon_0\varepsilon_r$. Therefore the phase velocity of EM wave above and below the upper plate is different and the antenna cannot support TEM wave. For theoretical analysis the entire region above and below the upper plate is represented by an equivalent uniform transmission medium of dielectric [4-5],

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left\{1 + 12\frac{h}{w}\right\}^{-1/2} \quad (1)$$

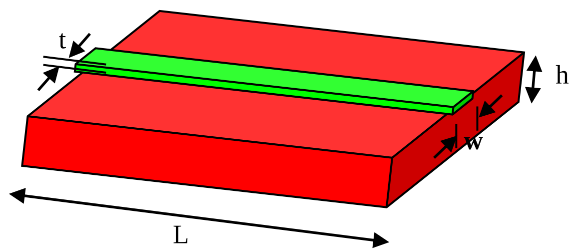


Fig.1. Basic patch antenna

The most widely used shape of patch antennas are square, circular, elliptical, rectangular, triangular and diamond. In this paper we considered only rectangular and circular patch. Feeding in patch antenna is achieved either by microstrip or co-axial line.

The electric and magnetic field in TM mode within the cavity is expressed as [6-8],

$$E_x = -j\frac{1}{\omega\mu\varepsilon}\left(\frac{\delta^2}{\delta x^2} + k^2\right)A_x;\ Hx = 0 \quad (2)$$

$$E_y = -j\frac{1}{\omega\mu\varepsilon}\frac{\delta^2 A_x}{\delta x \delta y} \quad H_y = -\frac{1}{\mu}\frac{\delta A_x}{\delta z} \quad (3)$$

$$E_z = -j\frac{1}{\omega\mu\varepsilon}\frac{\delta^2 A_x}{\delta x \delta z} \quad H_z = -\frac{1}{\mu}\frac{\delta A_x}{\delta y} \quad (4)$$

;where A_x is the vector magnetic potential obtained from the solution of homogeneous wave equation, $\nabla^2 A_x + k^2 A_x = 0$ and the boundary condition on the geometry of the antenna. We are more interested about the electric field outside of the antenna i.e. the radiation pattern of the antenna. The radiating field of the antennal is expressed as,

$$E_\varphi^t = j\frac{k_0 h W E_0 e^{-jk_0 r}}{\pi r}\left\{\sin\theta\frac{\sin(X)}{X}\frac{\sin(Z)}{Z}\right\}\cos\left(\frac{k_0 L_e}{2}\sin\theta\sin\varphi\right) \quad (5)$$

; where $X = \frac{k_0 h}{2}\sin\theta\cos\phi$ and $Z = \frac{k_0 W}{2}\cos\theta$, $V_0 = hE_0$ is the voltage across the slot, L_e is the effective length of the antenna.

The patch antenna behaves more like a cavity than a radiator so efficiency of such antenna is very poor but the efficiency can be enhances by using it in an array. In this paper, the concept of RWG edge elements of [9-10] has been explored to determine distribution of RWG elements, profile of input impedance, and radiation pattern of a patch antenna. Entire work is done changing geometry of the patch and the feed points and combining them in a linear array. In a small indoor network or in ad-hoc network the access point can use array of microstrip antenna to enhance coverage in a certain direction or can provide single link access to the Base Station instead of multi-hop ad-hoc connection.

The organization of the paper is like: section-II reveals the entire mathematical analysis of evaluation of impedance matrix based on RWG edge elements, section-III depicts the results based on analysis of previous section and section-IV concludes the entire analysis.

II. SYSTEM MODEL

A. RWG Elements

An antenna in receiving mode experiences the rate of change of EM wave on its surface hence voltage is induced on the antenna by transformer action. The distribution of potential on the surface of the antenna is analyzed by RWG elements. Each RWG element is a pair of adjacent triangle symbolically represented as T_m^+ and T_m^- share common edge l_m having areas A_m^+ and A_m^- [10-11]. The RWG edge element of a thin dipole of antenna is shown in fig.2.

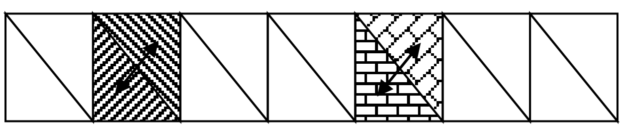


Fig.2. RWG edge elements on a thin dipole antenna

Fig.3 depicts the RWG element in details where parameters are:

V_m^+ is the free vertex point of triangle T_m^+,

V_m^- is the free vertex point of triangle T_m^-,

$\mathbf{r}_m^{C+}$ is the free centroid point of triangle T_m^+,

$\mathbf{r}_m^{C-}$ is the free centroid point of triangle T_m^-

$\rho_m^{C\pm}$ are the vectors between the free vector point V_m^+ and the continued point $\mathbf{r}_m^{C\pm}$.

Here, $\rho_m^{C+} = \mathbf{r}_m^{C+} - V_m^+$ and $\rho_m^{C-} = \mathbf{r}_m^{C-} - V_m^-$.

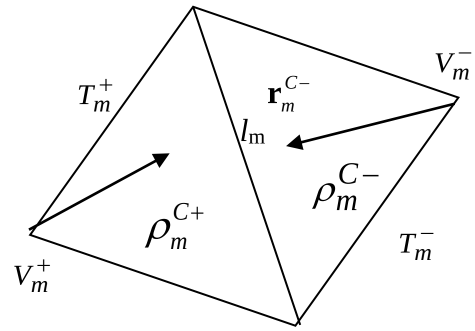


Fig.3. Close view of m-th RWG element

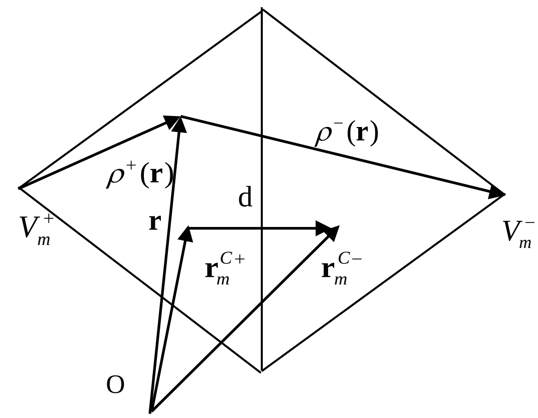


Fig.4. Observation Point on *m*-th RWG element

Fig.4 deals with a reference point O from which the distances of the centroids are: $\mathbf{r}_m^{C+}$ and $\mathbf{r}_m^{C-}$; that of the observation point is $\mathbf{r}$; the distances between the observation point and the free vertices are $\rho^+(\mathbf{r})$ and $\rho^-(\mathbf{r})$ respectively. The length of the dipole, is $d = \left| \mathbf{r}^{C-} - \mathbf{r}^{C+} \right|$.

Let us start with the Helmholtz wave equation, $\nabla^2 A + k^2 A = -\mu j$, where the source is $-\mu j$ and A is the vector magnetic potential [12]. The solution of the equation is Green function can be written as [13, 14],

$$g_m^{\pm}(\mathbf{r}') = \frac{e^{-jk\left(\mathbf{r}_m^{C\pm} - \mathbf{r}'\right)}}{\left|\mathbf{r}_m^{C\pm} - \mathbf{r}'\right|} \qquad (6)$$

Let us define two integrals,

$$I_{mn}^{+} = \int_{T_m^{\pm}} \rho_n^{+}(\mathbf{r}')\, g_m^{+}(\mathbf{r}')\, ds' \qquad (7)$$

$$I_{mn}^{-} = \int_{T_m^{+}} \rho_n^{+}(\mathbf{r}')\, g_m^{-}(\mathbf{r}')\, ds' \qquad (8)$$

Equations (7) and (8) can be compactly written as

$$I_{mn}^{\pm} = \int_{T_m^{+}} \rho_n^{+}(\mathbf{r}')\, g_m^{\pm}(\mathbf{r}')\, ds' \qquad (9)$$

; Where, the observation point is on T_n^+ triangle.

Similarly,

$$J_{mn}^{\pm} = \int_{T_m^{-}} \rho_n^{-}(\mathbf{r}')\, g_m^{\pm}(\mathbf{r}')\, ds' \qquad (10)$$

Where, the observation point is on T_n^- triangle.

Now, The vector magnetic potential,

$$A_{mn}^{\pm} = \frac{\mu l_n}{8\pi}\left[\frac{I_{mn}^{\pm}}{A_n^+} + \frac{J_{mn}^{\pm}}{A_n^-}\right] \quad (11)$$

Where, A_n^+ and A_n^- are respectively the areas of T_n^+ and T_n^-.

Again the scalar potential,

$$\varphi_{mn}^{\pm} = \frac{1}{4\pi j\omega\varepsilon}\left[\frac{l_n}{A_n^+}\int_{T_n^+} g_m^{\pm}(\mathbf{r}')\,ds' - \frac{l_n}{A_n^-}\int_{T_n^+} g_m^{\pm}(\mathbf{r}')\,ds'\right] \quad (12)$$

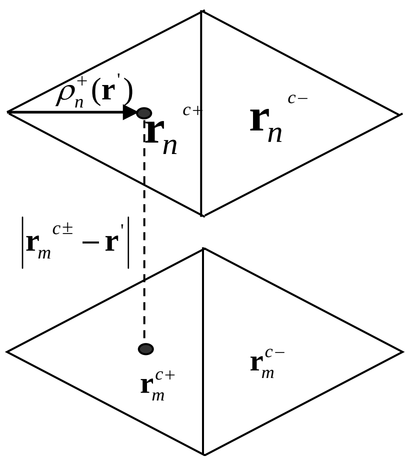


Fig.5. The *m*-th and *n*-th RWG elements

So, Impedance Z_{mn} correspond two edges elements *m* and *n* are

$$Z_{mn} = \ln\left[j\omega\left(\frac{A_{mn}^+ \cdot \rho_m^{C+}}{2} + \frac{A_{mn}^- \cdot \rho_m^{C-}}{2}\right) + \varphi_{mn}^+ - \varphi_{mn}^-\right] \quad (13)$$

Where, (**.**) denotes the dot product.

Integration in (12) can be done in short for triangle T_m of fig.6 as

$$\int_{T_m} g_m^{\pm}(\mathbf{r}')\,d\mathbf{s}' \approx A_m\, g\left(\mathbf{r}_m^c\right) \quad (14)$$

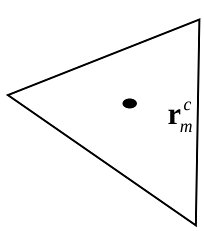


Fig.6. A single T_m triangle

Let E^{inc} is the electric field of an incident EM signal. In fig.7, electric field is in *x*-direction. Therefore, $E^{inc} = [E_x, 0, 0]$;

where $E_x = 1\times e^{-jkZ}$; $k = 2\pi/\lambda = \omega/c$. If the plate is located at Z = 0 then $E^{inc} = [1, 0, 0]$ V/m is the polarization of the plane wave. Now the voltage vector $V_m = l_m[E_m^+ . \rho_m^{c+}/2 + E_m^- . \rho_m^{c-}/2]$ where $E_m^{\pm} = E^{inc}(r_m^{\pm})$ and

$$E_m^{\mp} = [1\times e^{-jkr_m^{c\pm}}, 0, 0] \quad V/m \quad (15)$$

Where, m = 1, 2, 3, … , M .

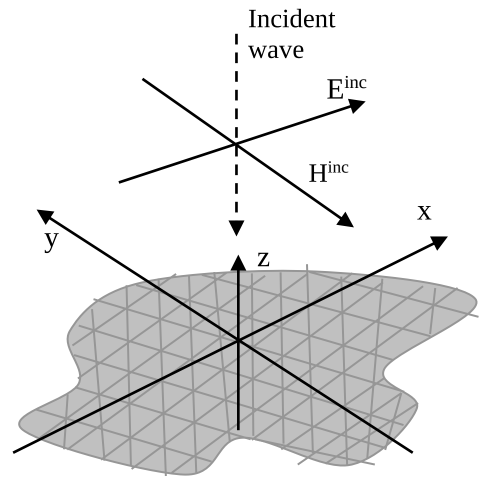


Fig.7. Incident field geometry for the patch

Now the moment equation **Z.I** = **V**, where **Z** is an *M* x *M* impedance matrix and **V** is the voltage vector with dimension **M** x 1 and $\mathbf{I} = [I_1, I_2, I_3, \cdots, I_M]^T$, is the **M** × 1 current coefficient vector, where *T* represents transpose.

Now, the surface current diversity J_K for a given triangle *k* is obtained as

$$J_K = \sum_{m=1}^{M} I_m f_m(\mathbf{r}) \quad (16)$$

;where **r** is an observation point in T_k and the basis function as [13-14]:

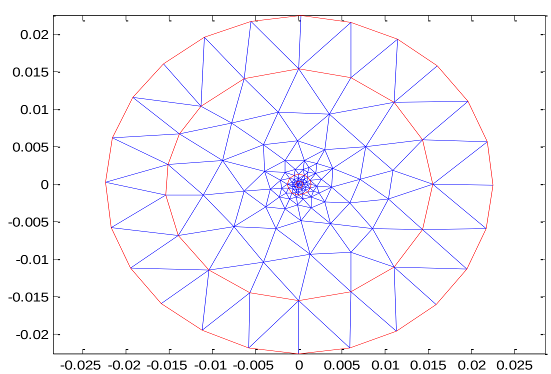
$$f_m(\mathbf{r}) = \begin{cases} \frac{l_m}{2A_m^+}\rho_m^+(\mathbf{r})\,; \mathbf{r}\ in\ T_m^+ \\ \frac{l_m}{2A_m^-}\rho_m^-(\mathbf{r}); \mathbf{r}\ in\ T_m^- \\ 0; \quad Otherwise \end{cases} \quad (17)$$

The entire analysis of this section is simulated using MATLAB 2013 and the corresponding result is shown in next section.

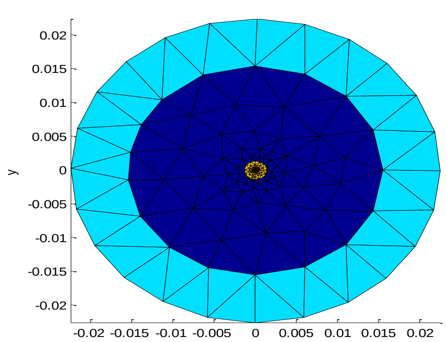
III. Results

Fig. 8(a) shows the top view of distribution of rwg elements of a circular patch antenna. The same figure is also shown in 8(b) in a different form to distinguish the microstrip and the ground plate. Here the feed point is at the center of the patch. Fig. 9(a) shows the 3D view of the patch antenna along with the distribution of the rwg elements where the fig. 9(b) includes the dielectric material. The dimensions of the antennas are visualized from the fig. 8 and 9.The profile of resistance and reactance of the antennal is shown in fig. 10. The resistance attains at its peak value at 2.3GHz and the reactance reaches at the peak value at 2.25GHz. The behavior of the impedance of the antenna is almost like a bandpass filter. Finally fig.11 shows the 2D and 3D radiation pattern of the antenna. The smaller circle of the fig. 11(a) indicates the radiation pattern of the cross-polar component and the outer circle indicates that of co-polar component. The directivity of the 'in-plane electric field component' is called the co-polar directivity that of the 'out of-plane electric field component' is called the cross-polar directivity. The small circle on 2D radiation pattern is the cross-polar component and the larger circle is the co-polar radiation pattern. Both the radiation pattern is omni-directional.

Let us now shift the feed point at one corner keeping the geometry of the antenna like before. The corresponding 2D and 3D distribution of RWG elements are shown in fig. 12 and 13 respectively. Now the peak amplitude of the resistance and reactance is shifted at 2.375GHz and 2.3GHa respectively shown in fig.14. The radiation pattern of in-polar and cross-polar components are shown in fig.15. (a). Instead of omni-directional now the radiation pattern of co-polar component becomes directional but still the cross polar component remains omni-directional but its coverage is reduced.

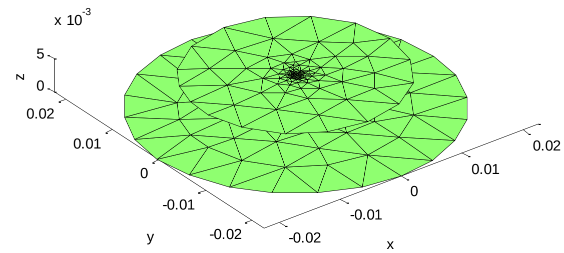


8(a)

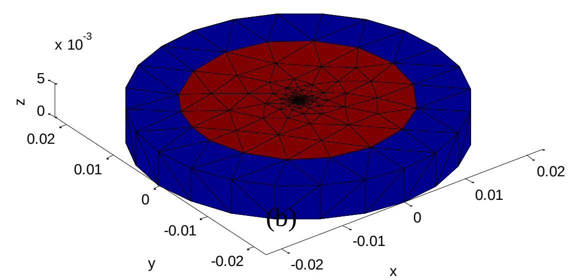


8(b)

Fig.8. Surface mesh of patch antenna (circular patch with feed at the center)



4(a)



4(b)

Fig.9. Volume mesh of patch antenna

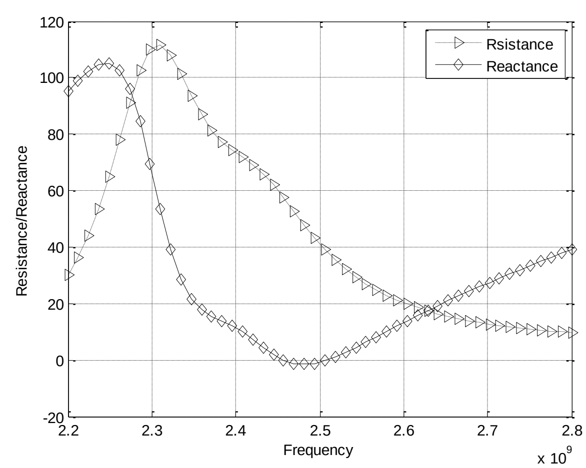
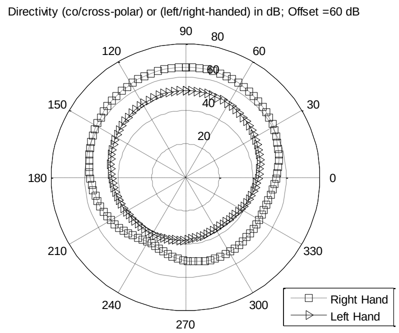
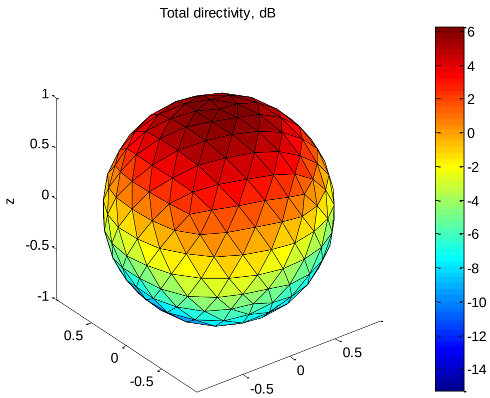


Fig.10. Profile of impedance of patch antenna

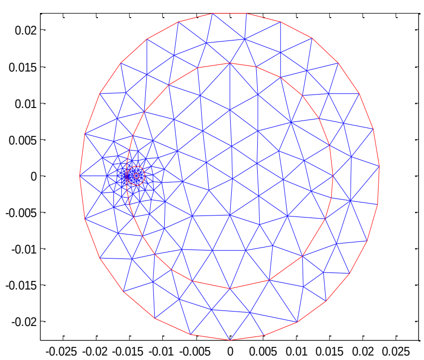


(a) E- plane

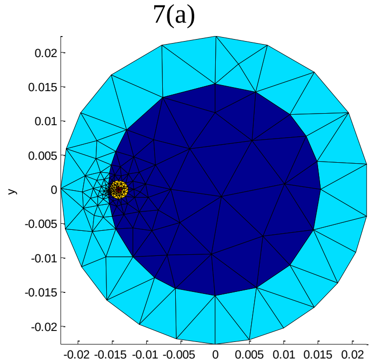


(b) 3D pattern (Directivity)

Fig.11. Radiation pattern of patch antenna (Circular shape with feed at the center)

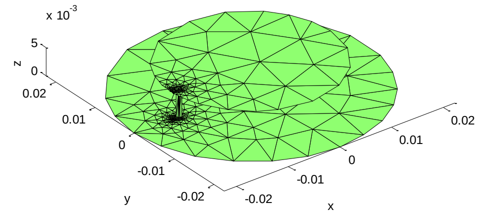


7(a)

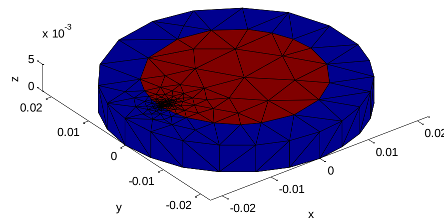


(b)

Fig.12. Surface mesh of patch antenna (circular patch with feed at one corner)



(a)



(b)

Fig.13. Volume mesh of patch antenna

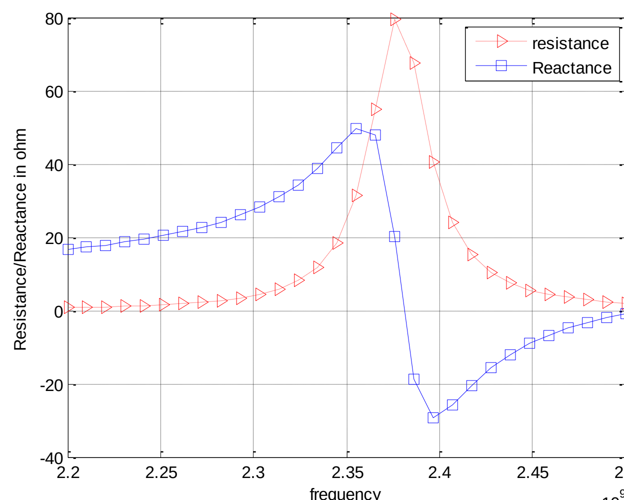
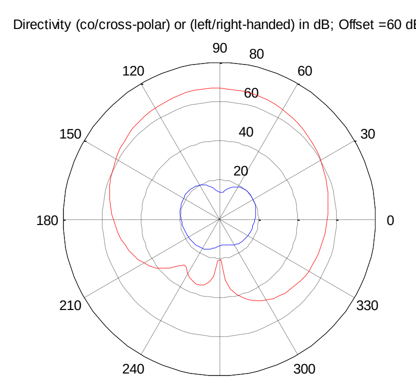
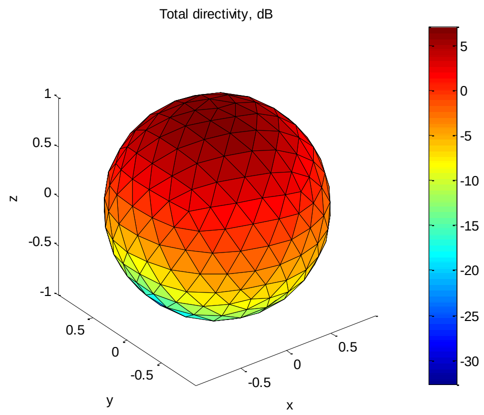


Fig.14. Profile of impedance of patch antenna



(a) E-plane plane



(b) 3D pattern (Directivity)
Fig.15. Radiation pattern of patch antenna (Circular shape with feed at one corner)

Next we used rectangular patch antenna of center feed whose RWG pattern is shown in fig.16 and 17 (both side view and top view). The peak amplitude of resistance and reactance (fig.18) are found almost at the same frequency like the case of circular patch. The radiation pattern of in-polar component is directional but that of cross polar component remains omni-directional but its coverage is reduced like edge feed case of circular patch shown in fig.19. For the case of edge feed of rectangular patch, the RWG components and the impedance profile are shown in fig. 20, 21 and 22. Finally the radiation pattern of in-polar component and cross polar component both are found directional but the coverage of cross polar component is reduced shown in fig.23.

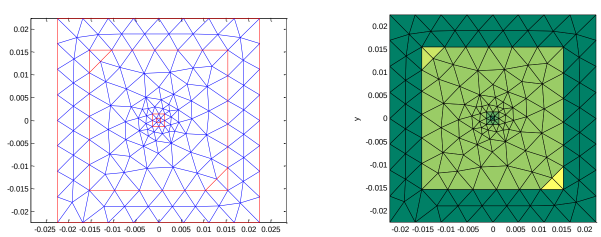
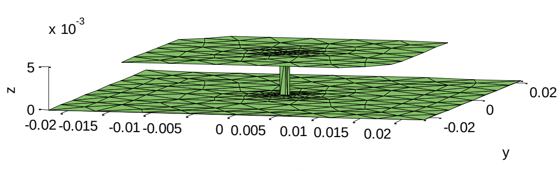
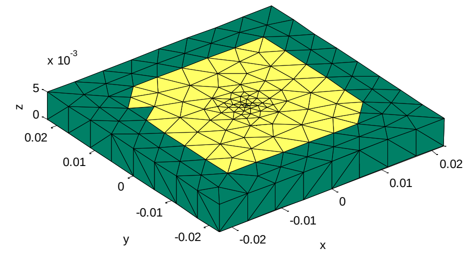


Fig.16. Surface mesh of patch antenna (rectangular patch with feed at the center)



(a)



(b)
Fig.17. Volume mesh of patch antenna

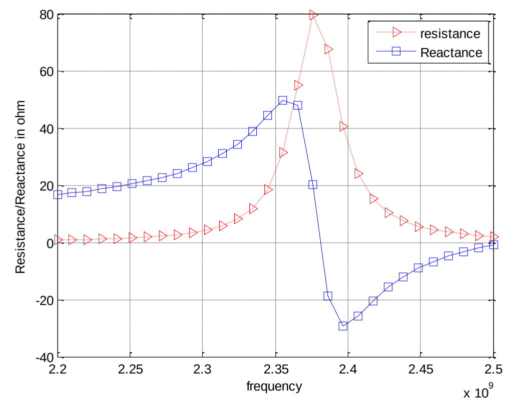


Fig.18. Profile of impedance of patch antenna

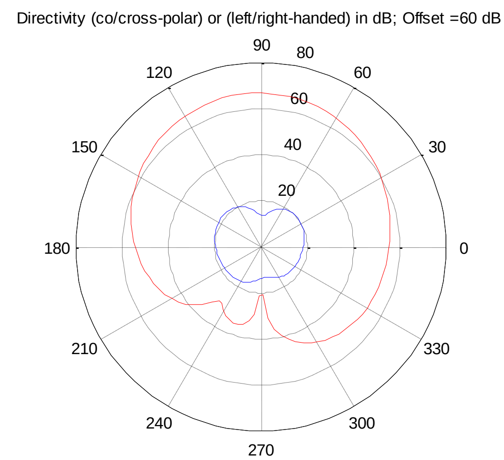


Fig.19. Radiation pattern of patch antenna on E-plane (rectangular shape with feed at the center)

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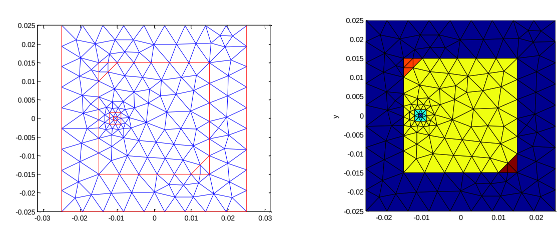
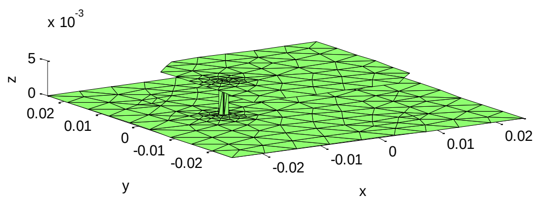
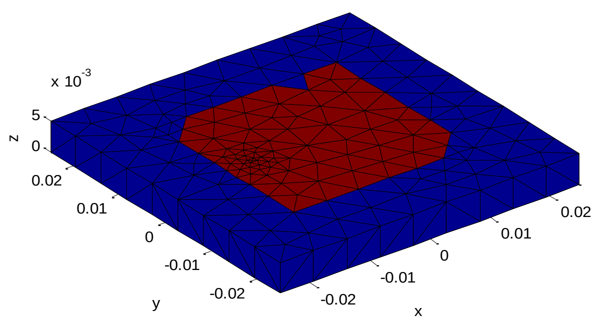


Fig.20. Surface mesh of patch antenna (rectangular patch with feed at one corner)



(a)



(b)
Fig.21. Volume mesh of patch antenna

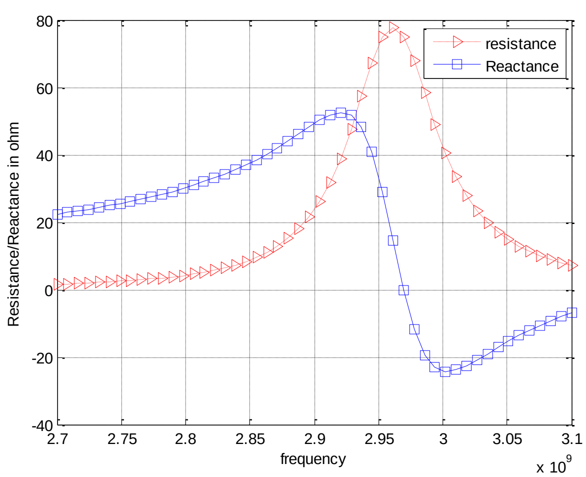


Fig.22. Profile of impedance of patch antenna

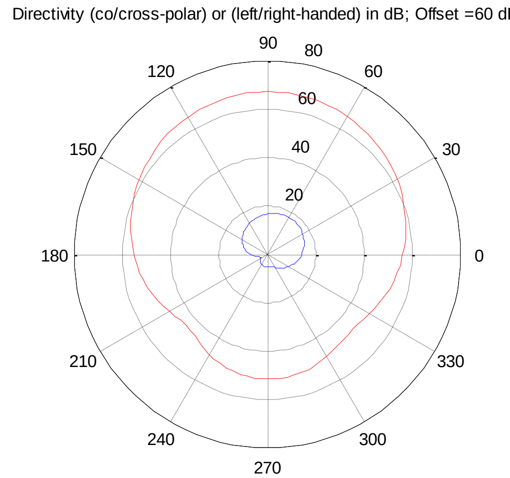


Fig.23. Radiation pattern of patch antenna on E-plane (rectangular shape with feed at one corner)

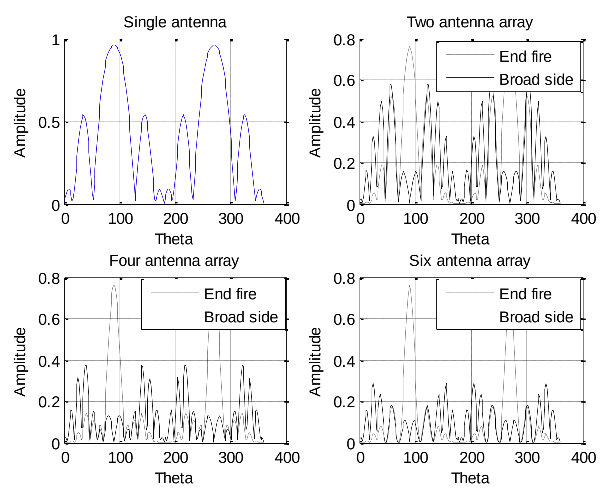


Fig.24. Radiation pattern of patch array

Finally the radiation pattern of a rectangular patch antenna with dimension of, λ = 12cm, $L_e = \lambda/2$, h =1cm and $w = \lambda/8$ is taken considering single antenna and linear array with separation of $d = \lambda/2$. Here both end-fire and broadside array is considered for 2, 4 and 6 antenna case and the corresponding radiation pattern is shown in fig. 24. It is visualized that patch antenna is more successful for end fire configuration since directivity becomes sharp and intensity of electric filed is found high.

IV. CONCLUSION

The paper compares the performance of rectangular and circular patch antenna changing the position of feed point taking input impedance and radiation pattern as parameters. The result of the paper reveals that for circular strip case the radiation pattern of both co-polar and cross-polar component are omni directional when the feed point is at the center. When the feed point is moved at one corner the co-polar component becomes directional but still the cross-polar component remains omni directional. In case of rectangular strip both the components are approximately omni when the feed point is at the center. For the case of corner feed point both the components become directional. Again for both circular and rectangular patch cases the peak value of resistance and reactance is shifted at higher frequency when the feed point is at the corner. Finally the weak radiation of the antenna is strengthen and made more direction using linear array. The analysis of the paper will be helpful for a wireless network planner to choose the optimum antenna for coverage of a small network.

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