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CHARACTERISTIC MODE ANALYSIS OF ANTENNA

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Abstract

The main objective is to design different types of antenna with the desired radiation characteristics using the most effective design methods. It is used to obtain numerical approach for antenna design and predicting radiating behaviour of antenna by analysis of characteristic modes. The theory of characteristics mode is used to synthesize desired current distribution and radiating behavior of an antenna. The surface current distribution of different modes of antenna identifies the optimum feeding point for the designed antenna. The designed antenna may operate at multiple standards so it may provide multiband or broadband operation. It may be facilitate orthogonal radiation patterns at a given frequency of multiple characteristic modes, which provide effective multiple input multiple output (MIMO) antennas.

***Key Words*:**Theory of characteristic modes (TCM), Modal analysis, microstrip antenna, reflection coefficient, current distribution, radiation pattern.

1 Introduction

At present antenna design is essentially utilized on commercial applications, especially cellular telephony systems and wireless systems. The proposing new antennas are mainly devoted to describe the antenna geometry and its radiating behavior, while the design procedure does not match the requirement and considerations, therefore the problems have to limit. Their problem is that the physical accuracy is less, so the operating principles of the antenna are mislaid. The theory of characteristic modes (TCM) gives the number of current distribution and radiation pattern with respect to the different modes of frequency. The theory of characteristic modes was first introduced by Garbacz [1] and later developed by Harrington and Mautz [2]. A procedure for conducting bodies of arbitrary shape is developed [3]. Then the theory of characteristic modes is revisited for modern applications designed antenna [4].The modal analysis is proposed for multiple input multiple output (MIMO) applications [5-7]. Using this technique, both multiband resonance and bandwidth is achieved [8]. This analysis is also used for performance improvement of circularly polarized slotted patch antenna [9].Characteristic mode analysis (CMA) can be used to optimize the shape of antenna, to improve the antenna topology, decide on the antenna placement and synthesize a desired antenna pattern for ultra wideband (UWB) transverse electromagnetic (TEM) horn and long term evolution (LTE) antenna using FEKO [10]. The analysis of eigen current distribution gives new feeding techniques. This technique will be of help to design compact ultra wideband antenna for chip integrating transceivers [11]. The characteristic mode is equivalent to the method of moments (MoM) equations using the singular value decomposition and later by its special case of spectral decomposition of matrix [12]. A new method of tracking procedures is introduced for theory of characteristic mode [13]. The MoM antenna is simulated with MATLAB using Rao-Wilton-Glisson (RWG) basis functions [14] and [15]. The modal methods are also used to design complicated shapes like fractal patch antenna [16]. The effects of ground plane size, effects of slot on the notched frequency characteristics and effects of miniaturization of monopole antenna is analyzed with the help of different modes of antenna [17].

The rest of the portion is organized as follows: Section II briefly reviews the theory of characteristic mode and flow chart of TCM. In Section III, IV and V, the design of antenna, reflection coefficient, current distribution and radiation pattern of the different modes of rectangular, circular and hexagonal shape of antennas are explained. Finally, some conclusions are given in Section VI.

2 THEORY OF CHARACTERISTIC MODES

The theory of characteristic modes (TCM) gives the number of current distribution and radiation pattern with respect to the different modes of frequency. The current distribution which is dependent upon eigen value and eigen vector. The mathematical formulation of characteristic modes that relates the current on conducting body as explained in [2],

$$[L(J)E^i]^{\tan} = 0 \tag{1}$$

where tan denotes the tangential components on the surface S. The operator L in (1) is linear and it is defined by

$$L(J) = j\omega A(J) + \Delta\Phi(J) \tag{2}$$

where A (J) and Φ (J) are vector and scalar potentials respectively. Physically, the term L (J) can be considered as the electric intensity at any point in space. This means that the operator L in (1) has the dimension of impedance:

$$Z(J) = [L(J)]_{\tan} \tag{3}$$

As drawn from [1], the impedance operator Z is complex, and it can be written as,

$$Z(J) = R(J) + jX(J) \tag{4}$$

The Characteristic current modes are obtained from the eigen value linear equation which is given as

$$X(\overrightarrow{J_n}) = \lambda_n R(\overrightarrow{J_n}) \tag{5}$$

where R and X are Real and imaginary parts of impedance operator Z=R+jX, λ_n is eigen value, $(\overrightarrow{J_n})$is eigen function. It is defined as the real currents on the surface of a conducting body that depends on shape and size. Thus design of antenna using theory of characteristic modes can be performed in way of:

- Characteristic current and associated characteristic fields are calculated.
- By the eigen values, determine the resonance frequency of the modes.
- The shape and size is modified until the desired frequency is obtained.
- At last, studying the current distribution of modes and obtain specific radiating field.

Fig.1. represents the flow chart of theory of characteristic modes (TCM).

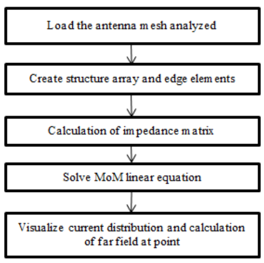


Fig.1. Flow chart of TCM

3 RECTANGULAR PATCH

Microstrip antenna is used for the applications such as aircraft, automobile vehicles and wireless applications. Microstrip antenna consists of dielectric substrate, a radiating patch on one side and a ground plane on the other side. Microstrip antennas are also referred to as patch antennas. The frequency of operation of the patch antenna is determined by the length L. The width W of the microstrip antenna controls the impedance on antenna feed. The radiation in microstrip patch antenna is along the width and not along the length of the patch. The electric field is zero at the middle of the patch, maximum at one side, and minimum on the opposite side.

A. Design of Rectangular patch

The rectangular patch is designed for 2.4 GHZ. The dimension of the rectangular patch depends on the length and width of the patch. The width of the microstrip patch antenna controls the impedance across the input. Larger width can also increase the bandwidth. Fig.1. illustrates the geometry of rectangular patch. Table I represents the dimensions of rectangular patch. The design calculation is given as follows:

Frequency, f = 2.4 GHz

Permittivity of FR4 substrate, ϵ_r= 4.3

Height of FR4 substrate, h=1.6mm

$a)Width of the Patch,$

$$W = \frac{c}{2f\sqrt{\frac{\epsilon_r+1}{2}}}$$

$$= 3 * 10^{11} * /4.8 * 10^9$$

Width of the Patch,

$$W = 38.39mm \tag{6}$$

b) Length of the Patch, L= $L_{eff} - 2\Delta$L Wavelength,

$$\lambda = \frac{c}{f} = \frac{3 * 10^{11}}{2.4 * 10^9}$$

= 125mm

Effective dielectric constant, ϵ_{eff}

$$= \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}[1 + 12h/w]^{1/2}$$

=2.65+1.65(0.8164)

=3.99706

Length Extension, Δ L

$$= 0.412h\frac{(\epsilon_{eff+0.3})(\frac{w}{h} + 0.264)}{(\epsilon_{eff-0.264})(\frac{w}{h} + 0.8)}$$

= 0.7412mm

Effective length, $L_{eff} = \dfrac{c}{2f\sqrt{\epsilon_r}}$= 31.2614mm

Length of the patch, L = $L_{eff} - 2\Delta$ L

L=31.2614 - 2(0.7412)

$$\textbf{Length of the patch, L=29.779 mm} \quad (7)$$

c) Feed length $= \dfrac{\lambda}{4\sqrt{\epsilon_r}} = 31.25/\sqrt{4.3}$

$$\textbf{Feed length = 15mm} \quad (8)$$

d) Feed width = 3 mm (For Characteristic impedance Z_o = 50Ω)

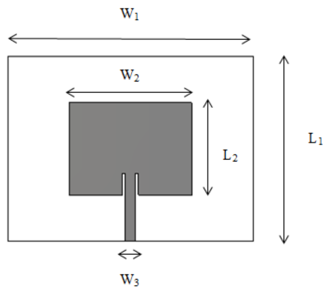


Fig.2. Rectangular Patch

TABLE I. Dimensions of Rectangular patch

Parameters	L_1	L_2	W_1	W_2	W_3
Dimensions (in mm)	59.558	76.78	29.779	38.39	3

B. Simulated Result

Fig.3. shows the current schematics of the six Eigen modes. Fig.4. shows the return loss of the rectangular patch. The return loss is obtained at -15 dB around 2.4 GHz. It covers applications of Bluetooth (2.4 - 2.484 GHz) and S band (2 4 GHz).

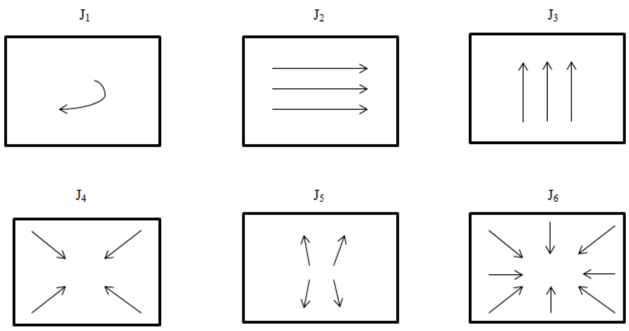


Fig.3. Current schematics for the six Eigen vectors

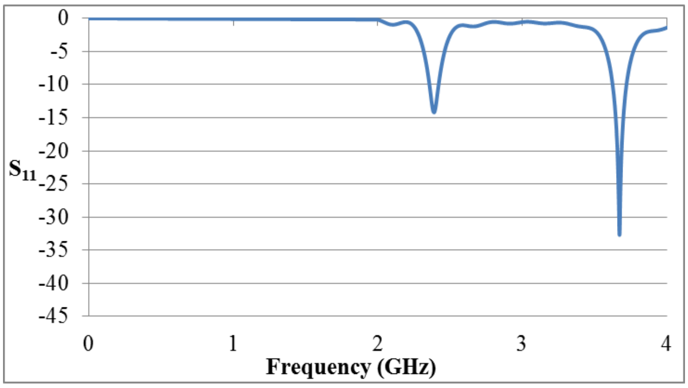


Fig.4. Return loss of Rectangular patch

C. Modal Analysis

The modal analysis which describes the current distribution and radiation pattern of different modes of resonant frequency. The Surface current of different modes of antenna is obtained by Eigen mode solver. It calculates the eigen values (resonant frequencies) and eigen modes (field patterns).

TABLE II. Modal analysis of Rectangular patch

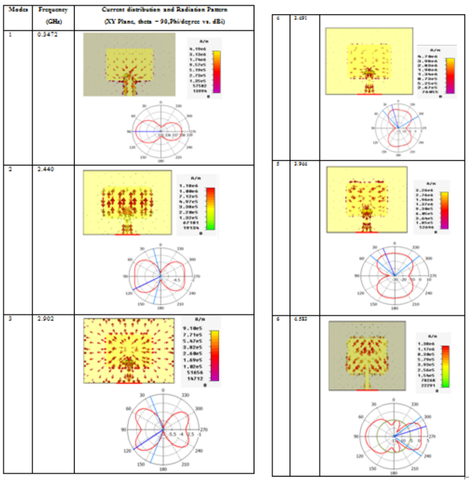


Table II represents the modal analysis of rectangular patch. The first mode J1 has current distribution near the feed point. It has less radiating behaviour. So this resonant frequency is not considered for antenna design. The second mode J2 has vertical currents. It has omnidirectional radiating pattern. The third mode J3 has high current distribution along z axis. It has omnidirectional pattern. J4 , J5 and J6 resonate at higher frequencies and the radiation is varied with respect to the resonant frequency.

4 CIRCULAR PATCH

The circular patch antenna consists of radiating patch, ground plane and the substrate material between the two planes. The circular patch of the antenna depends on the radius of the patch. It controls the modes of the antenna.

A. Design of Circular Patch

The circular patch is designed for 3.5 GHZ. The dimension of the rectangular patch depends on the radius of the patch. Fig.5. illustrates the geometry of circular patch. Table III represents the dimensions of circular patch. The design calculation is given as follows:

Radius of patch,

$$a = \frac{F}{\{1 + \frac{2h}{\pi a \epsilon_r [\ln(\frac{\pi a}{2h})] + 1.7726}\}^{1/2}}$$

Radius of patch, a= 12mm
where

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

The microstrip line is designed for impedance of 50 in order to match the feed line impedance which is given as

$$\frac{w}{h} = \frac{2}{\pi}[B - 1 - \ln(2B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r}(\ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r})]$$

h - Thickness of substrate
w - Width of microstrip line
ϵ- Dielectric constant of the substrate

$$B = \frac{60\pi^2}{Z_0 \sqrt{\epsilon_r}}$$

Z_0- Input impedance

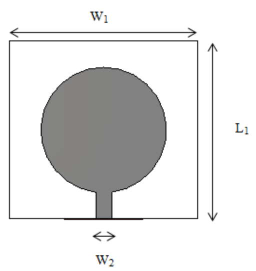


Fig.5. Circular Patch

TABLE III. Dimensions of Circular patch

Parameters	L_1	W_1	W_2
Dimensions (in mm)	36	34	3

B. Simulated Result

Fig.6. shows the return loss of the circular patch. The 10dB return loss bandwidth is from 3.5GHz to 5.8 GHz. It gives wide bandwidth. It covers applications of WiMax (3.3 4GHz) and C band (4 -8 GHz).

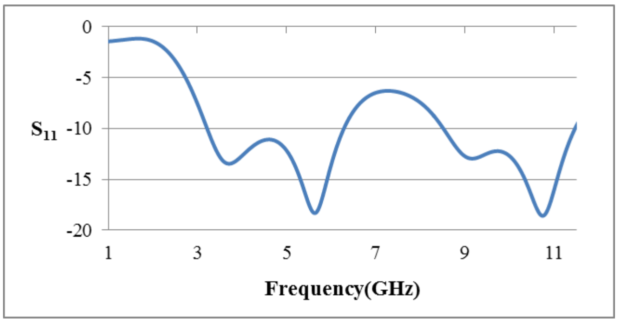
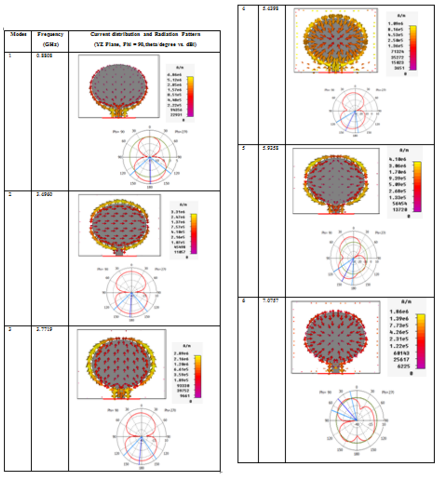


Fig.6. Return loss of Circular patch

Modal Analysis

Table IV represents the modal analysis of circular patch. The first mode J_1 has current distribution near the feed point. It has less radiating behaviour. So this resonant frequency is not considered for antenna design. The second mode J_2 has vertical currents. It has omnidirectional radiating pattern. The third mode J_3 has high current distribution along z axis. It has omnidirectional pattern. J_4, J_5 and J_6 resonate at higher frequencies and the radiation is varied with respect to the resonant frequency. The radiation pattern of all higher frequencies is directional and current distribution is better so it has return loss of less than 10dB. The spectrum gives wide bandwidth.

TABLE IV. Modal analysis of Circular patch



5 HEXAGONAL PATCH

The configuration of the hexagonal patch antenna is shown in Fig.7. withW_2=12mm, L_s=36mm, W_s=34mm, substrate thickness h=1.6mm, dielectric constant ϵ_r=4.3. Table V represents the dimensions of hexagonal patch.

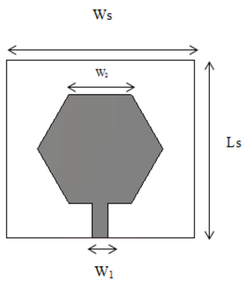


Fig.7. Hexagonal Patch

TABLE V. Dimensions of Hexagonal patch

Parameters	Ls	Ws	W1	W2
Dimensions (in mm)	36	34	3	12

A. Simulated Result

Fig.8. shows the return loss of the hexagonal patch. The 10dB return loss bandwidth is from 3.8 GHz to 10.6 GHz. It gives ultra

wide bandwidth. It covers applications of WiMaX (3.3 4GHz) and C band (4 -8 GHz).

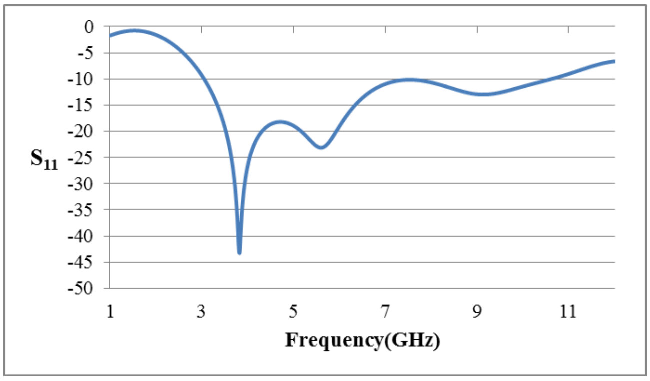
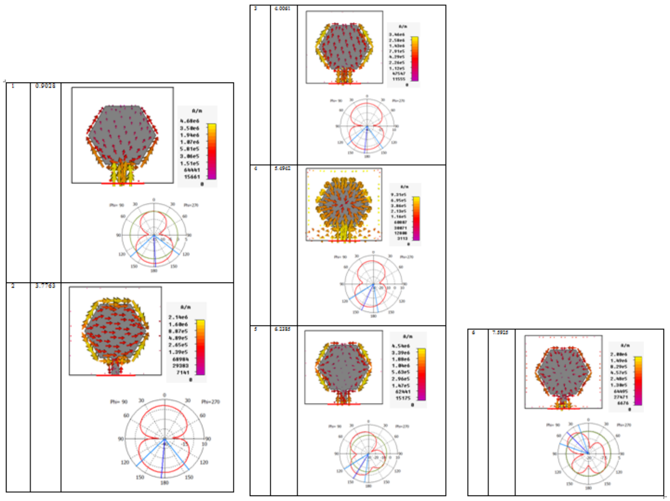


Fig.8. Return loss of Hexagonal patch

B. Modal Analysis

Table VI represents the modal analysis of hexagonal patch. The first modeJ_1has current distribution near the feed point. It has less radiating behaviour. So this resonant frequency is not considered for antenna design. The second mode J_2has vertical currents. It has omnidirectional radiating pattern. The third mode J3 has high current distribution along z axis. It has omnidirectional pattern. J_4, $J_5$and J_6 resonate at higher frequencies and the radiation is varied with respect to the resonant frequency. The radiation pattern of all higher frequencies is directional and current distribution is better so it has return loss of less than 10dB. The spectrum gives ultra wide bandwidth.

TABLE VI. Modal analysis of Hexagonal patch



6 CONCLUSION

The different types of antennas have been presented, with the aim of review the theory of characteristics mode and demonstrating the analysis of characteristic mode. In contrast to other classical design methods, characteristic modes bring physical insight into the current distribution and radiating behavior of the antenna. It is used to identify new shape of the antenna and gives a desired antenna pattern. This technique is used for multi band, ultra wide band and MIMO applications.

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