HEXAD LOOP (H-LOOP) ANTENNA IN FRONT OF 60^0 CORNER REFLECTOR FOR EMC MEASUREMENT

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ABSTRACT

A newly developed EMC (Electromagnetic Compatibility) antenna is proposed in this paper which can simulate highly directive standard EM (Electromagnetic) wave. The proposed antenna can be made by placing a one-sixth of conducting loop-wire (H-Loop) in front of a 60° degree corner reflector. The mathematical model of such a quasi-shield probe called H-loop is developed. Developed antenna parameters have been compared with those of the existing quarter loop antenna and a complete loop antenna. The designed H-loop antenna has been constructed and the radiation pattern of the antenna is measured to compare the theoretical radiation pattern. Comparison shows a very good agreement with the theoretical pattern.

I. INTRODUCTION

Scientists and engineers in the field of Electromagnetic Compatibility (EMC) are always interested in designing electronic systems which are invulnerable to hostile or interfering Electromagnetic environments and at the same time electromagnetically harmless to their neighbouring devices. The simplest way of reducing ingress or emission of Electromagnetic Interference (EMI) is by enclosing electrical and electronic equipment using conducting materials. Again, the level of shielding of the enclosure against EMI is usually determined by the measurement of Shielding Effectiveness (SE) of the material used for the enclosure [1].

Standard field simulation is the starting point of any SE measurement technique. Thus it is necessary for an antenna which could simulate standard EM waves. Recently, a Quarter loop antenna in front of 90° reflector was designed for near magnetic field SE measurement of the plannar sheet [2]. In this paper a H-Loop antenna has been proposed to simulate standard EM wave for magnetic-field shielding effectiveness measurement of the plannar sheet.

The paper is organised as follows. In section II the mathematical model of the H-Loop antenna is presented. Section III contains the H-Loop antenna parameters. Input impedance of the H-Loop antenna is presented in section IV. Comparison of developed H-Loop antenna parameters with that of a quarter loop as well as a complete loop antenna are presented in section V. Construction of the H-loop and measurement of radiation pattern of the designed H-loop antenna is given in section VI. Section VII contains the concluding remarks.

II. MATHEMATICAL MODEL

The mathematical model of the H-loop antenna has been developed by using the image theory and the theory of pattern multiplication [3]. The field due to the arc (one sixth of the loop) is to be calculated first and then applying image theory for determining the images of the arc. The effect of these images on the field of the original H-loop are then superimposed by a method similar to pattern multiplication.

One sixth of loop in front of a 60° corner reflector produces five image loops of the original one. Thus the H-Loop antenna can be considered an array of coplanar three pair of dipoles shown in Fig.1. Each pair of dipoles are parallel to each other carrying equal and out of phase current. It is assumed that the current through the arc is in the ϕ direction only, so the vector potential at any point in space will only be ϕ directed. The far field then is computed from the vector potential of coplanar hexad dipoles and the vector potential of the one sixth of loop element.

It is well known that an arc can be considered as an array of infinitesimal dipole. To compute the vector potential of the one sixth of loop and coplanar hexad dipoles the differential length $a d\phi$ of the arc is considered at point A_1, shown in Fig.2. The distance (r_1) between the observation point $P(r,\theta,\phi)$ and the point A_1 can be computed as [4]

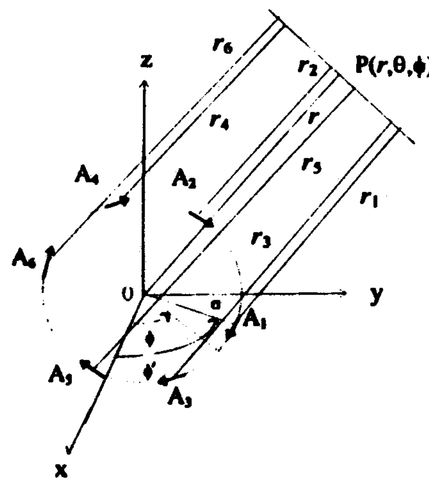


Fig. 1 Geometry of H-Loop and its images.

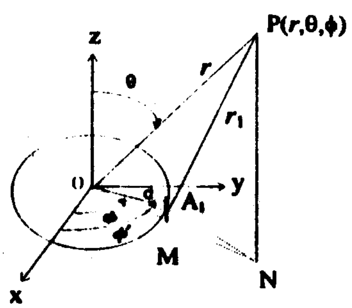


Fig. 2 Geometry of one sixth of loop for determining the vector potential of the H-Loop arc.

$$r_1 = r\left[1 - \frac{2a}{r}\sin\theta\cos(\phi' - \phi)\right]^{1/2} \qquad (1)$$

where a is the loop radius.

It is assumed that $a \ll r$, thus, for distance consideration only first term of the expression is taken. The eqn. 1 then becomes as $r_1 \cong r$. For phase consideration first two terms of the expression are taken and eqn. 1 then becomes as

$$r_1 \cong r - a\sin\theta\cos(\phi - \phi') \qquad (2)$$

Similarly the distances between the observation points and the dipoles at A_2, A_3, A_4, A_5 and A_6 can be computed as

$$\begin{aligned} r_2 &= r - a\cos(\phi' - \phi + 60^\circ)\sin\theta \\ r_3 &= r - a\cos(\phi' - \phi - 60^\circ)\sin\theta \\ r_4 &= r + a\cos(\phi' - \phi - 60^\circ)\sin\theta \\ r_5 &= r + a\cos(\phi' - \phi + 60^\circ)\sin\theta \\ r_6 &= r + a\cos(\phi' - \phi)\sin\theta \end{aligned} \qquad (3)$$

The vector magnetic potential at point P due to the dipole of length $a d\phi$ containing the uniform current along the length at point A_1 can be written as [5]

$$\vec{A}_1 = k e^{j\beta a\cos(\phi'-\phi)\sin\theta}\left[\hat{x}\sin\phi' - \hat{y}\cos\phi'\right] \qquad (4)$$

Where $k = \dfrac{\mu[I]a d\phi}{4\pi r_1}$

$[I] = I_o e^{j(\omega t - \beta r)}$ = retarded current at the point of observation P with respect to the centre of the loop arc.

β = propagation constant ($=2\pi/\lambda$)

$\hat{x}$ & $\hat{y}$ are the unit vector along the x and y direction of the ctangular co-ordinate system respectively.

Similarly, the vector magnetic potentials at point P due to the dipole at point A_6 can be written as

$$\vec{A}_6 = -k e^{-j\beta a\cos(\phi'-\phi)\sin\theta}\left[\hat{x}\sin\phi' - \hat{y}\cos\phi'\right] \qquad (5)$$

For $\lambda \gg a$, and $\beta a \ll 1$, the vector magnetic potential at point P due to the pair of parallel dipoles at points A_1 and A_6 can be written as

$$\vec{A}_{1+6} = 2jk\beta a\sin\theta\cos(\phi' - \phi)\left[\hat{x}\sin\phi' - \hat{y}\cos\phi'\right] \qquad (6)$$

Similarly, vector magnetic potential for the pair of dipoles at points A_2 and A_5, and A_3 and A_4 can be obtained.

The resultant vector magnetic potential due to the three pair of dipoles at the far field point $P(r,\theta,\phi)$, becomes as

$$\begin{aligned} \vec{A} &= \vec{A}_{1+6} + \vec{A}_{2+5} + \vec{A}_{3+4} \\ &= 3jk\beta a\sin\theta\left[\hat{x}\sin\phi - \hat{y}\cos\phi\right] \\ &= \hat{\phi}\,3jk\beta a\sin\theta \end{aligned} \qquad (7)$$

where, $\hat{\phi}$ is the unit vector along the ϕ direction.

It can be seen from eqn. 7 that, for any orientation of the three pair of parallel dipoles but opposite in phase, the resultant vector potential will be the $3j\beta a\sin\theta$ times of that of single dipole. The term $3j\beta a\sin\theta$ of eqn. 7 is known as the array factor.

The vector potential ($\vec{A}_{arc}$) at point $P(r,\theta,\phi)$ in free space due to the current in the one sixth of loop can be written as [5]

$$\vec{A}_{arc} = \frac{\mu[I]a}{4\pi r}\int_0^{\pi/3} e^{j\beta a \sin\theta \cos(\phi - \phi')} d\phi' \qquad (8)$$

For $\lambda >> a$ and $\beta a << 1$, the solution of definite integral of eqn. 8 equals to $\pi/3$ and eqn. 8 then reduces to

$$\vec{A}_{arc} = \frac{\mu[I]a}{4\pi r}\cdot\frac{\pi}{3}\vec{\phi} \qquad (9)$$

The same analysis can be extended to compute the vector potential due to original arc and its five similar images. The resultant vector magnetic potential due to the three pair of dipoles at the far field point $P(r,\theta,\phi)$ will be

$$\vec{A} = \hat{\phi} 3 j\beta a \sin\theta \times \vec{A}_{arc} \qquad (10)$$

Field Computation :

In the far field region of the H-loop antenna, only ϕ component of the electric field and θ component of the magnetic field are found. The expression for far electric and magnetic field produced by the arc alone can be obtained from the vector potential as

$$E_{\phi arc} = -j\omega A_{arc} = -j\omega\frac{\mu[I]a}{4\pi r}\frac{\pi}{3} \qquad (11)$$

$$H_{\theta arc} = -j\frac{\beta}{\mu}A_{arc} = -j\beta\frac{[I]a}{4\pi\ r}\frac{\pi}{3} \qquad (12)$$

The net radiated electric and magnetic field of the H-Loop antenna can be obtained by multiplying eqn. 11 and eqn. 12 with the array factor ($3j\beta a\sin\theta$) respectively. If the co-ordinate axes are chosen so that the loop is in the x-y plane and the reflectors in the x-z and y-z plane respectively then the net field expressions (i.e. eqn. 11 and eqn. 12) valid for azimuth angle ϕ of 0 to $\pi/3$ and the polar angle θ of 0 to π (i.e. in front of the reflector). Reflector is assumed as an infinite ground plane. Thus neither magnetic nor electric field is present behind the reflector. The radiated field expressions can then be written as

$$E_{\phi} = \frac{\mu\omega[I]a}{4r}\beta a\sin\theta \quad \text{for } 0 \le \phi \le \pi/3 \text{ and } 0 \le \theta \le \pi$$
$$= 0 \quad \text{elsewhere} \qquad (13)$$

$$H_{\theta} = \beta\frac{[I]a}{4r}\beta a\sin\theta \quad \text{for } 0 \le \phi \le \pi/3 \text{ and } 0 \le \theta \le \pi$$
$$= 0 \quad \text{elsewhere} \qquad (14)$$

From the field expressions of the quarter loop and those of the complete loop which are given in the literatures [2, 3], it can be seen that the radiation pattern of the H-loop is similar to that of a quarter loop and that of a complete loop but the radiated field area is different from each other.

III. ANTENNA PARAMETERS

To calculate two important antenna parameters (such as directivity and gain) it has been assumed that the antenna radiates only in front of the reflectors i.e. θ varies from 0 to π and ϕ from 0 to $\pi/3$ and $a<<\lambda$.

The directivity of an antenna is the ratio of maximum to average radiation intensity. Again, these radiation intensities are related to the total power radiated by the antenna. For H-Loop antenna total radiated power will be

$$P_r = \frac{5\pi^2\beta^4 a^4 I_o^2}{3} \qquad (15)$$

The maximum and average radiation intensities are

$$U_m = \frac{9}{4\pi}P_r,\ U_{av} = \frac{P_r}{4\pi} \qquad (16)$$

Hence, the directivity of H-Loop antenna (D_H) will be 9.

The gain of the H-Loop antenna can be written as

$$G_H = \eta D_H \qquad (17)$$

where the radiation efficiency η is

$$\eta = \frac{R_r}{R_r + R_{ohmic} + R_{ref}} \qquad (18)$$

where R_r is the radiation resistance, R_{ohmic} is the ohmic resistance and R_{ref} is the reflector resistance.

IV. INPUT IMPEDANCE

The equivalent circuit of the H-Loop antenna can be represented as [2]

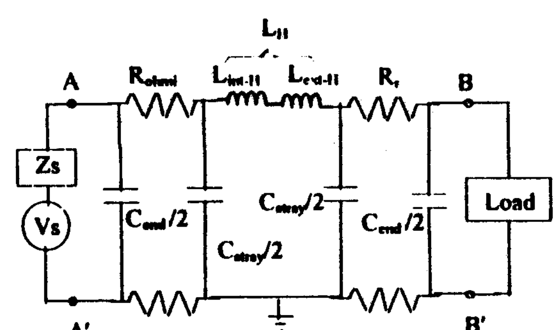


Fig.3 Equivalent circuit of the H-Loop antenna.

In Fig. 3, resistances are given as [4]

$$R_r = \frac{10}{3}\beta^4 A^2, \quad R_{ohmic} = \frac{a}{6r_w}\sqrt{\frac{\omega\mu}{2\sigma}}$$

$$R_{ref} = \frac{a}{(w+t)}\sqrt{\frac{2\omega\mu}{\sigma}} \qquad (19)$$

where A is the area of the loop, r_w is the wire radius, w is the width and t is the thickness of the reflector sheet.

Internal inductance (L_i) and external inductance (L_{ext}) are given as [5]

$$L_i = \frac{\mu_0 a}{24} \quad henry \qquad (20)$$

$$L_{ext} = a\mu\left[ln\left(\frac{8a}{r_w}\right) - 2\right] \quad henry \qquad (21)$$

The end capacitance (neglecting the fringing capacitance) is obtained as [4]

$$C_{end} = \varepsilon_0\varepsilon_r \frac{2\pi r^2}{t_n} \qquad (22)$$

where t_n is the width of the insulating material used between the reflector and the arc.

The stray capacitance (neglecting fringing capacitance) between the one sixth of loop and the reflector shown Fig. 4 is determined as [4]

$$C_{stray} = 2\varepsilon_0 r_w \sqrt{\pi}\int_{\pi/6}^{\pi/3} \frac{d\theta}{sin\theta} \qquad (23)$$

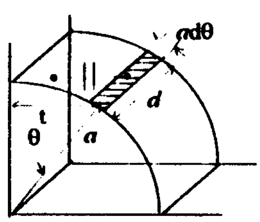


Fig. 4 Model of stray capacitance of the H-Loop antenna [2].

The input impedance of the H-Loop antenna (the impedance looking into the terminal AA') is then obtained from circuit theory.

V. RESULTS AND COMPARISON

Radiated fields and gain of the H-Loop antenna have been computed by considering a = 15cm, r_w = 8mm, the size of reflector plate as 60cm x 60cm x 2mm, and t_n = 3mm. Predicted normalized planar field pattern has been shown in Fig. 5. Predicted gain of the proposed H-Loop antenna has been compared with that of the quarter loop antenna and a complete loop antenna. This comparison is shown in Fig. 6. Fig. 6 shows that the gain of the proposed antenna is higher than that of the quarter loop and that of a complete loop. The directivity of the H-Loop has also been compared with that of quarter loop as well as that of a complete loop. It is found from the table that the directivity of H-Loop antenna is 1.5 times of that of a Q-loop and 6 times of that of a complete loop antenna.

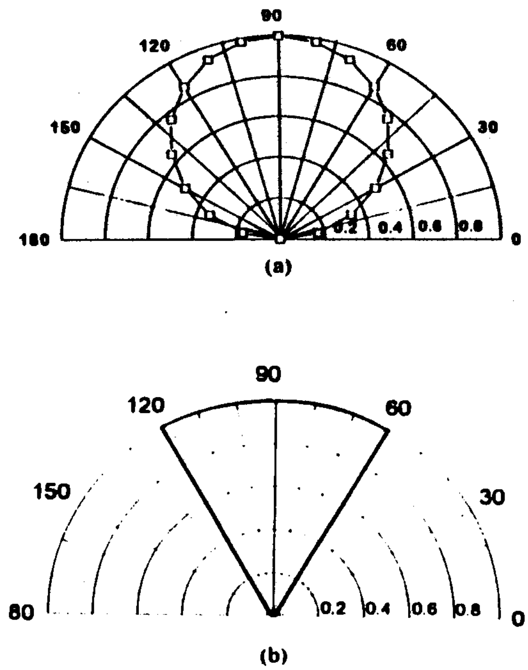


Fig. 5 Planar radiation pattern (E_ϕ) of the H-Loop antenna at a) ϕ = 90° plane with θ varying from 0° to 360° b) θ = 90° and ϕ varying from 0° to 360°.

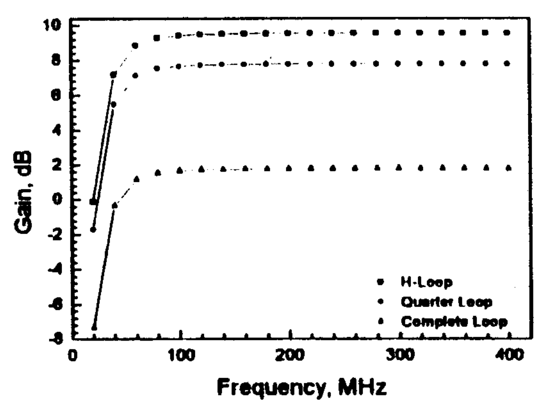


Fig. 6 Gain vs frequency curve of H-Loop, Quarter Loop & Complete Loop Antenna

Table : 1 Directivity comparison

Antenna	Complete loop [3]	Quarter loop [2]	H-loop[4]
Directivity	1.5	6	9

VI. CONSTRUCTION OF H-LOOP ANTENNA AND MEASUREMENT OF RADIATION PATTERN

Constuction :

An aluminum rod of 16mm dia is bended at a 60° arc to construct a fractional loop of 15cm radius. A square corner reflector is used to improve the directional property as well as gain of the H-Loop antenna. The length of the reflector is to be large as compared to the antenna-to-corner spacing (i.e. the length of the loop radius), so that the reflector can be considered as an infinite ground plane to hold the image theory. The minimum length of each side of the square-corner reflector is considered to be the three times of the antenna-to-corner spacing (i.e. loop radius) [3]. Therefore, for the present work each side of the reflector is assumed to be the four times of the loop radius (i.e. 4 x 15 = 60cm). The region behind the sheet reflector would not be a full shadow region due to the sharp edge of the reflector. Thus the diffracted radiated field is found into the shadow region [6]. However, this diffracted radiation can be reduced by converting the sharp edges of the reflectors into the rolled edges [7], which have a curvature of radius greater than $\lambda/4$. Thus in this work, the edges of the reflector are curved with a curvature radius of greater than 75cm to reduce the diffracted field at frequencies above 100MHz. An aluminum sheet of 2mm thickness is used in order to construct the reflector. Finally, the hexad loop is fixed onto the reflector by the plastic screw. A diagram of the H-Loop antenna with end connections is shown in Fig. 7.

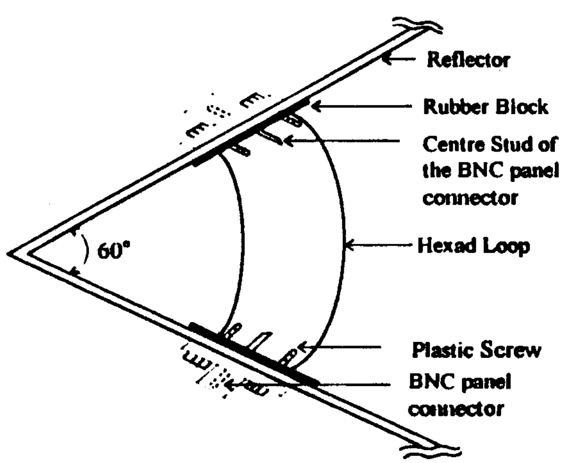


Fig. 7 H-Loop antenna in front of 60° corner reflector .

Radiation pattern measurement :

Throughout the measurement of radiation pattern, it is assumed that the developed H-loop antenna is treated as a passive, linear and reciprocal devices. Thus the two H-loop antennas of the same dimension are constructed in order to experimentally observe the radiation pattern of the developed antenna. One is used as a transmitting antenna while the other is used as a receiving antenna. Schematic block diagram of the test set- up is shown in Fig. 8.

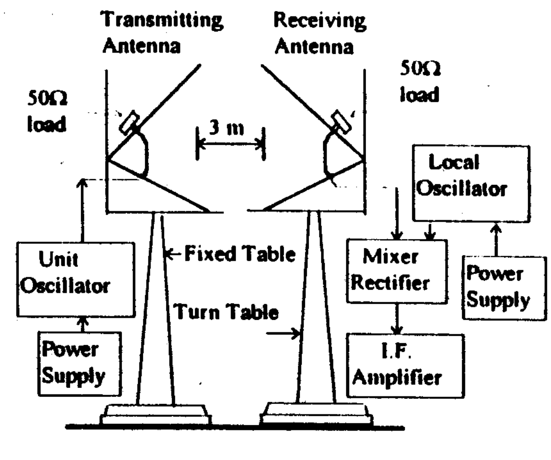


Fig. 8 Schematic block diagram of test set-up.

Field measurement is done at a radial distance of 3m and at a frequency of 150MHz. The unit oscillator is adjusted to feed a 150MHz R.F. signal into the transmitting antenna. The operating frequency of the I.F amplifier is 30MHz [8]. Thus the local oscillator at the receiving end is to be adjusted in such a way that a signal of frequency 30MHz (i.e. the difference between the local oscillator frequency and the received signal frequency) may be available at the output of mixer rectifier. A 30MHz signal having maximum amplitude at the I.F. amplifier output indicates the accurate adjustment of the local oscillator. In order to obtain horizontal pattern, the receiving antenna is rotated in the horizontal plane (i.e. $\theta = 90°$) where the azimuth angle (ϕ) varies from 0 to 180°.

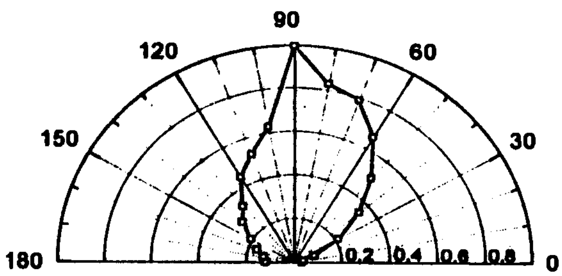
The receiving antenna is rotated to obtain the maximum field strength, which is found at $\phi = 90°$, and $\theta = 90°$. The position of maximum field strength is then considered as the reference position for the present task. The radiated EM field is recorded by rotating the receiving antenna in 10 degree step in both the clockwise and counter-clockwise direction. The measurement are also repeated at frequencies 200MHz and 250MHz.

Test results and Comparison :

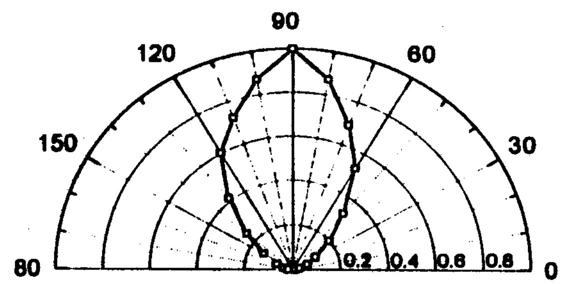
It has already been mentioned that the H-Loop antenna radiates in the azimuth angle (ϕ) varying from 0 to 60° in the horizontal plane (i.e. $\theta = 90°$). In this work the reference position is considered at $\phi = 90°$ and $\theta = 90°$. Therefore, the presence of the radiated field is to be expected in between $\phi \geq 60°$ and $\phi \leq 120°$ in the same plane. The measured field strength at different positions of the transmitting antenna are normalized by the maximum field strength which is obtained at the reference position. Polar plot of the measured radiated fields is shown in Fig. 9.

The computed normalized field pattern of the developed antenna in the horizontal plane ($\theta=90°$) has already been shown in Fig. 5(b). Fig. 9 & 5(b) shows that though the theoretical pattern and the measured pattern are identical but a weak field is found in the shadow region. In some cases field pattern is found to be distorted.

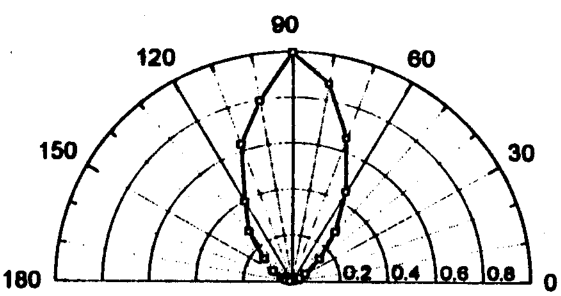
These may be due to the reflections from the metallic objects present in the room and associated cabling, radiation from the instruments, reception of other EM noise by both the receiving and transmitting antenna, the leakage current flowing through the reflector which also contributes to radiation. The distortion in the field pattern may also be due to the edge diffraction. Change in amplitude of the local oscillator during measurement can cause distortion in the radiation pattern.



(a)



(b)



(c)

Fig. 9 Radiated field pattern at θ=90° and ϕ varying from 0 to 180° at a radial distance of 3m (a) 150MHz; (b) 200MHz; and (c) 250MHz.

VII. CONCLUSIONS

This paper shows that, newly developed H-Loop antenna is a highly directive antenna. It is found that both the directivity and gain remains constant at all frequencies above 100 MHz.

It can also noted here that quarter loop antenna radiates over a solid angular surface in 90°[2] whereas the H-Loop radiates in only 60° which is two-third of such a surface (refer to Fig.5(b)). Measured radiation pattern has been found nearly identical to that of the computed pattern except at few cases. This may be due to the non-standard test environment for measuring the radiation pattern.

Two H-loop antenna (one acts as a transmitting antenna while the other acts as a receiving antenna) can be used to measure the low impedance magnetic field SE of a plannar sheet like conductive material. The developed H-loop antenna can also be a promising type of magnetic field probe which might be employed as near magnetic field characteristic of equipment for EMC testing.

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