Optimum Directivity Patterns of Concentric Ring Arrays with Dipole Radiators for Wireless Communications

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ABSTRACT
In the literature survey concentric ring arrays using isotropic radiators are reported. Sufficient data is not available to optimization of the first sidelobe level, null to null beamwidth and directivity. In this paper, the author is proposed the problem of designing concentric ring arrays with practical radiating element. The practical radiating element is considered as dipoles to achieve optimum directional patterns for wireless communications. The numerically simulated patterns are computed and compared with the concentric isotropic ring arrays for different number of concentric rings.

Keywords
Concentric Ring Array, Concentric Dipole Ring Array, Isotropic Radiators, Wireless Communications

1. INTRODUCTION
Antennas are used in several domestic, military and civilian communications and radar applications. Several researchers have been proposed on linear arrays. In most of the conventional applications, linear arrays are used [1]. In the applications where angular symmetry is required ring arrays are used. A ring array consists of desired number of elements on a circular ring [2-3].

A ring arrays Designed by Redlich [4] for aircraft navigation. A technique for synthesizing a ring array that radiates a prescribed pattern in the plane of the ring is developed. Royer [5] has investigates the properties of ring arrays for which i) the serration in the horizontal field pattern are small, ii) the mean horizontal directive gain is greater than that of one of the monopoles from the array. Cheng et al. [6] derived the expressions for maximization of directive gain for circular and elliptical arrays.

Hussian et al. [7] reported a method for the synthesis of a very larger circular array in as deterministic manner. Space tapered highly thinned array are considered for the design and implementation. Steyskal [8] described a procedure to produce a desired power pattern.

Pencil beams are produced with main beam along the off – axis investigated by Duncan [9]. The condition for maximizing the pattern gain function away from boresight is derived. Half power beam width and maximum gain are determined.

Preetham kumar et al. [10] has developed optimization technique for an antenna array, with a limited number of antenna array elements. The technique elaborates the design of a planar circular array with concentric rings of circular apertures with optimum elements radius for low sidelobe level.

Goto [11] reported a useful paper on the design for array antennas. Design is made in order to obtain high directivity and low sidelobes. The results are also presented. Harrrington [12] published excellent papers on the maximum realizable gain of arbitrary antenna enclosed by spherical surface.

Optimizations of small concentric ring arrays are designed by Huebner [13]. The desired pattern has either maximum directivity with minimum sidelobe level or maximum directivity with a specified sidelobe level. Hussain et al. [14] investigated clutter suppression for thinned array with phase only nulling. 16 concentric ring array directivity patterns are also presented.

A ring array produces first sidelobe level is about -8 dB. To overcome this concentric ring arrays are used and these are produces sidelobe level is about -17.6 dB for isotropic radiating elements. But most of the researchers [15-22], they are reported to control the sidelobe levels using different techniques. These techniques are decreases the first sidelobe level only. But, faraway sidelobes are increases and directivity is decreases. Most of the communications and radar applications required more directivity.

In view of the above facts, intensive studies are made to analyse on the concentric dipole ring arrays. In the present work the analysis is carried out and the directional patterns are numerically simulated for concentric dipole ring arrays compared with concentric isotropic ring arrays.

2. GENERAL ANALYSIS

2.1 Dipole Element Pattern
The radiation pattern obtained is valid for any length of the dipole, provided it is centre-fed. Now centre-fed dipoles are characterized by the direction of the characteristics, which are similar to deformed figure of eight pattern.

Consider a dipole of length *'2L'* extending from *-L* to *L* along *z*-axis as shown in figure (1). Let its centre be at *z*=0. When the length of the dipole is very small compared to λ, the current is approximated to be a constant. If its length is less than $\lambda/4$, the current distribution can be approximated to be triangular. For other lengths, it should be exact and it can be determined considering the antenna as an open ended transmission line.

However, the current distribution is found to be sinusoidal for lengths of order $\lambda/2$. For equilengths, it will be a low distorted sinusoidal distribution. Here, the sinusoidal distribution is assumed to find out the element patterns.

The current distribution is given by

$$I(z) = I_m \sin k(L - z),$$
$$I(z) = I_m \sin k(L - z), \quad \text{for} \quad z > 0$$
$$I(z) = I_m \sin k(L + z) \quad \text{for} \quad z < 0 \quad \text{and} \quad (1)$$

$$I(z) = 0, \quad \text{for} \quad z \geq \pm L \tag{2}$$

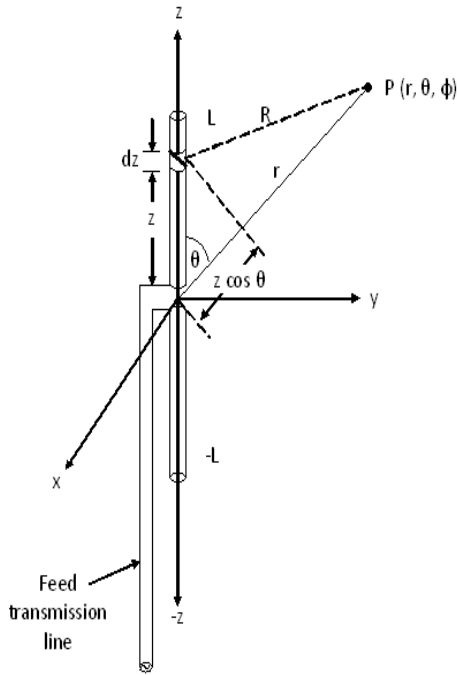Here, $k = \dfrac{2\pi}{\lambda}$, is wave number and $I_m =$ maximum current

Fig.1 Typical Geometry of Dipole Element

The vector magnetic potential due to the elementary length dz at a point P in free space is given by

$$dA_z = \frac{\mu I(z) \exp(-jkR)}{4\pi R} dz \tag{3}$$

The total vector magnetic potential is then given by

$$A_z = \frac{\mu}{4\pi} \int_{-L}^{L} \frac{I(z) \exp(-jkR)}{R} dz$$

$$= \frac{\mu}{4\pi} \left[\int_{-L}^{0} \frac{I_m \sin\beta(L+z) \exp(-jkR)}{R} dz + \int_{0}^{L} \frac{I_m \sin\beta(L-z) \exp(-jkR)}{R} dz \right] \tag{4}$$

For the distant or radiation field, R is considered to be very large and $R \approx r$. However, in the phase vector, the difference between R and r is important and it can be written as

$$R = r - z \cos\theta \tag{5}$$

$$A_z = \frac{\mu I_m \exp(-jkr)}{2\pi r} \left[\int_{0}^{L} \sin k(L-z) \cos(kz\cos\theta) \right] \tag{6}$$

Evaluating the integral and simplifying, we get,

$$A_z = \frac{\mu I_m \exp(-jkr)}{2\pi kr} \left[\frac{\cos(kL\cos\theta) - \cos kL}{\sin^2\theta} \right] \tag{7}$$

The spherical components of the magnetic potential are

$$A_r = A_z \cos\theta,$$
$$A_\theta = -A_z \sin\theta \quad \text{and} \tag{8}$$
$$A_\phi = 0$$

The magnetic field strength **H** is obtained through the relation

$$\mu H = \nabla \times \mathbf{A} \tag{9}$$

The current is entirely in z- direction and for radiation field r is assumed to be very large. Therefore,

$$\mu H_\phi = -\frac{dA_z}{dr} \sin\theta \tag{10}$$

$$H_\phi = \frac{jI_m \exp(-jkr)}{2\pi r} \left[\frac{\cos(kL\cos\theta) - \cos kL}{\sin\theta} \right] \tag{11}$$

The electric field strength for the radiation field is

$$E_\theta = \eta H_\phi \tag{12}$$

Here, $\eta = 120\pi$

$$E_\theta = \frac{jI_m 60 \exp(-jkr)}{r} \left[\frac{\cos(kL\cos\theta) - \cos kL}{\sin\theta} \right] \tag{13}$$

2.2 Pattern of Concentric Dipole Ring Arrays

The elements are arranged in planar circular arrays containing concentric circular dipole rings is shown in figure (2), which differ in radius and number of elements. A concentric dipole ring array with ring m having N_m elements and a radius of r_m. The distance between elements on ring m is given by d_m and distance between any two elements is constant.
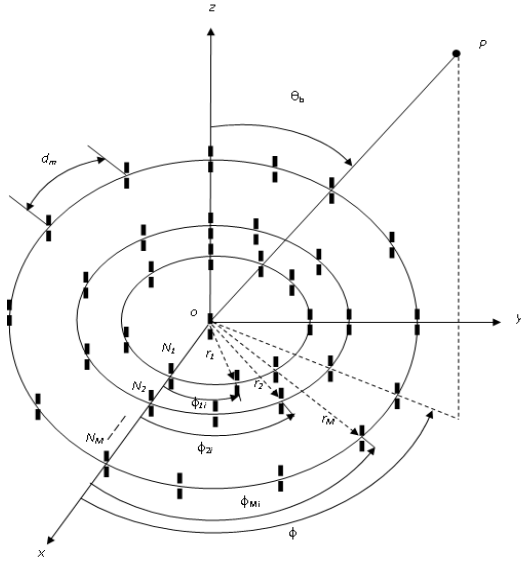
Fig. 2 Typical Geometry of Concentric dipole ring array

The far-field pattern of the concentric dipole ring array with a single element at the centre is given by

$$E_d = E_\theta \times \left(I_0 + \sum_{m=1}^{N_M} \sum_{i=1}^{N_m} I_{mi} \times \exp\left[jk\, r_m \sin\theta \cos(\phi - \phi_{mi}) + j\alpha_{mi} \right] \right) \qquad (14)$$

Here,
E_θ is normalized element pattern of dipole element
N_M is number of rings,
N_m is number of elements on the mth ring,
I_{mi} is current excitation of the ith element of the mth ring,
$I_0=1$ is considered,

$k = \dfrac{2\pi}{\lambda}$, λ is wavelength,

r_m = radius of the ring m,
$(x_i, y_i) = (r_i \cos\phi_{mi}, r_i \sin\phi_{mi})$ = location of the element i,
θ = Elevation angle, ϕ = Azimuth angle,

$\phi_{mi} = \dfrac{2\pi(i-1)}{N_m}$, where, m=1,2,…,M; i=1,2,…,N$_m$

ϕ_{mi} = Angular location of element i of the mth ring,
d_m = Interelement spacing of mth ring

$$N_m = \frac{2\pi r_m}{d_m} \ , \quad r_m = \frac{m\lambda}{2} \ , \quad d_m = \frac{\lambda}{2} \qquad (15)$$

If an additional phase is applied for each element, it is possible to scan the beam. Such a phase function is represented by

$$\alpha_{mi} = \exp\left[jk\, r_m \sin\theta_s \, \cos(\phi_s - \phi_m) \right] \qquad (16)$$

Here, (θ_s, ϕ_s) = Steering angle,

In the above expression (14), consider the elements of same weight in amplitude, and phase. The field pattern is

independent of ϕ, and it is dominated by the principle terms for each ring, where the residuals are negligible. The field pattern for a ring array is expressed in terms of Bessel function. The summation term in the above expression is the array factor. For the array of present interest, we have the far-field radiation patterns for concentric dipole ring array is expressed as

$$E_d = E_\theta \times \left(1 + \sum_{m=1}^{M} I_{mi} \ N_m \ J_0(k\, r_m \sin\theta) \right) \qquad (17)$$

Here, E_θ is normalized dipole element pattern is

$$E_\theta = \left[\frac{\cos(kL\cos\theta) - \cos kL}{\sin\theta} \right] \qquad (18)$$

2.3 Directivity
The directivity is evaluated for concentric dipole ring arrays' using the following expression is given by [1].

$$D = \frac{4\pi \left| E_d(\theta_s, \phi_s) \right|^2}{\displaystyle\int_0^{2\pi} \int_0^{\pi} \left| E_d(\theta, \phi) \right|^2 \sin\theta \ d\theta \ d\phi} \qquad (19)$$

The directivity is computed for concentric ring arrays using dipole radiators from the expression (17). To obtain the maximum directivity, considered uniform amplitude, uniform phase, and spacing between the elements to be $\lambda/2$.

3. RESULTS AND DISCUSSIONS
Using the expressions (17), the radiation patterns are numerically evaluated for the concentric dipole ring arrays. In expression (17), the element pattern E_θ to be considered as isotropic element (E_θ=1), then that produce the radiation pattern of concentric isotropic ring arrays. In figures (3–10), the directional patterns of the concentric dipole ring arrays and concentric isotropic ring arrays with different rings are presented.

From the figure (3) shown the comparison of two concentric dipole and isotropic rings. Considered as a two concentric rings (*M*=2), found that sidelobe level is -20.76 dB for dipole radiators and the sidelobe level is -17.6 dB for isotropic radiator, null to null beamwidth is 60.68 degrees for both cases. Similarly, the patterns are evaluated for different concentric rings (M=3, 5, 7, 9, 11, 17, and 21) and the data is presented in table 1 for concentric dipole rings.

Using the expression (19) the directivity is evaluated for the concentric dipole ring arrays and the data is presented in the table 1.

In the figure (11) shows the directivity increases while increasing the number of concentric dipole rings. Similarly, a figure (12) show the null to null beamwidth is reduces while increasing the number of concentric dipole rings.
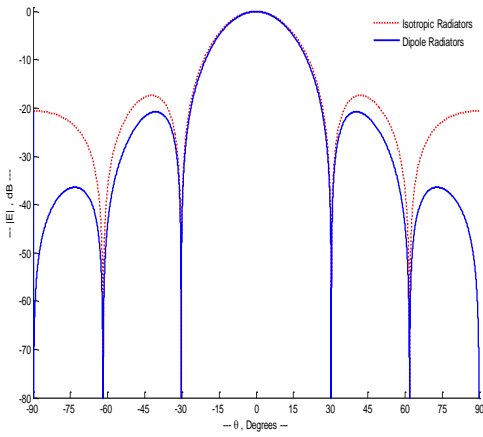
Fig. 3 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=2
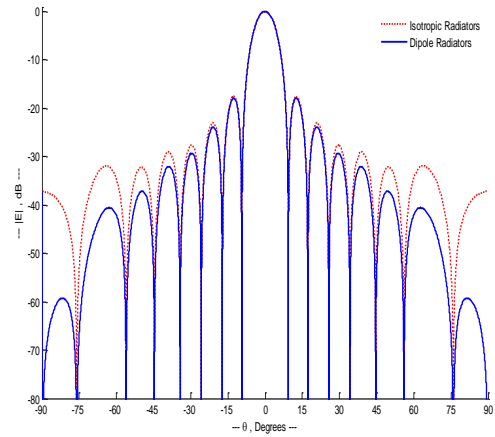

Fig.6 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=7
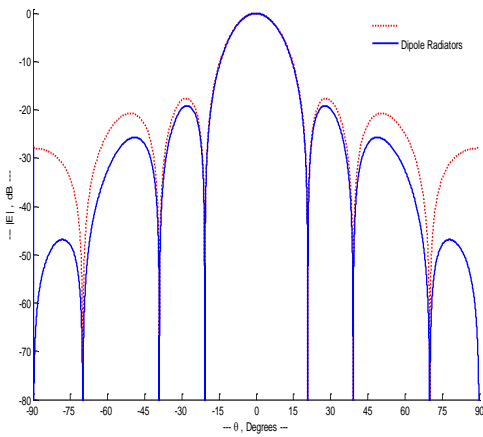

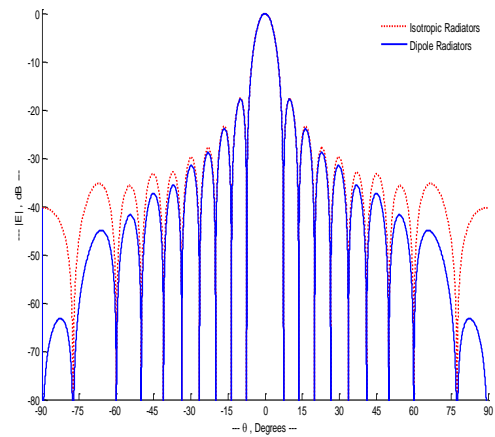**Fig. 4 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=3**

Fig. 7 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=9
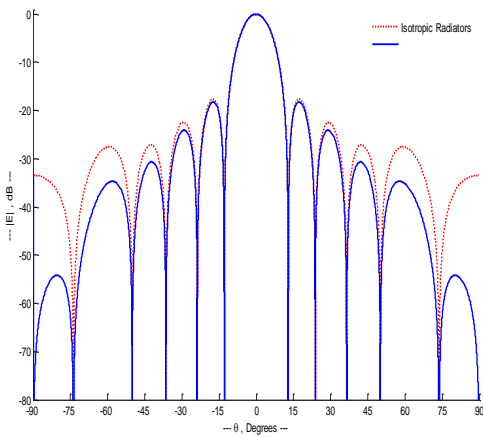

Fig. 5 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=5
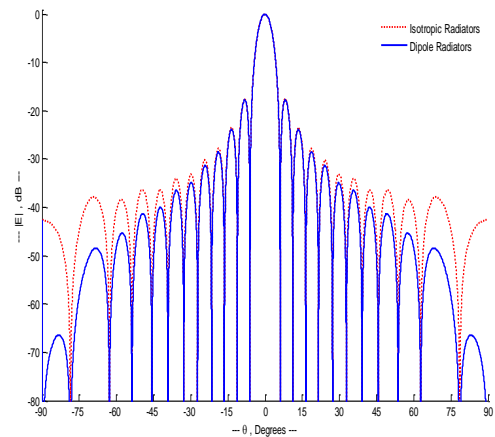

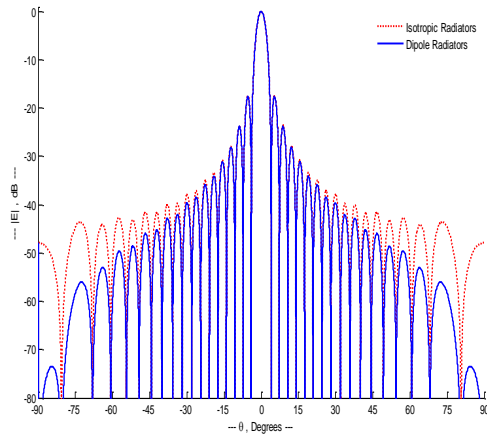**Fig. 8 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=11**

Fig. 9 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=17
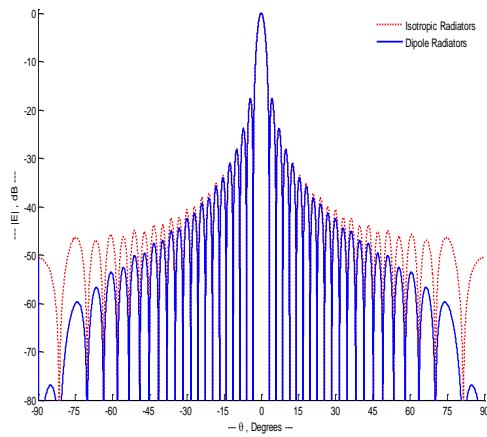

Fig.10 Patterns for a Isotropic and Dipole Concentric Ring Arrays of Number of Rings, M=21
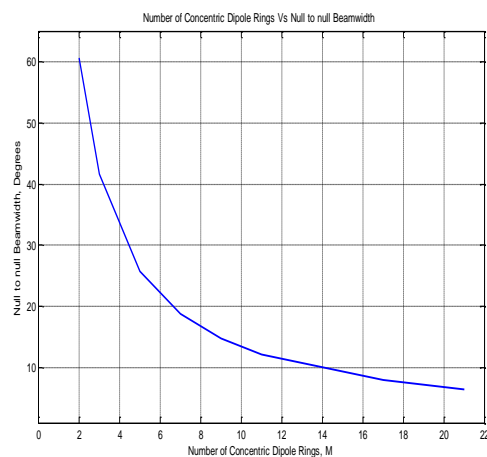

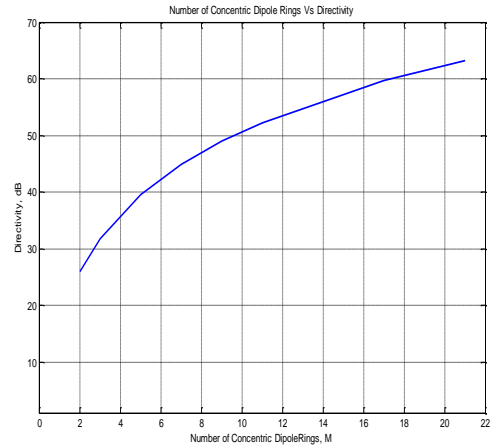**Fig. 11 Null to null beamwidth variations versus different number of concentric dipole rings**

Fig. 12 Directivity variations versus different number of concentric dipole rings

Table 1. Pattern characteristics of concentric dipole ring arrays

Number of rings (M)	First sidelobe level in dB	Last sidelobe level in dB	Null-to-null beamwidth in degrees	Directivity in dB
2	-20.76	-36.42	60.68	25.95
3	-19.14	-46.89	41.66	31.70
5	-18.19	-54.19	25.80	39.58
7	-17.90	-59.30	18.78	44.96
9	-17.78	-63.23	14.78	49.06
11	-17.71	-66.43	12.20	52.26
17	-17.63	-73.52	7.98	59.66
21	-17.62	-77.05	6.50	63.24

4. CONCLUSIONS

It is evident from the results that the sidelobe level of the concentric ring array dipole radiators is decreases compared to the concentric ring array of isotropic radiators without deteriorating the null to null beamwidth. The faraway sidelobe levels of the concentric dipole ring arrays are very less compared to the concentric isotropic ring arrays. While increasing the number of concentric rings the beamwidth is reduced and directivity is increased. These results are mainly used for wireless communications in broadband and narrowband applications. The data is helpful for array antenna designers to implement the real time applications.

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