Spherical array of annular ring microstrip antennas

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Abstract

The paper discusses the analytical study of spherical arrays of annular ring microstrip antenna (ARMSA) elements excited by electric dipole. A new empirical relation for calculating the nonunifrom current amplitude distributions of these elements has been obtained. The relation contains the information about the current amplitude factor (Δ) of the antenna elements of the spherical array. The narrow beamwidth and low side lobe levels can be obtain by choosing appropriate the current amplitude factor. It is found that for current amplitude factor $(\Delta = 0.5)$ the radiation pattern have narrow beamwidth and low side lobe levels compared with uniform current distribution array.

Circular polarization is realized by this study depends on the spherical array geometry. By using appropriate phase of each antenna elements in spherical arrays, radiation pattern is steered without change of gain and beamwidth.

Key Words: Spherical array , Antenna arrays , Microstrip antenna

1-Introduction

An array of radiators arranged on the surface of a sphere is of importance because such an array may radiate in any direction. Economies may, therefore, be realized in the construction of antennas designed to cover a very wide angular range. Consequently, interest exists in techniques for analyzing the patterns of a discrete array of identical elements on a sphere which have an arbitrary assignment of amplitude and phase (Murray 1963).

Spherical array antennas combine the capabilities of array antennas with the optimal geometry to achieve omni-directional coverage. So far spherical array antennas have received much less attention than planar or circular array antennas. Array antennas that are conformal to other surfaces than the line, circle or plane are a lot more difficult to model and design. Spherical array antennas however, are also highly symmetrical objects, a characteristic that can be exploited in the same way as was done for circular array antennas when phase mode processing was introduced (Erik and et al. 2006).

Spherical arrays are natural choice when complete hemispherical coverage with nearly constant beamwidth is needed. The advantages of using spherical arrays for satellite tracking, telemetry and command applications, performed from ground stations, have been discussed by (Boris and et al. 2002). The antenna elements are usually distributed on the surface of the spherical geometry, resulting in good uniformity of element spacing (Dipak and et al. 1968).

Microstrip patch antennas can be made easily to conform to the structure, and they are often used in a variety applications because of their thin profile, light weight and low cost (Sipus and et al. 2006). One common application of conformal array is an aircraft or helicopter satellite link, where the signal is circularly polarized, and zenith to horizon coverage is desired (Hansen 2001). This study was undertaken to obtain an array which provides high gain, circular polarization.

The annular ring has received considerable attention, like many forms of microstrip patches When operated in its fundamental TM_{11}-mode, this printed is smaller than its rectangular or circular counter parts (Kokotoff and et al. 1999). Annular ring microstrip antennas (ARMSAs) have a ring version that has been chosen as an alternative to the standard shape (Carver and Mink 1981).

In the present paper the radiation properties of a spherical array antenna consisting of annular ring microstrip antenna elements were discussed theoretically. The excitation is simulated by an electrical dipole located under the patch. Consequently, such an array with widely spaced elements appears to be capable of maintaining the desirable circularly polarized and other radiation characteristics.

2 - Analysis of array technique

A spherical array is an array of antenna elements distributed on the surface of a sphere. In calculating the pattern of an array of elements located on a sphere, the point on the sphere which is nearest to the field point being considered is the most convenient reference for computing the optical path differences traveled by the wavelets from each element. The reference point is at the intersection of the surface of the sphere and the line joining the center of the sphere and the field point. The $(m,n)^{th}$ element is shown in Fig.(1). Its axis makes an angle ψ_{mn} with the reference line (Murray 1963).

The elements are assumed to be ideal and the mutual couplings can thus be neglected. There are three options to select the rings and place the elements along them. The first configuration examined is the one with equal angular ring spacing along the circumference. It consists of $(2M+1)$ circular arrays with (M) rings in each hemisphere and one on the equator. The spacing (d) of the adjacent rings along the sphere circumference is uniform and equal to :-

$$d = \frac{\pi R}{2(M+1)} \qquad \text{.........(1)}$$

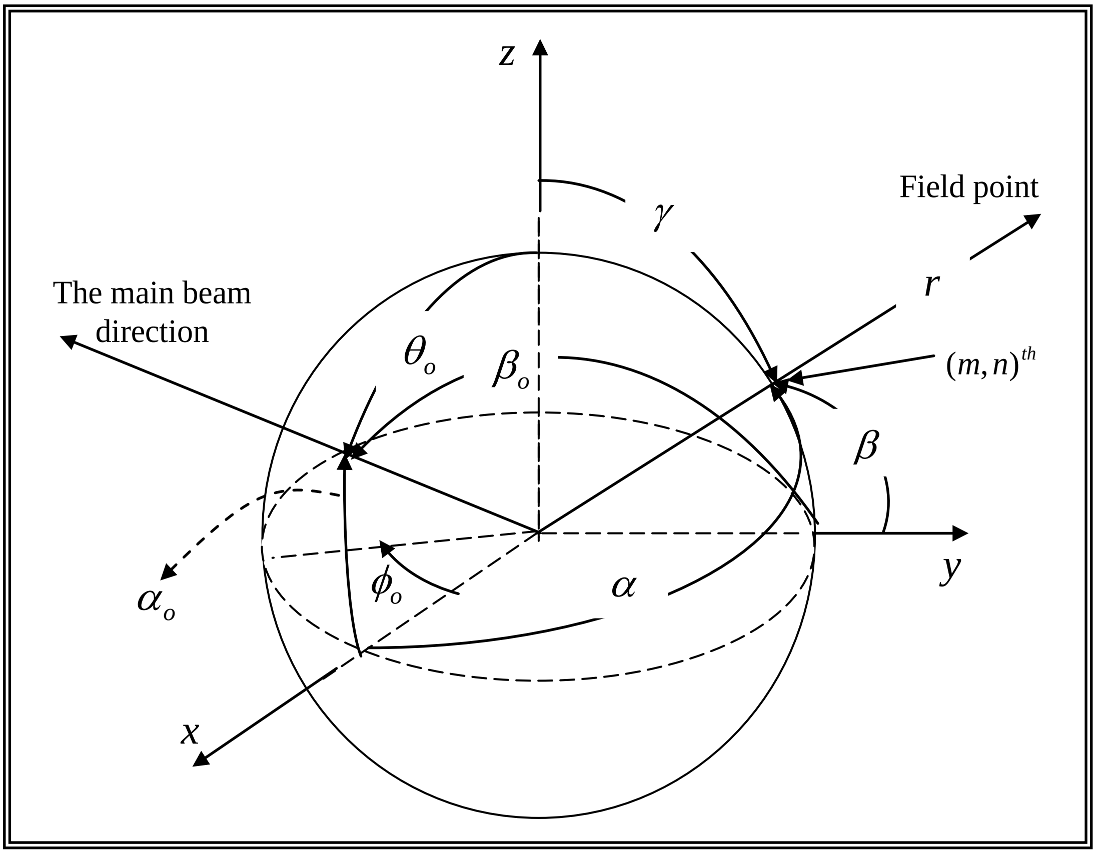


Fig.(1) : Spherical polar coordinate system and direction angles of spherical arrays.

There are N_m elements equally distributed in the m^{th} ring. The radius of the m^{th} ring, as shown in Fig.(2), is :-

$$R_m = R\sin\theta_m \qquad \text{.........(2)}$$

Where R is the radius of the sphere. The spherical coordinates of the $(m,n)^{th}$ element are given by (R,θ_m,ϕ_m) with :-

$$\theta_m = \frac{\pi}{2}\left(\frac{M+1-m}{M+1}\right), \qquad m = -M, (-M+1), ..., 0, ..., (M-1), M \qquad \text{.........(3)}$$

$$\phi_{mn} = \frac{2n\pi}{N_m}, \qquad n = 1,2,......, N_m \qquad \text{.........(4)}$$

Since N_m in each ring can be different, the element spacing may not be uniform.

The spacing of the adjacent elements (ARMSAs) along the circumference of the m^{th} ring is :-

$$d = \frac{2(\pi R_m - N_m g)}{N_m} \qquad \text{.........(5)}$$

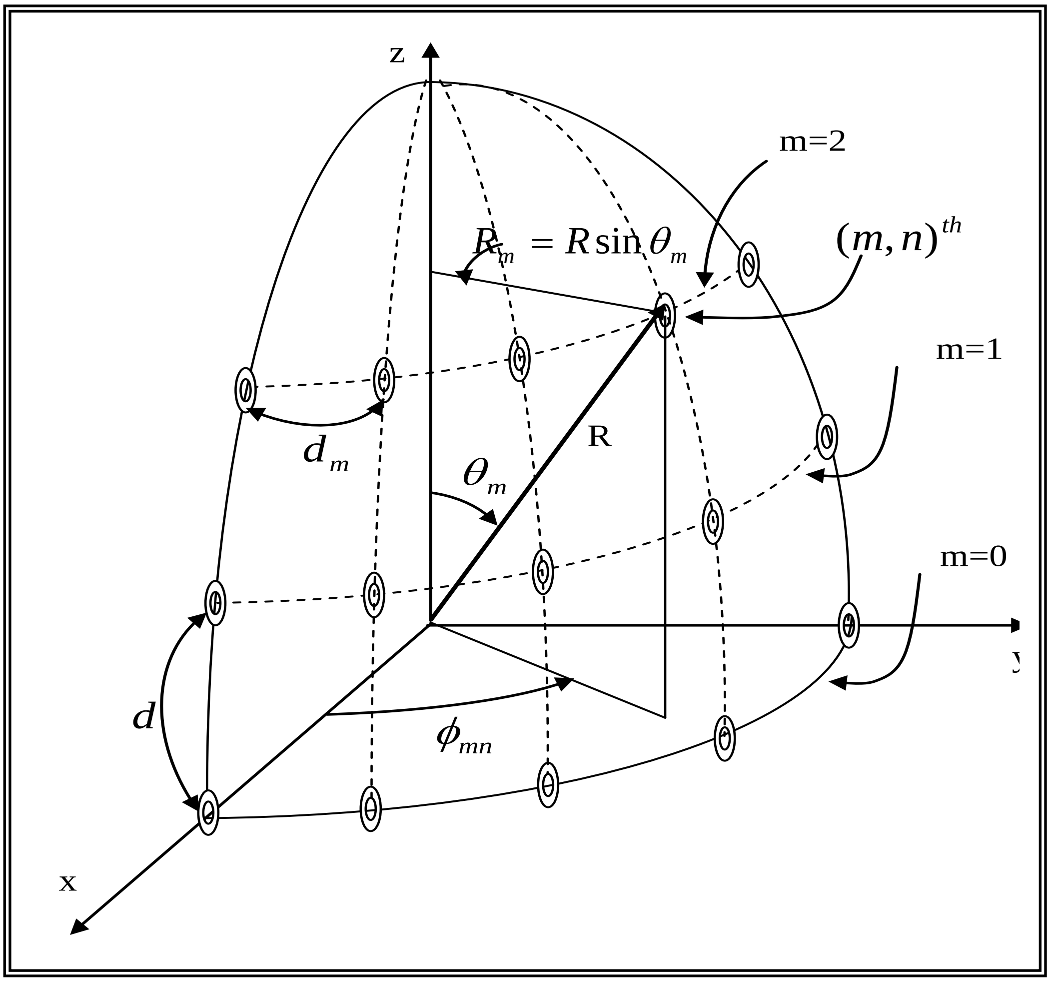


Fig.(2) : Spherical array geometry .

Where g is the radius of the ground plane of the ARMSA. The far electric field at the observation point $P(r,\theta,\phi)$ is (Wolf 1966) :-

$$E(\theta,\phi) = \frac{e^{jkr}}{r} \sum_{m=-M}^{M} \sum_{n=1}^{N_m} a_{mn} f_n(\theta,\phi) e^{-jkR\cos\psi_{mn}} \quad \text{......(6)}$$

where k is the propagation constant for free space, $f_n(\theta,\phi)$ describes the variation of the element pattern in space, a_{mn} is a complex number representing the magnitude and phase with which the $(m,n)^{th}$ element is excited relative to a common reference for all elements in the array and can be represented as :

$$a_{mn} = A_{mn} e^{j\zeta_{mno}(\theta_o,\phi_o)} \qquad \text{.........(7)}$$

Where A_{mn} can be fitted for the current distribution on the elements and calculated from an empirical formula obtained in this work :

$$\begin{aligned} A_{mn} &= A_{0n} && , \text{ for } m = 0 \\ A_{mn} &= -m\Delta A_{0n} && , \text{ for } m \langle 0 \\ A_{mn} &= \frac{A_{0n}}{m\Delta} && , \text{ for } m \rangle 0 \end{aligned} \quad \text{……(8)}$$

Here Δ is a current amplitude factor, and ζ_{mno} is the phase of the $(m,n)^{th}$ element and selected by :-

$$\zeta_{mno} = kR\cos\psi_{mno} \quad \text{………(9)}$$

The subscript of the angle θ and ϕ is selected to the direction of the main beam of the radiation pattern. and ψ_{mn} is the angle between the $(m,n)^{th}$ element axis and the field point , whose direction cosines are $\cos\alpha, \cos\beta, \cos\gamma$, and given by:

$$\cos\psi_{mn} = \cos\alpha\cos\alpha_{mn} + \cos\beta\cos\beta_{mn} + \cos\gamma\cos\gamma_{mn} \quad \text{……(10a)}$$

$$\cos\psi_{mn} = \sin\theta\sin\theta_{mn}\cos(\phi - \phi_{mn}) + \cos\theta\cos\theta_{mn} \quad \text{……(10b)}$$

3 - Elements of the array

The element considered in this analysis is the ARMSA. This antenna consists of a conducting patch of radius (a) and thickness (a_t) separated from the ground plane of radius (g) and thickness (g_t) by a dielectric material of thickness (h) and dielectric constant (ε). In this work the patch, dielectric and the ground plane surfaces are assumed to be rotationally symmetric to represent BoRs, as shown in Fig.(3). This antenna has the dimensions :-

Ratio (R_{ab}=a/b)	=	1.2
Ground plane radius (g)	=	11.0 (cm)
Ground plane thickness (g_t)	=	0.179 (cm)
Patch thickness (a_t)	=	0.179 (cm)
Thickness of dielectric material (h)	=	0.20 (cm)
Dielectric constant (ε)	=	2.32
Frequency (f_r)	=	1.67 (GHz)
Feed location (ρ_f, ϕ_f)	=	(2.00 cm , 0.0^o)

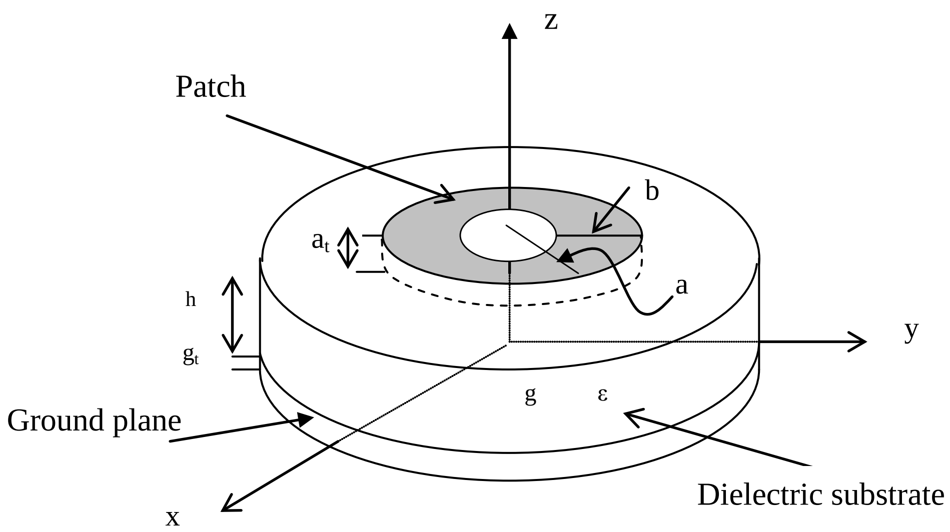
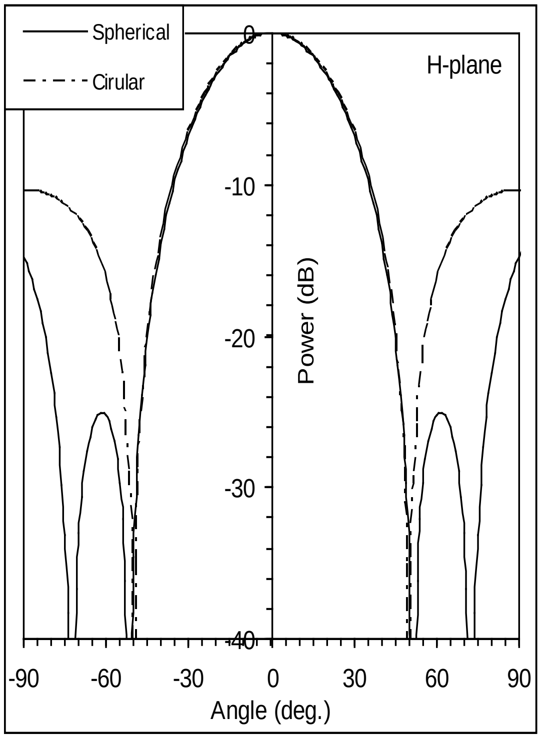


Fig.(3) : Geometry of the annular ring microstrip antenna .

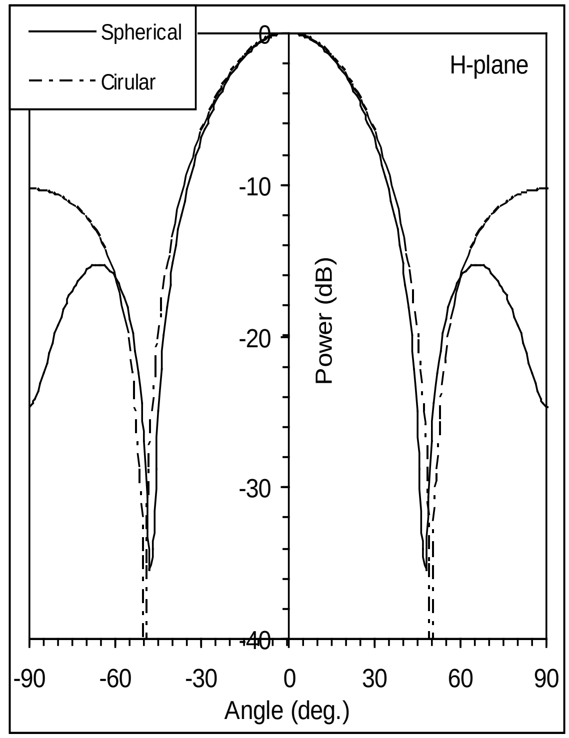
A rigorous analysis of the problems begins with the application of the equivalence principle that introduce an unknown electric current density on the conducting surface, and both unknowns equivalent electric and magnetic surface current densities on the dielectric surface. These currents densities satisfy the integral equations. The formulation of the radiation problems is based on the combined field integral equation (CFIE). This formulation coupled with the method of moments (MoMs), as a numerical solution for the CFIE, to translate them to a set of linear equations. The excitation is simulated by an electrical dipole located under the patch. The patch size is selected to excite the TM_{11}-mode. The plane of the ARMSAs were placed perpendicular to the z- axis of the sphere.

4-Results and discussion

Fig.(4) shows that the performance of spherical array in H-plane is preferable in comparison with circular array. In this figure the spherical array has three rings, the elements number in the 0^{th} ring is 4 and 5, respectively, while in the $\pm 1^{th}$ rings is two. It is clearly shown that the first side lobe level and the beamwidth in the spherical array is less than in the circular array.



(a)



(b)

Fig.(4) : Radiation patterns of a uniform spherical and circular arrays a point source elements with $R = \lambda / 2$ **(a) (Spherical** $(N_0 = 4, N_{\pm1} = 2)$ **,Circular** $(N = 8)$**),**
(b) (Spherical $(N_0 = 5, N_{\pm1} = 2)$ **Nm=5X2 ,Circular** $(N = 9)$**)**

The investigation also was done to study the effect of changing the radius of spherical array of ARMSAs elements on the radiation patterns. Fig.(5) shows that the sphere radius has significant effect on the radiation pattern parameters in the principle planes. As a result, increasing the radius of sphere increases the side lobe levels and narrow the beamwidth.

It may be desirable to study the effects of the contributions of the elements in the different rings on the radiation patterns of the spherical array. Three different types of spherical array configurations are examined. These arrays have three rings and 40 elements in each. The first configuration has 8 elements in each ring, while the second and third types have the number of elements $(N_0 = 10, N_{\pm1} = 9, N_{\pm2} = 6)$ and $(N_0 = 12, N_{\pm1} = 10, N_{\pm2} = 4)$,respectively.

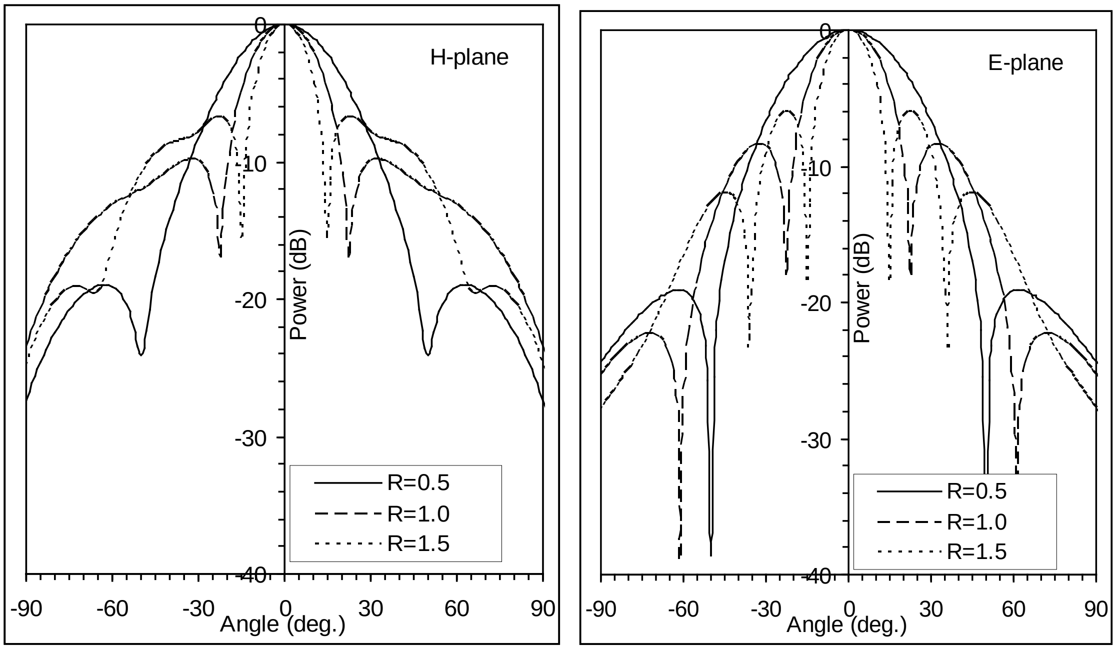


Fig.(5) : Radiation patterns of a uniform spherical array $(m=0)$ **of five ARMSA elements with** $(R=0.5\lambda, d=0.016\lambda), (R=1.0\lambda, d=0.64\lambda)$ and $(R=1.5\lambda, d=1.27\lambda)$.

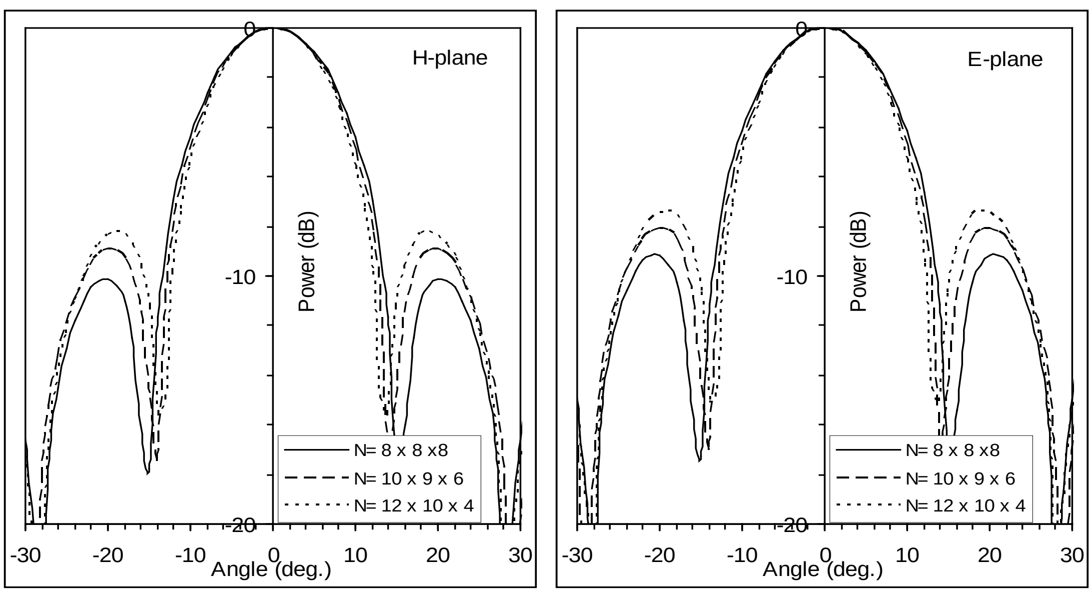


Fig.(6) : Radiation patterns of a uniform spherical array of arrangement:
$N=8\times8\times8\ (d_0=0.96\lambda, R_0=2.0\lambda), (d_{\pm1}=0.75\lambda, R_{\pm1}=1.73\lambda), (d_{\pm2}=0.17\lambda, R_{\pm2}=1.0\lambda)$
$N=10\times9\times6\ (d_0=0.64\lambda, R_0=2.0\lambda), (d_{\pm1}=0.60\lambda, R_{\pm1}=1.73\lambda), (d_{\pm2}=0.43\lambda, R_{\pm2}=1.0\lambda)$
$N=12\times10\times4\ (d_0=0.43\lambda, R_0=2.0\lambda), (d_{\pm1}=0.48\lambda, R_{\pm1}=1.73\lambda), (d_{\pm2}=0.96\lambda, R_{\pm2}=1.0\lambda)$

The elements spacing of these configurations are illustrates in Fig.(6). It is shown from this figure that by decreasing the number of elements in the third ring and increasing in the first and second rings gives narrow main lobe and high side lobe level.

To achieve a circular polarization we choose the first two types of spherical array arrangement examined previously, as shown in Fig.(7).

A new empirical formula (Eq.(8)), applied to the amplitudes current distribution on the elements of spherical array consists of four rings, was obtained in this study to achieve a appropriate pattern, which have a narrow beamwidth and low side lobes level. The effect of the uniform and nonuniform current distribution of the elements array for two values of Δ on the radiation pattern of spherical array antennas and their comparison were shown in Fig.(9).

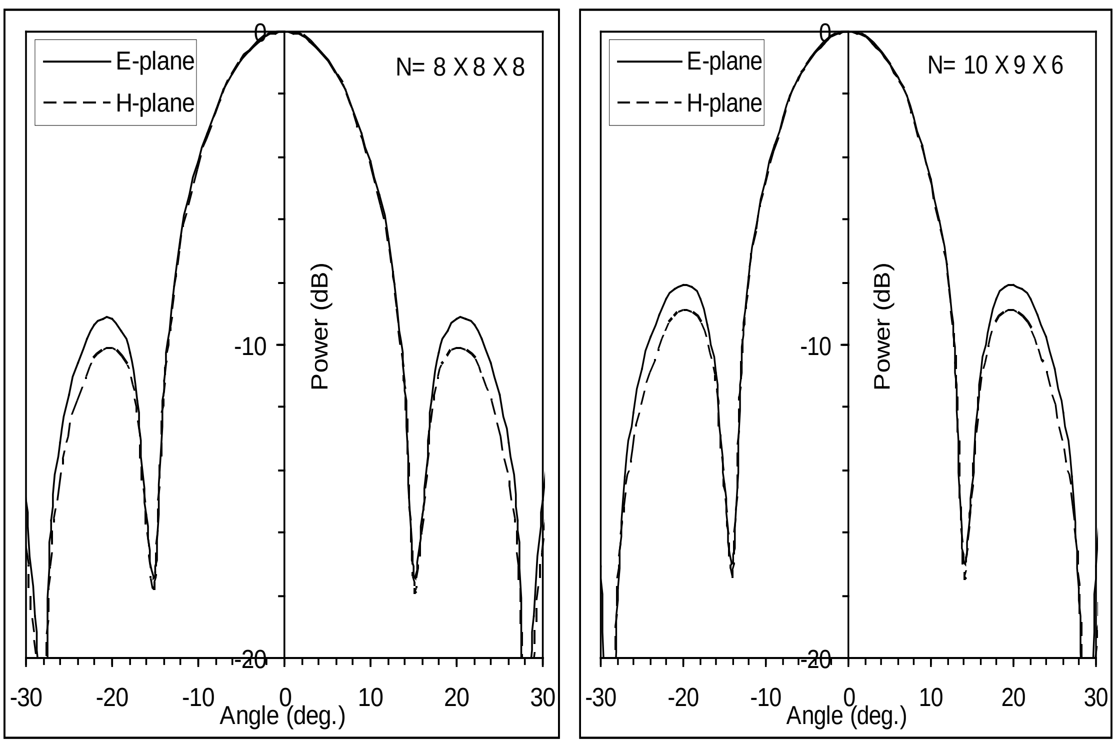


Fig.(7) : Radiation patterns of special arrangement of elements for circular polarization case. (Dimensions are that of Fig.(3))

Table (1) indicates the -3dB, -10dB beamwidth and first side level in the principle planes of the nonuniform current distribution of the elements array for different values of current amplitude factor (Δ). It is observed that by employing the nonuniform current distribution array with $(\Delta = 0.5)$, the first side lobe level is reduced by (5.4 dB and 6.7 dB) in H- and E- planes, over that of a uniform array patterns, respectively, and the -3dB, -10dB beamwidth reduce by about 3 degree

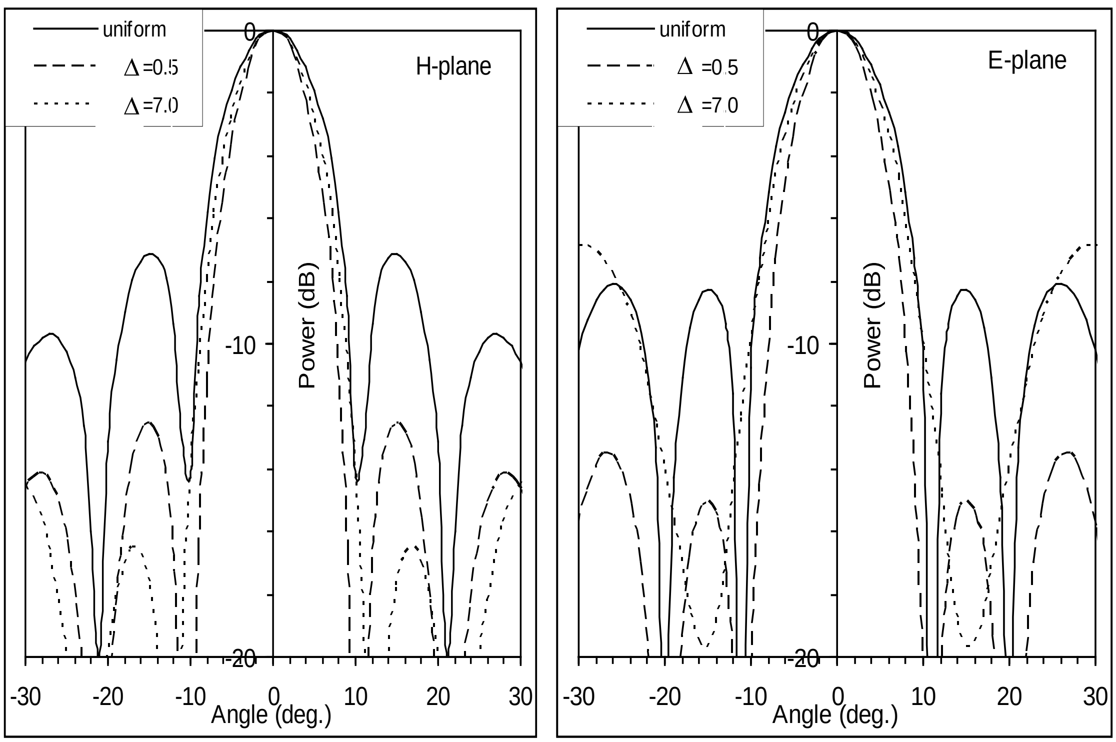


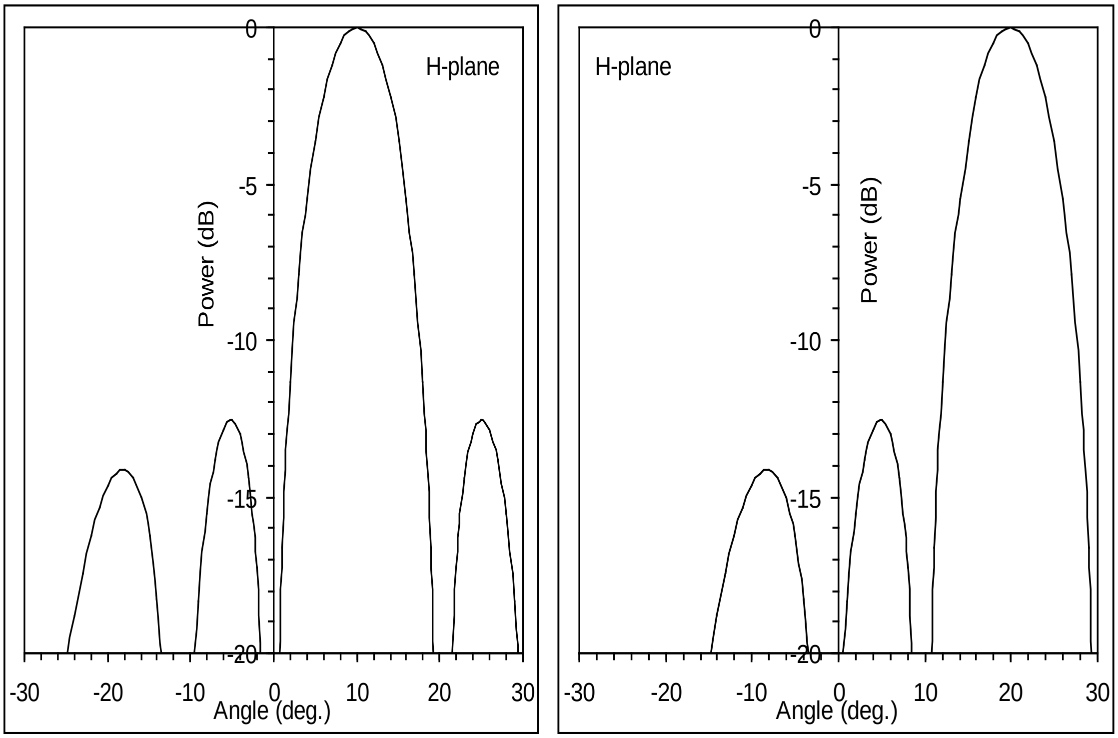
Fig.(9) : Comparison of radiation pa Δ of a uniform spherical array with :

$$N = 12 \times 8 \times 4 \times 2\ (d_0 = 0.69\lambda, R_0 = 2.5\lambda), (d_{\pm1} = 1.2\lambda, R_{\pm1} = 2.3\lambda), (d_{\pm2} = 2.16\lambda, R_{\pm2} = 1.76\lambda)$$
$$, (d_{\pm3} = 2.39\lambda, R_{\pm2} = 0.95\lambda), (d = 0.98\lambda)$$

Table (1): Radiation parameters of the spherical array antenna for different values of current amplitude factor (Δ) **.** (Dimensions are that of Fig.(9))

Δ	H-plane $(\varphi = 0^o)$				E-plane $(\varphi = 90^o)$			
	-3 dB (deg.)	-10 dB (deg.)	SLL		-3 dB (deg.)	-10 dB (deg.)	SLL	
			dB	(deg.)			dB	(deg.)
---	12.0	18.4	-7.1	15.0	12.6	20.0	-8.3	14.8
0.1	9.2	15.0	-12.0	15.1	9.6	15.8	-13.3	15.0
0.5	9.0	15.2	-12.5	15.1	9.6	16.0	-15.0	15.0
1	10.0	15.8	-13.8	15.2	10.0	17.0	-19.0	15.0
3	10.0	16.5	-15.8	16.1	10.2	19.0	-8.1	29.0
5	10.0	17.2	-16.4	16.5	11.4	19.8	-7.2	30.0
7	10.2	17.8	-16.5	17.0	11.6	20.0	-7.0	30.0

It is well-known that if the phase of each element in any array is changed with time, the radiation pattern is scanned and thus the main beam pointing direction (θ_o, ϕ_o) changes with time. Fig.(10) shows the effect of the element phase variation on the radiation pattern for two cases $(\theta_o = 10^o, \theta_o = 20^o)$. It is clearly seen that main lobe and side lobes are steered without change of radiation pattern parameters.



$\theta_o = 10^o$ $\theta_o = 20^o$

Fig.(10) : Radiation patterns of a uniform spherical array for different elements phase.
(Dimensions are that of Fig.(9), with $\varphi_o = 0^o$)

5-Conclusions

A new empirical relation which utilizes the amplitudes of nonuniform distribution currents of the elements in a spherical array to narrow the main beam and reduces the side lobe levels has been obtained. This relation practical in that it enables a designer to obtain the desired pattern by choosing the appropriate value of the current factor. The radiation field patterns of a nonuniform current distribution array of ARMSAs are preferable in comparison with that of a uniform current amplitudes.

It has been shown theoretically that in spherical arrays, in which the elements are fed with currents of uniform or nonuniform amplitude and appropriate phase, the beam can be steered without change of gain and beamwidth.

The antenna elements can be arranged on the sphere to obtain an spherical array which provides high gain and circular polarization, this results can be achievable by proper choosing of the elements arrangement in the spherical array geometry.

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المصفوفة الكروية المكونة من هوائيات شريطية حلقية

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الخلاصة

يتناول البحث دراسة نظرية للمصفوفات الكروية التي عناصرها مكونة من هوائي شريطي حلقي مغذا بثاني قطب كهربائي. تم في هذا العمل التوصل إلى علاقة تجريبية جديدة لحساب توزيع السعات غير المنتظمة لتيار عناصر المصفوفة. هذه العلاقة تتضمن معلومات حول عامل سعة التيار (Δ). والتي باختيار مناسب له يمكن الحصول على فلقة رئيسة ضيقة ومستوى فلقة جانبية واطئة. كان واضحاً من النتائج التي حصلنا عليها بأن قيمة $(\Delta = 0.5)$ ينتج عنها هيكل إشعاع ذو فلقة رئيسة ضيقة ومستوى واطئ للفلق الجانبية مقارنة مع تلك المعاملات الناتجة عن المصفوفة الكروية التي عناصرها تمتلك سعات تيار منتظمة. الاستقطاب الدائري تم تحقيقه في هذه الدراسة وذلك بالاعتماد على التوزيع الهندسي لعناصر المصفوفة الكروية. وأخيراً وباختيار مناسب للطور لكل عنصر في المصفوفة تم الحصول على توجيه هيكل الإشعاع دون تغيير في الاتجاهية وعرض الإشعاع.