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CONICAL ARCHIMEDEAN SPIRAL ARRAY ABOVE FLAT HOMOGENEOUS LOSSY GROUNDS

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A detailed theoretical analysis of far-field radiation patterns of conical Archimedean spiral array of half-wave dipole radiators with its mainbeam along a specified direction placed above flat homogeneous lossy ground surfaces have been made. The radiators are substantially thin, linear and centre-driven and are arranged at equal angular interval along the conical Archimedean spiral path. The radiators are in echelon and are placed horizontally parallel to X-axis. The analysis is based on induced EMF theory. The effect of various parameters (viz., height of the array from the ground surface, types of ground surfaces and different ϕ-planes) on the field radiation patterns have been studied. Thus from the knowledge of the types of ground, the conical Archimedean spiral array system can be used for directive beaming application by choosing suitable parameters.

Key Words : Conical Archimedean Spiral Array; Lossy Ground; Field Radiation Patterns

INTRODUCTION

IT was Rumsey[1] who first introduced the concept of an antenna whose shape is specified entirely in terms of angles. Such antennas have got pattern and impedance characteristics that are independent of frequency. Being guided by this concept, some studies on the design of the conical equiangular spiral antennas and their characteristics were made by several workers.[2-4] It is, however, known that an array of discrete elements whose geometry depends on the angular parameter gives a sharp mainbeam and higher directive gain as compared to the continuous structure. Cheng and Tseng[5] and Singh and Dey[6,7] on the basis of the above ideas, made studies on the excitation currents, driving point impedances, field radiation patterns and directive gain of circular, elliptical and conical Archimedean spiral array (CASA) of directive dipole elements.

It is, however, already known that imperfect grounds modify the radiation characteristics of the antenna array. Hence, it becomes necessary to determine the exact amount of deterioration in the performance of an array, both in the radiation patterns as well as in the antenna gain. Ledinegg *et al.*[8] studied the ground effect on induced current in loop antenna and its subsequent ground reaction impedance. Further, Hizal[9] made some studies for a HF circular array on homogeneous and inhomogeneous grounds from pattern and impedance point of view. A CASA of half-wave dipole radiators is expected to have a wide-band performance and sharp mainbeam. So a comprehensive study of the effect of

different types of ground on the far-field radiation patterns for different parameters of a CASA is a practical necessity.

The purpose of the present communication is to analyse theoretically the far-field radiation patterns of CASA of half-wave dipole radiators. The effect of various parameters (viz., types of grounds, height of the antenna array from the ground surface) on the radiation characteristics of CASA have been studied. In all the cases, the array geometry has been kept uniform and the analysis is based on induced EMF theory.

Theoretical Analysis

Fig 1 shows the geometry of one turn CASA of 9 half-wave dipole radiators. The dimensional radius and pitch height of the array are 'a' and 'p' respectively.

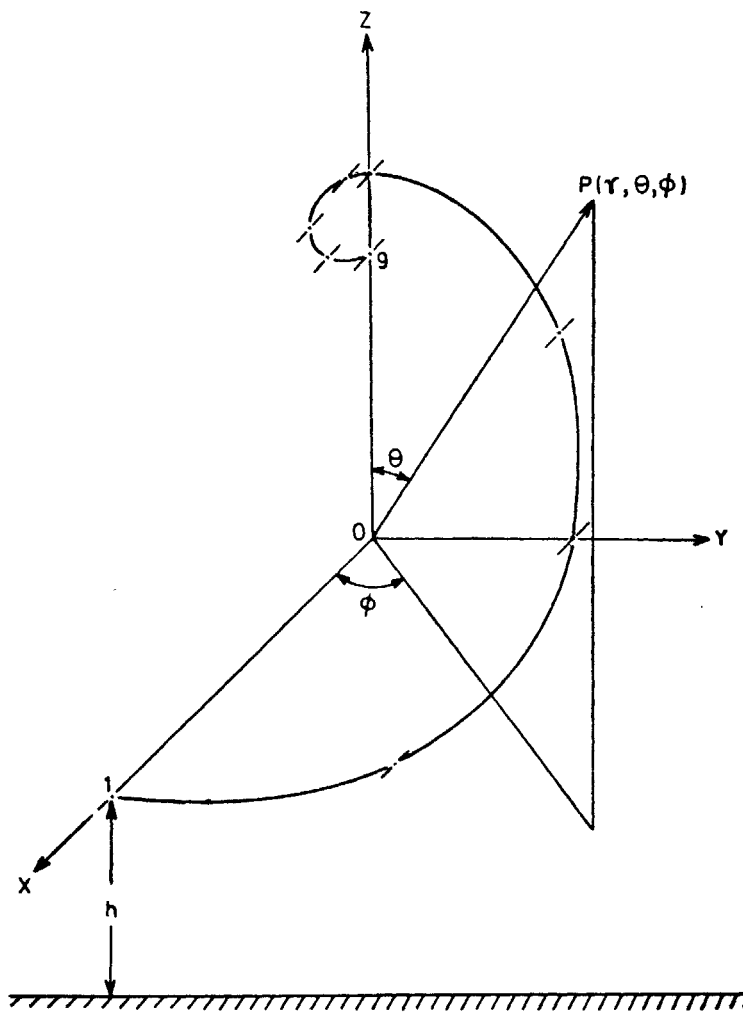

Fig 1 Conical archimedean spiral array (CASA). ($a = 2.0\lambda, p = 2.0\lambda$)

All the radiators of the array are arranged at equal angular interval along the spiral path and are placed in echelon horizontally parallel to X-axis. The array system is situated at certain height '*h*' above the *XY* plane of flat homogeneous lossy ground with its conical geometry being along *Z*-axis. A sinusoidal current distribution is assumed in the radiators. The radiators are linear, centre-fed and substantially thin with diameter less than $\lambda/100$.

In such arrays, the far-field radiation patterns produced at a distant point $P(r,\theta,\phi)$ which also include the ground reflected part, can be obtained by considering only the vertically polarised fields. The surface wave components are neglected because it contributes only near the grazing angle ($\theta = \pi/2$) and attenuate very rapidly with distance.

For vertically polarised fields, the complex reflection coefficient[10] is given by

$$R_V = \frac{\epsilon \cos\theta - \{\epsilon - \sin^2\theta\}^{1/2}}{\epsilon \cos\theta + \{\epsilon - \sin^2\theta\}^{1/2}}, \qquad \ldots(1)$$

where
$$\epsilon = \left(\epsilon_r - j\,\frac{1.80 \times 10^4\,\sigma}{f_{mHz}}\right), \qquad \ldots(2)$$

ϵ_r is the relative permittivity of the earth,
σ is the conductivity in mho/m and
f_{mHz} denotes the operating frequency in MHz.

Thus for a CASA with vertically polarised fields, the far-field radiation patterns in the *XZ* plane are expressed as

$$E(\theta,\phi) = u(\theta,\phi) \times \cos\theta \cos\phi \sum_{s=1}^{N} I_s \exp j \left\{ \beta \left[a \left\{ 1 - \left(\frac{s-1}{N-1} \right) \right\} \right.\right.$$
$$\left.\left. \sin\theta \cos(\phi - \phi_s) + p\left(\frac{S-1}{N-1}\right)\cos\theta \right] - \alpha_s \right\}$$
$$\times \{1 - R_s \exp(-j\,2\beta\, h_s \cos\theta)\}. \qquad \ldots(3)$$

In eqn (3), 'I_s' and 'α_s' are the amplitude and phase excitation of s^{th} radiator of CASA placed at an angular interval of azimuthal angle $\phi_s = 2\pi\left(\frac{s-1}{N-1}\right)$ along the spiral path, '*N*' is the total number radiators on the array and 'β' is the phase constant. The height of the *s*th radiating element of CASA from the ground is given by

$$h_s = h + p\left(\frac{s-1}{N-1}\right) \qquad \ldots(4)$$

In eq (3), $u(\theta,\phi)$ is the far-field function associated with a particular radiating element. For a horizontally placed half-wave dipole

$$u(\theta,\phi) = \frac{[\cos\{(\pi/2\cos\phi\sin\theta)\}]}{\sqrt{1 - \cos^2\phi\sin^2\theta}}, \qquad \ldots(5)$$

However, in order to direct the main beam of the far-field radiation pattern of CASA along a specified direction (θ_o, ϕ_o), the phase excitation α_s given to the radiator is

$$\alpha_s = \beta \left[a \left\{ 1 - \left(\frac{s-1}{N-1} \right) \right\} \sin \theta_0 \cos(\phi_0 - \phi_s) + p \left(\frac{s-1}{N-1} \right) \cos \theta_0 \right] \quad ...(6)$$

Thus the far-field radiation pattern for vertically polarised fields of the CASA can be obtained by using eq. (3) and substituting the values from eqs. (1), (4), (5) and (6). The excitation current 'I_s' of the s^{th} radiator of the array is obtained by the inversion of impedance matrix and is expressed as

$$[I] = [V]\,[Z]^{-1}, \quad ...(7)$$

where $[I]$ and $[V]$ are the column matrices and $[Z]$ is the square impedance matrix. The effective feed impedance 'Z' of the radiating dipole elements placed in echelon along the spiral path parallel to X-axis are obtained by determining the self and mutual impedances of the radiators.[6]

Results and Discussion

A computor (ICL 1904S) has been used for the computation of far-field radiation patterns of CASA placed above flat homogeneous lossy grounds. The parameters of the array are $N = 9$, $a = 2.0\lambda$ and $p = 2.0\lambda$. A unit real voltage excitation is assumed as the driving voltages across the input terminals of the radiating element of the array. In all the computations, the far-field radiation patterns in XZ plane ($\phi = 0°$-plane) have been obtained at the operating frequency 500 MHz with its mainbeam being made along $\theta_0 = 0^0$ and $\phi_0 = 0^0$ direction. Out of a large number of computations, only a few selective results have been presented in the form of graphs showing the effect of various parameters viz., height of the array above the ground and the type of lossy ground surfaces. The field patterns at different ϕ-planes of the array have also been computed.

Fig. 2 shows the far-field radiation patterns of CASA when it is placed at different heights from a flat homogeneous lossy ground surface. In this study, an average ground with $\epsilon_r = 15$, $\sigma = 5 \times 10^{-4}$ ℧/m has been considered as the lossy ground surface. It may be observed that the field amplitude of the mainbeam is higher for $h = 0.25\lambda$ as compared to both $h = 0.1\lambda$, and the free space value. This is due to the fact that for $h = 0.25\lambda$, the direct wave from the array and its ground reflected part are in the same phase at the far field point thereby increasing the resultant field amplitude whereas for $h = 0.1\lambda$, the direct wave and the ground reflected wave will not be in phase and thus the resultant field amplitude will be less than the corresponding free space value. The first side lobe level is nearly 20db down the mainlobe for $h = 0.25\lambda$ whereas in the other two cases, the amplitude level of the side lobes are comparatively higher. Half-power beam widths (HPBW) for $h = 0.1\lambda$, 0.25λ and free space value are 13^0, 11^0 and 12^0 respectively.

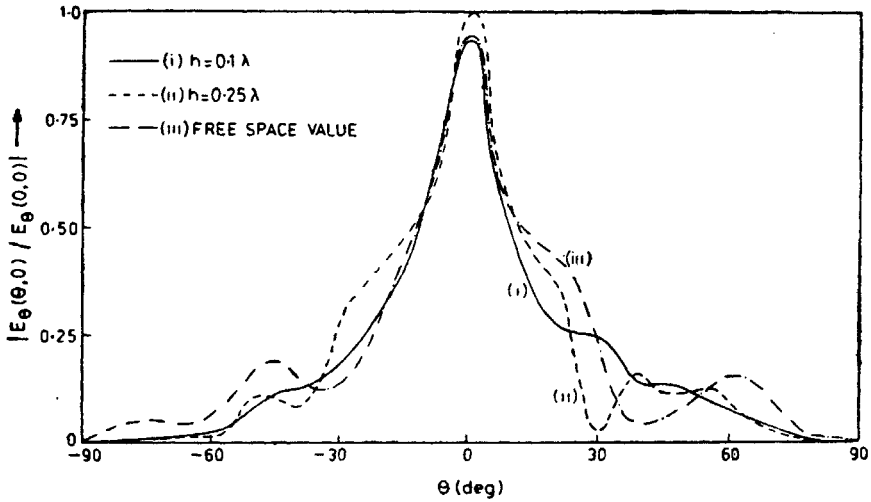

FIG 2 Field radiation patterns in XZ plane of CASA placed at different heights above average ground. ($\epsilon_r = 15$, $\sigma = 5 \times 10^{-4}$ ℧/m).

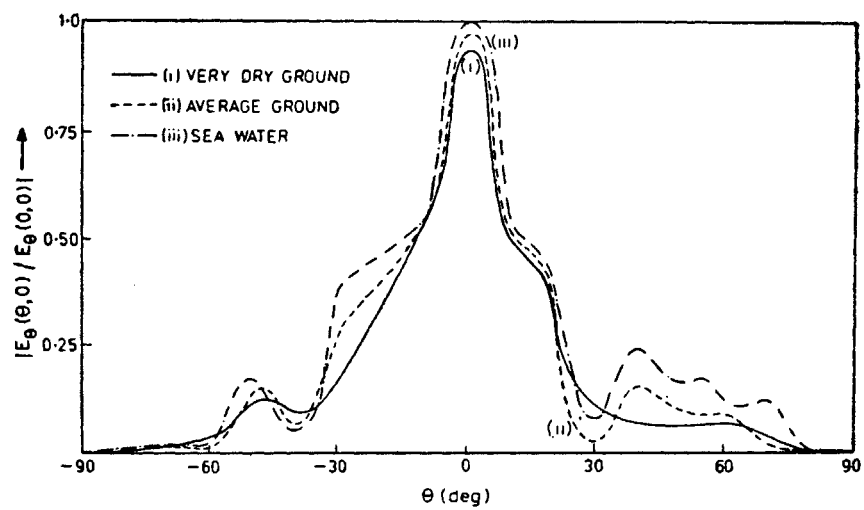

FIG3(*a*) Field radiation patterns in *XZ* plane of CASA placed above various types of lossy surfaces at a height $h = 0.25\lambda$.

The comparative study of field radiation patterns of CASA placed above various types of grounds (i.e., sea water : $\epsilon_r = 80$, $\sigma = 4$ ℧/m; Average ground : $\epsilon_r = 15$, $\sigma = 5 \times 10^{-4}$℧/m and very dry ground viz., industrial area : $\epsilon_r = 3$, $\sigma = 5 \times 10^{-5}$℧/m) are shown in Figs. 3(a) and 3(b). In Figs. 3(α) and 3(β), the array is placed at a height $h = 0.25\lambda$ and 1.0λ respectively. It may however, be observed from Fig. 3(α) that amplitude of the mainbeam is maximum for sea water and minimum for very dry ground. In Figs. 3(α) and 3(β), it may be observed that the field amplitudes of the mainbeam are substantially reduced

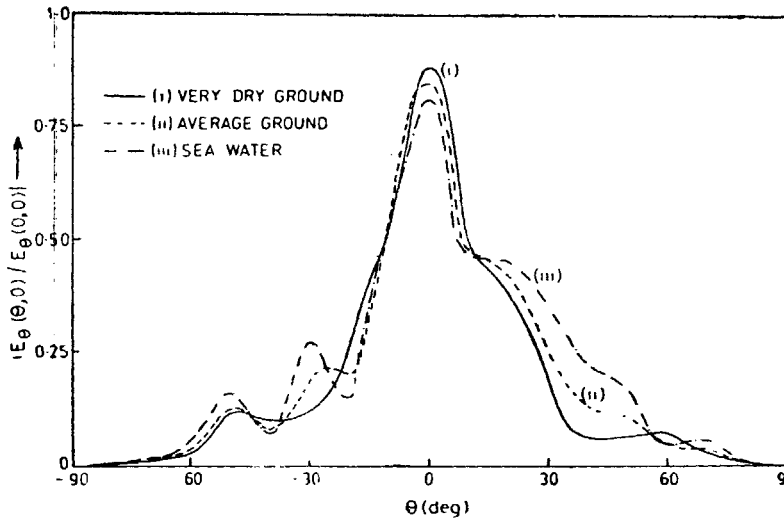

FIG3(*b*) Field radiation patterns in *XZ* plane of CASA placed above various types of lossy surfaces at a height $h = 1.0\lambda$.
Very dry ground : $\epsilon_r = 3$, $\sigma = 5 \times 10^{-5}$℧/m,
Average ground : $\epsilon_r = 15$, $\sigma = 5 \times 10^{-4}$℧/m,
Sea water : $\epsilon_r = 80$, $\sigma = 4$℧/m).

for $h = 1.0\lambda$ as compared to that of $h = 0.25\lambda$. This happens for $h = 1.0\lambda$ as the direct wave from the array and the ground reflected part are out of phase at the far-field point which deteriorate the resultant field amplitude. It may be noted that for height $h = 0.25\lambda$, the magnitude of ground reflected part increases with the increase in conductivity of the surfaces. For $h = 1.0\lambda$, first sidelobe level for sea water is 9.5db down from the mainbeam whereas for average ground, it is 12db down.

The vertical field response curves of CASA for different ϕ-planes are shown in Fig. 4. The array, in this case, is placed above very dry ground ($\epsilon_r = 3$, $\sigma = 5 \times 10^{-5}$℧/m) at a height $h = 0.25\lambda$. Since the radiators are placed horizontally parallel to X-axis, it may be seen that the amplitude level for the main beam at different ϕ = planes goes on decreasing as we move away from $\phi = 0°$-plane. The half-power beam-width (HPBW) for all the three cases $\phi = 0°$, 30° and 60°-planes are 14°, 16° and 19° respectively. Thus it may be concluded that the magnitude of the ground reflected part decreases as we move away from ϕ-0°-plane.

CONCLUSIONS

Detailed theoretical analysis of far-field radiation patterns of CASA placed at different heights from the lossy ground surfaces reveals interesting results. For $h = 0.25\lambda$, maximum field amplitude of the mainbeam is obtained as the direct wave and the reflected wave from ground are in phase at the far-field point.

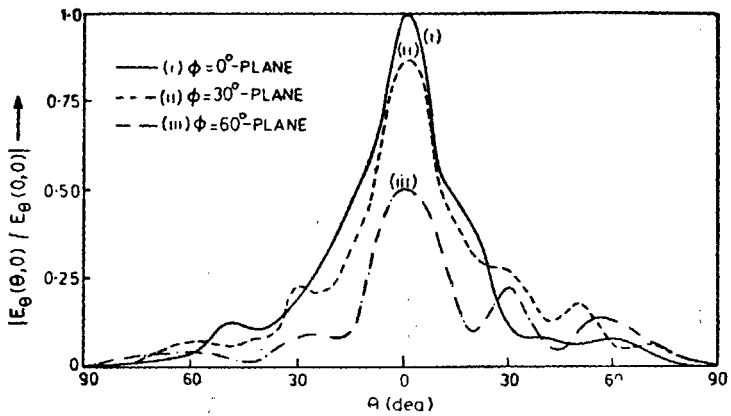

FIG 4 Vertical radiation patterns of CASA for different ϕ-planes placed at a height $h = 0.25\lambda$ above the ground.
Very dry ground : $\epsilon_r = 3$, $\sigma = 5 \times 10^{-5}$ ℧/m

Further, it was observed that for sea water, the maximum amplitude of mainbeam is obtained for $h = 0{,}25\lambda$ as compared to different types of ground used. Thus with proper choice of height of the array from the ground surface, the array system can be used for beam focussing purposes.

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