Biconical Ring Antenna Array for Wide Band Applications

C.SUBBA RAO
Department of ECE, Prasad V. Potluri Siddhartha Institute of Technology, Vijayawada, AP, INDIA
chalasanirao@yahoo.co.in

A.SUDHAKAR
Department of ECE, RVR & JC College of Engineering, Guntur, AP, INDIA
Alapati_sudhakar@yahoo.com

Abstract
Circular or ring arrays are conformal to the cylindrical surfaces unlike the linear arrays and can be mounted on moving objects. Biconical antenna is simple in construction and exhibits broad band characteristics. This antenna presents broad band radiation characteristics. In this paper circular or ring array of biconical antenna is proposed and its characteristics are analyzed for frequency band of 0.1 to 1GHz range. Radiation characteristics of the array with excitation phase change are presented. Simulated results of the radiation characteristics of the circular array are analyzed.

Key words- Biconical, circular array, cone angle

1. Introduction
Linear arrays are simple and are widely used but are not suitable to mount on cylindrical surfaces which are common in moving objects. In the past radiation characteristics of circular arrays for simple excitation are reported. The dipole is simple but narrow band antenna and its characteristics are frequency dependent. For applications that require coverage of a broad range of frequencies, such as television reception of all channels, wide- band antennas are needed [1]. While the biconical antenna is an excellent model but the small angle biconical antennas are seldom used in practice. Wide angle biconical antennas are frequently used as broad band antennas. The broad band impedance characteristics occur when the angle of the cones, \( \theta \), lies between 60\(^\circ\) and 120\(^\circ\). Biconical antenna is can be thought to represent a uniformly tapered transmission line [2]. A biconical antenna consists of two cones aligned along a common axis with their points together at the feed point. Biconical dipole antennas can provide uniform omnidirectional gain in the horizontal plane and slowly varying gain with elevation plane. The omnidirectional or broad-cast type pattern is used for many broad cast or communication services, where all directions are to be covered equally well. The horizontal plane pattern is generally circular, while the vertical plane pattern has some directivity in order to increase the gain. While omnidirectional coverage is the type most frequently desired and there is an occasional need for a bidirectional or unidirectional patterns when communication is desired along a given path such as a pipeline, a high way or a rail road [3]. The radiation pattern of a single element is relatively wide and each element provides low values of gain.

In many applications it is necessary to design antennas with very directive characteristics and very high gains to meet the demands of long distance communication. An assembly of radiation elements in an electrical and geometrical configuration is formed. One of the more common methods of obtaining directive gain is an arrangement of several individual antennas so spaced and phased that their individual contributions add in one preferred direction while canceling in others. Such an arrangement is known as an array of antennas. Several antennas may be arranged in various configurations such as straight lines, rectangles, circles, or triangles and so on. Several antennas can be arranged in space and interconnected to produce a directional radiation pattern. Such a configuration of multiple radiating elements is referred to as an array antenna, or simply an array[4]. Many small antennas can be used in an array to obtain a level of performance similar to that of a single large antenna. Arrays offer many advantages over aperture antennas. The radiation pattern of an array is determined by the type of individual elements used, their orientations, their positions in space, and the amplitude and phase of the currents feeding them. A single antenna element is usually not enough to achieve technical needs. That happens because its performance is limited. A set of discrete elements, which constitute an antenna array, offers the solution to the transmission and /or reception of electromagnetic energy. The geometry and the type of elements characterize an antenna array. Linear arrays are very useful and instructive but there are occasions
where a linear array is not appropriate for the building, structure or vehicle upon which it is mounted. Other array geometries may be necessary to appropriately fit into a given scenario. Circular array is one of such array. When an angular symmetry is desired in a two dimensional operation, ring or circular arrays can be considered to satisfy the requirement.

**General Analysis**

Linear arrays are very useful and instructive but there are occasions where a linear array is not appropriate for the building, structure or vehicle upon which it is mounted. Other array geometries may be necessary to appropriately fit into a given scenario. When an angular symmetry is desired in a two dimensional operation, ring or circular arrays can be considered to satisfy the requirement. Just as the linear array was used for increased gain and beam steering, the circular array can also be used. The circular array, in which the elements are placed in a circular ring, is an array configuration of very practical interest. Circular arrays are composed of identical, equidistant spaced elements placed along the circumference of a circle. Its applications span radio direction finding, air, and space navigation, radar, sonar, and many other systems. For special applications a circular array may be applied, and for the sake of completeness the array factor will also be presented. The main difference between the array factor of circular array and that for an equispaced linear array is that the array factor of circular array is a function of both \( \theta \) and \( \phi \).

The uniform circular array (UCA) is defined as an equispaced circular array for which the phases of excitation coefficients decrease uniformly along the circle so that the total decrease after one circuit is an integral multiple of \( 2\pi \).

The biconical antenna can be thought to represent a uniformly tapered transmission line. The analysis begins by first finding the radiated E and H fields between the cones, assuming dominant TEM mode excitation. Once these are determined for any point \((r, \theta, \phi)\), the voltage ‘V’ and current ‘I’ at any point on the surface of the cone \((r, \theta = \theta_c, \phi)\) will be formed. From Faraday’s law

\[
\nabla \times \mathbf{E} = -j\omega \mu \mathbf{H}
\]

Expanding in spherical coordinates and assuming that the E-field has only an \( E_\theta \) component independent of \( \phi \). Since H-field has only \( H_\phi \) component, necessary to form the TEM mode with \( E_\theta \). Equation (1) can be written as

\[
\frac{1}{r} \frac{\partial}{\partial r} \left( r E_\theta \right) = -j\omega \mu H_\phi
\]

From Ampere’s law

\[
\nabla \times \mathbf{H} = \mu \varepsilon \mathbf{E}
\]

Expanding in spherical coordinates

\[
\frac{1}{r \sin \theta} \frac{\partial}{\partial r} \left( r \sin \theta H_\phi \right) = -j\omega \varepsilon E_\theta
\]

\[
H_\phi = \frac{H_0}{\sin \theta} \frac{\exp(-jkr)}{r}
\]

\[
E_\theta = \eta H_\phi = \eta \frac{H_0}{\sin \theta} \frac{\exp(-jkr)}{r}
\]

Voltage produced between two corresponding points on the cones, a distance ‘r’ from the origin is

\[
V(r) = \int_E dl = \int_{a/2}^{\pi-a/2} E_\theta r d\theta
\]

\[
V(r) = 2\eta H_0 \frac{\exp(-jkr) \ln[cot(\alpha/4)]}{\alpha/2}
\]

The current on the surface of the cones, a distance ‘r’ from the origin is

\[
I(r) = \int_{0}^{2\pi} H_\phi r \sin \theta d\phi = 2\pi H_0 \exp(-jkr)
\]

Input impedance of single biconical antenna is

\[
Z_c = \frac{V(r)}{I(r)} = \frac{\eta}{\pi} \ln[cot(\alpha/4)]
\]
The characteristic impedance is not a function of the radial distance 'r' and represents the input impedance at the antenna feed terminals.

\[ Z_c = Z_{ua} = 120 \ln \left( \cot \left( \frac{\alpha}{4} \right) \right) \] (11)

\[ \alpha \] is the cone angle 90°

The radius of the circle is computed from

\[ \frac{\lambda}{2} = \frac{2\pi R}{N} \] (12)

\[ R = \frac{N\lambda}{4\pi} \] (13)

Where N = Number of elements of the array

\[ \lambda = \text{wave length in cm} \]

\[ R = \text{Radius of the circle} \]

Substituting N=12, f = 600MHz, \( \lambda = 50 \text{cm} \).

The radius of the circle is 47.75cm.

\[ E_n(r, \theta, \phi) = \sum_{n=1}^{N} a_n e^{-j k R_n} \] (14)

\( R_n \) - is the distance from the \( n^{th} \) element to the observation point .In general

\[ R_n = \left( r^2 - a^2 - 2ar \cos \psi_n \right)^{\frac{1}{2}} \] (15)

For \( r \gg a \) reduces to

\[ R_n \approx \left( r - a \cos \psi_n \right) = r - a \sin \theta \cos (\phi - \phi_n) \] (16)

For amplitude variations \( R_n \approx r \)

\[ E_n(r, \theta, \phi) = \frac{e^{-jkr}}{r} \sum_{n=1}^{N} a_n e^{j a \sin \theta \cos (\phi - \phi_n)} \] (17)

Where \( a_n \) = excitation coefficients (amplitude and Phase) of \( n^{th} \) element.

\( \phi_n = 2\pi \left( \frac{n}{N} \right) \) - Angular position of the \( n^{th} \) element on x-y plane

The excitation coefficient of the \( n^{th} \) elements can be written as

\[ a_n = I_n e^{j \alpha_n} \] (18)

\( I_n \) = amplitude excitation of the \( n^{th} \) element.

\( \alpha_n \) = phase excitation of the \( n^{th} \) element

Hence

\[ E_n(r, \theta, \phi) = \frac{e^{-jkr}}{r} AF(\theta, \phi) \] (19)

Where

\[ AF(\theta, \phi) = \sum_{n=1}^{N} I_n e^{\left[ k a \sin \theta \cos (\phi - \phi_n) + \alpha_n \right]} \] (20)

Equation (20) represents the array factor of a circular array of \( N \)- equally spaced elements. The phase excitation of the \( n^{th} \) element is

\[ \alpha_n = -k a \sin \theta \cos (\phi - \phi_n) \] (21)

\[ AF(\theta, \phi) = \sum_{n=1}^{N} I_n e^{\left[ k a \sin \theta \cos (\phi - \phi_n) - \sin \theta \cos (\phi_n - \phi) \right]} \] (22)

\[ AF(\theta, \phi) = \sum_{n=1}^{N} I_n e^{jka \cos \psi - \psi_n} \] (23)
\[ AF(\theta,\phi) = \sum_{n=1}^{N} I_n e^{jk \rho_o [\cos \phi - \zeta]} \]  

(24)

Where

\[ \zeta = \tan^{-1} \left[ \frac{\sin \theta \sin \phi - \sin \theta_o \cos \phi_o}{\sin \theta \cos \phi - \sin \theta_o \cos \phi_o} \right] \]  

(25)

\[ \rho_o = a \left[ (\sin \theta \cos \phi - \sin \theta_o \cos \phi_o)^2 + (\sin \theta \sin \phi - \sin \theta_o \sin \phi_o)^2 \right]^{1/2} \]  

(26)

2. Analysis of Circular Biconical Antenna Array

Every element in the array is of \( \lambda/2 \) in length with a cone angle of 90° is considered for the array. A circular array of 12-elements is formed with equal spacing between the elements.

![Fig.1 12-Element uniform circular Antenna array](image1)

![Fig.2. Circular Array Radiation Pattern](image2)

3.1 Excitation of array with uniform amplitude and out of phase

![Fig.3 Polar plot in Horizontal Plane](image3)

![Fig.4 Polar Plot in Elevation Plane](image4)

![Fig.5 Gain vs. Frequency](image5)

![Fig.6 Impedance vs. Frequency](image6)

A uniform circular array consisting of 12- biconical dipole antennas in x-y plane is shown in Fig.1. All the 12-elements are equally spaced with half wave spacing between the elements in the x-y plane along a circular ring of radius 477.5mm. Angular separation between the elements on the circumference of the circle is 30°. Cone angle of each biconical dipole is 90° and total height of each dipole is \( \lambda/2 \).

Radiation pattern of individual biconical dipole is omnidirectional with 360 degrees coverage in horizontal plane. A simple configuration of ring array with even number of elements (12) around the periphery is formed.
as shown in Fig1. Each element is excited at its apices with a magnitude of ‘1V’ and adjacent elements out of phase by 180°. Alternate elements in the array are excited with same amplitude and same phase. The elements in the array are designed to operate at a frequency of 600MHz and the array is simulated from 100MHz to 1GHz to investigate the broad band characteristics of the configuration. Radiation characteristics of the configuration have been observed for the entire frequency range of 100MHz to 1GHz. The circular array with the excitation mentioned above has produced 12- sharp beams in the horizontal plane. All the 12 beams are sharp, distinct and highly directional as shown in Fig2. These beams are identical in shape and size.

Observing individual beams in horizontal and vertical planes separately it is interesting to note that the beam in horizontal plane is so sharp that its width is almost zero degrees as presented in Fig3. In vertical plane the beam width of the radiation pattern is 30° as shown in Fig.4. All the 12- beams are pointing towards the corresponding elements of the array. Angular separation between the beams is 30°. Separation between the beams around the periphery of the circle is also λ/2.

Radiation pattern of the array in horizontal plane depicted in Fig.4 shows sharp beams starting from 0° to 360° at regular intervals of 30°. All the 12- beams are so sharp in horizontal plane that, it is not possible to identify the 3- dB points and hence the beam width in this plane is zero. Polar plots of the radiation pattern in horizontal and vertical plane indicate that the center of all the beams lies in xoy plane or θ=0° plane and exactly on the circle passing through the center of the array elements. Maximum radiation of each beam also lies in the same plane. Maximum radiation of each beam passes through the center of the corresponding element and away from the periphery of the circular array boundary. Maximum radiation points of the beams are exactly positioned at 0° to 360° with a separation of 30°. Half of the beam is above xoy plane (towards +Z axis) and the other half is below the xoy plane (towards -Z axis). The array maintains constant gain from 300 MHz. to 800 MHz. with a maximum gain of 6.89 dB as depicted in Fig5.

Radiation pattern of biconical dipole is omnidirectional with a gain of around 1dB. Uniform circular array configuration with equal amplitude and out of phase excitation has improved the gain to nearly 7 dB and also generates multiple beams. The number of beams is proportional to the number of elements in the array. Radiation pattern of 12-element array is presented but it is observed that the number of beams in 4, 6, 8, 10 element circular array the number of beams is proportional to the number of elements in the array provided all the elements are excited with same amplitude and 180° out of phase.

Impedance vs. frequency plot in Fig.6 shows constant self impedance of 300 ohms over the entire frequency band considered for simulation and is suitable for impedance matching with coaxial cables without any separate impedance matching network. Impedance of one element is presented and the remaining elements in the array also exhibit similar variation.

### 3.2 Excitation of the elements with uniform amplitude and same phase

![Fig.7 Elevation Plane pattern at 100 MHz](image1)

![Fig.8 Elevation Plane pattern at 300 MHz](image2)

![Fig.9 Elevation Plane pattern at 700 MHz](image3)

![Fig.10 Elevation Plane pattern at 1GHz](image4)
Radiation characteristics of the circular biconical array are investigated for 100MHz to 1GHz in order to establish its utility as broad band conformal array. At this frequency the pattern is perfectly omnidirectional as shown in Fig.7. As the frequency increases the radiation pattern is still omnidirectional but with side lobes without any change in direction of maximum radiation. At 1GHz the pattern breaks into small lobes separated by small angular distance in horizontal plane along the circular path, but still suitable for omnidirectional coverage. In elevation plane the pattern is shown only one side of the polar plot and the pattern is symmetrical in the opposite side.

Conclusions

Formation of the circular ring array suitable for mounting on cylindrical surfaces is presented with broad band biconical antenna elements. The results presented are very useful for applications in radar and communication systems. Excitation of elements of the array with uniform amplitude and out phase generates pencil beams whose number is proportional to the number of elements in the array. Scanning a single pencil beam at high speeds requires complex feed circuit in radar applications. Whereas the array with the proposed excitation requires simple feed and can cover 360°. Radiation pattern has no side lobes and the beams are highly directive. Usually beam width increases with reduction in side lobes, but the proposed excitation generates narrow beams without any side lobes. Now exciting the elements by uniform amplitude and in phase gives broad band operation of the array. At 100MHz frequency the radiation pattern is same as \( \sin \theta \) and the maximum radiation of the array is directed along the axis of the array. As the frequency increases side lobes also increases, but the pattern is omnidirectional. At 1GHz the radiation pattern small lobes along the axis of the array and is possible to use for 360 degrees coverage.

ACKNOWLEDGMENT

Authors thank the University Grants Commission, Govt. of India, New Delhi and the Management of RVR & JC College of Engineering, Guntur for their financial support for this work.

References