International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I3P223

Volume 69 Issue 3, 147-153, March 2021

Design and Analysis of Collinear Biconical Antenna Array

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Abstract — *This document gives Dipole antennas that are resonant and simple. The radiation pattern of dipoles and biconical antennas is Omnidirectional and used in broadcasting and mobile communication applications. Resonant antennas are narrow bands and mostly operate at a single frequency. Wideband antennas are in demand for modern wireless communication applications. The bandwidth of the dipole antenna is increased by increasing the top radius of the wire and results in a conical antenna. Array antennas of standard configurations are used for high gain and directivity applications. It is difficult to design a wideband array. But enhancing the band width of the antenna array makes them suitable for multiband and wideband operations. In this paper, the design and numerical analysis of the collinear array for wideband operation are presented. Collinear arrays provide high gain and directivity. Biconical antenna provides wideband width. A collinear antenna array with biconical elements is considered for the design and analysis. Also, the behavior of the individual elements of the array is also presented. The proposed array is designed at 6 GHz and is analyzed and compared with a common dipole array to evaluate its performance for 1-10 GHz. The proposed array is compact in size and is suitable for Ultra-Wide Band applications.*

Keywords — *Biconical Array, Collinear, Dipole, Wideband, Reflection Coefficient.*

I. INTRODUCTION

The first analysis of the conical antennas was provided by S.A.Schelkunoff with various cone angles. A wave guided by two coaxial conductors has been reported. The Biconical antenna is enclosed in a sphere, with the center of the sphere coinciding with the apices of the cones. Various parameters such as impedance and radiation from the elements are computed and plotted using the current distribution on the conductors [1]. Aspherical boundary is assumed for the analysis of the antenna region. The area around the antenna is divided into two regions, and the fields around the antenna are analyzed [2]. The conical antenna of wide-angle is analyzed using Legendre's functions orthogonal properties and their derivatives. The terminals of the wide-angle conical antenna are terminated in a spherical cap, and the fields are analyzed [3]. The Biconical antenna filled with dielectric is around the cones analyzed. Conical antennas are analyzed by considering higher-order modes and improved the field's computation as compared to predecessors [4]. The biconical antennas of different flare angles are analyzed the input impedances are derived and compared [5]. A biconical antenna added with a coaxial transmission line for efficient operation at low frequencies is designed. It gives an efficient performance at low frequencies. The effect on the field pattern of the antenna with the properties of the earth surface is also investigated [6]. A spherically capped biconical antenna with unequal cone angles is investigated. For a wide-angle biconical antenna, the expressions for terminal admittance radiated field and the effective height is developed. The results are derived for ultra-wideband operation [7]. A compact biconical antenna for ultra-wideband frequency range is designed and is used for body-worn applications. The antenna gives low directivity, and it's reduced by dielectric loading [8]. The biconical antenna with wide cone angles and terminated in the spherical cap. This antenna exhibits wide bandwidth and is analyzed for different electrical heights [9]. In this paper, a theoretical model of the coaxial collinear antenna with uniform and tapered current distributions is designed and analyzed [10]. An omnidirectional microstrip patch antenna is analyzed for its radiation characteristics, with gain control based on its length is reported [11]. Collinear arrays are widely used in the base stations of mobile earth communication stations. Collinear antenna arrays provide omnidirectional coverage with high gain. In a collinear array, the elements are placed in a line coaxial with equal spacing between the elements. The narrow omnidirectional radiation pattern reduces the unwanted radiation in the other directions. These arrays are used in the mobile base stations for broadcasting. The array axis is vertical, producing an omnidirectional pattern in the horizontal plane that is used in point-to-multipoint communications. A collinear antenna array using microstrip patch technology has been designed and analyzed. Geometrical perturbation of radiating patch is used to operate with higher-order modes. Narrow slots are placed at the center of the radiating patch so that the currents around the slot are out of phase and cancel on opposites. The directivity and beamwidth in the vertical plane are enhanced due to the collinear alignment of in-phase excited radiating elements [12]. A bandwidth-enhanced collinear microstrip patch array is designed, fabricated, and analyzed. The proposed array exhibits wide bandwidth around 1.1 GHz. Reduced side lobe level and narrow E-plane bandwidth are achieved [13]. Two and Three elements branched type microstrip co-parallel array is presented. The proposed array presents improved bandwidth and directivity [14]. A stacked biconical collinear array is designed for high omnidirectional gain at 30 GHz. The proposed antenna is fabricated and analyzed to provide a pencil beam in the vertical plane [15]. A biconical antenna with its edges terminated in a conductor is designed and analyzed. The proposed element provides wide bandwidth from UWB to 25 GHz [16]. Flared dipoles using microstrip patches are designed for C-band applications. This array provides improved gain and directivity for C-band [17]. A novel adaptive beam synthesis for adaptive arrays is reported [18]. In this paper, the biconical antenna array is formed by arranging the elements collinearly. The radiation characteristics are evaluated by simulating the configuration in the WIPL-D software. The merits of the configuration are obtained by comparing the parameters with the parameters of the dipole.

II. DESIGN OF THE ARRAY

A. Design of Biconical Antenna

The design frequency f = 6GHz.
Wavelength $\lambda = 3 \times 10^{11}/f$ = 50mm
Length of each cone $\lambda/4$ = 12.5mm
Radius of each cone is =12.5mm
Cone angle=90 degrees
Separation between the cones=1mm

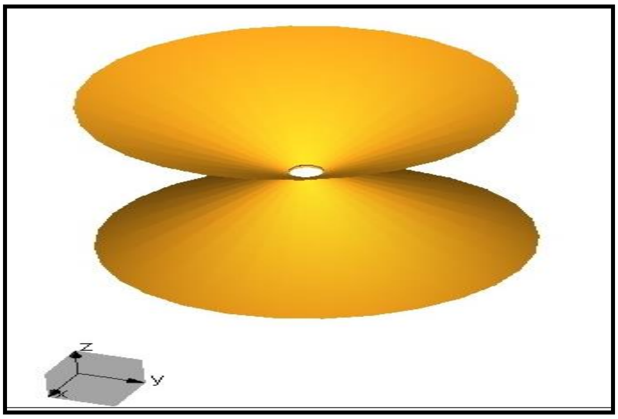

Fig.1 Biconical Dipole Antenna

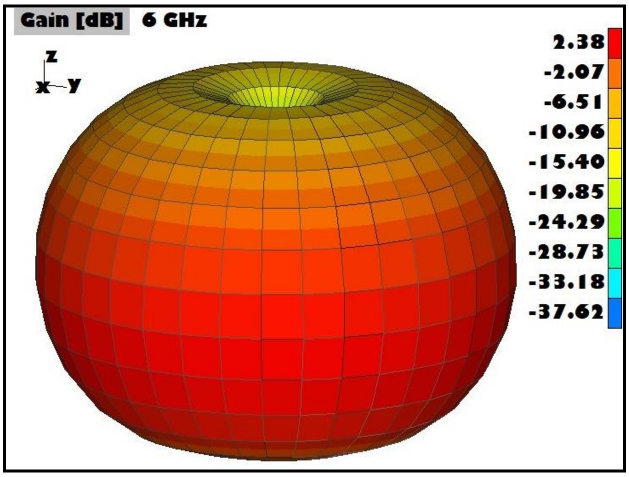

Fig.2 Radiation Pattern 3D

B. Radiation Patterns of the Biconical Antenna

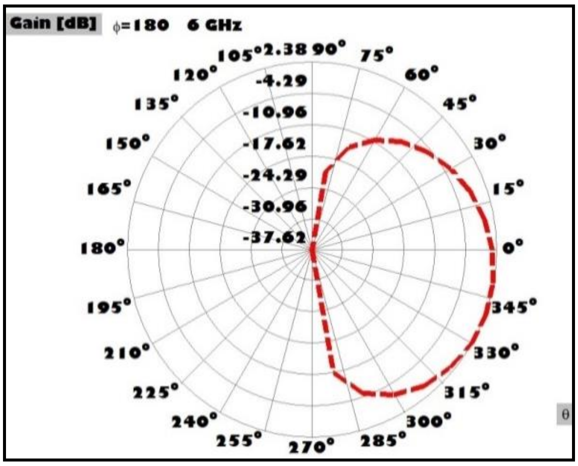

Fig.3 Radiation Pattern (Elevation Plane)

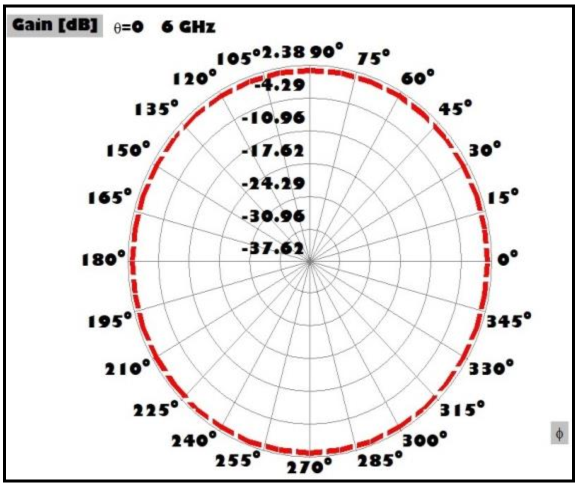

Fig.4 Radiation Pattern (Horizontal Plane)

C. Reflection Coefficients of the Biconical and Dipole antennas

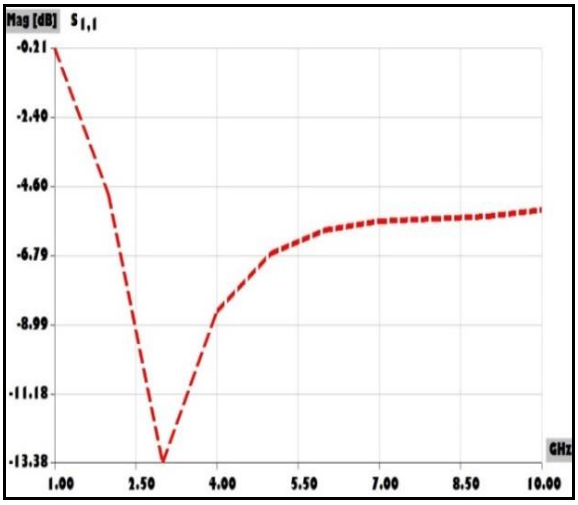

Fig. 5 S_{11} of Biconical Dipole

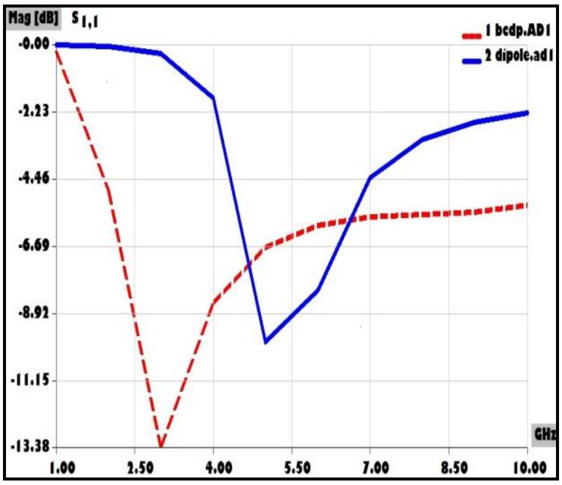

Fig.6 S11 of dipole & Biconical Dipole

A dipole is the fundamental element of the radiator with half-wavelength height and is a resonant antenna. Its radiation pattern is omnidirectional with a wide beamwidth. Every dipole is resonant at the frequency of design frequencies. A biconical antenna consists of two similar cones joined and fed at their apices. The height of the biconical antenna is also half wavelength at the design frequency. It is also called a biconical dipole, and its radiation pattern is omnidirectionally confined to the space between the cone surfaces. The biconical antenna is a wideband antenna due to the flaring of the edges of the wires. The cone angle is an important dimension for the biconical antenna. It is established that cones with angles between 60-90 degrees offer wide bandwidth than the simple dipole. In this paper, a biconical dipole with 90 degrees cone angle is used. Biconical antenna is designed with 6 GHz center frequency with a height of 25 mm (half wavelength). The height of each cone is 12.5mm with an angle of 12.5mm. As shown in Fig. 1, the cones are joined with the apices separated by a gap of 1mm and are excited at the apices. A proposed biconical antenna is modeled in WIPL-D software and is simulated from 1-10 GHz. The 3-dimensional radiation pattern is shown in Fig. 2. Radiation patterns in elevation and horizontal plane are depicted in Fig. 3 and Fig. 4, respectively. The maximum gain of the antenna is 2.38dB with a wide beamwidth of 90 degrees. The reflection coefficient of the antenna over a frequency range of operation determines the ability of the antenna to radiate the input power without reflection. A resonant antenna exhibits a low reflection coefficient at the design frequency only. At other frequencies, its value is usually high. But for the wideband antenna, the reflection coefficient shows a low value for a specific frequency range. The reflection coefficient of the biconical antenna is shown in Fig. 5. It is constant from 3 to 10 GHz with a value of -6dB. The reflection coefficient of the dipole with a biconical antenna is compared in Fig.6. The dipole is resonant at 6 GHz with -9dB as the reflection coefficient at the design frequency, but the dipole shows -6 dB from 3-10 GHz, and this clearly shows that the biconical antenna exhibits wide bandwidth. Therefore based on this result, it is proposed to design a collinear array using the biconical antenna elements and analyze its radiation properties in the next section.

III. BICONICAL AND DIPOLE ARRAY DESIGN

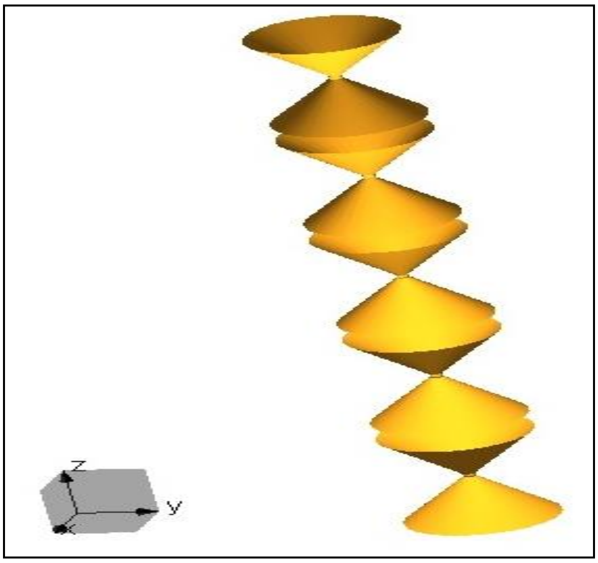

Fig.7 Biconical Array

The design frequency f = 6GHz.
Wavelength $\lambda=3x10^{11}/f$ = 50mm
Interelement spacing $\lambda/10$ = 5mm
Length of each cone $\lambda/4$ = 12.5mm
Radius of each cone is =12.5mm
Cone angle=90 degrees

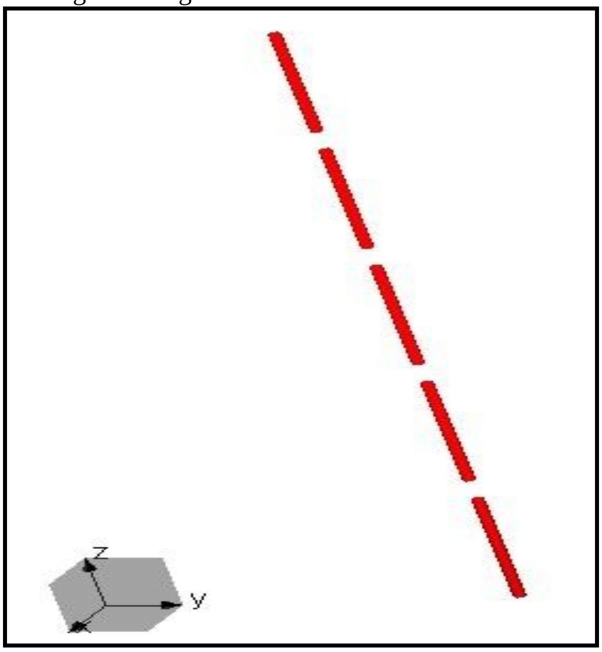

Fig. 8 Dipole Array

A five-element biconical array and dipole array are modeled and simulated in the numerical software WIPL-D as shown in Fig.7 and Fig.8, respectively. Radiation characteristics of the wideband collinear biconical array are analyzed and compared with those of the dipole array.

The elements of a collinear array are placed along a line on the Z-axis, and the currents in each element flow in the direction of that line. The elements of the array are equally spaced at a distance apart and have currents I_0, I_1, I_2, ….I_{N-1}. The total current is the sum of the Z-directed short dipole currents, and the vector potential integral is a sum over the element currents is expressed as

$$A_Z = \mu\frac{e^{-j\beta r}}{4\pi r}\Delta Z\left[I_0 + I_1 e^{j\beta d\cos\theta} + I_2 e^{j\beta 2d\cos\theta} + \cdots + I_{N-1} e^{j\beta(N-1)d\cos\theta}\right] \quad (1)$$

$$A_Z = \mu\frac{e^{-j\beta r}}{4\pi r}\Delta Z\sum_{n=0}^{N-1} I_n e^{j\beta nd\cos\theta} \quad (2)$$

The far field is expressed as

$$E_\theta = j\omega\mu\frac{e^{-j\beta r}}{4\pi r}\Delta Z\sin\theta\sum_{n=0}^{N-1} I_n e^{j\beta nd\cos\theta} \quad (3)$$

In Eq. (3), sinθ is the pattern of a single element and is the element pattern, and the remaining factor is the array factor given by Eq.(4)

$$\text{Array Factor(AF)} = \sum_{n=0}^{N-1} I_n\, e^{j\beta nd\cos\theta} \quad (4)$$

Array factor is the sum of the fields from isotropic point sources at the center of each array element and is obtained from the element currents and their locations. The element pattern is the radiation pattern of the individual element based on its current distribution and orientation in space.

The biconical antenna is a wideband antenna. This antenna consists of two cones whose apices are connected to the feed. Each biconical antenna is designed for 6GHz. The wavelength is 50 mm. The height of each cone is 12.5mm, which is a quarter wavelength. The length of each biconical antenna is 25mm. The array consists of five elements placed one above the other with an inter-element spacing of 5mm, which is λ/10 between the elements. Increasing the spacing between end to end of elements introduces constructional and feeding problems. Hence the elements in the collinear array are operated with their ends very close to each other. The gain doesn't increase in direct proportion to the number of elements used in the collinear array. Hence a maximum of 2-8 elements may be used to improve the gain and reduce the beamwidth.

The design frequency f = 6GHz.
Wavelength $\lambda = 3\times10^{11}/f = 50$mm
Interelement spacing λ/10 = 5mm
Length of each cone λ/4 = 12.5mm
Radius of each cone is =12.5mm
Cone angle=90 degrees

The individual elements in the array are fed equal amplitude and in phase.

IV. Radiation Characteristics of the array

A. Radiation Patterns

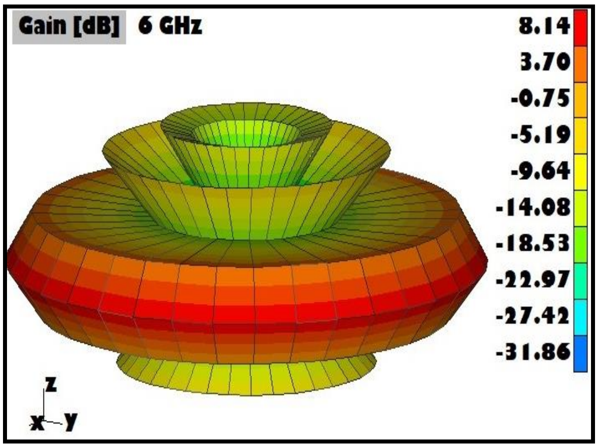

Fig.9 Radiation Pattern 3D

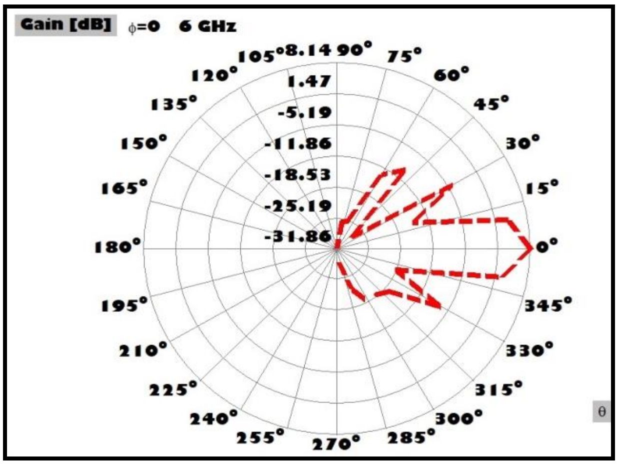

Fig.10 Radiation Pattern (Elevation Plane)

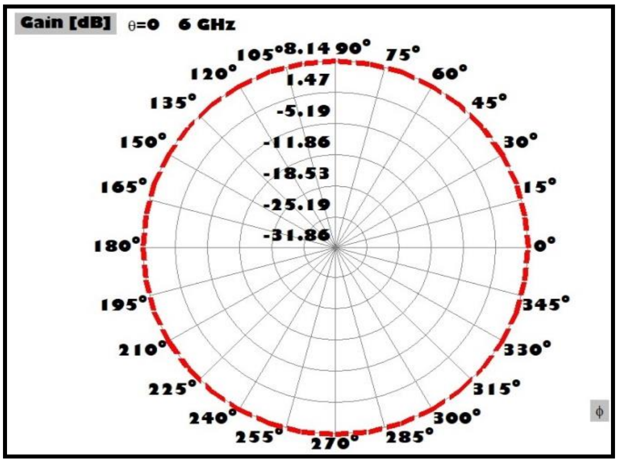

Fig.11 Radiation Pattern (Horizontal Plane)

In this array, the end-to-end gap between the elements is maintained only one-tenth of the wavelength. The 3-dimensional radiation pattern is shown in Fig. 10, and its pattern in elevation and horizontal planes are shown in

Fig.10 and Fig.11, respectively. The radiation pattern is omnidirectional, with its main lobe everywhere perpendicular to the principal axis of the array. Therefore this type of arrays is called broadcast or omnidirectional arrays. There is a similarity in the shape of the radiation pattern of collinear arrays, individual dipole, or biconical elements as all are omnidirectional. But beam width, side lobes, and gain are different for the collinear array. The number of side lobes increases, and the beam width is narrow around 25 degrees only, as shown in Fig. 10. Beamwidth is narrow 25degrees as compared to the individual biconical element in Fig. 3, which is around 90 degrees. The maximum gain of the individual biconical element in Fig. 2 is only 2.83 dB, but for the collinear array, it is 8.14dB shown in Fig. 9. Therefore the collinear array significantly improves the gain and reduces the beamwidth of the main beam. Reducing the beam width increases the side lobes and directivity; hence these arrays are suitable for application in mobile base stations and other communication base stations.

B. Reflection Coefficients of Biconical and Dipole arrays

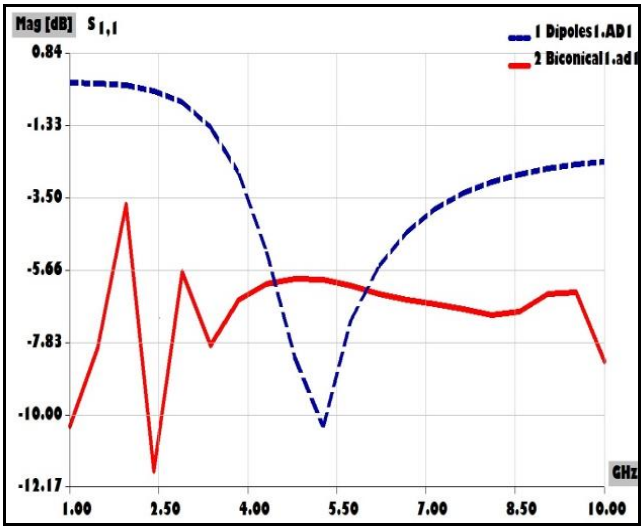

Fig. 12 Reflection Coefficient of Element 1

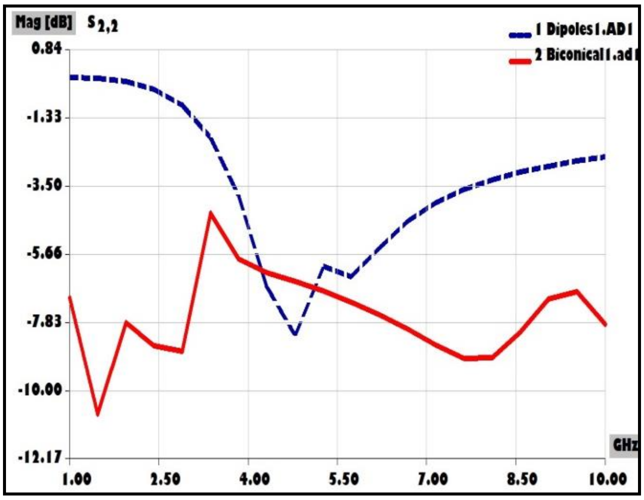

Fig. 13 Reflection Coefficient of Element 2

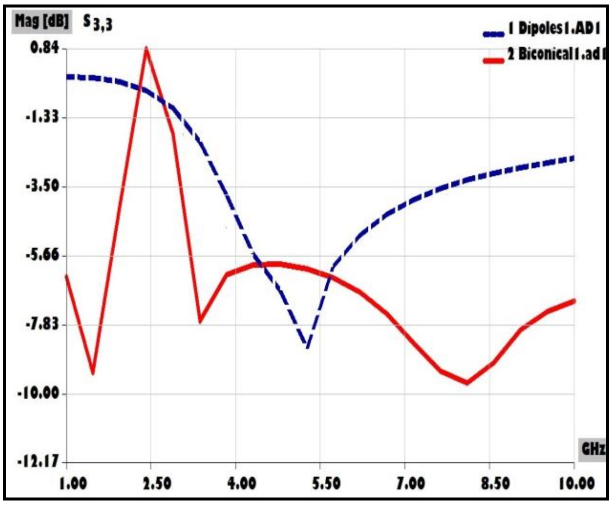

Fig. 14 Reflection Coefficient of Element 3

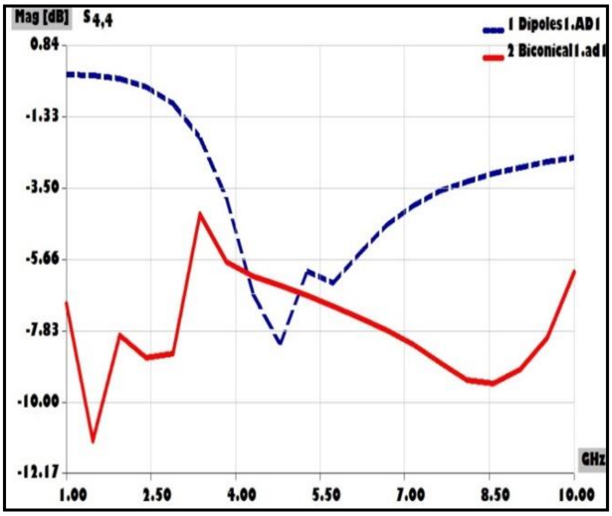

Fig. 15 Reflection Coefficient of Element 4

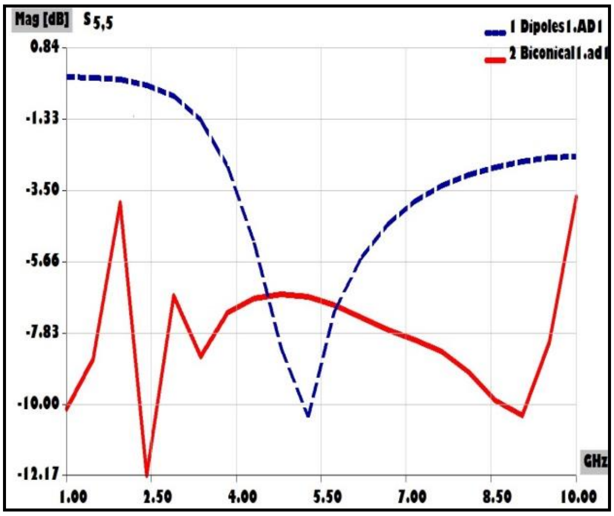

Fig. 16 Reflection Coefficient of Element 5

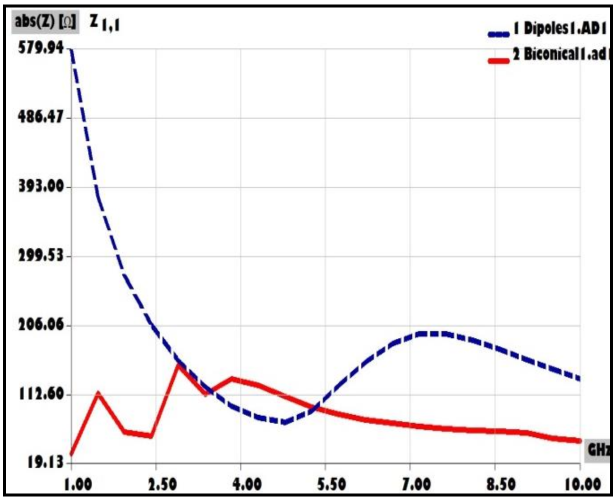

Fig. 17 Input Impedance of Element 1

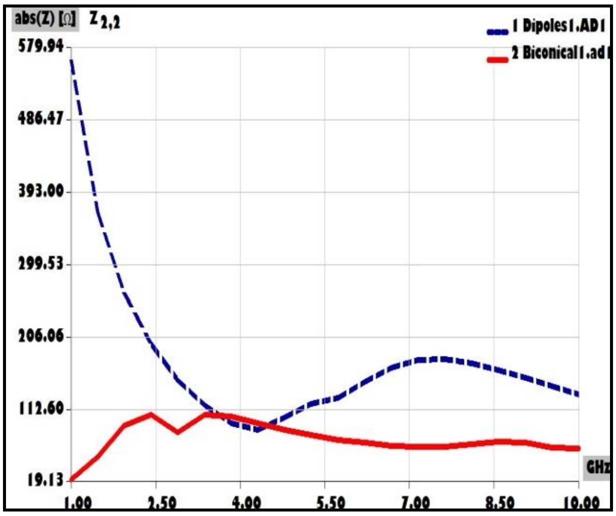

Fig. 18 Input Impedance of Element 2

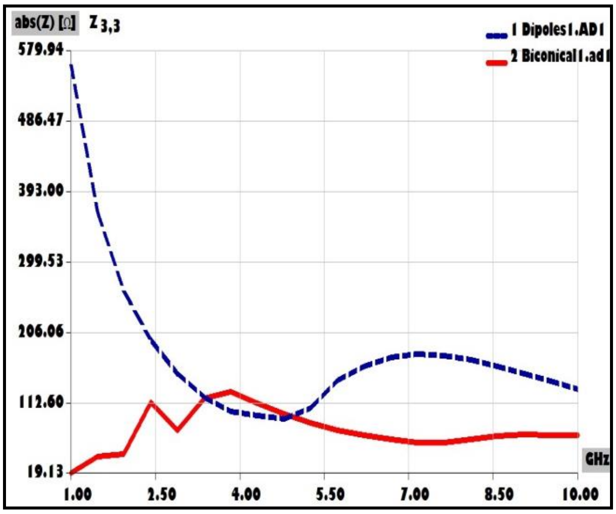

Fig. 19 Input Impedance of Element 3

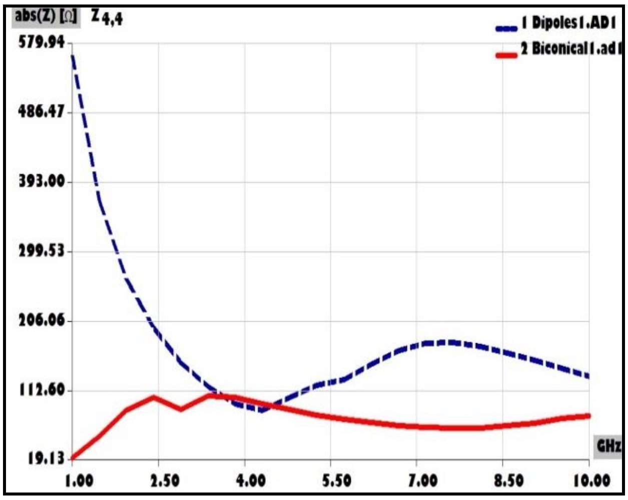

Fig. 20 Input Impedance of Element 4

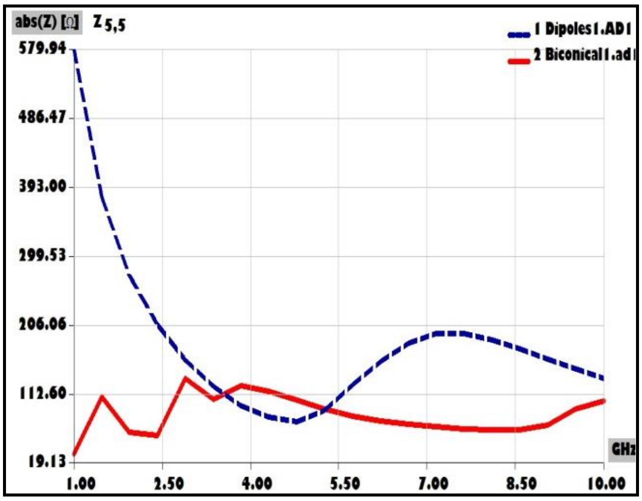

Fig. 21 Input Impedance of Element 5

The reflection coefficient S_{11} is an important parameter that determines the ability of impedance match of the element. Fig.12 to Fig.16 depicts the reflection coefficient of dipole and biconical antenna superposed between 1-10 GHz for each element. Each of the 5 plots shows two curves one is for dipole, and the other is for the biconical antenna of the respective array. In each plot, the reflection coefficient of the dipole is superposed with the biconical dipole. Every element of the dipole at 6GHz exhibits a very low reflection coefficient of around -10dB, but the reflection coefficient of each biconical dipole is less than -5dB over the entire frequency range. This shows that each element in the biconical collinear array exhibits a low reflection coefficient for a wide frequency range. But the reflection coefficient of each element in the dipole array is resonant at only one frequency of the design. This shows that the biconical collinear array exhibits wide bandwidth, and the collinear dipole array is a narrow band. Another import parameter is the input impedance of the elements in the array. Fig. 17 to Fig. 21 show the input impedance of the elements of the dipole and biconical arrays with five elements superposed. Here also, the input impedance is constant for the frequency range for the biconical array than for the dipole array.

IV. CONCLUSION

A wideband collinear array with biconical elements is designed for 6 GHz, and its performance is evaluated for 1-10 GHz. The performance of this array is compared with the dipole array to evaluate its performance. This proposed collinear biconical array provides improved gain and increased directivity than an individual element with an omnidirectional radiation pattern. Its bandwidth is enhanced as compared to the resonant dipole array of the same number of elements. Constant reflection coefficient and impedance of the elements over the proposed frequency range prove that the biconical array provides wide bandwidth with the same number of elements as that of a simple dipole array. The performance of this array is compared with a single element for beamwidth, directivity, gain, and sidelobe levels. Performance of the array is evaluated and compared with that of dipole array consisting of the same number of elements in terms of reflection coefficient and input impedance. It is found that gain and directivity improved significantly as compared to a single element biconical antenna. The radiation pattern of the array has side lobes, and the beam width is narrow than that of a single element. The input impedance and reflection coefficient remain fairly constant for 1-10 GHz for the biconical collinear array when compared with those of the dipole array. Therefore a wideband biconical collinear array with enhanced gain and directivity is proposed and analyzed numerically.

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