Radiation Pattern for Broad Side Array and End Fire Array Antennas

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***Abstract*— Antenna arrays are becoming increasingly important in wireless communications. In the antenna array system, the commonly used Antenna arrays are broadside array and end fire array. In many applications we have the maximum radiation of an array directed normal to the axis of the array, which is known as Broad side Array. The overall radiation pattern of an array is determined by array factor combined with the radiation pattern of the antenna element. The overall radiation pattern results in certain directivity and different lobes with different number of elements. Thus in this paper analysis is made on the effect of number of elements on broadside array and end fire array. And the comparative conclusions are drawn.**

Keywords- end-fire array; broad side array; array factor.

I. INTRODUCTION

The broadest definition of an antenna is that it is transducer-it changes energy from one form into another. A receiving antenna changes electromagnetic energy into electric or magnetic energy. A transmitting antenna changes the energy from electric or magnetic into electromagnetic energy. Current flowing in the antenna induces the electric and magnetic fields. Antennas have been used for over a century in a variety of applications. They can transmit over a massive range of frequencies, from a fraction of a kilohertz to over one hundred gigahertz.

An antenna does not radiate uniformly in all directions. For the sake of a reference, we consider a hypothetical antenna called an isotropic radiator having equal radiation in all directions. A directional antenna is one which can radiate or receive electromagnetic waves more effectively in some directions than in others. The relative distribution of radiated power as a function of direction in space is called the radiation pattern of the antenna. Instead of 3D surface, it is common practice to show planar cross section radiation pattern. E-plane and H-plane patterns give two most important views. The E-plane pattern is a view obtained from a section containing maximum value of the radiated field and electric field lies in the plane of the section. Similarly when, such a section is taken, such that the plane of the section contains H-field and the direction of maximum radiation.

The maximum radiation of a short dipole is along the direction perpendicular to the axis of the dipole, but when polar angle decreases the radiation also decreases. This type of radiation characteristics may be used for broadcast services. In point to point communication, the most of the energy is desired to be radiated in one particular direction which means that to have greater directivity in a desired direction [3]. This can be accomplished by making group of antennas excited simultaneously which is not possible by a single dipole antenna. Such a group of antennas is called an antenna array. Generally antenna array is the radiating system in which several identical or non-identical and/or either similarly oriented or differently oriented antennas are placed properly so as to get field strength at a far distance from the radiating system by combining radiations at point from all the antennas in the system [2].

This paper will give a brief introduction to antenna arrays and then discuss the various antenna array types and their counter applications.

It is difficult for a single antenna like motor connected parabolic dish to scan a radiation pattern or beam because the entire antenna system has to rotate to change the direction of the beam which leads to a considerable amount of aerodynamic drag when the antenna is airborne. Even when the antenna is on the ground plane and directs its beam in a direction to catch the target, the target will be in different direction due to its velocity being high and it will always be out of sight. It is possible to scan the beam from the array antenna electronically and it can be with either phase control or frequency control[1]. Array antennas are extremely useful in both airborne as well as ground based applications. Since there is no movement of the antenna there will be no aerodynamic drag with antenna array. Moreover, arrays provide a greater number of parameters and offer better flexibility for the designer [2]. Using antenna array gain and directivity can be increased and beam width can be reduced [3]. Broad side array, end fire array, collinear array and parasitic array are some of the practically used forms of antenna array. Circular Array is one of the most widely used antenna array designs. Its applications include radio direction finding, air and space navigation, underground propagation, radar, sonar, and many other applications [1]. A broadside uniform circular array radiates (receives) not only in the broadside direction, but, in the other directions as well. Such an array has a significant power loss due to along resting plane scanning property. The power radiation or reception pattern of a circular array is dependent on the linear distance between two consecutive elements, the radius, and the number of elements. Broadside arrays are used for a wide range of radio waves. At decameter (short) wavelengths, they are used chiefly for radio broadcasting over long distances [4].

II. ANTENNA ARRAY

Antenna array is a systematic arrangement of radio antennas working together. Kinds of antenna array include: Antenna array (electromagnetic), a geometrical arrangement of antenna elements with a deliberate relationship between their currents, forming a single antenna usually to achieve a desired radiation pattern.

An array of antennas may be used in a variety of ways to improve the performance of a communications system. Perhaps most important is its capability to cancel co channel interferences. An array works on the premise that the desired signal and unwanted co channel interferences arrive from different directions. The beam pattern of the array is adjusted to suit the requirements by combining signals from different antennas with appropriate weighting. An array of antennas mounted on vehicles, ships, aircraft, satellites, and base stations is expected to play an important role in fulfilling the increased demand of channel requirement for these services.

The study of a single small antenna indicates that the radiation fields are uniformly distributed and antenna provides wide beam width, but low directivity and gain. For example, the maximum radiation of dipole antenna takes place in the direction normal to its axis and decreases slowly as one moves toward the axis of the antenna. The antennas of such radiation characteristic may be preferred in broadcast services where wide coverage is required but not in point to point communication. Thus to meet the demands of point to point communication, it is necessary to design the narrow beam and high directive antennas, so that the radiation can be released in the preferred direction. The simplest way to achieve this requirement is to increase the size of the antenna, because a larger-size antenna leads to more directive characteristics. But from the practical aspect the method is inconvenient as antenna becomes bulky and it is difficult to change the size later. Another way to improve the performance of the antenna without increasing the size of the antenna is to arrange the antenna in a specific configuration, so spaced and phased that their individual contributions are maximum in desired direction and negligible in other directions. This way particularly, we get greater directive gain. This new arrangement of multi-element is referred to as an array of the antenna.

The antenna involved in an array is known as element. The individual element of array may be of any form (wire. dipole. slot, aperture. etc.). Having identical element in an array is often simpler, convenient and practical, but it is not compulsory. The antenna array makes use of wave interference phenomenon that occurs between the radiations from the different elements of the array. Thus, the antenna array is one of the methods of combining the radiation from a group of radiators in such a way that the interference is constructive in the preferred direction and destructive in the remaining directions. The main function of an array is to produce highly directional radiation. The field is a vector quantity with both magnitude and phase. The total field (not power) of the array system at any point away from its centre is the vector sum of the field produced by the individual antennas. The relative phases of individual field components depend on the relative distance of the individual clement and in turn depend on the direction.

When an element is excited, the radiated fields induce currents on nearby elements, which produce an additional contribution to the radiated fields. The equivalent current for an element in an array has a large component on the driven element, and smaller components on the other elements around the driven elements. For elements near the edge of the array, the coupled currents are different because there are fewer nearby elements than is the case for elements in the interior of the array. Even though the elements in the array are identical, the elements in the array are effectively represented by different equivalent currents. This means that the embedded element radiation pattern (including radiation from currents induced on neighboring elements) is different from the radiation pattern of the antenna element in isolation [3,4]. The array factor can be controlled by adjusting the complex excitations. The array radiation pattern is the product of the array factor and the pattern of one element located at the origin. If the array elements are electrically small, then the element pattern is broad and slowly varying with angle, and the array factor dominates in determining the shape of the radiation pattern. If the elements were ideal isotropic radiators, then the radiation pattern is equal to the array factor. The theory of array antenna beam forming provides methods for designing the excitations and locations of the elements in order to achieve various goals for the radiation pattern, such as high gain, electronic beam steering, low side lobes, or interference nulling [8,9].

***i. BROAD SIDE ARRAY*:** This is a type of array in which the number of identical elements is placed on a supporting line drawn perpendicular to their respective axes. Elements are equally spaced and fed with a current of equal magnitude and all in same phase. The advantage of this feed technique is that array fires in broad side direction (i.e. perpendicular to the line of array axis, where there are maximum radiation and small radiation in other direction). Hence the radiation pattern of broadside array is bidirectional and the array radiates equally well in either direction of maximum radiation.

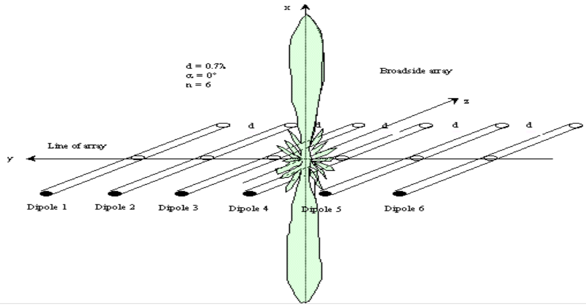


Fig.1.a: Linear broadside array of six radiating dipoles all elements in phase showing the position of the polar pattern

In Fig.1.a the elements are arranged in horizontal plane with spacing between elements and radiation is perpendicular to the plane of array (i.e. normal to plane of paper). They may also be arranged in vertical and in this case radiation will be horizontal. Thus, it can be said that broadside array is a geometrical arrangement of elements in which the direction of maximum radiation is perpendicular to the array axis and to the plane containing the array clement. A typical arrangement and Radiation pattern of a broad side array is shown in Fig.1.a. The bidirectional pattern of broadside array can be converted into unidirectional by placing an identical array behind this array at distance of $\lambda/4$ fed by current leading in phase by 90^0.

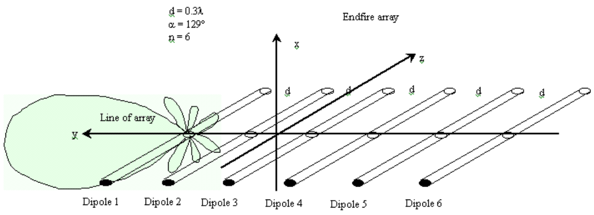


Fig.1.b.Linear end fire arrays of six radiating dipoles all elements in phase showing the position of the polar pattern.

ii. End Fire Array: The end fire array is very much similar to the broadside array from the point of view of arrangement. But the main difference is in the direction of maximum radiation. In broadside array, the direction of the maximum radiation is perpendicular to the axis of array; while in the end fire array, the direction of the maximum radiation is along the axis of array. Thus in the end fire array number of identical antennas are spaced equally along a line. All the antennas are fed individually with currents of equal magnitudes but their phases vary progressively along the line to get entire arrangement unidirectional finally. i.e. maximum radiation along the axis of array. Thus end fire array can be defined as an array with direction of maximum radiation coincides with the direction of the axis of array to get unidirectional radiation and its radiation pattern is shown in fig.1.b.

ARRAY FACTOR:

The capability of an antenna to increase the quality of the performance is depends on their parameters such as number of elements, spacing between elements, phase and amplitude excitation. The main parameters for linear array antenna are the number of elements and spacing elements which must be taken into consideration. Hence, these parameters are used to determine the antenna performance on the gain and HPBW.

The array factor(A.F.) is fundamental of the antenna parameters. It is the ratio of the magnitude of the resultant filed to magnitude of the maximum filed. This represents the relative value of the filed as function of θ .

$$A.F. = \frac{|E_T|}{|E_{\max}|} \tag{1}$$

Where, E_T represents total field intensity at point P, due to n number of sources having currents of amplitude and phase and maximum filed is $E_{\max}$.

This paper described the impact of the spacing and the number of elements on gain and HPBW through array factor algorithm for linear array antenna and simulated using MATLAB software as illustrated.

The array factor depends on the number of elements, the element spacing, amplitude and the phase of the applied signal to each element [1]. The antenna array can aligned either *z*-axis or *x* and *y*-axis. A uniform array is defined by uniformly spaces identical elements of equal magnitude with linearly progressive phase from element to element [2]. The radiation pattern of the array excluding the element pattern is referred to as the array factor. A general form for along the *z*-axis for linear array is given by [3].

III. DESIGN AND ANALYZE OF BSA AND EFA

The phasing of the uniform linear array elements may be chosen such that the main lobe of the array pattern lies along the array axis (end-fire array) or normal to the array axis (broadside array).

n-element uniform linear array:

At high frequencies, for point to point communication, it is necessary to have a pattern with single beam radiation. Such highly directive single beam pattern can be obtained by increasing the point sources in the arrow from 2 to N say. An array of N elements is said to be linear array if all the individual elements are spaced(d) equally along a line. An array is said to be uniform array if the elements in the array are fed with the currents with equal magnitudes and with uniform progressive phase shift along the line.

Phase angle: $\psi = (\delta + \beta d \cos\phi)$ (2)

Equation.(1) indicates the total phase difference of the fields from adjacent sources calculated at P. similarly α is the progressive phase shift between two adjacent sources. The value of ϕ may lie between 0^0 and 180^0 . If $\delta = 0^0$, we get n-element uniform linear broad side array. If $\delta = 180^0$, we get n element uniform end fire array. β is phase shift($\beta = 2\pi/\lambda$), λ = wave length.

The maximum of the array factor occurs when the array phase function ψ (angle) is zero.

$$\psi = (\delta + kd\cos\phi) = 0 \qquad (3)$$

For a broadside array, in order for the above equation to be satisfied with ϕ = 90 degrees, the phase angle δ must be zero. In other words, all elements of the array must be driven with the same phase. With $\delta = 0^0$ degree, the normalized array factor reduces $(AF)_n$ to

$$(AF)_n = \frac{1}{N}\frac{\sin\left(\frac{N\beta d}{2}\cos\phi\right)}{\sin\left(\frac{\beta d}{2}\cos\phi\right)} \qquad (4)$$

Here, If we plot the array pattern for□ ϕ = 90 degrees, we find that the element pattern is unity and the array pattern is the same as the array factor. Thus, the main beam of the array of *x*- directed short dipoles lies along the *y*-axis. The nulls of the array element pattern along the *x*-axis prevent the array from radiating efficiently in that broadside direction. End-fire arrays may be designed to focus the main beam of the array factor along the array axis in either the $\phi = 0^0$ or $\phi = 180^0$ directions [2]. Given that the maximum of the array factor occurs when $\psi = \delta + \beta d\cos\phi = 0$.

In order for the above equation to be satisfied with ϕ = 0 degree, the phase angle δ must be equal to negative of βd as given in equation

$$\delta = -\beta d \qquad (5)$$

For $\phi = 180^0$, the phase angle δ must be $\alpha = +kd$ (6)

The normalized array factor for an end-fire array reduces to

$$(AF)_n = \frac{1}{N}\frac{\sin\left(\frac{N\beta d}{2}(\cos\phi \mp 1)\right)}{\sin\left(\frac{\beta d}{2}(\cos\phi \mp 1)\right)} \qquad (7)$$

Thus using these equations (1) and (2) radiation pattern can be plotted. It is known that antenna arrays with different structures may radiate the different far-field characters, and generate the diversity of radiation patterns. Therefore, the effect of number of elements is analyzed and a comparison of radiation patterns between these two forms of antenna arrays is done. This work is carried out in this paper and conclusions are drawn.

IV. SIMULATION AND RESULTS

The optimization of directivity, number of minor lobes and main lobes for the various numbers of elements for broadside array and end fire array can be done by varying the number of elements to be placed then the analysis is done. And comparison is done between both. The radiation pattern is obtained using the MATLAB software.

a) Radiation pattern of BSA:

In many applications it is desirable to have the maximum radiation directed normal to the axis of the array($\phi_{\max} = 90^0$). To optimize the design, the maxima of the single element and of the array factor should both be directed toward $\phi_{\max} = 90^0$. Its radiation pattern also depends on choosing of the radiators and the proper separation and excitation of the individual radiators.

The first maximum of the array factor occurs when

$$(AF)_n = \frac{1}{N}\frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)} \approx \frac{\sin\left(\frac{N\psi}{2}\right)}{\sin\left(\frac{\psi}{2}\right)} \qquad (8)$$

$$\Rightarrow \psi = \beta d\cos\varphi + \delta = 0 \qquad (9)$$

Since it's desired to have maximum directed toward $\theta_{\max} = 90^0$, then

$$\Rightarrow \psi = \beta d\cos\phi + \delta = 0\text{; here } \delta = 0$$

It is necessary that all the elements have the same phase excitation (in addition to the same amplitude excitation), the separation between the elements can be of any value. To ensure that there are no principal maxima in other direction, which are referred to as grating lobes, the separation between the elements should not be equal to multiples of a wavelength.

One of the objectives in many designs is to avoid multiple maxima, in addition to the main maximum, which are referred to as grating lobes. Often it may be required to select the largest spacing between the elements but with no grating lobes.

Case 1: $d_{\max} < \lambda$ To avoid any grating lobe, the largest spacing between the elements should be less one wavelength.

Case 2: $d_{\max} = \lambda$

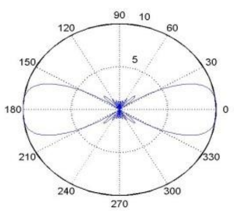
Case 3: if the spacing between the elements is chosen between $\lambda < d < 2\lambda$**,**

i. Then the maximum of figure 6.6 toward $\theta_0 = 0^0$ shifts toward the angular region $0^0 < \theta_0 < 90^0$.

ii. While the maximum toward $\theta_0 = 180^0$ shifts toward $90^0 < \theta_0 < 180^0$.

Case 4: $d = 2\lambda$ **:**

When $d = 2\lambda$, there are maxima towards $0^0, 60^0, 90^0, 120^0\, and\, 180^0$.



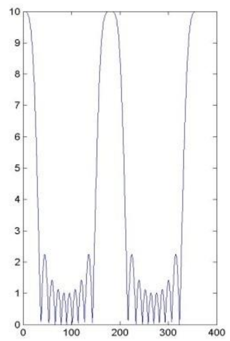


Fig.2. Raidation pattern of end-fire array.

b) Radiation pattern of EFA:

It is desirable to direct its radiation pattern along the axis of the array(end-fire). It may be necessary that it radiates towards only one direction ($\phi_{max} = 0^0$ or 180^0).

Case 1: To direct the first maximum toward $\phi_{max} = 0^0$

$$\Rightarrow \psi = \beta d \cos\phi + \delta = 0 \text{; Here } \phi_{max} = 0^0$$

$$\Rightarrow \psi = \beta d + \delta = 0 \Rightarrow \delta = -\beta d$$

Case 2: If the first maximum is desired toward $\phi_{max} = 180^0$, then

$$\Rightarrow \psi = \beta d \cos\phi_{max} + \delta = 0 \text{; here } \phi_{max} = 180^0$$

$$\Rightarrow \psi = -\beta d + \delta = 0 \Rightarrow \delta = \beta d$$

Thus end-fire radiation is accomplished when $\delta = -\beta d$ for ($\phi_{max} = 0^0$) or $\delta = \beta d$ for ($\phi_{max} = 180^0$)

Case 3: if the elements separation exists simultaneously in both directions ($\phi_{max} = 0^0$ and $\phi_{max} = 180^0$) as long as $\delta = \pm\beta d$.

Case 4: *if the element spacing is multiple of a wavelength (* $d = n\lambda, n = 1, 2, 3....$ *)*

Then in addition to having end-fire radiation in both directions, there also exist maxima in the broadside direction.

To have only one end-fire maximum and to avoid any grating lobes, the maximum spacing between the elements should be less than $d_{max} = \lambda/2$.

c) Effect of the number of elements on Radiation pattern

In this subsection, it is analyze the effect of number of elements on the radiation patterns of both the arrays and then they are compared. In case of end fire array, direction of main lobe remains unchanged, as the spacing remains unchanged throughout the results that are obtained. But the minor lobes increased and main lobe little bit become narrow as the number of elements increases. In case of broadside array, it is clearly shown in results its directivity is more than end fire array as the main lobe is very much narrow, and also pattern is symmetrical, but the grating lobes appears with increase in number of elements. End fire array is unidirectional as spacing is constant here, only the number of elements are varied, it may be bidirectional if the spacing is increased. The broadside array is bidirectional as it is shown in results, and produces more symmetrical pattern and can be used for long distance communication where directivity needed to be strong. End fire array provide directional radiations and stable unidirectional radiation pattern. Thus to get more directivity size of array has to be more. It can be used in satellite dish antennas, where a very high directivity is needed, because they are to receive signals from a fixed direction.

V. CONCLUSION

The Effect of number of elements on the radiation pattern of broadside array and end fire array are analyzed and compared in present paper. In general the directivity of broadside array is strongest as compared to end fire array, but the end fire produces stable unidirectional radiations. And broadside array give more symmetric pattern as the pattern is bidirectional and can be used for long distance communication as their directivity is strong. The end fire array can be used to construct directional antennas and can be used in satellite dish antenna to receive signal from fixed direction.

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REFERENCES

[1] The above theory was taken from the excellent book by, L.V. Blake, "Antennas," Artech House, Inc. (1984) (ISBN 0-89006-154-8). (Originally published by John Wiley & Sons, 1966.)

[2] W.W. Hansen and J.R. Woodyard, "A New Principle in Directional Antenna Design," Proceedings IRE, 26, 333-335 (March 1938).

[3] Boro M.Reljic, MICROWAVE AND OPTICAL TECHNOLOGY LETTERS / Vol. 50, No. 1, January 2008 DOI 10.1002/mop.

[4] G. S. N. Raju, Antennas and Wave Propagation, Pearson Education, Singapore: 2006.

[5] H. Oraizi, M. T. Noghani, "Design and optimization of linear and planar slot arrays on rectangular waveguides", *Proc. Eur. Microw. Conf.*, pp. 1304-1307, Oct. 2008.

[6] S. Clauzier, S. Avrillon, L. Le Coq, M. Himdi, F. Colombel, E. Rochefort, "Slotted waveguide antenna with a near-field focused beam in one plane", *Microwaves Antennas & Propagation IET*, vol. 9, no. 7, pp. 634-639, 2015.

[7] Amanpreet K. and Amandeep S. 2012. Analyze the effect of Number of elements on Radiation pattern of Broadside array and End fire array. International Journal of Computer Applications, Vol. 45, No. 18, 31-34

[8] Kraus J.D. 1988, Antennas. McGraw-Hill, Inc., USA, 2nd Edition, 26.

[9] Krishna P.R., Lakshmi S.S., Sreedevi I., Khan H., Aditya M.P.K., Krishna V.V., Lavanya J. 2012. Sidelobe suppression of concentric circular arrays using non-conventional beam forming technique. International Journal of Modern Engineering Research (IJMER), Vol. 2, No 3, 635-638.

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