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Investigating the Impact of Diverging Spacing Factors on Array Antennas

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ABSTRACT

This paper analyzed the antenna patterns for dipole array antennas of diverging spacing factor. In order to minimize the complexity of the task required in the computation, we assumed a negligible width for the dipole elements. Thus, the current flowing through the wire is assumedly constant. The Array Factor for dipole array antennas of diverging spacing factor was derived via Magnetic Vector Potential model. The required radiation patterns for the antennas were generated using the MatLab simulation tools. The generated results showed a trade-off between directivity and power loss as expected. While the diverging spacing factor results to a swift increase in the directivity of the radiation pattern, it produces many ripples for an increase in the array antenna element.

Keywords: dipole, array antennas, array factor, electromagnetic fields, diverging spacing factor, Magnetic Vector Potential.

1. INTRODUCTION

The computation of array antennas parameters is always a challenging task in the absence of a multiplier termed 'array – factor'. This challenge is most noticeable in a situation where the dimensions of the antenna elements are not similar, such as where there are variations in the length of the elements or the elements spacing. When these variations exist, it is expected that all the antenna elements that constitute the array be individually analyzed before computing the parameters of the array. Thus, this is a very challenging task, especially as the number of antenna element in the array increases [1], [2]. However, these antenna parameters are easily derived when there is an available array-factor. While the antenna structure discussed in [1] was analysed for an array of Log-Periodic circular loop antennas at a conventional spacing factor, $\tau<1$, this paper analyzed the patterns for dipole array antennas of similar dimensions at a diverging spacing factor ($\tau >1$) using the Magnetic Vector Potential (MVP) model. It engaged the MatLab R2010a object-oriented programming tools to simulate and plot the normalized array pattern for the array antennas at various numbers of dipole elements. The results obtained in this work conformed to that of the dipole array antennas of equal lengths and spacing as the spacing factor reduced to unity [3].

2. RELATED WORKS

Large antennas create the high gain needed to boost the received/transmitted signal for communications or radar systems. Today, reflectors and arrays compete for large aperture jobs in many types of systems [4]. The work in [3] postulated the Array-Factor for dipole arrays of uniform spacing and dimensions using Magnetic Vector Potential model. The author described the pragmatic pattern for analyzing the array factor of identical two-element array positioned along the *z*-axis and expressed it in a compact and closed form. The electric and magnetic fields produced by the antennas in the far field were also computed using the array factor. However, it's worth noting that the author's assumption of point sources with infinitesimal dimensions may not align with practical considerations.

In [2], the author developed the array factor for analyzing the signal generated in Log-Periodic antennas. The author employed the Magnetic Vector Potential (MVP) model and systematically derived the array factor for computing Log Periodic Array (LPA) antennas using Log Periodic Dipole Array (LPDA) antennas and Log Periodic Circular-Loop Array (LPCA) antennas. The parameters of the antenna were successfully analyzed with the derived array factor, and also simulated with MatLab software. However, the spacing factor for these array antennas was not diverging.

The report of [5] highlighted that Log Periodic Antennas were made up of a number of parallel elements that were progressively increasing in all the antennas dimensions. The angle formed between the linked elements and the antenna boom was kept constant in the analysis. Also, in [6], where Log-Periodic Array was made up of linear elements that were arranged in a plane surface – which thus decrease consistently in dimension, the admittance matrix technique was used by the authors to determine the currents at the bases of the Array Antennas elements. The spacing factor for these array antennas was not equally diverging.

Gurel and Ergul in [7] described the design and simulation of circular arrays of Trapezoidal–Tooth Log periodic Antennas using Genetic optimization. The authors remarked that the complicated structures of the trapezoidal – tooth array elements and the overall array configuration made their analytical treatments to be prohibitively difficult. Hence, the authors designed and explored a three – element Log Periodic array showing broadband characteristics. Log Periodic Array antennas also have no diverging array factor.

There were research works done on different areas of the array antennas which included the derivation of Array-Factors for analyzing array antennas of equal dimensions [8], and Log Periodic Dipole Array antennas [2]. Research has also highlighted the design and analysis of radiation patterns of antennas with converging spacing factor ($\tau < 1$) and unity spacing factor ($\tau=1$) [3], [8] except for diverging spacing factor ($\tau > 1$). Hence, this research investigated the impact of diverging spacing factor on the radiation patterns of dipole array antennas.

3. METHODOLOGY

Calculating the Array Factor for the antenna structure with a spacing factor greater than one demands that the elements be positioned along z-axes of the Cartesian coordinates. The antenna dipole elements were arranged as shown in Fig. 1. The $R_1, R_2, and\ R_3$ in the figure represent the distances from the source points to the far field of the antenna's elements, while the $r_1, r_2, and\ r_3$ represent distances from the antenna's origin to the field points, and d_1, and d_2 represent the elements spacing.

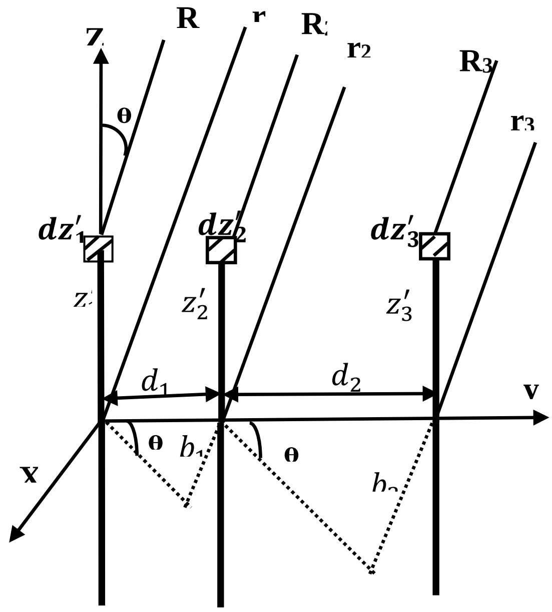

Fig. 1: Schematic diagram of the dipole array antennas with diverging spacing factor

The vector potential of each of the dipole elements$\boldsymbol{A_z}$shown in fig. 1 is given thus,

$$A_z = \frac{\mu}{4\pi}\int_{-l1/2}^{l1/2} I\ (Z_1')\ \frac{e^{-j\,k\,\hat{R}}}{|R|} dz_1' [3] \qquad (1)$$

where,
l= length of the antenna element
I= current flowing through the antenna element
k= wave number
r=distance from the antenna source point to the field point

The currents flowing through the elements were assumed to be constant in order to help reduce the complexity of the task. That is,

$$\mathrm{I}\ (\mathrm{Z}_1') = I_0 \qquad (2)$$

The observation was made at the far field, where the $\hat{\mathrm{R}}$ in the phase of the Green's function was reduced to $\hat{\mathrm{R}}=z_1'\cos\theta$, while the amplitude |R| was reduced to $|R|\approx r$.

Thus,

$$\mathrm{A_z} = \frac{\mu}{4\pi}\int_{-l1/2}^{l1/2} \mathrm{I}\ (\mathrm{Z}_1')\ \frac{e^{-\mathrm{j\,k}\,(\mathrm{r}-\mathrm{z}_1'\cos\theta)}}{r}\,\mathrm{dz}_1' \qquad (3)$$

After integrating over the length of the dipole element, we obtain thus

$$\mathrm{A_z} = \frac{\mu\,\mathrm{k}^2\,\mathrm{Il}^2 e^{-jkr}}{16\pi r k} \qquad (4)$$

For phase estimation, R_1, R_2, R_3 are calculated in terms of r_1, r_2, r_3. Hence,

$$\mathrm{R_1} = \mathrm{r} - \mathrm{z}_1'\cos\theta \qquad (5)$$

$$\mathrm{R_2} = \mathrm{r_2} - \mathrm{z}_2'\cos\theta \qquad (6)$$

$$\mathrm{R_2} = \mathrm{r} - \mathrm{d_1}\sin\theta - \mathrm{z}_2'\cos\theta \qquad (7)$$

$$\mathrm{R_3} = \mathrm{r_3} - \mathrm{z}_3'\cos\theta \qquad (8)$$

$$\mathrm{R_3} = \mathrm{r} - (\mathrm{d_1} + \mathrm{d_2})\sin\theta - \mathrm{z}_3'\cos\theta \qquad (9)$$

Note: $\mathrm{d_2} = \tau\,\mathrm{d_1},\ \mathrm{d_3} = \tau^2\,\mathrm{d_1}$ (10)

$$\mathrm{R_3} = \mathrm{d_1}\,(1+\tau)\sin\theta - \mathrm{z}_3'\cos\theta \qquad (11)$$

where $d_2 > d_1$ and $\tau > 1$
r stands for the distance from the origin to the field point;
Thus, manipulating the $\hat{\mathrm{R}}$ in the Green's function of the Magnetic Vector Potential of equation (3) to obtain the effective phase R_{eff} of the array antennas;

$$\frac{e^{-jkR_{eff}}}{r} = \frac{e^{-jkR_1}}{r} + \frac{e^{-jkR_2}}{r} + \frac{e^{-jkR_3}}{r} \qquad (12)$$

From equation (12),

$$R_{eff} = R_1 + R_2 + R_3 + \cdots \qquad (13)$$

where,
$R_1 + R_2 + R_3 + \cdots$ are phase approximations

$$R_{eff} = 1 + e^{jkd_1 sin\theta} + e^{jkd_1(1+\tau)sin\theta} + e^{jkd_1(1+\tau+\tau^2)sin\theta} + \cdots + \prod_{i=1}^{n} e^{jkd_1\tau^{i-1}sin\theta} \qquad (14)$$

Hence, for an infinite series of dipole array antennas elements, the Array Factor is represented as,

$$AF = 1 + e^{jkd_1 sin\theta} + e^{jkd_1(1+\tau)sin\theta} + e^{jkd_1(1+\tau+\tau^2)sin\theta} + \cdots + \prod_{i=1}^{n} e^{jkd_1\tau^{i-1}sin\theta} \qquad (15)$$

Assume $e^{jkd_1 sin\theta} = \gamma$

$$AF = 1 + e^{j\gamma} + e^{j\gamma}e^{j\gamma\tau} + e^{j\gamma}e^{j\gamma\tau}e^{j\gamma\tau^2} + \cdots + \prod_{i=1}^{n} e^{j\gamma\tau^{i-1}} \qquad (16)$$

The array factor is derived as,

$$AF = 1 + \sum_{n=1}^{N-1}\prod_{i=1}^{n} e^{j\gamma\tau^{i-1}} \qquad (17)$$

where;
N is the number of dipole elements
τ is the diverging spacing factor.

4. RESULTS ANALYSIS

This section presents the antenna patterns of the dipole array antennas of diverging spacing factor. The essence of this analysis is to highlight one of the simplest ways of minimizing the effect of power loss at the side lobes of antennas, thus ensuring increase in directivity of radiated patterns. It should be emphasized here that a diverging spacing factor has a significant role in actualizing a change in antennas radiation directivity and ripples generation.
The radiation patterns generated are presented alongside with the polar plots for different numbers of dipole elements as shown in figs. 2, 3, and 4.

Fig. 2 represents the antenna patterns for the dipole array antennas of similar lengths and diverging spacing factor for N= 2.

Fig.2: The plot of the antenna pattern for N= 2

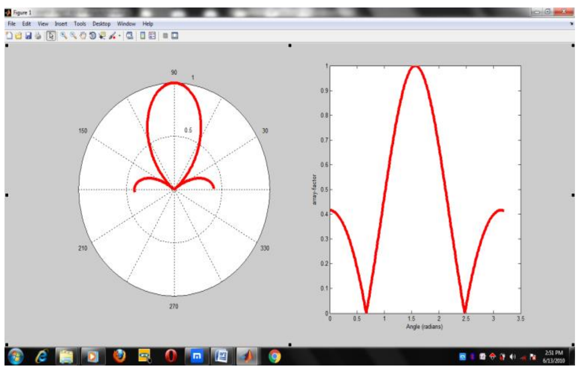

Fig. 2 shows the results of the antenna pattern for dipole array antennas of diverging spacing factor for N= 2, at design factor, τ =2. The radiation patterns generated showed minor side lobes. It could be observed that much of the antenna power was directed towards the main lobe with little side lobes.

Fig. 3 shows the plot of antenna patterns for N = 3.

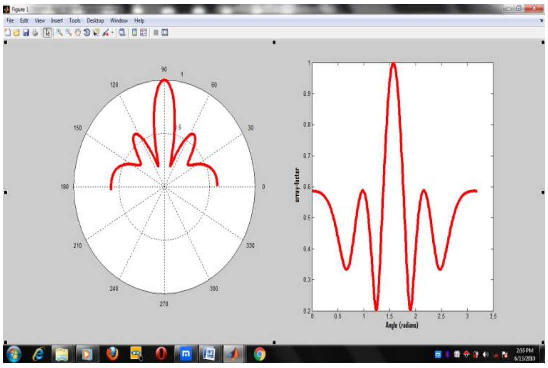

Fig. 3: The plot of the antenna pattern for N = 3

Fig. 3 showed the dipole array patterns for the antennas when an additional element was added to the array. The radiation patterns showed a sharp increase in the directivity of the main lobe compared to fig. 2. However, the side lobes showed a drastic increase. The increase of the ripples was almost twice that of fig. 2.

Fig. 4 is the plot of radiation pattern of equation (17) for spacing factor τ= 2and N = 5

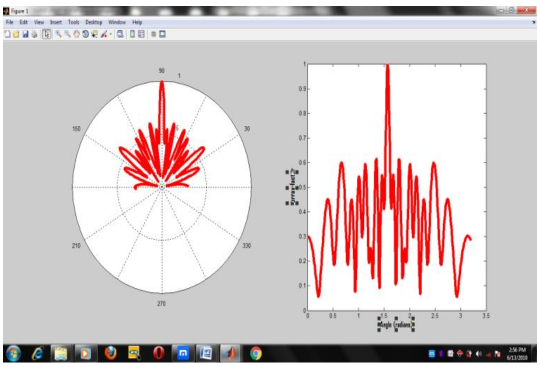

Fig. 4: The plot of the antenna pattern for N = 5

As the dipole element increased to 5, a very sharp main lobe was generated which indicated high directivity. However, this resulted to the generation of multiple ripples. In other words, it could be observed from figure 4 that there were many ripples (side lobes) on the response of few added dipole elements.

Figs. 2, 3, and 4 illustrate a relationship between the antenna's directivity and the power loss occurring at the side lobes. Similar to [1], when the number of elements in the array increased gradually, the number of ripples on the patterns and directivity increased suddenly. In other words, it shows that the side lobes swiftly increase with an increase in N.

The trade-off is between directivity and power loss. While a diverging spacing factor results to an increase in the directivity of the radiation pattern, it also leads to much power loss at the generated ripples for an increase in the number of antenna elements. However, the ripple generation could be minimized by reducing the angle within which the signal is radiated.

5. CONCLUSION

This paper evaluated the impact of diverging spacing factor on the radiation performance of dipole array antennas from first principle. It derived the array-factor for dipole array antennas of a diverging spacing factor via Magnetic Vector Potential model. Based on the observations made, diverging spacing factor has tremendous role to play on the transition region(directivity) as well as on the ripples(side-lobes) of the array antennas. The array factor derived for the array antennas had the same pattern with that of the dipole array antennas obtained in [3], at the same spacing factor, τ.

Unlike in the conventional spacing factor, $\tau < 1$, diverging spacing factor, $\tau > 1$, resulted to an abrupt increment in the directivity and side lobes of the array antennas for small increase on the number of dipole elements.

Thus, the knowledge of the diverging spacing factor in shaping the radiation patterns of array antennas, as exposed in the paper, highlights the cost implications of using such arrays in communication systems.

Declaration by Authors

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