

Multi-frequency Characteristics of Unequal Element Spacing Array Antenna for Mobile Base Station Use

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Abstract—In mobile base station antennas, linear array antennas are employed to achieve shaped beams in the vertical plane. Also, antennas are designed to achieve multi-frequency use. In the case of expanding multi-frequency range, conventional equal element spacing configuration shows a defect of producing grating lobes. In order to suppress grating lobes, unequal element spacing is promising.

In this paper, a radiation pattern synthesis based on a least mean square method (LMS) is applied to unequally spaced array configurations. In frequencies of 900 MHz, 1.5 GHz, 2.0 GHz, and 2.5 GHz, calculated results are presented. Suppression of grating lobes and increase of antenna gain are shown. Also, simulation results by FEKO using electric point source and dipole as array elements are shown to confirm accuracy of this method.

Keywords—Linear array antenna, unequally spaced array, radiation pattern synthesis, least mean square method

I. INTRODUCTION

Mobile base station antennas are requested variety of characteristics such as asymmetrical radiation patterns, low side lobe level, electrical beam tilt [1]. Also, multi-frequency use of 800 MHz, 1.5 GHz, and 2.0 GHz is achieved [2]. They are configured by linear array antennas of equally spaced array elements. In the case of designing radiation patterns, radiation pattern synthesis method of least mean square (LMS) is employed [3]. Although excellent low sidelobe characteristics are obtained, grating lobe appearances in higher frequencies are shown as problems. For suppressing grating lobes, unequally spaced arrays are considered [4]. However, possibility of radiation pattern synthesis in an unequally spaced array is not clear.

In this paper, an LMS program application for an unequal element spacing array configuration is studied. Shaped beam of a cosecant squared radiation pattern and low side lobe pattern is designed. Multi-frequency characteristics in 900 MHz to 2.5 GHz band are investigated. In order to ensure the results of MATLAB, radiation pattern results by electromagnetic simulations by FEKO [5] are obtained.

II. RADIATION PATTERN SYNTHESIS METHOD

A. Antenna configuration

An array antenna configuration and an objective radiation pattern are shown in Fig.1. Radiation elements number is q . Excitation coefficients are expressed by a column vector $[V]$ of q components. Antenna spacing is determined by the next expression.

$$d_n = d + n\Delta d \quad (n=1,2,\dots,q-1) \quad (1)$$

Here, Δd expresses the degree of unequally spacing. As for element spacing, spacing is gradually increased from the left end of an array. The objective radiation pattern is expressed by a column vector $[A]$ of p components.

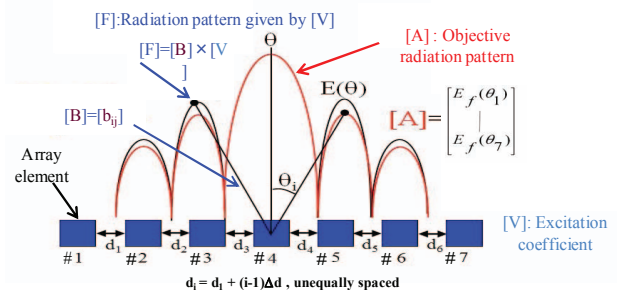


Fig. 1 Array configuration.

B. Fundamental equations

Radiation pattern ($[F]$) of p components is given by the next expression.

$$[F] = [B][V] \quad (2)$$

Here, $[B]$ is a $q \times p$ matrix which expresses contributions of $[V]$ to each direction of θ ; ($i=1,2,\dots,p$). Components of the matrix $[B]$ are given by the next expression.

$$b_{in} = v_n \exp[j2\pi/\lambda(d_1 + d_2 + \dots + d_n)\sin\theta_i] \quad (3)$$

$$(i=1,2,\dots,p), (n=1,2,\dots,q)$$

According to the conventional LMS method, the radiation pattern difference (ϵ) between the objective $[A]$ and $[F]$ is given by the next expression.

$$\epsilon = ([T][B][V] - [T][A])^H \times ([T][B][V] - [T][A]) \quad (4)$$

Here, H indicates complex conjugate and transpose of a matrix. $[T]$ is a weighting matrix, which has only diagonal components (t_i). In the case of $t_i = 1$ ($i=1,2,\dots,p$), all radiation levels of θ_i ($i=1,2,\dots,p$) have equal weighting. However, giving large number to t_j ($j=k,\dots,k+m$), radiation corresponding to the angular region from θ_k to θ_{k+m} are emphasized in pattern synthesis.

Equation (4) can be transformed to (5) by completing the square [6].

$$\begin{aligned} \epsilon = & \{ [V]^H - [A]^H [T]^H [T] [B] ([B]^H [T]^H [T] [B])^{-1} \} \\ & \times ([B]^H [T]^H [T] [B]) \times \{ [V] - ([B]^H [T]^H [T] [B])^{-1} [B]^H [T]^H [T] [A] \} \\ & + [A]^H [T]^H [T] [A] - [A]^H [T]^H [T] [B] ([B]^H [T]^H [T] [B])^{-1} \\ & [B]^H [T]^H [T] [A] \end{aligned} \quad (5)$$

The minimum value of (5) is achieved when $[V]$ is given by the next expression. Here, $[T]^H [T]$ is converted to $[T_0]$.

$$[V_0] = ([B]^H [T_0] [B])^{-1} [B]^H [T_0] [A] \quad (6)$$

By applying the condition of (6) to (5), the normalized aberration of $\epsilon/[A]^H [T_0] [A]$ is expressed as follows.

$$\begin{aligned} \epsilon = & \{ [A]^H [T_0] [A] - [A]^H [T_0] [B] [V_0] \} / [A]^H [T_0] [A] \\ = & \{ [A]^H [T_0] ([A] - [B] [V_0]) \} / [A]^H [T_0] [A] \end{aligned} \quad (7)$$

C. MATLAB program

The radiation pattern synthesis program is constructed on MATLAB software. Content of the program is shown in Fig.2. First, array antenna parameters such as calculation frequency (f), element number (N) and array spacing (d_i) are input. Next, design objectives of radiation pattern ($[A]$) and angular information (θ_i) are input. And the weighting matrix ($[T]$) is set. After these inputs, array excitation coefficient ($[V]$) is calculated. Moreover, a radiation pattern is calculated by using obtained $[V]$ value in order to ensure the design adequateness. The process from design objective setting to the radiation result is repeated until satisfactory radiation pattern is obtained.

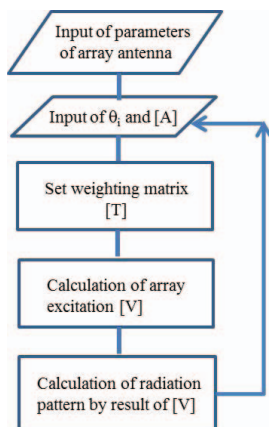


Fig. 2 Flow chart of MATLAB program.

III. MOBILE BASE STATION DESIGN

A. Antenna configuration multifrequency elements feed network cosecant squared beam

The structure of an array antenna for a mobile base station is shown in Fig. 3. For the purpose of electromagnetic waves spreading equally over an own radio zone, it is necessary to design an array antenna whose radiation pattern has a shape like a cosecant squared beam as shown in Fig. 3.

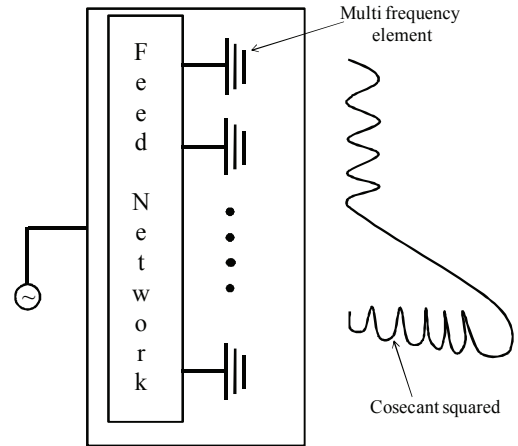


Fig. 3 Base station antenna.

B. Cosecant squared beam design of equal spacing array antenna

At $f = 900$ MHz, the radiation pattern achieved is displayed in Fig. 4. The calculation results are performed under the condition that the elements are spaced equally. In Fig. 4, the dashed line presents the objective values based on cosecant function, while the solid line depicts the calculation results of the proposed antenna's radiation pattern. The simulation parameters are shown in the table 1. As can be seen, at $f = 900$ MHz, the simulation radiation pattern is almost similar to the desired one. The values of the weighting matrix $[T]$ are illustrated in Fig. 5; the amplitudes and phases of the array elements are described in Fig. 6 and Fig. 7 respectively. It is clear that, the phases among the adjacent elements are almost linear, which in turn facilitates manufacturing the antenna. Keep the same state of the phases as well as amplitudes of the array elements like the previous simulations, when the operating frequencies are modified, the radiation patterns comparison is displayed in Fig. 8. As can be seen, there are some changes in the radiation patterns when the investigated frequencies are set at 2.0 GHz and 2.5 GHz. At higher frequencies, grating lobes appear. It is obvious that this array antenna has a narrow bandwidth; consequently, it is difficult to use this antenna for both 2G and 3G networks.

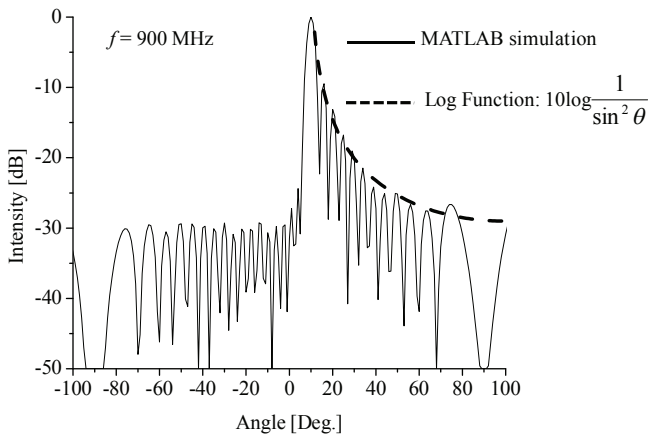


Fig. 4 Asymmetrical radiation pattern.
(Equal spacing)

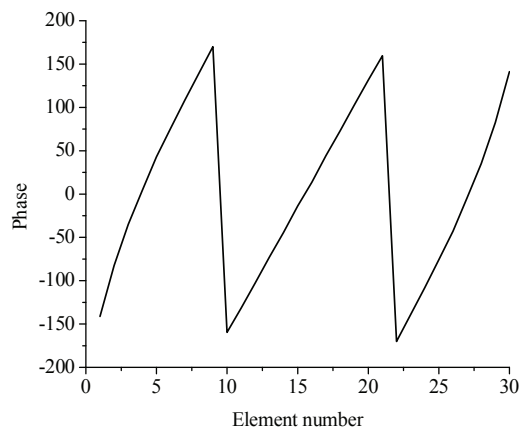


Fig. 7 Excitation phase.
(Equal spacing)

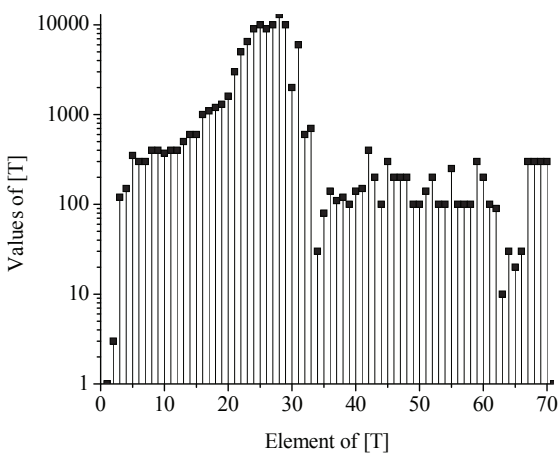


Fig. 5 Weighting values (Equal spacing).

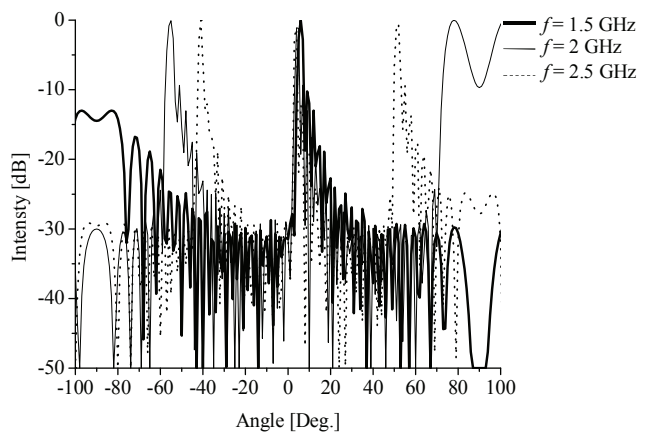
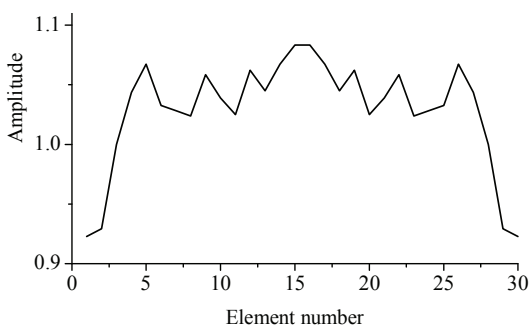


Fig. 8 Asymmetrical radiation pattern at
the three different frequencies.
(Equal spacing)



(a) Array configuration



(b) Excitation amplitude

Fig. 6 Array configuration and excitation amplitude.
(Equal spacing)

IV. UNEQUALLY SPACED ARRAY DESIGN

In the case of the array elements are spaced unequally with the first spacing is $d_1 = 0.56\lambda$, $\Delta d = 0.01\lambda$, it is capable to adjust the parameters of the weighting matrix [T] to achieve the cosecant squared radiation pattern at 900 MHz as shown in Fig.12. For the result mentioned above, the values of the weighting matrix [T] are set as shown in Fig. 9; the amplitudes and phases of the array elements are described in Fig. 10 and Fig. 11 respectively. Keep the same state of the amplitudes as well as phases and modify the frequencies at 1.5 GHz, 2.0 GHz, and 2.5 GHz, the radiation patterns change significantly. As can be seen in Fig. 13, Fig. 14, Fig. 15, even though the shapes of radiation patterns are not as good as the shaped beam at 900 MHz, the radiation patterns at other frequencies are still acceptable. Throughout all four frequencies, the beam tilt is from 5 to 8 degrees. The simulations are performed by FEKO [5] with electric point source elements. The results in the figures from 12 to 15 by FEKO and MATLAB agree completely with each other.

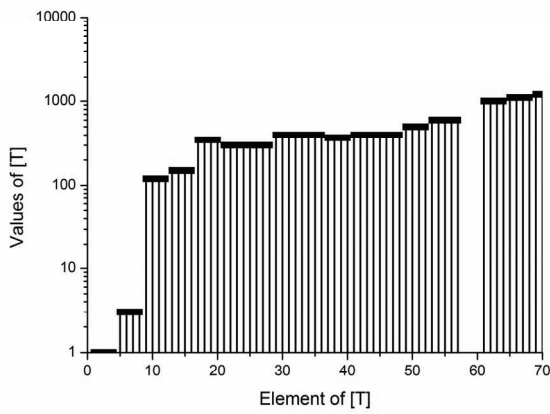


Fig. 9 Weighting values (Unequally spacing).

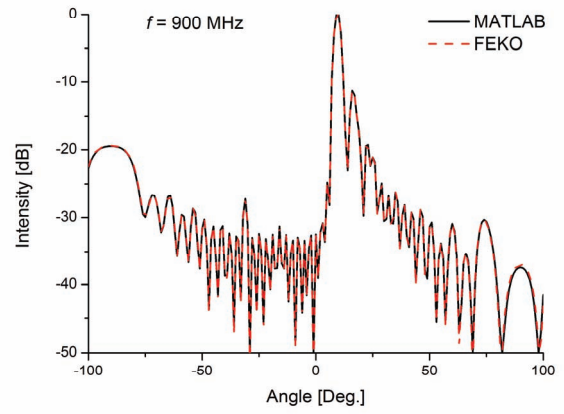
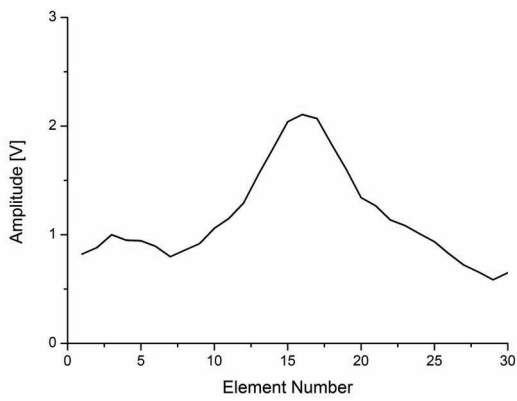


Fig. 12 Radiation pattern using electric point source at 900 MHz.



(a) Array configuration



(b) Excitation amplitude

Fig. 10 Array configuration and excitation amplitude (Unequal spacing)

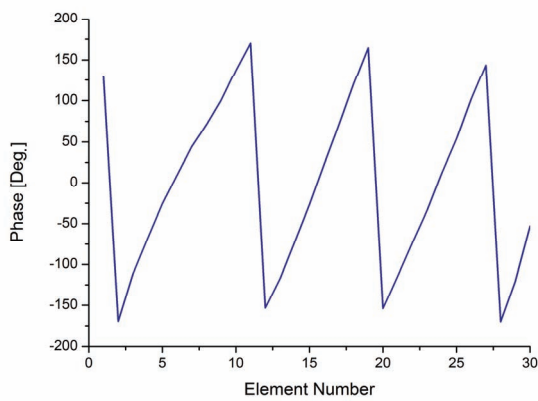


Fig. 11 Excitation phase (Unequal spacing).

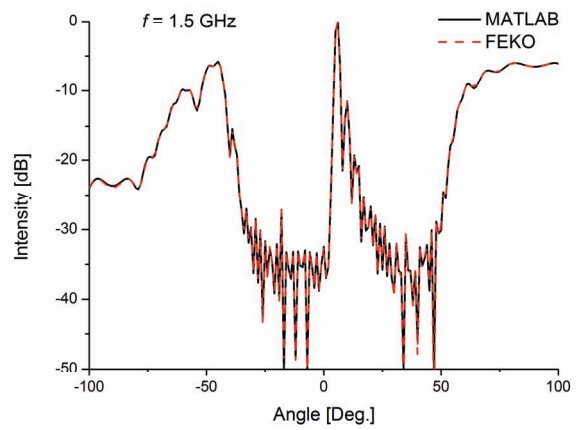


Fig. 13 Radiation pattern using electric point source at 1.5 GHz.

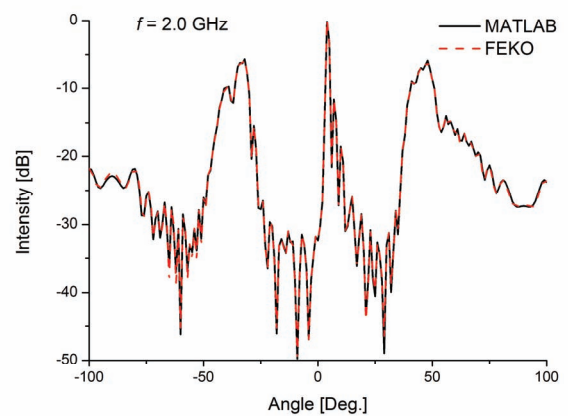


Fig. 14 Radiation pattern using electric point source at 2.0 GHz.

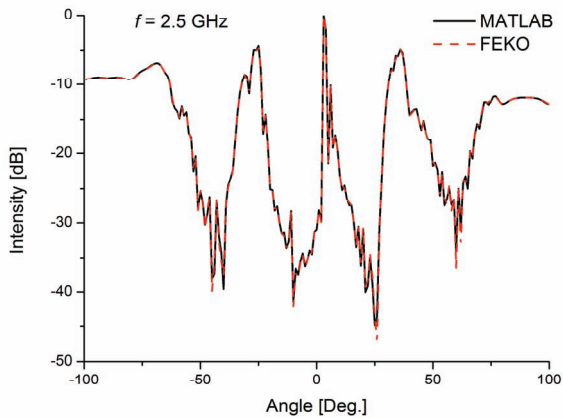


Fig. 15 Radiation pattern using electric point source at 2.5 GHz.

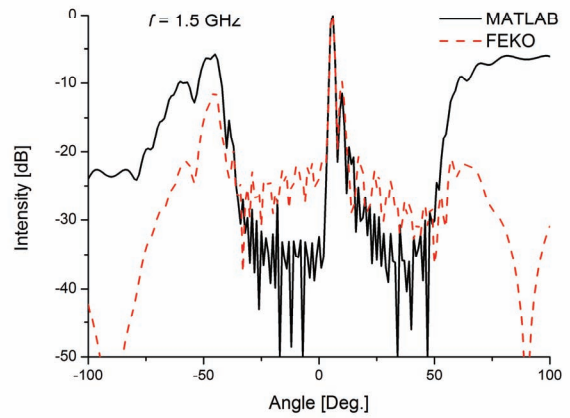


Fig. 17 Comparison of electric point source and half-wavelength dipole element at 1.5 GHz.

In the case of half-wavelength dipoles are used as array elements in these simulations, there are significant differences of radiation patterns by FEKO and MATLAB. The figures from 16 to 19 show the radiation patterns simulated at four frequencies. The radiation patterns by FEKO and MATLAB are just nearly the same. The reason for the differences is that in FEKO mutual coupling occurs among adjacent elements while in MATLAB we do not take mutual coupling into account. As can be seen in Fig. 20 the near fields of the two adjacent elements show that when the array elements are half-wavelength dipoles, the mutual coupling affects much more badly than electric point source elements. Once again, the simulation results with electric point source and half-wavelength dipole array elements by FEKO confirm the accuracy of this method. Antenna gain results by FEKO calculations are shown in Fig. 21. Antenna gain increases in accordance to frequency increases seem normal phenomena. So, the antenna gain result of dipole elements seems typical. The reason of antenna gain reductions of electric point sources is because of large values of grating lobes. From this result, importance of suppressing grating lobes is recognized.

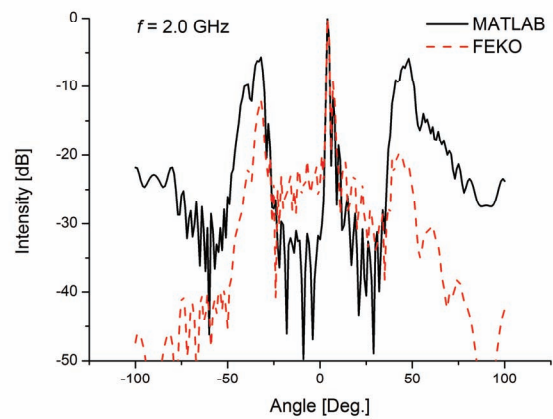


Fig. 18 Comparison of electric point source and half-wavelength dipole element at 2.0 GHz.

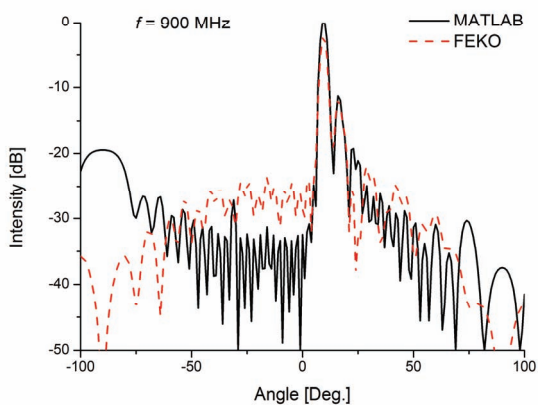


Fig. 16 Comparison of electric point source and half-wavelength dipole element at 900 MHz.

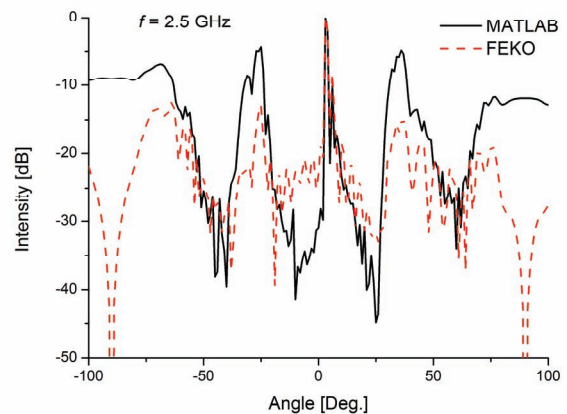


Fig. 19 Comparison of electric point source and half-wavelength dipole element at 2.5 GHz.

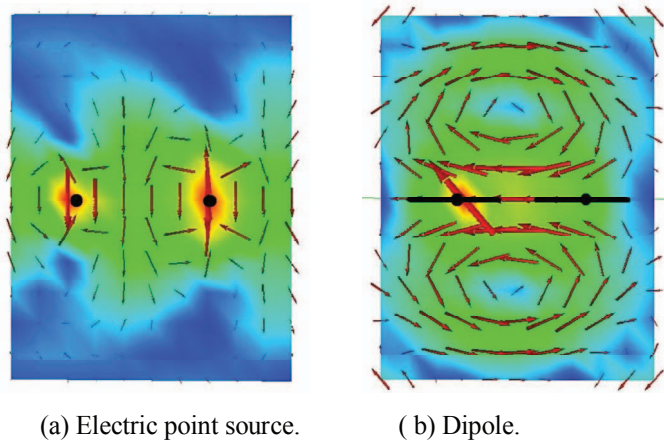


Fig. 20 Near field of the two adjacent elements.

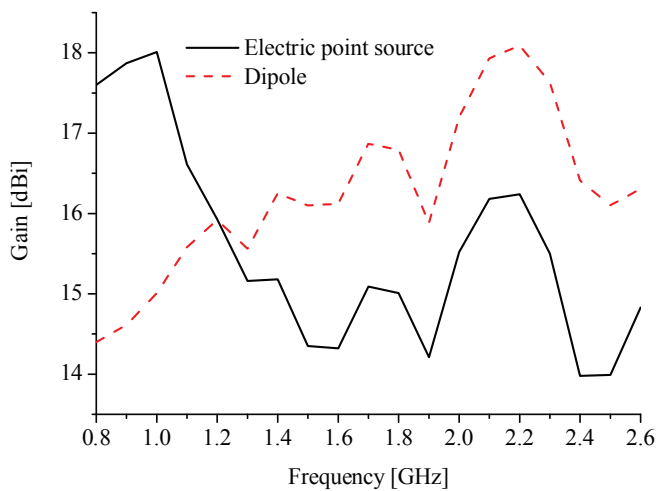


Fig. 21 Comparisons of antenna gain.

V. CONCLUSIONS

Radiation pattern synthesis program for an unequal element spacing array is achieved on MATLAB software. Radiation patterns in 900 MHz to 2.5 GHz are obtained. Reductions of grating lobes and increase of antenna gain in higher frequencies are achieved. For ensuring MATLAB results, electromagnetic simulation results are also obtained. Sufficient calculation accuracies are ensured.

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