A FREQUENCY-INVARIANT ARRAY ANTENNA FED BY LOG PERIODIC DIPOLE ANTENNAS

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ABSTRACT

Software radio applications demand extremely broadband antennas. An unequally spaced array antenna composed of log periodic dipole antennas (LPDAs) is proposed. First, the concept of an unequally spaced array elements is explained. Next, LPDAs are designed so as to achieve almost constant radiation patterns in 2 GHz to 10 GHz. Finally, radiation patterns of the LPDA array antenna are obtained. Constant beam widths and good sidelobe characteristics are achieved in 2 GHz to 10 GHz. Moreover, in order to reconfirm the achievement of excellent radiation patterns, mutual couplings between array elements are investigated.

1. INTRODUCTION

Software radio applications will advance strongly when we can develop high performance antennas such as adaptive antennas and extremely wide frequency band antennas [1]. Adaptive antennas are being widely studied. However, there is little research into wide band antennas. The achievement of wide band antennas is of equal importance as the development of adaptive antennas. An interesting unequally spaced array antenna that offers frequency-invariant broadband radiation characteristics was developed by D.B.Ward et al. [2]. Authors improved his idea to create the symmetrical array antenna structure [3]. The merit of this symmetrical structure is that it offers both constant beam width and low side lobe characteristics over a wide frequency range. However, how to realize the design concept was not shown.

This paper introduces proper LPDA configurations as radiators of a frequency-invariant array antenna (FIAA). Broadband radiation characteristics of designed LPDA are shown. In order to calculate electrical characteristics, an electromagnetic simulator based on the Moment Method is used. Ways of using LPDAs to compose an unequally spaced array antenna are discussed. Electric characteristics of FIAA such as broadband radiation patterns and induced currents on radiators are obtained. Constant beam widths from 10GHz to 2GHz are ensured. Moreover, the mutual coupling between array elements is studied through current distributions on LPDAs.

2. UNEQUALLY SPACED BROADBAND ARRAY ANTENNA

2.1 ARRAY ELEMENT ARRANGEMENT

The configuration of an unequally spaced array antenna is shown in Fig.1. In the central part, (P+1) radiation elements are spaced at $\alpha\lambda_1$ for operating frequency f1. Here, α represents the element spacing factor and lies within 0.5 to 1.0. Low pass filters of cut off frequency f1 are attached to the central p+1 elements. Array length (A1) at f1 becomes P times $\alpha\lambda_1$. The next operation frequency f2 (lower than f1) is determined through the relation that the product of (P-2) and $\alpha\lambda_2$ equals A1 as shown by the next formula.

$$A1 = P\,\alpha\lambda_1 = (p-2)\,\alpha\lambda_2 \qquad (1)$$

Two radiation elements (with low pass filters of f2) are added to on either side of A1 at $\alpha\lambda_2$ spacing. The total array length (A2) at f2 becomes the product of P and $\alpha\lambda_2$. Hence equal beam widths are achieved at f1 and f2. Generally speaking, for frequencies f_i and f_{i+1} (i=1,2,….,m), the radiation element positions have the following relation.

$$p\alpha\lambda_i = (p-2)\,\alpha\lambda_{i+1} \qquad (2)$$

According to this rule, element positions are determined from f_1 to the lowest frequency f_m. The frequency relation is given by the next expression.

$$f_m / f_1 = [\,(p-2)/\,p\,]^{m-1}. \qquad (3)$$

For radiation elements of frequencies f_i (i=1,2,….,m), low pass filters with the corresponding cut off frequencies are attached. The total element number (N) is given by the next expression.

$$N = p+1+2(m-1) \qquad (4)$$

2.2 ARRAY FACTORS

Calculated array factors are shown in Fig.2. Angle 0 deg. indicates the bore site of the array antenna. Here, element number is 10 (p=9) and starting frequency is f1=10GHz. Element spacing factor, α, is set at 0.9. Eq.(3) yields the design frequencies of f2=7.8GHz, f3=6GHz, f4=4.7GHz, f5=3.6GHz, f6=2.8GHz, and f7=2.2GHz. The total element number (N) of 22 is obtained by inserting P=9 and N=7 in Eq.(4). Array factors are shown at 10GHz, 8GHz, 6GHz, 4GHz and 2GHz. In this case low pass filters are not used. Instead of filters, excitation elements are selected as shown in Table 1. The left half of the array antenna elements, such as No.1 to No.11, are shown. Those elements marked by circles are excited. Corresponding elements on the right side are also excited. Here, excitation coefficients of excited elements have equal amplitude. Figure 2 shows that the beam widths are almost constant. At 10GHz, perfect sidelobe characteristics with uniform excitation are achieved. At the lower frequencies, sidelobe characteristics gradually change. The reasons for these sidelobe changes are thought to spacing the array elements unequally.

3. LPDA DESIGN AS ARRAY ANTENNA ELEMENTS

The log periodic dipole antenna (LPDA) is a well-known broadband antenna [4]. The configuration and a designed LPDA are shown in Fig.3. Many dipole antennas of different lengths (Li) are spaced at Si. Length and spacing are related by scale factor (k) as expressed by the next formulas [4].

$$k= L_2/ L_1= L_3/L_2=\ldots\ldots=L_N/L_{N-1} \quad \text{and} \quad k=S_2/ S_1= S_3/ S_2=\ldots\ldots = S_N/S_{N-1} \qquad (5)$$

We select k=1.2 and S1=0.16λ_1. Working frequency fi is determined so as to make Li = λ_i /2. The frequencies corresponding to Li are also shown in Fig.3. All dipole elements are fed through a feeder line. Radiation is directed in the backfire direction. Radiation patterns are shown in Fig.4. The direction of ϕ=90 deg. expresses the back-fire direction of Fig.3. Here, in order to calculate the electrical characteristics, an electromagnetic simulator employing the Moment Method is used. In the H-plane, main beams show rather frequency invariant characteristics. However, sidelobe levels are increased in accordance with the frequency increase.

4. RADIATION CHARACTERISTICS OF AN ARRAY ANTENNA COMPOSED OF LPDAs

As radiators of FIAA, LPDAs are uses. The arrangement is shown in Fig.5. The same LPDAs are arranged on the H-plane. Excitations of elements are done as the same manner in Table1. A Moment Method simulator was also used and the mutual coupling between radiation elements was well considered. Calculated results are shown in Fig.6. Angle 90 deg. indicates the bore site of the array antenna of Fig.5. Radiation patterns from 2 GHz to 10 GHz agree well with the array factors shown in Fig.2. Main beam widths and sidelobe levels are quite similar to those of Fig.2. At 2GHz, main beam width becomes slightly wider and sidelobe levels differ slightly. As a whole, the frequency invariance is quite satisfactory. This agreement is somewhat surprising. Even though mutual coupling between LPDAs was assumed, its influence on the radiation patterns was very small.

5. DISCUSSION OF MUTUAL COUPLING

In order to investigate the mutual coupling between radiation elements, we studied the induced currents on the radiation elements. . In the case of 2 GHz where mutual coupling is thought most severe, calculated current distributions are shown in Fig.7. The left half of the array antenna elements, such as No.1 to No.11, are shown. Arrows indicate the magnitude and direction of current distributions on the elements. Nearly the same current distributions are achieved as is also true for the right side. Mutual coupling is unexpectedly small this case so the radiation patterns are quite similar to the array factor in Fig.2. At elements No.7 to No.11, element spacing becomes 0.18 wavelength at 2 GHz. This spacing is sufficiently small in order to produce very strong mutual coupling. Calculated results of Fig.7 are somewhat surprising. The main reason of this small mutual coupling is considered as the H-plane radiation pattern of a LPDA. In Fig.4

(b), sidelobe levels in these adjacent element directions suppressed about 8dB from the main peak level. So, mutual couplings with the adjacent elements are considered to be suppressed by this amount.

Calculated results for each LPDA at 10GHz are shown in Fig.8. Total current represents the sum of individual currents. LPDAs No.7 to No.16 were excited. LPDAs No.6 and No.17 were not excited. The current distributions on LPDAs No.8 to No.15 are quite similar. The mutual coupling of these elements seems very small. However, the current distributions of No.7 and No.16 changed significantly. Strong currents are induced on the unexcited LPDAs No.6 and No.17. Mutual coupling between No.6 and No.7 and also between No.16 and No.17 was large. While the total currents of No.7 and No.16 was weak and negative, that of No.6 and No.17 was strong and positive. With reference to the influence of the current distributions on radiation patterns, the influence of those elements No.6, No.7 and No.16, No.17 becomes positive, respectively. As a result, the radiation pattern at 10 GHz agrees well with that of the array factor in Fig.2.

6. CONCLUSIONS

The unequally spaced array antenna realizes broadband radiation patterns by employing LPDAs. First, the concept of the broadband array antenna that has unequally spaced array elements was explained and broadband array factors (radiation patterns without mutual couplings) were shown. As actual array elements, LPDAs are designed so as to achieve almost constant radiation in the frequency range of 2 GHz to 10 GHz. The radiation patterns of an unequally spaced array antenna composed of LPDAs were calculated. Calculated radiation patterns agree rather well with the array factors. Constant beam widths were achieved in the range from 2 GHz to 10 GHz. Good sidelobe characteristics were also achieved. Moreover, in order to confirm the achievement of excellent radiation patterns, we investigated the mutual coupling between array elements. Though mutual coupling is appreciable at 10 GHz, its influence on main beam width was found to be slight. At 2 GHz, calculated mutual coupling became unexpectedly small. As a result, achievement of broadband radiation patterns is ensured.

REFERENCES

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Table1. Excited elements at each frequency

freq \ element	No1	No2	No3	No4	No5	No6	No7	No8	No9	No10	No11
2GHz	○	○	○	○	○	○	○	○	○	○	○
4GHz			○	○	○	○	○	○	○	○	○
6GHz					○	○	○	○	○	○	○
8GHz						○	○	○	○	○	○
10GHz							○	○	○	○	○

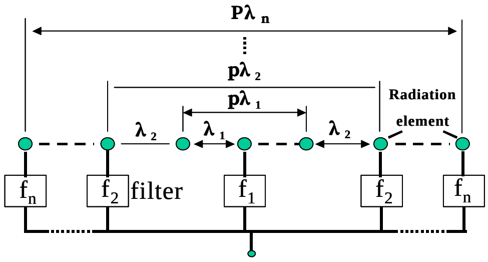


Fig.1 Configuration of an unequally spaced array antenna

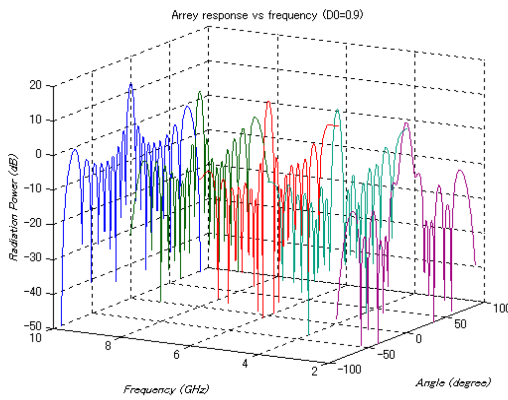


Fig.2 Frequency of an unequally spaced array antenna

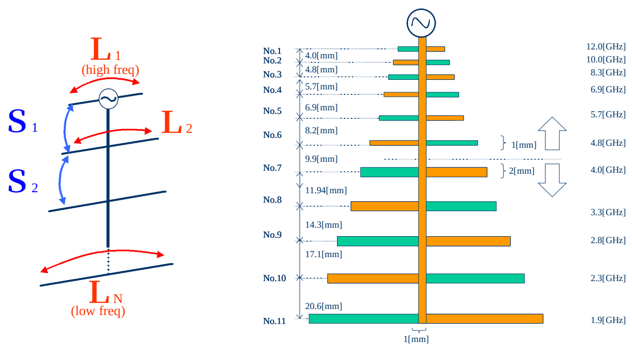
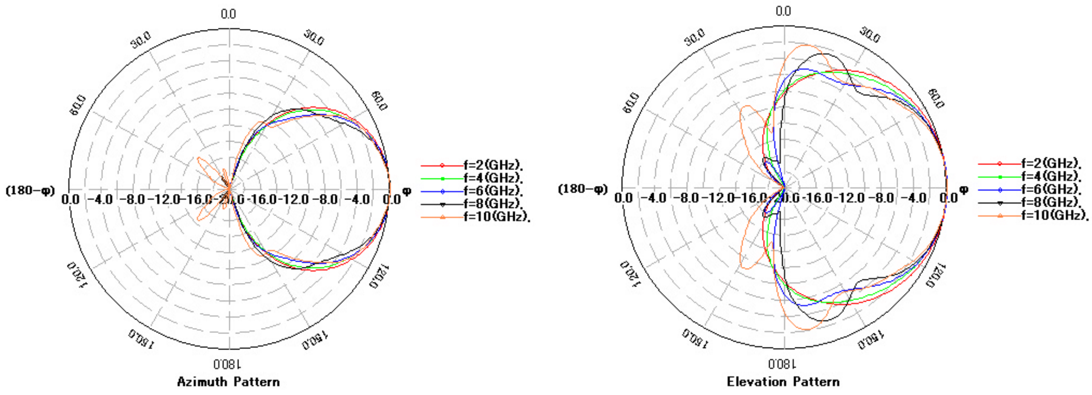


Fig.3 Configuration and designed LPDA



(a) E-plane pattern (b) H-plane pattern

Fig4 Radiation patterns of LPDA

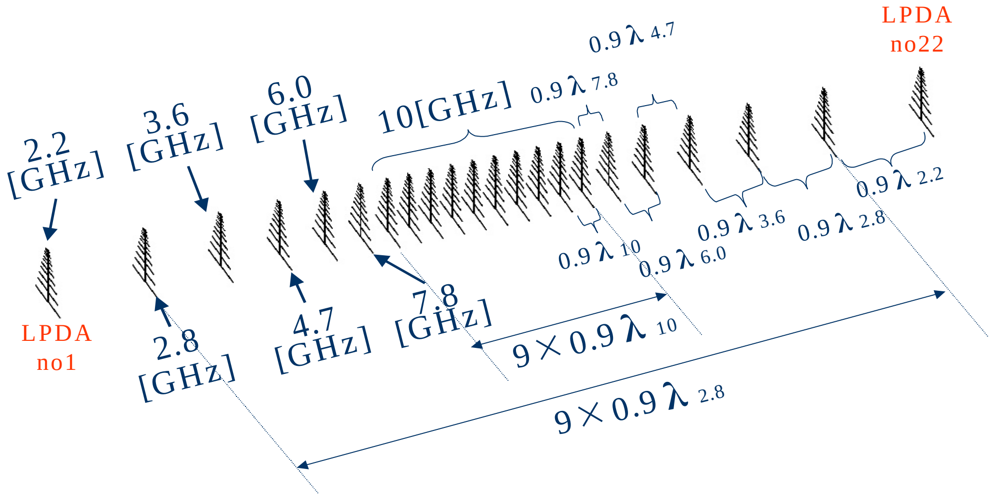


Fig.5 Configuration of an unequally spaced array antenna composed of LPDAs

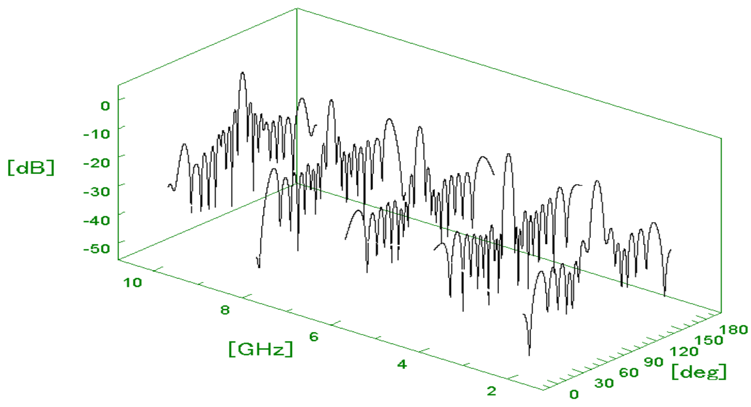


Fig.6 Frequency-invariant radiation patterns

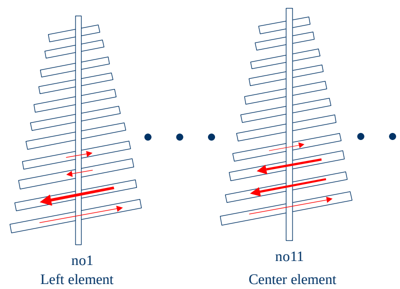


Fig.7 Current distributions of LPDAs at 2GHz

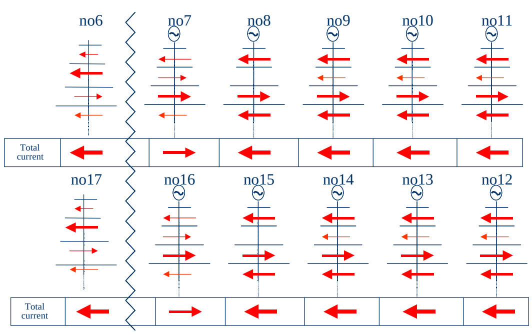


Fig.8 Current distributions of LPDAs at 10GHz