3-element super-directive endfire array with decoupling network

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***Abstract* - This paper presents a 3-element super-directive array antenna as a small and high gain antenna. Super-directive array is closely spaced array antenna and its directivity of an end-fire liner array of N isotropic radiators is N^2. However, antenna characteristics are degraded by strong mutual coupling. The proposed antenna can achieve antenna gain of 8.14dB by using decoupling network to suppress mutual coupling effect.**

***Index Terms* —Antennas, Super-directive array, Mutual coupling, Decoupling network.**

I. INTRODUCTION

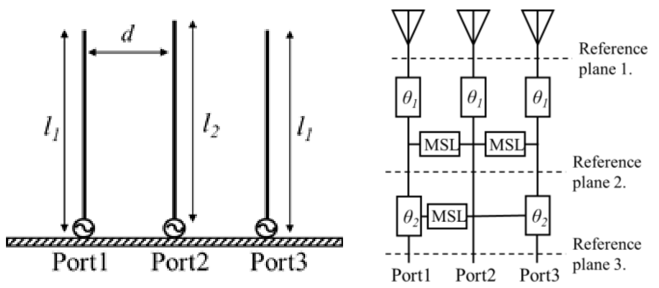
Super-directive array is an array antenna consisted in N-element radiators, which provides the maximum directivity of N^2 for end-fire direction by properly feeding condition [1]. Closely spaced array has strong mutual coupling and degrades input characteristics. 2-element super-directive array by using decoupling network to reduce mutual coupling is already reported [2]. In this paper, we consider design method of 3-element super-directive array and decoupling network. In [3], basic decoupling method is introduced and, decoupling network is realized by micro strip line only [4]. In this paper we apply it for closely spaced 3-element monopole array to obtain sufficient input characteristics and isolation at target frequency. Then, we demonstrate super-directive effect by properly feeding condition.

II. 3-ELEMENT DECOUPLING METHOD

In this paper, we consider 3-element monopole and decoupling network. To design decoupling network, we express mutual coupling as an admittance matrix.

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \quad (1)$$

To eliminate mutual coupling between adjacent antenna element, Y_{21} and Y_{23} is adjusted to be pure imaginary at reference plane 2 by changing phase shifter θ_1 as shown in Fig. 1 (b).



(a) Antenna geometry (b) Circuit diagram

Fig. 1 Antenna and decoupling network, l_1=0.224λ,l_2=0.235λ,d=0.1λ.

Self and coupling admittance of microstrip line added between port i and j become pure imaginary as shown in (2) and self admittance Y_{ii} and coupling admittance Y_{ij} are rewritten as (3).

$$Y_{M,ii} = \frac{1}{Z_0}\frac{\cos\theta}{j\sin\theta}, Y_{M,ij} = \frac{1}{Z_0}\frac{1}{j\sin\theta} \quad (2)$$

$$Y'_{ii} = Y_{ii} + Y_{M,ii}, \; Y'_{ij} = Y_{ij} + Y_{M,ij} \, . \quad (3)$$

where Z_0 is characteristic impedance and θ is electrical length of microstrip line. By adding this microstrip line between port 1 and 2, we can suppress mutual coupling Y_{21} and Y_{23}. Next we suppress Y_{31} by the same procedure at reference plane 3. Finally we obtain good input impedance and diagonal components of admittance matrix are matched to the 20mS(=1/50Ω) at reference plane 3.

III. DECOUPLING NETWORK DESIGN

Admittance matrix components of monopole array shown in Fig.1 (a) are expressed as

$$\begin{matrix} Y_{11} = Y_{33} = 19.8 + j24.3 & Y_{22} = 20.8 + j2.49 \\ Y_{21} = Y_{23} = -0.15 - j21.4 & Y_{13} = -19.6 - j7.83 \end{matrix} \; [\text{mS}].$$

In this matrix, effect of shunt matching inductor to eliminate imaginary part of input admittance Y_{11}, Y_{22} and Y_{33} are included, where 2.7nH is loaded to antenna 1 and 3 and 3.3nH to antenna 2. Because of coupling admittance Y_{21} is almost pure imaginary, phase shifter θ_1 is omitted. To reduce Y_{21}, we calculate decoupling line characteristic impedance and phase by (2), assuming self-admittance of decoupling line as 0, because Y_{22} is already matched to 20mS(=1/50Ω). Apply this decoupling line to this antenna, S_{21} is improved as shown in Fig. 2. Y_{31} is also suppressed by the same procedure to take an impedance matching by adding another inductors to port 1' and 3'. Its antenna structure and S parameters are shown in Figs. 3 and 4. By using this structure, all S parameters become less than -10 dB at target frequency.

To apply this antenna to super-directive array, antenna current amplitude ratio of 1:1.8:1 and phase difference of $0^\circ:187^\circ:14^\circ$ theoretically [1]. To realize this condition, we need to consider relationship between current on antenna element and voltage at each feeding port. This relationship is given by the impedance matrix.

$$\begin{bmatrix} V_1' \\ V_2' \\ V_3' \end{bmatrix} = \begin{bmatrix} Y_{1'1} & Y_{1'2} & Y_{1'3} \\ Y_{2'1} & Y_{2'2} & Y_{2'3} \\ Y_{3'1} & Y_{3'2} & Y_{3'3} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} \quad (4)$$

By substituting super-directive current condition to this equation, we can obtain feeding voltage ratio of 1:0.7:0.78 and phase difference of $0^\circ:197^\circ:-39^\circ$. Radiation pattern under this feeding condition is shown in Fig.5. Radiation pattern has good agreement to the pattern neglecting the mutual coupling. The ideal maximum directivity of 3-element endfire array is 9.54dB and antenna gain of proposed antenna compared with single monopole antenna is 8.14dB.

IV. Conclusion

This paper presented a design method of 3-element super-directive array antenna. By using decoupling network, S parameters could be improved to less than -10dB at target frequency. Theoretical maximum directivity of 3-element endfire array is 9.54dB and proposed antenna achieved 8.14dB compared with single monopole antenna by properly feeding condition.

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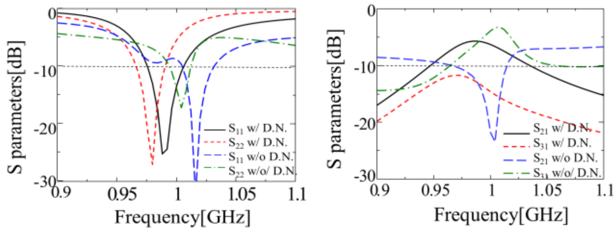


(a)Input characteristics (b)Coupling characteristics.

Fig.2 S parameters changing by decoupling line.

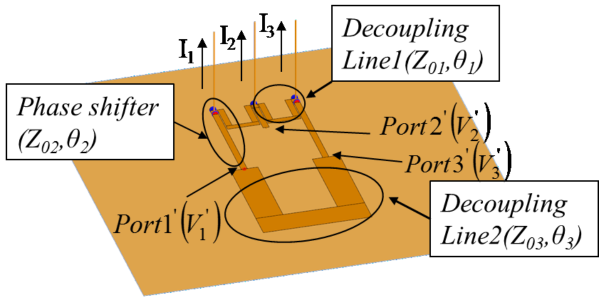
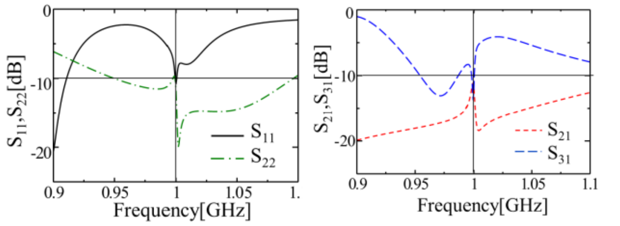


Fig.3 Antenna structure with decoupling circuit, $Z_{01}=50\Omega, \theta_1=0.25\lambda, Z_{02}=35\Omega, \theta_2=0.3\lambda, Z_{03}=10\Omega, \theta_3=0.85\lambda_o$



(a)Input characteristics (b)Coupling characteristics

Fig.4 S parameters with all port decoupling.

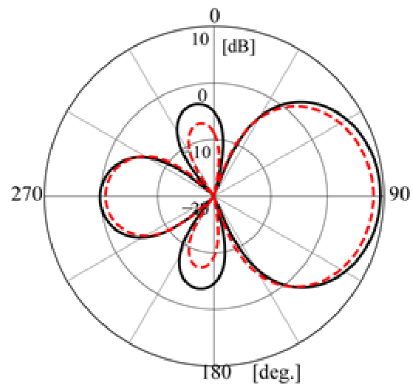


Fig.5 3-element super-directive radiation pattern, solid line is array pattern, dotted line is proposed antenna.