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MUTUAL COUPLING COMPENSATION IN ARRAY ANTENNAS

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1 Introduction

In the array environment, mutual coupling between individual elements is responsible for many undesirable effects. Some techniques have been developed to reduce the mutual coupling effects. Chiba has presented that the effect of mutual coupling can be treated as the perturbation of the aperture excitation [1]. Thus, by driving the array with modified element excitations such that the desired array aperture distribution is obtained, the mutual coupling can be compensated for.

Steyskal and Herd have proposed a technique which determines the mutual coupling coefficients from measured active element patterns[2], instead of computing coupling coefficients. But, as their technique is based upon Fourier decomposition method, the application is limited to equally-spaced linear or planar arrays. The presented technique describes a new technique to determine the mutual coupling coefficients from measured active element patterns, which is applicable to arbitrary array antennas.

2 Theory

2.1 Mutual coupling determination

We consider an arbitrary array of single-mode elements. Single-mode means that the element aperture currents(electric or magnetic) can be approximately designated by the single current mode function and the effect of higher order current distribution is negligible. As depicted in Figure1, we can describe the active element pattern of element i of N-element array as

$$g_i(\theta) = \sum_{n=1}^{N} c_{in} f_n(\theta). \tag{1}$$

Here $g_i(\theta)$ denotes the active element pattern of element i, c_{in} the mutual coupling from element n to i and $f_n(\theta)$ the isolated element pattern of element n including the space factor in the array, respectively. If $i = n$, c_{ii} denote the coupling from the aperture to the transmission line. In the case of the equally-spaced linear array, equation(1) is simplified to :

$$g_i(\theta) = f^i(\theta) \sum_{n=1}^{N} c_{in} e^{jknd\sin\theta} \tag{2}$$

Here $f^i(\theta)$ denotes the isolated element pattern, k the wavenumber and d the uniform element spacing, respectively. Eq.(2) shows that Fourier decomposition approach is possible

in the linear array [2].

Contrary to the equally-spaced linear array, such an approach is impossible for the arbitrary arrays. Therefore we introduce the next error-function

$$\epsilon = \int \left| \sum_{n=1}^{N} c_{in} f_n(\theta) - g_i(\theta) \right|^2 d\theta. \tag{3}$$

It is reasonable to assume that c_{in} satisfy the minimum ϵ condition. So we have

$$\frac{\partial \epsilon}{\partial c'_{in}} = \frac{\partial \epsilon}{\partial c''_{in}} = 0 \qquad (n = 1, 2, \cdots, N) \tag{4}$$

where c'_{in} and c''_{in} are real value and $c_{in} = c'_{in} + jc''_{in}$. Eq.(4) can be solved analytically and thus we obtain

$$\begin{bmatrix} c_{i1} \\ c_{i2} \\ \vdots \\ c_{iN} \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \cdots & \alpha_{1N} \\ \alpha_{21} & \alpha_{22} & & \vdots \\ \vdots & & \ddots & \vdots \\ \alpha_{N1} & \cdots & \cdots & \alpha_{NN} \end{bmatrix}^{-1} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_N \end{bmatrix} \tag{5}$$

where

$$\alpha_{mn} = \int f_m^*(\theta) f_n(\theta) d\theta \tag{6}$$

and

$$\beta_m = \int f_m^*(\theta) g_i(\theta) d\theta. \tag{7}$$

In Eq.(6) and Eq.(7), $f_m^*(\theta)$ denotes complex conjugate of $f_m(\theta)$. Using Eq.(5), we can determine the mutual coupling coefficients c_{in} $(n = 1, 2, \cdots, N)$ from the measured active element pattern of element i.

2.2 Mutual coupling compensation

Applying Eq.(5) to all elements i $(i = 1, 2, \cdots, N)$,we have

$$\mathbf{G} = \mathbf{CF} \tag{8}$$

where

$$\begin{aligned} \mathbf{G} &= \begin{bmatrix} g_1(\theta) & g_2(\theta) & \cdots & g_N(\theta) \end{bmatrix}^t \\ \mathbf{F} &= \begin{bmatrix} f_1(\theta) & f_2(\theta) & \cdots & f_N(\theta) \end{bmatrix}^t \\ \mathbf{C} &= \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1N} \\ c_{21} & c_{22} & & \vdots \\ \vdots & & \ddots & \vdots \\ c_{N1} & \cdots & \cdots & c_{NN} \end{bmatrix}. \end{aligned} \tag{9}$$

On the other hand, the array pattern synthesis using the isolated element pattern $f_i(\theta)$ $(i = 1, 2, \cdots, N)$ can be written as

$$E(\theta) = \mathbf{WF} = \begin{bmatrix} w_1 & w_2 & \cdots & w_N \end{bmatrix} \begin{bmatrix} f_1(\theta) \\ f_2(\theta) \\ \vdots \\ f_N(\theta) \end{bmatrix}. \tag{10}$$

where $E(\theta)$ is the desired array pattern, and w_i is the desired weight of element i. If we treat planer arrays, w_i can be calculated by using ordinary pattern synthesis techniques ,*i.e.* Dolph-Chebyshev linear array method or Taylor line source method. In the case of the nonplanar array, we can calculate w_i using the null points adjusting method[3]. From Eq.(8) and Eq.(10), the desired array pattern $E(\theta)$ is synthesized using active element patterns G as follows,

$$E(\theta) = \mathbf{W}\mathbf{C}^{-1}\mathbf{G}. \tag{11}$$

3 Experiments

The coupling compensation technique outlined in the preceding section was applied to an eight-element linear array of microstrip patch antenna. The element spacing of the array is 0.5λ. First, active element patterns of the array elements were measured and the coupling coefficients were then numerically evaluated according to Eq.(5) and the inverse matrix $\mathbf{C}^{-1}$ was computed. Next, array pattern was calculated according to Eq.(11). In Fig.2 obtained synthesized Taylor $\bar{n} = 2$,−30-dB sidelobe patterns with and without the mutual coupling compensation are shown. Apparently the compensation technique gives about 6dB improvement in sidelobe level, with the result that the actual pattern is quite close to the theoretical one.

4 Conclusion

We have developed and experimentally verified a technique to compensate for mutual coupling in arbitrary array. The technique should be helpful primarily for nonplanar arrays with digital beam forming systems, where the array element patterns differ from each other and low sidelobe pattern synthesis is required.

References

[1] T. Chiba, "On the realization of the synthesized pattern of scanning arrays," presented at Int. Conf. on Radar, Paris France,Dec.1978

[2] H.Steyskal,J S.Herd, "Mutual coupling compensation in small array antennas," *IEEE Trans. Antennas Propagat.*, vol. AP-38, pp. 1971-1975,Dec. 1990.

[3] K.Haryu,I.Chiba,S.Mano,T.Katagi, "Null points adjusting method providing low sidelobe patterns in conformal array antennas," in *Proc. IEEE Antennas Propagat. Symp.*, London, Ontario ,Canada, June 1991,pp. 1716-1719.

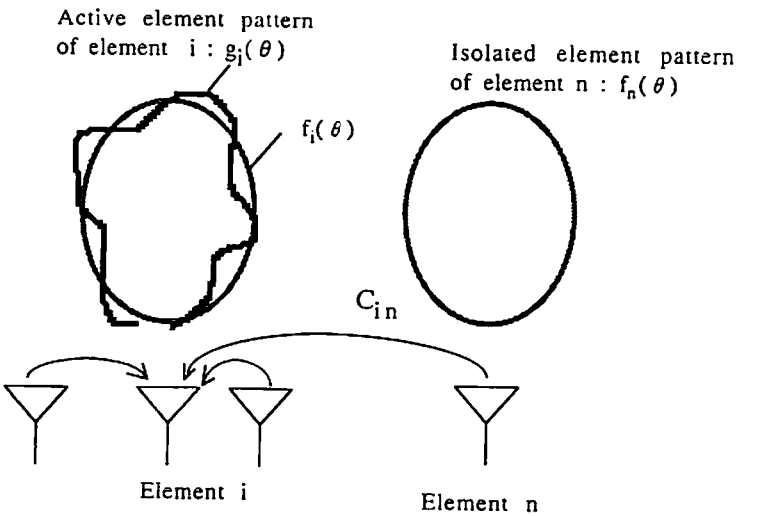

Fig.1 Mutual coupling between array elements.

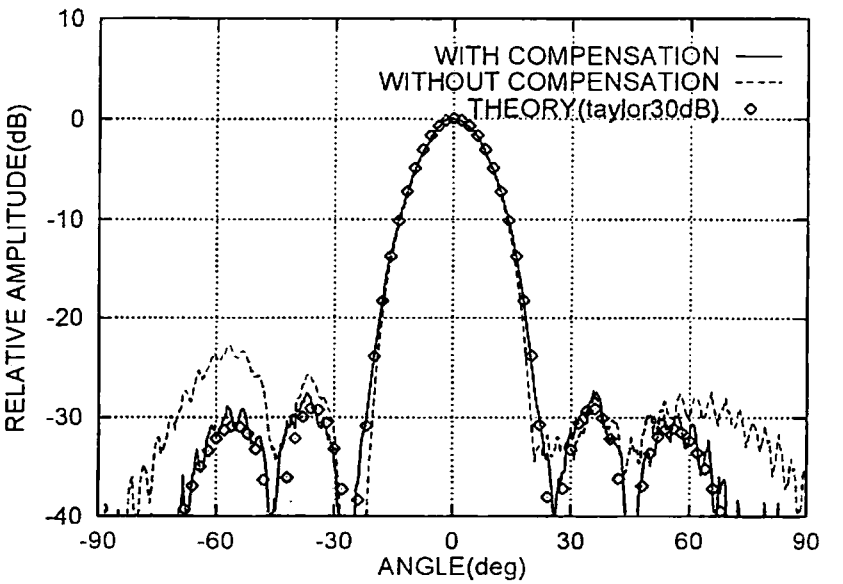

Fig.2 -30dB-Taylor pattern with and without coupling compensation.