ABSTRACT—Orthogonal method has been used to synthesis of linear array antenna with Aperture Coupled Microstrip Antenna (ACMA) elements to obtain a shaped beam radiation pattern. The ACMA has been used as the array element because of its wide bandwidth return loss. Also, to achieve the correct excitation for the array elements, mutual coupling between them has been considered in the synthesis procedure. The mutual coupling effect has been shown by comparing the simulation results with and without of this effect in the orthogonal synthesis procedure. Finally, based on the optimum results of the orthogonal synthesis method a suitable feeding network has been designed for the array.

KEYWORDS: orthogonal method; mutual coupling; aperture coupled microstrip antenna; array antenna

I. INTRODUCTION

Because of the advantages of array antennas these configurations are used for beam forming problems in communication systems [1]. Different methods have been used for synthesis and optimization of the array antennas. Many parameters should be considered in the synthesis of the array antennas. One of the most important of these parameters is mutual coupling between the array elements [2]. Different methods have been applied to compensate the mutual coupling by calculating the coupling coefficients such as Fourier decomposition and so on. In the synthesis of the array antennas the processing time and accurate results are so important. The orthogonal method that is extended and generalized for the synthesis of the array antennas can be used to obtain the excitation of the array elements with considering the mutual coupling to achieve the desired radiation pattern [3]. In the present work, to consider the mutual coupling the E-Field radiation pattern of each element in the presence of the other elements (Active Pattern) has been obtained from HFSS Ansoft. Then the active radiation patterns are used to synthesis the array by the orthogonal method to obtain the desired radiation pattern.

II. ORTHOGONAL METHOD

Orthogonal method is the technique that use the orthogonally between functions and obtain the excitation of array elements. If the mutual coupling between the elements will not be considered, derivation of the excitation is a simple procedure [3]. To this end, the array factor has the following form:
\[
AF(\theta, \phi) = \sum_{n=1}^{N} I_n e^{j\beta(x_n \sin \theta \cos \phi + y_n \sin \theta \sin \phi + z_n \cos \phi)}
\]

where, \((x_n, y_n, z_n)\) is the position of each element. \(\varphi_n(\theta, \phi)\) are the non-orthogonal independent functions. Based on the Gram-Schmidt theorem \[4\], \(\varphi_n(\theta, \phi)\) can be used to construct the orthonormalized basis functions \(\Psi_n(\theta, \phi)\) as:

\[
\Psi_n(\theta, \phi) = \sum_{i=1}^{N} C_i^{[n]} \varphi_i(\theta, \phi)
\]  

Using the orthonormalized basis functions the array factor will be:

\[
AF(\theta, \phi) = \sum_{i=1}^{n} B_i \Psi_i(\theta, \phi)
\]  

(3)

where

\[
B_i = (AF(\theta, \phi), \Psi_i(\theta, \phi))
\]  

Using (4), (3) and (1), the excitation coefficients of the array are determined as \[3\]:

\[
I_i = \sum_{j=1}^{N} B_j C_i^{[j]}
\]  

(5)

(A) Orthogonal synthesis Method and Mutual coupling Compensation

For the isolated array elements, the array factor is defined as \(6\). In which \(I_n^d\) is the excitation coefficient of \(n\)th element when mutual coupling is not taken into account and \(f^i(\theta, \phi)\) is the isolated radiation pattern of the elements. The excitation coefficients will be determined based on the orthogonal method procedure in the previous section, to shape the AF in a desired form.

\[
AF(\theta, \phi) = f^i(\theta, \phi) \sum_{n=1}^{N} I_n^d e^{j\beta(x_n \sin \theta \cos \phi + y_n \sin \theta \sin \phi + z_n \cos \phi)}
\]  

(6)

In the real array antenna the mutual coupling between the array elements affects the radiation patterns of elements and therefore, the radiation pattern of the array. In this case the array factor is defined as:

\[
AF(\theta, \phi) = \sum_{m=1}^{N} I_n f_n(\theta, \phi) e^{j\beta(x_n \sin \theta \cos \phi + y_n \sin \theta \sin \phi + z_n \cos \phi)}
\]  

(7)

In which, \(I_n\) is the excitation of each element with mutual coupling consideration and \(f_n(\theta, \phi)\) is the radiation pattern of each element in presence of the other elements. To use the orthogonally to synthesis the array, the \(f_n(\theta, \phi)\) is expressed as a sum of independent functions \(\varphi_m^{(n)}(\theta, \phi)\)

\[
f_n(\theta, \phi) = \sum_{m=1}^{N} K_{nm} f^i(\theta, \phi) \varphi_m^{(n)}(\theta, \phi)
\]  

(8)

where

\[
\varphi_m^{(n)}(\theta, \phi) = e^{j\beta(x_m-x_n)\sin \theta \cos \phi + (y_m-y_n)\sin \theta \sin \phi + (z_m-z_n) \cos \phi}
\]  

(9)

and \(f^i(\theta, \phi)\) is isolated radiation pattern of the elements and \(K_{nm}\) is coupling coefficient.

In this case to compensate the mutual coupling effect and to correct the excitation of the elements, it is necessary to calculate the coupling coefficients matrix \(K\). The orthogonal method is used to derive the coupling coefficient between the elements. To calculate this coupling coefficient it is necessary to measure or calculate the radiation pattern of each element \(f_n(\theta, \phi)\). In this work, this function is derived by HFSS simulator. By determining the coupling coefficients, compensated excitation coefficients to create the desired radiation pattern can be derived as \[5\]:

\[
[I^d] = [k]^T[I] \quad [I] = ([k]^{-1})[I^d]
\]  

(10)

III. ARRAY CONFIGURATION

(A) Array Element

Because of the advantages of microstrip antenna such as light weight, low cost and easy fabrication this antenna have been used widely in communication systems. In this paper the aperture coupled technique is used to excite the array elements \[6\]. Also to increase the return loss bandwidth, the H shape coupling aperture is used to excite the patch antenna \[7\]. By adjusting the coupling aperture parameters, suitable bandwidth for the
The 10dB return loss bandwidth of the antenna is about 21% and has been depicted in Fig. 2. Also, the gain of the antenna has been shown in Fig. 3.

(B) Array structure

The linear array antenna configuration (Fig. 4) that has been studied in this paper consists of 8 elements with $d=0.76\lambda$ at the center frequency 9.5GHz.

(C) Synthesis of the Array

Based on the synthesis procedure mentioned in the section II, the array antenna in the Fig. 4 are studied in this section. At first the array are studied without consideration of mutual coupling and then the effect of mutual coupling is considered based on the equations (7-10). In the presence of mutual coupling, the amplitudes and phases of E-Field radiation patterns of the elements are different and depicted in Fig. 5.
If the mutual coupling is not considered the E-Field radiation patterns for all elements will be similar. The normalized amplitude excitation coefficients of the array elements obtained from the orthogonal method are depicted in Fig. 6. The simulated radiation patterns of the array antenna based on the optimized excitation coefficients (Fig. 6) are shown in Fig. 7.

One of the feeding methods for microstrip antenna is related to aperture coupled. In this feeding method, two substrate is utilized, so that microstrip feed line and radiating patch are placed on the first and second substrates, respectively. Therefore, electromagnetic energy obtained through slot is coupled from the first dielectric substrate to radiating patch. Slot can have various shapes which H-shaped slot is applied in this paper. By this kind of slot, amount of energy coupled to radiating patch can be increased. Meanwhile, this type of slot (H-shaped slot) presents more parameters than rectangular slot. As a result, impedance bandwidth can be increased by its adjustment. After optimizing using the method explained in this paper and achieving the feeding amplitude related to each array element, appropriate feeding network based on these data should be designed. this feeding network includes unequal T-junctions. By utilizing equations related to power dividers, characteristic impedances of feed lines can be
obtained. Moreover, a quarter wavelength $\lambda/4$ is used for earning impedance matching. Using the optimization results derived by the orthogonal method in the previous section, the suitable feeding network is constructed for the array antenna. The basic section for the feeding network design is unequal T-sections that produce the optimum tapering of amplitudes in Fig. 8.

![Fig. 8 Schematic of final array](image)

The return loss of the array antenna with feeding network is depicted in Fig. 9.

![Fig. 9 Return loss of final array](image)

IV. CONCLUSION

In this paper the excitation coefficients of the linear array antenna with ACMA elements has been synthesized using orthogonal method by considering the mutual coupling effect between the array elements. The orthogonal method is the accurate and fast method to synthesize of the array antennas to obtain the desired shaped beam radiation pattern.

REFERENCES


