ESTIMATION OF PATCH ARRAY COUPLING MODEL THROUGH RADIATED FIELD MEASUREMENTS

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Abstract: In the design process of array antennas, coupling is one of the most important elements to be counted. The real feeding radiated coefficients can be quite different from the theoretical ones because of this effect. In this paper, a compensation method is presented allowing matching each element from the array. The parameters of the array coupling model are obtained through the measurement of radiation pattern of the elements without the feeding network. An application to linear patch array is presented as an example.

INTRODUCTION

Actual input impedance and radiated field from each element in the array can differ very much from the single element model. Input impedance can be computed through an N-port network model described by impedance (*Z*) or scattering (*S*) matrix. Radiated field can be computed if we know the active radiated field from each element that takes into account the complete array influence in each element radiated field, as presented by Mailloux [1]. In receiving antennas the model would be the same, giving an equivalent active diagram and active output impedance that depend on the loading circuit. In large arrays, most elements present similar conditions: their class, position and load. That situation provides almost equal active impedance and diagram for most elements in the array except the extreme ones. In [2], Wasylkiwskij shows the relation between input impedance and radiated field for Minimum Scattering Antennas (MSA). Many times, real antennas have been assumed as MSA with good results [3]. In other cases, that assumption is not as fortunate and relation between input coupling matrix (*Z*) and active radiated field is not so clear. One of the most important questions in the design of antenna diagram or in the active and adaptive antenna behaviour is if the coupling can be modelled by an *NxN* coupling matrix (*C*) as described in most studies of adaptive arrays [4].

In this paper, a matrix model is presented for array antennas fed through linear networks. The model is based in the several active modes of the array elements and active diagram computation as a function of these modes. If *k* independent modes can describe the electromagnetic behaviour of each element, *Nxk* modes will be needed to define all the array radiation characteristics. An *Nx(k+1)* square matrix will describe the array behaviour. This description is independent of the feeding network, feeding distribution or transmission-reception application [5]. For many printed patches only one resonant radiation mode can be used to describe the radiated field of each element. When this happens a *2Nx2N* matrix describes the complete array model. Based on this model, and applying the feeding network parameters, a coupling *C* matrix can be obtained to compensate the design model from the influence of element coupling. The parameters of this model can be obtained through the measurements of the radiation pattern for each individual element in the final array disposition. As an example, a printed antenna of rectangular patches as that described by Pozar in [6], allows us to demonstrate how accurate the matrix model introduced in this paper is.

RADIATED/RECEIVE FIELD MODEL

Transmission model for an individual antenna

The antenna electrical behaviour can be defined by its input impedance and its radiated field (1):

$$\vec{E}_{rad} = v_e\, \hat{e}_e(\theta,\phi) F(\theta,\phi) \frac{\exp(-jk_0 r)}{r} \tag{1}$$

where v_e is a voltage proportional to the input current. $F(\theta,\phi)$ is the radiation pattern, $\hat{e}_e(\theta,\phi)$ is the polarisation vector. The antenna can also be seen as a function of its scattering matrix. Then the radiated field and the radiated power can be expressed as (2) and (3).

$$\vec{E}_{rad}(\theta,\phi) = b_e \sqrt{2\eta_o}\; F(\theta,\phi) \frac{\exp(-jk_0 r)}{r} \hat{e}_e(\theta,\phi) \tag{2}$$

$$P_{rad} = \eta |a_0|^2 \left(1 - |S_a|^2\right) = |b_e|^2 \int_{4\pi} |F_s(\theta,\phi)|^2 d\Omega = |b_e|^2 \tag{3}$$

S_a represents the reflection coefficient at the input defined respect Z_o, b_e is a power wave proportional to the amplitude and phase of the input power wave (a_0). The input reference impedance is Z_o while the output reference impedance is $\eta_o = 120\pi$. The antenna gain can be expressed using the normalised radiation pattern and the antenna efficiency as (4)

$$G(\theta,\phi) = \eta 4\pi |F(\theta,\phi)|^2 = \frac{|S_e|^2}{1 - |S_a|^2} 4\pi |F(\theta,\phi)|^2 \tag{4}$$

Reception model for an individual antenna

When the antenna works in receiving way the equivalent surface $A_e(\theta,\phi)$ (5) represents the amount of power taken by the antenna. If S_a represents reflection coefficient of the circuit, then a power wave (b_0) can be extracted at the input port.

$$A_e(\theta,\phi) = \frac{\lambda^2}{4\pi} G(\theta,\phi) = \eta \lambda^2 |F(\theta,\phi)|^2 \tag{5}$$

$$P_{dis} = |a_e|^2 \frac{|S_r|^2}{1 - |S_a|^2} = |\hat{e}_i \cdot \hat{e}_e(\theta,\phi)|^2 \frac{1}{2\eta_0} |E_i|^2 \frac{|S_r|^2}{1 - |S_a|^2} \lambda^2 |F(\theta,\phi)|^2 \tag{6}$$

The reception power wave proportional to the impinging field is (7):

$$a_e = [\hat{e}_i \cdot \hat{e}_e(\theta,\phi)] \frac{1}{\sqrt{2\eta_0}} |E_i| \lambda |F(\theta,\phi)| \tag{7}$$

Finally, if the reciprocity principle is applied then $S_e = S_r$

Radiated/received field model for an array antenna

A first approach of a model to take into account the previous effects has been proposed in [5,7]. This new network takes into account the decomposition of the current distribution in multiple characteristic modes. Then, any N-array antenna can be represented as a $(k+1)\times N$-network. The new network has one input and k output ports corresponding to any of the radiating modes of each antenna (by input ports we mean any of the actual probes of the array while by output ports we mean fictitious ports representing any radiating function). Figure 1 shows the new $1+n$ port network (1 corresponding to the antenna input and n to the radiation modes). When the radiating elements are resonant microstrip antennas, only one radiating mode may be considered resulting in a $2N$-port network. This network is represented in Figure 2. The terminals at the left side of the *2N*-port network represent physical probes of the antenna that can be directly measured while the ones at the right side allow us to define the radiation functions. They will never be charged since they represent ideal radiating (b_e) or receiving (a_e) antennas. Then the matrix equation relating previous variables is given in (8)

$$\begin{pmatrix} b \\ b_e \end{pmatrix}_{(2N\times 1)} = S_{(2N\times 2N)} \cdot \begin{pmatrix} a \\ a_e \end{pmatrix}_{(2N\times 1)} \Rightarrow \begin{matrix} b = S_a \cdot a + S_r \cdot a_e \\ b_e = S_e \cdot a + S_s \cdot a_e \end{matrix} \tag{8}$$

where S_a represents the reflection coefficient, vector S_e represents the transmission parameter for each mode. S_r represents reception coupling for any of the defined modes and matrix S_s indicates the scattered field by each mode.

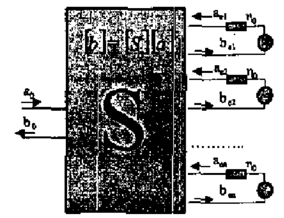

Figure 1: Equivalent $n+1$ port network for an individual antenna with several radiation modes

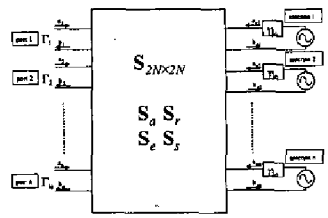

Figure 2: Equivalent 2N port network for an array antenna with only one radiation mode

When operating in a transmitting way, the array is fed through a set of generators with an equivalent incident wave $a_{g(N\times 1)}$ and source reflection coefficient $\Gamma_{g(N\times N)}$. In this case equation (8) can be simplified, because $a_e=0$.The total radiated field can be expressed as the sum of the contributions from any of the radiating elements. This can be written in vector form as the dot product of the steering vector and the transmitting power wave (9). A coupling matrix (C_e) can be defined (10):

$$E_{rad}(\theta,\phi) = \left(d^T(\theta,\phi)\cdot b_e\right)\sqrt{2\eta_o}\,\frac{\exp(-jk_o r)}{r} = d^T(\theta,\phi)\cdot C_e \cdot a_g \sqrt{2\eta_o}\,\frac{\exp(-jk_o r)}{r} \tag{9}$$

$$C_e = S_e \cdot \left(I - \Gamma_g \cdot S_a\right)^{-1} \tag{10}$$

d is the steering vector in (θ,ϕ) direction. Each term of matrix C_e (C_{ij}) represents the amount of signal coupled from antenna j to i. The radiation intensity can be expressed as the following dot product

$$U(\theta,\phi) = \frac{r^2}{2\eta_0}\left|\vec{E}_{rad}\right|^2 = a_g^H C_e^H \vec{d}^* \cdot \vec{d}^T C_e a_g = a_g^H \cdot M_e \cdot a_g \tag{11}$$

MODEL COEFFICIENTES CALCULATION

Once the model is defined, S_a can be obtained through measurements with a vector network analyser. Γ_g represents the generator reflection coefficient and S_e matrix can be calculated through measurements of the radiation pattern for each individual antenna of the array,as follows:

If a linear array of N independent patches (without feeding network) is measured exciting one patch each time (the elements of vector a are equal to zero for all of them but one), the columns of the matrix S_e (8) (considering a_e=0). b_e is obtained after processing the radiation pattern. The radiated field in a point of the space situated in far field respect every patch will be:

$$\vec{E}(\hat{r}_m)=\sum_n \vec{E}_n=\sqrt{2\eta_0}\sum_n b_{en}\,\hat{e}_n(\hat{r}_{m,n})F_n(\hat{r}_{m,n})\frac{\exp(-jk_0|\vec{r}_m-\vec{r}_n|)}{|\vec{r}_m-\vec{r}_n|} \qquad (12)$$

where the positions are shown in figure 3.

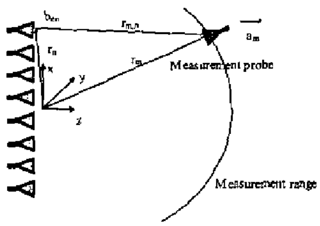

Figure 3: Dimensions in Measurement structure

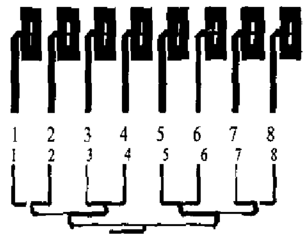

Figure 4: Application to design of the feeding network of a linear patch array

The reception power is obtained if measurement probe pattern (F_{sm}) is known (13). This equation represents the relation between the b_e and the measured pattern, as wanted.

$$a_{em}=\lambda\sum_n b_{en}\left\langle\hat{e}_n(\hat{r}_{m,n})\hat{e}_{sm}(\hat{r}_{n,m})\right\rangle F_n(\hat{r}_{m,n})F_{sm}(\hat{r}_{n,m})\frac{\exp(-jk_0|\vec{r}_m-\vec{r}_n|)}{|\vec{r}_m-\vec{r}_n|} \qquad (13)$$

Normally, more points than elements are measured, so an optimisation process can be developed to obtain the coefficients b_e, and the coupling matrix C_e. In [8] this procedure is followed to design the structure of figure 4. Measurements of this structure will be presented at the conference[1].

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[1] The simulations required have been done with CST Microwave Studio Software v.4.0, under a cooperation agreement between CST and Universidad Politécnica de Madrid.