COUPLING COMPENSATION IN A MICROSTRIP PATCH ARRAY

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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, thanks to the measurement of some its parameters.*

1. Introduction. In this paper, we present a method [1] to compensate coupling in a linear patch array. Patches with slot line feeding are structures with a high coupling value [2]. This coupling is bigger when we try to get a linear polarisation. All results presented are from simulations, proving the validity of the method.

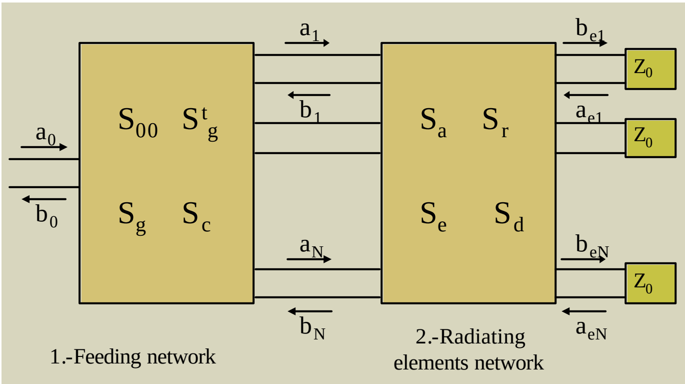

Fig.1 General scheme of linear array.

2. Theory. Array element active matching.

In Fig. 1 we can see that the array has been divided in two blocks. The first one is the feeding network and the other one is radiating elements network. These elements can radiate in several modes, but we suppose that patches do it in a main predominant radiating mode.

First network can be characterised by a [N+1]*[N+1] S parameters matrix. To give this matrix a physical sense, we have subdivided into four matrixes. When we try to design the feeding network of an array, we expect amplitude and phase at the output ports to be very close to theoretical values to get the desired pattern. Sg is the N dimension vector, which contains the excitations of the feeding network to obtain the desired pattern. However, coupling inside the feeding network modifies the feeding distribution. This effect is represented by the N*N matrix Sc. S_{00} is the passive reflection of the feeding network input port.

In the arrays of passive radiating elements, linearity and reciprocity conditions can be applied. So, in this case the relation between array feeding waves and radiating waves can be expressed in a matrix format. In this matrix representation, parameters in the diagonal show the elation between excitations and the different radiating modes, and parameters out of the diagonal represents coupling between all elements in the array.

The N dimension vectors "a" and "b" characterise the incident and reflected power waves at radiating elements input ports. "a_e" and "b_e" are N dimension vectors, which represent the main receiving and transmitting radiating modes of each radiating element. We will work with no receiving waves (a_e=0), assuming the array as transmitting antenna. The final loads indicated as Z_0 permit to establish the radiation variable in the coupling model [1], and represent and ideal free space matched load. In this conditions the equations of the whole structure can be written as:

$$b_0 ? S_{0,0}a_0 ? S_g^t b \qquad (1)$$

$$a ? S_g a_0 ? S_c b \qquad (2)$$

Network 1

$$b ? S_a a \qquad (3)$$

Network 2

$$b_e ? S_e a \tag{4}$$

$$b_e ? C_e S_g a_0 \tag{5}$$

$$C_e ? S_e \left(I ? S_c S_a\right)^{?1} \tag{6}$$

C_e is the total coupling matrix and contains the effect of coupling inside the feeding network (S_c), coupling in radiating elements terminals (N*N dimension matrix S_a) and main mode radiation coupling (N*N dimension matrix S_e).

As we can see in Eq.5, the radiated distribution is affected by all different coupling forms. This is the reason because the design feeding excitation (S_g) is quite different of the real radiated one, generating a not desired diagram pattern. The active impedance of each element in the array is quite different from the passive one, and it is necessary to match this active impedance to make possible a correct distribution of the power in the array.

The objective of the method is the design of the transmitting vector of the feeding network (S_g) to compensate the influence of the coupling between radiant elements and the feeding network. The only contribution will be from the radiation coupling (S_e) (see Eq.9), eliminating the effect of S_c and S_a (condition showed in Eq. 8).

$$S_g a_0 ? \left(I ? S_c S_a\right) S_e^{?1} b_e \tag{7}$$

$$S_c S_a S_e^{?1} b_e ? 0 \tag{8}$$

$$S_g ? S_e^{?1} b_e \tag{9}$$

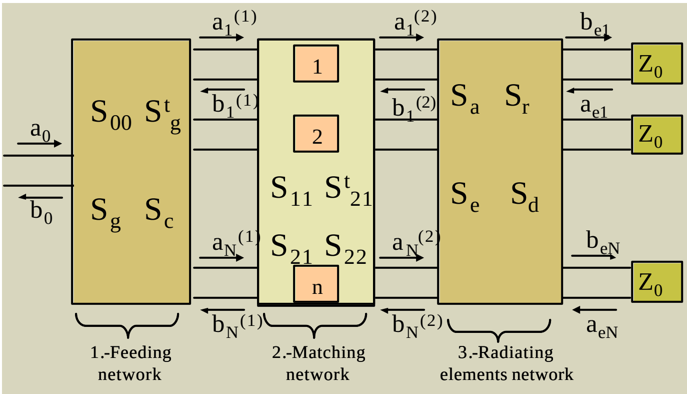

Fig.2 General scheme of linear array with individual matching networks.

The way to reach Eq.8 is to modify matrixes S_a and S_e introducing an individual matching network between the feeding network and each radiating element, as we can see in Fig.2. The new matrices are (S_{an}) and (S_{en}), and represent the joining block 2 and 3. In this condition, this new network verifies the condition of Eq. 10,

$$S_{an} S_{en}^{?1} b_e ? 0 \tag{10}$$

And the transmission feeding vector, which compensates the effect of coupling, is:

$$S_{gn} ? S_{en}^{?1} b_e \tag{11}$$

The total matching network has N ports to connect the feeding network and other N ports to connect the elements. This is a no losses reciprocal network. All these individual matching networks are independent between them. The total S parameters matrix can be divided in 4 parts corresponding to each reflection or transmission blocks between the N input ports and the N output ports. The equations, which relate San and Sen with the matching networks, are:

$$S_{an} ? S_{11} ? S_{21}^t S_a \left(I ? S_{22} S_a\right)^{?1} S_{21} \tag{12}$$

$$S_{en} ? S_e \left(I ? S_{22} S_a\right)^{?1} S_{21} \tag{13}$$

Applying the no losses and reciprocal properties of this matching networks and condition of Eq.10 we can get the s parameters of each individual matching network corresponding to each radiating element:

$$s_{22}^* ? D\left(S_e^{?1} b_e\right) S_a \left(S_e^{?1} b_e\right) \tag{14}$$

$$s_{21} ? \sqrt{1 ? |s_{22}|^2}\, e^{j?} \quad (15)$$

$$s_{11} ? ?s_{22} e^{?2j?} \quad (16)$$

The D[x] function means a diagonal matrix with its diagonal composed by vector x. As we can see in Eq.15-16, phase from s_{21} is a free design parameter.

As a summary, if we can determinate the matrixes S_a and S_e we are able to create individual matching networks for each radiating elements of the array configuration. These matching networks permit us to design a transmission excitation vector (S_{gn}) to compensate the coupling effect of the whole structure, being able to obtain the desired radiation pattern (b_e). In this paper, S_a and S_e matrices have been computed through electromagnetic simulators.

3. Practical application.

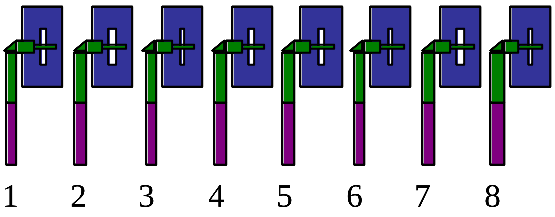

Fig.3a Radiating patches of the lineal array.

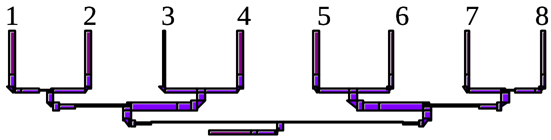

Fig.3b. Feeding microstrip network.

To apply the theory of point 2, we have simulated a lineal patch array structure as shows in Fig.3a. The feeding amplitude coefficients are [-6 -3 0 0 0 0 -3 -6] (dB), and the phase distribution is [0 0 0 0 0 0 0 0] (º). The network in Fig.3b is designed to get this response (S_g vector). The feeding network do not include isolation resistors so $S_c ? 0$. To get the S_a and S_e matrixes all ports of Fig.3a are fed with generators matched to Z_0, feeding one of the patches with normalised amplitude 1 and phase 0º. With this operation, we can see that in every patch exists only one dominant radiation mode, which has a polarisation parallel to the narrowest side of the patch. Doing the same for the other seven patches, we get S matrixes.

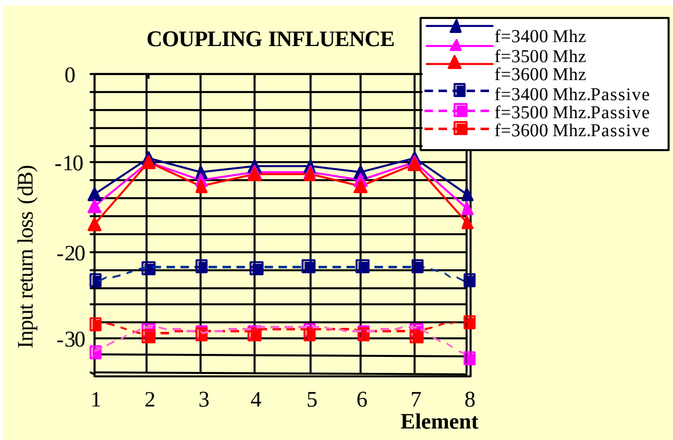

Fig.4. Influence in active impedance of total coupling.

In Fig.4 can be seen the influence of coupling in the active impedance of each patch. The simulation has been done between 3.4 and 3.5 GHz. We can compare the big degradation from passive impedance when coupling is considered. The value of mutual coupling between two side-by-side patches is about 15 dB. Another sample of the effect is shown in Fig.5 a-b, where ideal amplitude and phase distribution is compare to the values obtained if no matching network is done.

Applying Eq.14-16, we have calculated the s parameters of the eight individual matching networks for the radiating elements. As the feeding distribution is symmetrical, these matching networks are equal two by two. When we calculate the total input reflection of the array before and after the active matching process, we can see the big improvement (Fig.6).

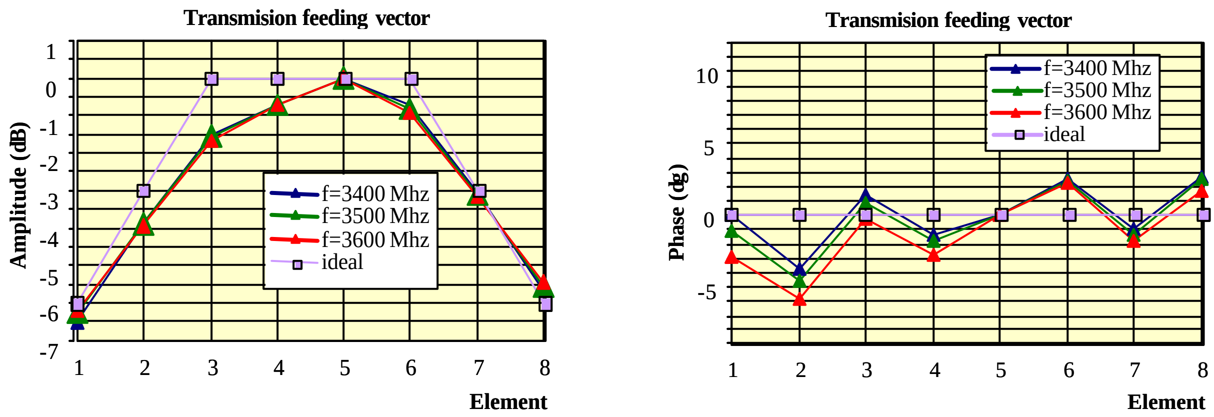

Fig.5. a) Amplitude of feeding vector. b) Phase of feeding vector.

With these matching networks we are able to know the new transmission feeding vector S_{gn} applying Eq.11 and 13.

Finally, the four different matching networks calculated with this process have been designed with real microstrip lines. The structure used for this part is quite simple. With an optimisation process we have tried to reproduce the s parameters calculated before. As we have as a free key the phase of s_{21}, we have supposed a linear behaviour for every network. Fig. 7a-c shows the s-parameter of the first and eighth patch matching network, comparing calculated results and real microstrip structure.

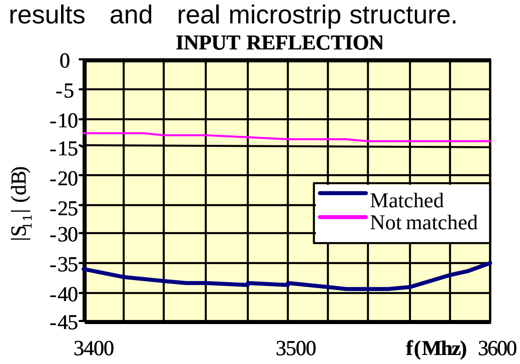

Fig.6. Input return loss with and withour matching network

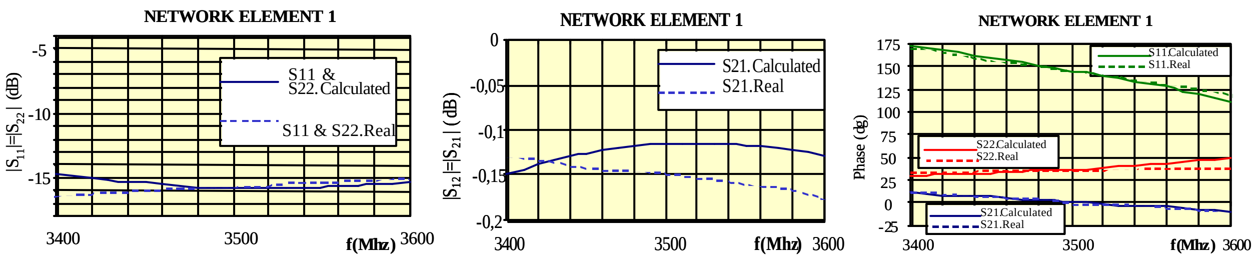

Fig.7. Matching network 1 and 8. a) $|s_{11}|=|s_{22}|$ b) $|s_{21}|=|s_{12}|$ c) Phases

4. Conclusions. The active matching of the elements in an array configuration can be reached using matching networks, which compensate coupling effects in the structure. In this paper, some simulated results have been presented. One important point in the s matrixes calculation is the real structures chosen to reproduce them. In future steps in this research, a real application will be developed.

5. References.

[1] J.R. Mailloux, Phased Array Antenna Handbook. Artech House Inc. 1994

[2] Manuel Sierra-Perez et all. Coupling Model In Array Antennas And Its Application To Array Design. Mediterranean Microwave Symposium 2002. Caceres. Spain. June 2002.