MUTUAL COUPLING IN MICROSTRIP ANTENNA ARRAY ELEMENTS

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ABSTRACT

The mutual coupling between adaptive antenna array elements degrades the performance of the array especially for direction finding purpose. There are many possible ways to compensate the coupling effects via electromagnetic analysis or via signal processing. We are going to follow the first approach to determine the mutual coupling and we are following signal processing to compensate the effects of the mutual coupling. Based on the results the compensation of the mutual coupling between array elements can also be corrected for minimising the direction-of-arrival estimation.

1. INTRODUCTION

There are many ways to compensate the mutual coupling effect, hence we created our algorithm for compensation at first. In this model the antenna array with *N* elements is regarded as a network with *2N* ports. There are *N* ports which are the ports of the array elements, and there are *N* theoretical ports between the array elements and the space.

We suppose ideal signals without any mutual coupling effect on the *N* theoretical ports in the case of direction-of-arrival (DoA) estimation. The signals on the ports of the elements are loaded by the mutual coupling via electromagnetic (EM) fields of elements.

We suppose ideal signals on the *N* ports of the elements in the case digital beam forming (DBF), but the signals on the *N* theoretical ports are loaded by the mutual coupling as well as we have seen it earlier.

In this aspect the mutual coupling can be describe with a *C* matrix called (mutual) coupling matrix which contains the element-by-element effects. That means that the C_{ij} element contains effect of the j^{th} element to the i^{th} element. The main diagonal of the matrix contains the effect of the elements to itselves. The *C* coupling matrix is symmetrical through the symmetry of the effects of the elements. These effects of the mutual coupling can be describe with transfer between the elements of the array. You can see below the description of the elements of the *C* matrix with the S-parameters (*eqs. 1-2*).

$$C_{ii} = \frac{1}{S_{ii}} \tag{1}$$

$$C_{ij} = S_{ij} \tag{2}$$

This description implies the symmetry of the coupling matrix on the symmetry of transfer.

After the determination of the *C* matrix, we have to multiply the measured signals of the physical ports by the inverse of the *C* matrix to compensate the effects of the mutual coupling. In the case of the DoA estimation that means that the signals after multiplying are equal to the ideal signals of the theoretical ports. In the case of the DBF the multiplying means a precompensation which cause ideal signals on the theoretical ports.

2. MUTUAL COUPLING IN MONOPOLE ANTENNA ARRAY ELEMENTS

At first we worked with an adaptive antenna which had four monopole elements in a line arrange (*fig. 1)*. The elements worked on 900 MHz.

Figure 1

We computed the *C* mutual coupling matrix with a commercial program called MATLAB. This calculation was based on the equation of Pocklington. We solved this equation with method-of-moments (MoM). This algorithm is very effective for the problems of the wire antennas, which have axial symmetrical EM patterns. The computed and measured effects of the mutual coupling with dependence on distance are showed in the *fig. 2*.

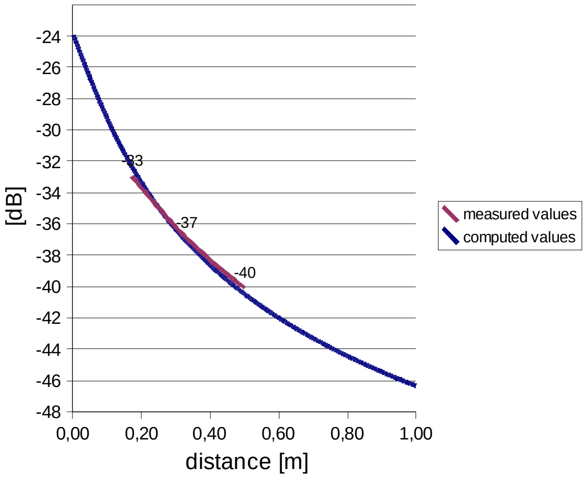

Figure 2

The measured and the computed values were very similar, hence we suspected that our calculation is right.

We did DoA estimation with this adaptive antenna. For faster DoA estimation we used maximum likelyhood algorithm without averages. The results of the DoA estimation are showed in the *tab. 1* with and without compansation.

Table 1

distance of elements	direction of arrival	computed DoA	computed DoA with compensation
λ/2	90°	92,20°	90,00°
2·λ/2	90°	93,00°	93,15°
3·λ/2	90°	90,85°	90,00°
3·λ/2	60°	113,70°	63,50°

The results showed the compansation of the effects of the mutual coupling can improve the DoA estimation. We suspect the improvement of DoA estimation can be more significant, if we measure the direction more than once and if we average the measured results. Of course, the multiple measurement takes more time.

Our adaptive antenna had line arrange as well as you can see in *fig. 1*. The computed and measured *C* matrix was symmetrical not only caused by the symmetrical transfer but caused by the symmetry of the geometry as well. There are some special geometries such as circle geometry which compensate the mutual coupling without any signal processing. In this case we only have to compute the sufficient distance between elements and the sufficient radius of the circle of the geometry. We have to notice that the compensation by the geometry is very sensitive to the changes of the enviroment.

3. MUTUAL COUPLING IN MICROSTRIP ANTENNA ARRAY ELEMENTS

We saw the possibility of the improvement of the DoA estimation using our mutual coupling compensation, therefore we started working with microstrip antenna (msa) arrays, because they are used nowadays.

The monopole elements have simple EM pattern, which is axial symmetrical. Hence we could find simple geometries which could compensate the mutual coupling by the arrangement. The microstrip elements usually have not got axial symmetrical EM patterns, because the EM pattern of msa elements depend on the position of the feeding of the elements. We simulated some typical msas, and we found different coupling between the patches. The coupling depends on the position of the patches to eachother as we expected. These results are showed in the *fig. 3*-*5*. The *fig. 3* shows the simulated antenna array.

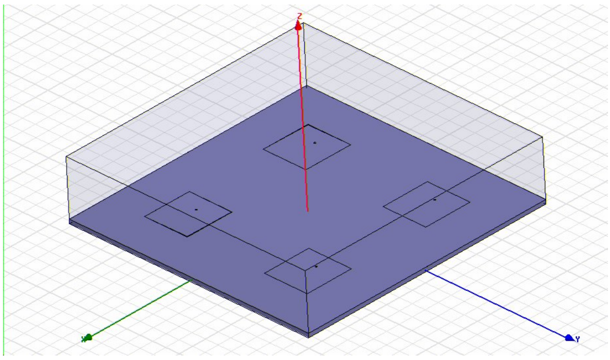

Figure 3

We simulated by a commercial program called Ansoft HFSS. This program divides the geometry to thethrahedrons. It use an adaptive solving algorithm, and the difference of the sequential approximations must be smaller than 2 percent.

The *fig. 4* shows the two main direction in the mutual coupling.

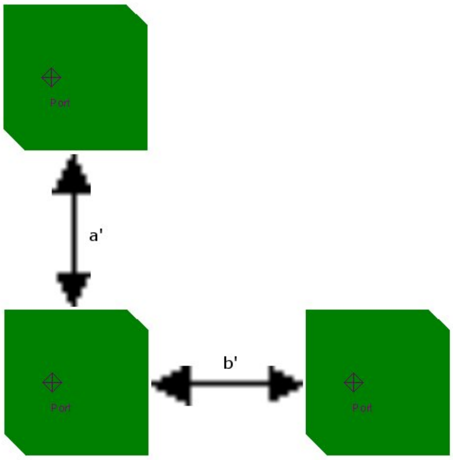

Figure 4

Our simulated arrangement had only four elements to reduce the time of the simulation. We investigated the EM patterns of the elements, and we found that the two direction of the *fig. 4* were the most significant in the mutual coupling.

The *fig. 5* shows the effects of the different coupling.

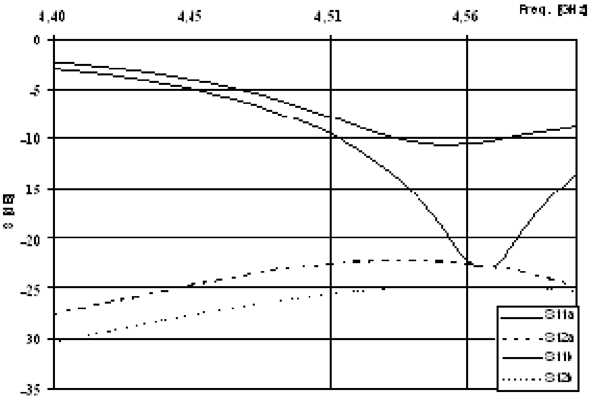

Figure 5

These results mean the *C* matrix has only one symmetry caused by the symmetry of the transfer between the elements if we use msa array elements. Hence we suppose more significant error in the DoA estimation in this case, because the effects of the mutual coupling cannot compensate eachother. So we searched msa elements with circle polarisation. The simulated and measured msa array is showed in the *fig. 6*.

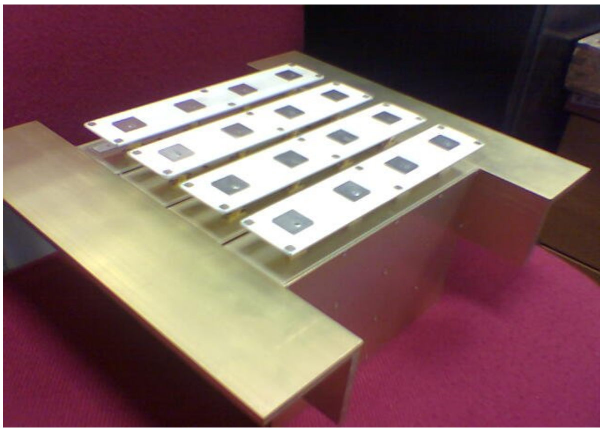

Figure 6

Our msa array contains four panels, each panel has four antenna elements. Thus the arrangement of the msa array can be changed. We used grid arrangement like it can be seen in the *fig. 6*. We simulated and measured the mutual coupling of the patches with depence on frequency. We found that the gaps between the panels make frequency shifting. This result is very important, because the manufacturing process of this msa array shows a new technology to reduce the effect of the mutual coupling.

The effect of the gaps is showed in the *fig. 7*. The figure shows the frequency shifting depened only on the existence of the gaps and is independent of the distance between the panels. Of course, the distance between the panels has influence to the effect of the mutual coupling, but the space between the panels with the frequency shifting causes an extra and significant peakreducing with about 5-10 dB.

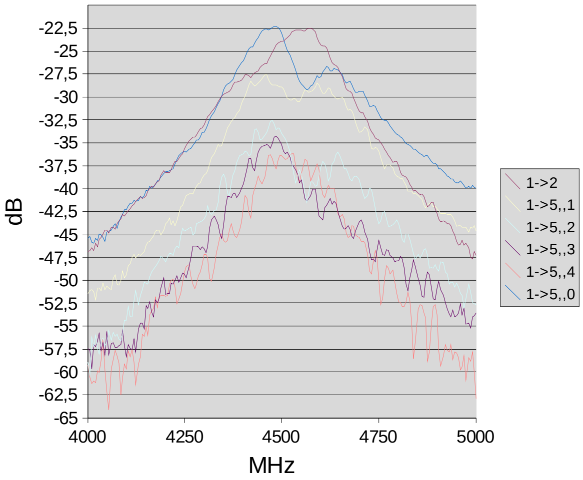

Figure 7

The *„1->2”* marking marks the coupling between the nearest patches on the same panel. The other markings mark the coupling between the patches which are on different panels. The number behind the commas means the distance between the panels in wavelength. Zero means the panels are abuted.

The gaps between the panels may be advantegeous because they reduce the effects of the mutual coupling. It is important to notice that the effects of the mutual coupling cannot compensate eachother in this case, hence the gaps may be disadvantageous.

4. ALGORITHMS OF COMPENSATION

We saw two ways for compensation. First, we can compensate by arrangement of the elements of the adaptive array. We can choose a special geometry, and the effects of the elements can compensate eachother via the symmetry of the arrangement. This method of compensation is very sensitive to the changes of the enviroment, however it allows a very fast DoA estimation.

Second, we can compensate by signal processing. The speed of the signal processing is very important, because we usually want to use our adaptive antennas in real-time applications. Our model can be very fast, because the mutual coupling matrix has to be calculated only once, and the compensation is just a matrix multiplying by the measured signals. Hence it does not matter if the calculation and calibration of the C matrix take a long time. We suggest to determine the C matrix by calculation of averages.

Our showed hardware measures 1-200 times for one DoA estimation, and it calculates correlation matrix of the incoming signals. Only the correlation matrix is sent to the control PC which calculate the direction-of-arrival estimation. It seems to be a good possibility to compensate the mutual coupling with the correlation matrix. So it seems to be simple to determine the C matrix with a suitable test signal. It is recommend to do some test measure while estimating of DoA.

Finally, we have an other algorithm to compensate the mutual coupling. We found if we use msa array, the gaps between the panels of the elements make frequency shifting. Probably we can produce an antenna array whose each element has a different panel. In this case we should investigate the radiation pattern of the array. This manufacturing means that we reduced all of the effects of the mutual coupling. If we used not air space in the gaps, but we would use some special materias, then propably the frequency shifting would be more significant, therefore the effects of the mutual coupling would be smaller.

5. CONCLUSION

In this paper we described a modell of compensation of mutual coupling. This modell has a new aspect and contains a fast method of the compensation of the mututal coupling.

We saw the compensation of mutual coupling can improve the performance of DoA estimation. We worked without averages, because this way of compensation is very simple and is fairly fast. We suppose we should use averages not only for the measurement of the direction-of-arrival, but for the definition of the C mutual coupling matrix. In this case we suppose good opurtinites at the compensation of the mutual coupling by signal processing.

Finally, we saw two type of method of compensation via geometry and via signal processing. We saw a special compensation method via manufacturing of the antenna array especially if we use microstrip antenna array elements too.

In everycase the calculation of the coupling matrix was based on EM analysis.

6. REFERENCES

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