# Mutual Coupling of Rectangular DRA in a Four Element Circular Array

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**Abstract**— Mutual coupling of DRAs in a four element circular array is investigated. For several values of the array radius mutual coupling and return loss are computed and illustrated. The FDTD method with a UPML boundary condition is used for simulation.

## 1. INTRODUCTION

Specific features of DRAs has made them suitable for a variety of applications specially MMW applications. DRAs have small size and low cost. They can be easily coupled to almost all types of transmission lines [1]. They can be integrated easily with MMIC circuits. In MMW applications conductor loss of metallic antennas become severe and the antenna efficiency decreases significantly, conversely the only loss for a DRA is that due to the imperfect material of the DRA which can be very small in practice [2]. Therefore DRAs have high radiation efficiency. In comparison to microstrip antennas, DRAs have wider impedance bandwidths. For a typical DRA with dielectric constant of 10 the impedance bandwidth of 10% can be achieved. Avoidance of surface waves is another attractive advantage of DRAs over microstrip antennas.

Single DRAs of different shapes has been studied, including rectangular, cylindrical, hemispherical, triangular, conical, etc. Among these different shapes cylindrical and rectangular are the most common and the rectangular has the advantage of having one more degree of freedom for design purposes.

There are a variety of feed configurations, which electromagnetic fields can be coupled to DRAs. Most common feed arrangements are microstrip aperture coupling, direct microstrip coupling, probe coupling and conformal strip coupling. Among these feed configurations, aperture coupling is more suitable for MMW applications. In aperture coupling configuration, since the DRA is placed on the ground plane of the microstrip feed, parasitic radiation from the microstrip line is avoided. Isolation of the feed network from the radiating element is another advantage of the aperture coupling method.

In many cases with a single element DRA, desired specifications can not be achieved. For example a high gain, directional pattern can not be synthesized with a single DRA of any shape. In these applications, a DRA array with appropriate element arrangement and feed configurations, can be used to provide desired specifications. In DRA arrays proximity of elements produces mutual coupling. Usually this mutual coupling is considered as an undesired phenomenon because it can alter the array characteristics. However with an exact knowledge of mutual coupling between different elements of an array, this undesired phenomenon may be optimally used to provide specific desired characteristics.

In this paper mutual coupling of different elements of a four element circular array of DRAs and its influence on return loss is computed and illustrated. For simulation, the FDTD method with a UPML boundary condition is applied.

Section 2 provides a brief introduction to the FDTD method including source modeling and the frequency domain parameter definitions. In Section 3 the single DRA dimensions and the simulated response with the FDTD is presented. Section 4 is main contribution of this paper. In this section mutual coupling between different elements of a four element circular array is investigated and simulated with the FDTD method. Section 5 concludes the work.

# 2. THE FDTD METHOD

FDTD is one of the most common numerical techniques in electromagnetics. With simple formulation it can be easily applied to complex structures. In order to have valid results from the FDTD simulations a boundary condition should be applied. In this paper for investigating circular array, the UPML is applied. Since UPML has the potential of modeling inhomogenuities which extend to infinity and in the DRA with aperture coupling it is assumed that the ground plane and microstrip line extends to infinity.

FDTD is a time domain technique and the source should be applied in time domain. A Gaussian resistive voltage source with the following parameters is used for simulations [3]:

$$v = e^{-\frac{(t-t_0)^2}{T^2}}$$
(1)

$$T = 15 \, ps, \qquad t_0 = 4T \tag{2}$$

where T and  $t_0$  are chosen to have desired frequencies in the output and the source resistance is selected 50  $\Omega$  which is approximately the resistance of the microstrip feed at resonant frequency. Once FDTD analysis is done, frequency domain parameters can be obtained with a FFT procedure.

Return loss and mutual couplings are computed with the following definitions [4]:

$$S_{ij} = \frac{b_i}{a_j} \tag{3}$$

$$a_i = \frac{1}{2} \left( \frac{V_i}{\sqrt{Z_0}} + \sqrt{Z_0} I_i \right) \tag{4}$$

$$b_i = \frac{1}{2} \left( \frac{V_i}{\sqrt{Z_0}} - \sqrt{Z_0} I_i \right) \tag{5}$$

With these definitions we don't need to run the FDTD simulation program twice as in [5].

## 3. SINGLE DRA

The single DRA configuration which is fed by aperture coupling method is shown in Figure 1. The DRA dimensions are:  $\varepsilon_{rs} = 10.2$ ,  $\varepsilon_r = 10.8$ , 2a = 15 mm, b = 7.5 mm, d = 3 mm, L = 6.1 mm,  $L_s = 2.2 \text{ mm}$ , w = 1.2 mm,  $w_f = 0.64 \text{ mm}$  and h = 0.64 mm. Return loss, computed with the FDTD method is plotted in Figure 2. Resonant frequency of the single DRA is approximately 7.2 GHz.



Figure 1: A single DRA [2]: (a) top view, (b) side view.

#### 4. CIRCULAR ARRAY

The four element circular array configuration is shown in Figure 3. The array consists of four rectangular DRAs which are placed symmetrically on the circumference of a circle with radius D. A port is assigned to each DRA. Investigating this array is more complicated than linear arrays, since in the proposed configuration in addition to mutual coupling between E-plane elements,  $S_{31}$ , there is mutual coupling between circular staggered DRAs, i.e.,  $S_{21}$  and  $S_{41}$ . Circular staggered configuration is thoroughly discussed in [6].

For investigating the proposed circular array, the array radius, D, is increased and mutual coupling and return loss are computed.

Mutual coupling between the E-plane DRAs,  $S_{31}$ , is computed and plotted in Figure 4. It is observed from this figure that for D equal to  $0.25\lambda$ ,  $S_{31}$  is high while for the other two values of D, mutual coupling is weak and below -20 dB. It is expected from this figure that for D equal to  $0.25\lambda$ , mutual coupling influence on return loss should be observable.



Figure 2: Single DRA return loss.



Figure 4: Mutual coupling between E-plane DRAs for several values of the array radius.



Figure 3: Circular array configuration.



Figure 5: Mutual coupling between staggered DRAs for several values of the array radius.

Mutual coupling between the staggered DRAs, i.e.,  $S_{21}$ , is computed and illustrated in Figure 5. This figure describes that for D equal to  $0.25\lambda$  mutual coupling can be as high as  $-12 \,\mathrm{dB}$  while for the other two values of D,  $S_{21}$  is lower. With this explanation it is expected that return loss curve for D equal to  $0.25\lambda$  should be considerably different from return loss for the other two values of D. The same phenomenon was observed in [6] where a circular staggered DRA was investigated.





Figure 6: Return loss for several values of the array radius.

Figure 7: Mutual couplings for D equal to  $0.25\lambda$ .

For different values of D, return loss is computed and plotted in Figure 6. It is clear from this figure that for D equal to  $0.25\lambda$  return loss curve is considerably different from the curves corresponding to the other greater values of D. This is because of the high mutual couplings  $S_{21}$ ,  $S_{31}$  and  $S_{41}$  for D equal to  $0.25\lambda$ , as it was explained in previous paragraphs. It is also observed that for this value of D, mutual couplings have resulted in improved bandwidth. For the other values of D equal to  $0.5\lambda$  and  $0.75\lambda$ , return loss curves are approximately the same and the same as a single DRA. This phenomenon indicates that mutual coupling for these values of D are not strong enough to affect return loss considerably.

In order to have a comparison among different mutual couplings of the array, in Figure 7,  $S_{21}$ ,  $S_{31}$  and  $S_{41}$  are plotted for D equal to  $0.25\lambda$ . This figure illustrates that,  $S_{31}$  is considerable and for frequencies above 7.4 GHz,  $S_{21}$  and  $S_{41}$  are also significant.



Figure 8: Mutual couplings for D equal to  $0.5\lambda$ .



Mutual couplings for  $D = 0.5\lambda$  are plotted in Figure 8. It is observed that all mutual couplings are below  $-18 \,dB$ .

Finally mutual couplings for D equal to  $0.75\lambda$  are shown in Figure 9. This figure demonstrates weak coupling between the arrays' elements for D equal to  $0.75\lambda$ .

#### 5. CONCLUSION

A four element circular array of rectangular DRAs was investigated. The FDTD method with a UPML boundary condition was used for simulations. For different values of the array radius return loss and mutual couplings were computed and illustrated. It was observed that for D equal to  $0.25\lambda$ , mutual couplings are high and affect return loss considerably. In this case mutual couplings result in improved bandwidth. For greater values of D mutual couplings are not strong enough to affect the return loss considerably.

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