Mutual Coupling Between IFF/SSR Microstrip Antennas with Reduced Transversal Size - Experimental Study

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Abstract. *Mutual coupling between IFF/SSR microstrip antennas is investigated experimentally in this paper. At the begining configuration and performance of isolated microstrip antenna fed by H-shaped coupling slot is presented. Next, the vertical and horizontal arrangement of the microstrip antennas array were investigated. The measurements of return loss and coupling coefficients at two operating frequencies for the two orthogonal planes are presented and compared with the results of numerical calculations, showing satisfactory agreement.*

Keywords

Mutual coupling, microstrip antenna arrays, IFF/SRR systems, patch antenna.

1. Introduction

The effect of mutual coupling between the microstrip antennas designed for IFF/SSR systems is investigated in this paper. IFF (Identify Friend or Foe) and SSR (Secondary Surveillance Radar) systems are the standard systems used in air traffic control [1]. IFF/SSR radars send impulses to flying objects at the frequency of 1.03 GHz. Configuration of impulses determines the type of inquiry. Transponders on the flying objects receive the inquiry and generate responses at the frequency of 1.09 GHz. Apart from the information about the identity of the flying object this response can also contain other important data (eg. velocity and altitude). Typically, IFF/SSR radars are built in form of 1D/2D antenna arrays that can be mounted on planar or cylindrical surfaces. In order to design and build such an array the effect of coupling between the adjacent antennas has to be investigated.

The problem of mutual coupling between the microstrip radiators is by far fundamental and for this reason it is the subject of numerous papers. Generally, two approaches were used in many studies independently for the applied models: (i) calculations of the scattering matrix elements $|S_{ij}|$ (e.g. [2] - [5]) or (ii) calculations of mutual conductance/resistance (e.g. [6], [7]). The results presented in the papers concern the effect of mutual coupling between two neighboring radiators. However, two different situations should be studied in practical array: (i) the element is placed between two other ones and (ii) the radiator is placed on the periphery of the array. This paper contains the results of numerical and experimental study of this problem, in two separate cases: horizontal and vertical configuration of antennas.

Configuration of the microstrip antenna with reduced transversal size which was applied as the array element is shortly described in Section 2. The methodology of the performed study is discussed in Section 3. In the next section the results of experimental study are presented and compared to the results of numerical simulations. Finally, concluding remarks are presented.

2. The Array Element

As IFF/SSR array element we have used the microstrip antenna with reduced transversal size due to the application of H-shaped coupling slot. Full study on this antenna, including the comparison of measurement and simulations, is described in [8]. The H-shaped coupling slot in common ground plane allows to reduce the transversal size of the antenna for about 36 % compared to the antenna with rectangular coupling slot. This reduction is preferable with regard to: (i) easier fixing of the antennas on the curved surface of cylindrical array and (ii) possibility to place two elements sufficiently closer to each other.

The structure of the designed antenna is presented in Fig. 1, whereas in Fig. 2 we show the photo of fabricated antenna with large bottom screen. It should be noted [8] that the reduction of the dimensions of this screen does not influence the VSWR abd the main lobe of the antenna in the important matter. Both Taconic RF-35 layers have the same thickness (0.76 mm) and permittivity ($\varepsilon_r = 3.5$). First (from the top) Rohacell 31 spacing layer has thickness of 40 mm and $\varepsilon_r \approx 1.05$, while the second one has thickness of 10 mm. During the fabrication process we have decided to cover the radiating element with another layer of Rohacell material for better mechanical protection. It was verified that such layer of low permittivity does not influence the antenna performance. The antenna dimensions are length L = 280 mm and width W = 120 mm (see Fig. 1).

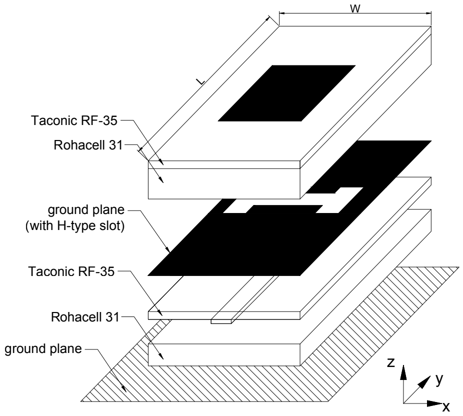


Fig. 1. The structure of microstrip patch antenna fed by coupling slot in common ground.

Fig. 2. The photography of manufactured antenna.

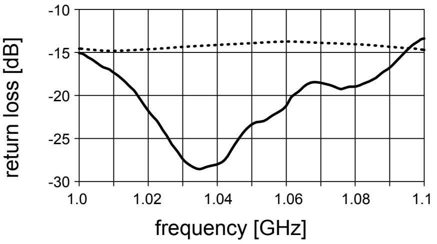
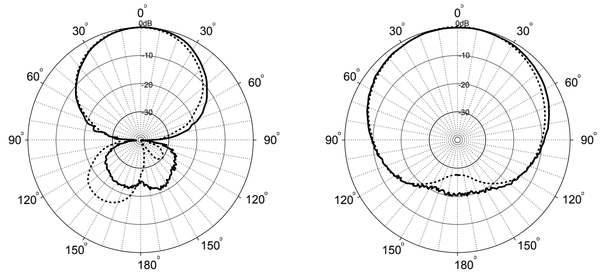


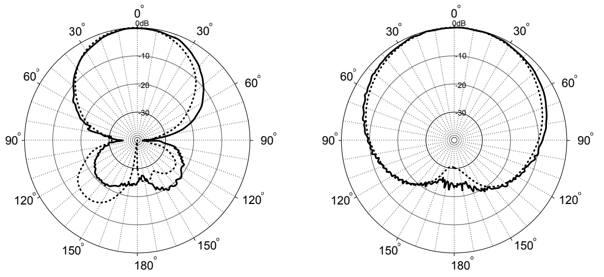
Fig. 3. Measured (solid line) and simulated (dashed line) return loss of the designed antenna.

We present only basic parameters of the isolated antenna. Fig. 3 shows return loss measured and calculated in range 1.0 ÷ 1.1 GHz. Fig. 4 presents radiation patterns measured and calculated in E-plane and H-plane at two IFF marginal frequencies (1.03 and 1.09 GHz).

Note that the measured return loss is lower than -15 dB at both considered frequencies. H-plane radiation patterns are regular and show backward radiation lower than -25 dB for both frequencies. In the case of E-plane patterns additional backward lobes are observed but they are -20 dB below the main lobe. Since the antenna shall be mounted on large conducting cylinder this effect seem to be of minor importance. It also has to be noted that the difference between corresponding measured results in the 0° - 180° axis can be caused by imperfection of measurement method, mostly during the change of antenna polarization for measurement in another plane [8].

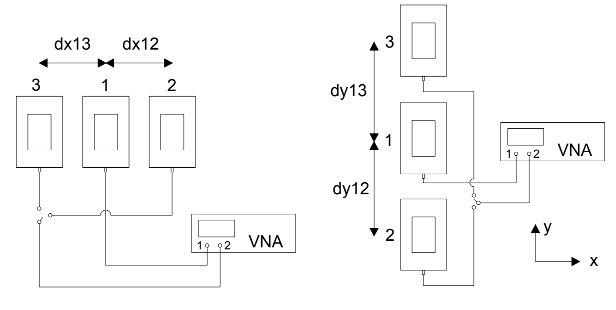


(a) E-plane at 1.03 GHz (b) H-plane at 1.03 GHz



(c) E-plane at 1.09 GHz (d) H-plane at 1.09 GHz

Fig. 4. Measured (solid line) and calculated (dashed line) radiation patterns of the fabricated antenna.



(a) horizontal (b) vertical

Fig. 5. Configurations of antennas for measurement the coupling effect.

3. Methodology of the Investigation

Target IFF/SRR antenna array, as mentioned, will consequently be built on a conducting cylinder with a small radius of curvature. It should allow us to approximate cylindrical surface with a flat conducting plane in numerical studies. Due to the fact that designed array will be two dimensional, two configurations (horizontal and vertical) have to be considered in the study, as it is seen in Fig. 5. For the purpose of experiment we have prepared a flexible conducting plane shown in Fig. 6. On this sheet one can see small mounting holes that correspond to the step taken in computer simulations and measurements.

By using three antennas with reduced bottom screen we can investigate two effects: (i) the influence of marginal sources '3' and '2' on the central source '1' (ii) the impact of two sources (e.g. '1' and '3') on the marginal element of the array (e.g. '2'). In both configurations central antenna was connected to the first port of the vector network analyzer, in this case HP 8753 D. Second port of the VNA was loaded with one of the marginal antennas. All measurements for both configurations and different distances between the antennas (denoted as d_{x12}, d_{x13}, d_{y12} and d_{y13}) were performed at two frequencies from the IFF band (1.03 GHz and 1.09 GHz).

Computer simulations were performed using Ansoft's HFSS 12.1 software. This environment is fully three dimensional (3D) and allows to build an acurate model of the experimental setting. It also needs to be noted that single antenna was modeled and optimised due to reflection coefficient, and then fabricated. Manufactured antenna had to be optimised once again, yet it was verified that slight changes in antenna's dimensions do not affect the results of this study. Final results of measurements compared to the results of simulations are presented and discussed in the next section.

(a) horizontal (b) vertical

Fig. 6. Flexible conducting plane for coupling measurements (with mounted antennas).

4. Results of Measurement and Numerical Study

Since both configurations of the antennas in Fig. 5 are symmetrical ($d_{x12} = d_{x13}$ and $d_{y12} = d_{y13}$) only the coupling between elements '1' and '2' in the presence of '3' is considered. For connected '1' and '3' we have received almost the same results. We do not consider phase parameters in the study since some difference may be introduced by coaxial cables connecting the antennas to the VNA (this effect was not included in the simulations).

In Fig. 7 and Fig. 8 we present scattering parameters for horizontal configurations at 1.03 GHz and 1.09 GHz, respectively. In this setting the distance step was equal to 15 mm, between 120 and 180 mm. We observe satisfying levels of return losses. Differences between measured and calculated values of the return loss are acceptable and do not exceed 5 dB in the worst case. They can be explained by imperfections in the measurements, where return loss of the antenna was measured indirectly with the flexible coaxial cable. For coupling coefficients (S_{21}, S_{12}) simulated curves agree well with experimental ones, only for f = 1.03 GHz we see important disagreement in case when d_{x12} = 120 mm. Generally, results of simulations are confirmed by the results of measurement.

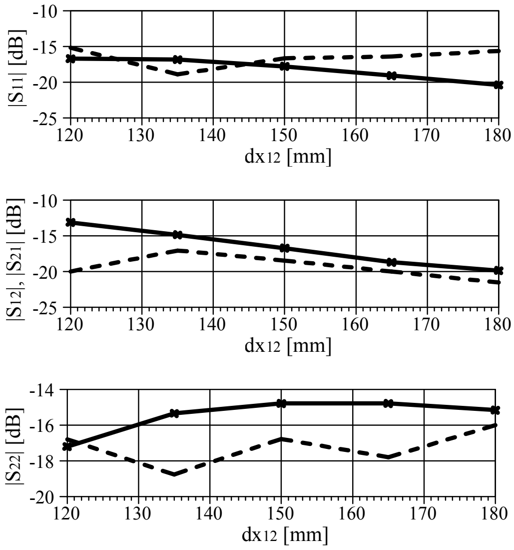


Fig. 7. Scattering parameters, horizontal configuration for 1.03 GHz, measurement (solid line) and simulation results (dashed line).

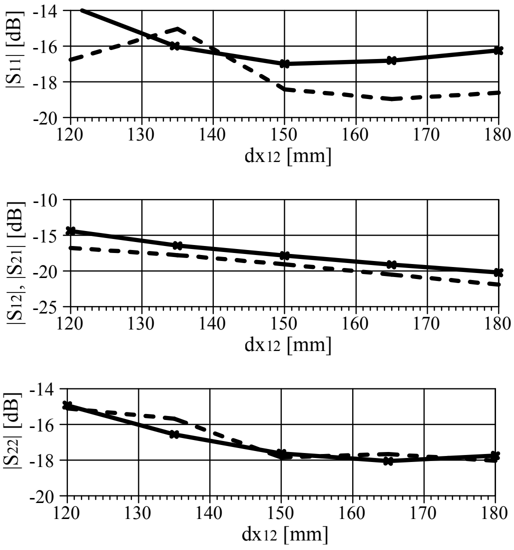


Fig. 8. Scattering parameters, horizontal configuration for 1.09 GHz, measurement (solid line) and simulation results (dashed line).

In Fig. 9 and Fig. 10 we show the results obtained for vertical configuration at 1.03 and 1.09 GHz, respectively. Distance step in this setting was equal to 20 mm (280 – 340 mm). Generally, measured values of S_{21} are lower than the simulated ones at both frequencies. They do not exceed -40 dB and -30 dB at f = 1.03 GHz and f = 1.09 GHz, respectively. In the most cases simulated values do not exceed -20 dB, which is satisfying result. Note that the measured coupling effect is weak enough. In such a case any imperfection in the setting (eg. positioning) can lead to important relative changes. Measured return loss almost do not change with the distance d_{y12}, when simulated curves oscillate around measured ones in accetable range. The one and only exception is the S_{11} at 1.03 GHz, where difference between both curves reaches about 10 dB.

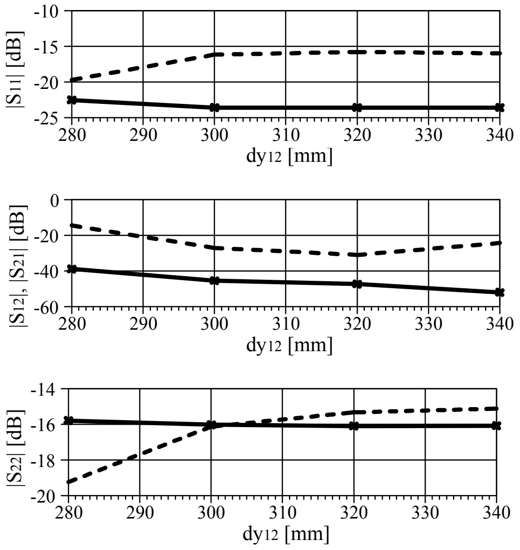


Fig. 9. Scattering parameters, vertical configuration for 1.03 GHz, measurement (solid line) and simulation results (dashed line).

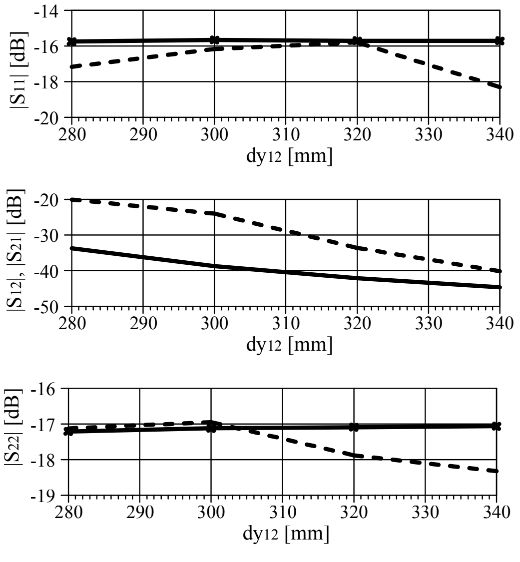


Fig. 10. Scattering parameters, vertical configuration for 1.09 GHz, measurement (solid line) and simulation results (dashed line).

Based on the results of the experiment we can assume that vertical distance between the antennas has slight influence on the level of coupling coefficient.

5. Conclusion

The results of numerical and experimental study of the coupling effect between microstrip IFF antennas have been presented and compared in the paper. Two orthogonal configurations of the antennas have been introduced in order to analyze the coupling effects in both horizontal and vertical planes. Magnitudes of S_{11}, S_{21} (S_{12}) and S_{22} were simulated and measured at two IFF frequencies (1.03 and 1.09 GHz). Satisfying agreement of all curves has been obtained for the horizontal configuration at both frequencies. Significant differences were observed for S_{11} in the vertical setting at 1.03 GHz. In this configuration there is also disagreement in coupling coefficients (at both freq.), yet level $\sim$-20 dB achieved in simulations still indicates very weak coupling effect.

This study can be treated as the preliminary step in designing the IFF/SSR cylindrical array and permits to estimate optimal distances between the radiating elements in both (horizontal/vertical) planes.

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