BROADBAND APERTURE COUPLED MICROSTRIP ANTENNA WITH REDUCED BACK RADIATION

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Abstract

A novel design for an aperture coupled microstrip antenna with reduced back radiation is proposed. The presented design is based on an add-on technique. A couple of parallel microstrip elements, etched on the opposite side of the coupling slot are employed to reduce the radiation into the half-space under the ground plain. Back radiation reduction within the desired frequency range 11.2 - 12.2 GHz is achieved due to the reflection from the supplementary elements. A numerical analysis is accomplished to verify the advantage of the modified structure. Simulation results obtained from antenna models with different types of reflector elements are demonstrated.

1. INTRODUCTION

The advantages of microstrip antennas make them suitable for numerous applications. The fact that the aperture coupled microstrip antenna has been fairly well established up to now in terms of design and modeling is once due to the nature of printed antenna technology, and on the other hand due to its multi-layer structure [1]. Increasing the operational bandwidth has been a major thrust of research in this field. In order to increase the impedance bandwidth various design modifications of ACMSAs have been evolved from the basic geometry. The main advantage of this MSA is the variety of possible materials and dimensional parameters that determine the antenna individual performance – shape, size and disposition of the radiating element and the coupling slot, type of feeding system, etc. Generally the simplicity of the base aperture coupled structure does not compromise its efficiency. Investigations show that a bandwidth up to 12.4 % can be achieved from the basic antenna structure [2]. The coupling aperture of the ACMSA is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration [3, 4]. In particular, the aperture coupled feed structure can provide the advantage of no probe penetration through the substrate layer and is more flexible in impedance matching [5]. The shape, size and location of the aperture influence the main electrical characteristics of the antenna such as return loss, polarization and radiation patterns. The resonant slot provides another resonance in addition to the patch resonance there by increasing the impedance bandwidth at the expense of an increase in back radiation [6]. One particular problem reveals, namely the apparent tradeoff between back radiation and radiation performance of resonant ACMSA. In addition to the fore-mentioned, the current paper represents a numerical analysis of a developed ACMSA structure, which is distinguished by its broadband operation and low back radiation losses. Similar, but principally different add-on technique is demonstrated in [7], nevertheless it could be considered as background of this investigation. Furthermore, an application in antenna arrays could be provisioned using the proposed optimal structure.

The general architecture of a linearly polarized ACMSA is shown in Figure 1.

In this geometry the electromagnetic coupling between the aperture and the 50Ω microstrip feeding line is governed by the tuning - stub length L_S. For linear

polarization, rectangular shape of the patch and aperture has been chosen. In addition, the ratio $K_P = W_P / L_P$ between the two principal patch dimensions affecting the antenna bandwidth of the patch has an average value K_p = 0.8125, so that to ensure high polarization purity [2]. However, the inherent bidirectional radiation of this antenna is undesired. Moreover, it is a drawback that limits the implementation in arrays.

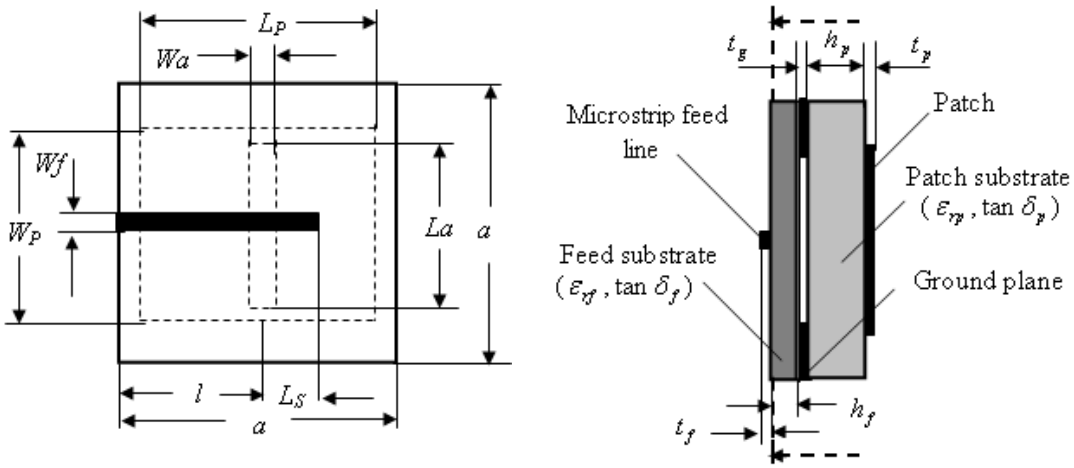


Figure 1. Geometry of a linearly polarized aperture coupled microstrip antenna (ACMSA).

For the purposes of the current analysis a couple of additional microstrip elements have been placed at the bottom of the antenna close to the feeding line. Thus, a simple feeding manner and supplementary elements have been combined to contribute both the return loss and back radiation characteristic.

2. ANALYSIS

The contemporary computing accessories of 3D EM-structures make it possible to design antennas with certain parameters on the ground of optimized models. The commercial EM simulator CST MICROWAVE STUDIO 5 is employed to analyze the models herein.

First, an optimized model of ACMSA regarding broadband operation [8] is used to form the prototype with reduced back radiation by adding a couple of supplementary elements symmetrically to the feeding. In this case, low-cost substrates by Taconic are chosen:

- Patch substrate: Taconic TLX-7: $\varepsilon_{rp} = 2.60, \tan\delta_p = 0.0019, h_p = 1.575$ mm;
- Feed substrate: Taconic RF-60A: $\varepsilon_{rf} = 6.15, \tan\delta_f = 0.0028, h_f = 0.635$ mm;

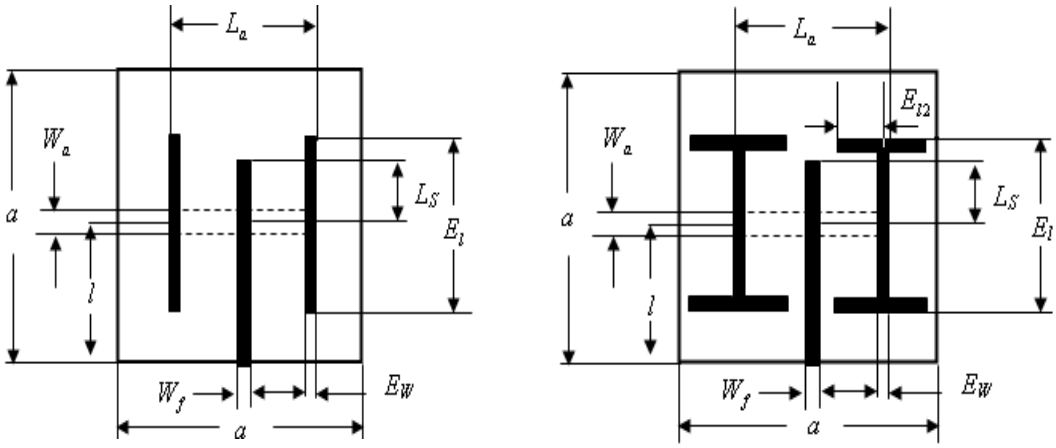
Regarding the numerical analysis of the mentioned optimized antenna back radiation varies from -11 dB to -14.4 dB within the operating frequency range and a value of around -11.5 dB has been ascertained at the central frequency.

The numerical analysis starts with the model, which employs reflector elements with simplest rectangular shape. By adjusting the suitable structure parameters L_P, L_a, L_S, E_l and E_w, the back radiation is significantly reduced, while broadband operation is not affected. The main dimensions of the prototype are shown in Table 1.

The shape and disposition of the antenna with reflector elements are displayed in Figure 2.

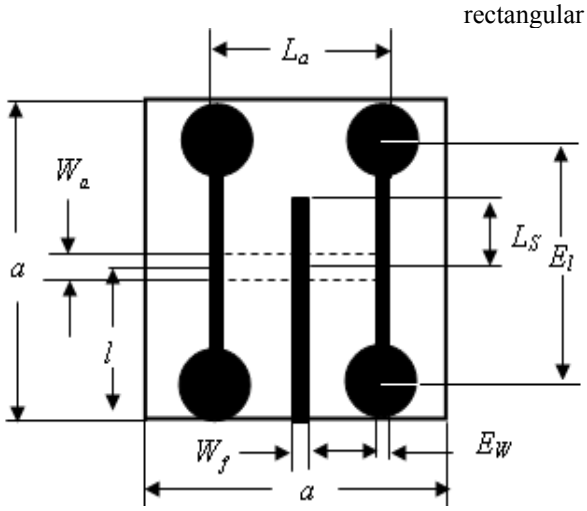
Table 1. Main dimensions of the prototype [mm].

a	53	Antenna Length/Width
W_a	$L_a/10$	Aperture Width
W_f	0.77	Microstrip Feed line Width
h_f	0.635	Feed substrate Thickness
W_P	$0.8125.L_P$	Patch Width
h_p	1.575	Patch substrate Thickness
t_f	0.0175	Microstrip Feed line Thickness
t_g	0.0175	Ground plane Thickness
t_p	0.035	Patch Thickness
L_a	5.2	Aperture Length
L_P	6.1	Patch Length
L_S	2.6	Tuning-Stub Length



a) Antenna with rectangular reflectors

b) Antenna with double bended rectangular reflectors

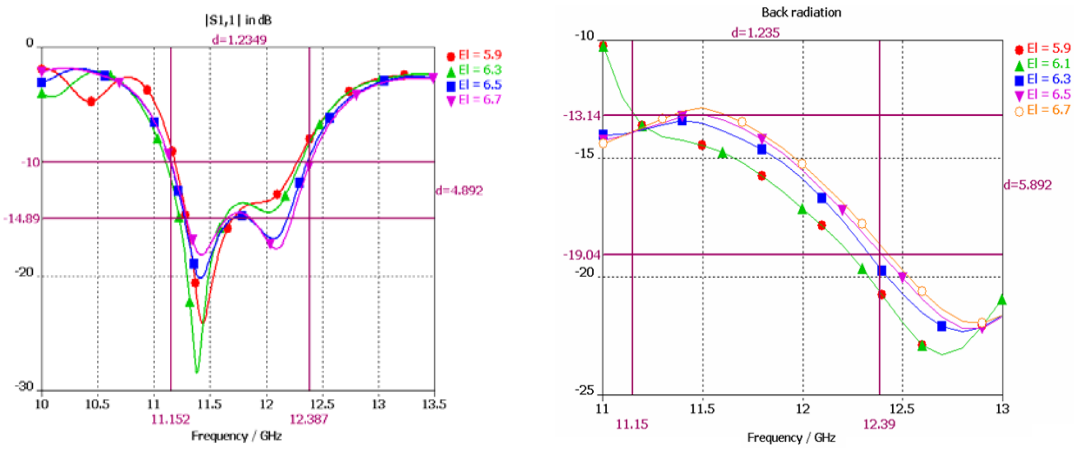


c) Antenna with rectangular reflectors with circular ends

Figure 2. Geometry of a linearly polarized ACMA with different reflector elements.

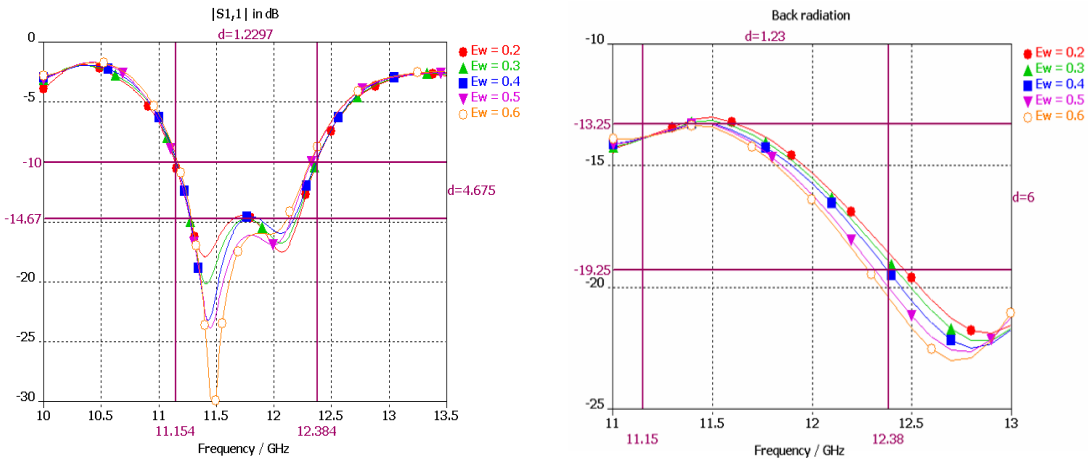
The main antenna dimensions (Table 1) intentionally remain constant during the subsequent simulations, so that to ease the analysis and the assessment of reflectors' contribution.

Figure 3 and Figure 4 illustrate the frequency dependence of the two significant electrical characteristics S_{11} [dB] and back radiation [dB] for several values of the parameters E_l=5.9 – 6.7 mm (E_w=0.3 mm) and E_w=0.2 – 0.6 mm (fixed E_l=6.5 mm). In case of rectangular reflectors the optimal performance is achieved for dimensions E_l=6.5 mm, E_w=0.3 mm, which represent the length and width of the supplementary couple, respectively.



a) Variation of the return loss S_{11} [dB] b) Back radiation [dB]

Figure 3. Diagrams of return loss and back radiation for different values of the parameter E_l = 5.9 – 6.7 mm



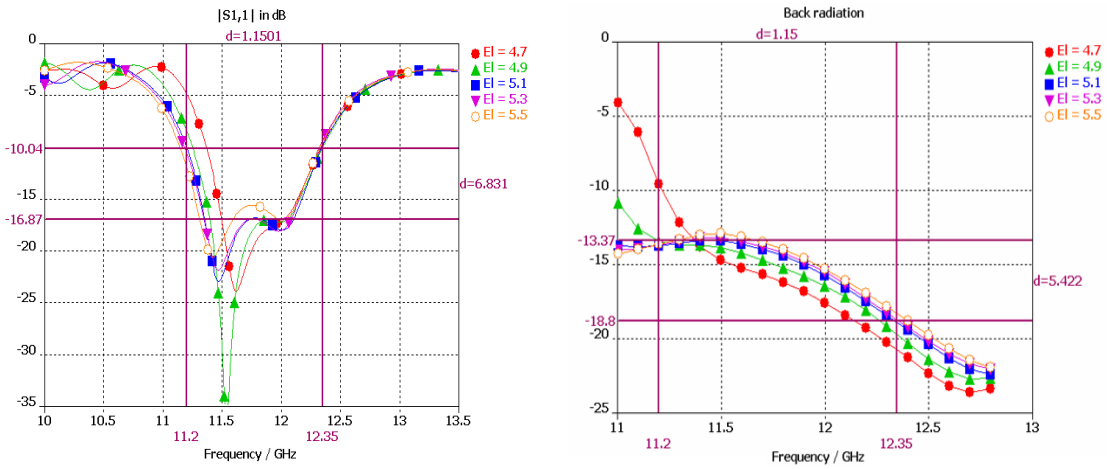
a) Variation of the return loss S_{11} [dB] b) Back radiation [dB]

Figure 4. Diagrams of return loss and back radiation for different values of the parameter E_w = 0.2 – 0.6 mm

With respect to the latter diagrams follows the general conclusion that antenna performance is strongly influenced by both the reflectors length and width, especially at higher frequencies. As it is seen from the figures optimal results are obtained for finer reflectors. Taking this into consideration, as well as the technological limitations further the reflectors width is fixed E_w=0.3 mm, so that to ensure antenna reliability

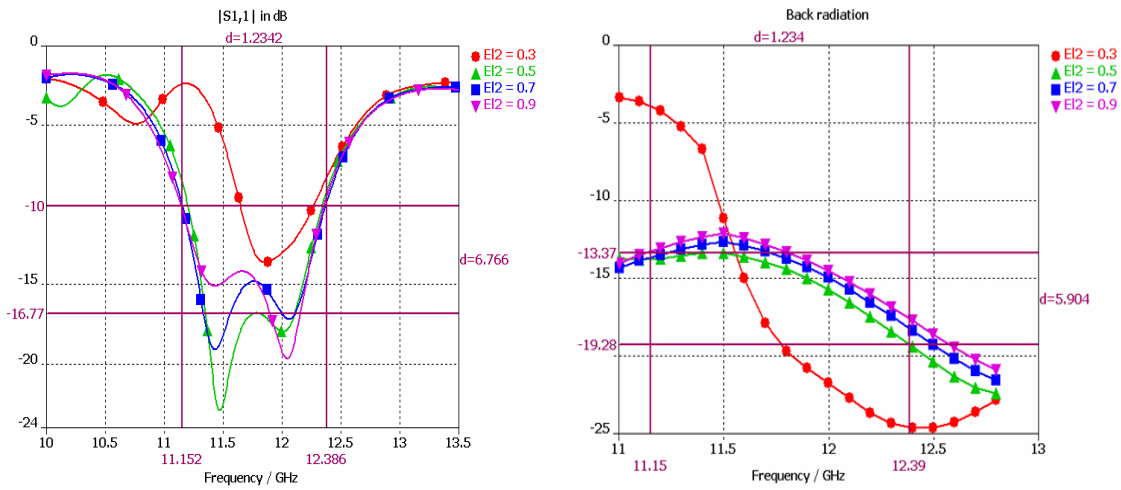
regarding the possible fabrication tolerances. The length of the reflectors has a crucial role for the resonant characteristic of the antenna, though the matching at the central frequency is not significantly affected. Predominant resonant behavior leads to increased back radiation. On the other hand, the optimal disposition of the elements is exactly under the two ends of the coupling slot, wherever a peak value of spurious radiation is expected. Thus, the effect of the supplementary microstrip couple is mostly due to reflection than resonance mismatch.

In the analysis of the second couple of reflectors another parameter is included, namely the length of the bends E_{l2}. After a few iterations with the simulator the optimal dimensions of the model have been specified. Figure 5 and Figure 6 show the fore-mentioned characteristics of S_{11} [dB] and back radiation [dB] for parameters' values within the range E_l=4.7 – 5.5 mm (E_{l2}=0.5 mm) and E_{l2}=0.3 – 0.9 mm (fixed E_l=5.1 mm).



a) Variation of the return loss S_{11} [dB] b) Back radiation [dB]

Figure 5. Diagrams of return loss and back radiation for different values of the parameter E_l = 4.7 – 5.5 mm

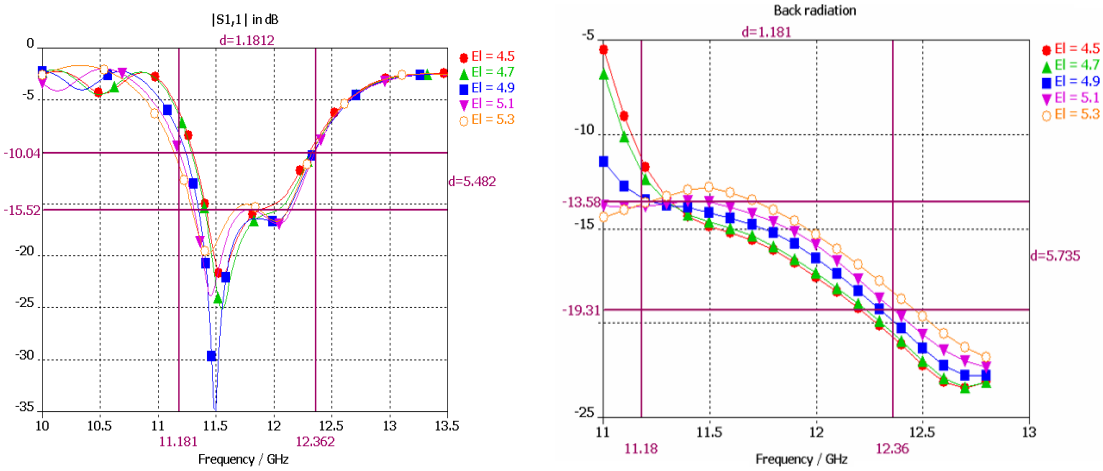


a) Variation of the return loss S_{11} [dB] b) Back radiation [dB]

Figure 6. Diagrams of return loss and back radiation for different values of the parameter E_{l2} = 0.3 – 0.9 mm

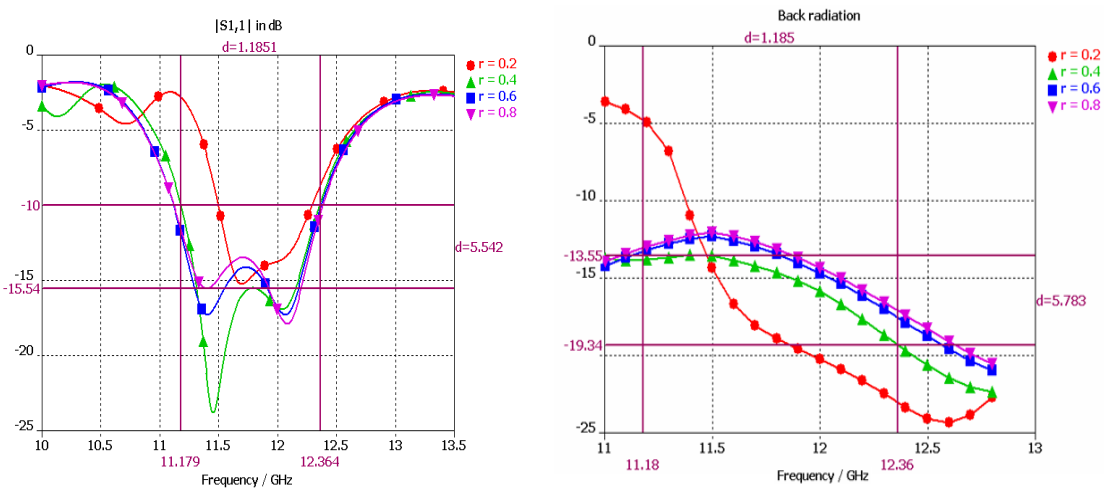
Adding of the bend reflectors contributes to the element minimization, which is an advantage when an array application is to be provisioned. The optimal parameters for double bended reflectors are chosen E_l=5.3 mm and E_{l2}=0.5 mm, so that to provide a broadband operation and back radiation reduction. The length of the bend dramatically affects the two characteristics, since the bend approaches the feeding microstrip line.

Final stage of the current analysis is the assessment of the results obtained from the model with 'dog bone' reflectors. The respective characteristics are displayed in Figure 7 and Figure 8. The numerical study herein is performed for parameter's values E_l=4.5 – 5.3 mm and radius of the reflector final ending r=0.2 – 0.8 mm. Once again, it can be seen that the improvement of one characteristic is on the expense of other. Having this in mind, the optimal values of the respective parameters are chosen E_l=5.1 mm and r=0.4 mm.



a) Variation of the return loss S_{11} [dB] b) Back radiation [dB]

Figure 7. Diagrams of return loss and back radiation for different values of the parameter E_l = 4.5 – 5.3 mm



a) Variation of the return loss S_{11} [dB] b) Back radiation [dB]

Figure 8. Diagrams of return loss and back radiation for different values of the parameter r = 0.2 – 0.8 mm

The electrical characteristics of the optimized antenna models are listed in Tables 2-4.

Table 2. Electrical characteristics of the optimized aperture coupled microstrip antenna with rectangular reflectors

$f_0 = 11.765GHz$	$\lambda_0 = 25.5mm$
$f_{\min} = 11.15GHz$	$f_{\max} = 12.38GHz$
$BW = 1.23GHz$	$bw = 10.455\%$
$D = (4.93;6.92)dB$	$D_0 = 6.24dB$
$G = (4.434;6.43)dB$	$G_0 = 5.9dB$
$BR = (-13.14;-18.93)dB$	$BR_0 = -14dB$
$\theta = (-46^0;46^0), \phi = 0^0$ $Co_pol_{E0} = (3.88;5.87)dB$ $Cross_pol_{E0} = (-53;-36.06)dB$	$\theta = (-46^0;46^0), \phi = 90^0$ $Co_pol_{H0} = (1.3;5.88)dB$ $Cross_pol_{H0} = (-54.02;-28.08)dB$

Table 3. Electrical characteristics of the optimized aperture coupled microstrip antenna with double bended reflectors

$f_0 = 11.75GHz$	$\lambda_0 = 25.532mm$
$f_{\min} = 11.16GHz$	$f_{\max} = 12.34GHz$
$BW = 1.18GHz$	$bw = 10.04\%$
$D = (5.00;6.9)dB$	$D_0 = 6.22dB$
$G = (4.5;6.44)dB$	$G_0 = 5.87dB$
$BR = (-13.1;-18.6)dB$	$BR_0 = -14dB$
$\theta = (-46^0;46^0), \phi = 0^0$ $Co_pol_{E0} = (3.68;5.82)dB$ $Cross_pol_{E0} = (-47.38;-32.16)dB$	$\theta = (-46^0;46^0), \phi = 90^0$ $Co_pol_{H0} = (1.51;5.81)dB$ $Cross_pol_{H0} = (-39.08;-29.32)dB$

Table 4. Electrical characteristics of the optimized aperture coupled microstrip antenna with 'dog bone' reflectors

$f_0 = 11.76GHz$	$\lambda_0 = 25.489mm$
$f_{\min} = 11.16GHz$	$f_{\max} = 12.36GHz$
$BW = 1.2GHz$	$bw = 10.20\%$
$D = (5.00;6.9)dB$	$D_0 = 6.25dB$
$G = (4.5;6.46)dB$	$G_0 = 5.9dB$
$BR = (-13.5;-19.3)dB$	$BR_0 = -14.4dB$
$\theta = (-46^0;46^0), \phi = 0^0$ $Co_pol_{E0} = (4.57;6.02)dB$ $Cross_pol_{E0} = (-52.12;-32.56)dB$	$\theta = (-46^0;46^0), \phi = 90^0$ $Co_pol_{H0} = (1.21;6.01)dB$ $Cross_pol_{H0} = (-54.23;-26.90)dB$

As it was expected, the model with circular ends of reflectors showed best results. Its advantageous characteristics, in conjunction with the minimized additional elements make it a preferable choice for array application. Taking into consideration the substrates parameters the proposed microstrip structure is also price-competitive. The computed radiation patterns of this antenna are shown in Figure 9 and Figure 10.

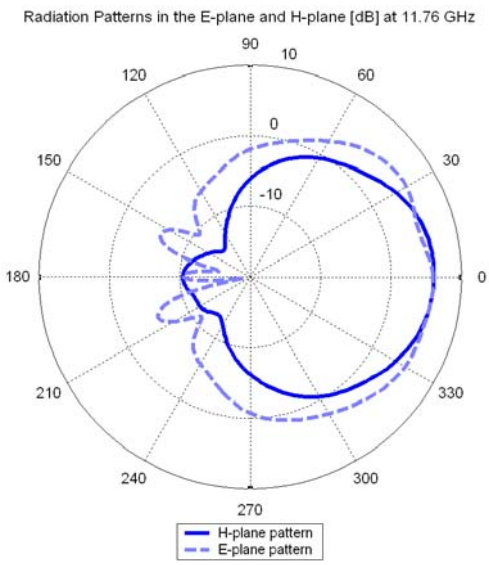
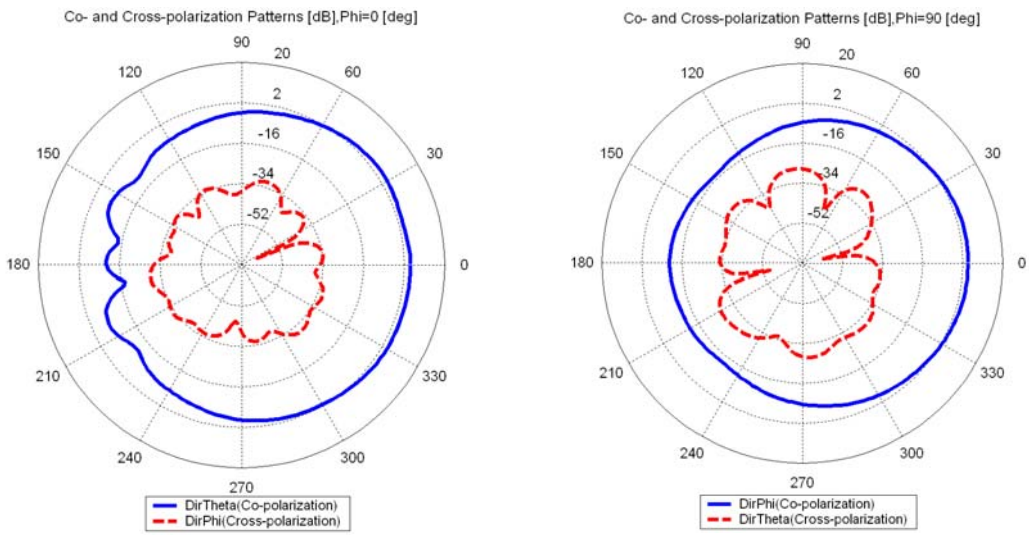


Figure 9. Radiation patterns of the ACMSA with 'dog bone' reflectors, *E*-plane and *H*-plane, f_0 =11.76 GHz



a) $(phi = 0^0; theta)$ b) $(phi = 90^0; theta)$

Figure 10. Co- and cross-polarization patterns of the ACMSA with 'dog bone' reflectors for operating frequency f_0 =11.76 GHz

While parasitic elements, generally placed on the top of the antenna in most cases improve the impedance bandwidth and directivity on the expense of high backlobe and cross-polarization levels, the design herein does not suffer from this contradictory relation. Low cross-polarization is observed in the three models due to the balanced feeding system and beam squint does not appear. Nevertheless, the maximum level of

cross-polarization in the principal planes is below –25 dB across the examined front sector. An optimal bandwidth is attained, though insignificantly affected in comparison with the optimized variant without reflectors. Moreover, the directivity and gain remain within the typical ranges for microstrip antenna elements. The radiation patterns do not vary significantly and the asymmetry, observed in the cross-polarization patterns can be explained with the computation method utilized for the analysis.

3. CONCLUSION

An optimized microstrip radiator by means of operating bandwidth and front-to-back ratio has been proposed. The idea to improve the antenna performance by an add-on technique has been realized applying a couple of reflector elements. Some design modifications of an aperture coupled microstrip antenna have been investigated using a commercial software product. Regarding the simulation results of the optimized models, a particular shape of the reflectors which best suits the initial requirements, namely frequency bandwidth within the range 11.2 – 12.2 GHz and desired performance has been specified. A simple cost-competitive antenna configuration is achieved. Further developments will focus on the antenna application in an array and the option the same technique to be employed in a design with circular polarization.

4. ACKNOWLEDGEMENT

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REFERENCES

[1] Pozar, D. M., “A Review of Aperture Coupled Microstrip Antennas: History, Operation, Development, and Applications,” Electrical and Computer Engineering, University of Massachusetts at Amherst, Amherst, MA 01003, May 1996.

[2] Kirov, G. S., “Analysis, Design and Realization of Commercial Printed Antenna Arrays for Satellite Communications with Mobile Vehicles,” Magdeburg University Otto-Von-Guericke, report, 2003.

[3] Balanis, C. A., *Antenna Theory: Analysis and Design*, John Willy & Sons, 3rd Ed., 2005.

[4] Chen, Z. N., and M. Y. W. Chia, ”Center-fed Microstrip Patch Antenna,” *IEEE Transactions on Antennas and Propagation*, vol. 51, No. 3, March 2003, pp. 483-487.

[5] Wong, Kin-Lu, *Compact and Broadband Microstrip Antennas*, John Wiley & Sons, Inc., New York, 2002.

[6] Kumar, G., K. P. Ray, *Broadband Microstrip Antennas*, Artech House, Boston, London, 2003.

[7] Rao, Q., T. A. Denidni, and R. H. Johnston, “A Single-Substrate Microstrip-Fed Slot Antenna Array With Reduced Back Radiation,” *IEEE Antennas and Wireless Propagation Letters*, Vol. 3, 2004, pp. 265-268.

[8] Mihailova, D. P., G. S. Kirov, “Broadband Aperture Coupled Microstrip Antenna,” Annual Proceedings of Technical University of Varna, Varna, 2007, pp. 60-65.