Circularly Polarized Aperture Coupled Microstrip Antenna with Resonant Slots and a Screen

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Abstract. *A broadband circularly polarized (CP) Aperture Coupled Microstrip Antenna (ACMSA) is described herein. In order to decrease the back radiation of the antenna due to resonant coupling slots (a cross-slot) in the ground plane, a three-layer structure with a screen is proposed. As a result, the back radiation of the antenna is reduced by more than 12 dB and its gain is increased by about 1.3 dB compared to the conventional two-layer ACMSA with non-resonant coupling slots. The antenna is designed to operate within the Ku-band. Keeping its simple and compact construction and high mechanical characteristics it can be used as an element of CP microstrip antenna arrays with various applications in the contemporary communication systems. A comparison with two similar CP antennas with resonant slots, a two-layer ACMSA and a three-layer ACMSA with a patch reflector is accomplished.*

Keywords

Aperture coupled microstrip antenna, back radiation reduction, circularly polarized microstrip antenna, cross-slot coupled, microstrip antenna with resonant slots.

1. Introduction

The microstrip antennas (MSAs) are the most rapidly developing area in the antenna field in the last years due to their light weight, low volume, thin profile configuration and low fabrication cost. Because of these advantages they are widely used in the contemporary communication systems such as personal communication systems, mobile satellite communications, direct broadcast television, wireless local area networks, etc… Additionally in these applications the circular polarization (CP) contributes to the high link's reliability and spectral efficiency [1].

The main disadvantage of the CP MSAs is their narrow bandwidth characteristic. The impedance bandwidth of a typical microstrip patch antenna, defined by –10 dB return loss, is several percent [2], while its 3 dB - axial ratio (AR) bandwidth is less than 1% [3]. Since the AR bandwidth of the CP antenna is usually less than its impedance and pattern bandwidths it limits the frequency bandwidth of the antenna. Thus the approach to enhance the bandwidth of the CP MSA consists of a broadbanding of its AR bandwidth.

There are some methods to enlarge the AR bandwidth of the CP MSA: 1) By multiple resonances due to parasitic patches [4]; 2) By means of complex (usually balanced) feeds [4] – [6]; 3) Using an air gap or a foam with low dielectric constant as a patch substrate [3] – [6]; 4) By using photonic bandgap structures and other approaches.

The CP MSAs designed according to the methods listed above have good electrical parameters but possess a complex configuration and low mechanical characteristics. The goal of this study is a design of a broadband CP MSA with simple and compact configuration and high electrical and mechanical characteristics. In [7] a broadband two-layer CP aperture coupled MSA (ACMSA) with a resonant cross-slot is investigated. An aperture coupled feed is chosen because it allows an independent optimization of the both parts of the antenna – the feed part and the radiating one. The use of a resonant cross-slot enlarges additionally the AR bandwidth (bw_{AR}) of the antenna. The result obtained in [7] for this parameter is bw_{AR} = 3.24% in Ku-band. Unfortunately the investigated antenna has a high level of back radiation (BR) – about – (9-10) dB. In [8] the BR level of a CP ACMSA is reduced using a three-layer ACMSA with an additional third substrate and reflector. The above approach is not suitable for a CP ACMSA with a resonant cross-slot because it reduces the antenna BR level in Ku-band by only 5 to 9 dB but also decreases its AR bandwidth by 20% (from 3.24% to 2.59%) [8]. In order to reduce the BR level due to the resonant cross-slot a three-layer CP ACMSA with a screen is designed and investigated by simulation in this study.

2. Description of the Antenna

Fig. 1 shows the geometry of the antenna with a screen and its dimensions are listed in Tab. 1. Three substrates are used in the antenna configuration as follows: patch substrate Taconic TLX-7: ε_{rp} = 2.60, $\tan\delta_P$ = 0.0019; feed substrate Taconic RF-60A: ε_{rf} = 6.15, $\tan\delta_f$ = 0.0028; screen substrate Arlon AD 600: ε_{rs} = 6.15, $\tan\delta_S$ = 0.0030.

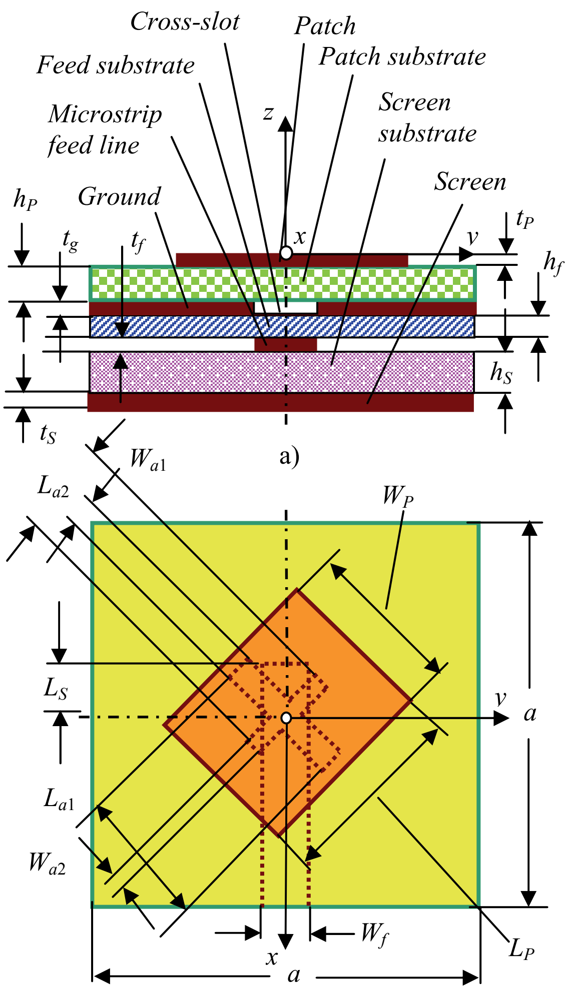

Fig. 1. Geometry of the antenna with a screen: (a) cross section, (b) front view.

In order to obtain a maximum radiation efficiency and frequency bandwidth a thick patch substrate with a low dielectric constant is chosen, while the feed substrate is thin with a high dielectric constant for maximum feed efficiency. The insertion of a second resonance (except the first resonance connected to the patch) due to the resonant cross-slot enlarges the frequency bandwidth of the antenna more than two times in comparison with the conventional two-layer CP ACMSA [9]. The higher BR level due to the resonant slot is limited by a metal screen. The thickness h_S of the screen substrate and the value of its dielectric constant ε_{rs} are chosen in compliance with the following fundamental phase condition

$$(2\pi/\lambda_a)(h_f + t_f + h_S) = \pi/2 \tag{1}$$

where λ_a is the corresponding equivalent wavelength in the space between the ground and the screen. Then

$$\sqrt{\varepsilon_{ra}}(h_f + t_f + h_S) = \lambda_0/4, \tag{2}$$

$$\sqrt{\varepsilon_{rf}}h_f + t_f + \sqrt{\varepsilon_{rs}}h_S \approx \lambda_0/4 \tag{3}$$

where λ_0 is the free space wavelength.

Dimension [mm]		Description
a	53	Antenna Length (Width)
$\boldsymbol{L_p}$	**5.6**	**Patch Length**
$\boldsymbol{K_p}$	**1.03**	**Patch Ratio L_p/W_p**
$\boldsymbol{L_a}$	**4.8**	**Average Aperture Length**
W_p	L_p/K_p	Patch Width
$\boldsymbol{K_s}$	**1.25**	**Slot Ratio L_{a1}/L_{a2}**
$\boldsymbol{L_s}$	**1.6**	**Stub Length**
L_{a1}	$2L_aK_s/(K_s+1)$	Aperture 1 Length
W_{a1}	$L_{a1}/10$	Aperture 1 Width
L_{a2}	$2L_a/(K_s+1)$	Aperture 2 Length
W_{a2}	$L_{a2}/10$	Aperture 2 Width
W_f	0.77	Feed line Width
h_p	1.575	Patch substrate Thickness
t_p, t_s	0.035	Patch and Screen Thickness
h_f	0.635	Feed substrate Thickness
t_g, t_f	0.0175	Ground plane and Feed line Thickness
h_s	1.905	Screen substrate Thickness

Tab. 1. Dimensions of the antenna with a screen.

The radiation mechanism of the antenna is the following: the electromagnetic energy provided by the feed microstrip line penetrates via the cross-slot into the patch resonator formed by the patch and the ground. By means of a suitable choice of the patch and slot dimensions the both orthogonal modes TM_{100} and TM_{010} excited in the resonator obtain equal amplitudes and phase quadrature. The energy of the so formed CP electromagnetic field is radiated into space in the broadside direction of the antenna. In this case the left-hand CP corresponds to a co-polar radiation, while the cross-polar one is presented by the right-hand CP. The metal screen reflects the BR energy from the resonant cross-slot in the direction of the basic radiation energy flux of the antenna improving its gain.

The results obtained in this study are compared with the results of two similar MSAs designed in the same frequency range: The first antenna is a two-layer CP ACMSA with a resonant cross-slot investigated in [7]. Its configuration differs from the antenna configuration shown in Fig. 1 only in the absence of a screen substrate and a screen. The antenna uses the same substrates and has the following dimensions and parameters obtained by an optimization technique: $L_P = 6.1$ mm, $K_P = 1.14$, $K_S = 1.06$ and $L_S = 1.2$ mm. The other dimensions are the same as in Tab. 1. The second antenna is obtained from the first one by addition of a reflector substrate (identical with the screen substrate from Fig. 1) and the patch reflector [8]. The reflector is a square patch with length (width) $L_r = W_r = 10.5$ mm, centered below the radiation patch. The antenna differs from the antenna with a screen only in the dimension $L_P = 5.5$ mm. All dimensions and parameters of the antenna with a reflector are also obtained by an optimization.

3. Simulation

Two steps are accomplished in the design of the antenna: the first step is a suitable choice of the substrates with standard values of their thickness and dielectric constant; the second one consists in an optimization by simulation of the rest antenna dimensions and parameters. As criteria in the optimization the AR bandwidth and the BR level are chosen. The simulation of the antenna model is carried out by the software package CST Microwave Studio 5. The final results are verified once again using the Ansoft software HFSS 10.

Five independent dimensions and parameters are chosen in the optimization: 1) Patch length L_P: it influences on the patch resonance; 2) Patch ratio $K_P = L_P/W_P$: it acts on the amplitude and phase conditions necessary to obtain CP operation; 3) Average aperture length L_a: this dimension determines the slot resonance; 4) Slot ratio $K_S = L_{a1}/L_{a2}$: this ratio acts on the conditions required for CP operation; 5) Stub length L_S: it influences on the impedance matching and the frequency bandwidth of the antenna.

There are still three dimensions W_P, L_{ai}, i = 1, 2 and W_{ai}, i = 1, 2 related to L_P and K_P, L_a and K_S, L_{ai}, i = 1, 2, respectively by corresponding interrelations given in Tab. 1. Several iterations are done to find the optimum values L_P = 5.6 mm, K_P = 1.03, L_a = 4.8 mm, K_S = 1.25 and L_S = 1.6 mm denoted in bold in Tab. 1.

4. Numerical Results

Figs. 2 to 5 show the main simulated electrical characteristics of the antenna with a screen (bold). For comparison the same characteristics of a two-layer antenna (dotted) and an antenna with a reflector (dashed) are also shown in the figures.

Fig. 2 shows the Return Loss (the module of the reflection coefficient S_{11}) of the three antennas. The first resonance at the lower frequency is that of the patch and the second one at the higher frequency is that of the cross-slot. It must be noted that these two resonances are not proper resonances but mutual resonances of the patch and the cross-slot.

Fig. 3 shows the axial ratio AR versus frequency of the three antennas. The AR bandwidths defined from this figure are the final bandwidths of the antennas.

Fig. 4 shows the BR level versus frequency of the antennas. This is the most important characteristic in this study.

Fig. 5 shows the gain G versus frequency of the antennas. It is seen from the figure that the antenna with a screen provides higher gain than the both other antennas, which is due to the presence of the screen in its construction.

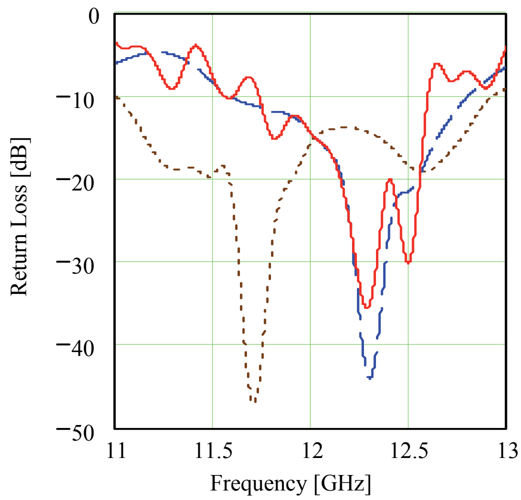

Fig. 2. Return Loss versus frequency of the three antenna models (dotted – two-layer antenna, dashed – antenna with a reflector, bold – antenna with a screen).

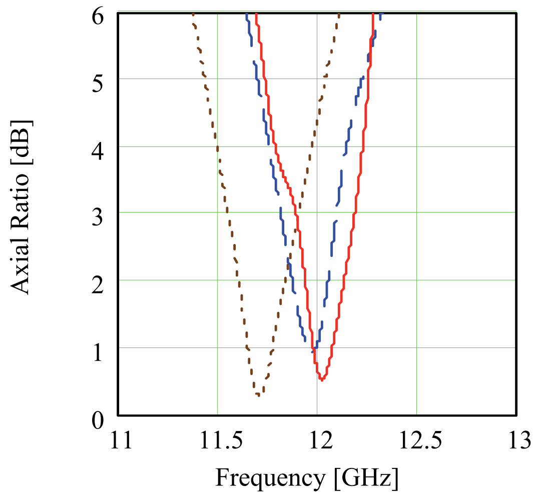

Fig. 3. Axial Ratio AR versus frequency of the three antenna models (dotted – two-layer antenna, dashed – antenna with a reflector, bold – antenna with a screen).

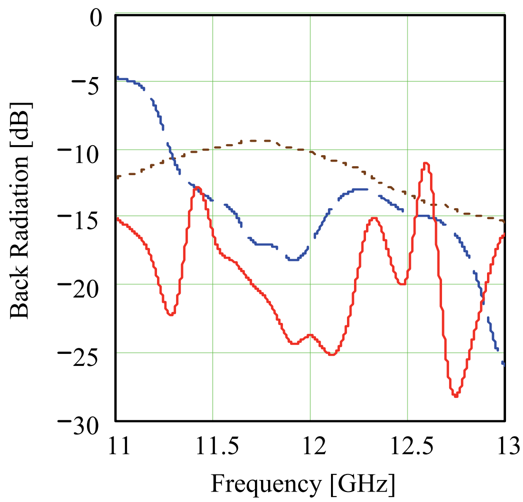

Fig. 4. Back Radiation BR versus frequency of the three antenna models (dotted – two-layer antenna, dashed – antenna with a reflector, bold – antenna with a screen).

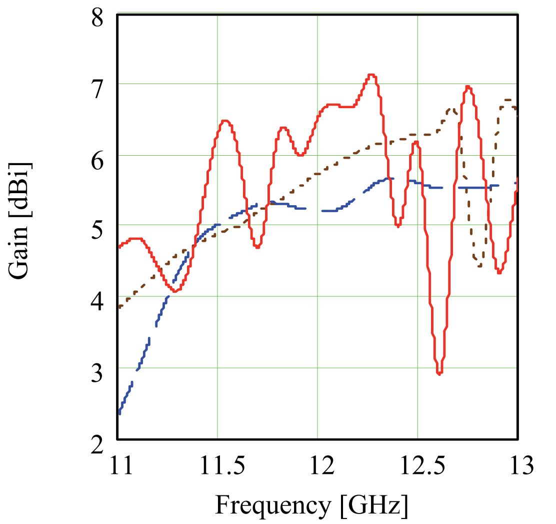

Fig. 5. Gain G versus frequency of the three antenna models (dotted – two-layer antenna, dashed – antenna with a reflector, bold – antenna with a screen).

The basic electrical parameters of the three antennas are summarized in Tab. 2. In the table the central frequency f_0 and the 3 dB-relative frequency bandwidth are defined as follows

$$f_{0(AR)} = 0.5(f_{\min(AR)} + f_{\max(AR)}), \quad (4)$$

$$bw_{(AR)} = 2\frac{f_{\max(AR)} - f_{\min(AR)}}{f_{\max(AR)} + f_{\min(AR)}} \times 100, \% . \quad (5)$$

Electrical Characteristic	Two-layer Antenna	Antenna with a Reflector	Antenna with a Screen
Impedance Bandwidth			
f_{min} [GHz]	10.96	11.57	11.7
f_{max} [GHz]	12.96	12.8	12.57
f_0 [GHz]	11.96	12.185	12.135
BW [GHz]	2.00	1.23	0.87
bw [%]	16.72	10.09	7.17
Axial Ratio Bandwidth, Back Radiation and Gain			
$f_{min\ AR}$ [GHz]	11.53	11.8	11.82
$f_{max\ AR}$ [GHz]	11.91	12.11	12.2
f_{0AR} [GHz]	11.72	11.955	12.01
BW_{AR} [GHz]	0.38	0.31	0.38
bw_{AR} [%]	**3.24**	**2.59**	**3.16**
BR_{min} [dB]	-9.9	-18.3	-25.3
BR_{max} [dB]	**-9.4**	**-14.4**	**-22.3**
G_{min} [dBi]	**4.9**	**5.2**	**6.2**
G_{max} [dBi]	5.53	5.27	6.8

Tab. 2. Electrical characteristics of the three antenna models.

The subscripts *min* and *max* for the *BR* level and the gain *G* are not related to the minimum and maximum frequencies $f_{\min(AR)}$ and $f_{\max(AR)}$ but correspond to their minimum and maximum values in the antenna frequency bandwidth. As seen from the table, the design with a screen has a considerable advance regarding the antenna back radiation.

Co- and cross-polar radiation patterns in $\varphi = 45^0$-plane of the three antennas are displayed in Figs. 6 to 8.

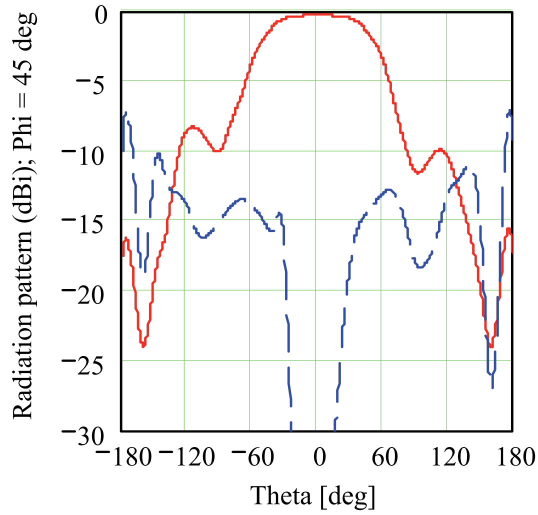

Fig. 6. Radiation pattern of the two-layer antenna in $\varphi = 45^0$-plane (bold – co-polar, dashed – cross-polar), $f_0 = 11.72$ GHz.

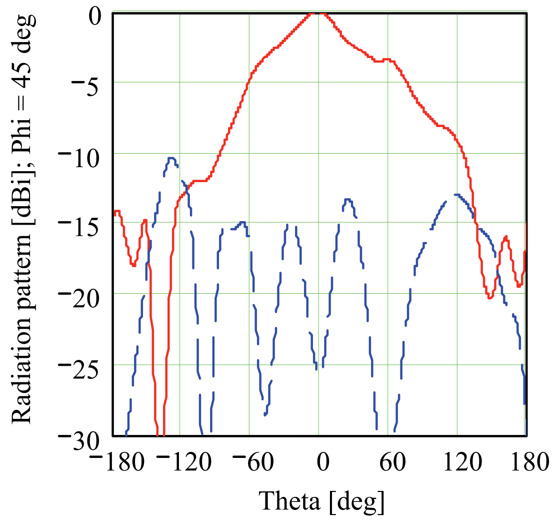

Fig. 7. Radiation pattern of the antenna with a reflector in $\varphi = 45^0$-plane (bold – co-polar, dashed – cross-polar), $f_0 = 11.955$ GHz.

Finally, the co-polar radiation pattern of the antenna with a screen in $\varphi = 90^0$- plane at frequency $f_0 = 12.01$ GHz carried out by means of the software package CST Microwave Studio 5 (bold) and the Ansoft software HFSS 10 (dashed) is shown in Fig. 9. A good agreement between the both curves is seen. In particular, there is a full coincidence between the two simulations in the front hemisphere, which indicates a high credibility of the obtained results.

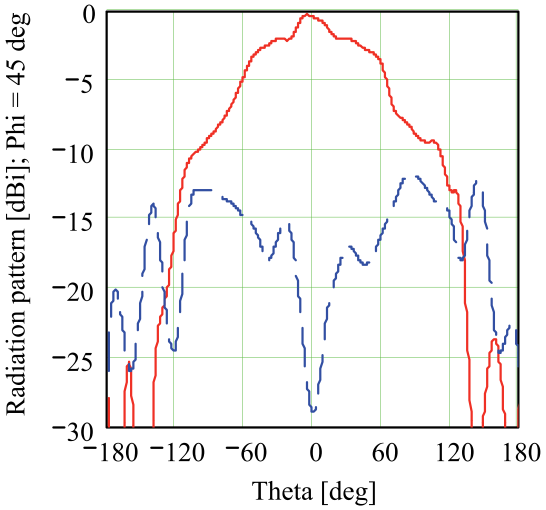

Fig. 8. Radiation pattern of the antenna with a screen in $\varphi = 45^0$-plane (bold – co-polar, dashed – cross-polar), $f_0 = 12.01$ GHz.

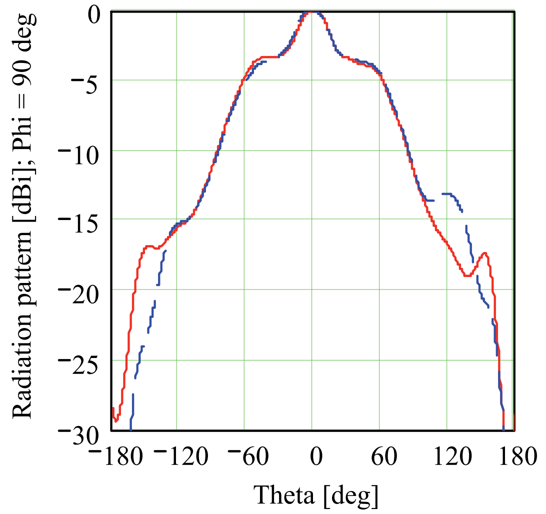

Fig. 9. Radiation pattern of the antenna with a screen in $\varphi = 90^0$-plane (bold – CST Microwave Studio 5, dashed – HFSS 10), $f_0 = 12.01$ GHz.

5. Points of Discussion

The antennas with a reflector and a screen may be obtained from the two-layer antenna by addition of a reflector or a screen, respectively. Because of this reason the two-layer antenna is chosen as a basis for comparison between the three antenna configurations in this section. Comparing the three optimized antenna models the following features have been ascertained:

- The two-layer CP antenna possesses a 3.24% bandwidth with a BR level less than – 9.4 dB;
- The presence of the patch reflector decreases the bandwidth by 20% (from 3.24% to 2.59%) with a BR level less than – 14.4 dB (a decrease by 5 dB);
- The antenna with a screen keeps almost the same bandwidth (a decrease by only 2.5%, from 3.24% to 3.16%) with a BR level less than – 22.3 dB (a decrease by 12.9 dB);
- The patch reflector improves insignificantly the antenna gain by about 0.3 dB (from 4.9 dB to 5.2 dB), while the screen increases the same parameter by about 1.3 dB (from 4.9 dB to 6.2 dB).
- The patch reflector and the screen influence insignificantly on the cross-polarization characteristics of the antenna.

6. Conclusion

A circularly polarized aperture coupled microstrip antenna with resonant slots and a screen with simple and compact configuration and high electrical and mechanical characteristics is designed. It has a gain higher than 6.2 dB and a back radiation level less than – 22.3 dB in the 3 dB – axial ratio bandwidth of 3.16% in Ku – band. The axial ratio bandwidth of the designed antenna is more than two times the respective value of the conventional microstrip antenna. The proposed antenna can be used as an element of microstrip antenna arrays in the contemporary communication systems.

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