Circularly Polarized Aperture Coupled Microstrip Antenna with a Screen and Impedance Transformer: Part 1. Effect of the Antenna Dimensions on the Electrical Characteristics of the Antenna

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Abstract – **A circularly polarized aperture coupled microstrip antenna with a screen and impedance transformer is described herein. The effect of the antenna dimensions on the main electrical characteristics is presented by means of a parameter study.**

Keywords – **Aperture coupled microstrip antenna, Circularly polarized microstrip antenna, Microstrip antenna with an impedance transformer.**

I. INTRODUCTION

The use of a resonant slot in the aperture coupled microstrip antenna widens more than two times its bandwidth [1]. The basic disadvantage of this technique is an increase of the antenna back radiation, especially in case of a circular polarization. In [2] a screen for reduction of the back radiation of a circularly polarized aperture coupled microstrip antenna (ACMSA) with a resonant slot is used. An impedance transformer for impedance matching of the antenna construction is employed in the presented study.

II. ANTENNA DESIGN

The ACMSA investigated in this paper is designed to operate within the Ku-band. In order to decrease the back radiation of the antenna, influenced by the electromagnetic coupling and the requirement for circular polarization, a layered structure with a screen and impedance transformer is proposed. Fig. 1 shows the geometry of the antenna.

The radiating microstrip patch element is etched on the top of the patch substrate. Similarly, the microstrip feed line is etched on the bottom of the feed substrate. The ground plane with its coupling aperture separates the feeding and the radiating parts of the antenna. Thus, two groups of parameters determine the antenna performance. Proper selection of the substrates is required as well. The substrates used are: 1) Patch substrate, Taconic TLX-7: ε_{rp}=2.60, tanδ_p=0.0019, *hp*=1.575 mm; 2) Feed substrate, Taconic RF-60A: ε_{rf}=6.15, tanδ_f=0.0028, *hf* =0.635 mm; 3) Screen substrate, Arlon AD 600: ε_{rs}=6.15, tanδ_s=0.003, *hs* =1.905 mm;

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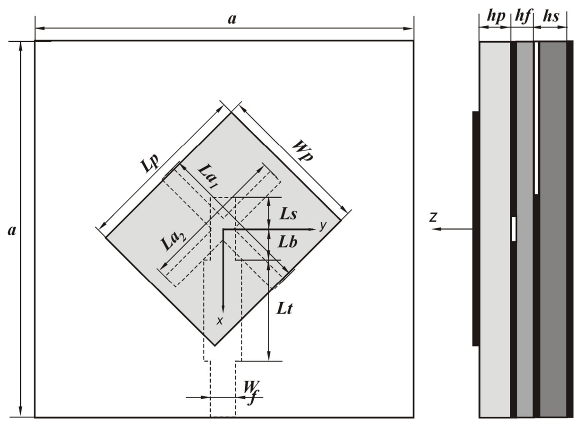


Fig. 1. Geometry of a circularly polarized ACMSA with a screen and impedance transformer

The main dimensions of the antenna are listed in Table I.

TABLE I
ANTENNA DIMENSIONS

Dimension [mm]		Description
a	*53*	Antenna Length/Width
Lp	*5.6*	Patch Length
Kp	*1.16*	Patch Ratio *Lp*/*Wp*
Ls	*1.0*	Stub Length
Wp	*Lp/Kp*	Patch Width
La	*4.8*	Initial Aperture Length
Ks	*1.06*	Slot Ratio La_1/La_2
La_1	*2LaKs/(Ks+1)*	Aperture 1 Length
Wa_1	$La_1/10$	Aperture 1 Width
La_2	*2La/(Ks+1)*	Aperture 2 Length
Wa_2	$La_2/10$	Aperture 2 Width
Wf	*0.77*	Feed line Width
tf	*0.0175*	Feed line thickness
hf	*0.635*	Feed substrate thickness
hp	*1.575*	Patch substrate thickness
hs	*1.905*	Screen substrate thickness
Lb	*1.0*	Distance from the centre
Lt	*6.0*	Transformer Length
Wt	*1.3*	Transformer Width
tg	*0.0175*	Ground plane thickness
tp	*0.035*	Patch/Screen thickness

III. Effect of the Antenna Dimensions on the Electrical Characteristics of the Antenna

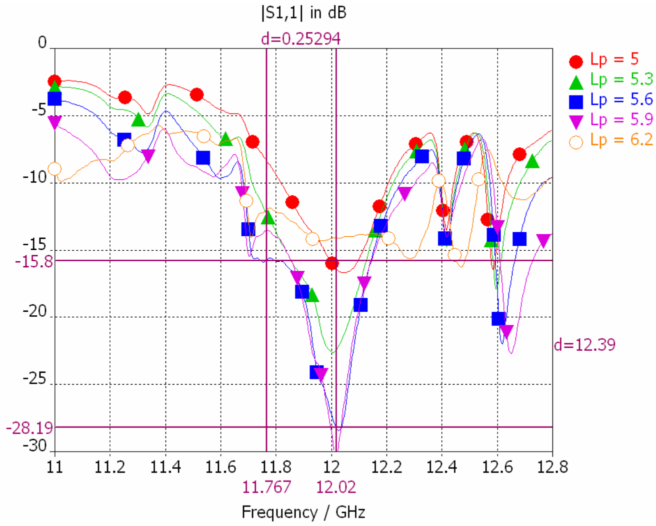
The aperture coupled microstrip antenna can be optimized in terms of different structural parameters while in the meantime keeping the simplicity of the structure. The main parameters responsible for the performance of the analyzed antenna – patch length *Lp*, patch ratio *Kp*, slot ratio *Ks* and stub length *Ls* have been ascertained after a few iterations with an antenna model using the commercial software CST Microwave Studio 5 [3].

The numerical analysis herein confirms that a reasonable compromise has to be done with the frequency dependent electrical characteristics of the antenna. In most cases the required impedance matching, broadband CP operation and low back radiation are likely confronting. In addition, the presence of a screen does not guarantee low back radiation all over the frequency range.

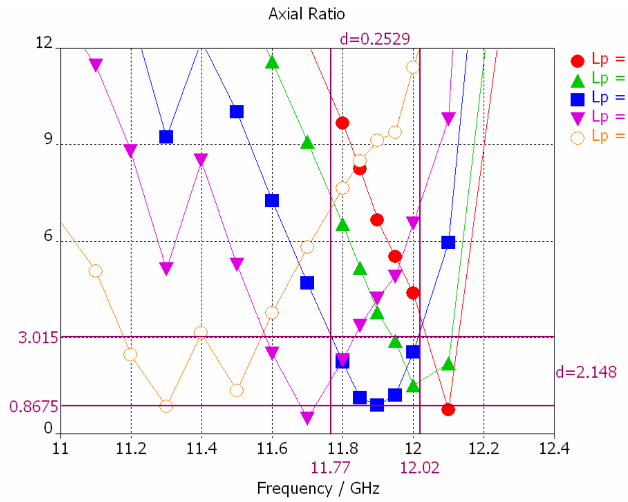
Fig. 2 illustrates the impact of the patch length *Lp*=5.0 – 6.2 mm on the three significant antenna characteristics – Return loss, Axial ratio and Back radiation. Choosing a proper value of this dimension requires fitting of two bandwidths. Usually, when referring aperture coupled microstrip antennas and their return loss characteristic multiple resonances are expected to appear in the operation bandwidth. It is assumed that one resonance is due to the patch and the other resonances result from the slot and its coupling to the patch. Note that the higher value of *Lp* widens the impedance and axial ratio bandwidths, but there is also an undesired offset between them. Consequently, an *AR* bandwidth of 3.4 % with central frequency 11.375 GHz exceeding the range of impedance matching (-5.7 dB at 11.375 GHz) is observed when *Lp*=6.2 mm. Respectively, the impedance bandwidth is 6.9 % with central frequency 12.1 GHz. The mentioned bandwidths actually would represent a significant improvement compared to the usual values *bw*=5 % and bw_{AR}<1.5 % for a standard single feed CP patch antenna, if they were conformable. The role of the available quarter-wave impedance transformer this time is insignificant since it improves impedance matching only within a certain frequency range.

In order to fit the two bandwidths a value of *Lp*=5.6 mm is appropriate. Moreover, minimal back radiation of about -18.4 dB is achieved at the central frequency 11.9 GHz. Fig. 2 (c) shows that a change of patch length *Lp* with 0.3 mm varies the back radiation of the antenna with approximately 2 dB in the operation bandwidth. The latter, however, is restricted in the range Δf_{AR}= 11.77 – 12.02 GHz (2.1 % bandwidth) due to circular polarization.

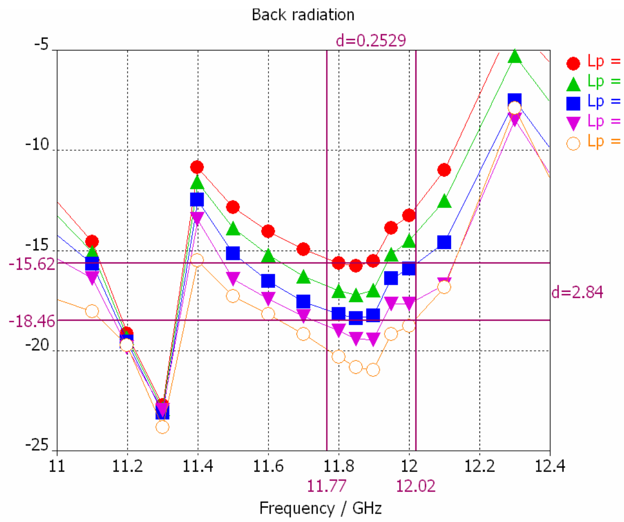
The antenna characteristics for different values of the patch ratio *Kp*=1.12 – 1.2 are displayed in Fig. 3. This parameter additionally contributes to the fitting of impedance and *AR* bandwidths. Input matching and back radiation influence *Kp* at higher frequencies. Nevertheless, the back radiation is below -14 dB within the band of circular polarization. Looking at the *AR* diagram, as patch ratio varies with step 0.02 the characteristic deforms. Optimal value of *Kp* is achieved when the *AR* characteristic is symmetrical. Thus, the effect of any technological tolerances, quite possible when the antenna is fabricated, is minimized.



a) Return loss S_{11} [dB].

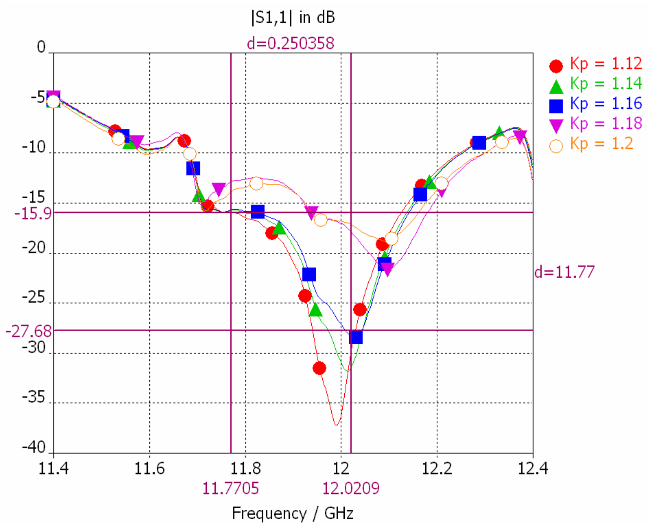


b) Axial ratio [dB].

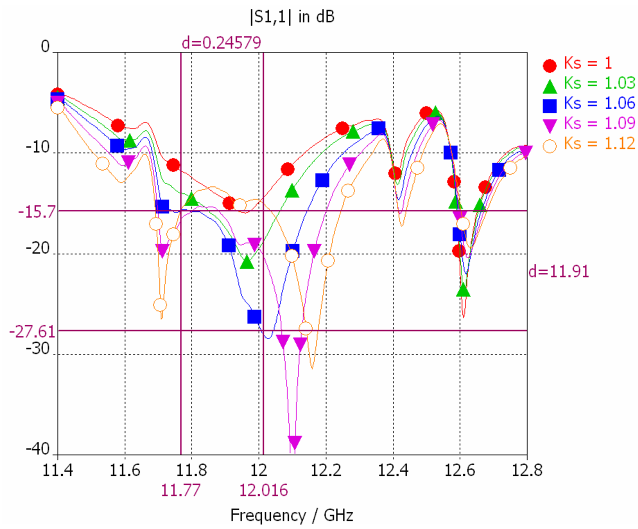


c) Back radiation [dB].

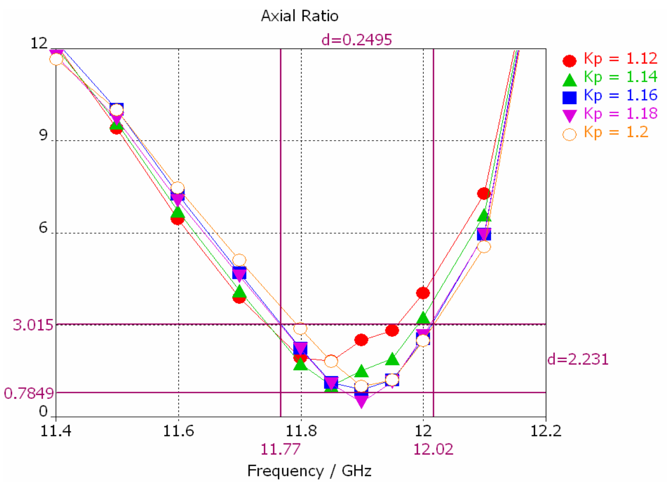
Fig. 2. Effect of patch length *Lp*=5.0 – 6.2 mm on the electrical characteristics of the antenna with a screen and impedance transformer: a) Return loss *S*11; b) Axial ratio (*AR*); c) Back radiation.



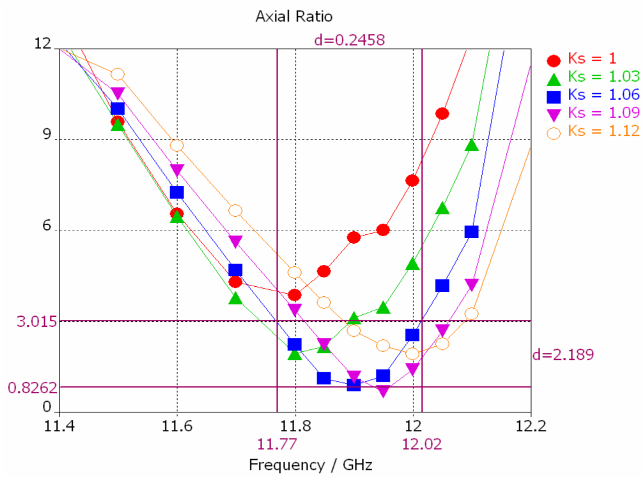
a) Return loss S_{11} [dB].



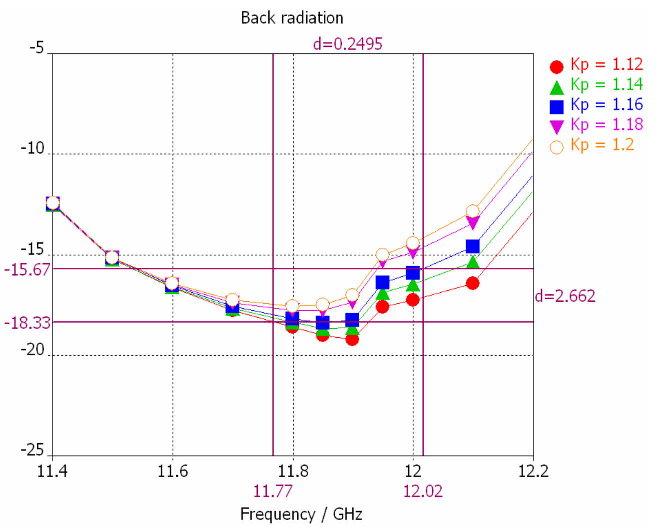
a) Return loss S_{11} [dB].



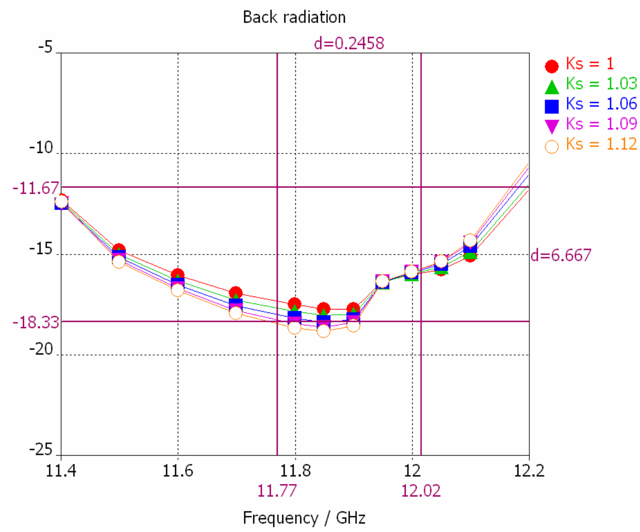
b) Axial ratio [dB].



b) Axial ratio [dB].



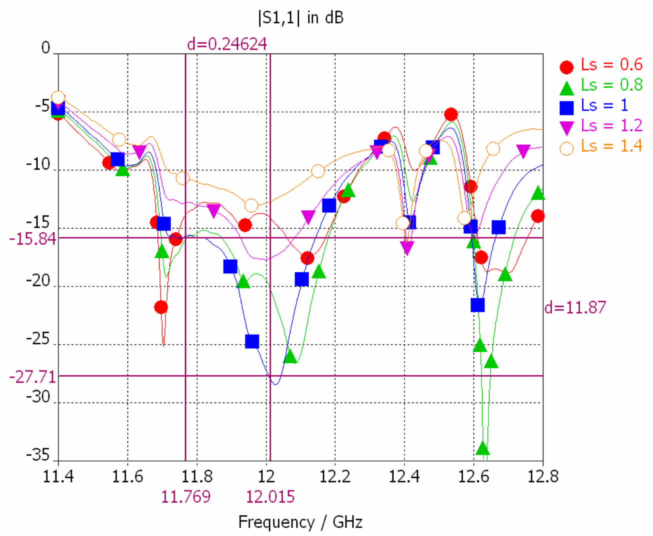
c) Back radiation [dB].



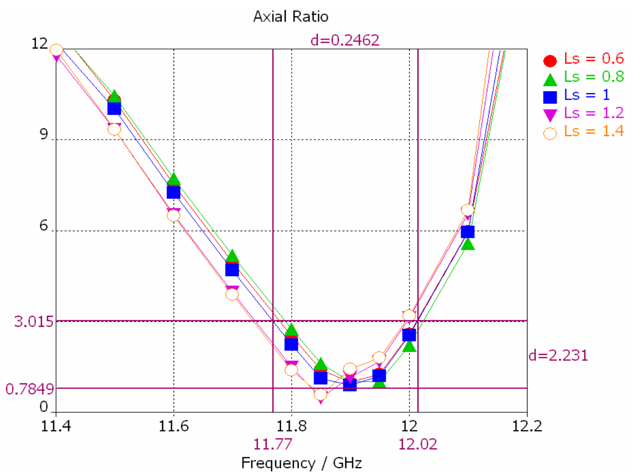
c) Back radiation [dB].

Fig. 3. Effect of Patch ratio Kp=1.12 – 1.2 on the electrical characteristics of the antenna with a screen and impedance transformer: a) Return loss $S11$; b) Axial ratio (AR); c) Back radiation.

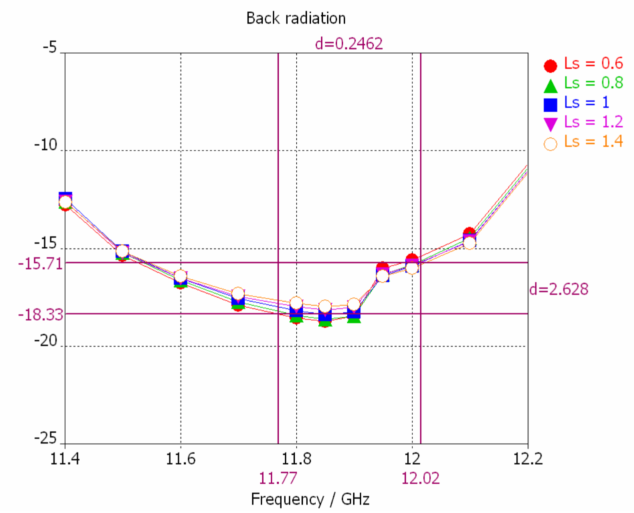
Fig. 4. Effect of slot ratio Ks=1.0 – 1.12 on the electrical characteristics of the antenna with a screen and impedance transformer: a) Return loss $S11$; b) Axial ratio (AR); c) Back radiation.



a) Return loss S_{11} [dB].



b) Axial ratio [dB].



c) Back radiation [dB].

Fig. 5. Effect of stub length *Ls*=0.6 – 1.4 mm on the electrical characteristics of the antenna with a screen and impedance transformer: a) Return loss S11; b) Axial ratio (*AR*); c) Back radiation.

Similarly to pareameter *Kp*, the slot ratio *Ks* has primarily effect on the return loss and *AR* characteristics. Fig. 4 shows the three antenna characteristics for different values of the slot ratio *Ks*=1.0 – 1.12 mm. The shape of the coupling aperture significantly affects the resonant behavior of the antenna. The increase of the slot ratio consequently results in multiple resonances in the return loss characteristic. Referring Fig.5 (c), it is seen that the back radiation of the antenna is much less influenced by *Ks* deviation. Comparing Figs. 3 (b) and 4 (b) it is pertinent to note the different values of *Kp* and *Ks* causing an inherent asymmetry of the structure and slightly increased cross-polarization levels. Both ratios, however, affect the curve of *AR* in a similar way. As the frequency moves away from the operating frequency 11.9 GHz, the axial ratio rapidly degrades while the input match usually remains acceptable.

Finally, the effect of the stub length *Ls*=0.6 – 1.4 mm has been investigated. The results obtained are shown in Fig. 5. This dimension is used to control the input match of the analyzed microstrip antenna. Consequently, *Ls* is defined, so that to ensure acceptable matching within the CP bandwidth. Referring Fig. 5 (a), only one resonance is marked for values of $Ls \geq 1.0$ mm. The other results hereby show that the effect of *Ls* on the CP bandwidth and back radiation is quite moderate. Since the intersection between the microstrip feeding line and the coupling aperture remains almost the same, the change of *Ls* is not expected to cause significant degradation of axial ratio.

IV. Conclusion

A study of the effect of the antenna dimensions on the electrical characteristics of a circularly polarized aperture coupled microstrip antenna with a screen and impedance transformer has been accomplished. The results obtained by the numerical analysis can be used for design of circularly polarized broadband microstrip antennas.

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