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A NOVEL CROSS-SLOT GEOMETRY TO IMPROVE IMPEDANCE BANDWIDTH OF MICROSTRIP ANTENNAS

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Abstract—Circular polarization (CP) designs of circular and rectangular microstrip patch antennas are demonstrated. Proximity coupled feed and aperture coupled feed methods are used. The proposed CP designs are achieved by implementing a suitable cross-slot either on the patch (in the case of proximity coupled feed method) or on the ground plane (in the case of aperture coupled feed method), which results in excitation of two near degenerate orthogonal modes of near equal amplitudes and 90° phase difference. Attempts are made to change the geometry of slots' ends to introduce a novel structure in order to achieve a better matching performance.

1. INTRODUCTION

Circularly polarized antennas with low profile, small size, light weight, and high impedance bandwidth and axial ratio bandwidth are on high demand for example in mobile satellite communications. Many types of microstrip antennas have been proposed and investigated such as [1, 7–17].

Two types of feeding techniques (single-feed type and dual-feed type) are commonly used to generate circularly polarized waves. The single-feed technique has the advantage of not requiring an external polarizer such as a 90° hybrid coupler. This technique can be found in literature such as [2] and [3].

Cross-slot of equal slot lengths can be used to generate circular polarization as stated in [4]. However, as noted in literature, for the microstrip-antenna case, this structure requires the designs of nearly square or nearly circular patches or square patches with truncated corners *et cetera* to achieve the excitation of two near-degenerate orthogonal modes for CP operation. Since the resulting CP operation is very sensitive to the small variations in the dimensions of these modified patches, there usually exist strict manufacturing tolerance errors for the implementation of these CP designs.

An imperfection of microstrip antennas is their narrow bandwidth, therefore many attempts have been made to increase their bandwidth.

This work modifies the cross-slots which have used in [2] and [3]. This modification improves the impedance bandwidth of the structure proposed in [3], but it does not have any effect on the proposed structure in [2]. Here we have used four structures. Two of them are proximity coupled fed patches with cross-slots on the patches, and the two others are patches with a cross-slots on their grounds' planes that fed through the cross-slot. It is shown that in two of these cases (proximity coupled fed patches with cross-slots on them) there are no changes in impedance performances unlike the other two cases (patches that fed through the cross-slots) that better impedance performance is achieved.

2. GENERAL ANTENNAS' CONFIGURATIONS

As stated in introduction we have used four structures. Fig. 1 shows one of them. It is a square patch with a cross-slot on its ground plane that is fed through the cross-slot. A similar structure for circular patch which uses this type of feeding is also included in this paper. The square patch has a side length of L (in case of circular patch the diameter would be R) and is printed on a substrate of thickness h_u and relative permittivity of ε_{ru}. The microstrip feed line of W_f is printed on a substrate of thickness h_d and relative permittivity of ε_{rd}. The coupling cross of unequal lengths, L_{sa} and L_{sb} is centered below the square (circular) microstrip patch on the ground plane. The cross-slot assumed to be narrow; that is, $W_s \ll L_{sa}$, L_{sb}. Both the two arms of the cross-slot are inclined with respect to the microstrip feed line with an angle of 45°. Obviously the resonant frequency of the microstrip patch depends on the coupling slot's length [5] and [6]. While choosing a proper length ratio between two arms of the cross slot, it is expected that by carefully adjusting their lengths, the fundamental resonant frequency of the square (circular) microstrip patch can be split into two near-degenerate resonant modes with near-equal amplitudes and 90° phase difference. With such an arrangement of the cross slot, the resonant frequency of the resonant mode in the direction perpendicular to the longer slot will be slightly lower than that of the resonant mode in the direction perpendicular to the shorter slot. Another scheme used here is shown in Fig. 2. It depicts a proximity coupled fed circular

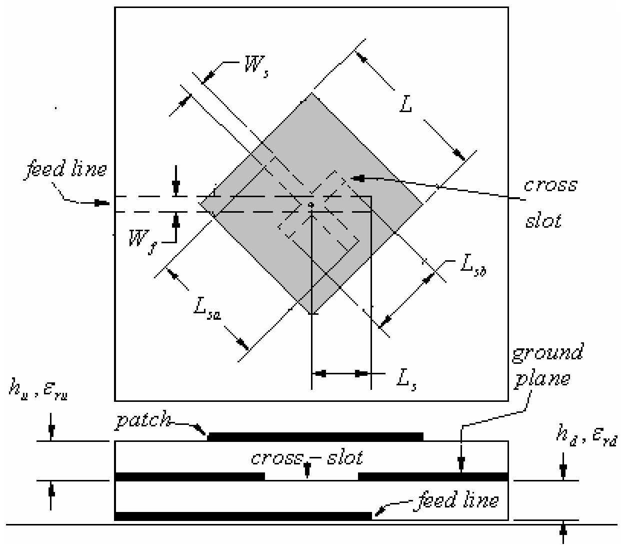

Figure 1. Geometry of a cross-slot-coupled circularly polarized square microstrip antenna.

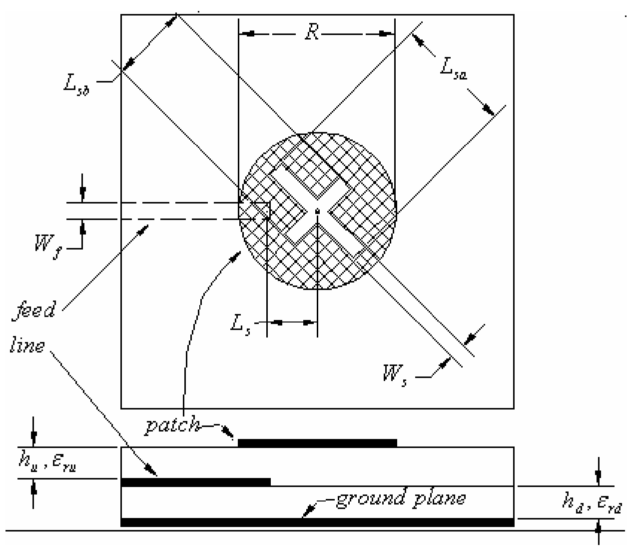

Figure 2. Geometry of a circularly polarized proximity coupled fed microstrip antenna.

patch with a cross-slot on the patch. A similar structure for rectangular patch which uses proximity coupled feed is also analyzed in this text. The dimensions nominations are like the previous case. Note the feed line. It somewhat crosses the center of the patch in the aperture feed method, but do not reach to the center of the patch in case of proximity coupled feed method.

Two of these four structures have been considered in [2] and [3]. Here we have analyzed two more structures for both square and circular patches. The next step is to optimize the slots' shapes to achieve a better matching performance as much as possible. We examined three kinds of geometries in slots' ends; triangular, square, and circular. One of these structures is shown in Fig. 3 to clarify the statement. The other reformations (such as rectangular and triangular) are completely like this case except that we locate these geometries instead of circles at the cross-slots' ends.

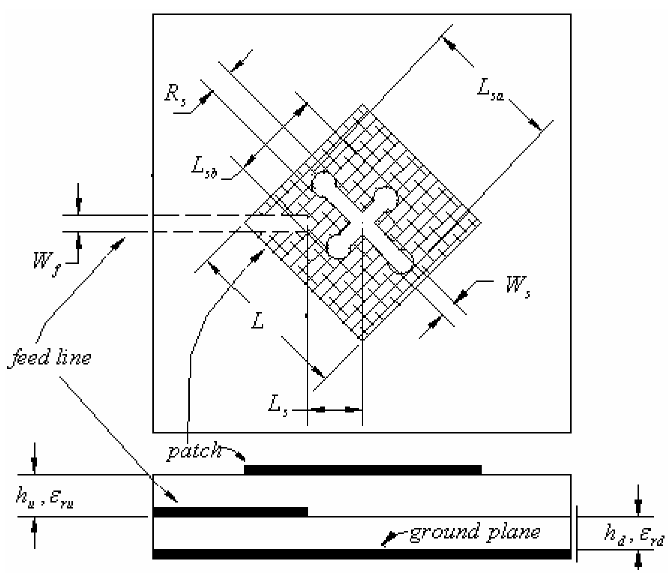

Figure 3. Geometry of cross-slots' ends reformation of one of three structures (circles at the cross-slots' ends).

As can be seen from Fig. 3, a reformation is made on slots' ends. The results are shown in the next section. This reformation is made for all of proposed structures.

3. SIMULATION RESULTS

Four schemes are designed. They are simulated using the High Frequency Structure simulator (HFSS). Operation frequency and the dielectric permittivities and heights are supposed to be constant parameters. We have designed all of the schemes to operate at near 10 GHz. The upper substrate has a 31 mils height and the lower has a 25 mils height. Their permittivities are chosen so that the antenna can propagate effectively, so the upper substrate is chosen to have a permittivity of 2.94 (Rogers RT/Duroid 6002), while the lower substrate is chosen to have a high permittivity, i.e., 10.2 (Rogers RO3010), to preserve most of the feed line fields within itself and don't perturb the radiation pattern of the patch. However, we know that because of the ground between the patch and the feed line, the first two schemes are not perturbed by the feed pattern. On the other hand, in the second two cases the feed line pattern perturbation is unavoidable and so the substrates are chosen to minimize this effect. The second reason to choose a high permittivity substrate for the feed line is to minimize the feedline width as much as possible to be prepared for designs and would not be as wide as the patch dimensions.

3.1. A Circular Patch with a Cross-Slot on Its Ground Plane That Fed through the Cross-Slot

Three kinds of geometries are used in slots' ends. Results are shown in Fig. 4. As can be seen, only the circular perturbation (–○–) has improved impedance matching performance without any effect on axial ratio. In the case of rectangular perturbation on slots' ends, there is degradation on the return loss curve. The axial ratio has also a poorer performance than the primary scheme (structure without any change on the slots' ends). When triangles used on slots' ends, there is an impedance bandwidth reduction in addition to a poorer axial ratio performance than the primary scheme. Finally, using a circular perturbation has improved the impedance matching performance, while it has no tangible effect on the axial ratio. So, from now on, we only consider the circular perturbation on slots' ends for the other schemes. From Fig. 4, a better impedance matching is obtained than the primary scheme. Also the 6.49% impedance bandwidth (VSWR $< 2:1$) of the primary scheme has improved with respect to [3], which is reported to be 5.86%. Refer to Fig. 1 for the dimensions. Note that we used R (patch diameter) instead of L (patch length) here. R_s is the circle diameter used on slots' ends in all reformed cases. We should mention that in the case of rectangular perturbation, R_s is the rectangle length and in the case of

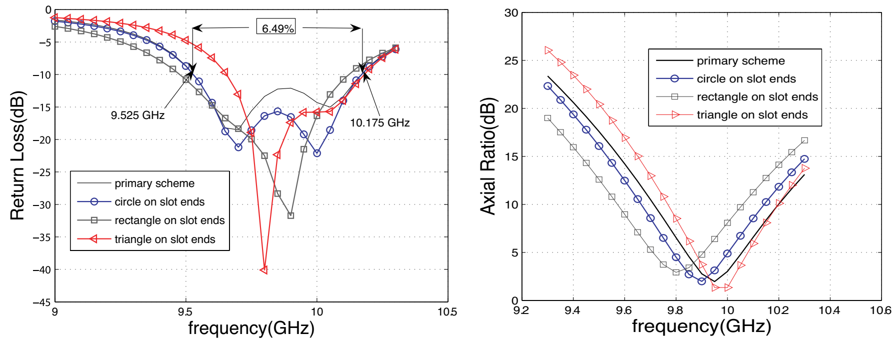

Figure 4. Plots for the first scheme. (a) Return loss and (b) axial ratio: $W_f = 0.6\,\text{mm}$, $W_s = 0.4\,\text{mm}$, $L_s = 1.8\,\text{mm}$, $L_{sa} = 4.2\,\text{mm}$, $L_{sb} = 3.3\,\text{mm}$, $R = 9\,\text{mm}$, $R_s = 0.6\,\text{mm}$.

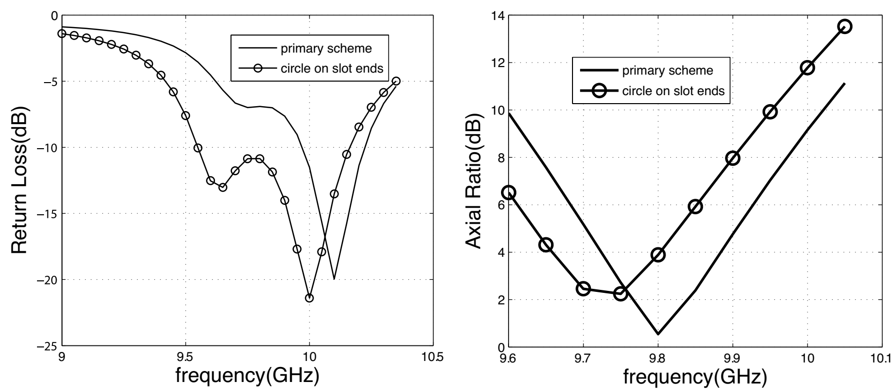

Figure 5. Plots for the second scheme. (a) Return loss and (b) axial ratio: $W_f = 0.6\,\text{mm}$, $W_s = 0.4\,\text{mm}$, $L_s = 2.1\,\text{mm}$, $L_{sa} = 3.8\,\text{mm}$, $L_{sb} = 3.1\,\text{mm}$, $L = 7.6\,\text{mm}$, $R_s = 0.6\,\text{mm}$.

triangular perturbation, R_s is the base of the equilateral triangle. It is noticeable that in the best case, we have approximately a 1% axial ratio bandwidth (AR $< 3\,\text{dB}$).

3.2. A Square Patch with a Cross-Slot on Its Ground Plane That Fed through the Cross-Slot

Results are shown in Fig. 5. The 3% impedance bandwidth (VSWR $< 2:1$) of the primary structure is improved to an approximately 5.5%. The axial ratio bandwidth (AR $< 3\,\text{dB}$) did not change severely (approximately 1.1%).

3.3. A Proximity Coupled Fed Circular Patch with a Cross-Slot on the Patch

Results are shown in Fig. 6. The impedance bandwidth in this case is 3.6% which is in order of what was reported in [2]. The axial ratio bandwidth is 1.98% which has an improvement of 1.33% with respect to [2]. But as can be seen, there are no considerable differences between the primary structure and the reformed structure answers in this case. It can be explained as follow. In the first two cases we changed the feeding structures by changing the cross-slots' ends as a part of the feeding path. So, this change led to improve matching performance. But in this case and also the next case, there are no reformations made on the feeding path, so the matching performance remains unchangeable.

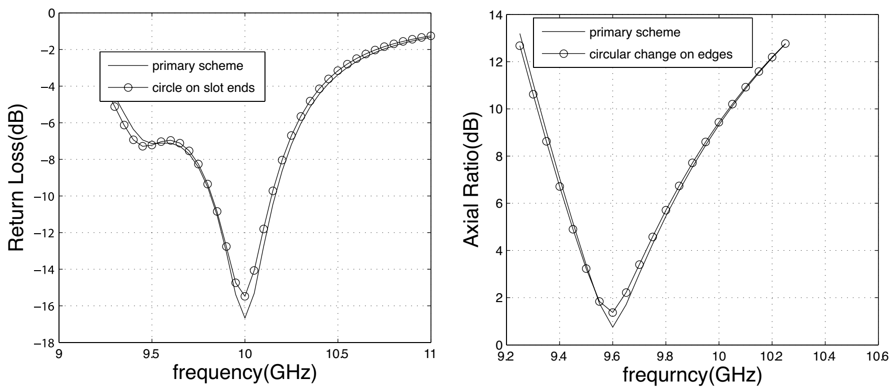

Figure 6. Plots for the third scheme. (a) Return loss and (b) axial ratio: $W_f = 0.6\,\text{mm}$, $W_s = 0.4\,\text{mm}$, $L_s = 0.4\,\text{mm}$, $L_{sa} = 4.3\,\text{mm}$, $L_{sb} = 2.5\,\text{mm}$, $R = 7.6\,\text{mm}$, $R_s = 0.6\,\text{mm}$.

3.4. A Proximity Coupled Fed Square Patch with a Cross-Slot on the Patch

Results are shown in Fig. 7. The impedance bandwidth (VSWR $< 2:1$) in this case is 5.1% which has an increase of 1.7% with respect to [2]. The axial ratio bandwidth (Axial Ratio $<$ 3-dB) is 2.16% which has an improvement of 1.51% with respect to [2]. But there are no considerable differences between the primary structure and the reformed structure answers in this case, like the previous case, as expected. The reason was explained in Section 3.3. There is another point that is good to be mentioned here. Generally, when the slots were used on the patches (Sections 3.3, 3.4), better axial ratio bandwidth

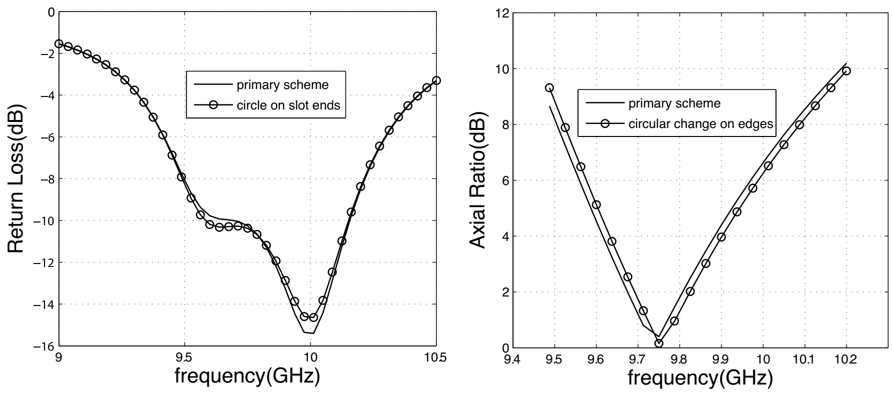

Figure 7. Plots for the forth scheme. (a) Return loss and (b) axial ratio: $W_f = 0.6\,\mathrm{mm}$, $W_s = 0.4\,\mathrm{mm}$, $L_s = 1.7\,\mathrm{mm}$, $L_{sa} = 4.8\,\mathrm{mm}$, $L_{sb} = 4\,\mathrm{mm}$, $L = 6.1\,\mathrm{mm}$, $R_s = 0.6\,\mathrm{mm}$.

were achieved, about 2%, than when the slots were used on the ground plane (Sections 3.1, 3.2), where only a 1% axial ratio were achieved. This is because of the natural characteristic of the geometries used there. When we uses the slots on the patches, circular production of waves is easier than when we uses them on the ground plane, and so, the wider axial ratio bandwidth is achieved.

4. CONCLUSIONS

This article describes the results for four different circularly polarized microstrip antenna structures with introducing a novel geometry on the cross-slots. When the cross-slots were used on the patch antennas (Sections 3.3, 3.4), better axial ratio performances were achieved than when they were used on the ground plane (Sections 3.1, 3.2). However better impedance performances are achieved when cross-slots were used on the ground plane. As we examined, when reformations were made on the cross-slots of the ground plane, the matching performance is improved, especially in the rectangular patch case, unlike the case of cross-slots on the patches. The use of circle on the cross-slots' ends is the best case among the other geometries. It is because that the circle makes the fields on the slots more uniform than the other cases. Generally, all of the above structures had better performances than what reported in literature [2] and [3], either in the impedance bandwidth or in the axial ratio bandwidth. Although is not discussed here, the introduced structures had a slightly more symmetric radiation patterns than the primary structures.

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