A Novel Approach for Miniaturization of Circularly Polarized Patch Antennas

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Abstract— **A novel approach for highly miniaturizing a patch antenna with circular polarization is presented in this paper. It is shown that the antenna is fabricated by using an anisotropic conductor supporting the proper electric current paths and extreme miniaturization can be accomplished by manipulating its geometry. Anisotropic conductivity is achieved by removing strips of metal from the ordinary patch parallel to direction of desired electric current but keeping two metallic strips at each end connecting all parallel strips. Next, the straight metallic traces are replaced by meandered metallic traces for size reduction. This in effect increases the inductance per unit length of the thin strips. This antenna can only produce linear polarization. To achieve circular polarization a second mode is excited by elongating end strips in a proper fashion and feeding the structure accordingly. It turns out that this miniaturization method enables the ease to control two resonant frequencies corresponding to two orthogonal polarizations, and the size reduction of about 72% as compared to the conventional corner-truncated square microstrip antenna fabricated on the same substrate.**

Keywords- antenna miniaturization; circularly polarized antennas; meandered traces

I. INTRODUCTION

A circularly polarized antenna has the ability to combine two orthogonal linearly polarized components of the radiated fields of equal amplitude and 90^0 phase difference. Although a circularly polarized antenna with a low profile, small size, and light weight is highly desirable in many applications such as compact satellite or mobile platforms with unknown orientations [1], most miniaturization techniques are developed for linearly polarized antennas. This is mainly due to the fact that antennas with extremely small lateral dimensions are incapable of generating the required phase shift internally.

Several compact circularly polarized antennas have been proposed and investigated [2][3][4]. The current efforts have only relied on intuitive techniques such as inserting several slots or slits in suitable positions. In such antenna designs, the splitting of two near-degenerate orthogonal modes of equal amplitudes and 90° phase difference is achieved by slightly adjusting the embedded slots such as a cross-slot in a patch or slits at the boundary of the patch. Theses inserted slots and slits can result in meandering of the excited fundamental-mode patch surface current, which lowers resonant frequencies. However, these approaches have yielded somewhat limited miniaturization due to lack of ability in simultaneously controlling the surface current paths as well as creating the 90^0 phase difference. It should be mentioned that size reductions of about 50% are reported using these intuitive approaches.

Circularly polarized patch antennas are often classified by feed type; single-fed type or dual-fed type, depending on the number of feed points necessary to generate the circularly polarized waves. The single-fed type has the advantage of not requiring an external power divider and phase shifter such as a 90° hybrid coupler. Although there are various single feed methods such as direct feed, aperture-coupled feed and proximity-coupled feed [5], the direct single feed is most desirable for its simplicity, light weight and low cost, and thus this will be the type of antenna feed we will investigate in this paper.

In this paper, a new approach to design miniaturized circularly polarized (CP) patch antennas with a single feed is presented. This is achieved by designing two meandered structures; one contributes to x-polarization and the other y-polarization. In the proposed topology, noticing exact surface current paths along meandered traces provides the ease in tuning the resonant frequencies. Details of each design step are discussed. The size reduction of 72% is achieved as compared to the conventional corner-truncated square microstrip antenna.

II. MIATURIZATION OF LINEARLY POLARIZED PATCH ANTENNAS USING MEANDERED METALLIC TRACES

In this section, a new approach to minimize an ordinary $\lambda_g/2$ microstrip antenna with linear polarization is described (where λ_g is a guided wavelength). Proposed design approach starts from miniaturization of a linearly polarized microstrip antenna using an anisotropic conductor formed by removing narrow parallel strips from the conductor. Then a method to obtain dual polarizations is presented in next section.

A. Wire-mesh Microstrip Patch Antenna

In order to examine the concept of operation for a patch antenna using an anisotropic conductor, an ordinary $\lambda_g/2$ microstrip antenna with linear polarization (=x-pol.) is considered as shown in Fig. 1. In a progressive modification the metal is replaced with a mesh which is thinned out. Fundamentally, the radiation pattern of this wired topology is same as that of a $\lambda_g/2$ microstrip antenna, while the resonant frequency of the wire mesh antenna with the same lateral

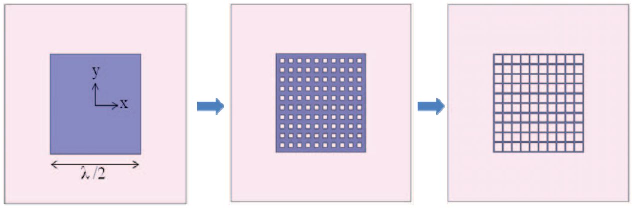
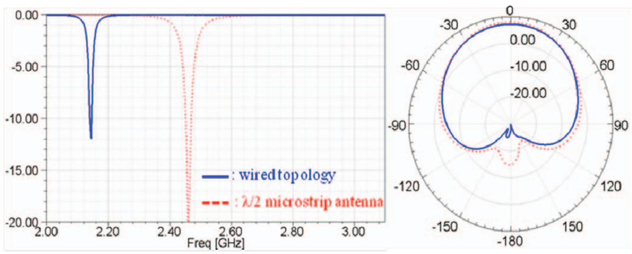


Figure 1. Conversion of a $\lambda_g/2$ microstrip antenna to an array of thin wires



(a) (b)

Figure 2. Simulated (a) S_{11} and (b) radiation pattern on XZ plane of a wired topology and $\lambda_g/2$ microstrip antenna

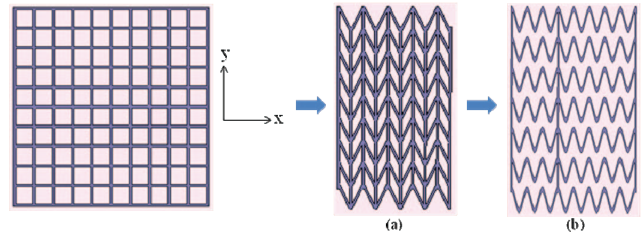
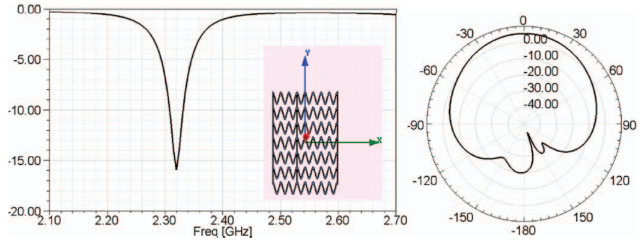


Figure 3. (a) Shrunk wires and (b) sinusoidal wires with the elimination of wires in parallel with y-axis



(a) (b)

Figure 4. Simulated (a) S_{11} and (b) radiation pattern on XZ plane of the wired antenna depicted in Fig. 3(b)

dimension is lower than that of the λg/2 microstrip antenna because thin wires have higher inductance per unit length. In this step featuring a simple idea, topologies are simulated based on perfect electric conductor (PEC), ignoring the conductor ohmic loss. In the next steps, the antenna topology is modified and simplified to lower ohmic loss, leading to the improvement of radiation efficiency. Ansoft HFSS 12.1 is used for simulations. Fig. 2 shows the simulated return loss (S_{11}) and radiation pattern corresponding to θ-polarization (=co-pol.) on XZ plane of the wire mesh topology, compared to an original $\lambda_g/2$ microstrip antenna. The gains of both antennas are about 7 dBi. The lateral dimension of $\lambda_g/2$ microstrip antenna is 40 mm and the thickness and dielectric constant of substrate are 3.175 mm and 2.2. The size of the ground plane is enough large as 80mm X 80mm. The wired mesh antenna is also designed to have the same physical dimension as the $\lambda_g/2$ microstrip antenna.

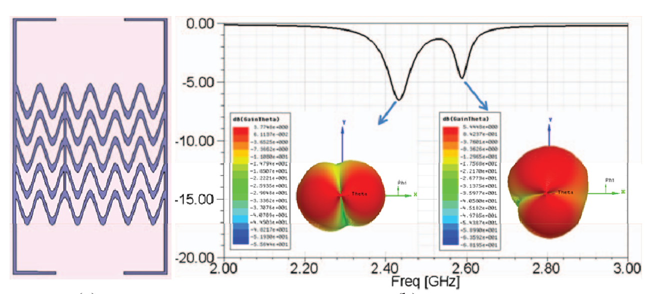
B. Substituting Straight Metallic Traces with Meandered Metallic traces

Straight wires in Fig. 1 can be meandered, leading to the miniaturization of linear dimension along x-axis, as shown in Fig. 3(a). In order to reduce ohmic loss, junctions among wires are made to be smoother, which renders a sinusoidal shape shown in Fig. 3(b). In addition, all metallic traces in parallel with y-axis are eliminated, creating an anisotropic conductor, except for two wires at both ends and a wire connected with a feeding pin. The end conductor strips are needed to establish the well-known magnetic currents responsible for the patch antenna radiation. The final topology shown in Fig. 3(b) still works as a linearly x-polarized antenna.

To consider ohmic loss from metallic traces, copper with finite conductivity is used . Fig. 4 shows simulated S_{11} and radiation pattern corresponding to co-polarization on XZ-plane of the antenna depicted in Fig. 3(b). The gain of this antenna is 5.5 dBi. The linear dimensions in x and y directions of the area covered by antenna pattern are 40mm (=$0.46\lambda_g$) and 25.4mm (=$0.29\lambda_g$), respectively. It suggests the size reduction of 40%, compared to a $\lambda_g/2$ microstrip antenna.

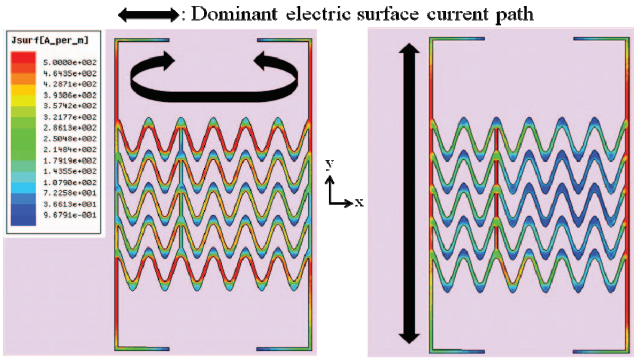
III. Excitation of Two Near-Degerate Orthogonal Modes

In Section II, a linearly x-polarized antenna based on meandered metallic traces was presented. This minimized topology was simplified and optimized to exhibit pure x-polarized radiation. In this section it is shown that modifying this geometry enables the excitation of y-polarized surface current as well, which results in a miniaturized CP antenna.



(a) (b)

Figure 5. (a) Topology of a dual polarized antenna and (b) simulated S_{11} and 3D radiation patterns at two resonant frequencies



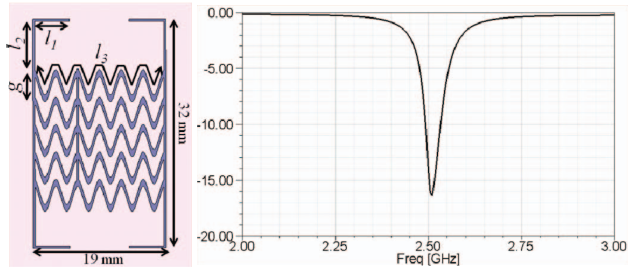
(a) (b)

Figure 6. Electric surface current distributions at the resonant frequencies where the antenna radiates (a) x- and (b) y-polarized fields

Examining the topology shown in Fig. 3(b), it is obvious that y-directed surface current can only be excited on the three y-directed wires. If a resonance can be created, then y-polarized radiation can also be generated. It is found that the two wires at both ends can act like two y-directed $\lambda_g/2$ dipole antennas. Suitably extending and bending the length of two wires at both ends, a resonant frequency related to y-polarized radiation can be lowered near the previous resonant frequency generated from the x-directed meandered wires, as shown in Fig. 5. Fig 5(b) shows 3D radiation patterns at two resonant frequencies. At the first resonant frequency where x-polarized radiation is dominant, a radiation null exists on y-axis, and at the second resonant frequency, the radiation null exists on x-axis. Fig. 6 shows surface current distribution at two resonant frequencies of the topology shown in Fig. 5. As expected, while the surface current on x-directed meandered wires is dominant at the resonant frequency related to x-polarized radiation, the surface current on y-directed two wires at both ends is dominant at the other resonant frequency related to y-polarized radiation.

IV. Design of CP Patch Antennas and Additional Size Reduction

In order to design CP antennas requiring two orthogonal modes of equal amplitudes and 90° phase difference, two resonant frequencies discussed in the previous section must be merged to single frequency, or be very close each other. This requirement makes the miniaturization of CP antennas very difficult because two resonant frequencies must be able to be controlled independently. Considering dominant electrical surface current paths shown in Fig. 6, design parameters can be extracted to independently tune the two resonant frequencies. Fig 7(a) shows the design parameters. While l_1 and l_2 affect both resonant frequencies, l_3 and g only affect the electrical length related to x-pol. and y-pol., respectively. Based on this approach, two split resonant frequencies are merged to a single frequency as shown in Fig. 7(b). The linear dimensions in x and y directions of the area covered by the antenna topology are 32mm and 19mm, respectively. This produces a size reduction of 59%, as compared to a corner-truncated circularly polarized (CP) square microstrip antenna on the same substrate.



(a) (b)

Figure 7. (a) Desing parameters in the proposed CP antenna and (b) simulated S_{11}

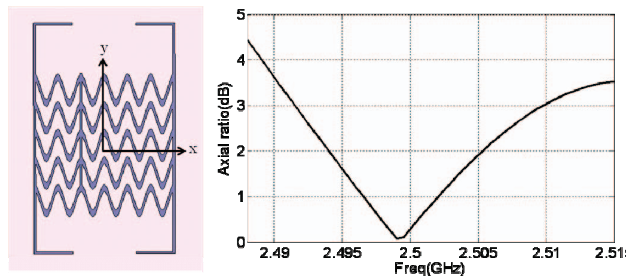
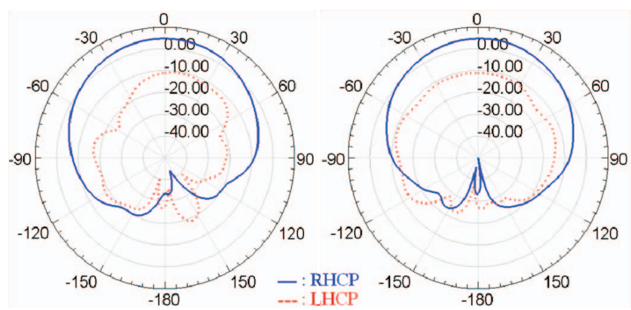


Figure 8. Simulated axial ratio in the broadside direction for the antenna shown in Fig. 7(a)

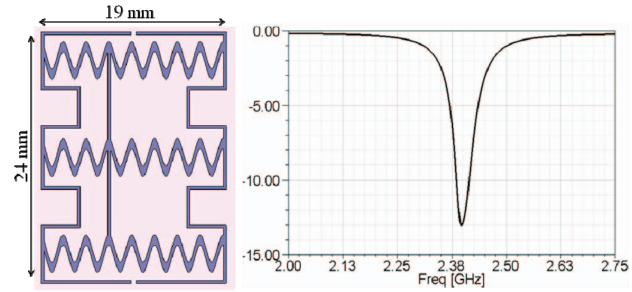


(a) (b)

Figure 9. Simulated radiation patterns in two orthogonal planes of (a)XZ and (b) YZ-planes for the antenna shown in Fig. 7(a).

In other words, the area of the proposed antenna is just 41% of that of a conventional CP square microstrip antenna.

Moving the positions of two resonant frequencies, both right-handed and left-handed CP can be obtained. When the resonant frequency of x-pol. is in front of that of y-pol., the antenna radiates with right-handed CP. Contrary to this, when the resonant frequency of y-pol. is in front of that of the x-pol., the antenna radiates with left-handed CP. Fig. 8 shows simulated axial ratio of the antenna shown in Fig. 7(a). 3dB axial bandwidth is about 0.9%. Good right-hand CP radiation is observed in Fig. 9. Gain (RHCP) in the broadside direction is 5 dBi which is 2 dB lower than the conventional corner-truncated square microstrip antenna due to size reduction. It is shown that additional size reduction can be achieved by modifying l_1, l_2, l_3



(a) (b)

Figure 10. (a) Topology and (b) simulated S_{11} of the proposed CP antenna exhibitibg 72% size reduction as compared to the conventional corner-truncated square microstrip antenna

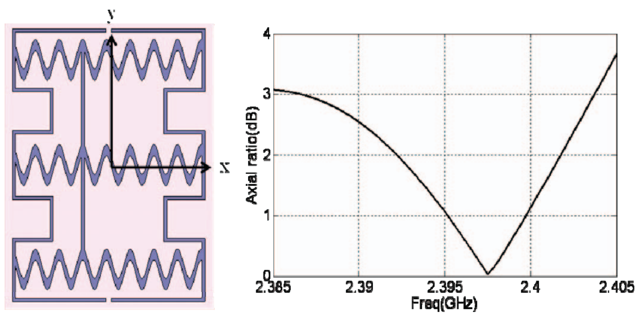


Figure 11. Simulated axial ratio in the broadside direction for the antenna shown in Fig. 10(a)

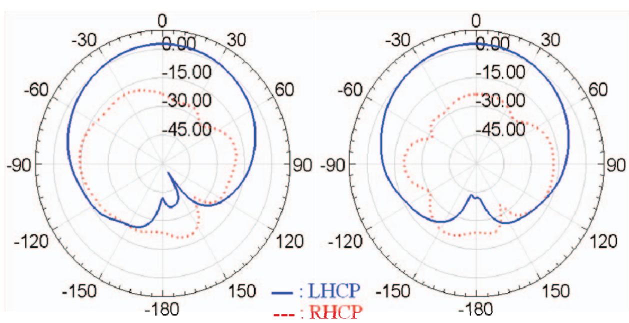


Figure 12. Simulated radiation patterns in two orthogonal planes of (a)XZ and (b) YZ-planes for the antenna shown in Fig. 10(a).

and g. The same principle described earlier is applied. Extending l1 and l2 leads to lowering both resonant frequencies. While L3 works only for the extension of the x-directed surface current path, g does for y-directed surface current path. Fig. 10 shows topology and simulated S_{11} of the proposed CP antenna exhibiting 72% size reduction as compared to the conventional corner-truncated square microstrip antenna. The antenna is designed to radiate with left-hand CP. Fig. 11 shows simulated axial ratio of the antenna in Fig. 10(a). 3dB axial bandwidth of 0.7 % is observed. Gain (LHCP) in the broadside direction is about 3 dBi as shown in Fig. 12.

V. Conclusion

A novel approach for miniaturization of circularly polarized patch antennas is presented. The approach is based on shrinking the resonant dimension by transforming the patch antenna into a wire-mesh and then squeezing it in an accordion fashion. The topology of the meandered wire mesh antenna is simplified maintaining the original linear polarization property. Through suitable modifications of the simplified meandered wire antenna, by tailoring the paths of the dominant surface currents, two degerate orthogonal modes are created. This enables the design of miniaturized CP antenna configuration. With this topology it is shown that size reduction as high as 72% can be achieved as compared to the conventional corner-truncated square microstrip antenna.

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