Single-Feed Circular Polarization Microstrip Antenna

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Abstract – This paper introduces a new method suitable for the design of the single-feed circular polarization (CP) microstrip patch antenna. Specifically, the proposed method imposes simultaneously the circular polarization condition as well as an arbitrary input impedance matching condition. The two conditions are enforced by an analytical method derived from an equivalent circuit model of a quasi-symmetrical patch antenna, and manipulated to control the modal detuning. This method can be used as an aid to speed up the design procedure for CP antennas even working with a numeric CAD tool. The validation of this approach is proven designing and fabricating a prototype implementing an original design, which consists of a circular disc slotted by a concentric elliptical cut with coaxial feed and operating at the center frequency of 2.40 GHz. The fabricated prototype exhibited a return loss of about 30 dB, within an impedance bandwidth of 130 MHz, a measured gain of 0.4812 dB and a 5.27 dB axial ratio at 2.40 GHz with a corresponding modal phase difference of 87 degrees.

Keywords – Antenna circuit model, circular polarization, microstrip patch antenna

I. INTRODUCTION

Circular polarization (CP) are largely involved in wireless system embedded in complex environments as an effective way to mitigate multi-path effects. The most common techniques to design compact and efficient CP microstrip patch antennas consist in exciting either two identical orthogonal modes of a symmetrical patch or in feeding two identical orthogonal patch antennas in quadrature. It is also possible to achieve the CP effect in a patch antenna, using a single probe that excites a quasi-symmetrical shape supporting two degenerated modes. The two modes, determined by detuning the fundamental mode, are sources of two orthogonal polarized linear fields; CP radiation is achieved when these two modes have the same magnitude and are in phase quadrature. This can be accomplished by appropriately tuning the asymmetry of the patch’s shape and choosing the position of the probe with respect to the asymmetry. In literature an analysis of this kind of radiating structure was carried out either by directly manipulating the eigen modes expression or with a variational approach; always focusing on specific shapes, primarily squares and disks. In a general multimodal analysis was proposed, although the results reached were not suitable for direct employment in either a problem of analysis or synthesis. In literature very few works tried to develop this approach, in spite of its potential impact on design, and very few studies dealt with the simultaneous radiative and circuital aspects in the CP antenna design: to our knowledge the analytical question of CP and matching at the same frequency was never handled without concentrating on a specific patch shape.

In this paper, the complex relations among the two main aspects of CP patch antenna are handled with an analytical approach based on the algebraic manipulation of circuital equivalent parameters. This approach can be considered a stand-alone instrument, which can be used for analysis purpose but it can be also employed as a tool for design task.

Differently from the available design methods, the proposed approach leads to a procedure capable to control simultaneously the operative frequency, the axial ratio as well as input impedance in CP microstrip patch antenna, and this control is directly applicable in the early steps of the design flow. In literature the CP issue and the matching issue are almost always considered separated task, leading to lengthy cut and trial procedures to accomplish the goals in different steps or at most obtained through lengthy numerical optimization.

Used in combination with a CAD tool like the electromagnetic solver HFSS, our approach can give physical insight of the operation principle and addresses the CP and matching design problems straightforwardly.
The paper is organized as follows: while Section II describes a design procedure based on the equivalent circuital model, which demonstrates how to impose both the CP and matching conditions consistently. Section III presents the experimental results obtained with a prototype antenna working at 2.40 GHz designed by the described design procedure.

II. CIRCULARLY POLARIZED ANTENNA DESIGN

The analysis technique discussed hereinabove can be applied to any patch shape supporting two orthogonal degenerated modes. In this section we want to demonstrate how to employ the proposed approach for the design process (synthesis).

There are many shapes suited for the modal degeneration: in addition to the canonic rectangular, circular and triangular shapes are good candidates. Focusing on the disc shape, a direct way to split the radiator fundamental TM\(_{11}\) mode consists in cutting a thin slit through the center. In this way the fields will not be affected significantly, since the fundamental mode exhibits a zero in this area. For the odd mode, oriented toward the cut, the perturbation is minimal if the cut width is sufficiently narrow, i.e., the \(J_x^s\) surface current should not be affected by this perturbation and the resonant angular frequency remains almost the unperturbed \(w_{11}\) of the TM\(_{11}\) mode. On the contrary, for the even mode, this perturbation is relevant, as the \(J_x^s\) surface current is forced to turn around the slot reducing. Following this reasoning, a second orthogonal cut could be practiced in order to also increase the path of the odd mode. In this way the overall microstrip patch dimension decreases keeping the same central frequency for the two modes. It was demonstrated that with annular shapes it is possible to enlarge the bandwidth because of the reduced amount of stored energy beneath the patch metallization, i.e., by lowering the quality factor. This effect is independent of the cuts and both modes observe an equivalent circuit affected in the same manner. A convenient way to combine the slit degeneration effect and the annular effect consists in using a central elliptical cut as a detuning element. While the disc radius is the main parameter for the determination of the central frequency, controlling the ellipse axes makes it possible to synthesize the two modal frequencies. We have chosen to adopt this elliptical slitted disc for the design of our CP antenna in order to demonstrate the generality of our approach.

III. EXPERIMENTAL VALIDATION

The design procedure described in the previous section was adopted to design a prototype on an FR4 substrate operating at 2.45 GHz, with an input impedance of 50 Ω, and suitable for WLAN applications. The resulting antenna layout and its dimensions, along with the prototype photograph, are shown in Fig 1. Although the prototype was fabricated with the two via pins, to drive the LH and RH polarizations respectively, the prototype in the picture adopts the RH polarization one. In Fig. 12 simulated and measured reflection coefficients are presented for the RH prototype, the achieved impedance matching at center frequency is better than 18 dB within a 10 dB RL bandwidth in excess of 130 MHz. The wide bandwidth exhibited by the prototype is due to the presence of the two resonant modes which, being separated by several tenths of MHz, determines the double minimum in the matching frequency behavior adopted for the prototype manufacturing. In Fig. 15 the measured axial ratio is presented within the bandwidth of interest. It exhibits the perfect ratio between the even and odd modes at the frequency of 2.45 GHz, while the axial ratio is maintained below 5 dB from 2.42 GHz up to 2.48 GHz, demonstrating a bandwidth comparably higher than the previously reported design. It is also remarkable that there is a substantial consistency with the modulus of beta locus expressed in dB form.
Fig. 3: Return Loss

Fig. 4: VSWR at 2.40 GHz exactly 0dB

Fig. 5: Impedance matching nearly equals to 50 ohms

Fig. 6: Gain in apple shape

Fig. 7: Axial ratio

Fig. 8: Radiation Pattern
IV. CONCLUSIONS

An analytical method for studying circularly polarized microstrip antennas has been discussed. This method is applicable to both synthesis and analysis stage and it is based on a simple yet effective circuitual equivalence of microstrip patch radiators. The proposed method enables the tuning of the circular polarization condition and the matching condition consistently. A prototype antenna based on the proposed method was designed, at the nominal center frequency of 2.40 GHz. The measurements showed a maximum gain of 0.481 dB and an unit axial ratio magnitude at the frequency of 2.40 GHz, where the phase error is lower than 3 degrees. Impedance of nearly 50 ohms was matched. The axial ratio was observed within 5 dB magnitude and 5 degrees phase in more than 30 MHz bandwidth around the design center frequency. The design method permitted to achieve an inherent 30 dB return loss at the central frequency and better than 10 dB within 130 MHz bandwidth.

The CP and matching goal was accomplished without external circuitry: the pins for LH and RH excitation are directly available for connection with a coaxial cable. A single pole double throw switch could be eventually integrated to control the polarization kind.

V. REFERENCES

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