
IETE Technical Review

ISSN: 0256-4602 (Print) 0974-5971 (Online) Journal homepage: http://www.tandfonline.com/loi/titr20

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IETE Technical Review
Vol 16, No 1, January-February 1999, pp 97 - 100

# Characteristics of a Single Fed Circularly Polarized Microstrip Antenna

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**The impedance and radiation characteristics are presented for a Single Fed Circularly Polarized (SFCP) square microstrip patch antenna with perturbation segments. The polarization behavior of this antenna is studied with the aid of various superstrates of different thickness. The complete design of the SFCP antenna is aided with the commercial software, Ensemble. A good agreement between simulated and experimental results is obtained.**



THE microstrip patch antenna is widely used as an efficient radiator in many communication systems. In particular, a circularly polarized microstrip patch of circular or square shape plays an important role to receive and transmit the signals[1-3] in these systems. In order to obtain circular polarization, two fundamental orthogonal modes in phase quadrature, under the patch, are excited. In this case, the sign of the relative phase gives the type (right-hand or left-hand) of circular polarization. There are a number of methods to generate the required two orthogonal modes. The simplest one is using the 3dB quadrature hybrid as an external polarizer. In this case, two signals of equal amplitude and 90° phase difference are fed to the two orthogonal feeds of the patch. In many applications, there is a demand for generating circular polarization without the aid of external polarizer. This can be achieved using a single feed and the perturbation technique as applied to the patch structure.

The present paper, an extension of our earlier work[4], gives the design criteria for a single-fed square-shaped microstrip patch antenna for which circular polarization is obtained using perturbation segments[5-6]. The polarization behavior of this antenna is studied in detail by loading its top with superstrates of different height and of different dielectric constants. This study is performed at 5 GHz. A powerful computer aided design tool ENSEMBLE® version 5 of Boulder Microwave Technology, Inc., USA is used to analyze and to optimize the patch performance. After obtaining its dimensions, the patch is fabricated using the PLG technique and experimentally tested in terms of its input impedance and polarization purity. The measured results agree well with the simulated results.



## DESIGN

The geometry of the SFCP microstrip patch antenna is given in Fig 1. In particular case of the square patch, the frequency response of the two orthogonal modes $TM_{1,0}$ and $TM_{0,1}$, which exist under the patch, are identical. Using a single feed and perturbation segments, the two modes can be excited simultaneously. In order to obtain a circularly polarized wave, the two generated modes have to be of equal amplitudes but of phase difference equal to 90°. This can be achieved by suitably truncating corners of the patch. The amount of perturbation required to obtain this result can be determined from the following relation:

$$|\Delta s / S| \; Q_o : ½$$

where $\Delta s$ is the area of the truncated corner, $S$ is the area of the patch and $Q_o$ the unloaded $Q$ factor

The left hand or right hand circular polarization can be obtained by simply repositioning the feed point.

The design of the corner truncated element involves accurately determining the patch dimension, $a$ and the truncated segment ($\Delta a$) . For a given substrate material, the designer has to adjust both, patch dimensions and the truncated segment length, to get the minimum axial ratio at the operating frequency. The determination of the feed point is also equally important to minimize the input reflection coefficient, as observed from the feeding coaxial line. A detailed analysis of the structure can be found in the literature[5]. Due to the high sensitivity of the truncation process, the use of an accurate simu-

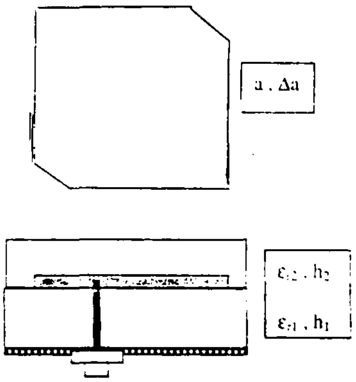



Fig 1 Configuration of the investigated microstrip patch antenna

lation tool becomes desirable in adjusting the patch and truncated segments dimensions. In the current paper, a versatile powerful software tool, Ensemble, equipped with the graphical interface, for drawing and adjusting the dimension of the patch element, and a full wave simulation engine is used to optimize the design.

## SOFTWARE TOOL

In the current communication, Ensemble Design version 5 is used to simulate the structure. Ensemble Design[7] consists of a graphical user interface and a numerical simulation program or engine. It has test bed environment for performing the numerical experimentation on multi-layer patch antennas as well as feed network elements. In general, this design tool is used to model geometry of irregular shapes such as patches with arbitrary slots including a subarray feed network with or without finite ground planes. The kinds of structures that can be designed with the Ensemble Design range from aperture coupled patch antenna to the asymmetrical feed network, with black boxes representing the subarray sections of a small array. The current version of this software handles up to 12 substrate layers, 7 metal layers and 4 infinite ground plane layers of any configurations. The simulation engine is based upon a full wave approach, using the mixed potential integral equation in conjunction with the method of moments. It takes into account all mutual coupling effects and simulates whatever structure is drawn in the Design screen. The simulation engine utilizes both electric and magnetic currents to model structures with patches on the metal layers and aperture on infinite ground layers.

The antenna configuration can be estimated from one of the in-built tools in Ensemble Design. A few manual iterations are required to get the proper dimensions of the SFCP antenna together with the truncated segments. Each iteration requires small variations in the antenna's dimensions, by either shrinking or stretching the length. After obtaining the satisfactory results, the patch can be loaded with superstrates of various thicknesses and the simulation process can then be continued.

## RESULTS AND DISCUSSION

Based on the above-described strategy, a square patch for operation at 5GHz was designed and fabricated using RT Duroid 5880 substrate. The dimensions of the patch, truncating corner and the substrate parameters are given in Table 1. The measurements were taken with the Network Analyzer HP-8510C. The manufactured patch resonated at 5.0 GHz with a return loss of better than 27 dB. This compares well with the predicted results which included the resonant frequency of 5.045 GHz and return loss of 34 dB. The measured impedance bandwidth (for the 10 dB return loss) was found to be 6.8% and the minimum axial ratio was 0.945 dB. The calculated results for the impedance bandwidth and axial ratio are 6% and 1.025 dB, respectively. The calculated results of the patch loaded with various superstrates of different thickness are shown in Table 2 and the measured results are shown in Table 3. The

**TABLE 1 Dimensions of the patch and the substrate parameters**

| Design parameter : | | In (mm) |
|---|---|---|
| Patch dimension | : | 19.7 × 19.7 |
| Truncated length | : | 3.1 |
| Dielectric constant ($\varepsilon_{r1}$) | : | 2.2 |
| Height($h_1$) | : | 1.54 |
| Feed point | : | 9.85 × 6.98 |
| Resonant frequency (GHz) | : | 5.045 |
| Measured res frequency (GHz) | : | 5.00 |
| Axial ratio (dB) | : | 1.025 |
| Measured axial ratio (dB) | : | 0.945 |
| Calculated bandwidth | : | 300 MHz (6%) |
| Measured bandwidth | : | 340 MHz (6.8%) |
| Ground plane dimension | : | 60 × 60 |

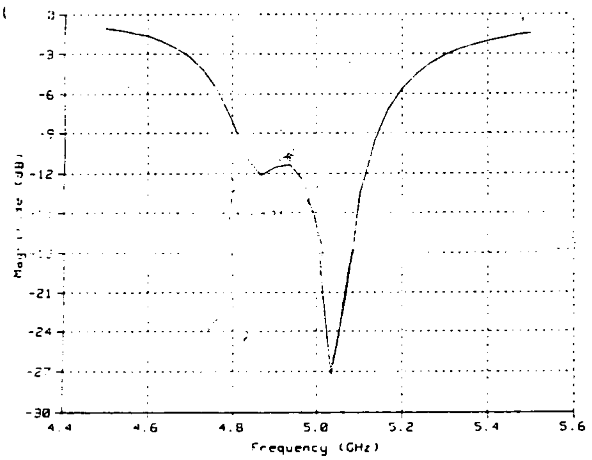
**TABLE 2 Calculated results of the SFCP antenna loaded with various superstrates**

| Sl no | $\varepsilon_{r1}$ | $h_1$ (mm) | $\varepsilon_{r2}$ | $h_2$ (mm) | $F_r$ (GHz) | AR dB | RL dB |
|---|---|---|---|---|---|---|---|
| 1 | | | Air | ∞ | 5.045 | 1.025 | -27 |
| 2 | | | 2.2 | 0.5 | 4.95 | 1.19 | -30 |
| 3 | | | | 1.0 | 4.88 | 1.25 | -35.88 |
| 4 | | | | 1.5 | 4.82 | 1.48 | -23.04 |
| 5 | 2.2 | 1.54 | 3.06 | 0.5 | 4.9 | 1.05 | -18.8 |
| 6 | | | | 1.0 | 4.75 | 1.87 | -18.4 |
| 7 | | | | 1.5 | 4.7 | 1.13 | -23.0 |
| 8 | | | 5.0 | 0.5 | 4.75 | 1.85 | -35.82 |
| 9 | | | | 1.0 | 4.6 | 1.68 | -26.85 |
| 10 | | | | 1.5 | 4.48 | 2.28 | -19.5 |

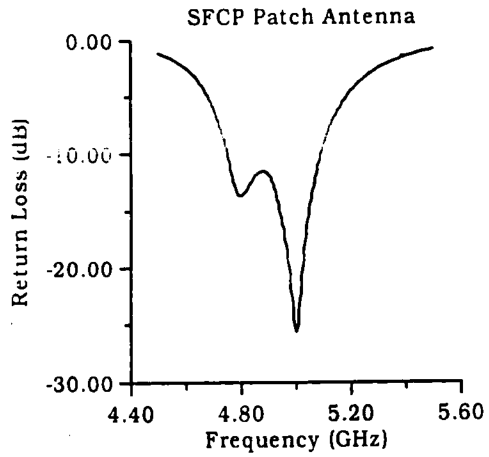
**TABLE 3 Measured results of the SFCP antenna loaded with various superstrate layers**

| Sl no | $\epsilon_{r1}$ | $h_1$ (mm) | $\epsilon_{r2}$ | $h_2$ (mm) | $F_r$ (GHz) Calc. | $F_r$ (GHz) Meas | AR dB | AR dB |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | 0.8 | 4.8 | 4.865 | 1.826 | 0.425 |
| | 2.2 | 1.54 | 3.00 | | | | | |
| 2 | | | | 1.6 | 4.74 | 4.8 | 2.462 | 0.464 |
| 3 | | | | 2.4 | 4.68 | 4.72 | 1.146 | 0.323 |

resonant frequency of the patch decreases as the thickness or the dielectric constant of the superstrate increases. From the calculated results, it is apparent that the variation of the axial ratio is not consistent with the superstrate thickness. At the resonant frequency, the axial ratio measured frequency decreases with the superstrate thickness and obtaines the minimum value of 0.323 dB for the superstrate of height 2.4 mm and dielectric constant of 3.00. The discrepancies between measured and calculated values may be attributed to the ground plane, which is considered as infinite in calculations, while it is of finite size during measurements.



(*a*)




(*b*)

Fig 2 (*a*) The calculated return loss of the SFCP antenna with $\varepsilon_{r1}$ = 2.2, $h$ = 1.54 mm and without superstrate layer. (*b*) The measured return loss of the SFCP antenna without superstrate layer

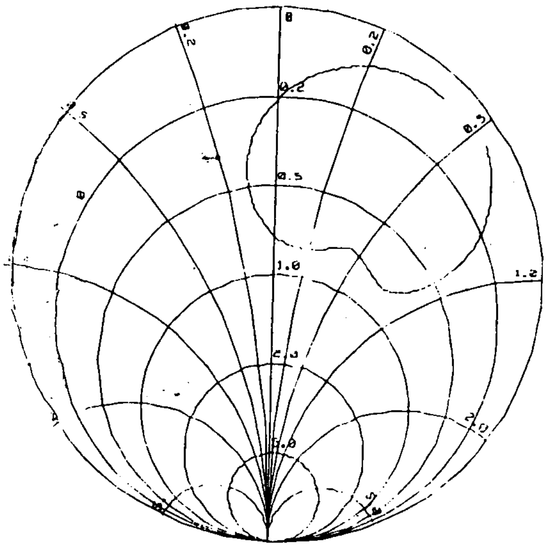


Fig 3 The impedance response of the SFCP antenna with the superstrate layer $\varepsilon_{r2}$ = 3.06, $h_2$ = 3.00mm

The calculated and measured return loss curves are shown in Fig 2*a*, 2*b* and are found to be in a good agreement. The calculated axial ratio bandwidth is found to be more then 2.5% whereas the measured axial ratio is less than 2%. The impedance locus of the loaded structure, as shown in Fig 3, reveals that as the dielectric material of the superstrate increases, then more inductance is added to the RL-circuit and the locus moves toward the inductive part of the Smith chart.

## CONCLUSION

In the presented paper, the effect of superstrate on the operation of a single fed square-shaped circularly polarized microstrip patch antenna has been discussed. Perturbation segments in the form of truncated corners have been employed to obtain circular polarization of this antenna. Commercially available software, Ensemble, has been used to obtain dimensions of the patch including its perturbation segments. The manufactured antenna has been tested in terms of its return loss and axial ratio. A 6.8% impedance bandwidth and 2% ellipticity bandwidth for the manufactured antenna have been obtained. Generally, very good agreement between the simulated and experimental results has been obtained. Slight discrepancies have been recorded with respect to the ellipticity bandwidth. These can be attributed to a finite size ground plane, which has not been taken into account during the simulations.

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# Author

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