Accurate Analysis and Design of Circularly Polarized Dual-Feed Microstrip Array Antenna Using Multiport Network Model

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Abstract - Microstrip Patch Antennas (MPAs) with circular polarization are used in many communication and radar systems. There are several methods and models in order to analyze and design of these antennas. Multiport Network Model (MNM) is considered as one of the best models of MPAs. This model includes several circuit networks that are connected to each other and each of them represents one characteristic of the MPA. Solution of this model is equivalent to calculation of the input and radiation parameters of the antenna. In this paper, a circularly polarized 2×2 array antenna with sequentially rotated microstrip elements is designed using the MNM. For producing the circular polarization, besides the sequentially rotation technique, two probe feeds are used in the E-plane and H-plane of each elements, respectively. These probes have currents with equal amplitudes and 90 degree phase difference.

1. Introduction

Nowadays, circularly polarized MPAs are one of the conventional antennas in the communication and radar systems. The most important characteristics of these antennas consist:

- Competition to faraday rotation
- Reduction of the raindrops reflection effects
- No need to estimate the necessary orientation of the antenna according to the polarization of the received signals
- Duplicating of the channel capacity using the positive and negative circular polarization
- Reduction of the fading effects

MNM is one of the best models to analyze and design of the MPAs [1, 2]. This model, in fact is the extension of the well-known Cavity Model. In the MNM, the underneath and external fields of the patch are separately modeled. The patch is modeled with a Multiport 2-D planar network. Mutual coupling effects are considered by mutual coupling network [3].

The final model includes several circuit networks connected to each other. Input impedance and the voltage of the antenna edge ports are achieved directly by solving the final model. The other input and radiation parameters of the antenna are achieved from input impedance and edge ports voltage, respectively [1, 2].

2. Design of Dual-Feed Circularly Polarized MPA

Rectangular MPAs are intrinsically linearly polarized antennas. One of the best techniques of production a circularly polarized wave by these antennas is the excitation of two perpendicular modes with equal amplitudes and 90 degree phase difference, using two probe feeds, respectively in the E-plane and H-plane. These probes have currents with equal amplitudes but 90 degree phase difference (Figure. 1).

The patch structure and its simple MNM are shown in figures 2 and 3, respectively.

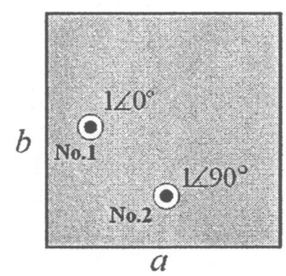

Figure 1: Circularly polarized dual-feed patch

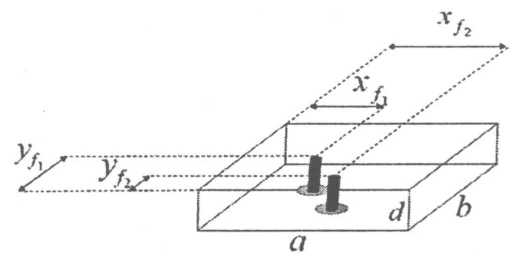

Figure 2: Structure of dual-feed patch

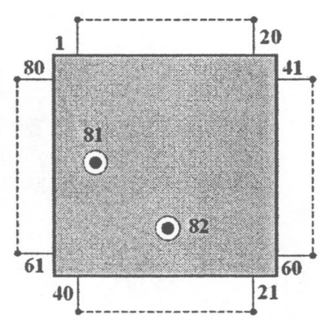

Figure 3: Simple MNM of dual-feed patch

In this design, 82 ports are considered in the MNM of dual-feed patch. The specifications of the designed patch are available in table 1.

Table 1: Antenna specifications

Square Patch	$a = 4cm$		$b = 4cm$
$d = 1/32$ *inch*	$\varepsilon_r = 2.33$		$\tan\delta = 0.0012$
$x_{f_1} = ?$	$y_{f_1} = b/2$	$x_{f_2} = a/2$	$y_{f_2} = ?$

2.1. Determination of Feed Location

The patch dimensions and dielectric material are designed for resonance frequency of 2.45 GHz. In this design mutual coupling between the patch edges is considered and x_{f_1} and y_{f_2} determined to achieve the $50\,\Omega$ input impedance in both ports.

Accurate quantities of x_{f_1} and y_{f_2} are achieved using the input resistance curve versus feed port location. This curve for both ports is shown in figure 4.

From this figure it is shown that $x_{f_1} = 1.21\,cm$ and $y_{f_2} = 1.21\,cm$ satisfies the antenna impedance matching. Of course, it is prospective that x_{f_1} and y_{f_2} have same quantities, because the patch structure is square and the feeds are in diagonal symmetry.

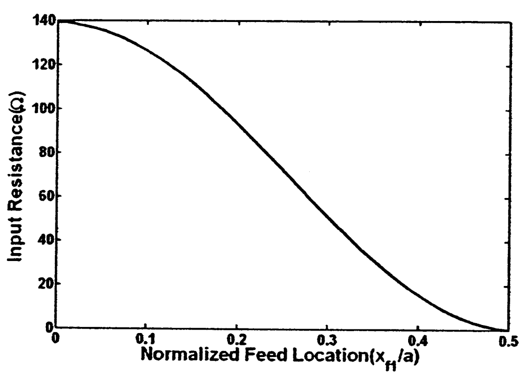

Figure 4: Input resistance of the patch at port #1 and #2

2.2. Simulation Results

Simulation results based on MNM are shown in figures 5-16.

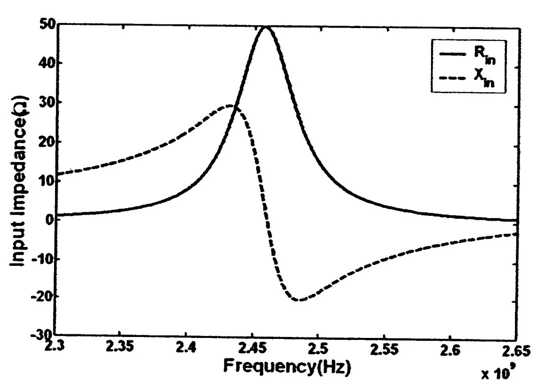

Figure 5: Input impedance in both ports

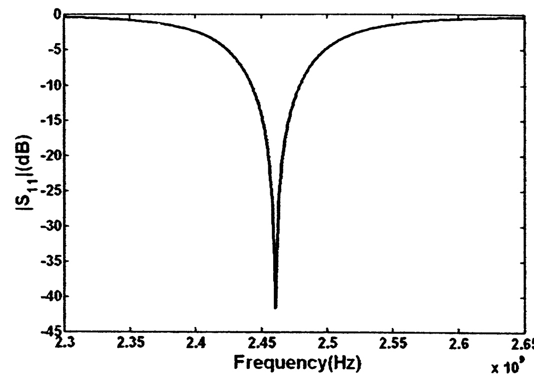

Figure 6: $|S_{11}|$ in dB

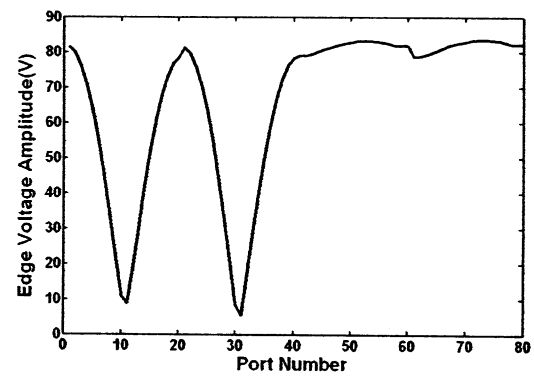

Figure 7: Edge voltage amplitude due to the feed port #1

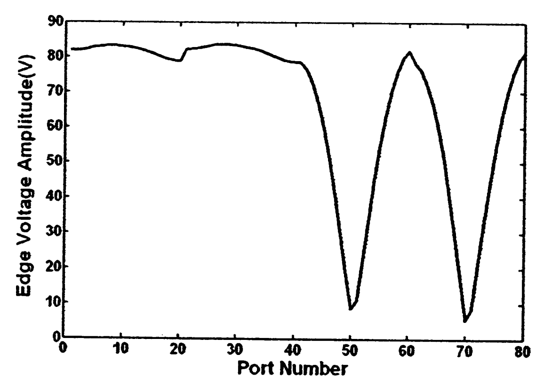

Figure 8: Edge voltage amplitude due to the feed port #2

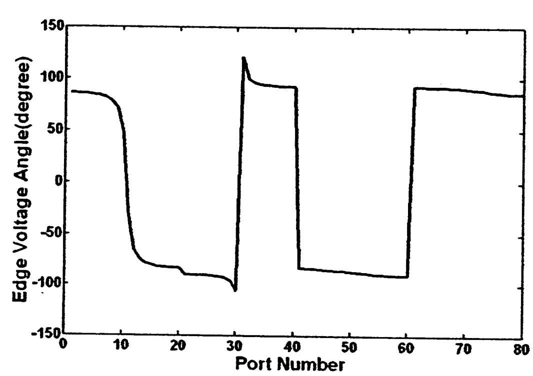

Figure 9: Edge voltage angle due to the feed port #1

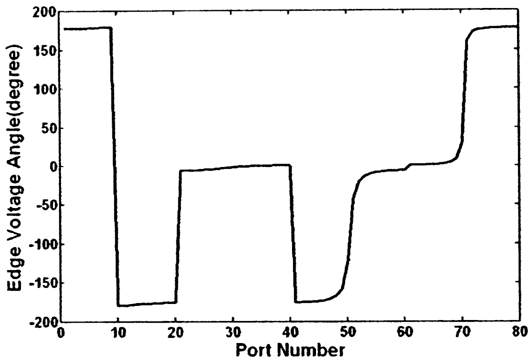

Figure 10: Edge voltage angle due to the feed port #2

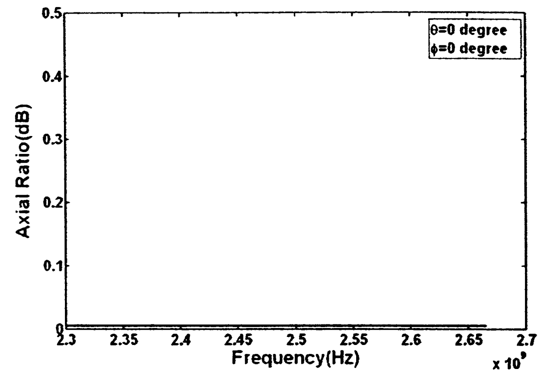

Figure 14: Axial ratio of total radiation pattern

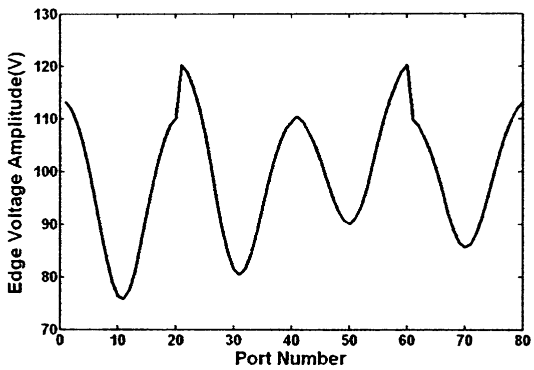

Figure 11: Edge voltage amplitude due to the both feed ports

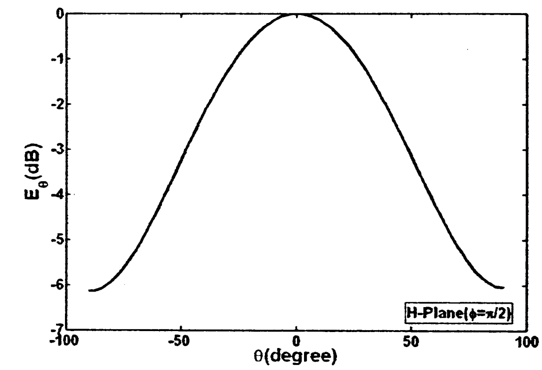

Figure 15: H-plane radiation pattern of E_θ

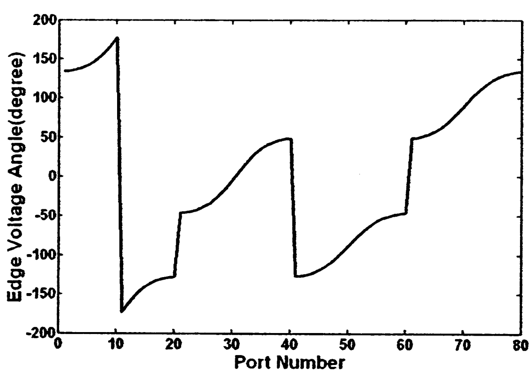

Figure 12: Edge voltage angle due to the both feed ports

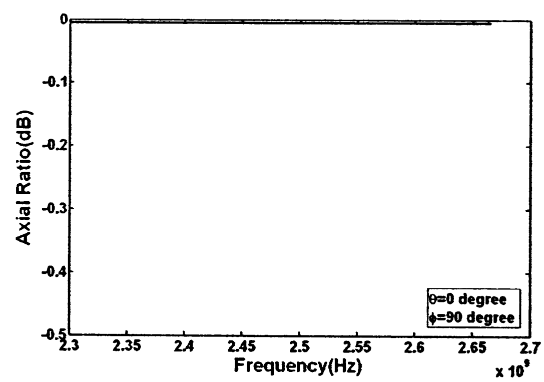

Figure 16: Axial ratio of total radiation pattern

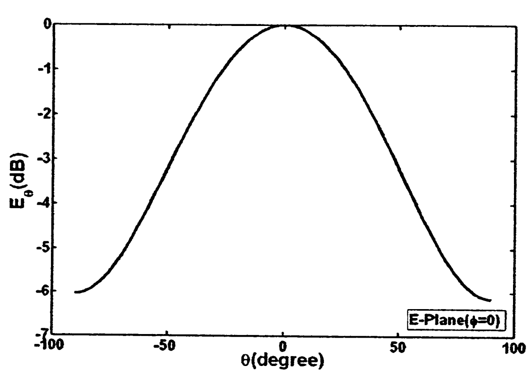

Figure 13: E-plane radiation pattern of E_θ

2.3. Discussion

As shown in figures 5 and 6, designed antenna has very good impedance matching in the frequency of 2.46 GHz. From figures 7 to 12, it is found that total phasor of the antenna edge ports voltage is sum of the phasors due to both feed ports. Thus, MPA has linear treatment and consequently the superposition theorem is usable in it. Finally, the figures 13 to 16 show the conventional radiation patterns and especially the near to 0 dB axial ratio in the frequency range 2.3 – 2.7 GHz for different angles of θ and ϕ. Thus, using this structure, very good circular polarization is achieved.

3. Design of the Sequentially Rotated Array

The array structure and its MNM are shown in figures 17 and 18, respectively. The array elements are dual-feed patches. These patches produce circularly polarized waves due to the 90 degree phase difference between their perpendicular feeds. Besides, the 90 degree phase difference between the sequentially rotated array elements produces a general circularly polarized wave that radiates by the array.

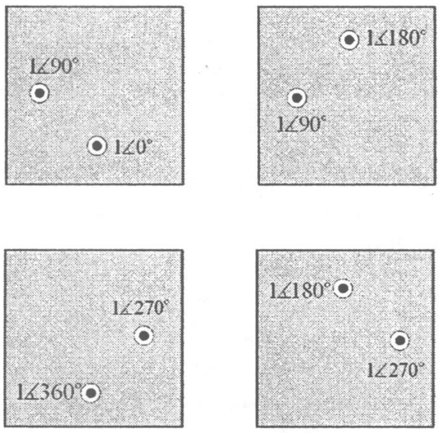

Figure 17: Circularly polarized 2×2 array

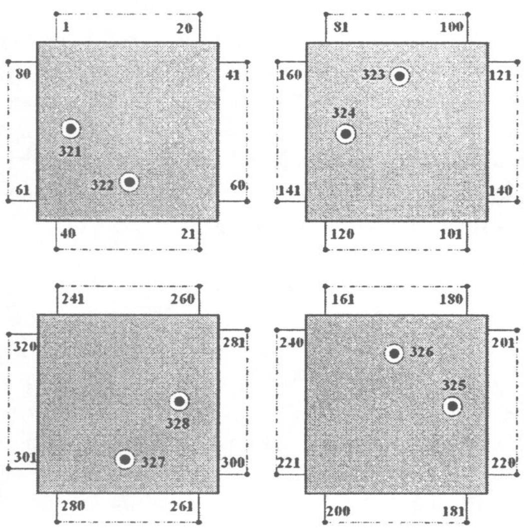

Figure 18: MNM of the circularly polarized 2×2 array

Array elements are the MPA in ISM band of 2.45 GHz that designed in the section 2 of this paper (Figure 2). The specifications of the designed array are available in table 2.

Table 2: Array specifications

$a = 4cm$		$b = 4cm$	$S = 0.47\lambda_0$
$d = 1/32\ inch$		$\varepsilon_r = 2.33$	$\tan\delta = 0.0012$
$x_{f_1} = 1.21\ cm$	$y_{f_1} = b/2$	$x_{f_2} = a/2$	$y_{f_2} = 1.21\ cm$

The feed locations are selected to provide impedance matching at all input ports.

S is the center to center distance between adjacent patches. This distance should be smaller than $0.5\lambda_0$ to prevent the production of grating lobes in the array pattern [4]. If the input parameters of the elements have been considered from the connecting location of the coaxial cable to the connector, the resistive and inductive effects of the probe length in the substrate should be included.

3.1. Calculation of the Input Impedance of the Probe Fed Patch Antenna

In the cavity model as the base of the MNM, a perfect magnetic wall is considered around the patch. In this case, it should be solved very complicated relations to calculate the probe resistance and inductance. However, if the probe radius is very small, the stored magnetic energy will concentrate in the probe surroundings and thus with a good approximation we can ignore these cavity magnetic walls and assume that the dimensions of the upper and lower planes of the cavity is infinite. Thus we have an infinite parallel plane waveguide with a wire current between the upper and lower planes. In this case, calculation of the probe resistance and inductance is easier than previous [5]. According to the above assumptions, the probe impedance is calculated from the following formulas [6]:

$$Z_{probe} = R_{probe} + jX_{probe} \tag{1}$$

$$R_{probe} = \frac{\omega\mu_0 d}{4} \tag{2}$$

$$X_{probe} = \frac{\eta_0}{2\pi} k_0 d \left\{ -\gamma + \ln\left(\frac{2}{\sqrt{\varepsilon_r}\, k_0 r} \right) \right\} \tag{3}$$

where ω, η_0, k_0, μ_0, r and d are angular frequency, free space characteristic impedance, phase constant, free space permeability, probe radius and substrate thickness, respectively. Also, γ is Euler number and equals to 0.5772156649. As we see in the equations 2 and 3, both resistance and inductive reactance increased with increasing the substrate thickness. With considering the probe impedance, the circuit model shown in the figure 19 is achieved for the patch antenna in frequencies near to resonance frequency [5].

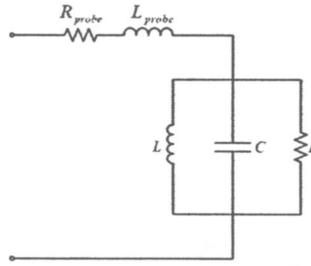

Figure 19: CAD model for the probe fed patch antenna

In this figure the patch has been modeled as a parallel RLC circuit.

$$Z_{in_{patch}} = R \,||\, L \,||\, C \tag{4}$$

Input impedance of the probe fed patch antenna is calculated with fallowing equation:

$$Z_{in_{eq}} = Z_{probe} + Z_{in_{patch}} \tag{5}$$

3.2. Simulation Results

Some of the simulation results of the array based on MNM are shown in figures 20-23.

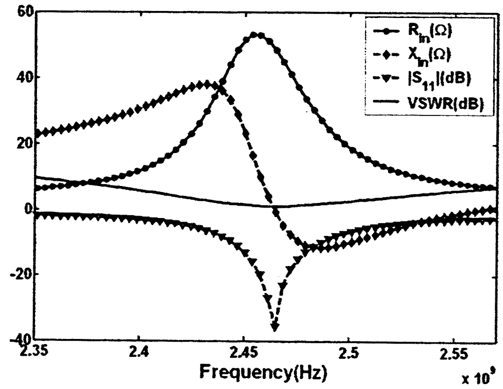

Figure 20: Input parameters in port #1

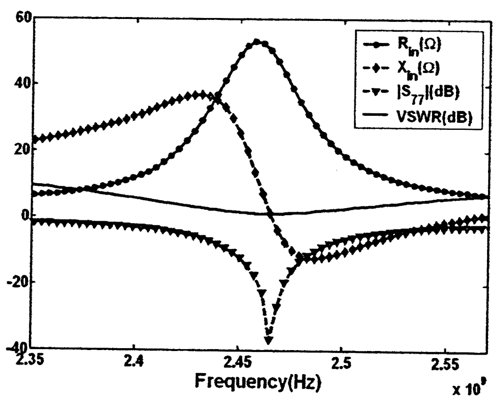

Figure 21: Input parameters in port #7

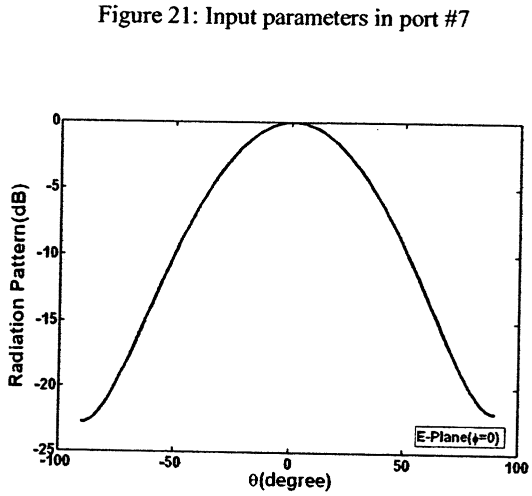

Figure 22: Radiation pattern of the array

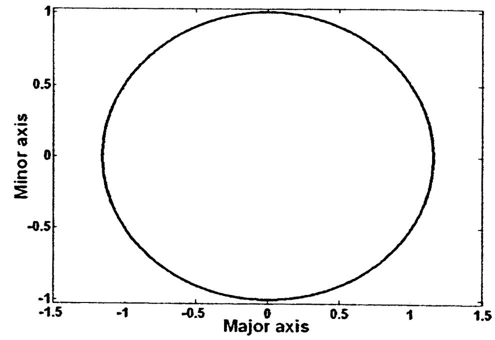

Figure 23: Polarization ellipse of total radiation pattern for $\theta = 0$, $\phi = 0$

3.3. Discussion

As it is shown in figures 20 and 21, impedance matching is achieved in all ports at frequency near to 2.46 GHz with $S_{ii} < -30$ dB for $i = 1,2,\ldots 8$.

Moreover, figures 22 and 23 show the radiation pattern of the array in the E-plane and Polarization ellipse of total radiation pattern for $\theta = 0$, $\phi = 0$ at the resonance frequency of 2.46 GHz. Thus circular polarization is achieved with a good quality.

4. Summary

This paper has indicated the capabilities of the MNM in the analysis and design of the useful practical MPAs and its flexibility to model the complicated structures. In order to increase the accuracy of design, mutual coupling between the single patch edges and between the edges of the elements is considered. With analysis of the achieved results, new and deep insight for the MPAs' operation is accrued.

References

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[6] J. P. Damiano and A. Papiernik, "Survey of analytical and numerical models for probe-fed microstrip antennas," *IEE Proc., Microw. Antennas Propag., Vol. 141, No. 1,* February 1994.