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Edge Fed Rectangular Slotted Microstrip Antenna - An Analytical Design Approach

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***Abstract*— An analytical model for designing, an edge fed rectangular slotted, Rectangular Microstrip antenna (RMSA) is proposed. The introduction of slots on the patch results in shift of resonant frequency towards left. The changes due to introduction of slots had been studied using numerous simulation softwares which are tedious and time consuming. A blind trial and error method of analysis is adopted to study the effects due to introduction of slots and no analytical approach is proposed till now. In this paper, an analytical approach to design an edge fed rectangular slotted MSA is explained. The curves, shift in resonant frequency V/s Ring width and Return loss corresponding to shifted frequency V/s Ring width have been studied and the best fit equations have been derived. Comparison of simulated results and values obtained from the curves for non-corner ring widths is done and it is seen that they are approximately equal. The derived equations are valid at a specific design frequency and can be used as an open source to find or predict the useful shift of resonant frequency from original designed frequency due to the introduction of slots without the aid of simulation softwares. The antenna simulations are carried out in HFSS.**

Index Terms— ***High Frequency Structure Simulator (HFSS), Microstrip patch antenna (MPA), Modeling, slotted edge fed.***

I. Introduction

Microstrip patch antennas (MPA) are widely used in many applications, mainly in wireless communication. This is due to its attractive features such as light weight, low profile, conformal shaping, low cost, high efficiency, simplicity of manufacture and easy integration to circuits. Other advantages include, they have a small volume and a planar configuration. Their ease of mass production using printed-circuit technology leads to a low fabrication cost. They allow both linear polarization (LP) [1] and circular polarization (CP) [2][3]. They allow for dual- and triple-frequency operations [4] .But the major disadvantage of the microstrip patch antenna is its inherently narrow impedance bandwidth. Bandwidth enhancement is a major problem in these antennas. This technique includes the utilization of thick substrates with low dielectric constant and slotted patch. But the use of electronically thick substrate usually gives limited success because the increased probe feed length introduces large inductance. It may result in few percentage of impedance bandwidth at resonant frequency. Compact size microstrip antennas can be obtained by loading some specific slots in the radiating patch of microstrip antennas. The loading of slots in the radiating patch can cause twisting of the excited patch surface current paths and it results in lowering of the antenna’s fundamental resonant frequency, which corresponds to the reduced antenna size for such an antenna, compared to conventional microstrip antenna at same operating frequency [5].

Usually there is no analytical approach to relate shift in resonant frequency and the shape of patch due to introduction of slots in radiating patch of RMSA. The changes occurring due to the introduction of slots have been studied using numerous simulation softwares which are tedious and time consuming. In this paper an attempt is made to create an analytical approach to relate shift in resonant frequency and its corresponding return losses with a ring shaped patch formed due to introduction of rectangular slots in radiating patch of RMSA. So that one can use this method as an open source to find or predict useful shift in resonant frequencies due to introduction of rectangular slots, without any knowledge of tedious and time consuming simulation softwares. This paper also aims at studying the effects of introduction of rectangular slots in the radiating patch of RMSA.

The organization of the paper is as follows. In the section II design and simulation in ANSOFT HFSS of basic RMSA and slotted RMSA is described. Section III consists of familiarization of ANSOFT HFSS and simulation results which is summarized in table I. Section IV deals with model generation using MATLAB Software and Section V concludes the findings of this paper.

II. ANTENNA DESIGN & SIMULATION

A. *Design & Simulation of basic RMSA.*

As an initial part of the work, an Edge fed basic Rectangular Microstrip Patch antenna (RMSA) resonating at a frequency of 5.2 GHz is designed using basic design equations and then simulated and analyzed using ANSOFT HFSS Software version 12.1. The structure of designed antenna is shown in Fig.1.

Design specifications:

Design frequency: 5.2GHz

Substrate = FR4 (ϵ_r= 4.4, μ = 1)

Standard thickness chosen (h) = 1.6 mm

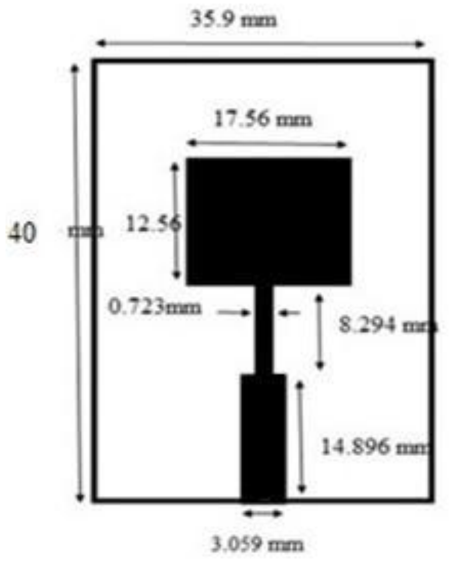

Fig. 1: Designed structure of basic RMSA, 5.2 GHz

B. Design & Simulation of slotted RMSA.

To analyze the effects of rectangular slots in microstrip patch antenna, a rectangular slot is made as shown in the Fig. 2 and the simulation is carried out in HFSS for different ring widths. The ring width is varied from 0.5mm to 6mm with 0.5mm increments.

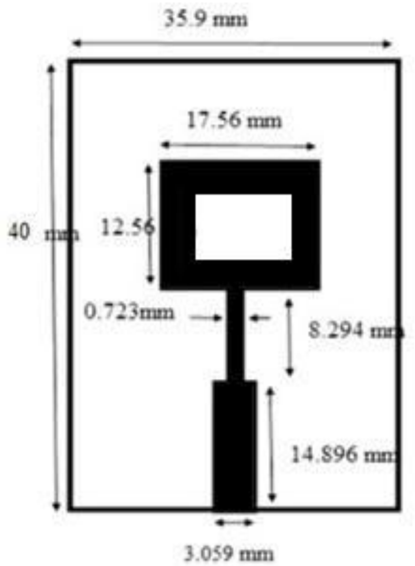

Fig. 2: Slotted RMSA

III. SIMULATION

Simulations are carried out in ANSOFT HFSS. ANSOFT HFSS employs the Finite Element Method (FEM). It can be used to calculate parameters such as S-Parameters, Resonant Frequency, gain, directivity and Fields [6].

It is observed that the introduction of rectangular slots on radiating patch results in ring shaped patch and it increases the current path. That is the effective length (perimeter) increases, which in turn increases the wavelength. As wavelength increases, frequency decreases.

The simulation is carried out in HFSS for different ring widths. The ring width is varied from 0.5mm to 6mm (corner ring widths) with 0.5mm increments and results are summarized in Table I shown below. From the simulation it is observed that the introduction of rectangular slots results in lowering of antenna's fundamental resonant frequency. That is, there is a shift of resonant frequency towards left from original designed frequency, 5.2GHz. From the simulated return loss plots for different ring widths in RMSA, it is also observed that introduction of slots results in multiple band of operation which can be used for wireless applications. For the ring widths greater than 4mm, a triple band of operation has been observed. The simulation return loss plots for ring widths 1.5, 2.5, 4 and 5mm are shown in Fig. 3, Fig. 4, Fig. 5 and Fig. 6 respectively.

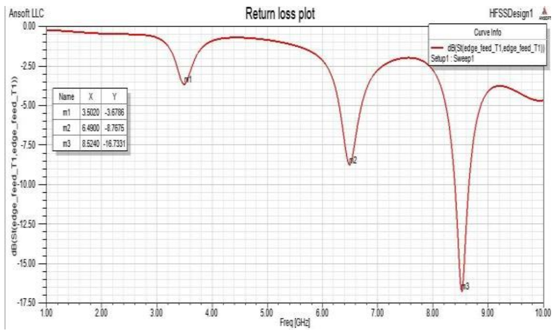

Fig. 3. Return loss plot for ring width 1.5mm

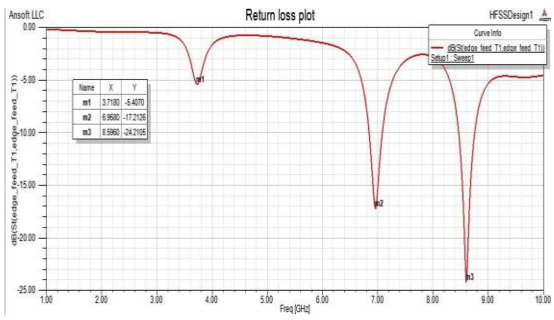

Fig. 4. Return loss plot for ring width 2.5mm

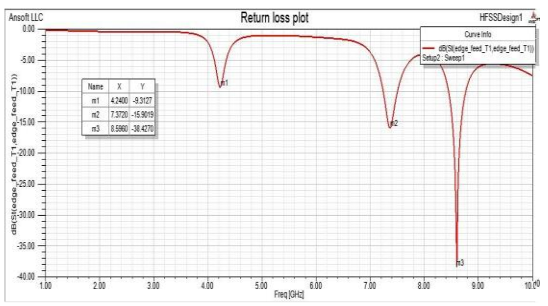

Fig. 5. Return loss plot for ring width 4mm

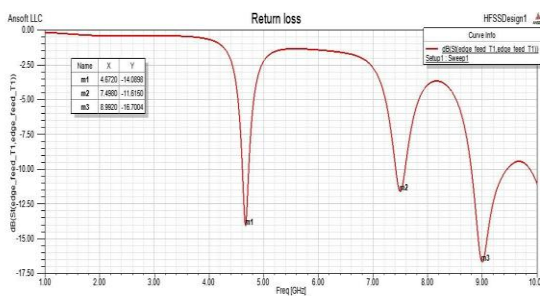

Fig. 6. Return loss plot for ring width 5mm

TABLE I. SIMULATION RESULTS

Ring Width (mm)	Shifted f_r (GHz)	S_{11} for shifted (dB)	Gain (dB)	Directivity (dB)
0.5	3.41	2.43	0.01	6.67
1.00	3.43	3.00	0.34	6.73
1.50	3.50	3.68	0.35	6.77
2.00	3.61	4.47	0.73	6.91
2.50	3.72	5.41	0.91	7.06
3.00	3.90	6.62	1.06	7.23
3.50	4.06	8.17	1.62	7.57
4.00	4.24	9.31	2.29	7.87
4.50	4.47	11.30	3.14	8.15
5.00	4.67	14.09	4.23	8.35
5.50	4.83	16.37	5.05	8.40
6.00	5.05	22.09	5.55	8.16

IV. MODEL GENERATION

Usually there is no analytical approach to relate shift in resonant frequency and the shape of patch due to introduction of slots in radiating patch of RMSA. As a part of research study an attempt is made to create an analytical approach to relate shift in resonant frequency and ring shaped patch formed due to introduction of rectangular slots in radiating patch of RMSA. For this, the curves, Shift in resonant frequency (f_r) V/s Ring width and return loss (S_{11}) corresponding to shifted resonant frequency V/s Ring width were plotted using the 'cftool' tool in MATLAB software and the best fit equations have been derived connecting them. The derived equation fits the data i.e. it produces a curve passing through all the data points. The simplest type of equation is a polynomial, which here takes the form:

$$P = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \ldots\ldots\ldots\text{etc.}$$

Fitting data to a polynomial is done in MATLAB by using the 'cftool' Interface. MATLAB finds the best fit equation that fits the simulated data.

First, the curve shift in resonant frequency (y) V/s Ring width (x) has been plotted and the best fit equation is derived. The Fig. 7 shows the plotted curve and derived equation.

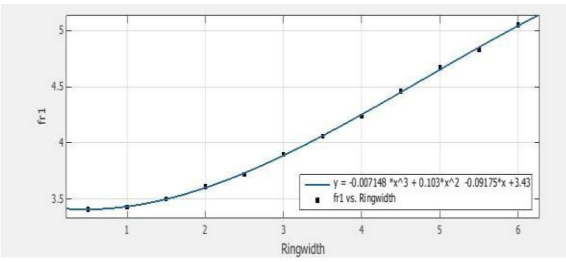

Fig. 7: Shift in resonant frequency V/s Ring Width

The derived equation is a cubic polynomial,

$$y = -0.007148\,x^3 + 0.103\,x^2 - 0.09175\,x + 3.43$$

with Root mean square error (RMSE)of 0.01356. Then a curve, Return loss (S_{11}) corresponding to shifted resonant frequency (y) V/s Ring width (x) has been plotted and the best fit equation has been derived. The Fig. 8 shows the plotted curve and derived equation.

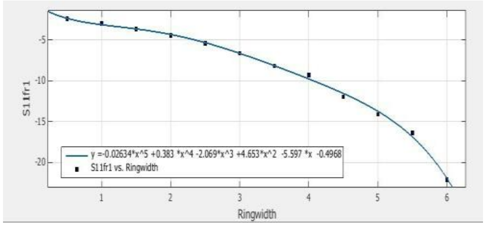

Fig. 8: Return loss corresponding to shifted frequency V/s Ring Width

The derived equation is a fifth degree polynomial,

$$y = -0.02634x^5 + 0.383x^4 - 2.069x^3 + 4.653x^2 - 5.597x - 0.4968$$

with Root mean square error (RMSE) of 0.3688.

Then, the obtained equations were verified for ring widths 0.3, 0.8, 1.2, 1.8, 2.3, 2.7, 3.8, 4.2mm (non-corner points). The validation results for shift in resonant frequency (f_r) and return loss (S_{11}) corresponding to shifted frequency are summarized in Table II and Table III respectively.

TABLE II. VALIDATION TABLE (f_r)

Ring width(mm)	Simulation results	Values obtained from polynomial
0.3	3.36	3.41
0.8	3.41	3.42
1.2	3.48	3.46
1.8	3.57	3.56
2.3	3.66	3.68
2.7	3.77	3.79
3:8	4.16	4.18
4:2	4.28	4.33

TABLE III. VALIDATION TABLE (S_{11})

Ring width(mm)	Simulation results	Values obtained from polynomial
0.3	2.08	1.81
0.8	2.76	2.91
1.2	3.21	3.36
1.8	4.13	4.04
2.3	5.08	4.91
2.7	5.91	5.84
3.8	8.90	9.12
4.2	10.69	10.46

The comparison of simulated results and values obtained from the curves is done and it can be seen that they are approximately equal. So the derived equations are valid at a specific design frequency and can be used as an open source to find or predict the useful shift of resonant frequency from original designed frequency due to the introduction of slots without the aid of simulation softwares.

It is observed that, introduction of slots increases the cur-rent path, i.e, the effective length (perimeter) increases, which in turn increases the wavelength. As wavelength increases, frequency decreases. So the shift of resonant frequency should be towards left. The ring width and shift of resonant frequency can be related by means of a cubic polynomial and also, ring width and return loss corresponding to shifted frequency can be related by means of a fifth degree polynomial. Introduction of slots results in multiple band of operation which can be used for wireless applications. For the ring widths greater than 4mm, a triple band of operation with significant gain and improved directivity has been seen.

V. CONCLUSION

In this paper, an analytical model for designing an edge fed rectangular slotted Microstrip patch antenna (MSA) is proposed. The introduction of rectangular slots on radiating patch results in ring shaped patch and it increases the current path. That is the effective length (perimeter) increases, which in turn increases the wavelength. As wavelength increases, frequency decreases. So there is a shift of resonant frequency towards left. The curves, shift in resonant frequency (f_r) V/s Ring width and return loss corresponding to shifted frequency (S_{11}) V/s Ring width have been studied and the best fit equations have been derived connecting them. The derived equation connecting Ring width and shift in resonant frequency is a cubic polynomial and that connecting ring width and return loss corresponding to shifted frequency is a fifth degree polynomial. Comparison of simulated results and values obtained from the curve for non-corner points is done and it can be seen that they are approximately equal. So the derived equations are valid at a specific design frequency and can be used as an open source to find or predict the useful shift of resonant frequency from original designed frequency due to the introduction of slots without the aid of simulation softwares. From the simulation, which is carried out in HFSS, for different ring widths in RMSA, it can be observed that introduction of slots results in multiple band of operation which can be used for wireless applications.

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