Design of Slot Cut Circularly Polarized Rectangular Microstrip Antenna

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ABSTRACT
Circularly polarized slot cut rectangular microstrip antenna on thinner substrate is proposed. The dimensions of the slots are modified such that the resonance frequencies of the two orthogonal modes are close to each other to realize circular polarization. To improve upon the gain, three layer suspended configuration is proposed which yields VSWR and axial ratio BW of 40 and 9 MHz, respectively. The antenna yields gain of more than 3 dBi over the axial ratio bandwidth. Further the formulation in resonant length at two orthogonal modes for slot cut patch on non-suspended and suspended configurations is proposed. The frequencies calculated using them closely agrees with the simulated results. Using proposed formulations, the design procedure for notch cut circularly polarized antennas in 1000 to 4000 MHz frequency band, is presented. It gives circularly polarized response with formation of small loop (kink) inside VSWR = 2 circle in the smith chart. Thus the proposed formulation can be used to design circular polarized antenna at any given frequency.

Keywords
Rectangular microstrip antenna, Circular Polarization, rectangular slot, suspended microstrip antenna

1. INTRODUCTION
Low profile and planar configurations of microstrip antenna (MSA) makes it useable in fields of mobile communication, satellite communications, etc. [1]. The disadvantages of MSA are like smaller bandwidth (BW) and lower gain which have been removed by using various broadband and higher gain techniques. Some of these techniques include use of thicker substrate, multi-resonator and slot cut configurations [1]. Circularly polarized (CP) MSA are used to avoid signal in case of applications where polarization of incoming wave is not known [1, 2]. Diagonally fed square MSA, cutting slot inside circular, square or equilateral triangle MSA's and chopping diagonal corners of the rectangular microstrip antenna (RMSA) are some of the techniques in which they are realized [1 – 3]. Two orthogonal feeds with power divider network method used to realize CP MAS's have lower efficiency due to losses in power divider network. U-slot, pair of rectangular slot and their modified variations are cut at an appropriate position inside the patch are other method to implement CP responses [7 – 4]. Better axial ratio BW, radiation pattern and gain are the performance improvement provided by these MSA's among other technique. Phase quadrature between the modes is achieved by the feed-point location selected in a way that it excites the two orthogonal modes with phase difference of +45° and -45°. The design formulation to realize slot cut CP RMSA at given frequency range is not available but its literature is reported earlier [1].

In this paper, first rectangular slot cut RMSA to realize CP response in 900 MHz frequency band on glass epoxy substrate (ε_r = 4.3, h = 0.16 cm, tan δ = 0.02) is presented. The parametric study to analyze the effect of slot on realized AR BW is given. The dimensions of the slots are modified such that the resonance frequencies f 1 and f 2 of the two orthogonal modes are close to each other to yield CP. The optimum VSWR and AR BW of 38 MHz and 8 MHz is obtained. These antennas have gain less than 0 dBi, as they are fabricated on glass epoxy substrate. To increase the gain, their three layer suspended configurations is presented. It yields VSWR and AR BW of 60 and 15 MHz, respectively with antenna gain of more than 5 dBi over AR BW. Further by studying surface current distribution at orthogonal resonant modes, a formulation of resonant length in terms of slot and patch dimensions is proposed for non-suspended as well as suspended configurations. The frequencies calculated using proposed formulation closely agrees with simulated results. Further using proposed formulation, detail procedure to design slot cut CP RMSA at any given frequency is presented. It yields CP response with formation of small loop (kink, which indicates the presence of CP) inside VSWR = 2 circle. Thus the proposed formulation can be used to design slot cut CP RMSA to realize CP on thinner as well as thicker suspended substrates. All these configurations have been first analyzed using IE3D software followed by experimental verifications [10]. The antennas were fed using SMA panel type connector of 0.12 cm inner wire diameter. The antennas were fabricated on low cost glass epoxy substrate. The impedance measurements were carried using R & S vector network analyzer (ZVH – 8). The RF source (SMB 100A) and spectrum network analyzer (FSC6) were used to measure radiation pattern and gain in minimum reflection surroundings with the required minimum far field distance between two antennas.

2. SLOT CUT CP RMSA
The slot cut CP RMSA is as shown in Fig. 1(a). The patch dimensions (L and W) are calculated such that it resonates at 900 MHz and it is found to be 8 x 8 cm. All the dimensions are given cm and the frequencies are mentioned in MHz. The rectangular slot is introduced in the patch center and coaxial feed is placed at the diagonal axis to get CP response. The parametric study was performed for different slot dimensions and the results for simulated resonance frequencies of two orthogonal modes are tabulated in Table 1.

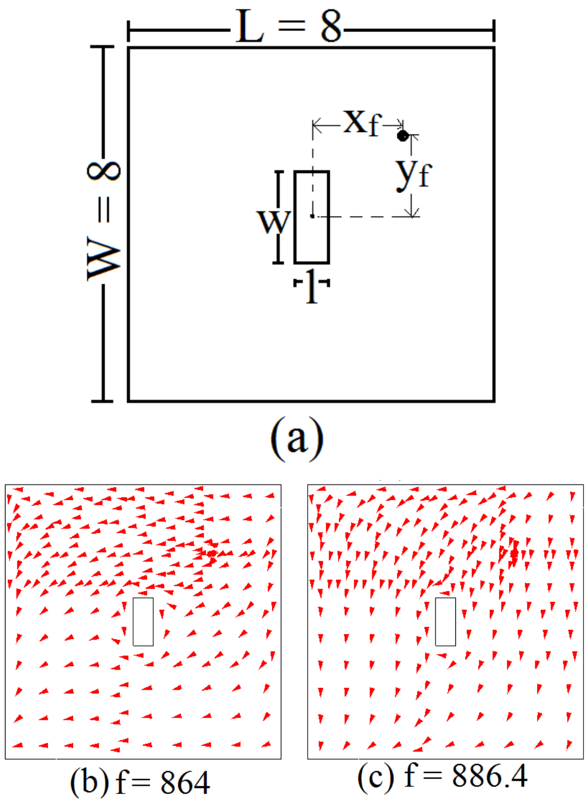

Fig.1. (a) Slot cut CP RMSA, and (b, c) its surface current distribution at two orthogonal modes

Table.1. Parametric study for varying slot dimensions

l x w (mm)	**Simulated frequency (GHz)**		**VSWRBW (MHz)**	**ARBW (MHz)**
	f_{s1}	**f_{s2}**		
6 x 13	0.8736	0.8864	27	2.4
6 x 14	0.8688	0.8864	30	7
6 x 15	0.864	0.8864	33	7.5
6 x 16	860	0.8864	37	6

The surface current distribution of two orthogonal modes for l = 6 and w = 15mm is given in Fig.1 (a, b).The VSWR and AR BW observed for different slot dimensions are also present in Table.1. The optimum results in terms of VSWBW and ARBW are obtained for slot dimensions w = 15mm. The simulated and measured impedance loci plot is given in Fig.2 (a). The simulated and measured VSWR BW are 33 MHz (3.66%) and 30 MHz (3.33%) respectively. The simulated AR BW for the same is 7.5 MHz as shown in Fig.2 (b). The configuration is optimized on lossy substrate so it has low gain of less than 0 dBi. In order to enhance the gain the same configuration is studied on suspended structure as shown in Fig.3. (a, b).

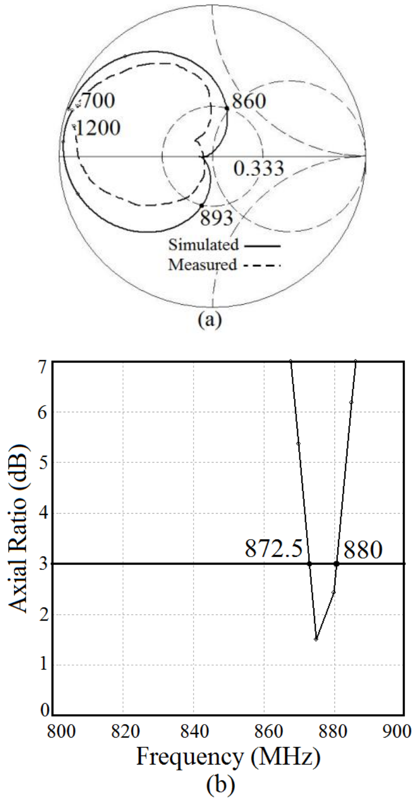

Fig.2. (a) input impedance plots and its (b) simulated AR plot against frequency for non-suspended configuration

The three layer suspended configuration is studied in which air gap of 1.6mm is present in between two glass substrate of 1.6mm thickness each. The panel type SMA connector is placed on bottom glass epoxy layer, which also acts as ground plane of the configuration whereas the patch is fabricated on top glass epoxy layer. The effective dielectric constant of suspended configuration is less as compare to non-suspended configuration, which increases the patch dimensions for the same fundamental mode resonance frequency. The effective dielectric constant is for the same is calculated using equation (1) and further by using resonance frequency equation [1] the patch dimensions are calculated. For 900 MHZ it is calculated to be 10.8 cm. The suspended configuration of slot cut RMSA is simulated for various slot dimensions and the simulated orthogonal frequencies are tabulated in Table.2.

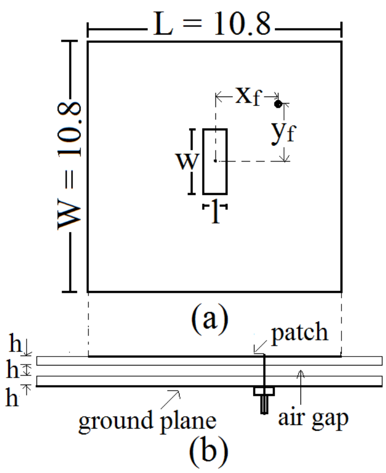

Fig.3. (a, b) top and side view of suspended configuration

$$\varepsilon_{re} = \frac{3\varepsilon_r}{\varepsilon_r + 2} \quad (1)$$

where, h = substrate thickness of glass epoxy and air gap

ε_r = permittivity of the substrate

f_r = desired resonance frequency in GHz,

The surface current distribution of two orthogonal for slot dimension l = 10 and w = 25 mm is given in Fig.4 (a, b). The VSWR and AR BW for different slot dimension are shown in Table.2.

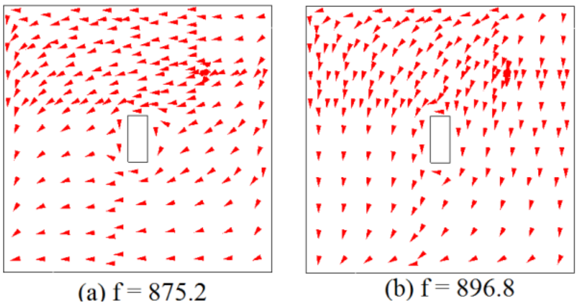

Fig.4. (a, b) surface current distribution at two orthogonal modes of suspended configuration)

Table.2. Parametric study for varying slot dimensions

l x w (mm)	Simulated frequency (GHz)		VSWRBW (MHz)	ARBW (MHz)
	f_{s1}	f_{s2}		
10 x 24	0.878	0.8986	35	7.6
10 x 25	0.8752	0.8986	42	9
10 x 26	0.874	0.899	46	7.8
10 x 27	0.869	0.896	49	7

The optimum VSWR and AR BW is obtained for W =25 mm .The simulated and measured input impedance loci plot is shown in Fig.5. The simulated BW is 40 MHz. the slot cut CP RMSA was fabricated for this slot length and its measured BW is obtained to be 38 MHz. the measurement was done using ZVH-8 Vector Network Analyzer (VNA). The simulated AR BW is of 9 MHz which is given in Fig.5 (b). The peak gain is obtained to be more than 3 dBi in VSWR and AR BW due to suspended configuration. The slot cut RMSA configuration is reported earlier but design formulation to get two orthogonal modes is not available. In this paper, after studying the surface current distributions of two orthogonal mode we have come up with the formulation of resonant length for two orthogonal modes. Using these formulations the design procedure to realize CP RMSA at any given frequency is also presented.

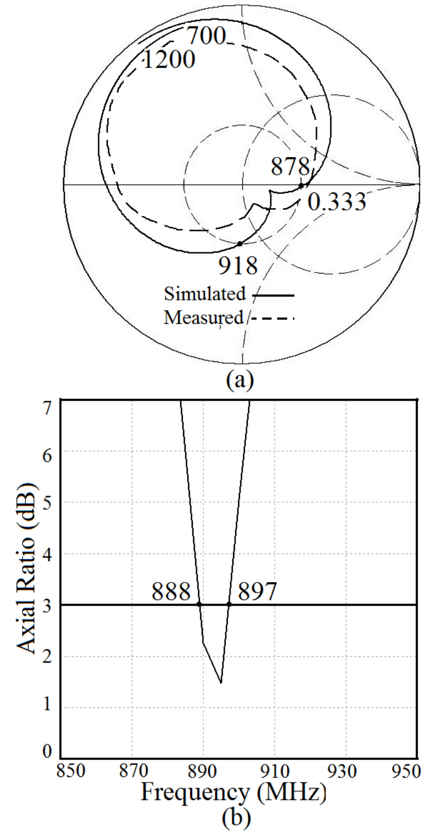

Fig.5. (a) input impedance plots and its (b) simulated AR plot against frequency for suspended configuration

3. FORMULATION OF RESONANT LENGTH FOR CP RMSA

As seen from the surface current distribution at two orthogonal modes current components are circulating around the slot edges. For non-suspended configuration, formulation of resonant length is achieved by varying patch dimensions in terms of slot dimensions as given in equation (2) and (3). The resonance frequencies are calculated using equation (4) and (5). And the %error is calculated using equation (6). The Fig.6. Shows the plots for simulated and measured orthogonal frequencies and the % error plot for the same. The plot shows the closer approximation between simulated and measured frequencies of both the modes.

$$L_e = L + \frac{w}{4} \quad (2)$$

$$W_e = W + \frac{l}{4} \quad (3)$$

$$f_r = \frac{c}{2L_e\sqrt{\varepsilon_e}} \quad (4)$$

$$f_r = \frac{c}{2W_e\sqrt{\varepsilon_e}} \quad (5)$$

$$E = \left(\frac{f_{s1} - f_{r1}}{f_{s1}}\right) x100 \quad (6)$$

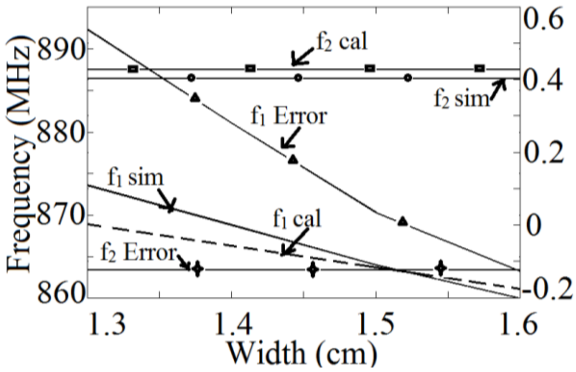

Fig.6. Dual frequency and % error plots for non-suspended slot cut CP RMSA

For the suspended configuration, by studying Fig.4 (a, b) the resonant length formulation of two orthogonal modes is given in equation (7) and (8). The effective resonant length is achieved by modifying patch dimensions in terms of slot dimensions. The Fig.7. Shows the plot of frequencies and % error which is calculated using equations (7) and (8). The closer approximation of simulated and calculated frequencies is obtained for entire range of slot dimension.

$$L_e = L + w/3 \quad (7)$$

$$W_e = W + l/2 \quad (8)$$

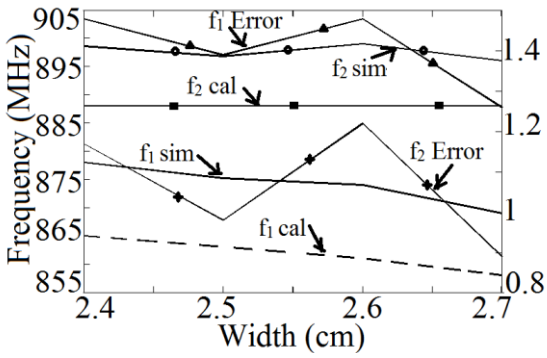

Fig.7. Dual frequency and % error plots for suspended slot cut CP RMSA

Using the formulations done above, slot cut CP RMSAs are designed for various frequency bands. In above configurations at 900 MHz, f_2/f_1 ratio for non-suspended configuration is optimized to be 1.015 and for suspended configuration it is 1.02. The slot length (l) is selected to be $0.018\lambda_0$ in non-suspended and $0.03\lambda_0$ in suspended one. Whereas, the slot width is chosen to be $0.045\lambda_0$ and $0.075\lambda_0$ for non-suspended and suspended configurations respectively. The feed is present at diagonal axis i.e. $x_f = y_f = 0.06\lambda_0$. The substrate thickness for non-suspended configuration is $0.005\lambda_0$ and for non-suspended configuration is $0.014\lambda_0$. The air gap thickness of suspended configuration is $0.005\lambda_0$. First the design of non-suspended configuration for two different frequency bands is presented. The patch dimensions are calculated using RMSA equation [1]. Using the proposed formulation for non-suspended MSA, and there ratio against slot width is generated at respective frequencies and they are plotted in Fig.8. From the plot, value of slot width is selected which gives f_2/f_1 of approximately 1.015 is selected. The slot of selected width and $0.018\lambda_0$ in length is cut inside the patch and it is simulated using IE3D software. For the individual frequencies measurements were done and there plots are presented in Fig.8. It shows closer agreement with simulated results. At both the frequencies CP response with formation of loop (kink) inside VSWR = 2 is achieved. The various antenna parameters for different range are tabulated in Table.3.

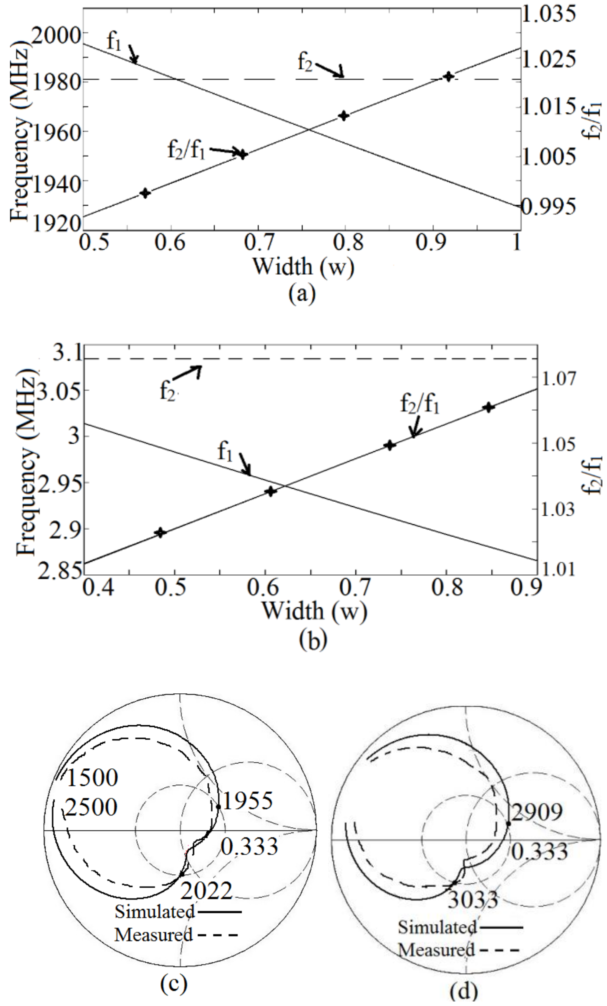

Fig.8. Dual frequency and their ratio plots at (a) 2 GHz, (b) 3 GHz and input impedance plots at (c) 2 GHz, (d) 3 GHz for non-suspended slot cut CP RMSA

In case of suspended configuration, an air gap of $0.005\lambda_0$ is selected at a desire frequency. The patch dimensions are calculated using RMSA equation [1]. The air gap spacing is maintained to be 0.7mm and 0.48mm for 2 and 3 GHz respectively. Using the formulation dual frequency and their ratio plot is given in Fig.9. The slot width for which ratio is $1.02\lambda_0$ is selected. The slot of selected dimensions is introduced in the patch. The patch is simulated and its impedance plot is presented in Fig.9 (c, d).

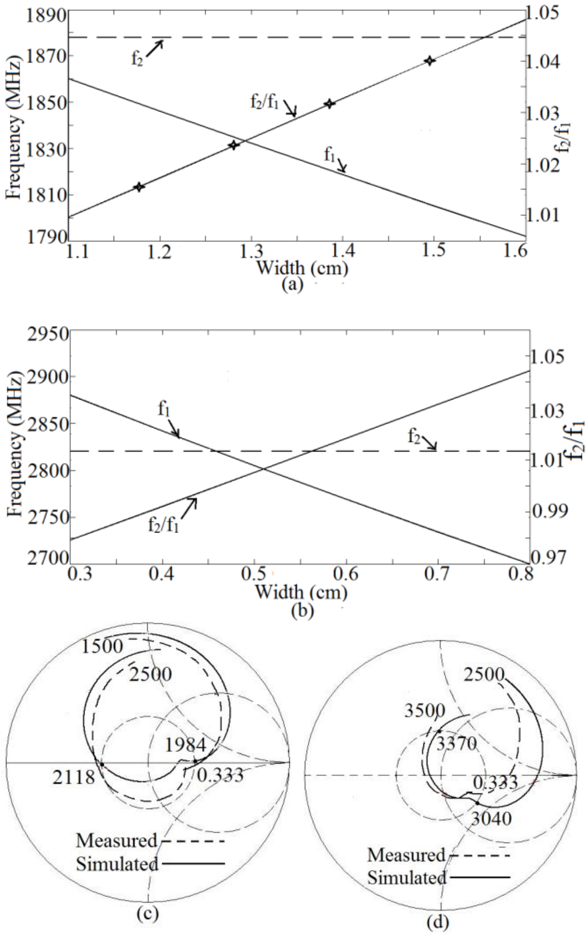

Fig.9. Dual frequency and their ratio plots at (a) 2 GHz, (b)3 GHz and their input impedance plots at (c) 2 GHz, (d) 3 GHz for suspended slot cut CP RMSA

The impedance plot shows the presence of small loop inside VSWR = 2 circle showing the presence of CP. The measurement shows closer approximation with simulated results.

Table 3. Various parameters for suspended and non-suspended configurations

f_r (GHz)		l (mm)	W (mm)	VSWR BW (MHz)		ARBW (MHz)
				sim	meas	
2	Non-suspended	2.7	7.2	67	52	12
	suspended	4.5	13	134	110	25
3	Non-suspended	1.8	6	124	115	29
	suspended	3	4.75	330	299	40

4. CONCLUSION

The rectangular slot cut CP CMSA is proposed. The dimensions of the slot bring two orthogonal frequencies close to each other to yield CP. To enhance its gain a three layer suspended configuration of the same is proposed which gives VSWR and AR BW of 9 and 40 MHz, respectively with antenna gain of more than 3 dBi over the AR BW. Further by studying the surface current distributions, a formulation in resonant length at two orthogonal modes in terms of slot and patch dimensions is proposed. The frequencies calculated using proposed formulations agree closely with the simulated results. Using proposed formulations, design of slot cut RMSA at other frequencies is presented, which gives CP response with formation of small loop inside VSWR = 2 circle. Thus proposed formulations can be used to design CP RMSA in desired frequency band.

5. REFERENCES

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