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Design of Truncated Corner Circularly Polarized Rectangular Microstrip Antenna

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ABSTRACT
Formulations and design procedure for three layer suspended and non-suspended configurations of rectangular slot cut rectangular microstrip antenna have already been reported. In this paper, atruncated cornerrectangular microstrip antenna to realize circular polarization on thinner substrate is proposed. The truncated cornersdegenerates' fundamental TM_{10} mode into two orthogonal modes, to yield circular polarization. To improve upon the gain, three layer suspended configuration is proposed which yields VSWR and axial ratio BW of 49 and 9.5 MHz, respectively. The antenna yields gain of more than 6dBi over the axial ratio bandwidth. Further the formulation in resonant length at two orthogonal modes for truncated corner 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 truncated corner circularly polarized rectangular microstrip antenna 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, truncated corner, suspended microstrip antenna

1. INTRODUCTION
Circularly polarized (CP) Microstrip antennas (MSAs) are used in applications which require reduced signal loss present due to mismatch between antenna polarization and polarization of incoming waves [1, 2]. The CP response can be realized by cutting various slots/notch inside or on the edges of the patch and the necessary 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° [3 - 5]. There are some slots i.e. U slots and a pair of rectangular which are frequently used to generate CP response.In U slot cut MSAs an unequal length of the two arms is taken which helps in realizing equal contribution of vertical and horizontal surface current components that yields CP response. CP response can also be achieved by chopping the diagonally opposite corners of the rectangular MSA (RMSA) and feeding it along horizontal/vertical axis of the RMSA [6 - 9].In truncated corner RMSA an unequal length of the two diagonalshelps in realizing the CP response. These U-slot or rectangular slot cut CP MSAs yields better response in terms of AR BW and gain as compared to slot/notch cut , truncated corner MSAs. Two orthogonal feeds with power divider network method can also be used to realize CP MSA's but havelower efficiency due to losses in power divider network. However in most of reported CP configurations, formulation of resonant length for two orthogonal patch modes and design procedure to realize CP response at any given frequency is not given. In [10], 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) was presented. The parametric study to analyze the effect of slot on realized AR BW wasgiven. The dimensions of the slot were modified such that the resonance frequencies f 1 and f 2 of the two orthogonal modes were close to each other to yield CP. The optimum VSWR and AR BW of 38 MHz and 8 MHz was obtained. These antennas had gain less than 0 dBi, as they were fabricated on glass epoxy substrate. To increase the gain, their three layer suspended configurations was 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 was 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 was presented. It yields CP response with formation of small loop (kink, which indicates the presence of CP) inside VSWR = 2 circle. In this paper, first truncated corner 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 chopped length of RMSAdegenerate fundamental TM_{11} mode into two orthogonal modes to yield CP. The parametric study to analyze the effect of notch on realized AR BW is given. The optimum VSWR and AR BW of 34MHz and8 MHz is obtained. These antennas have gain less than 0 dBi, sincethey are fabricated on glass epoxy substrate.To increase the gain,their three layer suspended configurationsis proposed. It yields VSWR and AR BWof 49 and 9.5 MHz, respectively with antenna gain of more than6dBi over AR BW. Further bystudying surface current distribution at two orthogonal resonant modes, a formulationsof resonant lengths in terms oftruncated length and patch dimensions are proposed for non-suspended as well as suspended MSAs. The frequencies calculated using proposed formulation closely agrees with simulated results. Further using proposed formulation, procedure to design truncated corner CP RMSA at any given frequency is outlined.It yields CP response with formation of

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small loop (kink, which indicates the presence of CP) inside VSWR = 2 circle.Thus the proposed formulation can be used to design truncated corner RMSA to realize CP response on thinner as well as thicker suspended substrates. The RMSAs were first studied using IE3D software [11] followed by experimental verification. The antennas were fed using SMA panel type connector of 0.12 cm inner wire diameter.Theimpedance 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 gainin minimum reflection surroundings with the required minimum far field distance between the two antennas.

2. SLOT CUT CP RMSA

In [], the non-suspended configuration of the slot cut CP RMSA was presented as shown in Fig: 1. All the dimensions are given in cm. By studying the surface current distributions at two orthogonal resonant modes shown in Fig 1,we had presentedthe formulation of resonant length for both the modes in terms of slot and patch dimensions as given in equations (1) and (2). The resonance frequencies were calculated using equation (3) and (4). And the %error wascalculated using equation (5).

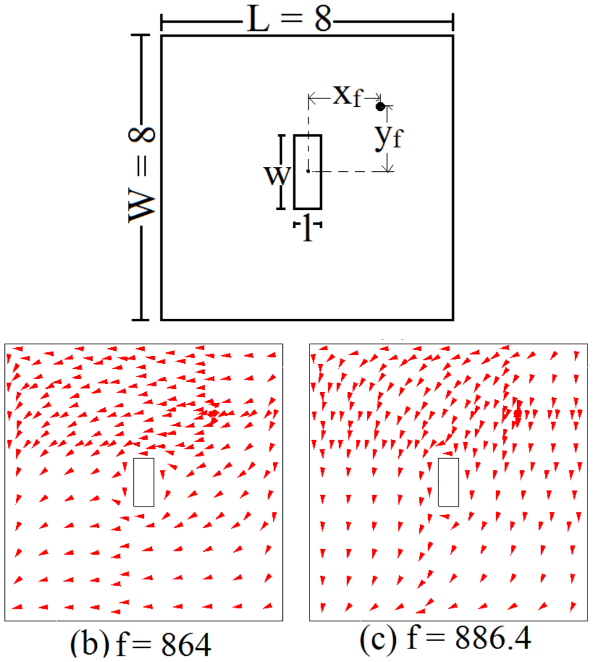

Fig: 1(a) Slot cut CP RMSA, and (b, c) its surface current distribution at two orthogonal modes

$$L_e = L + w/4 \quad (1)$$

$$W_e = W + l/4 \quad (2)$$

$$f_r = \frac{c}{2L_e\sqrt{\varepsilon_e}} \quad (3)$$

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

$$E = \left|\frac{f_{s1} - f_{r1}}{f_{s1}}\right| \times 100 \quad (5)$$

As slot cut CP RMSA was fabricated on lossy substrate it has gain less than 0 dBi. To improve the same its three layer suspended configuration was proposed. The three layer suspended configuration is studied in which air gap of 3mm is present in between two glass substrate of 1.6mm thickness each. 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 for the same is calculated using equation (6) and the formulation of resonant length for the suspended configuration was given by equation (7) and (8). Further the frequencies can be calculated using equation (3) and (4) and percentage error using equation (5). The closer approximation of simulated and calculated frequencies is obtained for entire range of slot dimension for both the configurations.

$$\varepsilon_{re} = \frac{\varepsilon_r \varepsilon_{r1}(2h + h_1)}{2h\varepsilon_r + h_1\varepsilon_{r1}} \quad (6)$$

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

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

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

ε_r= permittivity of the substrate

ε_{r1} = permittivity of the substrate

Using the formulations done above, slot cut CP RMSAs were 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. Using the proposed formulation for non-suspended MSA, there ratio against slot width is generate0d at respective frequencies and they are plotted in Fig: 2 and 3(a).

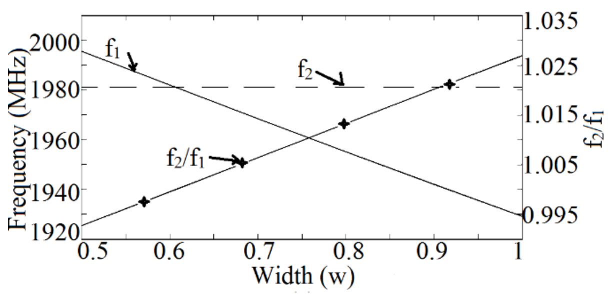

Fig: 2 Dual frequency and their ratio plots at 2 GHz

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: 3 (b, c).

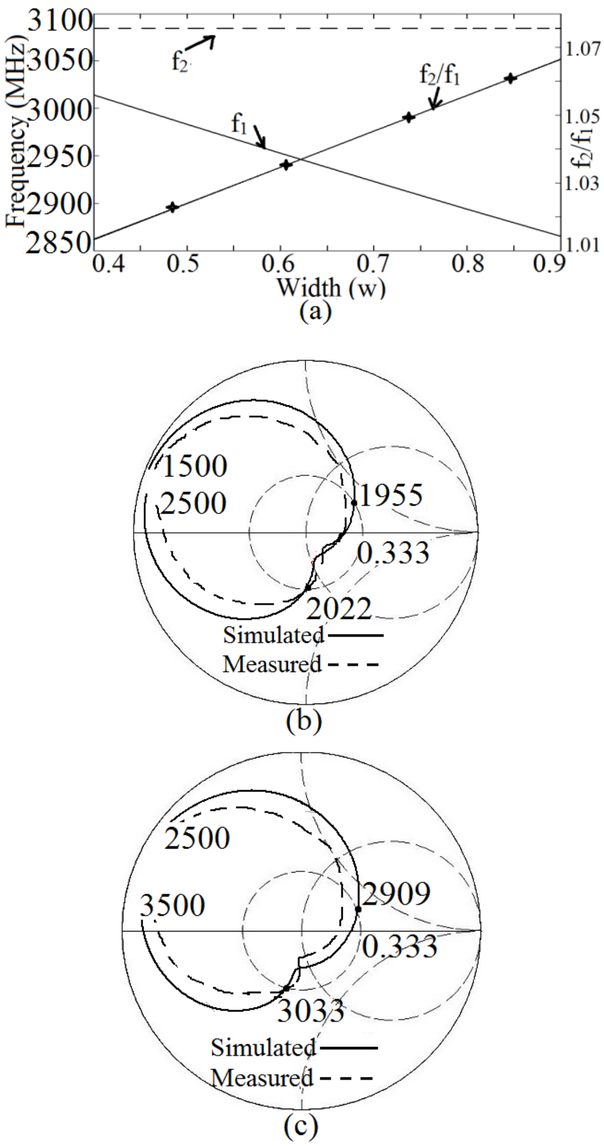

Fig: 3 (a) Dual frequency and their ratio plots at 3 GHz andInput impedance plots at (c) 2 GHz, (d) 3 GHz for non-suspended slot cut CP RMSA

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: 3 (a, b). The slot width for which ratio is $1.02\lambda_0$ is selected and slot length is selected to be $0.03\lambda_0$. The slot of selected dimensions is introduced in the patch. The patch is simulated and its impedance plot is presented in Fig: 3 (c, d). 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.

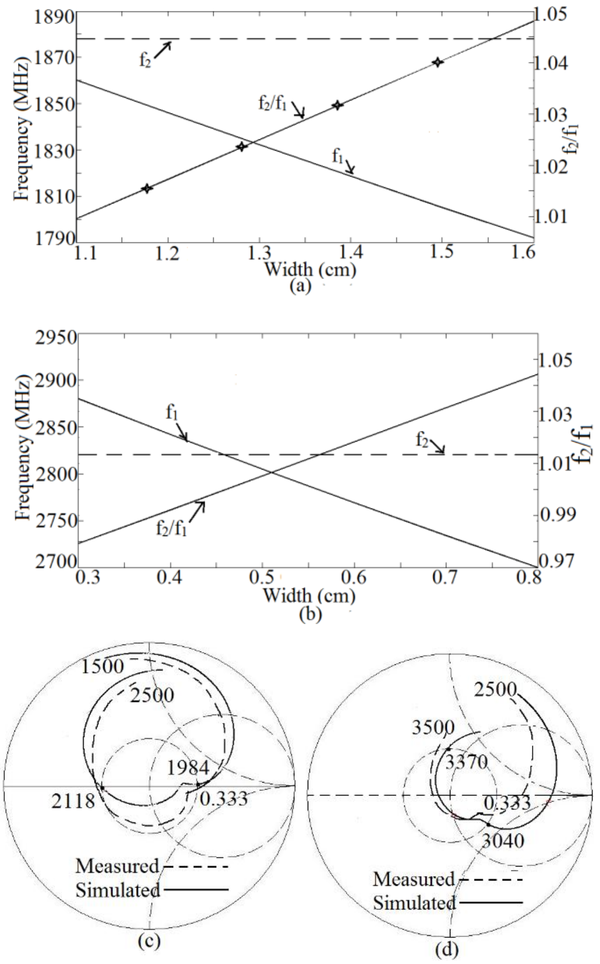

Fig: 4Dual frequency and their ratio plots at (a) 2 GHz, (b)3 GHz and their input impedance plots at (c) 2 GHz, (d) 3 GHz for suspended slot cut CP RMSA

3. TRUNCATED CORNER CP RMSA

The truncated corner CP RMSA is shown in Fig:5 (a). The patch dimensions (L and W) are calculated such that it resonates at 900 MHz and it is found to be 8x 8 cm. All the dimensions are given in cm and the frequencies are mentioned in MHz.The diagonally opposite corners of RMSA are chopped,the truncated corners on patch periphery degenerates fundamental TM_{10} mode into two orthogonal modes that realizes CP.At both the modes, currents are varying along the diagonals. Further the parametric study was performed for different truncated lengths and the results for simulated resonance frequencies of two orthogonal modes and its effect on VSWR and AR BW are tabulated in Table 1.The surface current distributions at two orthogonal modes for truncated length 'l' = 9.5mmare shown in Fig. 5 (b, c) , For these value of truncated length, optimum results in terms of VSWR and AR BW is obtained as shown in Fig. 4(d, e). The simulated and measured BW's are, 34 MHz (3.77%) and 32 MHz (3.77%), respectively, whereas simulated AR BW is 7.5MHz.For truncated length (l) more than 9.5 mm, spacing between two modes increases which does not maintain necessary phase quadrature and nearly equal amplitudes between two modes to realize AR less than 3 dB. Hence ARBW reduces for w ≥ 9.5 mm.

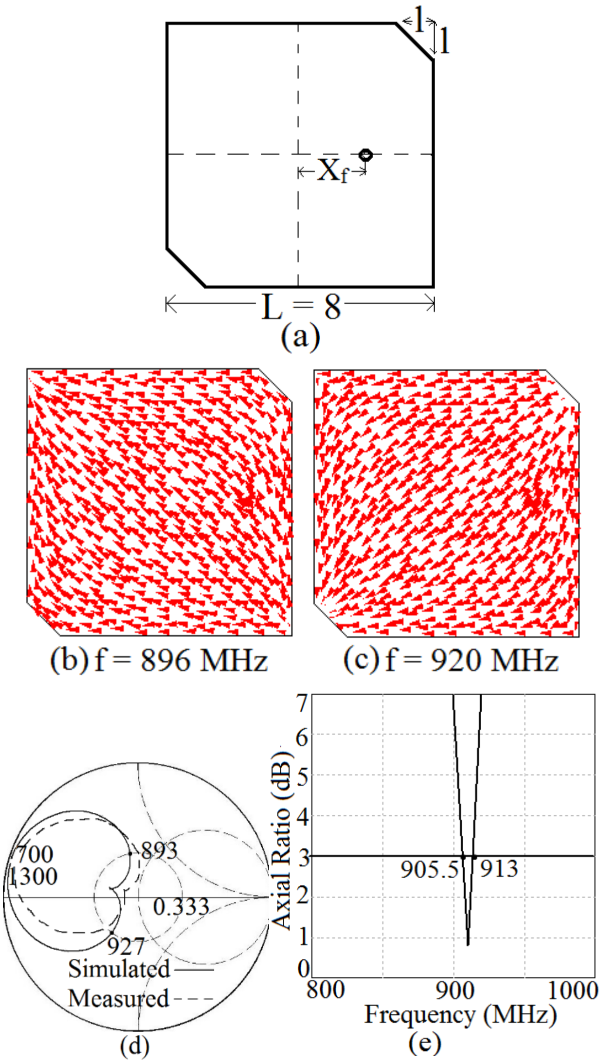

Fig: 5 (a) Truncated corner CP RMSA,(b, c) its surface current distribution at two orthogonal modes, (d) Input impedance plots and its (b) simulated AR plot against frequency

Table1. Parametric study for dimension of truncated length

l (mm)	Simulated frequency (GHz)		VSWRBW (MHz)	ARBW (MHz)
	f_{s1}	f_{s2}		
8.5	0.898	0.9148	29	4
9	0.896	0.917	32	6
9.5	0.896	0.920	34	7.5
10	0.896	0.922	36	6

As truncated corner RMSA is fabricated on lossy substrate it has gain less than 0 dBi. To improve the same its three layer suspended configuration is proposed as shown in Fig. 6(a, b).In three layer suspended configuration two layers of glass epoxy substrate are separated by an air gap of thickness 3 mm ($0.015\lambda_0$). The patch is fabricated on top glass epoxy layer whereas panel type SMA connector is connected to bottom glass epoxy layer. The effective dielectric constant reduces in suspended configuration, which increases the patch dimensions for the same TM_{10} mode frequency. The effective dielectric constant (ε_{re}) is calculated by using equation (6) and further by using equations in [1] patch dimensions are calculated.

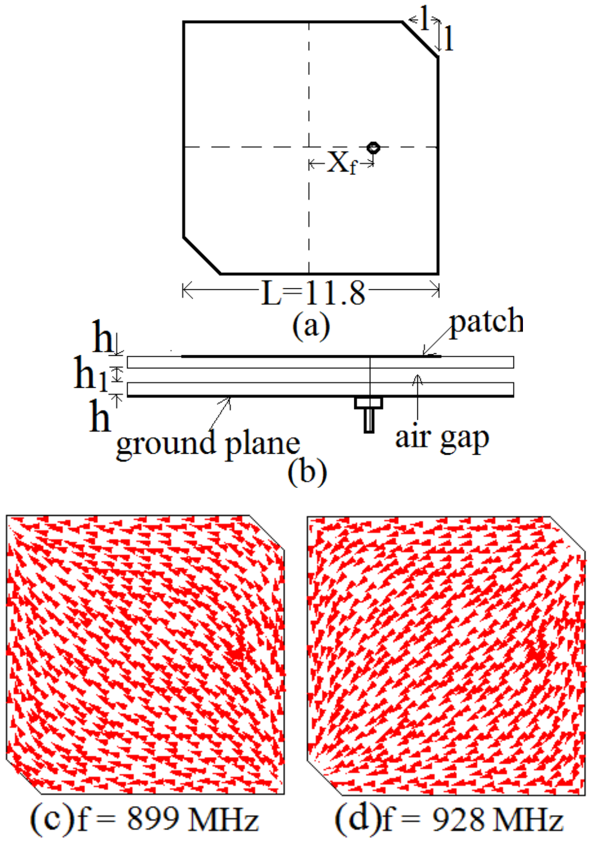

Fig: 5(a, b) top and side view of suspended configuration and (c, d)surface current distribution at two orthogonal modes of suspended configuration

The parametric study for variation in truncated length is carried out and their results are given in Table 2. The optimum result in terms of AR BW is obtained for l = 16 mm and it's simulated and measured input impedance plots and simulated AR plot is shown in Fig. 6(a, b).

Table 2. Parametric study for varying dimension of truncated length

l (mm)	Simulated frequency (GHz)		VSWRBW (MHz)	ARBW (MHz)
	f_{s1}	f_{s2}		
14	0.899	0.918	41	6.3
16	0.899	0.928	49.7	9.5
17	0.899	0.932	51	7
18	0.899	0.937	59	2

The simulated and measured BW's are, 49 MHz (5.44%) and 50 MHz (5.55%), respectively, whereas the simulated AR BW is 9.5 MHz.Due to suspended configuration, antenna gain is more than 6dBi over VSWR and AR BW. The current distributions in suspended configuration at orthogonal modes are similar to that observed in non-suspendedRMSA.

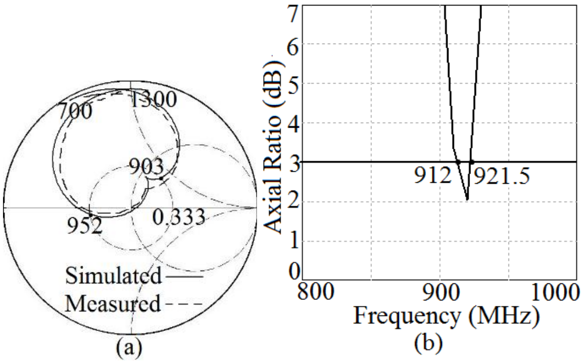

Fig: 6 (a) Input impedance plots and its (b) simulated AR plot against frequency for suspended configuration

In reported literature on CP RMSAs, similar configurations are reported [1 – 3]. However the formulation of resonant length at orthogonal modes as well as procedure to design truncated corner CP RMSA using proposed formulations at any given frequency is not available. In following sections by studying surface current distributions at orthogonal modes, formulation in resonant length at two modes and procedure to design truncated corner CP RMSA at any given frequency, is explained for non-suspended and suspended configurations.

4. FORMULATION OF RESONANT LENGTH FOR CP RMSA

As seen from the surface current distribution at two orthogonal modes current components are circulating alongthe diagonals of the RMSA. For non-suspended configuration, formulation of resonant length is achieved by varying patch dimensions in terms of truncated length as given in equation (9) and (10). The resonance frequencies are calculated using equation (3) and (4). And the %error is calculated using equation (5). The Fig: 7Shows 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.

$$L_{e1} = L \tag{9}$$

$$L_{e2} = W - l/6 \tag{10}$$

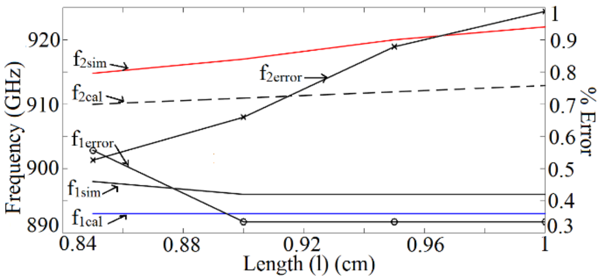

Fig: 7 Dual frequency and % error plots for non-suspended slot cut CP RMSA

Similarly using equations (11) and (12) formulation for suspended CP RMSA is obtained. The frequencies and % error plots calculated using equations (6) – (8) shows closer match with an error less than 2% as shown in Fig. 8.

$$L_{e1} = L \tag{11}$$

$$L_{e2} = W - l/4 \tag{12}$$

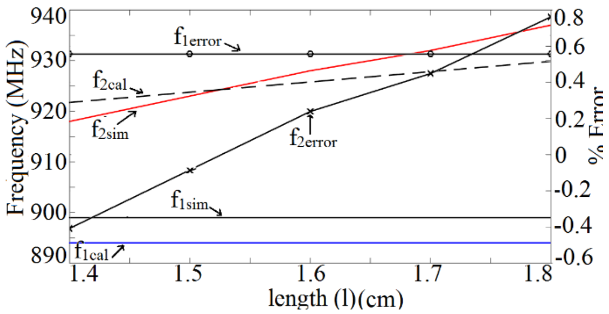

Fig: 8 Dual frequency and % error plots for suspended slot cut CP RMSA

Using proposed formulations truncated corner CP RMSA is designed at different frequencies. At 900 MHz, f_2/f_1 ratio in optimized CP RMSAis 1.021 and 1.036 for non-suspended and suspended MSAs, respectively as shown in Fig: 9 (a, b).The design of truncated corner CP RMSA at 2 and 3 GHz, using above formulations is presented for non-suspended glass epoxy substrate. The patch dimensions at 2 and 3 GHz are calculated [1]. Using non-suspended MSA formulations,plots of orthogonal frequencies and their ratio against varying truncated length are generated at respective frequencies and they are plotted in Fig. 10(a) and (b) for 2 and 3 GHz, respectively.

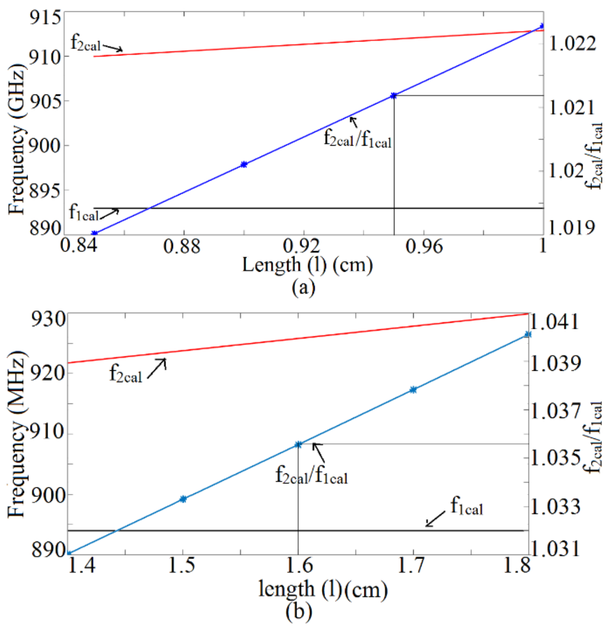

Fig: 9 Dual frequency and their ratio plots at 900 MHz for (a) non-suspended and (b) suspended configuration

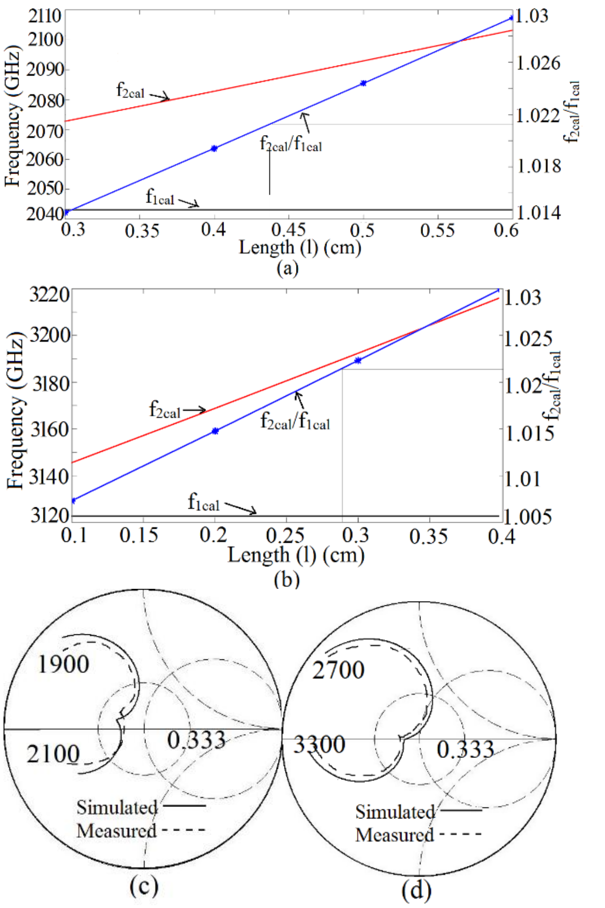

Fig: 10Dual frequency and their ratio plots at (a) 2 GHz, (b)3 GHzand input impedance plots at (c) 2 GHz, (d) 3 GHz for non-suspended slot cut CP RMSA

Using frequency plots, value of truncated length that gives f_2/f_1 of nearly 1.021 is selected. The MSA is simulated using IE3D software and its input impedance plot is shown in Fig. 10 (c, d). At both frequencies, CP response with formation of loop (kink) inside VSWR = 2 circle is obtained. The measurement was carried out to validate the simulated results which show a closer match. In case of suspended configuration, an air gap of $0.09\lambda_0$ is selected at a desired frequency. The air gap spacing is maintained to be 1.35 mm and 0.9 mm for 2 and 3 GHz respectively. Using the formulation dual frequency and their ratio plot is given in Fig: 11 and 12(a). The truncated length for which ratio is $1.036\lambda_0$ is selected. The RMSA is simulated and its impedance plot is presented in Fig: 12 (b, c).

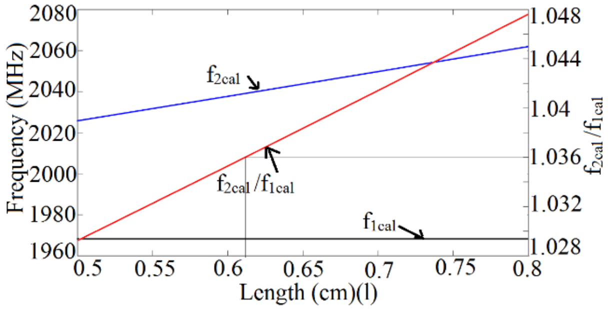

Fig: 11 Dual frequency and their ratio plots at 2 GHz

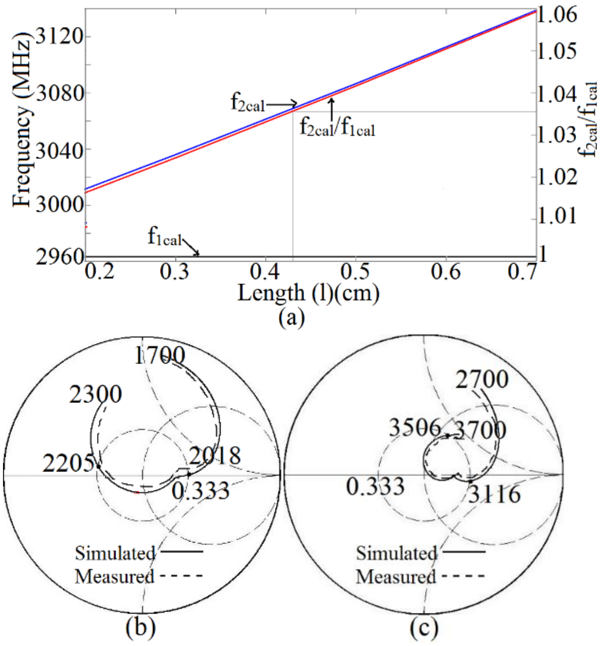

Fig: 11(a)Dual frequency and their ratio plots at 3 GHz, and their input impedance plots at (b) 2 GHz, (c) 3 GHz for suspended slot cut CP RMSA

5. CONCLUSIONS

The design of truncated corner CP RMSA at 900 MHz on thinner and thicker suspended substrate is discussed. The formulation of resonant length at orthogonal modes in terms of patch and truncated length is proposed. The frequencies calculated using them closely agrees with simulated results. Using proposed formulations, design of truncated length CP RMSA at different frequencies and on thinner as well as thicker substrate is presented. They give CP response with formation of small loop inside VSWR = 2 circle. Thus the proposed formulations can be useful for designing truncated corner CP RMSA at any desired frequencyband.

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