1. INTRODUCTION

Various applications require a single radiating element, which are tunable to operate in multiple frequency bands. When microstrip antennas (MSA) are loaded with monolithic stubs, shorting pins or slots, the electrical resonant length of the patch gets modified and hence tunable or multiple frequency antennas can be realized. [1]. A RMSA with a \( \lambda/2 \) short-circuited or \( \lambda/4 \) open circuited stub placed along radiating or non-radiating edge of the patch, exhibits dual frequency operation [2]. As the stub is protruding out from the periphery of the patch, this configuration occupies more space and hence limits its application where compact dual frequency antennas are required. This paper describes a compact dual frequency RMSA in which, the effect of reactive loading is realized by cutting a slot of nearly \( \lambda/4 \) length along one of its non-radiating edges as shown in Fig. 1. This configuration with broadside radiation pattern at both the resonance frequencies \( f_1 \) and \( f_2 \) has been analyzed using contour integral method (CIM) with modified edge admittance network method [3, 4]. The simulated results have been verified using method of moment based IE3D software [5] followed by experimental verification.

![Diagram of slot loaded RMSA](image)

Fig. 1 (a) slot loaded RMSA and (b) its N-port model

2. CIM FOR ANALYZING SLOT LOADED RMSA

The slot loaded RMSA shown Fig. 1 has been analyzed using CIM in which the wave equation is converted to contour integral form, that relates the voltage and current along the circuit periphery as per equation 1.1 [3].

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\[ V(s) = \frac{1}{2\pi c} \left[ K \cos \theta H^\parallel (kr) V(s) - j\omega d H^\parallel (kr) j_i(s) \right] ds \]

The physical periphery of the patch is extended outwards to account for the fringing fields. The extended periphery is divided into number of sections as shown Fig. 2 so that the magnetic and electric field intensities over each section are assumed to be constant. Hence, the integral equation results in a system of matrix equations from which the \( Z \)-matrix corresponding to the field under the patch can be evaluated. The radiation from the periphery is taken into account by loading these ports with the corresponding radiation conductance evaluated over the respective port width [4]. These impedance matrices are combined using segmentation method to evaluate the input impedance \( Z_{in} \) and voltage distribution along the periphery of the patch.

3. SIMULATED RESULTS

A RMSA of length \( L = 4 \) and \( W = 6 \) cm having \( \varepsilon_r = 4.3, \) thickness \( h = 0.159 \) cm and loss tangent \( \tan \delta = 0.02 \) fed at the edge of the patch has been simulated using CIM and the resonance frequency \( f \) of the patch corresponds to 1.778 GHz. When this patch is loaded with a slot of length \( l = 6 \) mm, width \( w = 0.5 \) cm, at the center of the patch, the simulated results shows that the resonance frequency \( f \) of the patch corresponding to the fundamental mode reduces to 1.705 GHz due to the elongated path length as the surface current circulates along the slot. The small loop in the impedance plot of this configuration shown in Fig. 2 (a), indicates the excitation of another new mode similar to \( T_{M1} \) which would not have excited in the absence of the slot.

Fig. 2 Input impedance plots of slot loaded RMSA using CIM for (a) slot length \( l = 6 \) mm (b) 14 mm.

The patch has been simulated for different slot lengths and the input impedance plots corresponding to slot length of 14mm is shown in Fig. 2 (b). It is observed that as the slot length increases the first resonance frequency \( f_1 \) of the patch reduces and the second resonance becomes prominent resulting in dual band operation of the patch. The peripheral voltage distributions of the patch corresponding to a slot length of 20 mm at the respective resonance frequencies of 1.187 and 2.02 GHz are shown in Fig. 3(a) and
(b) respectively. This configuration has also been simulated using IE3D and the corresponding resonance frequencies of 1.203 and 2.003GHz are in good agreement with that of CIM. The simulated radiation patterns using IE3D depicted in Fig. 4 (a) and (b) respectively are along the broadside direction with the cross polar levels below -14dB.

![Voltage distribution around the periphery of slot loaded RMSA at (a) f_1 = 1.187 and (b) at f_2 = 2.02 GHz using CIM](image1)

![Simulated radiation pattern using IE3D (a) at f_1 = 1.203 and (b) f_2 = 1.997 GHz](image2)

3. EFFECTS OF VARIATIONS IN SLOT DIMENSIONS

The surface current path length of the patch depends on the slot dimensions and the effect is more dominant at the lower resonance frequency. The variation of f_1 and f_2 for different slot lengths are presented in Fig. 5. As the slot length l is increased from 0.6 to 3 cm, f_1 decreases from 1.705 to 0.985 GHz whereas f_2 remains almost constant at around 2.03 GHz. Hence, the frequency ratio (f_r = f_2/f_1) of up to 2.06 can obtained for appropriate choice of the slot dimensions. The resonance frequencies are affected by the slot location also. The surface current has its maxima at the center of the patch and is tending to zero towards the edge of the patch. As the slot is moving towards the edge of the patch, the lower resonance frequency which corresponds to the perturbed fundamental mode of the patch increases to the fundamental frequency of the patch without the slot and the higher resonance mode of the configuration vanishes due to the reduction in perturbation on the surface current.
4. EXPERIMENTAL RESULTS

The simulated results of the slot loaded RMSA fabricated on glass epoxy substrate having $\varepsilon_r = 4.3$, thickness $h = 0.159$ cm and loss tangent $\tan\delta = 0.02$ with slot dimensions corresponding to $l = 20$ mm and $w = 5$ mm, fed at $x = 1$ mm using CIM has been verified experimentally and the corresponding VSWR plot is shown in Fig. 6. The simulated resonance frequencies of 1.187 and 2.03 GHz are within 1.5 % the measured frequencies of 1.203 and 2.016 GHz. The VSWR at both the bands are closer to 1 indicating that the $Z_{in}$ is matched to 50 $\Omega$.

Fig. 5. Variation of $f_1$ (-----) and $f_2$ (----) for different slot lengths

Fig. 6 Simulated and plots of slot loaded RMSA measured VSWR

6. CONCLUSIONS

A RMSA embedded with rectangular slot along the non-radiating edge of the patch, yielding dual frequency operation with broadside radiation pattern has been theoretically analyzed using both CIM and IE3D. The slot is modifying the resonant length of the fundamental mode of the simple RMSA and is introducing a new resonant mode similar to TM$_{11}$. The effects of slot dimensions and the location of the slot on both the resonance frequencies have been investigated. The proposed configuration is tunable for appropriate choice of the slot length and location of the slot. The simulated results have been verified experimentally and the theoretical resonance frequencies are within 1.5 % of the measured values.

REFERENCES