A Compact Broadband and High Gain Tapered Slot Antenna with Stripline Feeding Network for H, X, Ku and K Band Applications

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Abstract*—In this paper, a planar travelling wave tapered slot antenna with compact size is proposed for wireless communication applications. The prototype of antenna is developed on Roger RT/Duroid 5880 laminate with tan δ = 0.0009, a relative permittivity of 2.2 while working in the range of 6GHz – 21GHz. The simple feeding technique transits with radial cavity and the opening taper profile. The antenna dimensions of the antenna have been designed in such a manner so as to enable impedance matching. The parametric study of the variables is carried out by various scrupulous simulations. The designed characteristic antenna has achieved an impedance bandwidth in the broadband spectrum of 111.11% at the minimum 10-dB return loss and peak realized gain of 7dBi is obtained for a resonant frequency of 19.6GHz. The simulated results are in good agreement with experimental results and hence make the antenna suitable for H (6 - 8 GHz), X (8 - 12 GHz), Ku (12 - 18 GHz) and K (18 - 26 GHz) and future wireless communication applications.

Keywords—Tapered slot antenna (TSA); compact; radial cavity; broadband impedance bandwidth; peak realized gain; etched slots

I. Introduction

Wireless communication is rapidly growing the demand of smart antennas for the users to provide the more information on a rapid rate. Broadband and high gain antennas are essential components in enabling wireless connectivity. Various wideband communication antenna devices require different features such as low profile, linear polarization, compact dimensions and the unidirectional radiation pattern [1]. A tapered slot antenna (TSA) is one of the types of travelling wave antennas or planar end-fire antennas which have received considerable attention due to their wide impedance bandwidth characteristics. Vivaldi antennas have been used in numerous applications like satellite communications [2], Ultra-wideband (UWB) [3-4], scanning phased array [5-6], vehicular communication system [7], imaging construction material [8], medical imaging [9-10], cognitive radio [11], brain tumors [12], and GPR system [13-14]. The end-fire travelling wave antennas have demonstrated broadband bandwidth, high gain and symmetrically E – H beam pattern. TSA possessed many advantages of compact size, low profile, compatibility with microwave integration circuits, planar structure and ease of fabrication process [15]. The tapered slot antenna consists of a feedline, which is usually stripline or microstrip line transition and the radiating structure are constructed by linearly, exponentially and elliptically curves. All these properties particularly have the larger physical and electrical dimensions, narrower impedance bandwidth and moderate gain i.e. the major concern for the antenna researchers. Improving the main parameters of the proposed antennas like gain and stable radiation pattern as well as impedance bandwidth for the H, X, Ku and K band applications has been the focus of antenna designers [16]. In satellite communications, the microwave prescribed frequency bands allocated by IEEE standard for radio waves and radar communication with frequency which range from 6GHz-8GHz, 8GHz-12GHz, 12GHz-18GHz and 18-26GHz, respectively.

Last few years, the researchers have published numerous reports on the different shapes of antennas with compact dimensions to improve the bandwidth, gain and radiation pattern with analysis of alternative techniques and the optimization of the antenna parameters in the approved spectrum. In the literature, some antennas have large dimensions, preventing their use in miniaturized applications. In [17], Zhang et al. presented the small size microstripline-fed LTSA (Linear Tapered Slot Antenna) with the design of tilt grooves. The proposed antenna designed on Teflon substrate with the compact dimensions of $16 \times 21 \times 0.6\ mm^3$ to improve the wide bandwidth and beamwidth of LTSA antenna. But with larger electrical size and complex structure. Besides, a broadband TSA for Microwave imaging applications with the size of $48 \times 36 \times 0.762\ mm^3$ have been proposed in [18]. The presented antenna has been covered 8-18GHz bandwidth with the larger antenna size. In [19], Tseng demonstrated the linear tapered slot antenna (LTSA) for UWB radar sensor applications with the antenna dimension of $110.2 \times 31.5 \times 0.762\ mm^3$. Furthermore, a broadband microstrip

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antenna for C, X and Ku band applications with physical size of 21×15×31.75 mm^3 have been outlined in [20]. The exhibited antenna structure consists of semi-triangular patch shape with a coplanar waveguide feedline. The proposed antenna has achieved 107% fractal bandwidth and 5.3dBi gain. The new shape of wideband antennas were presented in [21-22]. However, the employed techniques have achieved the broad impedance bandwidth with larger dimensions. Furthermore [23], provides an antenna design with a tapered slot to be used in microwave band communication underwater. The proposed antenna achieved the above 57% bandwidth with electrical size 90×69×1.2 mm^3. We propose the antenna for H, X, Ku and K band applications with compact physical size.

In this paper, we present the compact high gain antenna with a tapered slot that operates in the broadband spectrum and can be used for the satellite communications, radar system, weather monitoring and very small aperture terminal (VSAT), etc. applications. The proposed antenna dimensions are (18.9×13.2×0.508) mm^3 and the broadband impedance bandwidth of 111.11% at the 10-dB return loss has been achieved. Finally, the proposed antenna design provides maximum gain, stable radiation pattern and strong current distribution along the direction of opening tapered aperture.

The organization of the paper is categorized mainly in four sections. Section II covers antenna layout and design strategy. The effect of antenna performance parameters and simulated results and discussion are analyzed in Section III, and finally Section IV gives the conclusion.

II. Antenna Design Layout

Fig. 1(a) depicts the antenna design structure. The design of TSA antenna is performed simple these steps:

- It consists of dielectric substrate, ground plane and cavity stub used with slot and tapered lines.
- The feedline is constructed with radial stub balun and the matching transformer which is put a top the substrate.
- The performance of antenna mainly depends on the aperture width (H). Generally, it should be greater than $\lambda_0/2$.
- A coaxial-fed tapered antenna cannot provide wideband impedance bandwidth which is needed in many broadband antenna applications. Hence alternative feed network such as several types of baluns, stripline to slotline or microstrip line to slotlines is used.

The top of the substrate is engraved with the tapered profile with compact dimensions (18.9×13.2×0.508) mm^3. The wavelength of antenna is used the minimum frequency of interested band. The dielectric substrate RT/Duroid 5880 laminate is used with a value of 2.2 for its relative permittivity, loss tan $\delta = 0.0009$ and the standard thickness of 0.508mm. The linear tapered slot can be classified two sections, antenna design parameters and the substrate. The antenna design elements can be categorized into the opening tapered rate, circular cavity, the slotline and stripline transition connected with balun.

Furthermore, the slotline or stripline transition is specified by the stripline (w_1, w_2 and w_3) and the slotline (W_{sl} and W_4) width. The width of W_4 is usually cut for the proper broadband impedance matching. The linearly tapered profile can be parameterized R (the opening rate) and the two tapered points P_1 (x_1, y_1) and P_2 (x_2, y_2). P_1 and P_2 which are the starting and ending points of the opening tapered profile. The proposed antenna structure provides a suitable radiation pattern and the wide impedance bandwidth from the 6 GHz – 21 GHz.

The tapered T_{sl} is (x_2 - x_1) and aperture height H is $2(y_2 - y_1) + w_{sl}$. For the case where R tends to zero, the taper layer results in a LTSA with a slope given as $s_0 = (y_2 - y_1) / (x_2 - x_1)$. In the case of an exponential taper slope, s will change from its initial value of s_1 to s_2 where these values are taper slopes for $x = x_1$ and $x = x_2$ respectively and $s_1 < s < s_2$ for $R > 0$. Moreover, $\alpha = \tan^{-1}s$ is the flare angle for the taper. Furthermore, the parameters which define the flare angle, H, T_{sl}, R and w_{sl} are interrelated. Fig. 1(a) also shows the parameters relating to the circular slotline cavity and stripline feeding. The below figures depict the top and side view geometry of the tapered slot antenna. However, the below section deliberates on the impedance matching, parametric studies and feedline transition of the proposed antenna structure. Fig. 1(a & b) also illustrate the dimensions of the Duroid substrate and patch remains same.

The designed antenna is simulated by using the EM solver High frequency structure simulator (HFSS). Table I lists the optimized values of the parameters.

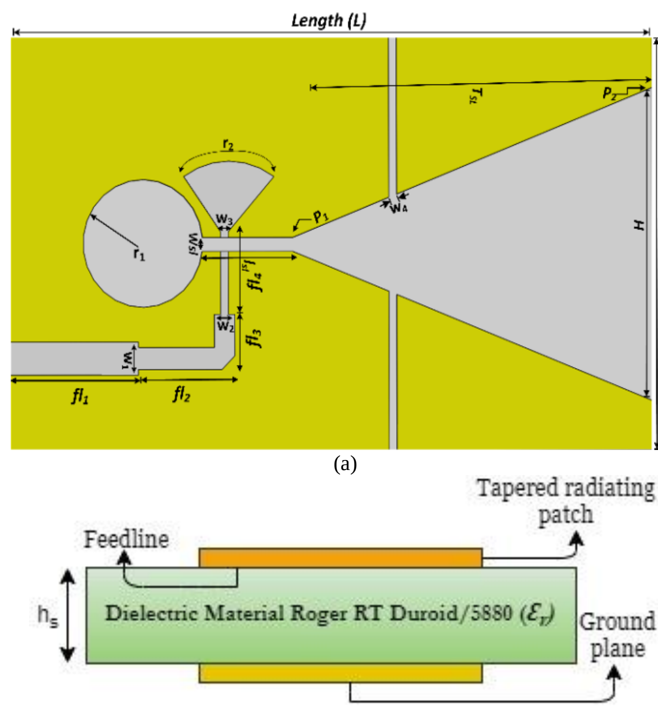


Fig. 1. (a & b) Top and Side view Geometry of the Proposed Antenna.

TABLE I. GEOMETRIC DEFINED VARIABLES OF PROPOSED ANTENNA (UNIT: MM)

Variable name	***Optim.Value***	***Variable name***	***Optim.Value***
W	13.2	l_{sl}	2.85
L	18.9	W_{sl}	0.55
h_s	0.508	W_1	1.6
H	11.4	W_2	0.7
r_1	1.55	W_3	0.4
r_2 (theta)	100 deg	W_4	0.3
phi	50 deg	$f_{l.P}$	0.25
T_{sl}	10.925		

III. SIMULATED RESULTS AND ANALYSIS OF THE PROPOSED ANTENNA

This section details the impedance matching of the designed antenna in relation to the defined variables.

Furthermore, the results of the peak realized gain (dBi), radiation pattern, return loss (S_{11}) and surface electric current (J_{surf}) distribution are also discussed and analyzed.

A. Parametric Study of the LTSA Antenna

The section discusses the effect of feeding line width (w), feedline position (f_{lp}), the effect of radius (r) and the width of slot (w_{sl}). These parameters realize the running the multiple times accurate simulations which effects the matching behavior of proposed antenna. Lastly, the best values are used to test the suggested antenna design.

1) Variation in feedline widths (w_1,w_2 & w_3): The width of the feeding lines is the essential parameter in the proposed antenna. Initially, the values of feedline width are chosen according to the antennas frequency of operation which is near to the 1.55mm at the 50Ω of the feedline and then optimized the variable with iterative methods. The proposed antenna can be excited by microstrip feed via slot line transition and radial stub for best impedance matching performance. Fig. 2(a)-(b) and (c) illustrates the wideband performance in 6GHz to 21GHz frequency range.

Fig. 2(a) illustrates the various optimetric values used for feedline width (w_1) ranges from 1.3mm to 2.0mm. It is observed that the suggested antenna attains the proper matching at 1.6mm which can clearly appear in solid line.

Applying the variation in the feedline width of (w_2) ranges from 0.5mm to 0.9mm and (w_3) varies from 0.35mm to 0.7mm, the optimum results have been achieved at the 0.7mm (blue color) and 0.4mm (red color), the initially calculated values were 0.88mm and 0.42mm at the operable frequency.

2) Variation in feedline position (f_{lp}): The performance of the antenna feedline position is analyzed to improve impedance matching characteristics. The tapered antenna radiator can be excited with feedline. Fig. 3 illustrates the variation of the feedline position from -0.25mm to 0.25mm. The optimized feeding position has been achieved at -0.25mm. Moreover, the dimensions of feedline transition also influence the antenna impedance. It is analyzed to set proper dimensions of the feedline length and width to achieve broad bandwidth performance and impedance matching.

3) Effect of radial cavity (r) and slotline width (W_{sl}): The effect of TSA radial stub and slot line width on performance are analyzed by varying antenna dimensions such as width, length and stripline. TSA antenna radius cavity is connected to the slotline and tapered section which represent the fixed monopole radiation characteristics of an antenna. Fig. 4(a) gives the results of radial stub variation against frequency. The optimum results are achieved at 1.55mm.

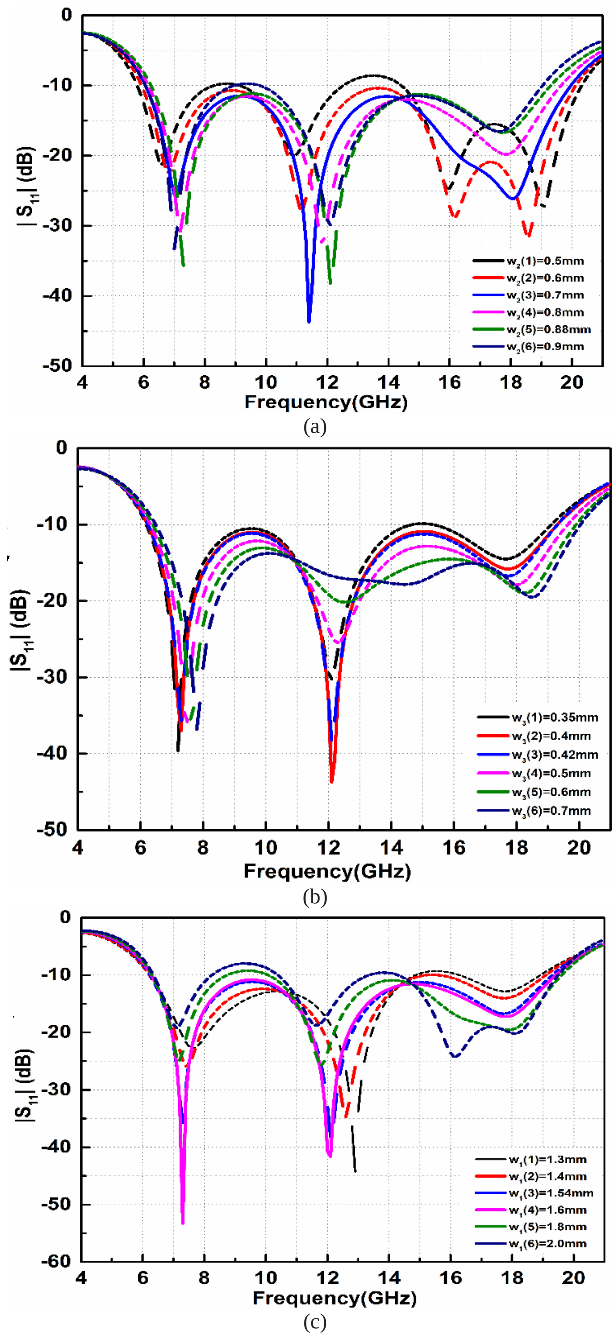


Fig. 2. (a, b & c) Return Loss (S_{11}) Performance of Feedline widths (w_1,w_2 & w_3) Against Operable Frequency Range.

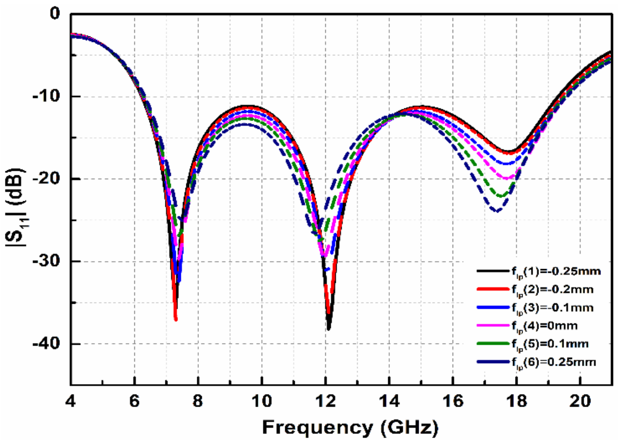


Fig. 3. Variation of Return Loss (S_{11}) with Frequency for different Values of Feedline Position (f_{lp}) of Proposed Antenna.

The width of slotline (w_{sl}) transition is varied with different optimetries values ranging from 0.35mm to 0.7mm. It can be observed from Fig. 4(b) that the best result for impedance matching is achieved at the value of 0.55mm.

Initially, we design the proposed antenna without cutting the slot on top of substrate. The simulated results cover the BW from 9.87GHz to 21GHz. The slotline is etched at the top of the tapered patch, the simulated return loss covers the broad impedance bandwidth of 111.11% as illustrated in the Fig. 5.

The multiple optimetric variations of the slotline width further enhances the impedance characteristics of the tapered antenna. The slotline is cut on the top of tapered profile, the antenna covers the (6GHz – 8GHz) broad impedance bandwidth with the optimetric slotline width (w_4) at 0.3mm. The length of slot cavity section and tapered rate covers the high frequency resonance.

B. Simulated Results and Discussion

1) Return Loss (S_{11}) and Peak Realized Gain (dBi): The simulated analysis of return loss and the gain is presented in this section. Fig. 5 depicts the return loss for all frequency sweeps performed in the experiment. The simulated analysis of return loss (S_{11}) has been generated by using the Ansys high frequency structural simulator (HFSS).

It can be seen from the results, that the relative impedance bandwidth has been achieved 111.11% at minimum return loss i.e. 10-dB with multiple resonant frequencies of 7GHz, 11.8GHz, 15.8GHz and 19.6GHz. The geometrical parameter of theta (r_2) and phi have been affected on the impedance matching which have considered 50^0 and 100^0. The proposed antenna is analyzed that lower and upper frequency range from 6GHz to 21GHz at 15GHz broadband impedance BW. It covers the H, X, Ku and K band applications.

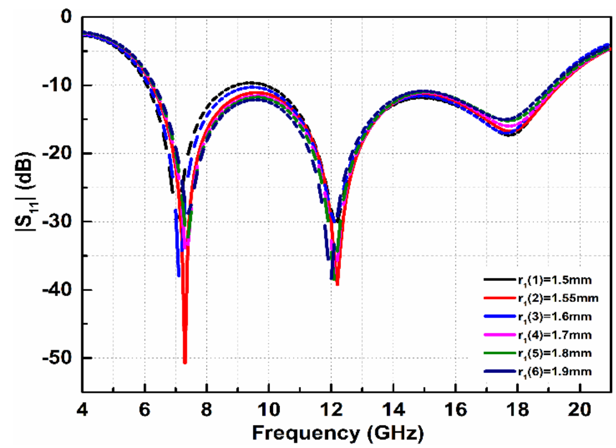
The value of VSWR for this antenna are declining at the multiple resonances 1.09 @7GHz, 1.01 @11.8GHz, 1.02 @15.8GHz and 1.2 @19.6GHz at the desired operable frequency which are remains < 2.

From Fig. 6 plots peak realized gain achieved for the proposed antenna. For each of the multiple resonant frequencies, at 7GHz the antenna shows a gain of 3.42dBi, at 11.8GHz the acceptable gain of 3.24dBi, at 15.8GHz the noted gain of 6.40dBi and the 19.6GHz the gain of approximately 7dBi is achieved. Moreover, the maximum peak realized gain of 7.38dBi has been obtained at 17.5GHz. The suggested antenna achieved the peak realized gain of multiple bands for wireless communication applications.

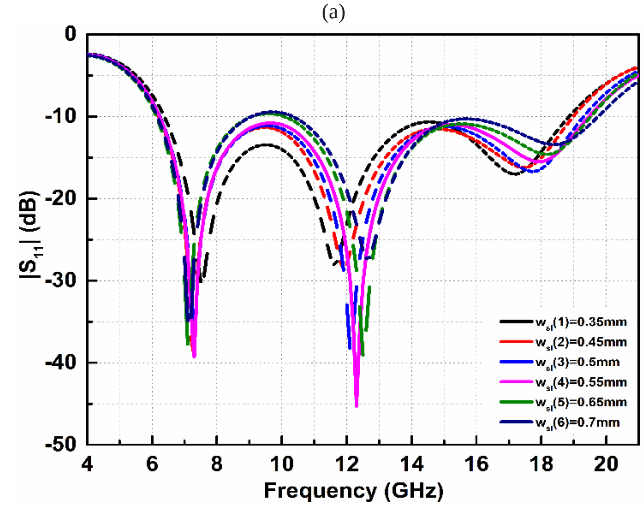
2) Radiation pattern: Fig. 7 illustrates the far-field radiation pattern in 2D for the antenna along standard planes (E-plane and H-plane) with Fig. 7(a) – (d) showing the antenna radiation pattern for the multiple resonant frequency case. It can be seen that the travelling wave antenna exhibits a stable radiation pattern at multiple resonance frequencies. The antenna beam directs itself towards the 0-degree direction as required while radiating equally in the other plane too.

The antennas surface current distribution (J_{surf}) is shown in Fig. 8. The feed line and radial cavity with slot line show a high intensity of current levels at the various resonant frequencies.

The surface current is distributed across the tapered section which represent the stable characteristics of the radiation pattern in 3D view.



(a)



(b)

Fig. 4. (a & b) Impedance Matching Analysis Related to Radial Cavity (r) and width of Slotline (w_{sl}) with different Values of the Proposed Antenna.

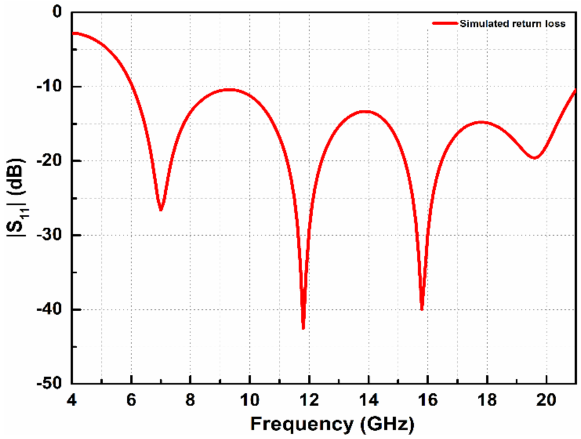


Fig. 5. Response of Return Loss Against Frequency.

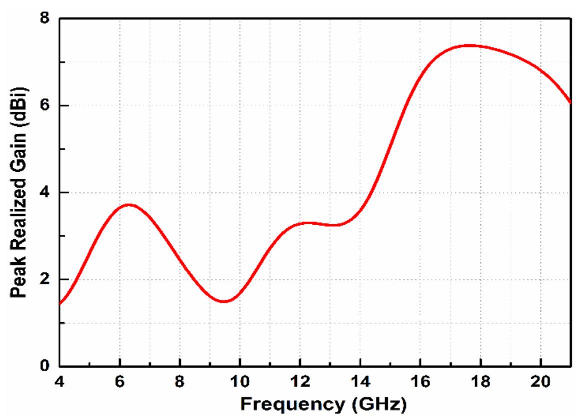


Fig. 6. Simulated Peak Realized Gain Across the Operating Frequency Span.

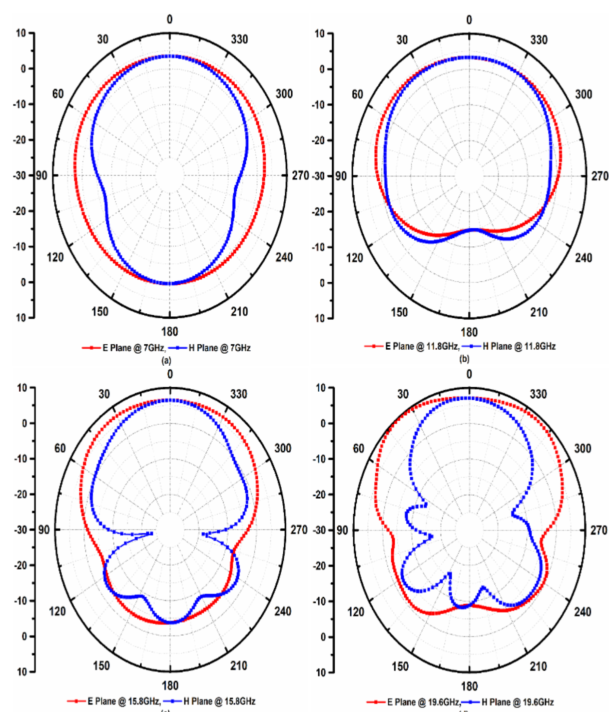


Fig. 7. Radiation Pattern at Azimuth and Elevation Plane of the Proposed Antenna at Multiple Resonances; (a) 7GHz at $\theta=0^0$ and $\theta=90^0$. (b) 11.8GHz at $\theta=0^0$ and $\theta=90^0$(c) 15.8GHz at $\theta=0^0$ and $\theta=90^0$(b) 19.6GHz at $\theta=0^0$ and $\theta=90^0$.

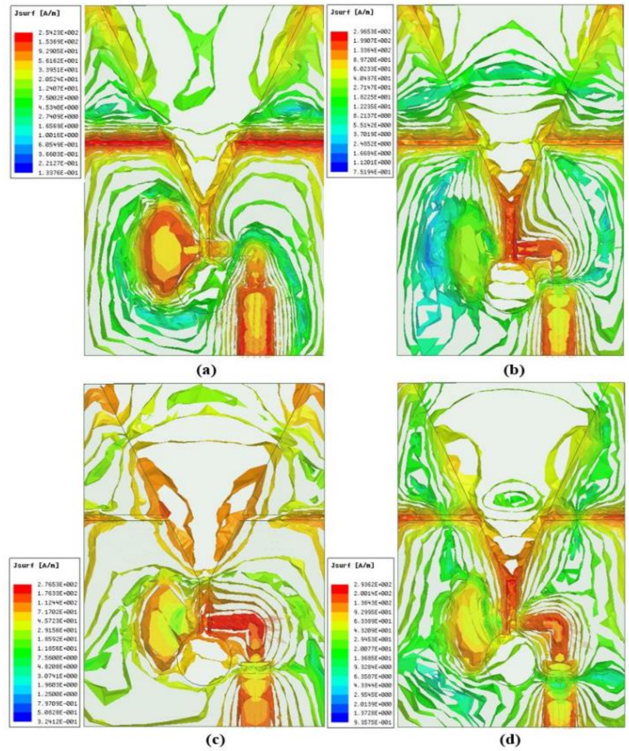


Fig. 8. Simulated Surface Electric Current Distribution Sketches (a) Resonance @7GHz, (b) Resonance@11.8 GHz, (c) Resonance @15.8 GHz and (d) Resonance @19.6 GHz.

IV. Conclusion

The travelling wave tapered slot antenna for H, X, Ku and K band application towards wireless communication has been studied and proposed. The proposed antenna structure contains of the dielectric substrate, opening taper profile, feeding network and ground plane. The broadband impedance matching of designed antenna has been attained by setting up the proper dimensions of feedline transition and the slot cut on both sides at opening taper of antenna. The antenna has been shown to provide impedance bandwidth of 111.11% and high gain of 7-dBi at K-band frequencies, substantial gain of 6.40-dBi at Ku-band, gain of 3.24-dBi at X-band and the acceptable gain of 3.42-dBi for H-band wireless communication. The tapered slot antenna has been designed and simulated by HFSS 17.1. Moreover, this antenna will be further extended by suing the efficient Wilkinson power divider and then its performance will be studied in a real time environment for further exploration.

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