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Frequency Formulation of Composite Wide Slot Antenna with Parasitic Element

Abhay Shukla[1], Nagendra Patel[2]
[1]*M.tech Scholar, Rewa Institute of technology Rewa, abhayshukla33@gmail.com, India;*
[2]*HOD,ECE, Rewa Institute of technology Rewa, India;*

Abstract— *In this article, a composite wide slot antenna with crescent-shaped tuning stub and a hybrid parasitic element is analyzed, which is printed on the FR-4 epoxy substrate ($tan(\delta) = 0.02, \varepsilon_r = 4.3$). Bandwidth of the antenna is altered by adjusting the size of the composite slot and tuning stub.The proposed antenna exhibited the simulated impedance bandwidth of 141.15 % for $|S_{11}| < -10\ dB$ which resonates at five frequencies 1.1, 1.73, 3.02, 4.63 and 5.43 GHz. The mathematical equation has been formed after inspecting the surface current distribution at simulated resonating frequencies at 1.1, 1.73, 3.02, 4.63 and 5.43. To predict the electromagnetic response of the proposed antenna, structural analysis has been also done.*

Keywords: *Current Distribution, Composite slot, Impedance bandwidth, Modes, Parasitic element.*

I. Introduction

The vogue of wide slot antenna has grown in modern communication system due to its qualities like impedance bandwidth, planar structure, offer the abundance of the resonating modes, low cost and generates bidirectional radiation pattern [1], [2]. The geometrical area of slot critically affects the impedance bandwidth of the planar antennas. A narrow area of slot exhibits smaller fractional bandwidth which is the main constraint of the narrow slot antenna [3], [4]. Slot modifies the effective capacitance of the antenna that changes the phase velocity ($v_p = 1/\sqrt{LC}$) of modes, alter the distribution of current vectors and location of modes (TM_{10}, TM_{01},TM_{12} and TM_{20}) [5], [7]. The limitation of the narrow slot antenna can be thrashed by expanding the geometrical area of the slot. The larger area of the slot generates a large number of the resonating modes. By choosing the appropriate dimension of the tuning stub and slot, the frequency separation between two adjacent modes can be adjusted. When slot area is comparable to the ground plane area, the bandwidth of the antenna is significantly reduced due to less capacitive coupling between slot and tuning stub. For enhancement of mutual coupling, parasitic element is added which adjust the frequency separation between modes and improve the bandwidth of the antenna. [8], [9]. The bandwidth of the antenna is improved by selecting the proper geometry of wide slot, parasitic element and tuning element. Proper shape of the elements (slot, parasitic and tuning stub) overlaps the resonating modes and improves the capacitive coupling [10], [11], [12]. Some reported geometry of slots is tapered slot [13], elliptical slot [14] and fractal slot [15]. Jan embedded the parasitic strip and claimed the fractional bandwidth of 108 % from 1.8 GHz to 6.04 GHz [16]. Rotation of the parasitic element also affects the reflection coefficient characteristic of the antenna and responsible for tuning of modes [17].

In this paper, we communicate a composite wide slot antenna with crescent tuning stub and the parasitic element for wideband applications. This antenna exhibits the fractional bandwidth of 141.15 % for $|S_{11}| < -10\ dB$. The simulated values of lower and higher cut off frequency are 1.05 GHz and 6 GHz. The proposed antenna shows resonance (measured) at 1.1, 1.73, 3.02, 4.63 and 5.43 GHz. The tuning and overlapping of resonating modes have accomplished by adjusting the radius of tuning stub, wide slot and a

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parasitic element. The mathematical equation has been formed after inspecting the surface current distribution at simulated resonating frequencies at 1.1, 1.73, 3.02, 4.63 and 5.43. To predict the electromagnetic response of the proposed antenna, structural analysis has been also done.

II. Antenna Configuration

The physical structure of composite wide slot antenna with the elliptical parasitic element and crescent-shaped tuning stub has depicted in Fig. 1 which is modeled on the FR-4 substrate. The ground plane is kept on the azimuthal plane and Z axis is orthogonal to the proposed structure. This antenna has energized by hybrid feed technique which is the union of micro strip and coaxial feed. For the smooth transition between tuning stub and strip line (F_l (feed length), F_w (feed width)), a triangular shaped element has been integrated which play a prominent role in impedance matching. The dimension of the triangular shaped element are 9.4 mm (base length) and 7 mm (height). A circular tuning element with the parameter R_4 has printed on the top surface of the substrate which contains circular slot (R_3) and elliptical slot R_5 (radius of the major axis), R_6 (radius of the minor axis). These two slots enhance the impedance matching in the interested frequency spectrum (1 to 6 GHz). To overlap the resonance frequencies and enhance the bandwidth of the antenna, an elliptical shaped parasitic element with variables R_1 (radius of the major axis), R_2 (radius of the minor axis) is printed on top with center coordinates (0 mm, 14 mm, 1.67 mm). For impedance matching in lower and higher frequency band, two right angle triangular slots with variables L_1 (height), W_1 (base length) are etched on the bottom edge of the ground plane. However, two right angle triangular element has been added in the periphery of the wide slot. These elements enhance the capacitive coupling between the wide slot and tuning stub and directly affect the reflection coefficient characteristic in the mid frequency band. In addition, a triangular shaped notch has been created on the circumference of the wide slot which changes the effective capacitance of the antenna and the position of higher cut off frequency.

TABLE I. STRUCTURAL PARAMETERS AND DIMENSIONS OF COMPOSITE WIDE SLOT ANTENNA

Parameter	Dimension (mm)	Parameter	Dimension (mm)
F_l	15.94	R_3	13
F_w	3	R_4	15
L	83	R_5	6
W	70	R_6	3
R_1	12	S_1	4.67
R_2	8	S_2	26.02
L_1	10	S_3	50.06
W_1	35	S_4	27.28
		S_5	9.18

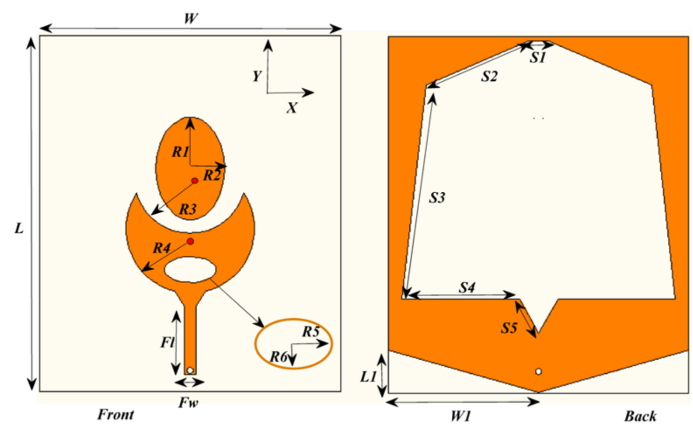

Fig. 1. Geometry and parameters of composite wide slot antenna.

III. Structural Parameter Analysis

In the structural parametric examination, one parameter has altered at a time and rest of the parameters are kept constant. Fractional bandwidth and electromagnetic property of the antenna can be altered by the structure of the antenna. For optimization of the antenna, structural analysis has been done in this section.

III.1 Impact of radius (R_3) of the circular slot

The radius of the circular slot (R_3) changes the shape of tuning stub which affects the mutual coupling between the wide slot and tuning stub. As shown in Fig. 2, the impedance matching in the lower frequency band (1 to 2 GHz) has influenced by this parameter. With the increase in R_3, the matching has been fluctuated at resonating frequencies f_{r1} and f_{r3} whereas the location of resonating frequency f_{r2} is drifted in the rightward direction. The drift in resonance frequency has occurred due to the slow wave effect. Good impedance bandwidth has been achieved for $9 < R_3 < 15$. The optimized value of this parameter is 13 mm.

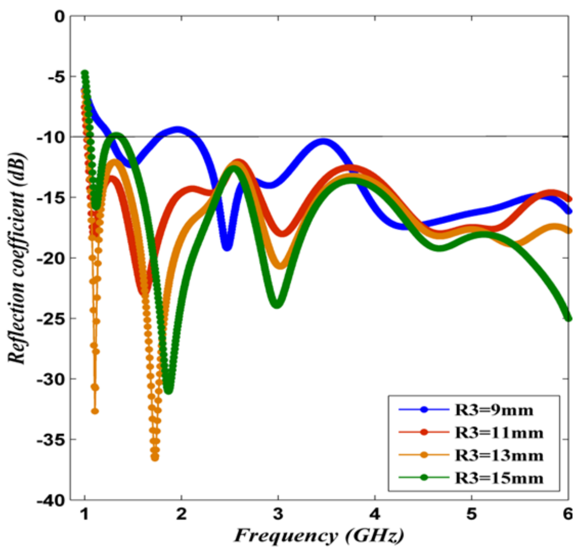

Fig. 2. Impact of $\mathbf{R_3}$ on reflection coefficient characteristic of the proposed antenna.

III.2. Impact of radius (R_4) of the circular tuning stub

The impact of R_4 on bandwidth is illustrated in Fig.3. With the extend in R_4, the capacitive coupling between parasitic element, wide slot and tuning stub increases. Due to this, bandwidth and impedance matching in the entire frequency spectrum is also upgraded. The impedance matching at fundamental mode frequency f_{r1} has increased while resonance frequency f_{r2} is displaced in the rightward direction. For R_4>15 mm, the bandwidth of the antenna has been become worst due to over coupling between tuning element and wide slot.

III.3. Impact of diagonal (S_5) of the triangular notch

Area of triangular notch changes the effective capacitance between the wide slot and tuning stub which fluctuates the capacitive coupling between these elements. It is inspected that by modifying the S_5 (Fig.4) the bandwidth of the antenna has upgraded and impedance matching at first resonating frequency is also improved. The leftward shift of f_{r2} has been also observed. This occurs because the effective capacitance between wide slot and tuning stub is increased which reduces the phase velocity of the second resonating mode. A larger value of S_5 also degrades the bandwidth of the antenna.

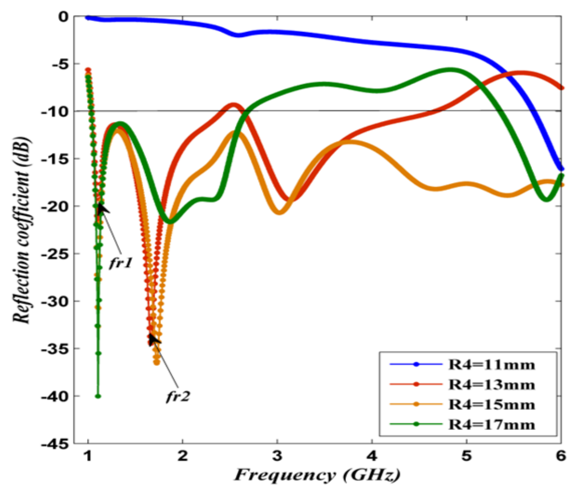

Fig.3. Impact of $\mathbf{R_4}$ on reflection coefficient characteristic of the proposed antenna.

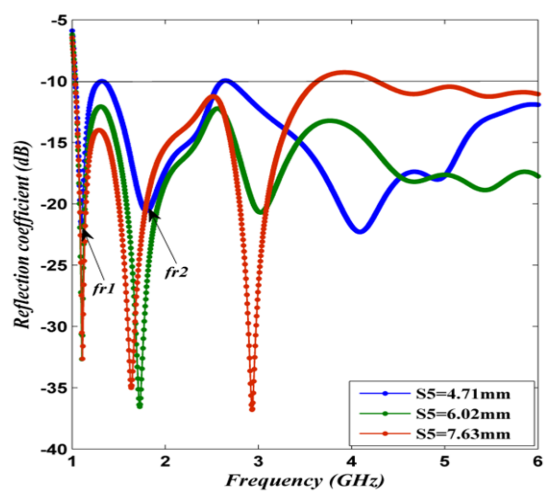

Fig.4. Impact of S_5 on reflection coefficient characteristic of the proposed antenna.

III.4 Impact of S_3 (Side arms)

The composite wide slot has been formed after the integration of two side arms. The area of sidearm affects the parameter S_3 which also modifies the area of the composite wide slot and changes the path length of current vectors. Fig.5shows the influence of S_3on the bandwidth of the antenna and lower cut off frequency. On decreasing the value of S_3, the area of wide slot increases which upgrades the path length of current vectors. Due to this, the position of fundamental mode frequency and lower cut off frequency are shifted in leftward direction. In addition, the impedance matching has been degraded in the higher frequency band. The good bandwidth has been found for $S_3 > 47.90$ mm.

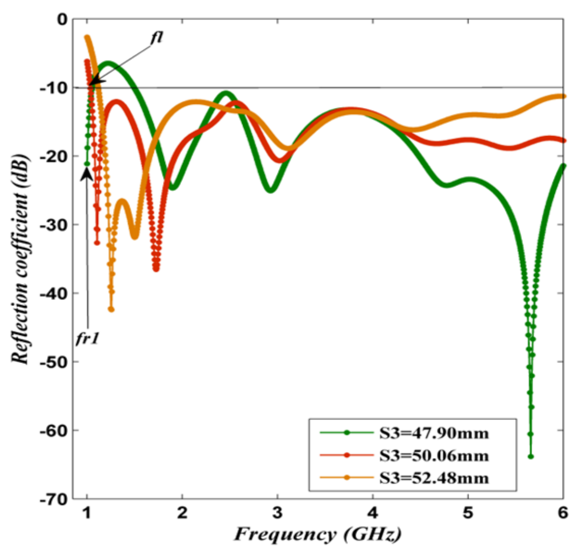

Fig.5. Impact of S_3 on reflection coefficient characteristic of the proposed antenna.

IV. Result and Discussion

The $S_{11}(dB)$parameter and impedance characteristics of the proposed antenna has evaluated using CST Microwave Studio. The proposed antenna exhibits the impedance bandwidth $(B.W. = 200 * (f_h - f_l)/(f_h + f_l))$ of 141.15 % for $S_{11} < -10\,dB$. The lower cut off and higher cut off frequencies are 1.05 GHz and 6 GHz (fig 6). The resonating frequencies are 1.1, 1.73, 3.02, 4.63 and 5.43 GHz. It has been noticed that by modifying the physical structure of the ground plane, tuning stub and feed line, the bandwidth of the antenna can be modulated. At frequencies 1.1 GHz and 1.73 GHz, return loss values are -33 dB and -37 dB respectively. It is noticed that the proposed antenna exhibits good transmission property at lower frequency band as compare to high frequency band.

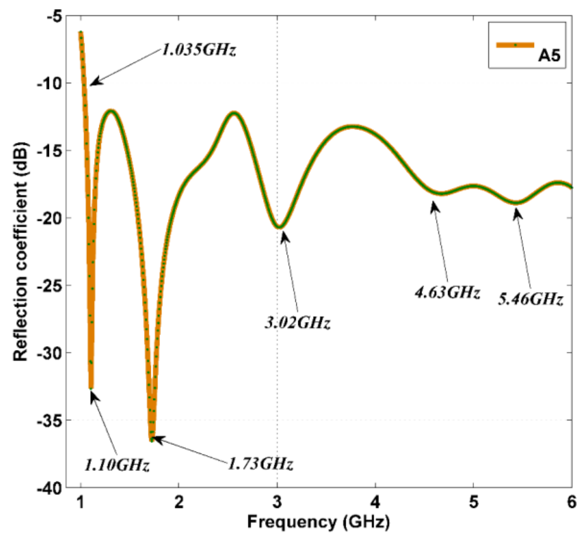

Fig. 6. S_{11} characteristic of Composite wide slot antenna with parasitic element.

The vector current distribution at 1.10, 1.73, 3.02, 4.63, 5.46 GHz has been investigated which are illustrated in Fig.7. The following points are observed after inspecting the current distributions 1) Number of null points (where current intensity is zero) along the resonating elements are increased as frequency increases. 2) The concentration of current is maximum on the edges of the elements. 3) The symmetric surface current distribution has been found along the y-axis. At a specific frequency, the current distribution is formed after a combination of numerous resonating modes.

As shown in Fig.7, the intensity of the current is higher at edges of wide slot and ground plane at frequency 1.1 GHz which indicates that antenna is operated by fundamental mode. After inspection of the current distribution, it has noticed that the fundamental mode is generated by a composite wide slot. The frequency (1.1 GHz) of the fundamental mode depends on the perimeter of the composite wide slot which can be computed by following equations.

$$L_1 = S_1 + S_2 + S_3 + S_4 + S_5 \quad (1)$$

$$f_1 = \frac{c}{L_l\sqrt{\varepsilon_r}} \quad (2)$$

Where ε_r is permittivity of the dielectric substrate. The evaluated value of f_1 is 1.24 GHz which is near to the simulated value of f_1. The lower cut off frequency (f_l) of the antenna is controlled by the size of the antenna. For proposed antenna the value of f_l can be evaluated by following equations

$$L_l = W + L - L_1 - W_1 + \sqrt{{L_1}^2 + {W_1}^2} \quad (3)$$

$$f_l = \frac{c}{L_l\sqrt{\varepsilon_r}} \quad (4)$$

The determined value of f_l is 0.99 GHz. An inaccuracy of 4.34 % has been estimated between simulated (1.035 GHz) and computed lower cut off frequency. At f_2 (second resonating frequency) 1.73 GHz, the current vectors are spread like TM_{10} mode in the parasitic and tuning element. This frequency is originated due to the slot which can be estimated by following equations

$$L_2 = S_1 + S_2 + S_3 \quad (5)$$

$$f_2 = \frac{c}{L_2\sqrt{\varepsilon_r}} \quad (6)$$

The estimated value of f_2 is 1.83 GHz which is near to 1.73 GHz which is the simulated value of f_2. The computed inaccuracy between simulated and calculated f_2 is 5.46 %. It has been investigated that the third harmonic ($f_3 \approx 3 * f_1$) of the composite wide slot is present in the spectrum. The fundamental mode originates by tuning element which is

$$a_{eff} = (R_4)[1 + \frac{2h}{\pi\varepsilon_r(R_4)}\{\ln(\frac{(R_4)}{2h}) + (1.41\varepsilon_r + 1.77)]^{1/2} \quad (7)$$

$$f_{stub} = \frac{1.8412 * C_0}{2 * \pi * a_{eff} * \sqrt{\varepsilon_r}} \quad (8)$$

calculated by below given equations

where C_0 is the speed of light. The calculated value of f_{stub} is 3.23 GHz. The wideband frequency response near 3.02 GHz is realized after the overlapping of the third harmonic of fundamental mode (f_3) and the fundamental mode of tuning element (f_{stub}). At frequency 4.63 GHz, the fourth harmonics of fundamental mode frequency ($f_4 \approx 4 * f_1$), and fourth harmonic of lower cut off frequency ($f_{4l} \approx 4 * f_l$)are present. Due to the overlapping of f_4 and f_{4l} broad frequency spectrum has been achieved. The fundamental mode originates by the parasitic element which is calculated by below given equations

$$P_1 = (\pi) * \sqrt{(R_1^2 + {R_2}^2)/2} \quad (9)$$

$$f_p = \frac{c}{P_1\sqrt{\varepsilon_r}} \quad (10)$$

where P_1 is the half-perimeter of the elliptical shaped parasitic element. The calculated value of f_p is 4.9 GHz. Near frequency 5.43 GHz, the fifth harmonic of the fundamental frequency ($f_5 \approx 5 * f_1$), fifth harmonic of lower cut off frequency ($f_{5l} \approx 5 * f_l$) and the fundamental mode of parasitic element are present. After superposition of these modes, broadband response has occurred near 5.5 GHz.

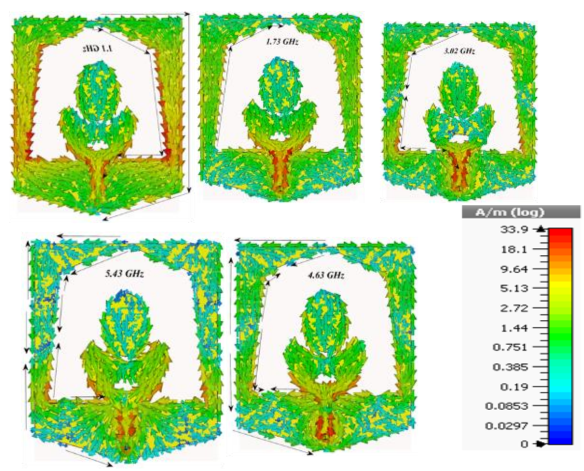

Fig.7. Simulated surface current distribution of proposed antenna at frequencies 1.1 GHz,1.73 GHz, 3.02 GHz, 4.63 GHz and 5.43 GHz.

V. Conclusion

A composite wide slot antenna with crescent-shaped tuning stub and the parasitic element has been numerically investigated. It has been perceived that bandwidth and impedance matching of the proposed antenna is controlled by thedimension of the slot and tuning stub. This antenna offers the fractional bandwidth of 141.15 % for $|S_{11}| < -10\,dB$. The value of lower and higher cut off frequency is 1.05

GHz and 6 GHz. The surface current distribution has been investigated and series of equations are deduced at simulated resonating frequencies 1.1, 1.73, 3.02, 4.63 and 5.43 GHz.

References

[1] A. Dastranj and H. Abiri, "Bandwidth enhancement of printed E-shaped slot antennas fed by CPW and microstrip line," IEEE Transactions on Antennas and Propagation, Vol. 58, pp. 1402-1407,2010.

[2] F. W. Yao, S. S. Zhong, W. Wang, and X. L. Liang, "Wideband slot antenna with a novel microstrip feed," Microwave and optical technology letters, Vol. 46, pp. 275-278, 2005.

[3] Y. Yoshimura, "A microstripline slot antenna (short papers)," IEEE Transactions on Microwave Theory and Techniques, Vol. 20, pp. 760-762, 1972.

[4] J. F. Huang and C. W. Kuo, "CPW-fed bow-tie slot antenna," Microwave and optical technology letters, Vol. 19, pp. 358-360, 1998.

[5] A. A. Alazza, F. J. Harackiewicz, and H. R. Gorla, "Very compact open-slot antenna for wireless communication systems," Progress In Electromagnetics Research Letters, Vol. 51, pp. 73-78, 2015.

[6] A. A. Deshmukh, and K. P. Ray, "Formulation of resonance frequencies for dual-band slotted rectangular microstrip antennas," IEEE Antennas and Propagation Magazine, Vol. 54, pp. 78-97, 2012.

[7] A. A. Deshmukh and K. P. Ray, "Analysis of broadband variations of U-slot cut rectangular microstrip antennas," IEEE Antennas and Propagation Magazine, Vol. 57, pp. 181-193, 2015.

[8] M. C. Tang, R. W. Ziolkowski, and S. Xiao, “Compact hyper band printed slot antenna with stable radiation properties,” IEEE Transactions on Antennas and Propagation, Vol. 62, No. 6, pp. 2962-2969, June 2014.

[9] P. N. Shinde and J. P. Shinde, "Design of compact pentagonal slot antenna with bandwidth enhancement for multiband wireless applications," AEU-International Journal of Electronics and Communications, Vol. 69, pp. 1489-1494, 2015.

[10] A. K. Arya, R. S. Aziz, and S. O. Park, "Planar ultra-wideband printed wide-slot antenna using fork-like tuning stub," Electronics Letters, Vol. 51, pp. 550-551, 2015.

[11] R. B. Rani, and S. K. Pandey, "A parasitic hexagonal patch antenna surrounded by same shaped slot for WLAN, UWB applications with notch at vanet frequency band," Microwave and Optical Technology Letters, Vol. 58, pp. 2996-3000, 2016.

[12] Y. Tan, L. Yan, X. Zhao, C. Liu, and K. M. Huang, "Bandwidth Enhancement of a Printed Slot Antenna with a Diamond-Shaped Tuning Stub," Progress In Electromagnetics Research C,Vol. 50, pp. 87-93, 2014.

[13] R. Azim, M. T. Islam, and N. Misran, "Compact tapered-shape slot antenna for UWB applications," IEEE Antennas and Wireless Propagation Letters, Vol. 10, pp. 1190-1193, 2011.

[14] P. Li, J. Liang, and X. Chen, "Study of printed elliptical/circular slot antennas for ultra wideband applications," IEEE Transactions on antennas and Propagation, Vol. 54, pp. 1670-1675, 2006.

[15] W. L. Chen, G. M. Wang, and C. X. Zhang, "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna with a fractal-shaped slot," IEEE Transactions on Antennas and Propagation, Vol. 57, pp. 2176-2179, 2009.

[16] J. Y. Jan and L. C. Wang, "Printed wideband rhombus slot antenna with a pair of parasitic strips for multiband applications," IEEE Transactions on Antennas and Propagation, Vol. 57, pp. 1267-1270, 2009.

[17] Y. Sung, "Bandwidth Enhancement of a Microstrip Line-Fed Printed Wide-Slot Antenna With a Parasitic Center Patch," IEEE Transactions on Antennas and Propagation, Vol. 60, pp. 1712-1716, 2012.

[18] Kamakshi, J. A. Ansari, A. Singh, A. Mohammad, "Desktop shaped broadband microstrip patch antenna for wireless communication," Progress in electromagnetics research letters, Vol.50, pp. 13-18, 2014.

[19] A. A. Deshmukh and K.P. Ray, "Compact Broadband Slotted Rectangular Microstrip Antenna," IEEE Antennas and Wireless Propagation Letters, Vol.8, pp. 1410-1413, 2009.