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An Investigation of Composite Wide Slot Antenna with Parasitic Element

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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 ($tan(\delta) = 0.02, \varepsilon_r = 4.3$). The capacitive coupling between elements, overlapping of excited modes and impedance bandwidth of the antenna are amended by adjusting the size of the composite slot and tuning stub. From simulation outcomes, the simulated impedance bandwidth of this antenna is 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 bidirectional pattern has been obtained at lower frequencies (1.18 GHz, 2.38 GHz) whereas distorted patterns are noticed at the higher frequency (5.25 GHz) due to the existence of higher order modes.*

Keywords: *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 parasitic element. In addition, the Omni directional far field pattern is investigated at lower frequencies while distorted pattern has been found at higher frequencies.

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

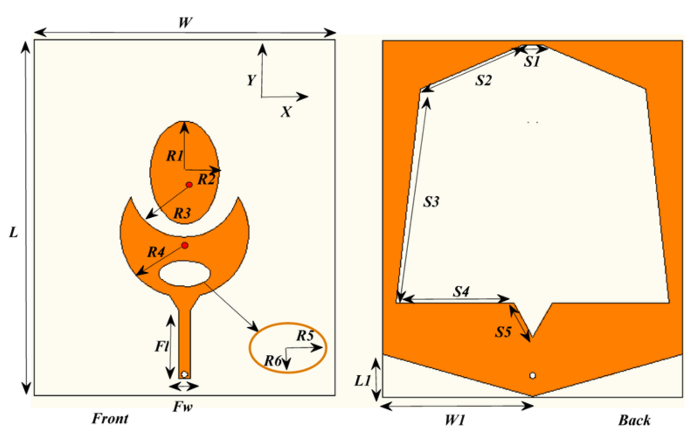

Fig. 1. Geometry and parameters of composite wide slot antenna.

III. Development of Composite Wide Slot

The successive modification in the geometry of the antennas has been displayed in Fig. 2. To attain optimum performance, the shape of the wide slot, edges of the ground plane, and geometry of tuning element have customized and the electromagnetic coupled parasitic element is also integrated on the top surface of the substrate. The combined reflection coefficient characteristic of the antennas (*A1, A2, A3, A4* and *A5*) has depicted in Fig. 3. The reference antenna (*A1*) encompass trapezoidal shape wide slot and deformed circular shaped tuning element. It exhibits tri-band response with two resonance frequencies which are arranged in Table 2. For bandwidth rectification, two right angle triangular element has been united with the wide slot (Antenna 2 (*A2*)). These two elements upgrade the mutual coupling between the wide slot and tuning stub and reduce the width of the notched frequency band (2.24 to 2.50 GHz). The truncation of the slot generate new frequencies or modify the location of resonating frequencies [18], [19].In next step (*A3*), two right angle triangular slots have been etched on the bottom edge of the ground plane which advances the matching in the lower frequency band, higher frequency band and generates new resonating frequency (1.12 GHz).

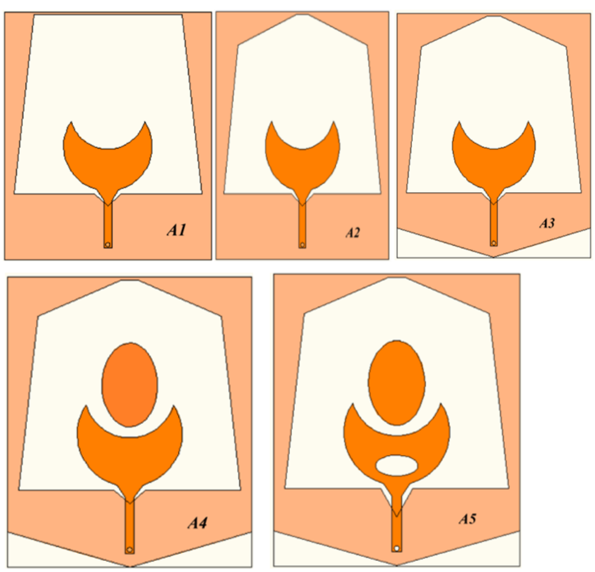

Fig. 2. Development of Composite wide slot antenna with parasitic element.

These slots also change the position of resonating frequencies (1.87 GHz and 4.62 GHz). This occurs because the slot modifies the value of inductance and capacitance of the antenna which is directly related to the phase velocity of the resonating frequencies [5]. The electromagnetic coupled parasitic element playsa vital role in the entity of the wide slot antenna which generates new resonance frequencies and also responsible for tuning of the modes [8]. In antenna 4 (*A4*), an elliptical shaped parasitic element has been embedded on the top surface of the FR-4 substrate. This element upgrade the impedance matching level in the entire frequency band (1 to 6 GHz) and it exhibits the fractional bandwidth $(BW(\%) = 200 * (f_h - f_l)/(f_h + f_l))$ of 140.90 % from 1.04 to 6 GHz with four resonating frequencies which are listed in Table 2. In the final step (*A5*), an elliptical shaped slot has etched on tuning stub which improves the impedance matching at the fundamental frequency (1.1 GHz), second resonating frequency (1.73 GHz) and higher frequency band. The bandwidth achieved by antenna 5 is 141.15 % for $S_{11} < -10\ dB$ with five resonance frequencies.

Table Ii. Antennas and Their Frequency Response With Resonance Frequency and Bandwidth

Name of Antenna	**Response**	**Band**	**Bandwidth (%)**	**Resonance frequency (GHz)**
A1	Triple	1.48 to 2.24 GHz	40.86	1.86, 4.64
		2.50 to 5.53 GHz	75.46	
		5.86 to 6.00GHz	2.36	
A2	Triple	1.48 to 2.52 GHz	52	1.87, 4.62
		2.72 to 5.55 GHz	68.44	
		5.86 to 6.00 GHz	2.36	
A3	Triple	1.08 to 1.195 GHz	10.10	1.12, 1.93, 4.74
		1.50 to 2.56 GHz	52.21	
		2.63 to 6.00 GHz	78.09	
A4	Single	1.04 to 6.00 GHz	140.90	1.10, 1.81, 4.21, 4.89

A5	Single	1.035 to 6.00 GHz	141.15	1.10, 1.73, 3.02, 4.63, 5.46

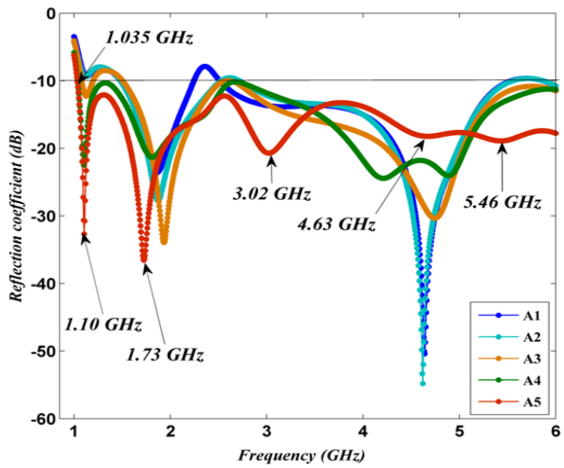

Fig. 3. Development of Composite wide slot antenna with parasitic element.

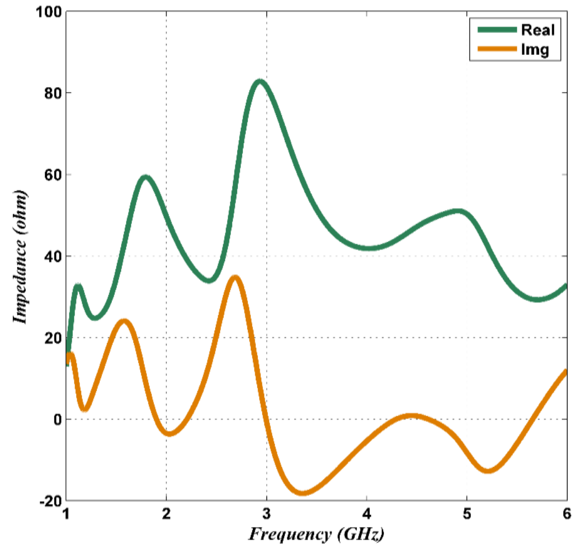

Fig.5. Impedance characteristic of Composite wide slot antenna with parasitic element.

IV. Result and Discussion

The $S_{11}(dB)$parameter and impedance characteristics of the proposed antenna has evaluated using CST Microwave Studio and these characteristics are shown in figure 4 and 5. The proposed antenna exhibits the impedance bandwidth $(B.W. = 200*(f_h - f_l)/(f_h + f_l))$ of 141.15 % for $S_{11} < -10\,dB$.

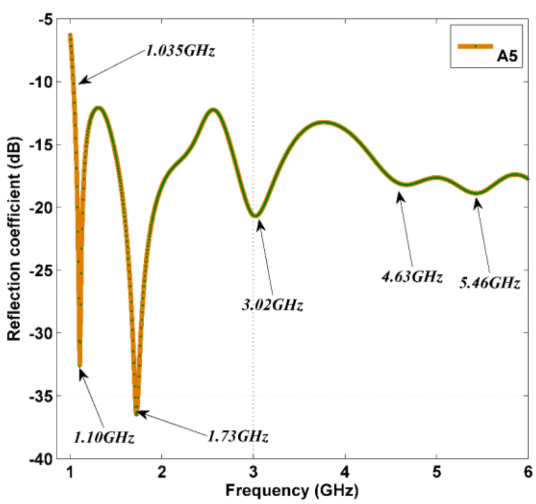

Fig. 4. S_{11} characteristic of Composite wide slot antenna with parasitic element.

The lower cut off and higher cut off frequencies are 1.05 GHz and 6 GHz. 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. In figure 4, the real part of the impedance oscillates from 20 ohm to 82 ohm. The imaginary part of the impedance varies from -20 ohm to 30 ohm. Fig.5demonstrates the far field distribution of composite wide slot antenna with theparasitic element at measured resonance frequencies 1.18, 2.38, 3.3 and 5.25 GHz. It has been noticed that at frequencies 1.18 GHz and 2.38 GHz, the approximate Omni-directional pattern has been obtained in H-plane while eight shape pattern is found in E-plane. As frequency increases, the number of excited modesare also increased which changes the shape of the pattern. At frequencies 3.3 and 5.25 GHz, the Omni-directionality of the pattern has been lost in the H plane. The shape of thepattern in E-plane has also distorted because of higher order modes.

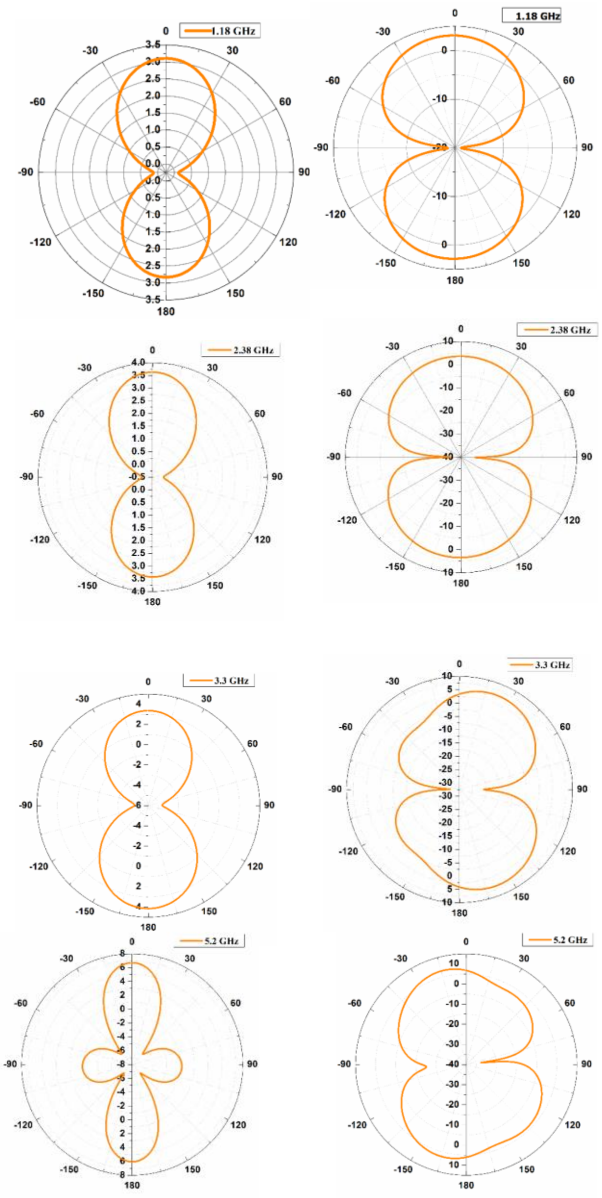

Fig.6 . E plane (left) and H plane pattern at frequencies 1.18 GHz, 2.38 GHz, 3.3 GHz and 5.25 GHz.

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 measured value of lower and higher cut off frequency is 1.05 GHz and 6 GHz. The proposed antenna shows resonance 1.1, 1.73, 3.02, 4.63 and 5.43 GHz. The far field pattern has been inspected in E plane and H plane. The Omni directional pattern has been investigated at lower frequencies (1.1 and 2.38 GHz) whereas, at other frequencies, the distorted pattern has been found.

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