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Frequency Formulation of Scarecrow Antenna with Boat Shaped Ground

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Abstract: - *In this article, an analysis of modified version of the Scarecrow antenna with boat shaped ground for wideband application is presented. The proposed monopole configuration consists of composite shaped radiating element and truncated ground plane which is modelled on FR-4 substrate ($tan(\delta) = 0.02, \varepsilon_r = 4.3$)The overlapping and tuning of resonating modes is achieved by augmenting composite slot on top edge of the boat shaped ground plane. The electromagnetic energy is delivered to radiating patch through the feed line which is connected with SMA connector. The proposed antenna has exhibited the fractional bandwidth of 128.76 % from 1.3 GHz to 6 GHz for $|S_{11}| < -10\ dB$with resonating frequencies 1.53, 2.45, 3.47, 4.85 and 5.54 GHz. Formulation of the resonating frequencies is also presented after inspecting the current distribution. To predict electromagnetic behaviour of the antenna, structural parametric analysis is also carried out with the help of CST Microwave Studio.*

Keywords: - *Impedance Bandwidth, Hybrid slot, Resonating modes*

I. Introduction

Printed monopole antennas have received valuable attention in wireless technology because of their attractive characteristics like wide impedance bandwidth and far-field pattern. Apart from these features, monopole antennas also exhibit characteristic like easy integration with microwave circuitry, small volume and cheap fabrication cost [1-2]. Fractional bandwidth of the planar antenna depends on tuning and overlapping of the resonating modes which is achieved by proper selection of geometry of the slot, radiating patch and feed structure [3]. In printed antennas, slot introduces the slow wave effect that alters the phase velocity ($v_p = 1/\sqrt{LC}$) of the resonating modes (TM_{10}, TM_{01},$TM_{12}$and TM_{20}) by changing the value of inductance (L) and capacitance (C) [4-6]. In addition, bandwidth of printed monopole antennas can be altered by reshaping of feed structure which is responsible for tuning of resonating modes [7-10]. Apart from above mention techniques, shape of radiating structure changes the fractional bandwidth of the monopole antennas because it changes the mutual coupling with ground plane. Some reported shapes are theta shaped, cross shaped, ring shaped and hybrid shaped [11-14]. Truncation of ground plane introduces the capacitive effect and generates new edges for fringing [15]. Such truncation improves the impedance matching throughout the frequency band. By adding the shorting stub [16] and flaring the arm of the ground plane [17], the bandwidth of the monopole antenna can be also enhanced. In this communication, we present modified Scarecrow antenna [18] with boat shaped ground plane for wideband application. The radiating patch of Scarecrow antenna has been modified by adding small elliptical shape element while ground plane is amended by adding four triangular slots and elliptical slot. For bandwidth improvement, a hybrid elliptical slot (combination of two elliptical slots) is loaded on top edge of the boat shaped ground plane. This structure covers the bandwidth of 128.76% from 1.3 GHz to 6 GHz for $|S_{11}| < -10$ dB. Frequency formulations of each resonating frequencies are also done.

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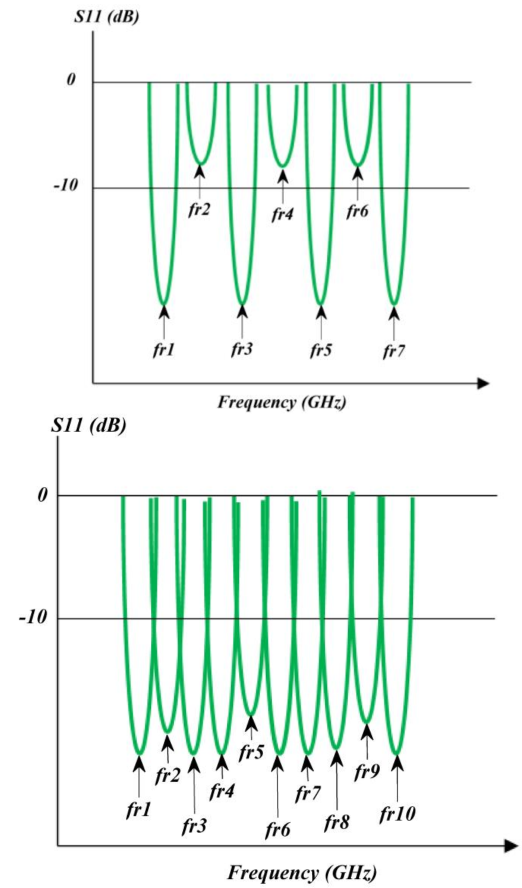

Fig. 1 Schematic of overlapping of modes a) Before tuning, b) After tuning of modes.

II. Antenna Configuration

The physical geometry along with parameters of the proposed modified Scarecrow shaped antenna is shown in figure 2. The optimized dimensions are listed in table 1. The proposed antenna is fabricated on FR4-epoxy substrate ($\tan(\delta) = 0.02, \varepsilon_r = 4.3$and $h = 1.6$ mm) which is placed on $Z = 0$ plane. The overall volume of antenna is $85 \times 70 \times 1.6\ mm^3$. A hybrid radiating patch (Combination of two elliptical elements) and feed line have been printed on top of the dielectric layer. For bandwidth improvement, two elliptical shaped slots have etched on partial ground plane. These slots introduce capacitive effect and control the impedance bandwidth of the antenna. Further, four triangular shaped slots are truncated on the corners of the partial ground plane for impedance matching. These triangular slots improve the VSWR characteristics in frequency band 1 to 6 GHz. The radiating structure is excited by optimized feed line which is connected with inner conductor of sub-miniature version A (SMA) connector. In numerical analysis, the radius of inner and outer conductor is taken 0.7 mm and 0.02 mm respectively. In simulation, we have taken 0.035 mm thin conducting layer and the structure is excited by wave guide port.

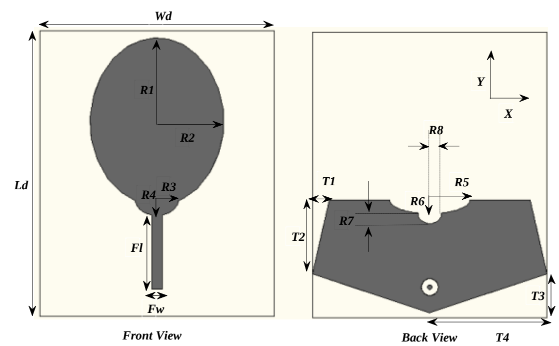

Fig. 2. Geometry of modified Scarecrow antenna (a) Front view, (b) Back view.

Table 1. Structural parameters and dimensions of modified Scarecrow antenna.

Parameter	Dimension (mm)	Parameter	Dimension (mm)
F_l	23	R_5	12
F_w	3	R_6	4
R_1	25	R_7	3
R_2	20	R_8	3.5
R_3	6.5	T_1	5
R_4	5	T_2	22
L_d	85	T_3	13
W_d	70	T_4	35

III. Structural Parameter Analysis

In parameter study, only one variable is varied at a time and the others are unchanged. Variation of structural parameters alter the position of resonating frequencies, impedance bandwidth, impedance matching and position of higher and lowers cut-off frequency. Structural parameters also affect the mutual coupling between ground plane and radiating element.

III.1 Effect of radius (R_1, R_2, R_3 and R_4) of hybrid radiating element

The impact of R_1 has displayed on figure 3. It has been investigated that the size of major axis radius R_1 directly affects the mutual coupling between ground plane and patch. It changes the impedance matching significantly at resonating frequencies f_{r1}, f_{r3} and f_{r4}. On modifying the R_1, the resonance frequency f_{r3} is blue shifted while resonance frequency f_{r4} is red shifted. At optimized value of R_1 which is equal to 25 mm, a new resonating frequency f_{r2} is investigated on spectrum. In numerical analysis, it has been noticed that the optimum bandwidth is occurred for range $23\,mm \leq R_1 \leq 25mm$. Modifications of the other radius (R_2, and R_3) of radiating element do not affect the impedance bandwidth of the antenna. Figure 4 shows the impact of parameter R_4 which alters the impedance matching in entire frequency band. For larger value of $R_4 > 6mm$, the bandwidth is deteriorated due to less mutual coupling between ground and patch. This parameter also alters the position of resonance frequencies f_{r3} and f_{r4}.

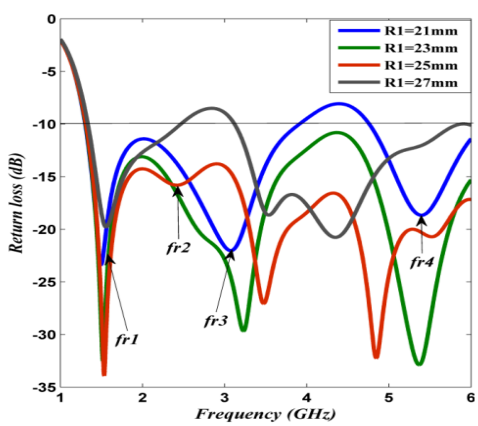

Fig. 3. Impact of R_1 on S_{11} characteristic of the modified Scarecrow antenna.

III.2 Effect of radius (R_5, R_6, R_7 and R_8) of hybrid slot

Slot introduces the capacitive effect on antenna and also responsible for overlapping of modes. The major axis radius R_5(figure 5) of hybrid slot changes the impedance bandwidth of the antenna due to change in capacitive effect. Moreover, this parameter significantly affects the higher frequency band. After simulation, It has been noticed that the optimum bandwidth is found for when $R_5 \geq 10mm$. The impact of radius R_6 is displayed in figure 6. This parameter alters the impedance matching level in entire frequency band due to capacitive effect. On modifying the R_7 (figure 7), the resonance frequency f_{r3} is blue shifted while frequencies f_{r2} and f_h are red shifted. In simulation, it has been noticed that higher value of R_7 deteriorates the impedance bandwidth of the antenna. The parameter R_8 does not affect the impedance bandwidth.

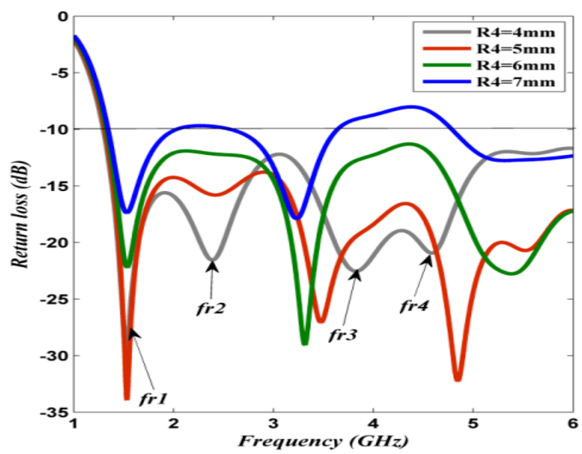

Fig. 4. Impact of R_4 on S_{11} parameter of the modified Scarecrow antenna.

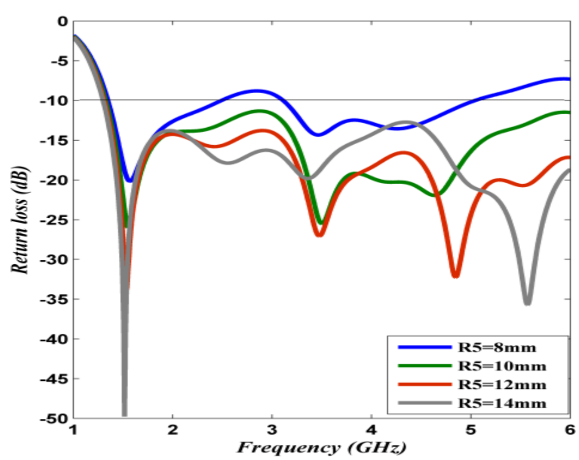

Fig. 5. Impact of R_5 on S_{11} characteristic of the modified Scarecrow antenna.

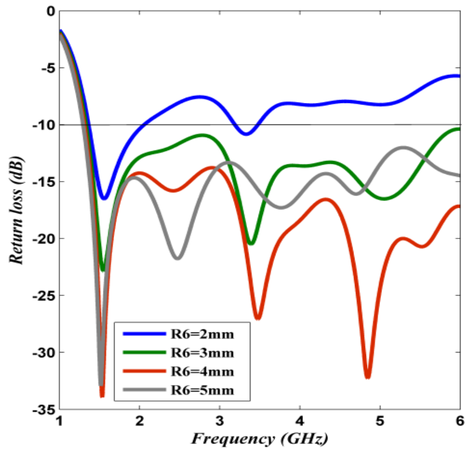

Fig. 6. Impact of R_6 on S_{11} parameter of the modified Scarecrow antenna.

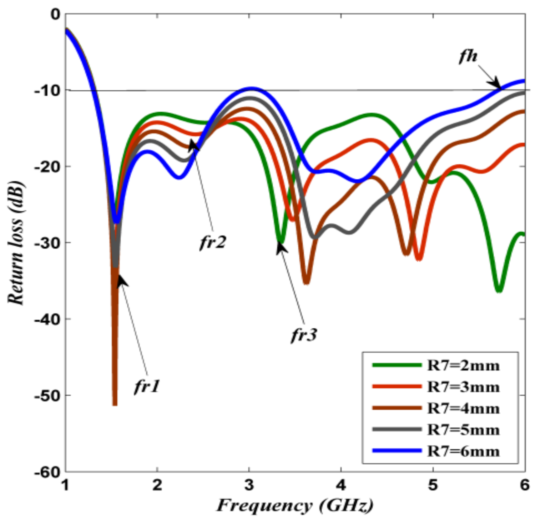

Fig. 7. Impact of R_5 on S_{11} characteristic of the modified Scarecrow antenna.

III.3 Effect of area of triangular slot on VSWR characteristic

The impact of area of upper triangular slot ($0.5 * T_1 * T_2$) and lower triangular slot ($0.5 * T_3 * T_4$) on VSWR are illustrated in figure 8 and 9 respectively. It can be noticed from both figure that the smaller area of the slot up shift the VSWR. The optimized area we have taken 88 mm^2 and 210 mm^2.

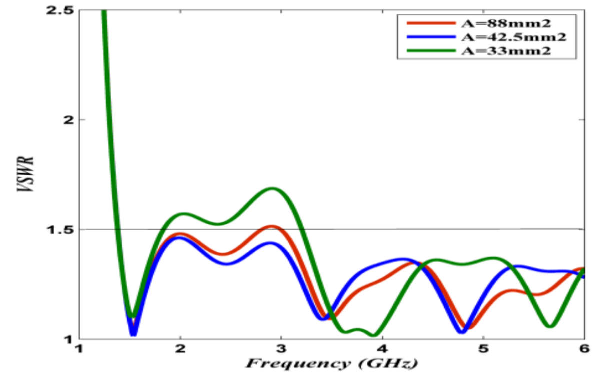

Fig. 8. Impact of upper triangular slot on VSWR characteristic of the modified Scarecrow antenna.

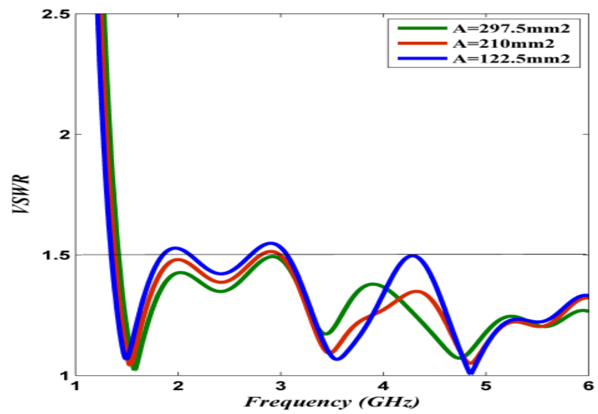

Fig. 9. Impact of lower triangular slot on VSWR characteristic of the modified Scarecrow antenna.

IV. Current Distribution

To understand the electromagnetic behaviour of the antenna, the vector current distributions (figure 10) have been examined at resonating frequencies. After investigation, we have concluded following points. 1) Number of higher order modes increases as operating frequency increases. 2) Current distribution is symmetric about y axis and distributed on patch and ground plane. At frequency 1.53 GHz, the current vectors are distributed like TM_{10} mode on composite radiating element and one half wave variation of the current vector along the periphery is also noticed. The resonance frequency of the fundamental mode ($f_1 = 1.53\ GHz$) is developed due to composite radiating element. It is also notices from current distribution that current is stronger on feed line and patch that confirms that antenna is operated due to fundamental mode. The frequency f_1 is estimated by following equation

$$a_{eff} = (R_1 + R_4)[1 + \frac{2h}{\pi\varepsilon_r(R_1 + R_4)} \{\ln(\frac{(R_1 + R_4)}{2h}) + (1.41\varepsilon_r + 1.77)]^{1/2} \quad (1)$$

$$f_1 = \frac{1.8412 * C_0}{2 * \pi * a_{eff} * \sqrt{\varepsilon_r}} \quad (2)$$

The calculated value of f_1 is 1.52 GHz. An error of 0.65 % (equation 3) has been calculate between simulated and calculated value of f_1

$$E1\,(\%) = \frac{f_{1\,simulated} - f_{1\,calculated}}{f_{1\,simulated}} * 100 \quad (3)$$

The edges of boat shaped ground plane also radiate the electromagnetic energy. The second resonating mode (f_2) is caused by edges of the ground plane. The frequency (f_2) of second resonating mode is determined by the following equations.

$$L = \sqrt{{T_1}^2 + {T_2}^2} + \sqrt{{T_3}^2 + {T_4}^2} \quad (4)$$

$$f_2 = \frac{c}{L\sqrt{\varepsilon_r}} \quad (5)$$

The calculated value of f_2 is 2.39 GHz. The broadband response of the antenna is realized after the overlapping of the modes. At frequency 3.47 GHz, we can notice that the two half wave variation of the current vectors has been investigated along the composite radiating patch which is equal to the second harmonics $(f_a = 2f_1 = 3.06\,GHz)$ of the fundamental mode. We have also noticed that another frequency is developed by the ground. This frequency can be estimated by following equations

$$L_1 = \sqrt{{T_1}^2 + {T_2}^2} + T_4 - R_5 - T_1 + (\pi/2) * \sqrt{(R_5^2 + (R_6 + R_7)^2)/2} \quad (6)$$

$$f_g = \frac{c}{L_1\sqrt{\varepsilon_r}} \quad (7)$$

The calculated value of f_g is 3.46 GHz. Due to mutual coupling between ground plane and radiating patch the two frequencies (f_g and f_a) come closer and after overlapping gives broadband response at 3.47 GHz. At frequency 4.85 GHz, third harmonics $(f_b = 3f_1 = 4.59\,GHz)$ mode of composite radiating patch, and other higher order modes of ground plane have been investigated. The Current is stronger on radiating element and feed line which confirms that antenna is operated due to third harmonic of radiating element.

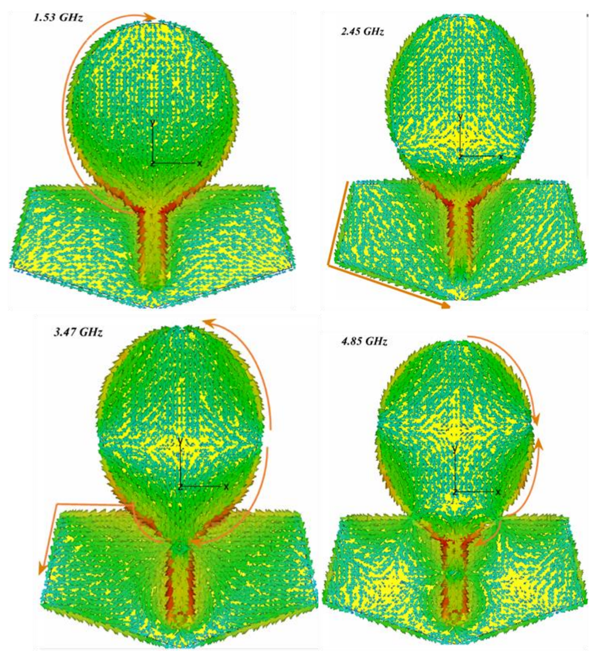

Fig 10. Simulated surface current distribution of proposed antenna at frequencies f_1= 1.53 GHz, f_2 = 2.45 GHz, f_3 = 3.47 GHz and f_4 = 4.85 GHz

VI. Conclusion

A modified version of Scarecrow antenna with boat shaped ground has been studied. It has been investigated that wide band property of the antenna depends on geometry of hybrid slot which is truncated at top edge of the ground plane. This topology offers the fractional bandwidth of 128.76 % from 1.3 GHz to 6 GHz for $|S_{11}| < -10$ dBwith resonating frequencies 1.53, 2.45, 3.47, 4.85 and 5.54 GHz.The series of equations have been deduced after studied the current distribution at resonating frequencies (1.53, 2.45, 3.47 and 4.85 GHz).

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