Design of a Tri band 5-Fingers Shaped Microstrip Patch Antenna with an Adjustable Resistor

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***Abstract*—This paper presents a tri band 5-fingers shaped microstrip patch antenna, which resonates initially at dual band of 3.2 GHz and 5.2 GHz frequencies for VSWR < 2. The antenna is modified by adding an adjustable resistor between the conductor and the reflecting plane giving a third resonant frequency of 2.4 GHz. A decrease in the return loss at 2.4 GHz is observed by modifying the value of the resistance. Impedance bandwidth and the resonant frequencies are examined with respect to the variability of the parameters of the antenna and the position of the adjustable resistor. The size of the antenna has been reduced by 57.9% in length and 14.06% in width. The proposed antenna can be used for 4G, WLAN, and Wi-MAX. The antenna is designed and optimized by using the commercial CST software.**

Index Terms—finger shaped microstrip antenna; adjustable resistor; tri band

I. INTRODUCTION

In recent years, because of the increase in the need for miscellaneous wireless technology services like voice, data, and multimedia, the microstrip patch antennas are the most widely preferred in wireless communication. They can be printed and fabricated easily, have low cost, low profile, compatibility with planar or non-planar surfaces, can be shaped and meandered into various forms, have high performance, ease of installation and dual as well as triple polarization property [1] [2].

Generally, narrow beam and low efficiency are the two major operational disadvantages of the microstrip patch antennas. The proposed 5-fingers shaped microstrip antenna obtained popularity due to its wideband, high efficiency and tri band property, which may gain attention for various applications in modern communication systems including Wi-Max and Wi-Fi [3]. Many new forms of microstrip patch antennas have appeared over the years and have been used in many applications [4] [5] [6]. The 5-fingers shaped microstrip patch antenna (5FSMPA) with an adjustable resistor connected between the radiating patch and the ground plane is a novel model with various directivities, polarization, bandwidth and good pattern characteristics. The resonant length of the 5FSMPA is approximately $\lambda_0/2$. The parameters of the antenna are optimized to include multiple operation frequencies and to have a small physical size [7].

In this paper, novel broadband 5 fingers shaped microstrip patch antenna with an adjustable resistor is presented, the designed antenna resonates at a tri band of 2.4 GHz, 3.2 GHz and 5.2 GHz with improved bandwidth (BW). The results are compared with the case of an adjustable resistor is loaded and unloaded. Furthermore, many methods have been proposed by researchers such as closely spaced parasitic patches, shorting pins, photonic band gap and multilayer of substrates [8] [9]. An adjustable resistor is a technique has been added as a novel method of optimization.

The adjustable resistor enables tuning gradually the resistance value that ranges between 1-10 Ohms to optimize the antenna's performance. The EM waves fringe off the top radiating patch into the dielectrical material of the substrate and the adjustable resistor, reflecting off the ground plane and radiates out into the air [10]. In other words, the ddition of an adjustable resistor is the main reason for having the third resonant frequency of 2.4 GHz. Selection of the feeding system is managed by numerous factors. The most important is the efficient transfer power between the radiating plane and the feeding point [11] which requires impedance matching between these components. The size of the antenna has been reduced as much as possible. Based on these properties, a broadband 5-fingers shaped microstrip antenna could find a wide range of applications in many wirelesss communication ystems.

II. ANTENNA DESIGN

A. *Concept*

As noted in the previous section, the antenna is designed and optimized for performance and minimum physical size. The design consists of the following steps: (1) the radiating patch is shaped to obtain the 5FSMPA as shown in Fig.1, (2) an adjustable resistor is loaded and the feeding system is located in suitable positions, which are adjusted by trial and error method [12], (3) unfilled spaces between the radiating patches are regulated accurately, (4) a convenient thickness and dielectric material with low loss is selected.

B. *The design of 5FSMPA*

The proposed antenna consists of a conducting patch of planar geometry on the first face of the substrate with the ground plane on the other face. The antenna is fed at the center of the middle patch with a coaxial conductor of a radius R

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=0.065 cm (0.0052 λ_o). The dielectric material is chosen as FR-4 with a dielectric constant of ε=4.3 with a thickness of h=0.2 cm (0.016 λ_o), which has been picked out to be a factor for reducing the dimension of the patches. The patch size is mainly characterized by the dimensions of length L1, width W1 and height h. The geometry of the proposed 5FSMPA is illustrated in Fig. 1.

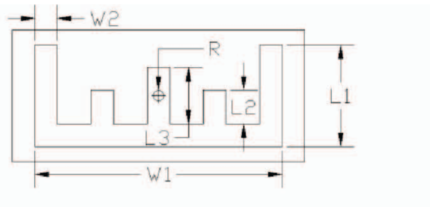

Figure 1. 5-fingers shaped microstrip patch antenna

C. Calculating of the dimensions of the 5FSMPA

To design the 5FSMPA, the basic parameters are calculated using the simplified equations of Transmission Line Method (TLM) [12]. The width of the 5FSMPA is given as:

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (1)$$

Therefore, W is 3.84 cm when c is the speed of the light taken as 30*10^9 cm/s, f_r is the resonant frequency of 2.4 GHz and ε_r is the dielectric constant of 4.3. The effective dielectric constant is calculated as:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{1+12\frac{h}{W}} \qquad (2)$$

where h is the height of the substrate. The effective length is calculated as:

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \qquad (3)$$

The normalized extension of the length is calculated as:

$$\Delta L = 0.412h\frac{(\varepsilon_{eff+0.3})(\frac{W}{h}+0.264)}{(\varepsilon_{eff-0.258})(\frac{W}{h}+0.8)} \qquad (4)$$

Thus, the actual length is given as:

$$L = L_{eff} - 2\Delta L \qquad (5)$$

Substituting the values of L_{eff}=3.4 cm, ΔL=0.0946 cm and ε_{eff} = 3.3 into the equation above the actual length of L= 3.21 cm is obtained.

Notice that the used physical length L1 of the antenna has been reduced by a ratio of 57.9% of the calculated actual length L. The physical dimension L1 is chosen as 1.35 cm (0.108 λ_o) which represents the longest patch of the antenna and is also mirrored to the left side. L2 has a value of 0.45 cm (0.036 λ_o) and mirrored to the left side as well, L3 is 0.75 cm (0.06 λ_o) positioned in the middle of the antenna and the feeding system is located at the center of L3 for feeding each side (right and left) of the 5FSMPA with equal amplitudes. Hence, the current is maximum at the center of the half-wave patch. Based on the above, the antenna has been realized using five patches linked in the down edges by a width of W1= 3.3 cm (0.264 λ_o) which has been reduced by a ratio of 14.06% of the calculated W in (1).

The unfilled distances between the patches L1, L2 and L3 are adjusted carefully and symmetrically to avoid the effect of mutual coupling and correlation between the patches which has a value of 0.45 cm (0.036 λ_o) and to control the bandwidth [12].

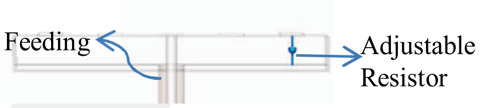

Figure 2. Location of the feeding system and the adjustable resistor

The adjustable resistor has values ranging from 1-10 ohms, and is connected as shown in Fig. 2. The optimum location for the adjustable resistor is at the bottom of the L1 patch. Because the size of the resistor should be small, Surface Mounted Resistors (SMDs) are selected [13].

III. Results And Discussion

A. 5FSMPA without an adjustable resistor

In this section, the 5FSMPA is simulated without adding the adjustable resistor. The reflection coefficient (S_{11} Parameter) as a function of frequency is achieved for a target S_{11} of -10 dB with a dual band that resonates at 3.24 GHz and 5.16 GHz with return losses of -14.5 dB and -28.5 dB respectively. The corresponding bandwidths are 0.23 GHz and 0.83 GHz respectively as shown in Fig. 3. The voltage standing wave ratio (VSWR) is illustrated to obtain the values of 1.5 and 1.1 at 3.24 GHz and 5.16 GHz respectively as shown in Fig. 6 (dotted line).

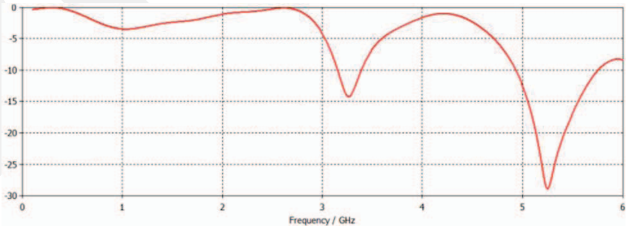

Figure 3. Simulated reflection coefficient without an adjustable resistor

The radiation patterns of antennas are the most important characteristic and the easiest to determine. The radiation patterns are defined in the far-field region and are represented as a function of directional coordinates [10]. The main beam pointed in the $\emptyset = 0°$ direction at two resonated frequencies is shown in Fig. 4.

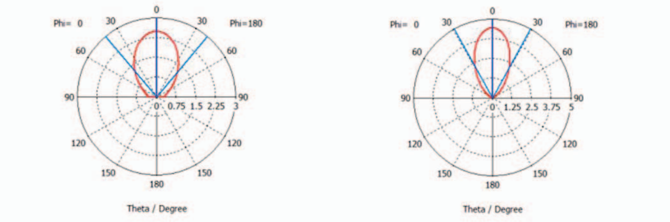

Figure 4. Linear scaled radiation pattern for $f = 3.24\ GHz$ (left) and $f = 5.16\ GHz$ (right)

Accordingly, the results without loading the adjustable resistor are tabulated in Table I. Notice that the main beam direction is at 0º.

TABLE I. RESULTS OF DIRECTIVITIES AND HPBW WITHOUT RESISTOR

NO	***Frequency(GHz)***	***Directivity (dBi)***	***HPBW***
1	3.24	4.15	39.6º
2	5.16	6.45	29.45º

B. *5FSMPA with an adjustable resistor*

The 5FSMPA is simulated by inserting the adjustable resistor to achieve a tri band while minimizing the value of return losses and maximizing the bandwidths slightly. In this case, the value of the resistor is 1 Ohm. Therefore, the resonant frequencies are observed at 2.4 GHz, 3.25 GHz and 5.29 GHz with return losses of -27.27 dB, -15.7 dB and -30.5 dB respectively. The bandwidths also have changed partially to be 0.11 GHz, 0.22 GHz and 0.98 GHz respectively as shown in Fig. 5. The VSWR values are observed as 1.1, 1.4 and 1.1 at the tri resonant frequencies respectively as shown in Fig. 6 (solid line).

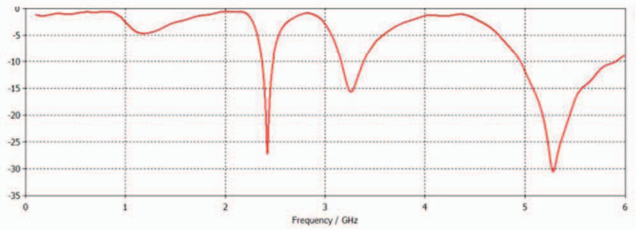

Figure 5. Simulated reflection coefficient with loading a resistor of 1 Ohm

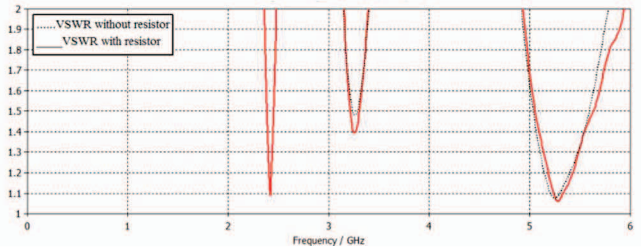

Figure 6. Simulated VSWR versus frequency with loading a resistor of 1 Ohm

The values of directivities and half power beam width (HPBW) with an angular width of 3 dB are tabulated in Table II. It has been observed that the main beam directed 8º to the left side (LS) at 2.4 GHz, 1º and 2º to the right side (RS) at 3.25 GHz and 5.29 GHz respectively, as shown in Fig. 7.

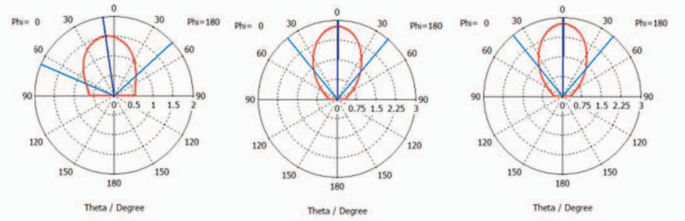

Figure 7. Linear scaled radiation pattern for $f = 2.4\ GHz$ (left), $f = 3.25\ GHz$ (mid) and $f = 5.29\ GHz$ (right)

TABLE II. RESULTS OF DIRECTIVITIES AND HPBW WITH 1 OHM RESISTOR

No	***Frequency (GHz)***	***Directivity (dBi)***	***HPBW***
1	2.4	3.43	57.3º
2	3.25	4.39	39.7º
3	5.29	6.31	29.1º

C. *The effects of using an adjustable resistor*

In this section, the effect of adjusting the resistance value is analyzed. Note that when the value of resistor decreases the return loss also decreases at the resonant frequency of 2.4 GHz, which means the relationship between the value of the resistor and the value of return loss is directly proportional. However, some shift is observed at the frequencies of 3.25 GHz and 5.29 GHz. The direction of the main lobe at the frequencies of 3.25 GHz and 5.29 GHz range between 1-2º to the RS. The value of the adjustable resistor and the return loss are tabulated in Table III and the S_{11} Parameters are shown in Fig. 8.

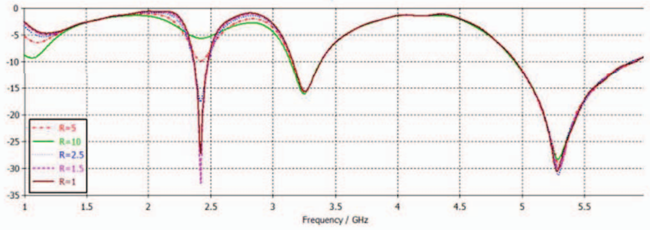

Figure 8. Simulated reflection coefficient with an adjustable resistor

From Table III, it is observed that the main beams are directed to the LS, which are affected by the location of the resistor loaded in the bottom of the right side of L1. That means, in the case of loading the adjustable resistor in the bottom of the mirrored L1 which is located in the left side of the 5FSMPA the main beams will be directed to RS with similar degree values, as a natural result of the symmetricality of the antenna shape.

TABLE III. Results Of Loading An Adjustable Resistor In 5FSMPA

No	***Freq. (GHz)***	***adjustable Resistor (Ohm)***	***Return Loss (dB)***	***Directivity (dBi)***	***Beam Direction (Degree)***
1	2.4	10	-5.67	3.65	31° (LS)
2		5	-9.88	3.53	21° (LS)
3		2.5	-17.54	3.44	13° (LS)
4		1.5	-32.79	3.47	10° (LS)
5		1	-27.27	3.43	8° (LS)

IV. CONCLUSION

A tri band 5FSMPA is achieved and its size has been reduced by the concept of shaping the radiating patch, adding an adjustable resistor positioned between the radiating patch and the ground plane and selecting the most suitable dielectric material. The radiation patterns are almost the same when the adjustable resistor is not loaded, but there is a left direction by different degrees at 2.4 GHz when it is loaded. It is noticed that, if the value of the resistor increases the main beam direction also increases. The return loss of the 5FSMPA shows that the antenna is a wide band, multi frequency, has attractive features of simplicity and flexibility of controlling the frequencies and the return loss. The ability to adjust the resistor value and its position enables to generate a novel resonant frequency at 2.4 GHz. It is observed that the performance of 5FSMPA can be controlled by adjusting the parameters. The dimensions presented are the optimums found after several experiments.

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