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Compact Dual-Band Triangular Microstrip Antenna with Broadband Characteristics for WLAN Applications

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Abstract- This paper presents the design and performance analysis of a compact dual-band equilateral triangular microstrip antenna (ETMSA) with broadband characteristics for wireless local area network (WLAN) applications at 2.4 and 5.2 GHz, respectively. Fundamental design equations of triangular microstrip antenna were used to determine the physical parameters of the antenna such as sidelength and simulation was done using CST Studio on a Flame Retardant-four (FR-4) substrate having a dielectric constant, ε_r of 4.3 with a height of 1.6 mm. A bandwidth of 41.4 MHz and 774 MHz at 2.4 GHz and 5.2 GHz, respectively were attained by the proposed antenna. This makes the proposed antenna adaptable to broadband applications in the 5 GHz band. Other antenna parameters such as voltage standing wave ratio (VSWR) and directivity are also presented.

Keywords- *Equilateral Triangular Microstrip Antenna, Flame Retardant-Four, Slot Patch, Dual-Band*

I. INTRODUCTION

Wireless communication as defined by [1] is the transfer of information or power between two or more points that are not connected by an electrical conductor. There can be no wireless communication without the use of antennas which serve as the link between the transmitter and the receiver [2]. Considering the trend in modern communication devices, the planar, compact, ease of fabrication, low cost and light weight nature that is characteristic of microstrip antennas (MSAs) qualifies them for integration in modern communication devices [3].

According to [4], microstrip antennas find usefulness in various applications requiring conformity with the host; telemetry and communication antennas on missiles need to be thin and conformal and are often MSAs, radar altimeters use small arrays of microstrip radiators, some aircraft-related applications including antennas for telephone and satellite communications employ MSAs. Microstrip arrays have been used for satellite imaging systems. Microstrip (patch) antennas have also been used on communication links between ships or buoys and satellites. Smart weapon systems use MSAs because of their thin profile. Pagers, the global system for mobile communication (GSM), and the global positioning system (GPS) are major users of MSAs. The size of antenna used in a communication system is dependent on the frequency involved and as such for microwave frequency (f >1 GHz), microstrip antennas are usually very suitable [5].

Several methods have been put forward by many author and some adopted to increase the usable impedance bandwidth of the narrow bandwidth that is inherent in microstrip antennas such as the use of dual-band, array and broadband configurations. Among these configurations, reactive loading technique for dual-band configuration has been proposed as a means of bandwidth enhancement which makes use of a slot on both patch and ground plane for current and field redistribution around the patch.

II. REVIEW OF RELATED LITERATURES

Since the discovery of microstrip antenna in 1953 by Deschamps and its subsequent practical development by Munson and Howel in the 1970s [6], the idea for multi-frequency operation has been put forward by a number of authors adopting different techniques for its realization. The concept of dual patch equilateral triangular antenna with form substrate in-between for mechanical support was used by [7]. The top patch was used as the parasitic patch while the bottom patch was used as driven patch with a coaxial field; a bandwidth of 13.2 percent was measured by the authors around a centre frequency of 2.50 GHz. Triangular microstrip antenna loaded by slots for global positioning system (GPS) was proposed by [8], a tapered equilateral microstrip antenna with two spur lines of narrow width and length embedded on both sides of the patch on a FR-4 substrate was designed at operating frequencies of 1.227 GHz and 1.575 GHz, respectively. Multimode excitation of equilateral triangular antenna was adopted by [9] on an RT-Duroid substrate with operating frequencies of 1.298 GHz and 2.266 GHz. An equilateral triangular microstrip dual band microstrip antenna with Koch boundary was proposed by [10] using FR-4 substrate designed at frequencies of 5.2 GHz, and 5.8 GHz and simulated on Advanced Design System (ADS).

III. ANTENNA DESIGN PROCEDURE

A. *Design Procedure and Simulation*

Generally, the preliminary step to every patch antenna design is to choose some design parameters as stated by [11] such as the substrate, the substrate height (h = 1.6 mm), dielectric constant of the substrate ($\varepsilon_r = 4.3$) and the first operating frequency of the patch (2.4 GHz), respectively. The final optimization for the dual band resonation was done using CST Microwave Studio. The design procedures are as follows:

Step one: Considering the dominant TM_{10} mode of an equilateral triangular microstrip antenna (ETMA), the sidelength, a, as stated by [5] is given as:

$$a=\frac{2c}{3f_r\sqrt{\varepsilon_r}} \tag{1}$$

Substituting the values of c = 3×10^8 m/s, f_r= 2.4×10^9 Hz and $\varepsilon_r = 4.3$, the sidelength of the proposed antenna at 2.4 GHz is calculated thus:

$$a=\frac{2\times3\times10^{11}}{3\times2.4\times10^9\times\sqrt{4.3}}=0.04019\text{ m}=40.19\text{ mm}$$

Step two: The effective side length which takes into consideration the effect of spurious radiation from the antenna given in (2) was determined by substituting a = 40.19 mm, h = 1.6 mm, f_r=2.4×10^9 Hz and ε_r=4.3 as follows;

$$a_e=a\begin{bmatrix}1+2.199\frac{h}{a}-12.853\frac{h}{a\sqrt{\varepsilon_r}}+16.436\frac{h}{a\varepsilon_r}\dots\\ +6.182\left(\frac{h}{a}\right)^2-9.802\frac{1}{\sqrt{\varepsilon_r}}\left(\frac{h}{a}\right)^2\end{bmatrix} \tag{2}$$

$$=40.19\times\begin{bmatrix}1+2.199\times\frac{1.6}{40.19}-12.853\times\frac{1.6}{40.19\times\sqrt{4.3}}\dots\\ +16.436\times\frac{1.6}{40.19\times4.3}\dots\\ +6.182\times\left(\frac{1.6}{40.19}\right)^2\dots\\ -9.802\times\frac{1}{\sqrt{4.3}}\times\left(\frac{1.6}{40.19}\right)^2\end{bmatrix}$$

$$=0.03761\text{ m}=37.61\text{ mm}$$

Step three: The minimum length of ground plane, L_g as adopted from [4] given for rectangular patch is calculated thus:

$$L_g=6h+a \tag{3}$$

where: h = 1.6 mm

a = 40.19 mm

$$\therefore L_g=6\times1.6+40.19=0.04979\text{ m}=49.79\text{ mm}$$

Step four: Applying a modified expression for calculating the edge impedance of rectangular patch adopted from [4],[11] and [12] to estimate the edge impedance of ETMA given thus:

$$Z_{edge}=90\frac{{\varepsilon_r}^2}{\varepsilon_r+1}\left[\frac{a_e}{L_g}\right]^2=90\times\frac{4.3^2}{4.3+1}\times\left[\frac{37.61}{49.79}\right]^2=179.15\ \Omega \tag{4}$$

The edge impedance does not match well with 50 Ωstandard microstrip lines and therefore a quarter-wavelength transformer is used to connect the microstrip line to the resonating patch. The Characteristic impedance of the transition section as given by [11] was calculated as follows:

$$Z_{qw}=\sqrt{Z_0Z_{edge}}=\sqrt{50\times179.15}=94.64\ \Omega \tag{5}$$

Hence, setting the width of the 50 Ω line to be W_f and that of the 94.64 Ω to be W_q.

Step five: The width of the 50 Ω transmission line, W_f, as given by [1] is calculated thus:

$$Z_o=\frac{120\pi}{\sqrt{\varepsilon_r}(W_f/h+1.393+0.667\ln(W_f/h+1.44))}\ \text{for}\ \frac{W_f}{h}\geq1 \tag{6}$$

$$50=\frac{120\pi}{\sqrt{4.3}\times\left[\frac{W_f}{1.6}+1.393+0.667\ln\left(\frac{W_f}{1.6}+1.44\right)\right]}$$

$$\frac{W_f}{1.0672}+\ln\left(\frac{W_f}{1.6}\right)=5.0867$$

Solving the above equation by iteration, the solution was at;

$$W_f = 0.004367\text{ m} = 4.367\text{ mm}$$

The width of the 94.64 Ω transition section, W_q , is calculated thus:

$$Z_o=\frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{8h}{W_q}+\frac{W_q}{4h}\right)\ \text{for}\ \frac{W_f}{h}\leq1 \tag{7}$$

$$94.64=\frac{60}{\sqrt{4.3}}\ln\left(\frac{8\times1.6}{W_q}+\frac{W_q}{4\times1.6}\right)$$

$$\log\left(\frac{94.64\times\sqrt{4.3}}{60}\right)=\frac{8\times1.6}{W_q}+\frac{W_q}{4\times1.6}$$

$${W_q}^2-3.294W_{q2}+81.92=0$$

$$W_q=0.001647\text{ m}=1.647\text{ mm}$$

Step six: The length of the quarter-wave microstrip transmission line, L_q was calculated thus

$$L_q=\frac{\lambda}{4}=\frac{\lambda_{air}}{4\sqrt{\varepsilon_r}}\ \ [11] \tag{8}$$

$$\lambda_{air}=\frac{3\times10^8}{2.4\times10^9}=0.125\text{ m}=125\text{ mm}$$

$$\therefore L_q=\frac{125}{4\times\sqrt{4.3}}=0.01507\text{ m}=15.07\text{ mm}$$

The length of the 50 Ω transmission line, L_f was calculated as follows:

$$L_f=\frac{6h}{2}\quad[13] \tag{9}$$

$$=\frac{6\times0.1588}{2}=0.0048\text{ m}=4.8\text{ mm}$$

The first step in designing the dual band ETMA was the insertion of rectangular slot on the 2.4 GHz antenna. After some iteration and due to the presence of the slot on the patch, centre frequency of the patch increased to 4.94 GHz conforming to the inverse relationship between size of antenna and frequency. Basic parameters obtained using MATLAB program for single patch were computed alongside the slot parameters - which enabled the actualization of dual frequency resonation on a single patch - on the ground plane of designed antenna were determined using modified equations adopted from Shafai's design in [14], thus:

$$W_{slot}=\frac{\lambda_{air}}{Lq}=8.29\text{ mm}$$

$L_{slot}=\frac{\lambda_{air}}{a}$=3.11 mm

where: $\lambda_{air(2.4GHz)}$ = 125 mm

a = 40.19 mm, L_q = 15.07mm

The inclusion of slot on the ground plane changed the centre frequency as stated earlier to 4.94 GHz which was subsequently used in redesigning the antenna into a smaller patch for dual frequency resonation. Some computed design parameters are:

λ_{air} = 0.06073 m= 60.73 mm

L_f=0.0048 mm=4.80 mm

L_q=0.00732 m=7.32 mm

a = 0.01950 m =19.50 mm

Z_{edge}=160 Ω

Z_0=50 Ω

Z_{qw}=90.01 Ω.

The final optimization process was done in CST MW Studio. The summary of results of design calculation for various dimensions of the proposed dual band ETMA is given in Table 1.

The geometry of the designed antenna is given in Fig. 1, while Fig. 2 shows the designed antenna in CST MW Studio.

IV. RESULTS AND DISCUSSION

The return loss, directivity and VSWR of the proposed dual band ETMA antenna are presented in Fig. 3 to Fig 7. From the return loss plot of the proposed dual band ETMA given in Fig. 3, it was observed that a maximum return loss of -14.4137 dB and -20.0915 dB were achieved at 2.4 GHz and 5.2 GHz respectively, and a bandwidth of 41.4 MHz and 774 MHz at 2.4 GHz and 5.2 GHz, respectively were achieved by the dual band antenna.

The percentage bandwidth of the antenna was calculated using equation from [15] thus;

$$\text{Bandwidth at 2.4 GHz} = \frac{2.4156\text{-}2.3742}{2.4} \times 100\% = 1.74\ \%$$

$$\text{Bandwidth at 5.2 GHz} = \frac{5.8717\text{-}5.0977}{5.2} \times 100\% = 14.88\ \%$$

Evidently, the proposed antenna exhibits broadband characteristics at 5.2 GHz band.

The E-plane (φ = 90°) directivity of the proposed dual band ETMA was shown in Fig. 4 and Fig. 5, it was observed that the proposed antenna achieved a main lobe magnitude of 7 dBi and 3.29 dBi at 2.4 GHz and 5.2 GHz, respectively.

The VSWR plot of the proposed dual band antenna at 2.4 GHz and 5.2 GHz was illustrated in Fig. 6 and Fig. 7. The results show that the antenna resonated within the prescribed limits of 1<VSWR<2. As seen from Figures 6 and 7, a VSWR of 1.4843 and 1.6613 at 2.4 GHz and 5.2 GHz, respectively were obtained.

TABLE I. DUAL BAND ANTENNA DESIGN PARAMETERS

Parameter	Value (mm)
Patch dimensions: Side length, a	19.50
Effective side length, a_e	14.78
Dielectric constant, ε_r	4.30
Height of substrate, h	1.60
Quarter-wave fed dimensions:	
Width of transition section, W_q	1.57
Width of transmission line, W_f	4.37
Length of quarter wave, L_f	4.80
Length of quarter wave, L_q	7.32
Resonance Frequency, f_r	2.4 and 5.2 GHz
Ground plane dimensions:	
Length of ground plane, $L_g = W_g$	29.10
Slot dimensions:	
Width of slot, W_{slot}	8.29
Length of slot, L_{slot}	3.11

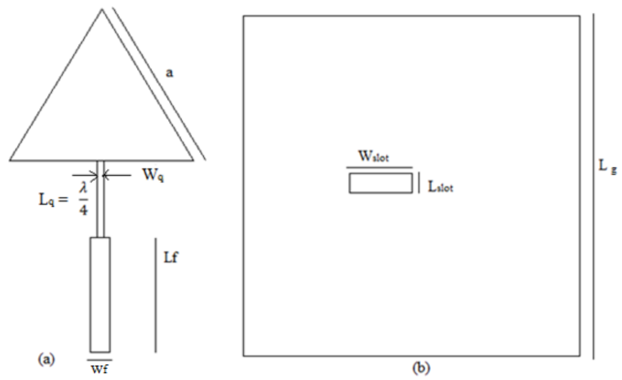

Figure 1. Geometry of the designed antenna (a) top view and (b) bottom view

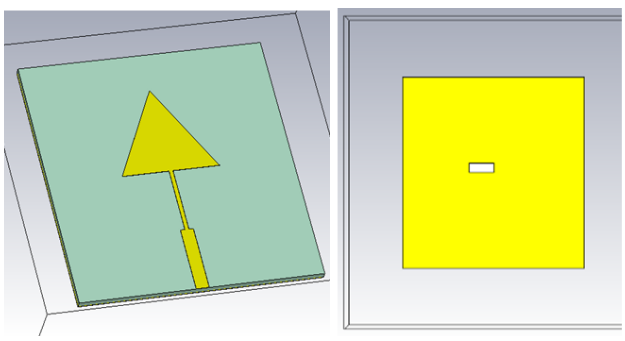

Figure 2. Top and bottom view of designed dual-band ETMA in CST MW Studio

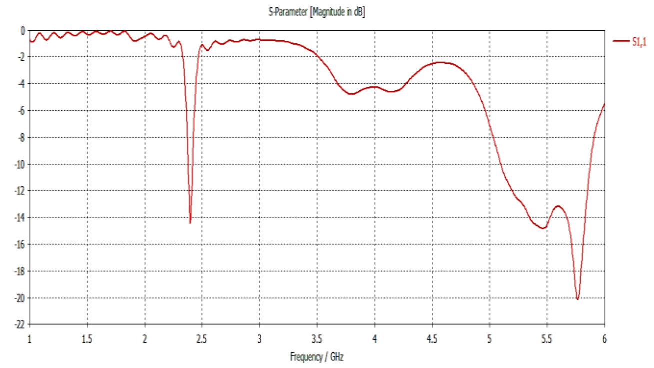

Figure 3. Return loss of the proposed antenna

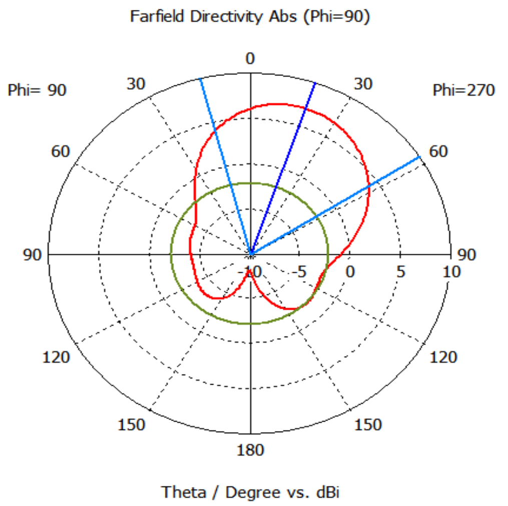

Figure 4. Directivity of proposed dual-band ETMA at 2.4 GHz in E-plane (φ = 90°)

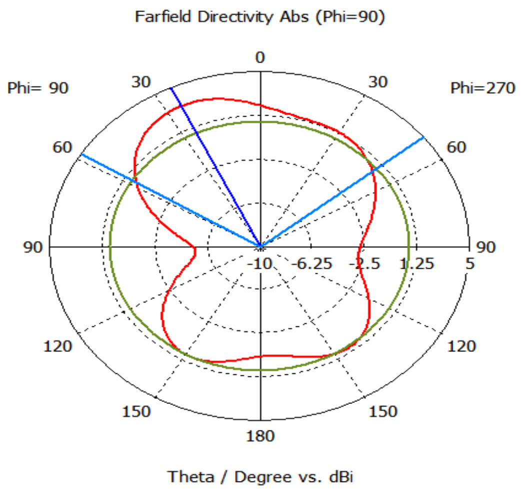

Figure 5. Directivity of proposed dual-band ETMA at 5.2 GHz in E-plane (φ = 90°)

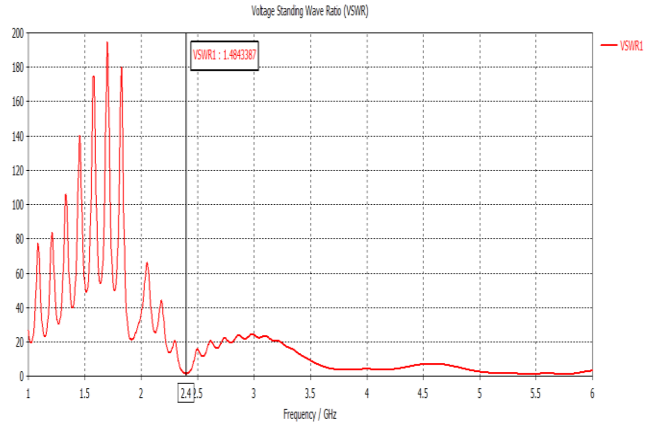

Figure 6. VSWR of the proposed antenna at 2.4 GHz

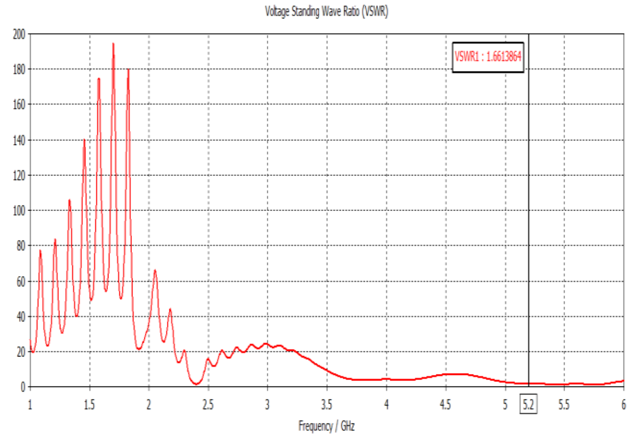

Figure 7. VSWR of the proposed antenna at 5.2 GHz

V. CONCLUSION

In conclusion, a compact dual-band triangular microstrip antenna with broadband characteristics for WLAN applications was presented. It was shown that two frequencies can be excited on the same patch with the aid of an embedded rectangular slot on the ground plane having good antenna parameters from simulation results. The VSWR, directivity and impedance bandwidth of the proposed antenna are satisfactory to fulfil most mobile communication conditions as may be required in modern devices.

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