Dual-Frequency Microstrip-Fed Basic-Structured Slot Antennas for Wireless LAN Applications

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Abstract

This study reported the techniques used in the design of microstrip-fed slot antennas for 2.40-2.4835 GHz (ISM) and 5.15-5.35 GHz (UNII) or 4.9-5.091 GHz band, which support Wireless LAN (Local Area Network) communications standardized by IEEE 802.11 b/g and a or h/j. Three basic-structured antenna configurations were investigated. The first antenna was a simple linear slot antenna designed to operate in dual-frequency range of both 2.40-2.4835 GHz and 5.15-5.35 GHz band. The second antenna was an L-shaped slot antenna designed for 2.4-2.4835 GHz and 4.9-5.091 GHz band. The third antenna was a U-shaped slot antenna for 2.40-2.4835 GHz and 5.15-5.35 GHz. The effects of feeding position on the antenna characteristics were analyzed by Method of Moments (MoM), using IE3D commercial software from Zeland, Inc. The simulation result revealed that, the microstrip feed line position played a significant role in creating the dual-frequency support characteristics in an antenna. By selecting the appropriate position of the microstrip feed line dual-frequency characteristics were obtained for the three antennas investigated. For the simple linear slot antenna, further refinement was made by adjusting the microstrip feed length for optimum antenna characteristics. In the case of the L-shaped slot antenna, adjustment for optimum antenna response was performed on the ratio of the length of the vertical to the total arm length. For the U-shaped slot antenna, a further adjustment on the proportion of the vertical arm was needed to obtain the optimum design condition. The proposed dual-frequency antennas have covered the bandwidth with acceptable return loss, therefore, satisfied the design requirements.

1. Introduction

A microstrip-fed slot antenna has been investigated since 1970s. Reference [1] presented an effect of offset-fed slot on input impedance and radiation patterns. The mathematical model to analyze a simple slot structure was proposed by [2].

Slot structure has many advantages on wider bandwidth. For example, it provides less surface wave and isolation from feeding networks. However, there is a drawback of bi-directional radiation, which can be improved by inserting a reflective element at the back of the slot.

Since 1997, the dual-frequency characteristics were investigated by Akhavan and Mirshekar-Syahkal [3]. The characteristics of fundamental and first higher-order modes of microstrip-fed slot antennas were proposed. Method of Moments (MoM) was adopted to analyze the antenna characteristics. These researchers also reported that the antenna characteristics found from simulation agreed very well with the measured results.

Nowadays antenna is expected to be used in more than one frequency range. This investigation made use of the fundamental and the first higher-order modes on a narrow slot structure to support dual-frequency range of 2.40-2.4835 GHz (IEEE802.11 b/g) and 5.15-5.35 GHz (IEEE802.11 a) or 4.9-5.091 GHz (IEEE802.11 h/j) band. The proposed antennas were then designed to validate the presented method of creating dual-frequency characteristics.

In this investigation, the Method of Moments (MoM), which was well accepted, was adopted to analyze the proposed antennas by simulation through IE3D software from Zeland, Inc, as referred in [4]. The remarkable performance in both 2.40-2.4835 GHz and 5.15-5.35 GHz or 4.9-5.091 GHz band from simulation is suitable to be utilized in WLAN standard and therefore satisfied the design purpose.

2. Basic Calculations

From preliminary trials, a simple linear half-wavelength slot structure for single-frequency was selected as a good starting design to be further developed. This linear antenna structure and parameter are shown in Fig. 1.

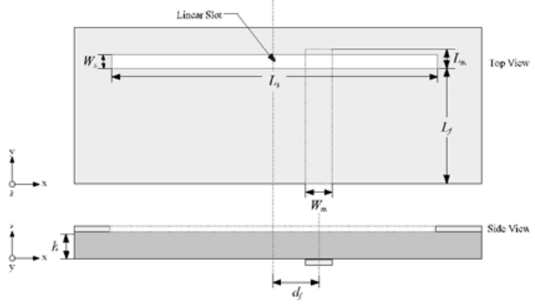

Fig. 1: Parameters of a Linear Slot Antenna

The slot is edged on the ground plane, while the microstrip feed line is on the other side of the substrate. The middle layer is the substrate, which is RT/duroid 5880 with 2.2 of permittivity (ε_r) and 1.575 mm of thickness (h) with the copper coating thickness 0.035 mm.

The wavelength of the fundamental frequency (λ_o) is found from (1).

$$\lambda_o = \frac{c}{f} \quad (1)$$

When light velocity c = 2.998 × 10^8 m/s or 3.00 × 10^8 m/s approximately, and f is the fundamental frequency used by the antenna in receiving and sending signals.

Effective dielectric constant (ε_{reff}) is known from (2)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W_m}\right]^{-\frac{1}{2}} \quad (2)$$

Guided wavelength (λ_g) is determined by (3).

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{reff}}} \quad (3)$$

There are two steps in designing a microstrip antenna, ie. the slot design and the microstrip feeding design.

A. *Slot Design*

The slot is responsible for creating resonance. In principle, the length of the slot (L_s) should be one half of the guided wavelength (λ_g). The antenna designed according to this approach is then a half-wavelength antenna, i.e.

$$L_s = \frac{\lambda_g}{2} \quad (4)$$

A usual design prefers narrow slot for simplicity. The width of narrow slot (W_s) should be kept smaller than $\frac{1}{10}$ of L_s so that $W_s < \frac{L_s}{10}$ or $W_s < \frac{\lambda_g}{20}$.

B. *Microstrip Feeding Design*

F. A. Benson and T. M. Benson [5] presented equations for width of the feed line (W_m) by (5)

$$\frac{W_m}{h} = \frac{2}{\pi}\{B' - 1 - ln(2B' - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B' - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\} \quad (5)$$

For $\frac{W_m}{h} \geq 2$, $B' = \frac{120\pi^2}{2Z_o\varepsilon_r^{\frac{1}{2}}}$ and Z_o was a characteristic impedance.

From these equations the W_m was then determined by numerical method. The theoretical guided wavelength of the lowest order resonant frequency at 2.44 GHz was 91.41 mm whereas the width of a microstrip feed line was 4.853 mm. The length of a microstrip feed line, L_m, and the width of a slot was obtained by arbitrarily adjusting for the optimum matching point.

The calculated dimension was then truncated as listed in TABLE 1. This dimension was used to design a single frequency linear slot antenna. The characteristic of this antenna satisfied to the design objective.

TABLE 1CALCULATED DIMENSION

Parameter	Dimension (mm)
W_s	1.0
L_s	44.0
W_m	4.8
L_m	3.3

3. DUAL-FREQUENCY LINEAR SLOT

Dual-frequency antenna design then initially followed the usual approach [3]. In the beginning, a simple linear half-wavelength slot structure was selected to support the lower frequency application. Then the linear slot antenna for dual-frequency support was developed from the single-frequency linear half-wavelength antenna allowing for more complexity to achieve dual-frequency characteristics. While earlier reports on microstrip slot antenna apparently achieved dual-frequency using a rather complicate and arbitrary approach [6]. In this investigation a simpler and more systematic approach was attempted. Parameters that produced dual-frequency characteristics in the simple slot structure antenna were determined. The value of such parameters was then adjusted so that the antenna characteristics satisfied the design requirements.

The microstrip feed line position was represented by the linear distance left or right of the central position (or the off-set feeding distance, d_f), and the length of the microstrip feed line (L_m). These two parameters were used to induce the dual-frequency characteristics of the antenna

The effect of d_f was investigated first. By slightly shifting the off-set feeding position to the left side of symmetrical slot, observations on the dual-frequency response were made. Similar investigation was repeated by slightly shifting the feeding position to the right side of the central position.

The effects of d_f are shown in Fig. 2 and Fig. 3. Fig. 2 indicated that, as d_f decreased, the lower resonant frequency shifted down while the higher resonant frequency shifted up. On the contrary, the lower resonant frequency shifted up when d_f increased, while the higher resonant frequency shifted down.

As illustrated in Fig. 3, when d_f increased the return loss of the lower frequency increased, while the return loss of the higher frequency decreased. This unsatisfied matching could be corrected by redesigning the length L_m.

For designing purposes, in the beginning, d_f should be determined to achieve dual- frequency close to the desired frequency according to IEEE 802.11 a/b/g with even return loss. In the following step, the length L_m was adjusted, and the optimum value of L_m was selected for optimum matching.

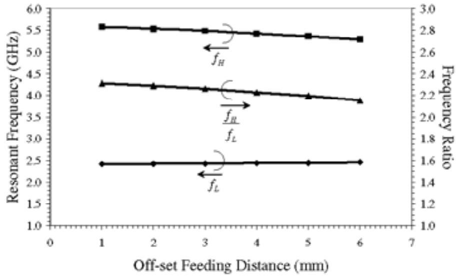

Fig. 2: Effect of Off-set Feeding on Resonant Frequency of a Linear Slot

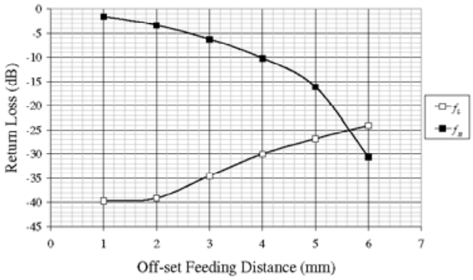

Fig. 3: Effect of Off-set Feeding on Return Loss of a Linear Slot

4. DUAL-FREQUENCY L-SHAPED SLOT

Although many researchers have studied the right angle-shaped (L-shaped) antenna, the controlling of dual matching resonant frequency was rarely investigated. The logical relationship between the straight slot antenna and the L-shaped antenna has not been properly investigated.

In this paper, the L-shaped antenna was considered as an extension of the straight slot antenna with an addition of a vertical slot. A novel idea of transforming a straight slot into L-shaped slot will be presented as follow.

The L-shaped slot antenna, as shown in Fig. 4 was investigated by slightly increasing the length of vertical slot, L_v, while the total length of slot was denoted by L_s.

The effects of transforming from a straight line to an L shape antenna were shown in Fig. 5 and Fig. 6, while

$$\text{Normalized } L_v = \frac{L_v}{L_s}.$$

The L-shaped antenna with dual-frequency range between 2.4–2.4835 GHz (IEEE 802.11 b/g) and 4.9–5.0 GHz (IEEE 802.11 j), 5.03–5.091 GHz (IEEE 802.11 h) was then designed based on Fig. 5 and Fig. 6. The proposed antenna could be achieved by using the design ratio of the vertical slot length to the total slot length, or the normalized L_v, at 0.39.

The position of the microstrip feed was then slightly moved and microstrip feed length was adjusted for optimum matching.

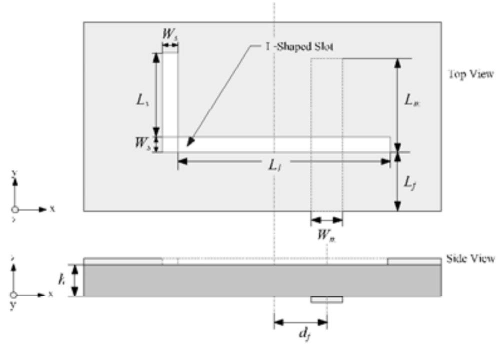

Fig. 4: Parameters of an L-Shaped Slot Antenna

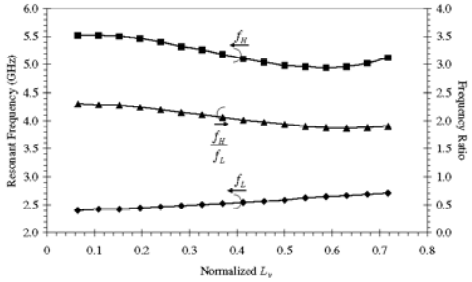

Fig. 5: Effect of Transforming from Linear Slot to L- Shaped Slot Antenna on Resonant Frequency

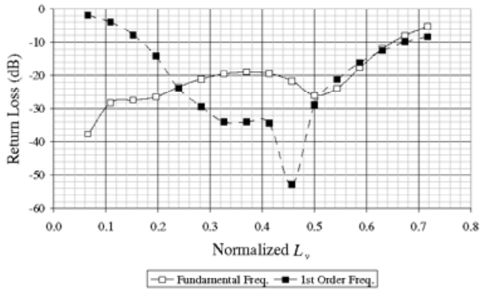

Fig. 6: Effect of Transforming from Linear to L-Shape Slot Antenna on Return Loss

5. DUAL-FREQUENCY U-SHAPED SLOT

Recently, C. Keawarsa et al. [8-9] presented dual U-shaped for WLAN dual-frequency operation. However, in this study, a single U-shaped element for dual-frequency followed WLAN standards was developed. The dual-frequency design for a single antenna was apparently a simpler and more effective alternative.

The U-shaped antenna is illustrated in Fig. 7. The total length of the U-shaped slot (L_s) was represented by the sum of vertical and horizontal length

The method of varying the position of microstrip feed line, similar to that used in the cases of linear slot and L-shaped slot, was again used to achieve dual-frequency characteristics in the range of 2.44 GHz and 5.2 GHz. After a slight adjustment of the microstrip feed length L_m, the result U-shaped slot showed acceptable characteristics with respect to the design objective.

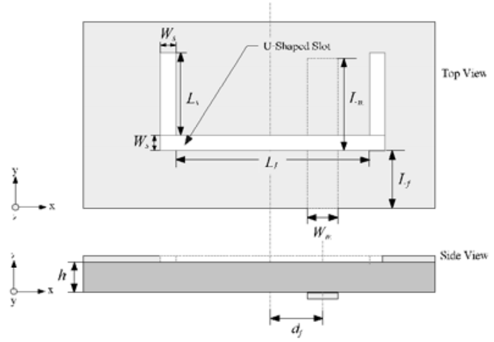

Fig. 7: Parameters of a U-Shaped Slot Antenna

The method of varying the position of microstrip feed line, similar to that used in the cases of linear slot and L-shaped slot, was again used to achieve dual-frequency characteristics in the range of 2.44 GHz and 5.2 GHz. After a slight adjustment of the microstrip feed length L_m, the result U-shaped slot showed acceptable characteristics with respect to the design objective.

6. Results

The simulated characteristics were shown in TABLE 2. The final dimensions of the proposed antennas were presented in Fig. 8 for the single-frequency linear slot, dual-frequency linear slot, L-shaped slot and U-shaped slot.

TABLE 2: CHARACTERISTICS OF THE PROPOSED ANTENNAS

Antenna	Frequency (GHz)	S_{11} (dB)	Z_{in} (Ω) Real	Z_{in} (Ω) Imag.	BW (%)	VSWR
Linear Single-Frequency	2.42	-44.69	49.75	0.52	5.79	1.01
Linear Dual-Frequency	2.44	-36.82	48.66	0.46	5.99	1.05
	5.27	-52.42	50.03	0.24	4.48	1.01
L-Shaped	2.43	-35.39	51.29	-1.14	4.65	1.04
	4.96	-36.41	50.31	-13.48	5.32	1.03
U-Shaped	2.42	-37.96	49.15	0.92	5.37	1.03
	5.30	-30.49	51.22	-2.77	3.49	1.06

7. Conclusion

Simple slot structures ie. linear, L-shaped and U-shaped, were developed to show their dual-frequency characteristics. The systematic approach used in developing the dual-frequency antennas was reported. These basic-shaped microstrip antennas were designed to support WLAN communication and satisfied the requirements.

The approach used in the design was reported and the simulated characteristics of the antennas were investigated. The design antennas well satisfied the design objective.

Acknowledgement

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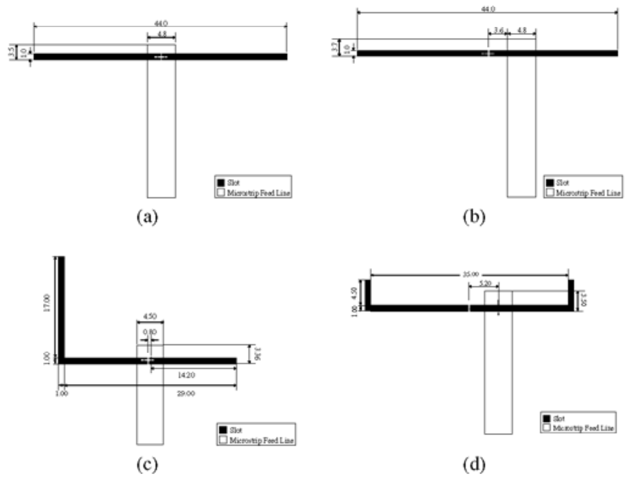

Fig. 8: Dimension of the proposed antennas

(a) A Single-Frequency Slot Antenna
(b) A Dual-Frequency Slot Antenna
(c) A Dual-Frequency L-Shaped Slot Antenna
(d) A Dual-frequency U-Shaped Slot Antenna

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