A quad-band slot antenna with spiral stub and interdigital CPW Feed

T. Archevapanich[1], P. Chomtong[2] and P. Akkaraekthalin[3]

[1]Faculty of Engineering and Architecture, Rajamangala University of Technology Suvarnabhumi, Nonthaburi, 7/1 Nonthaburi Road, Nonthaburi 11000, Thailand
[2]Department of Teacher Training in Electrical Engineering, Faculty of Technical Education,
King Mongkut's University of Technology North Bangkok, Bangkok, Thailand
[3]Department of Electrical and Computer Engineering, Faculty of Engineering
King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

Corresponding author's e-mail: tuanjai.theta@gmail.com

Abstract. This paper proposes a quad-band slot antenna with spiral stub and interdigital CPW feed. The antenna has a compact size and can be used for four frequency bands of 1.8 GHz, 2.45 GHz, 3.7 GHz and 5.2 GHz applicable for LTE, WiMAX and WLAN systems. The important technique designs of the proposed antenna are divided into 2 parts. The first part includes the stepped slot antenna added with square-shaped spiral stub. As a result, the resonance frequencies of the third and fourth harmonics can be controlled as desired. For the second part, the technique of interdigital capacitive CPW is employed at the feeding line, resulting in length reduction from $\lambda/4$ of the conventional one to $\lambda/8$, which is caused by the slow-wave effect. Moreover, with this technique the resonance frequency of the second harmonic can be independently controlled. The optimized antenna has good performances for all frequency bands with bandwidths of 190 MHz (1.72 GHz-2GHz) at 1.8 GHz band, 280 MHz (2.34GHz-2.53GHz) at 2.45 GHz band, 410 MHz (3.54 GHz-3.95 GHz) at 3.7 GHz band and 220 MHz (5.10 GHz-5.32 GHz) at 5.2 GHz band, respectively.

1. Introduction

Nowadays, wireless communication devices and systems are rapidly developed to meet the diverse usages of users. Therefore, all communication systems need to be expanded to accommodate all needs. In all wireless communication systems, one of the most important and necessary parts is an antenna. The superior antenna performances are required for modern wireless communication systems, including high efficiency, high gain, good matching at the operating frequency with a return loss of better than 10 dB. Also, most of antenna propagations require omnidirectional patterns, resulting in antenna transmitting/receiving in all directions. It has been found that there is a wide variety of antenna designs, ranging from simple monopoles and dipoles to very complicated structures. However, the current trend of antenna designs is to use low cost microwave printed circuit boards with simple, low profile and lightweight structures. Therefore, several researchers have designed the antennas on microstrip structure to enhance all antenna capabilities, whether it is a single-band or multi-band antenna design [1], [2]. Especially, to design the multi-band antennas various techniques have been employed including multi-radiators, wide-band antennas [3], [4], and fractal structures [5], [6]. The later technique becomes more and more popular for multi-band antenna design. The fractal antenna based on the loop structure was proposed and it was found that the second harmonic frequency band can be controlled [7]. However, the disadvantage of using this technique is that the antenna has high cross-polarization, especially when the fractal order is high. Many researchers used the slot patch technique to make wide-band antennas with band-notched function, resulting in multi-band operation [8]. The disadvantage is that the overall antenna size is still large due to the feed length is needed to be $\lambda/2$. To reduce the antenna size, the RF circuits may be required. The RF circuit design technique uses a variety of circuit elements such as capacitive load that some capacitors will be connected at the end of transmission line. With this technique, the length of feed line could be reduced [9]. However, using the RF circuits results in more complicated design and it is difficult when further length reduction is required. Therefore, some other techniques must be studied for size reduction. The interdigital technique is of interest to increase the capacitance value and it is practically used more than capacitive-loaded technique. It is found that this technique not only increases the capacitive value at the end of feed line, but also controls the harmonic frequency bands of the antennas as well [10].

This paper presents a quad-band stepped slot antenna with spiral stub and interdigital CPW (ICPW) feeding line. The design of antenna is based on a wide-band slot antenna covering all required application bands. The CPW feeding line with interdigital technique can create the capacitance value between centre conductor and ground plane, generating four resonance frequency bands. In addition, its capacitance value can result in feeding length reduction. It can be found that with the optimal design, the feeding length can be reduced from $\lambda/4$ of the conventional one to approximately $\lambda/8$. The spiral stub is also used for not only impedance matching but also controlling the harmonic frequency bands. The details of antenna design using simulation software will be demonstrated in the next section. Then, the proposed antenna will be implemented and measured. The simulated and measured performances of the proposed antenna will be stated and compared. Finally, conclusion remarks will be given.

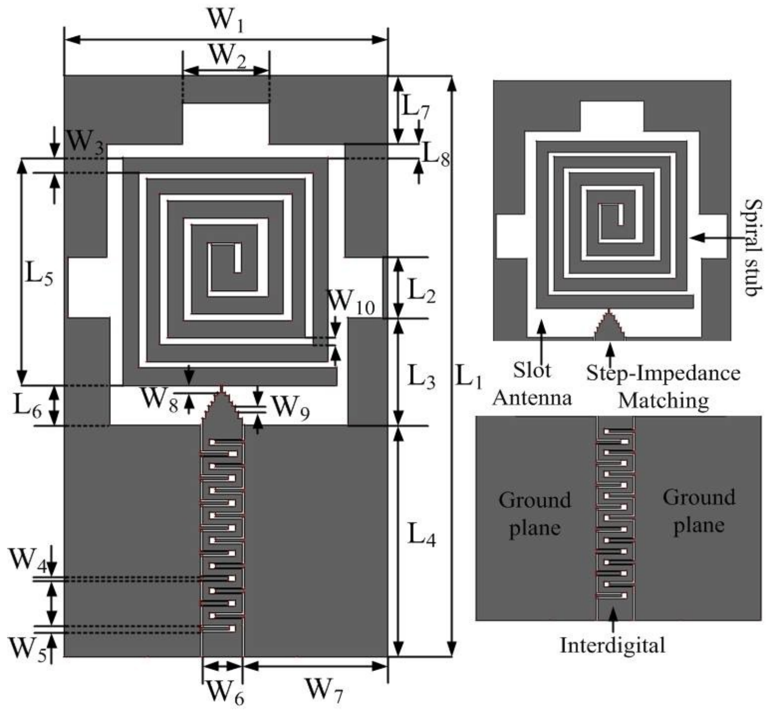


Figure 1. Structure of the proposed quad-band slot antenna.

2. Antenna Design

The proposed antenna is divided into two major sections including slot and feeding line. The slot was designed to be stepped structure for wide-band operation. The feeding line is based on interdigital coplanar waveguide structure, which is applied for size reduction and harmonic frequency controlling. The antenna was designed at the operating frequency of 1.8 GHz, 2.45 GHz, 3.7 GHz and 5.2 GHz. The FR-4 printed circuit board with dielectric constant of 4.3, dielectric thickness of 1.6 mm, copper thickness of 0.035 mm, and loss tangent of 0.018 was employed. The CST software package was used to simulate the proposed antenna. The details of antenna structure are shown in Fig.1. The slot was designed at fundamental frequency of 1.8 GHz. Its length was about $\lambda/4$, however, the stepped sections were created on the slot. This stepped slot could control the harmonics to be resonated at frequencies of 2.4 GHz, 3.38 GHz and 4.1 GHz. The ICPW feeding line with stepped impedances at the feed point was applied to the stepped slot antenna, resulting in the same resonance frequencies of 1.8 GHz and 2.45 GHz. Together, the spiral stub was designed to match the slot antenna. It is also found that adding the spiral stub could control the third and fourth harmonic resonance frequencies to be at 3.7 GHz and 5.2 GHz as shown in Fig.2. It means that the proposed antenna can operate at all four resonance frequencies of 1.8 GHz, 2.45 GHz, 3.7 GHz and 5.2 GHz, respectively. The optimum parameters of the proposed antenna obtained from the design include W_1=23.25 mm, W_2=5 mm, W_3=0.25 mm, W_4=0.125 mm, W_5=0.15 mm, W_6=2.5 mm, W_7=12 mm, W_8=1.2 mm, W_9=8.7 mm, W_{10}=1.25 mm, L_1=23.5 mm, L_2=5.2 mm, L_3=10.25 mm, L_4=12.5 mm, L_5=15 mm, L_6=5 mm, L_7=5 mm, and L_8=2.5 mm. In Fig.2, the bandwidths are found to be 190 MHz (1.72 GHz-2GHz) at 1.8 GHz, 280 MHz (2.34GHz-2.53GHz) at 2.45 GHz, 410 MHz (3.54 GHz-3.95 GHz) at 3.7 GHz and 220 MHz (5.10 GHz-5.32 GHz) at 5.2 GHz. In addition, the simulated antenna radiation patterns at all operating frequencies are omnidirectional and the antenna gains at all resonance frequencies are 2.01 dB, 2.12 dB, 2.03 dB and 2.06 dB, respectively.

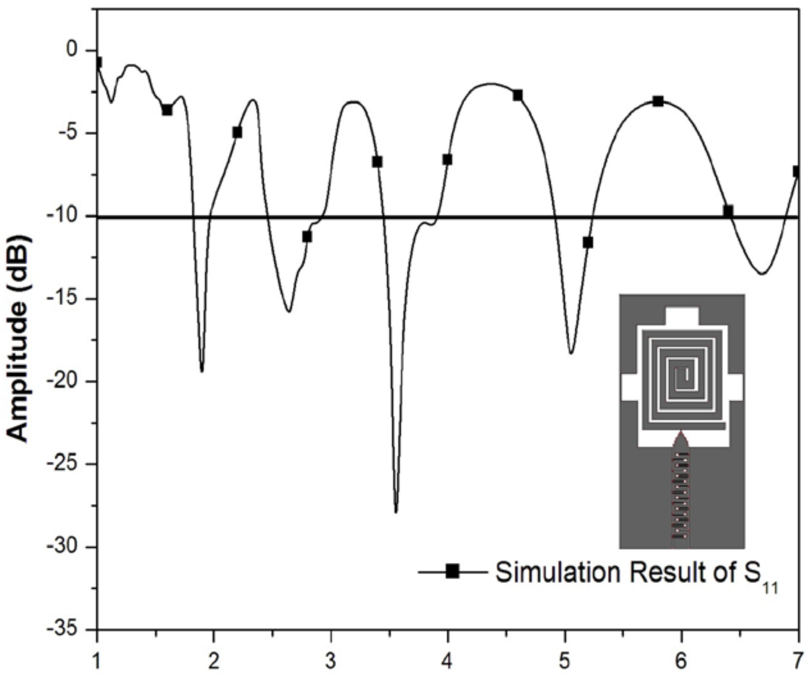


Figure 2. Simulation result of S11 of the proposed antenna

With the structure of ICPW feed, it is found that the capacitance value along the feeding line is significantly increased, when comparing with the conventional line. The coupling capacitance at the end of the line makes it possible to control the harmonic frequencies for achieving the desired frequency bands. In addition, another feature of such a technique is that it reduces the size of the feeding line by about half of the total length due to the slow wave effect on the line.It is also found that the feeding length could be reduced form λ/4 to about λ/8. The proposed ICPW was designed at the fundamental frequency of 1.8 GHz. The second resonance frequency is at 2.45 GHz, which the normal resonance frequency of the conventional line is at 3.6 GHz ($2f_0$). It is clearly seen that the ICPW technique allows the second resonance frequency to be freely controlled for resonating at the desired frequency.

3. Implementation and Results

After designing by the proposed techniques, the antenna prototype was then constructed using the milling machine. The CPW feeding line was then connected with an SMA connector. The photograph of the implemented antenna is shown in Fig.3. The antenna was measured by using a network analyzer. Figure 4 shows the measured results of frequency response compared with the simulated results, which a very good agreement can be noticed. It can be clearly seen that the proposed antenna has matched impedances at all resonance frequencies with the measured bandwidths of 190 MHz, 280 MHz, 200 MHz and 190 MHz, respectively. The measured radiation patterns are found to be omnidirectional as shown in Fig.5. Also, the measured gains at all resonance frequencies of the proposed antenna are 1.92 dB, 2.03 dB, 2.16 dB and 2.36 dB, respectively.

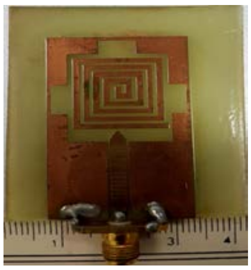


Figure 3. A photograph of the proposed antenna.

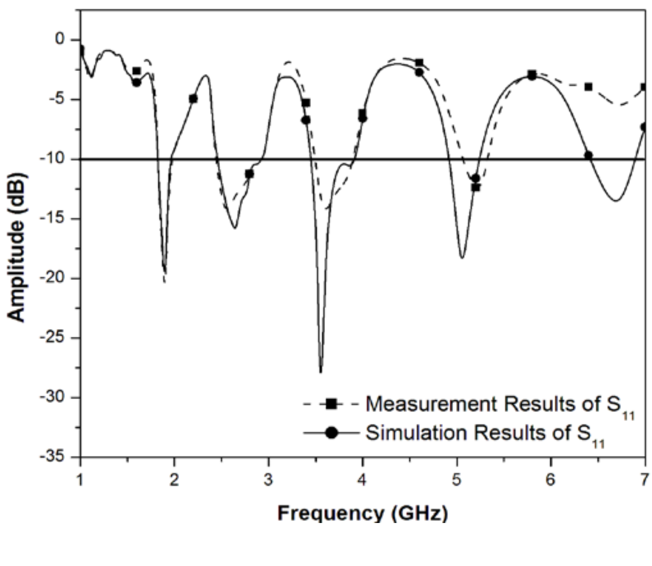
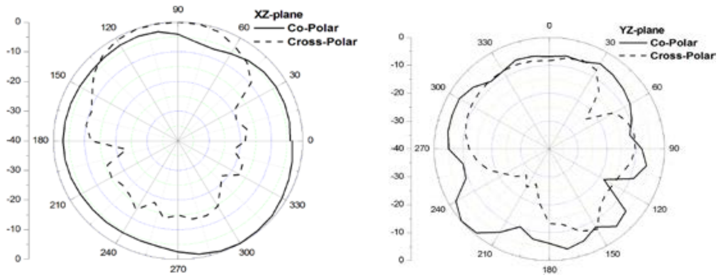
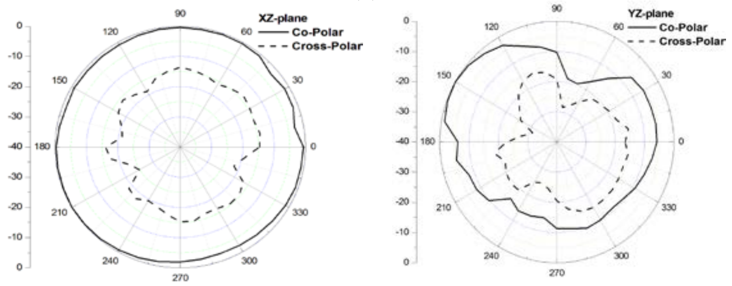


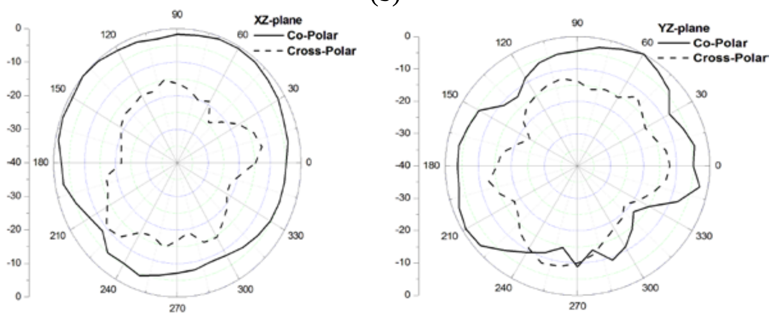
Figure 4. Comparison of simulation and measurement results of S_{11}.



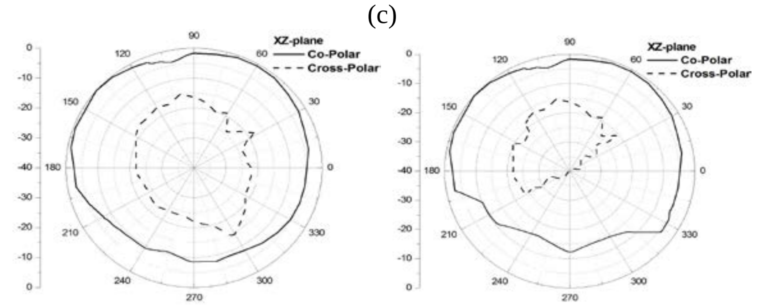
(a)



(b)



(c)



(d)

Figure 5. The measured radiation patterns of on XZ and YZ planes at (a) 1.8 GHz, (b) 2.45 GHz, (c) 3.7 GHz and 5.2 GHz.

4. Conclusions

The quad-band antenna with compact size was presented. The harmonic frequency bands can be independently controlled by the parameters of the stepped slot, spiral stub international CPW feeding line. The proposed antenna can operate at the resonance frequencies of 1.8 GHz, 2.45 GHz, 3.7 GHz and 5.2 GHz, respectively. The antenna has omnidirectional patterns at all frequency bands and the gains at the resonance frequencies are 1.92 dB, 2.03 dB, 2.16 dB and 2.36 dB, respectively. With its high performances and compact size, the proposed antenna can be a good candidate for multi-band wireless applications including LTE, WiMAX and WLAN systems.

Acknowledgement
This work has been supported by the Thailand Research Fund (TRF) under the Senior Research Scholar Program with the grant number RTA 6080008.

4. References

[1] Archevapanich T and Anantrasirichai N 2007 Inversed e-Shape slot Antenna for WLAN Applications *ICCAS* p 2854
[2] Archevapanich T, Raklue P, Anantrasirichai N, Purahong B and Chutchavong V 2014 Rectangular Slot Antenna with Asymmetrical Conductor Strip for Bandwidth Enhancement Coverage UWB Standard *AsiaSim* p 105
[3] Archevapanich T, Chomthong P and Akkaraekthalin P 2018 triple-band high-gain planar dipole with double interdigital structure for indoor LTE and WLAN base stations *IEEJ Transactions on Electrical and Electronic Engineering* p 1
[4] Zhang G, Xu L, Chen A, Su D 2008 A microstrip-fed wide-band tapered slot antenna *International Conference on Microwave and Millimeter Wave Technology* p 1
[5] Krishna D D, Gopikrishna M, Anandan C K, Mohanan P and Vasudevan K 2008 CPW-Fed Koch Fractal Slot Antenna for WLAN/WiMAX Applications *IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS* p 1
[6] Hankins G, Vahala L, and Beggs J H 2005 Propagation prediction inside a B767 in the 2.4 GHz and 5 GHz radio bands *Antennas and Propagat. Int. Symp* p 791
[7] Kaouris A, Zaras M, Revithi M, Moraitis N and Constantinou P 2008 Propagation measurements inside a B737 aircraft for in-cabin wireless networks *IEEE Vehicular Technology Conference* p 2932
[8] Mohammadi S, Nourinia J, Ghobadi C and Majidzadeh M 2011 Compact CPW-fed rotated square-shaped patch slot antenna with band-notched function for UWB applications *Electronics Letters* p 1307
[9] Quendo A C, Coupez J PH, Person C, Rios E, Le Roy M, and Toutain S 1999 Band-pass filter with self-filtering resonators: a solution to control spurious resonances *IEEE MTT-S International Microwave Symposium* p 1135
[10] Chomtong P and Akkaraekthalin P 2014 A multiband slot CPW antenna using capacitive feed and interdigital capacitor for GSM, Wi-MAX and WLAN systems *APCC* p 446.