Development of Triple Band Planar Inverted F-Antenna (PIFA) for GSM 800 MHz, DCS 1800 MHz and Bluetooth 2400 MHz

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ABSTRACT

A triple band Planar Inverted F-Antenna (PIFA) antenna for GSM900, DCS1800 and Blutooth2400 is presented. The antenna consists of square planar radiating patch with dual L-shaped slots suspended above the FR4 dielectric substrate. A shorting plate is employed between the top patch and the ground plane. The antenna is fed by using coaxial feeding as it is easier to design. The antenna is designed and simulated using CST Microwave Studio. Different parameters such as shorting width, height of antenna, ground plane size and patch slot size that effect PIFA antenna characteristics are also studied. The designed antenna is fabricated, assembled together and tested using network analyzer. The result obtained for the S11 parameter in measurement for the three bands are 0.966 GHz, 1.836 GHz and 2.50 GHz with return loss of -25.84 dB, -32.52 dB and -24.2 dB respectively. Comparison for the measurement and the simulation are carried out in terms of S11 parameter, bandwidth, VSWR, input impedance and radiation pattern.

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LIST OF ABBREVIATIONS

DCS	Digital Cellular System
GSM	Global System for Mobile
WLAN	Wireless Local Area Network
PCS	Personal Communication System
IMT	International Mobile Telecommunications
SAR	Specific Absorption Rate
PIFA	Planar Inverted F-Antenna
PCB	Printed Circuit Board
CST	Computer Software Technology
MWS	Microwave Studio
EM	Electromagnetic
BW	Bandwidth
FNBW	First-Null Beamwidth
HPBW	Half-power Beamwidth
IEEE	Institute of Electrical and Electronic Engineers
S11	Return Loss
dB	Decibels

VSWR	Voltage Standing Wave Ratio
SWR	Standing Wave Ratio
SMA	Sub Miniature A
FR4	Fire retardant 4
UTHM	University Tun Hussien Onn Malaysia

LIST OF SYMBOLS

GHz	Gigahertz
MHz	Megahertz
λ	Lambda (wavelength)
H	height of antenna
L	length of the ground plane
L1	length of the top radiating patch
L2	length of the outer L-shaped slot (for 1.8GHz)
L3	length of the second L-shaped slot (for 2.4GHz)
W	width of the ground plane
W1	width of the top radiating patch
W2	width of the outer L-shaped slot (for 1.8GHz)
W3	width of the second L-shaped slot (for 2.4GHz)
ε r	dielectric constant of the substrate
c	speed of light 3x 10^{-8} m/s
Ω	Ohm

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CHAPTER 1

INTRODUCTION

1.1. Introduction

The origination of wireless communications started in 1886 when Heinrich Hertz did an experiment to confirm the presence of electromagnetic waves based on James Maxwell's (1864) theoretical foundation for electromagnetic radiation. It was then in 1897, Guglielmo Marconi first establish the capabilities of wireless communications through continuous contact with ships sailing the English Channel [1]. Since then, antennas have always been evolving due to the development of wireless technologies which has led to radio, television, mobile phone and satellite communications.

Planar antennas are the newest generations of antennas boasting the attractive features required, such as broad operating bandwidth, low profile, light weight and ease of integrations into arrays of radio frequency circuits, to make them ideal components of modern communications systems. Planar antennas have variety of types and one of them is planar inverted F antenna (PIFA). Planar Inverted-F Antennas (PIFAs) are resonant at a quarter-wavelength and are widely used for mobile phone applications and other communication devices due to its merits of small size, light weight, low SAR values, good gain & multiband operation [2]-[8].

This antenna resembles an inverted F, which explains the PIFA name. The PIFA antenna is popular because it has a low profile and an omnidirectional pattern. The antenna can be miniaturized since there is a limited space in the printed circuit, without causing degradation to the performance of the antenna parameters such as the bandwidth and radiation patterns [2].

In this work, a triple band operating PIFA antenna was designed which covers frequency bands of GSM 900 MHz, DCS 1800 MHz and Bluetooth 2400 MHz. In order to obtain the triple band operation, two slots of L-shaped was created on the patch of the antenna. The dual L-shaped slots will make the antenna to operate a triple band operation.

1.2. Objectives

a) To design triple band PIFA antenna for mobile handheld devices that operates frequency bands of GSM 900 MHz, DCS 1800 MHz and Bluetooth 2400 MHz by using CST MWS software.
b) To measure and evaluate the antenna performance in terms of return loss, VSWR, bandwidth and radiation pattern.

1.3. Scope of study

This project is intended to develop and analyze a triple band Planar Inverted-F Antenna (PIFA) that is capable to cover Cellular frequencies of GSM900 and DCS1800 and non-cellular frequency such as Bluetooth/WLAN 2400 MHz. The antenna will be modeled and simulated with CST MWS simulation software. This simulation tool is used to evaluate the operation of the antenna at the prescribed frequencies in terms of input impedance, radiation patterns and return loss values for the S11 parameters. The final stage is to fabricate, measure and evaluate the antenna S parameter, efficiency and field pattern. A parametric study will also be carried out to find the effects of different parameters (such as shorting plate, height of antenna, ground plane and slots on the patch) to the operating frequency and bandwidth of the antenna. The measurement can be carried out by using network analyzer.

1.4. Problem Statement

In recent years integration of technology in mobile communication system has led to a great demand in developing small size antenna with multi-band operation that is able to operate in the required system. Single band antennas only support one or two frequencies of wireless services and these days more and more wireless standards are being supported by the devices. So they employ several antennas for each standard. This leads to large space requirement in handheld devices. Therefore, due to the space constraints in mobile devices, an antenna which will cover multiple bands of frequencies will be the best solution in order to allow more space in the mobile devices. The multi band operation of the antenna can be achieved by using a low profile antenna structure like PIFA (Planar Inverted F-Antenna) with additional features to enhance the bandwidth coverage and other important performance parameters. This will even allow mobile devices to be very small in thickness.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This section talks about the theoretical information related to the project such as the basics of antenna and its characteristics.

This section of the thesis also reviews a number of papers, which have formed the basis for the research component. This thesis provides an insight into the background of co- formality antennas. A few papers have been studied in order to gain required knowledge needed in the design process. There are also references from source such as books and articles. From data collection, it has points that capable to increase the knowledge especially about this paper.

2.2. Basics of Antenna

There are many basic types of antenna elements such as the dipole, horn, slot, spiral, long wire, and monopole. There are also many different types of systems where these elements are arranged in some form of an array, fixed or electronically controlled. Antenna can be divided into four types and operated at different frequencies based on their structure and configurations. There are resonant antenna, broadband antenna, aperture antenna and electrically small antenna.

2.2.1. Resonant antenna

The antenna of this type is usually used because its structure is simple and has good input impedance for application at frequency that has narrow bandwidth. Its input impedance is real and this antenna also has a low gain. An example of resonant antenna such as in figure 2.1 is half wave dipole and figure 2.2 is Yagi-Uda with 3 element [9].

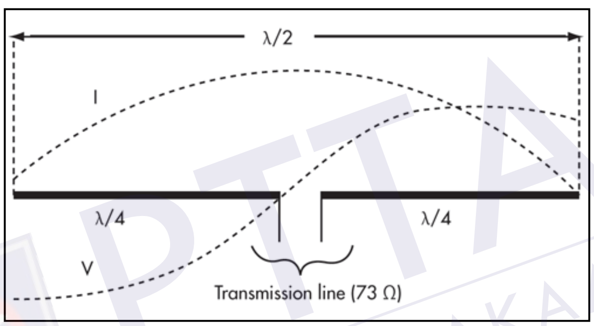

Figure 2.1: Half wave dipole

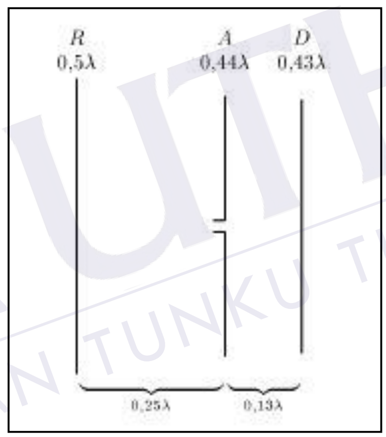

Figure 2.2: Yagi-Uda with 3 elements

2.2.2. Broadband antenna

These antennas show characteristics at an active area. Wave propagation is coming from a feed point then which will propagate to an active area to produce broadband characteristic. It also has low gain and real input impedance [9]. An example of broadband antennas such as figure 2.3 is spiral antenna and figure 2.4 is log periodic antenna.

Figure 2.3: Spiral antenna

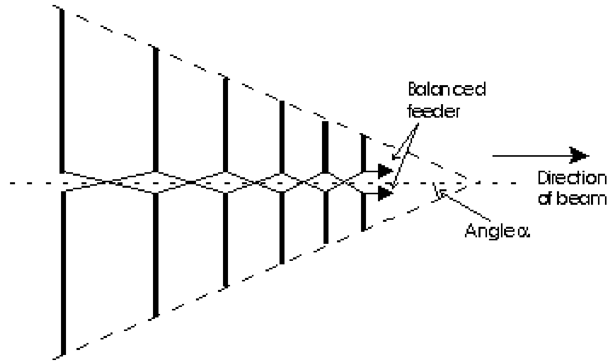

Figure2.4: Log-periodic antenna

2.2.3. Aperture antenna

Antenna of this type has an open physical structure that allows the wave to pass through it. This antenna has a high gain that is proportional to the frequency of operation. Aperture size of this antenna depends of the wavelength and its effective aperture increase as the wavelength becomes shorter [9]. The main radiation pattern is narrow and has a high gain. An example of aperture antenna such as figure 2.5 (a) is pyramidal horn antenna and figure 2.5 (b) is conical horn antenna.

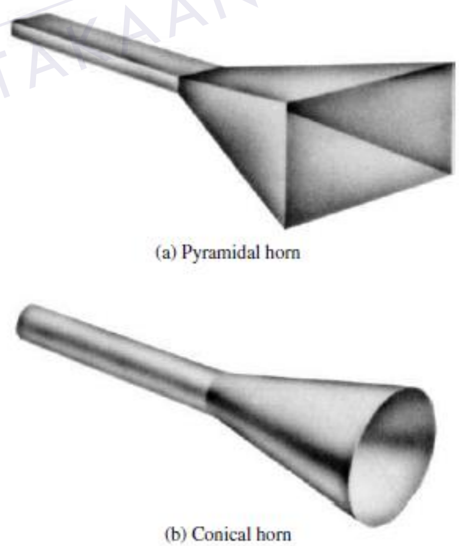

Figure 2.5: Aperture antennas

2.2.4. Electrically small antenna

This antenna has electrically length much smaller compared to the wavelength λ (L<< λ). Besides, it also has a simple structure and fabrication is insensitive to specific shape. Monopole antenna which is implemented on car is a best example of this antenna. The length of this antenna is around 0.003λ and has an omnidirectional radiation pattern. The disadvantages of this antenna are low resistance and high reactance at the input [9]. An example of electrically small antenna such as figure 2.6 is short dipole antenna and figure 2.7 is small loop antenna.

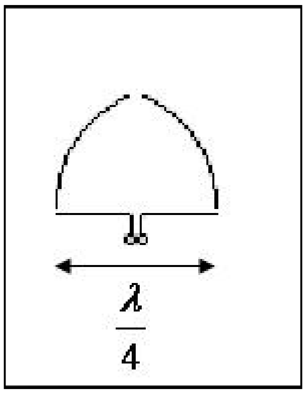

Figure 2.6: Short dipole

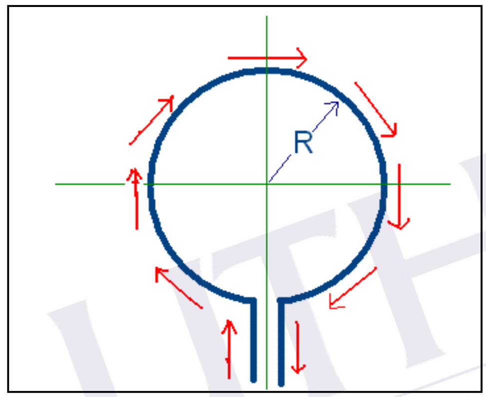

Figure 2.7: Small loop antenna

2.3. Antenna characteristics

Having considered the basic elementary antenna types, some important characteristics of an antenna as a radiator of electromagnetic energy are discussed. These characteristics include return loss, radiation pattern, bandwidth, voltage standing wave ratio (VSWR), beam width, directivity, gain and also impedance matching.

2.3.1. Return loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line.

The relationship between SWR and return loss is the following:

$$return\ loss(in\ dB) = 20\log_{10}\frac{SWR}{SWR-1}$$

A very good antenna might have a value of -10 dB (90% absorbed and 10%reflected) [9].

2.3.2. Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization. The radiation property of most concern is the two or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. Often the field and power patterns are normalized with respect to their maximum value, yielding normalized field and power patterns. Also, the power pattern is usually plotted on a logarithmic scale or more commonly in decibels (dB). This scale is usually desirable because a logarithmic scale can accentuate in more details those parts of the pattern that have very low values, which later we will refer to as minor lobes [10].

2.3.3. Bandwidth

[2] Kin-Lu Wong, "Planar Antennas for Wireless Communication", Published by John Wiley & Sons, Inc., Chapter: 2, Page(s): 26-65, 2003.

[3] Belhadef, Y.; Boukli Hacene, N., "PIFAS antennas design for mobile communications", 7th IEEE International Workshop on Systems, Signal Processing and their Applications (WOSSPA), Page(s): 119 – 122, May 2011.

[4] H. Li, W. Chen, and Z. Feng, "Design of Triple-band Planar Inverted-F antenna," *2005 Asia-Pacific Microw. Conf. Proc.*, vol. 4, pp. 1–3, 2005.

[5] P. Song, P. S. Hall, H. Ghafouri-Shiraz, and D. Wake, "Triple-band planar inverted F antenna," *IEEE Antennas Propag. Soc. Int. Symp. 1999 Dig. Held conjunction with Usn. Natl. Radio Sci. Meet. (Cat. No.99CH37010)*, vol. 2, pp. 908–911.

[6] P. C. S. I.-B. Applications, D. Sim, J. Moon, and S. Park, "An Internal Triple-Band Antenna for," vol. 3, pp. 23–25, 2004.

[7] N. Kumar and G. Saini, "A Multiband PIFA with Slotted Ground Plane for Personal Communication Handheld Devices," pp. 2–7.

[8] N. Kumar and G. Saini, "A Novel Low profile Planar Inverted-F Antenna (PIFA) for Mobile Handsets," no. 1, pp. 1–4.

[9] C. A. Balanis, Antenna *Theory, Analysis and Design, 3rd edition,* John Wiley & Sons, Inc., 2005.

[10] Kin- Lu Wong, "Compact and Broadband Microstrip Antennas" John Wiley & Sons, Inc., 2002.

[11] A. Thomas Milligan, "Modern Antenna Design" 2nd edition, John Wiley & Sons, Inc., 2005.

[12] C. H. See, R. a Abd-Alhameed, D. Zhou, and P. S. Excell, "Dual-Frequency Planar Inverted F-L-Antenna (PIFLA) for WLAN and Short Range Communication Systems," *IEEE Trans. Antennas Propag.*, vol. 56, no. 10, pp. 3318–3320, 2008.

[13] Hang Wong, Kwai-Man Luk, Chi Hou Chan, Quan Xue, Kwok Kan So, Hau Wah Lai, "Small antennas in Wireless Communications", Proceedings of the IEEE Journal, Vol.

[14] W. Geyi, Q. Rao, S. Ali, and D. Wang, "Handset Antenna Design: Practice And Theory", Progress In Electromagnetic Research Journal (PIER) , Vol. 80, Page(s) : 123–160, 2008.

[15] Ray J.A, Chaudhuri S.R.B., "A review of PIFA technology", IEEE Indian Antenna week (IAW), Page(s): 1 – 4, Dec. 2011.

[16] H. Chen, Y. Lin, P. Cheng, H. Lin, C. T. P. Song, and P. S. Hall, "Parametric study on the characteristics of planar inverted-F antenna," vol. 152, no. 6, pp. 534–538, 2005.

[17] D. Kim, J. W. Lee, C. S. Cho, and T. K. Lee, "Design of a Compact Tri-Band PIFA Based on Independent Control of the Resonant Frequencies," *IEEE Trans. Antennas Propag.*, vol. 56, no. 5, pp. 1428–1436, May 2008.

[18] D. Choi, C. Shin, N. Kim, and H. Shin, "Design and SAR Analysis of Broadband PIFA with Triple Band," *PIERS Online*, vol. 1, no. 3, pp. 290–293, 2005.

[19] Shih-Huang Yeh, Kin-Lu Wong, Tzung-Wern Chiou, and Shyh-Tirng Fang: "Dual-Band Planar Inverted F Antenna for GSM/DCS Mobile Phones", IEEE Trans. On Antennas and Propagation, Vol. 51, No. 5, May 2003

[20] M, Fan, Z. Feng, X. Zhang, "Dual frequency double-branch printed inverted-F antenna," Antennas and Propagation Society International Symposium, 2002. IEEE Volume 3, 16-21 June 2002 Page (s):508 – 511

[21] Yong-Xin Guo, M. Y. W. Chia, and Z. N. Chen: "Miniature Built-In Quad-Band Antennas for Mobile Handsets", IEEE ANTENNAS AND WIRELESS PROPAGATION LETTERS, Vol.2, 2003.

[22] S.-H. Yeh, K.-L.Wong, T.-W. Chiou, and S.-T. Fang, "Dual-Band planar inverted F antenna for GSM/DCS mobile phones," IEEE Trans. Antennas Propagat., vol. 51, pp. 1124–1126, May 2003.

[23] C. W. Chiu and F. L. Lin, "Compact dual-band PIFA with multi-resonators," Inst. Elect. Eng. Electronics Lett., vol. 38, pp. 538–540, 2002.

[24] D. Manteuffel, A. Bahr, D. Heberling, and I. Wolff, "Design considerations for integrated mobile phone antennas," in Proc. Antennas and Propagation 11th Int. Conf., vol. 1, Manchester, U.K., 2001, Inst. Elect. Eng. Conf. Publ. 480, pp. 252–256.

[25] Y. J. Wang, C. K. Lee, W. J. Koh, and Y. B. Gan, "Design of small and broad-band internal antennas for IMT-2000 mobile handsets," IEEE Trans. Microwave Theory Tech., vol. 49, pp. 1398–1403, Aug. 2001.

[26] W. Choi, S. Kwon, and B. Lee, "Ceramic chip antenna using meander conductor lines," Electron. Lett., vol. 37, pp. 933–934, July 2001.

[27] K.-L. Wong, G.-Y. Lee, and T.-W. Chiou, “A low-profile planar monopole antenna for multiband operation of mobile handsets,” IEEE Trans. Antennas Propagat., vol. 51, pp. 121–125, Jan. 2003.

[28] Z. M. Chen and Y. W. M. Chia, Eds., Broadband Planar Antennas Design and Applications. New York: Wiley, 2006, ch. 4.

[29] W. P. Dou and Y. W. M. Chia, “Novel meandered planar inverted-F antenna for triple-frequency operation,” Microw. Opt. Technol. Lett., vol. 27, no. 1, pp. 58–60, Oct. 2000.

[30] P. Salonen, M. Keskilammi, and M. Kivikoski, “Single-feed dual-band planar inverted-F antenna with U-shaped slot,” IEEE Trans. Antennas Propag., vol. 48, no. 8, pp. 1262–1264, Aug. 2000.

[31] H. Park, K. Chung, and J. Choi, “Design of a planar inverted-F antenna with very wide impedance bandwidth,” IEEE Microw. Wireless Compon. Lett., vol. 16, no. 3, pp. 113–115, Mar. 2006.

[32] P. Ciais, R. Staraj, G. Kossiavas, and C. Luxey, “Design of an internal quad-band antenna for mobile phones,” IEEE Microw. Wireless Compon. Lett., vol. 14, no. 4, pp. 148–150, Apr. 2004.

[33] M. K. Kärkkäinen, “Meandered multiband PIFA with coplaar parasitic patches,” IEEE Microw. Wireless Compon. Lett., vol. 15, no. 10, pp. 630–632, Oct. 2005. M. F. Abedin and M. Ali, “Modifying the ground plane and its effect on Planar Inverted-F Antennas (PIFAs) for mobile phone handsets,” IEEE Antennas Wireless Propag. Lett., vol. 2, pp. 226–229, 2003.

[34] K. L. Virga and Y. Rahmat-Samii, “Low-profile enhanced-bandwidth PIFA antennas for wireless communications packaging,” IEEE Trans. Microw. Theory Tech., vol. 45, no. 10, pp. 1879–1888, Oct. 1997.

[35] B. J. Herting, A. Perrotta, and J. T. Bernhard, “Finite ground plane packaging effects on a dual-band PIFA,” in Proc. IEEE Topical Meetings on Electrical Performance of Electronic Packaging, Oct. 2002, pp.95–98.

[36] Z. D. Liu, P. S. Hall, and D. Wake, “Dual-frequency planar inverted- F antenna,” IEEE Trans. Antennas Propag., vol. 45, no. 10, pp.1451–1458, Oct. 1997.