SLOTTED SERIES ITERATION LOG PERIODIC FRACTAL KOCH ANTENNA WITH STUB-LOADED FOR UHF TVWS APPLICATIONS

by

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Specially dedicated to my beloved parents, husband, brothers, sister and friends

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LIST OF SYMBOLS

c	Speed of light
D	Directivity
D	Distance
f_r	Resonant frequency
G	Gain (electromagnetic)
h	Height
K	Impedance scaling factor
w	Width
ε_r	Relative permittivity
ε_0	Permittivity in free space
λ	Wavelength
λ_0	Wavelength in free space
Γ	Reflection coefficient
Ω	Ohm
η	Efficiency
μ	Permeability
γ	Propagation constant
α	Attenuation constant
σ	Relative spacing constant
β	Phase constant
Λ	Guided wavelength

LIST OF ABBREVIATIONS

AUT	Antenna Under Test
CITEL	Inter-American Telecommunication Commission
CEPT	European Conference of Postal and Telecommunications Administrations
CST	Computer Simulation Technology
dB	Decibel
dBm	Decibel of Measured power referenced to 1 mille watt (mW)
DTV	Digital Television
DVB	Digital Video Broadcasting
DVB-T2	Digital Video Broadcasting-Second Generation Terrestrial
EM	Electromagnetic
F/B	Front to Back ratio
FCC	Federal Communications Commission
GHz	Giga Hertz
GPS	Global Positioning System
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
LPDA	Log Periodic Dipole Array
LPFKA	Log Periodic Fractal Koch Antenna
LPMA	Log Periodic Microstrip Antenna
MAC	Media Access Control
MHz	Mega Hertz
MCMC	Malaysian Communications and Multimedia Commission
mm	Millimeter

NATO	*North Atlantic Treaty Organization*
PCB	*Printed Circuit Board*
PHY	*Physical Layer*
RF	Radio Frequency
S-LPFKA	Slotted Series Iteration Log Periodic Fractal Koch Antenna
SAR	Specific Absorption Rate
SNR	Signal Noise Ratio
TVWS	Television White Space Spectrum
UHF	Ultra High Frequency
USA	United States of America
UV	Ultraviolet
VHF	Very High Frequency
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WSD	White Space Devices

Slot Siri Lelaran Log Berkala Fraktal Koch Antena (S-LPFKA) dengan Puntung-Dimuatkan untuk Aplikasi-aplikasi Frekuensi Ultra Tinggi (UHF) Spektrum Televisyen Ruang Putih (TVWS)

ABSTRAK

Kerja-kerja penyelidikan di dalam tesis ini lebih memberi tumpuan kepada pembangunan slot siri lelaran log berkala fraktal Koch antena (S-LPFKA) untuk aplikasi-aplikasi frekuensi ultra tinggi (UHF) spektrum televisyen ruang putih (TVWS). Log berkala, struktur fraktal Koch dan teknik puntung membantu meningkatkan frekuensi pengendalian yang lebar dan pengecilan saiz selain meningkatkan kelangsungan dan dapatan. Tiga struktur antenna yang berbeza; S-LPFKA, S-LPFKA dengan puntung segi empat dan S-LPFKA dengan puntung berbentuk C telah direka dengan menggunakan perisian simulator 3D Computer Simulation Technology (CST) untuk mengkaji dan membuktikan kesan setiap teknik ke atas prestasi antena. Kesemua antena yang dicadangkan terdiri daripada 10 elemen terpancar siri lelaran fraktal Koch dengan 30° sudut suar di kedua-dua sisi substrat dalam susunan berselang-seli. Kesemua antena telah difabrikasikan pada FR-4 substrat dengan pemalar dielektrik iaitu ε_r=4.7 dan kehilangan tangen iaitu tan δ=0.019. Kedua-dua keputusan pengukuran dan simulasi menunjukkan penambahbaikan dalam jalur lebar untuk kesemua S-LPFKA yang meliputi 100% daripada frekuensi yang diperlukan daripada 0.47 GHz kepada 0.79 GHz apabila struktur fraktal Koch dan teknik puntung ditambah pada antena jajaran dwikutub log berkala (LPDA). Tambahan pula, 30.23%, 43% dan 48.8% pengurangan saiz telah dicapai untuk S-LPFKA, S-LPFKA dengan puntung segi empat dan S-LPFKA dengan puntung berbentuk C, masing-masing. Antena yang dicadangkan merekodkan polarisasi linear dan corak satu arah. Antena-antena ini mampu mengekalkan galangan masukan 50 Ω pada frekuensi-frekuensi UHF TVWS. Keputusan yang diukur bersetuju dengan baik dengan keputusan simulasi. Antena-antena ini mempamerkan dapatan yang tinggi antara 4 dBi hingga 7.8 dBi dan corak radiasi stabil diantara 0.47 GHz hingga 0.79 GHz julat frekuensi.

Slotted Series Iteration Log Periodic Fractal Koch Antenna with Stub-Loaded for Ultra High Frequency (UHF) Television White Space (TVWS) Spectrum Applications

ABSTRACT

The research works in this thesis mainly focusses on the development of slotted series iteration log periodic fractal Koch antenna (S-LPFKA) for ultra high frequency (UHF) television white space (TVWS) spectrum applications. Log periodic, fractal Koch structure and stub technique facilitates the achievement of wide operating frequency band and size miniaturization, besides enhancing directivity and gain. Three different structure of antennas; S-LPFKA, S-LPFKA with rectangular stub-loaded and S-LPFKA with C-shaped stub-loaded have been designed by using 3D simulator software Computer Simulation Technology (CST) to study and verify the effect of each techniques on the performances of the antenna. All the proposed antennas consist of 10 radiating elements of series iteration fractal Koch technique with 30° flare angle on both sides of the substrate in a criss-cross arrangement. All antennas are fabricated on FR-4 substrate with dielectric constant of ε_r=4.7 and loss tangent of tan δ=0.019. Both measured and simulated results show an enhancement in bandwidth for all S-LPFKA which covering 100% of the required frequencies from 0.47 GHz to 0.79 GHz when fractal Koch structure and stub technique are employed to the log periodic dipole array (LPDA) antenna. Furthermore, 30.23%, 43% and 48.8% size reduction are achieved for S-LPFKA, S-LPFKA with rectangular stub-loaded and S-LPFKA with C-shaped stub-loaded, respectively. The proposed antennas recorded linear polarization and unidirectional patterns. The antennas maintain input impedance approximately 50 Ω over UHF TVWS frequencies. The measured results agree well with the simulated results. Those antennas exhibits high gains of between 4 dBi to 7.8 dBi and stable radiation patterns within 0.47 GHz to 0.79 GHz frequency range.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless technology is define as a transmission of information from one place to another place without any cables or wires (T. K. Sarkar, Robert Mailloux, Arthur A. Oliner, M. Salazar-Palma & Dipak L. Sengupta, 2006). It has expanded tremendously not only for commercial and military purposes but also for Ultra High Frequency (UHF) Television White Space Spectrum (TVWS) applications. UHF TVWS antenna has attracted much attention in wireless communication system such as for point to point propagation, television broadcasting, Wi-Fi and several other applications.

During 2008, the Federal Communications Commission (FCC) has hand out a Report and Order to permit the use of temporarily unoccupied VHF and UHF bands in USA under certain conditions. These unused spectrum are known as television white spaces spectrum (TVWS) which is allocated for broadcasting services (Yohannes D. Alemseged, Gabriel Porto Vivaldi, Chen Sun, Ha-Nguyen Tran & Hiroshi Harada, 2012). There are many advantages of TVWS bands such as broader coverage and have a very long range when compared to traditional 2.4 GHz bands. In addition, the propagation characteristics of these bands is useful for many wireless transmission services since TVWS bands resides below than 1 GHz frequency and the obstacles material is less risky as compared to higher frequencies. Nowadays, industries and standardization bodies have expressed an interest in using TVWS bands for providing countryside area with broadband services through extended Wi-Fi. A new standard which is IEEE 802.11af is established to state the fresh super Wi-Fi networks. This new standard states about the international specifications for spectrum allocation between registered services and unregistered white space devices (WSD) (Adriana B. Flores, Ryan E. Guerra, Edward W. Knightly, Peter Ecclesine & Santosh Pandey, 2013).

During the early years when the technology was first developed, microstrip patch antenna (MPA) has been widely applied for defence and astronomical applications. Nowadays, microstrip patch antenna has been used extensively in wireless communication systems. It offers many attractive benefits such as light weight, small dimension, easy fabrication as well as planar geometry (J. R. James & P. S. Hall, 1989). Furthermore, it is very easy to obtain linear or circular polarization in microstrip patch antenna by adjusting the location of the feed (R. Garg, P. Bhartia, I. Bahl & A. Ittipiboon, 2000). Nevertheless, MPA suffered from some weaknesses including narrow bandwidth and low effectiveness (C. A. Balanis, 1996). Additionally, it is very difficult to fulfil the bandwidth requirements for UHF TVWS bands since it operates over a restricted range of frequencies.

This difficulties has motivate researchers in UHF antennas and RF field to construct antenna with various methods in order to increase the bandwidth and performances as well as reducing their physical size (A. A. Gheethan & D. E. Anagnostou, 2008). Lots of technique have been recommended and the most common techniques are by using low permittivity substrate (Bahl. I. J. & P. Bhartia, 1980), stacked patches (F. Klefenz, A. Dreher, 2000), slot patch (Parikshit Vasisht & Taruna Gautam, 2012) and parasitic patches (Ang Yu & Xuexia Zhang, 2003).

In this thesis, log periodic structure has been applied to improve the bandwidh of traditional microstrip patch antenna. Log periodic antenna offers many advantages including high bandwidth and low cross-polarization ratio over a wide frequency range (M. N. A. Karim, M. K. A. Rahim, H. A. Majid, O. Ayop, M. Abu & F. Zubir, 2010). There are many types of log periodic antenna and log periodic dipole array (LPDA) is one of it. There are several numbers of dipole elements with different dimension in the LPDA structure. All the dipoles elements are connected by a transmission line. According to (Rumsey, V. H., 1957), the input impedance and gains of log periodic antenna are almost same throughout its operating frequencies. The combined resonance effects of multiple elements which are arranged in nonlinear scale of the frequencies resulting the wideband characteristic of log periodic antenna. Every element in LPDA is responsible to be radiate at a specific frequency thus it will produce an overlapping radiation that cover the whole desired bandwidth (Shih-Chang Wu & N. G. Alexopoulus, 1992).

Instead of enhancing the bandwidth, a good antenna has to be in smaller dimension with non-considerable degradation of radiation patterns and performances. There are some challenges in designing a small and light weight LPDA while sustaining its bandwidth, efficiency and gain. This is mainly owing to the length of dipole element which is half of the wavelength. Moreover, TVWS band has a large wavelength of 400–640 mm which covering a frequency of 0.47 GHz to 0.79 GHz (A. Moallemizadeh, H.

R. Hassani & S. M. A. Nezhad, 2012). To overcome this problem, the technique to miniaturize the size is required.

Fractal shaped structure is usually implemented in designing compact size of antenna due to its capabilities in reducing dimensions (D. Li, F. S. Zhang, Z. N, Zhao, L. T. Ma & X. N. Li. 2012). Koch curve fractal structure is one of the fractal geometries which is normally used in UHF antenna design (K. J. Vinoy, 2002). Koch curve is an example of space-filling geometries. The shape of the Koch curve is same at all scales of magnification thus resulting in self-similar features (C. Puente, J. Romeu, R. Pous, J. Ramis & A. Hijazo, 1998). Fractal Koch curve is applied in this research work due to its possibilities in miniaturize the dimension of the antenna by increasing the numbers of iterations such as 0^{th} iteration, first iteration and series iteration.

Besides using fractals, slots can also be used as a method to minimize the dimension of the antenna (S. A. Bokhari, 1996; J. Huang, 2001). The shape and the dimension of the slots will affected the bandwidth and size of the antenna. The current beneath the resonating patch will travel from one side to another side and take a longer distance around the slots in order to reach at the opposite side. As the distance is become farther, the resonant frequency and the dimension of the proposed antenna will become smaller. Another effective miniaturization approach is by adding stub at the radiating element (Bing Gong, Ling Hua Su, Ying Zeng Yin, Hui Ma & Qiu Rong Zheng, 2012). This method manages to reduce the antenna’s dimension while capable to enhance the bandwidth and gain. By adding stub, the length of operative current path is increases thus reduces its longitudinal dimension. The length and width of the stub can be optimized for a smaller size of antenna.

Due to the growing demand of low size UHF TVWS antenna, a novel slotted series iteration of log periodic fractal Koch antenna operating over UHF TVWS frequency range from 0.47 GHz to 0.79 GHz is proposed in this thesis. This operating frequency is equal to the Digital Video Broadcasting-Second Generation Terestrial (DVB-T2) standard. DVB-T2 is a continuation of the television standard DVB-T which is released by the consortium Digital Video Broadcasting (DVB) and designed for the broadcasting transmission of digital terrestrial television (Telemi Sato, Brugger Roland, Pena Ivan & Angueira Pablo, 2015).

Here in this thesis, the proposed antenna is a combination techniques of log periodic, series iteration of fractal Koch and stub for bandwidth enhancement and size reduction purposes. Hence, a slotted series iteration log periodic fractal Koch antenna (S-LPFKA), S-LPFKA with rectangular stub-loaded and S-LPFKA with C-shaped stub-loaded have been designed and fabricated. FR-4 is using as a substrate with permittivity of 4.7 and thickness of 1.6 mm. The simulation and measurement results are illustrated and analyzed to show the effects of different improvement methods on antenna's performances thus proven the novelty of S-LPFKA for UHF TVWS applications.

1.2 Problem Statement

The UHF TVWS applications demand an antenna that are lightweight, small size, robust and maintains an excellent performance. Microsrip patch antenna is one of the options. However, the constraint of microstrip patch antennas are its low gain and narrow bandwidth. The requirement for a small size antenna deteriorate these two parameters. This is due to the relationship among size, bandwidth and effectiveness of the antennas. The gain is related to the size of antenna. For example, small size of antenna will produces lower gain compared to the large one. To overcome these issues, several techniques such as log periodic (R. H. DuHamel and D. E. IsBell, 1957), using low permittivity substrate (Bahl. I. J. & P. Bhartia, 1980) and using stacked patches (F. Klefenz, A. Dreher, 2000) have been implemented.

Due to its uniqueness, LPDA has provide many advantages such as wide bandwidth and high gain. But, the length of every single element in LPDA is a half wavelength of the operating frequency and the dimension could be too bulky for UHF TVWS bands (0.47-0.79 GHz). The wavelengths in UHF TVWS bands is very large which is 400–640 mm, thus the antenna is difficult to be implemented. Moreover, it requires compact size and wide bandwidth. Some techniques have been presented to make the structure solid, such as using multiple layers substrate or higher dielectric substrate (Stuart M. Wentworth, Robert L. Rogers, John G. Heston & Dean P. Neikirk, 1990). However this will limit the bandwidth and lead to gain reduction due to the rising in capacitive coupling through the substrate.

Therefore, the main task of this thesis is to develop a new method to miniaturize the large size of LPDA which operates over UHF TVWS bands with wide bandwidth, gain and efficiency. To reduce the size of conventional LPDA, fractal Koch structure with series iteration and titled slots have been proposed. The employment of fractal geometry to the LPDA structure will increase the electrical length thus reduces the dimension of antenna. In this thesis, a slotted series iteration log periodic fractal Koch antenna (S-LPFKA), S-LPFKA with rectangular stub-loaded and S-LPFKA with C-shaped stub-loaded have been designed and fabricated using FR-4 as substrate material with permittivity and layer thickness of 4.7 and 1.6 mm, respectively. The simulated and measured results indicate a significant size reduction and improvement in bandwidth while maintaining high gain and efficiency. The antenna configuration, design methodology, simulated and measurement results will be discussed in the following sections.

1.3 Objectives

The main objectives of this research work are as follows:

i. To design and fabricate log periodic dipole array (LPDA) antenna for UHF TVWS (0.47-0.79 GHZ).

ii. To miniaturize size of LPDA antenna by using series iteration of fractal Koch and titled slot technique.

iii. To investigate the effect of stub on proposed slotted series iteration log periodic fractal Koch antenna (S-LPFKA).

1.4 Scope of work

The scope of this research work was begin with the information of log periodic antenna that was gathering via a lot of sources such as IEEE Explorer, journals, conference papers and books. The issues and problems related to the conventional UHF antenna have been considered. Microstrip patch antenna usually operates over a limited frequency ranges and unable to satisfy the bandwidth requirements for UHF TVWS applications. Several techniques to enhance the bandwidth has been proposed such as by using parasitic element, multilayer structure antenna, non-contact feeding technique and different shape slots. Another effective approach is log periodic technique. Log periodic antenna are broadly used because they have the characteristics of multi element, directional and designed to operate over a wide range of frequencies.

A good antenna has to be in smaller dimension with non-considerable degradation of radiation patterns and performances. UHF TVWS antenna is very difficult to be implemented due to the respective large wavelength of 400-640 mm. Antenna miniaturization techniques that can considered are high permittivity material, metamaterial, co-planar waveguide, fractal Koch structure and stub technique.

The design and simulation process have been performed by using Computer Simulation Technology (CST) software. The simulation process started by designing the LPDA structure with 0^{th} iteration based on the formulas. The values of each radiating elements are determined. Then the parameters of the proposed antennas are optimized to obtained the best result.

The proposed antennas are fabricated on FR-4 substrate by using wet etching technique after the best design is confirmed. The measurement process has been carried out in term of reflection coefficient, radiation pattern and gain by using Network Analyzer, Spectrum Analyzer and Anechoic Chamber. Lastly, the simulated and measured results are compared, evaluated and documented.

1.5 List of Contributions

List of contributions throughout the works that have been done are as follows:

i. Three antennas have been developed:
   a) Slotted series iteration log periodic fractal Koch antenna (S-LPFKA)
   b) S-LPFKA with rectangular stub-loaded
   c) S-LPFKA with C-shaped stub-loaded

ii. Bandwidth enhancement for S-LPFKA, S-LPFKA with rectangular stub-loaded and S-LPFKA with C-shaped stub-loaded.

iii. Size reduction for S-LPFKA, S-LPFKA with rectangular stub-loaded and S-LPFKA with C-shaped stub-loaded.

1.6 Thesis Outline

This thesis is separated into five chapters. Chapter 1 comprises of introduction which offer the information about the background of the previously research works, problem statements, and objectives. Scope of studies, project contributions and thesis organization also will be provided in this chapter.

Chapter 2 consists of a brief review about log periodic antenna, fractal Koch structure, stub technique and previously used techniques for UHF bands. The technique to increase the bandwidth of traditional microstrip patch antenna, size reduction and feeding technique also will be included. The effects of iteration number on log periodic