



UNIVERSITI PUTRA MALAYSIA

***SINGLE-BAND AND DUAL-BAND MICROSTRIP FILTER-ANTENNA FOR
WIRELESS APPLICATIONS***

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WIRELESS APPLICATIONS**

By

MOHAMMED KADHIM KHUDHAIER

**Thesis is Submitted to the School of Graduate Studies, Universiti Putra
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DEDICATION

*To my ever-beloved mother and the memories of my father...
To my supportive mother in law and the memories of my father in law...
To my dearest and altruistic wife...
To my beloved siblings...*

*To every person has supported me and made an effort to provide scientific
advice...
To everyone looking for freedom and peace in this world...*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

SINGLE-BAND AND DUAL-BAND MICROSTRIP FILTER-ANTENNA FOR WIRELESS APPLICATIONS

By

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December 2017

Chairman : Ratna Kalos Zakiah Sahbudin, PhD
Faculty : Engineering

In conventional narrow band radio frequency (RF) systems, all RF components are designed separately and all the input/output ports are matched to a standardized value typically 50Ω . For simplicity and miniaturization, it is preferable to integrate the filter and the antenna into a single module that achieves filtering and radiating functions at the same time, known as filter-antenna. Integration of microstrip filter and microstrip antenna represents a challenge for many researchers. The filter-antenna circuit suffers from some design problems that affect its performance. These problems were the main reasons for the variation between the simulation and experimental results.

This study presents two different types of microstrip filter-antenna structures. It is the effort to improve the performance characteristics of the single-band filter-antenna and the dual-band filter-antenna. A single-band, dual-mode filter-antenna was designed using a Chebyshev lowpass prototype with passband ripple of 0.1 dB and fractional bandwidth (*FBW*) of 10.5 %, which operates at a centre frequency of 5.794 GHz. The measured S_{11} of the filter-antenna is better than -21 dB. This microstrip filter-antenna is designed by using the modified shaped dual-mode square open-loop resonator structure. These types of resonators behave as a double tuned circuit. This new design not only reduces the circuit size of about 50 % as compared with the single-mode resonators, but also got the crucially less insertion loss. The single-band, dual-mode filter-antenna design is then modified by using U-shaped slot etched on the patch antenna to improve its performance. This filter-antenna is suitable for portable communication applications; because of its compact size of $22 \times 22 \times 1.6 \text{ mm}^3$. The folded Stepped Impedance Resonator (SIR) dual-band filter-antenna was designed using Butterworth lowpass prototype. The measured fractional bandwidth for the first frequency band is 24.37 % and the measured fractional bandwidth for the second frequency band is 17.24 %. The measured first frequency passband of the filter-

antenna operates at a centre frequency of $f_o^I = 5.75$ GHz, and the measured second frequency passband operates at a centre frequency of $f_o^{II} = 8.35$ GHz. The measured S_{11}^I of the first frequency passband is better than -24 dB, and S_{11}^{II} of the second frequency passband is better than -15 dB. The folded SIR dual-band filter-antenna is designed by using four-folded SIR, where any two-folded SIR is connected together. These folded SIR are used instead of the conventional SIR to miniaturize the overall circuit size. The folded SIR dual-band filter-antenna is designed, and then modified by using the dumbbell-shaped Defected Ground Structure (DGS) to improve the filter-antenna performance and for further reduce the size of the circuit. The dual-band filter-antenna is suitable for mobile communication because of its compact size of $41.4 \times 30 \times 1.6$ mm³. The comparison of the simulated and measured S_{11} -parameters of the folded SIR dual-band filter-antenna shows an acceptable matching between the simulation results and experimental results. The centre frequency of the first frequency passband moves down from 5.8 GHz to 5.75 GHz and the centre frequency of the second frequency passband is shifted from 8.184 GHz to 8.35 GHz. This frequency shifting is due to the difference in the design component values of the theoretical and the practical design.

Some comparisons have been made between the proposed designs and other literature works, also among some literature works for both single-band and dual-band filter-antennas. The aim of these comparisons is to investigate the achievement of the research objectives.

Single-band, dual-mode filter-antenna is compared with other filter-antennas literature works such as Ref. [85] and Ref. [109]. The specification and design comparison show that the proposed filter-antenna has a good design performance such as insertion loss, return loss, gain, and band edge selectivity. The proposed single-band, dual-mode filter-antenna has a circuit size reduction as compared with the circuit of Ref. [85] of about 50 %, and 70 % as compared with the circuit of the Ref. [109]. The design comparison of the proposed dual-band, folded SIR filter-antenna and other literature works such as Ref. [110], Ref. [89], and Ref. [111] shows that the proposed filter-antenna has good design performance and good band edge selectivity. The proposed dual-band, folded SIR filter-antenna has a circuit size reduction as compared with the circuit of Ref. [110] more than 85 %, and 43 % as compared with the circuit of the Ref. [89].

The single-band, dual-mode filter-antenna is designed and fabricated to cover the Worldwide Interoperability for Microwave Access (WiMAX) application. Based on IEEE 802.16-2005 (802.16e), this technology supports mobility networking between the fixed base station and mobile devices. In addition, enables high signal speed required for communications with users moving by vehicles to have speed which is below 100 km/h. This technology provides symmetric bit rates of 70 Mbps and operates in the frequency range 2-6 GHz. The folded SIR dual-band filter-antenna is designed and fabricated to cover a Wireless Local Area Network (WLAN) application (5.75 GHz) for the first frequency passband and X-band (8-12GHz) applications for

the second frequency passband. Satellite communication operates in part of the X-band or Super High Frequency (SHF) spectrum which is specified by (ITU). Satellite communication has the frequencies in the range 7.25 GHz to 7.75 GHz (space to earth) and 7.9 GHz to 8.4 GHz (earth to space).

The main contributions of this study represented by the design and fabrication of a new structure single-band, dual-mode filter-antenna which used a novel shaped of the dual-mode resonator. The dual-mode resonator has highly contributed to the overall circuit size reduction and improved its band edge selectivity. In addition, the design of a new dual-band filter-antenna structure which used folded SIR and defected Ground Structure (DGS) are for more size reduction and band edge selectivity improvement. Single-band and dual-band microstrip filter-antennas are developed and analyzed using 3-D Computer Simulation Technology electromagnetic simulator software (CST). In order to verify the simulation results, the single-band filter-antenna and the dual-band filter-antenna are fabricated on FR-4 epoxy glass substrate material with a dielectric constant of 4.3 and loss tangent $\tan\delta = 0.02$. The experimental measurements are carried out by using a Vector Network Analyzer (VNA Anritsu 37347D). The design of the filter-antenna models are fabricated and tested. A good agreement was found between simulated and measured results. The results were also compared to previous work to show the uniqueness of the design process implemented in the present work. All the objectives of the study have been achieved with a significant improvement in the performances of the proposed filter-antennas compared with previous works.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENAPIS-ANTENA MIKROJALUR DWI-JALUR DAN JALUR TUNGGAL
UNTUK APLIKASI WAYARLES**

Oleh

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Dalam sistem frekuensi radio (RF) jalur sempit konvensional, semua komponen RF telah direka bentuk secara berasingan dan semua pangkalan masukan / keluaran telah dipadankan dengan nilai yang seragam iaitu biasanya 50Ω . Untuk mendapatkan keringkasan dan pengecilan, adalah menjadi pilihan untuk mengintegrasikan penapis dan antenna ke dalam modul tunggal yang mencapai fungsi penapisan dan pancaran pada masa yang sama, ia dikenali sebagai penapis-antenna. Integrasi penapis mikrojalur dan antenna mikrojalur merupakan satu cabaran bagi kebanyakan penyelidik. Litar penapis-antenna menghadapi beberapa masalah dari segi reka bentuk dan menjejaskan prestasinya. Masalah ini menjadi sebab utama perbezaan antara keputusan teori dan praktikal.

Kajian ini membentangkan dua jenis struktur penapis-antenna mikrojalur. Ia adalah usaha untuk meningkatkan ciri-ciri prestasi penapis- antenna jalur-tunggal dan penapis-antenna dwi-jalur. Penapis-antenna jalur tunggal dwi-mod direka bentuk menggunakan prototaip lurus rendah Chebyshev dengan riak jalur lurus sebanyak 0.1 dB dan lebar jalur pecahan (*FBW*) sebanyak 10.5%, yang beroperasi pada frekuensi pusat 5.794 GHz. Nilai S_{11} penapis- antenna yang diukur lebih baik daripada -21 dB. Penapis-antenna mikrojalur ini direka bentuk dengan menggunakan struktur resonator gelung terbuka dua dimensi persegi yang diubah suai. Resonator jenis ini bertindak sebagai litar tertala dua kali. Reka bentuk baru ini bukan sahaja mengurangkan saiz litar sebanyak kira-kira 50% berbanding dengan resonator mod-tunggal, tetapi juga yang penting kehilangan penyisipan yang kurang. Reka bentuk penapis-antenna jalur tunggal, dwi-mod kemudian diubahsuai dengan menggunakan slot berbentuk U diikatkan pada antenna tampal untuk meningkatkan prestasinya. Penapis-antenna ini sesuai untuk aplikasi komunikasi mudah alih; kerana ia bersaiz padat $22 \times 22 \times 1.6 \text{ mm}^3$. Penapis-antenna dwi-jalur Resonator Impedans Bertangga (SIR) terlipat telah direka bentuk

menggunakan prototaip lurus rendah Butterworth. Jalur lebar pecahan untuk jalur frekuensi pertama ialah 24.37 % dan untuk jalur frekuensi kedua ialah 17.24 %. Jalur frekuensi pertama penapis-antena beroperasi pada frekuensi pusat $f_o^I = 5.75$ GHz, dan jalur frekuensi kedua beroperasi pada frekuensi pusat $f_o^{II} = 8.35$ GHz. Nilai S_{11}^I jalur pertama yang diukur adalah lebih baik daripada -24 dB, dan S_{11}^{II} jalur kedua adalah lebih baik daripada -15 dB. Penapis-antena dwi-jalur SIR terlipat direka bentuk dengan menggunakan SIR terlipat empat, di mana SIR terlipat dua disambungkan bersama-sama. SIR terlipat ini digunakan, dan bukannya SIR konvensional untuk mengecilkan saiz litar keseluruhannya. Penapis-antena dwi-jalur SIR yang direka bentuk, dan kemudian diubah suai dengan menggunakan Struktur Bumi Tersingkir (DGS) berbentuk dumbel untuk meningkatkan prestasi penapis-antena dan untuk mengurangkan lagi saiz litar. Penapis-antena dwi-jalur sesuai untuk komunikasi mudah alih kerana saiznya yang kompak $41.4 \times 30 \times 1.6$ mm³. Perbandingan antara parameter S_{11} yang disimulasikan dan diukur untuk penapis-antena SIR dwi-jalur terlipat menunjukkan satu persamaan yang boleh diterima antara keputusan simulasi dan keputusan eksperimen. Frekuensi pusat untuk jalur frekuensi pertama berkurangan dari 5.8 GHz ke 5.75 GHz dan frekuensi pusat untuk jalur frekuensi kedua beralih daripada 8.184 GHz kepada 8.35 GHz. Peralihan frekuensi ini disebabkan oleh perbezaan dalam nilai komponen untuk reka bentuk teori dan reka bentuk praktikal.

Beberapa perbandingan telah dilakukan antara reka bentuk yang dicadangkan dan kerja-kerja penyelidikan yang lain, juga antara beberapa kerja-kerja penyelidikan untuk penapis-antena jalur tunggal dan dwi-jalur. Tujuan perbandingan ini adalah untuk menyiasat pencapaian objektif penyelidikan.

Penapis-antena jalur-tunggal, dwi-mod dibandingkan dengan kerja-kerja saringan penapis-antena lain seperti Ref. [85] dan Ref. [109]. Spesifikasi perbandingan dan reka bentuk menunjukkan bahawa penapis-antena yang dicadangkan mempunyai prestasi reka bentuk yang baik, seperti kehilangan sisipan, kehilangan pulangan, gandaan, dan selektiviti jalur pinggir. Penapis-antena jalur-tunggal, dwi-mod yang dicadangkan mempunyai pengurangan ukuran litar berbanding dengan litar Ref. [85] kira-kira 50 %, dan 70 % berbanding dengan litar Ref. [109]. Perbandingan reka bentuk dwi-jalur yang dicadangkan, penapis-antena SIR terlipat dan kajian semula penyelidikan yang lain seperti Ref. [110], Ref. [89], dan Ref. [111] menunjukkan bahawa penapis-antena yang dicadangkan mempunyai prestasi reka bentuk yang baik dan selektiviti jalur pinggir yang baik. Dwi-jalur yang dicadangkan, penapis-antena SIR terlipat mempunyai pengurangan ukuran litar berbanding dengan litar Ref. [110] lebih daripada 85%, dan 43% berbanding dengan litar Ref. [89].

Penapis-antena jalur-tunggal, dwi-mod direka bentuk dan difabrikasi untuk menampung penggunaan Kebolehgacaraan Seluruh Dunia untuk Akses Microwave (WiMAX). Berasaskan kepada IEEE 802.16-2005 (802.16e), teknologi ini menyokong mobiliti rangkaian antara peranti mudah alih dan stesen pangkalan yang tetap. Di samping itu, membolehkan kelajuan isyarat tinggi yang diperlukan untuk

komunikasi dengan pengguna bergerak dengan kendaraan yang mempunyai kelajuan di bawah 100 km/j. Teknologi ini memberikan kadar bit yang simetri pada 70 Mbps, dan beroperasi dalam julat frekuensi 2-6 GHz. Penapis-antena SIR dwi-jalur terlipat direka bentuk dan difabrikasi untuk menampung penggunaan Rangkaian Kawasan Setempat Tanpa Wayar (WLAN) untuk (5.75 GHz) jalur lulus frekuensi pertama dan jalur-X (8-12 GHz) untuk jalur lulus frekuensi pertama kedua. Komunikasi satelit beroperasi dalam bahagian spektrum jalur-X atau frekuensi tinggi super (SHF) yang ditetapkan oleh (ITU). Komunikasi satelit mempunyai julat frekuensi dalam 7.25 GHz ke 7.75 GHz (angkasa ke bumi) dan 7.9 GHz ke 8.4 GHz (bumi ke ruang).

Sumbangan utama kajian ini adalah reka bentuk dan fabrikasi struktur baru penapis-antena jalur-tunggal, dwi-mod yang menggunakan bentuk resonator dwi-mod yang laru. Resonator dwi-mod telah menyumbang dalam mengurangkan saiz keseluruhan litar dan mempertingkatkan selektiviti jalur pinggir. Di samping itu, reka bentuk struktur penapis-antena dwi-jalur yang baru dengan SIR terlipat dan DGS digunakan untuk lebih mengurangkan saiz dan menambahbaik selektiviti jalur pinggir.

Penapis-antena mikrojalur jalur tunggal dan dwi-jalur dibangunkan dan dianalisis dengan menggunakan perisian Simulator Elektromagnetik Teknologi Simulasi 3-D (CST). Untuk mengesahkan hasil simulasi, penapis-antena jalur tunggal dan penapis-antena dwi-jalur dibina di atas bahan substrat kaca epoksi FR-4 dengan pemalar dielektrik sebanyak 4.3 dan kehilangan tangent $\tan\delta = 0.02$. Pengukuran eksperimen dilakukan dengan menggunakan Vector Analyzer Network (VNA Anritsu 37347D). Reka bentuk model penapis-antena dibina dan diuji. Kesepakatan yang baik telah ditemui di antara keputusan simulasi dan pengukuran. Hasilnya juga dibandingkan dengan kerja sebelumnya untuk menunjukkan keunikan proses reka bentuk yang dilaksanakan dalam kerja sekarang. Semua objektif kajian telah dicapai dengan peningkatan yang signifikan dalam prestasi penapis-antena yang dicadangkan berbanding dengan kerja sebelumnya.

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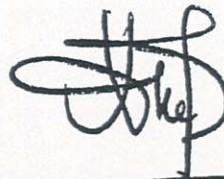
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LIST OF ABBREVIATIONS

BPF	Bandpass Filter
BSF	Bandstop Filter
CPW	Coplanar Waveguide
dBm	A logarithmic unit to measure power in milli Watt
DGS	Defected Ground Structure
FCC	United State, Federal Communication Commission
FR-4	Epoxy glass dielectric material
<i>FBW</i>	The fractional bandwidth
GPS	Global Positioning System
HPF	Highpass Filter
IMT 2000	International Mobile Telecommunication for the year 2000
LPF	Lowpass Filter
MPA	Microstrip Patch Antenna
MMIC	Monolithic Microwave Integrated Circuits
OCS	Open Circuited Stubs
OLR	Open-Loop Resonator
PCB	Printed Circuit Boards
PCS 1900	Personal Communications Service 1900
RF	Radio frequency
<i>RLC</i>	Resistance, Inductance, capacitance
SIR	Stepped Impedance Resonator
TEM	Transverse Electromagnetic wave

UWB	Ultra-Wideband
<i>VSWR</i>	Voltage Standing Wave Ratio
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network



LIST OF SYMBOLS

$A_v(\Omega)$	The network (filter) attenuation
BW	Bandwidth
$D(s)$	The denominator of the transfer function $H(s)$
$E(s)$	The numerator of the characteristic function $K(s)$
$H(s)$	Rational function of a complex frequency variable (s)
$K(s)$	The characteristic function
$N(s)$	The numerator of the transfer function $H(s)$
$t(j\Omega)$	The inverted of the transfer function $H(j\Omega)$
W	A metal strip (conducting-strip) width
t	A metal strip (conducting-strip) thickness
s	Complex frequency variable
S_{11}	Forward Reflection Coefficient
S_{12}	Reverse Transmission Coefficient
S_{21}	Forward Transmission Coefficient
S_{22}	Reverse Reflection Coefficient
Q_e	External quality factor
$M_{i,i+1}$	Coupling coefficient between i and $i+1$ resonators
h	Height of the dielectric material
H	Magnetic field
G	Conductance
E	Electric field
D	Antenna directivity

C	The light speed (i.e., 3×10^8 m/s)
ΔL	The patch antenna extended the length
φ_{21}	The phase response
λ_o	The free space wavelength
β	The propagation constant
λ_g	The guided wavelength
θ	An electrical length of the microstrip line
ϵ_{reff}	The effective dielectric constant
ϵ_r	Substrate dielectric constant
$v_o(t)$	Output voltage in the time domain
v_p	Phase velocity
α_c	Attenuation conductor loss
$\tau_d(\Omega)$	The group delay
a_n	The definition of the incident voltage signal
b_n	The normalized reflected voltage signal
f_c	Cutoff frequency
f_o	Centre frequency
f_{pass}	Passband frequency
f_{stop}	Stopband frequency
g_i	Chebyshev lowpass filter prototype components
t_{pd}	Microstrip propagation delay
$v_i(t)$	Input voltage in the time domain
A_{stop}	Stopband gain
$I_L(\Omega)$	The transmission loss (dB)

$R_L(\Omega)$	The reflection loss (return loss) (dB)
$P_{inc.}$	Incident power
$P_{radiated}$	Radiated power of the antenna
$P_{ref.}$	Reflected power
P_s	Supplied power to the antenna
Q_{BP}	Bandpass quality factor
Q_u	The unloaded quality factor
R_L	The loss resistance
R_r	The radiation resistance
R_s	Surface resistance in ohms per unit area
$T_N^2(\frac{\omega}{\omega_p})$	The square magnitude of a Chebyshev approach transfer function
$V_i(s)$	Input voltage in the frequency domain
$V_{inc.}$	The incident wave amplitude, voltage
V_{max}	The maximum amplitude voltage
V_{min}	The minimum amplitude voltage
$V_o(s)$	Output voltage in the frequency domain
$V_{ref.}$	The reflected wave amplitude, voltage
Ω	Angular frequency
μ_o	Free space permeability
α_d	The microstrip attenuation due to the dielectric loss
ϵ	Material permittivity
μ	Material permeability
ϵ	The passband ripple parameter

N	The filter order
ω_p	The upper-frequency passband edge
η	Antenna radiation efficiency
ρ	Reflection coefficient
σ	The real part of (s) and is called Neper frequency (neper/second)
$\tan\delta$	The loss tangent of the dielectric substrate
Z_0	Characteristic impedance



CHAPTER 1

INTRODUCTION

1.1 Background

The filter and the antenna are the major parts of wireless communication systems. It is known that the antenna transmits and receives electromagnetic waves and the filter, especially Band Pass Filters (BPF) selects signals in the specific band and rejects the spurious (out-of-band) signals [1]. This caused many inventions in wireless services and products such as Global Positioning System (GPS), Wireless Local Area Network (WLAN), Bluetooth, and mobile phone [2]. In order to obtain the requirements of compactness, low cost, and low profile passive component, many researchers attempts to design filters and antennas simultaneously on a small single module [3]. The integration of filters and antennas in one module achieves filtering and radiating functions at the same time, called filter-antenna [4]. Filter-antenna improves the system performance, such as insertion loss, return loss, Voltage Standing Wave Ratio (*VSWR*), gain and reduces the pre-filtering requests. Several topologies of filter-antenna are designed using filter synthesis approach. Filter synthesis approach consideration that the antenna acts as the last resonator within the filter. Filter-antenna has performed in several forms as well as rectangular patch antenna [5], circular patch antenna [6], patch array antenna [7], Γ -shaped antenna [8], inverted L-antenna [9], slot dipole antenna [10], monopole antenna [11], conductor slot antenna [12], and stuff resonator antenna [13]. Different studies in the literature applied for integration of filter and antenna in a single microwave module [1, 4]. A predesigned BPF with appropriate configurations is directly inserted into the feed position of the patch antenna [1]. For the particular system of measurement, the BPF is often integrated properly with the antenna [2, 4] by exploitation, an additional impedance transformation structure sandwiched the filter and the antenna. The transition structure needs for additional size; therefore, the design did not have a good filter response among the frequency ranges. The design of the filter-antenna following the bandpass filter synthesis method is assigned in [5, 8]. In these designs, an antenna is treated as a series or parallel Resistance, Inductance, and Capacitance (*RLC*) equivalent circuit substituted the last resonator and the load resistance of the BPF. The co-design approach of the filter-antenna did not have a good band-edge selectivity and stopband rejection [2]. This is often due to deficiency of the extraction of the antenna equivalent circuit over a suitable bandwidth, especially at the centre frequency, which has extracted and utilized in the filter synthesis. Furthermore, the antenna gain versus frequency, which is a vital characteristic of the filter-antenna, has been considered in this study. Integration of a compact dual-band microstrip filter with dual-band antenna leads to the formation of a dual-band filter-antenna. The WLAN is usually used in commercial and residential complex networks providing wireless access to their customers. Almost all WLAN's modems are based on IEEE 802.11 standards. The bandwidths of IEEE 802.11b/g and 802.11a/j are 2.4 - 2.483 GHz and 4.905 – 5.845 GHz, respectively. For this reason, it requires a dual-band with broadband for higher data rates to allow for the greatest number of devices to share the available space [14].

Various designs of patch antennas for WLAN applications have been done to improve the patch antenna performance [15]. Furthermore, the patch antenna typically has a narrow bandwidth and second-harmonic radiation characteristics of the radiation patterns of the high band. Ultra-Wideband (UWB) technology has a big possibility in the development of different modern transmission systems. In February 2002, the U.S Federal communications commission (FCC) licensed the unlicensed use of UWB devices for a spread of applications. Now UWB approach is another way to make high data rate links between devices. This standard depends on a very low power level over very large bandwidth (3.1-10.6 GHz). This requires introducing filtering after or inside the antenna [16]. Many researchers have raised the development of the UWB filters and UWB antennas [17].

1.2 Problem Statement

In this study, integration of microstrip filter and microstrip antenna represents a challenge for many researchers. The filter-antenna circuit has several problem sources, which of course affect the performance of the circuit. These problems are the main reasons for the difference between the simulation and experimental results. Some of these problems can be solved or at least minimizing the adverse effects on the overall circuit performance. The important problem sources are:

- The filter-antenna did not show a good filter performance, especially the band-edge selectivity and stopband suppression [18].
- Filter-antenna generally consists of two separate circuits, therefore; the mismatch problem may exist.
- Size and cost are also the problems faced by the designers, especially in the modern mobile communication systems, such as Wireless Local Area Network (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), satellite communication, and so on which required a small circuit size. Some single-band filter-antenna literature works having a relatively big size such as the design includes in Ref. [19], which has a size of $42.6 \times 42.6 \text{ mm}^2$. In addition, some dual-band filter-antenna literature works having a bigger size such as the design includes in Ref. [20], which has a size of $140 \times 140 \text{ mm}^2$.
- Most microstrip antennas, especially patch antennas have narrow bandwidths of about (2 – 5 %) of the operating frequency that does not cover the requirements of WLAN, WiMAX, and other wireless applications [21].

1.3 Motivation of Study

The microstrip transmission line has become the best known and most widely used planar transmission line for RF/microwave circuits. The microstrip transmission line has some of the favourite specifications such as it is planar nature, ease of fabrication, easily integrated with other RF/microwave circuits and solid-state devices, and good heat sinking. The significance of this study comes from the importance of this topic (filter-antenna). The filter-antenna plays an important role in the overall circuit size

reduction and improvement of the system noise reduction. In addition, this study focuses directly on the problem sources experienced by the filter-antenna and find the suitable solutions to remove, or at least reduce their effects on the overall circuit performance. Design and fabrication of a compact, low cost, and highly selective single-band and dual-band filter-antennas have been done by using the Computer Simulation Technology software (CST) Microwave Studio Suite. The motivation behind the design of single-band, dual-mode filter-antenna at a center frequency $f_o = 5.794$ GHz is to cover the WiMAX applications. This frequency band is included in the Industrial, Scientific, and Medical radio band (ISM band). Generally ISM bands are open frequency bands, which are different based on regions and permits. The motivation behind the design of folded SIR dual-band filter-antenna at a first center frequency band $f_o = 5.75$ GHz is to cover the WLAN requirements based on IEEE 802.11 standards. The bandwidths of IEEE 802.11b/g and 802.11a/j are 2.4 - 2.483 GHz and 4.905 – 5.845 GHz. The second frequency passband is designed at $f_o = 8.35$ GHz to cover the X-band requirements (8-12GHz). Satellite communication operates in part of the X-band or Super High Frequency (SHF) spectrum which is specified by (ITU). Satellite communication has the frequencies in the range 7.25 GHz to 7.75 GHz (space to earth) and 7.9 GHz to 8.4 GHz (Earth to Space). On the other hand, the designers and researchers should search other frequency bands because many researchers have covered the frequency bands of 2.4GHz, 3.3GHz, 5.2GHz, and 5.8GHz.

Comparison of the proposed filter-antenna design theoretically and experimentally and also a comparison with other research works are important. This is to investigate and validate the performance of the proposed filter-antenna design.

1.4 Aim and Objectives

The aim of this study is to design and develop microwave filter-antennas and investigate the performance by comparing with other kinds of filter-antenna structures. Although the filter-antenna designs are small and compact in size, the application in wireless communication requires much smaller size. Thus new filter-antenna design with low loss and high selective single-band and dual-band is introduced.

To achieve the aim, the main objectives of the study are as follows:

1. To design a compact, low loss and high selective single-band, dual-mode filter-antenna suitable for WiMAX applications for first frequency passband and dual-band filter-antenna suitable for WLAN applications and satellite communication wireless applications in a second frequency passband, respectively.
2. To simulate, fabricate, and investigate the performance of the single-band and dual-band filter-antennas by comparing with other literature works.
3. To compare the simulated and measured results such as insertion loss, return loss, $VSWR$, gain and circuit size against other filter-antennas at the specific frequency band to achieve the uniqueness of the design process performed in the proposed works.

1.5 Scope of Research

The scope of this thesis is to design and fabricate a new compact microstrip single-band, dual-mode filter-antenna and a new compact folded SIR dual-band filter-antenna for wireless applications. The main reason for the work done in this study is to achieve new compact microstrip filter-antenna designs have filtering and radiating simultaneously on a small single module. The integration of filters and antennas will reduce the overall size of the resulting circuit and highly improve its performance. The design of a single-band filter-antenna is performed by using a new efficient kind of dual-mode resonators to enhance the performance of the filter-antenna. The design of a dual-band filter-antenna is performed by using folded SIR resonators to give a further reduction in the circuit size. The flow chart of this study is shown in Figure 1.1. The yellow colour blocks represent the direction followed in this study to achieve the objectives, while the blue colour blocks are referred to other research areas which are out of the scope of this study.

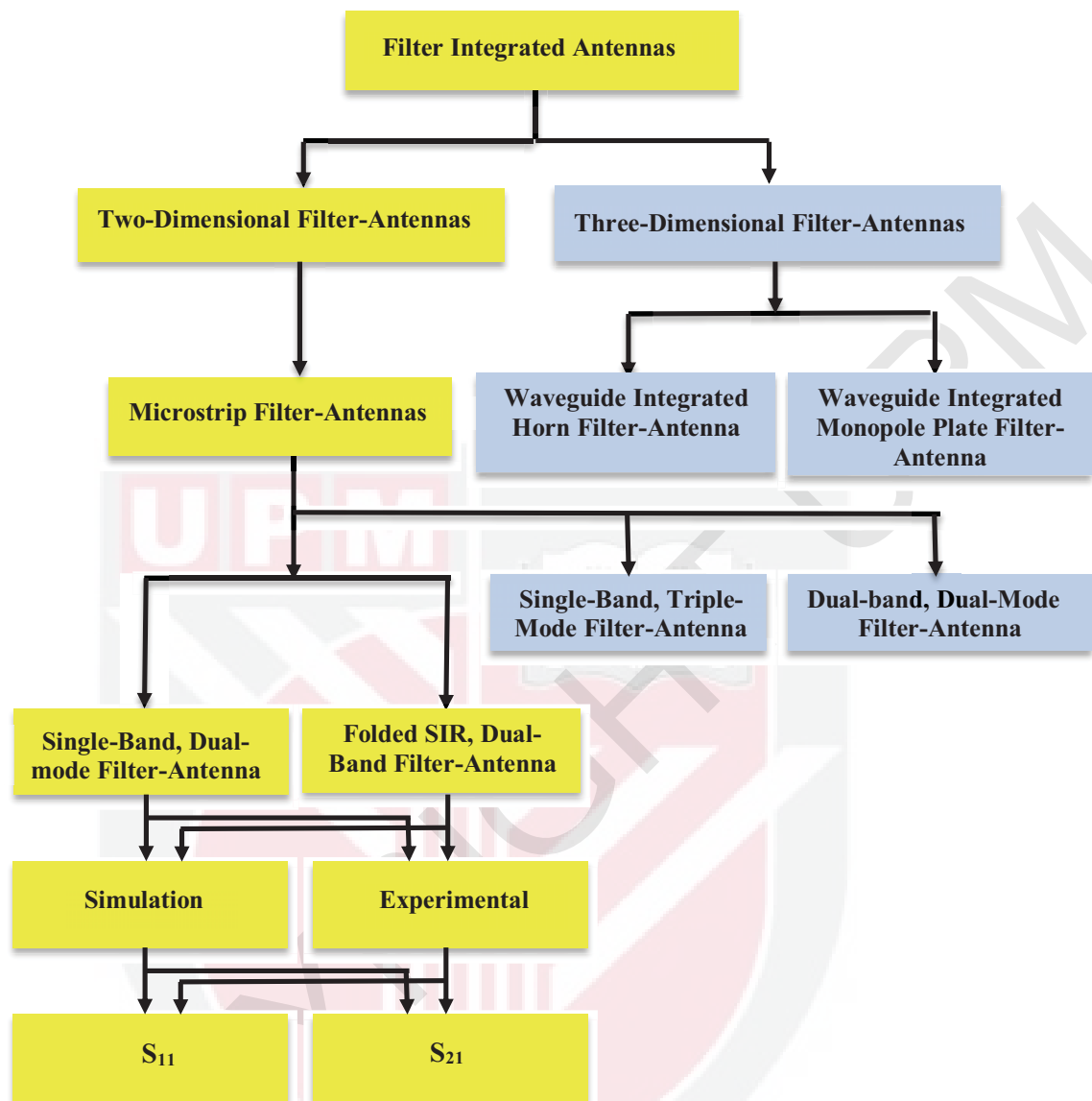


Figure 1.1 : Thesis scope

1.6 Thesis Organization

This thesis is arranged into five chapters, each one is summarized as follows Chapter 1 covers a general introduction to the research study and distinguishes the existing problems in designing the filter-antennas. It also presents the problem statement and motivation of the study, the aim, and objectives, scope of research as well as the organization of the thesis.

Chapter 2 is the literature review. It first gives a background of the filter network theory, which includes the transfer function of the linear system, scattering parameters of the two-port network, filter classifications. It also focuses on the filters, which are

based on maximally flat function response and Chebyshev function response. It introduces the frequency transformation and a realization of filters in a microstrip transmission line with some of the design examples. This chapter includes a review and background of a microstrip patch antenna and presents some design examples for different types of patch antennas. Finally, chapter 2 introduces a background and review of microstrip filters integrated microstrip antennas and some of the techniques, for designing filter-antenna. In addition, it presents some of the design examples for different types of filter-antennas for various frequency band applications.

Chapter 3 contains the research methodology and materials that have been performed in the synthesis and design of microstrip single-band and dual-band filter-antennas. It includes the main contribution of this research, which is the design methodology for two new compact microstrip filter-antennas using a new structure of dual-mode resonators and folded SIR resonators. The design procedure steps include choosing the substrate, calculation of some typical parameters and optimized dimensions of the single-band and dual-band filter-antennas.

Chapter 4 is devoted to the results and discussion. All simulated and measured many results of the single-band; dual-mode filter-antenna and the dual-band filter-antenna are stated and compared to prove the validity of the method. It includes the research outcomes and the achievements of the research objectives.

Chapter 5 is the conclusion of the entire thesis that can be acquired from the results of this study. It is followed by the discussion of the main contribution of this study. Finally, possible ideas for future work are proposed.

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