FREQUENCY AGILE ANTENNA INTEGRATED WITH BAND PASS FILTER

AHMAD MARWAN BIN MOHAMAD DAHLAN

UNIVERSITI TEKNOLOGI MALAYSIA
FREQUENCY AGILE ANTENNA INTEGRATED WITH BAND PASS FILTER

AHMAD MARWAN BIN MOHAMAD DAHLAN

A thesis is submitted in fulfilment of the requirements for the award of the degree of Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2013
To my beloved parents Mohamad Dahlan Omar and Norlida Nordin,
my lovely wife and daughter
and finally my cherished siblings.
ACKNOWLEDGEMENT

In the Name of ALLAH The Most Benevolent, The Most Merciful

Alhamdulillah, praise be to ALLAH s.w.t to Whom we seek help and guidance and under His benevolence we exist and without His help this project could not have been accomplished.

I would like to express my deepest appreciation and gratitude to my supervisor, Dr Muhammad Ramlee bin Kamarudin, for all the support, guidance and time he given to me during my research. I am most thankful to my family members especially my parents and fiancé for their nonstop encouragement. Not to be forgotten my fellow researches in wireless technology, Norsiha, Rajaei, Musyidul Izdam, Arsany, Zairil, Faizal and Amirudin for the knowledge and help they share. Not to be forgotten all Wireless Communication Centre (WCC, FKE UTM) members (staffs and research students) for their readiness to lend a hand in time of need. Finally, thank you to all who has contributed to this research directly and indirectly.
ABSTRACT

In the era of wireless communication, new problem arises when user’s attention increases together with new development of wireless applications. The limited frequency spectrum, which allows only one application to operate at the same time and frequency, has created resource issue for the wireless communication industry. Hence, new frequency agile technologies such as Software Define Radio and Cognitive Radio systems are being developed. One of the requirements of this type of application is an antenna system that is able to change its operating frequency as instructed by the back end system. This research explores the possibility of integrating band pass filters to manipulate the operating frequency of a broadband antenna. RF diode, inductors and capacitors are used as switching mechanism to actively change the operating frequency. Based on the spectrum allocation in Malaysia, frequency range from 1GHz to 6GHz was chosen due to the allocation of many types of communication applications such as mobile applications, unlicensed band and satellite communication. A proof of concept was done for active switching at 1.3GHz and 2GHz of the antenna prototype. Another structure was fabricated to implement frequency reconfigurability operation at 1.3GHz, 2GHz, 3GHz, 4GHz, 5GHz and 6GHz using copper strips instead of active elements. Simulated and measured results showed good agreement for 1.3GHz – 2GHz active switching prototype while 1.3GHz – 6GHz copper strip prototype shows minor shifts and degradation at high frequencies in measured result. From the data collected in this research, band pass filter integrated antenna shows high potential to be used as frequency agile antenna with active switching capability. The results from simulation and measurement of fabricated structures are analyzed and discussed in detail in this thesis. This research contributes to the development of frequency agile antenna design for future frequency agile application.
ABSTRAK

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td></td>
<td>xvi</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td></td>
<td>xvii</td>
</tr>
<tr>
<td>LIST OF APPENDIX</td>
<td></td>
<td>xviii</td>
</tr>
</tbody>
</table>

1 INTRODUCTION

1.1 Background

1.2 Problem Statement

1.3 Objectives

1.4 Scope of Work

1.4.1 Literature Review

1.4.2 Structure Design, Modification, Simulation and Optimization

1.4.3 Antenna Fabrication

1.4.4 Structure Testing and Measurement

1.5 Thesis Outline
## THEORY AND LITERATURE REVIEW

### 2.1 Antenna

- 2.1.1 Basics
- 2.1.2 Types of Antenna
- 2.1.3 Performance Enhancement on Printed Antennas

### 2.2 Microwave Filter

- 2.2.1 Printed Band Pass Filter

### 2.3 Reconfigurable Antenna

- 2.3.1 Frequency Reconfigurable Antenna

### 2.4 Frequency Agile Applications

### 2.5 Related Work in Frequency Reconfigurable Antenna and Filter

- 2.5.1 Two Port Frequency Reconfigurable Antenna For Cognitive Radio
- 2.5.2 A Dual Port Wide-Narrowband Antenna for Cognitive Radio
- 2.5.3 Implementation of UWB Antenna with Bandpass Filter using Microstrip-to-CPW
- 2.5.4 Electronically Switchable Dual-Band Microstrip Interdigital Bandpass Filter for Multistandard Communication Application

## METHODOLOGY

### 3.1 Introduction

### 3.2 Design Specifications

### 3.3 Considerations and Limitations

### 3.4 Materials and Components

### 3.5 Procedures

- 3.5.1 Simulation
- 3.5.2 Fabrication
4 ANTEenna and Band Pass Filter

4.1 Introduction

4.2 Antenna Design

4.2.1 Glass-Shaped Printed Monopole

4.2.2 U-Shaped Printed Monopole

4.2.3 Shorted Circular Patch Printed Monopole with Steps

4.3 Antenna Performance and Discussion

4.4 Filter Design

4.4.1 1.3GHz and 2GHz Interdigital Band Pass Filter

4.4.2 3GHz and 4GHz Interdigital Band Pass Filter

4.4.3 5GHz and 6GHz Interdigital Band Pass Filter

4.5 Interdigital Filters Results and Discussions

5 Antenna Integrated With Band Pass Filter

5.1 Introduction

5.2 Antenna Integrated with Band Pass Filter

5.3 Antenna Integrated with Band Pass Filter Results and Discussions

5.3.1 Return Loss Analysis

5.3.2 Radiation Pattern Analysis

5.3.3 Surface Current Plot

6 Conclusion and Recommendations

6.1 Conclusion

6.2 Recommendation for future research
REFERENCES 76
Appendix A: Diode Biasing Circuit 79
<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Summary, advantages and room for improvement</td>
<td>24</td>
</tr>
<tr>
<td>2.2</td>
<td>Summary, advantages and room for improvement for dual port dual antenna design</td>
<td>26</td>
</tr>
<tr>
<td>2.3</td>
<td>Summary, advantages and room for improvement for antenna integrated with fixed BPF</td>
<td>28</td>
</tr>
<tr>
<td>2.4</td>
<td>Summary, advantages and room for improvement for frequency reconfigurable interdigital band pass filter</td>
<td>31</td>
</tr>
<tr>
<td>4.1</td>
<td>Parameters for the 1.3GHz and 2GHz filter</td>
<td>49</td>
</tr>
<tr>
<td>4.2</td>
<td>Parameters for the 3GHz and 4GHz filter</td>
<td>51</td>
</tr>
<tr>
<td>4.3</td>
<td>Parameters for the 5GHz and 6GHz filters</td>
<td>52</td>
</tr>
<tr>
<td>5.1</td>
<td>Wavelengths at specific frequencies</td>
<td>58</td>
</tr>
<tr>
<td>5.2</td>
<td>List of activated switches for each frequency</td>
<td>61</td>
</tr>
<tr>
<td>5.3</td>
<td>Simulated gain of finalized structure</td>
<td>70</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Return loss versus frequency graph</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>E-Plane radiation pattern</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>H-Plane radiation pattern</td>
<td>10</td>
</tr>
<tr>
<td>2.4</td>
<td>3D plot of radiation pattern</td>
<td>11</td>
</tr>
<tr>
<td>2.5</td>
<td>Conventional shapes of patch antennas</td>
<td>12</td>
</tr>
<tr>
<td>2.6</td>
<td>Basic structure of monopole (a,b) and dipole (c) antenna</td>
<td>12</td>
</tr>
<tr>
<td>2.7</td>
<td>Parabolic dish antenna for satellite communication</td>
<td>12</td>
</tr>
<tr>
<td>2.8</td>
<td>A circular printed monopole with slots and steps. (a) antenna structure (b) surface current distribution at 4GHz (c) surface current distribution at 6GHz (d) surface current distribution at 9GHz [12]</td>
<td>14</td>
</tr>
<tr>
<td>2.9</td>
<td>Types of filter</td>
<td>15</td>
</tr>
<tr>
<td>2.10</td>
<td>Low pass filter configurations. (a) T-Network (b) $\pi$-Network</td>
<td>16</td>
</tr>
<tr>
<td>2.11</td>
<td>High pass filter configurations. (a) T-Network (b) $\pi$-Network</td>
<td>16</td>
</tr>
<tr>
<td>2.12</td>
<td>General configuration of end-coupled microstrip bandpass filter</td>
<td>17</td>
</tr>
<tr>
<td>2.13</td>
<td>General structure of parallel-coupled microstrip bandpass filter</td>
<td>17</td>
</tr>
<tr>
<td>2.14</td>
<td>General configuration of interdigital bandpass filter</td>
<td>18</td>
</tr>
<tr>
<td>2.15</td>
<td>A design of frequency retuneable square ring patch antenna</td>
<td>20</td>
</tr>
<tr>
<td>2.16</td>
<td>Dual band reconfigurable CPW patch antenna with MEMs</td>
<td>20</td>
</tr>
<tr>
<td>2.17</td>
<td>Antenna and filter design</td>
<td>23</td>
</tr>
</tbody>
</table>
2.18 Transmission loss with varying slot gap width 23
2.19 Narrow band return loss 23
2.20 Very wide band return loss 24
2.21 Dual port and dual antenna design 25
2.22 Return Loss of Dual port and Dual Antenna Design: a) UWB Antenna, b) Narrow Band Antenna 25
2.23 Overall structure of antenna integrated with fixed BPF 27
2.24 Components of antenna integrated with fixed BPF: a) UWB antenna, b) BPF with band reject 27
2.25 Return loss of antenna integrated with fixed BPF: a) UWB antenna, b) BPF with band reject, c) simulated and measured results for whole structure 28
2.26 “Near Frequency” reconfigurable interdigital BPF: a) filter design, b) return loss while switch is “ON” and “OFF” state 30
2.27 “Far Frequency” reconfigurable interdigital BPF: a) filter design, b) return loss while switch is “ON” and “OFF” state 30
3.1 Flow chart of the overall project activities part 1 32
3.2 Structure of FR4 Board 34
3.3 UV Mask using transparency 36
3.4 UV exposure device 36
3.5 Developing image on FR4 board 36
3.6 Removing unwanted part of copper layer 37
3.7 Agilent E5071C-2K5 2-port VNA 38
4.1 Glass-shaped printed monopole antenna 41
4.2 U-shaped printed monopole antenna 42
4.3 Shorted circular printed monopole antenna: a) front side, b) back side 44
4.4 Simulated Return Loss (dB) versus frequency (GHz) for Glass-Shaped, U-Shape and Shorted-Circular patch printed monopole 45
4.5 Simulated and measured Return Loss (dB) versus 46
frequency (GHz) for Shorted-Circular patch printed monopole
4.6 Simulated radiation pattern 3D plot at 2GHz: a) Glass-Shape Antenna, b) U-Shape Antenna, c) Shorted-Circular Patch Antenna
4.7 1.3GHz and 2GHz frequency reconfigurable interdigital filter design
4.8 1.3GHz and 2GHz frequency reconfigurable interdigital filter parameters
4.9 3GHz and 4GHz frequency reconfigurable interdigital filter design: a) 3GHz, b) 4GHz
4.10 Basic structure of interdigital filter for 5GHz and 6GHz operation
4.11 Simulated and measured Return Loss (dB) versus frequency (GHz) for Filter A with diode “On”
4.12 Simulated and measured Return Loss (dB) versus frequency (GHz) for Filter A with diode “Off”
4.13 Simulated and measured Return Loss (dB) versus frequency (GHz) for Filter B, Filter C and Filter D
5.1 Block diagram of final structure
5.2 Top layer of finalized structure with transmission line dimensions
5.3 Top layer of integrated structure with switch numbering
5.4 Bottom layer of integrated structure
5.5 Integrated structure prototype: a) Top layer, b) Bottom layer
5.6 Simulated Return Loss versus frequency for antenna integrated with band pass filter
5.7 Measured Return Loss versus frequency for antenna integrated with band pass filter
5.8 Simulated and measured return loss versus frequency of finalized structure at 1.3GHz
5.9 Simulated and measured return loss versus frequency of finalized structure at 2.0GHz
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.10</td>
<td>Simulated and measured return loss versus frequency of finalized structure at 3.0GHz</td>
</tr>
<tr>
<td>5.11</td>
<td>Simulated and measured return loss versus frequency of finalized structure at 4.0GHz</td>
</tr>
<tr>
<td>5.12</td>
<td>Simulated and measured return loss versus frequency of finalized structure at 5.0GHz</td>
</tr>
<tr>
<td>5.13</td>
<td>Simulated and measured return loss versus frequency of finalized structure at 6.0GHz</td>
</tr>
<tr>
<td>5.14</td>
<td>Simulated radiation pattern for finalized structure: a) 1.3GHz, b) 2.0GHz, c) 3.0GHz, d) 4.0GHz, e) 5.0GHz, f) 6.0GHz</td>
</tr>
<tr>
<td>5.15</td>
<td>Simulated surface current for integrated structure at 1.3GHz</td>
</tr>
<tr>
<td>5.16</td>
<td>Simulated surface current for integrated structure at 2GHz</td>
</tr>
<tr>
<td>5.17</td>
<td>Simulated surface current for integrated structure at 3GHz</td>
</tr>
<tr>
<td>5.18</td>
<td>Simulated surface current for integrated structure at 4GHz</td>
</tr>
<tr>
<td>5.19</td>
<td>Simulated surface current for integrated structure at 5GHz</td>
</tr>
<tr>
<td>5.20</td>
<td>Simulated surface current for integrated structure at 6GHz</td>
</tr>
</tbody>
</table>
LIST OF SYMBOLS

\( \varepsilon_{\text{eff}} \) - Effective Dielectric Constant
\( \varepsilon_r \) - Dielectric Constant
h - Substrate Thickness
W - Width
L - Length
\( f_r \) - Resonant Frequency
\( v_0 \) - Free-space Velocity of Light; \( 3 \times 10^8 \)
\( \Delta L \) - Length extension
\( \lambda_0 \) - Wavelength
\( f_H \) - Higher Operating Frequency
\( f_L \) - Lower Operating Frequency
a - Radius of sphere
\( \eta_a \) - Efficiency of ESA
Rr - Radiation Resistance
Rm - Material Loss Resistance
\( \eta_s \) - Efficiency of system
\( \eta_{\text{m}} \) - Efficiency of matching network
Tx - Transmitter
Rx - Receiver
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR</td>
<td>Cognitive Radio</td>
</tr>
<tr>
<td>SDR</td>
<td>Software Defined Radio</td>
</tr>
<tr>
<td>GHz</td>
<td>Giga Hertz</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial Scientific Medical</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>TV</td>
<td>Television</td>
</tr>
<tr>
<td>FR4</td>
<td>Flame Retardant 4</td>
</tr>
<tr>
<td>MHz</td>
<td>Mega Hertz</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
<tr>
<td>BW</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>CPW</td>
<td>Co-planar Waveguide</td>
</tr>
<tr>
<td>SMA</td>
<td>SubMiniature version A</td>
</tr>
<tr>
<td>IF</td>
<td>Interdigital Filter</td>
</tr>
<tr>
<td>UWB</td>
<td>Ultra Wide Band</td>
</tr>
<tr>
<td>dB</td>
<td>Decibel</td>
</tr>
<tr>
<td>LPF</td>
<td>Low Pass Filter</td>
</tr>
<tr>
<td>BPF</td>
<td>Band Pass Filter</td>
</tr>
<tr>
<td>HPF</td>
<td>High Pass Filter</td>
</tr>
<tr>
<td>BSF</td>
<td>Band Stop Filter</td>
</tr>
<tr>
<td>CST</td>
<td>Computer Simulation Technology</td>
</tr>
<tr>
<td>VNA</td>
<td>Vector Network Analyzer</td>
</tr>
<tr>
<td>MEMs</td>
<td>Microelectromechanical Systems</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
</tbody>
</table>
# LIST OF APPENDIX

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Diode Biasing Circuit</td>
<td>79</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

Research background, problem statement, objective of the research, scopes of the project and thesis outline is presented in this chapter.

1.1 Background

The emergence of reconfigurable antennas has enabled wireless communication industry to expand wireless technology and system complexity. Reconfigurability in frequency has enable multi operating frequency while antenna with beam steering capability able to focus the antenna coverage towards desired location. Cognitive Radio (CR) and Software Defined Radio (SDR) are two examples that uses multiple operating frequency [1-2]. The purpose of these technologies is to increase the utilization of the available frequency spectrum hence enabling the network to have larger capacity.

Generally, the spectrum can be classified into two categories, the license and unlicensed band. The unlicensed band or the ISM band (Industrial, Science and
Medical) which is 2.4 GHz and 5.8 GHz are usually used by various short range wireless consumer products such as WiFi, Bluetooth, wireless mouse, keyboard and other wireless user interface [3]. The free ISM band suffers from high spectrum occupancy due to the number of users that would create interference even though various techniques such as frequency hopping and code division multiple access have been applied.

On the other hand, the licensed band could only be use by the company that pays for the certain frequency range. Example of such band is the GSM band, TV band, armature radio band and Satellite bands [3]. These bands are not usually being utilized all time. In some cases, the bands would be used periodically and in some scenario, the band would be occupied only once a year in a small area.

Currently, CR has gained attention from researchers around the world to develop the system as it is hoped to be the solution to spectrum insufficiency problem. There are no standards presently set for CR but some of the researchers are focusing on the TV band while others set their own operating frequency range [4]. In Malaysia, the Multimedia and Communication Commission (MCMC) has allocated 1GHz to 6GHz of the spectrum to applications such as mobile communication, satellite communication and ISM [3]. Some of these applications will not always use the frequency allocated for them or their coverage are small. It is suitable for unlicensed applications such as SDR and CR to temporary occupy the licensed band. Hence, the frequency range from 1GHz to 6GHz was chosen as the frequency range for this research.

One of the most important components in a wireless system is the antenna. A good antenna ensures the coverage area specification is met as well as the signal power and quality. For frequency agile application, new types of antenna need to be designed since the concept of dynamic operating frequency in this system requires the antenna to operate at broad bandwidth for scanning process as well as narrow bandwidth for the data transfer process [5].
In this research, a broadband antenna were designed from conventional circular patch antenna by implementing bandwidth enhancing techniques such as shorting pin, slot and steps. The designed broadband antenna will be integrated with filters to limit and control the operating frequency. A proof of concept was done by integrating the broadband antenna with a dual frequency band pass filter operating at 1.3GHz and 2GHz. RF diodes were used as switches to manipulate the filter stub length for narrow band operation. Another structure was also fabricated to incorporate four band pass filter for narrow band operation at 1.3GHz, 2GHz, 3GHz, 4GHz, 5GHz and 6GHz. Copper strips were used instead of RF diodes for the second structure. However, by integrating multiple filters to the antenna, the overall structure will be larger and the complexity in fabrication will also increase.

1.2 Problem Statement

Spectrum is a scarce recourse in wireless communication world. Nowadays, most of the available spectrum has been assigned to specific applications, the only free band to be used by general consumer is the ISM bands. A lot of application such as Bluetooth and WiFi that operates in small coverage areas share the ISM bands. In some areas such as highly populated cities, the number of ISM band users is high which would cause interference between the users. This fact calls for a solution to avoid further disturbance in the wireless service as more users will use the services each coming day.

Antennas need to be designed for each application so that it could deliver the signal to its best. Moreover, compact antenna is highly desirable in modern society where everything is preferred to be mobile, small and light weighted. For frequency agile applications, the antenna should not only meet the expectation of normal antennas, it should also be able to reconfigure its operating frequency on demand by the back end system. Additional requirement for CR system is the antenna should
also be able to operate at broad bandwidth so that it could detect “holes” in the spectrum. The antenna and system development of Cognitive Radio (CR) are still in early stage. Some prototype antenna designs published in papers, conferences and journals can be use as reference in designing future antennas for CR.

1.3 Objective

- To design a frequency reconfigurable antenna for frequency agile applications.
- To design band pass filters to be integrated with a broadband antenna that will limit and determine the operating frequency of the antenna.
- To analyze the performance of the structure designed in terms of bandwidth, operating frequency, return loss and gain.

1.4 Scopes of Work

This research involves four scope of work, which begins with literature review, followed by structure design process, fabrication and measurement.
1.4.1 Literature Review

Some reviews from previous works that have been done on the design of reconfigurable antenna specifically for CR.

1.4.2 Structure Design, Modification, Simulation and Optimization

Several structures of antenna integrated with filters were designed which are reconfigurable, compact and suitable for frequency agile application. The structure of the antennas will be planar on the FR4 dielectric substrate. The design will include an antenna simulations and optimizations using CST Design Studio.

1.4.3 Antenna Fabrication

The designed and simulated antennas were fabricated on the dielectric material (FR4 substrate). Implementation of RF diodes and SMA connectors will be conducted in this stage.
1.4.4 Structure Testing and Measurement

The fabricated structures were measured at different frequencies ranging from 1GHz to 6GHz. The return loss of the reconfigurable antenna will be measured at all possible configuration. The measured and simulated results will be compared for further optimization purpose until a finalized design is obtained.

1.5 Thesis Outline

The thesis consists of seven chapters starting with introduction which explains the background, problem statement, scope of work and objectives of this research. In Chapter 2, fundamental theories on antenna and filter design are explained as well as review on previous researches that are related to this research. The methodology, considerations and limitations involved in this research are discussed in Chapter 3. Chapter 4 explains the design of the antenna and filter prototypes in detail which includes all measurements and functions. Results obtained from simulation and measurement for antenna and filter designed are also analyzed this chapter. Chapter 5 explains about the design of integrated structure. The simulated and measured results of the integrated structure are discussed as well as comparison on performance between stand alone structure and integrated structure. Discussions are focused on return loss as this affects the operating frequency. Conclusion of the research and recommendations on future research are stated in Chapter 6.
REFERENCES


10. www.wikipedia.com


