

**COMPACT MICROWAVE HAIRPIN LINE BAND PASS FILTER USING
FOLDED QUARTER-WAVE RESONATOR**

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**For my Mom, Wife, beloved son Akmal Safiy, my little angels Nina, Harith, Irsya,
Amirul, Ilham and Sara. To Ajan, Kak Jie, Aca, Kak Nim and Ayu...**

I am wealthy beyond measure because I have you all around



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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ABSTRACT

Compact microwave hairpin band pass filter using half-wavelength folded resonator as a method to miniaturize resonator structure has been thoroughly studied in this thesis. Design were done by using the mathematic formulas and verified by using *SONNET LITEPlus* 8.0 software. Synthesis of the filter is using the insertion loss method. The initial design of a miniature hairpin filter was achieved by carefully selecting the resonator shape and the initial frequency. The shape was then fine tuned, and the response for the changes was plotted. This would indirectly represent the behavior of the circuit when parameter variation occurs. The step by step procedure to design the filter is presented. The design performance and characteristics in terms of electrical and physical parameters were compared with the conventional hairpin filter. The final design of the miniaturized hairpin filter has an overall size of 46% smaller compared to the conventional hairpin size. Better return loss properties were also observed from the miniaturized version. The first spurious frequency occurs at a higher frequency compared to that of the conventional hairpin filter. It is tunable depending on the value of the even-mode impedance that was chosen at the early stage of the design process. The bandwidth, however, was slightly narrower, which is 80% of the desired 100 MHz. In terms of the response, miniaturized hairpin filter is having steeper skirting. However, it is comparable to that of the conventional hairpin filter.

ABSTRAK

Rekabentuk akhir penapis pin rambut model kecil mempunyai saiz keseluruhan yang 46% lebih kecil berbanding saiz pin rambut konvensional. Ciri kehilangan kembali yang lebih baik diperolehi. Frekuensi spurious pertama wujud pada nilai yang lebih tinggi. Ini pula boleh dilaraskan bergantung kepada nilai galangan mod genap yang telah dipilih pada peringkat awal proses rekabentuk. Walaubagaimanapun, lebar jalur adalah sempit sedikit iaitu 80% daripada lebarjalur yang dikehendaki iaitu 100 Mhz. Cerun sambutan pula lebih curam. Namun, ini sebanding dengan penapis pin rambut konvensional.



CONTENTS

CHAPTER	ITEM	PAGE
	TITLE PAGE	i
	TESTIMONY	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT (ENGLISH)	v
	ABSTRAK (MALAY)	vi
	CONTENT	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiv
	LIST OF APPENDICES	xvi
CHAPTER I	INTRODUCTION	1
	1.1 Project Objective	2
	1.2 Project Scope	2
	1.3 Project Motivation	3
	1.4 Layout of thesis	3

CHAPTER II	BANDPASS FILTER THEORIES	4
2.1	Scattering parameter (S-Parameter)	4
2.2	Synthesis technique	7
2.3	Filter response	8
2.4	Microstrip bandpass filter	12
2.5	Hairpin filter	14
2.6	Miniaturization	15
2.7	Step impedance resonator (SIR)	15
2.8	Internally coupled SIR	18
2.9	Resonance condition of internal coupled SIR	19
CHAPTER III	METHODOLOGY	27
3.1	Filter Specification	27
3.2	Hairpin line band pass filter	28
3.3	Miniature hairpin line filter	33
3.4	Design consideration	35
3.5	Miniaturize resonator design	36
3.6	SONNET LITE software	41
3.7	MathCAD	43
CHAPTER IV	RESULT AND ANALYSIS	45
4.1	Resonator Design Selection	45
4.2	Initial Frequency Selection	51
4.3	Resonator Final Size and the response	59
4.4	Study of Resonator Behavior	62
4.5	Filter Realizations	65

4.6	Filter Performance to Parameter Variations	66
4.7	Coupling coefficient	67
4.8	Effect of resonator gap to filter bandwidth	70
4.9	Effect of resonator gap to reflection coefficient	74
4.10	Effect of resonator gap to operating frequency	75
4.11	Effect of feed location to bandwidth	75
4.12	Effect of feed location to Q-Value	79
4.13	Effect of feed location to return loss	80
4.14	Effect of feed location to operating frequency	81
4.15	Additional investigation to feed point effect	82
4.16	Final design	84
4.17	Miniature filter and conventional filter comparison	86
CHAPTER V	RECOMMENDATION AND CONCLUSION	90
5.1	Conclusion	90
5.2	Recommendation	92
REFERENCES		95
APPENDICES		97
	Appendices A – G	97 - 118

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Filter Specifications	27
4.1	Dimensions for various initial frequency	52
4.2	Summary of filter's parameter variation to filter's profile	83
4.3	Overall comparison between conventional and miniaturize filter	88



LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Low Pass profile of Chebyshev and Butterworth response	9
2.2	End Coupling bandpass filter	11
2.3	Parallel coupled filter	12
2.4	Hairpin Line Filter	14
2.5	Structural variations of a half-wavelength type resonator	16
2.6	Basic structure of a stripline split-ring resonator	18
2.7	Miniaturized hairpin resonator, Network model, Odd-Mode model Even-mode model	19
2.8	Effect of impedance ratio and length ratio on the fundamental-mode resonant frequency	22
2.9	Effect of impedance ratio and length ratio on the first spurious-mode resonant frequency	25
3.1	Design flow	34
3.2	Folded resonator section	35
3.3	To determine odd mode impedance and length ratio	37
3.4	To determine even mode impedance and length ratio	38
3.5	Characteristic impedance versus transmission line width	39
3.6	Project editor graphical interface	41
3.7	MathCAD professional window work space	44
4.1	Shape comparison of available modified hairpin resonator	45
4.2	Resonator circuit and its response	54
4.3	Resonator circuit with coupled line length of 3.12 mm	54

4.4	Resonator circuit with coupled line length of 3.72 mm	55
4.5	Coupled line length versus frequency	55
4.6	Resonator circuit with coupled gap of 0.02 mm	56
4.7	Resonator circuit with coupled gap of 0.08 mm	57
4.8	Resonator circuit with coupled gap of 0.6 mm	57
4.9	Internal coupled gap versus frequency	58
4.10	Resonator design and response for initial frequency of 4.5 GHz	59
4.11	Resonator design and response for initial frequency of 3 GHz	59
4.12	Resonator design and response for initial frequency of 2.9 GHz	60
4.13	Resonator design and response for initial frequency of 2.8 GHz	61
4.14	Circuit response after optimization	62
4.15	Feed point in the middle of transmission line and the response	63
4.16	Feed point at the top of transmission line and the response	64
4.17	Resonator circuit without internal gap and the response	65
4.18	Resonator arrangement for band pass filter realization	65
4.19	Parameters that affected filter performance	66
4.20	Frequency response of a resonator pair	67
4.21	A pair of resonator with gap size of 0.05 mm	68
4.22	A pair of resonator with gap size of 0.2 mm	68
4.23	A pair of resonator with gap size of 0.35 mm	69
4.24	Relationship between coupling coefficient and resonator gap	70
4.25	Filter with resonator gap of 0.3 mm and the response	71
4.26	Filter with resonator gap of 0.7 mm and the response	71
4.27	Filter with resonator gap of 1 mm and the response	72
4.28	Relationship between bandwidth and resonator gap	73
4.29	Relationship between return loss and resonator gap	74
4.30	Relationship between operating frequency and resonator gap	75
4.31	Feed point locations	76
4.32	Filter response when feed location at lowest feed point	76
4.33	Filter response when feed location at middle feed point	77
4.34	Filter response when feed location at highest feed point	78

4.35	Feed location versus bandwidth	79
4.36	Feed location versus Q-value	80
4.37	Feed location versus reflection coefficient	81
4.38	Feed location versus frequency	81
4.39	Filter response when feed point at random locations	82
4.40	Final circuit design and the dimensions	84
4.41	Circuit response and its spurious frequencies	84
4.42	Enlarged circuit response	85
4.43	Measured bandwidth from simulation	85
4.44	Shape comparison between miniature and conventional filter	86
4.45	Response comparison between miniature and conventional filter	87
5.1	Circuit 1 posses low pass response profile	92
5.2	Circuit 2 posses band stop response profile	93



LIST OF SYMBOLS

BW	-	Bandwidth
C	-	Capacitance
F	-	Fractional bandwidth
f_i	-	Initial frequency
f_o	-	Centre frequency
g	-	Prototype element
h	-	Substrate thickness
IL	-	Insertion loss
I_e	-	Even mode current
I_o	-	Odd mode current
J	-	Admittance inverter
K	-	Coupling coefficient
L_{AR}	-	Ripple factor
n	-	Number of element
P	-	Net power
P_{in}	-	Input power
P_{LR}	-	Power loss ratio
P_r	-	Reflected power
Q	-	Q-value
S	-	Gap size
S_{11}	-	Return loss at port 1
S_{12}	-	Insertion loss from port 2 to 1
S_{22}	-	Return loss at port 2
S_{21}	-	Insertion loss from port 1 to 2

V_e	-	Even mode voltage
V_o	-	Odd mode voltage
W	-	Width
Z_o	-	Characteristic impedance
Z_{oe}	-	Even mode characteristic impedance
Z_{oo}	-	Odd mode characteristic impedance
Z_t	-	Transmission line impedance
ϵ_r	-	Dielectric Constant
ϵ_{eff}	-	Effective dielectric Constant
θ_e	-	Coupled line length of even mode
θ_o	-	Coupled line length of odd mode
θ_t	-	Coupled line length of transmission line
λ	-	Wavelength
λ_g	-	Effective Wavelength



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Procedure to design conventional hairpin line filter	97
B	Relationship between impedance ratio and length ratio during odd-mode resonance	104
C	Relationship between impedance ratio and length ratio during odd-mode resonance	107
D	To determine resonator dimension (Internal couple impedance < transmission line impedance)	110
E	To determine resonator dimension (Internal couple impedance > transmission line impedance)	113
F	Comparison of Chebyshev and Butterworth low pass filter Response	116
G	To estimate width of transmission line	117

CHAPTER I

INTRODUCTION

Band pass filter is widely used in telecommunication system, be it in receiving or transmitting devices, to filter out unwanted frequency. Smaller size and high performance filters are always desired to enhance system performance and to reduce the system cost. There are various ways of designing a filter. The most attractive configuration is planar structure due to its compactness and fairly easy to be manufactured [1]. There has been much research on planar resonators, which is the main component of a planar filter. Examples are parallel-coupled resonator, hairpin resonator, stepped-impedance resonator and miniaturized hairpin resonator. The main purpose of all these studies is to make the filters more compact.

The resonator is the main and basic component of a planar filter, hence it is necessary to properly select the resonator type to ensure the compact size of a filter is maximized. Conventional parallel-coupled filter is too space consuming. Hairpin-line resonator was then introduced to reduce the resonator size and shape [2]. The concepts of miniaturize hairpin resonator was introduced by Sagawa *et al* in 1989 [3]. The brilliant concept integrates lumped element capacitor and the planar resonator to reduce the size further. Therefore, this type of resonator possesses smaller size compared to conventional hairpin. This type of resonator is actually a variation of stepped-impedance resonator. Thus, combining stepped-impedance resonator in conventional hairpin structure has eliminated the need of the lumped-element capacitor and hence enhanced the whole structure. Consequently, this made it more stable in terms of frequency variations.

This thesis presents the concept pioneered by Sagawa *et al* and improved by CM Tsai in developing a miniaturized hairpin resonator that operates at 2.45 GHz, the common frequency for ISM band application. A method to select proper resonator

design is presented. Besides resonator design, filter topology is also taken into consideration. For microwave circuits, parallel-coupled-line and hairpin filters are widely used. These topologies can only be realized by using Chebyshev and Butterworth response. Since miniature hairpin resonator is a modified version of conventional hairpin resonator, the selection of the initial frequency has to be carefully considered. The study of filter parameters and the effect to filter response are also presented. These information is important especially for circuit optimizations.

Finally, SonnetLite Plus [4] software is then used to optimize and simulate the circuits with the aid of MathCAD [5] software for computation of design formulations.

1.1 Project objective

The objective of this project is to design a compact version of hairpin-line resonator configuration operating at 2.45 GHz.

1.2 Project scope

The scopes of the project are:

- i) To modify the conventional hairpin resonator structure into more compact design configuration.
- ii) To simulate the response and compare the results with the conventional hairpin filter in terms of performance and physical size.
- iii) To study circuit behavior in terms of resonator element and in terms of filter configuration.

1.3 Project motivation

The trend of today's telecommunication device is to have high performance but small and handy devices. As people gets busier, electronic devices that allow users to be mobile, has become a necessity. The smaller the size, the easier for them to be carried around. The better the performance, the higher is the reliability. The factor that determines the overall size is the size of the components itself. Hence, if there are ways to reduce component size, this will indirectly compact the overall device appearance. The challenge is to built smaller circuit component but with same material and with minor changes in the manufacturing process and also able to maintain attractive features of the original circuit. One such component is the band pass filter. It is widely used in telecommunications system especially at the receiver and transmitter. Most of electronics components nowadays are made of VLSI technology that make them smaller relative to the band pass filter size that uses microstrip technology. Hence, in order to enhance the overall circuit compactness and integrate them together, compact filter structures have to be designed and developed.

1.4 Layout of thesis

The report consists of five chapters. The first chapter describes the objective, the project scope and project motivation. Chapter two covers theories on filters relevant to this project. This includes S-parameters application in microwave circuits, a brief discussion on the subject and equations concerning the theory were presented. Filter synthesis technique method were described together with discussion on filter response. This chapter also covers theories of resonator miniaturization, hairpin filter realization and characteristics of internal coupled resonator. Design methodology, specification and the discussion on the tools involved for circuit simulation was covered in chapter three. Chapter four discussed the result and analysis of the findings. These include the study of resonator behavior and all parameter variations that affect filter performance. Finally, chapter five covers the project conclusion and discuss in detail on recommendation and possible future work that can be done to enhance the application of miniaturize resonator and improve the performance.

CHAPTER II

BANDPASS FILTER THEORIES

This chapter describes briefly the history, requirements and considerations taken related to the development of a conventional hairpin band pass filter and miniaturized hairpin band pass filter. This includes all the related mathematical formulae and calculations of the responses. The concept of miniaturization is also presented to give clearer idea on how the process is being done.

2.1 Scattering Parameter (S-Parameter)

To characterize a microwave circuit, incident and reflected amplitudes of microwave at any port are referred [6],[10]. The incident and reflected wave amplitudes are normalized so that the square of these variables gives the average power in that wave in the following manner:

Input power at the n th port,
$$P_{in} = \frac{|a_n|^2}{2} \quad (2.1)$$

Reflected power at the n th port,
$$P_r = \frac{|b_n|^2}{2} \quad (2.2)$$

Where a_n and b_n represent the normalized incident and reflected wave amplitude at n th port. Supposed, a two port network is considered. The net power flows into any port is given by:

Net power, P is:

$$P = P_{in} - P_r$$

$$P = \frac{|a_n|^2 - |b_n|^2}{2} \quad (2.3)$$

The relation between incident wave and reflected wave are expressed in term of scattering parameter S_{ij} 's, so:

$$\begin{aligned} b_1 &= S_{11} a_1 + S_{12} a_2 \\ b_2 &= S_{21} a_1 + S_{22} a_2 \end{aligned} \quad (2.4)$$

The physical significance of the S-parameters is described as:

$$S_{11} = \frac{b_1}{a_1}, \text{ when } a_2 = 0$$

This is the reflection coefficient at port 1 when port 2 is terminated with matched load ($a_2 = 0$)

$$S_{22} = \frac{b_2}{a_2}, \text{ when } a_1 = 0$$

This is the reflection coefficient at port 2 when port 1 is terminated with a matched load ($a_1 = 0$)

$$S_{12} = \frac{b_1}{a_2}, \text{ when } a_1 = 0$$

Attenuation of wave traveling from port 2 to port 1.

$$S_{21} = \frac{b_2}{a_1}, \text{ when } a_2 = 0$$

Attenuation of wave traveling from port 1 to port 2.

When considering microwave circuits it is important to express several losses in term of S-Parameter (when the ports are matched terminated). For two ports network, if power fed at port 1 is P_{in} , power reflected at same port is P_r and power out put at port 2 is P_o , the following losses are defined in term of S-Parameter.

$$\begin{aligned} \text{Insertion loss (dB)} &= 10 \log \frac{P_{in}}{P_o} = 10 \log \frac{|a_1|^2}{|b_2|^2} \\ &= 20 \log \frac{1}{|S_{21}|} \\ &= 20 \log \frac{1}{|S_{12}|} \end{aligned} \quad (2.5)$$

$$\begin{aligned} \text{Transmission loss or} &= 10 \log \frac{P_{in} - P_r}{P_o} \\ \text{Attenuation (dB)} &= 10 \log \frac{1 - |S_{11}|^2}{|S_{12}|^2} \end{aligned} \quad (2.6)$$

$$\begin{aligned}
 \text{Reflection loss (dB)} &= 10 \log \frac{P_{in}}{P_{in} - P_r} \\
 &= 10 \log \frac{1}{1 - |S_{11}|^2} \quad (2.7)
 \end{aligned}$$

$$\begin{aligned}
 \text{Return loss (dB)} &= 10 \log \frac{P_{in}}{P_r} \\
 &= 20 \log \frac{1}{|S_{11}|} \quad (2.8)
 \end{aligned}$$

2.2 Synthesis technique

Two most popular techniques of filter synthesizing are *image parameter method* and *insertion loss method* [6]. The insertion loss method gives complete specification of a physically realizable frequency characteristic over entire stop and pass bands. It is the most preferred method for microwave filter design.

The basic design of microwave filters are made from a prototype low pass design. In the insertion loss method, a physically realizable network is synthesized that will give the desired insertion loss versus frequency characteristic. This method consists of the steps below:

- (i) Design of a prototype low pass filter with the desired pass band characteristic.
- (ii) Transformation of this prototype network to the required type filters with the specified center and band-edge frequency.
- (iii) Realization of the network in microwave form using sections of microwave transmission lines whose reactance correspond to those of distributed circuit element.

2.3 Filter Responses

Filter response is defined by its insertion loss or power loss ratio, P_{LR}

$$P_{LR} = \frac{\text{Power available from source}}{\text{Power delivered to load}}$$

This quantity is the reciprocal of $|S_{12}|^2$ if both load and source are matched.

There are three main filter responses approximation, they are:

(a) Butterworth Response

Butterworth response is also known as Maximally flat response. The response is optimum in providing the flattest possible pass-band response for a given order.

The insertion loss characteristic can be represented with formula :

$$IL = 1 + a_m^2 \omega \varpi^{2n}; \quad \text{where } \varpi = \frac{\omega}{\omega_c} \quad (2.9)$$

The Butterworth approximation exhibits a flat response in the pass-band and an increased of attenuation (monotonically) in the stop band. The rate of increase of the insertion loss for $\omega > \omega_c$ depends on the exponent $2n$, which is related to the number of filter order used in the filter network. The response is illustrated in Figure 2.1

(b) Chebyshev Response

The second approximation is Chebyshev response or well known as equal ripple response. As the name specified, Chebyshev response has ripple in the pass-band and stop-band. Compared to Butterworth, the insertion loss exhibits a much faster increment rate beyond cut off frequency, ω_c . Hence, this response is expected to have steeper skirting properties if compared to Butterworth. The ripple size of Chebyshev response is however controllable. It depends to the application requirement and a designer can specify the desired magnitude of the ripple. It is however related to the number of filter order in the filter system. Approximation of low-pass Chebyshev insertion loss response can be expressed as:

$$IL = 1 + a_m^2 T_n^2(\omega') \quad (2.10)$$

where $\omega' = \omega / \omega_c$ and $T_n^2 = \cos(n \cos^{-1}x)$ for $x \leq 1$ or $\cosh(n \cosh^{-1}x)$ for $x > 1$.

The notation ' n ' denotes the number of reactive element. Comparison of both responses is illustrated in Figure 2.1.

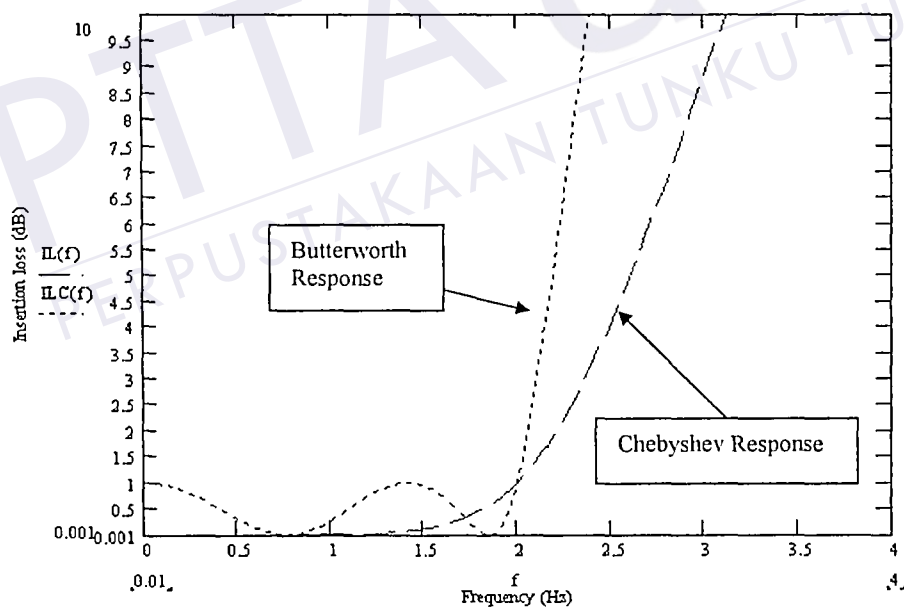


Figure 2.1: Low Pass profile of Chebyshev and Butterworth responses computed from MathCAD.

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