Faculty of Electronic and Computer Engineering

DESIGN AND DEVELOPMENT OF X-BAND HYBRID BANDSTOP FILTERS

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A thesis submitted in fulfillment of the requirement for the degree of Master of Science in Electronic Engineering

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DECLARATION

I declare that this thesis entitle "Design and Development of X-band Hybrid Bandstop Filters" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

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ABSTRACT

This report presents two designs of hybrid BSF for X-band (8 – 12 GHz). The BSF is widely applied in microwave communication such as in radar and satellite. It is used at the RF receiver for protection against strong interference and blocking signals. Furthermore, it is also used to reject high-power signals outside the receiver band and is usually located at the front-end of receiver prior to pre-amplifier. Waveguide filter offers low loss and is well known for high-power and millimeter-wave applications. In contrast, it comes with bulky size, non-planar, hollow structure and high-cost of fabrication process compared to the other planar circuit design. Due to the non-planar structure, it is difficult to integrate waveguide with the other planar circuit. The main focus of this research is to produce hybrid BSF by integrating two planar circuits by using simple microstrip transition. The first design is hybrid notch BSF which consists of two-part of filter network that is integrated with the impedance inverter. SIW BPF is used as a two-port network and impedance inverter is represented by four-port directional coupler. The SIW BPF is initially designed from rectangular waveguide filter. This waveguide BPF is then converted into a planar circuit by implementing the SIW technique. This method reduces the overall size of the filter due to the dimension being inversely proportional to $\sqrt{\varepsilon_r}$ of the substrate. The second design is the hybrid reflection-mode BSF. It is constructed from the same structure of impedance inverter as the previous design, but it is connected to the even and odd-mode of SIW BPF. All simulations have been conducted using the HFSS and ADS software. In order to validate and prove the concept and theory, all simulated designs are fabricated and measured using VNA. The standard PCB with low cost fabrication process is used. Dimension of both filters is quite similar but the hybrid notch BSF produces a lower loss compared to hybrid reflection-mode BSF. Both designs have successfully transformed from BPF (Chebychev response) to BSF (Inverse-Chebychev response). The hybrid notch BSF has an insertion loss of about 3.83 dB and a return loss of 9.1 dB. Meanwhile, the insertion loss and return loss for hybrid reflection mode BSF is 5 dB and 12 dB respectively. This shows that hybrid notch produces lower loss compared to hybrid reflection-mode BSF. The design method also proves that SIW filter can be easily integrated with coupler (planar circuit), using simple transition methods such step impedance, compared to conventional waveguide. Step impedance is used to ensure a field matching between the microstrip line and SIW over a broad bandwidth. Probe feeding transition can be use for integration between waveguide and planar circuit, but it needs a metal short block with a quarter-wavelength on the substrate. This contributes to the complexity of the transition and requires another accessories in order to complete the transition.

ABSTRAK

Laporan ini membentangkan dua reka bentuk BSF hibrid untuk X-band (8.4–12 GHz). BSF digunakan secara meluas dalam komunikasi gelombang mikro seperti dalam radar dan satelit. Ia digunakan pada penerima RF untuk melindungi daripada gangguan yang kuat dan untuk menapis dan menyekat isyarat yang berkuasa tinggi di luar frekuensi penerima. Biasanya diletakkan di bahagian depan penerima sebelum pra-penguat. Penapis pandu gelombang mempunyai 'loss' yang rendah dan terkenal dengan aplikasi untuk kuasa tinggi dan untuk kegunaan gelombang milimeter. Sebaliknya, ia mempunyai saiz yang besar, bukan satah dan struktur yang berongga. Ia juga mempunyai kos yang tinggi untuk proses fabrikasi. Oleh kerana strukturnya yang bukan satah, adalah sukar untuk mengintegrasikan pandu gelombang dengan litar satah lain. Fokus utama di dalam kajian ini adalah untuk menghasilkan 'BSF' dengan mengintegrasikan antara dua satah litar dengan menggunakan peralihan mikrostrip. Reka bentuk yang pertama ialah 'hybrid notch BSF' dan ia menggunakan dua-port rangkaian penapis dan penyonsang impedans. 'SIW BPF' digunakan sebagai dua-port rangkain penapis dan penyonsang impedans diwakili oleh empat-port pegganding arah. 'SIW BPF' pada mulanya di reka daripada penapis pandu gelombang yang berbentuk segi empat. Kemudian ia ditukarkan kepada litar satah dengan menggunakan teknik 'SIW'. Keseluruhan saiz litar dapat dikurangkan kerana kesemua dimensi adalah berkadar songsang dengan $\sqrt{\varepsilon_r}$ substrat. Reka bentuk yang kedua ialah 'hybrid reflection-mode BSF'. Ia terdiri daripada struktur penyonsang impedans yang sama seperti reka bentuk sebelumnya tetapi dihubungkan dengan 'even-and odd-mode SIW BPF'. Kesemua simulasi dilakukan dengan menggunakan perisian HFFS dan ADS. Untuk mengesahkan konsep dan teori, semua reka bentuk yang akan diukur menggunakan VNA. PCB digunakan untuk proses fabrikasi kerana kosnya yang rendah. Dimensi untuk kedua-dua reka bentuk adalah hampir sama tetapi 'hybrid notch' yang dihasilkan mempunyai 'loss' yang kurang berbanding 'hybrid refelction-mode'. Kedua-dua reka bentuk berjaya ditukarkan kepada daripada 'BPF' (penapis 'Chebychev') kepada 'BSF' (penapis songsang-'Chebychev'). 'Hybrid notch' mempunyai 'insertion loss' kira-kira 3.83 dB dan 'return loss' sekitar 9.1 dB. Sementara itu, 'insertion loss' dan 'return loss' untuk 'hybrid reflection-mode' adalah 5 dB dan 12 dB. Selain itu, ia menunjukkan bahawa penapis 'SIW' boleh disepadukan dengan litar satah dengan menggunakan kaedah peralihan langkah impedans yang mudah berbanding dengan pandu gelombang konvensional. Ia digunakan untuk memastikan sepadan bidang antara garis mikrostrip dan 'SIW'. Bagi pandu gelombang ke litar satah, peralihan seperti 'probe feeding' telah digunakan tetapi ia memerlukan satu blok logam pendek dengan suku panjang gelombang pada substrat tersebut. Ini sekaligus menyumbang kepada kerumitan kepada peralihan dan memerlukan aksesori yang lain untuk melengkapkan proses peralihan tersebut.

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LIST OF ABBREVIATIONS

3D	-	3-Dimensional
ADS	-	Advanced Design System
BPF	-	Bandpass Filter
BSF	-	Bandstop Filter
C	-	Coupling
CAD	-	Computer-aided Design
D	-	Directivity
DBS	-	Direct Broadcast Satellite
DGS	-	Defect Ground Structure
DSSR	-	Double Split Ring Resonator
EM	-	Electromagnetic
GPS	-	Global Positioning Satellite
HFSS	-	High Frequency Simulated Structure
I	-	Isolation
ISAR	-	Inverse Synthetic Aperture Radar
L	-	Insertion Loss
LNA	-	Low Noise Amplifier
LTCC	-	Low Temperature Co-fired Ceramics
MCM	-	Multichip Module
MMIC	-	Monolithic Microwave Integrated Circuits
MSL	-	Microstrip Line
NRD	-	Non-radiating Dielectric
NRN	-	Non-resonating Nodes
PA	-	Power Amplifier
PCB	-	Printed Circuit Board
Q	-	Quality

RF	-	Radio Frequency
RX	-	Receiver
S	-	Scattering
SAR	-	Synthetic Aperture Radar
SIW	-	Substrate Integrated Waveguide
SMA	-	Sub-miniature version A
TE	-	Transverse Electric
TEM	-	Transverse Electric & Magnetic
TM	-	Transverse Magnetic
TX	-	Transmitter
UWB	-	Ultra Wide Band
VNA	-	Vector Network Analyzer
WGS	-	Wideband Global SATCOM
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

ω	-	Angular frequency
ω_o	-	Angular at centre frequency
ω_c	-	Angular at centre frequency
ω_p	-	Angular frequency at passband
ω_s	-	Angular frequency at stopband
K	-	Ripple factor
A	-	Amplitude
A_{min}	-	Minimum amplitude
α	-	Attenuation constant
c	-	Velocity of light in free space ($3x10^{8)}$
λ	-	Wavelength
λ_o	-	Wavelength at center frequency
λ_g	-	Guide wavelength
N	-	Number of order/degree
f_o	-	Resonant frequency
f_c	-	Cut-off frequency
f_r	-	Resonant frequency
f_l	-	Low frequency
f_h	-	High frequency
ε_o	-	Permittivity of free space
ε_r	-	Relative permittivity (Dielectric constant)
ε	-	Ripple factor
h	-	Height or thickness

V	-	Voltage
I	-	Current
Z	-	Impedance
Z_o	-	Characteristic impedance
Z_1	-	First impedance
Z_2	-	Second impedance
S	-	S-parameters
S_{11}	-	Reflection coefficient at Port 1
S_{12}	-	Transmission coefficient from Port 2 to Port 1
S_{21}	-	Transmission coefficient from Port 1 to Port 2
S_{22}	-	Reflection coefficient at Port 2
Y_e	-	Even-mode admittances
Y_o	-	Odd-mode admittances
Γ_e	-	Reflection-mode admittances
Γ_o	-	Reflection-mode admittances
L_A	-	Insertion loss
L_R	-	Return loss
θ	-	Phase length (in radian)
ψ	-	Electrical length
ψ_R	-	Electrical length (r = number)
β	-	Phase / propagation constant
B'	-	Susceptance (theoretical)
T_N	-	Function number of order
Z_r	-	Element value
w	-	Real width of SIW cavity
l	-	Real length of SIW cavity
L	-	Shunt inductor
a	-	Width of inside dimension of rectangular waveguide
b	-	Height of inside dimension of rectangular waveguide
Q_U	-	Unloaded quality factor
P	-	Distance between metal posts

k	-	Medium wave number
μ	-	Dielectric permeability
w_{eff}	-	Effective width
l_{eff}	-	Effective length
μ_r	-	Relative permeability
d	-	Diameter of via hole
p	-	Pitch or distance between adjacent vias
w_{siw}	-	Width of SIW
D_{via}	-	Diameter if via hole
S_{vp}	-	Distance two adjacent via hole
E_o	-	Electric field at origin
E_x	-	Electric field at x-axis
E_y	-	Electric field at y-axis
E_Z	-	Electric field at z-axis
H_x	-	Magnetic field at x-axis
H_y	-	Magnetic field at y-axis
H_Z	-	Magnetic field at z-axis

LIST OF PUBLICATIONS

Journal:

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CHAPTER 1

INTRODUCTION

1.0 Background

The rapid changes in broadband personal communications, third and fourth generation mobile, wireless, internet and ultra-wideband systems have created the need for new microwave components with more stringent specifications. Moreover, satellite systems have moved from traditional fixed telecommunications to mobile, navigation and remote sensing applications. Microwave filter is basically a device that is used to discriminate between wanted and unwanted signals within a specified frequency band. The term microwave refers to the frequency range between 300 MHz and 30 GHz.

The filter requirements in terms of selectivity have become more stringent due to the limited available frequency spectrum. Other filter specifications are generally dictated by the intend application. The technological developments have created a more demanding requirement that imposes new challenges to design, optimize and and finally to ensure the realization of these components. In the case of microwave filters, more challenging specifications such as selectivity, bandwidth, phase linearity and compactness are required. The main scope of this thesis is to find new techniques for design, optimization, practical realization and tuning of microwave filters, especially in hybrid BSF. Although the discussion in this thesis is limited to microwave filters, the techniques that are developed can be applied to other resonant microwave components with the necessary modifications.