MINIATURIZED WIDEBAND HYBRID DIRECTIONAL COUPLER USING SLOW WAVE STRUCTURE SND MEANDERING LINES TECHNIQUE

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Specially dedicated to

my friends, and family.

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ABSTRACT

Branch-line coupler is an important element in modern microwave circuit. A more compact and wideband prototype is preferred, since; it lowers the production cost and could operate well in wider bandwidth. However, most conventional branch line couplers consume bigger spacing and operate in narrow bandwidth. In this research, a wideband three-branch line coupler and four-branch line coupler, which are 20.6 % and 50.2 % respectively, compact than conventional couplers, had been miniaturized using Slow Wave Structure (SWS) and Meandering Line (ML) techniques. The cascade method is implemented on conventional coupler for increasing its bandwidth. The fabricated area of modified three-branch line and four-branch line coupler is (1729.9 mm^2) and (1927.8 mm^2), respectively. Both prototypes were fabricated using etching technique. The performance results were obtained using Keysight E5071C VNA (Vector Network Analyzer). Calibration had been done to VNA for all types of measurement. Its important parameters such as return loss $|S_{11}|$, through $|S_{21}|$, coupling $|S_{31}|$ and isolation $|S_{41}|$ are studied for both conventional and modified designs, within the frequency range of 1.0 GHz to 5.0 GHz. The AWR Microwave Office Software is used for simulation, and designing the prototypes using 2.4 GHz as centre frequency, where the operating bandwidth remains at 1.5 GHz to 3.5 GHz. The performance of both prototypes were validated by comparing the simulation and measurement results, where, they show good agreement in *S*-parameters performance similar to the conventional ones, or even better. The modified three-branch line coupler experienced $|S_{11}|$ below -13 dB with operating frequency band of 1.5 GHz, which is 0.1 GHz wider than conventional design performance with 1.4 GHz frequency band, whereas, the modified four-branch line coupler experienced $|S_{11}|$ below -13 dB with operating frequency band of 2.0 GHz, which is 0.6 GHz wider than conventional design performance with 1.4 GHz frequency band. In conclusion, the modified prototypes are more compact, making it make portable and operates well within wider operating bandwidth.

ABSTRAK

Cawangan talian pengganding adalah elemen penting dalam litar gelombang mikro moden. Satu prototaip lebih padat dan jalur lebar telah direkacipta kerana ia merendahkan kos pengeluaran dan boleh beroperasi dengan baik dalam jalur lebar yang lebih besar. Walau bagaimanapun, kebanyakan cawangan talian pengganding konvensional mengambil jarak yang lebih besar dan beroperasi dalam jalur lebar sempit. Dalam kajian ini, tiga cawangan garis talian pengganding dan empat cawangan garis talian pengganding, yang 20.6% dan 50.2% masing-masing, padat daripada pengganding konvensional, telah bersaiz kecil menggunakan Struktur Gelombang Perlahan (SWS) dan teknik garis berliku-liku (ML). Kaedah lata dilaksanakan pada pengganding konvensional untuk meningkatkan jalur lebar. Kawasan prototypaip yang diubahsuai garis tiga cawangan dan empat cawangan garis pengganding adalah (1729,9 mm^2) dan (1927,8 mm^2), masing-masing. Kedua-dua prototaip direka menggunakan teknik punaran. Keputusan pengukuran telah diperolehi dengan menggunakan Keysight E5071C VNA (Vektor Penganalisis Rangkaian). Penentukuran telah dilakukan untuk VNA untuk semua jenis pengukuran. Parameter yang penting seperti kehilangan pulangan $|S_{11}|$ melalui $|S_{21}|$, gandingan $|S_{31}|$ dan pengasingan $|S_{41}|$ dikaji untuk kedua-dua reka bentuk konvensional dan diubah suai, dalam julat frekuensi 1.0 GHz kepada 5.0 GHz. Perisian AWR Microwave Office digunakan untuk simulasi, dan mereka bentuk prototaip menggunakan 2.4 GHz sebagai frekuensi pusat, di mana jalur lebar operasi kekal pada 1.5 GHz kepada 3.5 GHz. Prestasi kedua-dua prototaip telah disahkan dengan membandingkan keputusan simulasi dan keputusan pengukuran, di mana, kedua-dua keputusan menunjukkan perjanjian yang baik dalam keputusan *S*-parameter yang sama dengan prototaip konvensional, atau lebih baik. Prototaip yang diubah suai dengan tiga cawangan mengalami $|S_{11}|$ di bawah -13 dB dengan operasi jalur frekuensi 1.5 GHz, iaitu 0.1 GHz lebih luas daripada prestasi reka bentuk konvensional dengan 1.4 GHz jalur frekuensi, manakala, prototaip yang diubah suai empat cawangan garis pengganding mengalami $|S_{11}|$ di bawah -13 dB dengan operasi jalur frekuensi 2.0 GHz, iaitu 0.6 GHz lebih luas daripada prestasi reka bentuk konvensional dengan 1.4 GHz jalur frekuensi. Kesimpulannya, prototaip yang diubahsuai adalah lebih padat, menjadikannya membuat mudah alih dan beroperasi dengan baik dalam lebar jalur operasi lebih luas.

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LIST OF ABBREVIATIONS

ATL	–	Artificial Transmission Line
AWR	–	Apply Wave Research
BCB	–	Benzo Cyclobutene
CCS CL	–	Complementary-Conducting Strip Coupling Line
ECPW	–	Elevated Coplanar Waveguides
LTCC	–	Low Temperature Co-fired Ceramics
ML	–	Meandering Lines
MMIC	–	Monolithic Microwave Integrated Circuit
MPC	–	Microstrip Printed Circuit
PCB	–	Printed Circuit Board
SWS	–	Slow Wave Structure
TFMS	–	Thin Film Microstrip Lines
TLs	–	Transmission Lines
UHF	–	Ultra High Frequency
VNA	–	Vector Network Analyzer
VHF	–	Very High Frequency

LIST OF SYMBOLS

D	–	Dimensions
$\|S_{11}\|$	–	Return loss
$\|S_{21}\|$	–	Insertion loss
$\|S_{31}\|$	–	Coupling
$\|S_{41}\|$	–	Isolation
$\|S_{21}\|$	–	Insertion loss
S	–	Scattering parameters
$\sim^{2}$	–	Through factor
^{2}	–	Coupling factor
P_1	–	Input power
P_2	–	Through power
P_3	–	Coupled power
P_4	–	Isolated power
C	–	Coupling factor
dB	–	Decibel
Δ¤	–	Phase different
n	–	Number of coupler’s main lines
v	–	Phase velocity
L	–	Inductance per length
C	–	Capacitance per length
λ	–	Electrical wave length
Z_o	–	Characteristic impedances
μ	–	Mikro

μ	–	Normalized frequency
C_s	–	Shunt Capacitor values
C_p	–	Coupling Capacitor values
ε_r	–	Dielectric constant
$\tan \delta$	–	Loss tangent
h	–	Substrate thickness
W	–	Strip width
θ	–	Phase in degree
f_c	–	Center frequency
Δf	–	Operating bandwidth

CHAPTER 1

INTRODUCTION

1.1 Introduction

A hybrid junction is a four port network in which a signal on any one of the ports divides between two out ports with the remaining port being isolated (Rizzi, 1988). The first hybrid junction, known as Magic Tee Junction was developed by (Tyrell, 1947) as shown in Figure 1.1. The hybrid junction was modified by Mumford (1947), and transformed it into slot directional coupler as shown in Figure 1.2. Finally, it was improved again and turned into microstrip directional coupler by Lange (1969), as shown in Figure 1.3.

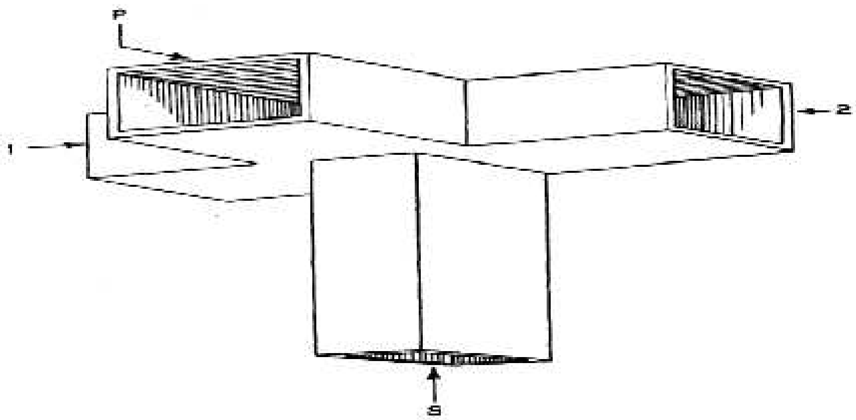
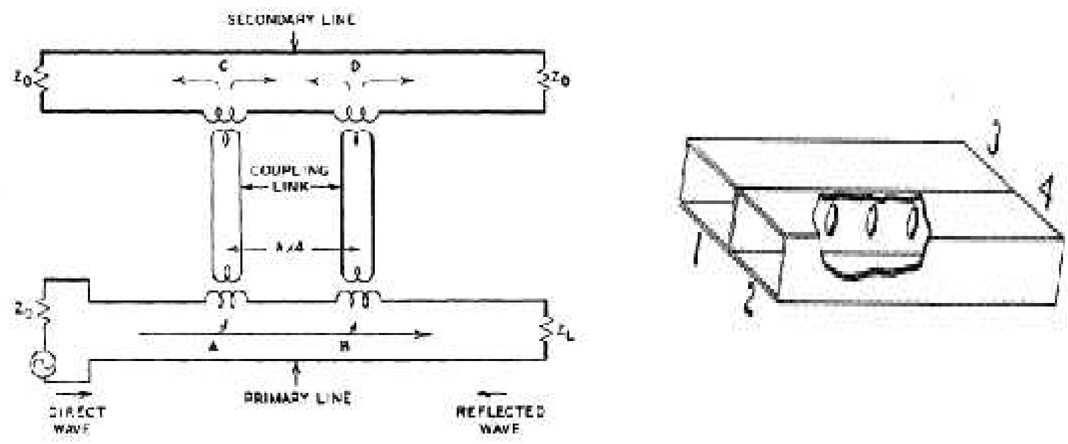


Figure 1.1: The waveguide hybrid junction



(a) (b)

Figure 1.2: Diagram of two-element Directional Coupler

(a) Diagrammatic configuration (b) 3D configuration (Mumford *et al.,* 1947)

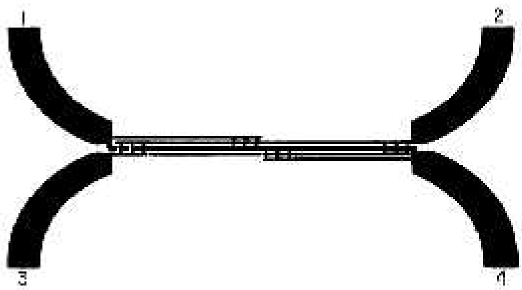


Figure 1.3 Interdigitated 3-dB Coupler (Lange *et al.*, 1969)

1.2 Background of the Problems

In the modern era, the slow wave structure (SWS) was applied by Sun *et al.* (2005) to miniaturize conventional coupler. The performance of its *S*-parameters remains almost the same value as conventional design. However, this approach does not improve its bandwidth, where the operating bandwidth is remaining narrow.

Most research emphasis size miniaturization only in two branch coupler. Sakagawi *et al.* (1997) proposed two branch line coupler miniaturization using eight stubs. Eccleston *et al.* (2003) employing artificial transmission line (ATL) to miniaturize the two-branch coupler. Here, miniaturization is conducted to three branch line coupler and four-branch line coupler using slow wave structure (SWS) and meandering lines technique (ML).

Some researcher did emphasize the miniaturization of three branch line coupler. Chun *et al.* (2005) proposed three branch line coupler using lumped distributed elements. But, its bandwidth is only 1.1 GHz using -13 dB as standard level. In 2012, Nejad proposed a compact three branch line coupler which is 47 percent smaller than conventional one. Even though the size is 47 percent compact, its bandwidth performance is only 1 GHz at – 13 dB, which is consider as narrower band. Chun *et al.* (2006) proposed a compact four branch line coupler modified by using lumped distributed element. However, its bandwidth is only 1.4 GHz.

In this research, the main interest is to design and produce a prototype, which is able to operate in wider operating frequency range (1 GHz - 5 GHz). The purpose is to reduce the power loss, less than – 13 dB or lower during the prototype's operation within a wider operating frequency. Also, a more compact prototype is produced for making it more portable in modern consumer market, by using the slow wave structure (SWS) and meandering lines (ML). Its *S*-parameters performance such as return loss $|S_{11}|$, through $|S_{21}|$, coupling $|S_{31}|$ and isolation $|S_{41}|$, measured in dB (Decibel), remains the same, or, even better than conventional design performance.

1.3 Problem Statement

Conventional branch line coupler has narrow band characteristics and requires larger circuit area in its fabrication process, especially for the coupler which is operating at lower frequency (< 2 GHz). The cascaded method is able to increase the operating bandwidth. However, such method might increase the size of the coupler. It is an undesired scenario in MMIC (Monolithic Microwave Integrated circuit) production, which is requiring a more compact spacing in circuit fabrication.

Also, modern consumers are expecting electrical apparatus that is more portable. Bigger prototype area can also increase its fabrication cost. Hence, the slow wave structures (SWS) and meandering lines (ML) technique are implemented in prototype design in order to solve the above problems. Slow wave structure (SWS) would be able to shortening the coupler branch lines, whereas, and the folding approach of meandering lines could reducing the area occupying by a narrow microstrip lines.

1.4 Objectives of the study

The main objectives of the research are

(1) To develop compact directional couplers, which are modified from three branch line coupler (180 º) and four branch line coupler (270 º).
(2) To design and fabricate a prototype, which is able to operate in wider operating frequency range (1.5 GHz – 3.5 GHz) and lower frequency (1 GHz - 5 GHz).
(3) To miniaturize conventional coupler using slow wave structure (SWS) and meandering techniques (ML) at its branch lines area.
(4) To study the *S*-parameters measured in dB (Decibel) of the prototype for ensuring that the performances of prototypes are validate for wideband operation.

1.5 Scope of the project

In this study, the wideband compact branch line couplers were developed. Three branches and four branches were applied on the quadrature branch line coupler in order to achieve the wider operating bandwidth. A slow wave structure (SWS) and meandering lines (ML) techniques are applied on the branch line parts of the designed couplers in order to miniature the size of the couplers. Both techniques did reduce the area occupied by the fabricated prototype.

The modified prototypes are designed using 2.4 GHz as the center frequency. TX Line program calculator was used to roughly determine the dimensions of the microstrip line of the coupler. A Microwave Office (AWR) simulator was used to re-exam the performance of the couplers with first draft dimensions. From the simulation results, a minor corrections of the dimensions for the couplers have been made to achieve the desired performances with 1.4 GHz bandwidth (Operating frequency: (1.6 GHz to 3 GHz), return loss, $|S_{11}|$ better than –13 dB and its size turns 50 % smaller than conventional branch line couplers. The performance is considered acceptable within the wide operating frequency range (1.5GHz – 3.5 GHz).

The prototypes were fabricated and measured using Vector Network Analyzer (VNA) within the range of 1 GHz to 5 GHz. The measured performance of the prototype couplers were analysis and compared to the simulation results based on the return loss, $|S_{11}|$, insertion loss, $|S_{21}|$, coupling, $|S_{31}|$, isolation, $|S_{41}|$ and phase balance (90º± 2º), respectively for determining its validity. From the results comparison, the simulation and measured results show good agreement even though there is minor deviation of 1 to 5 %.

1.6 Report Organization

This research thesis consists of five chapters overall. Chapter 1 as an introduction, it describes the problem statement, objectives of research, and scope of project. Some background of quadrature hybrid and branch line directional coupler will be discussed.

Next, chapter 2 will describe some basic historical background of directional coupler theory development that leads to development of miniaturize directional coupler. Also, the characteristics of the coupler especially its parameters are described in detail. Besides, various type branch line couplers and approaches of miniaturization are discussing in detail within this chapter.

In chapter 3, it discusses the research process or methodology involved in completing the research project. The design specifications of a conventional coupler and modified coupler will be described in detail. It also includes the design dimensions, process and material specifications used.

Chapter 4 will present a report about the results of the measurement, analysis and discussion of research project. Also, the measurement and evaluation of variables method is analyst and explained. Simulation and measurement results of *S*-parameters, in graph, are also included. The measured results will be used to compare with simulation results. The purpose is to double confirm of its validity.

Finally, chapter 5 summarized all about multi-branch branch line coupler project, objectives achieved and the conclusion of the research project, suggestion of future work and its future prospect.

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