SIX-PORT NETWORK AS COMPLEX RATIO MEASURING UNIT FOR WIRELESS COMMUNICATION SYSTEM

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Dedicated and thankful appreciation to
My beloved husband, Mohd Hilmi Ab. Hamid
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ABSTRACT

The demand of wireless communication usage nowadays is exceeded current network application structures. Many researchers are trying to overcome this problem by performing various studies to find new and better solution compared to available products in the market. One of the devices is a six-port network. The concept of six-port network is applied in the invention of Complex Ratio Measuring Unit (CRMU). In this research, the operating frequency from 2 to 6 GHz is chosen due to the compatibility of CRMU with many applications that operated in that frequency range such as Worldwide interoperabiliy for Microwave Access (WiMAX) and Wireless Local Area Network (WLAN). The operation of CRMU implements six-port network mechanism with two inputs, four outputs and one port is terminated to the matched load. The chosen configuration of CRMU is formed by three 3-dB quadrature couplers and one in-phase power divider. These components are designed individually and integrated on Rogers RO4003C substrate. The design of coupler, power divider and CRMU are obtained based on the microstrip slot multilayer technique. This multilayer microstrip-slot technique consists of three conductive layers sandwiched with two substrate layers. The conductive layer on top and bottom layer are broadside-coupled by slotline formed at the middle layer of common ground plane. This technique allows the designed components to be operated in wideband operating frequency. The design of 3-dB quadrature coupler has three-section rectangular-shaped microstrip with and without additional rectangular stub at the top and bottom layer, and slotline at the ground plane. Meanwhile, in-phase power divider design employs the concept of microstrip-to-slot-microstrip transition with rectangular or circular stub terminating the transmission line. These two designed components are then used to form the CRMU. All designs are simulated using CST Microwave Studio for numerical solution of the electromagnetic fields and fabricated using wet etching technique. Their performances are verified via the measurement using a Vector Network Analyser (VNA). The final design of coupler has measured return loss better than 17 dB, coupling of 3 ± 1 dB, isolation better than 18 dB and phase difference of 90º ± 3º. While, the power divider has measured return loss better than 10 dB and output at Port 2 and Port 3 of 3 ± 0.5 dB. The design of CRMU can modulate information signal into any modulation scheme depending on the termination used at the four output ports. For the case of Quadrature Phase Shift Keying (QPSK) modulation, the output port is connected to short or open termination depending on the modulation state. Therefore, the CRMU can act as a modulator in transceiver application of communication system.

ABSTRAK

Permintaan terhadap penggunaan komunikasi tanpa wayar adalah melebihi jaringan aplikasi sedia ada. Ramai pengkaji cuba mengatasi masalah ini dengan kajian baru yang lebih baik berbanding produk yang ada di pasaran. Salah satu peranti ialah rangkaian enam terminal. Konsep rangkaian enam terminal digunakan di dalam penghasilan Alat Pengukur Nisbah Kompleks (CRMU). Di dalam kajian ini, frekuensi operasi dari 2 hingga 6 GHz dipilih kerana kesesuaian CRMU dengan banyak aplikasi yang berfungsi di dalam rangkaian frekuensi ini seperti *Worldwide interoperability for Microwave Access* (WiMAX) dan *Wireless Local Area Network* (WLAN). Operasi CRMU menggunakan mekanisme rangkaian enam terminal dengan dua input, empat keluaran dan satu terminal dipadankan dengan beban sepadan. Konfigurasi CRMU dibina dari tiga 3 dB pengganding kuadratur dan satu pembahagi kuasa sefasa. Komponen direka secara individu dan dipadukan di atas substrat Rogers RO4003C. Reka bentuk pengganding, pembahagi kuasa dan CRMU menggunakan teknik mikrostrip slot berlapis. Teknik ini terdiri daripada tiga lapisan konduktif dilapiskan dengan dua lapisan substrat. Lapisan konduktif atas dan bawah diganding melintang dengan garisan slot dilapisan tengah satah dasar sepunya. Teknik ini membolehkan komponen-komponen beroperasi dalam frekuensi berjalur lebar. Reka bentuk pengganding kuadratur 3-dB mempunyai tiga seksyen mikrostrip berbentuk segi empat dengan dan tanpa tambahan puntung di lapisan atas dan bawah, dan garisan slot di satah dasar. Manakala, reka bentuk pembahagi kuasa sefasa menggarap konsep peralihan mikrostrip-ke-slot-ke-mikrostrip dengan punting segi empat atau bulatan digunakan untuk menamatkan jalur transmisi. Kedua-dua komponen ini kemudiannya membentuk CRMU. Semua reka bentuk disimulasi menggunakan perisian CST Microwave Studio untuk solusi penomboran medan electromagnet dan difabrikasi mnggunakan teknik goresan lembap. Prestasi reka bentuk diuji dengan menggunakan Penganalisis Rangkaian Vektor (VNA). Reka bentuk akhir pengganding mempunyai nilai ukuran kehilangan pulangan lebih baik dari 17 dB, nilai gandingan iaitu 3 ± 1 dB, nilai pengasingan baik dari 18 dB dan beza fasa 90º ± 3º. Manakala, pembahagi kuasa sefasa mempunyai nilai ukuran kehilangan pulangan lebih baik dari 10 dB dan -3 ± 0.5 dB pada terminal 2 dan 3. CRMU yang di reka bentuk boleh mengatur isyarat maklumat ke skim modulasi berlainan bergantung kepada penamat di empat terminal keluaran. Bagi modulasi Kekunci Anjakan Fasa Kuadratur (CPSK), terminal keluaran disambungkan ke penamat pintas atau buka bergantung kepada keadaan modulasi. Maka, CRMU boleh bertindak sebagai pengatur di dalam aplikasi pemancar-penerima di dalam sistem komunikasi.

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LIST OF ABBREVIATIONS

MICs	-	Microwave Integrated Circuits
MMICs	-	Monolithic Microwave Integrated Circuits
CRMU	-	Complex Ratio Measuring Unit
CAD	-	Computer Aided Device
CST MS	-	Computer Simulation Technology Microwave Studio
ADS	-	Advanced Design System
Q	-	Quadrature coupler
D	-	Power divider
T	-	Complex ratio
SMA	-	SubMiniature version A
QPSK	-	Quadrature Phase Shift Keying
QAM	-	Quadrature Amplitude Modulation
WiMAX	-	Worldwide interoperability Microwave Access
WLAN	-	Wireless Local Area Network
FFT	-	Fast Fourier Transform
PCB	-	Printed Circuit Board
FR-4	-	Fire Retardant-4
IF	-	Intermediate Frequency
S	-	Scattering
MDC	-	Multiport Directional Coupler
VNA	-	Vector Network Analyzer
FIT	-	Finite Integration Technique
PBA	-	Perfect Boundary Approximation
BW	-	Bandwidth
DC	-	Direct Current

CITI	-	Common Instrumentation Transfer and Interchange
IC-CAP	-	Integrated Circuit Characterization and Analysis Program
RF	-	Radio Frequency

LIST OF SYMBOLS

dB	-	decibel
f	-	transmission frequency
BW	-	bandwidth
Z	-	impedance
Δ	-	phase difference
T	-	complex ratio
f_o	-	operating frequency
ΔL	-	fringe factor
L	-	length of meander line
W	-	width
v	-	normalized impedance factor for shorted slot stub
u	-	normalized impedance factor for open microstrip stub
r	-	radius
P	-	power at output ports
q_i	-	circle centres
V	-	voltage

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Complex Ratio Measuring Unit (CRMU) is a device that allows the ratio measurement of the information signals at the two ports. This multi-port network is build from N-port networks where the N should be greater than 5, equipped with scalar power detectors at its output ports. Where, the multi-port network such as six-port is extensively implemented in many applications such as microwave parameter measurements [1-3], phase detectors in positioning systems [4-6], modulators [7-8], radar system [9-10] and wireless communications [11]. Particularly in wireless communication system, this network is widely used in transmitter and receiver system design [12-16]. The opening of an unlicensed low power use spectrum of Ultra wideband (UWB) in 2002 had given high impact to the communication sector. Since then, rapid development had been conducted parallel to the technology invented nowadays.

Other than that, the increment in Internet usage are exceeding the current network structures. A lot of efforts have been done to overcome this problem due to the market demand. One of the solutions is worldwide interoperability for microwave access (WiMAX) which specified by IEEE 802.16e standards [17] that covers 2 to 6 GHz operation bandwidth. As it under metropolitan area network (MAN) access scheme, WiMAX not just offers wide bandwidth but also able to provide access to point-to-point (PTP) and point-to-multipoint (PMP) applications [17].

In RF front-end configuration for microwave applications, an important design characteristic in that system is the mixer based approach. The design of mixer will involve of active devices, which need a certain biasing voltage to be in the active state. In order to reduce the complexity of the design, this mixer based approach can be replaced by Complex Ratio Measuring Unit (CRMU) [12]. CRMU can also be known as complex voltmeter [2] or correlator [3]. It is formed by only passive devices such as coupler, power divider and/or H-hybrid. This device offers the measurement of the complex ratio between two signals which can be used for modulation and demodulation purposes such as quadrature phase shift keying (QPSK) and quadrature amplitude modulation (QAM) [14, 16, 18-19].

As far as this research is concerned, the wideband operation of 2 to 6 GHz is chosen as many applications are operated in this frequency band. Therefore, this CRMU will compatible with the many applications that cover the frequency range of WiMAX (801.16e) and WLAN (802.11n), which include band of 2.3-2.9 GHz, 3.3-3.7 GHz and 4.9-5.9 GHz. Previous bulky, complex and narrowband CRMU had given motivation to design a compact and simple CRMU with low manufacturing cost and have good wideband performance.

In this thesis, a design of CRMU, which consists of three couplers and on in-phase power divider, is presented. The measurement of complex ratio of two signal offered by this device is obtained from the measured powers at four output ports [9]. This proposed CRMU can overcome the bandwidth limitation reported in [12], [13] and [16]. In [12] and [16], they only consider single frequency of 60 GHz and 2.4 GHz, respectively while in [13], it considers the frequency band of 3.1-4.8 GHz. Another design for 3-5 GHz band is reported in [19] which has improved operating

frequency, but the bandwidth is still limited. In order to improve the bandwidth performance, multilayer microstrip-slot technology is used in the design of coupler and power divider constituting the CRMU. The designs of 3-dB coupler, in-phase power divider and CRMU are implemented in CST Microwave Studio. While, the analysis on S-parameter performance to evaluate *q*-points and QPSK constellation is performed using Agilent's Advanced Design System software

1.2 Problem Statement

The development of systems utilizing a wideband spectrum requires the designed components to have the optimum performance, especially for the spectrum with the higher density of applications such as 2.4 GHz and 4.85 GHz. Therefore, a device with wideband features will be designed not only for the dual band but also with wide bandwidth of 2-6 GHz that can cover more frequency operation of applications. Therefore, the market value of the device would be higher and able to provide better expectation. As noted from literature, the CRMU design as [2, 12-13, 16] presents limitation in term of bandwidth. Therefore, this research will be able to overcome the problem of bandwidth limitation.

Another problem in designing CRMU is the size. Conventional coupler and power divider usually large in size and one of the way to reduce the size is by employing the multilayer integration technology like the low temperature co-fired ceramic (LTCC) [2]. LTCC technology is accomplished by employing a rows of metallic vias of the top and bottom in the dielectric substrate [20]. However in this research, the microstrip-slot multilayer technology is used. This multilayer technology promises the size reduction and bandwidth improvement of CRMU as suggested in [13, 20].

The complexity of the transceiver design presented in the previous research had attracted the researchers to design a CRMU with passive device. In literature, there is a design of six-port transceiver using an active device which is field effect transistor (FET) [8]. This FET needs a certain biasing voltage to be in the active state. As the proposed CRMU is formed by only passive devices such coupler and power divider, it provides an alternative solution to the six-port transceiver design without the need to have additional voltage source connected to its individual components. As a result, it will reduce the complexity of the design.

In addition, typical modulation technique which is mixer-based approach is commonly used to modulate or demodulate the signal [21]. The six-port transceiver which is consisted of CRMU can be used to replace the mixer-based design [12]. So, CRMU is an alternative solution to modulate and demodulate signal for example QAM and QPSK modulation schemes without using mixer. This project proposes a compact CRMU for wideband operation that would be an advantage for applications in communication system.

1.3 Objectives of the Research

This research is divided into three objectives. The objectives are as follows:-

1. To design and analyse wideband 3-dB coupler and in-phase power divider, in multilayer microstip-slot technology.
2. To develop the Complex Ratio Measuring Unit (CRMU) using proposed 3-dB coupler and in-phase power divider.
3. To investigate the performance of CRMU in the communication transceiver as a QPSK modulator in a transmitter.

1.4 Research Contributions

This research is started with the design of each individual component. Therefore the contributions of this research are based on individual component and the integrated component which is CRMU. The first contribution is the design of 3-dB coupler with virtual short stub. This coupler is improved from the designed coupler from the previous research by performing the analysis on the effect of virtual short stub at the top and bottom conductive layer of coupler.

The other contribution is the design of in-phase power divider in multilayer microstrip-slot technology with two types of stubs which are rectangular and circular-shaped. The performances of in-phase power divider with different stubs are analysed and the design with better performance is chosen to be integrated with 3-dB coupler to form CRMU.

The next contribution is the Complex Ratio Measuring Unit (CRMU) which is formed by the designed 3-dB coupler and in-phase power divider. The performance of the CRMU is observed and analysed. When the performance of CRMU does not achieve the design goal, the action is to improve the performance of individual component which are 3-dB coupler and in-phase power divider. With improved individual components, the performance of CRMU is expected to be better and meeting the design goal.

Furthermore, the contribution concerns on the investigation of performance as a QPSK modulator in a transmitter. The designed CRMU can modulate the information signal based on modulation state that is controlled by the termination at the four output ports.

1.5 Scopes of Work

The research is started by brainstorming the concept of six-port network that feature a wideband operation and easy for integration. In order to have a device that is easy for integration, the investigation on the architecture of six-port network with suitable performance is carried out.

Firstly, the entire process is divided into two stages, which are software and hardware stage. The software part is responsible for the designing and simulating the devices from a single component to the whole CRMU. This process is the decision stage for this research. The simulated design and the possible process for the hardware must be engaged to avoid any problems during the fabrication/prototyping. This design of the components is using the CST Microwave Studio software and the S-parameter analysis is performed using the ADS Software.

In order to develop a CRMU design, which is formed by coupler and power divider, all the components need to accurately design with the optimum performance. The factor of size and the parameter such as return loss, isolation, coupling and phase difference are highly concerned. The minimal transmission line usage is one of the solutions to ensure the size of the CRMU is compact. CRMU is only formed by passive components which are in planar form. Therefore, it will be easy to integrate them in the system. Meanwhile, the operating bandwidth is chosen based on the WLAN (802.11n) and WiMAX (801.16e) frequency range. The applications density is the factor of the selection of this frequency range in order to grab the potential market.

The process of designing, simulating and optimizing are carried out for the single component of coupler and also power divider. The effect of the virtual stub on the design of coupler and power divider is studied. Other than that, the analysis and the possible improvement are discussed and presented. The design theory and previous reported works are the basis for the outcome of each simulation either the simulation for coupler, power divider or CRMU.

The second part of this research is concerning the prototype development of the designed components from simulation stage. The wet etching technique is used. Since the simulation is using the multilayer structure, the manual procedure is quite constrained. However, the fabrication process is possible with the facilities in this centre. The prototypes are measured using Vector Network Analyzer (VNA) and the results are presented and documented.

1.6 Organization of the Thesis

This section discusses on the thesis organization from the concept until the fabrication procedure, problem statement and the outcomes in later chapter. Chapter 1 presents the introduction of the Complex Ratio Measuring Unit (CRMU), which is one of the devices formed by using the concept of six-port network. The general applications of CRMU are discussed. Other than that, the main objectives and problems to be solved are stated in this chapter. The scope of study is also presented.

Chapter 2 discusses the literature review on the technique and method used in coupler, power divider and CRMU design. Previous works done by other researchers become the motivation to improve the performance of the design. Several solutions and techniques are decided based on the literature. This chapter also sorts out the characteristics of the CRMU and the parameters that been used to specify it.

Chapter 3 explains on the methodology, approach, design goals and research flow from the simulation to the fabrication stage. The concerned parameters for each component are described.

Chapter 4 presents the design of the proposed 3-dB rectangular-shaped coupler and in-phase power divider employing the microstrip-to-slot transition technique using two substrates. This technique is known as multilayer microstrip-slot

technology. The analysis is performed for each design of coupler and power divider. Their good wideband performances are presented in this chapter.

Chapter 5 discusses the combination of coupler and power divider to form complex ratio measuring unit (CRMU). The performance of CRMU is studied and application of CRMU as QPSK modulator is investigated.

Lastly, the conclusion is drawn in Chapter 6. The finding from the study, contributions and recommendations for future works that related to this research will be described. Then, the list of references and appendices are attached at the end of this thesis.

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