COMPACT 8X8 BUTLER MATRIX FOR ISM BAND

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To my beloved parents -

Thanks for the smiles during the darkest days,

Thanks for the warmth during the coldest nights,

Thanks for standing by my side when I’m torn at the seams,

Thanks for understanding my wildest dreams.

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ABSTRACT

Mitigation of interference due to multiple signals coexisting in the same frequency band can be achieved through the implementation of a smart antenna system that employs scanning of multiple and simultaneously available beams. These multiple and simultaneously available beams can be generated through beamforming networks such as the Butler Matrix, of which its design is the focus of this thesis. By employing passive devices in a butterfly layout configuration, a completely planar microstrip 8x8 Butler Matrix to perform in the ISM Band of 2.4 GHz to 2.5 GHz was designed. Recently, research has been focusing on the miniaturization of passive microwave devices and components. Artificial Transmissions Lines is a relatively new method that achieves miniaturization of a transmission line through periodically loading the line capacitively in order to lower the phase velocity characteristic of a high impedance line to an appropriate value. The higher the impedance of the line in question, the greater the level of miniaturization obtained. 40 percent area savings and 59 percent area savings were achieved in the design of the passive component hybrid and crossover structures, respectively, compared to conventional design methods. Through the implementation of 12 hybrids, 8 fixed phase shifters and 16 crossover structures, the final layout of a compact Butler Matrix can be designed. Simulations were performed using *Microwave Office* electromagnetic packages. Design calculations were verified using *MatchCad*.

ABSTRAK

Kesan gangguan yang disebabkan kewujudan pelbagai isyarat pada jalur frekuensi yang sama dapat dikurangkan melalui implementasi sistem antena cerdas yang dapat mengimbas rangkaian pelbagai alur serentak. Rangkaian pelbagai alur serentak ini dapat dihasilkan menerusi rangkaian membentuk alur seperti Matriks Butler yang rekabentuknya menjadi fokus utama tesis ini. Dengan menggunakan peranti pasif dalam suatu konfigurasi rama-rama, Matriks Butler 8x8 mikrojalur yang planar dapat direkabentuk untuk kegunaan dalam Jalur ISM yang merangkumi 2.4 GHz hingga 2.5 GHz. Baru-baru ini, penyelidikan juga tertumpu kepada pengecilan rekabentuk peranti gelombang mikro pasif serta komponennya. Talian Penghantaran Buatan merupakan kaedah baru yang berjaya mengecilkan talian penghantaran melalui pembebanan kapasitif berkala bagi mengurangkan ciri halaju fasa talian penghantaran bergalangan tinggi kepada nilai yang dikehendaki. Galangan yang lebih tinggi akan dapat mencapai tahap pengecilan yang lebih besar. Penjimatan keluasan sebanyak 40 peratus untuk rekabentuk komponen hibrid pasif dan 59 peratus untuk rekabentuk komponen litar *crossover* dapat dicapai berbanding dengan kaedah konvensional. Menerusi implementasi 12 hibrid, 8 penganjak fasa tetap dan 16 litar *crossover*, konfigurasi akhir Matrix Butler yang padat dapat direkabentuk. Simulasi telah dilaksanakan melalui pakej perisian elektromagnet *Microwave Office* manakala pengiraan rumus rekabentuk telah disahkan melalui perisian *MathCad*.

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α	Attenuation constant
β	Propagation constant
ε_{eff}	Effective dielectric constant
ε_o	Dielectric constant of free space
ε_r	Dielectric constant / permittivity
ϕ	Electrical Length
Γ_{in}	Input reflection coefficient
Γ_o	Reflection coefficient
λ	Wavelength
λ_g	Guided wavelength
λ_o	Free space wavelength
μ_o	Permeability of free space
ω	Angular frequency
c	Velocity of light
C	Capacitance
C_p	Periodic Capacitance
f	Frequency
G	Conductance
h	Substrate height
I	Current
j	Complex number
k	Complex propagation constant
L	Inductance
P_i	Incident power

P_{max}	Peak handling capability
P_r	Reflected power
P_t	Transmitted power
R	Resistance
t	Conductor thickness
V	Voltage
v_p	Phase velocity
w	Conductor width
w_{eff}	Effective conductor width
Z_f	Wave impedance in free space
Z_0	Characteristic impedance

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Increasing importance is placed upon the mobility of portable devices for embedded information and telecommunication, including PDAs, pagers, cellular phones and active badges. Advances in sensor integration and electronic miniaturization make feasible the production of sensing devices equipped with significant processing memory and wireless communication capabilities to create smart environments where scattered sensors can coordinate to establish networks.

Increasing wireless technologies are developed, e.g. IEEE 802.11, Bluetooth, and Home Radio Frequency (HomeRF) that promises to outfit portable and embedded devices with high bandwidth, localized wireless communication capabilities that may reach the globally wired Internet.

The 2.4 GHz Industry, Scientific and Medical (ISM) unlicensed band constitutes a popular frequency band suitable to low cost radio solutions such as those proposed for Wireless Personal Area Networks (WPANs) and Wireless Local Area Networks (WLANs), more so due to its almost global availability. Sharing of the spectrum among various devices in the same environment, however, may lead to severe interference and significant performance degradation [1].

Primary and secondary users are allowed in the 2.4 GHz ISM band. Secondary use are unlicensed, although may have to follow rules of respective national communications commissions relating to total radiated power and use of the spread spectrum modulation schemes. As long as these rules are adhered to, interference among the various uses is not addressed. Therefore, the major downside of the unlicensed ISM band is that the frequencies must be shared and potential interference tolerated. Although spread spectrum and power rules are quite effective when dealing with multiple users in the band of radios that are physically separated, the same cannot be said for close proximity radios.

Smart Antenna Systems are defined when multiple antenna elements are combined with a signal-processing capability to optimize the radiation and/or reception pattern automatically in response to the signal environment. An antenna is defined as the structure associated with the region of transition between a guided wave and a free-space wave, or vice versa. Antennas convert electrons to photons or vice versa. An antenna is the port through which radio frequency (RF) energy is coupled from the transmitter to the outside world and, in reverse, to the receiver from the outside world.

Antennas have typically been the most neglected of all personal communication system components. However, the way energy is distributed and collected from the ambient space has a profound influence on the spectrum efficiency, cost in setting up new networks and the network service quality.

Utilizing adaptive beamforming techniques allows an antenna array to reject interfering signals having a direction of arrival different from that of a desired signal. Additionally, interfering signals having different polarization states from the desired signal can also be rejected should a multi-polarized array be used, even if the signals have the same direction of arrival. Improvements in capacity of wireless communication systems can be improved by exploiting these capabilities.

Two or more antenna elements that are spatially arranged and electrically interconnected to produce a directional radiation pattern is termed as an array. The feed network which forms the interconnection between elements can provide fixed phase to each element or can form a phased array. In optimum and adaptive beamforming, optimal received signal is obtained by adjusting the phases (and usually the amplitudes) of the feed network. Performance of an array is influenced by the geometry of an array and the patterns, orientations, and polarizations of the elements.

Multiple simultaneously available beams can be generated using array beam forming techniques [2, 3, 4]. Furthermore, the formed beams can be shaped to have high gain and low sidelobes, or controlled beamwidth. Adaptive beamforming techniques can adjust the array pattern dynamically to optimize certain characteristics of the signal received. In beam scanning, a single main lobe of an array is steered and the direction varied either continuously or in discrete steps. Antenna arrays using adaptive beamforming techniques can reject interfering signals having a direction of arrival different from that of a desired signal. Multi-polarized arrays can also reject interfering signals having different polarization states from the desired signal, even if the signals have the same direction of arrival.

Beamforming is defined as focusing the energy radiated by an aperture antenna along a specific direction. The beamformer is therefore the device or apparatus that performs this function [4]. To form multiple beams, an array of N antenna elements in connected to a beamformer of N beam ports. This architecture acts as though the antennas are directional, forming beams in orthogonal directions with increased directivity and described as a beamforming network.

The Butler Matrix (BM) is an example of a multiple-beamed antenna system. The system measures angle of arrival on multiple input signals when multiple receivers are used in conjunction with the Butler Matrix. Linear arrays and a beam-forming network are utilized and it characteristically has binary numbers of input antennas, 2^n, where n is an integer.

One characteristic of *NXN* Butler Matrices is that the overall circuit grows exponentially as *N* increases. Although increased *N* will mean more multiple beams in an *8X8* design compared to a *4X4*, this advantage comes with it the expense of increased circuit size.

This dissertation utilizes capacitive loading of transmission lines to reduce the size of the passive components of the Butler Matrix, specifically the branch line hybrid and crossover circuits. By implementing these components in a final 8x8 Butler Matrix design, an overall decreased area can be obtained. A planar design was simulated for microstrip implementation.

A further contribution of this dissertation is the reusability of the hybrid and crossover structures in other microwave circuit designs.

1.2 Objectives

- To design a compact planar 8x8 Butler Matrix for use in an ISM band Smart Antenna System.

1.3 Scope Of Project

The scope of this dissertation relates to the design of the *8X8* Butler Matrix to function over the ISM band constituted by a frequency band of 2.4 GHz to 2.5 GHz. A Butler Matrix comprises of 12 hybrids, 8 fixed phase shifters and 16 crossovers as shown in Figure 1.1.

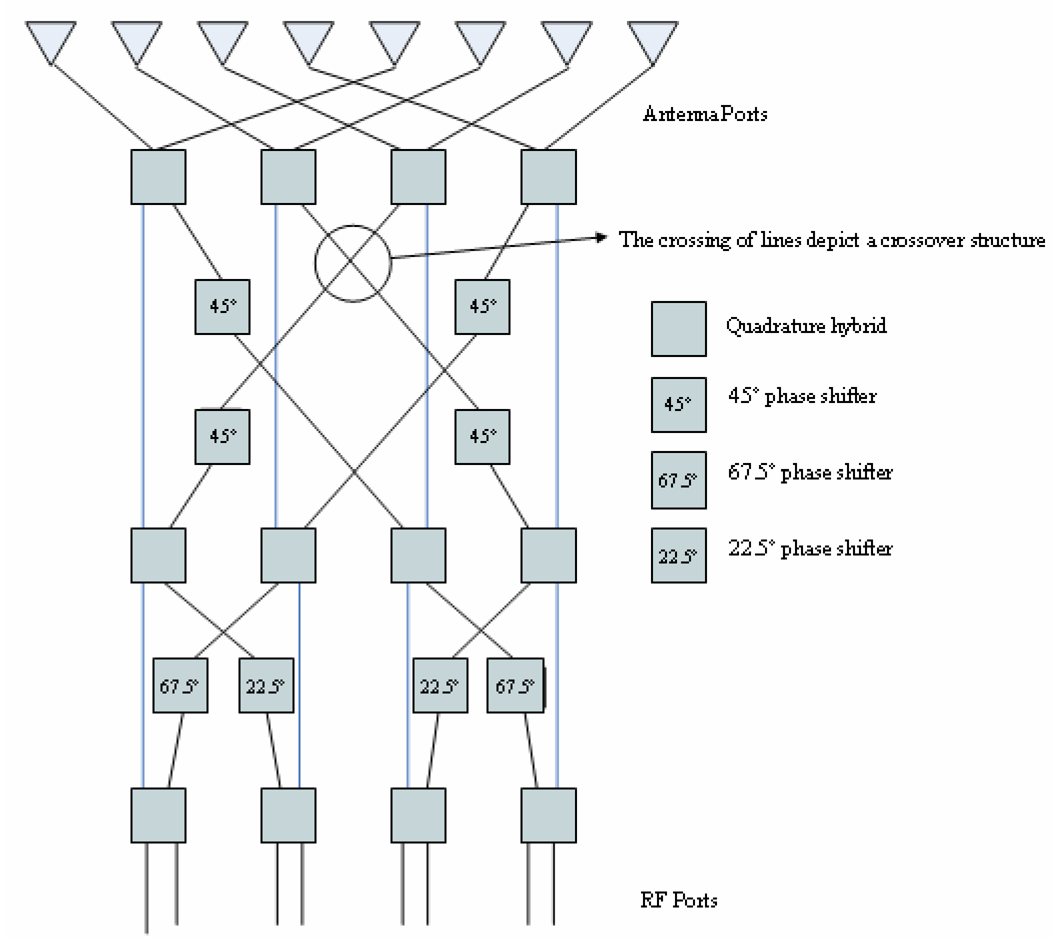

Figure 1.1 Block Diagram of a Conventional *8X8* Butler Matrix

The individual passive components were designed in microstrip. The quadrature hybrid, as shown in Figure 1.2 is a power divider that generates a 90 degree phase shift between its two outputs. In Figure 1.1, it is evident that the crossing of lines between the various components is unavoidable. This crossing of lines poses a design problem issue to the layout of a planar design. By implementing a crossover circuit that will have isolation between series ports but allow the good coupling between diagonal input and output ports, the crossing of lines issue can be resolved. This circuit is shown in Figure 1.3.

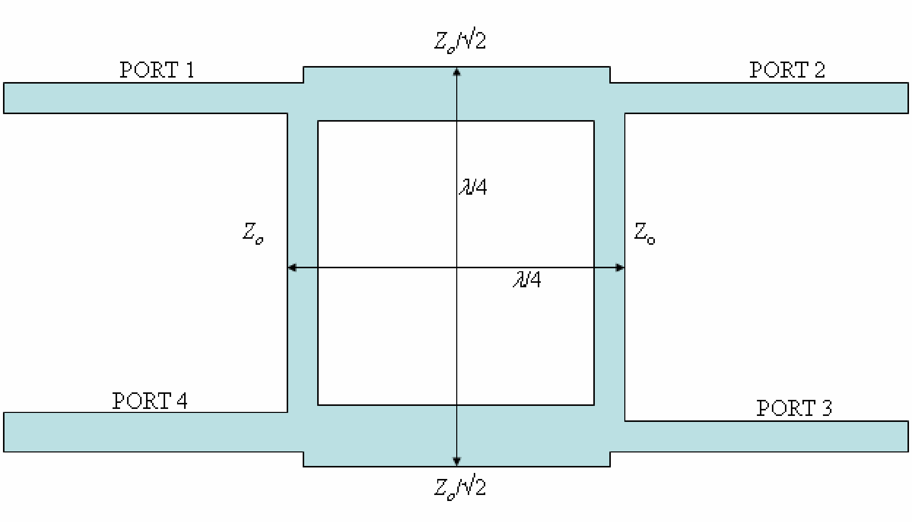

Figure 1.2 Quadrature hybrid

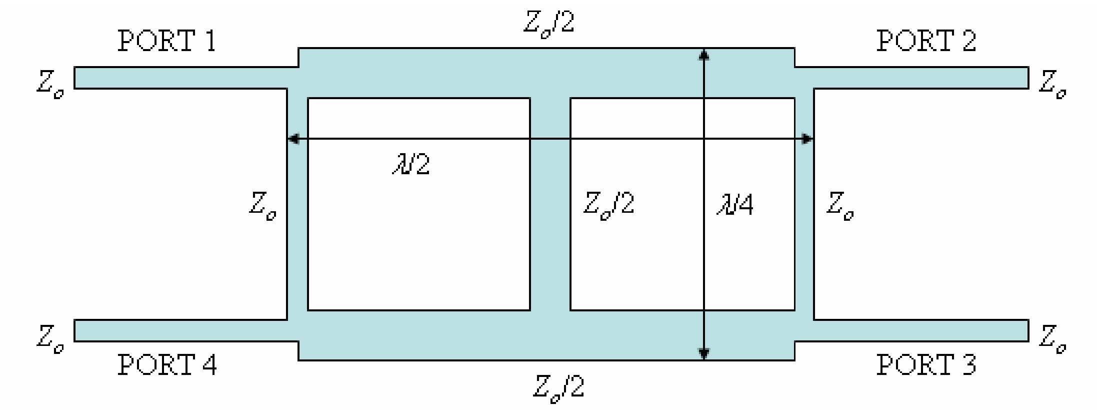

Figure 1.3 Crossover circuit

Electromagnetic simulations were performed on the individual passive components and the final *8X8* design. Design calculations were verified using MathCad. Analysis of the S-parameters of the component designs and final matrix was performed to give an indication of performance.

1.4 Summary of Chapters

The first chapter gives an introduction to the dissertation, providing relevant information concerning the project background, objective and the scope of the project.

The second chapter deals with transmission line theory related to microstrip implementation. A general description of the microstrip material is also given, together with an overview of circuit and antenna requirements.

In chapter three, antenna array and beamforming theory are examined in detail. Equations related to array factor derivations and beam space representation are presented here.

An overview of the relevant theory related to the passive components required in the final design in considered in chapter four. In this chapter, a conceptualization of passive component theory is shown and the corresponding number of components required for the design is also presented.

In chapter five, the theory related to the method of miniaturization, artificial transmission lines is examined. Details of the methodology and design procedure are expounded in the sixth chapter. The entire design process is discussed in detail in this chapter.

Simulation results are analyzed in the seventh chapter. Finally, the whole project is concluded in the final chapter. Suggestions for future work were given.