



THE UNIVERSITY OF QUEENSLAND
A U S T R A L I A

RF Switching system for Biomedical Radar systems

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Dear Professor Strooper,

In accordance with the requirements of the degree of Bachelor of Engineering in the division of Electrical Engineering I present the following thesis entitled “RF Switching System for Biomedical Radar Systems”. This work was performed under the supervision of Dr. Konstanty Bialkowski.

I declare that the work submitted in this thesis is my own, except as acknowledged in the text and footnotes, and has not been previously submitted for a degree at The University of Queensland or any other institution.

Yours sincerely,

Matt Pascoe

Matt Pascoe.

Abstract

This document is a skeleton thesis for 4th-year students. The printable versions (`skel.dvi`, `skel.ps`, `skel.pdf`) show the structure of a typical thesis with some notes on the content and purpose of each part. The notes are meant to be informative but not necessarily illustrative; for example, this paragraph is not really an abstract, because it contains information not found elsewhere in the document. The \LaTeX 2 ϵ source file (`skel.tex`) contains some non-printing comments giving additional information for students who wish to typeset their theses in \LaTeX . You can download the source, edit out the unwanted material, insert your own frontmatter and bibliographic entries, and in-line or `\include{}` your own chapter files. Of course the content of a particular thesis will influence the form to a large extent. Hence this document should not be seen as an attempt to force every thesis into the same mold. If in doubt about the structure of your thesis, seek advice from your supervisor.

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Chapter 1

Introduction

1.1 Background

There has been a growing demand for the development of wireless systems, to meet the increasing demands of consumers. In order to meet this demand researchers have looked to software defined radio's (SDR); this interest in SDR is due to the ease and simplicity for the development and implementation in various applications. This rise in interest has led to a large spike in development of SDR, which is resulting in a broadened application for SDR. [1]

SDR's are being applied in a variety of different scenarios, but this thesis focuses primarily on the development of a switching system to complement the research done using SDR as a tool for medical imaging. The use of SDR in microwave imaging has provided an alternative diagnostic tool that presents significant benefits of current technology, primarily because of its low cost, portability, non-invasiveness and uses non-ionization radiation. This allows the system to be compact and suitable for medical application in the field. [2] [3]

As the demand for faster wireless systems increases, so does the interest in researching the application of using multiple antenna wireless links for digital communication; using multiple antennas introduces a greater range of possibilities by increasing the speed of the networks traffic [?]. To accommodate for the control of multiple radio frequency (RF) front ends the communication system will require a RF switching system; there are two primary categories for RF and microwave switches, electromechanical relay (EMR) and solid-state relay (SSR).

There are advantages and disadvantages in use either, SSR's are available in smaller packages and have a higher switching speed but are restricted to single pole, EMR's have a lower isolation loss but are have slower speed due to their physical construction. SSR don't have a wearable switching mechanism while EMR do, making them impractical in scenarios which require large amounts of switching [?]. Therefore,

this thesis will primarily focus on utilising SSR's as opposed to EMR's, to meet the high speed requirements while maintaining a low cost and compact design.

This thesis project looks into the development of an RF switching system to allow an RF front end to be connected to a large number of antennas or sensors, by developing a RF switch matrix that provides a high speed switching on multiple antennas. The results obtained from this will facilitate and support the expansion in the current development of biomedical RF imaging systems as well as future projects.

1.2 Aims/Objectives

This thesis aims to evaluate the current available designs and products to develop a low-cost and portable RF switch matrix.

The primary objective are to complete the following tasks:

- Evaluate and Design a RF Switch matrix
- Develop and Construct the RF Switch matrix
- Finalise and construct a housing for the switch matrix

1.3 Thesis Structure

Chapter 2 investigates the prior technology available that can be adapted or utilised in order to assist in the development of RF switching system.

Chapter 3 defines the relevant theory that is required to understand the topics discussed in this thesis.

Chapter 4 looks into the analysis and development of RF switches.

Chapter 5 depicts the flow of the project, starting from the thesis's definition and following it through the solution, design, simulation, implementation and results.

Chapter 6 contains performance results of the RF switch matrix, and the RF switch matrix's characteristics.

Chapter 7 discusses the performance of the produced switch matrix and future work.

1.4 Expected Contribution

The thesis will look at developing a low-cost RF switch matrix capable of providing a 2 input, 16 output switching matrix. It should reveal the possibility of developing switch matrix's that are better suited to low-cost, portable projects in contrast to commercially available switches.

This thesis is expected to produce a proprietary switch matrix that can enable the further development of low-power RF development in biomedical and radar applications.

Chapter 2

Literature review

2.1 Prior Art

This chapter looks into the currently available designs used for high speed RF switching as well as relevant theory that has and is being completed in the field.

2.1.1 Currently Available Technology

There is currently a wide variety of application for RF switching systems, EMR are primarily used but there has been recent interest in SSR applications. EMR switching systems are a predominate choice due to their low losses and have been utilised in many various applications. A journal article in [24] looks at the performance of microelectromechanical systems (MEMS) and the wide field of application for MEMS in communications, medical and aerospace; this wide field means that there is a large application that can benefit from the development of RF switching systems. As seen in [24] RF switching systems have a wide range of application, it can be seen in [25], which investigate the interference problem of a MIMO beam-switching antenna. In order to control the multiple beam switching antennas requires a high speed switching system, therefore they utilised a SSR allowing them to achieve speeds from 1-100ns; this high speed capability is ideal for the application of the thesis [25].

There is also a large application for RF switching systems in medical imaging, which is the primary focus of this thesis. The journal article in [3] describes a medical imaging system that uses a RF system, it rotates a body around an antenna by a stepper motor to obtain measurements from antenna at different positions; this system utilises a SDR and a single antenna to obtain its measurements as it rotates around the body. It was determined that the current microwave imaging system currently takes 45 minutes to complete its analysis, but by replacing the rotating platform with an array of 20 antennas using a EMR switching network could reduce

the time to less than 1 minutes [3]. Since we are expecting SSR to provide a faster switching speed reducing the time taken for the measurements to be completed.

The journal articles [26, 27] that discuss the use of EMR technology to allow a RF front end to control multiple antennas in different applications of biomedical engineering. In [26] a network of EMR is used to allow a VNA to perform radar measurements through 16 antennas in the frequency domain. The switches are controlled by a computer and takes around 3 minutes for the measurements to be taken [26]. An article from [27] looks at using an array of RF antennas switched by an EMR so they can image a head to detect a haemorrhage stroke [27]. The need for RF switching systems can be seen but the use of SSR instead of EMR can potentially reduce the size and noise of the switching while increasing the speed allowing their design to be faster, more compact and quieter which is potentially ideal for medical applications.

2.1.2 Previous designs

In order to develop the PCB

2.2 Software Defined Radio

The application of the RF switching system this thesis looks a developing, is to provide an RF front end such as a software defined radio (SDR) or Vector Network Analyser (VNA) with the ability to communicate multiple antennas or sensors. An SDR is a radio that is partially or entirely controlled by software in the physical layer in the Open Systems Interconnection (OSI) model. The OSI model is used to describe the subsystems of a communication system, where the physical layer represents the data. This allows for the software or firmware to be adjusted resulting in the change the carrier frequency, data rate, modulation, coding, etc. without having the reconstruct the hardware of the radio [6]. This project doesn't look into the control of an SDR, instead focuses on interfacing the switching system with the SDR. It is expected that the SDR will have an impedance of $50\ \Omega$ which is common of most SDR technology or a less common impedance of $75\ \Omega$ [7].

2.2.1 Analysing SDR Signals

2.2.2 Radar Signal Analysis

2.3 Microwave Theory

To design and develop microwave circuits a fundamental understanding of how microwaves operate and ... in ... is required

2.3.1 Transmission Line Theory

A transmission line is a medium that transfers electromagnetic energy along its path, an example can be seen in Figure 2.1. Transmission lines will form the primary basis of this thesis since it will be primary medium for the signal travelling through the RF switching system. It is crucial to ensure that the transmission line matches the source and antenna; otherwise it can cause the power to be reflected back.

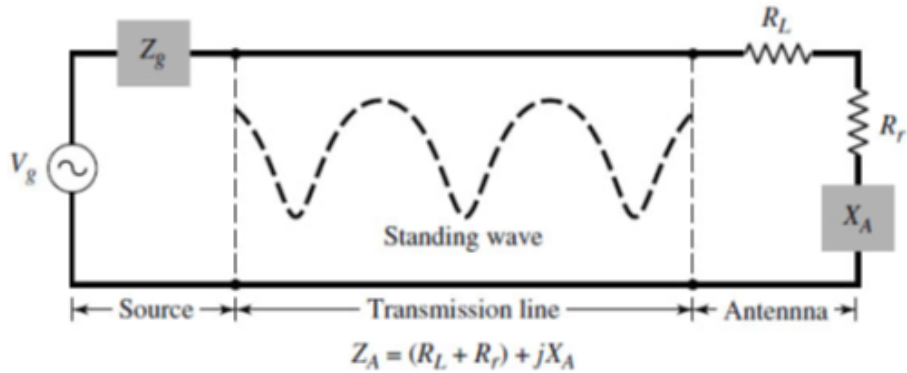


Figure 2.1: Transmission line Thevenin equivalent of antenna and transmitter

To prevent this reflection, the impedances at each end must be matched to the transmission lines characteristic impedance. This can be done through L-section matching, stepped transmission lines or filters.

L-section is a method used for matching transmission lines; this involves using a capacitor and inductor in a series and parallel combination to match the load. Stepped transmission lines provides impedance matching for lumped elements. Finally, filters can also be used for impedance matching; they are typically used to provide an adjustable match for the circuit over different frequencies. By inserting a filter that is a perfect match for the transmission line at a known frequency [9]. This theory will be considered when evaluating the design for the development boards and if required the PCB so they are perfectly matched to reduce any unnecessary losses in the system.

2.3.2 Scattering Parameters

Scattering parameters (S-Parameters) are a matrix that describes the behaviour of linear electrical networks; this matrix is used over a broad range of disciplines of electrical engineering but is particularly useful in microwave engineering. Since the RF switching system this thesis is designing will not generating its own signal or provide any RF front end's; even though the system is switching, it will always have a single input and single output. Therefore, this design can be simplified to be a 2-port network, as shown in Figure 2.2.

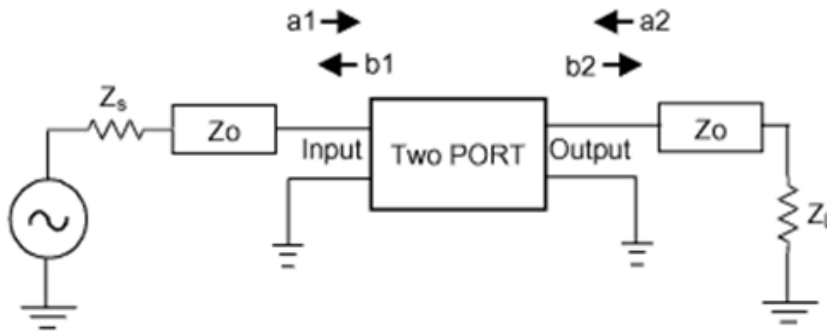


Figure 2.2: 2-port switching system [10]

2-port networks are most commonly used and can easily be adapted to systems that are more complex, Figure 2.2 shows a simple diagram of a 2-port network and Equation 2.1 shows the matrix and equations given for the network [9].

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \quad (2.1)$$

$$b_1 = S_{11}a_1 + S_{12}a_2$$

$$b_2 = S_{21}a_1 + S_{22}a_2$$

These parameters can be directly measured with a network analyser and will be used to determine the characteristics of the different RF switches.

2.3.3 System Losses

When working with RF and microwave systems it is important to understand the different types of losses that can occur in the system and how it will affect the performance. There are three significant losses to be consider, these are insertion loss, return loss and isolation. Insertion loss is the loss of the signals power in decibels (dB) from the insertion of a device in the input or output of the system.

The loss can be determined given the scattering equation of the system, as defined in Equation 2.2.

$$\text{Insertion loss} = -20 \cdot \log_{10} (|\Gamma|) \quad (2.2)$$

The return loss is the loss of the signals power in dB from the signal reflection; this is often caused by an impedance mismatch on the load. The loss can be determined given the reflection coefficient, as shown in Equation 2.4.

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \quad (2.3)$$

$$\text{Return loss} = -20 \cdot \log_{10} (|\Gamma|) \quad (2.4)$$

The isolation is the degree of attenuation from other signals from outside or on other channels in the system. Increasing the isolation of the device reduces the influence of other signals. The isolation of the system can be determined by measuring the signal strength at an output where the input is not routed to [9]. All of these parameters need to be seriously considered, and form the base of the analysis for the design and development of the RF switching system.

2.4 RF Switch

There are two typical types of switches that are used in RF and microwave switching systems, electromechanical switches (EMR) and solid-state switches (SSR). These switches are often available in four different topologies:

- Single-pole double-throw (SPDT)
- Single-pole-multiple-throw (SPnT)
- Double-pole-double-throw (DPDT)
- Bypass switch [11]

This project is interested in the development of a single input with multiple outputs so will look into utilising combinations of SPDT and SPnT topologies to meet this requirement.

Solid-state relay's (SSR) are typically constructed in semiconductor packaging, giving them a small size and are switched by applying an external voltage across its control terminals. Since there are no physical switching mechanisms for SSR, there is no component to wear out allowing the SSR to potentially switch an infinite amount of times.

Whereas electromechanical relays (EMR) rely on a mechanical contact to switch the outputs, resulting in an often larger size. Since there is a physical movement required to switch the outputs the EMR, there will be limit on the number of switches

before it begins to fail; this is not particularly ideal for the RF switching system this thesis is looking at as it will require switches to be replaced after set period depending on its usage.

EMR's have a larger frequency range than most SSR's, they support frequencies from DC to the GHz range whereas SSR's often begin around the KHz up to GHz; both switches are ideal as the switch will be working in high frequencies. The insertion loss is often greater in SSR compared to most EMR's but SSR's provide a greater isolation in comparison against EMR. On average, the SSR's provide a greater switching speed with significantly lower settling time making them ideal for high speed switching [5].

Both switches have advantages and disadvantages; however, this project looks into the development of a switching system to switch at high speeds with minimal losses, size, noise and power. SSR are the most suitable for meeting these requirements and will therefore be the primary focus of this project.

2.5 RF Switches Matrix

This thesis topic looks into the development of a RF switching system, this will be done by utilising RF and microwave switches to create an RF switching matrix. An RF switch matrix are used to route RF signals from an input to an output.

There are several different types of switching matrix's, there is multiple input multiple output (MIMO), multiple input single output (MISO), single input multiple output (SIMO) and single input single output (SISO) [12]. For this project we are looking at controlling multiple outputs with a single input, so will be implementing a SIMO RF switching matrix.

2.5.1 Switch Architecture

2.5.2 Switch Topologies

When constructing a RF switch there are two typical topologies, these are multiplexers and general purpose relays; examples can be seen in Figure 3. General purpose relays are commonly a SPDT or SDnT relay's that are used for routing a signal between multiple paths. Multiplexers are devices that route a single input to multiple outputs or vice versa, they are commonly built from multiple SPDT relays but have a greater inherited insertion loss from this configuration [13].

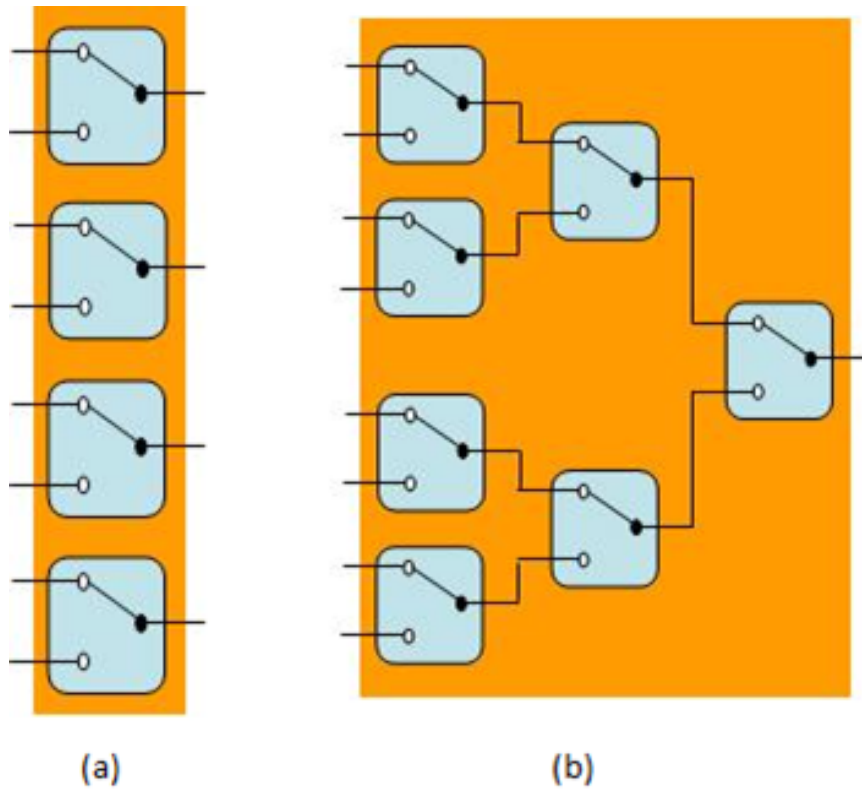


Figure 2.3: (a) is a Quad SPDT, (b) 8x1 multiplexer. [14, 15]

Looking at Figure 2.3 (b) it can be assumed that there will be losses through each path it takes, insertion losses through first switch, first cable/track, second switch, etc. Therefore, it is ideal to develop a topology as close to Figure 2.3 (a) to ensure there is little loss through multiple cascaded switches and cable/tracks. This thesis will be looking into designing a 2x16 MIMO multiplexer, similar to the design in Figure 2.3 (b) to provide the available ports as well as a consistent loss through the system.

2.5.3 Cabling

When developing the RF switching system it is probable to require cables to connect the switches together. If the development boards are used it will be a requirement, and the PCB development could be built into separate daughter boards and connected together via cable.

There are three main types of coax cabling:

- Semi-rigid
- Comfortable
- Flexible

This project will look into the use of semi-rigid SMA cables, as they typically have low losses for signal transmission and are well suited for fixed devices [16]. The connection between will need to be measured and matched as discussed in section 2.1.1 to ensure that the signal retains its integrity.

2.6 Substrate Selection

There are various substrates that are available for developing the RF switching matrix. Four key substrates were looked at these include:

- FR-4
- Epoxy

Table ?? contains the characteristics of these four substrates that are utilised to calculate the dimensions of the RF tracks. When designing PCB's for

2.7 RF Track Design

For designing the RF tracks on the PCB there are three primary options available

- Micro-strip
- Coplanar Wave-guide, and
- Strip-line

RF tracks provide ...

For designing the tracks we need to consider:

$$\lambda = \frac{c}{f\sqrt{\epsilon_{eff}}} \quad (2.5)$$

$$\theta = \frac{2\pi}{\lambda} \quad (2.6)$$

We need to consider the Figure 2.5 and 2.6 as these are the fundamentals for designing any type of track. To determine which track is best suited this thesis will look at each available option.

These equations are used for the approximate design of RF tracks, in order to obtain a more precise design which consider a wider range of variables dedicated software is used to further verify the design of the tracks.

2.7.1 Micro-strip

Microstrip RF tracks are the most common RF transmission line currently used in practice. Figure 2.4 presents a typical microstrip which has been labelled the critical dimensions of this transmission line.

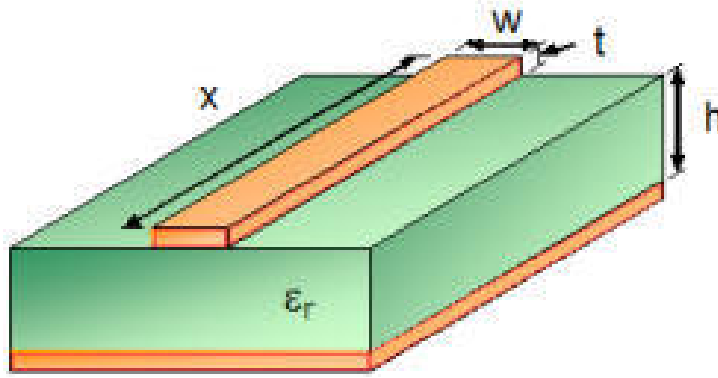


Figure 2.4: Microstrip diagram

We are able to calculate the dimensions shown in Figure 2.4 by using the following:

$$W = \frac{t}{\pi} \left[\ln \left(\frac{2h}{t} \right) + 1 \right] \quad (2.7)$$

$$H = h - 2t \quad (2.8)$$

$$\epsilon_{eff} = \begin{cases} \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + \frac{12H}{W}}} + 0.04 \left(1 - \frac{W}{H} \right)^2 \right] & \text{when } \left(\frac{W}{H} \right) < 1 \quad (2.9a) \\ \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2\sqrt{1 + \frac{12H}{W}}} & \text{when } \left(\frac{W}{H} \right) > 1 \quad (2.9b) \end{cases}$$

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon_{eff}}} \cdot \ln \left(\frac{8H}{W} + \frac{W}{4H} \right), & \text{when } \left(\frac{W}{H} \right) < 1 \quad (2.10a) \\ \frac{120\pi}{\sqrt{\epsilon_{eff}} \cdot \left[\frac{W}{H} + 1.393 + \frac{2}{3} \ln \left(\frac{W}{H} + 1.444 \right) \right]}, & \text{when } \left(\frac{W}{H} \right) > 1 \quad (2.10b) \end{cases}$$

In order to calculate the dimensions of the micro-strip track we are required to make key decisions for the design. By selecting the frequency range, impedance, phase shift substrate and track thickness we are able to determine the dimensions for the track.

We are able to determine the width (W) and length(X) of the track by selecting a substrate determining the dielectric constant (ϵ_{eff}), copper thickness (t) and height(H). We can set the

2.7.2 Strip-line

Stripline RF tracks are ...

We are able to calculate the dimensions shown in Figure 3.2

$$\begin{aligned}\beta &= \frac{\omega}{v_p} \\ &= \sqrt{\epsilon_r} \cdot k_0\end{aligned}\tag{2.11}$$

$$\begin{aligned}Z_0 &= \sqrt{\frac{L}{C}} \\ &= \frac{1}{v_p \cdot C}\end{aligned}\tag{2.12}$$

$$\frac{W_e}{b} = \begin{cases} \frac{W}{b} & \text{when } \left(\frac{W}{b}\right) > 0.35 \\ \frac{W}{b} - \left(0.35 - \frac{W}{b}\right)^2 & \text{when } \left(\frac{W}{b}\right) < 0.35 \end{cases}\tag{2.13a}$$

$$\tag{2.13b}$$

$$\frac{W}{b} = \begin{cases} x & \text{when } \sqrt{\epsilon_r} \cdot Z_0 < 120 \Omega \\ 0.85 - \sqrt{0.6 - x} & \text{when } \sqrt{\epsilon_r} \cdot Z_0 < 120 \Omega \end{cases}\tag{2.14a}$$

$$\tag{2.14b}$$

$$x = \frac{20\pi}{\sqrt{\epsilon_r} \cdot Z_0}\tag{2.15}$$

2.7.3 Coplanar Wave-guide

C

2.8 Radiation Emission

2.8.1 Picket Fencing Technique

2.8.2 Shielding

Chapter 3

RF Switch Evaluation

In this chapter the design of discrete RF switches is evaluated in comparison to commercially available switches. This chapter will look into the design and simulations of SPDT, SP4T and SP8T RF switches within the frequency range of 100MHz-4GHz to gain a better understanding of RF switch functionality and variants.

3.1 RF Switch Design

There are two

3.1.1 PIN Diode

3.1.2 FET

3.2 Topologies

3.3 Available RF Switches

Chapter 4

Methodology

For this Thesis the design has been broken into five primary sections:

- Evaluation of RF switches
- Design a switch matrix
- Develop PCB design
- Evaluate the RF switch matrix
- Construction of matrix enclosure

This chapter will cover the progression of the design and development of the RF switch matrix for the thesis.

4.1 Evaluation

This section looks at evaluating the currently available RF switches in Section 4.1.1 that can be used, and alternative possibilities in developing a custom RF switch matrix.

4.1.1 Evaluation Boards

We currently have 3 evaluation RF switch boards available; these include:

asdf	\$50 USD
asdf	\$50 USD
asdf	\$50 USD

The three available evaluation boards we investigated using a ABCD VNA; each switch was wired so that the input is connected to the output, while all other ports were 50Ω terminated. The switch was powered and the controls set to allow the signal to propagate down the open path, then changed the state to have a closed

path; this was conducted for each evaluation board. The results were exported to a .s2p file to be analysed using ADS, and the results can be seen in Appendix ?? 's Figure's ??, ?? & ??.

These simulations

The results of ... is the most ideal RF switch out of the three boards, but the overall price to construct the switch matrix is far too expensive to construct as it will cost \$50 which is unrealistic to rival

4.1.2 RF Switches

It was seen in previous section that the EMR and switch relay provided significantly better results for: insertion, isolation and reflection but are significantly larger and heavier than SSR's tested. Since this thesis is looking at developing a lightweight switch matrix it is decided that high performance SSR's will be looked at instead of EMR.

There is a large variety of RF switches available in varying topologies, therefore the following RF switches will be looked at:

asdf	\$50 USD
asdf	\$50 USD
asdf	\$50 USD

These are the RF switches that will be further investigated in this thesis to determine if a custom RF switch design is able to constructed at a competitive price to the evaluation boards seen in Section 4.1.1. It can already be seen that the individual price is significantly cheaper but will require a PCB to be constructed; this will allow the design to be custom designed to fit in the most space efficient package possible to allow for a portable and lightweight design.

4.1.3 Transmission Line Design

Using the ADS three different transmission lines were tested, using the parameters seen in Appendix B, Table 4.1 was constructed.

Track Type	Width	Length	Gap
Micro-strip			-
Strip-line			-
Co-planar Wave-guide			

Table 4.1: Transmission Line Design Parameters

Therefore looking at Table 4.1 it can be seen that the most space efficient transmission line is the CPWG design; therefore, the CPWG design allows the PCB to be the most space efficient design for the RF switch design.

4.2 Design

For the design of the RF switch matrix, several key design criterias were identified to be required for the final product of the switch matrix; these specifications are:

- Two RF inputs
- Sixteen RF outputs
- Maximum path loss of 3dB
- Power-able from low-power device (such as USB)
- Input and output are $50\ \Omega$

In order to achieve this design the switch matrix will consist of two SP16T's where the output of each switch is wired to a SPDT.

In order to meet these specifications several different designs have been developed, which can be seen in Section 4.2.1 - 4.2.5. There are three different SP16T switch designs for the input and two SPDT output switch designs for the output; to determine the most suitable design these five designs are designed to determine a suitable low-loss, high isolation switch matrix.

4.2.1 Design 1

This design looks at constructing a SP16T RF switch using the SKY13418-485LF; this is a SP8T switch which doesn't require any external DC blocking capacitors on the RF ports.

To get 16 outputs the design requires a SPDT switch on each output of the SP8T; from the switches that are being looked at the ... is the most suitable. It has a poor reflection on the input and output but has high performance for the insertion and isolation, since the input and output reflection are determined by the SP8T switch and second SPDT switch.

This design was developed in Altium Designer and can be seen in Figure 4.1.

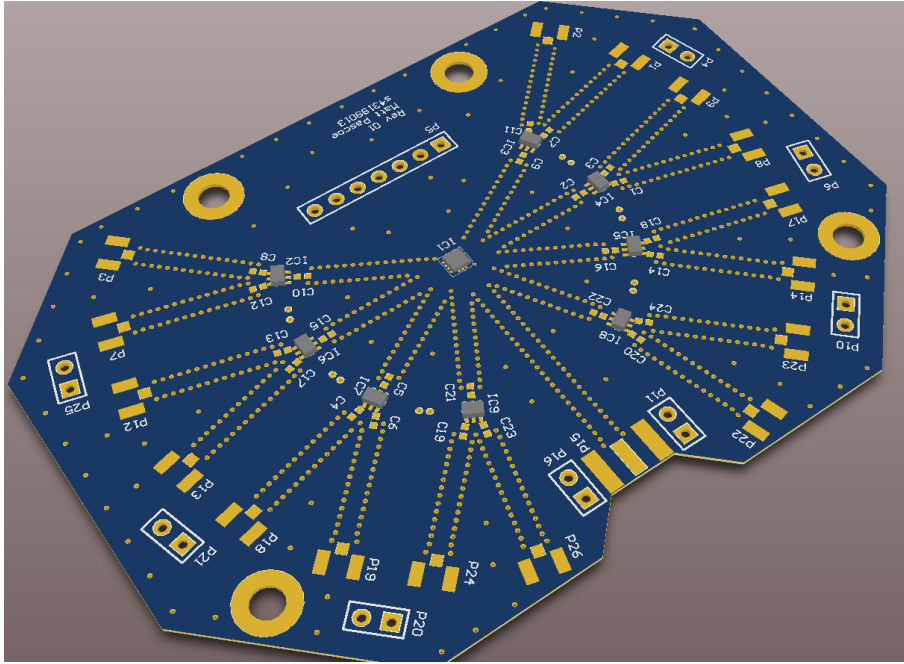


Figure 4.1: PCB Design for ‘Design 1’

Therefore using this combination of SP8T and SPDT switches we are able to estimate the parameters of the switch based off of the specifications in the data-sheet as seen in Table 4.2.

Parameter	Value			
	1GHz	2GHz	3GHz	4Ghz
Insertion				
Isolation				
Input Reflection				
Output Reflection				
Max Switching Speed				

Table 4.2: Design 1 Ideal parameters

4.2.2 Design 2

This design looks at constructing an alternative SP16T RF switch using a different topology from Section 4.2.1, it was found that the tested in Section 4.1.1. By using the RF chips and transmission line design an alternative construction of the SP16T switch can be designed that is significantly more space efficient and cost effective than the evaluation boards seen in Appendix

This design was developed in Altium Designer and can be seen in Figure 4.2.

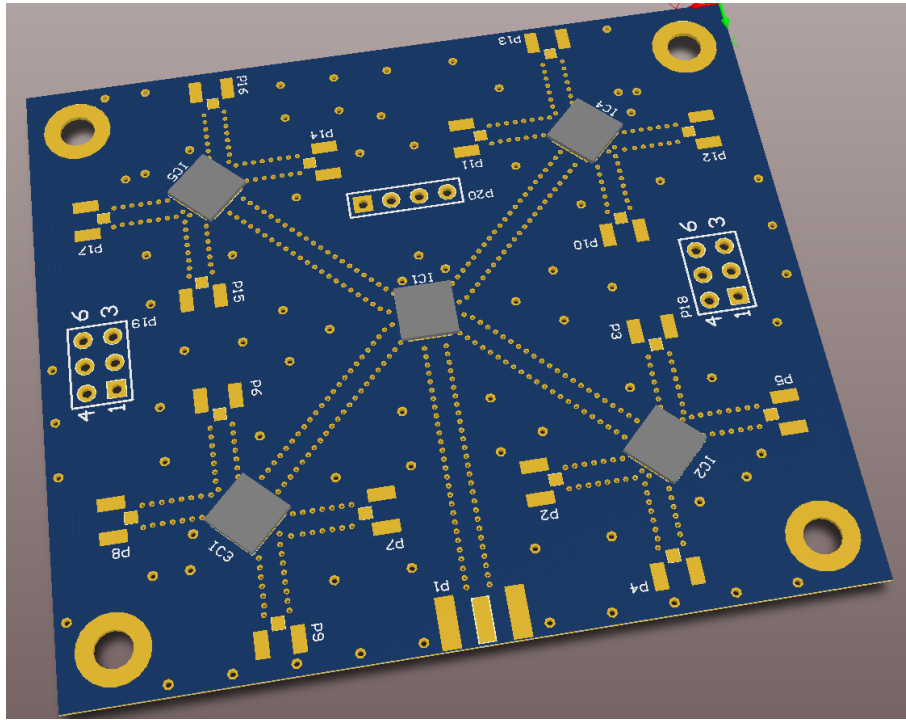


Figure 4.2: PCB Design for ‘Design 2’

Parameter	Value			
	1GHz	2GHz	3GHz	4Ghz
Insertion				
Isolation				
Input Reflection				
Output Reflection				
Max Switching Speed				

Table 4.3: Design 2 Ideal parameters

4.2.3 Design 3

This design looks at constructing a SP16T RF switch using

Parameter	Value			
	1GHz	2GHz	3GHz	4Ghz
Insertion				
Isolation				
Input Reflection				
Output Reflection				
Max Switching Speed				

Table 4.4: Design 3 Ideal parameters

4.2.4 Output 1

The output design requires constructing a SPDT switch for the output of the RF switch matrix, this requires a switch that has low insertion loss and isn't reflective. The switch should also include

This design was developed in Altium Designer and can be seen in Figure 4.3.

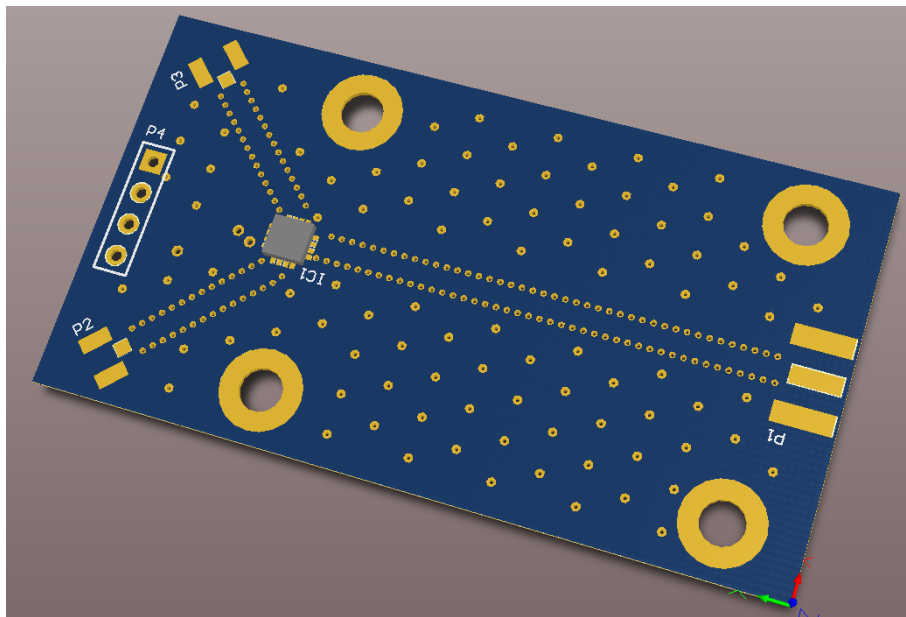


Figure 4.3: PCB Design for 'Output 1'

Parameter	Value			
	1GHz	2GHz	3GHz	4Ghz
Insertion				
Isolation				
Input Reflection				
Output Reflection				
Max Switching Speed				

Table 4.5: Design 3 Ideal parameters

4.2.5 Output 2

This design looks at constructing a SP16T RF switch using

Parameter	Value			
	1GHz	2GHz	3GHz	4Ghz
Insertion				
Isolation				
Input Reflection				
Output Reflection				
Max Switching Speed				

Table 4.6: Design 3 Ideal parameters

4.3 Development

This section looks at the development of the RF switch matrix.

4.3.1 PCB Development

One of the key design parameters is for developing a portable device, this requires the switch matrix to be as small as possible. To determine the best solution ADS's LineCalc is used to

4.3.2 RF Switch Development

After the design of the PCB had been completed the order was processed by a PCB development company. During this project two companies were used: PCBZone and PCBWay. The key difference between these companies was price, quantity and quality;

Table 4.7: Design ... Logic Table

The RF switch chips that were selected are only available in QFN, or ... packages; this limited the design capabilities to SMD

4.4 Physical Construction

4.5 Micro-controller Development

In order to control and operate the RF Switch system a some type of micro-controller is required to be used to switch the inputs and outputs of the system. The micro-controller needs to meet the following key design parameters:

- Capable of supporting control pins.
- Enable a switch speed of 100 ns
- Low power requirements, less than 5 W
- Source power from USB, and communicate using 15260 Baud rate.
- Capability to sync other controllers,

The ideal device is a low-powered micro-controller, for this project the PSOC4-BLE has been selected to ensure that it is able to control the

4.5.1 Design

For each development board a logic table was developed, the table for the can be seen in Table 4.7. This table determines the logic required to ensure that the control is kept to its most simplistic form. Therefore using this we are able to determine:

4.5.2 Evaluation

Chapter 5

Verification

5.1 Individual Board's

This section looks at the results obtain from each of the individual boards, each board was tested with a ABCD VNA. By evaluating these boards it can be determined which is most suited for the final design of the RF switch matrix; Section 5.1.1 - 5.1.5 details the analysed results and discusses the benefits and disadvantages of that design.

5.1.1 Design 1

Design 1 has been tested with a VNA, there are 3 different characteristics that were subjected to the analysis of the DP16T RF switch: losses, speed and power.

Losses

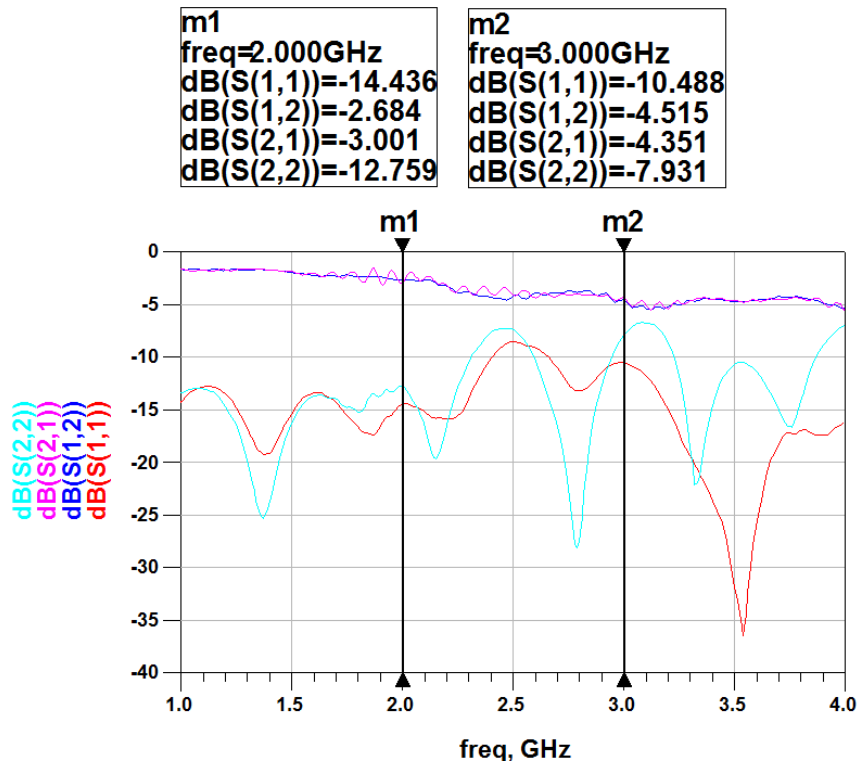


Figure 5.1: Design 1 S-Parameters - Track Open

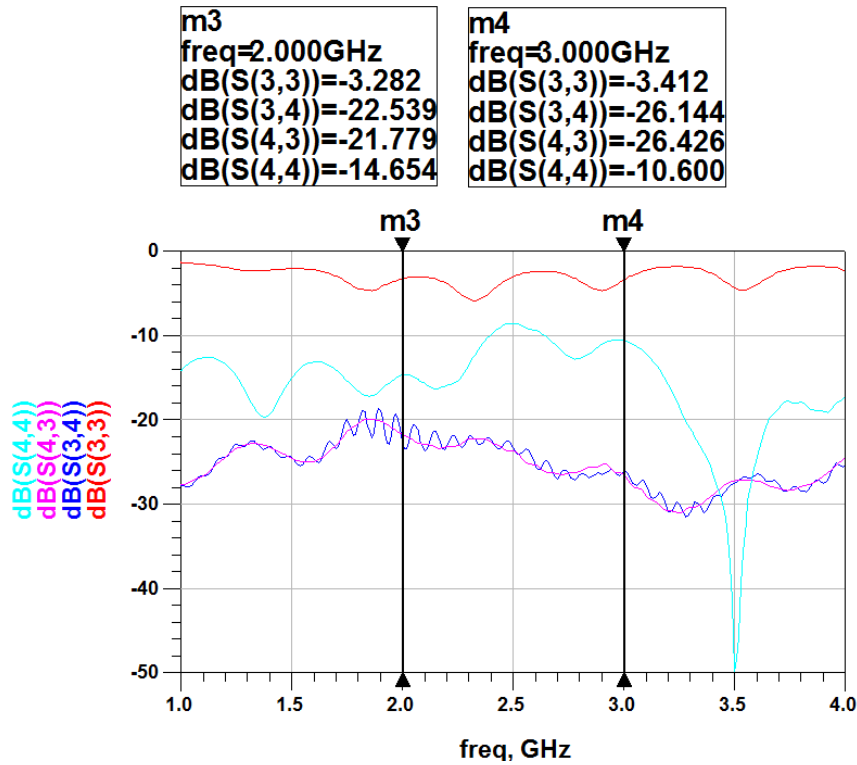


Figure 5.2: Design 1 S-Parameters - SP8T Open, SPDT Closed

It can be seen looking at the results that the results obtained in Figure 5.2

Switch Speed

Power Requirements

5.1.2 Design 2

Design 2 has been tested with a VNA, there are 3 different characteristics that are key to the analysis of the SP16T RF switch: losses, speed and power.

Losses

Figure 5.3: Design 2 S-Parameters

Switch Speed

Power Requirements

5.1.3 Design 3

Design 3 has been tested with a VNA, there are 3 different characteristics that are key to the analysis of the SP16T RF switch: losses, speed and power.

Losses

Figure 5.4: Design 3 S-Parameters

Switch Speed

Power Requirements

5.1.4 Output 1

Output 1 has been tested with a VNA, there are 3 different characteristics that are key to the analysis of the SP16T RF switch: losses, speed and power.

Losses

Figure 5.5: Output 1 S-Parameters

Switch Speed

Power Requirements

5.1.5 Output 2

The design for ‘Output 2’ seen in Section 4.2.5 was developed and tested using a VNA; it was found that the design wasn’t operating. So due to time constraints, since the RF chip was not functioning it was decided to disregard this design as it would be too expensive and time consuming to re-design & develop this design.

5.1.6 Cabling

There are several different cabling options available; three different cabling options have been looked at, this includes flexible and rigid SMA cables, and UFL cabling. Looking at Figure 5.6 - 5.9 we can determine the effects of cabling in the final design.

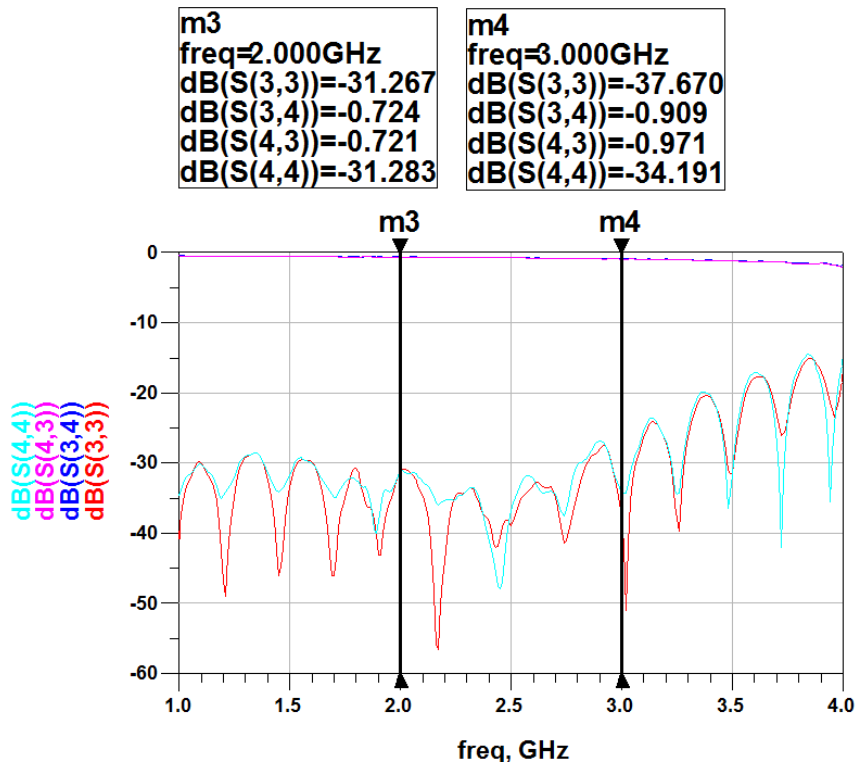


Figure 5.6: Flexible 0.5m SMA cable S-Parameters

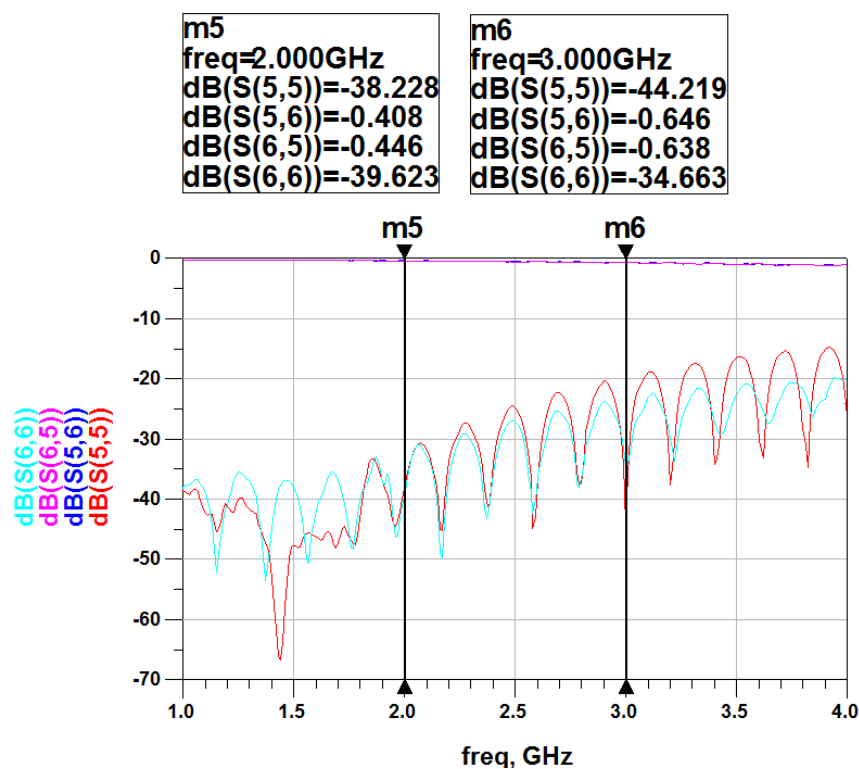


Figure 5.7: Rigid 0.5m SMA cable S-Parameters

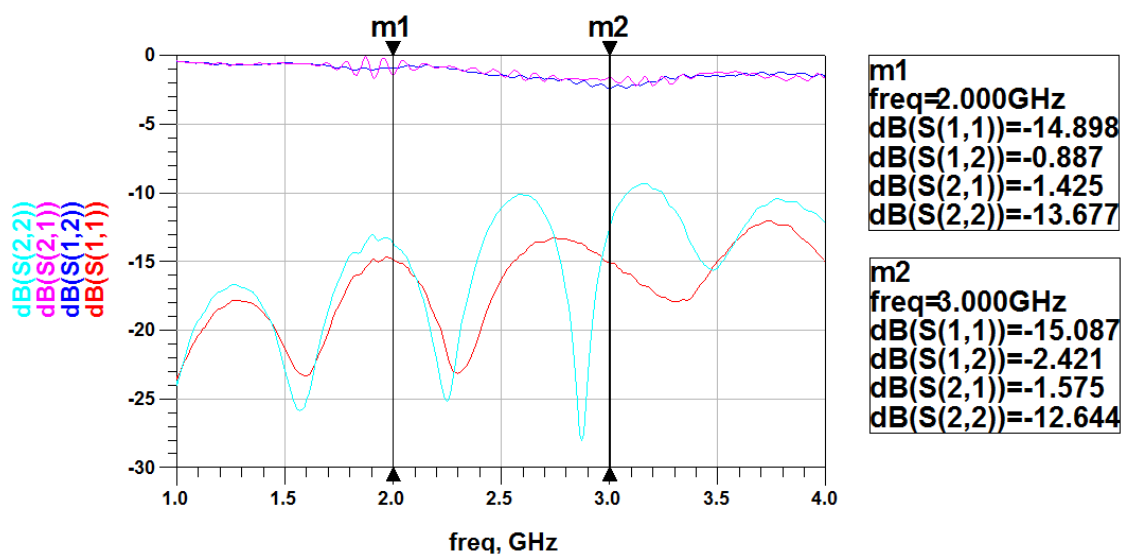


Figure 5.8: 0.5m UFL cable S-Parameters

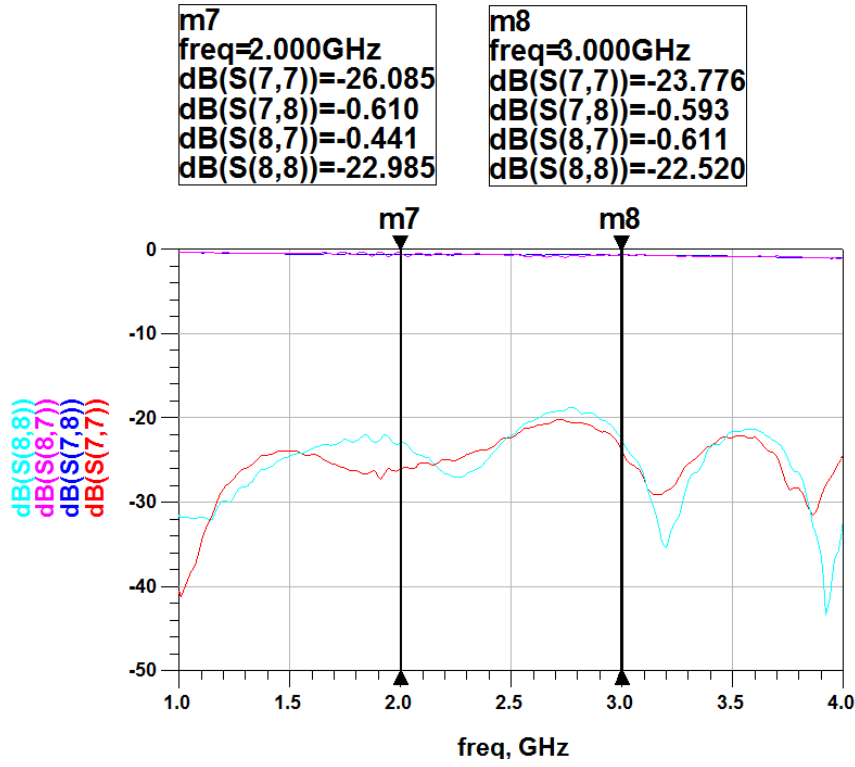


Figure 5.9: 0.5m UFL cable S-Parameters

It can be seen that there is a larger loss from the UFL cable seen in Figure 5.9 in comparison to the SMA cabling seen in Figure 5.6 and 5.7. It has been decided that the design would suffer this loss in order to allow for a more flexible cabling method allowing for a device which is significantly more portable and smaller.

An issue was found that can be seen in Figure 5.8, this is a UFL connector that has been connected and disconnected multiple times; UFL cabling is commonly designed for less than 20 mating's. A new UFL cable was tested which can be seen in Figure 5.9, giving a significantly better response for insertion and reflection.

5.2 RF Switch Matrix

This section looks at the overall characteristics of the final RF switch matrix design. To determine the overall performance of the system, this required evaluating the performance, speed, size and power constraints.

5.2.1 Final Design

From looking at the results obtained in Section 5.1 it can be seen that the only option for the output SPDT switch is 'Output 1'. Therefore the 16 output terminals will have the reflection seen in Figure 5.5 S_{22} signal, this will be connected to the

SP16T via a UFL-UFL connector seen in Figure 5.9.

Looking at the results obtained, it can be seen that ‘Design ...’ has an insertion loss of ...dB

Therefore the final design will use ‘Design ...’ and ‘Output 1’.

5.2.2 Losses

In order to determine the characteristics of the designed RF switch matrix, its characteristics can be modelled using S-Parameters to evaluate the final design. Using the ABCD VNA the switch matrix was analysed to determine the amount of losses that are present in the system.

Looking at Figure ?? we can determine the performance of the overall system. There are multiple paths that need to be considered in order to fully evaluate the RF switch, there are 9 different paths that can be taken; these can be seen below in Figure 5.10 - 5.18.

Figure 5.10: S-Parameters of RF switch matrix
(Left) Path 1, (Right) Diagram

Figure 5.11: S-Parameters of RF switch matrix
(Left) Path 2, (Right) Diagram

Figure 5.12: S-Parameters of RF switch matrix
(Left) Path 3, (Right) Diagram

Figure 5.13: S-Parameters of RF switch matrix
(Left) Path 4, (Right) Diagram

Figure 5.14: S-Parameters of RF switch matrix
(Left) Path 5, (Right) Diagram

Figure 5.15: S-Parameters of RF switch matrix
(Left) Path 6, (Right) Diagram

Figure 5.16: S-Parameters of RF switch matrix
(Left) Path 7, (Right) Diagram

Figure 5.17: S-Parameters of RF switch matrix
(Left) Path 8, (Right) Diagram

Figure 5.18: S-Parameters of RF switch matrix
(Left) Path 9, (Right) Diagram

5.2.3 Speed

We know from Section 4.5 that micro-controller is capable of controlling the switches at ns, but the SSR's are not capable of operating at this speed. Therefore the maximum switching frequency needs to be determined for this RF switch.

Looking at the datasheets it can be seen that the is the slowest chip in this system which bottlenecks the maximum performance of the switch. Therefore we can say that theoretical switching speed is limited to μ s.

With the fully developed RF switch matrix it can be fully evaluated to determine its performance in regard to speed; as can be seen in Figure 5.19 the switch matrix is wired so that one input and output are connected to the VNA.

Figure 5.19: Speed test set-up for RF Switch Matrix

Using the set-up shown in Figure 5.19 the VNA monitor's the signal strength to determine the speed which causes the insertion loss to drop below the level seen in Figure 5.10. By doing this it was determined that the maximum switching speed of the micro-controller is ... μ s, which is close to the expected limit of the RF chip.

5.2.4 Power Requirements & Control

Chapter 6

Discussion

6.1 Problems

6.1.1 Resource Availability

6.2 Objective Fulfilment

6.2.1 Comparison to Available Technology

6.3 Contributions

Chapter 7

Conclusions and Future Work

7.1 Conclusion

7.2 Future Work

Appendix A

PCB Design

A.1 Design 1

A.2 Design 2

A.3 Design 3

A.4 Output Design 1

A.5 Output Design 2

A.6 Output Design 3

Appendix B

Substrate Parameters

The following tables contain the parameters and details for the substrates investigated in this thesis.

Parameter	Value
Er	4.7
Mur	1
H	even

Table B.1: *Parameters for simulation of FR-4 substrate*

Appendix C

Bill of Materials

In order to construct the design of the Switching Matrix we require the following components, a Bill of Materials has been constructed and can be seen in Table ??.

Name	Description	Digikey Part no.	Min Order no.	Price	Quantity	Total

Total:						\$100
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Table C.1: *Bill of Materials*

Appendix D

RF Switch Controls

D.1 Design 1

Table D.1: Add caption

Design 1															
Input				Output											
x_3	x_2	x_1	x_0	$SPDT_1$		$SPDT_2$		$SPDT_3$		$SPDT_4$		$SPDT_5$		$SPDT_6$	
				Input 1	Input 2	Input 1	Input 2	Input 1	Input 2	Input 1	Input 2	Input 1	Input 2	Input 1	Input 2
0	0	0	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	0	0	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	0	1	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	0	1	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	1	0	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	1	0	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	1	1	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
0	1	1	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	0	0	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	0	0	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	0	1	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	0	1	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	1	0	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	1	0	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	1	1	0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0
1	1	1	1	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0	x_0	\bar{x}_0

D.1.1 Design 2

D.1.2 Design 3

D.1.3 Output 1

D.1.4 Output 2

Appendix E

Companion disk

If you wish to make some computer files available to your examiners, you can list and describe the files here. The files can be supplied on a disk and inserted in a pocket fixed to the inside back cover.

The disk will not be needed if you can specify a URL from which the files can be downloaded.

Bibliography

- [1] “Wireless prototyping with software defined radio.(ni usrp rio software defined radios)(product feature),” *Microwave Journal*, vol. 57, no. 5, p. 208, 2014.
- [2] J. Marimuthu, K. S. Bialkowski, and A. M. Abbosh, “Software-defined radar for medical imaging,” *Microwave Theory and Techniques, IEEE Transactions on*, vol. 64, no. 2, pp. 643–652, 2016.
- [3] —, “Software-defined radar for medical imaging,” *Microwave Theory and Techniques, IEEE Transactions on*, vol. 64, no. 2, pp. 643–652, 2016.