SAW SENSOR PROPERTIES AT ELEVATED AND CYCLIC TEMPERATURE

By

MOHAMAD KHAIRUL ZULFADLY BIN MOHD IZHAM

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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Dr Zainal Arif Bin Burhanudin

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohamad Khairul Zulfadly Bin Mohd Izham

ABSTRACT

This project was conducted to obtain SAW sensor properties at elevated and cyclic temperature. The main objective is to apply certain range of temperature towards the SAW sensor. Amplitude and phase of the S parameter of the sensor then will be analyzed. S Parameters that will be focused on this project is S11 and S21 which are the reflection coefficient and tranmission coefficient. Variation of temperatures from 25^{0}C to 100 ^{0}C will be applied to the sensor in order to observe and analyze any changes in the amplitude and phase of the S21 and S11 parameters. The result shows that the properties of the sensor does not affected too much by the variance of temperatures. It can be concluded that the sensor can be functional at elevated and cyclic temperature without produce significance changes at the S21 and S11 parameters.

ACKNOWLEDGEMENT

I would like to express my gratitude to Allah s.w.t. for the strength and opportunity to complete my Final Year Project (FYP). It would not have been possible without the kind support and help of many individuals. I would like to extend my sincere thanks to all of them.

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INTRODUCTION

1.1 Background of Study

Corrosion to pipeline and facilities need to be minimized. For corrosion to take place, several elements like water and oxygen, need to be present. Measuring or monitoring any one of the elements could help minimize corrosion. For corroded pipes, one can apply composite wrappings and wrap it around to protect and repair corroded sections of the pipelines. The composite wrappings has been developed and applied to many PETRONAS facilities. Unfortunately, the biggest concerns nowadays are the integrity of the composite wrappings and the pipe underneath it. To address the concerns, one proposes to use Surface Acoustic Wave (SAW)-based corrosion sensor. After been introduced, SAW sensor has been used widely in many fields.

Sensor	Finding
Gas	Gas molecules will be absorbed by the sensor and change the propagation of surface wave. This change can be detected by the sensor using electronic device.
Small Vibration	Any composite on the sensor will cause delay time of the surface wave. This change will able the sensor to detect any small vibration occurs.
Chemical	Propagation speed and attenuation of surface wave will be modified in the presence of various chemical substances. Variety of chemical substances can be detected by the sensor.

Table 1.1: SAW Sensor Findings

Throughout the various findings on SAW sensor, this sensor has been found to be a suitable type of sensor to be used in pipeline corrosion detection. The sensor has been developed and lab-tested at room temperature. It can sense corrosion and gives an approximate metal loss. It shows great potential and warrant further research and development.

1.2 Statement of Problem

The SAW-based sensor has been demonstrated at room temperature. However, in real world, it needs to operate at cyclic temperature similar to the pipeline cyclic temperature. Therefore, characterization of the SAW-based sensor at elevated and cyclic temperature needs to be done.

1.3 Research Objective

The objective of this project is to characterize the SAW-based sensor at elevated and cyclic temperature.

1.4 Scope of Study

The study of this project mainly focuses on the background of SAW sensor and its characteristics, the properties of temperature and familiarization with experiment instruments. Besides that, this project also focuses on characterization analysis of SAW sensor at elevated and cyclic temperature based on experimental design. As corrosion under insulation (CUI) is active at 60°C to 80°C for carbon steel, the temperature manipulated will be in the range of room temperature to 100°C.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The review of literature covers the pipeline corrosion, pipeline corrosion inspection technique, Surface Acoustic Wave (SAW) technology, principle of SAW sensor and S21 and S11 parameters.

2.2 Pipeline Corrosion

Pipeline corrosion is a major issue and need to be minimized as it plays an important role in oil and gas industries. In term of flexibility of routes and large quantity to be moved on, pipeline is perhaps the most economical and efficient means of large scale fluid transportation for crude oil and natural gas compared to tanker, truck and rail transportation [1]. Major elements of oil pipeline are built with carbon steel pipes with certain diameter up to 500mm. In the presence of water and high corrosive agents, it increases the risk of pipeline corrosion [2].

The composite wrappings has been developed and applied to many PETRONAS facilities in order to prevent corrosion of the pipeline. Unfortunately, the biggest concerns nowadays are the integrity of the composite wrappings and the pipe underneath it. In a long term, corrosion will gradually reduce the performance of mechanical components and structures [3]. Most of the studies in pipeline corrosion are more focusing on internal corrosion instead of external corrosion of the pipeline.

2.3 Pipeline Corrosion Inspection Technique

However, it needs to be highlighted that either internal or external corrosion of pipeline are vital in term of reducing cost for maintenance and operation. Pipeline requires inspection and maintenance activities over a period of time in order to keep corrosion risks under control [4]. However, using conservative inspection techniques for maintenance activities are quite costly. To address the concerns, new technique need to be introduced and SAW-based corrosion sensor has been proposed to give a new era in pipeline corrosion inspection technique

2.4 SAW Technology

In 1885, Lord Rayleigh had explained about Surface Acoustic Wave for the first time and the wave mode of propagation and its predicted properties have been described in his classic paper [5]. SAW technology and devices have been commercialized widely in the fields of communication, automotive and environmental sensing [6]. SAW is difference compared to another type of wave in term of propagation medium as it is a type of acoustic waves that travelling along the surface of a material. SAW devices are suitable for sensor applications such as temperature sensors, mass sensors and pressure sensors due to their high accuracy and crystal stability over time [7].

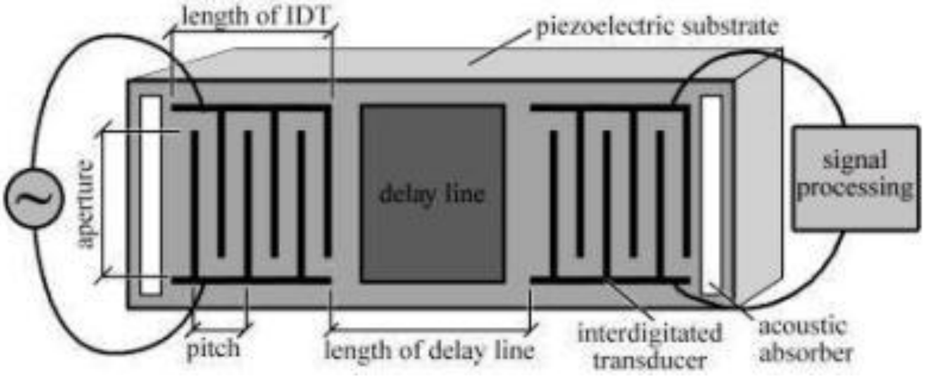

Figure 2.1: General SAW Sensor Diagram

2.4 Principle of SAW Sensor

The principle of operation of SAW sensor is based on the wave's delay time measurement. In order to detect pipeline corrosion, SAW sensor will be located at the outer surface of the pipeline. Delay time and propagation speed of SAW will be interrupted when there are small changes in the composition of the SAW sensor surface [8]. These changes will indicate corrosion of the pipeline. The SAW-based corrosion sensor can sense corrosion and gives an approximate metal loss. The sensor has been developed and lab-tested at room temperature.

2.5 S21 and S11 Parameters

Transmission coefficient, S21 and reflection coefficient, S11 are the S parameters that will be used as the references to detect corrosion using SAW sensor. Any changes in the magnitude and phase of the S21 and S11 will be the indicator for corrosion.

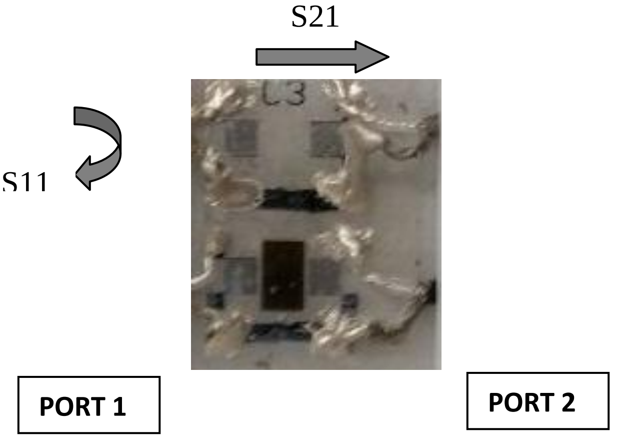

Figure 2.2: Diagram on S21 and S11 Parameters

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Introduction

The research methodology consists of project planning and experimental design. Project planning includes the preparation of plan in tabular form such as Gaant chart. Experimental design is to produce experimental procedure in order to conduct experiment.

3.1.1 Research Flowchart

This study emphasis more on results obtained from the characterization of the sensor at room and cyclic temperature. The S21 and S11 parameters of the sensor will be analysed and any findings will be recorded. Thus, the study will more toward the analysis of results obtained.

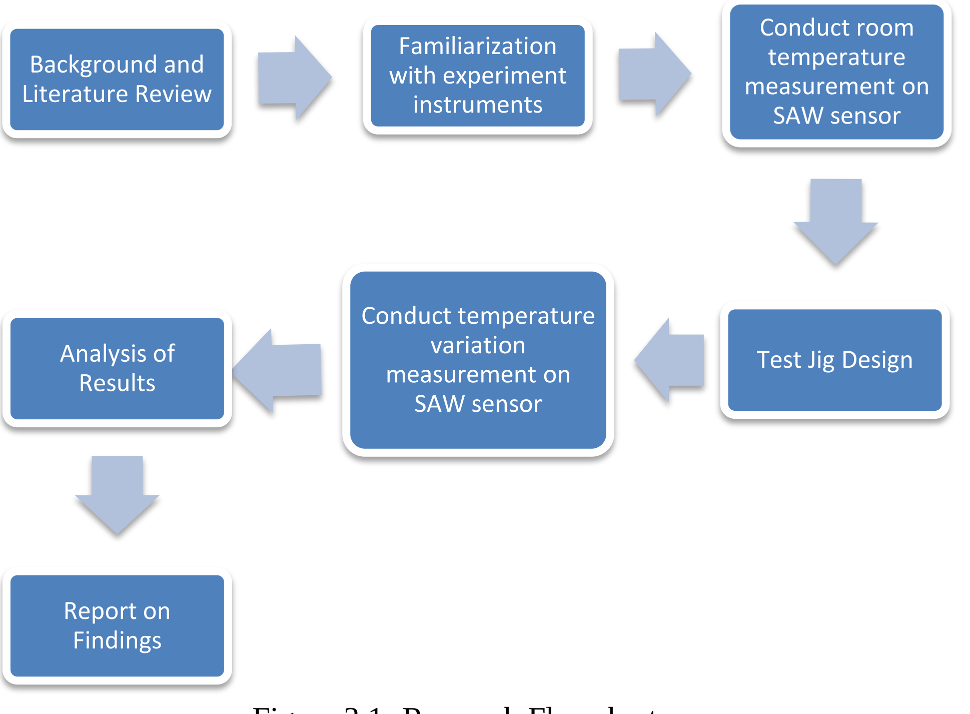

Figure 3.1: Research Flowchart

In this project, SAW sensor is the main component that needs to be analyzed in term of physical background and characteristics. SAW based corrosion sensor has been developed and be tested in room temperature. Further experiments need to be done in order to characterize the sensor at elevated and cyclic temperature. For that purpose, experiment instruments need to be familiarized before the experiment can be started. An example of instrument that will be used during the testing is fieldfox network analyzer.

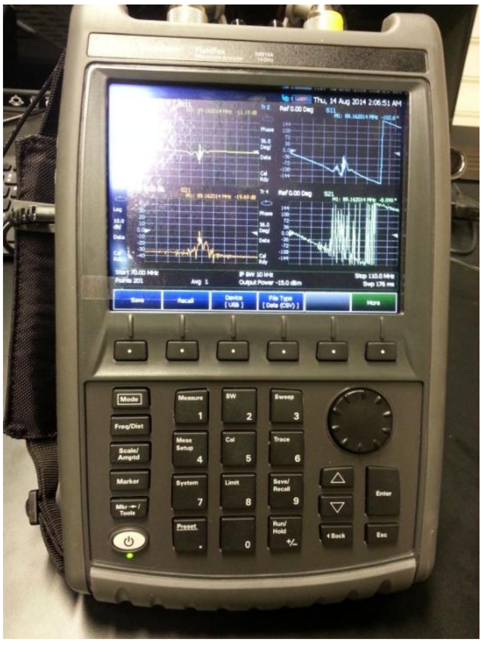

Figure 3.2: Fieldfox Network Analyzer

To commence the project, experimental design needs to be prepared for the prototype testing as the design will determine the control and manipulated variables for the experiment. The sensor will undergo several tests with different temperatures before analyzation of data can be started.

3.1.2 Project Activities

The project activities include the planning of the project and the execution of experiment. The detailed of the plan for this project can be seen in **APPENDIX 1**.

3.2 List of Chemical and Equipments

Listed below are the chemicals and equipment required in order to conduct the study.

CHEMICALS	EQUIPMENT
• Silver Paste	• Network Analyzer • Fieldfox Network Analyzer • Environmental Chamber

Table 3.1: List of Chemical and Equipments

3.3 Experimental Procedures

Three experiment procedures were produced in order to conduct the experiment. The procedures were for the sensor testing, test jig design and testing in elevated and cyclic temperature.

3.3.1 Sensor Testing

A testing has been done towards the SAW sensor in room temperature using Vector Network Analyzer. The understanding of the sensor and application of two port network has been done before the testing be conducted. Main element to be observed in the testing is S parameters which are reflection coefficient, S21 and transmission coefficient, S22.

Figure 3.3: Vector Network Analyzer

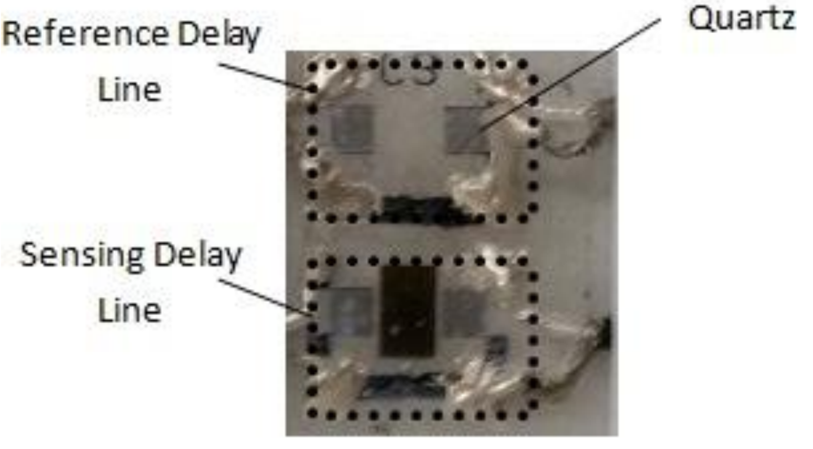

Figure 3.4: SAW Sensor

The result of the simulation is summarized in below graphs. The central frequency of this sensor is 90MHz. This test is conducted in a frequency range from 75MHz to 115MHz. From the magnitude graphs, power loss of S21 is 10 dB while power loss for S11 is 22 dB. Based on phase graphs, the range of the degree for S21 is between 150° and -150°, while range of the degree for S11 is between -50° and -150°,

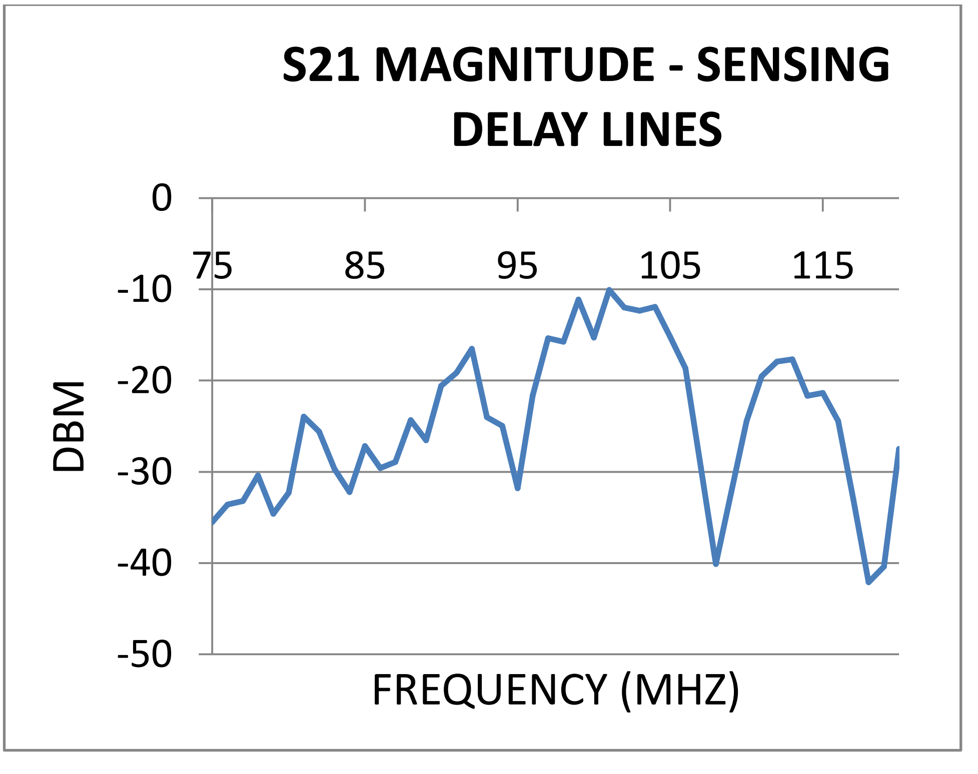

Figure 3.5: Graph of S21 Magnitude for Sensing Delay Lines

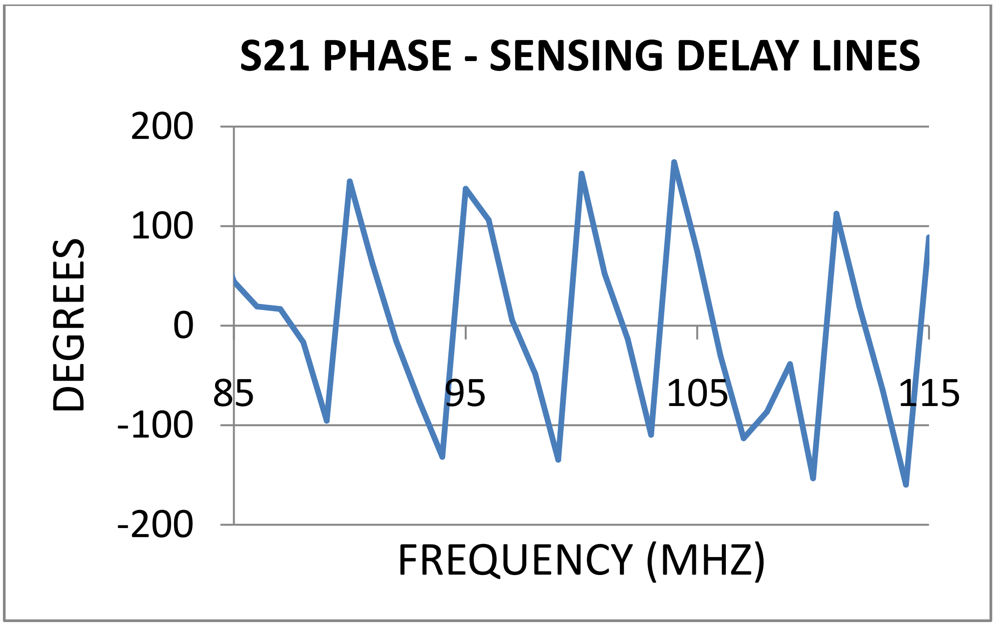

Figure 3.6: Graph of S21 Phase for Sensing Delay Lines

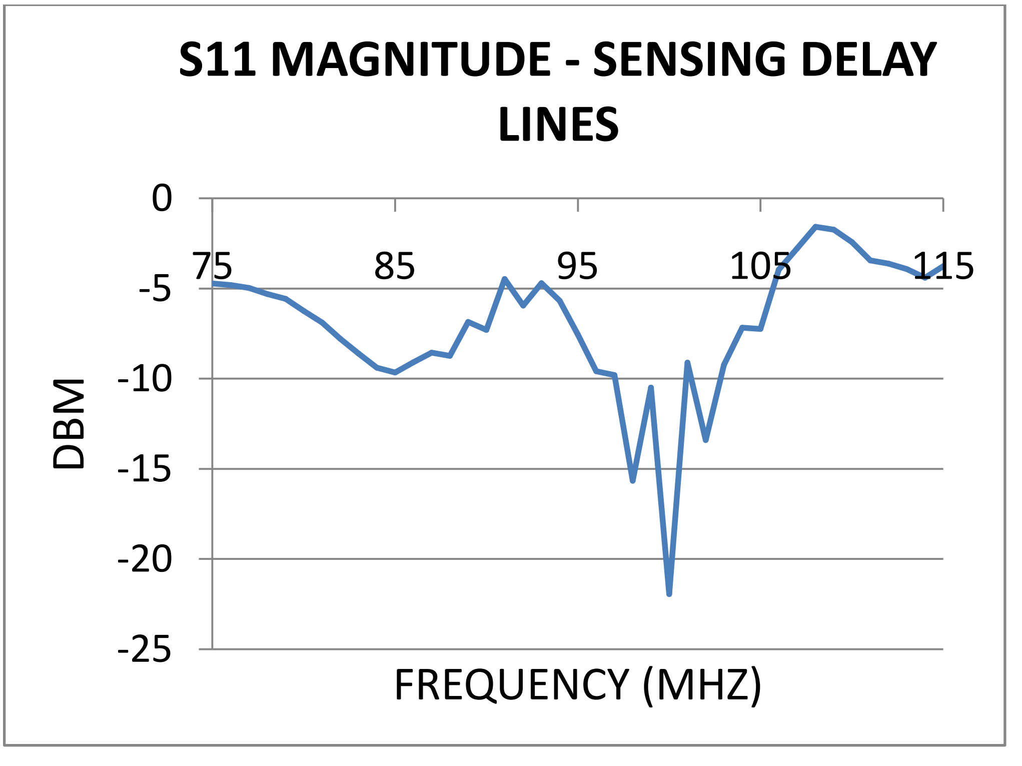

Figure 3.7: Graph of S11 Magnitude for Sensing Delay Lines

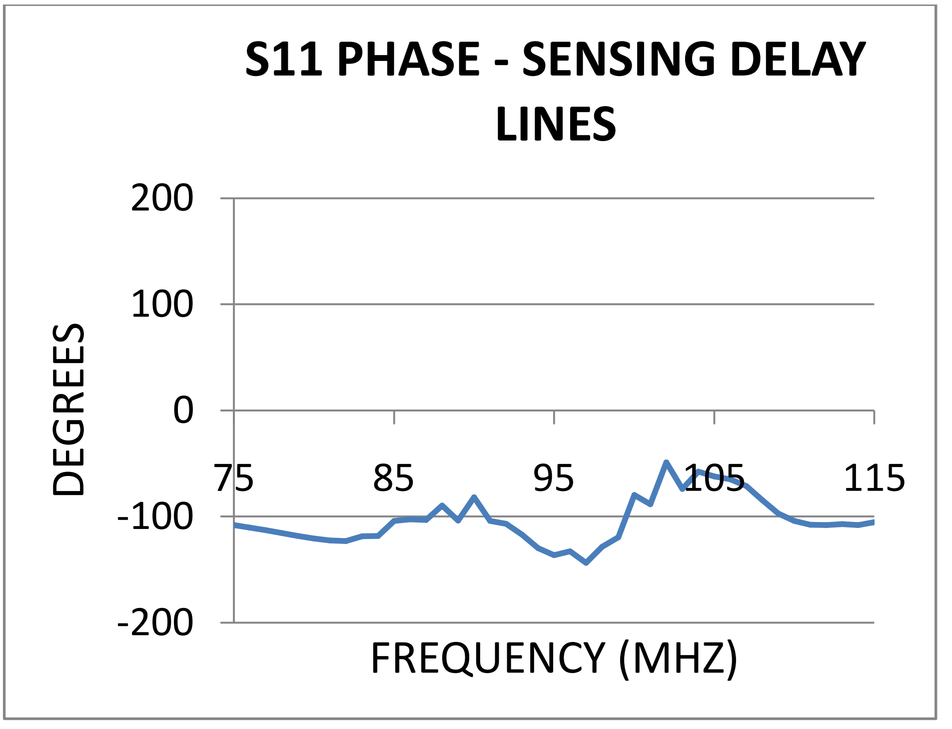

Figure 3.8: Graph of S11 Phase for Sensing Delay Lines

3.3.2 Test Jig Design

In order to hold the sensor during the testing, a holder needs to be designed. Holding the sensor is important in order to reduce error during measurement. The holder has been designed using software, CATIA and later the fabrication of the sensor has been made using 3D printer. There are two types of holders for the sensors. First holder is been designed for sensor B and D, while the other holder is for sensor A and D. The difference of the designs is due to the size of the sensors. All the measurement of the holders is in millimetre.

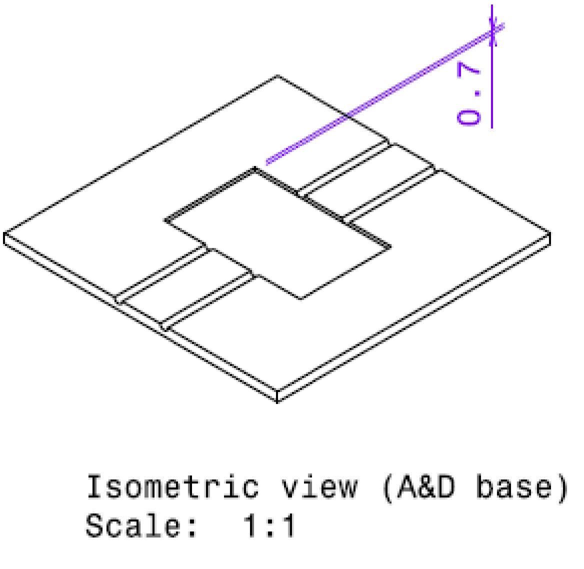

Figure 3.9: Design of Holder Base for Sensor A and D

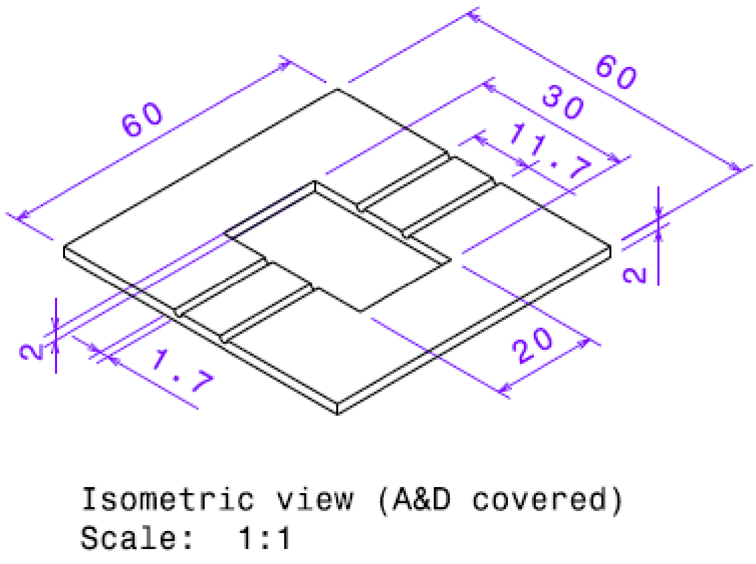

Figure 3.10: Design of Holder Cover for Sensor A and D

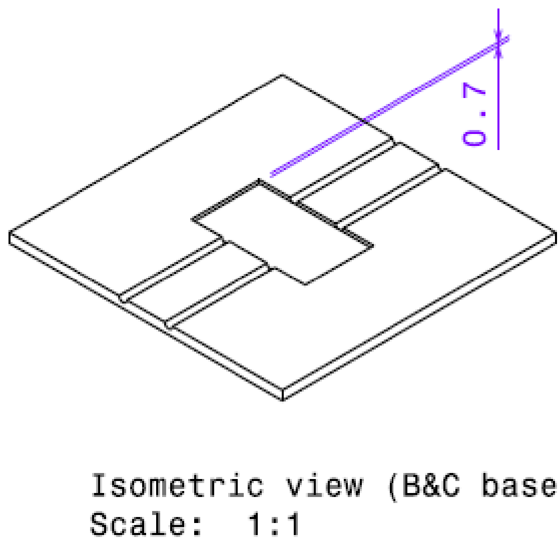

Figure 3.11: Design of Holder Base for Sensor B and C

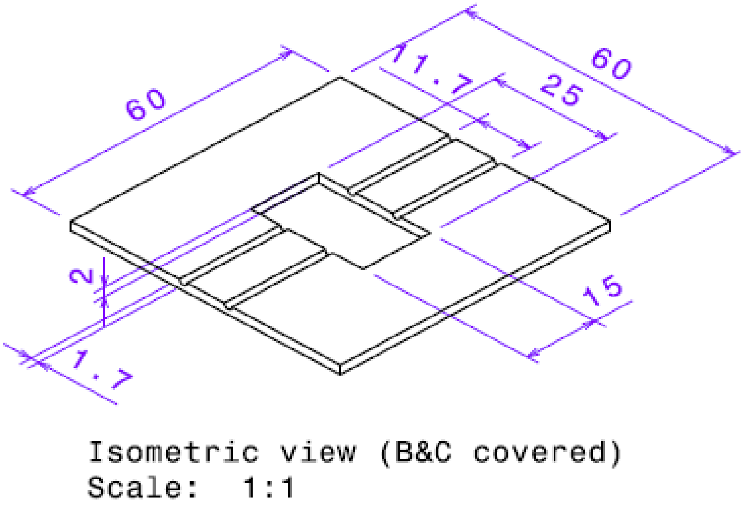

Figure 3.12: Design of Holder Cover for Sensor B and C

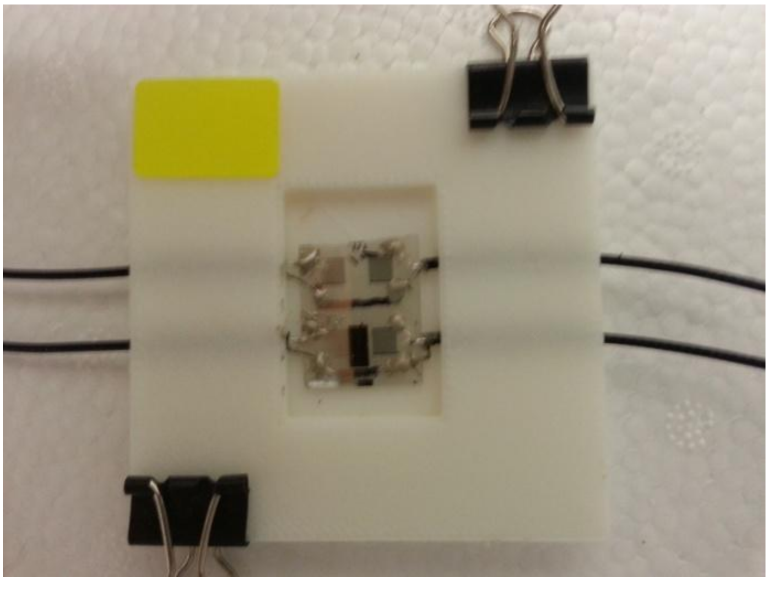

Figure 3.13: Holder Prototype

3.3.3 Testing in Elevated and Cyclic Temperature

The SAW sensor has been tested in room and cyclic temperature using Environmental Chamber. During the testing, measurement of the S21 and S11 has been taken in order to observe and analyze the result. The temperature range for this testing is between 25 ^{0}C until 100 ^{0}C.

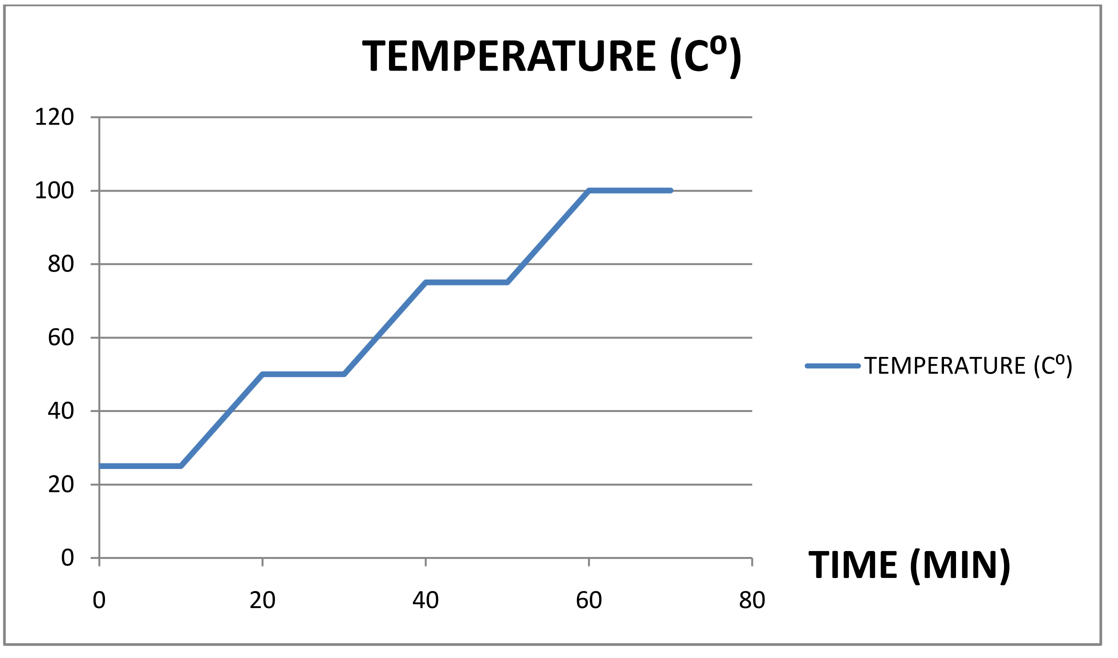

Figure 3.14: Cyclic Temperature Profile

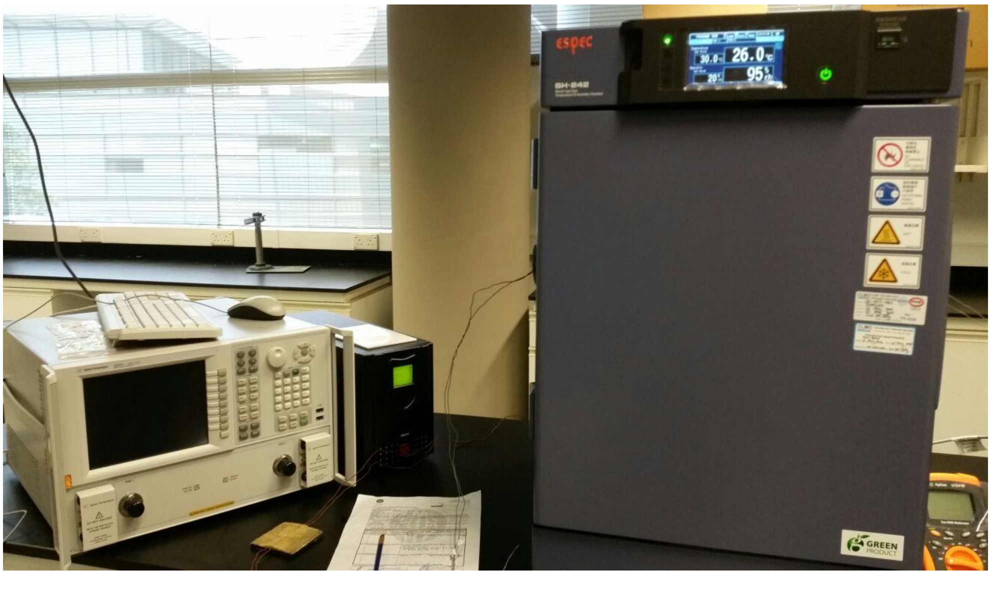

Figure 3.15: Environmental Chamber

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

For overall, this project is presented as having three implementation phases. Further research and study has been carried out in first phase, thus give an idea for JIG designing and testing in second phase. Third phase will involve in measurement where characterization of the sensor will be done in elevated and cyclic temperature. The S21 and S11 parameter at the cyclic temperature will be analyzed and discussed here.

4.2 Characterization of SAW Sensor at Cyclic Temperature

The characterization of the SAW sensor is analysed using Fieldfox Network Analyzer to identify any changes in S21 and S11 measurement of the sensor in cyclic temperature. Temperature variations have been done using Environmental Chamber. The result of the measurement at temperature of 25 ^{0}C, 50 ^{0}C, 75 ^{0}C and 100^{0}C has been taken to be analyzed later.

4.2.1 S21 and S11 Parameters at 25^{0}C Results

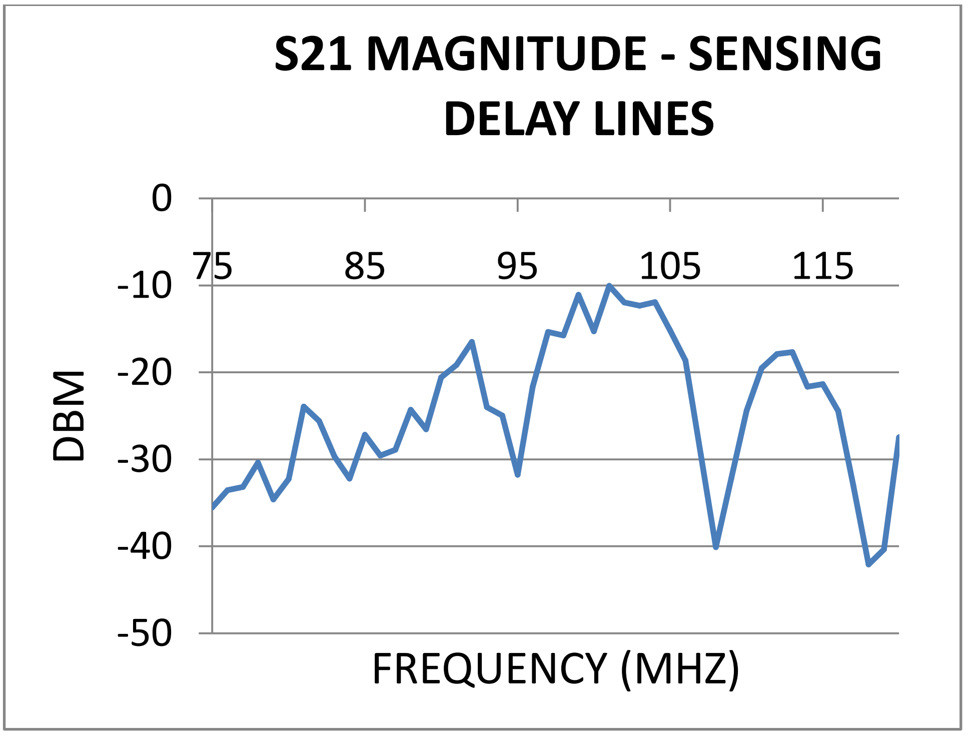

Figure 4.1: S21 Magnitude for Sensing Delay Lines at 25 ^{0}C

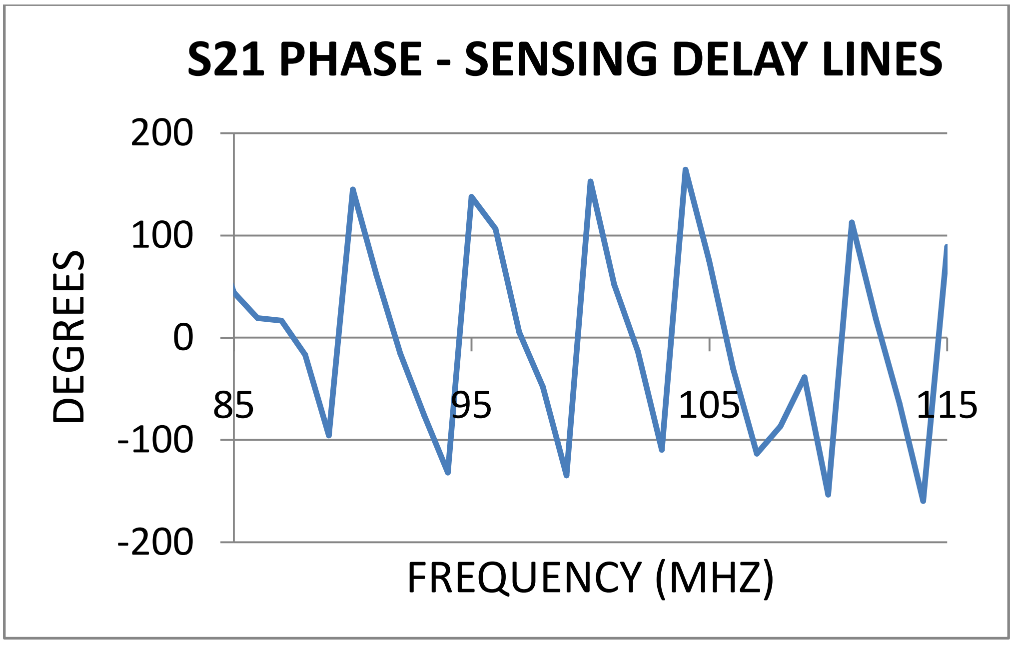

Figure 4.2: S21 Phase for Sensing Delay Lines at 25 ^{0}C

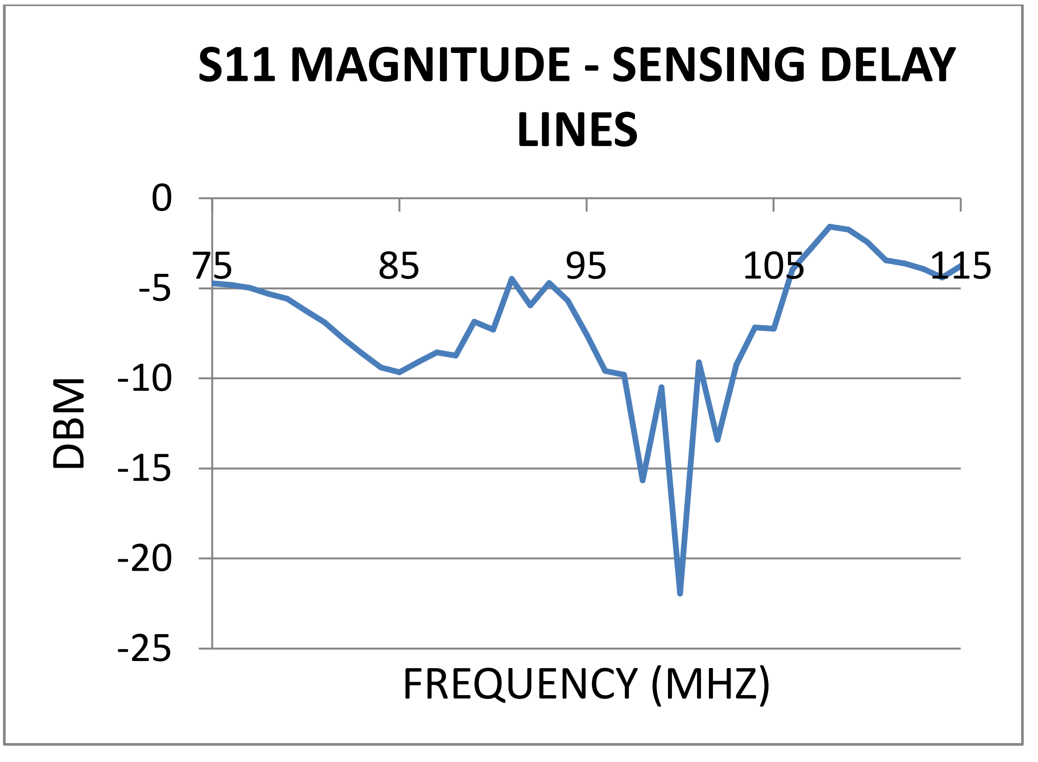

Figure 4.3: S11 Magnitude for Sensing Delay Lines at 25 ^{0}C

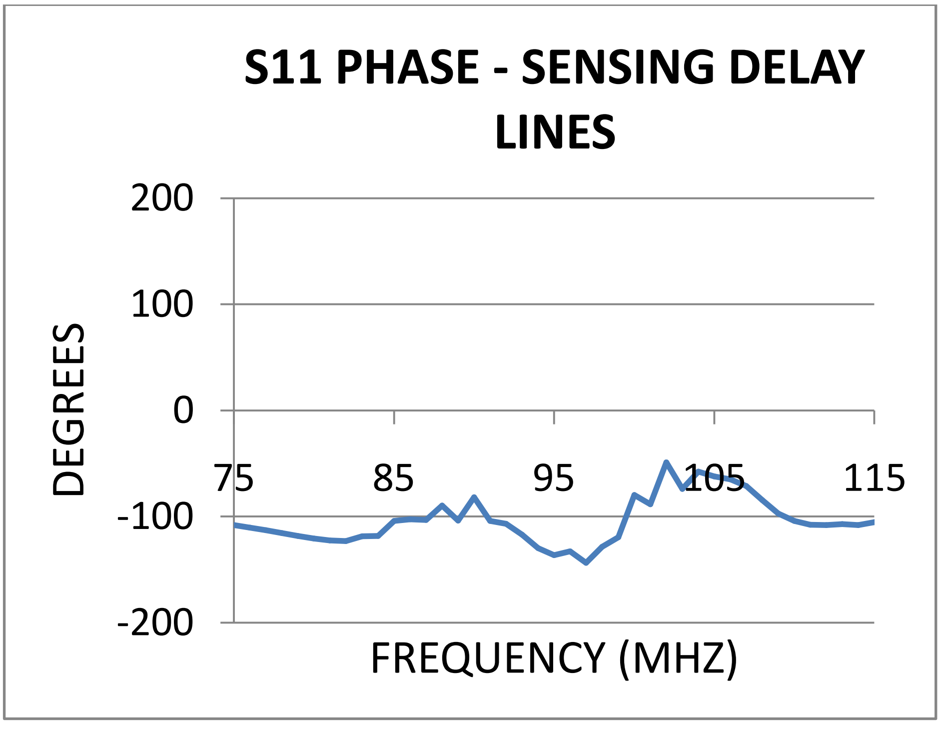

Figure 4.4: S11 Phase for Sensing Delay Lines at 25 ^{0}C

From the S21 and S11 magnitude graphs, S21 experiences power loss of 10 dB while S11 has power loss of 22 dB. From the S21 and S11 phase graphs, the range of the degree for S21 is between 165° and -160°, while range of the degree for S11 is between -49° and -143°.

4.2.2 S21 and S11 Parameter at 50^{0}C Results

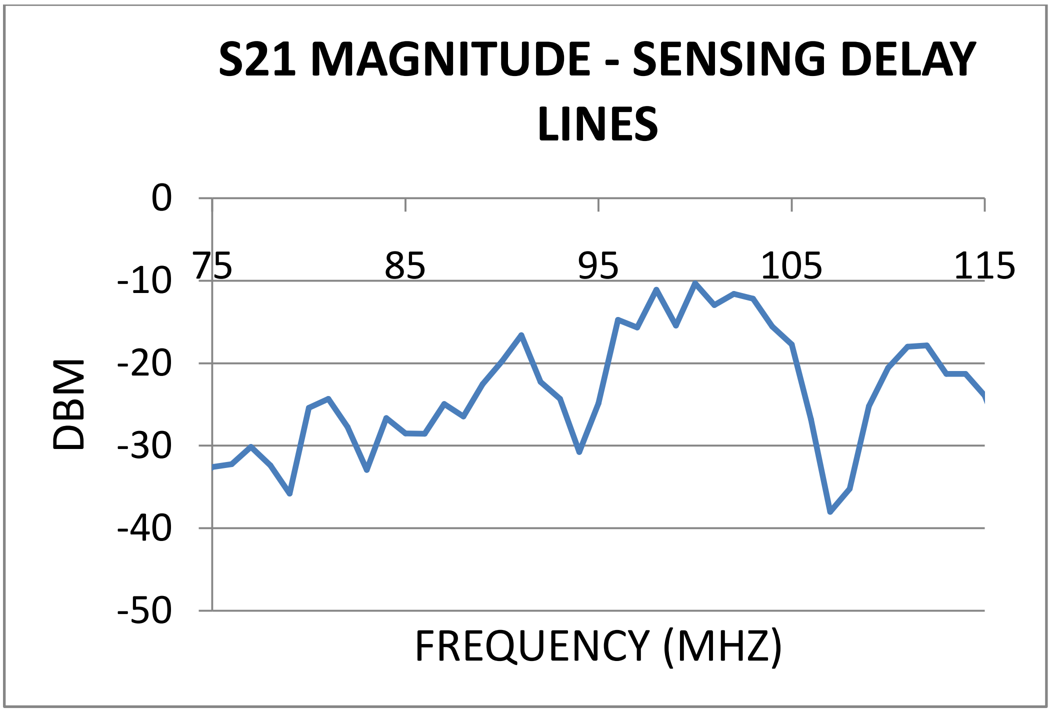

Figure 4.5: S21 Magnitude for Sensing Delay Lines at 50^{0}C

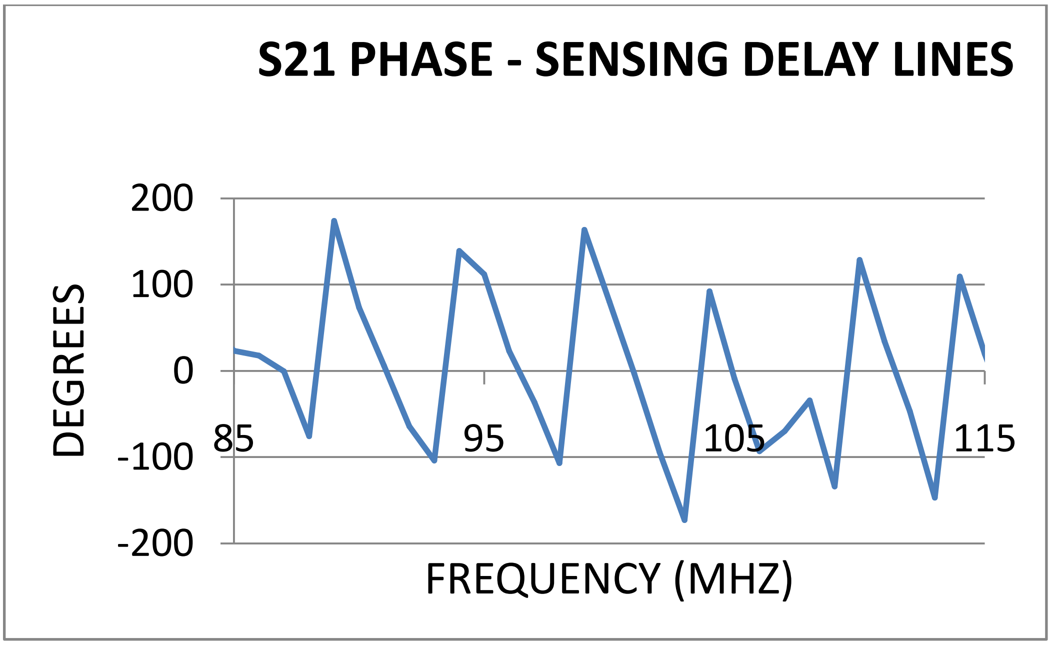

Figure 4.6: S21 Phase for Sensing Delay Lines at 50^{0}C

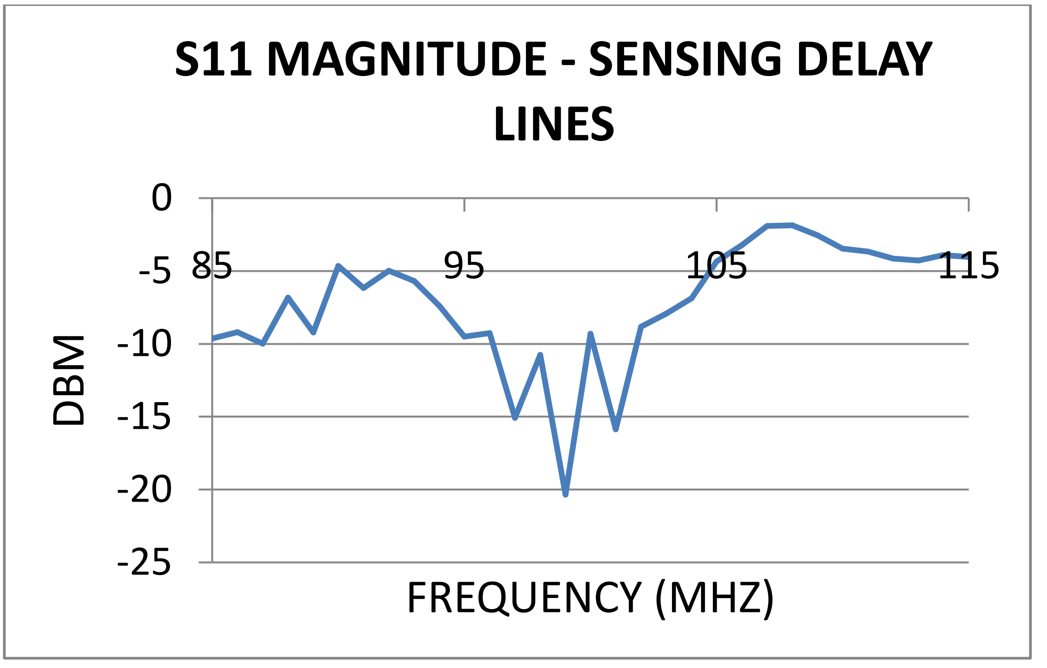

Figure 4.7: S11 Magnitude for Sensing Delay Lines at 50^{0}C

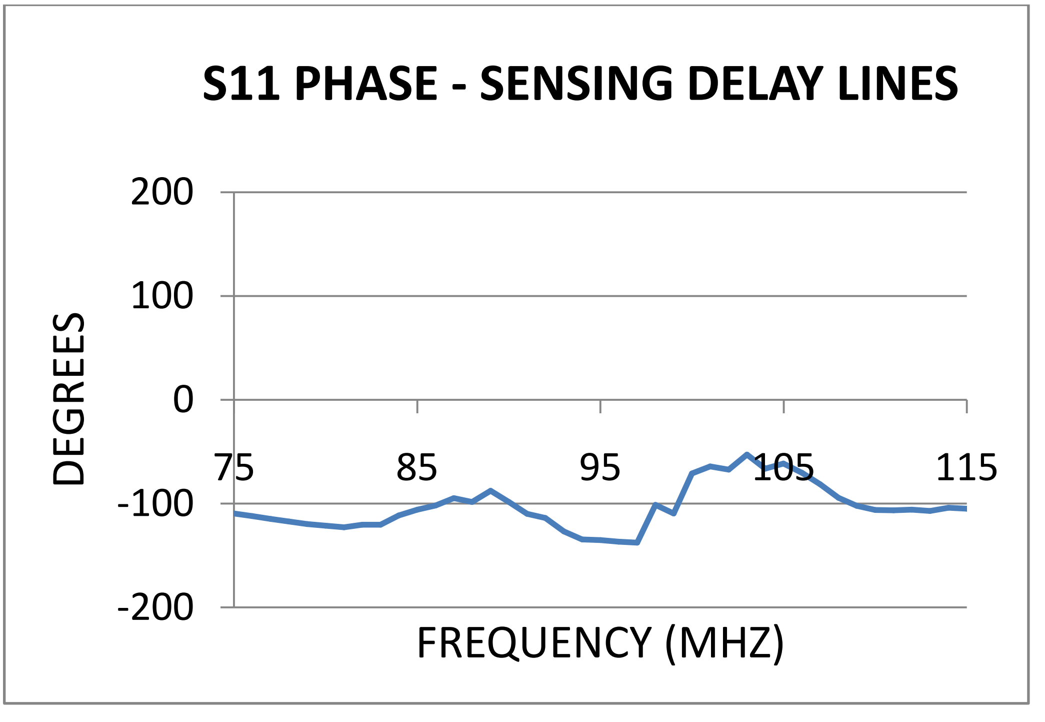

Figure 4.8: S11 Phase for Sensing Delay Lines at 50^{0}C

From the S21 and S11 magnitude graphs, S21 experiences power loss of 10 dB while S11 has power loss of 20 dB. From the S21 and S11 phase graphs, the range of the degree for S21 is between 174° and -173°, while range of the degree for S11 is between -53° and -138°.

4.2.3 S21 and S11 Parameter at 75^0C Results

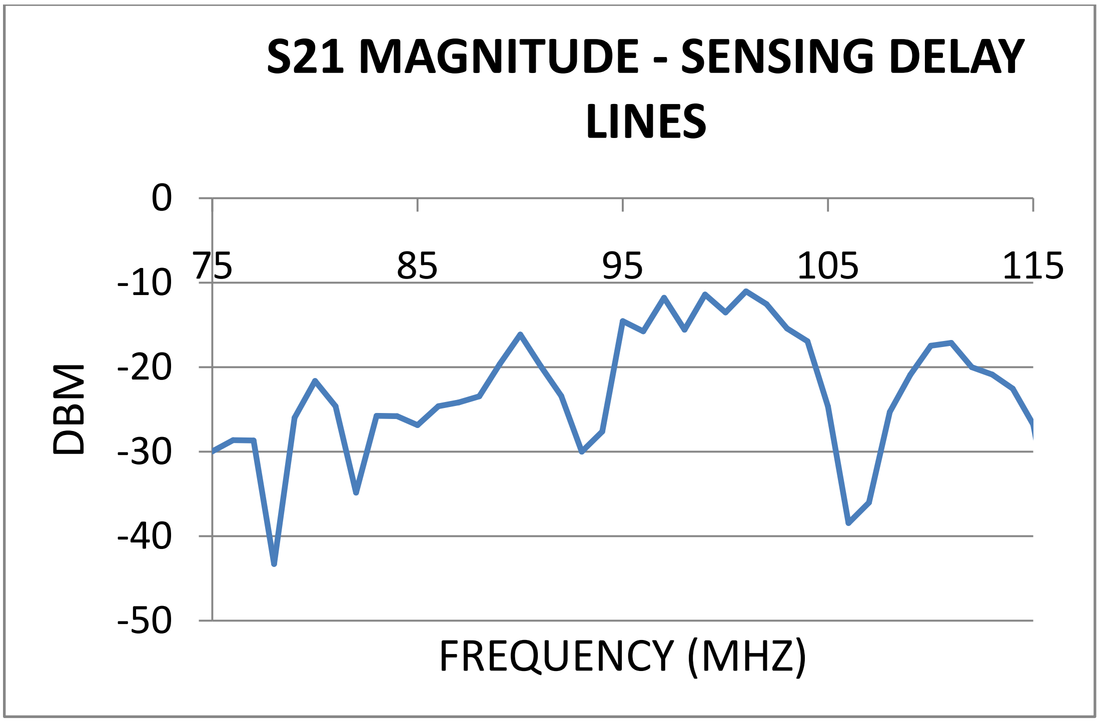

Figure 4.9: S21 Magnitude for Sensing Delay Lines 75^0C

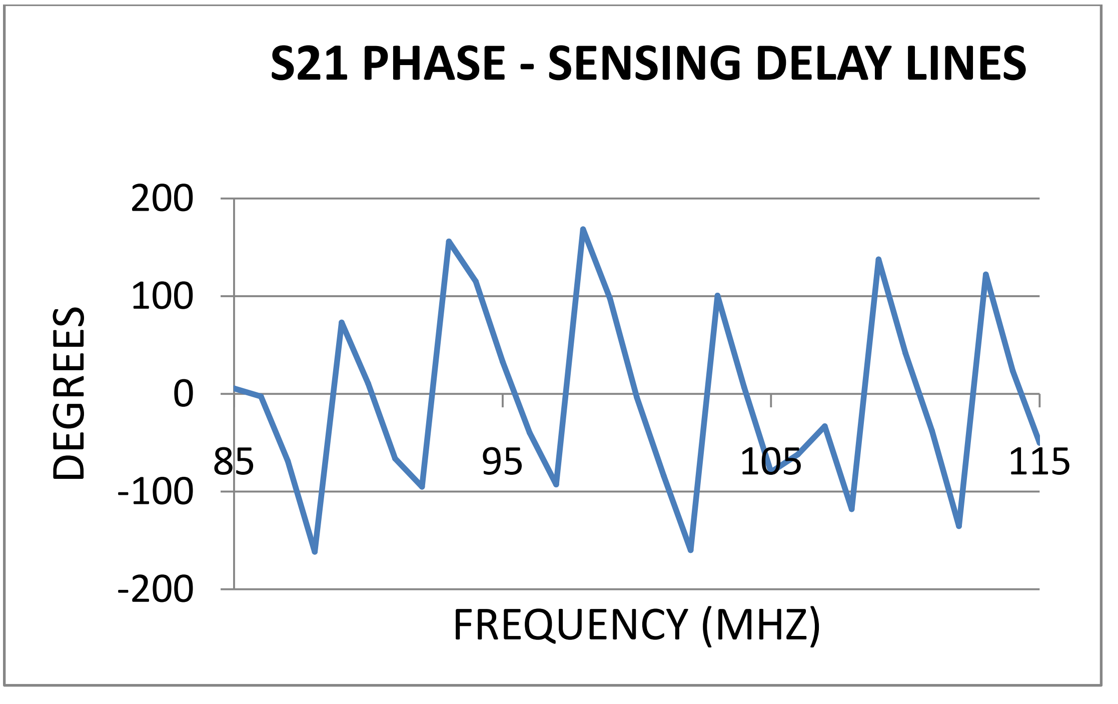

Figure 4.10: S21 Phase for Sensing Delay Lines at 75^0C

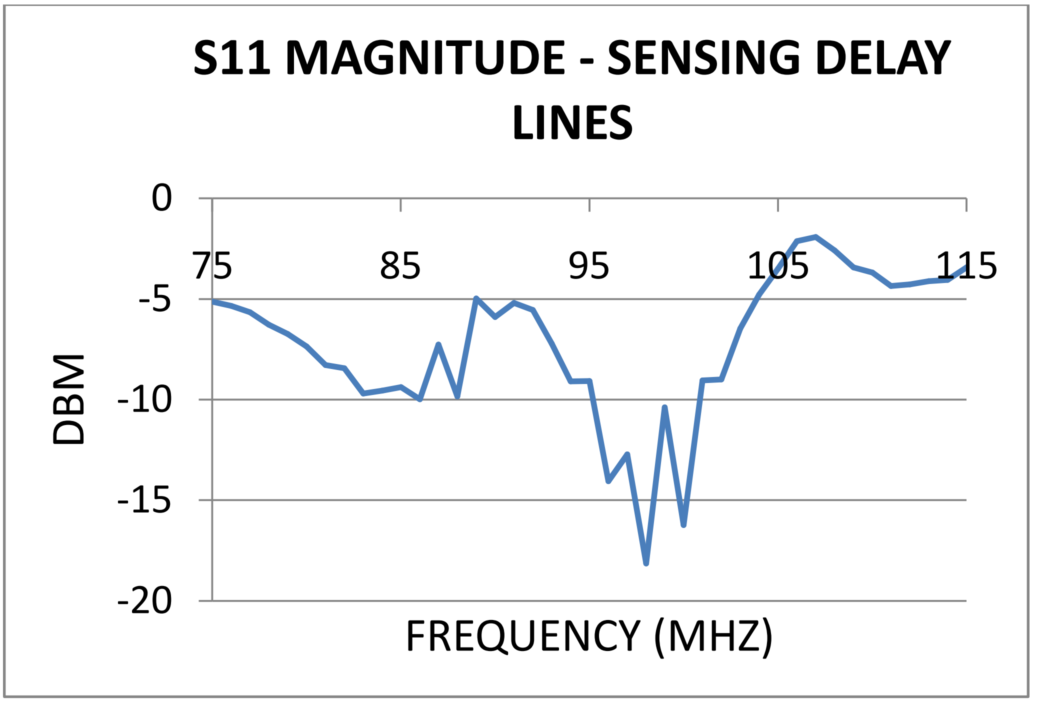

Figure 4.11: S11 Magnitude for Sensing Delay Lines at 75^{0}C

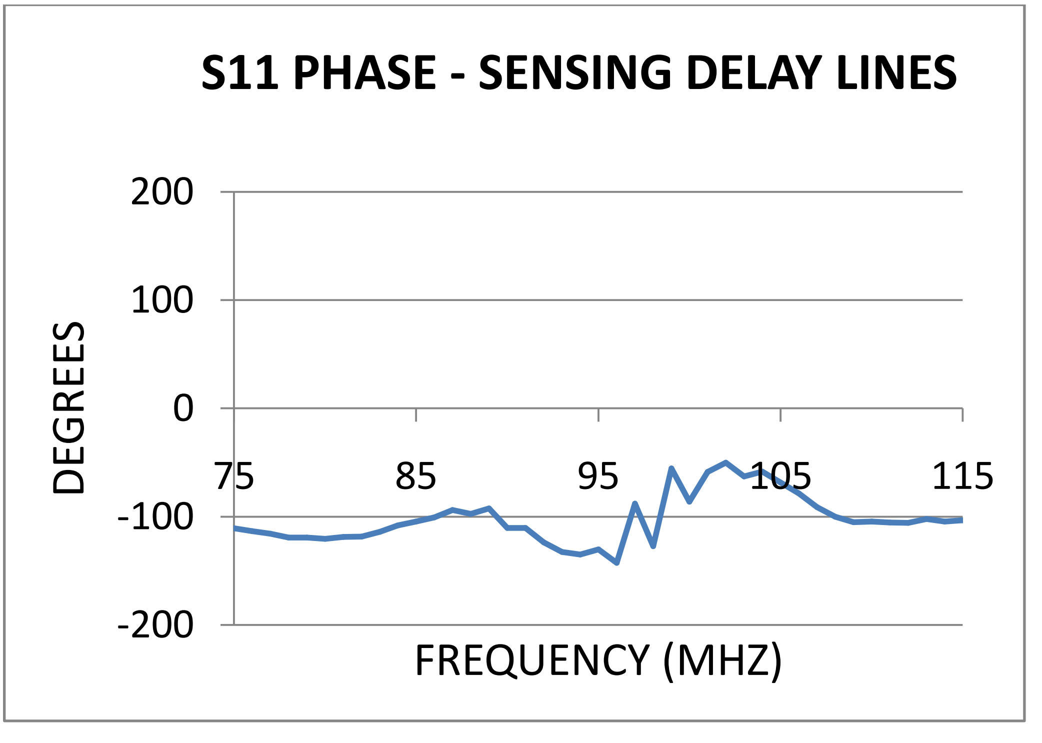

Figure 4.12: S11 Phase for Sensing Delay Lines at 75^{0}C

From the S21 and S11 magnitude graphs, S21 experiences power loss of 9.8 dB while S11 has power loss of 18 dB. From the S21 and S11 phase graphs, the range of the degree for S21 is between 168° and -161°, while range of the degree for S11 is between -55° and -143°.

4.2.4 S21 and S11 Parameter at 100^{0}C Results

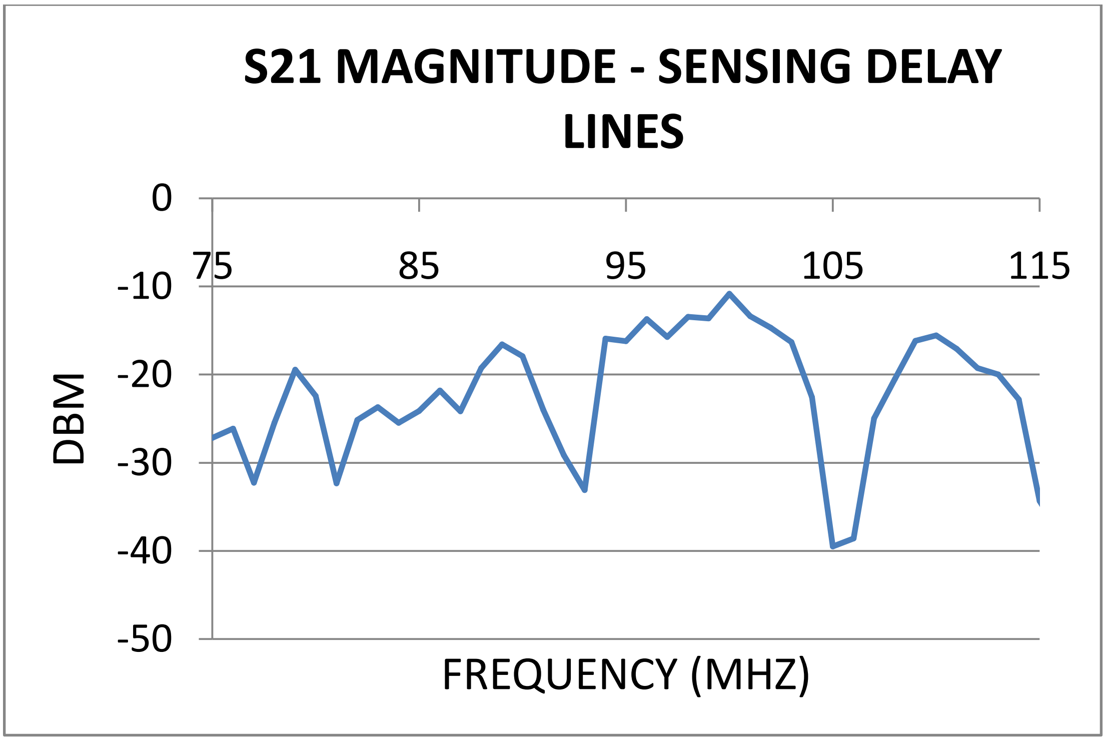

Figure 4.13: S21 Magnitude for Sensing Delay Lines at 100^{0}C

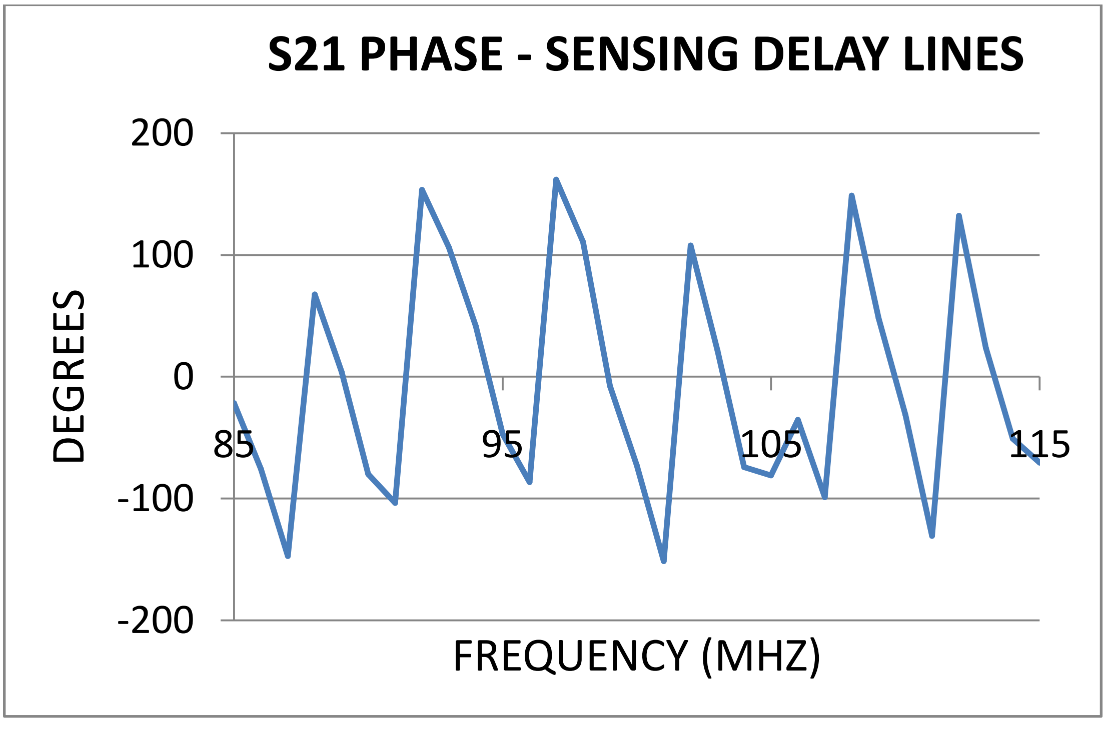

Figure 4.14: S21 Phase for Sensing Delay Lines at 100^{0}C

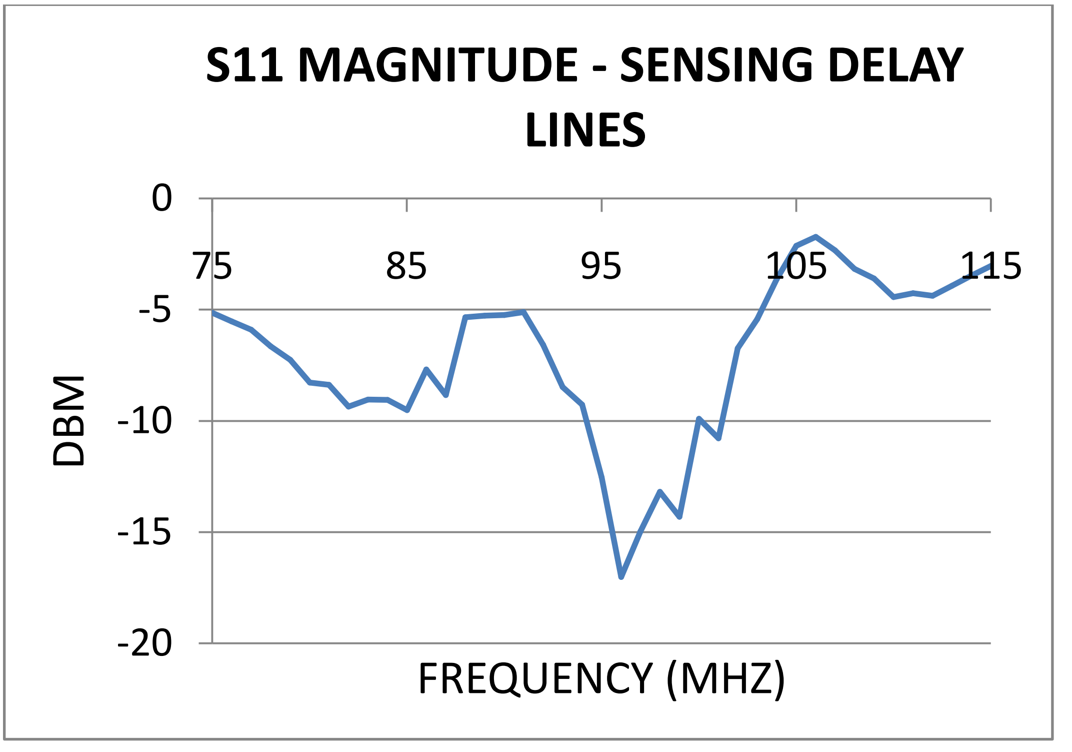

Figure 4.15: S11 Magnitude for Sensing Delay Lines at 100^{0}C

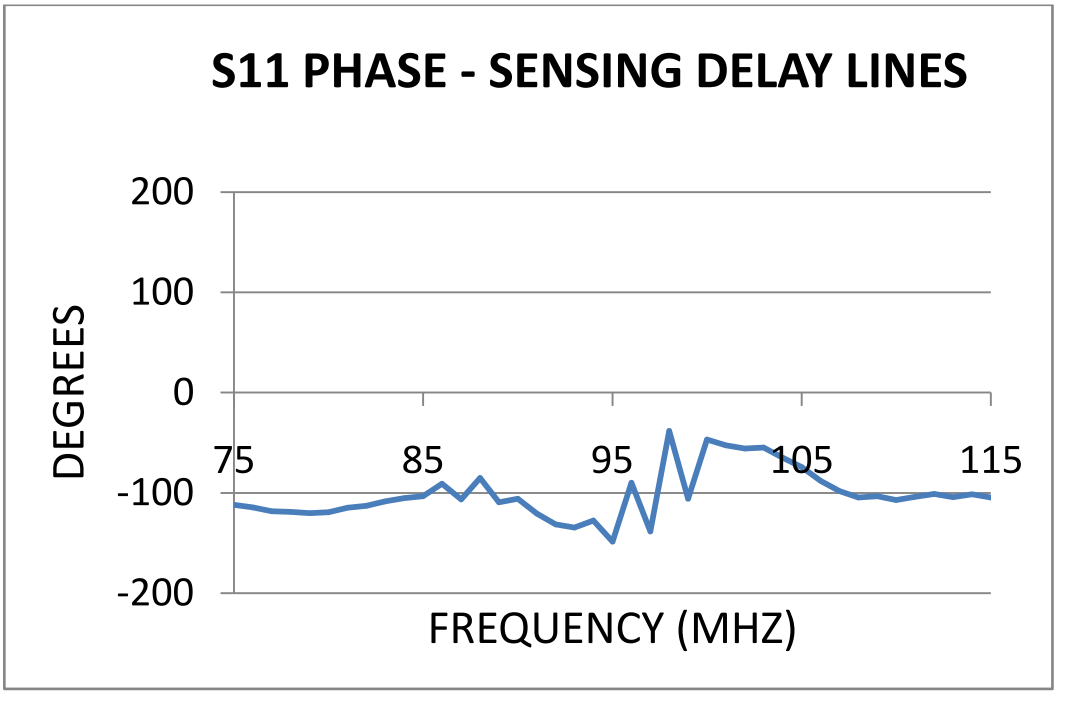

Figure 4.16: S11 Phase for Sensing Delay Lines at 100^{0}C

From the S21 and S11 magnitude graphs, S21 experiences power loss of 9.8 dB while S11 has power loss of 17 dB. From the S21 and S11 phase graphs, the range of the degree for S21 is between 162° and -151°, while range of the degree for S11 is between -38° and -149°.

4.2 Discussions

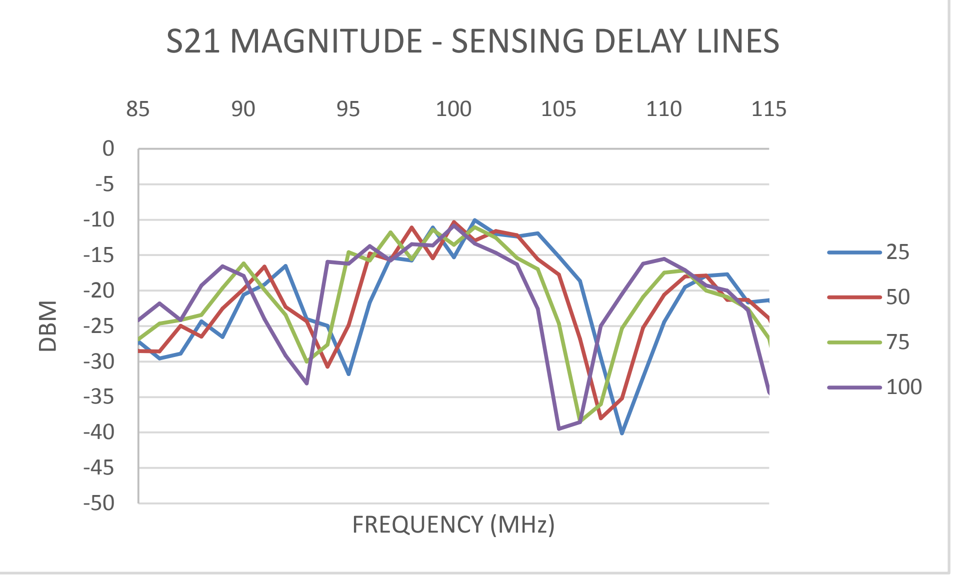

Figure 4.21: S21 Magnitude Compilation Graph

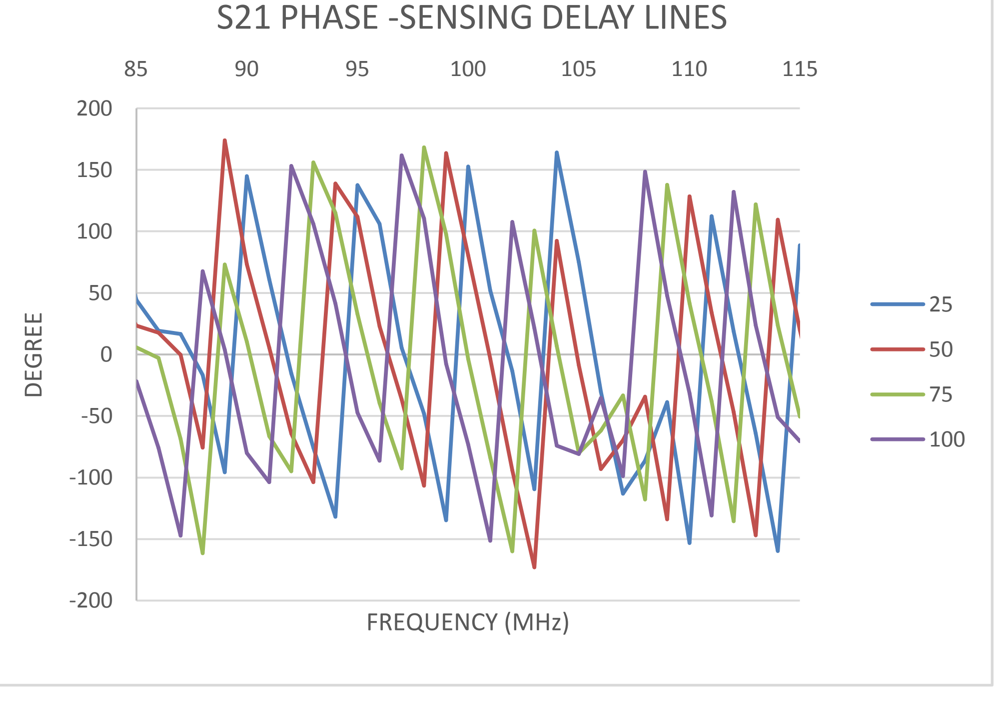

Figure 4.22: S21 Phase Compilation Graph

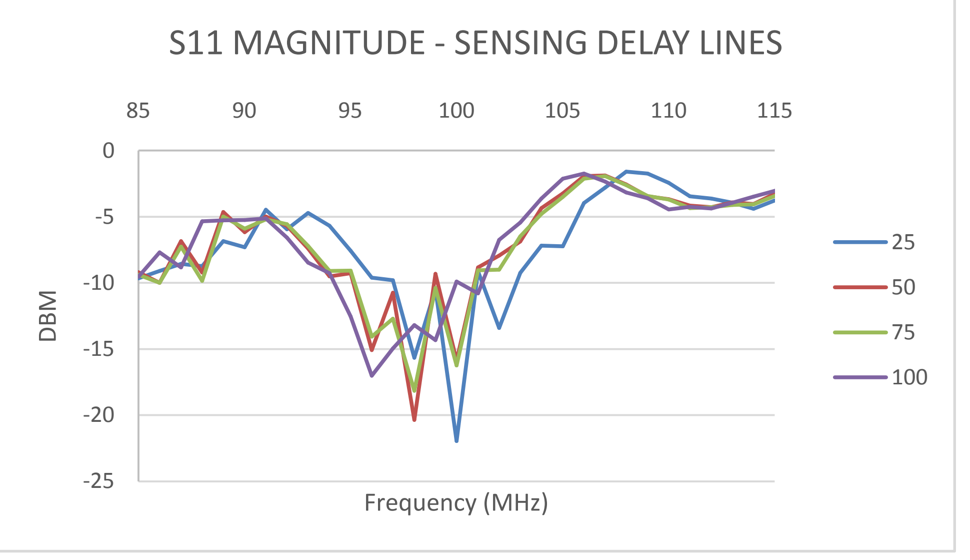

Figure 4.23: S21 Magnitude Compilation Graph

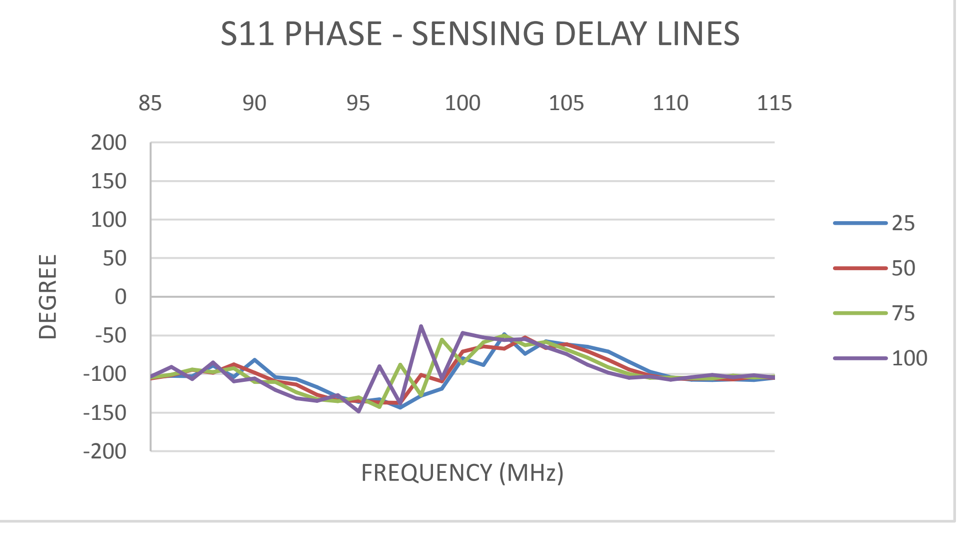

Figure 4.24: S11 Phase Compilation Graph

Based on figure 4.21 and 4.23, it is found that there are slightly changes of DBM value for S21 and S11 magnitude at difference temperature. However, the change is not significance because the differences of DBM values are relative small. Temperature causes minute amount of changes to the S21 and S11 magnitude parameters. Error from the instrument also might influence the results.

From figure 4.22 and 4.24, it is observed that by elevating temperature, no significance changes were observed on the phase parameters. This illustrates that the increasing of temperature does not affect much on the changes of the S21 and S11 phase parameters. The changes might be due to error from the instrument which may affect the readings.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The scope of study comprises characterization analysis of SAW sensor at elevated and cyclic temperature based on experimental design. The temperature manipulated will be in the range of room temperature to 100°C. The purpose of the study is to characterize the SAW-based sensor at elevated and cyclic temperature.

5.2 Conclusion

After the SAW sensor has been subjected to difference temperatures which are 25°C, 50°C, 75°C and 100°C, it is found out that properties of the sensor does not affected too much by the variance of temperatures. It can be concluded that the sensor can be functional at elevated and cyclic temperature without produce significance changes at the S21 and S11 parameters.

5.3 Future Work and Recommendation

Due to time constraint, the project has some limitations. Some recommendation for future works can be done to further improve the project. It is suggested to test the SAW sensor at actual environment of the pipeline in order to characterize the SAW sensor in a real situation.

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APPENDICES

APPENDIX 1: GAANT CHART

Details/WEEK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of FYP Title	■	■												
Preliminary Research			■											
Literature Review				■	■									
Proposal Defense						■								
Familiarization with Instruments						■	■	■						
Procument						■	■	■						
Experimental Design							■	■						
Extended Proposal								■	■					
Preparing Interim Report										■	■	■	■	
Submission of Interim Report														■

Table 1: FYP 1 Gaant Chart

Details/WEEK	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Test in Controlled Temperature	■	■	■	■	■									
Test in Manipulated Temperature	■	■	■	■	■	■	■	■	■					
Preparing Progress Report					■	■								
Progress Report Submission							■							
Thesis/Report								■	■	■	■	■		
Submission of Technical Paper												■		
Oral Presentation													■	
Submission of Dissertation														■

Table 1: FYP 2 Gaant Chart