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The performance analysis of optically transparent materials used in tunable devices

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Abstract

Comparative analyses, as well as the performance of optically transparent materials such as glass, Mylar, quartz, PET and PEN, were presented. Different methods of measuring techniques have been used to determine the dielectric property of the optically transparent materials at low and high frequencies. Due to the unavailability of materials, time and test equipment in the antenna laboratory, three (3) methods were implemented in this research. Namely, split cylinder cavity resonator, quasi-optical mm-wave measurement technique and the matching technique, where simulated return loss matched with the measured value of a simple micro-strip patch antenna.

An Electromagnetic (EM) modelling tool (i.e. Computer Simulation Technology, (CST) Studio suite) that takes into consideration finite integration techniques to execute computational analysis (i.e. Simulations) had been used in the matching technique to extract the physical properties of the material under test, by comparing measured and computational data. A frequency range of 8GHz-10GHz was used in the split resonant cavity measuring Glass, PET, and PEN at low frequencies. This method did not give accurate readings on glass simply because its measurement for accuracy was limited to low dielectric loss materials. Therefore, a glass material with high loss property at low and high frequencies could not be a good candidate for a split cylinder resonant cavity method regardless of its size and thickness. As shown in table 3.1, the loss tangent of glass (1.11mm) was noticed to be the same as the low-loss values of PEN and PET materials with 55µm, 0.131mm (i.e. 0.00622, 0.00608, and 0.00358). However, Quasi-optic millimetre measurement bench was able to depict the real loss properties of glass at low and high frequencies. The frequency ranges of 75GHz-110GHz and 220GHz-325GHz were used in this method. The results from this reading showed that glass is a material with very high loss at low and high frequencies. Mylar, on the other hand, is the optically transparent material with the lowest loss property. However, due to its complexity in fabrication and measurement at high frequency, the Matching Technique was, therefore, more preferable. The Matching Technique was observed to be more efficient and reliable.

Keywords: Polyethylene naphtha late (PEN), Polyethylene Terephthalate (PET), Photosensitive organic semiconductor poly-(3-hexylthiophene), Mylar, Glass

1. Introduction

Optically transparent materials have played an important role in wireless communication due to their numerous applications (E.R. Escober et al., 2015). One of its applications is when using as a substrate in the design of antennas and printed on screens and building glazing (A. Martin et al., 2015). These materials are also used in medical diagnostic equipment. Optically transparent materials serve as a "reinforcement material in surfboards and wind turbines (Adam Willsey, 2005).

Research on optically transparent materials has been done in the literature and A. martinet al (2015) depicts the fact that optically transparent antennas are being printed on the "surfaces of cars" as well as "building glazing". The fabrication of these antennas is being done on very "thin films" of optically transparent materials. Indium tin oxide (I.T.O) that is part of the transparent conducting oxide (T.C.O) family was found to be "the most usual type".

"The performance of an optically transparent antenna that operates from 8.8GHz-9.8GHz" was also analysed by A. Martin et al (2015) and according to their research, this antenna comprises of "mesh silver film that is printed onto a glass substrate" in which very high level of transparency was achieved. Similarly, Tang et al (2007) using organic semiconductor poly (3-hexylthiophene) have designed an optically controlled phase shifter. This organic semiconductor was being considered as a tunable dielectric in the phase-shifter structure. Under optical illumination, P3TH changes the real part of the permittivity of the material. Similarly, A. S Andy et al designed a two-patch antenna array using soda-lime glass as the primary substrate and indium-tin-oxide (ITO) as the ground plane. In the design, organic semiconductor heterojunction P3TH: PCBM is considered as the secondary substrate and drop-cast onto the glass. (A.S. Andy et al) None of these authors has considered the high loss that these optically transparent materials possess at low and high frequencies.

As a result, in this research, different measuring techniques such as Split cylinder cavity resonator, quasi-optical mm-wave measurement, and the matching technique is used to determine amongst the optically transparent materials the most suitable one with low-loss at low and high frequencies. Also, the simulated return loss S11 (dB) matched with measured value (S11dB) of a simple micro-strip patch antenna were compared. This technique accurately outputs the lossy behaviour of glass. This research also intends to figure out amongst the listed down measuring techniques, the most appropriate one to use at low and high- frequency domains.

2. Literature review

Techniques such as Quasi-optic bench (mm-wave frequencies), Transmission line/Matching technique using a simple micro-strip patch antenna, split cylinder cavity resonator, Electromagnetic Material Characterization Chamber (EMMCC), parallel plate capacitor, Coaxial line technique and so on, have been developed and use these days by different researchers to characterized the dielectric properties of materials.

M.S. Kheir et al (2008) developed a measuring technique such as ring resonator, together with a "rectangular waveguide cavity". This technique is used to determine the dielectric constant of liquids with the help of resonance frequency. In a similar way, H. Fang et al. (2004) use a ring resonator together with special software that is used in antenna engineering called "Ansoff HFSS electromagnetic simulation software". Then, this combination is used to determination of the dielectric constant of a material.

Furthermore, A. Kumar, S. Sharma and G. Singh (2007) initiated a new technique called "rectangular shaped perturb cavity". This technique is used to put homogenous dielectric materials into different categories. The placement of the sample is put in "cylindrical form" at the cavity centre point. This group to determine both real and imaginary parts of the relative permittivity of the material used the pattern known as "shift in the resonance frequency". C.Y. Tan et al (2004) also did the development of a micro-strip dual resonator system in order to put the material's permittivity into different categories. The system is divided into two halves of wavelength resonator and ferroelectric thin films, which were used to cover the gap between these two resonators. This design was inconsistency at some point during measurements. The inconsistency behaviour of this design was caused by the gap between the resonators and ferroelectric films.

Using quality factor and resonant frequency measurements, the dielectric constant of materials was still determined with this design.

Victor F.M.B. Melo et al (2009) initiated a newly proposed configuration technique. This was done to configure the ring resonator in such a way that it would be used to accurately determine the dielectric permittivity of printed circuit boards (PCBs) that will operate at high frequencies. Andrew. R. Fulford et al (2005) did the development of a pair of micro-strip Tee resonator. This system was having "different impedance resonating elements". The said designed system is used for removing conductor-sheet resistance as well as the dielectric properties of materials.

Sushanta Sen, et al (1997) presented a technique that was only suitable for the dielectric property of a material with a low-loss property called cavity perturbation. This technique uses a modified cylindrical re-entrant cavity for the purpose of microwave characterization of dielectric constant. Elenea Semouhkina et al (2001) simulated the scattering parameters of a ring resonator with the help of a finite-difference-time-domain (FDTD) method. The dielectric constants of alumina and rutile substrates were determined.

Barbar Dziurdzia, Jerzy Krupka and Wojciech Gregorczyk presented the split-post resonator method as the most appropriate method to use especially for low-loss materials. They used this method to determine the relative permittivity, as well as the loss tangent of the alumina substrate and got a good result as expected. They also implement software in order to fabricate microwave double-layered circuits (Barbar Dziurdzia et al, 2004). An analogue technique system that allows the measurement to be done in the time-domain was developed by William.B. Weir. With this measurement approach, the relative permittivity and permeability of a material can only be determined through Fourier transformation (William. B. Weir, 1974) A LabVIEW software was developed by Renè Grignon et al. (2003) and the analysis of complex dielectric permittivity of low loss solids has been done using this software. Multiple reflections have an adverse effect on the performance of the system. They, therefore use the free-space method to correct reflection errors (Renè Grignon et al, 2003).

3. Methodology and Model

During the research process, various data and information relevant to the research obtain through the following:

- The visit of departmental library for previous student's projects write-ups.
- Visiting general university library, or surfing the internet using goggle scholar.

- Supervisor Interaction for more professional guidance base on the concept of the research.

Math Lab and CST microwave suites were the two simulating programs use in this research.

3.1. Permittivity of dielectric material

Material interaction with the electric field can be the permittivity of the material denoted as ε. This can also know as the dielectric constant of a material denoted as K. Given that ε_r or ε are relative permittivity and (ε_o) the permittivity of free space. Taking into consideration that ε_{r1} is the real part and ε_{r2} is the imaginary part of the permittivity. i.e. ε_r or $\varepsilon = \varepsilon_{r1}-j\varepsilon_{r2}$

The measurement of how lossy a material is in the presence of external forces such as electric field is known as the loss tangent denoted by

tan⍰=$\varepsilon_{r2}/\varepsilon_{r1}$ (Tereshchenko, O.V et al, 2011),

3.2 Theory of complex permittivity

The complex dielectric permittivity of material can simply be extracted using the following equation; $S_{21}= T\,(1-\Gamma^2)/\,(1-\Gamma 2)\,T^2$………………………………………… (1)

Where T=transmission coefficient, Γ= reflection

The equations that determine the respective values of reflection and transmission coefficient are as follows; Γ=Zsm-1/Zsn +1……………………………… (2)

$T'=e^{-\gamma d}$………………………………… (3)

Where Zsn in equation two represent the sample impedance and d represent the sample thickness. Therefore, the sample impedance can be determined using the following equations;

Zsn= 1/**√Ɛ*……………………………… (4)**

$\gamma = K_o/$**√Ɛ*………………………………… (5)**

Ɛ*= $Ɛ_{r1}$-j $Ɛ_{r2}$…………………………………………………… (6)

$K_o= 2\pi/\lambda_o$………………………………………………………………… (7)

(Renè Grignon et al, 2003)

3.3 **Methods used to measure the dielectric property of materials**

Since the dielectric of a material is subject to changes that can be either physical or chemical, its measurement has really gained important in the industry these days. This is because under certain circumstances, used for non-destructive monitoring of certain material properties. Measurement of the dielectric properties of any material using several methods is possible depending on the type of material targeted and the frequency range chosen. Again, any dielectric material would be measured provided the required measuring equipment and sample holder will solely depend on the sample material.

It is very true that dielectric material is subject to changes but the following factors are considered, whenever their measurement and characterization from one category to the other is done. They are frequency, required accuracy, temperature, sample size/thickness, cost, contacting/non-contacting and destructive/non-destructive (M.T. Khan, 2012). In this research, even though there are different methods used to measure the dielectric properties of a material, only three methods implemented. Namely; split cavity Resonator method, matching techniques using standard micro-strip patch antenna, and Quasi-optic mm measurement bench.

3.3.1. **Split cylinder Cavity Resonant Method**

As shown in figure one below, the operation of the split cavity resonant method is very simple to implement and it is based on the fact that turning the cavity makes a shift in resonant frequency and this is caused by putting a material that is very lossy at the centre of the device. It is design to either intransverse electric mode (TE) or in transverse magnetic mode (TM). Due to the simplicity of this method, it supports higher temperature and normally gives out accurate results especially for a dielectric material with very low loss and low loss factor like Mylar. A waveguide of any type (i.e. Circular or Rectangular) can be use and the sample of the material is always place at the centre of the waveguide even though doing that will bring some changes to the centre resonant frequency as well as the quality factor of the cavity. The values shown on the changes it made to each material are used to calculate the dielectric constant of the said material. The quality factor in this context is the ratio of energy to energy dissipated. The complex permittivity and permeability of each sample material is calculated. The frequency range that is used in this method can be from 50 MHz-100 GHz but can be extended up to1 THz and it takes a measurement of dielectric material both at low and high temperatures say like 140C to -20C. (M.T. Khan et al, 2012) (R= reflected power, T=transmitted power)(M. S. Venkatesh, 2005)

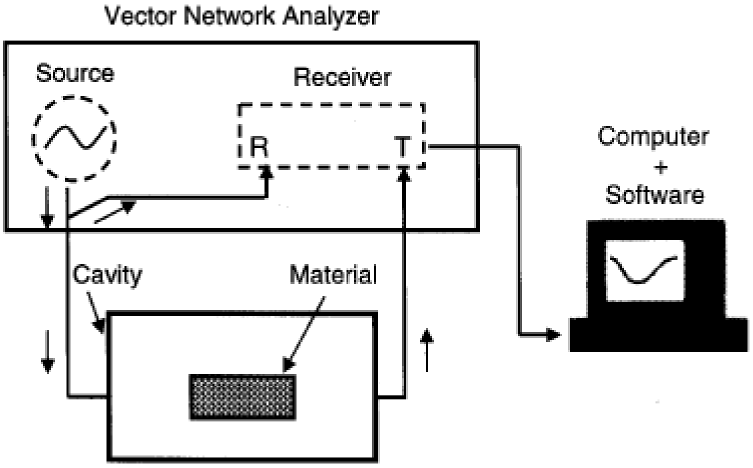


Fig.3.3.1 shows a schematic of a resonant cavity method

3.3.2 Quasi-optical mm-wave measurement bench

The vector network analyser (VNA) also known as a signal generator connected to Quasi-optic mm-wave measurement bench whenever an experiment is performed. Even though too sophisticated by design, it can give out an output that will detect both phase and amplitude of radiation that has frequencies up to 325GHz. Presently it has the ability to extend frequencies to 1Thz and different configurations can be done on to this test bench using different types quasi-optic bench elements. One of these elements can be corrugated horns, flat reflectors, grid polarizers and focusing reflectors. As shown in figure two, the quasi-optic bench and for any test to be carried out through this bench, it must have the following elements; pairs of horns label as H, pairs of quasi-optical directional couplers label as C, pairs of ellipsoidal reflectors label as F, pairs of polarization grids label as G and Vector Network Analyser Extenders (VNA_E). The purpose of the horns is to do transmission and reception of transmitted signals. That is, one can transmit signal while the other receive the transmitted signals. The mm- wave extender is serving there as frequency multiplier and work together with the horns to transmit signals. Figure 3.3.2 given below shows how horns work with certain amount centre frequency and connected to the vector network extenders. The ellipsoidal reflectors collimate through signal beams and in order to get rid of the horizontal polarisation beams, the vertical polarisationis applied which in turn gives out a pure vertical polarisation. Whenever a sample material is placed at the beam width, the blue dotted lines with the arrows show the actual path of the quasi-optical beam during measurement (Hansheng SU, 2011)

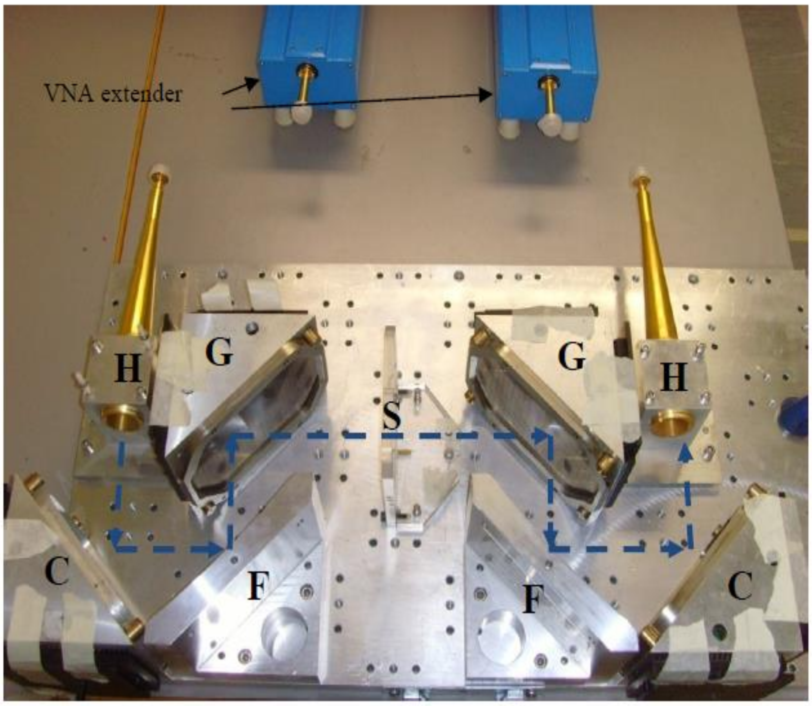


Fig. 3.3.2. Shows mm-wave transmission measurement bench (Hansheng SU, 2011)

3.3.3 Matching Technique

Table 2.3 shows results got from using the Split cylinder cavity resonator. Amongst the optically transparent materials (i.e. glass, Mylar, Quartz, PEN, and PET) measured, glass is one of the material with very high loss property at low and high frequencies. Table 2.3 shows the various loss tangent (i.e. Tan□=$\varepsilon_{r2}/\varepsilon_{r1}$) and from the listed down optically transparent materials, the loss tangent of the glass material is low which gives the opposite loss property possessed by glass material at low and high frequencies. This is due to the loss measurements limit of the Split cylinder cavity resonator. This type of measuring techniques only gives out accurate values for low-loss optically transparent materials and glass material is not found in that category. Therefore, matching technique is use in this research solely for this scientific reason.

A. Andy et al had also used this method in the case of estimating approximately the value of conductivity as well as the plasma's layer depth for the active state. It was by matching the data of the measured active state to that of simulation. In this research, a simple micro-strip patch antenna is a model in CST studio suites that contains three layers. The Copper tape serves in the capacity of these two layers and use for both path and ground. The third layer, placed in the middle of the model, is a soda-lime glass that serves in the capacity of substrates. Figure 3.3.3 shows the picture of the model.

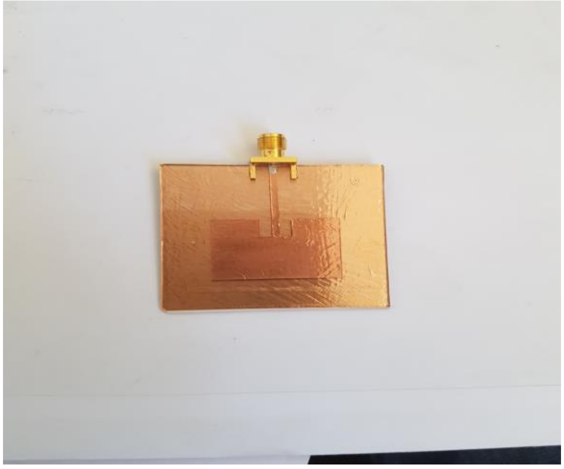


Figure 3.3.3 Simple micro-strip patch antenna

The modelled micro-strip patch antenna would have a return loss of S11 (dB) as measured value. The structure is then fabricated using a vector network analyser (VNA) which also have return loss of S11 (dB) as simulated value. Thereafter, the two return loss values (i.e. S11 (dB) measured and S11 (dB) simulated) are compared or matched as shown in figure 3.3.3.

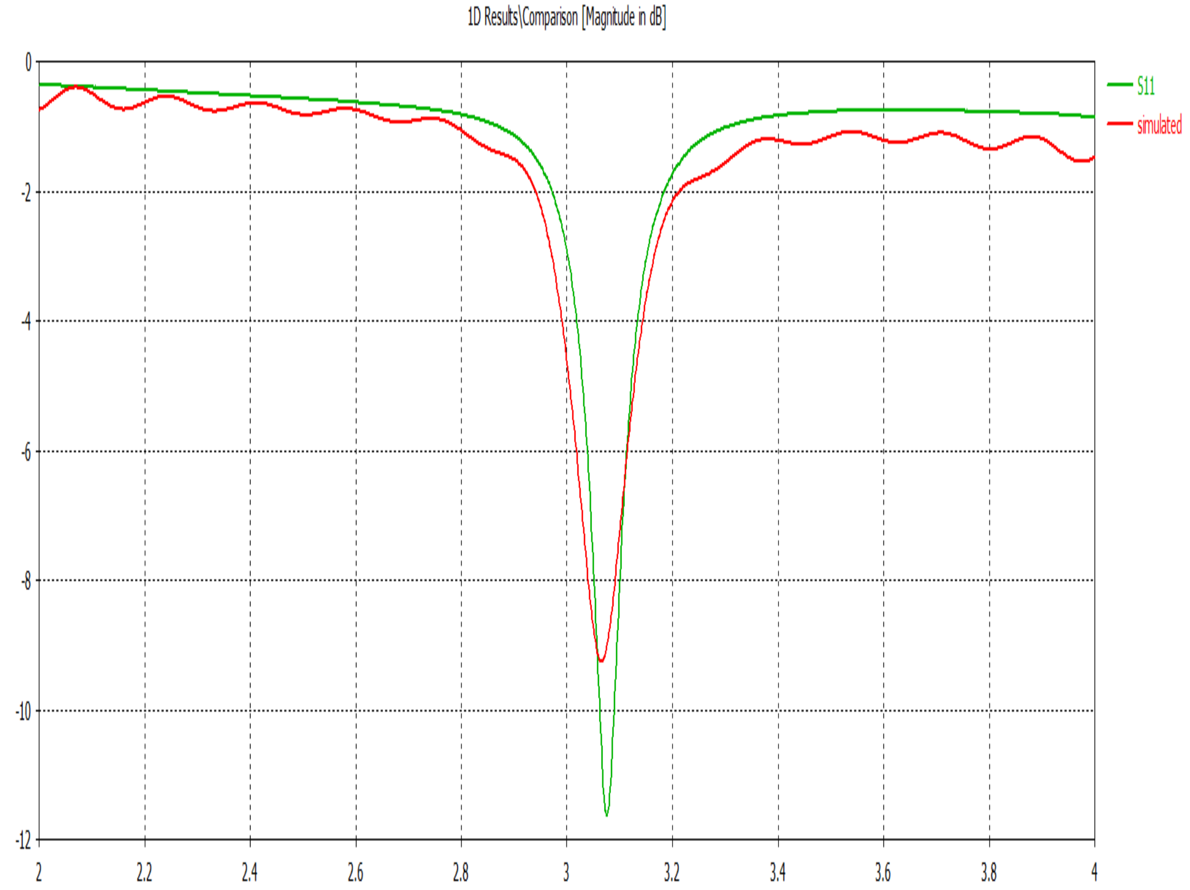


Figure 3.3.4 showing the graph comparing the measured return loss (i.e. S11dB) and simulated (i.e. S11dB).

The main purpose of doing this technique is to determine the real part and imaginary part of the dielectric property of glass material that will lead to getting the loss tangent of material. This is achieving by running a parametric scanning in CST studio suites as shown in table 2.1.

Table 3.3.4 shows the real part and loss tangent of glass

No	Real part (ε_{r1})	Loss tangent(tanδ)
1	5.6	0.1
2	5.7	0.2

3	5.8	0.3
4	5.9	0.4
5	6.0	0.5

This is also depicted in figure 3.3.4 and from that figure, the following values are found for the dielectric property of glass material; real part (εr1) as 5.85, imaginary part (εr2) as 0.014625 and Loss tangent (tan⍰) of 0.025. Since the focus of this research is to lose the loss tangent value, therefore, depicts the actual loss property of glass material at low and high frequencies. This made the matching technique the most appropriate method since it gives out values that are more precise during measurement.

3.3.5 **Comparison of different dielectric measuring techniques**

Table 3.3.5 below shows the advantages and disadvantages of some measuring techniques/methods used to determine the dielectric permittivity of a material.

Table 3.3.5 Dielectric measuring techniques

Method	Measured quantity	Advantages	Disadvantages
Matching	ε_r	▪ Has accurate readings	▪ Needs more time
Transmission line (waveguide)	µ ε_r	▪ Support high frequency	▪ sample preparation is difficult

		▪ Allows both solids & liquids	
Resonant cavity	μ ε_r	▪ Design for low-loss materials ▪ support both solids & liquids	▪ measurement is done at single frequency
Parallel plate	ε_r	▪ Design for high loss materials ▪ Simple to perform	▪ Electrode polarization effect
Free space	μ ε_r	▪ useful for high temperature ▪ support wide frequency	▪ Diffraction problem from material edges
Coaxial probe	ε_r	▪ provide high accuracy for high materials ▪ use broadband frequency	▪ Air gaps causes errors
Quasi-optic mm-wave measurement bench	ε_r	▪ Design for both low and high frequencies	▪ Very complex

Reference: (Khan, et al., 2012)

4. characterizations of optically transparent materials at microwave frequencies

There has been a great interest to researcher to do research on how to measure the dielectric properties of a material in recent years. This is due to the vast means of microwave frequencies applications in the communication/electronic industry. They are applied in most mobile communication systems such as mobile phone, Bluetooth devices, search radars and so on (Adam and Chris). Several papers have been reviewed base on the characterization of optically transparent materials at microwave frequencies (L.F Chen et al, 2004). The application of low-loss materials is done on microwave devices and circuits, communication devices, and antenna windows. Therefore, in antenna windows as well as high power microwave devices, characterising the dielectric properties of a material in terms of temperature variations should be timely done before using the device (E.Li et al, 2009).

In order to determine the loss-factor of a material, the determination of the dielectric constant is first considered. Different measuring techniques have been developed and use to calculate this constant. The reflection coefficient or resonant frequencies of each measuring techniques used is solely dependent on the type of measurement level (A. Kumar and S. Sharma, 2007). Therefore, in this research, a split cylinder resonant cavity measuring techniques at microwave frequencies has been used. This device has a low-loss factor measurement limit and it measures the complex permittivity of a material at room temperature. Moreover, the split cylinder resonates cavity system is divided into two halves and the sample material is always placed at the centre of the cavity. Therefore, there is any support to protect the sample material from dislocation during measurements (E.Li et al, 2009).

4.1 Measurement setup for split cylinder cavity resonator

The measurement setup of a Split cylinder cavity resonator is shown in figure 4.1 below.

Figure 4.1 Split cylinder cavity resonator setup (Analyser, V.N., 2007)

The measurement setup showed in figure 3.1 uses an integrated digital micrometre screw to measure the thickness of the samples. The side mounting of the cylinders allows the measurement of large samples.

The cavity connected to the vector network analyser. It uses two ports namely port1 (S11) as well as port2 (S21) which will measure the scattering parameters (S-parameters). The work of port1 is to measure the reflected signals as well as the transmitted one coming from port2. The same process is done with port2.

This setup has a single resonant frequency in air and the sample of the dielectric material placed between the moving and fixed cavity. The system is calibrated for every set of measurement. In this research, Mylar material with 10-micrometer thickness was too thin to be measured using this method and the same reason goes for quartz material (very small). These two materials measured using the Quasi-optical mm-wave measurement bench.

4.2 **Results and Discussion**

Table 4.1 Relative permittivity (εr) and tanδ of glass, PET & PEN.

no	**Material name**	**Thickness=t**	**real part ε_{r1}**	**imaginary part ε_{r2}**	**tanδ=loss tangent**	**frequency**	**Method used**
	Glass						
1		1.122mm	5.63513	0.03504	0.00622	8.74GHZ	Split cylinder Cavity Resonator
2		1.103mm	5.28203	0.01020	0.00193	8.86GHZ	Split cylinder Cavity Resonator
3		1.102mm	5.28660	0.01019	0.000193	8.86GHZ	Split cylinder Cavity Resonator
	PET						
1		0.131mm	3.19566	0.01944	0.00608	9.98GHZ	Split cylinder Cavity Resonator
2		0.147mm	2.94129	0.01718	0.00584	9.98GHZ	Split cylinder Cavity Resonator
3		0.142mm	3.03397	0.01825	0.00602	9.98GHZ	Split cylinder Cavity Resonator
	PEN						
1		55µm	3.26778	0.01169	0.00357	10GHZ	Split cylinder

							Cavity Resonator
2		48 µm	3.26276	0.01189	0.00364	10GHZ	Split cylinder Cavity Resonator
3		56 µm	3.20901	0.01190	0.00371	10GHZ	Split cylinder Cavity Resonator

Table 4.1 outline the results of the three optically transparent materials. The loss tangent values of PET and PEN materials show well. Considering the size and thickness of these three materials, glass has the highest value. Similarly, even though glass is with such value, they almost have the same loss tangent values. In a scientific point of view, the Split cylinder cavity resonator does not give out accurate measurement values on materials with high loss property such as glass. It is designed for low-loss material measurement. The matching technique is therefore used in this research in order to get the actual loss tangent value that will depict the scientific behaviour of glass at low and high frequencies.

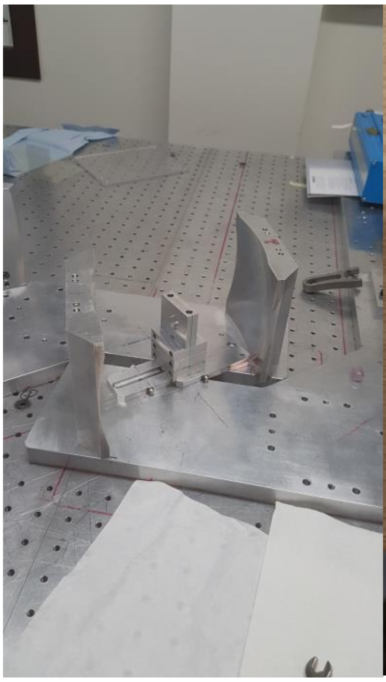
4.3 **The mm-wave Measurement of the physical properties of materials at W-band frequency.**

Different materials have different application areas depending on the understanding of the dielectric properties such as loss factor and complex permittivity. Several Researched and methods done on these materials (A. Elhwil et al, 2007).

In this research, 75GHz-110GHz frequency range was use in the first measurement and 220GHz-325GHz in the second measurement. Both of them were measuring glass, Mylar, Quartz, PET and PEN using the Quasi-optical mm-wave bench. Diagrams below shows the setup of this measurement, use to determine the real part, imaginary part and loss tangent of the five optically transparent materials with a bandwidth frequency of 300Hz. The horn antenna (transducer device) used in this setup is responsible for the transmission and reception of signals. Similarly, the millimetre wave extenders are frequency multipliers that work together with the antennas in the transmission and reception of signals.

4.4 **Sample Preparation**

The sample of each material was placed on top of a sample holder where the sample is rectangular aluminium metal with a central circular cut-out of 1.7cm diameter. The sample holder is aligning on the quasi-optic bench in order to avoid the reflection of signals. The system is normalised before taken any measurement shown below. The sample holders with samples of optically transparent materials mounted on them.

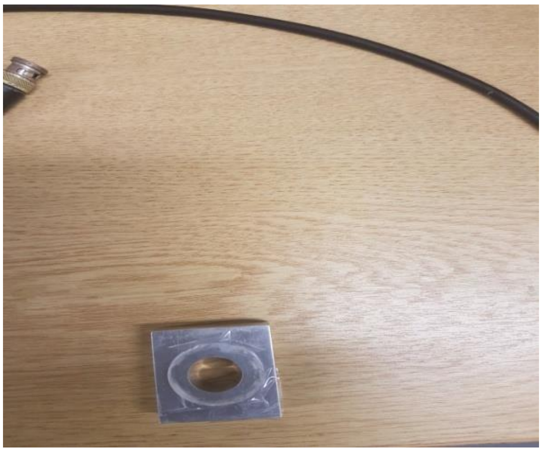


Sample holder alignment

PET Material

PEN Material

Vainer calliper measuring glass



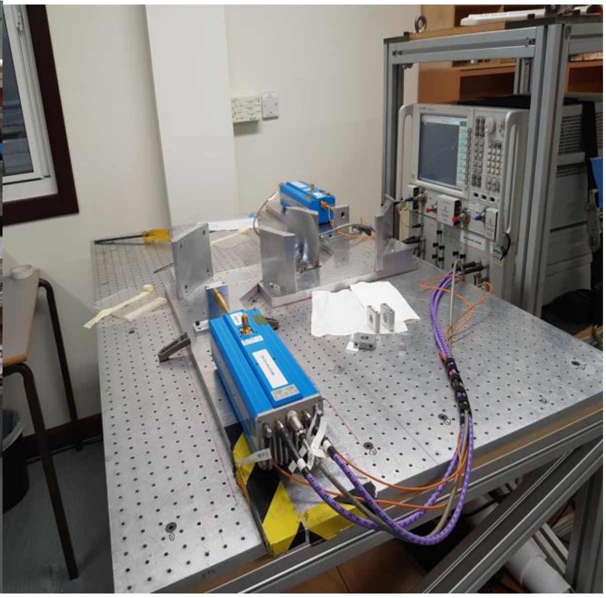
Glass (1.11mm, 80um) mounted on top of sample holder

4.5 Measurement setup for Quasi-optical mm-wave measurement bench

The Quasi-optic mm-wave bench is connected to the vector network analyser and the VNA measures the S-parameters (Scattering Parameters) of S11 (dB) and S21 (dB). The Vanier calliper is used to measure the sample thickness.

In this research, two different measurements presented using different frequencies levels. The first frequency measurement is from 75GHz-110GHz and the second frequency measurement from 220GHz-325GHz. The setup on how these were done in the antenna laboratory is shown in diagrams below respectively. Figure 4.3 shows the alignment of the sample holder on the Quasi-optic bench.

75GHz-110GHz measurement setup



220GHz-325GHz measurement setup

5. Results and Discussion

The result fairly reflects on the loss behaviour of each material and a brighter example of it is glass. For 75GHz-110GHz measurements, looking at figure 5.1a and figure 5.1b, glass has very high loss property at low and high frequencies regardless of its size and thickness. Mylar has better low-loss property than all the other materials mentioned in this research as shown in figure 5.1c.

PEN, on the other hand, is second with low-loss property to Mylar and much better than PET and Quartz as shown in figure 5.1d. Similarly, looking at figure 5.1e, PET is much better than Quartz.

Furthermore, in the 220GHz to 325GHz measurement, the high loss behaviour of glass is still the same as shown in figure 5.1f and figure 5.1g, Mylar, in the same way, has almost 0dB loss where PEN was observed to be better than PET and Quartz. Looking at figure 5.1h and figure 5.1l, PET has better loss property than Quartz but Quartz, in turn, was observed to be better than glass.

In summary, the first and second Quasi-optic mm-wave measurement bench have shown it clearly that glass has the highest loss property and Mylar, on the other hand, contains the lowest loss property at low and high frequencies. Hence, the goal of this research.

5.1 **75GHz-110GHz measurements of optically transparent materials**

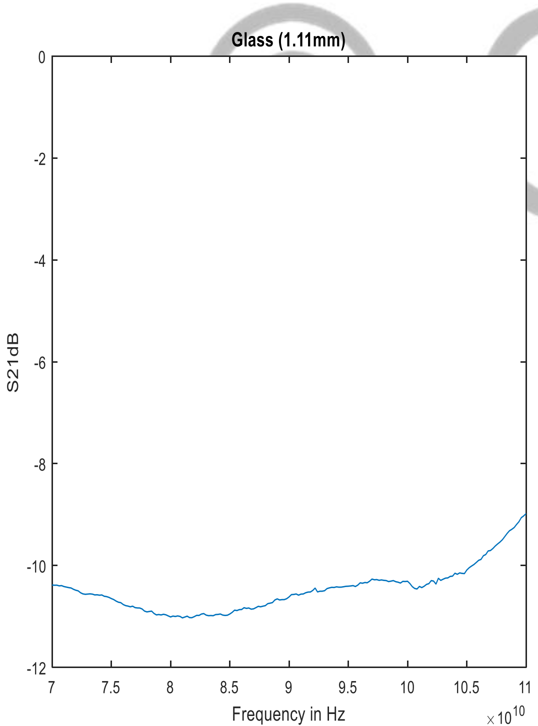


Fig. 5.1a glass (1.11mm)

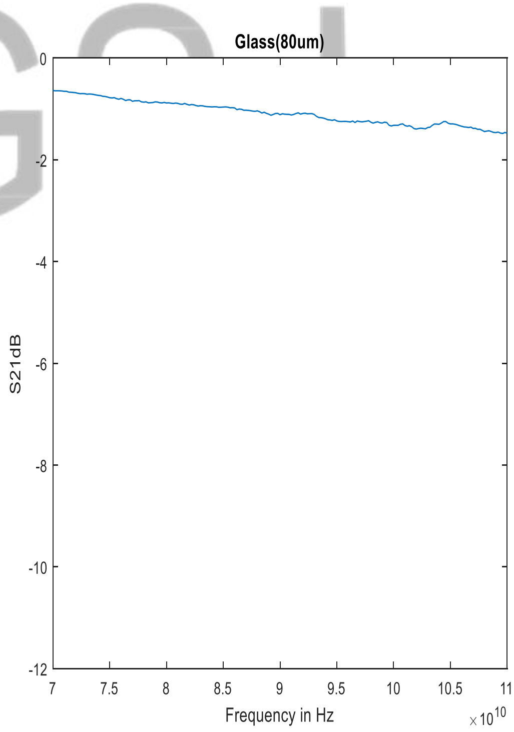


Fig. 5.1b glass (80um)

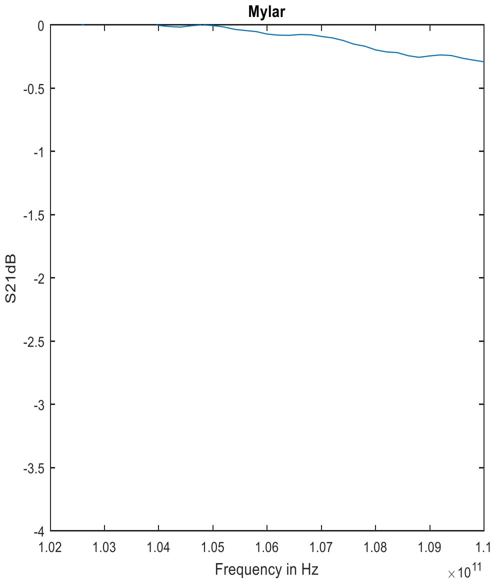


Fig. 5.1c Mylar at 75GHz-110GHz

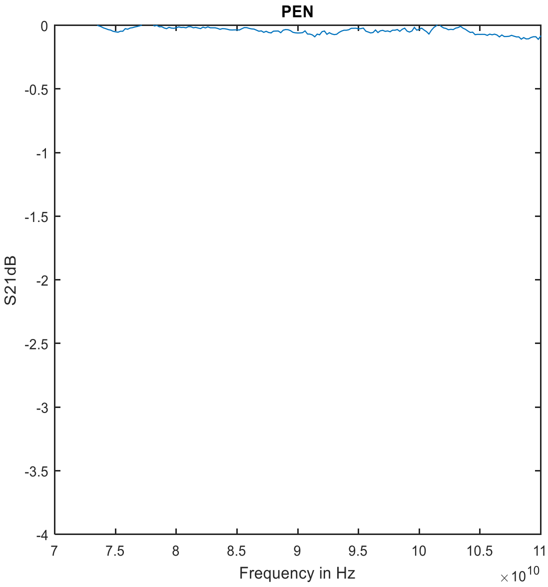


Fig. 5.1d PEN at 75GHz-110GHz

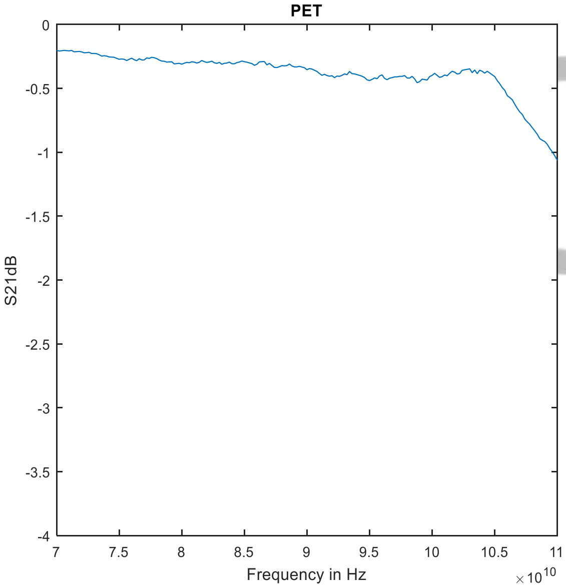


Fig. 5.1e PET at 75GHz-110GHz

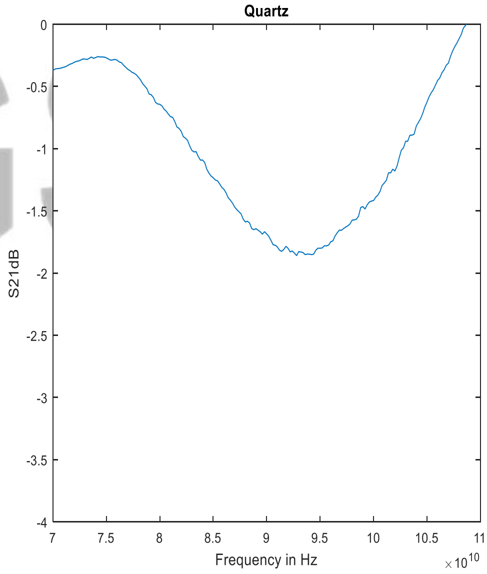


Fig. 5.1f Quartz at 75GHz-110GHz

5.2 220GHz-325GHz measurements of optically transparent materials

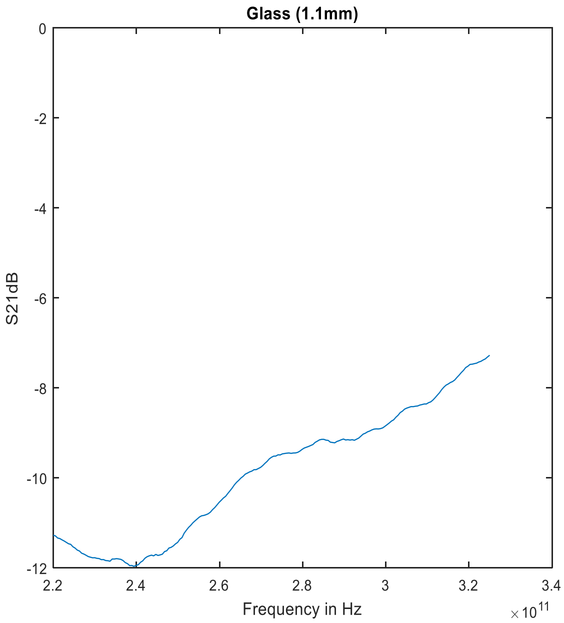


Fig. 5.2g glass (1.11mm)

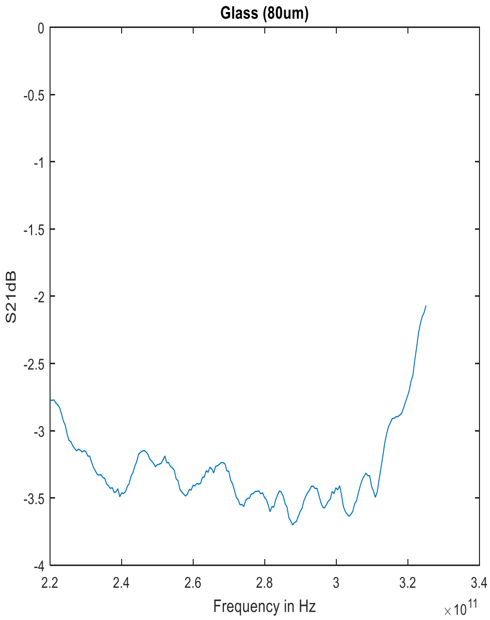


Fig. 5.2h glass (80um)

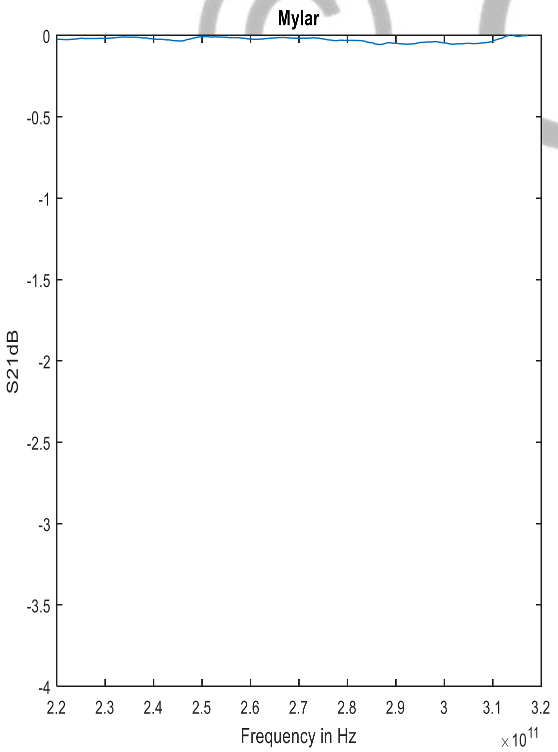


Fig. 5.2i Mylar at 220GHz-325GHz

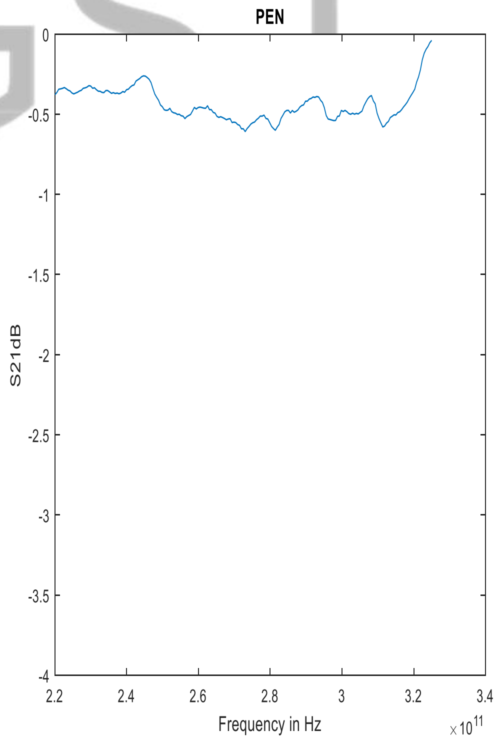


Fig. 5.2j PEN at 220GHz-325GHz

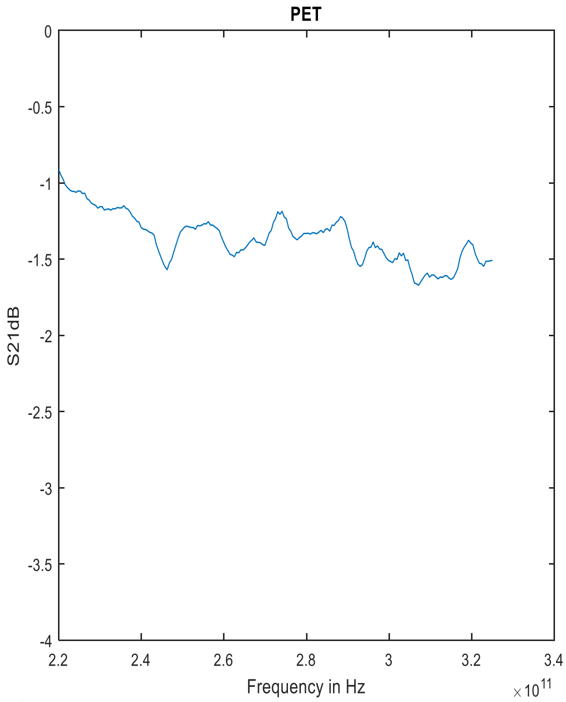


Fig. 5.2k PET at 220GHz-325GHz

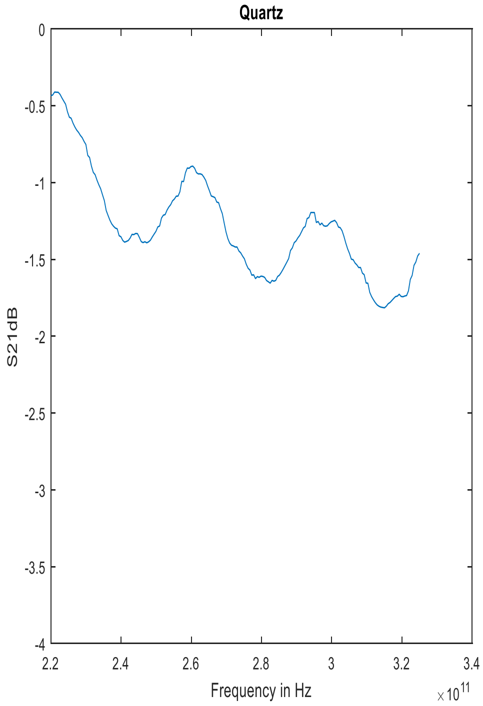


Fig. 5.2k Quartz at 220GHz-325GHz

6. Summary and conclusion, and future work

This research presents three different measuring techniques used to determine the dielectric property and loss tangent of materials. Amongst these techniques, Quasi-optical mm-wave bench and the matching technique measure these materials at low and high frequencies. Matching technique provides precise loss tangent value of glass that depicts glass high loss property at low and high frequencies. Split cylinder cavity method, on the other hand, uses single frequency and is only suitable for low-loss materials. Two different frequency measurements are performing in Quasi-optical mm-wave measurement bench and Mylar was found to be the optically transparent material with the low-loss property. In addition, glass regardless of size and thickness was proved as the optically transparent material with the highest loss property at low and high frequencies.

Lastly, even though all these techniques have advantages and disadvantages, for this research, matching technique is more appropriate to measure a material with high loss property.

6.1 Result from simulation

The simulation using CST studio a suite of a modelled patch antenna (i.e. S11dB) is compared to the return loss (i.e. S11dB) measured value as shown in figure 3.3.4. This process gives out a precise loss tangent value (i.e. 0.025) and relative permittivity of 5.85 for glass which is the actual behaviour of glass at low and high frequencies. In addition, the simulation did using Math Lab from the two different frequency measurements in the Quasi-optical mm-wave bench shows that Mylar is the optically transparent material with lowest loss property and glass with the highest loss property.

6.2. Result from measurement

Table 4.1 shows measurement results from Split cylinder cavity resonator and from the scientific point of view, it shows that such technique cannot give accurate readings on optically transparent materials with high loss property such as glass. Looking at table 4.1, glass has the same loss tangent value with PET and PEN.

6.3. Future work

Performance and analysis of optically transparent materials using simulation/measurement were carried out in this project. The identification of material with the lowest loss tangent and highest loss tangent was achieved. There is still room for improvement for these optically transparent materials to perform well when applied as a substrate in communication systems. The reduction of the high loss property possessed by these materials such as glass at low and high frequencies is still an issue. Therefore, doubling these optically transparent materials as the primary substrates in the design of patch antennas could be done in the future.

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