The Effect of Frequency and Percentage on Reflection and Transmission Coefficient of Soda Lime Silica-High Density Polyethylene Composites using Waveguide technique for Microwave application

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***Abstract*: A composite material description was established for soda lime silica glass as the filler and High Density Polyethylene as host matrix (SLS-HDPE) for waveguide termination (dummy loads) application, by determining the effect of frequency and percentage with respect to SLS-HDPE composite's reflection (S_{11}) and transmission (S_{21}) coefficient. The proposed SLS-HDPE composites material was studied at frequencies 8 to 12 GHz. The study was conducted using the X111644A X-Band waveguide (TRL) method of the Agilent 85071 software kit Material Measurement. The study found that SLS percentages have significantly influenced (S_{11}) and (S_{21}) both in magnitude and across the frequency. The effect of frequency and percentage on reflection (S_{11}) and transmission (S_{21}) coefficient for SLS-HDPE composites with different percentages of SLS and HDPE (10%SLS-90%HDPE, 20%SLS-80%HDPE, 30%SLS-70%HDPE, 40%SLS-60%HDPE, 50%SLS-50%HDPE) were investigated. Results showed that the frequency and percentages significantly influenced the reflection (S_{11}) and transmission (S_{21}) coefficient properties of the composites. Moreover, the reflection (S_{11}) coefficient increase with increase in percentage of SLS filler and decrease with frequency while the transmission (S_{21}) coefficient decrease with increase in percentage SLS filler and decrease with increase in frequency. The smallest reflection (S_{11}) coefficient of the SLS-HDPE composites was found at 100% HDPE (0.6372) and largest reflection (S_{11}) coefficient of the SLS-HDPE composites was found at 50% HDPE (0.8407), and the smallest transmission (S_{21}) coefficient of the SLS-HDPE composites was found at 50% HDPE (0.4899) while the largest transmission (S_{21}) coefficient of the SLS-HDPE (0.7644) composites was found at100% HDPE. The magnitude of reflection (S_{11}) coefficient decreased with increase in frequency from (8 GHz to 12 GHz) and the magnitude transmission (S_{21}) coefficient increased with increase in frequency from (8 GHz to 12 GHz).**

***Keywords*: soda lime silica glass; High density polyethylene; microwave; the reflection (S_{11}) and transmission (S_{21}) coefficient; waveguide**

I. INTRODUCTION

The material RS-4050 is a rigid epoxy based magnetic castable microwave absorbing material, it has been applied in many ranges of waveguide application as a microwave terminator (dummy loads). This material is prototype for fabrication of low power loads, ring chokes, attenuators and other radio frequency (RF) absorbing elements at microwave frequencies. RS-4050 can be useful in standard stock shapes of plates, custom cast configurations, rods and bars, or in pourable kits Meli et al., (2019). Regrettably, RS-4050 contains epoxy which is expensive, and it is magnetic based which is not needed for microwave termination. One particular risk associated with epoxy resins is sensitization. [An assessment of skin sensitisation by the use of epoxy resin in the construction industry, (2003)]. Recently there is huge demand in composites material capable of increase in the magnitude of reflection with increased in the percentage and decreased across the frequency, while decrease in the magnitude of transmission with increased in the percentage and increased across the frequency. Composites of such description can be used for waveguide termination (dummy loads) application. Composite characterizations for microwave applications have attracted much attention due to recent huge development of radio frequency (RF) sources and speedy development of electronic devices and communication; these resulted to increasing in electromagnetic interference (EMI) pollution problems (Iwamaru et al., 2012). Amongst the various types of polymeric dielectrics, High Density Polyethylene (HDPE) has been an outstanding raw material for the production of spacers, insulators, as well as cable conductors coating used in electrical power distribution networks. For this kind of application, the reflection (S_{11}) and transmission (S_{21}) coefficient strength is one of the major properties that have to be taken into account in order to check plant. On the polymers issues, macroscopic properties are determined by the two factors; microstructure and composition [Mandal et al., (2016), Yamamoto et al., (2004)]. The polymeric material composition differs in various ways, as a result of addition of fillers, plasticizers, cross-linkers, antioxidant, etc. Addition of inorganic fillers to thermoplastic will increase its stiffness, albeit at the expense of decreased elongation at break [Yamamoto et al., (2004), Green et al., (2008)]. In developing microwave applications, ascertaining the suitable material to meet the obligation is significant. Many studies have been conducted and focused on the polymer-silicate composites that display excellent luminescent, optical, dielectric and bio-sensitivity properties. Investigation have been carried out on the electrical properties of polymer-oxides composites prepared by in-situ polymerization and melt blending (Sami et al., 2009) and whether they are fully biodegradable, environmentally friendly, abundantly available, renewable, cheap and of low density (Yaacoba et al., 2015). It has been established that the reflection (S_{11}) and transmission (S_{21}) coefficient have a close connection with the interfacial behaviour among the fillers and polymer matrix in a composites. The optical and electrical properties of these materials have been discovered to be highly dependent on the dimension, concentration, and structure of the microparticles, as well as the class of polymeric matrix [Sami et al., (2009), Lynn et al., (2009), and Shah et al., (2009)]. A glass composite of remarkably good combination of properties is not a dream today. Glass-reinforced composites are known to be light and resilient. This means with proper processing techniques, glass treatments, and compatibilizers/coupling agents, composites with optimum properties can be used to make automobiles lighter, and thus much more fuel efficient. Few years ago, polymers have substituted many of the conventional metals/materials in numerous ranges of applications. This was achieved due to the advantages polymers have over conventional materials. The most significant advantages of these polymers are the ease of processing, productivity and cost effective. In most of these applications, the properties of polymers are modified using fillers and glasses to suit the high strength and high modulus requirements. Glass-reinforced polymers offer advantages over other conventional materials when specific properties are compared (Sami et al., 2009). These composites have extensive range of applications in different fields from appliances to space crafts. Polyethylene (PE) is used as insulation material in order to reduce the losses in signals. It is also widely used for insulation of cables as a result of it decrease in the reflection coefficient S_{11} with increase in frequency and increase in magnitude of reflection coefficient S_{11} with increase in the SLS filler percentage, whereas the transmission coefficient S_{21} increase with increase in frequency and decrease in the magnitude of transmission coefficient S_{21} with increase in the SLS filler percentage. Above 8 GHz, reflection coefficient S_{11} decrease with increase in frequency and transmission coefficient S_{21} increase with increase in frequency (Nioua, 2017). Over the years, the attention of scientists and technologists have been focused to the use of glass powder instead of conventional reinforcement materials. These glass powders are of low-cost, low density and high specific properties. They are nonabrasive and biodegradable, as compare to other reinforcing materials. Also, they are readily available and their specific properties are comparable to those of other glass used for reinforcements (Ibrahim et al., 2011) However, disadvantages such as incompatibility with the hydrophobic polymer matrix, the possibility of forming aggregates during processing, and poor resistance to moisture serve as setbacks to the potentials of glass as reinforcement in polymers (Ibrahim 2011). Fillers with unique chemical, physical and mechanical properties that are blended with polymers comprises of composite materials with great advantage for technological innovation. A small quantity of SLS micromaterials increases the surface area of the material and creates a large interfacial interaction between them and the pure polymer (Gouda, 2018). Conventional metal oxides such as barium titanate ($BaTiO_3$), titania (TiO_2), alumina (Al_2O_3) and silica (SiO_2) are widely known as effective reinforcement materials that enhance the dielectric and mechanical properties of polymers. Previously, semiconducting oxides (SiO, CaO, and Na_2O) have fascinated so much interest due to their potential for different electronic and photonic device applications (Ibrahim et al., 2011). Recent studies have shown that the polymer-silicate composites display excellent luminescent, optical, dielectric and bio-sensitivity properties. Researches have been carried out on the electrical properties of high density polyethylene polymer reinforced with silicon dioxide (SiO_2-HDPE) nanocomposites prepared by in-situ polymerization and melt blending (Sami et al., 2009).

This research work present the SLS-HDPE substrate as a substitute to RS-4050 for microwave termination, it is easy to fabricate, cost effective and easy accessible. The coefficient properties of (SLS-HDPE) composites material was compromised with different percentage of SLS to be compatible with RS-4050 complex permittivity. The effect of different percentage of SLS fillers and frequency on the reflection (S_{11}) and transmission (S_{21}) coefficient strength of the SLS-HDPE composites using the X111644A X-Band waveguide (TRL) method of the Agilent 85071 software kit Material Measurement from 8-12 GHz.

II. EXPERIMENTAL

As for the preparation of the SLS-HDPE composites, a total of 25.0 g was prepared for each composition of the composites. The compositions for easy identification are labeled 50% HDPE, 60% HDPE, 70% HDPE, 80% HDPE, 90% HDPE and 100% HDPE. The summary of the masses and percentages for each element is presented in a tabular form in table 1. For the purpose of this study, the following raw materials were used;

High density Polyethylene granules (HDPE) 99.9% purity, with chemical formula $(CH_2CH_2)_n$, melting point at 160^0C and a density of 0.939 g/cm^3 (Alfa Aesar, a Johnson Matthey company). Soda lime silica (SLS) obtained as explained above, and Acetone with chemical formula C_3H_6O, density 0.78998 g/ml at 20 ^0C and evaporating temperature above 53.0^0C at 1atm. Figure 1 present the flow chart of the methodology

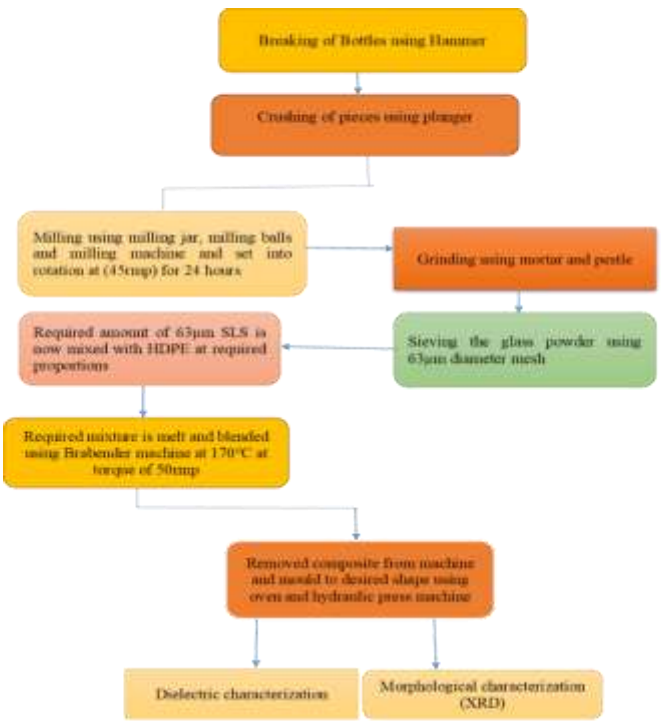


Figure. 1: Flow chart of sample preparation

Table 1: Composition of raw materials used in composites preparation

Glass (SLS)		Polymer (HDPE)		Total
Percentage (%)	Mass (g)	Percentage (%)	Mass (g)	Mass (g)
10.0	2.50	90.0	22.50	25
20.0	5.00	80.0	20.00	25
30.0	7.50	70.0	17.50	25
40.0	10.0	60.0	15.00	25
50.0	12.5	50.0	12.50	25

The SLS-HDPE composites was prepared using the melt blending technique via the Brabender poly-drive three-phase motor with a drive of 1.5 kW, 3x230 V, 40 A and speed range of 0-120 rpm. In this method, the machine was set to 170 ^0C for heating; the rotation of the rotors was set to 50 rpm. As the Brabender attained the required temperature (170 ^0C), the high density polyethylene (HDPE) polymer was poured into the vial of the Brabender heating block. After 5 minutes the SLS powder 63µm grain size is introduced into the vial. The mixture was allowed for another 5 minutes before taken out and fabricated into desired dimension. The composites are then moulded according to desired shape and dimensions. In this research, rectangular shape of 0.22 cm x 0.11 cm with thickness 6 mm, were fabricated using an oven (Shel Lab. 1330 GX Sheldon manufacturing Inc.), and hydraulic press machine (Fred S. Carver part No.:973110A) at 4 tonnes. The oven was set at temperature of (170 ^0C), the composites was then set into the oven and was allowed to melt for 30 minutes, after melting the composites was taken to be pressed in a desired shape using hydraulic press at 4 tonnes.

III. RESULTS AND DISCUSSION

This part explores the effect of SLS filler percentage in the HDPE host matrix and frequency on reflection S_{11} and transmission S_{21} coefficient magnitudes of SLS-HDPE composite pellets. The Y axis calibrated from 0 to 1 represents the magnitudes of S_{11} and S_{21} while X axis is the frequency from 8 to 12 GHz. The result obtained for an empty waveguide and with waveguide filled with SLS-HDPE composite pellets are shown in Figures 2, 3 and 4. The S_{11} and S_{21} values measured using the Vector Network Analyzer are very accurate within 0.001. However it is extremely difficult to fit a thick sample into the waveguide with no air gaps between the sample and the waveguide walls. Therefore all the reflection coefficient S_{11} data not only were due the reflection between the air and sample interface but also due internal multiple reflection between the two interfaces of the waveguide. Similarly transmission coefficient S_{21} values were the combined transmission coefficients resulting from material absorption and multiple reflection between the dielectric walls. The higher the percentage of SLS the higher the reflection coefficient S_{11} and the lower the transmission coefficient S_{21}, this is due to the increase in the rigidity and the density of the composite as the SLS filler percentage increases. These were not taken into account in all the algorithms used in the Agilent 85070B Material measurement Software. The variation of $|S_{11}|$ and $|S_{21}|$ with frequency are presented in Figure 1 for an unloaded waveguide. Theoretically, magnitude of S_{11}=0, and the magnitude of S_{21}=1, this is from $S_{11}^2 + S_{21}^2 P_{loss}=1$. The magnitude of $|S_{11}|$ and $|S_{21}|$ were found to be constant at 0 and 1, correspondingly throughout the entire ranges of frequencies. This was predictable as the dielectric constant of air $\varepsilon^*=1-j0$. The unloaded waveguide is filled with air and air is a lossless material. Thus there is no attenuation in the propagation of waves in an air-filled section of a hollow waveguide. The effects of SLS fillers content on reflection coefficient $|S_{11}|$ of the SLS-HDPE composites are shown in Figure 3. The corresponding transmission coefficient $|S_{21}|$ results are shown in Figures 4. And the ripple nature is due to half wavelength effects and might also be attributed to the internal surface roughness of the rectangular waveguide, air gap between the samples and the internal walls of the rectangular waveguide, sample imperfections and voids within the sample impedance mismatched between input impedance of the waveguide, the surface impedance of the sample and the characteristics impedance of the cable (Pozar, 2009). The results 3 and 4 reveals multiple reflections for both S_{11} and S_{21}.

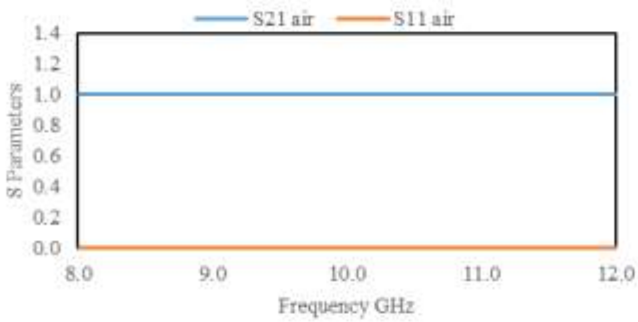


Fig. 3: S_{11} and S_{21} for an unloaded waveguide

Evidently from Figures 3 and 4, the ripples nature of the $|S_{11}|$ and $|S_{21}|$ could be attributed to the sample thickness being relatively small about 6 mm. However, if samples are sufficiently thick, there will be no multiple reflections rather absorption and S_{21} will decrease with frequency (Abdalhadi et al., (2017). The spikes or half wavelength effect in the graph is repeated every $\lambda/2$ due to multiple reflection effect in the sample (Ismail, 2022). Table 2 list the magnitudes of S_{21} and S_{11} for all composites at 8 and 12 GHz. The result revealed that the higher the HDPE the higher the S_{21}, whist the higher the HDPE the lower the S_{11}. This is attributed to increase in loss factor as the % HDPE is decreased and the % SLS filler increased. The higher the loss factor ε'', the higher is the reflection is observe in the composites and also the lower the transmission is observe as the % of SLS filler is increase.

HDPE (%)	S_{21}		S_{11}	
	8 GHz	12 GHz	8 GHz	12 GHz
100	0.7644	0.8261	0.6256	0.3911
90	0.7157	0.8743	0.6428	0.4716
80	0.6745	0.8378	0.6802	0.4763
70	0.6451	0.8350	0.7091	0.4976
60	0.5782	0.8062	0.7674	0.5642
50	0.4899	0.7900	0.8407	0.6372

Table 2 Magnitudes of S_{21} and S_{11} at 8 GHz and 12 GHz

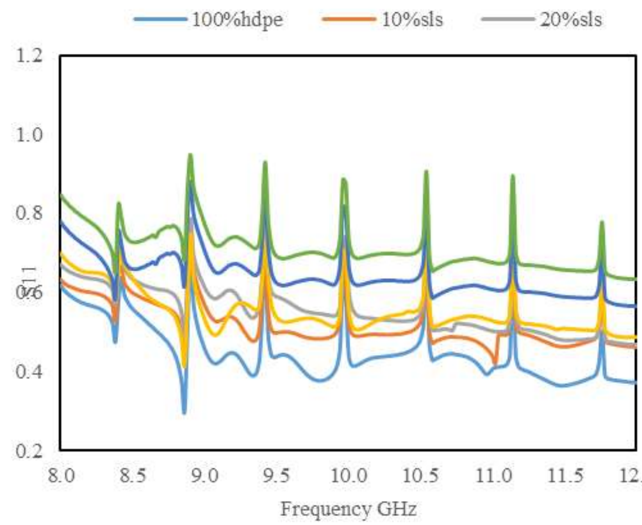


Fig. 3 Variation in S_{11} SLS-HDPE for different % ratio of composites

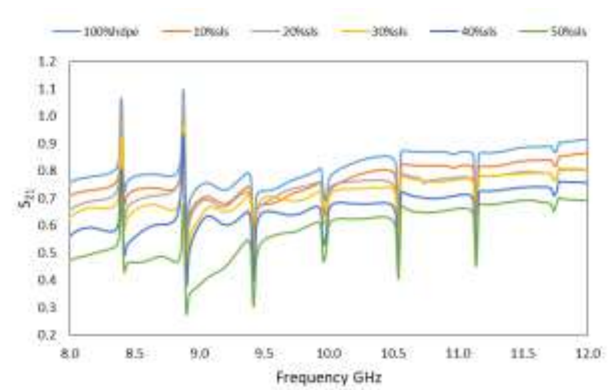
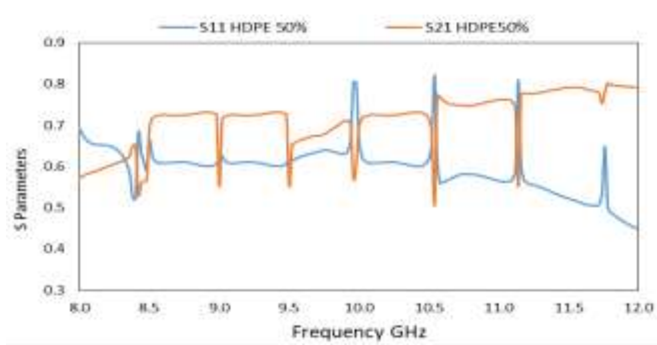
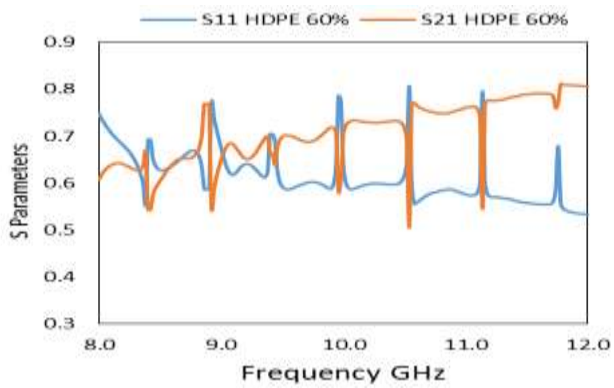
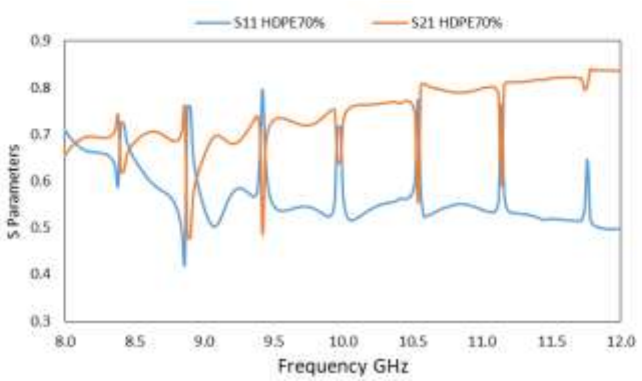


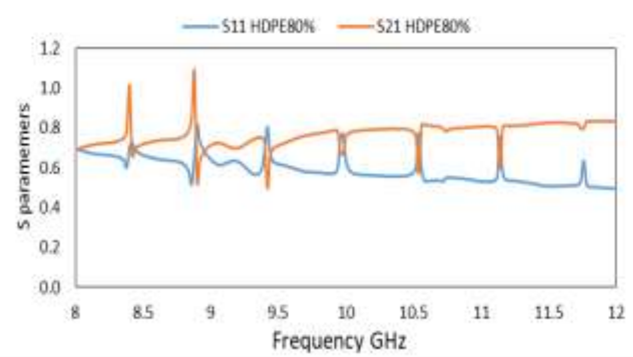
Fig.4 Variation in S_{21} SLS-HDPE for different % ratio of composites

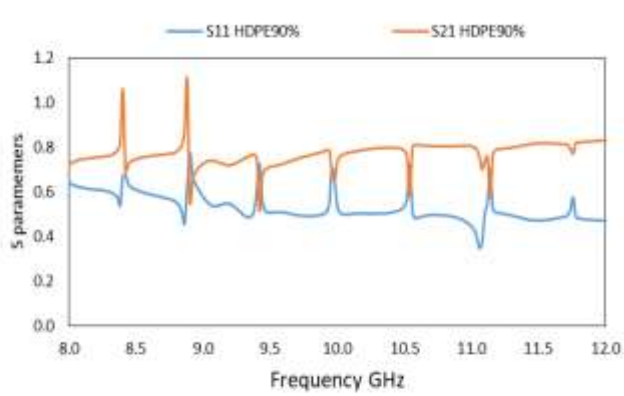
Figure 5 is the combined variation effects of $|S_{11}|$ and $|S_{21}|$, the ripples nature of the $|S_{11}|$ and $|S_{21}|$ could be attributed to the sample thickness being relatively small about 6 mm as was explained under Figure 3 and 4 above. However, if samples are sufficiently thick, there will be increased in absorption no multiple reflections rather and S_{21} will decrease with frequency (Abbas et al., 2001)











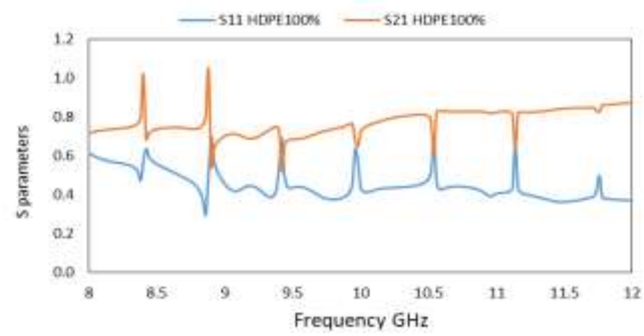
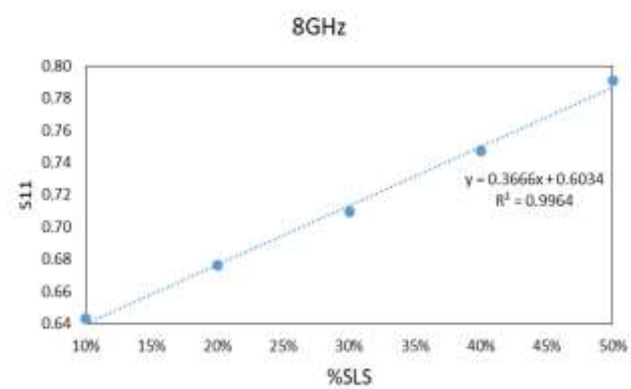


Fig. 5: Variation in S_{11} and S_{21} SLS-HDPE for different % ratio of composites

The variations in S_{11} and S_{21} with respect to % SLS filler content are presented in Figures 6 and 7 respectively. From the result, it can be deduced that the change in S_{11} and S_{21} with % SLS are proportional and inversely proportional respectively. The increase in S_{11} with %SLS is because SLS has higher Ɛ′ than HDPE therefore, increase in the percentage of SLS brings about decrease in the percentage of HDPE and that increase the rigidity of the composite which resulted to increase in the reflection coefficient, so also attributed to impedance matching. The S_{21} decrease with % SLS because SLS has higher Ɛ″ than HDPE and also due to absorption within the composite which is attributed to the particles present in the SLS, therefore increase in the SLS percentage increases the absorption of the composites and that decreases the magnitude of transmission of the composites which resulted in the decrease of the transmission coefficient. By interchanging x and y axis, the research can always predict % of HDPE or SLS in the composite for a given frequency by applying the regression equations in both cases. For example, using the S_{11} value of 50% SLS is 0.79 at 8 GHz, the prediction for the SLS filler is 50% using the equation. The result can be confirmed by using the equation at different frequency range



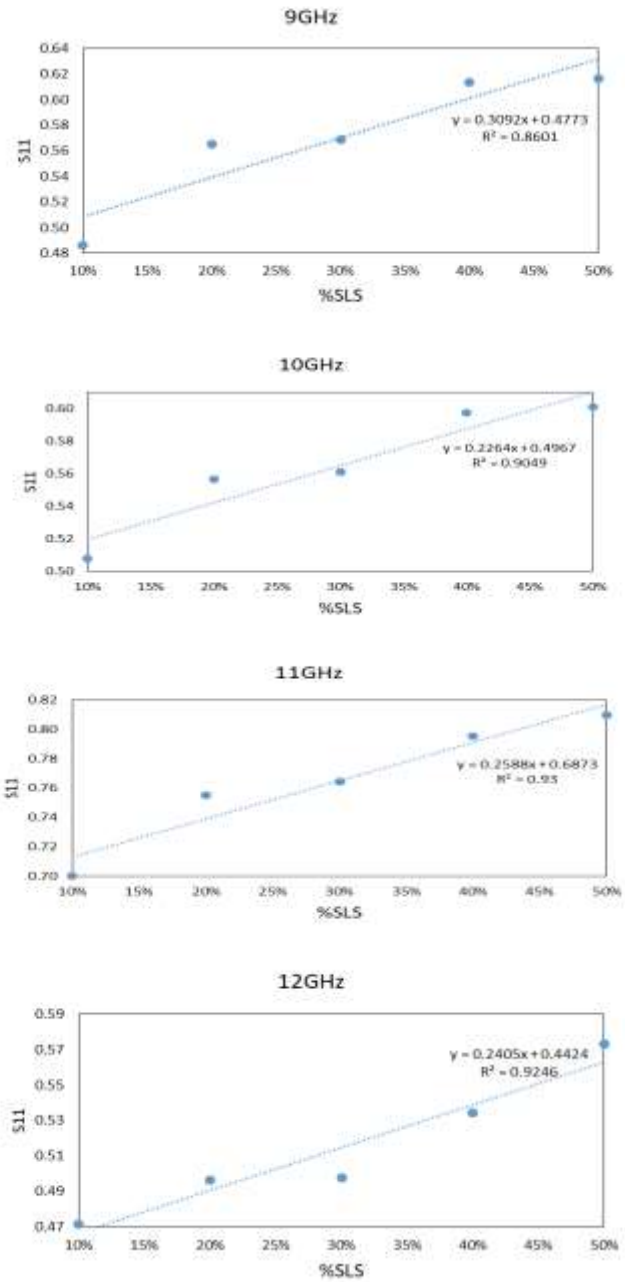
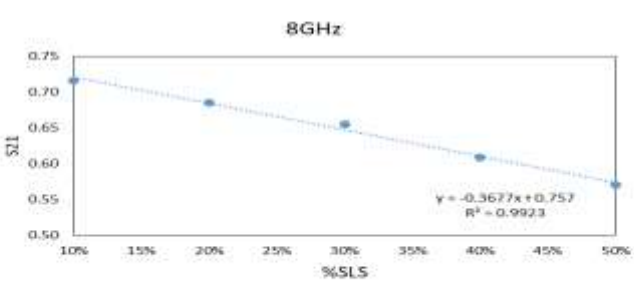


Fig. 6: Variation in S_{11} with % SLS at selected frequencies



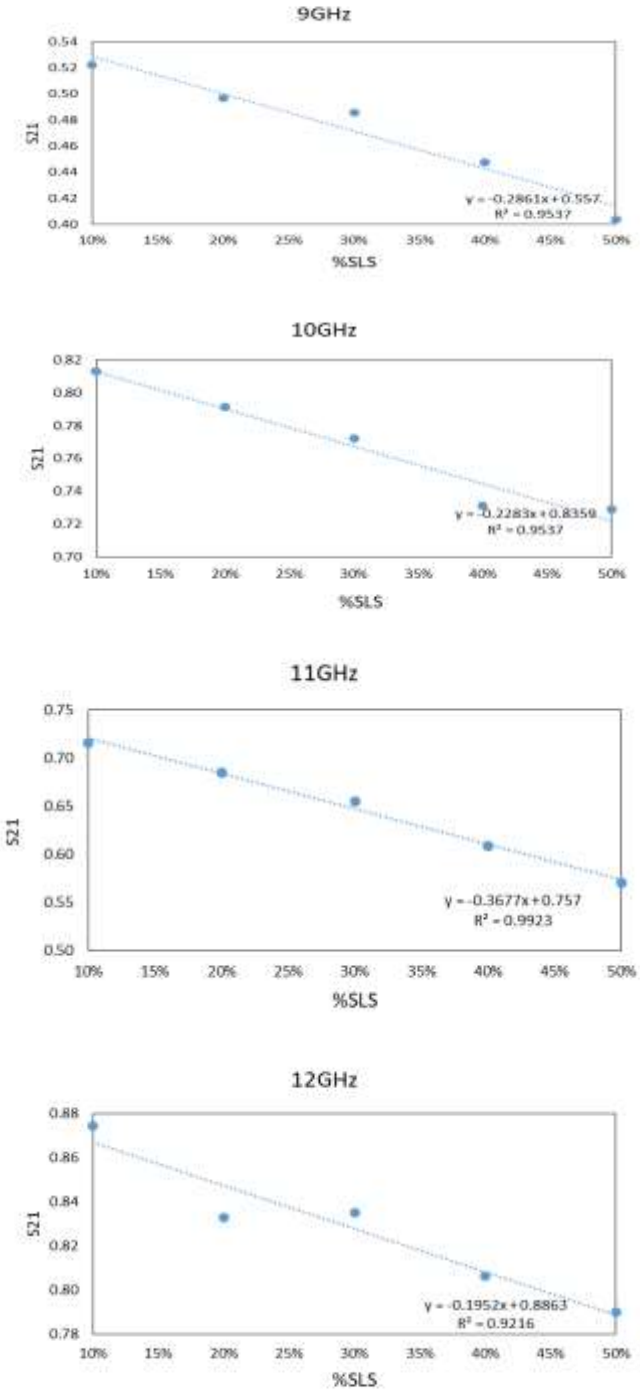


Fig. 7: Variation in S_{21} with % SLS at selected frequency

From Figures 6 and 6, R^2 of S_{21} are better than the S_{11} in all samples due to the sample thickness which is 6 mm, for S_{11} the reflection occurred at both the front and back faces of the sample while in S_{21} the reflction only occurres at front face of the sample.

IV. CONCLUSION

SLS-HDPE composites were prepared using melt blend technique. Six different percentages of SLS and HDPE from 10%SLS, 90%HDPE to 50%SLS, 50%HDPE and 100%HDPE composites were analyzed based on their reflection and transmission coefficient. The 100% HDPE composite was found to have the highest transmission coefficient and lowest reflection coefficient while the 50%HDPE was found to have lowest transmission coefficient and highest reflection coefficient. The transmission and reflection coefficient was measured using the rectangular waveguide method. The effect of the different percentages of SLS fillers on the reflection and transmission coefficient of SLS-HDPE composites were analyzed for the whole frequency range between 8 GHz and 12 GHz (X-band). The magnitude of reflection coefficient of the SLS-HDPE composites increase with increase in percentage of SLS filler from 0.6428 for 10%SLS to 0.8407 for 50%SLS while the magnitude of transmission coefficient decrease with increase in the percentage of SLS filler from 0.7157 for 10%SLS to 0.4899 for 50%SLS. It was also found that the transmission coefficient increase with increase in frequency while reflection coefficient of SLS-HDPE composites decrease with increasing in frequency

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