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# Microwave properties of the talc filled polypropylene

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A microwave bench operating in the frequency range 8–12 GHz (X-band) was used to investigate some of the electrical characteristics of the talc filled polypropylene composite. The impedance, return loss, and insertion loss are measured as a function of frequency in the X-band range. It was found that electromagnetic waves interact with the material via the impurities, inclusions and voids existing in the bulk composite. The impedance, return loss and insertion loss show relatively low frequency dependence. Also, the return loss and the impedance exhibit a resonance behaviour at 11.91 GHz. The results suggest that this composite material could be used in some microwave applications.

## 1. Introduction

During the last few years a considerable effort has been devoted to improve the properties and quality of the composite materials to meet engineering requirements. Various technical demands of the modern technology of such materials depend on their structure and physical behaviour. The characterization of such composite materials needs a knowledge of a number of physical parameters. However, for a two-phase composite material, the electrical and mechanical behaviour depend on both the type and volume fraction of the filler and the matrix and their interaction [1–6]. In a previous publication the equivalent impedance $Z$, the insertion loss ($IL$), and the return loss ($RL$) of Magnex DC composite material were reported at the microwave frequencies. It was found that the equivalent impedance for the Magnex DC decreases as the frequency increases; and the insertion loss is greater than 8 dB; while the return loss is around 2 dB. On the other hand it was reported that both the filler concentration and the matrix controlled the microwave characterization of the Magnex DC composite [7]. The present work is an attempt to investigate the properties of the talc filled polypropylene in the X-band range (8–12 GHz). To the best of the author's knowledge, no study has yet been reported to characterize the talc filled polypropylene composite at microwave frequencies. This composite is a non-magnetic material and has relatively low permeability. It exhibits a broad relaxation at the microwave range. The knowledge of $Z$, $IL$, and $RL$ behaviour at the microwave frequencies would enable a better understanding of the application of such polymer composite in microwave applications.

## 2. Experimental details

Measurements were performed on a 30% talc filled polypropylene sheet produced by Reifenhauser GMBH, West Germany. A specimen of dimensions (22 mm × 10 mm × 1.8 mm) was cut from the composite sheet. The measurements were carried out using a conventional microwave bench operating in the X-band range. The specimen was placed perpendicular to the waveguide axis. The transmitted and the reflected signals from the specimen were detected and measured using a standing wave ratio (SWR) meter or power meter. The reflected signal was obtained by using a 20 dB directional coupler. Measured data were obtained either by using a point by point method or by the swept frequency technique. In the swept mode, the $X$–$Y$ chart recorder was used to obtain continuous measurements over the $X$-band range of frequencies. Values of the SWR, needed for impedance measurements, were obtained directly using the SWR meter, and also by using the SWR meter as an indicator and the values of the SWR were determined from the readings of a reference attenuator. The impedance, $Z = R - jX$ (in ohms), was obtained point by point using the slotted waveguide method as reported elsewhere [7–9]. Uncertainties in the measurements were reduced by correct matching of the set up, i.e. reducing the multireflection and disturbances of the wave inside the guide to a minimum. The reproducibility of the measured values were acceptable and the deviations were much less than 10%.

## 3. Results and discussion

Polypropylene polymer is an insulator and it can be considered transparent to high frequencies. When the filler is added to the matrix, its electrical behaviour may change according to the type, volume fraction, and the concentration of the filler. Hence, the microwave characterization is very important from the point of view of the relaxation phenomena, design, and specification of the electrical components such as absorbing material [10–12].

The variation of the $IL$ and $RL$ as a function of frequency gives an insight into the processes occurring

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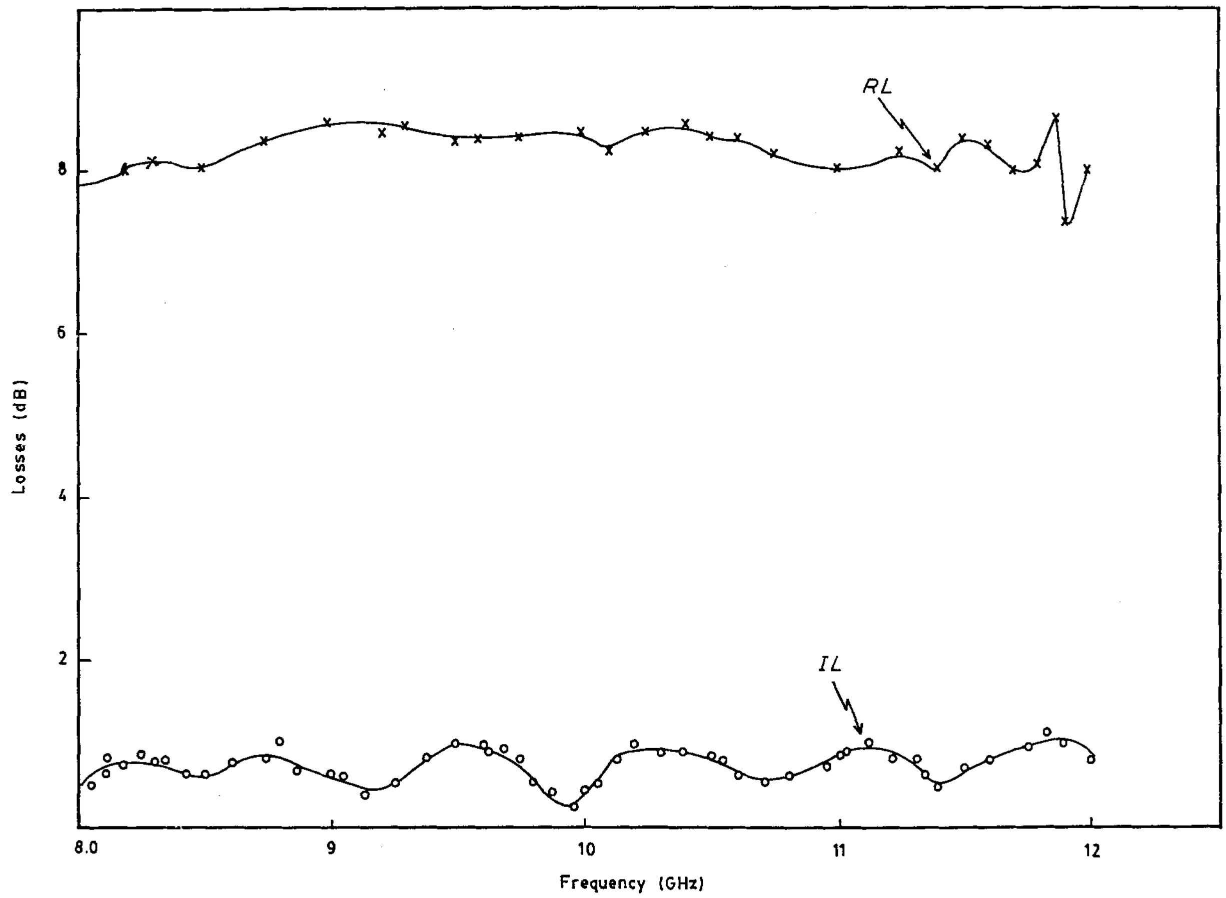


*Figure 1* The calculated return and insertion losses as a function of frequency.

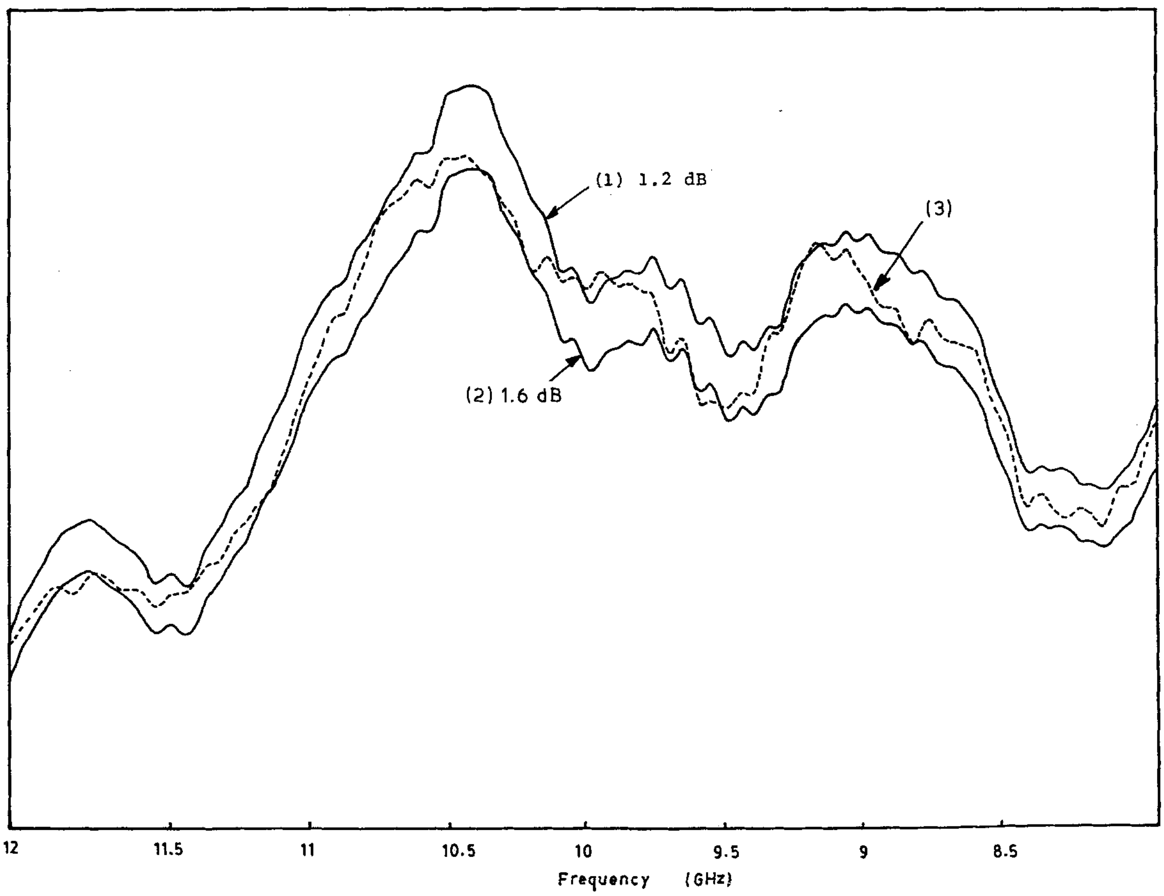


*Figure 2* The insertion loss as a function of frequency. Curves 1 and 2 are reference lines representing attenuator settings without specimen; curve 3 represents the insertion loss of the specimen.

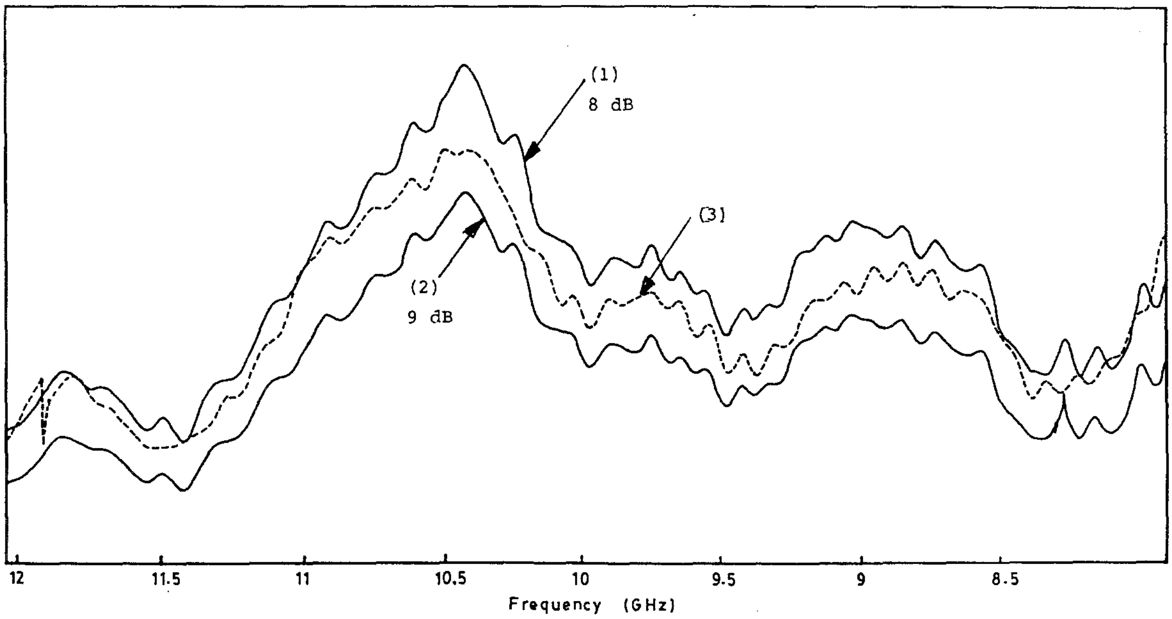


*Figure 3* The return loss as a function of frequency. Curves 1 and 2 are reference lines representing attenuator settings without specimen; curve 3 represents the return loss of the specimen.

in the sample. The nature of the electromagnetic wave absorption may be understood by considering the phonon interaction model in the presence of different processes which are responsible for the relaxation phenomena. This can be estimated via the reflected, transmitted, and the absorbed components of the incident electromagnetic energy. If $P_0$ is the received signal level with sample in place and $P_i$ is the received signal level with no sample; then these quantities are related to each other by a relation proposed by Bigg *et al.* [13, 14] for the shielding effectiveness (*SE*)

$$SE = 10 \log (P_0/P_i) = A_1 + A_2 + A_3 \text{ dB} \quad (1)$$

where $A_1$ is the energy absorption, $A_2$ is the reflected energy, and $A_3$ is the internal reflection of the incident signal. Expression 1 also represents the *IL* of the specimen. The *RL* is given by the difference, in dB, between the incident and the reflected signal levels [7, 15, 16]. Variation of the *IL*, and *RL* as a function of frequency are shown in Fig. 1. Results of the continuous measurements of *IL* and *RL* using the *X–Y* chart recorder are shown in Figs 2 and 3. The solid curves are the reference lines obtained for different variable attenuator settings, while the dotted lines represent the variations of both *IL* and *RL* of the specimen when the setting of the variable attenuator is equal to zero. These curves show that the average values of the *IL*, and *RL* are relatively frequency independent. The *IL* varies from 1.2 to 1.6 dB over the whole X-band, while the *RL* varies from about 7.5 to

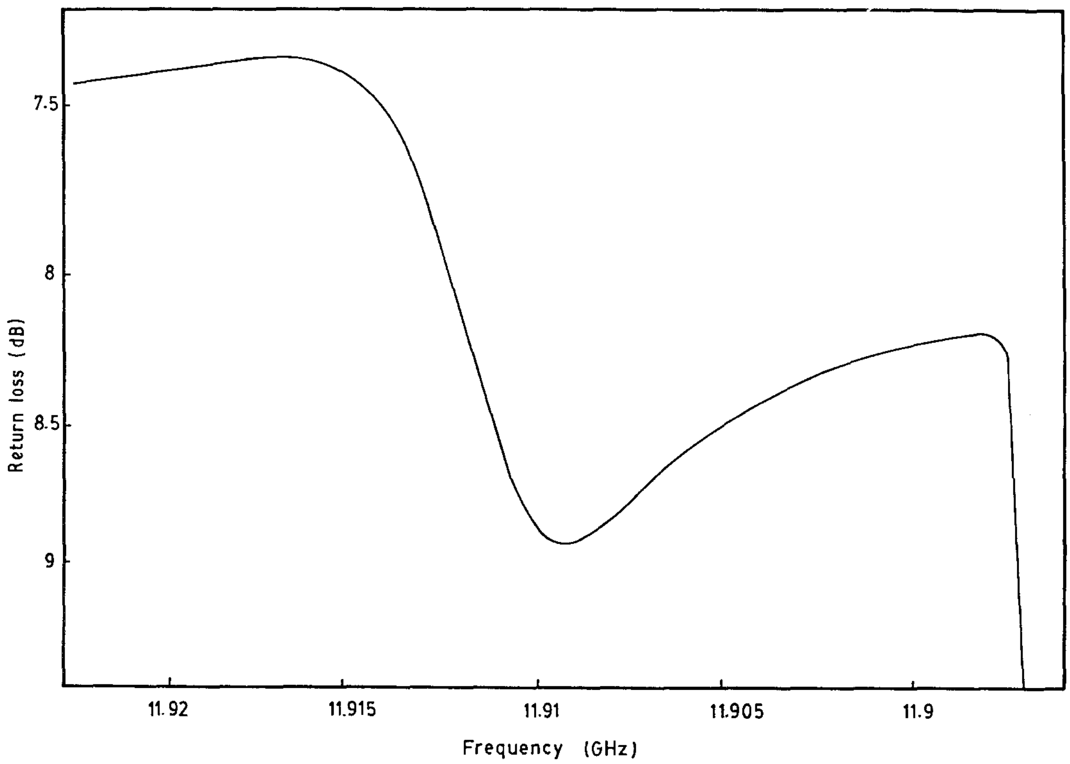


*Figure 4* The expansion of the return loss around 11.91 GHz.

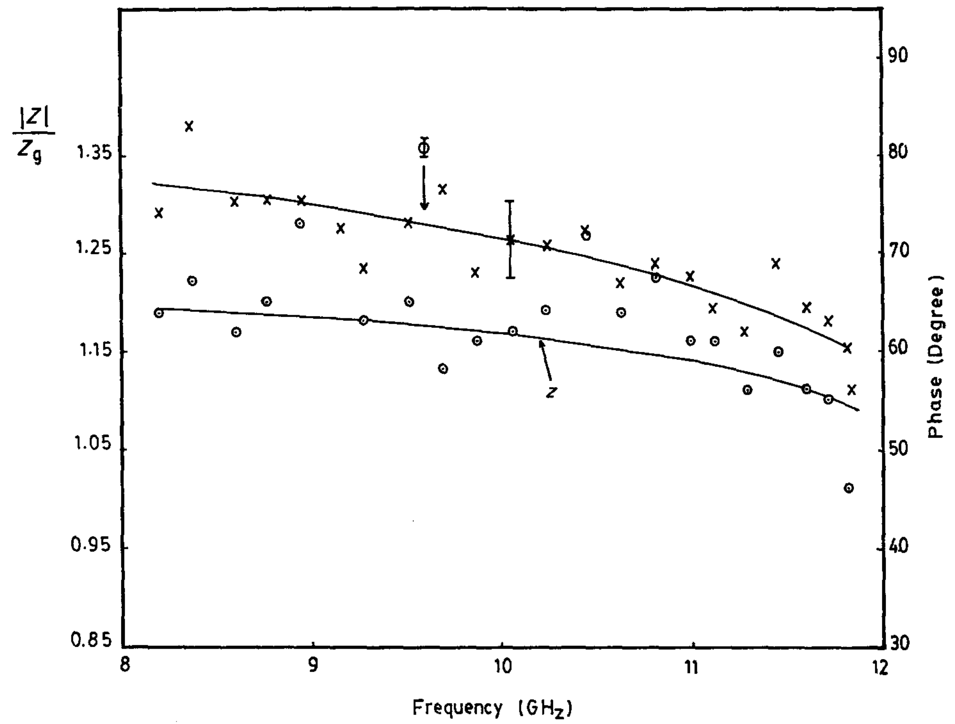


*Figure 5* The magnitude of the normalized impedance and the phase angle as a function of frequency.

8.5 dB. These variations may be due to the composite structure and the measurement uncertainties. In view of the composite polymer, it is expected that the absorption processes produced from phonons or elastic/inelastic interactions with impurities, pores, and air inclusions [17–19]. Therefore, the low values of *IL* suggest that such a polymer composite is a relatively homogeneous dielectric.

A noticeable dip in the *RL* variation with frequency is indicated in Figs 3 and 4. This dip occurs in the frequency range 11.905–11.915 GHz with a bandwidth of about 10 MHz which is about 0.1% of the centre frequency. The dip level is found to be dependent on the different set up waveguide configurations. The occurrence of this dip could be attributed to the structure of the composite material. This material which exhibits such a sharp dip may be utilized in building microwave resonators and filters.

Results of the impedance measurements performed on the talc polypropylene specimen are shown in Figs 5, 6 and 7. These measured data are obtained by using the slotted line section and the Smith chart. These curves show that the magnitude of the normalized impedance

$$z = (R - jX)/Z_g = Z/Z_g$$

where $Z_g$ represents the waveguide impedance of the dominant mode (real value), and the phase $\phi$ of the impedance $Z$ are weakly dependent on frequency over the whole X-band region (see Fig. 5). This is also obvious in the curves representing the variations of $r = R/Z_g$, and $x = X/Z_g$ as a function of frequency

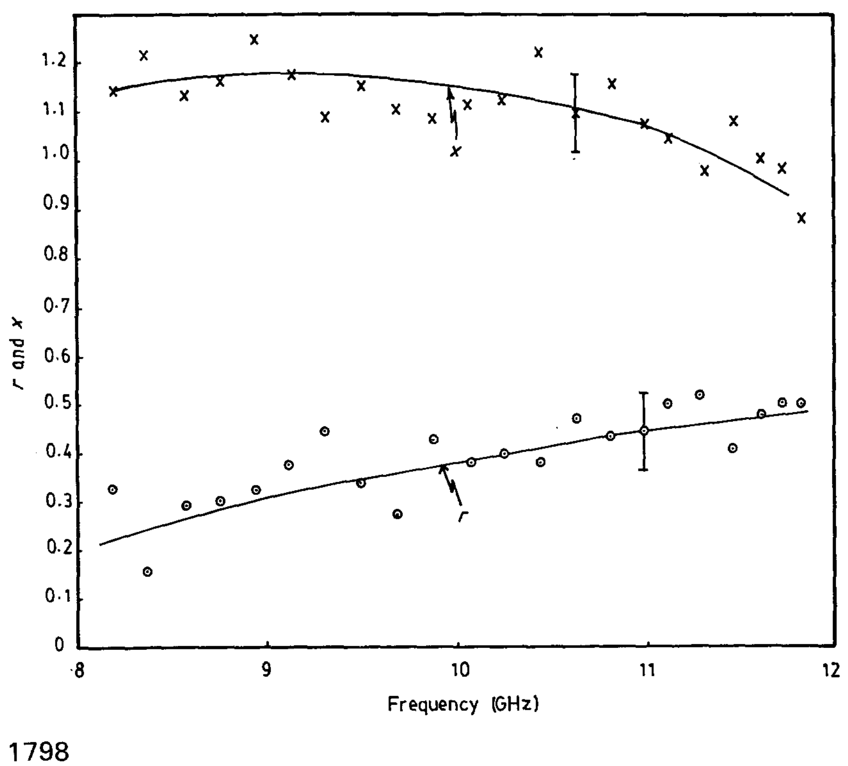


*Figure 6* The normalized values of the real and imaginary parts of the equivalent impedance of the specimen.

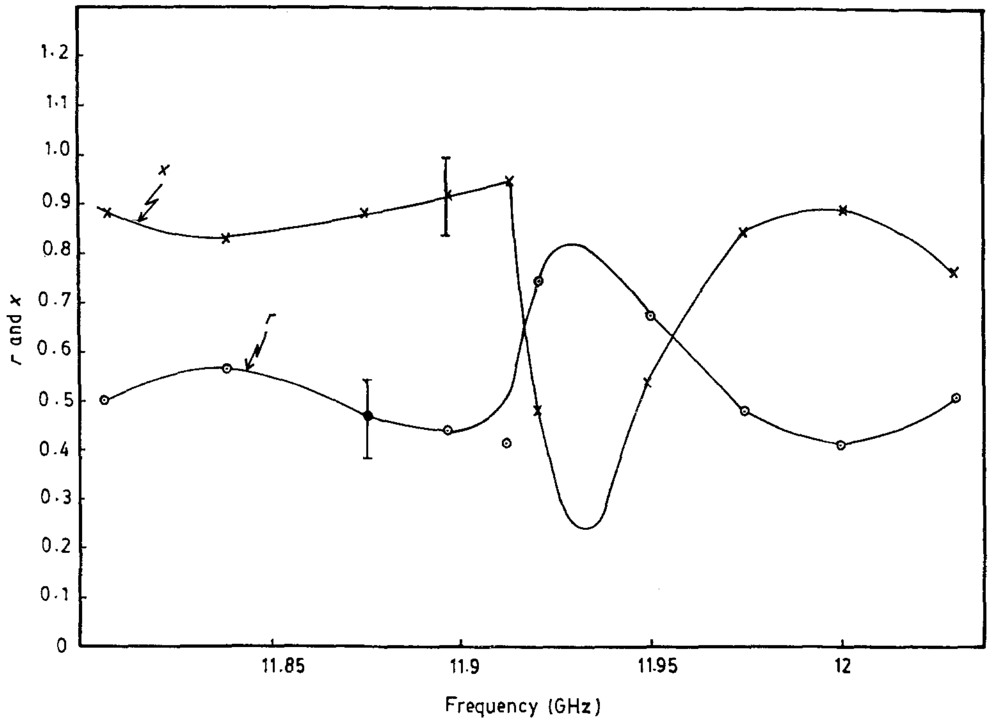


*Figure 7* The normalized values of the real and imaginary parts of the impedance around 11.91 GHz.

(see Fig. 6). Hence the ratio of the imaginary and the real components of the dielectric constant remain unchanged. This would suggest that the bulk relaxation time is large compared to the time of the fluctuation of the incident electric field. The variations of the normalized real part $r$ and the normalized imaginary part $x$ of the impedance around 11.91 GHz are shown in Fig. 7. The variation of the equivalent impedance of the specimen $Z = R - jX$ in ohms is shown in Fig. 8. The real part is almost constant except in the region around 11.91 GHz where its value drops by 25%, exhibiting a minimum. The imaginary part starts with 700 Ω and decreases monotonically by 40% over the X-band. The value of this impedance is associated with a particular mode and the frequency of the signal in the transmission system set up; consequently the normalized impedance (normalized with respect to the waveguide impedance) will give the variation of the impedance of the specimen irrespective of the transmission system configuration.

The results obtained in the present study reveal that the polymer composite is a nonpolar material and the observed losses are due to the same structural effects. This may be attributed to different factors such as metallic impurities, pores, space charges and composite processing. Impurities are such particles which may be surrounded by matrix structural units causing an electrical conduction which is affected by both of

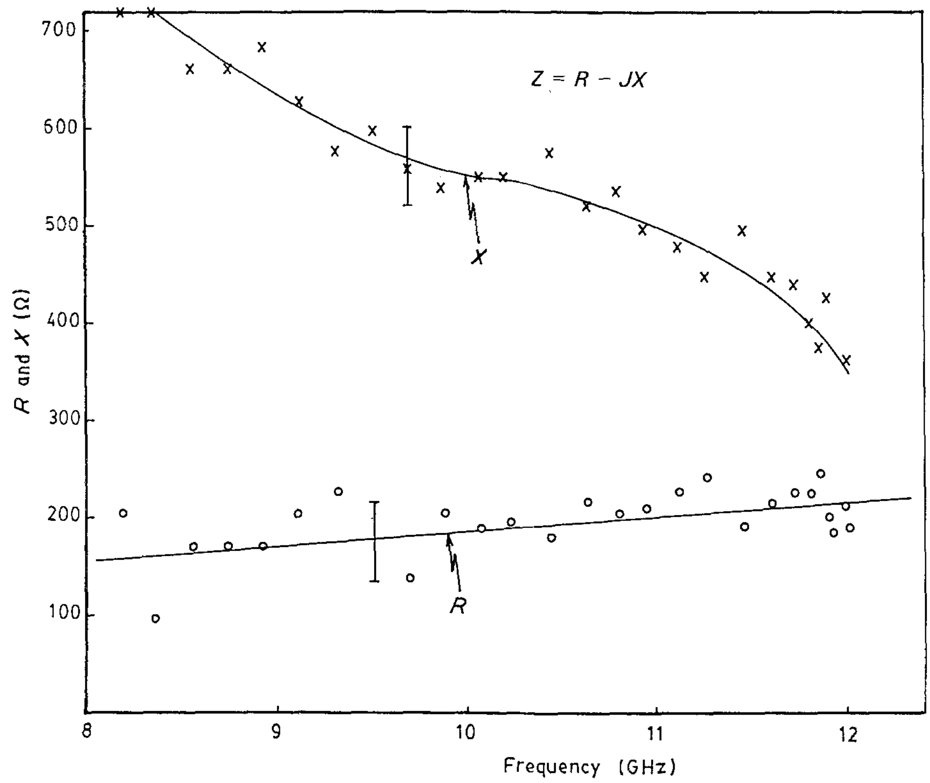


*Figure 8* The measured values of the real and imaginary parts of the specimen impedance.

the filler and the matrix [10, 13, 14, 19]. On the other hand, the properties of such a polymer composite may vary in different places in the bulk due to some pores or voids being filled with air bubbles of hygroscopic water, the temperature gradient and differences take place in the conditions of the product manufacturing and processing.

## 4. Conclusion

A study was conducted on the talc filled polypropylene in the X-band microwave frequencies. From the obtained results we can conclude the following:

1. The insertion loss shows a relatively small frequency dependence.
2. Both the impedance and the return loss exhibits a minimum at 11.91 GHz. This minimum is attributed to the electromagnetic wave interaction with impurities, inclusions, and voids existing in the composite bulk.
3. The imaginary component of the complex impedance decreases to 40% within the X-band range; while the real part does not show a frequency dependence.
4. The obtained results of the impedance and losses may be utilized in some microwave applications.

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