Chapter 7

MICROWAVE PROPERTIES OF SELECTED THERMOPLASTIC CONDUCTING COMPOSITES

Abstract: To improve the processability of a conducting polymer, various methods to incorporate conducting polymer into processable insulating polymer have been reported. In this study we have prepared thermoplastic conducting composites of selected conducting polymers with PVC and PU. Thermoplastic conducting composites of PPDA, PTH, PEDOT and PANI with PVC and PU were prepared. In the preparation of PTH-PVC, PEDOT-PVC, PANI-PVC, PEDOT-PU and PANI-PU composites, in situ polymerisation of the monomer in thermoplastic polymer solution using FeCl₃ as the oxidising agent was employed. The conditions for preparation of PTH-PVC composites were optimized. The microwave properties of all the composites like dielectric constant, dielectric loss, absorption coefficient, heating coefficient, skin depth and conductivity in the microwave frequency (S band) were studied in the S band and the best composite was selected for further studies.

Though various novel properties have been observed in conducting polymers, their practical applications have been rather limited, because of poor processability. To improve the processability of a conducting polymer, various methods to incorporate conducting polymer into processable insulating polymer have been reported. Methods of the preparation of insulating polymer - conducting polymer composite in which electrical conductivity can be varied by many orders of
magnitude ranging from insulator to metal by changing the concentration of conducting polymer have been described [1-14].

Conducting polymers show some specific characteristics in microwave frequencies that make them far more interesting than traditional dielectric materials. The intrinsic conductivity of conjugated polymers leads, in the field of their microwave properties, to a dynamic conductivity leading to high levels of dielectric constant [1-4]. One of the inherent problems with conducting polymers is that they are typically intractable. To overcome the problems of processing some of the conducting polymers are made into emulsions and suspensions (PEDOT, PPY etc) ready for coating [5-7]. Formation of composites with thermoplastic materials either by physical blending [8-9] or forming a core-shell type of structures is another method [10-11]. Polypyrrole, has been polymerised on the surface of PVA, PVC and within it to form composites. Textile materials have been used as substrates for a number of materials and have been coated with conducting polymers by soaking them with oxidant and then exposing them to monomer. The use of polypyrrole coated fabrics (including glass fibres) enables the formation of structural Radar Absorbing Material (RAM). The properties of the fabric-coated materials were modelled and made as Salisbury Screens and Jaumann layers [12-14]. It is now possible to design materials possessing permittivities, which have low variation with the frequency ($\varepsilon'' \propto \omega^{-0.3}$) or high variation ($\varepsilon'' \propto \omega^{-0.7}$) directly correlated to the intrinsic conductivity of the polymer. To obtain the best performance (large bandwidth) these materials have to be associated in multilayer structures. Moreover, the use of structural laminates allows the integration of two functions, stealth and mechanical [1].

It has been shown that PANI can be made compatible with a range of common organic solvents and polymers, with the aid of an appropriate sulfonic acid.
Microwave properties of selected thermoplastic conducting composites

Dodecylbenzene sulfonic acid (DBSA) is particularly important in this regard. This simultaneously renders the PANI conductive and, by acting in a manner analogous to a surfactant [15], presents the possibility of solution blending [16-18] or direct melt-mixing [19] with a range of conventional plastics, to produce blends which show little or no evidence of a percolation threshold [20]. Although similar electrical results obtained from nanoparticle blends of PANI doped with hydrochloric acid [21] imply that the absence of a percolation threshold is not necessarily associated with thermodynamic compatibility, it is evident that conducting polymer blends differ fundamentally from composites containing conducting fillers, in that the two components are intimately mixed on the nanometer scale. Consequently, extensive control of conductivity is theoretically possible, simply by varying the protonating acid, processing conditions, doping level and the amount of PANI within the blend [22].

PVC and PU are among the most versatile thermoplastics widely used alone and as blends with other polymers. They have good processability and are polar in nature making them soluble in many solvents and partially miscible with many polymer matrices. In this study, the preparation of composites of PPDA, PTH, PEDOT and PANI with PVC and PU by in situ polymerisation is proposed to be undertaken. In the preparation of PTH-PVC, PEDOT-PVC, PANI-PVC, PEDOT-PU and PANI-PU composites, FeCl₃ was used as the oxidising agent. The optimum quantity of FeCl₃ required for the polymerisation of thiophene in PVC solution has to be determined. For further studies this optimum quantity of FeCl₃ will be used for the polymerisation of EDOT and aniline in PVC and PU solutions. The microwave properties of all the composites will be studied in the S band and the best combination is proposed to be identified.
7.1 OPTIMISATION OF RATIO OF FeCl₃: THIOPHENE IN PREPARING PTH-PVC COMPOSITES

One of the easiest routes to prepare polythiophenes is by chemical oxidation of thiophenes using FeCl₃. The ratio of FeCl₃: Thiophene for polymerisation used by different research groups was different. [23-25]. Since the PVC-PTH composite is prepared by in situ polymerisation of thiophene in PVC solution, the FeCl₃: Thiophene ratio is very critical. If the amount of FeCl₃ added is not adequate, it will lead to incomplete polymerisation. If the quantity of FeCl₃ is more than that is required it will affect the properties. So blends with various FeCl₃: Thiophene ratios were prepared and their microwave properties were studied to find an optimum FeCl₃: Thiophene ratio.

7.1.1 Experimental methods

Thiophene was added to the PVC solution in THF to get a 10% 1:1 PVC-Thiophene mixture. FeCl₃ dissolved in THF was then added to this mixture and the reaction is carried out for 24 hrs. Composites were prepared with FeCl₃: thiophene ratio of 1.5, 2, 2.5 and 3. About 10 ml of the composite solutions were cast in petridish and allowed to dry at room temperature for 24 hrs. Thin strips of the film were cut and the dielectric properties in microwave frequencies (S band 2-4 GHz) were evaluated by Cavity Perturbation Technique. The transmission type resonator used in this experiment was excited with TE₁₀₅ mode by connecting it to an HP8510 C Network Analyzer.

The resonant frequency ‘f₀’ and the corresponding quality factor ‘Q₀’ of each resonant peak of the empty cavity are first determined. Now, after selecting a
particular resonant frequency, the dielectric sample is introduced into the cavity and the position is adjusted for maximum perturbation (i.e. maximum shift of resonant frequency towards the low frequency region, with minimum amplitude for the peak) and the corresponding change in the frequency of the resonant peak is observed. The new resonant frequency \( f_s \) the corresponding 3 dB bandwidth and the quality factor \( Q' \) are determined. The procedure is repeated for other resonant frequencies and the measurements are carried out for all the samples. Knowing the volumes of the sample and the cavity resonator the dielectric parameters can be evaluated. The parameters are calculated using the following formulae (1-7)

\[
\begin{align*}
\varepsilon' &= 1 + \frac{f_0 - f_s}{2f_s} \left[ \frac{V_c}{V_s} \right] \\
\varepsilon'' &= \frac{V_c}{4V_s} \left[ \frac{Q_0 - Q_s}{Q_0 Q_s} \right] \\
J &= \frac{1}{\varepsilon \tan \delta} \quad (3) \\
\alpha &= \frac{\varepsilon'' f}{n c} \quad (4) \\
\sigma &= 2 \pi f \varepsilon_0 \varepsilon'' \quad (5) \\
\tan \delta &= \frac{\varepsilon''}{\varepsilon} \quad (6) \\
d &= \frac{1}{\alpha} \quad (7)
\end{align*}
\]

Where,

\( \varepsilon' \) = Dielectric constant  \( \varepsilon'' \) = Loss factor
\( \varepsilon_0 \) = Permittivity of free space  \( \alpha \) = Absorption Coefficient
\( d \) = Penetration depth  \( \sigma \) = conductivity
\( J \) = Efficiency of heating  \( c \) = velocity of light
\( V_c \) = Volume of cavity  \( V_s \) = Volume of sample

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7.1.2 Results and discussion

7.1.2.1 Effect of ferric chloride on dielectric constant ($\varepsilon'$) of PTH-PVC composite

Figure 7.1 shows the variation of dielectric constant with FeCl$_3$: Thiophene ratio at various frequencies.

![Graph showing variation of dielectric constant ($\varepsilon'$) with FeCl$_3$: Thiophene ratio at various frequencies.](image)

Figure 7.1 Variation of dielectric constant ($\varepsilon'$) with FeCl$_3$: Thiophene ratio at various frequencies.

Dielectric constant is found to be lower at the ratio 2.5. The values for 1.5 and 2 are higher may be due to the incomplete polymerisation of thiophene. At the ratio 3, there is not much change in the dielectric constant compared to that at 2.5. So we
may infer that the polymerisation would have taken place to a considerable extent at a FeCl₃: Thiophene ratio of 2.5 and can be taken as the optimum value. Figure 7.1 also shows that dielectric constant decrease with increase in frequency. As the frequency of the applied field is increased the polarization has no time to reach its steady field value and the orientation polarisation is the first that falls. Due to the orientation polarization of the dipoles, the possibility of dielectric relaxation (so also dielectric loss) cannot be ruled out at higher frequencies. This might result in the decrease of $\varepsilon'$ with frequency [18-19].

### 7.1.2.2 Effect of ferric chloride on dielectric loss ($\varepsilon''$) of PTH-PVC composite

Figure 7.2 shows the variation of dielectric loss with FeCl₃: Thiophene ratio at various frequencies.

![Figure 7.2 Variation of dielectric loss ($\varepsilon''$) with FeCl₃: Thiophene ratio at various frequencies.](image)

Figure 7.2 Variation of dielectric loss ($\varepsilon''$) with FeCl₃: Thiophene ratio at various frequencies.
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Dielectric loss is found to be high at the ratio 2.5. The values for 1.5 and 2 are lower may be due to the incomplete polymerisation of thiophene. At the ratio 3, there is not much change in the dielectric loss compared to that at 2.5. So we may infer that the polymerisation would have taken place to a considerable extent at a FeCl$_3$: Thiophene ratio of 2.5 and can be taken as the optimum value.

Dielectric loss tends to increase with increase in frequency within the range 2.4 to 2.9 GHz. As the frequency is increased the inertia of the molecule and the binding forces become dominant and it is the basis for high dielectric loss at higher frequencies.

7.1.2.3 Effect of ferric chloride on conductivity ($\sigma$) of PTH-PVC composite

Figure 7.3 shows the variation of conductivity with FeCl$_3$: Thiophene ratio at various frequencies. Conductivity is found to be high at the ratio 2.5. The values for 1.5 and 2 are lower may be due to the incomplete polymerisation of thiophene. At the ratio 3, there is not much change in the conductivity compared to that at 2.5. So we may infer that the polymerisation would have taken place to a considerable extent at a FeCl$_3$: Thiophene ratio of 2.5 and can be taken as the optimum value.

The microwave conductivity is a direct function of dielectric loss and so it shows a similar variation with frequency as the dielectric loss factor. Figure 7.3 shows that conductivity increases with increasing frequency.
Figure 7.3 Variation of conductivity (\(\sigma\)) with FeCl\(_3\): Thiophene ratio at various frequencies.

From Figure 7.1, 7.2 and 7.3, it is clear that the optimum FeCl\(_3\): Thiophene ratio for insitu chemical oxidative polymerization of thiophene in PVC solution is 2.5.

### 7.1.3 Conclusions

PTH-PVC composites were prepared with different FeCl\(_3\): Thiophene ratio viz. 1.5, 2, 2.5 and 3. Films were prepared from the samples and the dielectric constant, dielectric loss and conductivity of the samples were evaluated at the microwave frequencies 2-4 GHz using cavity perturbation technique. The major conclusions are:
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- Optimum FeCl₃: Thiophene ratio for in situ chemical oxidative polymerisation of thiophene in PVC solution is 2.5
- Dielectric constant of the PTH-PVC composites decrease with increase in frequency.
- Dielectric Loss and Conductivity of the PTH-PVC composites increases with increase in frequency.

PART-II

7.2 EFFECT OF DRYING CONDITION ON MICROWAVE PROPERTIES OF CONDUCTING POLYMER-PVC COMPOSITES

The properties of polymer blends are largely dependent on the morphology. The processing method employed has a major impact on the morphology of a blend. Temperature and duration of drying of solution cast blend films are supposed to affect its morphology [20, 21]. In this study an attempt is made to compare the properties of room temperature dried and vacuum dried PVC- conducting polymer composite films. The optimum FeCl₃: Thiophene ratio for in situ chemical oxidative polymerization of thiophene in PVC solution is to be found. In subsequent studies this ratio will be used for the chemical oxidative polymerizations of thiophene, EDOT and aniline in PVC solutions.

7.2.1 Experimental methods

Conducting polymer-PVC composites in the ratio of 1:1 were prepared with a FeCl₃: Monomer ratio of 2.5. Monomer (thiophene, EDOT or aniline) was added to PVC solution in THF to get a 10% 1:1 PVC-Monomer mixture. THF solution of
FeCl$_3$ was added to the solution and the reaction is carried out for 24 hrs. Doping of PVC-PANI was done by adding camphor sulfonic acid to the blend solution in the ratio aniline: CSA (1: 0.5). PTH and PEDOT gets in situ doped with FeCl$_3$.

About 10 ml of the composite solutions were cast in petridish and allowed to dry at room temperature for 24 hrs and in vacuum oven at 40 °C for 2 hrs. Thin strips of the films were cut and the dielectric properties in microwave frequencies (S band 2-4 GHz) were evaluated by Cavity Perturbation Technique. The transmission type resonator used in this experiment was excited with TE$_{101}$ mode by connecting it to an HP8510 C Network Analyzer.

7.2.2 Results and discussion

7.2.2.1 Variation of dielectric constant ($\varepsilon'$) for vacuum dried and room temperature dried conducting polymer- PVC composites

Figure 7.4 shows variation of dielectric constant for vacuum dried and room temperature dried Conducting polymer-PVC composite with frequency. It can be seen that the dielectric constant is higher for room temperature dried samples of all the compositions. This may be due to more extent of phase separation and heterogeneous structure in room temperature dried samples. In room temperature drying, the rate of drying is low and hence the molecules get more time for diffusion into domains. This may lead to isolation of certain conducting polymer domains and hence conducting path may be interrupted. So it can be inferred that vacuum oven drying is more suitable for casting this type of composite films. PANI-PVC composites are showing highest dielectric constant followed by PEDOT-PVC composites and lowest by PTH-PVC.
Figure 7.4 Variation of dielectric constant ($\varepsilon'$) for vacuum dried and room temperature dried conducting polymer-PVC composites with frequency.

Figure 7.4 shows that dielectric constant decrease with increase in frequency. As the frequency of the applied field is increased the polarization has no time to reach its steady field value and the orientation polarisation is the first that falls. Due to the orientation polarization of the dipoles, the possibility of dielectric relaxation (so also dielectric loss) cannot be ruled out at higher frequencies. This might result in the decrease of $\varepsilon'$ with frequency [18-19].
7.2.2.2. Variation of dielectric loss ($\varepsilon''$) for vacuum dried and room temperature dried conducting polymer- PVC composites

Figure 7.5 shows variation of dielectric loss for vacuum dried and room temperature dried conducting polymer - PVC composites with frequency.

From the Figure 7.5 it can be observed that dielectric loss is higher for vacuum oven dried samples for all the composites. This may be due to more extent of phase separation and heterogeneous structure in room temperature dried samples. In room temperature drying, the rate of drying is low and hence the molecules get more time for diffusion into domains. This may lead to isolation of certain conducting polymer domains and hence conducting path may be interrupted. So it
can be inferred that vacuum oven drying is more suitable for casting this type of composite films. Dielectric loss tends to increase with increase in frequency within the range 2.4 to 2.9 GHz. As the frequency is increased the inertia of the molecule and the binding forces become dominant and it is the basis for high dielectric loss at higher frequencies.

7.2.2.3. Variation of conductivity (σ) for vacuum dried and room temperature dried conducting polymer-PVC composites

Figure 7.6 shows variation of conductivity for vacuum dried and room temperature dried conducting polymer-PVC composites with frequency.

![Graph](image)

Figure 7.6 Variation of conductivity (σ) for vacuum dried and room temperature dried conducting polymer-PVC composites with frequency.
From the Figure 7.6 it can be observed that conductivity is higher for vacuum oven dried samples for all the composites. This may be due to more extent of phase separation and heterogeneous structure in room temperature dried samples. In room temperature drying, the rate of drying is low and hence the molecules get more time for diffusion into domains. This may lead to isolation of certain conducting polymer domains and hence conducting path may be interrupted. So it can be inferred that vacuum oven drying is more suitable for casting this type of composite films. The microwave conductivity is a direct function of dielectric loss and so it shows a similar variation with frequency as the dielectric loss factor. Figure 7.6 also shows that conductivity of all composites increases with frequency.

7.2.2.4 Variation of absorption coefficient (\(\alpha\)) for vacuum dried and room temperature dried conducting polymer- PVC composites

Figure 7.7 shows variation of absorption coefficient for vacuum dried and room temperature dried conducting polymer-PVC composites with frequency. From the Figure 7.7 it can be observed that absorption coefficient is higher for vacuum oven dried samples for all the composites. This may be due to more extent of phase separation and heterogeneous structure in room temperature dried samples. In room temperature drying, the rate of drying is low and hence the molecules get more time for diffusion into domains. This may lead to isolation of certain conducting polymer domains and hence conducting path may be interrupted. So it can be inferred that vacuum oven drying is more suitable for preparing films. Absorption coefficient is directly related to the dielectric loss factor and therefore it shows the same behaviour as that of dielectric loss.
7.2.3 Conclusions

1:1 composites of polythiophene, PEDOT and polyaniline with PVC were prepared by casting the composite solution both at room temperature and vacuum oven. The dielectric constant, dielectric loss, absorption coefficient and conductivity of the samples were evaluated at the microwave frequencies 2-4 GHz using cavity perturbation technique. The major conclusions are.

- Vacuum oven drying is more suitable for casting Conducting polymer-PVC composite films.
- Dielectric constant of the PTH-PVC composite decreases with increase in frequency.
PART-III

7.3 COMPARISON OF MICROWAVE PROPERTIES OF THERMOPLASTIC CONDUCTING COMPOSITES

Blending of conducting polymers with other insulating polymer matrices have been done to improve processability, obtaining graded conductivity and tuned microwave absorption characteristics, EMI shielding etc [2,22-24]. Blends formed by conducting polymer as the guest and an insulating polymer as the host matrix, constitute a novel class of conducting materials, which present attractive mechanical and processing performance imparted by the insulating polymer matrix with controlled levels of electrical conductivity. These blends are normally obtained by in situ polymerization of the monomer in the presence of the insulating polymer or blending of soluble or processable conducting polymer with an insulating polymer in solution or melts [25, 26]. PANI blends with EVA [27], nylon-6, polyacrylamide, polyoxymethylene [25], PET [28], PMMA [29] etc are reported. Polythiophene blends with polybutadiene [30], PMMA, PS, PVC etc[31] have been studied.

In a heterogeneous system, an interfacial polarisation is created due to the space charges. This polarisation corresponds to the electron motion inside conductive charges, dispersed in an insulated matrix (Maxwell-Wagner Model). This phenomenon will appear as soon as two materials 1 and 2 are mixed so that

\[ \sigma_1 / \varepsilon_1 \neq \sigma_2 / \varepsilon_2 \]
where ‘σ’ is the conductivity and ‘ε’ is the dielectric constant at zero frequency [32].

In this study dielectric constant, dielectric loss, conductivity, loss tangent, absorption coefficient, heating coefficient and skin depth of PEDOT-PVC, PTH-PVC, PPDA-PVC and PANI-PVC composites are proposed to be compared in order to identify the most suitable composition.

7.3.1 Experimental methods

1:1 composites of conducting polymer with PVC and PU were prepared with a FeCl₃: Monomer ratio of 2.5. Monomer (Thiophene, EDOT or Aniline) was added to the PVC or PU solution in THF to get a 10% 1:1 Thermoplastic-Monomer mixture. THF solution of FeCl₃ was added to the solution and the reaction was carried out for 24 hrs. Doping of PANI composites were done by adding camphor sulfonic acid to the composite solution in the ratio aniline: CSA (1:0.5) after the polymerisation is over. PTH and PEDOT gets in situ doped with FeCl₃. 1:1 PPDA-PVC composite solution was prepared by mixing PPDA powder in PVC solution to get a 10% solution.

About 10 ml of the composite solutions were cast in petridish and allowed to dry in vacuum oven at 40 °C for 2 hrs. Thin strips of the films were cut and the dielectric properties in microwave frequencies (S band 2-4 GHz) were evaluated by Cavity Perturbation Technique. The transmission type resonator used in this experiment was excited with TE₁₀₀ mode by connecting it to an HP8510 C Network Analyzer.
7.3.2 Results and discussion

7.3.2.1 Comparison of dielectric constant ($\varepsilon'$) of thermoplastic conducting composites

The variation of dielectric constant of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.8.

![Figure 7.8 Variation of dielectric constant ($\varepsilon'$) of conducting polymer - thermoplastic composites with frequency.](image)

It can be observed from the Figure 7.8 that the dielectric constant decreases with frequency for all the composites. This is due to the orientation polarization in the microwave field. The polarization is caused by the alternating accumulation of charges at the interfaces between different phases of the material. This dipole polarization may be related to the frictional losses caused by the rotational displacement of molecular dipoles under the influence of the alternating electrical field.
field. As the frequency of the applied field is increased the polarization has no time to reach its steady field value and the orientation polarisation is the first that falls. Due to the orientation polarization of the dipoles, the possibility of dielectric relaxation (so also dielectric loss) cannot be ruled out at higher frequencies. This might result in the decrease of \( \varepsilon' \) with frequency [18-19]. PANI-PU composite has highest dielectric constant followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC and PPDA-PVC respectively.

7.3.2.2 Comparison of dielectric loss (\( \varepsilon'' \)) of conducting polymer - thermoplastic composites

The variation of Dielectric Loss of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.9.

![Figure 7.9 Variation of dielectric loss (\( \varepsilon'' \)) of conducting polymer - thermoplastic composites at S band frequency.](image-url)
It can be observed from the Figure 7.9 that the dielectric loss decreases with frequency for all the composites. PANI-PU composite has highest dielectric loss followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC and PPDA-PVC composite have the lowest dielectric loss.

### 7.3.2.3 Comparison of conductivity (σ) of conducting polymer - thermoplastic composites

The variation of conductivity of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.10.

![Figure 7.10 Variation of conductivity (σ) of conducting polymer - thermoplastic composites at S band frequency.](image)

It can be observed from the Figure 7.10 that the conductivity increases with frequency for all the composites. The microwave conductivity is a direct function
of dielectric loss and so it shows a similar variation with frequency as the dielectric loss factor. PANI-PU composite has highest conductivity followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC and PPDA-PVC composite have the lowest conductivity.

In the low frequency range, \( \sigma \) is constant and equal to \( \sigma_{dc} \) and beyond a frequency called relaxation frequency, \( f_r \), the ac conductivity appears. From the experimental results it was found that \( f_r \approx \sigma_{dc} \times 10^{10} \). In heterogeneous systems, the relaxation frequency is given by

\[
f_r = \frac{\sigma_2}{2\pi \varepsilon_0 (2\varepsilon_1 + \varepsilon_2)}
\]

where \( \varepsilon_1 \) represents the dielectric constant of the matrix and \( \varepsilon_2 \) represents that of the inclusion [33]. This model predicts that the conductivity is proportional to \( \omega^2 \) from low frequencies until the relaxation frequency and that beyond this frequency conductivity is constant [34, 35]. So it seems that the relaxation frequencies of these blends are above 2.9 GHz.

### 7.3.2.4 Comparison of absorption coefficient (\( \alpha \)) of conducting polymer - thermoplastic composites

The variation of absorption coefficient of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.11.
It can be observed from the Figure 7.11 that the absorption coefficient increases with frequency for all the composites. Absorption coefficient is directly related to the dielectric loss factor and therefore it shows the same behaviour as dielectric loss. PANI-PU composite has highest absorption coefficient followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC and PPDA-PVC composites respectively.

7.3.2.5 *Comparison of loss tangent (tanδ) of conducting polymer - thermoplastic composites*

The variation of loss tangent of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.12.
Figure 7.12 Variation of loss tangent (tan δ) of conducting polymer - thermoplastic composites at S band with frequency

It can be observed from the Figure 7.12 that the loss tangent increases with frequency for all the composites. Since it is directly related to the dielectric loss it shows the same behaviour as that of dielectric loss. PANI-PU composite has highest loss tangent followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC and PPDA-PVC composites respectively.

7.3.2.6 Comparison of heating coefficient ($J$) of conducting polymer - thermoplastic composites

The variation of heating coefficient of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.13.
It can be observed from the Figure 7.13 that the heating coefficient decreases with frequency for all the blends. The heating coefficient is inversely related to the loss tangent and hence it decreases with increase in frequency. PANI-PU composite has lowest heating coefficient followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC and PPDA-PVC composites in the ascending order. Higher the \( J \) value, poorer will be the polymer for dielectric heating purposes. The heat generated in the polymeric material comes from the loss tangent, but that loss may not come entirely from the relaxation loss. Rather, conductivity of the polymeric material may also contribute to the tan \( \delta \). This situation may be compared with ohmic heating of metals [36].
Practically all applications of polymers in electrical and electronic engineering require materials with a low tan δ. However, one application that takes advantage of a high value of loss tangent is high frequency dielectric heating.

7.3.2.7 Comparison of skin depth \((d)\) of conducting polymer - thermoplastic composites

The variation of skin depth of conducting polymer - thermoplastic composites at S band frequency is given in Figure 7.14.

![Figure 7.14 Variation of skin depth \((d)\) of conducting polymer - thermoplastic composites at S band with frequency.](image_url)

It can be observed from the Figure 7.14 that the skin depth decreases with frequency for all the composites. The self inductance of the conductor effectively limits the conduction of the signal to its outer shell and the shell thickness is the
skin depth, which decreases with increase in frequency. PANI-PU composite has
lowest skin depth followed by PEDOT-PU, PANI-PVC, PEDOT-PVC, PTH-PVC
and PPDA-PVC composites in the ascending order.

7.4 CONCLUSIONS

In this chapter the microwave properties of PEDOT-PU, PANI-PU, PEDOT-PVC,
PTH-PVC, PANI-PVC, and PPDA-PVC composites were studied. The major
conclusions are

- The optimum ratio of FeCl₃, Thiophene in preparing insitu PTH-PVC
  composites is found to be 2.5.
- Vacuum oven drying is more suited for film preparation as it gives better
  microwave properties compared to room temperature dried film.
- Comparing the different blends, better microwave properties are shown by
  PANI-PU and PEDOT-PU composites.
- For all the composites, dielectric constant, heating coefficient and skin
  depth tend to decrease with increase in frequency and dielectric loss,
  conductivity, loss tangent and absorption coefficient increases with
  frequency in S band.

7.5 REFERENCES

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