Reflection and Absorption Contribution to the EMI Shielding Efficiency of SWCNT-Polymer Composites

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Declaration

We hereby declared that we have completed project on the topic entitled “Reflection and Absorption Contributions to the EMI Shielding Efficiency of SWCNT-Polymer Composites” as well as prepared as research report to the department of Electronics and Communications Engineering East West University in partial fulfillment of the requirement for the degree of MS in Telecommunication Engineering under the course “Research/internship (TE=598)”.

We further assert that this report question is based on my original exertion having never been produced fully and partially anywhere for any requirement.

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Abstract

Materials that protect against electromagnetic interference (EMI) with high shielding effectiveness (SE) have gained great importance due to their applications in telecommunication sectors , electronic, aerospace, medical, and military devices. Metals perform well as EMI shields, but they are relatively heavy and inflexible, with greater sensitivity to oxidation. In contrast, the prototyping of polymer conductive composites suggests that they are more chemically stable, cost-effective, and easier to process as shielding materials than their metal counterparts. Metal polymer nano composites are advanced materials for high electrical conductivity, which are critical for the synthesis of conductive polymer nano composites using extremely low amounts of conductive filler. A nano tube SWCNT-polymer system which utilizes functional group interactions for achieving uniform dispersion with low electrical percolation concentrations and enhanced microwave shielding effectiveness and light weight than other shielding materials . Analysis of the total observed EMI shielding was used for investigating the mechanisms of absorption and reflection in the composite. The aim of this thesis is to using functionalized CNT-polymer composites together with our obtained results could be used as a basis for light-weight, high shielding efficiency materials for EMI applications. SWCNT composites with well-dispersed SWCNTs were prepared using a simple physical mixing method and increasing shielding efficiencies

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Chapter 1

Introduction

Introduction

Electromagnetic shielding is the practice of reducing the electromagnetic field in a space by blocking the field with barriers made of conductive or magnetic materials. Shielding is typically applied to enclosures to isolate electrical devices from the 'outside world', and to cables to isolate wires from the environment through which the cable runs. Electromagnetic shielding that blocks radio frequency electromagnetic radiation is also known as RF shielding.

The shielding can reduce the coupling of radio waves, electromagnetic fields and electrostatic fields. A conductive enclosure used to block electrostatic fields is also known as a Faraday cage. The amount of reduction depends very much upon the material used, its thickness, the size of the shielded volume and the frequency of the fields of interest and the size, shape and orientation of apertures in a shield to an incident electromagnetic field.

Materials that protect against electromagnetic interference (EMI) with high shielding effectiveness (SE) have gained great importance due to their applications in electronic, aerospace, medical, and military devices[1-2]. Metals perform well as EMI shields, but they are relatively heavy and inflexible, with greater sensitivity to oxidation. In contrast, the prototyping of polymer conductive composites suggests that they are more chemically stable, cost-effective, and easier to process as shielding materials than their metal counterparts [3].

Metal polymer nano composites are advanced materials for electrically conductive applications. Metal nano wires have high surface area, high aspect ratios, and high electrical conductivity, which are critical for the synthesis of conductive polymer nano composites using extremely low amounts of conductive filler. In this work, lightweight, thin, and highly conductive polystyrene nano composites were prepared using a novel method of nano composite preparation termed miscible solvent mixing and precipitation (MSMP). Suspensions of high aspect ratio copper nano wires were mixed with polystyrene solutions to produce polymer nano composites with segregated nano wire networks resembling cell-like structures.

Electrically conductive polymer nanocomposites composed of conductive nanoparticles dispersed in organic polymer matrixes are advanced materials with tremendous opportunities in electronics, aerospace, automotive, solar cells, packaging, and sensors because they can be light weight, transparent, thin materials that show outstanding electrical properties at extremely low nanofiller concentrations (<0.01 volume fraction) [4–5]. This is due to the ability of high aspect ratio conductive nano particles like nanotubes, nanowires, and nanoplatelets to form conductive networks and switch the electrical properties of a polymer matrix from electrically insulative to electrically conductive at very low concentrations. In particular, conductive nanocomposites are novel and promising materials for electrostatic dissipation (ESD) and electromagnetic interference (EMI) shielding applications.Several electrically conductive nanoparticles for the synthesis of novel conductive polymer nanocomposites have been studied: carbon nanotubes (CNTs)4 including single walled (SWCNTs) [6–8] and multi-walled nanotubes (MWCNTs), [9–10] vapour grown carbon nanofibers (VGCNFs),[11] graphene nanoplatelets,2 and nanostructures of intrinsically conductive polymers (ICPs).[12] Carbon nanotubes have been the most intensively studied nanomaterials for conductive applications. However, despite the high interest in nanotube-based materials, these materials still face challenges like the high price of SWCNTs, the lack of control in the final electrical properties of the nanotubes, the need for purification steps (i.e. removal of catalyst impurities), the challenging dispersion of entangled nanotubes and generally low electrical conductivity of their nanocomposites. The conductivity of these materials is mainly controlled by electron tunneling mechanisms.[13]

Metal nanowires exhibit high electrical conductivity; they can be synthesized with high aspect ratios, and their structure, composition, and surface properties can be controlled by the conditions of their synthesis. High electrical conductivity is not a requirement for EMI shielding,[14] it is clear that the higher the electrical conductivity of polymer-filled composites,the higher their EMI shielding performance.[15,16] Thus, highly electrically conductive polymer nanocomposites, with electrical conductivities approaching that of the conductive nanofillers are desirable. Interestingly, high electrical conductivities (>102 S/m) in polymer nanocomposites containing low nanofiller concentrations have been rarely reported in literature. For instance, highly conductive carbon nanotube-filled polymers have been only obtained using SWCNTs, high nanotube concentrations or special processing conditions.[17]

In our study we consider carbon nanotube reinforced polymer composite as EMI shielder. Due to their very light weight, outstanding electrical conductivity, temperature stability, structural integrity, outstanding mechanical properties SWCNT are attractive to satisfy electromagnetic compatibility requirements. Mixing SWCNT with polymer, we calculated the shielding efficiency of SWCNT-polymer shield, and predicted the effects percentage volume of SWCNT in polymer. We have also predicted the effets of frequency on the shielding effectiveness.

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Chapter 2

Theoritical Background

2.1 Introduction

As commercial, military, and scientific electronic devices and communication instruments are used more and more widely, electromagnetic interference (EMI) shielding of radio frequency radiation continues to be a more serious concern in this modern society. Light weight EMI shielding is needed to protect the workspace and environment from radiation coming from computers and telecommunication equipment as well as for protection for sensitive circuits [1]. Compared to conventional metal-based EMI shielding materials, electrically conducting polymer composites have gained popularity recently because of their light weight, resistance to corrosion, flexibility and processing advantages [2–9]. The EMI shielding efficiency (SE) of a composite material depends on many factors, including the filler's intrinsic conductivity, dielectric constant, and aspect ratio [10,11]. The high conductivity, small diameter, high aspect ratio, and super mechanical strength and so on of carbon nanotubes (CNTs) make them an excellent option to create conductive composites for high-performance EMI shielding materials at low filling concentration.

2.2 Electromagnetic shielding working process

Electromagnetic radiation consists of coupled electric and magnetic fields. The electric field produces forces on the charge carriers , electrons within the conductor. As soon as an electric field is applied to the surface of an ideal conductor, it induces a current that causes displacement of charge inside the conductor that cancels the applied field inside, at which point the current stops.

Similarly, varying magnetic fields generate eddy currents that act to cancel the applied magnetic field. (The conductor does not respond to static magnetic fields unless the conductor is moving relative to the magnetic field.) The result is that electromagnetic radiation is reflected from the surface of the conductor: internal fields stay inside, and external fields stay outside.

Several factors serve to limit the shielding capability of real RF shields. One is that, due to the electrical resistance of the conductor, the excited field does not completely cancel the incident field. Also, most conductors exhibit a ferromagnetic response to low-frequency magnetic fields, so that such fields are not fully attenuated by the conductor. Any holes in the shield force current to flow around them, so that fields passing through the holes do not excite opposing electromagnetic fields. These effects reduce the field-reflecting capability of the shield.

In the case of high-frequency electromagnetic radiation, the above-mentioned adjustments take a non-negligible amount of time, yet any such radiation energy, as far as it is not reflected, is absorbed by the skin (unless it is extremely thin), so in this case there is no electromagnetic field inside either. This is one aspect of a greater phenomenon called the skin effect. A measure of the depth to which radiation can penetrate the shield is the so-called skin depth.

2.2.1: Mechanisms of shielding

The primary mechanism of EMI shielding is usually reflection. For reflection of the radiation by the shield, the shield must have mobile charge carriers (electrons or holes) which interact with the electromagnetic fields in the radiation. As a result, the shield tends to be electrically conducting, although a high conductivity is not required. For example, a volume resistivity of the order of 1 V cm is typically sufficient. However, electrical conductivity is not the scientific criterion for shielding, as conduction requires connectivity in the conduction path (percolation in case of a composite material containing a conductive filler), whereas shielding does not. Although shielding does not require connectivity, it is enhanced by connectivity. Metals are by far the most common materials for EMI shielding. They function mainly by reflection due to the free electrons in them. Metal sheets are bulky, so metal coatings made by electroplating, electron less plating or vacuum deposition are commonly used for shielding [12–13]. The coating may be on bulk materials, fibers or particles. Coatings tend to suffer from their poor wear or scratch resistance.

A secondary mechanism of EMI shielding is usually absorption. For significant absorption of the radiation by the shield, the shield should have electric and/or magnetic dipoles which interact with the electromagnetic fields in the radiation. The electric dipoles may be provided by $BaTiO_3$ or other materials having a high value of the dielectric constant. The magnetic dipoles may be provided by Fe_3O_4 or other materials having a high value of the magnetic permeability, which may be enhanced by reducing the number of magnetic domain walls through the use of a multilayer of magnetic films [14-15].

The reflection loss decreases with increasing frequency, whereas the absorption loss increases with increasing frequency.

Other than reflection and absorption, a mechanism of shielding is multiple reflections, which refer to the reflections at various surfaces or interfaces in the shield. This mechanism requires the presence of a large surface area or interface area in the shield. An example of a shield with a large surface area is a porous or foam material. An example of a shield with a large interface area is a composite material containing a filler which has a large surface area. The loss due to multiple reflections can be neglected when the distance between the reflecting surfaces or interfaces is large compared to the skin depth, $\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$. Typically, multiple-reflection decreases the overall shielding if the shield is thinner than the skin depth and can be ignored if the shield is thicker than the skin depth [16].

The losses, whether due to reflection, absorption or multiple reflections, are commonly expressed in dB. The sum of all the losses is the shielding effectiveness (in dB). The absorption loss is proportional to the thickness of the shield [17].

2.2.2: Composite materials for shielding

Due to the skin effect, a composite material having a conductive filler with a small unit size of the filler is more effective than one having a conductive filler with a large unit size of the filler. For effective use of the entire cross-section of a filler unit for shielding, the unit size of the filler should be comparable to or less than the skin depth. Therefore, a filler of unit size 1 mm or less is typically preferred, though such a small unit size is not commonly available for most fillers and the dispersion of the filler is more difficult when the filler unit size decreases.

Polymer–matrix composites containing conductive filers are attractive for shielding [18–19] due to their process ability which helps to reduce or eliminate the seams in the housing that is the shield. The seams are commonly encountered in the case of metal sheets as the shield and they tend to cause leakage of the radiation and diminish the effectiveness of the shield. In addition, polymer–matrix composites are attractive in their low density. The polymer matrix is commonly electrically insulating and does not contribute to shielding, though the polymer matrix can affect the connectivity of the conductive filler and connectivity enhances the shielding effectiveness.

2.2.3: Polymer nanocomposite mixing

For a general EMI shielding material in the form of a composite material, a filler that is effective at a low concentration is also desirable, although it is not as critical as for EMI gaskets. This is because the strength and ductibility of a composite tend to decrease with increasing filler content when the filler–matrix bonding is poor. Poor bonding is quite common for thermoplastic polymer matrices. In order for a conductive filler to be highly effective, it preferably should have a small unit size (relative to the skin depth), a high conductivity (for shielding by reflection) and a high aspect ratio (for connectivity). Fibers are more attractive than particles due to their high aspect ratio.EMI shielding is one of the main applications of conventional short carbon fibers [20].

2.3: Polymer-SWCNT synthesis

A composite of CNTs and a Reactive Ethylene Terpolymer constituted from (1) polyethylene, (2) a polar methyl-methacrylate group, and (3) epoxide functional groups – Fig. 1. While (1) and (2) contribute to the mechanical characteristics (e.g., elastomeric properties) and corrosion resistance underlying the utility of RET as a hot-melt adhesive and coating, the epoxy group has high reactivity[12] and is amenable for effective anchoring of the ring bonds with functional groups(e.g. -OH, COOH, -NH2 etc.) on the CNTs. The underlying rationale is that the epoxide ring rupture [21] on the RET would be facilitated by the –COOH groups on the functionalized nanotubes (Figure 1b) and then contribute to bonding of the COOH on the SWNT .

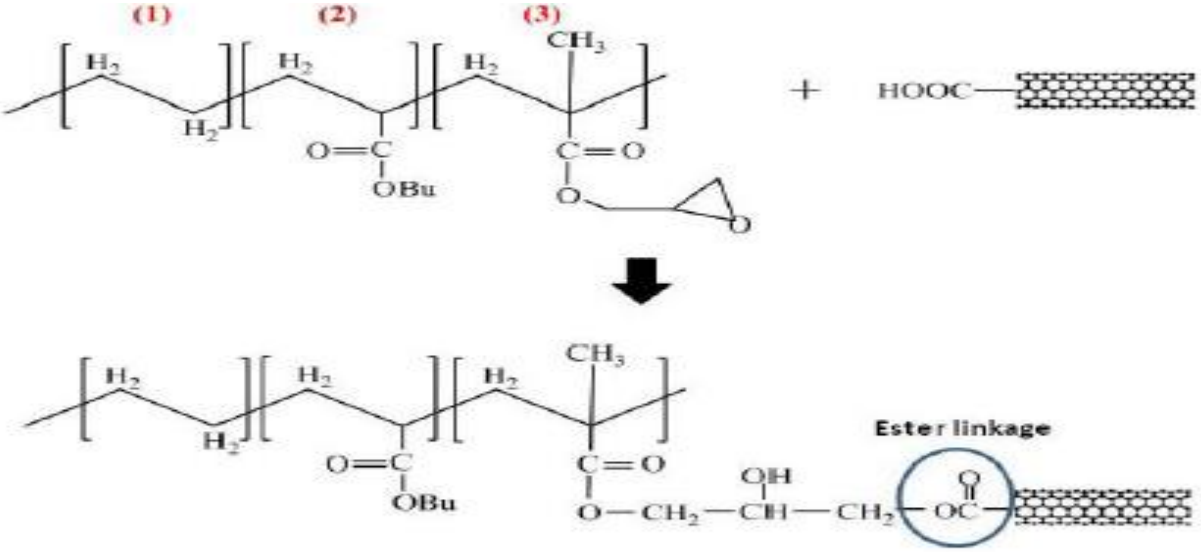

Figure 2.1: Schematic diagram of the reaction between functional groups on the CNT with the epoxy groups of the Reactive Ethylene Terpolymer (RET) constituted from (1): polyethylene, (2) methyl-methacrylate, and (3) epoxide functional groups. While (1) and (2) contributes to the mechanical robustness, (3) is used for forming ester linkages to the –COOH groups on the functionalized nanotubes for enhanced bonding and dispersion.

The effects of both pristine and carboxyl functionalized SWNTs and multi-walled carbon nanotubes MWNTs, average diameter 5.95 nm, length 1430nm, 90% purity, and density 1.7g cm-3 were examined. A mixture of sulfuric and nitric acids in a 3:1 ratio was used both for nanotube surface fictionalization, with –COOH groups, and for removing impurities[22]. Subsequently, the CNTs were rinsed with deionizer water, and then dried at 60 oC for 10 hours. The MWNTs and SWNTs were then dispersed in toluene with sanitation for 20 minutes. To remove excess solvent, the mixture was stirred, at 60 oC for 3 hours, poured into glass dishes and then evacuated in vacuum for 12 hours. Subsequently, a hot press was used to fabricate the composites into desired thickness.

2.4: EMI shielding effectiveness of mixed polymer composites

Three mechanisms have been reported to be involved in EMI shielding, namely: reflection, absorption and multiple-reflection.

The primary mechanism of EMI shielding is usually reflection. For reflection of the radiation by the shield, the shield must have mobile charge carriers which interact with the electromagnetic fields in the radiation. As a result, the shield tends to be electrically conducting, although a high conductivity is not required.

2.5: EMI shielding calculation

EMI SE is the logarithm of the ratio of the transmitted power when there is no shield (P_I) to the power when there is a shield (P_T), Eqn. (2.1).

$$\mathbf{SE = 10\log(P_I/P_T)} \qquad \mathbf{(2.1)}$$

where ,

Pin= power incident

Pout=transmitted power.

For a transverse electromagnetic wave propagating into a sample with negligible magnetic interaction, the total shielding efficiency (SE_T) of the sample is expressed as Eqn. (2.2) [23-24,]:

$$\mathbf{SE_T = SE_R + SE_A + SE_I} \qquad \mathbf{(2.2)}$$

SET is expressed in decibels **(dB).**

SEA = absorption shielding Efficiencies.

SER =reflection shielding Efficiencies,

Respectively. The third term (SEI) is a positive or negative correction term induced by the reflecting waves inside the shielding barrier, which is negligible when SEA> 15 dB.

The term can be described as:

$$\mathrm{SE_A} = 8.68\alpha l \qquad \textbf{(2.3)}$$

$$\mathrm{SE_R} = 20\log\frac{|1+n|^2}{4|n|} \qquad \textbf{(2.4)}$$

$$\mathrm{SE_I} = 20\log\left|1-\frac{1-n^2}{1+n^2}\exp(-2\gamma l)\right| \qquad \textbf{(2.5)}$$

where λo is the wave length, ε_o the real part of complex relative permittivity, the ± signs are applied for positive and negative r, respectively.[25] The loss tangent Tanδ=$\sigma\varepsilon_o$ $\varepsilon_r$where ei is the imaginary part of the relative permittivity; ω = 2πF, where F is the frequency; ε_0 is the dielectric constant in free space and r the conductivity.Here we use the alternative conductivity (αac) to express the conducting ability of the alternative electromagnetic wave in the composites:

αac = ωε_o ε_r. The estimation of the SE in this study is in the far-field limit [26], which assumes that the distance from the source to the shielding barrier is long enough and not to apply near-shielding effects.

From Equ.2.3 we get,

$$\mathrm{SEA} = 8.68\left[\frac{\frac{2\pi}{c}}{f\sqrt{Ep+\frac{V}{\frac{1}{E_{CNT}-E_p}+\frac{(1-V)}{3E_p}}}}\sqrt{Ep+\frac{\frac{V}{\frac{1}{E_{CNT}-E_p}+\frac{(1-V)}{3E_p}}\left(\sqrt{1+tan^2\delta}\mp 1\right)}{2}}\right]l\ ,$$

From Equ.2.4 we get,

$$SE_R=20\log\frac{\left|\frac{1+\sqrt{\varepsilon_r((\sqrt{1+\tan^2\delta}\mp 1)}}{2}+i\frac{\sqrt{\varepsilon_r((\sqrt{1+\tan^2\delta}\mp 1)}}{2}\right|^2}{4\left|\frac{\sqrt{\varepsilon_r((\sqrt{1+\tan^2\delta}\mp 1)}}{2}+i\frac{\sqrt{\varepsilon_r((\sqrt{1+\tan^2\delta}\mp 1)}}{2}\right|}$$

Where ,

σ = conductivity of shield

V = Volume Fraction

ε_o = Relative permittivity

ε_r = Real Part of Complex Relative permittivity

ε_p = Polymer Relative permittivity

ε_{cNT} = CNT Relative permittivity

c = Light Velocity.

f = frequency of the EM wave [Hz]

$\tan\partial$ = loss tangent

According to the equation parameter is:

L =1430nm

tanδ =$\sigma\varepsilon_o\,\varepsilon_r$=9.09*10^^{7}*2.6

$\varepsilon_o = 8.86 * 10^{-12}$ F/m

V = 0.5

F = 10GHZ

$\varepsilon_p = 2.2 - 2.36$ F/m

$\varepsilon_{cNT} = \varepsilon_o\,\varepsilon_r$=$8.86 * 10^{-12} * 2.6 * 10^{-12} F/m$

σ =9.09x10^7 s/m

C =3x10^8 m/s

ϵ_r = 2.6

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Chapter 3

Result and Discussion

3.1 Introduction

The SE describes the ability to prevent the transmission of electromagnetic waves from the outside to the inside or vice versa.

The main factors which determine the shielding effect are the capability of shielding materials (the conductivity and the permeability), the thickness and the frequency of the incident wave. If we know all these factors, the material's shielding effects can be calculated by our previous study.

3.2 Calculation

From our previous study in chapter 2, we found total sheilding from Eqn. (2.3) is

$$SE_T = SE_R + SE_A \tag{3.1}$$

$$SE_T = 17.28 + 8.68\left[\frac{\frac{2\pi}{c}}{f\sqrt{Ep+\frac{Vl}{\frac{1}{E_{CNT}-E_p}+\frac{(1-Vl)}{3E_p}}}}\sqrt{Ep+\frac{\frac{Vl}{\frac{1}{E_{CNT}-E_p}+\frac{(1-Vl)}{3E_p}}(\sqrt{1+tan^2\delta}\mp1)}{2}}\right]l \tag{3.2}$$

where,

$$SER=20\log\frac{\left|\frac{1+\sqrt{\varepsilon_r((\sqrt{1+tan^2\delta}\mp1)}}{2}+i\frac{\sqrt{\varepsilon_r((\sqrt{1+tan^2\delta}\mp1)}}{2}\right|^2}{4\left|\frac{\sqrt{\varepsilon_r((\sqrt{1+tan^2\delta}\mp1)}}{2}+i\frac{\sqrt{\varepsilon_r((\sqrt{1+tan^2\delta}\mp1)}}{2}\right|} \tag{3.3}$$

Here,

σ = conductivity of shield

V_l = Volume Fraction

ε_o = Relative permittivity

ε_r = Real Part of Complex Relative permittivity

ε_p = Polymer Relative permittivity

ε_{cNT} = CNT Relative permittivity

c = Light Velocity.

f = frequency of the EM wave [Hz]

3.3 Results and discussions

In this work, we have investigated the shielding efficiency of mixed polymer and for a frequency range of 1 MHz to 5 MHz.

3.3.1: EMI shielding by absorption

From Equation 2.3 our previous study,

$$\mathrm{SE_A} = 8.68\alpha l$$

SEA

$$= 8.68\left[\frac{\frac{2\pi}{c}}{f\sqrt{Ep+\frac{V}{\frac{1}{E_{CNT}-E_p}+\frac{(1-V)}{3E_p}}}}\sqrt{Ep+\frac{\frac{V}{\frac{1}{E_{CNT}-E_p}+\frac{(1-V)}{3E_p}}\left(\sqrt{1+tan^2\delta}+1\right)}{2}}\right]l$$

After simplifying this equation we plot shielding efficiency versus frequency for EMI shielding

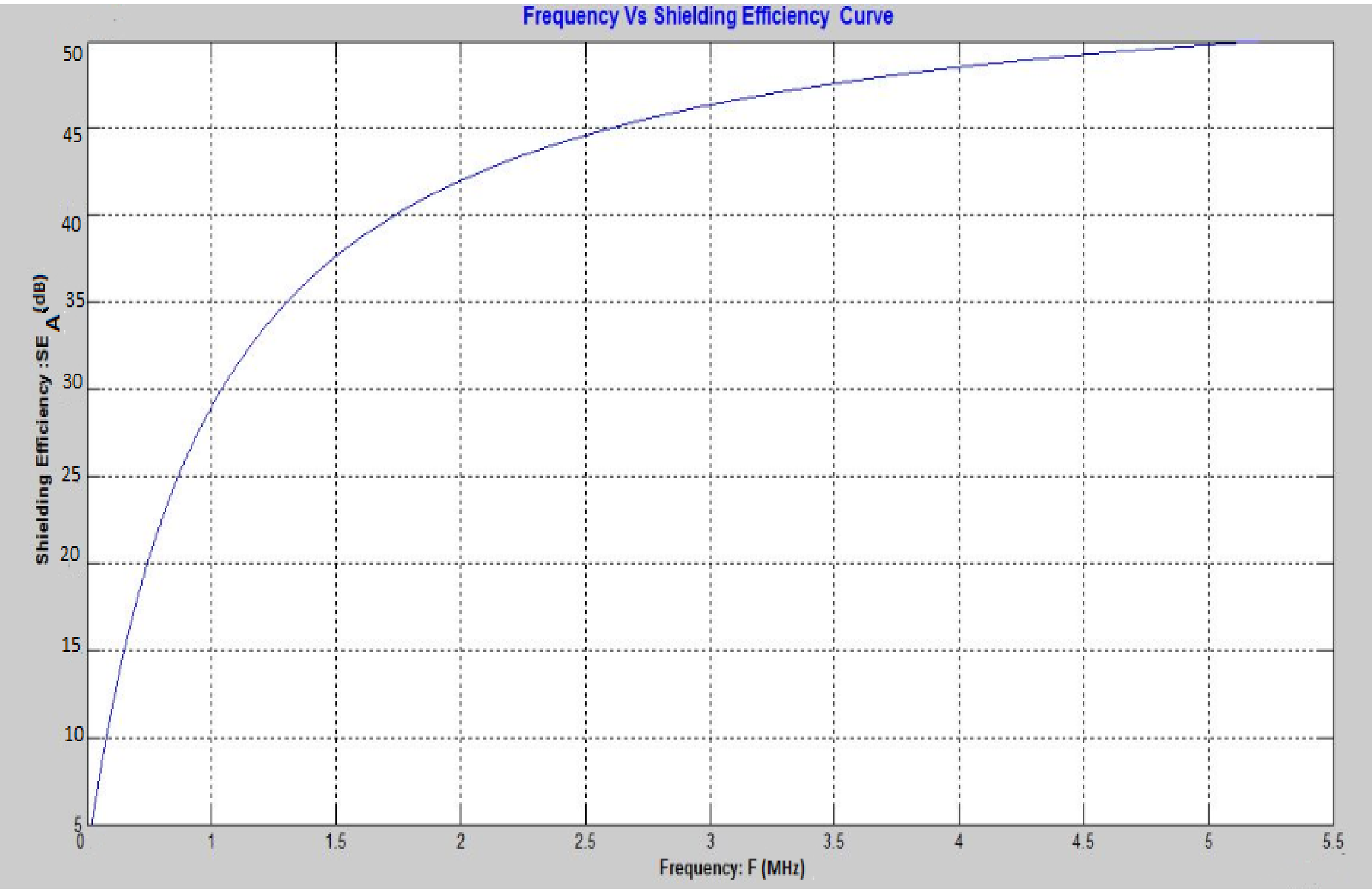

Figure 3.1: Shielding Efficiency of absorption for loss tangent positive compare with frequency.

The loss tangent Tanδ=$\sigma\varepsilon_o$ $\varepsilon_r$where ei is the imaginary part of the relative permittivity; ω = 2πF, where F is the frequency; e0 is the dielectric constant in free space and r the conductivity.Here we use the alternative conductivity (αac) to express the conducting ability of the alternative electromagnetic wave in the composites: αac = ωε_o ε_r. The term tan δ, also called loss tangent, indicates the ability of a material to convert stored energy to heat. Thus, large values of loss factor and loss tangent would indicate a better radio absorbing material.

The loss tangent has both positive and negative value. We compare both positive and negative value of loss tangent and vary with frequency.

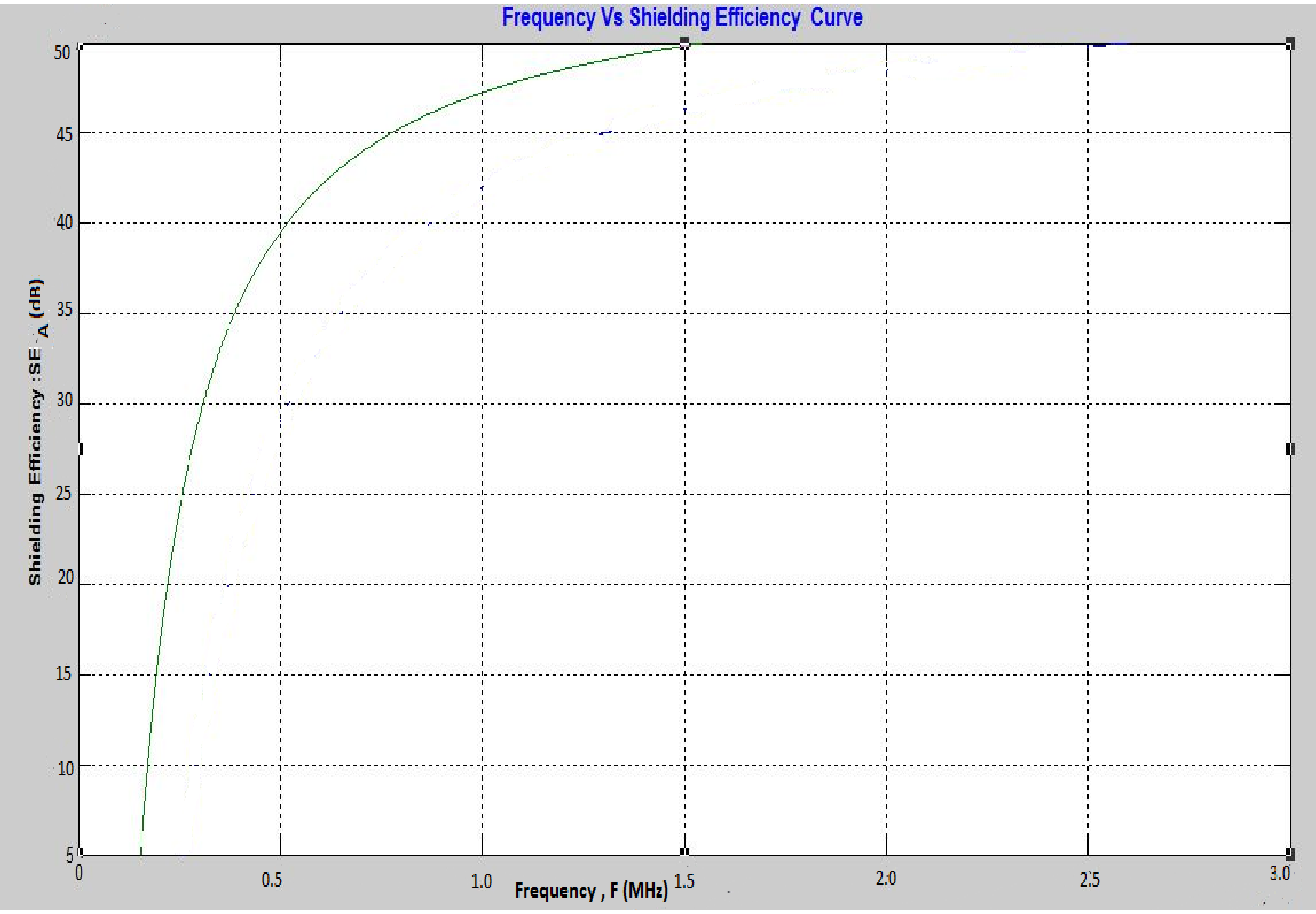

Figure 3.2: Shielding Efficiency of absorption for loss tangent negative value compare with frequency.

Now we compare shielding efficiency of absorption with 50% volume fraction.

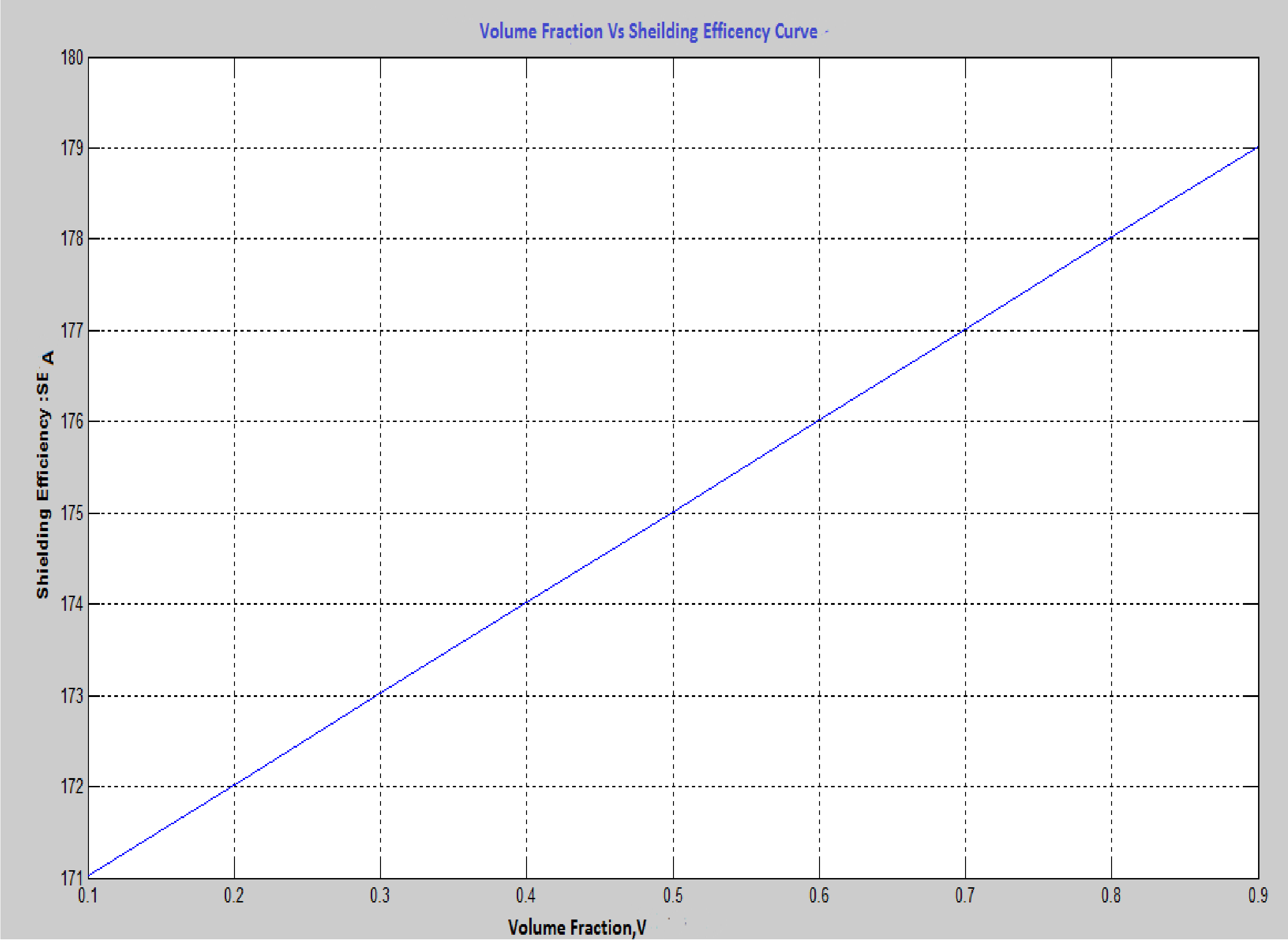

Figure 3.3: Shielding efficiency of absorption compare with volume fraction.

Finally we calculate SE_T value from previous chapter and plot curve.

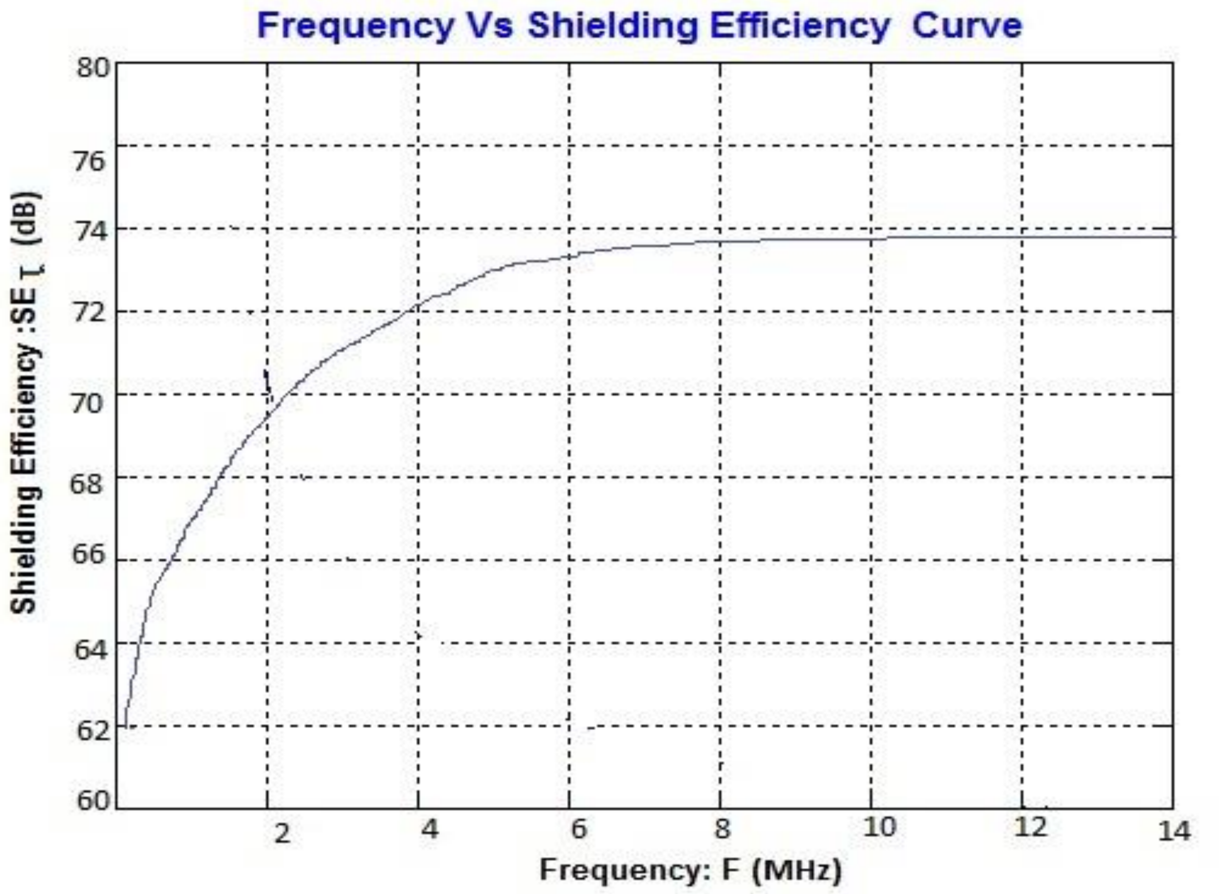

Figure 3.4: Total Shielding Efficiency compare with frequency.

The EMI performance of composites is highly coupled with the filler's intrinsic conductivity, dielectric constant, and aspect ratio. As can be seen, the conductivity of the PU/SWCNT composites exhibits a dramatic increase at low loadings, indicating the formation of percolating network.

Finally we calculate SE_T value from previous chapter and plot curve with volume fraction and we get final curve result.

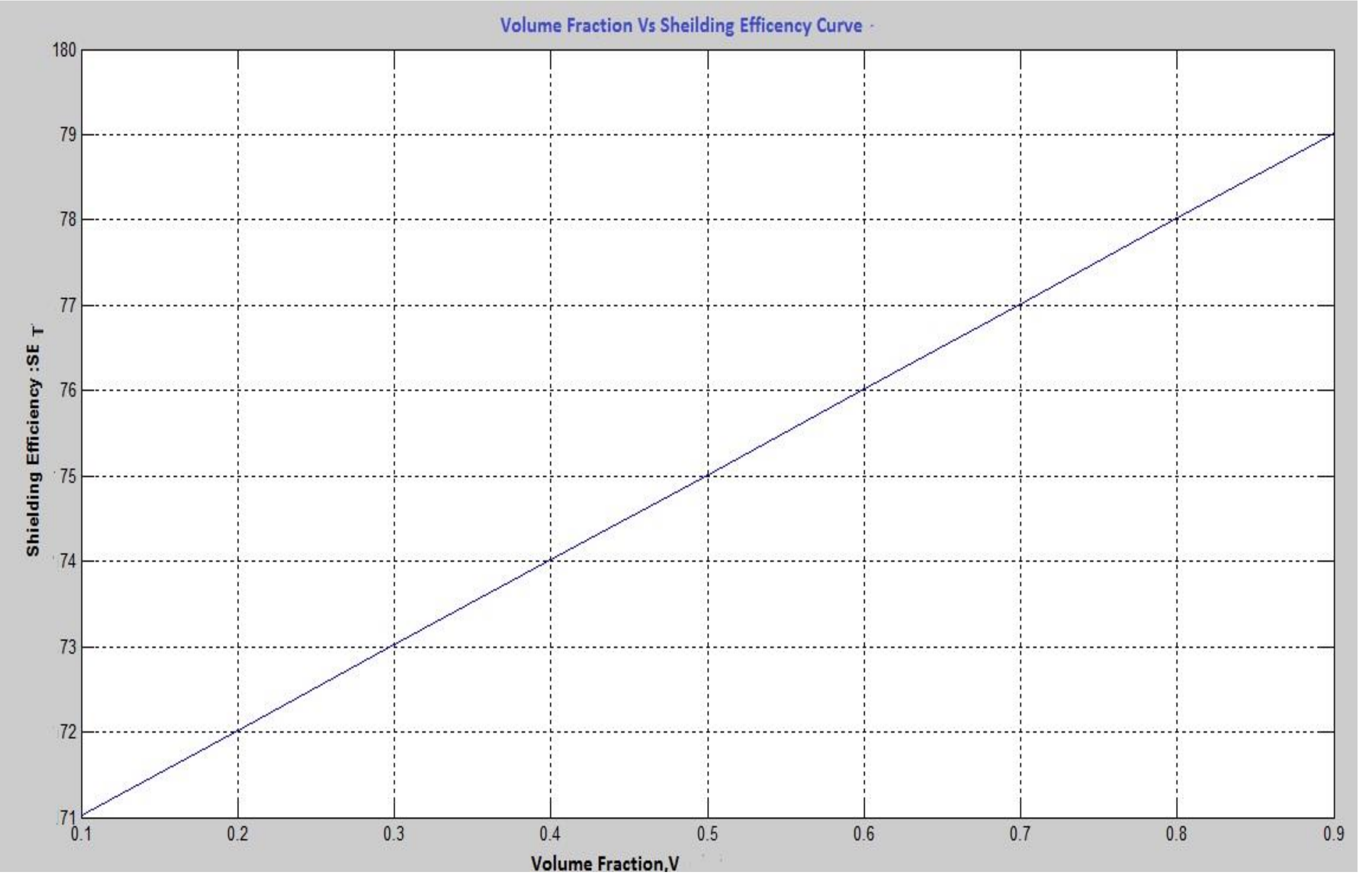

Figure 3.5: Total Shielding Efficiency compare with volume fraction.

EMI shielding refers to the reflection and absorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through the shield.

Chapter 4

Conclusion

Our study has provided an example of a nanotube SWCNT-polymer system which utilizes functional group interactions for achieving uniform dispersion with low electrical percolation concentrations and enhanced microwave shielding effectiveness. Analysis of the total observed EMI shielding was used for investigating the mechanisms of absorption and reflection in the composite, where a cross-over from reflection dominated shielding to absorption dominated shielding was observed at a CNT volume fraction of 50%.

Polymer composites have indicated increased tensile strength as a function of increasing volume fraction of the CNTs. and shielding efficiency. Synthetic metal is good EMI shield due to their lightweight, noncorrosive nature and commercial viability, but they have very poor heat dissipating capacity due to small thermal conductivity. That’s why PU can be the best alternative and most attractive as EMI shield due to their very lightweight, high current density, high thermal conductivity higher than copper. It is also observed that the total shielding efficiency increases at higher frequencies with larger thickness.

In summary, our proposed scheme of using functionalized CNT-polymer composites together with our obtained results could be used as a basis for light-weight, high shielding efficiency materials for EMI applications. SWCNT composites with well-dispersed SWCNTs were prepared using a simple physical mixing method and increasing shielding efficiencies.

Appendix

A.1 Matlab code for finding EMI shielding efficiency for volume fraction.

```
clear all;
close all;
clc;

char a b c c1 d e g h i j k l m n o p q r s t u v w x y z z1 z2
z3

f = 5e6;
V = [0.1:0.1:0.9];
C = 3e8;
B = 2.303e-11;
E = 2.2e-12;
T = 1.000002192;
L = 1430e-9;

a = B-E;
b = 1./a;
c = 3.*E;
c1= 1-V;
d = c1./c;
e = b+d;
g = V./e;
h = E+g;
i = sqrt(h);
j = f.*i;
k = T+1;
l = T-1;
m = (2*pi)./C;
n = m./j;
o = g.*k;
p = g.*l;
q = o./2;
r  =p./2;
s = E+q;
t = E+r;
u = sqrt(s);
v = sqrt(t);
w = n.*u;
```

```
x = n.*v;
y = L.*8.68;
z = y.*w;
z1 = y.*x;
z2 = semilogx(f,10*log10(z));
z3 = semilogx(f,10*log10(z1));


plot(V,z1)

%plot(z1)
grid on;

xlabel('Velocity fraction:
V','FontSize',10,'FontWeight','bold','Color','k')

ylabel('Shielding Efficiency :SE
,a','FontSize',10,'FontWeight','bold','Color','k')

title('Velocity Vs Shielding Efficiency
Curve','FontSize',12,'FontWeight','bold','Color','b')
```

A2. Matlab code for finding EMI Shielding efficiency for frequency

```
clear all;
close all;
clc;

syms a b c d e g h i j k l n o p q r s t u v w x y z z1

f = [0.5e6:0.5:5e6];
C = 3e8;
B = 2.303e-11;
E = 2.2e-12;
T = 1.000002192;
L = 1430e-9;

a = B-E;
b = 1./a;
c = 3.*E;
d = 0.5./c;
e = b+d;
```

```
g = 0.5./e;
h = E+g;
i = sqrt(h);
j = f.*i;
k = T+1;
l = T-1;
m = (2*pi)./C;
n = m./j;
o = g.*k;
p = g.*l;
q = o./2;
r  =p./2;
s = E+q;
t = E+r;
u = sqrt(s);
v = sqrt(t);
w = n.*u;
x = n.*v;
y = L.*8.68;
z = y.*w;
z1 = y.*x;


plot(z1,f)

%plot(z1)
grid on;

xlabel('Frequency:
F','FontSize',10,'FontWeight','bold','Color','k')

ylabel('Shielding Efficiency :SE ,
a','FontSize',10,'FontWeight','bold','Color','k')

title('Frequency Vs Shielding Efficiency
Curve','FontSize',12,'FontWeight','bold','Color','b')
```