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EMI Shielding Fundamentals

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1.1 Fundamentals of EMI Shielding Theory

Electromagnetic shielding is process of reducing the dispersion of electromagnetic waves into a desired space by hindering the waves with a shield made of conductive material. The effective performance of electrical instruments or the working of electrical instruments is interrupted, degraded, obstructed, or limited due to the electromagnetic interference (EMI). In a material the main mechanisms for EMI attenuation are reflection, absorption, and multiple reflection [1, 2]. Reflection is the primary mechanism of EMI shielding. For reflection the material must possess mobile charge carriers such as electrons or holes that interact with the electromagnetic radiation. Metals are the most common material for EMI shielding and the available free electrons in metals interact with the electromagnetic waves [3]. If the material is highly conductive the shielding against EM (electromagnetic) waves will occur through the reflection mechanism. However, conductivity is not a condition for EMI shielding but it does enhance the reflection mechanism of an EMI shielding material.

The secondary mechanism for EMI shielding is absorption, which requires the existence of electric or magnetic dipoles to interact with the electromagnetic radiation. It changes with the thickness of the material. Materials that have a high dielectric constant provide electric dipoles and materials with high magnetic permeability provide magnetic dipoles for the EMI shielding by absorption [1].

The third mechanism is multiple reflections, which is the reflections at different surfaces or at the interface of the material. Materials that have large specific internal surfaces or composites with fillers show a multiple reflection mechanism. Generally, multiple-reflection decreases the total shielding value if the material is thinner than the skin depth and the value can be neglected if the material has a higher thickness than the skin depth. At higher frequencies electromagnetic radiation penetrates only to the near surface region of the electrical conductor. This is known as the skin effect. The intensity of penetration of an electromagnetic wave decreases exponentially with increasing depth of the conductor [4].

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The skin depth is the depth of the conductor at which the intensity of the incident field drops in to 1/e of the incident value and is denoted by δ [5]:

$$\text{Skin depth, } \delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

Here f is the frequency, μ is the magnetic permeability, and σ the electrical conductivity in $\Omega^{-1}\,m^{-1}$. Skin depth is not directly proportional to frequency, magnetic permeability, and conductivity, i.e. skin depth decreases with increase in frequency, magnetic permeability, or electrical conductivity. Owing to this skin effect, a material that contains a conductive filler with a small unit size of filler is more effective for shielding than a filler with a large unit size. The complete cross section of the filler unit can be used only when the unit size of the filler is less than or comparable with the skin depth.

Shielding effectiveness, which is expressed in dB, is the sum of reflection loss, absorption loss, and multiple reflections [6]. When electromagnetic waves strike the surface of an object they undergo reflection, multiple reflection, absorption, and transmission as shown in Figure 1.1. To be a shield against the EM wave, the material should reflect or absorb the electromagnetic wave. Factors determining shielding effectiveness (SE) are classified in Figure 1.2.

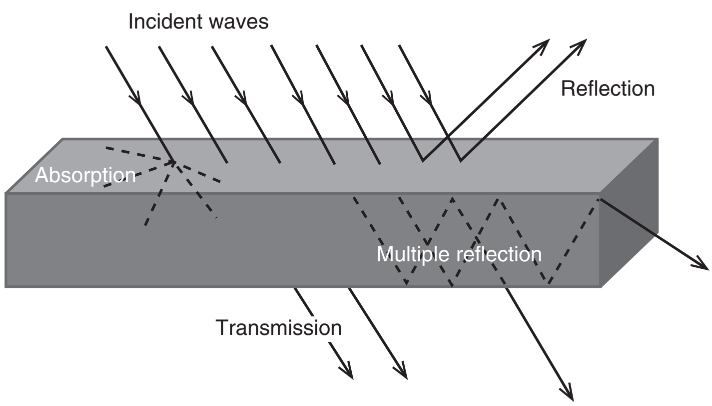

Figure 1.1 Schematic representation showing mechanism of electromagnetic shielding.

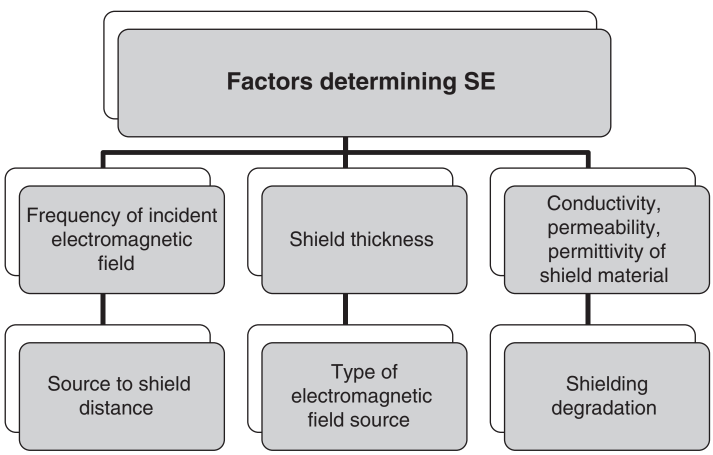

Figure 1.2 Factors determining shielding effectiveness [7]. *Source:* Adapted from Gooch 2007.

1.2 Materials for EMI Shielding

Owing to the increasing use of electronic equipment the shielding of other instruments and of human beings from electromagnetic waves is a very serious issue in the present scenario, which is detailed in Chapter 2. The EM waves harmfully affect both the device performance and human beings. Nowadays, a reduction in the use of electronic equipment is not always practical. What we are able to do is to reduce the penetration of EM waves produced from electronic instruments. To decrease the penetration we must use a shield or block the EM waves from the desired surface.

Metals are commonly used for EMI shielding application in the form of thin sheets or sheathing in automotive applications. But, metal is expensive, prone to corrosion, heavy, and the cost of manufacturing processes is also very high, which makes them an undesired choice for electronic application. Conductive polymer nanocomposites have attracted a great deal of academic and industrial interest by considering the cost-effectiveness, easy processability, and their possible applications in many areas including EMI shielding. Polymer nanocomposites based on CNTs (carbon nanotubes), carbon black (CB), graphene, metal nanoparticles, carbon fibers, foams, and magnetic nanoparticles show good shielding capacity against EM waves. Several groups have studied and reported the EMI shielding effectiveness of different materials and mechanisms behind the EMI shielding ability of those materials. Characterization and requirement for EMI shielding materials are mentioned in the classification chart in Figure 1.3. Chapters 7–14, 16, and 17 describe these materials in detail in accordance to EM shielding.

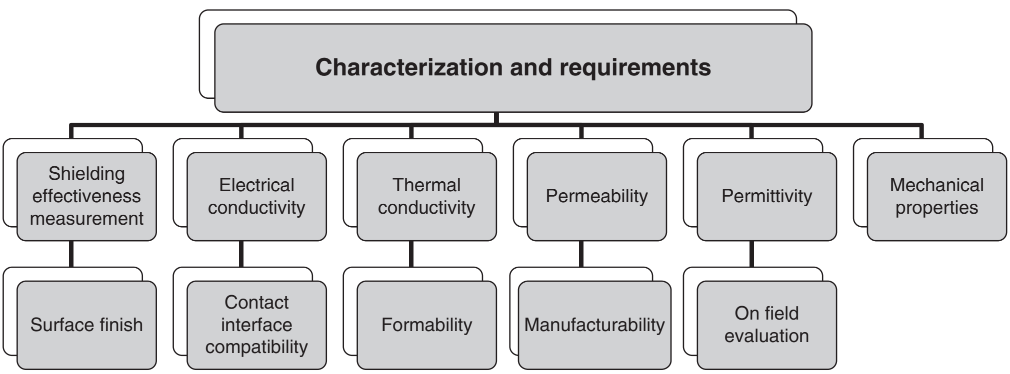

Figure 1.3 Characterization and requirements for EMI shielding materials [8]. *Source:* Adapted from Tong 2009.

1.3 Mechanism of EM Shielding Materials

Carbon nanotubes, a 1D nanostructure, are rolled up sheets of graphene, made up of a hexagonal lattice of sp^2 hybridized carbon atoms. Depending upon the number of graphene sheets used to form the cylindrical shape the carbon nanotubes are of different types, namely single walled, double walled, multiwalled. Carbon fibers (CFs) come under 1D carbon nanoallotropes, having interlocked sheets of graphene. Carbon black is a good filler to enhance the EMI shielding effectiveness of a material; it is produced by the thermal decomposition of hydrocarbons. Carbon black has graphite layers different from that of amorphous carbon.

Every carbon atom in the graphite layer forms three covalent bonds with neighboring carbon atoms and the free p-orbits from each carbon atom overlap to from delocalized π electrons. The presence of these freely moving π electrons make carbon black a good conducting material.

Carbon fiber paper (CFP) and nickel coated carbon fiber paper (NCFP) reinforced epoxy composites show EMI shielding efficiencies of 30 and 35 dB, respectively, in the frequency range 3.22–4.9 GHz for 0.5 mm thick sheets at 8 wt% fiber content. This is due to the increased conductivity shown by the nanocomposites; in addition, both absorption loss and reflection loss contribute to the total EMI shielding but the major contribution is from reflection. The material shows higher electrical conductivity due to the presence of mobile charge carriers. These charge carriers interact with the EM waves, which induces reflection as the major mechanism for the shielding [9].

Carbon black reinforced cement composites show a good EMI shielding value due to the presence of freely moving π-bond electrons. The shielding effectiveness increased with increase in carbon black content because of the conductive network path and through the reflection mechanism [10].

Carbon black reinforced polyaniline/poloxalene composites can be used as a lightweight EMI shielding material with a shielding effectiveness of 19.2–19.9 dB at 10 wt% CB. The good EMI shielding value obtained is due to the formation of a network between carbon black and the blend system. The interconnected network contributes to the shielding value obtained through reflection as the shielding mechanism [11].

Carbon micro coils (CMCs) are another material used as a filler in making EMI shielding material. The polyurethane composites with CMCs show an increased EMI shielding value that depends on the layer thickness of the material. Hence the mechanism is based on absorption [12].

In the case of multiwalled carbon nanotube (MWCNT)/polypropylene (PP) composites the contribution of absorption loss to the total EMI shielding is higher than reflection so the major mechanism is absorption and reflection is the secondary shielding mechanism [13]. Here, multiple-reflection is excluded from the discussion because it lowers the overall EMI SE.

Figures 1.4a–c show power balance graphs for different MWCNT/PP composites with various amounts of MWCNT and different plate thickness. The percentage of power blocked by reflection is increased with increase in MWCNT content in all three cases (Figures 1.4a–c), but in the case of 0.34 and 1 mm plates the percentage of absorption initially increases with increasing MWCNT content and then decreases. In the third case (2.8 mm thick plates) the contribution by absorption increases linearly with increasing MWCNT content [13].

The EMI shielding effectiveness shown by samples of MWCNT, CNF, and high structure carbon black (HS-CB) nanoparticles with acrylonitrile–butadiene–styrene (ABS) polymer [14] showed that whatever the nanofiller type the reflection loss was always less than the absorption loss (Figure 1.5a and b). The contribution of absorption loss to total EMI SE is 75%. When the shielding by absorption exceeds 10 dB most of the re-reflected wave will be absorbed within the shield itself and so multiple reflections were ignored.

The electromagnetic interference shielding effectiveness of lightweight graphene/polystyrene composite [15] is shown in Figure 1.6a and b. The graphs show that the contribution of reflection loss is negligible over the entire frequency range. The composite has a porous structure. This means that power is dissipated as heat rather than reflected back from the composite's surface, which clearly describes why absorption is the primary mechanism and the secondary mechanism is reflection for such conductive porous composites in the X-band frequency region.

The EMI shielding mechanism of PTT/MWCNT composites was studied by resolving the total EMI SE into absorption and reflection loss. Figure 1.7 shows the effect of MWCNT

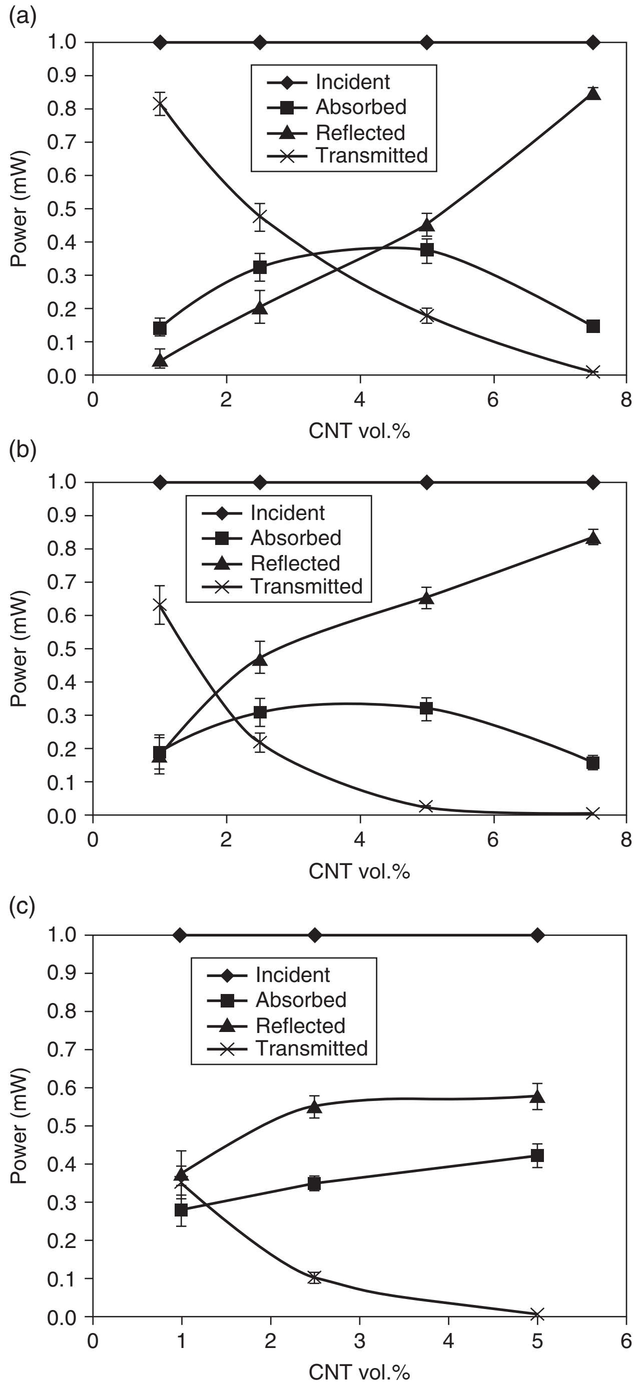

Figure 1.4 Power balance graph for MWCNT/PP nanocomposite in the X-band frequency range of plate thickness (a) 0.34, (b) 1, and (c) 2.8 mm [13]. Reproduced with permission of Elsevier.

content on absorption and reflection. The graphs shows that with increasing amounts of MWCNT both SE_A and SE_R increased, but the rate of increase of SE_A was higher compared to that of SE_R. At 0.24 vol.% of MWCNT the absorption contribution was 16% but with 4.76 vol.% of MWCNT the absorption contribution increased to 73%. These results show

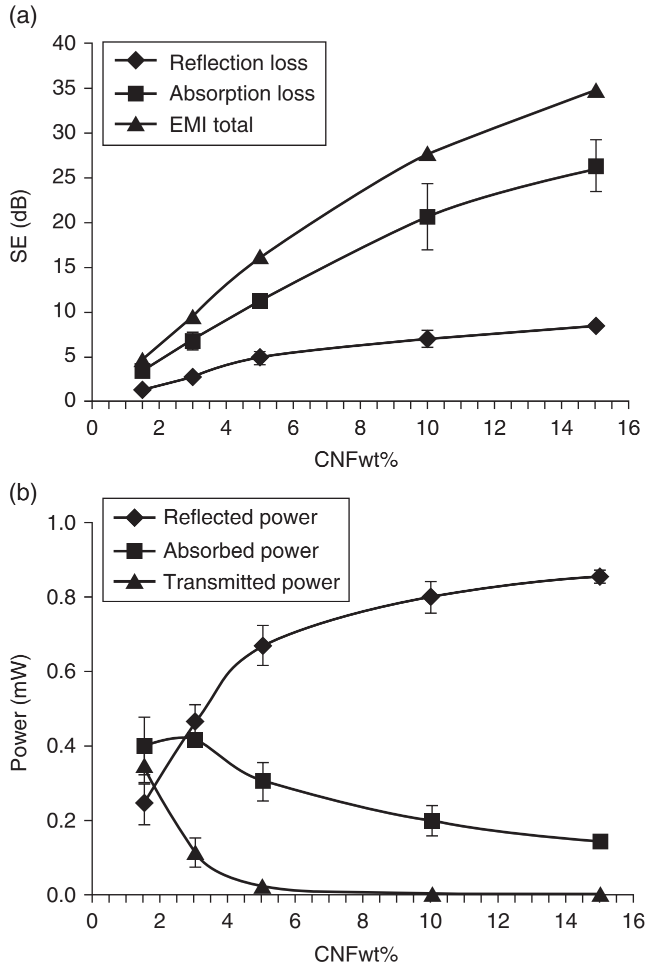

Figure 1.5 Shielding mechanisms: (a) absorption loss, reflection loss, and total shielding as function of CNF content; (b) power balance as function of CNF content [14]. Reproduced with permission of Elsevier.

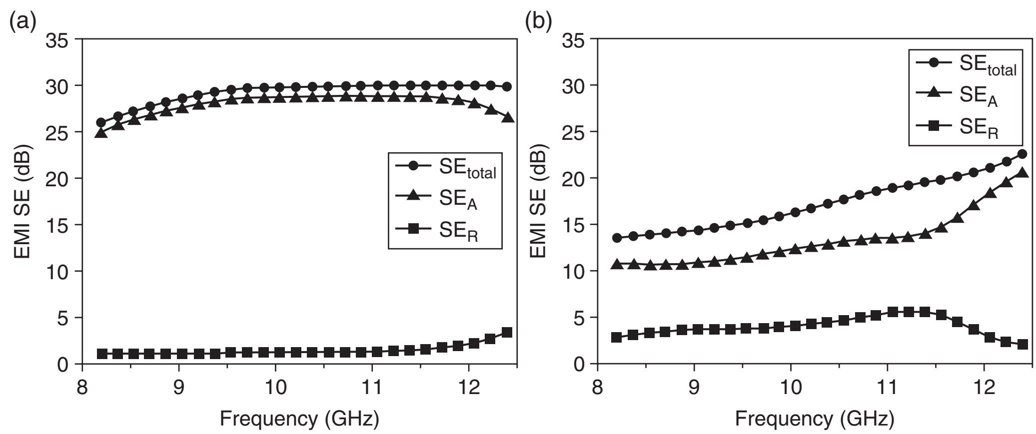

Figure 1.6 Comparison of SE_{total}, SE_A, and SE_R for GPS045 (a) and GPS027 (b) in the 8.2–12.4 GHz range [15]. Reproduced with permission of the Royal Society of Chemistry.

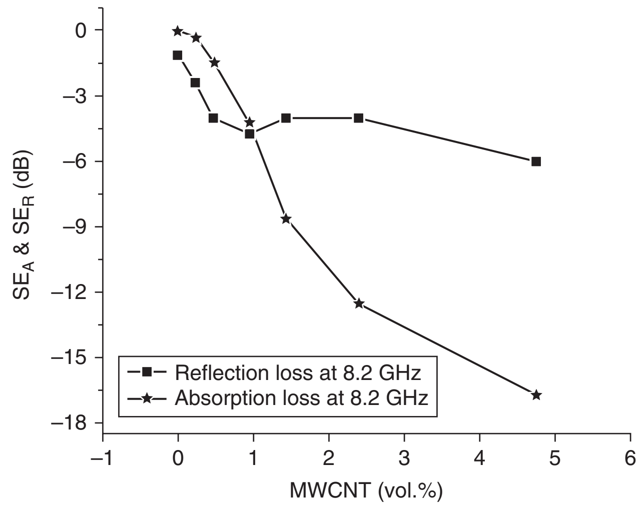

Figure 1.7 Graph showing contribution of reflection and absorption loss to total EMI SE in PTT/MWCNT composites [16]. Reproduced with permission of Springer.

that for PTT/MWCNT composites the primary shielding mechanism is absorption rather than reflection in the observed frequency range [16].

The composite fabricated by dip-coating process using silver nanowire (AgNW)-coated cellulose papers shows a reflection dominant EMI shielding mechanism. Figure 1.8 shows that there was a rapid increase in the reflectance, R, at three dip-coating cycles, which means the dominant shielding mechanism changed from absorbance to reflectance around the number of cycles [17].

An EMI shielding investigation of PET fabric/PPy composite showed that absorption as well as reflection contributes to the total EMI shielding of the composite and that with increasing electrical conductivity the EMI shielding through reflection increased. Figure 1.9 shows that the reflection dominated absorption by considering the total EMI shielding. As shown in Figure 1.9, with decreasing specific volume resistivity shielding effectiveness by reflection increased, and shielding effectiveness by absorption decreased. The increase in reflection mechanism is due to a smaller skin depth of the composite [18].

Graphene is a single sheet of carbon nanostructure in which the carbon atoms are in sp^2 hybridization. Graphene is a 2D carbon nanostructure. Graphite is the next member of the

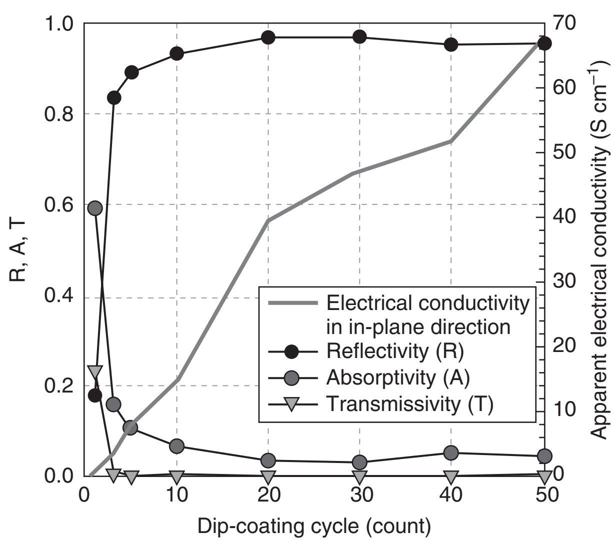

Figure 1.8 Graph showing contribution of reflection, absorption, and transmittance to total EMI shielding of AgNW/cellulose papers and their dependence on electrical conductivity at 1.0 GHz [17]. Reproduced with permission of the American Chemical Society.

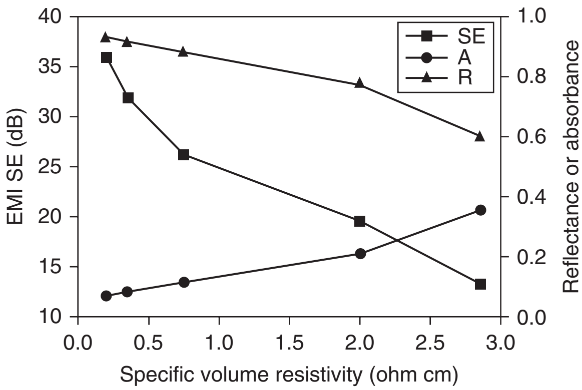

Figure 1.9 Graph showing contribution of absorbance, reflectance, and total EMI SE of PET fabric/PPy composites with various specific volume resistivities [18]. Reproduced with permission of Elsevier.

graphene family, made by the stacking of graphene monolayers. These layers interact through Van der Waals forces of attraction.

Graphene nanosheets consist of a monolayer or a few monolayers of graphene and act as an EMI shielding material. These carbon forms are made from sp^2 hybridized carbon atoms, with the edges or deformation sites showing the presence of some sp^3 hybridized carbon atoms. Graphene oxide (GO), another two-dimensional material coming under the graphene family, is formed by the introduction of covalent CO bonds in graphene. These graphene forms also contain delocalized π bond electrons – the presence of these freely moving electrons make them conducting.

Graphene nano-platelets with polyaniline and poly(3,4-ethylenedioxythiophene) (PEDOT)/ poly(styrene sulfonate) (PSS) with different ratios give paint like layers and act as an EMI shielding material. The contribution of absorption and reflection to the total EMI shielding value depends on the graphene/polyaniline ratios [19].

Graphene nanoplatelets (GNPs) in the insulating polymer matrix ultrahigh molecular weight polyethylene (UHMWPE) form a conductive network, and with 15 wt% filler the material shows 99.95% EMI shielding attenuation. The presence of a conductive path and the calculation using the power balance point out that the material absorbs more radiation than it reflects [20].

Another EMI shielding material obtained from PEDOT coated MWCNT and polyurethane matrix shows EMI shielding effectiveness through the absorption mechanism [21].

This chapter focuses the fundamentals of EMI shielding (reflection, absorption, and multiple reflections). Details on materials used for EMI shielding are given in further chapters of this book. The materials used for EMI shielding are fabricated in the form of an enclosure, i.e. a shielding enclosure. A shielding enclosure is a box or housing or cover providing isolation to the EMI emitter or receiver. This specialized cover is fabricated by considering the requirements for a particular EMI application. The materials covered in this book are fabricated and form part of a shielding enclosure. General principles for designing an enclosure should be followed; the current book deals only with materials for EMI shielding and with advancements in material sciences related to EMI shielding.

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