**Hybrid Carbon based Conducting Polymer Nanocomposite for Improved Electromagnetic Interference Shielding Effectiveness**

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**ABSTRACT**

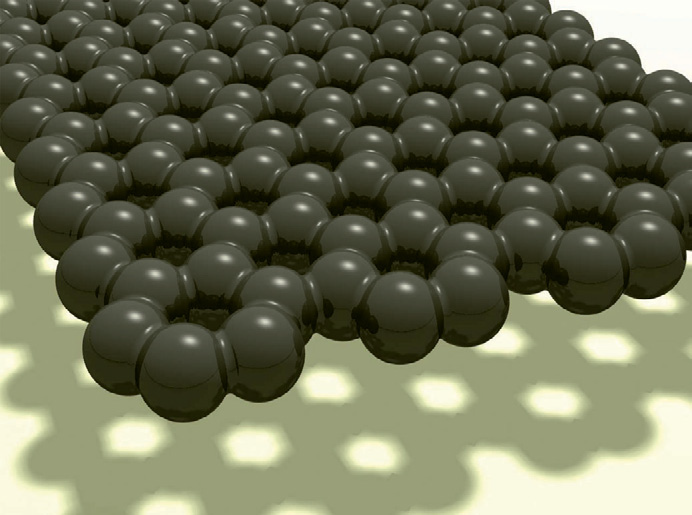
The growing demand for high-quality electronic and communication devices in military, industrial, and commercial applications has resulted in electronic device and system compactness, which increases circuit complexity. This is a novel form of challenge that necessitates a slew of decisions on electromagnetic radiation as a result of repeated efforts. These electromagnetic radiations interfere with one another and have the potential to ruin the system, which is referred to as electromagnetic (EM) pollution. Because it interferes with the operation of a device or transmission channel, electromagnetic interference is a key source of concern. To solve this issue, scientific and research organizations have started to create a variety of materials for electromagnetic interference (EMI) shielding applications. Carbon has long been an enthralling chemical; allotropes of carbon, such as fullerenes, graphite, graphene, carbon nanotubes, and other fillers that improve EMI shielding, are of significant interest in a variety of frequency bands. Initially, Multiwalled Carbon Nanotubes (MWCNT) and Graphene (GNS) were functionalized to improve conducting polymer interface. Polyaniline/Carbon nanotube/Graphene (PANI)/(MWCNT)/(GNS) were synthesized using an in situ oxidative polymerization process, with the weight percent of MWCNT remaining constant while the weight percent of GNS increasing from 1-3, and then characterized using SEM and FTIR analysis. When compared to pure polyaniline, the electrical conductivity of the nanocomposites rises with increasing weight percent of GNS. Carbon-based conducting polymer nanocomposites demonstrated semi conductivity and improved EMI shielding performance. The EMI Shielding effectiveness (SE) of hybrid carbon-based conducting polymer nanocomposites grows as the weight percent of GNS increases. Absorption is the major mechanism for synthesized ternary nanocomposites and can be employed as an Electromagnetic Interference shielding material.

**Keywords-**Electromagnetic Interference Shielding; Ternary Nanocomposites; Conducting Polymers

**I. INTROUCTION**

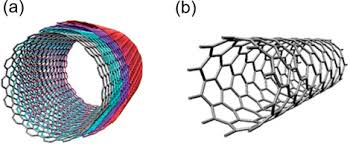
Because of the rapid rise of nanoscience and nanotechnology, the electronic industries have thrived. The electronic system within the instrument is tiny and densely packed with electrical components. This massive growth in electrical, telecommunications, and instrumentation results in an unwelcome and unfavorable consequence known as electromagnetic interference (EMI). A signal that is conducted and/or transmitted is referred to as electromagnetic interference (EMI). It is produced by any equipment or apparatus that transmits, distributes, processes, or uses electrical energy in any way. This EMI may interact with any other electronic device in the same area, reducing the performance of other equipment or systems. Receiving equipment can be affected by EMI, leading it to malfunction or fail. The effects of electromagnetic interference are becoming more visible as a result of increased demand for high-speed electronic devices operating at extremely high frequencies, the more demanding use of electronics in computers, communication equipment such as mobile and smart phones operating at 2-3 GHz for data transmission, and the miniaturization of these electronic devices. Electronic noise grows when electronic components become more compact and tightly packed. EMI may also have an impact on space exploration, military machinery, electronic devices, and communication instruments, among other things [1]. On a daily basis, people work and live in a state of electromagnetic radiation. Electromagnetic radiation not only impairs normal equipment operation, but it also has an effect on the human body [2]. As a result, EMI radiation blocking methods must be provided to isolate an appliance's microscopic electrical components from the surrounding environment. To manage the amount of electromagnetic (EM) energy created by the circuit that can escape into the external environment or to limit the amount of EMI radiation from the external environment that can penetrate the circuit, a shielding material must be provided. The blocking of electromagnetic radiation by a barrier made of conductive or magnetic material is known as electromagnetic interference shielding. The shield must completely wrap the device and contain no penetrations such as holes, slots, or cables in order to function. Any hole in a shield can greatly reduce its effectiveness. The main reason for good shield design is to construct a device that meets National/International Electromagnetic Interference Regulatory Standards [3]. Excessive use of electronic devices such as cell phones, laptop computers, and others can result in a range of ailments including leukemia, breast cancer, migraines, heart attacks, and even miscarriages. As a result, electromagnetic radiation pollutes the environment and poses a health risk to humans. It also has a deleterious impact on electronic gadgets [4]. Polymers are organic substances with a high molecular weight. A polymer is composed of several small molecules known as monomers. A monomer is a substance with a low molecular weight that, when mixed with other substances, generates a polymer with a high molecular weight [5]. Traditional polymers, such as plastic rubber, are dielectrics or insulators due to their great resistance to electric conduction. In the mid-1970s, conducting polymers were created. Scientists Hideki Shirakawa, Alan MacDiarmid, and Alan Heeger announced the discovery of polyacetylene doped with halogens, the simplest conducting polymer. The term "synthetic metals" refers to a new class of conducting polymers [6,9]. Conducting polymers are metal-like compounds with semiconductor characteristics. Conjugated double bonds along the polymer backbone are an important property of conductive polymers. [6]. Most polymeric materials are poor conductors of electricity because a large number of free electrons are not available to participate in the conduction process [5]. Doping significantly boosts the electrical conductivity of conducting polymers [10]. Andre Geim and colleagues at the University of Manchester discovered graphene using the seemingly simple Scotch tape method, igniting a revolution in Condensed Matter Physics. The 2004 discovery by Geim and Novoselov et al. of a method for generating individual graphene sheets ignited a frenzy of scientific activity [11]. The Nobel Prize in Physics was awarded to Andre Geim and Konstantin Novoselov in 2010 for their "groundbreaking experiments on the two-dimensional material graphene." The two researchers revealed that carbon in such a flat form contains exceptional quantum physics-derived properties. Graphene is not only the thinnest substance known, but it is also 200 times stronger than steel and conducts electricity better than any other material known to man at room temperature. Graphene, according to Columbia University researchers, is the strongest substance ever measured. Since then, graphene has been marketed as the next-generation material for nano-electronic devices [12].

Graphene is a graphite derivative [13]. A conductive nanomaterial is a one-atom-thick planar sheet of sp2 connected carbon atoms [14-16]. It is a two-dimensional hexagonal lattice. Figure 1.1 depicts the honeycomb structure of the sheet [17, 18].



**Figure 1.1: Structure of Graphene**

Graphene is recognized as the critical underpinning for fullerene allotropic dimensionalities. In addition to its planar state, graphene may be 'wrapped' into zero-dimensional spherical buckyballs or C60 and 'rolled' into one-dimensional Carbon Nanotubes (CNTs) [18, 19]. Carbon nanotubes were further categorized as single-walled or multi-walled (SWCNTs/MWCNTs) depending on the number of graphene layers present [14]. Graphite is a three-dimensional stack of graphene layers held together by van der Waals forces [20-22]. In other words, as a building block, graphene is the "mother of all carbon forms" [14]. When infinite graphene crystals become limited, surface and boundaries emerge, generating non-three coordinated atoms with nanoscale dimensions at the edges. The graphitic nanostructure's characteristics differ from those observed in bulk. Graphitic nanostructures include nanoribbons and nanoclustures [23]. Carbon atoms in graphene form a strong lattice and a p- orbital perpendicular to the graphene plane, resulting in a delocalized p electron system. At low energies, the linear energy dispersion relation associated with massless electrons, or Dirac fermions, results in a material with a zero band gap and a linear density of states [24]. Graphene offers a variety of intriguing features. It is impermeable to gases. Individual graphene has also been found to have improved electronic transport properties [25]. Graphene is a rising star in the world of nanomaterials due to its exciting properties, which include sensors, transistors, terahertz imaging, composites, energy storage devices, batteries, and thin coatings for solar cells, LCD displays, and electromagnetic interference shielding [23]. Iijima developed carbon nanotubes (CNTs), which have subsequently helped to enhance research in the disciplines of physics, chemistry, and material sciences. Many works have been conducted on the structure, properties, and prospective uses. Because of their cylindrical geometry and nanometric scale, carbon nanotubes are excellent for potential uses such as hydrogen storage. Because of their well-defined atomic structure, high length to diameter ratio, and chemical stability, single wall carbon nanotubes (SWNTs) is one-dimension molecules. SWNTs have specific electrical properties and can be metallic or semiconducting depending on their geometry [26]. Carbon nanotubes are sheets of graphite that have been coiled into tubes. Nanotubes are regarded to be almost one-dimensional structures due to their remarkable length to diameter ratio. The most important structures are depicted in Figure 1.2, which are single walled nanotubes (SWNTs) and multi walled nanotubes (MWNTs). A SWNT is a cylinder that contains only one wrapped graphene sheet. MWNTs are multiwalled nanotubes that resemble a ring of concentric SWNTs. The length and diameter of these structures, as well as their properties, differ greatly from those of SWNTs [27].



**Figure: 1.2: (a) Multi walled nanotubes (MWNTs), (b) Single walled nanotubes (SWNTs)**

The most common methods for manufacturing SWNTs and MWNTs are carbon-arc discharge, laser ablation of carbon, or chemical vapour deposition (typically on catalytic particles). The most prevalent method of generating high-volume CNTs is chemical vapour deposition (CVD), which uses fluidized bed reactors that allow consistent gas flow and heat transmission to metal catalyst nanoparticles. The diameters of SWNT nanotubes range from 0.4 to 3 nm, while MWNT diameters range from 1.4 to at least 100 nm. A nanotube's diameter can thus be exploited to alter its properties. Unfortunately, SWNTs are currently only produced on a small scale and at a high cost. The exceptional mechanical, electrical, transport, vibrational, thermal, and other properties of carbon nanotubes, most of which are due to their quasi-one-dimensional sp2-bonded structure [28,29]. Carbon nanotubes have grabbed the interest of many scientists worldwide. Because of their small size, strength, and extraordinary physical properties, these structures are a very uncommon material with a wide range of intriguing applications. They can be used as mechanical reinforcements in high performance composites, as nanotube-based field emitters, as nanoprobes in metrology and biological and chemical investigations, and as templates for the creation of other nanostructures. The electronic properties of carbon nanotubes allowed them to be used in device applications. They have a wide range of applications in energy storage, sensors, supercapacitors, and other domains [30] . Polymer nanocomposites (PNC) are polymers that have been reinforced in small amounts (less than 5% by weight) with nano-sized particles with high aspect ratios (L/h >300). To create polymer nanocomposites reinforced with filler nanoparticles, four interdependent areas must be balanced: constituent selection, cost-effective processing, fabrication, and performance. The matrix, reinforcement (fibre), and interfacial region are the three major material elements of any composite. The interfacial area is responsible for communication between the matrix and the filler due to its proximity to the filler's surface, and its properties differ from those of the bulk matrix. The nanoparticles introduced to the matrix or matrix precursors are made up of two types of nanoparticles based on this grouping: (i) low-dimensional crystallites and (ii) aggregates [31]. In recent years, the dispersion of nanoparticles CNT/GNS in a polymer matrix has emerged as a fresh and fascinating topic in materials research. Traditional composites and pure polymers cannot compete with the qualities of these nanocomposite materials. The increased properties are due to the dispersion of the nanofillers in the polymer matrix. Even at low filler loadings in the polymer matrix, the properties of these nanocomposites improve [32]. Because these nanocomposites have a positive temperature co-efficient, resistance increases as temperature rises. [33].

**A. Literature Review:**

Metals were previously used as EMI shielding materials in the form of thin sheets or sheathing; however, metals were costly, heavy, prone to corrosion, and difficult to manufacture. As a result, conducting polymers and composites with conductive fillers were developed as an alternative EMI shielding material. These materials are lightweight, low-cost, corrosion-resistant, and easy to work with. Because of their vast range of uses, conducting polymers (CPs) have gained importance in the last four decades. Carbon nanofibres, carbon nanotubes, and graphene are gaining prominence because to their high aspect ratio and potential applications as ideal absorbers.

Chen and colleagues Sai Hu et al prepared the PANI/CuS/reduced graphene oxide (RGO) composites, which exhibit remarkably enhanced shielding effectiveness. The average EMI SE of composites with a thickness of 3mm reached -18dB from -7.5dB in the frequency range of 300 KHz-3GHz. Wu et al created a combination of graphene foam (GF) and poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS). The GF/PEDOT:PSS composites had an ultralow density of 18.2X10-3 g/cm3 and a high porosity of 98.8%, as well as a nearly fourfold increase in electrical conductivity from 11.8 to 43.2 S/cm after the introduction of the conductive PEDOT:PSS. The composites exhibit extraordinary EMI shielding performance with a shielding efficiency (SE) of 91.9 dB thanks to their superior electrical conductivity, extremely light porous structure, and effective charge delocalization. Cheng et al synthesized a high heat- resistance crystallite, stereo complex crystallites (Sc), by stereocomplexation crystallization of enantiomeric poly(L-lactide) (PLLA) and poly(D-lactide) (PDLA), and introduced it into a conductive carbon nanotube (CNT)/ Poly(lactic acid) (PLA) composite foam. The freeze-dried CNT/ PLA foam has a low foam density of 0.10 g/cm3 and a high 216 dB cm3/g specific EMI shielding efficacy. Jeddi et al developed hybrid polyurethane foam/silicon rubber/carbon black/nanographite composites, and the EMI SE results showed that reflection loss was the primary shielding mechanism in all samples. Fletcher et al. developed an elastomer nanocomposite of MWCNTs in a fluorocarbon polymer, with EMI SEs of 50 dB for a MWCNT filler loading of 12 wt% and 20 dB for a loading of 6 wt%. Their measured samples, on the other hand, were relatively thick (3.8 mm). To lower the size and weight of electronic gadgets, the EMI shielding materials that surround them should be thin as well. They reported that the EMI SE for MWCNT filler loading of 12 wt% was around 15 dB when the thickness was 0.8 mm, because the EMI SE in decibels is roughly proportional to thickness. Keto et al created a flexible and elastic EMI shielding material by incorporating SG-CNTs (1 wt%) into a fluorinated rubber, resulting in a high EMI SE (20 dB, 90% shielding) without hardening or embrittling the rubber. Choudhary et al created flexible shielding materials comprised of Fe3O4 nanoparticles, mesocarbon microbeads, and multiwalled carbon nanotubes (MCMBs/MWCNTs) composite paper for excellent EMI shielding in the X-band. The addition of Fe3O4 nanoparticles in the MCMBs/MWCNTs composite paper improves its interfacial polarisation and anisotropy energy, resulting in an outstanding absorption dominated EMI shielding effectiveness (SE) of 80 dB at 0.5 mm thickness. Sing et al. and colleagues created a three-dimensional (3D) nanostructure comprised of chemically modified graphene/Fe3O4(GF) integrated polyaniline as a high-performance shielding material against electromagnetic pollution. Verma et al created a ternary hybrid nanocomposite with a thermoplastic polyurethane matrix and a filled inclusion of graphene nanoplates carbon nanotubes hybrid (GCNT). For a 10% loaded GCNT sample, these hybrid nanocomposites demonstrated good electromagnetic interference shielding of up to 47 dB in the Ku-band of microwave frequency. Rao et al developed lightweight, flexible, and thin Fe3O4-loaded, functionalized multiwalled carbon nanotube buck papers for enhanced X-band electromagnetic interference shielding. A buck paper with a thickness of 50 m and a density of 0.51 g cm-3 exhibits a high total specific shielding effectiveness of around 49.56 dB.

**II. MATRIALS AND METHODS**

A. Materials:

Merck Limited., India supplied the chemicals, which included aniline (C6H5NH2), sulphuric acid (H2SO4), nitric acid (HNO3), and ammonium persulfate [(NH4)2S2O8]. Graphite flakes and carbon nanotubes (CNTs) are now available from NPL in New Delhi, India. Aniline was distillated under reduced pressure and at temperatures below 4 degrees Celsius. Distilled water was employed in all synthesis processes.

B. Synthesis of Polyaniline (PANI):

Before usage, aliline was distilled and stored at temperatures below 5oC. Polyaniline was created by the chemical oxidative polymerization technique. The 0.2M H2SO4 solution in 50 ml of deionized water was divided in half. The mixture was agitated for roughly 5 hours after one part 0.2M aniline was added. Another half was mixed with 0.2M ammonium persulphate (APS) and added to the whirling monomer solution drop by drop. After mixing the reactants, the solution turns greenish before turning violet. The dark precipitate was recovered after 6 to 7 hours. This hue indicates that the product was in the conducting phase of emerald salt. This precipitate was allowed to settle overnight before being diluted with deionized water until the filter was colorless. Finally, it was cleaned with ethanol and dried overnight in an oven at 80oC [34-36].

C. Synthesis of Graphite Oxide (GO) and Graphene Nanosheets (GNS):

The Hummers method was used to synthesize graphite oxide (GO) from graphite flakes, and GO exfoliation was used to produce graphene nanosheets (GN). A typical process was combining the appropriate amount of graphite flakes and NaNO3 with H2SO4. Potassium permanganate was gently added to the suspension while rapidly swirling for 1 hour at low temperature. The reaction system was stirred at room temperature to generate a thick paste. As the reaction progressed, the mixture became pasty and the colour changed to a light brownish hue. Finally, with vigorous agitation, H2O2 was gradually added to the pasty, altering its hue from brown to yellow. After that, the GO was vacuum filtered and washed with deionized water. Exfoliation was achieved by sonicating the GO dispersion for 30 minutes at room temperature. To create graphene nanosheets, ammonia solution and hydrazine monohydrate were added to a sonicated GO dispersion, and the mixture was heated at 90oC for 2 hours with vigorous stirring. Following the completion of the process, the reduced graphene nanosheets (GNS) were collected as a black powder by filtration [37-45].

D. Functionalization of Graphene and Carbon Nanotubes:

Functionalized graphene (FGNS) or functionalized carbon nanotubes (CNT) are graphene or CNT that have been changed by adding additional functional groups to their surfaces. By modifying the surface of to obtain functional groups that act as precursors for the anchoring of suitable organic/inorganic molecules, as well as to improve its dispersion in solvents, functionalization improves the properties. This serves as a substrate for nanoparticle nucleation and growth, resulting in homogeneous size distribution and nanoparticle deposition on two-dimensional nanosheets. There are two types of functionalization approaches for grapheme and carbon nanotubes: covalent and noncovalent techniques. Covalent and noncovalent modification approaches are both extremely effective in producing process able graphene [46,47].

The surface functional groups of graphene nanosheets are constrained, allowing for chemical interactions with polymers. As a result, acid treatment was used to functionalize GNS. A solution of 6M H2SO4 and 6M HNO3 in a 3:1 ratio was agitated for 10 minutes to functionalize GNS. GNS was added to the solution, which was then sonicated for 4 hours at 50oC. GNS was centrifuged and then filtered, washed, and dried to produce functionalized GNS [48, 49]. The same process was used to functionalize carbon nanotubes.

E. Synthesis of PANI/CNT/GNS composites:

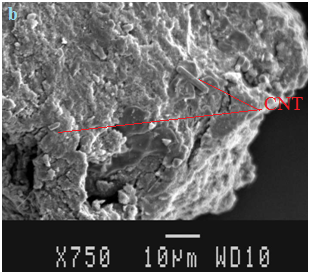
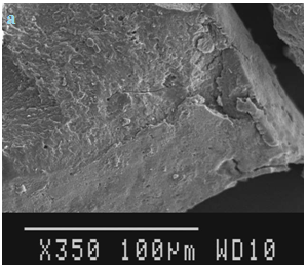
An in-situ chemical oxidative polymerization of aniline in the presence of CNT/GNS was used to create the PANI/CNT/GNS composites. The weight percentage of CNT remained constant while the weight percentage of GNS to aniline fluctuated from 0% to 5%. The 0.2M H2SO4 solution in 50 ml of deionized water was separated into two halves. The mixture was ultrasonicated for 30 minutes after adding 0.2M aniline and functionalized CNT/GNS to one portion. After ultrasonication, the mixture was stirred for around 5 hours at 5oC to maximize yield. Another half was combined with 0.2M ammonium persulphate (APS) and added drop by drop to the swirling monomer solution. After combining the reactants, the solution takes on a greenish color before turning violet. After 6 to 7 hours, the black precipitate was collected. This precipitate was left overnight before being diluted with deionized water until the filtrate was colorless. Finally, it was rinsed with ethanol and dried in an oven at 80oC [50-57] overnight.

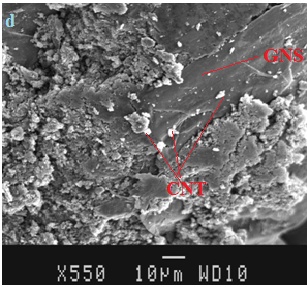
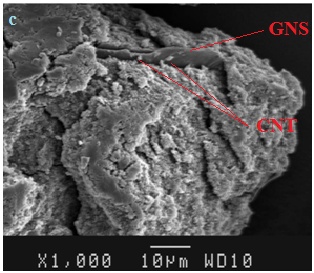
**III. RESULT**

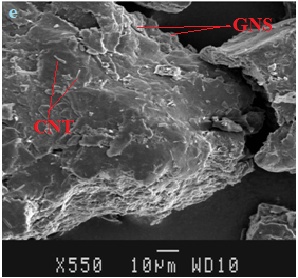
A. Scanning Electron Microscopy:

Nanocomposites under research must be characterized in order to understand the structure, morphology, and interaction of different components. SEM can be used to study the morphological and structural aspects of composites [56]. This study used scanning electron microscopy (SEM) to provide surface information on the materials as well as a complete assessment of the morphological aspects of all the samples. The GNS, CNT, and PANI/CNT/GNS materials were spectroscopically characterised after being prepared in powder form. A scanning electron microscope (SEM) is a type of electron microscope that scans a sample with a concentrated beam of electrons to produce pictures. Electrons interact with atoms in the sample, producing a variety of detectable signals that carry information on the surface topography and composition of the sample [58].

Figure 3.1 depicts SEM micrographs of pure PANI, PANI/CNT, and PANI/CNT/GNS nanocomposites with varying weight percentages of GNS loading. MWCNTs (CNT) are hollow cylindrical shaped tubes structure of carbon atoms, whereas graphene is two-dimensional sheets of carbon atoms. PANI displays surfaces that are rough, smooth, or flaky. According to (Fig. 3.1a-e), increasing the concentration of aniline monomer causes an increase in the degree of roughness and aggregation in the morphology of composites. The shape of the composite with the highest monomer concentration (Fig. 3.1b&c) revealed rough and heavily aggregated globules. This finding suggests that a higher monomer content in the initial polymerization solution resulted in a faster polymerization rate, resulting in a trough surface and poor adhesion. Because of this weak adherence, the contact resistance between the hybrid carbon assemblage substrate and PANI increases. The composite of PANI/CNT/3%GNS and PANI/CNT/5%GNS, on the other hand, lacks aggregated globular shape (Fig. 3.1d&e). This suggested that the polymer and three-dimensional hybrid carbon assemblage formed a strong bond.







**Figure 3.1: SEM Images (a)Pure PANI, (b)PANI/CNT, (c) PANI/CNT/1%GNS, (d) PANI/CNT/3%GNS, (e) PANI/CNT/5%GNS**

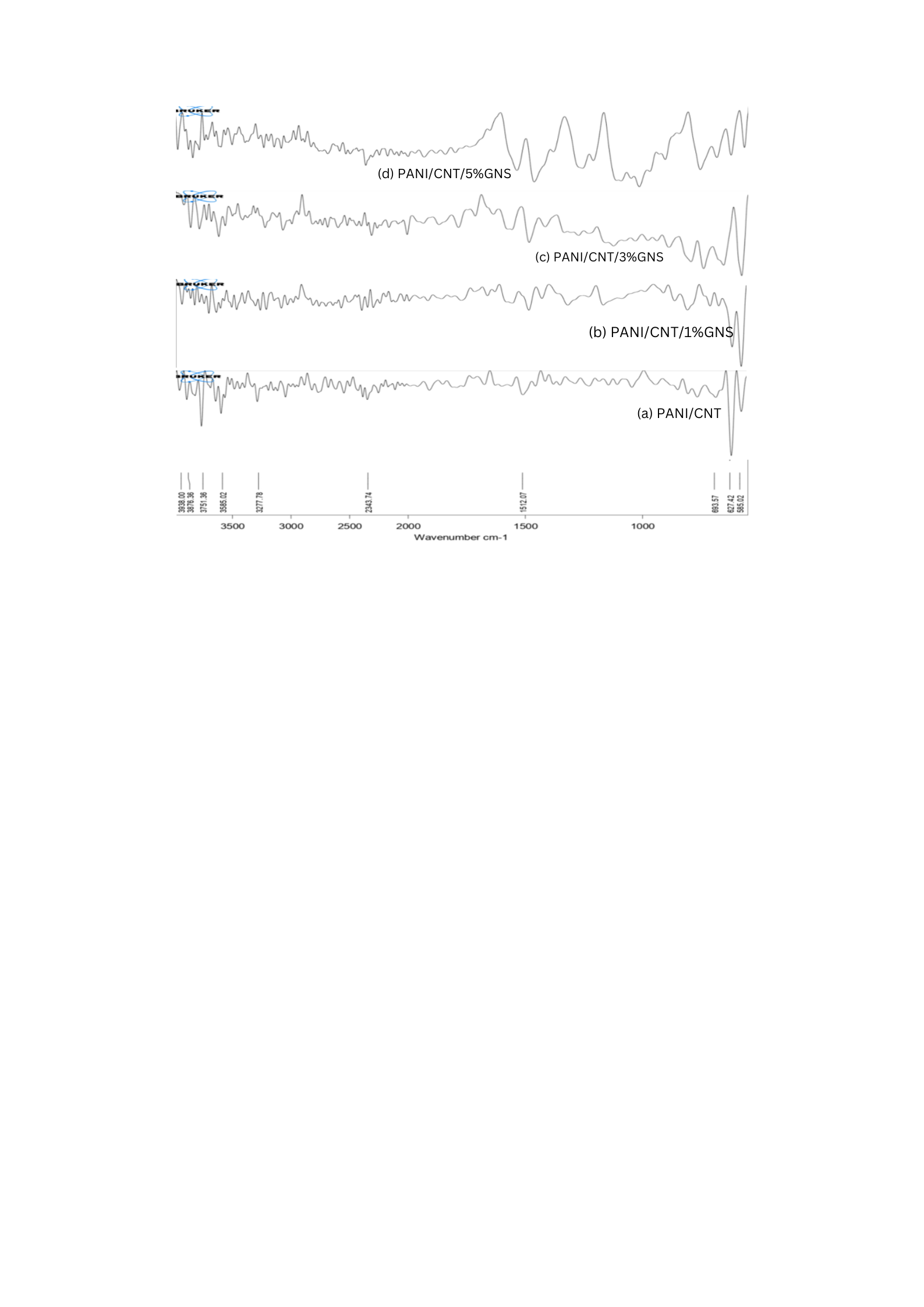
MWCNTs are not independently visible in the PANI/CNT/3%GNS nanocomposite; there are places with a high concentration of agglomerated MWCNTs and small areas with an extremely negligible concentration of carbon nanotubes. Strong van der Waals interactions between carbon nanotubes could explain the agglomerates. Carbon nanotubes are sandwiched between PANI and graphene sheets. The interactions between the sheets of graphene nanoplatets result in huge agglomerates of GNS in PANI/CNT/5%GNS composites. A smooth GNS surface may result in weak interfacial interaction with the polymer. In the polymer matrix, GNS agglomerates of varied sizes are randomly distributed. The extent of visibility of the GNS rises as the GNS concentration in the nanocomposites grows, as do the nanotubes of various lengths seen and trapped in the polymer matrix. In addition, graphene sheets and MWCNTs can be seen in all of the samples [59,60].

B. Fourier Transform Infra Red:

The FT-IR spectroscopy identifies and confirms the structure and existence of various groups on the GNS sheet, as well as the presence of various linkages in PANI/CNT/GNS nanocomposites. This is a critical characterisation approach for chemical identification. The far infrared, or FIR, spectral spectrum spans 4000 to 500 cm-1 wavenumbers. This frequency range encompasses both backbone vibrations of big molecules and fundamental vibrations of molecules containing heavy atoms [61]. FT-IR has been frequently utilized to identify different types of chemical bonds (functional groups) in a molecule. FTIR spectroscopy is a technique for determining qualitative and quantitative properties of IR-active compounds in organic or inorganic solid, liquid, or gas samples. It is a quick and low-cost approach for analyzing crystalline, microcrystalline, amorphous, or film-like substances [62].

In the current study, the FTIR spectra of all materials were acquired using the KBr pellet technique on a Thermo Nicolet, Avatar 370 infrared spectrometer at Nagpur University's superior test and instrumentation

laboratory.



**Figure 3.2: (a) PANI/CNT, (b) PANI/CNT/1%GNS, (c) PANI/CNT/3%GNS, (d) PANI /CNT/5%GNS**

PANI/CNT FTIR spectra show peaks at 1512 cm\_1 due to C=C bonds that create the framework of the CNT sidewall. However, after oxidation, certain new peaks are found in the composite that were not present in pure PANI, owing to MWCNT functionalization. The stretching mode of carboxylic groups connected to MWCNTs is associated with the peak at 1740 cm\_1 [63]. The O-H stretching vibrations of carboxylic groups are responsible for the tiny peak at 3450 cm\_1. Acid functionalization is shown by these two peaks. These findings indicated that the MWCNTs were successfully oxidised into carboxylated carbon nanotubes. The absorption band at 1512 cm-1 is attributed to the MWCNT's skeletal vibration (Figure 3.2 a), which overlapped with the C=C stretching of PANI's quinone rings. The peaks at 1290 and 1105 cm-1 are attributed to the secondary aromatic amine group's C-N stretching vibration and aromatic C-H in plane bending vibration, respectively. The peak at 627 cm-1 corresponds to C-H out of plane bending vibration, and the minor peak at 693 cm-1 corresponds to para-distributed aromatic rings, indicating polymer production. The modest peak at roughly 1200 cm-1 is due to the conducting form of polyaniline, showing that it exists in conducting emaraldine form. This enables the creation of PANI on the MWCNT wall via an in-situ chemical polymerization process. Figure 3.2(b),(c),(d) depicts the FTIR spectra of PANI, hybrid carbon composite. The peak at 3479 cm-1 in the PANI hybrid carbon assemblage spectra corresponds to NH2 stretching, which changes to 3484 cm-1 with increased GNS concentration. The N-H bending of amine was represented by the peak at 1632 cm-1. Furthermore, the peaks at 1176 and 1045 cm-1 are related to the primary structure of MWCNTs and graphene's C-C stretch vibration. The charge delocalization over the polymeric backbone is responsible for the modest peak about 1100 cm-1 (C-N stretching). NH2 stretching vibrations caused the conspicuous peak at 3484 cm-1. A minor shift in the position of the main characteristic peaks in the composite spectrum was found, indicating interaction of the hybrid carbon assemblage with PANI. This shows that the strong interaction between PANI, MWCNTs, and GNS promotes an effective degree of electron delocalization, which improves polymer chain conductivity. The PANI linked to the hybrid carbon assemblage may be responsible for the rise in relative intensity of peaks around 3484, 1483, and 1045 cm-1 [64,65].

C. Electrical Conductivity:

Filler content influences the electrical conductivity of polymer composites. The distance between conductive particles in an insulating polymer matrix with a low filler concentration is large, and conductivity is limited. Increased filler content in composites causes a non-linear increase in electrical conductivity as filler concentration increases. At a given filler concentration, known as the percolation threshold (c), the electrical conductivity of a composite quickly increases by several orders of magnitude, converting it from an insulator to a conductor. Sometimes a very small amount of conducting particles can be added to a filler to create an effective conducting channel, so making the entire composite conductive. CNTs and GNS could be used as effective fillers to build a conductive polymer composite with an extraordinarily low percolation threshold [66]. Percolation threshold values for MWCNT composites range from 0.002 to more than 2 wt.% [67-69] and from 1 to 8 wt.% for GNS composites [70, 71]. The importance of nanofiller content, aspect ratio, dimensions, and geometrical arrangement, as well as composite processing conditions, is demonstrated by such wide variances in percolation threshold values [72, 73]. The key challenges limiting polyaniline's expected improvement are that such nanoparticles create agglomerates due to vander Waals forces [74, 75], and a sufficient network in the polymer matrix is not generated, resulting in a higher percolation threshold. Agglomeration could be decreased by increasing the dispersion of the filler in the polymer matrix. Combining two carbon fillers into a hybrid structure is one of the most promising methods, which could result in a possibly new multifunctional material in research and application due to the synergy effect of both fillers, increasing mechanical, thermal, and electrical properties [76,77]. Smaller nanofillers with varying shapes provide a bigger surface area, allowing more polymer to come into touch with the filler. When the volume content of the nanofiller is high enough, the inter-phase becomes the dominant phase in the composite. Furthermore, the use of different forms of nanoparticles (1D - CNT and 2D - GNS) allows for increased efficiency at lower filler content. With the same number of filler particles and different geometrical arrangements of the chains, different particle lengths and shapes can be generated. In mixed MWCNT/GNS composites, electrical transport can occur via 1) electron hopping and tunneling in the MWCNT subsystem, 2) electron hopping and tunnelling in the GNS subsystem, and 3) electron tunneling between the GNS and MWCNT subsystems [78].

**Figure 3.3: Variation of Electrical Conductivity with respect to temperature for PANI/CNT and different weight percent of GNS**

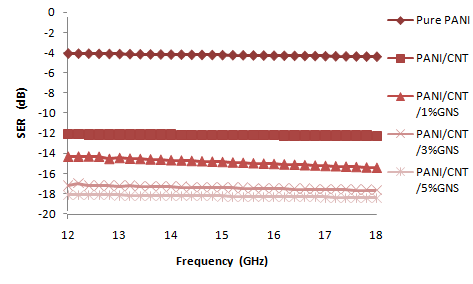
**Figure 3.4: Variation of Electrical Conductivity with different weight percent of GNS in PANI/CNT**

The increase in conductivity with increased GNS concentration for hybrid composites improved MWCNT distribution and electron tunneling between the GNS and the MWCNTs, resulting in an increase in electrical conductivity of mixed composites. The formation of a more effective conductive network as a result of the combination of MWCNT and GNS conductive particles could explain the increase in electrical conductivity of the conducting polymer [79].

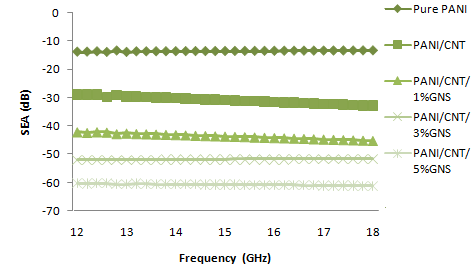
An improved four probe electrical conductivity metre was used to measure the electrical conductivity of PANI/CNT/GNS nanocomposites with increasing GNS concentration. The PANI class of conducting polymers is widely known; its electrical conductivity is in the order of 1-2 S cm\_1 at ambient temperature, but it was found to be 3.8 S/cm at 80 degrees C. Graphene and MWCNTs have exceptionally high electrical conductivity when compared to PANI. However, the presence of multilayer graphene and MWCNTs has a considerable impact on the electrical conductivity of PANI. Previous research has shown that incorporating MWCNTs into PANI during processing boosts its electrical conductivity fourfold, which is linked to the formation of a conductive network. At room temperature, the electrical conductivity of nanocomposites was shown to be significantly higher than that of pure PANI. The electrical conductivity of the nanocomposite rises continually after reinforcing a varied weight percent of GNS in the PANI/CNT. The extent of increase in electrical conductivity, electrical conductivity is 10.11 S/cm for PANI/CNT and increases from 14.09, 15.03, 15.84 S/cm for PANI/CNT/1%GNS, PANI/CNT/3%GNS, PANI/CNT/5%GNS, respectively, as shown in figures 3.3 and 3.4. Because GNS has a high electrical conductivity, increased concentrations of GNS provide a good networking electrical conduction pathway. This is determined by the creation of a conductive network in the polymer matrix by MWCNTs and graphene.

D. Electromagnetic Interferences Shielding Effectiveness:

The electromagnetic interference shielding performance of PANI/CNT nanocomposite material and hybrid assemblage or ternary nanocomposites of PANI/CNT/GNS was investigated. When compared to conventional materials, the polymer matrix incorporating nano particles of CNT and GNS improves the interfacial polarization and effective anisotropy energy of the sheets, resulting in higher scattering and high shielding effectiveness. The addition of nano particles such as CNT and GNS to PANI improves absorption properties, which are highly dependent on the volume fraction of the filler. As a result, absorption rather than reflection is responsible for the high value of EMI SE. The EMI shielding efficacy of all synthesized nanocomposites increases as the GNS concentration increases. The volume resistivity of composites decreases as GNS increases from 1% to 5%, whereas Shielding Effectiveness increases. The number of percolating networks grows as the number of GNS grows. Conductive networks produced by the dispersion of CNT and GNS act similarly to conductive meshes. As GNS loading increases, so does the size of the conductive mesh, which functions as a barrier to incident Electromagnetic radiations and results in greater EMI SE. This is due to the fact that the electrical conductivity of a composite tends to increase with increasing GNS content, and as a result of the action of electromagnetic radiation, induction current made on the interface or in the interior of the sample produces reversal electromagnetic field, which leads to an increase in surface reflection attenuation of electromagnetic wave, and thus the EMI shielding effectiveness of the composite increases. The attenuation of incident waves can be increased by increasing the absorption and scattering cross sections of absorbent particles. The incident wave energy is also attenuated more. The greater the specific surface area of GNS, the greater the plane wave absorption cross section and scattering cross section of the absorbing particle, and hence the greater the electromagnetic wave loss. The overall Shielding Effectiveness of PANI is widely known to be dominated by absorption phenomena caused by the presence of localised charges (polarons and bipolarons), resulting in a high divergence and relaxation impact. The PANI coating on the GNS can dominate the polarisation, and the functional groups of functionalized GNS and functionalized CNT result in electromagnetic radiation absorption. The functional groups of GNS and CNT are also responsible for absorption; as the content of GNS grows, so do the functional groups responsible for electromagnetic radiation absorption. Many factors influence a material's EMI SE, including conductivity, dielectric constant, aspect ratio, state of dispersion of conductive fillers, and shielding material thickness. Conductivity is the most important factor for an EMI shielding material out of all of these. In the case of a conductive material such as metal, EMI SE is mostly caused by EM radiation reflection, whereas in the case of a conductive composite, EMI SE is primarily caused by radiation absorption.



**Figure 3.5: (a) Shielding Effectiveness due to Reflection**



**Figure 3.5: (b) Shielding Effectiveness due to Absorption**

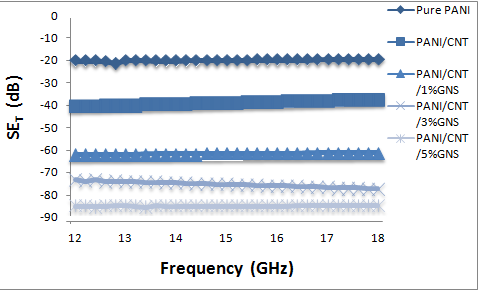
  
**Figure 3.5: (c) Total Shielding Effectiveness of composites**

Figure 3.5 (a), (b), and (c) show the SER, SEA, and SET of PANI/CNT, and hybrid assemblage or ternary nanocomposites of PANI/CNT/GNS nanocomposites as a function of frequency in the range 12-18 GHz (Ku band) of weight% 1,3, and 5. The SER is almost linear for each composition across the whole frequency range of measurement and exhibits a small variation even as GNS loading increases. With a 1 to 3 wt% increase in GNS loading, the SEA rises from 13 to 60 dB. According to the experimental data, absorption is the major shielding process, whereas reflection is the secondary shielding mechanism. The SET of nanocomposite as a function of frequency demonstrates that the nature of SET for each composition is almost linear with frequency, while the SET of composite is found to increase as GNS loading increases. The total electromagnetic interference shielding effectiveness of pure PANI, PANI/CNT, PANI/CNT/1%GNS, PANI/ CNT/3%GNS, and PANI/ CNT/5%GNS, respectively, is 20, 40, 61, 73, and 85 dB. The EMI SE of synthesized composites obtained is greater than the required EMI shielding efficacy (20 dB) for commercial applications. Such a high value of EMI SE with such a low loading of GNS demonstrates the outstanding efficiency. The EMI SE results reveal that synthesized composites have an absorption-dominant mechanism and can be employed to protect electronic equipment and components from electromagnetic radiation as lightweight, effective EMI shielding or microwave absorption materials.

**IV. CONCLUSION**

The PANI/CNT/GNS nanocomposites were synthesized in this study utilizing an in-situ chemical oxidation polymerization process with a modification in the weight fraction of GNS. SEM and FTIR were used to characterize the synthesized materials. The SEM pictures of PANI/CNT/GNS nanocomposites show that the GNS surface has been covered with a smooth thin polyaniline layer. Because of the contribution of PANI to the layered GNS surface, the surface is rough and the characteristic layered structure has vanished, revealing a coralline-like shape. There is no free GNS in PANI/GNS nanocomposites, indicating that the PANI covers the GNS surface uniformly. Carbon nanotubes can also be found in the composites, but in modest amounts.

The vibration and rotation of the chemical bonding and molecular structures of the produced PANI/CNT/GNS nanocomposites are revealed by Fourier Transform Infrared Spectroscopy (FTIR).

The electrical conductivity of PANI/CNT/GNS composites was observed to increase as the weight percent of GNS in the PANI matrix increased. At room temperature, the electrical conductivity of nanocomposites was shown to be significantly higher than that of pure PANI.

The EMI shielding efficiency (SE) of PANI/CNT/GNS nanocomposites was studied in the 12-18 GHz frequency range using a vector network analyzer. EMI shielding involves three mechanisms: reflection, absorption, and multiple-reflection. Absorption is the major shielding mechanism for conducting polymer/hybrid carbon-based composites samples, followed by reflection shielding. The electromagnetic shielding effectiveness (SE) was found to increase with increasing GNS content. The obtained EMI SE for synthesized composites is greater than the required value of EMI shielding effectiveness (20 dB) for commercial applications. It was discovered that absorption was dominant, implying that PANI/CNT/GNS nanocomposites can be employed as lightweight EMI shielding materials.

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