CHAPTER I

INTRODUCTION TO THE RESEARCH PROBLEM

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1.1 INTRODUCTION

Wireless technology usages have led the need to support simultaneous operation of different wireless systems in the same environment without effecting the normal functioning of each individual system. The electromagnetic radiations emitted from various systems hinder the operation of electronic devices and communication systems causing electromagnetic interference (EMI) [1]. The electromagnetic interference (EMI) is basically electrical in nature and is due to unwanted electromagnetic emission being either radiated or conducted. The issues of tackling electromagnetic compatibility are challenging and proper EMI shielding mechanism has to be ascertained.

The EMI shielding can be achieved either by reflection or absorption of the interfering electromagnetic wave [2]. Metal is considered to be the best material for reflection electromagnetic shielding but the reflected wave may interfere with the electronic component inside the enclosure or in its vicinity. Modern warfare where radar system of weapons detection and guiding missiles are needed; hiding radar signatures and camouflaging war equipments are also important issues to be considered [3].

EMI shielding through absorption mechanism, works on the principle of absorption of the interfering electromagnetic wave by converting the wave energy into thermal energy, thereby reducing the interference to a sufficiently low value [4]. However, shielding by absorption requires certain design conditions while developing the absorber and this shielding mechanism is frequency dependent. Absorbers used for shielding in microwave or radio frequency range are termed as microwave absorbing material (MAM) or radar absorbing material (RAM). The RAM also finds applications as coating on the surface of the military aircraft to avoid detection, in radio frequency anechoic chamber, in food processing technology etc.[5-8].

In general, RAMs are fabricated in the form of sheets that consist of insulating polymer, like rubber, and magnetic or dielectric loss materials such
as ferrite, permalloy, carbon black, and short carbon fiber [5, 9]. An electromagnetic wave absorption characteristic of material depends on its dielectric properties (complex permittivity, $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$), magnetic properties (complex permeability, $\mu_r = \mu_r' - j\mu_r''$), thickness and frequency range [10]. Dielectric composite absorption at microwave frequencies depends on the ohmic loss of energy, generally achieved by adding conductive fillers like carbon black, graphite or metal particles. On the other hand, magnetic composite absorption depends on magnetic hysteresis effect of the magnetic materials, like ferrite, incorporated into the matrix [11-13]. Of the two techniques, the magnetic composite absorber has two main shortcomings; firstly, density of the magnetic materials is too high to use them in large quantity as filler of absorbers. Secondly, the resonance frequency range showing effective characteristics exist in the MHz range and hence the efficiency of absorbers decreases rapidly in the GHz and beyond this range. Thus, the technical requirement for the absorber limits the number of ferromagnetic materials that can be used in the microwave range [14]. On the other hand, dielectric RAMs using carbon based materials such as carbon black, single and multiwalled carbon nanotubes (SWCNTs and MWCNTs), short carbon fibers etc. got widest attention as RAMs due to lightweight and corrosion resistant [15-17]. Infact, the research into the development of carbon based RAMs dates back in 1936 when a quarter-wave resonant absorber based on carbon black (CB) and titanium dioxide and was patented in Netherlands [18]. During World War II, America developed “Halpern Anti Radiation Paint (HARP)”, an absorbing material based on rubber filled with CB, disc shaped aluminum flakes and barium titanate and used in airborne and seaborne vehicles for radar detection avoidance with 15–20 dB absorption at the X-band [19, 20]. During that time Germans developed “Wesch” material and also produced Jaumann absorbers which is multilayer layer device of alternating resistive sheets and rigid plastics[21]. Salisbury screen was another narrow
band resonant absorber consisting of resistive sheet placed at odd multiple of \( \frac{1}{4} \) wavelength from the metal plate and was patented in 1952.

With progressive development of wireless technology during the post world war period, the need of broadband absorbers became major challenge with the requirement of quality anechoic chamber for accurate indoor measurement. Carbon loaded plaster of Paris and graphite was studied for microwave absorbing materials [22].

In the 1950s, the sponge product company developed a broadband microwave absorber called Spongex composed of C-coated animal hair of thickness 50.8 mm and showed 20 dB attenuation of normal incidence in the frequency range 2.4-10 GHz [21].

During 1960s and 1970s, the particulate as well as fibrous C was used to fabricate netlike, knitted or honeycomb structures [23]. Till the discovery of carbon nanotubes (CNTs) in the 1990s, CB and graphite remained the most studied microwave absorbing materials. The CNTs including single walled and multi walled have been exploited widely in developing EMI shielding materials [15, 24-31] and showed a strong microwave absorption in the frequency range 8.2-12.4 GHz [32]. High aspect ratios (= length/diameter) of CNTs help in attaining percolation threshold at very low concentration [33], consequently microwave absorption properties can be achieved at low wt. % of CNTs. Although CNT/composites showed low percolation threshold, there are other issues for commercially available microwave absorbers such as cost effectiveness, ease of production etc. CNT has difficulties in mixing with polymer matrix due to poor compatibility with polymers, also breakage of CNT during processing with acids resulting in decrease of aspect ratio and moreover, making cost of CNT is about 500 times than that of graphite [34].

Another promising composite reinforcement can be expanded graphite (EG) flakes, with the characteristics of very low density ~ 0.005-0.01 g/cc, high electrical conductivity ~10^4 S/cm, good thermal and mechanical properties with resistant to environmental corrosion [35-39]. EG flakes are
bi-dimensional carbon nanostructures consisting of small stacks of graphene sheets having thickness in the range from one to few tens of nanometers and the lateral linear dimensions varying from a few micrometers up to hundreds of micrometers [40]. The percolation threshold of EG/polymer composites are found to be low in comparison to that of graphite/polymer composites. Krupa and Chodak [41] reported a percolation threshold of ~12-13 vol% for graphite/polymer composites whereas the percolation threshold was achieved at 2.5 vol% for EG/polystyrene composite as reported by RK Goyal and group [42]. A low percolation threshold of 3 wt% was reported by Zheng et al. [43] for high density polyethylene (HPDE)/EG nanocomposites. The low percolation threshold of EG is due to its high aspect ratio and large surface area [34]. Considering these facts EG can be used for microwave absorbing or EMI shielding materials as an alternative to CNTs. Moreover, due to its low density, EG composites will be reasonably light weight. Lee Sang-Eui and group [39] studied the microwave absorption properties of graphite nanoplatelet/epoxy composites in the frequency range 12-18 GHz and found a reflection loss ~22dB at 15 GHz.

Another aspect to be considered while fabricating microwave absorbing material is the influence of base matrix. Reference [44] reports, that the use of phenolic resin matrix in carbon black composite instead of epoxy resin matrix enhances the electrical properties of the composite. NPR being good heat resistance has dimensional stability, flame and chemical resistance as well as low cost [45, 46] can be used as base matrix while developing microwave absorbing materials.

The flexibility of designing microwave absorber using lossy reinforcements and base matrix, is the tuning of microwave absorption for a desired frequency ranges by varying the properties of material composition [47]. Considering these tunable properties of dielectric-polymer composites, interesting application possibilities of EG-NPR composites as microwave absorbing materials for application over the X-band has been studied.
1.2 THE RESEARCH DIRECTION

The research is essentially directed towards:

- Synthesis and development of light weight dielectric composite materials as broadband EMI shielding/microwave absorber having the desirable microwave permittivity and dielectric loss properties for application over the X-band frequency.
- Investigating other necessary factor requirements of microwave absorber applications like homogeneity of filler in the base matrix, light weight, thermal, electrical and environmental inertness.
- Design and fabrication of single layer microwave absorber based on developed dielectric composites.
- Design optimization of multilayer microwave structure to enhance the absorption bandwidth.
- Geometrical modification of developed microwave absorber to improve the absorption bandwidth.

1.3 THESIS STRUCTURE AND OUTLINE

The thesis structurally consists of nine chapters and one appendix. A thorough understanding of electromagnetic wave propagation through the absorber and its equivalent Transmission line model is discussed in chapter II. The synthesis of expanded graphite as reinforcing in novolac phenolic resin filler as possible dielectric absorber is dealt in chapter III. The chapter also includes microstructural studies conducted for structural, size and ascertaining the homogeneous distribution.

Other essential property required for absorbers like thermal stability, density, water absorbance and thermal dissipation are included in chapter IV. In-plane and through-plane dc conductivity measurements on the developed composite system is also conducted and included in the chapter.

Chapter V includes studies on complex permittivity at microwave frequencies for different weight percentage compositions. Nicolson-Ross technique is used and a detail treatment to the approach is presented.
Single layer Dallenbach absorber using EG-NPR composite with conductor backing is designed and fabricated and the thickness is optimized to achieve minimum reflection loss and discussed in chapter VI.

Chapter VII describes enhancement of bandwidth of using multilayer structure where the thickness of individual layer and permittivity of the composition is optimized to achieve a broad absorption bandwidth.

A perforated absorber structure is designed on the single and double layer structure to reduce the weight and enhance bandwidth and is discussed in chapter VIII.

Chapter IX summarizes the suitability of the developed EG-NPR dielectric material as broadband X-band absorber. The limitations and future direction of work that can be incorporated are also highlighted.

Appendix - A gives the detail of mathematical formulation for theoretical thickness limitation for broadband microwave absorption. MATLAB programs developed for computing complex permittivity, optimizing single and multilayer layer microwave absorber parameters is also discussed in this Appendix.
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