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A cost effective solution for development of broadband radar absorbing material using electronic waste

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Abstract

Electronic-waste items like disassembled mobile and computer printed circuit boards (PCBs) have been processed in a high energy planetary ball-mill for 10 h, to investigate the dielectric, magnetic and radar absorbing properties. The main goal of present paper is to achieve wide bandwidth for <-10 dB reflection loss at minimum cost in the frequency range of 8.2 to 12.4 GHz. The frequency dependent complex permittivity and permeability values of electronic waste composite material have been measured using transmission/reflection approach, and are used for computation of reflection loss with varying absorber layer thickness ranging from 1.0 to 3.5 mm. A single layer absorber is fabricated with optimal coating thickness of 2.5 mm (i.e., thickness value for reflection loss <-10 dB). The measured reflection loss value has been found to -27.98 dB at 9.3 GHz with absorber layer thickness of 2.5 mm, which may ascribe to proper impedance matching and large dielectric loss. Moreover, broadest bandwidth (for <-10 dB reflection loss) covering the maximum frequency range of X-band has been noticed as 3.9 GHz. Results demonstrate the enormous potential of the electronic waste composite material to act as highly efficient, cost effective, and broadband radar wave absorber for various practical electromagnetic applications.
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Keywords: Radar absorbing material (RAM); Printed circuit boards (PCBs); Electronic waste composite material; Reflection loss

1. Introduction

Radar absorbing materials (RAMs) have provoked great interest among researchers since the invention of radar systems used by military for identification of defence based objects. The X-band frequency radar systems are well known in defence sector for their high resolution imaging as well as greater precision target identification [1]. Since World War II, radar absorbing materials (RAMs) have received much attention of researchers due to their unique and promising applications in the field of modern stealth technology of aircrafts, warships, tanks and missiles by making them invisible to radar wave [2].

Managing the alarming quantum of electronic waste has become a challenging job. Over the past few decades, with increasing innovations, the production of electrical and electronic equipment has increased incredibly, resulting in a huge amount of un-degradable electronic-waste (or E-waste) [3,4]. Computer and mobile printed circuit boards (PCBs) are used to mechanically support and electrically connect electronic components using conductive pathways and are the major inventory for electronic industry. Every year, a huge amount of electronic-waste is thrown in open space, out of which computers and mobiles are disproportionately abundant because of their short lifespan [5,6] and still it is very difficult to find out an effective solution to reuse and recycle them due to their diverse nature as pointed out by Marques et al. [3].

On the other hand, there is a stringent requirement to provide cost effective solution for radar wave absorption, but selection of proper material that can provide good absorption and wide bandwidth with low cost, is still under research. Therefore, broken

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computer and mobile PCBs based electronic-waste may be expected to achieve all these attributes together due to the presence of precious magnetic, dielectric and conducting elements, which may be helpful for impedance matching. Overall, heterogeneous nature of composite, ease of availability and low cost are few strong points due to which an electronic-waste composite material may be expected for radar wave absorbing applications.

Researchers have studied numerous composites for various electromagnetic applications [7,8]. But, few have paid attention over waste composite material to be used for X-band frequency range especially for defence based applications. Recently, Lee et al. [9] have studied the microwave absorption properties of rice husk–carbon nanotube (CNT) based composite material with varying percentages of CNTs. The rice husk–rubber tyre dust based composite material with enhanced microwave absorption over the frequency range of 7 to 13 GHz has been introduced by Cheng et al. [10]. The powdered forest fire ash of various trees like eucalypt, bracken fern, she oak, wattle, and cypress [11], sugar cane bagasse [12], and rubber and oil palm leaf [13] are another important class of waste composite materials, which have been recently studied for various applications. But agriculture wastes are eco-friendly and are biodegradable as compared to toxic hazardous electronic-waste. Therefore, current need of research is to focus over effective utilizations of the electronic waste for different applications.

The electronic waste components have been studied by material scientists for various applications [14,15]. But the use of discarded electronic waste items like printed circuit boards (PCBs) for radar wave absorption are rarely reported so far in X-band frequency range. Therefore, this investigation focuses to analyze low cost, easily available waste computer and mobile printed circuit boards for radar wave absorbing applications in a systematic manner. This paper addresses the design and fabrication of absorbers using frequency dependent measured complex permittivity and permeability values of the electronic waste composite in the range of 8.2 to 12.4 GHz.

2. Material and method

In the present work, 1Kg of waste mobile and computer PCBs of disassembled mobile phones and computers have been collected and subsequently crushed/weakened with the help of a standard double-cut flat file before size reduction (grinding) by ball milling. The weight of disassembled mobile and computer PCBs was found to be within the weight range from 5–20 g and 200–300 g, respectively, depending on shape, size and brand of product.

The fine weakened powder of approximately 500 g by weight was collected, out of which 30 g powder was milled for 10 h in a high energy planetary ball mill (Model: Retsch, PM 400, Germany) followed by top-down nanofabrication approach. The powder to ball ratio was 1:5 with 200 rpm rotary speed. Cylindrical stainless steel jar with hardened steel balls of diameters 18, 8 and 4 mm were used for milling. The morphology of milled powder samples has been characterized by Carl Zeiss Scanning Electron Microscope, SEM (Model: MA15/EVO18) with attached Energy Dispersive Spectroscopy (EDS) at an accelerating voltage of 20 kV.

The two port waveguide transmission/reflection method has been employed for measurement of complex permittivity and permeability values of electronic waste composite material in the range of 8.2 to 12.4 GHz. The measurement set up consists of a Vector Network Analyzer (VNA), Model No. Agilent N5247A PNA series, working frequency range of 10 MHz to 67 GHz, X-band waveguide calibration kit, sample holder/fixture, and Agilent 85071E material measurement software.

The milled electronic waste composite material (70 wt%) was uniformly blended with Bisphenol A Novolac epoxy resin (30 wt%) followed by continuous ultrasonication of 1 h. The experimentally measured dielectric constant of cured epoxy was in the range of 3.2–3.4 for X-band. The electronic waste-epoxy composite mixture has been used for the preparation of rectangular sample of dimension 22.86 mm (length) $\times$ 10.16 mm (width) as well as for the coating on aluminium alloy substrate for the experimental measurement of reflection loss. The purpose of using same electronic waste-epoxy composite (70:30) is to provide same process conditions for both of the samples i.e., rectangular pellet and coated Al alloy sample respectively. Instead of preparing rectangular pellet, prepared milled electronic waste-epoxy paste was directly poured in to the sample holder with a dimension of $22.86 \times 10.16 \times 9.7\ mm^3$ in order to avoid any chance of air-gap between the sample holder and sample. Finally curing was carried out to samples at 60 °C for 5 h. The transmission line approach with rectangular waveguide has been used to measure the complex permittivity and permeability values in the range of 8.2 to 12.4 GHz. The scattering parameters i.e., S_{11} (reflected signal) and S_{21} (transmitted signal) of rectangular sample placed in the U.S. standard WR-90 waveguide having inner cross section dimension (22.86 mm $\times$ 10.16 mm) has been measured. The frequency dependent complex permittivity (ε', ε'') and complex permeability (μ', μ'') values have been obtained from the *S*-parameters based on the "Ref/Trans μ and ε Polynomial fit model" using commercial 85071E material measurement software and these experimentally measured values have been used for computation of reflection loss as per transmission line theory. All the measurements have been performed at room temperature.

According to generalized transmission line theory, the reflection loss values for a single layer absorber has been calculated from experimentally measured complex permittivity and permeability at given frequency and absorber layer thickness using the following equations [1]:

$$Z_{in} = Z_o(\mu_r/\varepsilon_r)^{1/2} tanh\{ j(2\pi f d/c)(\mu_r/\varepsilon_r)^{1/2}\} \tag{1}$$

where, f is the measurement frequency (i.e., 8.2 to 12.4 GHz), d is the thickness of radar wave absorber layer, c is the velocity of light, Z_o is the wave impedance of free space which can be expressed as $Z_o = 120\pi = 377\ \Omega$ and Z_{in} is the input wave impedance of the absorber.

Reflection coefficient (Γ) for normal incidence can be defined as the ratio of amplitudes of the reflected and incident electric fields and it is expressed as:

$$\Gamma = E_{reflected}/E_{incident} = |(Z_{in} - Z_o)/(Z_{in} + Z_o)| \tag{2}$$

and it can be written in dB as expressed in Eq. (3)

$$RL(dB) = -20log|(Z_{in} - Z_o)/(Z_{in} + Z_o)| \tag{3}$$

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