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Identifying smart conducting materials for Wi-Fi electromagnetic interference shielding

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Abstract—The objective of this paper is to identify a suitable coating material in order to tune the microwave radiation and produce absorption losses for Wi-Fi devices. It is also desirable to obtain high absorption losses outside the Wi-Fi microwave frequency range of 2.4 GHz. Literature reviews of several types of material are described and compared for the use of the selected material in order to coat a Wi-Fi device for the desired absorption losses for that device. The selected material for the Wi-Fi device is usually a metal material or a combination of metals like Aluminium in polymer matrix with different types of composites. The choice of materials will aim to target the tuning of the electromagnetic spectrum at a frequency in the range of 2.4 GHz. The paper focuses on two groups of polymer materials; conducting material as a result of composites like Carbon Nanotube Composites (CNC) or other metal composites. The second group is the Intrinsic Conducting Polymer (ICP) which conducts as a result of doping with other materials. A third group is the highly conductive metals like copper and aluminum. The metals are used as a reference comparator to the other two groups.

Index Terms—EMI shielding, Intrinsic conducting polymer,

I. INTRODUCTION

THERE is a great need to shield Wi-Fi and mobile phones from different unwanted communication systems signals, while at the same time preserving the amount of electromagnetic interference radiated and/or absorbed from the device/system. This is a balance which is called electromagnetic compatibility (EMC). There is now the European Directive 89/336/EEC, which specifically deals with EMC. The Australian Communications and Media Authority (ACMA) introduced EMC regulations to cover all communication equipment and gave the responsibility to comply with the regulation to the supplier who is the manufacturer, importer, and authorised agent. The communication/electronic systems need to have an accurate, reliable and safe output without unwanted EMI from other communication systems.

Magnetic The magnetic field strength measurements are effective at low frequencies which is 50/60Hz in transformers, overhead lines, busbar systems, switchboard and near to HV cables, and train, underground railway cables and tracks.

Electric Field strength measurements at high frequencies; (9 kHz - 22 GHz); the electric fields are generated by transmission equipment, such as GSM and UMTS towers, radar systems, and wireless devices etc. The communication/electronic systems can be a mobile phone, IPOD, IPAD,

games, TV, computers, new super-phones, GPS systems, e-readers, pocket-size computers and other electronics-based products, which were unheard of few years ago but are now commonplace. Furthermore, all-mechanical products such as cars, planes, home appliances and machine tools now have increasing levels of electronic circuitry.

Currently some of the EMI shielding is provided by using a silver conductive coating which is used to cover a broad frequency spectrum in the range of 30 - 10000 MHz. This type of shielding has been used in mobile phones for more than 14 years and it is intended, in this review, to select a tunable material which can be tuned to the frequency spectrum between 1 - 6 GHz and can replace the current EMI shielding.

II. ELECTROMAGNETIC INTERFERENCE EMISSION

As the Wi-Fi and mobile phone systems increase in speed and design complexity, the EMI emissions increase. The EMI emissions need to be reduced, and the EMI energy absorbed in order to enhance the performance of the Wi-Fi and mobile phone device. The EMI design affects the power consumption and the continuous use of the mobile system. There is also the environmental issues of how safe and disposable are the coated materials used to shield the instrument from EMI.[1] EMI comes from either unwanted conducted signals or comes from being radiated from other devices [2].

The EMI may cause symptoms such as insomnia, nervousness, languidness, and headaches [3], [4]. Also it was reported that EM fields can cause diseases, such as leukaemia, miscarriage and breast cancer, that are related to the continuous exposure to EM fields and pulses. Thus various EMI shielding methods have been developed, not only to reduce the probability of occurrence of the aforementioned hazards, but also to increase the lifetime of electronic devices and the efficiency of use of frequency sources[3], [5], [6][7].

The three interactive components of EMI emissions are the transmitter source of electromagnetic energy, second the receiver source of the electromagnetic energy and, third a propagation path for the electromagnetic energy. In this article the focus will be on the radiation effects of EMI. The EMI radiation is divided according to the distance from the

transmitter, near field (induction) less than $\lambda/2\pi$, or far region (greater than $\lambda/2\pi$). λ is the wavelength.

III. ELECTROMAGNETIC INTERFERENCE FREQUENCY RANGE

EMI shielding can be divided into four types depending on the frequency range; continuous or pulse. The first type, called EMI power spectrum shielding, is for the range 1 - 100 KHz. The second type of EMI shielding is the radio frequency range 100 KHz - 1 GHz. The third type is the microwave and beyond frequency band of the electromagnetic energy. The fourth type is the electromagnetic pulse (EMP), which has a broadband, with high intensity short duration bursts of electromagnetic energy, such as nuclear explosion and electric discharge. The focus of this review will be on the EMI frequency range of the third type.

IV. EMI SHIELDING MATERIALS

The most common material for shielding equipment is metal as it can reflect, absorb very little and transmit electromagnetic energy. The electrical conductivity of metals varies from 6.8×10^5 for silver to 5×10^2 for graphite. Those conductors are based on metals and suffer from problems of brittleness, low impact and corrosion, which leads to a non-linear effect on the receiver and this affects the EMI shielding. Polymers and rubbers are nonconducting and are transparent to electromagnetic radiation. The neat polymer materials are insulators which do not reflect or absorb radiation. EMI needs to be tuned to the Wi-Fi frequency to limit outside interference and incoming radiation. There are two groups of materials that can be used to shield a mobile phone from electromagnetic radiation:

1. Non conducting materials compounded with conductive fillers
2. Intrinsically Conductive Polymer (ICP) with other doping fillers.

V. NON CONDUCTING MATERIALS (POLYMERS) COMPOUNDED WITH CONDUCTIVE FILLERS

A non-conductive polymer material is coated with conductive metals in order to provide the EMI shielding. Copper, nickel, and zinc are used as paint which is sprayed manually or robotically. Electrolysis plating and vacuum metal techniques combined with other materials are required to make the minerals adhere to the polymer. Mobile phones, laptop computers, and other wireless networks (LAN) use this EMI shielding method. This method has several disadvantages in terms of its flexibility, heavy weight, corrosion, and varying the tuning of both the shielding efficiency and frequency spectrum. SnO_2 nanowires (NWs) are of a novel metal which was researched for microwave absorption properties rather than the reflection properties. The research measured the complex permittivity and permeability of the SnO_2 NWs/paraffin in a frequency range of 0.1 - 18 GHz [8].

Carbon Nanotubes (CNT) and other conductive fillers in non conducting polymers were investigated for EMI shielding. A low volume fraction of CNT in the non conductive polymer provides conductivity without changing the polymer properties.

VI. INTRINSICALLY CONDUCTIVE POLYMER (ICP) WITH OTHER DOPING FILLERS

The Intrinsically Conductive Polymers (ICP) are polymers that conduct electricity without the addition of inorganic materials (metals). ICP is composed of macromolecules having fully conjugated sequences of double bonds along the chains. Polyaniline (PAni) is the most studied material since ICP was confirmed by the awarding of the 2000 Nobel Prize in Chemistry to Alan Heeger, Alan MacDiarmid, and Hideki Shirakawa "for the discovery and development of ICP material". The most important property of ICP materials is the electrical conductivity. The conductivity of this type of polymer is similar to that of some metals. The ICP macromolecules conduct by acquiring positive or negative charges through adding an electron acceptor or donor called doping. The common ICP materials are polyaniline, polythiophene, polypyrrole, and polyacetylene. The ICP operates in the same way semiconductor materials operate through charge carriers (holes, electrons) and not ionic conduction.

Polyaniline (PAni) is the most popular of the ICP materials and was researched for the possible use in EMI shielding [1] in 1993. It was found that the grafted PANI fabrics exhibit shielding effectiveness of 16 - 18 dB at the frequencies range of 0.1 MHz - 1 GHz, and more than 40 dB at lower frequencies because of its conductivity and also the methods which are used to prepare the material. ICP can be prepared by two types of systems; an aqueous two-phase system [9] and Liquid-liquid extraction. Results show with higher PANi composites concentration of more than 24% will make the material suitable for EMI shielding. This EMI shielding level was reported to change when the material is doped with benzene sulfuric acid or other protonic acid (fatty acid). The dielectric properties of polyaniline-nano ferrite ($\text{PANI-Fe}_2\text{O}_3$) composites were studied and found to possess a conductivity of 2.5 S/cm. The composites were prepared using chemical oxidative polymerisation [9]. A common method is used to synthesise PANi by the electrochemical polymerisation of thiophene. Another method can be used to coat a thin film material with PANi by using Electro polymerisation with a thin film of 10 μm - 100 nm.

- ICP materials conductivity can be controlled and adjusted by varying the amount of doping material. This conductivity is reversible and makes ICP material good for electromagnetic absorption within the polymer.

- ICP synthesis approach makes for a very easy and inexpensive material. It is reported that the process of polymerization takes less than 1 hour, but its conductivity reached 2.76 S cm⁻¹ at 25 °C [2].

- ICP materials have low cost and resistance to corrosion thus lowering the cost of maintainance. Also ICP show good electromagnetic properties

- ICP materials are environmentally stable and highly resistant to heat [8]

- ICP material PANi blends may be made with varying conductivity between 10^{-9} and 10^2 S/cm and that is good for shielding against electromagnetic interference (EMI). Also PANi nanofibre can be synthesized by using electrochemical methods.

- The ICP polymers exhibit a dominant shielding characteristic of absorption rather reflection like most metals [10].
 - Different types of metal catalysed coupling reactions can be used to obtain PANi. This is good for very high frequencies such as 2-8 GHz magnetic are not effective as permeability is very low (near 1). This will give the freedom to use any metal material.
 - There are several suppliers for PANi, Ormecon, Fibron, Eeonyx and Panipol.
- The disadvantages of using ICP are:
- ICP materials are not soluble in ordinary solvents and are difficult to melt and soften, and cannot be treated like other thermoplastic polymers.
 - It is commercially difficult to find a high conductivity ICP and requires other metals, CNT to increase the conductivity.
 - Poor mechanical properties that may require other metals or CNT to enhance the mechanical properties.
 - ICP is sensitive to changing environmental conditions. ICP changes its colour and conductivity.
 - ICP materials have not been used for EMC in mobile phones and Wi-Fi devices.

VII. INTRINSICALLY CONDUCTIVE POLYMER (ICP) CURRENT APPLICATIONS

Polypyrrole, polythiophene, and polyaniline (PANi) are the main ICPs materials. ICPs materials are applied in two types of applications[11], first as a conductor to replace copper in static applications and second as an active component in applications which require sensing. ICP is used in antistatic coating applications in electronics components. As an active component, ICP is used to make the windows and mirrors reflective when electric energy is applied [12], poly(3,4-ethylenedioxythiophene)-poly(styrene sulfonic) (PEDOT-PSS) product Clevios P has been extensively used as an antistatic coating and commercialised by Bayer AG laboratory [6].

VIII. EMI SHIELDING USING ICP

Polyaniline (PANi) was researched for its EMI shielding performance as a film PANi was blended with polystyrene and was tested for EMI shielding under different loadings of PANi. The best EMI shielding effectiveness was reported with 50% loading of PANi and achieved more than 58 dB. PANi shielding effectiveness was reported to be more than 60 dB when PANi was used with ABS[9], [13]. The conducting film was produced from PANI with SiO_2 . Another conducting film was made by using a hybrid of dodecylbenzene sulfonic acid-doped polyaniline (DBSA-PANI) and 3-glycidopropyltrimethoxysilane (GPTMS) through the sol-gel route[14]. It was found that with PANi having room-temperature conductivities in excess of 1,000 S/cm, that the resistivity decreases monotonically as the temperature is lowered down to 5 K. This finding was reported in Nature (2006). This has made ICP material a good replacement to metal and further research into different blending and doping were researched. A new conducting material of PANI-doped (benzene sulfonic acid) BSA was successfully synthesized by conventional oxidative polymerization. This material was

reported to have a dielectric constant and conductivity which may prove useful in electromagnetic shielding[15]

IX. EMI SHIELDING USING CARBON NANOTUBE (CNT)

The ideal material for EMI shielding is metal but metals suffer from several disadvantages; high reflection, corrosion, tendency to crack with use due to these brittle nature, costly, and high weight. Carbon Nano Tubes (CNT) offer many benefits which include low cost compared to metal, low weight, high-performance, and thin thickness. CNT can be used with a polymer binder layer to enhance performance, increase adhesion, abrasion resistance, and flexibility, broad range of conductivity (10 - 10^7), with uniform and linear conductance, excellent transparency, good adhesion durability, good chemical resistance, flexibility, ease of patterning, outstanding microwave, and shielding efficiency for electromagnetic interference applications. CNT ranks among the strongest materials known, acts as a semiconductor or conductor depending on the way the original sheet of graphene is rolled. CNT has excellent applications in electronic devices and sensors and is used for fuel cells and batteries. However CNT suffers from some disadvantages, and these are:

1. Difficult to control the dopant amount.
2. Difficult to synthesise for a particular type and shape of Nanotube and especially very long CNT (1 mm or more).
3. Difficult to grow a high quality CNT.
4. The main three methods to synthesise CNT, arc discharge, laser ablation, chemical vapour deposition (CVD) are all expensive.

X. CONCLUSIONS

This review identified two groups of EMI materials, which have the potential to replace the current technology of EMI shielding for Wi-Fi and mobile phones. The current technology is to use metal/carbon shielding which achieves an excellent shielding effectiveness (SE). The metallic shields suffer however from two problems; corrosion and weight. The use of carbon is becoming more interesting with the cost of carbon black only a few dollars and also 20 times cheaper than nano-carbon and 7 times cheaper than carbon fibres, however the use of carbon fillers suffers from four problems; cost, sloughing, health, and long term environmental issues. Carbon use has been reported in several research papers for use in EMI shielding. ICPs, as a material in general are suitable for a new generation of EMI shielding for mobile phones because they are lightweight, cheap and has no health or environmental issues reported. ICPs, and especially polyaniline will have a critical future use in communication equipment, because of their special features of tunable conductivity, ease of processing, and the shielding of devices by absorption rather than reflection.

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