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Electromagnetic shielding properties of ceramic spheres coated with paramagnetic metal

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Abstract. This study utilized a setup of radiofrequency generating and metering instruments to measure the reflective and pass-through properties of the innovative material of paramagnetic metal coated ceramic hollow spheres (MCS). The dimensions of the spherical articles reside around 50–250 µm, the thickness of metal (Cu) coating is 0.5–1.3 µm. The radiofrequency field was of 2.4 GigaHertz (GHz) frequency and radiated towards the material via a waveguide-horn antenna at 100 mWt power output. Two additional waveguide-horn antennas connected to a radiofrequency analyzer measured the reflection and pass-through characteristics of the material. Reflection and pass-through coefficients (from 0 to 1) were calculated to each tested sample. The material was tested at different thicknesses: from single – to multi (up to 5) mono-layers and 5 mm layer in bulk condition of MCS.
The measurement results show insignificant shielding characteristics for 1 to 5 layer thickness samples: pass-through coefficient from 0.96 to 0.92. Noteworthy shielding characteristics were starting to show in case of MCS mixed with graphite emulsion: transmission coefficient dropped to 0.16.
The latter sample demonstrates the prospective shielding characteristics of the material, since most of the radiofrequency radiation was not allowed to pass through the material neither to be reflected, but absorbed within the structure of the material.

Key words: electromagnetic fields, microwaves, shielding, absorption, cenospheres.

INTRODUCTION

With the emergence of new high intensity radiofrequency technologies in the workplaces has risen the workers exposure to the electromagnetic fields. Also, the modern urban environment is packed with new wireless communication protocols, because of which the environmental radiofrequency electromagnetic fields have shown abrupt rise during the last ten years. Controlling the propagation of these fields has become increasingly relevant both in living and occupational environments.

The importance of minimizing exposure to the electromagnetic fields is also stressed by the high level European bodies. Reduction of environmental risk factors, where possible, is in fact the corner stone of European occupational health legislation (EP&EC, 2013).

Electromagnetic radiation from high intensity sources may have adverse effects on human health. Development of new coating materials has become relevant in order to suppress the above mentioned fields where needed. Reducing the electromagnetic fields would allow better controlling such technologies in a way that these would not pose a risk to human health nor to other technologies in the area. The civil construction domain would gain a new material, which would allow shielding houses or rooms from high level electromagnetic fields, infrared radiation, and noise. Due to the electromagnetic shielding properties of the material, it could also be used to reduce the risk of industrial espionage from electronic eavesdropping.

Non-destructive testing using microwaves is a method used to characterize various properties of material without braking it or making it useless in another way. Mainly non-destructive testing is used for material dielectric characterization, fatigue surface crack evaluation of metals, layered composite inspection, microwave measurements and imaging.

Microwaves penetrate into dielectric materials easily. The limitation is the depth, from where useful information can be received, which is mainly a function of the loss factor of that material or testing from both sides – reflection and transmission measurements. Microwave non-destructive testing is sensitive to geometrical and dimensional properties of the given material (Zoughi, 2000).

Therefore microwaves could be used for testing density, thickness, hardness, porosity, moisture, anisotropy, chemical composition, degree of aging, presence of voids, cracks, delaminations. Tests could be made from a distance, since microwave travel relatively a long way. Therefore such tests are utilized in to determine the moisture in grains of cereals and detecting buried metal objects. Microwave techniques have proved very effective in locating delaminations in honeycomb structures and fibre composites, but they are not useful in detecting thinner cracks (Blitz, 1997).

It is expected that while hitting the material, some microwaves will bounce back (reflection) and some will penetrate the material (transmission). Another part of the microwaves gets trapped inside the material (absorption). The latter portion would desirably claim the largest part of the given three, since materials that allow the microwaves to penetrate are useless in controlling the emissions of the electromagnetic fields. From another side, reflection is also not desirable in some instances, since reflecting microwaves would just create countless reflections in the environment, therefore increasing the levels of microwave many folds or even many orders of magnitude. Each application of the microwave controlling material could have their own prescriptions on how much of the incident wave is passed, reflected or absorbed. For example, in environments where communications are done by means of wireless devices, having some transmission of microwaves could be required.

The applications of this innovative material include shielding the objects from incoming electromagnetic emissions but also from outbound electromagnetic fields. Examples of such applications may be to build casing for sensitive electronic equipment, but also to protect the environment and humans within the environment from the high intensity electromagnetic fields. Also, the radiofrequency electromagnetic fields may be shielded at their source i.e. by using the material in the construction of the equipment that generates and propagates such intense fields.

Also the current safety guidelines refer that the obligation of the employer is not only to assure the workplace's compliance with the limits but also to ensure that EMFs are reduced to the minimum. Special risk groups should also be considered – pregnant women and people wearing passive or active medical implants (EP&EC, 2013).

There are many places where people in work or in public are exposed to the EMFs. An international study done in several European countries, monitored peoples overall exposure to the EMFs, and it was found that the highest exposures were encountered in transportation vehicles (e.g. people using mobile devices simultaneously in a closed metal casket), followed by exposure in outdoor urban environments (wireless transmission antennas), and then in offices, followed by urban homes (Wout et al., 2010).

Modern office environment consists of a many EMF propagating appliances: some produce EMFs as a by-product; others use EMFs intentionally (e.g. wireless data link). Many of such types of products are new and not fully covered by compliance standards, therefore may create exposures to the EMFs that are currently unaccounted for in the guidelines (Kühn et al., 2007).

Frequencies of the electromagnetic fields produced by the laptop computers also vary from model to model. Besides typical sinusoidal waveforms, the EMFs have also an impulsive nature forming a complex waveform (Zopetti et al., 2011). Switching mode power supplies should be considered as main contributors to the impulse EMFs in the PC usage. A study by Zopetti et al. (2011) concluded that power supply units are the main source of high EMFs.

Bellieni et al. (2012) reported that next to the power supply unit, also the laptop PC's body itself (being in contact with a human body) gives off nearly the same levels of EMFs, and these can be higher than these found in the proximity of high tension power lines, transformers and domestic video screens.

This study is set to investigate shielding of paramagnetic metal material under Wi-Fi frequency microwaves.

MATERIALS AND METHODS

This study investigates electromagnetic shielding properties of ceramic hollow spheres coated with paramagnetic metal. The composite powder is a ceramic hollow sphere (cenosphere, obtained from fly ash of coal combustion at a thermal-power plant) coated with a paramagnetic metal (Cu) by magnetron sputtering. The samples MCS outer and internal structure are shown in figure 1. MCS has bulk density 0.44 ± 0.003 g cm^{-3}, metal coating has thickness 0.5–1.3 µm sphere wall thickness is 10–15 µm (Fig. 1a) and sphere diameter is 50–250 µm (Fig. 1a).

The material was tested at different thicknesses: from 1 mono-layer of ceramic hollow spheres coated with metal to a 5 mm layer in bulk condition. The sample sheet size was 270.0 x 390.0 mm.

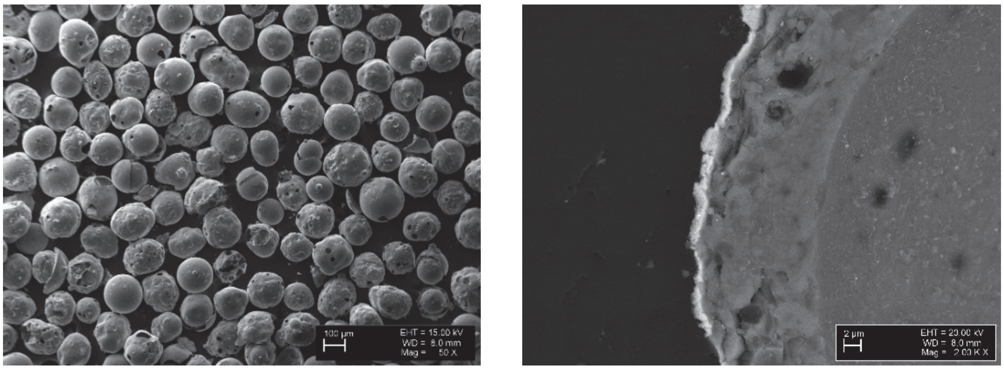
The sheets of MCS were produced by laying down MCS on a self-adhesive polymer film (ORACAL 1640, by ORAFOL Europe GmbH). The self-adhesive film was put on a flat surface and the protective paper removed. The adhesive film was covered with 2 mm layer of MCS. The layer was applied with a pressure of 980 N m^{-2} for 1 min. The excess amount of MCS was cleaned off from the film so that a monolayer of MCS would remain attached to the film.

The outlay of ceramic hollow spheres coated with paramagnetic metal was 71.9 ± 1.2 g m^{-2} for a single sheet which was determined by weighing adhesive films before and after being covered by MCS.

The MCS bulk material of 2 to 5 mm was produced by using a radiofrequency transparent tray that was covered evenly with a specified amount of MCS.

A graphite PVA (polyvinyl alcohol) emulsion with MCS contains of 45 vol % of polyvinyl alcohol (20%), 33 vol % of MCS and 22 vol % of graphite.

An aluminium foil used in covering 5mm MCS bulk material was of thickness 100 μm.



a) b)

Figure 1. Scanning electron microscope images of MCS: a) common view at magnification x 50 and b) cross section of at magnification x 2,000.

The study was founded on a premise that hollow spheres absorb the electromagnetic fields. Like shown by Panigrahi & Srivasava (2015) the synthesized spherical hollow spheres act as a conducting trap in absorbing electromagnetic (EM) wave by internal reflection.

A setup of three standard gain (2.4 GHz) horn antennas were used (Fig. 2) to determine the electromagnetic properties of the materials under testing (MUT). One of the horn antennas (Tx1) acted as an irradiator radiating a microwave beam on to the tested material. The other two antennas were used for receiving and measuring the amplitude of the signal (Rx1 and Rx2). Horn Rx1 collected the signal reflected back from the material under testing. Horn Rx2 collected the signal that penetrated the material under testing. From both receiving horn antennas the signal was routed via RF switch to a Universal Protocol Test Platform Rohde & Scharz CRTU which measured the amplitude of the signal. The signal was generated by the same unit and amplified by an external amplifier (Power output-Po 100 mW). In this study the testing frequency was 2.45 GHz as the intention was to test the materials under Wi-Fi frequency. The power output was also selected to reflect the nominal irradiating power of the Wi-Fi routers.

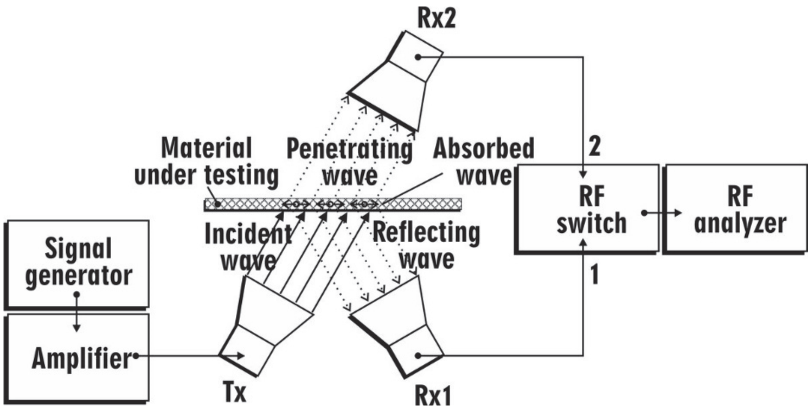


Figure 2. Material testing setup.

In case of transmitting horn antenna, the radiation emerges from the horn in a parallel beam, called near-field or Fresnel zone. Divergence of the field takes place in the so-called far-field or Fraunhöfer zone with the wave intensity decreasing by the inverse square law – the amplitude decreases in inverse proportion to distance from the opening of the horn (Blitz, 2012).

The length of the near field zone (l) in case of rectangular horn opening was considered based on the formula by Botsco et al. (1986) (formula 1), where A is the dimension of the largest side of the rectangle and λ the wavelength. The wavelength in case of 2.45GHz electromagnetic field is 0.122 m.

$$l = \frac{A^2}{2\lambda} \tag{1}$$

In making the microwave measurements where determining the amplitude and attenuation was the goal, it is important to take into account the beam propagation from the horn into the far field.

Prior to a measurement the setup was prepared by following a calibration procedure which included measuring full and zero reflection/transmission microwave levels. The full reflection was measured by placing a sample size aluminium plate to the sample tray. The full transmission was obtained by leaving the sample tray empty and measuring the detected microwaves at the transmission registering horn antenna.

Reflection and transmission coefficients (from 0 to 1) were calculated to each tested sample as a transmitted/reflected wave ratio to the full transmission/reflection.

RESULTS

Altogether nine variations of the paramagnetic metal coated ceramic spheres were investigated. The measurement results show insignificant shielding characteristics for 1 to 11 layer thickness samples: pass-through coefficient from 0.96 to 0.87 (96 to 87 per cent of the radiation passes through the material), see Table 1.

Increasing MCS thickness up to 5mm provided no satisfactory results – the thicker the sample got, the more radiation was reflected, the rest was transmitted through.

Noteworthy electromagnetic shielding characteristics were starting to show when the paramagnetic metal coated cenospheres were used in conjunction with graphite PVA emulsion: transmission coefficient only 0.16 (only 16 per cent of the radiation was passing through); the reflection coefficient rose to 0.63 (63 per cent radiation was reflected).

Cenospheres without paramagnetic coating (CS) in turn offered little reflective properties, allowing most of the radiation to pass through (transmission coefficient 0.88).

Table 1. EMF exposure and intervention scenarios investigated in this study

Sample model	Transmission coeficient	Reflection coeficient
MCS 1 monolayer	0.96	0.01
MCS 5 monolayers	0.92	0.01
MCS 11 monolayers	0.87	0.03
MCS 2 mm layer	0.76	0.03
MCS 5 mm layer	0.45	0.68
MCS 5 mm layer+Al.foil	0.01	1.00
CS 15 mm layer	0.88	0.01
Graphite PVA emulsion	0.73	0.12
MCS graphite PVA emulsion	0.16	0.63

CONCLUSIONS AND DISCUSSION

The results indicate that a significant amount of radiation was absorbed within the paramagnetic metal coated cenospheres emulsion. The latter sample demonstrates the prospective shielding characteristics of the material, since most of the radiofrequency radiation was not allowed to pass through the material neither to be reflected, but absorbed within the structure of the material.

Monolayer MCS from 1 to 11 layers did not produce any significant results because of single spheres being not connected to one and another. For the same reason, also bulk material of MCS of 2 mm thickness provided unsatisfactory shielding properties. However, starting from 5 mm bulk material thickness we see significant reflection coefficient increase due to spheres being interconnected due to increased quantity. With adding an aluminium foil sheet on the 5mm bulk material the reflection coefficient is increased to maximum due to the radiation that passes through the bulk material, reflected by the aluminium layer. By introducing PVA to the MCS bulk material the matrix material withheld some of the radiation and allowed less microwaves to be reflected.

The future research should focus on determining optimal ratio of MCS, graphite, matrix material and the quantity of these.

Absorption of the radiofrequency electromagnetic fields would allow to reduce the fields at their source and to eliminate countless reflections that would occur in case of using simple metallic reflectors in shielding applications.

Most shielding materials available on the market only reflect the electromagnetic field while creating countless reflections and increasing the field in some hotspots. The material discussed in this study would allow minimizing the reflections by attenuating the reflective properties of the material.

The new material studied in this paper would offer an alternative in shielding rooms in public and occupational environments where high intensity radiowaves are present. Such occupational environments could be: radiofrequency welding; microwave heating; radiofrequency treatments in hospitals; areas near radar, radio and television transmitters etc. Also the office environments may have an increased level of radiofrequency electromagnetic fields due to ever increasing amount of wireless protocols and transmitters positioned near the workstations.

The relevance of usage of such material is also stressed by recent developments in European legislation (Directive 2013/35/EU) which stresses the protection of risk groups. Such risk groups may include maternity hospitals, hospitals, kindergartens, schools etc. (EP&EC 2013). Besides legally binding safety limits, there are also recommendations from non-governmental sector: Bionititative working group, based on the review of the scientific literature, has suggested safety limits many orders of magnitude lower than in the European directive (Bioinitiative, 2007 and 2012). In order to achieve such low microwave levels in the urban area, as set in the Bioinitiative reports, the usage of microwave absorbing materials is inevitable. The reason for limiting exposure to electromagnetic fields is also argued as a precautionary principle (EEA, 2007).

In long-term perspective, the implementation of such shielding materials would improve environmental health conditions and result in a positive effect on population's health.

REFERENCES

Bellieni, C.V., Pinto, I., Bogi, A., Zopetti, N., Andreuccetti, D. & Buonocore, G. 2012. Exposure to Electromagnetic Fields From Laptop Use of 'Laptop' Computers. *Archives of Environmental & Occupational Health* **67**(1), 31–36.

BioInitiative Working Group. 2007. Bioinitiative report: A Rationale for a Biologically Based Public Exposure Standard for Electromagnetic Fields.

BioInitiative Working Group, Editors Cindy Sage and David O. Carpenter. 2012. BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Radiation – http://www.bioinitiative.org

Blitz, J. 1997. Microwave methods. Chpt Electrical and Magnetic Methods of Non-destructive Testing, Vol 3 of the series Non-Destructive Evaluation Series pp. 184–213.

Blitz, J. 2012. Electrical and Magnetic Methods of Non-destructive Testing. Springer Science & Business Media.

Botsco, R.J., Cribbs, R.W., King, R.J. & McMaster, R.C. 1986. *Microwave methods and applications in nondestructive testing. In: nondestructive testing handbook—electromagnetic testing: eddy current, flux leakage, and microwave nondestructive testing*, American Society of Nondestructive Testing. 4, section 18.

EEA – European Environment Agency 2007. Radiation risk from everyday devices assessed – http://www.eea.europa.eu/highlights/radiation-risk-from-everyday-devices-assessed

EP&EC – The European Parliament and the Council 2013. Directive 2013/35/EC of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). *Official Journal of the European Union* 26.06.13.

Kühn, S., Lott, U., Kramer, A. & Kuster, N. 2007. Assessment Methods for Demonstrating Compliance With Safety Limits of Wireless Devices Used in Home and Office Environments. *IEEE Transactions on Electromagnetic Compatibility* **49**(3), 519–525.

Panigrahi, R. & Srivastava, S.K. 2015. Trapping of microwave radiation in hollow polypyrrole microsphere through enhanced internal reflection: A novel approach, *Sci. Rep*. **5**, 7638.

Wout, J., Frei, P., Roösli, M., Thuróczy, G., Gajsek, P., Trcek, T., Bolte, J., Vermeeren, G., Mohler, E., Juhász, P., Finta, V. & Martens, L. 2010. Comparison of personal radio frequency electromagnetic field exposure in different urban areas across Europe. *Environmental Research* **11**0(7), 658–663.

Zopetti, N., Andreuccetti, D., Bellieni, C., Bogi, A. & Pinto, I. 2011. Evaluation and characterization of fetal exposures to low frequency magnetic fields generated by laptop computers. *Progress in Biophysics and Molecular Biology* **107**, **pp.** 456–463.

Zoughi, R. 2000. Microwave Non-Destructive Testing and Evaluation Principles. Kluwer Academic Publishers, Dordrecht/Boston/London.