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EMC-Compatible Shielding

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Preface to the Third Edition

The current developments in the field of EMC and shielding using magnetic materials are the main reason for the third edition of this book. On the one hand, the EMC standards world is in a state of upheaval. This means that more and more standards take into account the higher source frequencies and push the upper frequency limit above 3 GHz. In contrast to these technical conditions and the existing ferrite interference suppression materials (which do not correspond to these new frequency ranges), there are hardly any new EMC magnetic materials available on the market. New EMC ferrites of hexagonal crystal systems take these new requirements into account. These hexagonal materials are presented in the chapter "EMC future ferrites—hexagonal volume materials."

Further shielding rules are also listed in the appendix of the book.

As in the first and second editions of the book, the editorial office Technik of Springer Vieweg Verlag—represented by Mrs. Broßler and Mr. Dapper—and the design office Fromm—represented by Mrs. Fromm—have strongly influenced the development of this book and supported the author very much in its elaboration. We would like to express our sincere thanks for this.

Nordhausen, Germany
October 2015

Frank Gräbner

Preface to the Second Edition

The motivation for the second edition is the increasing demand of experts for shielding with the use of magnetic materials.

The reason for this is the updates of the generic standards for interference emission and radio interference field strength in industrial/residential areas.

The upper frequency limit of 1000 MHz no longer applies. Depending on the internal frequencies of the interferers, an emission frequency limit of more than 6000 MHz can be assumed.

This regulation announces a need for new shielding concepts, which are presented in this book by means of practical examples.

Moreover, a new chapter "Shielding formulas" in the appendix adds an important contribution to the book.

This collection of formulas is intended to introduce the "quick reader" to the basics of the various shielding effects in a condensed form.

The author would especially like to thank the media design office Fromm from Selters/ Taunus for helping with the book.

Nordhausen, Germany
October 2012

Frank Gräbner

Preface to the First Edition

The main aim of this book is to show how newly developed materials can improve shielding.

The engineer of the next decades will be given the opportunity to use the developed method of a novel EMC shielding philosophy by using absorber materials, consisting of volume materials or nanomaterials, to facilitate the EMC work by simple shielding rules.

The physical principles of these materials are not new, but have been discussed from a different angle.

In times of very fast introduction of new technologies and seemingly unlimited technical possibilities, the developer of devices and systems is under pressure to understand the complex EMC coupling paths and to suppress a device very quickly. This book is written for these “long-suffering” experts and it should make your work a little easier.

Many of the tasks and solutions have been developed by evaluating practical experiments and research projects. This is due to many research groups, such as the Institute IMG Nordhausen, the Competence Centre BRUNEL IMG GmbH, and Hörmann IMG GmbH (Mr. Hungsberg, Mr. Kallmeyer, Mr. Hildenbrandt, and Mr. Hesse) in Nordhausen, the Ilmenau University of Technology (Mr. Prof. Dr. Dr. Knedlik, Dr. Teichert from the Department of Materials in Electrical Engineering), the University of Telecommunications Leipzig, the former HITK Hermsdorf (Ms. Pawlowski), and the colleagues from the TITK Rudolstadt (Mr. Pflug and Mr. Dr. Schrödner).

Nordhausen, Germany Frank Gräbner
March 2011

Symbols and Abbreviations

Latin Letters

$\vec{A}, A$	Vector, RMS value
$\underline{A}$	Especially surface
$\overleftarrow{A}$	Tensor
a	Grating constant
$\vec{B}, B$	Magnetic flux density, effective value
c	Speed of Light
$\vec{D}$	Electric flux density
D	Particle size, crystallite
d_i	Thickness of the material
d	Penetration depth
d_{si}	Layer thickness
d	Network level distance
$\vec{E}$	Electric field strength
E	Energy
$\vec{e}_x, \ \vec{e}_y, \ \vec{e}_z$	Unit vectors
f	Frequency
$\vec{H}, \ H$	Magnetic field strength, effective value
ΔH	Half width of the FMR
$\vec{H}_{z0}$	Average magnetic field strength component in the z-direction
$\vec{H}_0$	Static pre-magnetizing field strength
$\vec{H}_{\mathrm{a}}$	Anisotropic field strength
I	Electric current
$\vec{J}$	Current density
$\vec{k}$	Wave number,$\underline{k} = k' - \mathrm{j}k''$
K_{u}	Anisotropy constant, total
m	Ground
$\vec{M}$	Vector of magnetization
$\vec{M}_0$	Saturation magnetization
M_0	Magnetic constant

S	Surface
$\vec{S}$	Spin vector
S_{11}, S_{12}, S_{22}, S_{21}	Complex scattering matrix elements
T	Temperature
t	Time
U	Real function
U	Scalar (any)
V	Volume
x	Degree of inversion
Z	Sheet resistance
Z	Impedance
Z_0	Field characteristic impedance of air

Greek Letters

α	Damping constant of relaxation
β	Phase constant
γ	Damping constant electromagnetic field
γ_0	Gyrotropy constant
γ_0	Inversion constant
γ_a	Propagation constant
Δ	General difference
ε	Permittivity
ε_0	Dielectric constant
ε_r	Relative permittivity
μ	Permeability
μ_r	Relative permeability
κ	Electrical conductance
λ	Wavelength
μ_B	Drill Magneton
ρ	Surface charge density
τ	Relaxation time constant
χ	Magnetic susceptibility
ω_0	Natural frequency of the recession movement of the magnetization vector
ω_m	Natural frequency of the saturation magnetization vector

Abbreviations

AC	Alternating current
CISPR	International Committee for Radio Electronics
CRAM	Currentless Radiation Absorption Material
DC	Direct current
EMC	English abbreviation for EMV
EMI	Electromagnetic emission

EMS	Electromagnetic immunity
EMC	Electromagnetic compatibility
EN	European Norm
ESD	Electrostatic discharge
FFT	Fast Fourier Transformation
FMR	Ferromagnetic resonance
HCP	Horizontal coupling plate
RF	Radio frequency
IEC	International standard
MOM	Moment matrix method
PFC	Power factor correction
RAM	Radiation Absorption Material
TLM	Transmission line matrix method
UMTS	Universal Mobile Telecommunications System
VDE	Association of German Electrical Engineers

Contents

Part I Basics

Part I

Basics

1 Introduction

This book is aimed at engineers, scientists, students, researchers and practical professionals. Electromagnetic compatibility (EMC) has been developing since its beginnings in the 1950s to 1960s as a result of the pulse problems in automation/control engineering.

EMC reached a great upswing and a high with the German EMC Act (EMCA) in 1996. Since then, it has been generally known to the industry that devices in an electromagnetic environment must operate without failure and interference-free.

Developers in various branches of industry are intensively engaged in the interference suppression or EMC hardening of electrical devices/systems. The understanding of the couplings in an assembly/device and the resulting EMC phenomenon is demonstrated by simple shielding examples using RF materials.

This book, in a condensed presentation of the basics of the materials and the solutions of the application of these special materials for shielding, should enable the experts to approach the problem of interference phenomena at a high scientific and technical level. It is intended to provide suggestions in which way materials can be used, from which the possibilities for interference suppression can be derived. Because there is no such thing as an "ideal shielding material as a solution for all problems". Therefore, knowledge of the interaction of a special material with the EMC fields is important and is presented in the book in a highly topical way.

The effect of the materials for shielding is explained to the reader by means of examples and is shown in very concentrated form in shielding rules.

The expert should be able to deal with the EMC phenomena with the help of the examples presented and to provide solutions for special shielding by penetrating the effects himself. This book avoids too extensive theoretical explanations, but the most important basics are mentioned.

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1.1 EMC Act Standardization

Modern devices for communication, navigation and data transmission, such as cell phones, GPS receivers, etc., operate in the frequency range under 6 GHz. However, the conducted signal transport within the devices is accompanied by the emission of an electromagnetic wave, so that the exposure to electromagnetic radiation is becoming increasingly important.

The devices are therefore subject to the legal regulations for EMC. While the “Law on the Electromagnetic Compatibility of Devices (EMCA)” of 18 September 1998 was an important guideline for controlling the functionality of devices and was then revised several times until 2001, there is a need to comply with and control the guarantee of personal protection in electromagnetic fields (DIN VDE 0848 Part 2).

The European standards defined here are EN 50081 (1 + 2) of 1992 and 1993 on EMC, generic standard for emitted interference, and EN 50082 (1 + 2) of 1997 and 1995 on EMC, generic standard for interference immunity (i.e. susceptibility to interference by EMC).

As the number of electrical devices and in particular mobile telecommunication (cell phones) and navigation devices is constantly growing and these are subject to constant technical development, it is necessary to make them more reliable in operation. In order not to influence existing frequencies, this requires the use of new higher frequency ranges (currently cell phones use 0.9 and 1.8 GHz, Universal Mobile Telecommunication System (UMTS) is transmitted at 2.4 GHz). One aim must therefore be to achieve optimum shielding of devices that emit such radiation (except for the transmitting antenna, which radiates directionally).

However, the use of these high frequencies poses new problems compared to lower frequency devices (<around 100 MHz, although there is no clear limit):

- The high frequencies cause multiple reflections in metal housings or metallized enclosures because of the so-called skin effect (i.e. in simple terms, the electrical conduction no longer occurs over the entire cross section of the metal layer of the metal, but is concentrated on the surface).
- In addition, this RF exposure leads to a reduction in the operational reliability of other electronic components into which an RF wave can be coupled.

2 Volume Materials

2.1 Introduction

In the research and development (R&D) of novel RF materials for housing technology and in materials development, the description of the manifold resistive, dielectric and magnetic material properties is of interest [43]. The aim of this R&D project is to improve the EMC properties of packages. An increased shielding loss with simultaneous smoothing of the internal field amplifier resonances is to be achieved. Electronics should function safely in metal housings without internal field excesses. For this purpose, new RF ferrite materials are to be developed. The focus of this research project is on the exact formulation of the interaction of EMC interference energy with the ferrite material, the development of an RF ferrite material and the testing of the EMC properties of the RF materials and the new types of housings.

RF materials are roughly divided into RAM (resistive radioabsorbing material) and CRAM (currentless radioabsorbing material) [1]. The difference between the CRAM and RAM is that current flows through the RAM and not through the CRAM. The subdivision can be seen more clearly in Fig. 2.1.

The RAMs are the conductive RF materials, the CRAMs are the limited conductive materials.

The ferrite compound material is thus classified in the CRAM specifically under the CRM (currentless radiofrequency material). The layer thicknesses of the volume materials are approximately >100 µm. The ferrimagnetic layers, still to be discussed, are classified as CRC (currentless radiofrequency coating) materials. They form a special group as non-volume material.

One difference between the RAM and CRAM is the mathematical description. The RAMs have a mathematically continuous space-time consideration. Current flows through the material, even if the conductivity is frequency dependent. The conductive layers are

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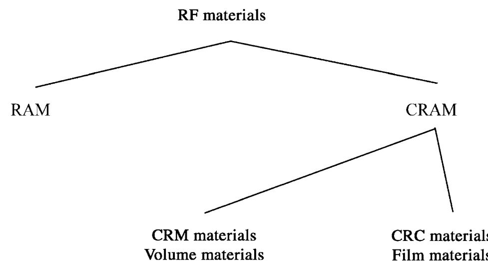

Fig. 2.1 Diagram according to Mikhailowski for the classification of RF materials. (Source: [1])

difficult to observe, especially the nanoscale conductive layers. The graphite-containing foam absorbers (cones or laminates) are easier to observe. With this type of RAM, it is practically "only" necessary to consider conductivity.

CRAM, also called spin materials, are more difficult to consider. Since a discrete mathematical space-time observation is required, it is no longer possible to use simple continuous models [1]. One has to consider the difficult conditions of the discrete lattice models of ferrite crystals, for example. An extensive material-physical consideration of the CRAM—as shown in Sect. 2.2—is therefore inevitable.

The main subject of the present work is therefore the description of the interrelation between microscopic/macroscopic material properties—RF behaviour. Purely continuous observations as with graphite absorbers are not helpful.

A word about the difference between ferrimagnetic volume materials and ferrimagnetic layers. The consideration of ferrimagnetic layers is a contribution to basic research. Many articles on ferrimagnetic layers with a layer thickness of <1 μm do not exist. According to Perthel in [2], the effects of conventional solid state physics (ratios of spin–crystal interaction) merge into the effects of statistical near-order (spin–spin interaction of the layer). We are dealing with spin wave absorption. The observations in this thesis can only be a beginning for the characterization of the RF ratios in thin ferrimagnetic layers.

The main goal in modelling ferrimagnetic volumes or layer materials is the high RF loss as $\mu''_{\mathrm{rel}}(f)$ or as reflection factor $r(f)$, which should result in an optimal measurement signal for the RF visualization. The considerations are limited to a frequency range from 30 to 1000 MHz. The frequency range >1000 MHz is discussed in the outlook (Sect. 2.4).

In the theoretical modelling, the continuous model of Landau and Lifschitz (LL) for the description of the discrete conditions in the volume material was dealt with. In the layer modelling, the LL model with damping term was applied.

The novel scientific approach of this work is the introduction of material parameters such as magnetic moment, grain size, anisotropy into the theoretical model and the subsequent analysis of the RF conditions in the material. This approach was also used for the extremely complex layer modelling.

Important for the modelling of the materials is the structural composition of the ferrite materials themselves. Without knowledge of the material properties of the ferrites, the RF material cannot be developed. Simpler interrelationships without more in-depth material considerations, as in the case of graphite absorbers, cannot be used.

The aim of the development of a safe passive electromagnetic protection system to achieve electromagnetic “immunity” is to increase the shielding effectiveness and ensure a high level of functional reliability of electronic systems.

The problem in today’s metal enclosures is the greatly reduced shielding effectiveness of subracks from 500 MHz and the existing internal reflections and resonances of electromagnetic radiation when an internal electromagnetic source is present. If a sensitive component/assembly is located in a resonance point, it can be influenced.

The approach to a solution for such a protection system consists of developing composite material systems with distinct RF-absorbing properties, which can be used instead of or in combination with metallization or metal shielding, which has the considerable disadvantage of internal housing reflections and field elevations.

With regard to their properties, these materials must be able to form layers and adhere to metallic and non-metallic substrates, they must have high permeability and high dielectricity, and they must be combinable or mixable with plastics used for the manufacture of housings.

Effective RF absorption or loss must be achieved even with layer thicknesses below 1 mm (ideal < 0.1 mm).

With their special electrical/magnetic properties, the new materials to be developed should help to master the ever increasing demands on electronics that are insensitive to interference in the information society of the twenty-first century.

The aim of the work is to achieve a high degree of reliability in information processing electronics by a new type of housing design. New materials, which should have special electrical/magnetic RF properties, have the task of replacing the simple metal housing of information electronics by a material composite consisting of metal/RF-absorbing thin material or a polymer-absorber-solid mixture.

Thus, materials with special properties that are not yet available are derived from the target, such as:

- high RF damping
- high ε''- and μ''-values
- low thickness
- special mechanical values: low hardness, drillable
- the smallest possible change in electromagnetic properties under voltage stress
- aggregate state: solid, liquid, or as a laminate can be applied/adhered.

2.2 Microscopic and Macroscopic Properties of Spinel Ferrites

The knowledge of the crystal structure of microwave ferrites is of great importance, since the absorption effects also have their origins in atomic or crystalline structural properties. With physical models, starting from the material fundamentals, the absorption effects of RF energy, the conversion effects and the resulting energy forms (wall movement of the domains, quantized spin waves, relaxation effects, resonance effects, dynamic rotational movements, etc.) can be described.

Ferrites are materials with a high resulting magnetic moment [5]. This manifests itself in the presence of a difference torque or a resulting spin in the material [3]. The ferrimagnetic materials are very diverse and exist in a wide variety of structures. The most important types of ferrite are listed in Table 2.1.

In this chapter, the structure of the ferrites shall be presented as simple as possible. The ferrites are divided into the following main groups:

- Spinels
- Grenade
- Magnetoplumbite
- Y-type ferrites with hexagonal structure
- W-type ferrites with hexagonal structure
- Orthoferrite

A description of the exact structure of the ferrites mentioned would go beyond the scope of this work with knowledge of the basic relationships, so only the most important

Table 2.1 Application and properties of the most important ferrite groups

Crystal	Structure type	Representative	Frequency range	Technical application
Cubic unit cell	$Me_x^{2+}Me_{3-x}^{3+}O_4$	Manganese, zinc, ferrite Nickel, zinc, ferrite	1 MHz–1 GHz	Ultrashort wave, EMC
Cubically complicated	$(Me)_3^{2+}(Me)_5^{3+}O_4$	Rare earths	1.5–3.5 GHz	Communications engineering
Hexagon unit cell	$(Me)_1^{2+}(Me)_{12}^{3+}O_{19}$	Sr-ferrites	1–25 GHz	Microwave technology
Hexagonally symmetrical	Sequence of T and S, spinels	$Ba_2Me_2Fe_{12}O_{22}$	500 MHz	Field-controlled device
Hexagonal, consisting of three spinel structures	Sequence of M, Y and S, spinels	$Ba_2Me_2Fe_{24}O_{41}$	> 1 GHz	Microwave m.
Orthoferrite				No technical application