UNIVERSITY OF ZAGREB
Faculty of Electrical Engineering and Computing

Use of Conduction Materials in Protection from Electromagnetic Fields

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Contents

Introduction

The telecommunications field is in constant and rapid evolution. The number of electronic devices surrounding our lives is undoubtedly increasing. Many of those, are devices that constantly transmit information through the electromagnetic (EM) spectrum.

This EM spectrum is formed by a wide variety of electromagnetic waves and therefore it is more used and reserved for our telecommunication systems. This rapid evolution leads to a permanent exposure of our bodies and our health to electromagnetic radiation. Although this radiation has a considerable effect on plants and animals, the truth is that the human body regulates body thermodynamics better and therefore the effect on humans is less pronounced, but they are still a potential risk. However, many studies have determined that this radiation can harm our health, damaging cells and turning them into harmful. One way to prevent such exposure and the consequent dangers is, electromagnetic shielding.

Electromagnetic shielding is the ability to slow down the incidence power of electromagnetic radiation. The latter is defined as the ratio between the magnitude of an incident wave power and the magnitude transmitted after passing through a material. Interestingly, numerous conductive materials have been developed to cope with such radiation. These materials were initially very expensive, but they have been increasingly adapted and prepared for commercial use. In fact, they have begun to be manufactured for private use to protect ourselves in our homes, rooms, workplaces, by attenuating electromagnetic fields over our body.

In this work, we will first have a brief analysis of the behaviour of these electromagnetic fields, going into detail of the different types of existing waves, as well as an example of their distribution in the electromagnetic spectrum. Next, we will study electromagnetic shielding, its behaviour, its propagation mechanisms and the factors that influence its efficiency. We will follow by explaining the current status of the measuring devices and methods. Then, we will also show some materials that have been proven to attenuate EM radiation and can therefore be used to help shielding and protection, such as paint made out of carbon, textiles made out of polyesters, metals or even stainless-steel fibbers. Finally, we will touch base on a very timely and controversial matter: the use of 5G. We will give a brief explanation of what this new worldwide implantation consists of as well as some examples of products prepared to offer resistance to this type of frequencies.

Overall, this work is intended is to give a general idea of how EM shielding can cope with electromagnetic fields and how it protects us.

2

Overview of the Electromagnetic Field

The electromagnetic (EM) spectrum is the range of frequencies of electromagnetic radiation with their respective wavelength, frequency and photon energies.

EM radiation covers waves below 1 Hz (ELF) corresponding to wavelengths from thousand kilometres up to wavelengths above 30 ZHz (Gamma rays) corresponding to atomic size wavelengths.

1.2 Wave and Frequency

Frequency and wavelength are related by the following expression:

$$\lambda = \frac{c}{f} \qquad (2.1)$$

Where c represents approximately speed of light (3.10^8 m/s) and f represents the frequency (Hz). Wavelength is inversely proportional to the wave frequency.

EM waves are described too with their photon energies. The energy of the particular range is defined by:

$$E = h.f \qquad (2.2)$$

Where h represents the Planck's constant ($6{,}626.10^{-34}$ J.s) and f is the frequency. Photon energy is usually expressed in eV and as we can see, the higher frequency is, the higher the energy photon is. One eV is equal to the amount of energy gained by a single unbound electron when it accelerates through an electrostatic potential difference of 1 volt. It is also the energy needed to break the chemical bond in the cell.

2.2 Overview of the Frequency Spectrum

The EM radiation is divided in decades (Figure 2.1). Radio waves are widely used to transmit information and covers frequencies from 9 kHz (VLF) to 300 GHz (SHF) (Figure 2.2).

Microwaves are included in the radio spectrum, from 300 MHz (UHF) to 300 GHz (SHF). The size of microwaves goes from 1 mm to 1 m.

All antennas we normally see use radio waves. Radio spectrum is basically used for telecommunication systems like TV, radio broadcasting, wireless networking, satellite communications, mobile phones, etc…

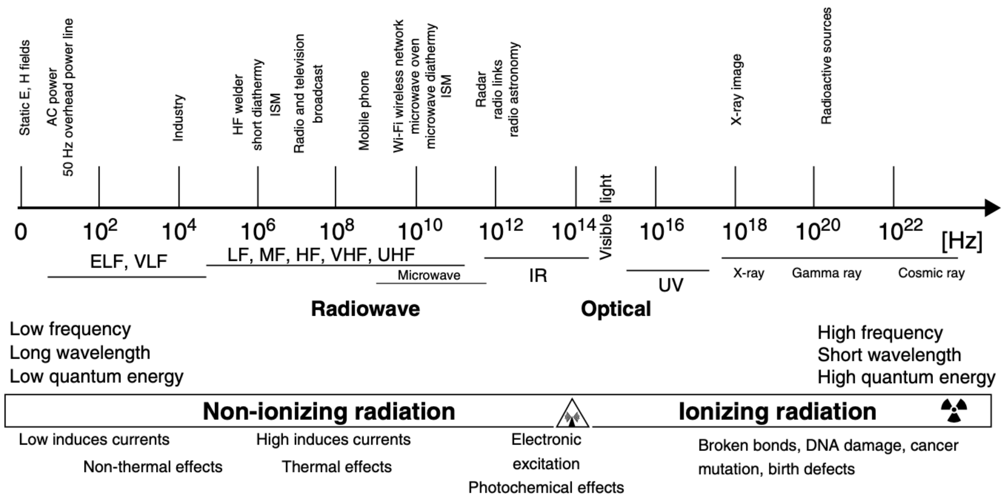

Figure 2.1: Spectrum of electromagnetic field and radiation

Range	*Frequency*	*Wavelength*	*Energy (eV)*
Extremely low frequency (ELF)	3 Hz–30 Hz	10^8m–10^7m	$1.24 \cdot 10^{-14}$–$1.24 \cdot 10^{-13}$
Super low frequency (SLF)	30 Hz–300 Hz	10^7m–10^6m	$1.24 \cdot 10^{-13}$–$1.24 \cdot 10^{-12}$
Ultra low frequency (ULF)	300 Hz–3 kHz	10^6m–10^5m	$1.24 \cdot 10^{-12}$–$1.24 \cdot 10^{-11}$
Very low frequency (VLF)	3 kHz–30 kHz	10^5m–10^4m	$1.24 \cdot 10^{-11}$–$1.24 \cdot 10^{-10}$
Low frequency (LF)	30 kHz–300 kHz	10^4m–10^3m	$1.24 \cdot 10^{-10}$–$1.24 \cdot 10^{-9}$
Medium frequency (MF)	300 kHz–3 MHz	10^3m–10^2m	$1.24 \cdot 10^{-9}$–$1.24 \cdot 10^{-8}$
High frequency (HF)	3 MHz–30 MHz	10^2m–10^1m	$1.24 \cdot 10^{-8}$–$1.24 \cdot 10^{-7}$
Very high frequency (VHF)	30 MHz–300 MHz	10^1m–1m	$1.24 \cdot 10^{-7}$–$1.24 \cdot 10^{-6}$
Ultra high frequency (UHF)	300 MHz–3 GHz	1m–10^{-1}m	$1.24 \cdot 10^{-6}$–$1.24 \cdot 10^{-5}$
Super high frequency (SHF)	3 GHz–30 GHz	10^{-1}m–10^{-2}m	$1.24 \cdot 10^{-5}$–$1.24 \cdot 10^{-4}$
Extremely high frequency (EHF)	30 GHz–300 GHz	10^{-2}m–10^{-3}m	$1.24 \cdot 10^{-4}$–$1.24 \cdot 10^{-3}$
Infrared (IR)	0.3 THz–400 THz	10^{-3}m–$750 \cdot 10^{-9}$m	$1.24 \cdot 10^{-3}$–1.65
Visible	400–790 THz	$750 \cdot 10^{-9}$m–$380 \cdot 10^{-9}$m	1.65–3.27
Ultraviolet (UV)	750 THz–30 PHz	$400 \cdot 10^{-9}$m–$10 \cdot 10^{-9}$m	3.10–124
X-ray	30 PHz–30 EHz	$10 \cdot 10^{-9}$m–$0.01 \cdot 10^{-9}$m	124–124,000
Gamma ray	30 EHz–30 ZHz	$0.01 \cdot 10^{-9}$m–$10 \cdot 10^{-15}$m	0.124–$124 \cdot 10^3$

Figure 2.2: Electromagnetic spectrum, wavelength, frequencies and energies

Extra Low Frequency (ELF)

Extra low frequency waves are present on the surface of Earth because they are generated by lighting and natural disturbances of Earth’s magnetic field. Also, they are used for submarine communications due to the big size of the wave (above 10 000 km) that can easily penetrate the surface of water.

Super Low Frequency (SLF)

Similar to ELF, these waves can be observed in natural atmospheric conditions and are also used to communicate with submarines under the sea.

Ultra-Low Frequency (ULF)

These frequencies are observed in the magnetosphere and on the ground. They can easily penetrate the surface of earth and are used for communication mines.

Very Low Frequency (VLF)

The VLF band can penetrate some meters into the sea and is used for radio navigation and secure military communications. They appear naturally in atmospheric phenomena such the aurora or lighting.

Low Frequency (LF)

The LF spectrum is used for AM broadcasting. These waves diffract easily with the mountains and with the ionosphere and are good for long-distance communications. This band is available too for radio amateur, meteorological broadcasts and communications under the sea.

Medium Frequency (MF)

MF is very similar to the LF. These waves can also travel the longest distances via skywave propagation. During the night, these waves can propagate further because the ionospheric layer virtually disappears. They are used for AM broadcasting too.

High Frequency (HF)

HF is a short-wave frequency band that can travel long or medium distances. They are used for aviation air-to-ground communications, amateur radio and military use.

Very High Frequency (VHF)

This frequency band is used for digital audio broadcast, FM radio and TV broadcasting, amateur radio, marine communications, air traffic control, navigation systems, radio astronomy, satellite communications and more.

Ultra-High Frequency (UHF)

This band travels by line-of-sight propagation and ground reflection but is strongly affected by rain. UHF band is commonly used for Wi-fi, Bluetooth, Global Position System, cell phones, walkies-talkies, RFID, television broadcast and more uses.

Super High Frequency (SHF)

This band is used for point-to-point communication, data links and for radar because they have small size wavelength and the beams has to be direct. It is used for radar, wireless LANs and satellite communication.

Extra High Frequency (EHF)

Radio waves of EHF have high atmospheric attenuation since they are absorbed by gases in the atmosphere. They are used for military purposes like fire-control radar or security airports scanners, and scientific research.

Infrared (IR)

Infrared can be visible to the human eye in certain conditions using a specially pulsed infrared laser. This band is used for astronomy, metrology, climatology, spectroscopy, thermography, etc. Some animals and plants are sensible to infrared waves. IR data transmission is used for short-range communication like personal digital assistants, computers or PDAs.

Visible (V)

Visible refers to the part of the EM spectrum that is visible by the human eye. These frequencies are line-of-sight and suffers interference from other light sources. This band is used in communications for optical fibbers systems.

Ionizing rays

These electromagnetic waves are part of the EM spectrum and have high energy that damage our body cellules. Gamma rays, X-rays and high Ultraviolet are examples of this frequencies. These are out of the scope of this project since they are not in the radio-wave spectrum.

2.3 Spectrum Division

Since EM radiation is mostly artificial and manmade activity, most of population live in EM atmosphere. In addition to power supply lines, Broadcasting (radio and TV), wireless communications such WLAN. Wi-Fi and other networks, GPS, radio navigation and other science, medicine and industry frequencies, are some examples of typically sources

The use of the EM spectrum is regulated by governments and the International telecommunications Union (ITU).

ITU manages international radio frequencies, allocating the spectrum and frequencies in order to avoid interference between radio stations of different countries. In recent years, radio communication systems have expanded largely. The radio frequency spectrum is a natural resource, and its allocation has to be planned well ahead. Each country has its own frequency bands reserved for its own uses. Figure 2.3 below shows the most common wireless system's frequency band used in Spain.

Wireless System	Operating Frequency
Advanced Mobile Phone Service (AMPS)	T: 824-849 MHz R: 869-894 MHz
Global System Mobile (European GSM)	T: 890-915 MHz R: 925-960 MHz
Personal Communications Services (PCS)	890 - 960 MHz
US Paging	929-931 MHz
Global Positioning Satellite (GPS)	L1: 1559 MHz L2: 1610 MHz
Direct Broadcast Satellite (DBS)	11,7-12,5 MHz
Wireless Local Area Networks (WLANs)	863-868 MHz 2400 -2483,5 MHz 5150 -5350 MHz 5470-5725 MHz
Local Multipoint Distribution Service (LMDS)	26 GHz
US Industrial, Medical, and Scientific bands (ISM)	863-868 MHz 2400 -2483,5 MHz 5150 -5350 MHz 5470-5725 MHz
Radio	87,0-108,1 MHz
Digital TV	830-862 MHz
Galileo Sat. Navigation	5- 5,03 GHz
Cordless Telephone	31,025 - 40,225 MHz 870-871 MHz 915 - 916 MHz

Figure 2.3: Wireless System Frequencies in Spain

3

Electromagnetic Shielding

Telecommunications have notably increased over the past years. This leads to a greater exposure to electromagnetic radiation. These EM rays can be harmful for our health and then shielding effectiveness is needed for it. The process of limiting the penetration of electromagnetic fields into a space by blocking them with a barrier made of conductive material is electromagnetic shielding. In this chapter, we are going to study the efficiency of the EM shielding, its nature and how it behaves towards a material.

3.1 Electromagnetic Shielding Efficiency

The shielding effectiveness (SE) is the ratio between the magnitude of the incident electric field E_i, and the magnitude of the transmitted electric field, E_t. It is normally expressed in decibels (dB):

$$SE = \left|\frac{\vec{Ei}}{\vec{Et}}\right| \qquad SE(\text{dB})=20\log_{10}\left(\frac{Ei}{Et}\right) \ (\text{dB}). \tag{3.1}$$

This definition of shielding effectiveness is usually referred to the electric field amplitude but also for the magnetic field amplitudes and plane-wave strength caused by shielding.

In addition, $SE=A_1-A_2$ where A_1 is the source attenuator setting, in decibels, for a measurable output of a specified detector in the absence of the material, and A_2 is the source attenuator setting for the same output of the detector in the presence of the material.

The higher the SE value in decibels is, the less energy passes through the shield and therefore, most of the energy is absorbed or reflected by the shielding of the material. SE will be negative if less power is received with the material present than when it is absent.

3.2 Mechanism of Electromagnetic Shielding

All materials act by 3 mechanisms (Figure 3.1):

1. Reflection of the wave form the front face of the shield
2. Absorption of the wave as it passes through the shield
3. Multiple reflections of the waves at various interfaces

SE is then the sum of these 3 mechanisms that we will now deal with in detail.

$$SE_{TOTAL} = SE_R + SE_A + SE_M \tag{3.2}$$

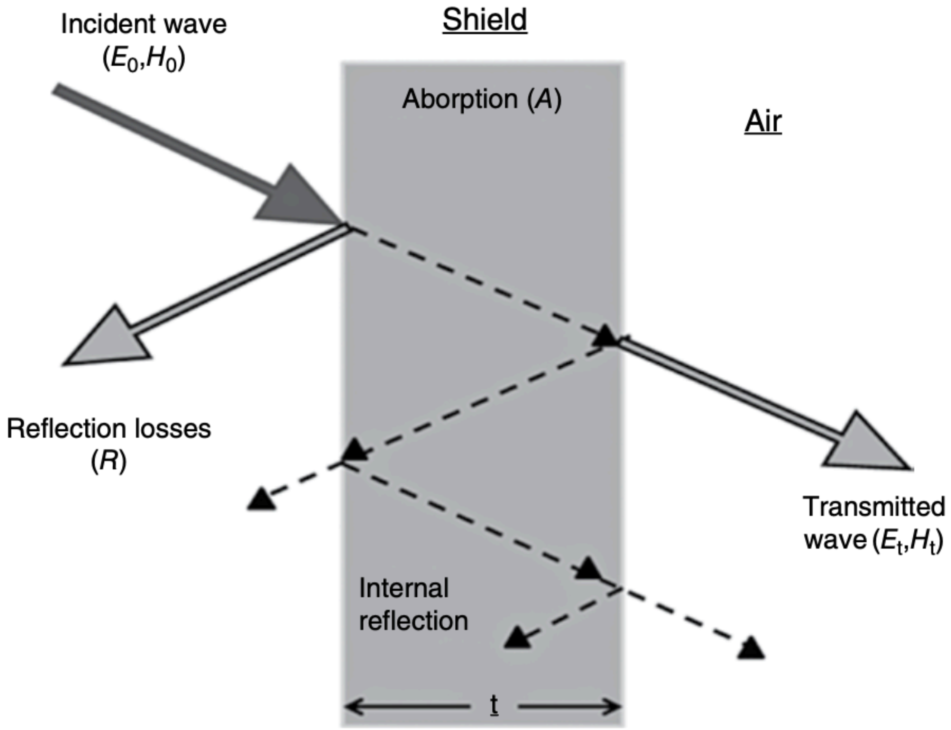

Figure 3.1: Conceptual Scheme of an Incident Wave in a Material

3.2.1 Reflection loss

Reflection loss depends on the difference between the intrinsic impedance of the shielding and the free space. It is totally independent of the thickness of the shield. Expressions of equations of electric, magnetic and plane-wave field are given below:

$$R_E = 353.6 + 10\log\frac{G}{f^3\mu r_1^2} \tag{3.3}$$

$$R_H = 20\,log_{10}\left(\frac{0.462\sqrt{\mu}}{r_1\sqrt{Gf}} + 0.136r_1\sqrt{\frac{fG}{\mu}} + 0.354\right) \tag{3.4}$$

$$R_P = 108.2 + 10\,log_{10}\left(\frac{G\times 10^6}{\mu f}\right) \tag{3.5}$$

Where R_E is the reflection for electric field, R_M for magnetic and R_P for plane wave field expressed in dB; G is the relative conductivity referred to copper, f is the frequency in Hz, μ is the relative permeability in free space and r_1 is the distance from the source to the shield.

3.2.2 Absorption loss

Absorption loss (or penetration loss) occurs when the EM wave passes through a medium and starts to decrease exponentially. Current induced in the medium produces ohmic losses and heating of the material.

For shielding material, the skin depth (δ) is the distance up to which the intensity of the EM wave decreases to *1/e* of its original strength.

$$\delta = \frac{1}{\sqrt{f\sigma\mu\pi}} \tag{3.6}$$

The absorption loss is the same for the 3 fields since it is only determinated by physical characteristics of the materials and is independent of the source.

$$SE_A = 3.338 \times 10^{-3} \times t \times \sqrt{\mu f G} \tag{3.7}$$

Where SE_A is the absorption level expressed in dB; *t* is the thickness of shield*,* *G* is the relative conductivity referred to copper, *f* is the frequency in Hz, μ is the relative permeability in free space.

If material thickness increases, absorption loss will increase too.

For the skin depth, SE_A,

$$SE_A = 8.7\left(\frac{t}{\delta}\right) \tag{3.8}$$

3.2.3 Multiple Reflection Correction Factor

Multiple reflections occur inside a medium between different boundaries. If the shield is thicker than δ, the conductive material absorbs the reflected wave from internal surface and thus multiple-reflection can be ignored.

In most cases, this factor is negative and can be ignored, but for frequencies near 20 kHz and thin materials, this factor becomes important.

Multiple reflection correction factor can be expressed as:

$$SE_M = 20log\left|1 - \frac{(K-1)^2}{(K+1)^2}\left(10^{\frac{-A}{10}}\right)\left(e^{-i227A}\right)\right| \tag{3.9}$$

where *A* is the absorption loss and *K* is:

$$K = \frac{z_S}{z_H} = 1.3\sqrt{\frac{\mu}{2fr\sigma}} \tag{3.10}$$

where Z_S and Z_H are the impedance of the shielding and the incident magnetic field respectively.

3.3 Factors of effectiveness of the Electromagnetic Field:

There are some factors that determine the effectiveness of an electromagnetic field:

1. Frequency of the incident electromagnetic field:

   The reflection loss decreases when the frequency increases due to the increase of shield impedance. The absorption loss increases with the frequency because the skin depth decreases.

   We can rewrite the SE_R and the SE_A as:

$$SE_R = 39.5 + 10log\ \frac{\sigma}{2\pi f\mu} \quad (3.11)$$

$$SE_A = 8.7d\sqrt{\pi f\mu\sigma} \quad (3.12)$$

   where μ is the permeability, σ is electrical conductivity and f is frequency.

2. Shield material parameters (conductivity, permeability, permittivity or dielectric constant)

   SE can be expressed with these terms:

$$SE_A = 20d\frac{\sqrt{\mu_r\omega\sigma}}{\sqrt{2}}log_{10}(e) \quad (3.13)$$

$$SE_R = 10log_{10}(\frac{\sigma}{16\mu_r\omega\varepsilon_0}) \quad (3.14)$$

   Where ε_0 is the dielectric constant, μ_r is the permeability, ω is the angular frequency, σ is the electrical conductivity and e is 2.781.

3. Shield thickness:

   The absorption loss increases when the thickness increases too. The reflection loss is totally independent of the thickness shielding.

4. Type of electromagnetic field source (plane wave, electric, magnetic field):

   SE depends of the type of field source because the equations for determinate the reflection loss are different

5. Distance from the source:
   For near field, magnetic and electric field have different rate, being $(1/r)^3$ and $(1/r)^2$ respectively. For far field, both have a rate of (1/r).

6. Shielding degradation caused by any shield apertures and penetration

7. Polarization of the field because the SE value depends of material properties results from ionic, electronic, orientation and space charge polarization.

8. The SE value varies with some properties of the shielded volume: geometry, direction of incidence, position.

3.4 Materials for EM shielding

Metals are the most commonly application for EM shielding but are expensive, sometimes heavy and not as practical as other materials. Some new conductive polymers are the ideal substitute since the price is lower, they can be flexible and have many applications for EM shielding. In this regard, we are going to see some shielding paints and fabrics made carbon black, carbon fibers and metal nanoparticles.
Next Figure 3.2 shows main properties of materials for EM radiation protection.

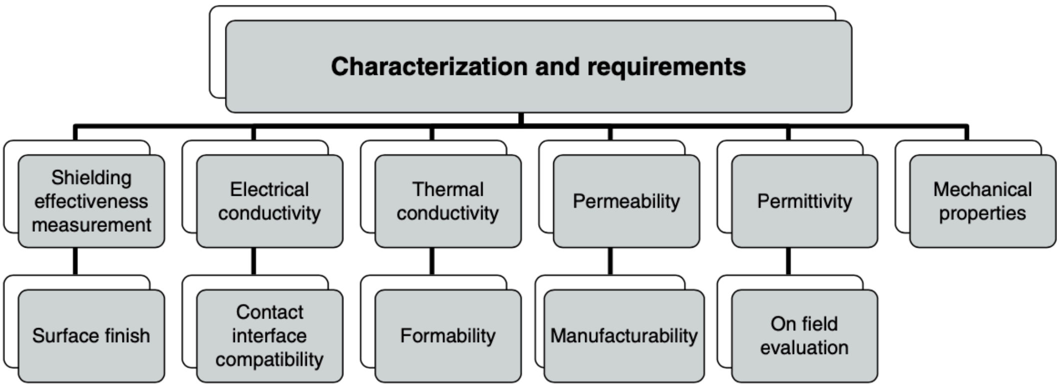

Figure 3.2: Characterization and requirements for EM shielding materials.

4

Measurement devices

Nowadays, electromagnetic radiation is measurable. These waves can be measured by devices sensitive to electromagnetic fields. This means that the ratio of the magnitude incident wave will be different, after passing through a material, then the magnitude of the transmission wave. Some methods are proposed below, as well as some example devices.

4.1 Methods for Measuring Shielding

Before going into detail of some of the possible methods for measuring SE we are going to see two test examples of shielding effectiveness of some materials.

Different test methods are commonly used to measure EMI shielding effectiveness of a given material. We present two:

The first one is called “Open field” or “Free Space Test”. It determines the level of EMI produced due to the noise level meter measuring. This test is used to measure the radiated emissions of an electronic device and the object is placed at 30m from the receiving antenna and registers the radiated emissions as is shown in next Figure 4.1.

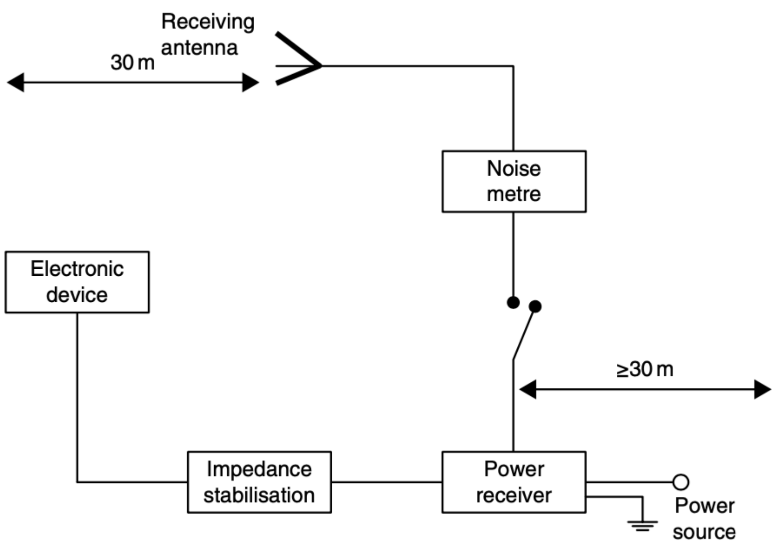

Figure 4.1: Open field SE measurement.

The second test is made for shield materials, instead of electronic devices as before.

It is called “Shielded Box Test” (Figure 4.2) and it works by putting a specimen into a metal box with a receiver antenna connected to it. Another antenna is transmitting and then the EM signals are compared (Figure). This test works with frequencies under 500 MHz

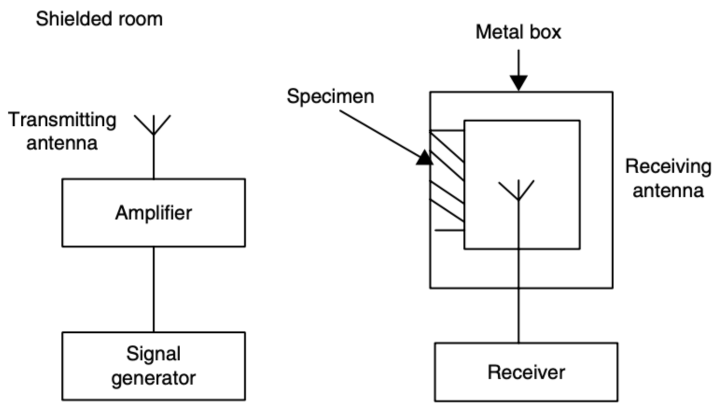

Figure 4.2: Shielded box SE measurement

4.2 Shielding Effectiveness Measurement Methods and Systems

The aim of shielding effectiveness measurement is to quantify the decrease of the incident wave due to the interaction of it with a material sample. This technique makes use of the insertion loss measurement. Firstly, power from a transmitting antenna is integrated to a receiving antenna P_i without any material, and secondly, power from a transmitting antenna is linked again to the receiving antenna P_t but this time with the test material.

The logarithm to calculate the SE value ratio of the received power first without the sample (reference measure) and then with the sample is:

$$SE(\text{dB})=20\log_{10}\left(\frac{Pi}{Pt}\right) \quad (\text{dB}). \tag{4.1}$$

And the table of the attenuation due to the SE value ratio of the power densities,

dB	Attenuation
10	90 %
20	99 %
30	99,9 %
40	99,99 %
50	99,999 %
60	99,9999 %
...	...

Figure 4.3: Attenuation in % due to the difference SE ratio of power densities

The first method we are going to explain uses plaques measurements and it makes use of two shielded rooms with one common wall as is shown in next Figure 4.4 and Figure 4.5.

The transmitter antenna is placed in one and the receiving antenna is placed in the other room, separated by an aperture. The distance between the antennas is fix and we will make two measurements. The first one with no material in the aperture, and then we will register the power radiated between antennas. This power radiated is called P_i. The second measurement is with a material texter in the aperture, and then we will register the new value of the power radiated. EMI shielding effectiveness is computed using the equation (4.1).

This method has many variations such using a coaxial transmission line or using a dual TEM cell method, but we are not going into detail.

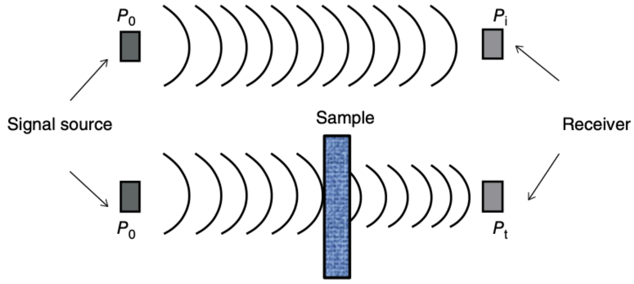

Figure 4.4: Experimental scheme of SE with reference measurement and with sample

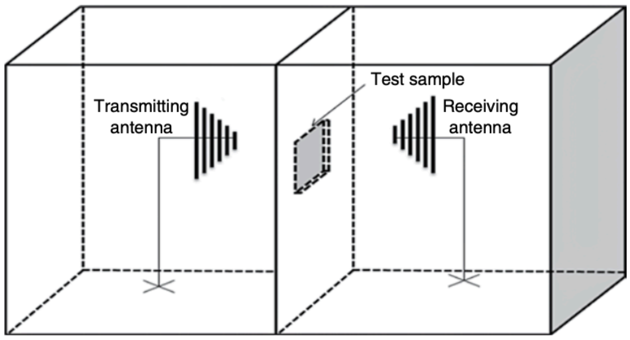

Figure 4.5: Two boxes method experimental determination of SE

Other method for measuring effectiveness is the Free Space Method (Figure 4.6). This method permits extensive frequency range measurements, with the upper frequency limit around tens of GHz and SE measurement for large samples. We acquire the SE for each frequency by establishing the field sensed by the antenna R in two situations: without and correspondingly with the sample/panel.

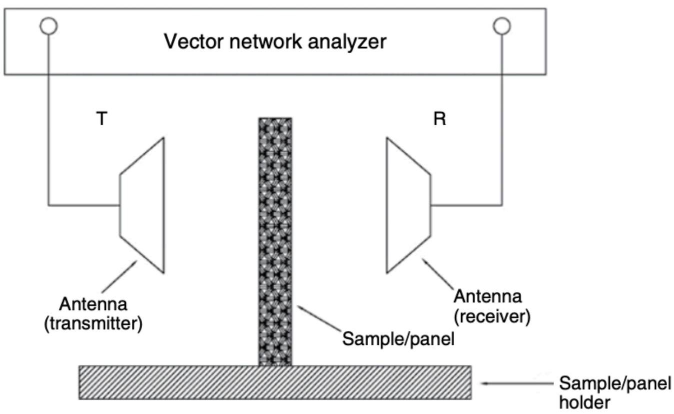

Figure 4.6: Free-space transmission measurement method.

4.3 Measurement Devices: Examples

Some examples of measuring instruments for electromagnetic fields are shown below. These devices are capable of detecting intensities and forces, both in the electric, magnetic field and the radio frequency spectrum.

These measuring instruments are classified according to the radio frequency spectrum to which they are sensitive to.

- Low frequency instruments are capable of measuring electromagnetic fields in the range of 5 Hz to 100 kHz. They are ideal for EM fields caused by electrical networks, such as distribution networks, transformer stations, etc.

- High-frequency measuring devices are ideal for measuring the radio frequency signal of TV, radio, WLAN, WIFI, WIMAX, etc.

- Electro-smog devices are useful for making measurements of the magnitude of the electric or magnetic field only.

These devices, besides being differentiated by the radio frequency spectrum in which they operate, they also differ in the way in which the results are obtained.

Some display the detected peak value, the RMS (average value) or the highest values of a certain time on a digital screen. However, others operate with a coloured light that varies according to the registered field strength and is then seen in an attached table. Others, will emit a sound that increases as we get closer to the source since the origin of an electromagnetic contamination. The sound signal proportional to the intensity of the field facilitates the evaluation. This can be easily located due to the fact that the intensity of the measured field increases constantly the closer the meter gets to this source. Since fields (specifically magnetic fields) can also penetrate massive building materials, keep in mind that the origin can also be found outside the room (for example power lines, overhead railway lines, transformers, or even electrical appliances in nearby homes).

In order to identify fluctuations in pollution values, measurements should be made both at different times during a day and at different days during a week. They should also be repeated frequently.

It is important to note that it is not possible to reliably measure the power density (W / m^2) within 2 meters of the emission source.

4.3.1 High Frequency Analyser

HF-Analyzer for frequencies from 800 MHz to 3.3 GHz.

		
800 – 2.500 MHz	2,4 – 6 GHz	Frequency range
0,1 – 1,999 µW/m²	1 - 1,999 µW/m²	Measuring range
6 dB, 9 digits	6 dB, 7 digits	Accuracy

Figure 4.7: High frequencies analysers

In the Figure 4.7 we can see HF-analysers, and these have different modes that can measure the peak of the signal, the RMS or the peak hold.

The antenna provided with this instrument is shielded against ground influences. We should “aim” about 10 degrees below the emitting source subject to measurement so as to avoid distortions in the area of sensitivity transition as is shown in Figure 4.8.

Figure 4.8: Scheme of the correct antenna pointing 10º over the point of interest

4.3.2 Low Frequency Analyser

LF-Analyzer for frequencies from 5 Hz to 100 kHz for electric and magnetic fields.

			
16 Hz – 2 kHz	16 Hz – 100 kHz	5 Hz – 100 kHz	Frequency range
1 nT/Vm – 2,000 nT/Vm	1 nT/Vm – 2,000 nT/Vm	1 nT/Vm – 2,000 nT/Vm	Measuring range
2%, 20 digit	2%, 14 digit	2%, 14 digit	Accuracy

Figure 4.9: Low frequencies analysers

LF-analysers are shown in Figure 4.9. They are able to detect frequencies between 6 Hz and 100 kHz. The screen shows the peak value of the EM field. As values are changeable, we can obtain the result in V/m or in nT. To get better results, it can be grounded.

An acoustic signal helps to identify the strength of the EM field.

In Figure 4.10 we can see that it is not necessary to rotate the device in all directions, but one particular direction will show the highest reading and the meter shows the "resulting" field strength response magnetic flux density.

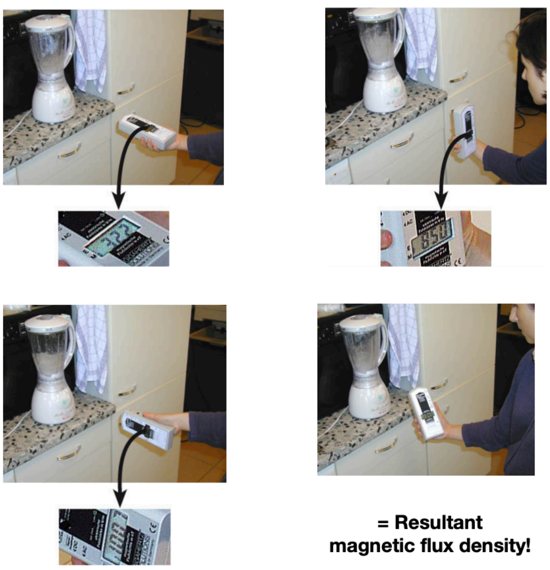

Figure 4.10: Standard (left side) and optimum (right side) position for correct measurement of the magnetic flux

4.3.3 Electro-Smog Detector

Radio frequencies detection shown in Figure 4.11 with enhanced sensitivity from 50 MHz to 10 GHz.

				
-	16 Hz – 3 kHz	16 Hz – 3 kHz	16 Hz – 3 kHz	Electric field
-	16 Hz – 3 kHz	16 Hz – 3 kHz	16 Hz – 3 kHz	Magnetic field
50 MHz – 8 GHz	-	50 MHz - 6 GHz	50 MHz - 10 GHz	EM field

Figure 4.11: Electro-Smog detectors

An Electro-Smog Detector is a device to find Electro-Magnetic Fields produced by technology. Depending on which electro-smog we use, is able to detect electric fields, magnetic fields and EM fields. It is perfect for identification of pulsed radiation sources as mobile radio, GSM, WLAN (Bluetooth), radar stations, etc…

Even though it is suitable for low frequencies such as power, distribution and domestic installations, it does not display the exact field value on the screen, but lights illuminate depending on their intensity.

Each device has its own table (Figure 4.11), and for each one a colour light indicates the field strengths for RF (V/m and μW/m²), electric field (V/m) and magnetic field (nT). Example of the guide colours light for an electro smog next Figure 4.12.

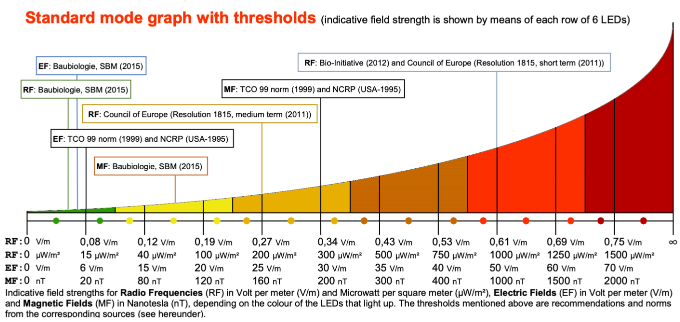

Figure 4.12: EM strength based on the colour light of the device

Recommended limit values for alternating electric fields: less than 10 V/m, ideally less than 1 V/m. Recommended limit values for magnetic fields: less than 200 nT, ideally less than 20 nT.

4.3.4 Tenmars meter

Radio frequencies detection with enhanced sensitivity from 10 MHz to 8 GHz are shown in next Figure 4.13.

		
50 MHz – 3,5 GHz	10 MHz – 8 GHz	Frequency range
4 – 600,000 μW/m²	4 – 300,000 μW/m²	Sensitivity

Figure 4.13: High frequencies radio detectors

This meter is used to indicate electromagnetic pollution generated artificially.

It uses a non-directional (isotropic) triple axis antenna for measurement of high EM fields in frequencies range between 10 MHz and 8 GHz. This device can be set to display the instantaneous value, max value and average value in units of electromagnetic strength radiation and power density.

It has been shown to be ideal for measurements for TV, radio, etc. It includes Wireless LAN (Wi-Fi), microwave and cellular detection. For far fields, it will calculate the magnetic field from the electric field value.

Data logger up to 200 samples.

5

Commercial Products

5.1 Shielding Fabrics

EM shielding is the process to protect from the penetration of the EM rays and some materials act better than others. These materials block EM rays like a barrier made of conductive materials. These shields against EM radiation are normally very rigid, not flexible and uncomfortable. They mainly serve to isolate a room, a circuit, an apparatus.

Interestingly, now it is possible to protect comfortably the human body with textiles covered with conductive layer.

With the technological progress, these conductive materials, usually metals, have been developed into fibbers and mixed with the textiles. These materials, owning their flexibility, durability, ease of manufacturing and applications, are the new commercial revolution of the EM shielding.

Since we have talked before about EM shielding efficiency and their mechanisms, in this regard, different methods of shielding and a variety of EM shielding fabrics are exposed.

5.2 Methods of Shielding Fabrics

We can protect ourselves or else from EM rays by covering with an electro-conductive media which can generate and transport free charges. It is known that artificial fibbers, for example polyester fibbers, exhibit a very poor electric conductivity and one highly hydrophobic. When one of these fibbers is rubbed, static electricity is generated and stays on the fibbers. Sometimes, this level of electricity reaches high levels and results in various annoyances and items of apparel cling to the body are attracted to other garments. Fine particles of lint and dust are attracted to the fabric. The most effective way to prevent these undesirable phenomena is to utilize fibbers having a high electrical conductivity, such metals. Fabric fibbers are not electrically conductive while metal fibbers are (silver, copper, carbon, etc).

Inserting metallic fibber in a fabric is an expensive and delicate process since the fibbers have to be correctly placed. The disorder of these will provide a displacement of the material.

In order to provide a good electrically conductive material, between the 15-20 % of the weight of the fabric should be metal fibber as we are going to see later. The colour of the fabric is then, the colour of the metal fibber predominant.

The method of metalizing the textile fabric consists in coated the fabric with metals such nickel, silver, copper or a combination of them. The chemical method is the mostly used. The metallization of fibbers and fabrics is usually based on laminating with aluminium foils, dyeing with copper sulphide or electroless plating with certain metallic components.

Next method is known for coated the metallic fibber with a polymer laying containing inorganic compounds and absorbers. To improve the shielding efficiency, this method can be used.

5.3 Commercial fabric products

Commercial products for application of electromagnetic radiation shielding fabric belong to YshieldYterm ®. They have a report of their screen attenuation with indicates values according to standards of IEEE. Screening attenuation, that appears on all products, is a graphic showing the level of attenuation (dB) as a function of increasing frequency (measured in hertz). Frequency range is usually 600 MHz to 40 GHz.

The first example refers to a standard semi-transparent ecological cotton fabric for the shielding of high-frequency EM fields (Figure 5.1). This fabric is washable, and is made of cotton without chemicals. The materials are 82 % cotton, 17 % copper and 1 % silver.

As we can see, it uses a combination of metals.

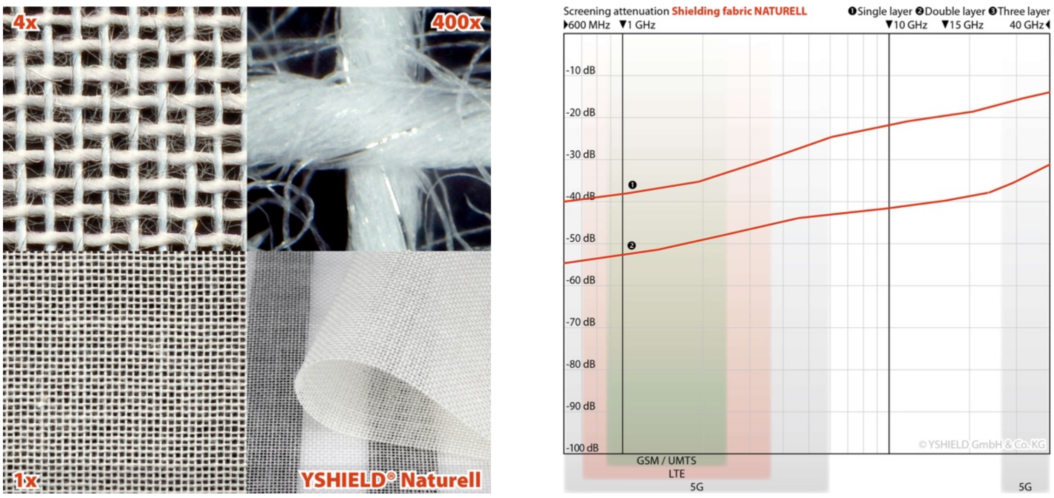

Figure 5.1: a) semi-transparent ecological cotton fabric with different views,
b) Screening attenuation.

As we can observe, this material has a 38 dBs attenuation for 1 GHz and 16 dBs for 30 GHz. Frequencies belonging 5 G.

This material has commercial applications such shielding canopy, box for bed (Figure 5.2) and this product is not groundable.

Figure 5.2: Box for bed made of semi-transparent ecological cotton fabric

Shielding Sleep Accessories

Next item is a compact cotton, polyester and stainless-steel fabric (Figure 5.3) for low and high frequencies shielding. This fabric is not as soft as other products but is washable and suitable to be in contact with the skin. The materials are 40 % cotton, 30 % polyester and 30 % stainless-steel. It has a surface conductivity of 100-800 ohm (square resistance).

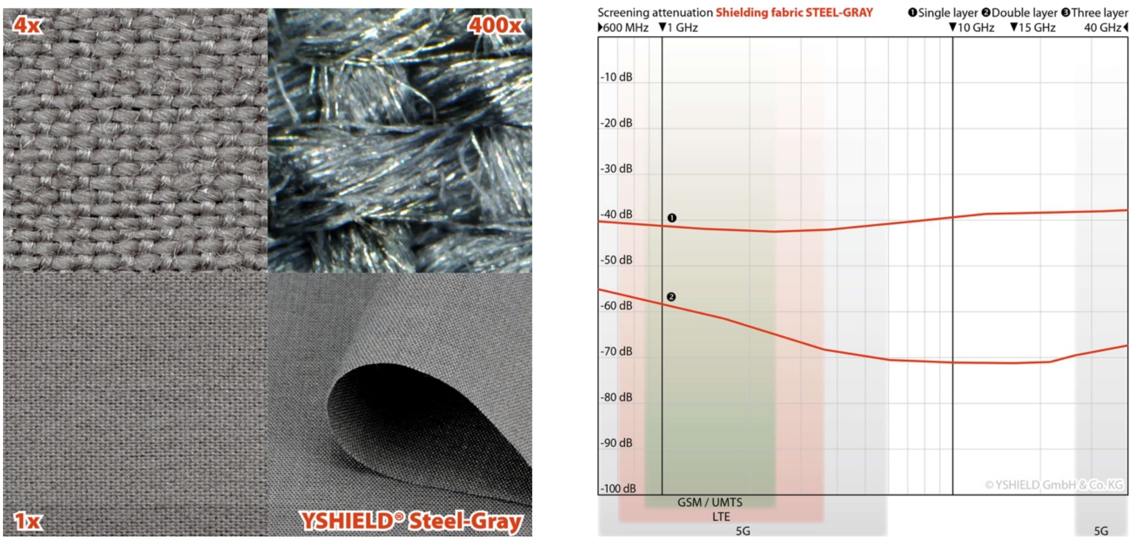

Figure 5.3: a) compact cotton fabric with different zoom, b) Screening attenuation.

As we can observe, this material has a 42 dBs attenuation for 1 GHz and 38 dBs for 30 GHz. Frequencies belonging 5 G.

Figure 5.4: Shielding sleeping bed made of cotton, polymer and stainless steel.

This material is made of stainless-steel and polymer has commercial applications such shielding blanket (Figure 5.4), shielding sleeping bed and shielding headscarf. All of them products in grey colour.

Shielding Clothes

The main interest in the next example lies on its elasticity (80% length, 50 % width). This fabric is a full silvered spandex fabric (Figure 5.5) for low and high frequencies shielding. Due to the elasticity, is a perfect fabric for clothes. Is washable, silver colour, groundable and has a surface conductivity of 0.5 ohm/inch (2,54 cm). The materials are 80% spandex and 20% silver.

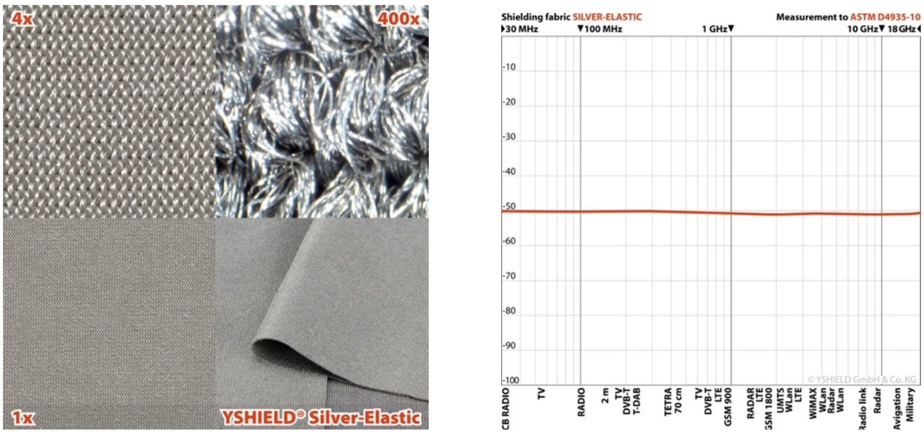

Figure 5.5: a) silvered spandex fabric with different view, b) Screening attenuation.

This material has 50 dB attenuation for 1 GHz and it's very constant for all frequencies. Shielding underpants, hoodies and headgear are made of this elastic fabric.

Shielding Bed Products

Next material is a cotton fabric with a silver thread for shielding against low frequencies fields (Figure 5.6). This material is the softest of this list since is made of 95% cotton, 4% polyester and 1% silver. Washable and groundable.

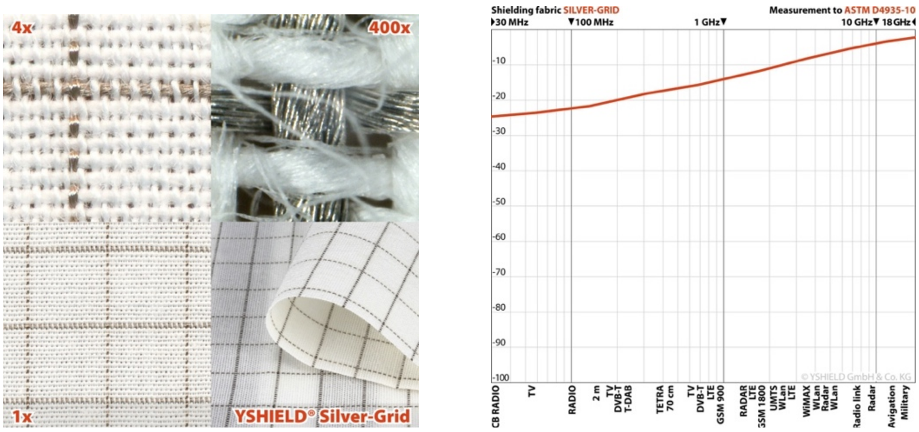

Figure 5.6: a) cotton fabric with silver thread with different view, b) Screening attenuation.

This material has 15 dB attenuation for 1 GH. It works better in low frequencies.

Commercial applications of this fabric are bed products such sheets, blankets, cover duvets, pillow covers and sofa cushions. It is probably the most comfortable material of the list (Figure 5.7).

Figure 5.7: a) shielding pillow cover, b) shielding duvet cover.

Shielding Rooms

Next product is an example of shielding fine metallized polyester fleece (Figure 5.8). It is used for protecting against low and high frequencies, mostly used for walls, ceiling and floors. It is made of polyester, copper and nickel and has a surface conductivity of 0.01 ohm per square resistance. The thickness is 0.16 mm and it needs to be gluing to walls.

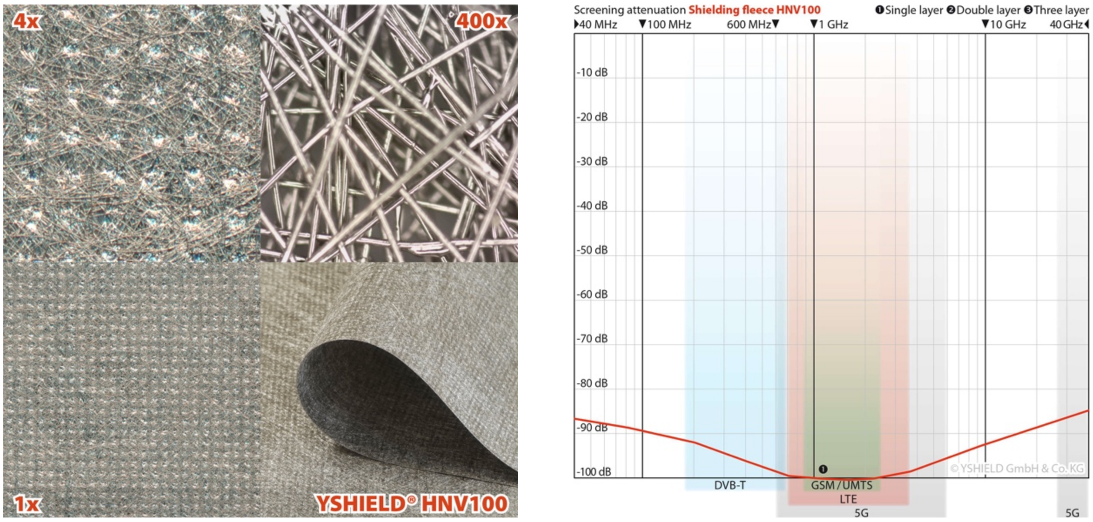

Figure 5.8: a) Fine metalized polyester fleece with different view, b) its screening attenuation.

In the screening attenuation we can observe that fleece has more attenuation tan all the last materials we have seen. With a peak value of 100 dB for 1 GHz, is by far, the best material against high frequencies. As we can observe in the Figure 5.8, is ready for 5 G technology. Since this is a stronger product, is not available for commercial purposes but only for data centres, laboratories and investigation purposes.

Shielding Windows

This product is a shielding window film and it consists of a metal coated adhesive for shielding glass surfaces such windows for high frequencies (Figure 5.9). It is a sticker placed on the window with thickness of 75 µm a light transmission of 72 %.

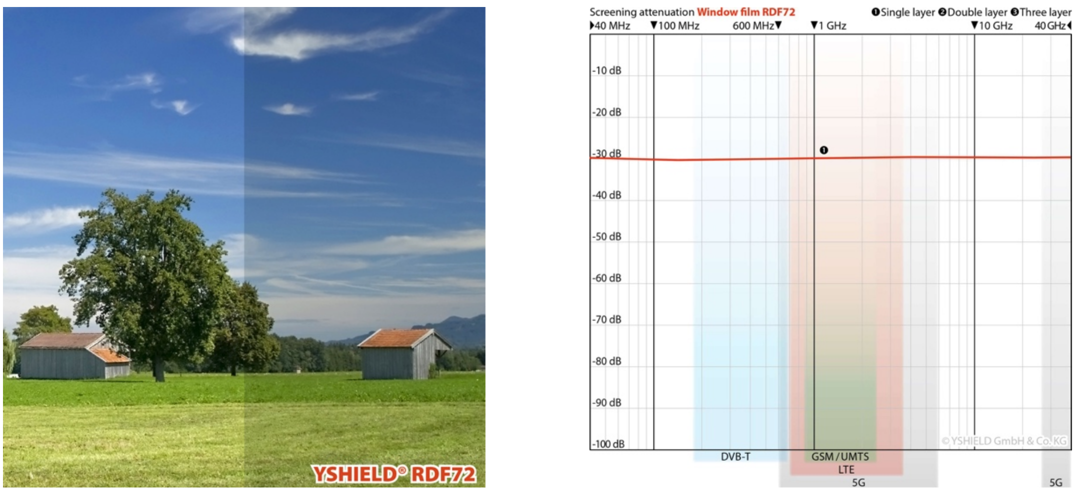

Figure 5.9: a) Fine metalized polyester fleece with different view, b) its screening attenuation.

The shielding window film is made only for indoor and has the constant attenuation of 30 dB for all frequencies.

5.4 Shielding Paints

Shielding paintings against EM radiation are electro-conductive base coatings to shield High-frequency EM fields and/or Low-frequency electric fields. Low-frequency magnetic fields are not shielded.

Walls, ceilings and floor areas are examples of areas of application. Typical areas of application are living areas (e. g. bedrooms, nurseries, living rooms), or the protection of whole buildings.

There are different types of shielding paintings depending on the frequency band we want to attenuate. For each painting, we are going to see the screen attenuation between 40 MHz and 40 GHz, almost linear for all of them.

Typical radiation sources in our homes as GSM/UMTS, LTE, DVB-T, TV, radio, etc. This includes 5G frequency spectrums FR1 (600 MHz – 6 GHz) and FR2 (24 GHz – 40 GHz), last global telecommunication technology implanted in 2020.

Different layers of paint can be applied to obtain greater attenuation. The following graphs show the attenuation of up to 3 layers of paint.

Initially, these shielding paintings are black colour, but it’s possible to add a new colour layer of paint without affecting protection against EM fields.

Materials, characteristics, properties and a brief description of the product are also attached in next point: Examples of shielding paint materials.

Technical applications are not shown in this document and neither some physical nor chemical properties since they are out of the scope of this project. Neither will we dwell on their official certificates or on their ways of disposing of them (they exist).

We will not go into detail of the price of each product, more or less we have the average of 40 €/L to get an idea.
Catalogues and web sites that provide this information will be attached at the end of the document.

All of these shielding paintings must be grounded.

At the end of this section an example will be shown together with a diagram and its explanation.

Some complementary products to these shielding paintings are interesting and also shown in this section because they improve some shielding characteristics.

All of them are for sale to the public and can be easily obtained. No special permissions are needed for their use and all of the measures shown in this section are according to standards IEEE Std 299-2006.

5.5.1 Examples of Shielding Paint Materials

First shielding paint (Figure 5.10) is made with pure acrylics dispersion, carbon fibbers and natural graphite mixed with water and additives. These ingredients are electrical conductively and this paint is suitable for shielding low and high frequencies. Ready for 5 G technology, this paint has excellent adhesion on almost all substrates for indoor and outdoor (Figure 5.11).

Figure 5.10: a) Shielding paint bottle made of carbon fibbers, b) screening attenuation.

Layer	1	2	3
1 GHz value (dB)	32	40	48
Thickness (Ω/sq)	7.8	4.3	2.9

Figure 5.11: 1, 2- and 3-layer's attenuation for 1 GHz (dB) and thickness (in Ω/sq)

Next shielding paint (Figure 5.12) is made of black carbon, natural graphite and pure acrylics dispersion mixed with water and additives. Shielding against high and low frequencies and ready for 5G.

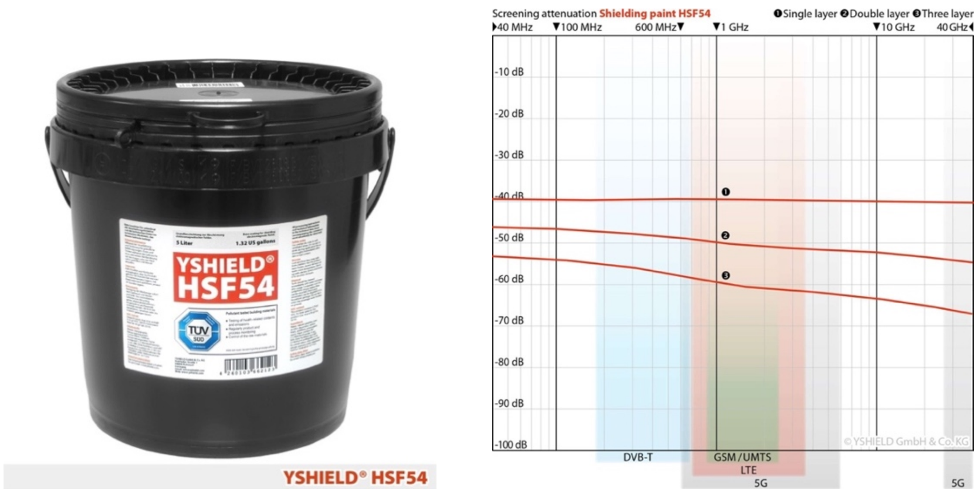

Figure 5.12: a) Shielding paint bottle made of black carbon, b) its screening attenuation.

Layer	1	2	3
1 GHz value (dB)	39	49	59
Thickness (Ω/sq)	5	3	2

Figure 5.11: 1, 2- and 3-layer's attenuation for 1 GHz (dB) and thickness (in Ω/sq)

This shielding paint (Figure 5.12*)* has a very fine surface but is also made for all frequency's attenuation. Made of natural graphite, pure acrylics dispersion and carbon black additives mixed with water and additives (Figure 5.13).

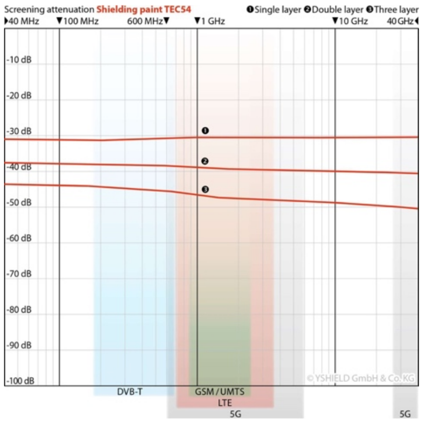

Figure 5.12: a) Shielding paint bottle made of natural graphite, b) its screening attenuation.

Layer	1	2	3
1 GHz value (dB)	30	38	46
Thickness (Ω/sq)	8.6	4.7	3.2

Figure 5.13: 1, 2-and 3-layer's attenuation for 1 GHz (dB) and thickness (in Ω/sq)

Next shielding paint (Figure 5.14) is made of potassium silicate, natural graphite, carbon black and pure acrylics. Is made for all frequencies and its ready for 5 G (Figure 5.15).

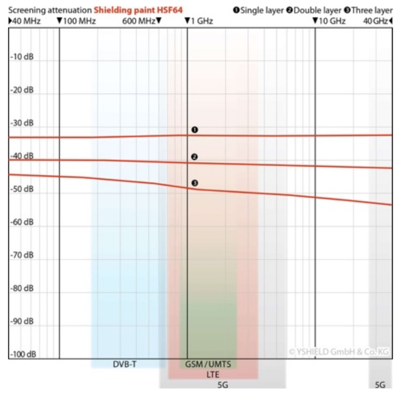

Figure 5.14: a) Shielding paint bottle made of potassium silicate, b) its screening attenuation.

Layer	**1**	**2**	**3**
1 GHz value (dB)	32	40	48

Figure 5.15: 1, 2- and 3-layer's attenuation for 1 GHz (dB)

This shielding paint (Figure 5.16) is made for low frequencies from power lines and electrical devices (Figure 5.17).

Figure 5.16: a) Shielding paint bottle made of carbon black

Layer	**1**	**2**	**3**
1 GHz value (dB)	40	-	-
Thickness (Ω/sq)	70	40	30

Figure 5.17: 1,2- and 3-layer's attenuation for 1 GHz (dB) and thickness (in Ω/sq)

5.5 Accessories for shield painting

Some accessories for shield painting are also available to improve the shield painting. They are made of some carbon fibbers, additives and acrylics to vary the properties of shield painting. In the case of the polymer mixer, it increases the electrical resistance and the adhesion of the paint. Other products can increase the viscosity, promote the adhesion, regulate absorbency or even made the paint so electrically conductive that it doesn't need to be grounded.

Some examples are shown below in next Figure 5.18.

Figure 5.18: a) Polymer for carbon coatings, b) thickener for increasing viscosity, c) carbon fibber additive for guarantee grounded

5.6 Global Approach of Commercial Shielding Materials

As we have seen, the progress of technology in shielding materials has produced a lot of new items now available for home-use to protect us from the EM radiation. In this regard, a variety of electromagnetic shielding fabrics and garments are developed for suitable applications, preferably indoors.

We can observe that their attenuation against frequency varies by product and there is a wide variety of both paint and textile models to protect us from almost all frequency radiations. Various approaches have been observed to prepare textile materials as electromagnetic fields.

Conventionally metallic fibbers are applied to textile materials to improve the attenuation against the EM radiation. As we can approach, conductive metals such copper, silver and nickel are used for theses textiles materials by different techniques. But new materials such some polymers have appear to satisfy some results against EM rays.

6

Special 5G

The 5G, successor of 4G, is the technology that is currently being implanted worldwide. This technology tries to achieve coverage for everyone in any part of the world which means that we are exposing ourselves to new high frequencies of radiation.

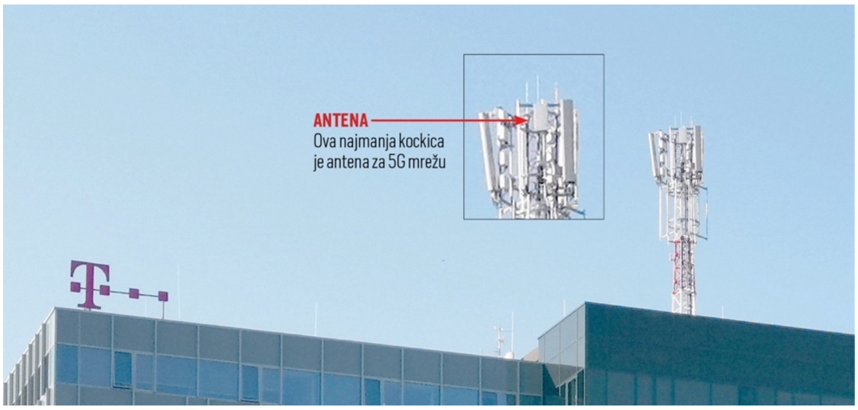

Figure 6.1: 5G Antenna installed in the Telecom building in Zagreb, Croatia

The main advantage of that new network is that they will have greater bandwidth, giving higher download speeds, up to 10 Gbit/s and reducing the latency of the communication. This technology uses different frequency bands to work. Since it has two different frequency spectrums in which it operates, the mid band FR is between 600 MHz – 6 GHz, and the upper band is between 24 and 40 GHz. These bands are demonized FR1 (600 MHz – 6GHz) and FR2 (24 GHz – 40 GHz) as can be seen in the following graphs.

Next, we will see some examples of shielding materials against high frequencies and how can we protect against this radiation. Shielding paints, fabrics and fleeces are exposed then.

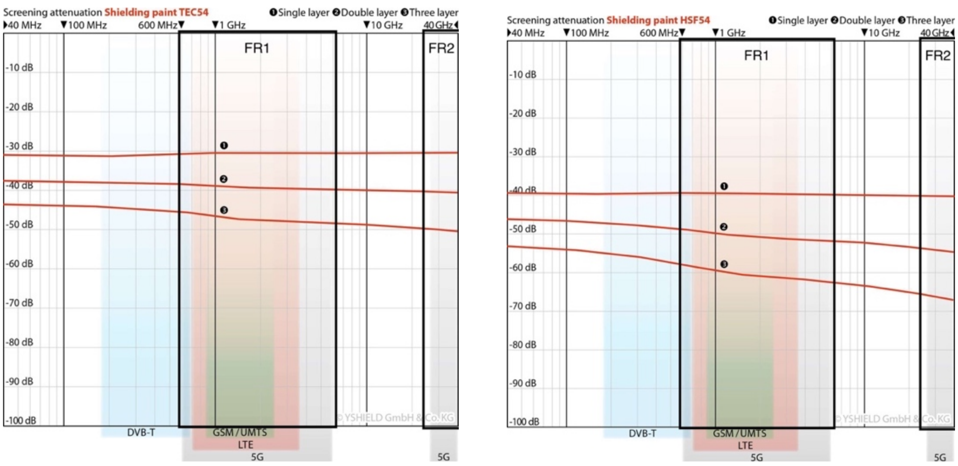

Figure 6.2: Screening attenuation of two shielding paints;
standard one (left) and prepared for 5 G (right)

In the Figure 6.2 we can see the screening attenuation of a standard shielding paint versus the screening attenuation of a shielding paint prepared for 5G technology. Red lines indicate number of layers and the attenuation according to the frequency. The more layers of shielding paint we applied, the more we are protecting and shielding against frequency.

Both frequencies ranges in which 5G operates are also marked.

For the FR1, we can observe that for 1 GHz, with a standard shielding paint we have 30dB, while for shielding paint prepared for 5G, we have 40dB. There is a difference of 10 dB for only one layer. For 3 layers, more than 12 dBs separate these curves.

For the FR2, the second frequency spectrum in which 5G operates, we have 50 dB for a standard paint, against the 67 dB of a shielding paint prepare for high frequencies.

In the case of fabrics, they also exist products better than others. Products used for clothes, curtains or bed sheets have the screening attenuation similar or even more pronounced than shielding paints. Since metals are the best material against the EM radiation, the most effective fabric is made from silver or stainless-steel threads. Is interesting to see that for fabric, only two layers are more effective than the shielding paint. Next Figure 6.3 we can observe the screening attenuation of a fabric that contains stainless-steel.

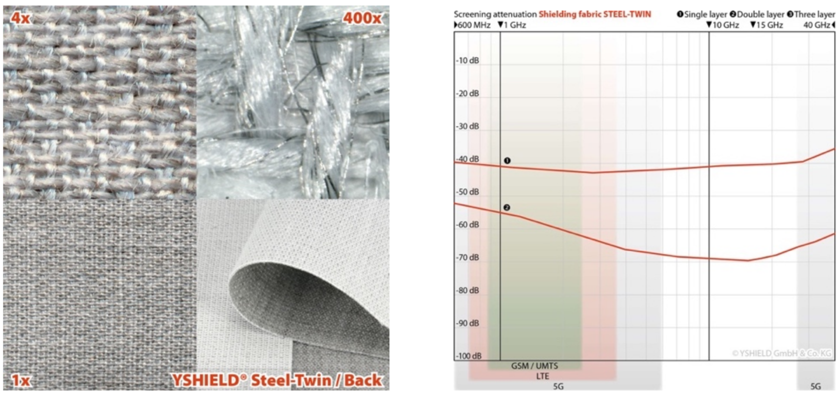

Figure 6.3: a) Stainless steel fabric in different extensions, b) screening attenuation of a shielding fabric prepared for 5G technology

In Figure 6.3: a) we can observe at the maximum zoom the stainless steel mixed with the cotton. This metals usually represents the 17% of the materials. In Figure 6.3: b), we can see that the attenuation of the fabric is strong in high frequencies, with the max value of 70 dB at 15 GHz.

However, the best product against 5 G radiation is a metallized polyester fleece for walls, ceiling and floors made of metals such nickel or copper. With only one layer, can reach values of 100 dB attenuation. Next Figure 6.4 shows the screening attenuation of the shielding fleece. We can observe that attenuation values are even better than shielding paints and fabrics.

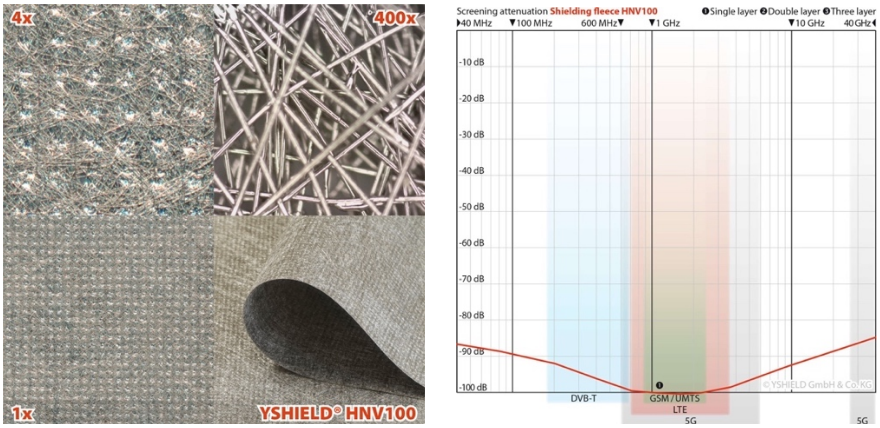

Figure 6.4: a) Shielding fleece in different extensions, b) screening attenuation of a shielding fleece prepared for 5G technology

In Figure 6.4: a) we can observe that more fibbers of metals are present in the material. In Figure 6.4: b), we can see that the attenuation of the fabric is strong in high frequencies, with the max value of 100 dB between 1 and 2 GHz. For measurement equipment, they exist devices prepared and specialised for high frequencies measurements. We will not go into details since we have seen them in the section of measurement devices.

7

Conclusion

In this analysis of EM shielding of materials we have seen how they can protect us from EM radiation. We have seen the diversity of variable electromagnetic rays in the spectrum and the mode of wave propagation waves. We have studied how they behave when they pass through a material, the efficiency with which they do so and the factors that affect this phenomenon. We have also seen that today these EM fields can be easily measured with electronic devices prepared for it and what can be done with certain materials prepared to attenuate these fields. We have seen that there are commercial products that are easy to obtain and that have the necessary technology to protect us from radiation frequencies. We have also discussed a current topic, 5G, the latest advancement and telecommunications technology that is currently implemented today worldwide.

As we have been able to realize, every day we are more affected by electronic objects that emit radiation frequencies, and therefore these materials, still rare and uncommon in our homes, face these signals. Perhaps in the future, it will become normal to have the interiors of the houses painted with shield paint, clothing made from metal fibbers or even window glass that attenuate the electrical and magnetic signal. It is still a challenge for humanity to become aware to protect our health from the diversity of artificial EM radiation that we are creating.

8

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