
WÜRTH ELEKTRONIK CÁTEDRA EMC
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# Magnetic Materials: External solutions to reduce EMI without redesigning

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WÜRTH ELEKTRONIK CÁTEDRA EMC

**CATEDRA EMC WE-UV**

**Würth Elektronik – University of Valencia**

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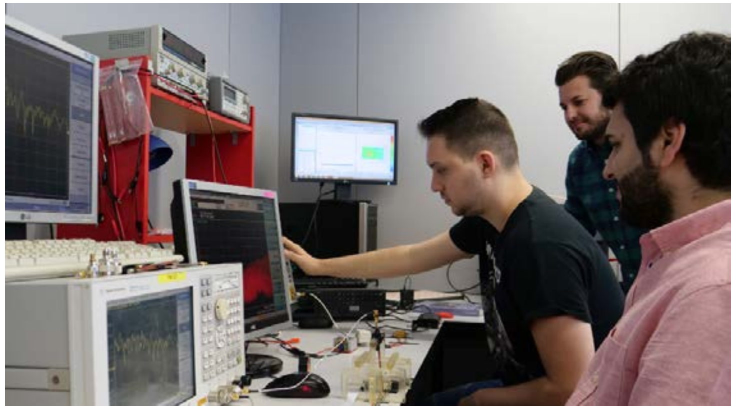
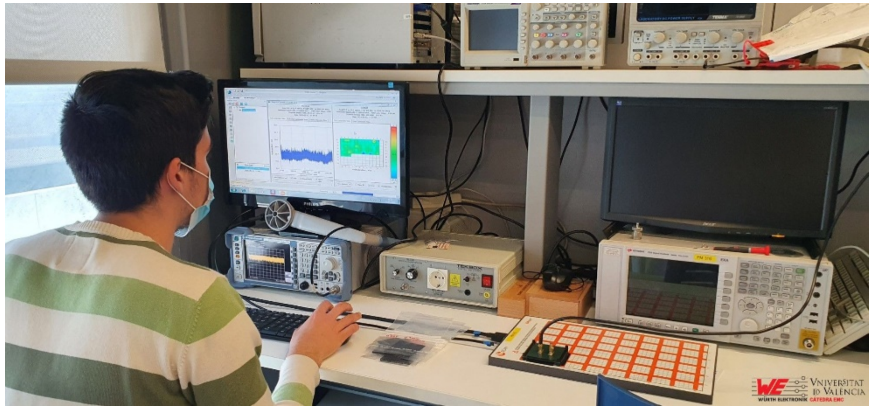
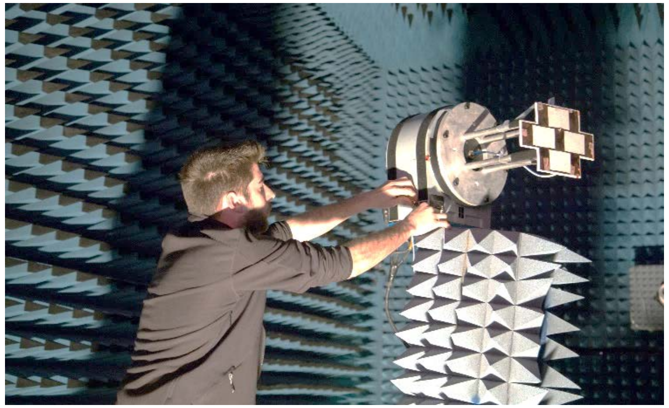
# Catedra EMC WE-UV

- Catedra EMC is a wide and long-term academic collaboration between the company Würth Elektronik and the University of Valencia, which reaches several areas of knowledge related to EMC.
- It extends its activities to all the areas of the university activity:
  - Teaching and Dissemination of science, technology and culture
  - Research and Innovation
  - Training and talent attraction



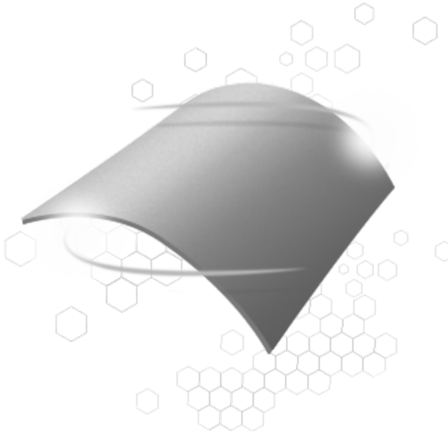




# Outline



1. Electromagnetic Shielding
   - 1.1. Introduction to EM Shielding
   - 1.2. Properties of magnetic materials
   - 1.3. EM Shielding techniques (video-demo 1)
   - 1.4. Shielding RFID/NFC systems (video-demo 2)
2. Cable Ferrites
   - 2.1. Introduction and applications
   - 2.2. Properties of cable ferrites
   - 2.3. Selecting the best cable ferrite
   - 2.4. Insertion loss parameter
   - 2.5. Live-demo



# Outline

1. Electromagnetic Shielding
   1.1. Introduction to EM Shielding
   1.2. Properties of magnetic materials
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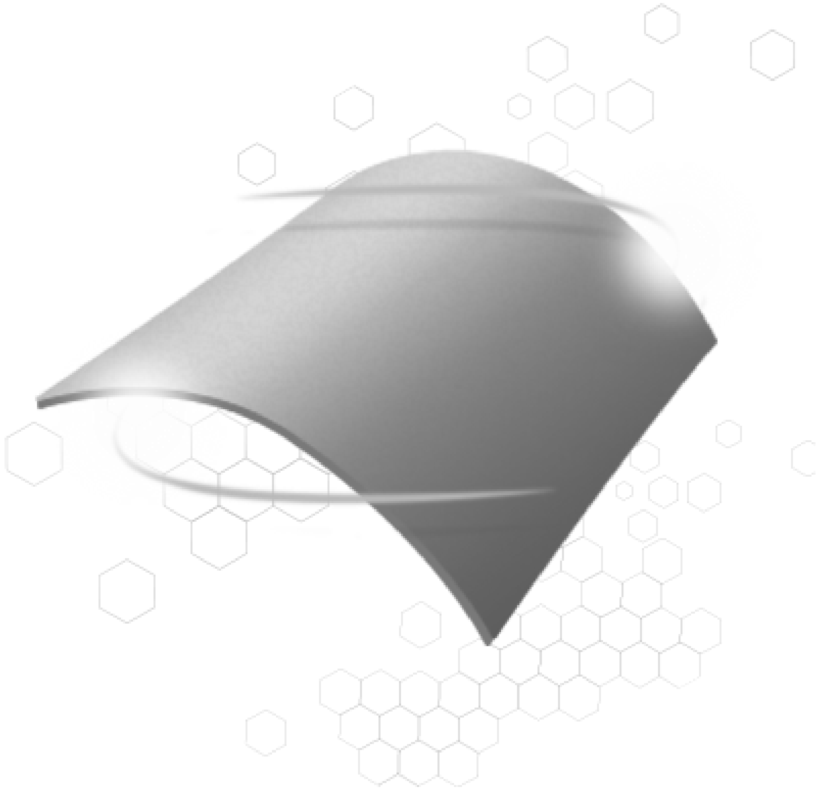
   1.4. Shielding RFID/NFC systems (video-demo 2)



# 1.1. Introduction to EM Shielding



- The trend towards developing smaller electronic devices with more features and better is increasing the problems caused by Electromagnetic Interferences.
- These design requirements may result in the next features:
  - higher component integration
  - PCB size and thickness reduction
  - the miniaturization and weight reduction of the device housing
  - higher switching frequencies in power converters and communication data rates in digital circuits
  - possibility of devices interconnection (wired or wireless)
- Consequently, EMC engineering should be handled with the *system approach*, considering EMC throughout the design process to prevent possible EMI problems that could degrade device performance.
- Adopting specific solutions as early as possible in the design stage to meet the EMC requirements is essential to reduce penalties in costs, time-to-market, and performance.

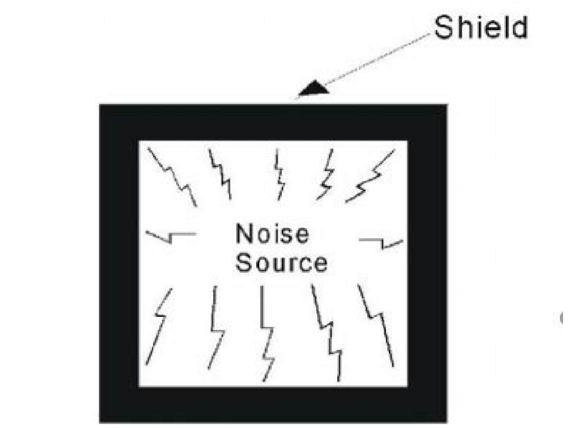
# 1.1. Introduction to EM Shielding

- However, it is not always possible to predict EMI problems during the design stage because it is difficult to consider the real behavior of the final system.
- When a designer faces an EMI problem, the following elements should be identified:

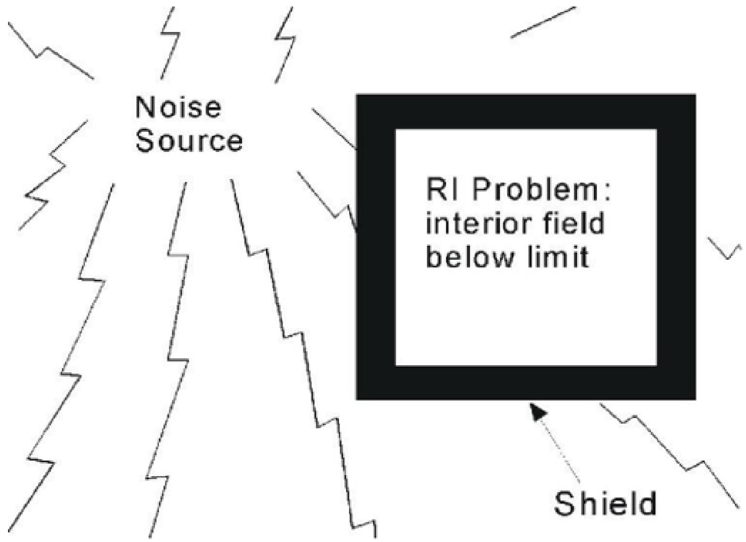

- It is recommended to suppress EMI at its source whenever possible, rather than increasing immunity through the victim's circuit protections.
- A single EMI source could find multiples propagation paths and affecting to several victims.

# 1.1. Introduction to EM Shielding

- An interesting technique used to reduce EMI problems is the use of EM shielding products.
- It can be used to contain the electromagnetic fields generated by an EMI source (reducing its emission) or protecting a sensitive device against the field present in the work environment (increasing its immunity), .




RE Problem: Exterior field below limit




For external noise source (immunity):

# 1.1. Introduction to EM Shielding

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- An innovative technique to solve complex EMI problems is the use of shielding flexible sheets based on magnetic materials.
- These shielding products can be obtained by these two solutions:

Flexible Absorber Sheets (FAS)

FAS solution consists of a composite material with magnetic particles embedded in a polymer.

Flexible Sintered Ferrite Sheets (FSFS)

FSFS is composed of precracked thin ferrite plates placed between a layer of adhesive tape and a PET cover layer.

# 1.2. Properties of magnetic materials

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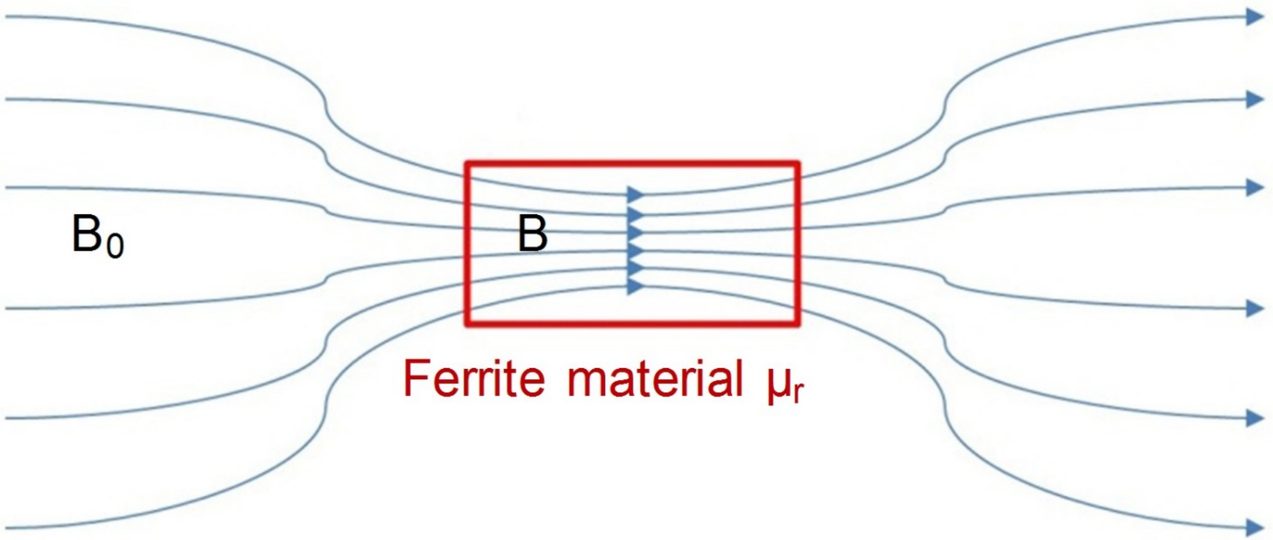
- These magnetic materials have a property which allows them to influence the magnetic field in its environment: RELATIVE PERMEABILITY ($\mu_r$)
- These materials have a greater permeability to magnetic fields than the air around them, which thus concentrates the magnetic field lines.

$$\mu_r = B / B_0 = \mu / \mu_0$$



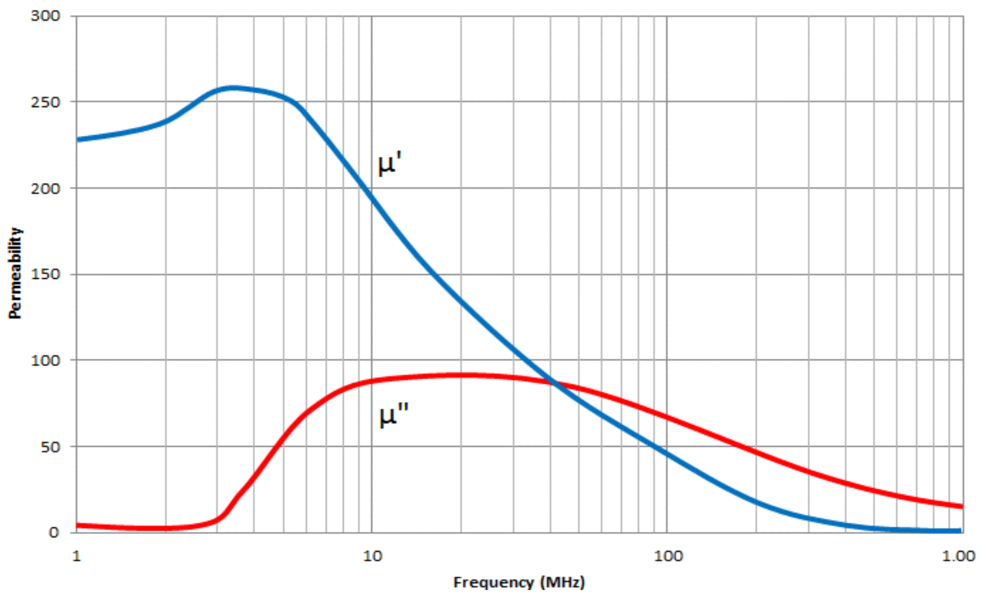
# 1.2. Properties of magnetic materials



- By separating $\mu_r$ into its complex form, the real component provides the reflection part and the imaginary component the absorption part:

$$\mu_r = \mu' - j\mu''$$

- Depending on the application it is possible to choose materials that absorb emissions in a certain frequency range or reflect to concentrate the magnetic flux.




μ′ Inductive part

μ″ Resistive part

# 1.2. Properties of magnetic materials

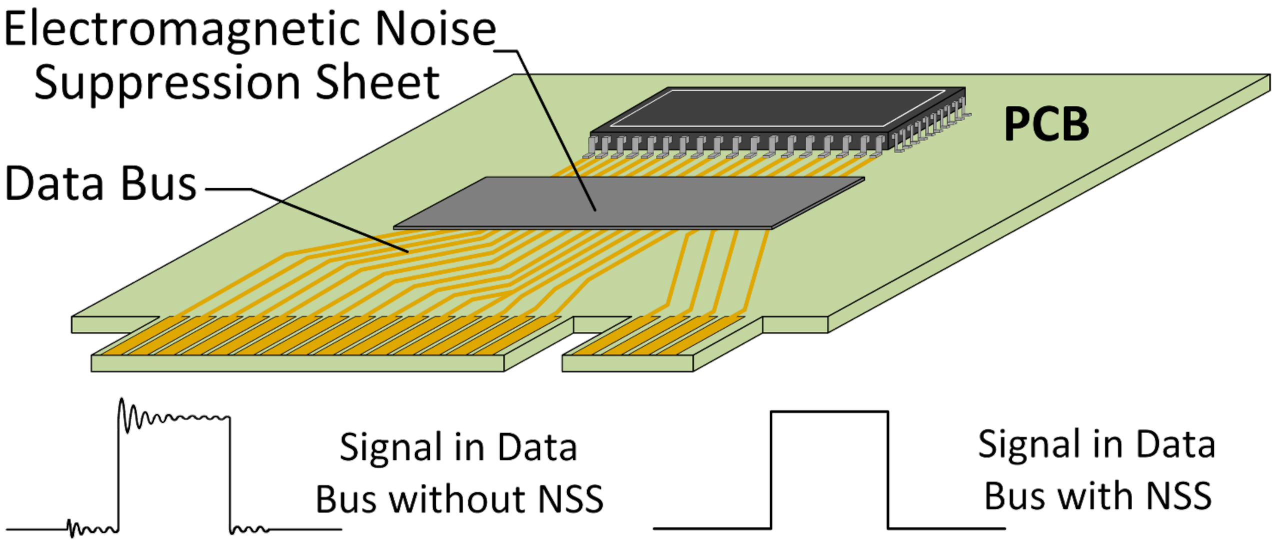


- Besides the permeability, other factors that defines the performance of these sheets are:
  - Sheet thickness.
  - Size and geometry of the sheet.
  - Kind of adhesive.
  - Distance between the sheet and the EMI source.
- In order to analyze the response of these shielding solutions in different applications, it is better to obtain a real approach through some experimental characterization methods.
- Thereby, it is possible to analyze the shielding performance by comparing several sheets and thicknesses that provide different performances.

# 1.3. EM Shielding techniques: Transmission Lines



- This kind of problem can appear in data buses where there are some digital signals switching at some MHz.
- By placing the shielding on the data bus, it acts as a low-pass filter attenuating high-frequency interferences.
- It is possible to use a characterization experimental setup that provides an approach of the shielding effectiveness provided by shielding sheets to reduce transmission line problems.



# 1.3. EM Shielding techniques: Transmission Lines

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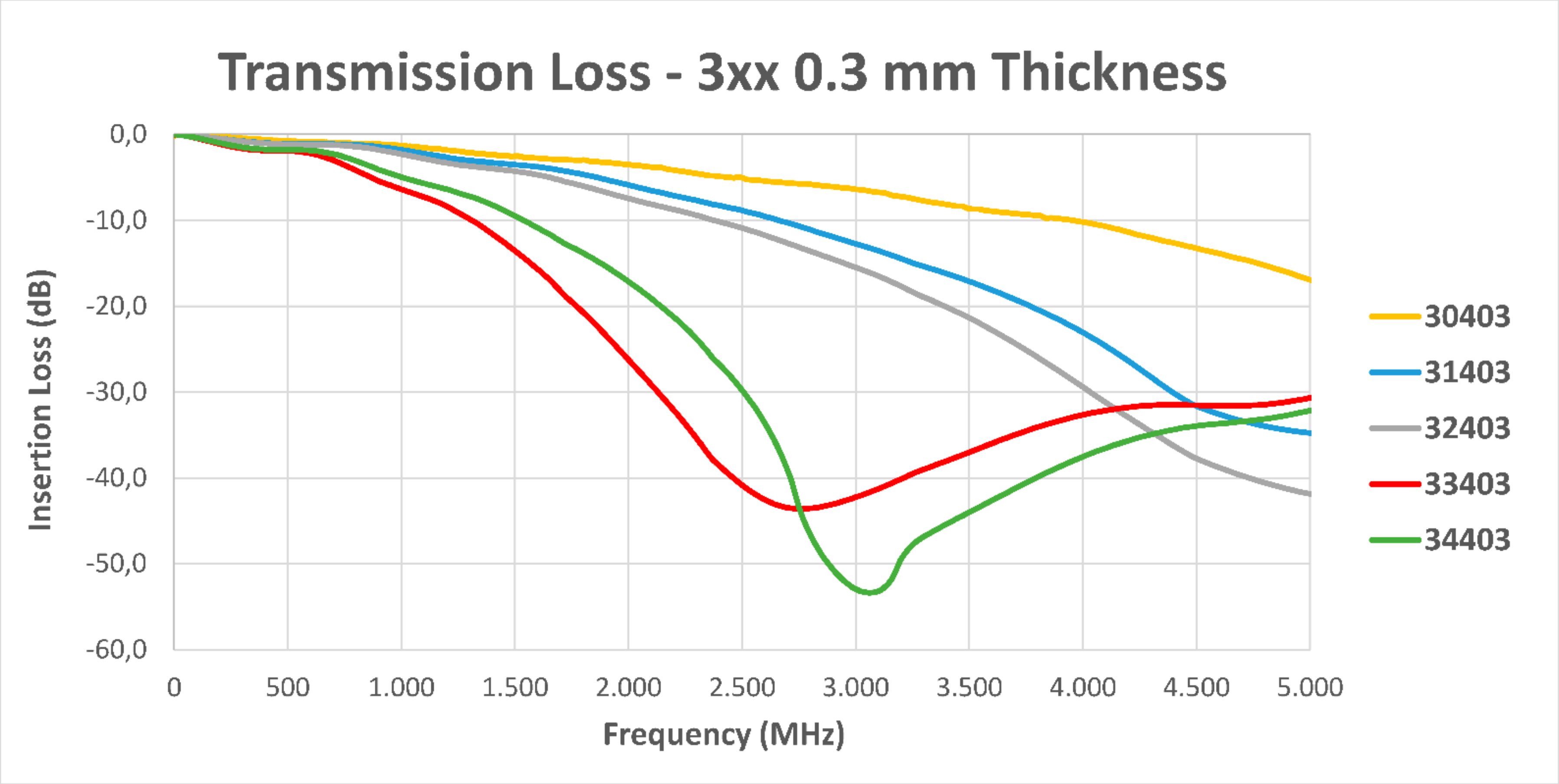
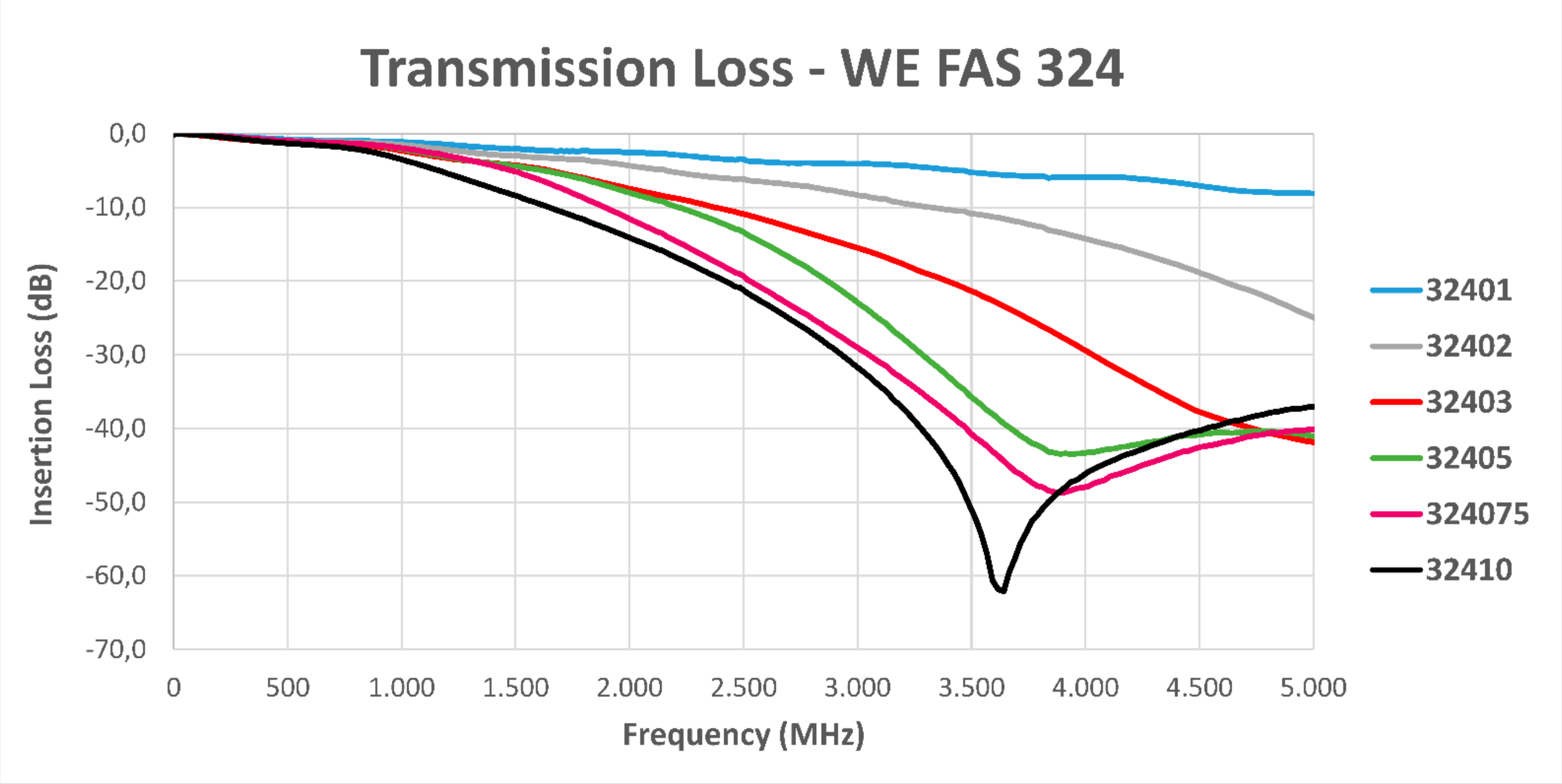
- Transmission Loss parameter measured by selecting some FAS based on different material composition, but the same sheet thickness: 0.3 mm.



# 1.3. EM Shielding techniques: Transmission Lines



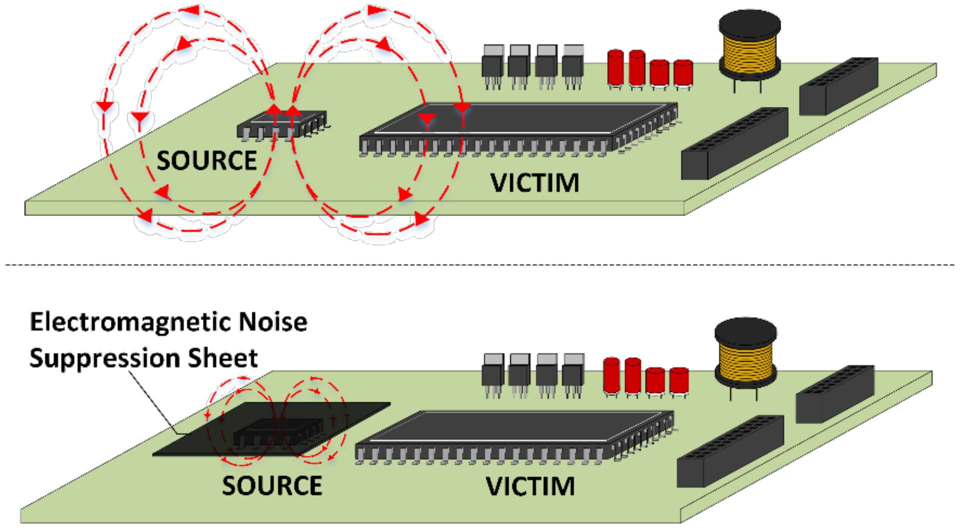
- Transmission Loss parameter measured by selecting the same FAS material composition, but with different sheet thicknesses: from 0.1 mm to 1.0 mm.



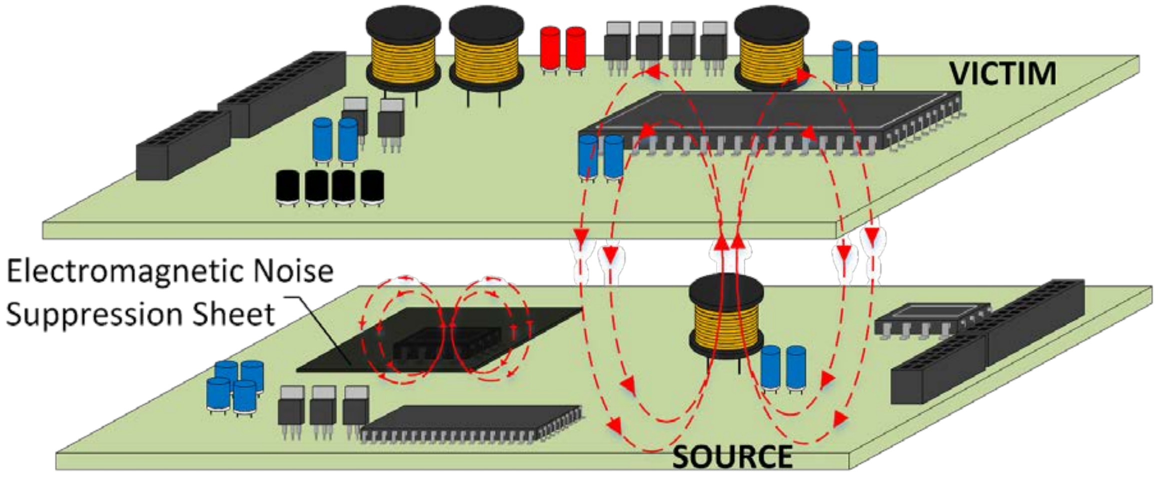
# 1.3. EM Shielding techniques: Magnetic Decoupling

- Magnetic decoupling is a common problem in electronic systems which hold some PCBs or devices with space limits that contain very close electronic circuits.
- It is possible to reduce the interferences by placing the shielding sheet on the EMI source or the victim, to protect it against interferences.

Intra-Decoupling (same PCB)

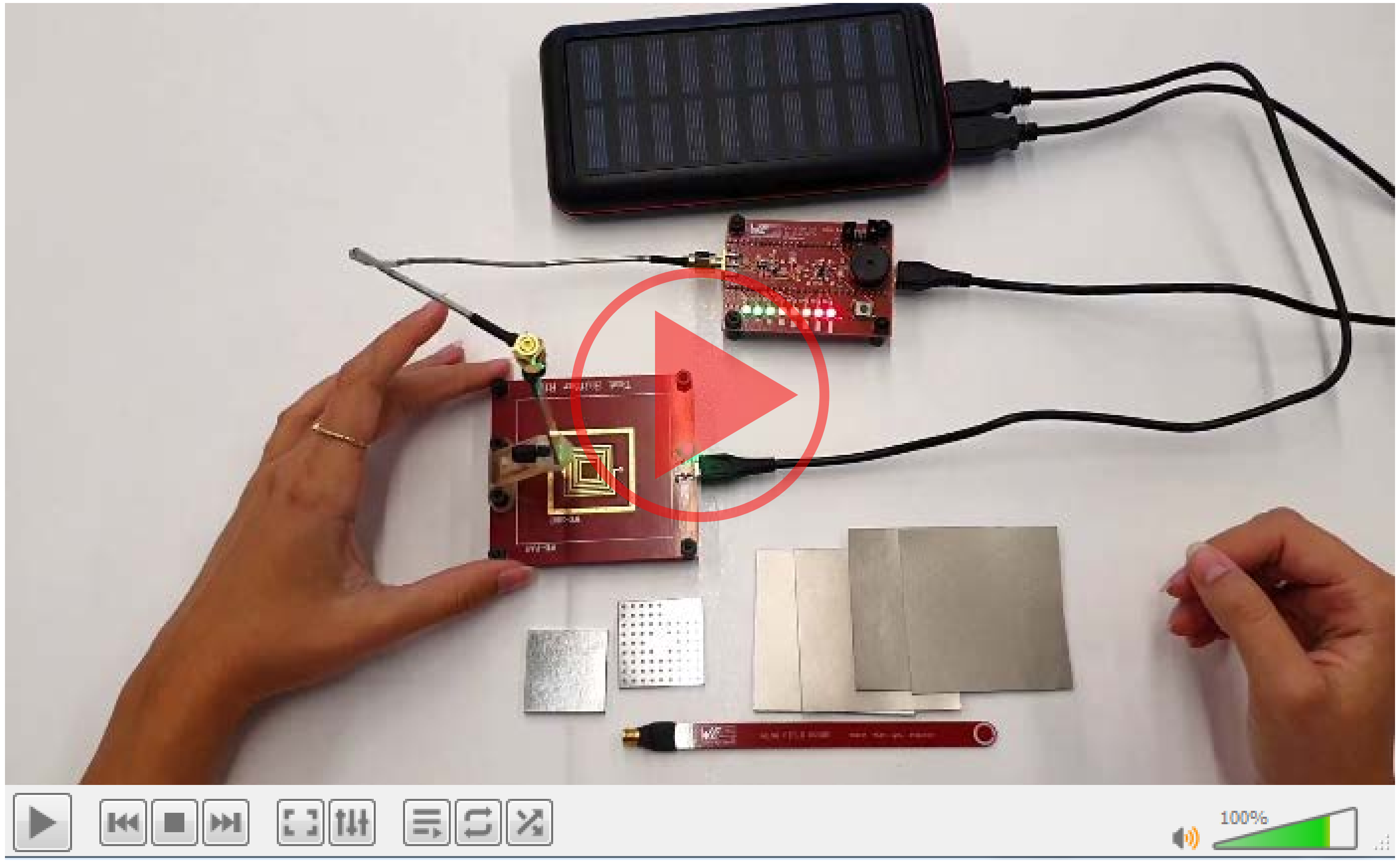



Inter-Decoupling (different PCBs)



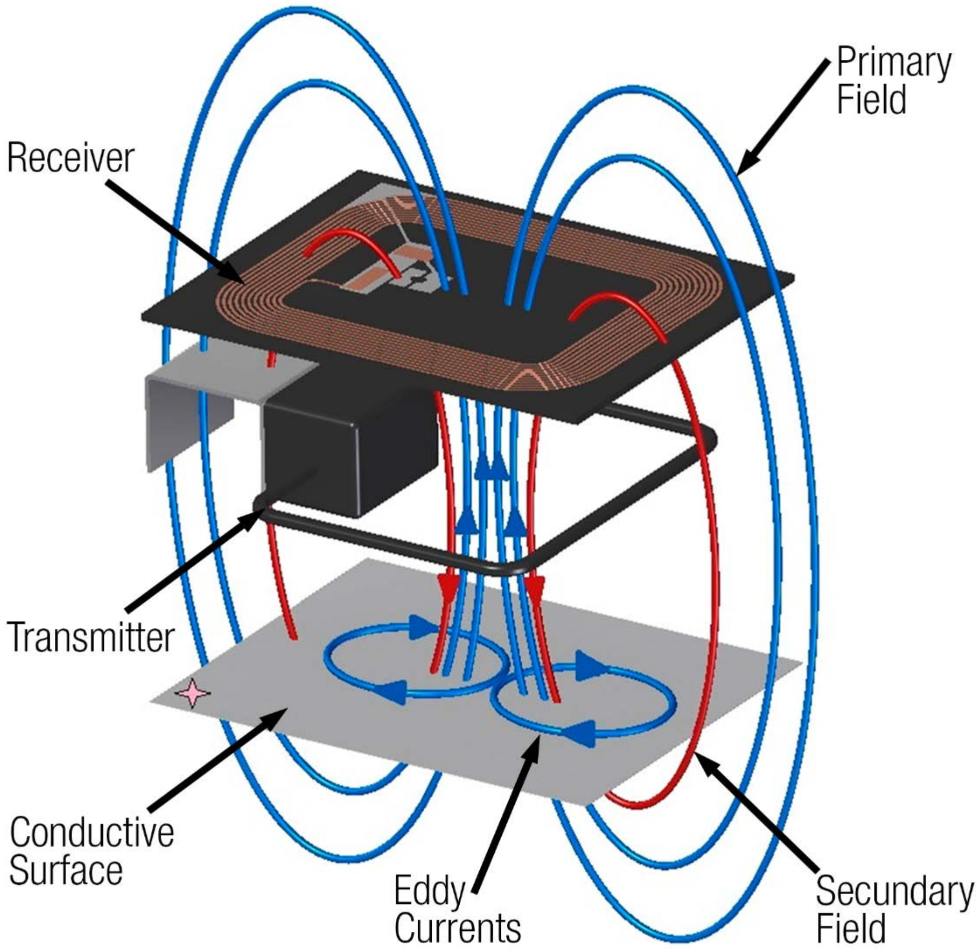
# 1.3. EM Shielding techniques: Magnetic Decoupling

- Next video shows a demonstration about the effectiveness of Flexible Absorber Sheets to reduce magnetic decoupling problems. A high-permeability FAS (3441) is evaluated by using different sheet thicknesses.



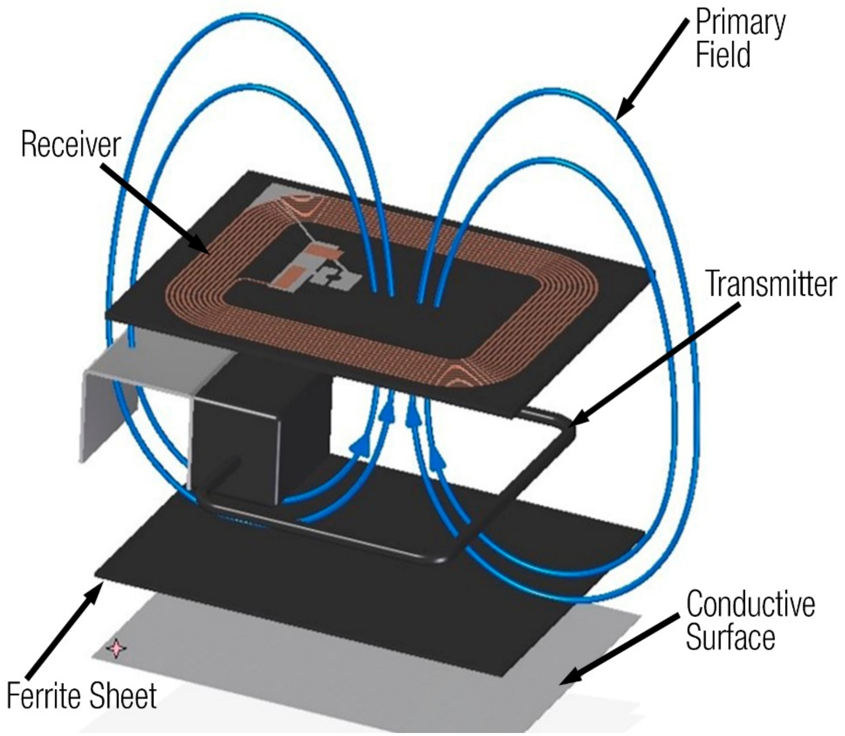
# 1.4. Shielding RFID/NFC systems

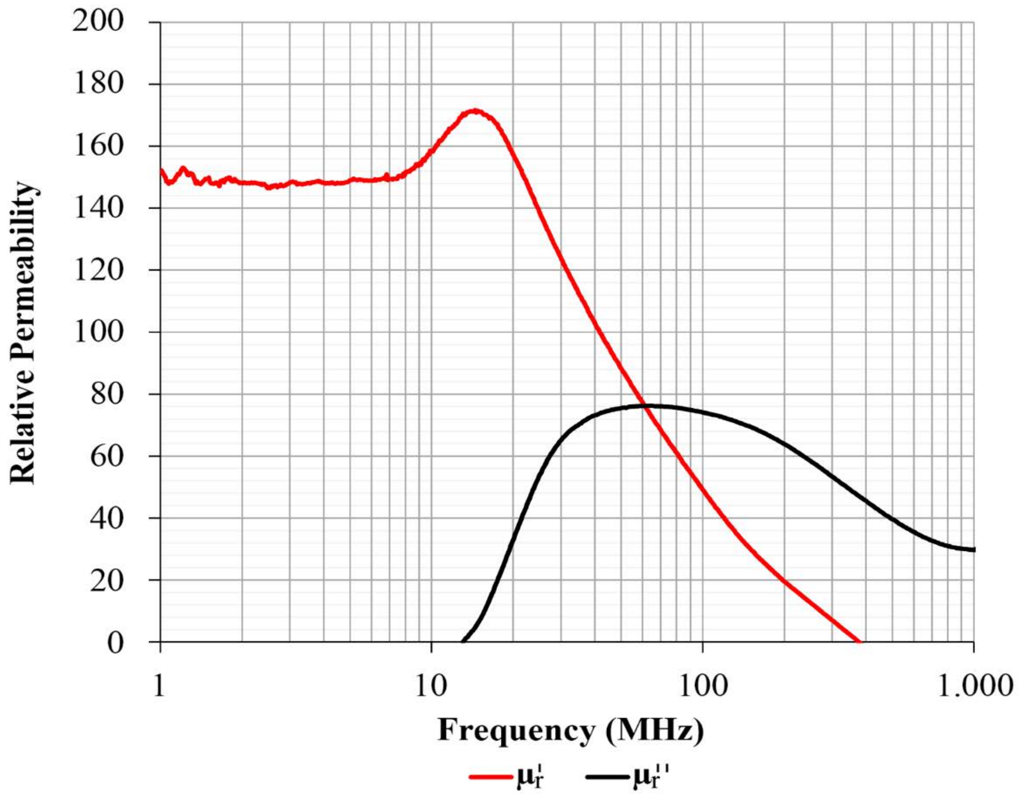
- The reduction of embedded portable devices involves a magnetic field interference problem when it integrates Near Field Communication due to the presence of conductive surfaces such as ground planes, batteries or metallic enclosures.
- When a conductive plane is located under the communication area, the magnetic field lines produce eddy currents, which, generates an opposite stray *H* to the intended primary *H*.
- Therefore, the performance of the magnetic coupling is reduced, resulting in an efficiency reduction of the communication distance.



# 1.4. Shielding RFID/NFC systems

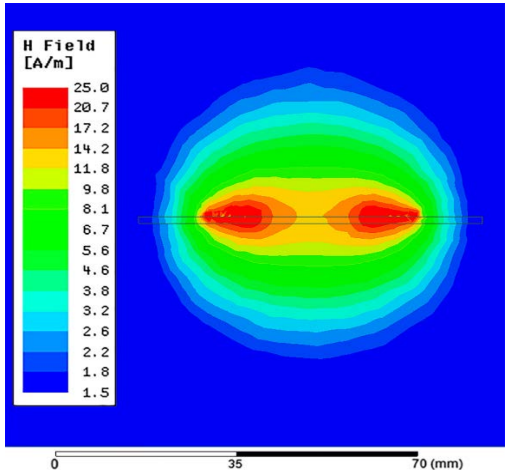
- Magnetic shielding sheets represent an interesting solution to prevent EMI problems related to NFC or RFID thanks to their ability to control the magnetic flux.
- It is important to select a shielding sheet that provides high μ’ and low μ’’ at the communication frequency (13.56 MHz).



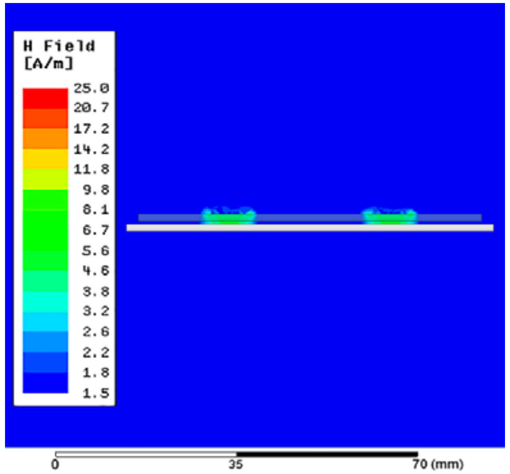



# 1.4. Shielding RFID/NFC systems

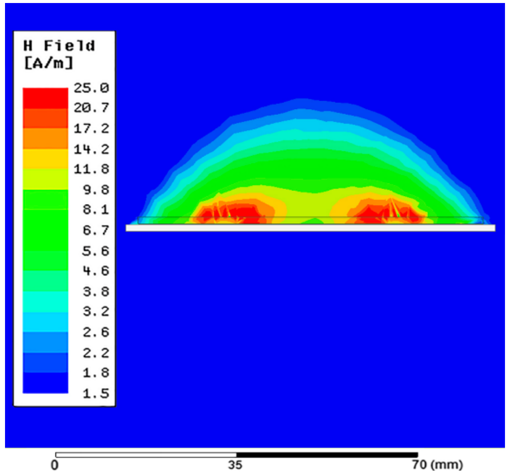
- The simulation of an RFID antenna shows the effect of introducing a conductive surface under the transmitter antenna and the performance of the FSFS shielding to recover the original field of the antenna.
- The FSFS analyzed is the 3641 with the thicknesses 0.14 mm, 0.3 mm, 0.4 mm, and 0.5 mm.



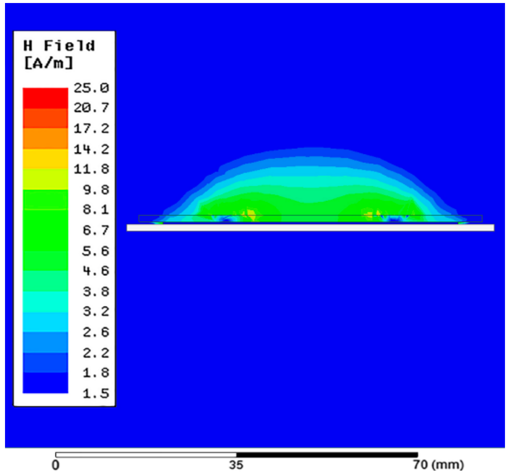
Original Antenna



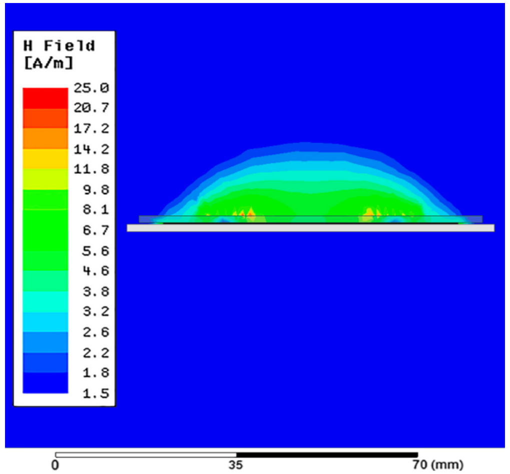
Antenna+Metal surface



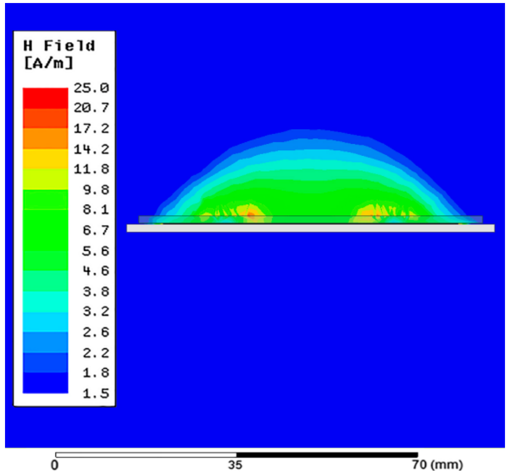
3641014 (0.14 mm)



364103 (0.3 mm)



364104 (0.4 mm)



364105 (0.5 mm)

# 1.4. Shielding RFID/NFC systems

- Next video shows a demonstration about the effectiveness of Flexible Sintered Ferrite Sheets to shield a RFID/NFC communication system against the proximity of conductive surfaces. A high-permeability FSFS (3641) is evaluated.

# Outline



## 2. Cable Ferrites

2.1. Introduction and applications

2.2. Properties of cable ferrites

2.3. Selecting the best cable ferrite

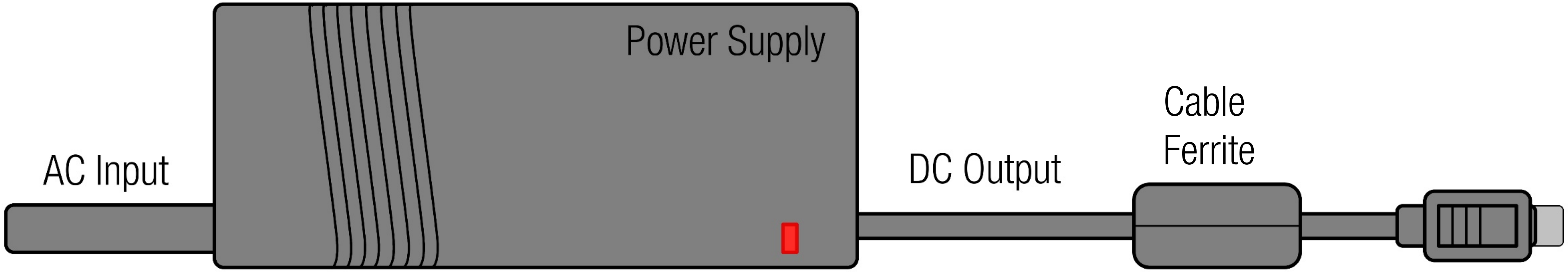
2.4. Insertion loss parameter

2.5. Live-demo

# 2.1. Introduction and Applications of Cable Ferrites



- Unexpected EMI sources in cables can appear in our system when it is connected to another device.
- One of the most used techniques for reducing interferences in cables is applying an EMI suppressor such as a cable ferrite to them.
- This EMI suppressor provides selective attenuation of undesired interference emissions that the designer may wish to suppress and it does not affect the intended signal.
- Thereby, this component is widely used to filter:
  - EMI in power cables to reduce high-frequency oscillations generated by switching transients or parasitic resonances within a circuit.
  - EMI in peripheral cables of electronic devices such as multiconductor USB or video cables.



# 2.1. Introduction and Applications of Cable Ferrites

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## Advantage

It does not involve redesign the electronics and, generally, the mechanical redesign. This is an important advantage because determining in the testing stage which is the EMI source, may not be simple.

## Drawbacks

The addition of an extra component results in increasing the size and weight of the product besides the cost of this.

## Optimization

Determine which material best solve the problem of our design and select the cable ferrite with the lowest weight, dimensions and cost.

# 2.2. Properties of cable ferrites



## Conventional Materials: MnZn and NiZn

Ceramic materials, heat resistance, stability over a wide temperature range,
hardness, high resistance to pressure, possibility of manufacturing components with many different shapes and dimensions

### MnZn

- Initial Permeability: 1000 - 20,000
- Low resistivity: 0.1 – 100 Ω·m
- Frequency range: from hundreds of kHz to some MHz

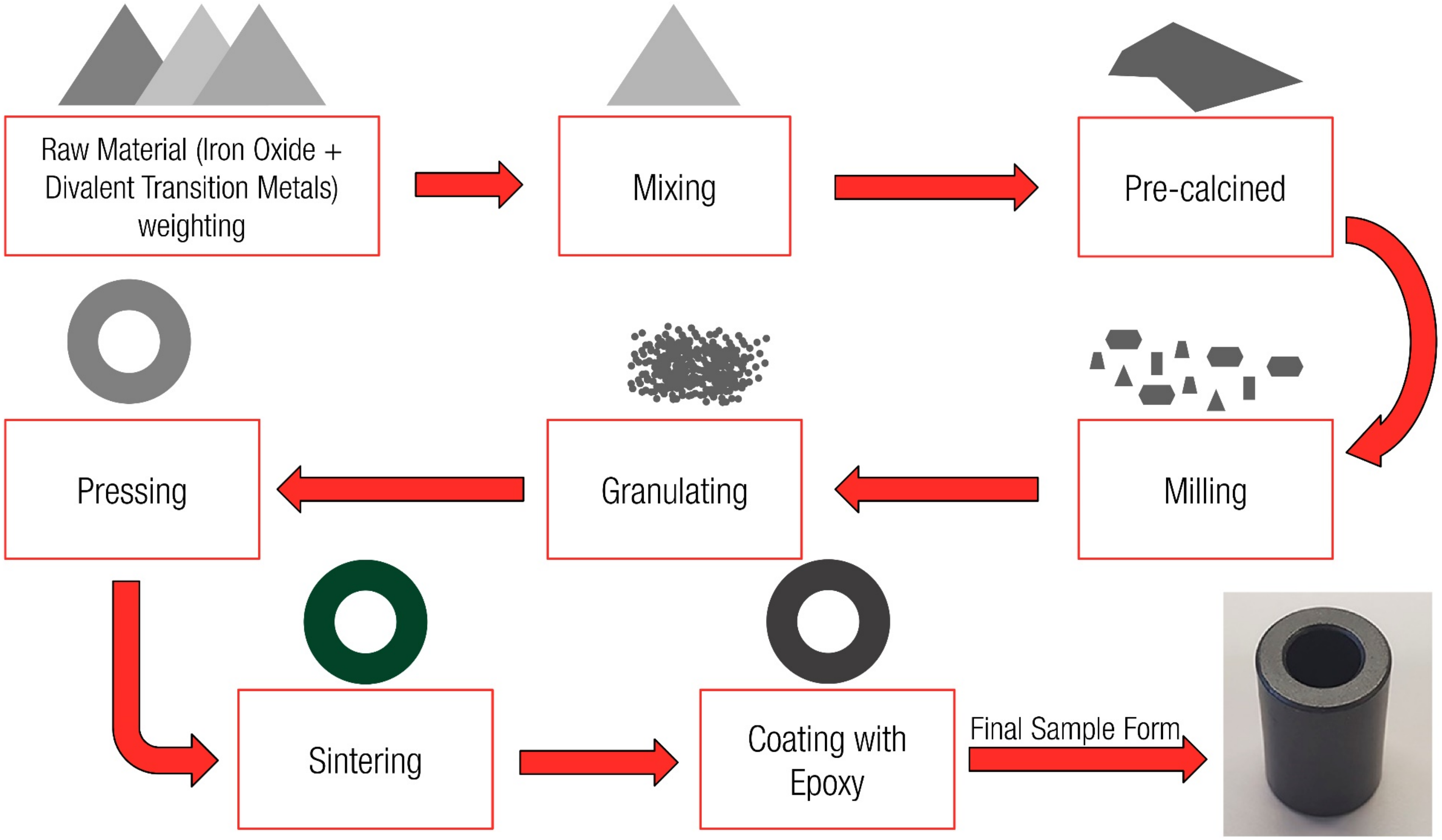
### NiZn

- Initial Permeability : 100 - 2000
- High resistivity : $10^4$–$10^6$ Ω·m
- Frequency range: from tens of MHz up to several hundreds of MHz

# 2.2. Properties of cable ferrites



## Conventional Materials: MnZn and NiZn

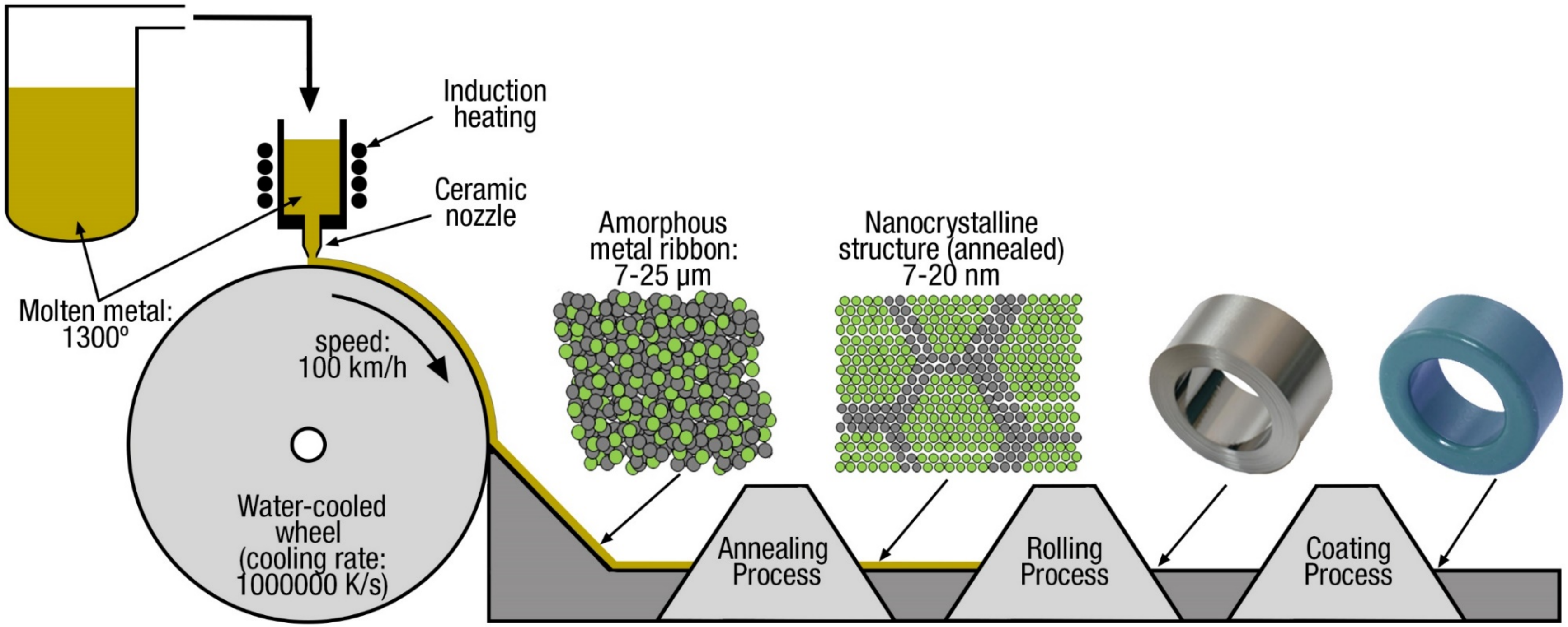


# 2.2. Properties of cable ferrites



## Materials with Nanocrystalline structure

- Very high initial permeability (15,000 to 150,000)
- Low resistivity since it is defined as a metal ($10^{-6}\ \Omega\cdot m$)
- Complicated manufacturing non-toroidal samples
- Protected with a case or epoxy coating



# 2.2. Properties of cable ferrites

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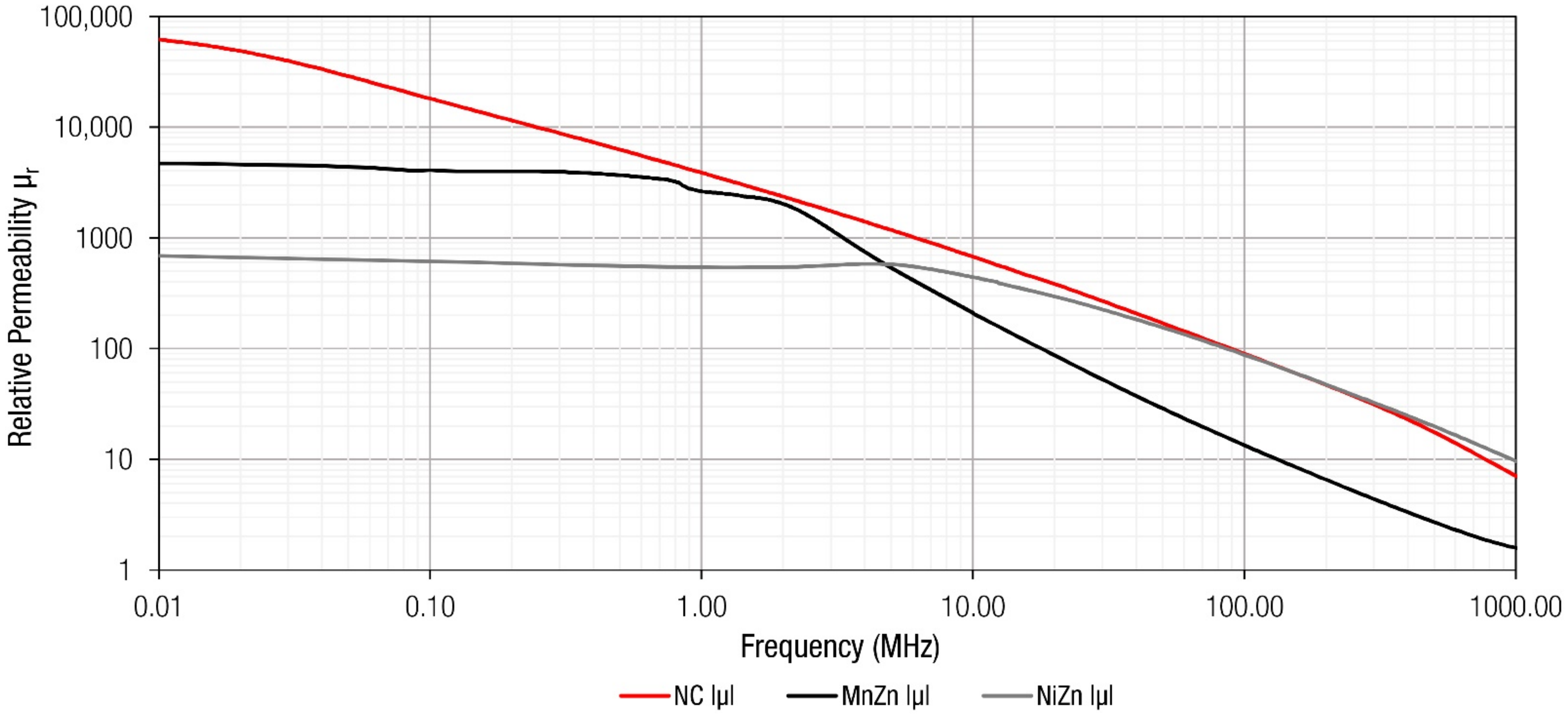
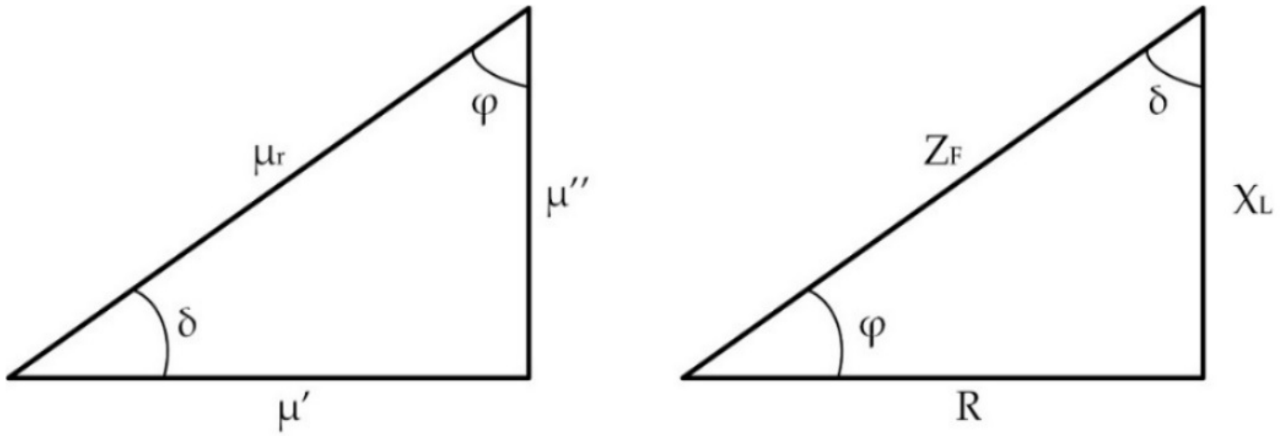
## Relative Permeability |μ|



# 2.2. Properties of cable ferrites

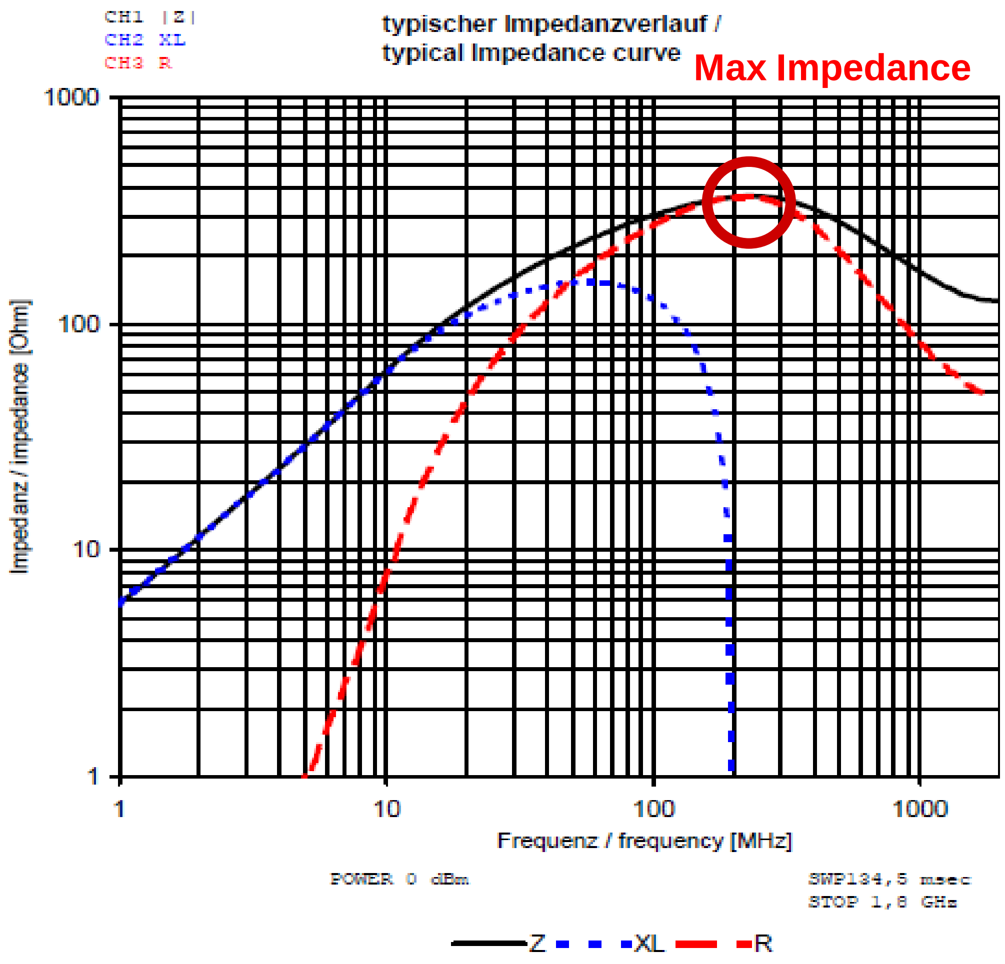
## Permeability and Impedance relation




$$L = \frac{\mu_0 \mu' N^2 A}{\ell} \qquad R = \frac{\mu_0 \mu'' N^2 \omega A}{\ell}$$

*N* is the number of turns, *A* ferrite transversal section and *l* is the magnetic path length

## Impedance vs Frequency

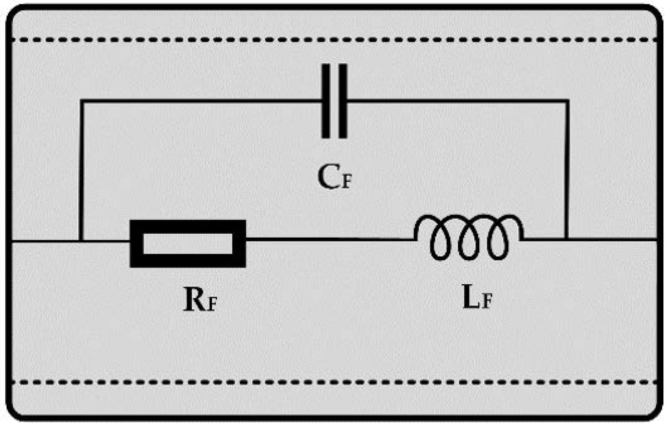


# 2.2. Properties of cable ferrites

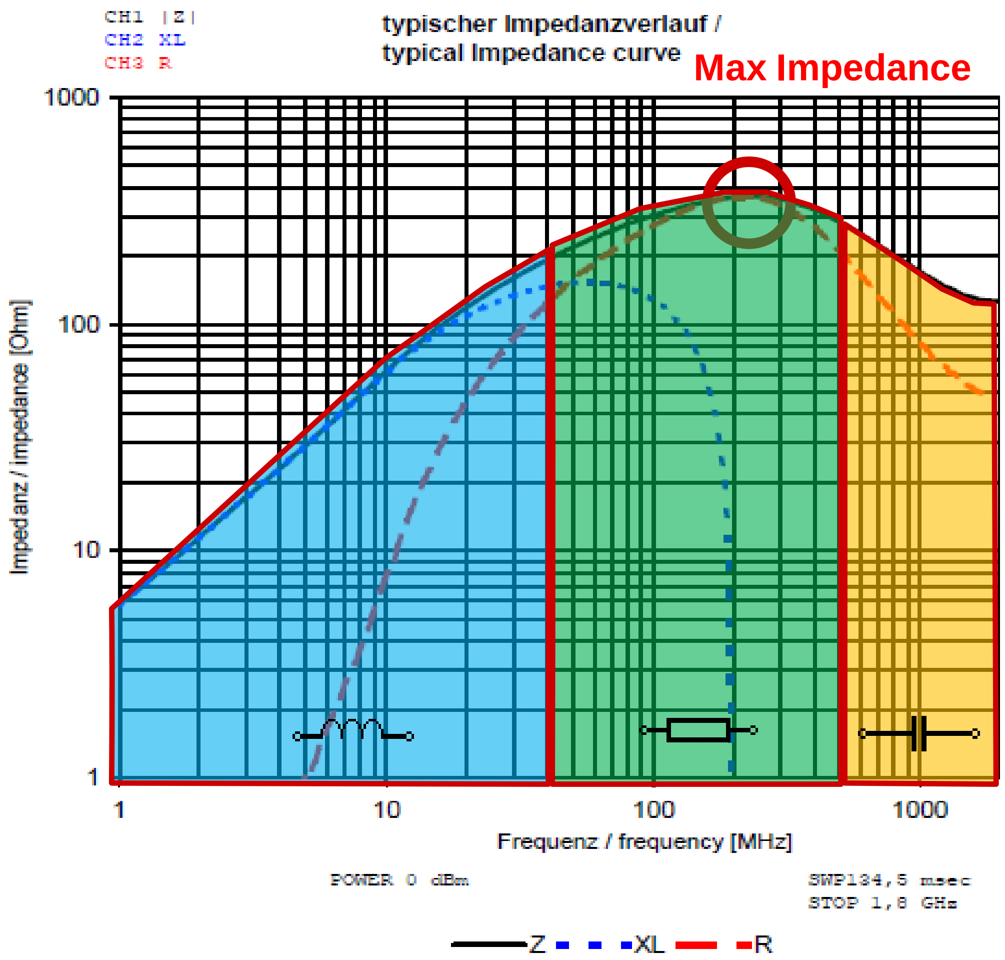


## Cable Ferrite equivalent model

$$|Z_F| = \sqrt{R^2 + (X_L)^2}$$




## Impedance vs Frequency



# 2.3. Selecting the best cable ferrite

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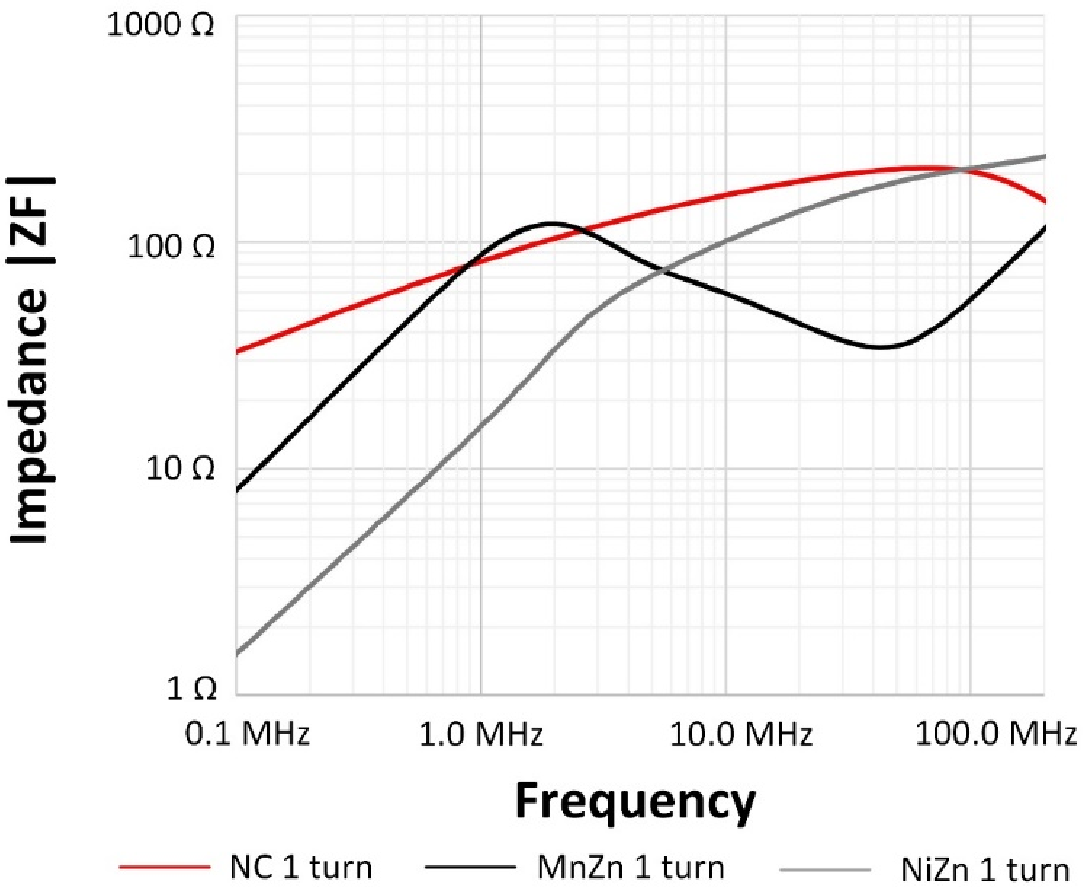
- It is essential to know at which frequencies are located the EMI problems to select the most suitable cable ferrite material.



# 2.3. Selecting the best cable ferrite

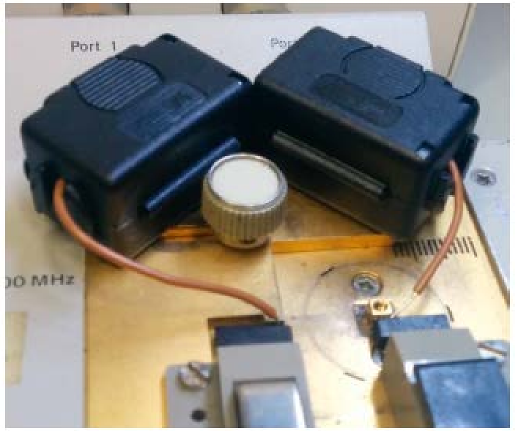
- It is possible to increase the impedance that a cable ferrite introduce into a cable by placing two of them or by increasing the number of turns but, which solution is more interesting?

Increasing the number of turns N does not increase in costs and allows to obtain an impedance proportional to the square of N. However, the L and C are increased and the SFR decreases in frequency.

$$|\underline{Z}| = \mathbf{N^2} * \mu_0 * \sqrt{(\mu_r'')^2 + (\mu_r')^2} * f * l * \ln(\mathbf{A})$$

Increasing the number of ferrites N increases costs and makes it possible to obtain an impedance proportional to twice that of N. It increases L, but also R.

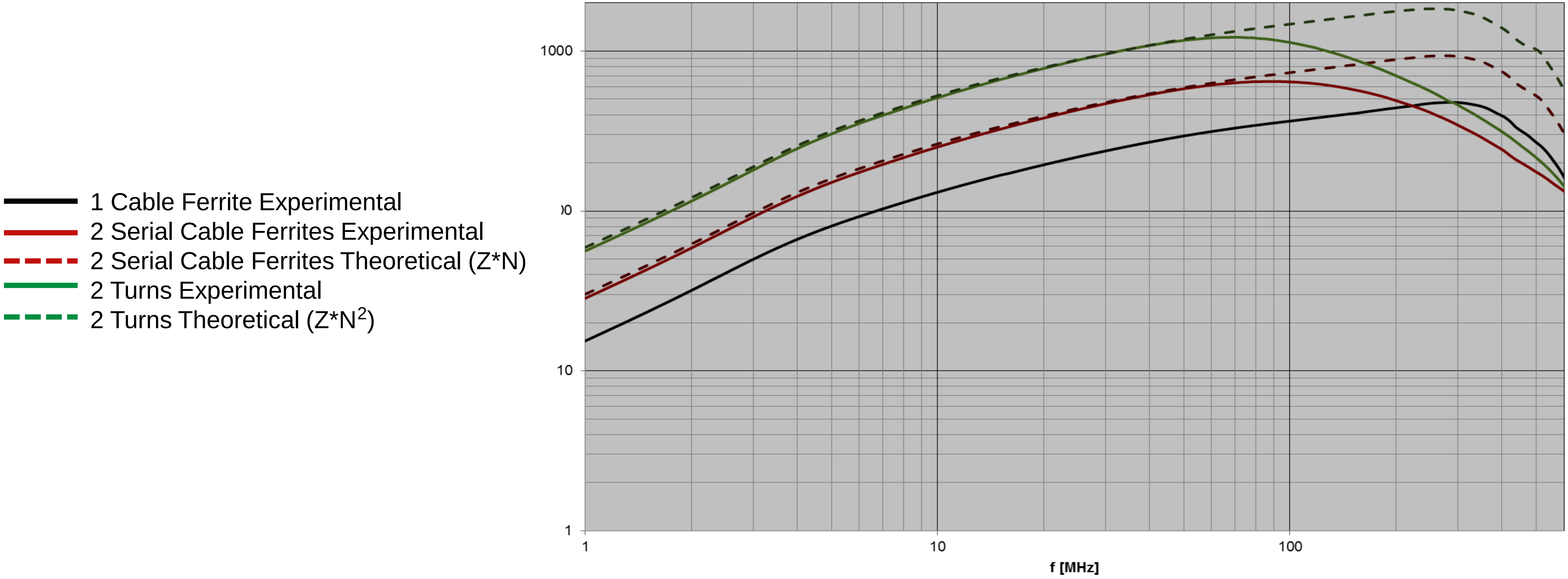
$$|\underline{Z}| = \mathbf{N} * \mu_0 * \sqrt{(\mu_r'')^2 + (\mu_r')^2} * f * l * \ln(A)$$



# 2.3. Selecting the best cable ferrite



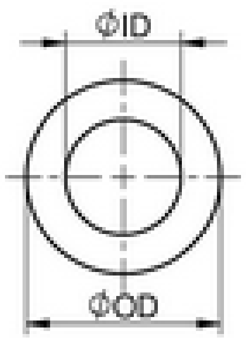
- It is possible to increase the impedance that a cable ferrite introduce into a cable by placing two of them or by increasing the number of turns but, which solution is more interesting?

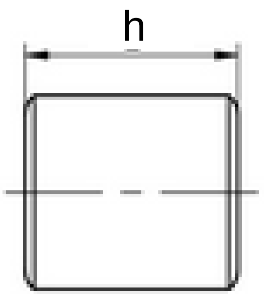


# 2.3. Selecting the best cable ferrite



- Other important parameter to be considered in the selection of the cable ferrite is the dimensions.
- The optimized dimensions of the cable ferrite can be determined by considering the impedance needed to attenuate the interferences in the cable to be protected.
- This formula makes it possible to calculate the impedance provided by a certain cable ferrite by knowing its dimensions and relative permeability:




$$L_0 = \frac{N\Phi_B}{I} = \frac{\mu_0 N^2 h}{2\pi} ln\left(\frac{OD}{ID}\right)$$

$$L_F = \mu_r L_0 = \frac{\mu_0 \mu_r N^2 h}{2\pi} ln\left(\frac{OD}{ID}\right)$$

$$Z_F = \omega L_F$$

# 2.3. Selecting the best cable ferrite

- Considering these parameters, to maximize the impedance provided by the cable ferrite it is interesting select the maximum *OD/ID* ratio and height while the *ID* is as tight as possible to the cable diameter.
- Nevertheless, the increase of the dimensions is usually proportional to its weight, volume and cost. Hence, a balance between these three features and performance should be carried out.
- Thereby, it should be taken into account that:
  - the impedance is proportional to the natural logarithm of the ratio of the outer to the inner diameter and directly proportional to the height.
  - even though *h* is directly proportional to the impedance, the natural logarithm provides an attenuation factor when the ID is lower than 2.7 times the *OD*, so that it is crucial not selecting thin cores since
    - for instance, *OD/ID* ratios of 2.0 or 1.5 reduce the performance of the sleeve core about 30% and 60%, respectively.

# 2.3. Selecting the best cable ferrite

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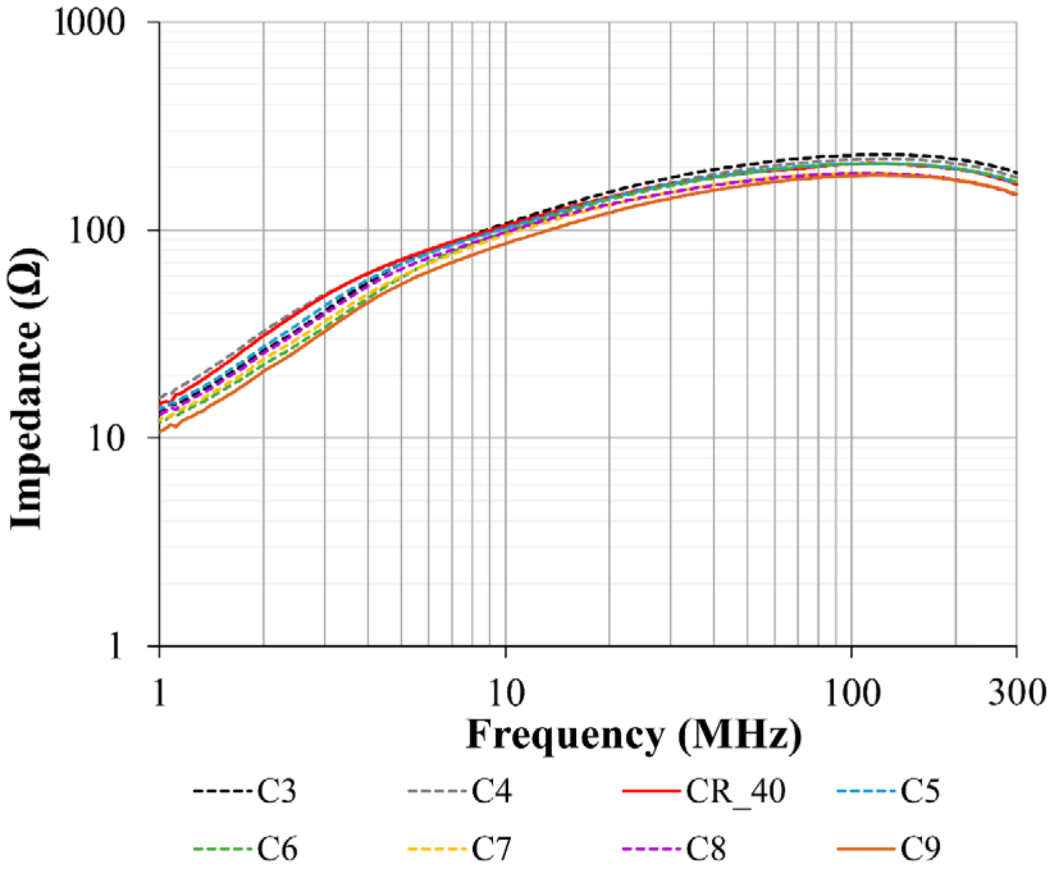
- Therefore, not always the cable ferrite with higher volume provides the best performance.

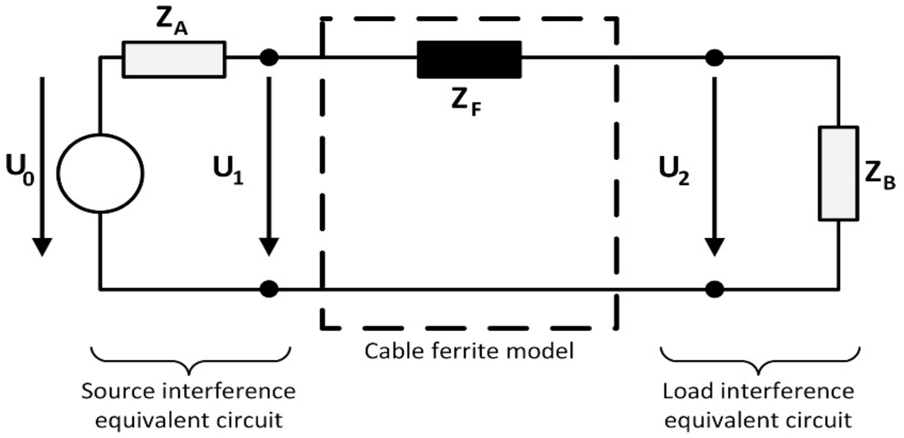
| ID | h (mm) | OD/ID (mm) | Vol. (cm³) | $L_0$ (nH) | $Z_F$ @100 MHz (Ω) | $L_0$/h (nH/mm) | $Z_F$/h (Ω/mm) |
|---|---|---|---|---|---|---|---|
| C3 | 28.5 | 2.22 | 3.50 | 4.55 | 228.0 | 0.16 | 8.00 |
| C4 | 28.5 | 2.12 | 4.18 | 4.29 | 217.4 | 0.15 | 7.63 |
| CR_40 | 40.0 | 1.65 | 7.19 | 4.02 | 208.0 | 0.10 | 5.20 |
| C5 | 28.5 | 2.00 | 4.30 | 3.95 | 207.8 | 0.14 | 7.29 |
| C6 | 28.5 | 2.00 | 11.35 | 3.95 | 207.4 | 0.14 | 7.28 |
| C7 | 15.0 | 3.33 | 1.54 | 3.61 | 186.9 | 0.24 | 12.46 |
| C8 | 28.5 | 1.84 | 4.83 | 3.48 | 187.0 | 0.12 | 6.56 |
| C9 | 25.0 | 1.97 | 2.94 | 3.40 | 181.9 | 0.14 | 7.28 |



# 2.4. Insertion Loss parameter



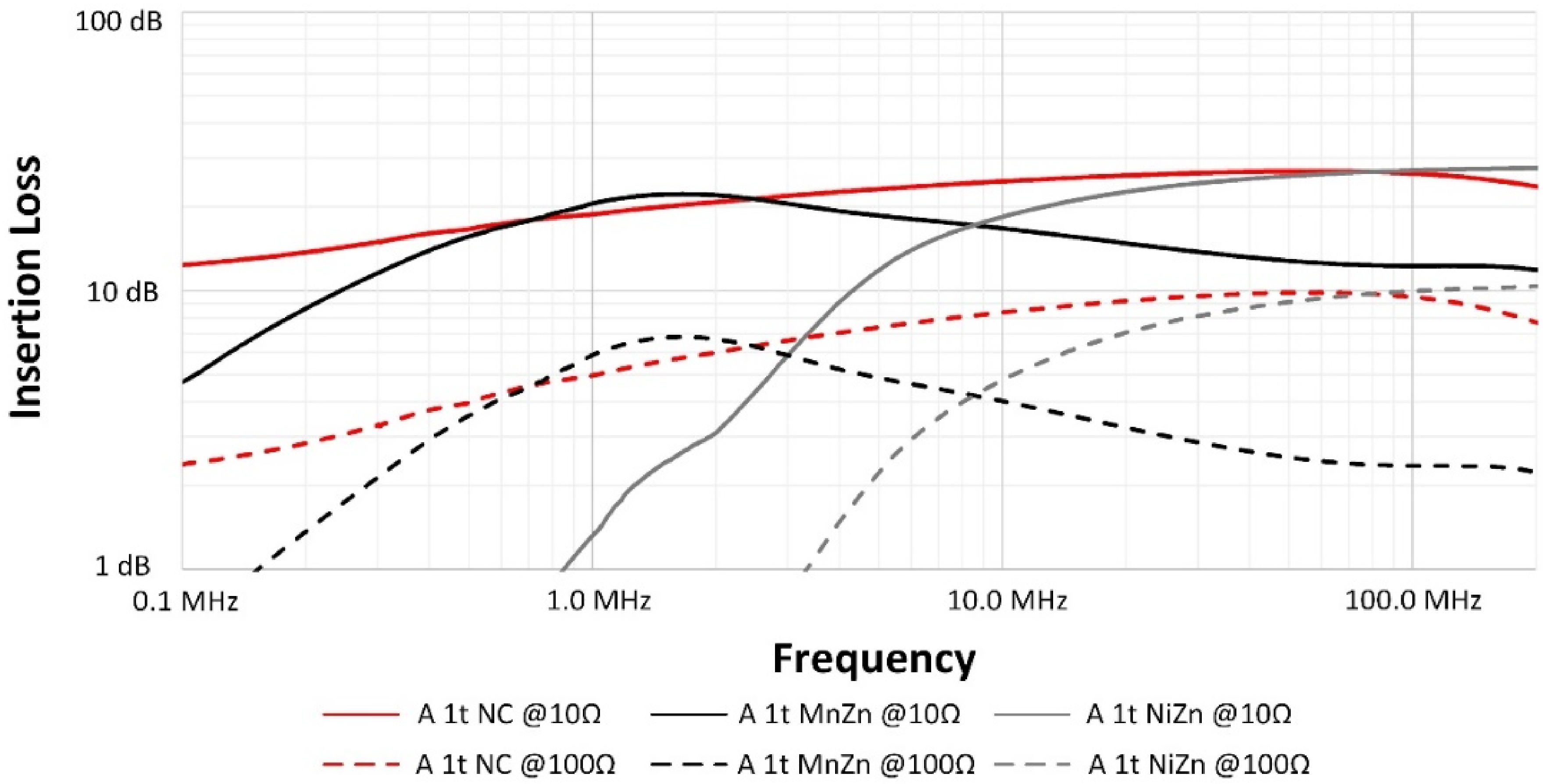
- Sometimes it is difficult to determine the impedance of the system with EMI problems accurately; however, depending on the signals that flow through the cable, it is possible to estimate this value:
  - Ground surfaces usually present impedances from 1 to 2 Ω.
  - Supply voltage lines have impedances from 10 to 20 Ω.
  - Video, clock, and data lines from 50 Ω to 90 Ω.
  - Long data lines from 90 Ω to 150 Ω and higher.
- The theoretical insertion loss or attenuation of a specific cable ferrite can be determined from its impedance response by considering the equivalent circuit approach.




$$IL(dB) = 20 \log \left( \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \right)$$

# 2.4. Insertion Loss parameter

- If ZA = ZB = 10 Ω (solid lines) and ZA = ZB = 100 Ω (dashed lines) cases are considered, the following Insertion Loss is obtained for N=1:

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## THANKS FOR YOUR ATTENTION!

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