WHEN ELECTRONICS MISBEHAVE: AN INTRODUCTION TO EMC

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WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

CATEDRA EMC WÜRTH ELEKTRONIK

TIMELINE

1. INTRODUCTION

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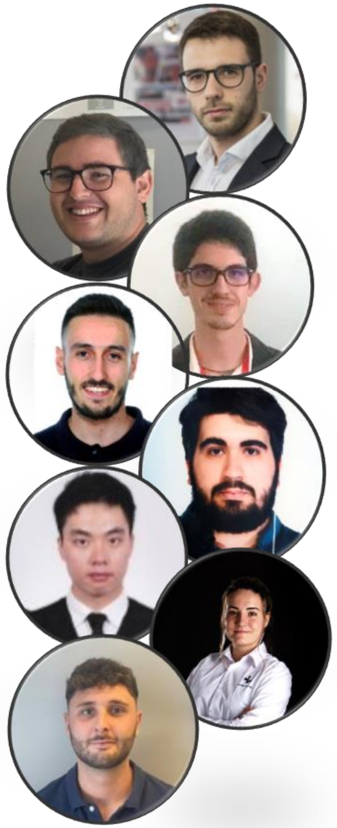
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

VNIVERSITAT DE VALÈNCIA
CATEDRA EMC

Born in Valencia, Spain, I studied Physics and Telecommunications Engineering. I hold Master's degrees in Electronic Engineering and Medical Physics. Currently, I combine my work as a professor in the field of Electrical Technology with research in WE EMC Catedra into new electromagnetic shielding materials. Specifically, my most active research area is the electromagnetic characterization of materials. We develop new measurement methods and new algorithms for extracting permeability and permittivity. This characterization allows us to build highly reliable simulation models and predict the behavior of new materials.

1. INTRODUCTION

CATEDRA EMC WÜRTH ELEKTRONIK - UNIVERSIDAD DE VALENCIA

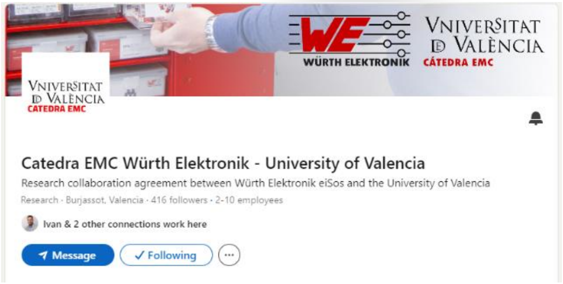


Promoting the Catedra/WE, managing the projects and internships carried out by the students, and giving them specific training according to the project they are going to support.

- Finding Young Talents for WE.
- Mentoring and management of internships in the Catedra.
- Management of summer internships in Waldenburg.
- Giving students technical training about the range of products of WE and advanced measurement equipment.
- Organization of EMC Seminars for companies (Würth Elektronik Spain together with the Catedra).
- Organization of Talent-Fest event at the School of Engineering.
- Participation in webinars organized by Würth Elektronik such as EMC Digital Days.
- Representing the Catedra and Würth Elektronik in meetings, conferences and events.
- Promotion of the Catedra EMC in University of Valencia corporative websites, Catedra EMC website and social networks.

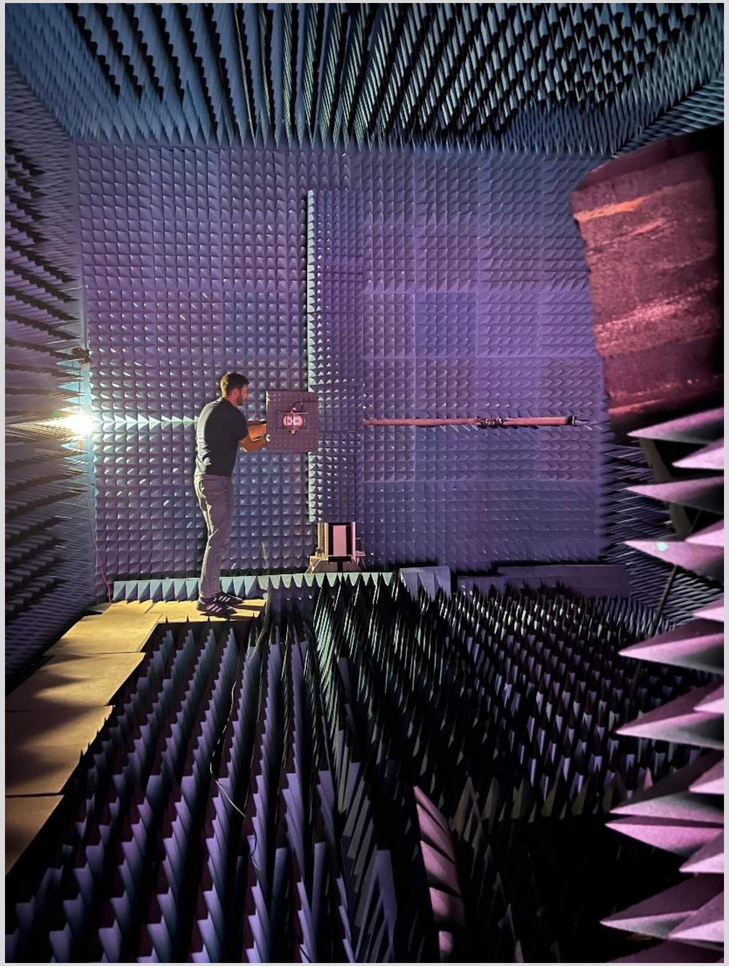
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

VNIVERSITAT DE VALÈNCIA CATEDRA EMC



1. INTRODUCTION

CATEDRA EMC WÜRTH ELEKTRONIK - UNIVERSIDAD DE VALENCIA

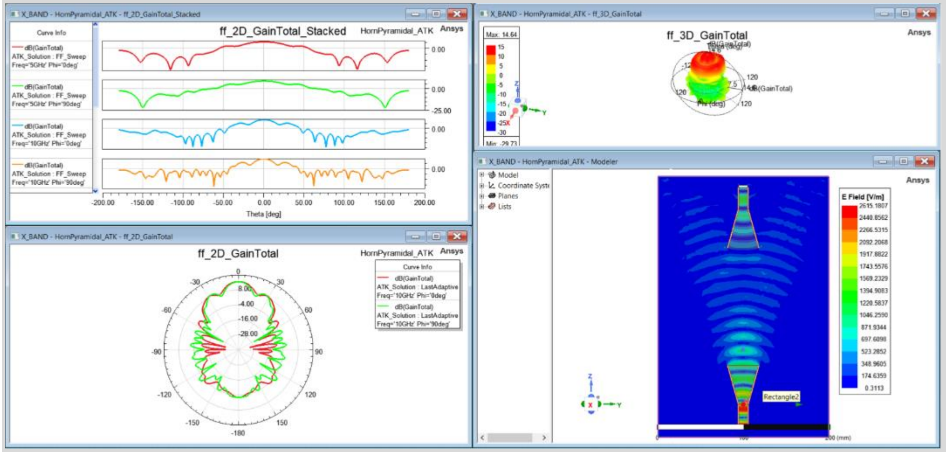


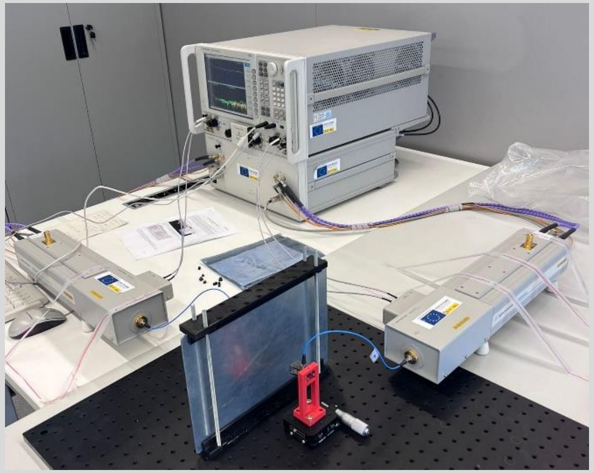
RF and microwave Laboratory

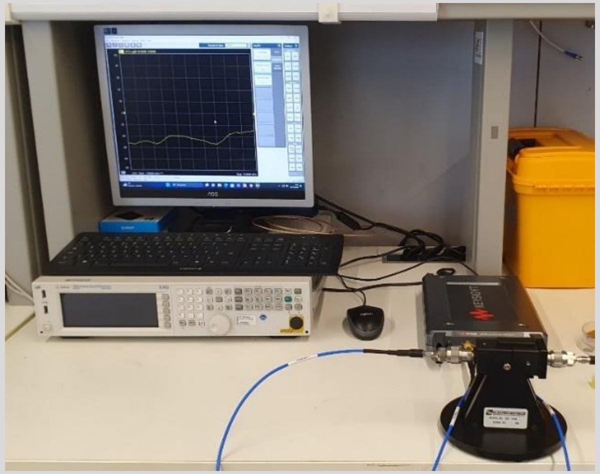
2 Laboratories
1 Anechoic Chamber (6 m x 4.5 m x 4.5 m)

Operating frequency up to 110 GHz

Ansys

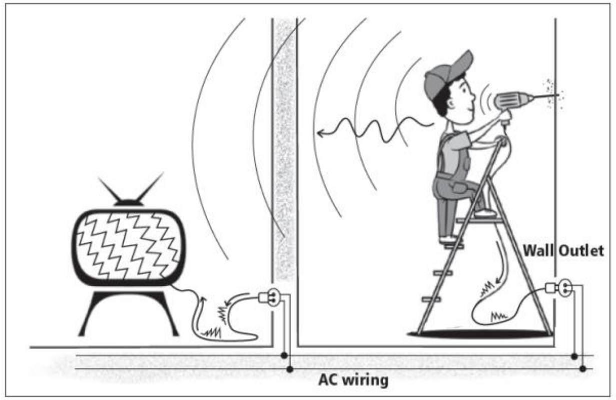


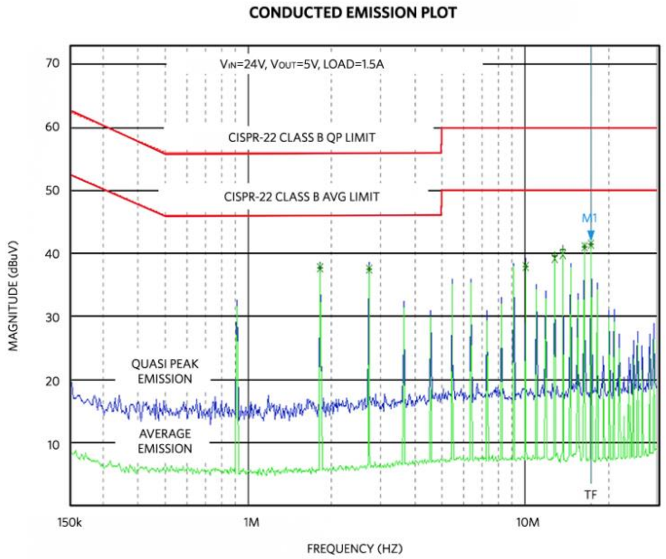




2. EMC OBJECTIVES

1. Limit electromagnetic emissions
2. Ensure immunity to electromagnetic disturbances
3. Ensure coexistence between electronic systems
4. Control electromagnetic coupling paths:
    - Conducted paths.
    - Radiated paths.
5. Maintain functional performance and safety
6. Comply with applicable EMC regulations and standards





2. EMC OBJECTIVES

- An **EMC directive** is a legal/regulatory obligation; an **EMC standard** is a technical specification that tells you how to demonstrate that a product meets certain requirements.
- For example, in Europe, the main one is **Directive 2014/30/EU**, on electromagnetic compatibility. Each country or territory has its own directive. They are all very similar.

- **EMC standards** is a technical document that establishes how to measure, test, or evaluate the EMC **behavior** of equipment. For example:
  - CISPR 32 → Emissions from multimedia equipment.
  - CISPR 35 → Immunity of multimedia equipment.
  - IEC 61000-4-2 → Immunity against electrostatic discharge (ESD).
  - IEC 61000-4-3 → Immunity against radiated electromagnetic fields.
  - IEC 61000-4-4 → EFT/Burst.
  - IEC 61000-4-5 → Surge.
  - IEC 61000-4-6 → Conducted disturbances induced by RF.
  - IEC 61000-4-8 → Magnetic fields at mains frequency.
  - CISPR 16 → Instrumentation and methods for measuring radio disturbances.

2. EMC OBJECTIVES

- **Electromagnetic Compatibility (EMC)** of electrical, electronic, and telecommunications devices and equipment is currently one of the main quality requirements worldwide.

- For the EMC of a device or piece of equipment to be effective and economically feasible, it must be considered from the **earliest design stages**, ensuring that it operates correctly in a specific electromagnetic environment.

- Developers and manufacturers must comply with EMC standards to achieve **high quality** in processes involving electrical and electronic devices and equipment.

2. EMC OBJECTIVES

Würth Elektronik Iberia
2h • Edited •

📊 A few weeks ago we asked you at what stage problems usually appear in electronic projects.

Based on your experience and what you live and hear in the industry, these were the results:

🥇 Certification → 43%
🥈 Initial design → 36%
🥉 Production → 14%
🏅 Prototype → 7%

At first glance, it might seem that certification is the most problematic phase.
However, these results lead us to an interesting reflection:

💡 Many problems are not born in certification, but become visible at that moment.

In fact, if we add up the certification and initial design votes, we see that almost 80% of the participants consider that the greatest challenges appear before reaching production.

Aspects such as:

✅ Component selection
✅ The PCB Design
✅ EMI/EMC Management
✅ Component availability
✅ Project planning

They can have a direct impact on the final result of the certification.
Therefore, the earlier potential risks are identified, the greater the margin for action and the lower the impact on deadlines, costs and redesigns.

At Würth Elektronik we accompany our customers from the early stages of development with tools, resources and technical support aimed at facilitating design and reducing risks before reaching the most critical phases of the project.

💬👇 What is the most common problem you have encountered during a certification?

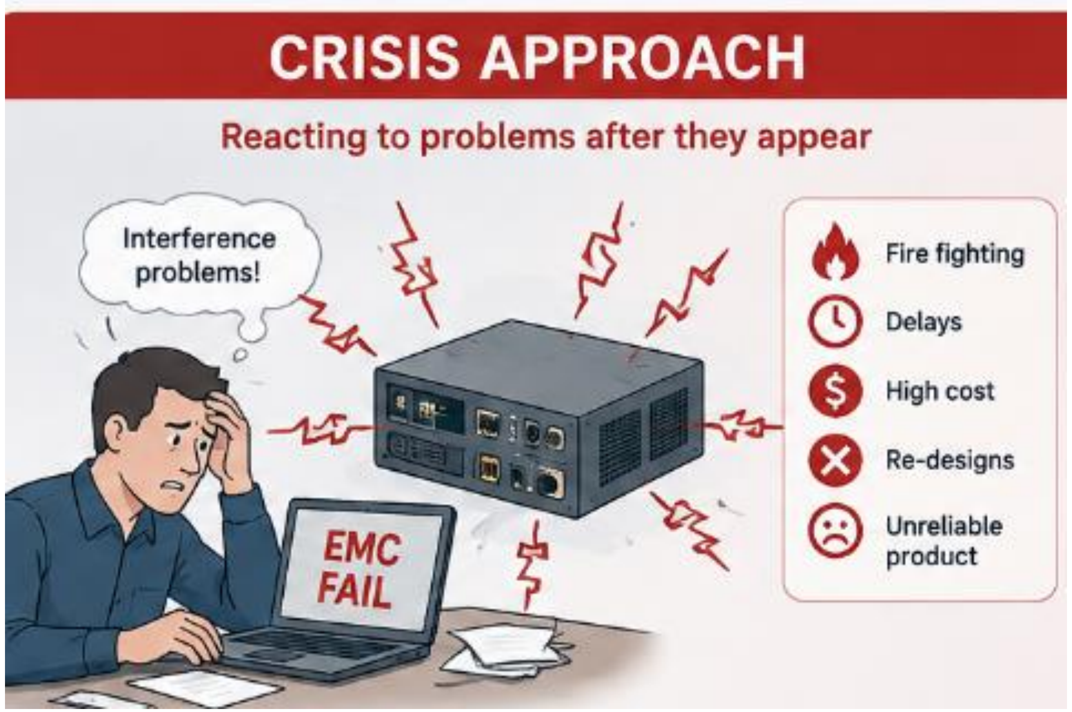
WHERE DO PROBLEMS USUALLY ARISE?

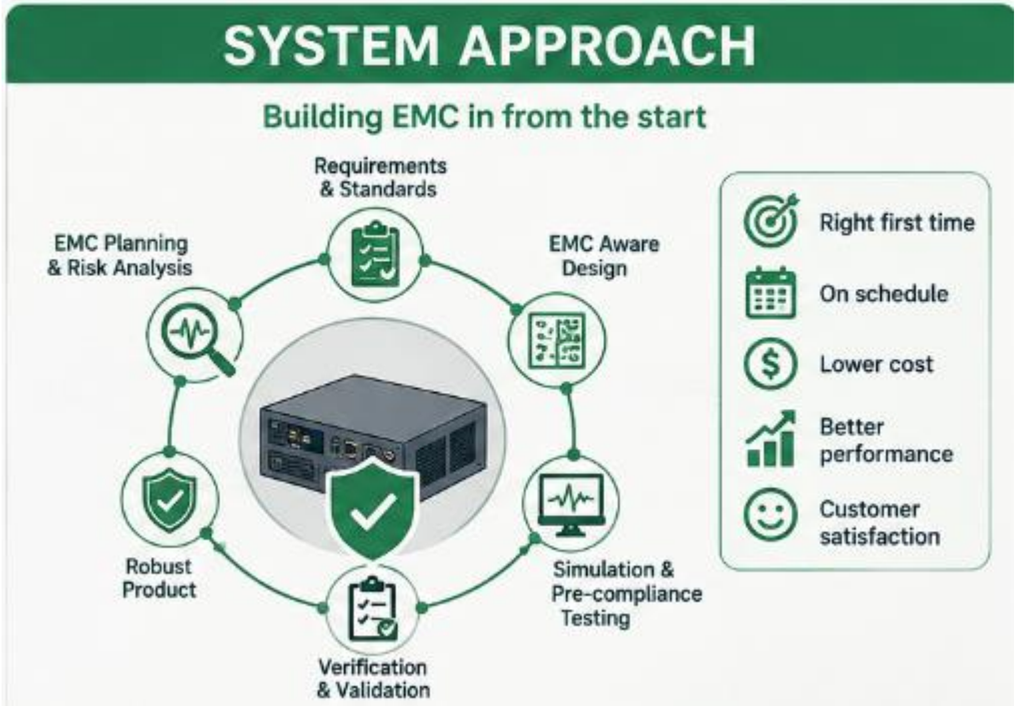
Design	Prototype	Certification	Production
36 %	7 %	43 %	14 %

2. EMC OBJECTIVES

Design perspectives

- Electronic design for EMC can be approached from **two perspectives**:
  - **Crisis approach** (approach or solution to the problem)
  - **Systems approach** (solution of the system a priori)

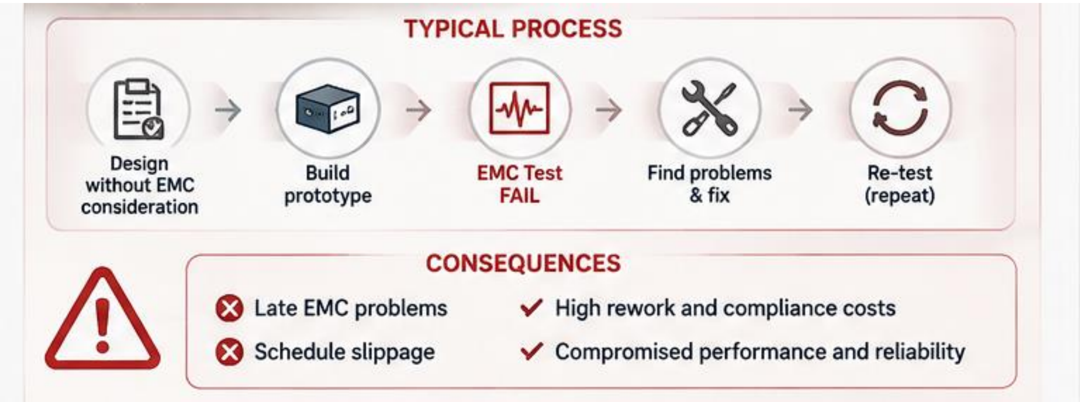




2. EMC OBJECTIVES

Design perspectives

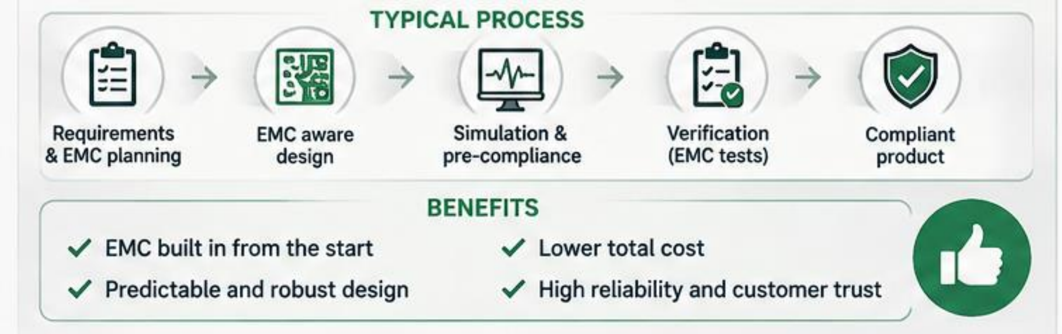
- With the **Crisis approach**, the designer disregards EMC until the functional phase is complete, or worse, until the equipment fails, when it is already operating in the environment for which it was developed. **PROBLEMS!!!**
  - Solutions implemented in the later stages of design are costly (time, analysis, and troubleshooting; otherwise, redesign).
  - They also introduce elements that were not considered, and the solution can be very complicated.
  - This is also known as the Band-Aid Approach.



2. EMC OBJECTIVES

Design perspectives

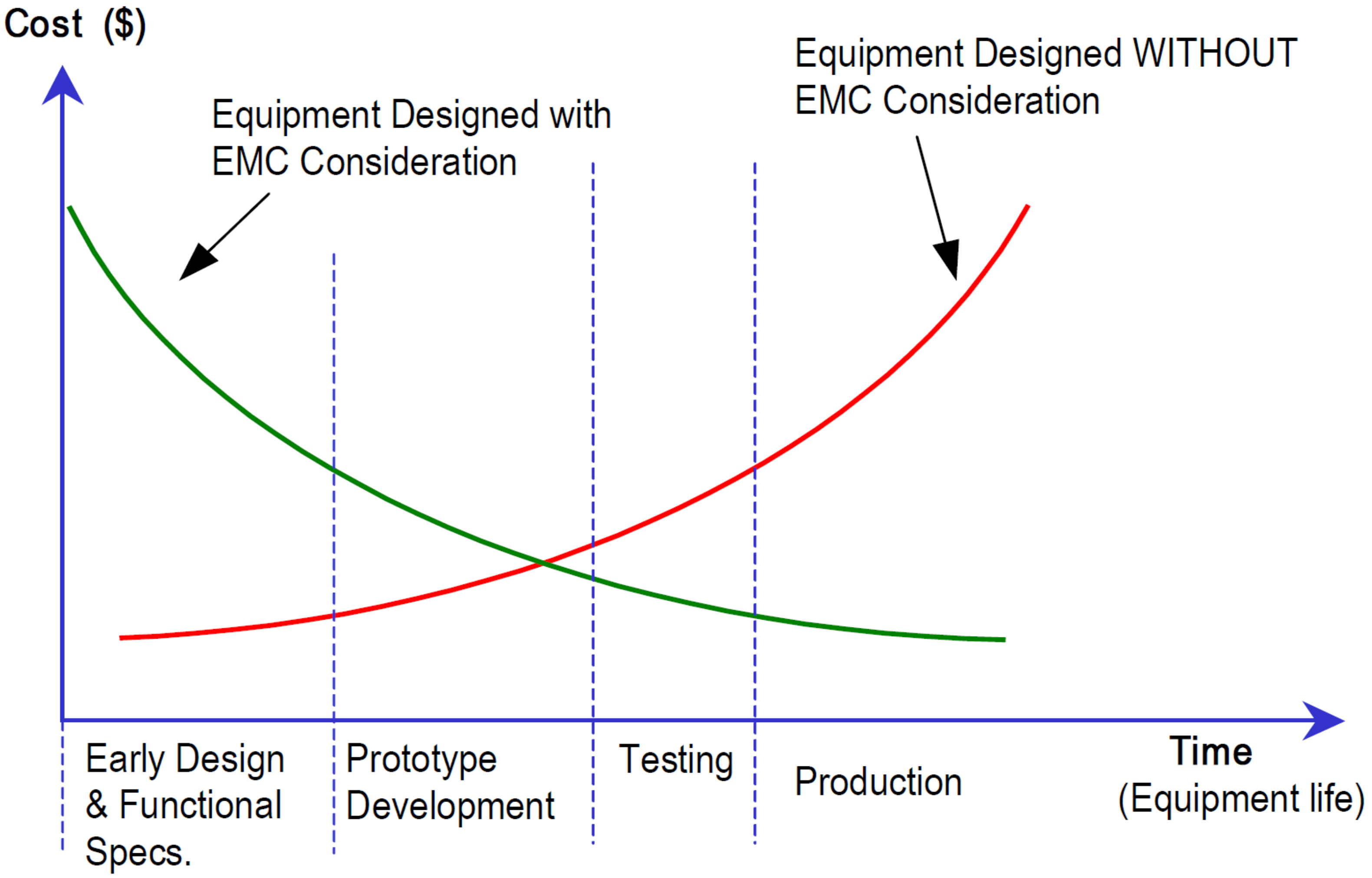
- **Systems approach**: This approach considers EMC from the very beginning of the design process:
  - It anticipates EMC problems before development begins.
  - It finds solutions to identified problems before designing anything.
  - It tests prototypes as thoroughly as possible.
- In this way, EMC becomes an integral part of:
  - Electronic and/or Electrical Engineering.
  - Mechanical Engineering.
  - Firmware/Software Development.



- **RESULT**: EMC is part of the design (prevention). It is NOT added to the product as a "band-aid" (cure).

2. EMC OBJECTIVES

Design perspectives



2. EMC OBJECTIVES

Design perspectives

System/Device Specification

EMC engineers must be aware of the specifications before the contract is signed

EMC/EMI Control Plan

Interpret the necessary EMC requirements from the specifications.
Summarize the applicable documentation, specifications, and standards.
Organization and responsibilities of the EMC program.
Define procedures and techniques.

Mechanical design

Chassis and shell

- Shielding
- Material selection
- Shell
- Enclosure
- Cover

Grounding

- Multipoint or single point

Electronic design

Floorplan Hardware

- Functional system
- Separation of the digital part from the analog part

PCB Layout design

- Microstrip
- Number of layers
- GND and PWR layers
- Separation of Analog, RF, Digital and PWR

System Design

Power supply distribution

- Topologies: linear, PWM, etc.
- Connectors
- Filters

Signal distribution

- Single-Ended or Differential
- Logic Family
- IoT Connectors
- Filters
- Protections
- Cables
- Shielding

2. EMC OBJECTIVES

Design perspectives

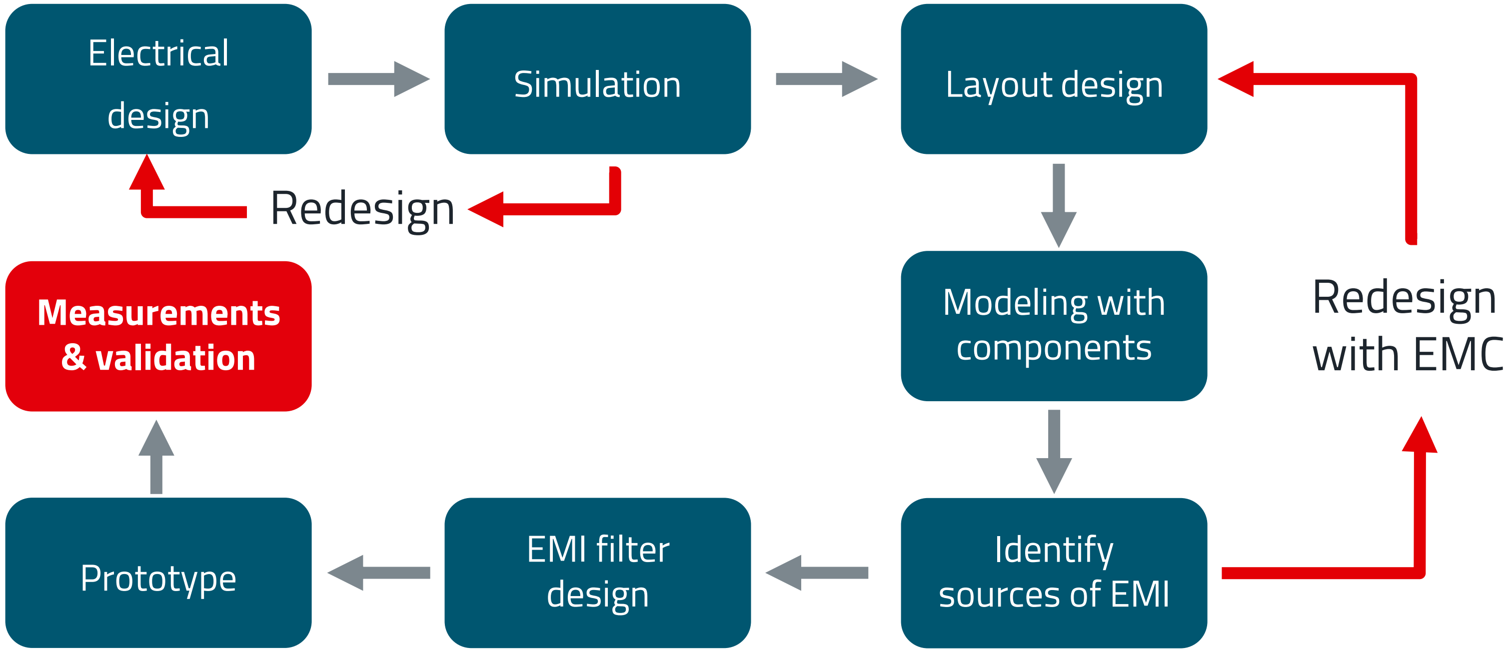
Typical tasks of EMC engineers

Tasks	Phase
Prepare EMC proposal Review system specifications	Pre-adjudication
Interference prediction Test design Interference control design EMC control plan preparation Mechanical, electronic, and electrical design reviews EMC design review with the client Critical interference testing EMC control plan reviews	Design
Manufacturing review Inspections during manufacturing	Manufacturing
Preparation of the EMC test procedure and plan Evaluation of test performance Redesign from and where necessary Preparation and submission of test reports	Test

2. EMC OBJECTIVES

Design perspectives

EMC should be considered from the very first steps of a design.



2. EMC OBJECTIVES

Design perspectives

EMC Requirements

Required by the manufacturer:

- ✓ To satisfy the customer
- ✓ To ensure product reliability and quality
- ✓ Specific to each system

Quality

Required by various regulations

- ✓ Control of "electromagnetic pollution"
- ✓ Legal requirements
- ✓ Compliance with regulations does not imply the absence of interference

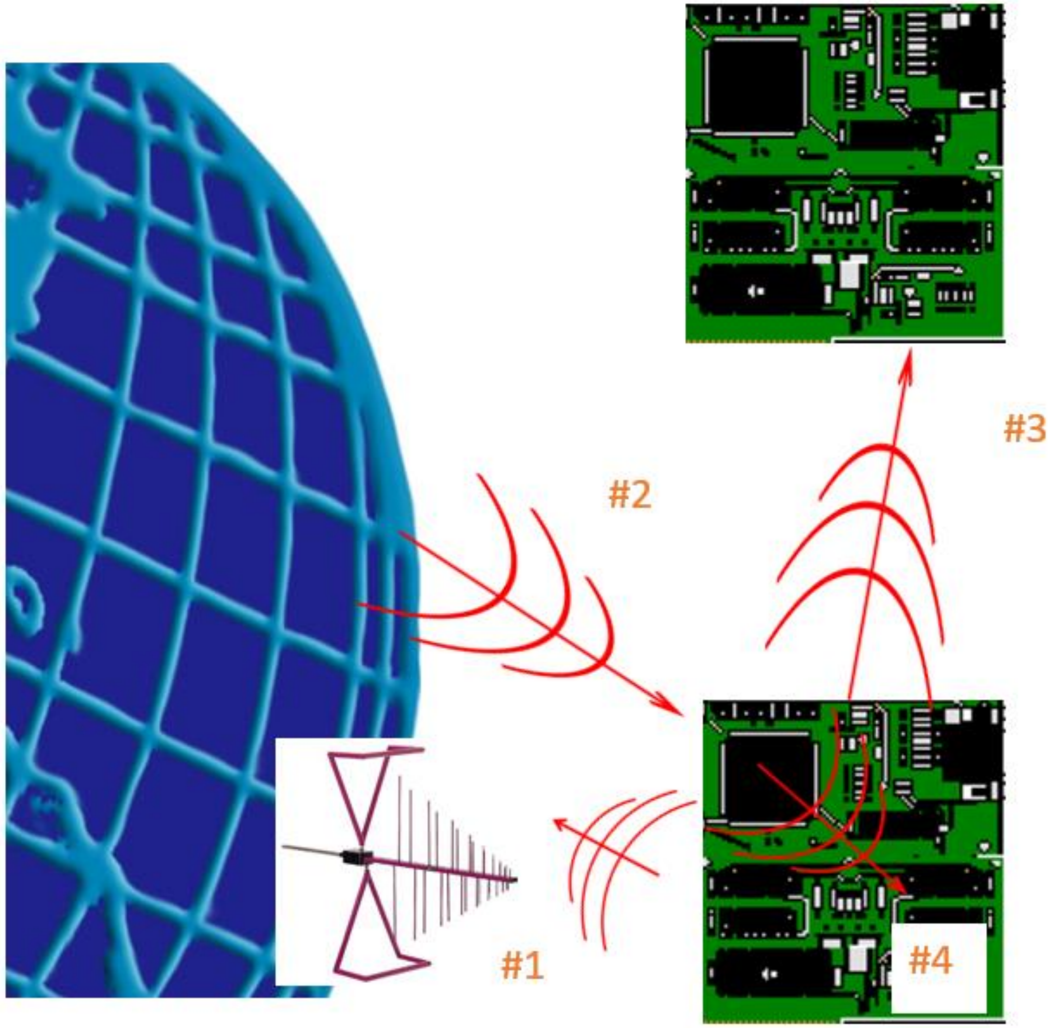
Legality

EMC requirements are not just EMC regulations!

2. EMC OBJECTIVES

Elements involved

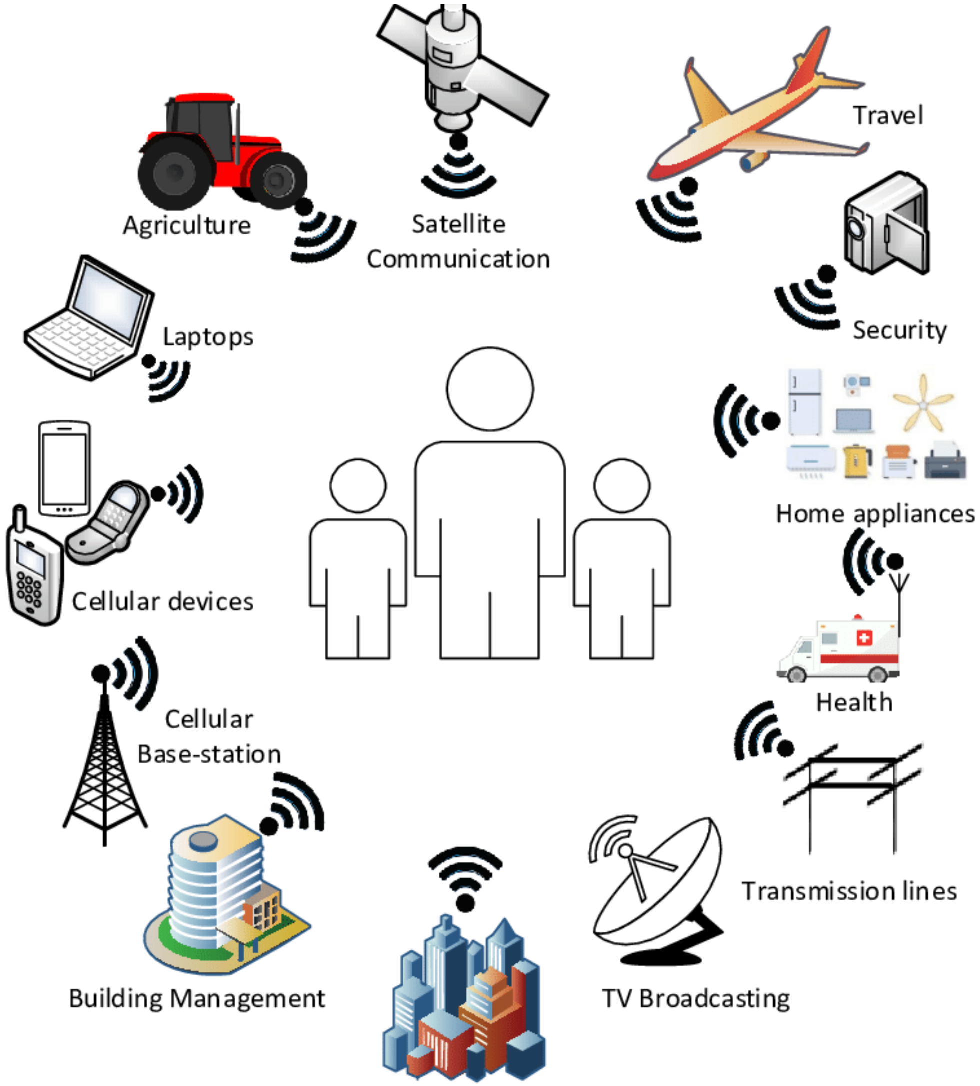
1. EMI -> Environment.
2. EMS -> Environment
3. EMI -> Inter-system
4. EMI + EMS -> Intro-system



3. DEFINITIONS

Electromagnetic Environment

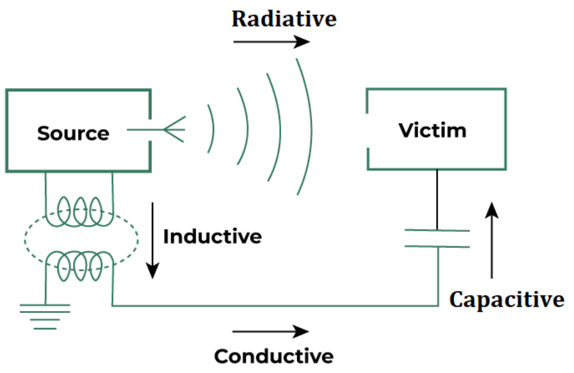
- The electromagnetic environment is defined as the totality of time-varying electromagnetic phenomena present in a given region. This includes both desired and unwanted electromagnetic signals.
- It can be described by sources that may be active or by measurable parameters:
  - Voltages and intensities of electric and magnetic fields.
- Just as an active, switched-on device contributes actively to the environment, a passive or switched-off device can also contribute passively.



3. DEFINITIONS

Electromagnetic disturbance

- Any electromagnetic phenomenon capable of creating anomalies in the operation of a device, apparatus, or system that is intended to function in a predetermined manner, or of adversely affecting it.



- It can be:
  - Electromagnetic noise.
  - An unwanted signal.
  - A modification of the propagation medium itself.

- **Electromagnetic interference**: any anomaly introduced into the operation of a device, apparatus, or system by an electromagnetic disturbance.
- **Performance degradation**: an unwanted deviation from the operating characteristics of a device, apparatus, or system that is intended to function in a predetermined manner, in the presence of an electromagnetic disturbance.

3. DEFINITIONS

Electromagnetic Compatibility (EMC)

- According to international standards outlined in the International Electrotechnical Commission Technical Report 61000-1-1, EMC is defined as "the ability of any device, equipment, or system to function satisfactorily in its electromagnetic environment without causing electromagnetic disturbances to anything in that environment.“
  - To function satisfactorily means that the equipment is tolerant of other equipment, being immune to electromagnetic signals emitted by other equipment in the environment.
  - It also means not producing intolerable electromagnetic disturbances, so that the emission of electromagnetic signals by the system itself does not cause EMC problems with other equipment.

3. DEFINITIONS

- **ELECTROMAGNETIC IMMUNITY:** This device, equipment, or system must be able to operate properly in that environment without interference from other devices or from itself.

- **ELECTROMAGNETIC SUSCEPTIBILITY (EMS):** The inability of a device, equipment, or system to function without degradation in the presence of an electromagnetic disturbance.

- Although susceptibility and immunity differ only in their respective incapacity and capacity, they are complementary concepts with distinct applications:
  - Susceptibility is a fundamental characteristic of equipment. It is always possible to find an electromagnetic environment that adversely affects equipment.
  - Immunity indicates the degree to which the environment can be electromagnetically contaminated before it adversely affects equipment.

3. DEFINITIONS

- **ELECTROMAGNETIC INTERFERENCE (EMI):** It must not be a source of interference that affects other equipment in the surrounding environment (electromagnetic emissions).
- **Electromagnetic Emission (EME):** Electromagnetic emission is the phenomenon by which electromagnetic energy emanates from a source.
- Electromagnetic energy can reach a system:
  - By radiation (radiated interference)
  - By conduction (conducted interference)
- These two forms of interaction or coupling can be present simultaneously and can lead to unwanted effects inside and outside the system containing the sources of disturbance.

3. DEFINITIONS

- **Radiated Emission:** This is the radio frequency energy component transmitted through a medium in the form of an electromagnetic field.
- **Conducted Emission:** This is the radio frequency energy component transmitted through a physical medium such as a cable, track, or wire.
  - LCI (Line Conducted Interference): Interference on power lines.
  - Signal Conducted Interference (SCI): Interference on signal lines.
- **Electrostatic Discharge (ESD):** The transfer of electricity between two bodies with different electrostatic levels.

4. EMC PROBLEMS

EMC = EMI + EMS

SOURCES OF INTERFERENCE (EMI) → **COUPLING PATH** → **INTERFERENCE RECEIVERS (EMS) VICTIM!!**

SOURCES OF INTERFERENCE (EMI)	COUPLING PATH	INTERFERENCE RECEIVERS (EMS)
Minimize	**Minimize**	**↑ Inmunity**

Sources of interference: Minimize

- Appropriate component selection.
- Circuit topology selection and layout.
- Contact protection

Coupling path: Minimize

- Proper wiring
- Power distribution (circuit topology)
- Avoid ground loops

Interference receivers: ↑ Inmunity

- Filter
- Shielding
- Circuit topology

4. EMC PROBLEMS

Radiated couplings

They are transmitted through the air in the form of an E field, H field, or plane wave

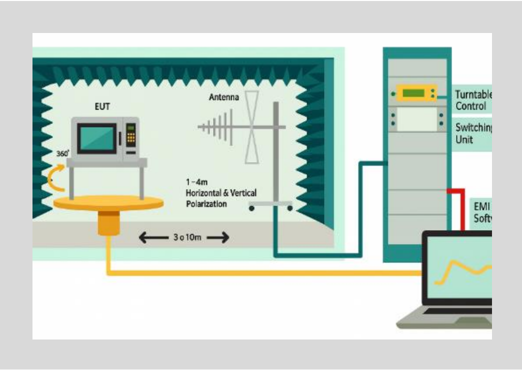
Near field (coupled interferences)

E or H field
d < λ/2π.

- **Capacitive coupling** — E Field
- **Inductive coupling** — H Field

Far field (radiated interferences)

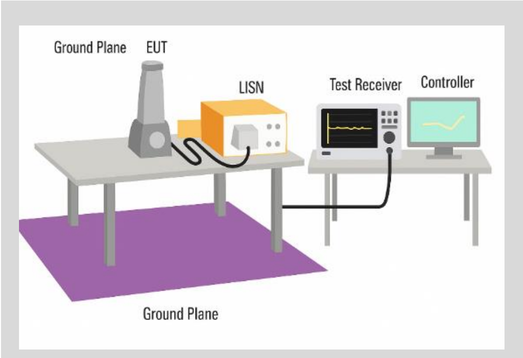
E or H field
Plane wave
d > λ/2π.



Conducted couplings

They are transmitted through electrical conductors in the form of Voltage and Current

- **Differential mode**
- **Common mode**
- **Power supply**
- **Common impedance**

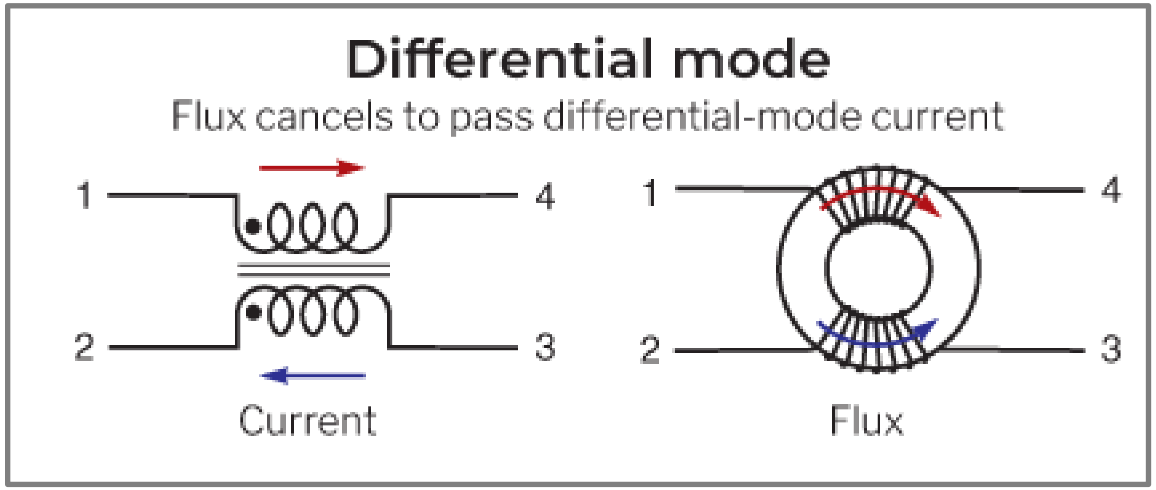


4. EMC PROBLEMS

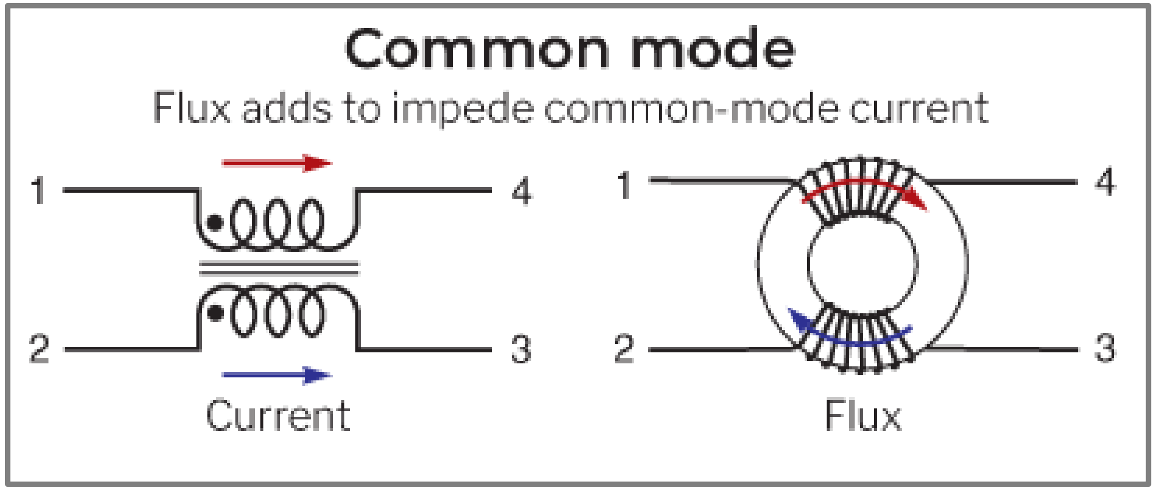
Conducted couplings

Differential mode

Common mode

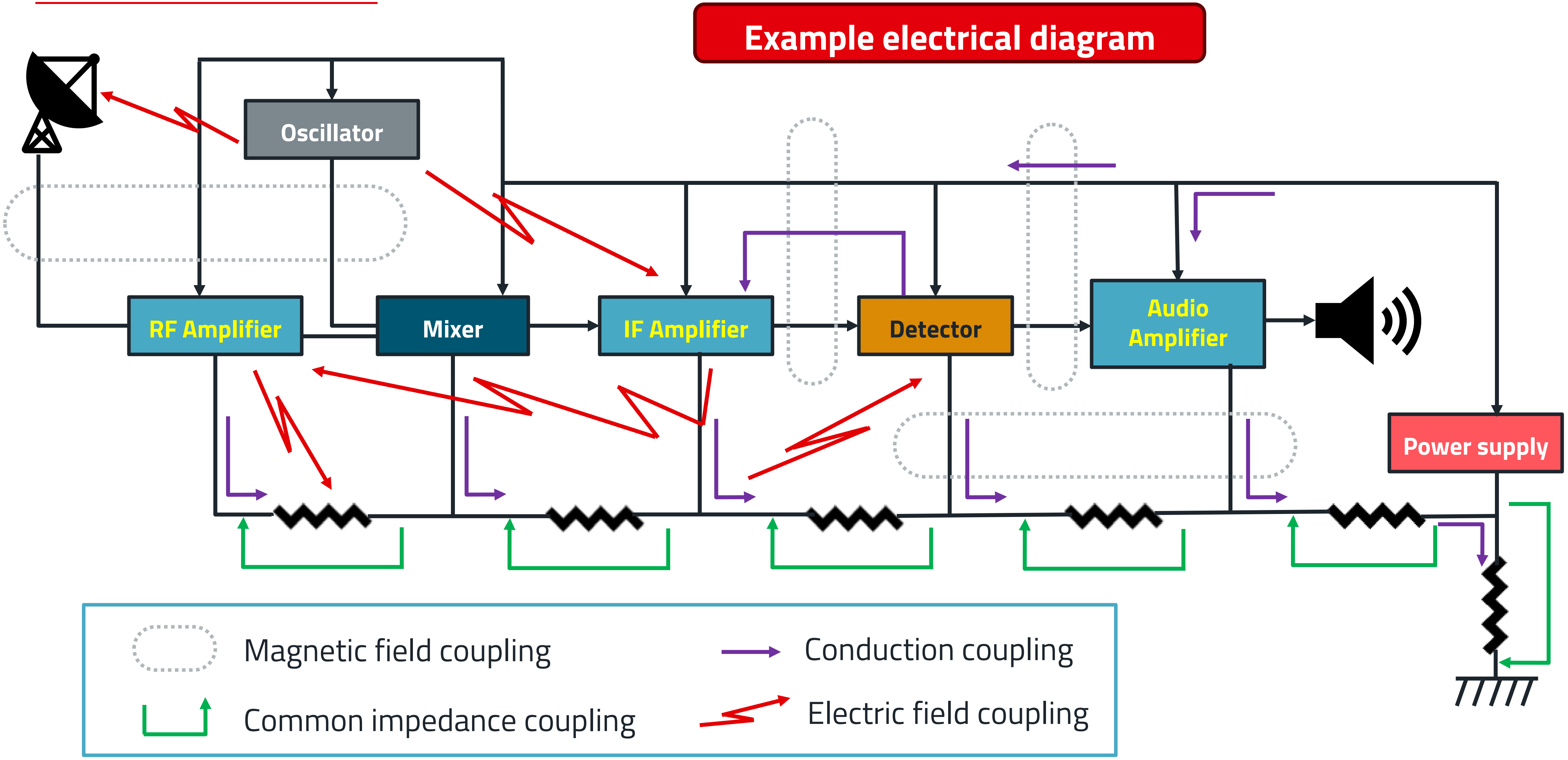


Functionality as designed



Abnormal functioning, **to be avoided**

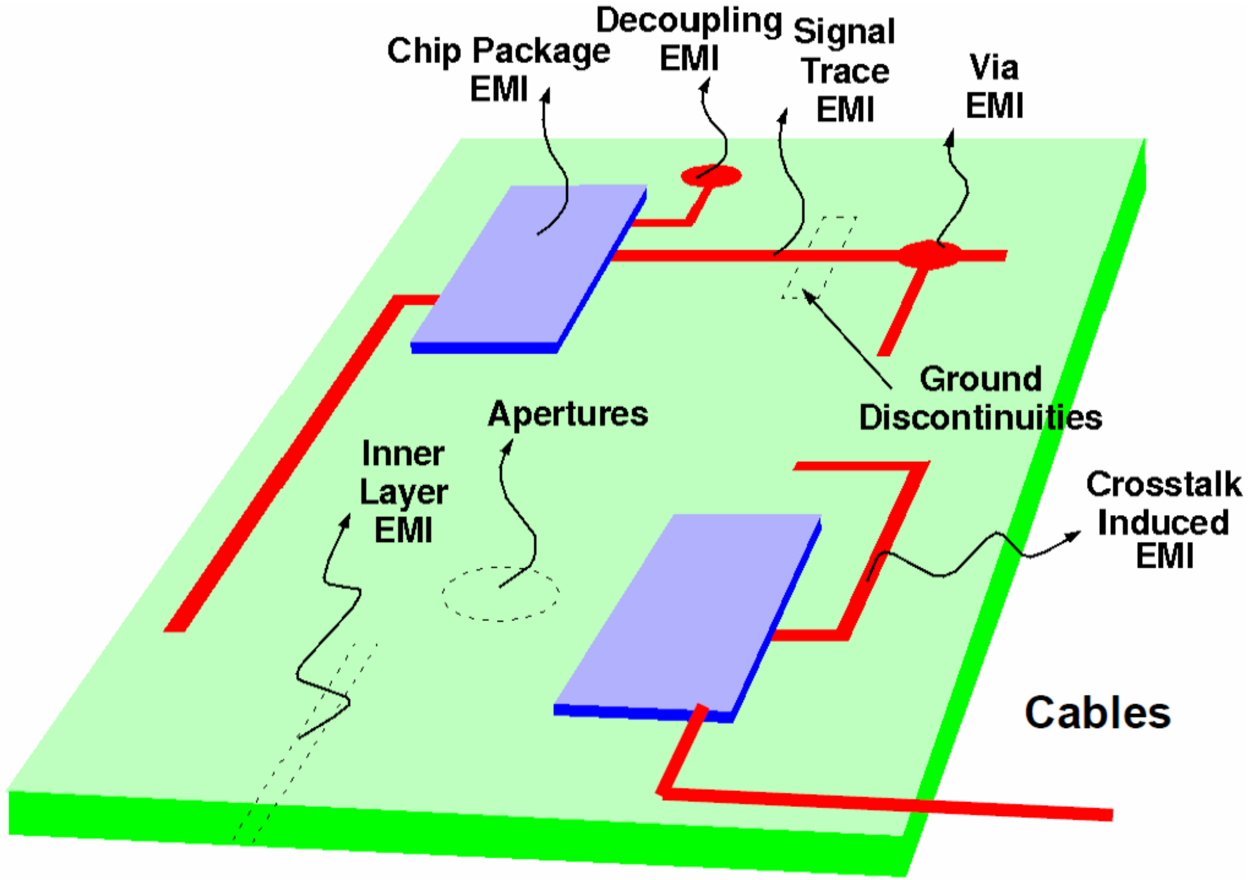
4. EMC PROBLEMS



4. EMC PROBLEMS

- ICs
- Capacitors
- Trace
- Vias
- Planes, ground bounce…
- Apertures
- Cables
- Xtalk between traces

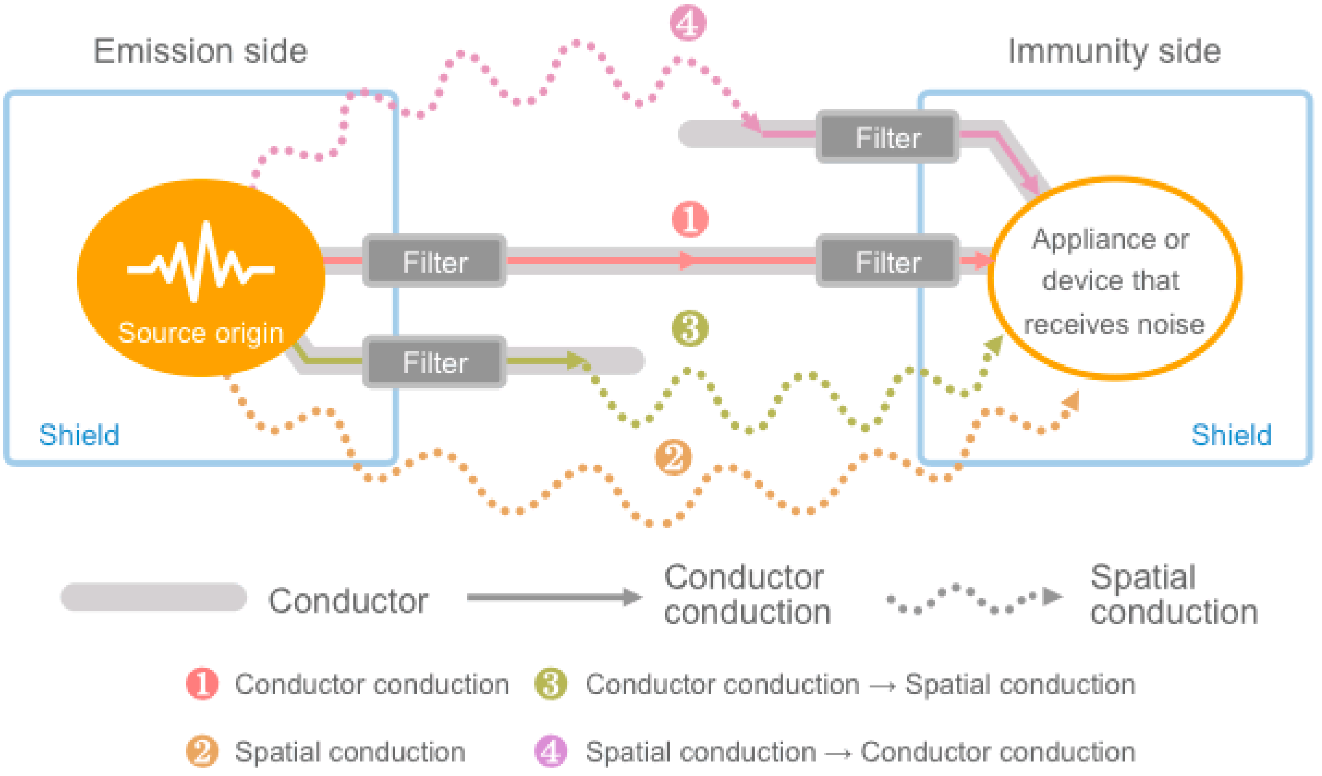
PCB EMC Problems



5. EMC SOLUTIONS

EMI Filters

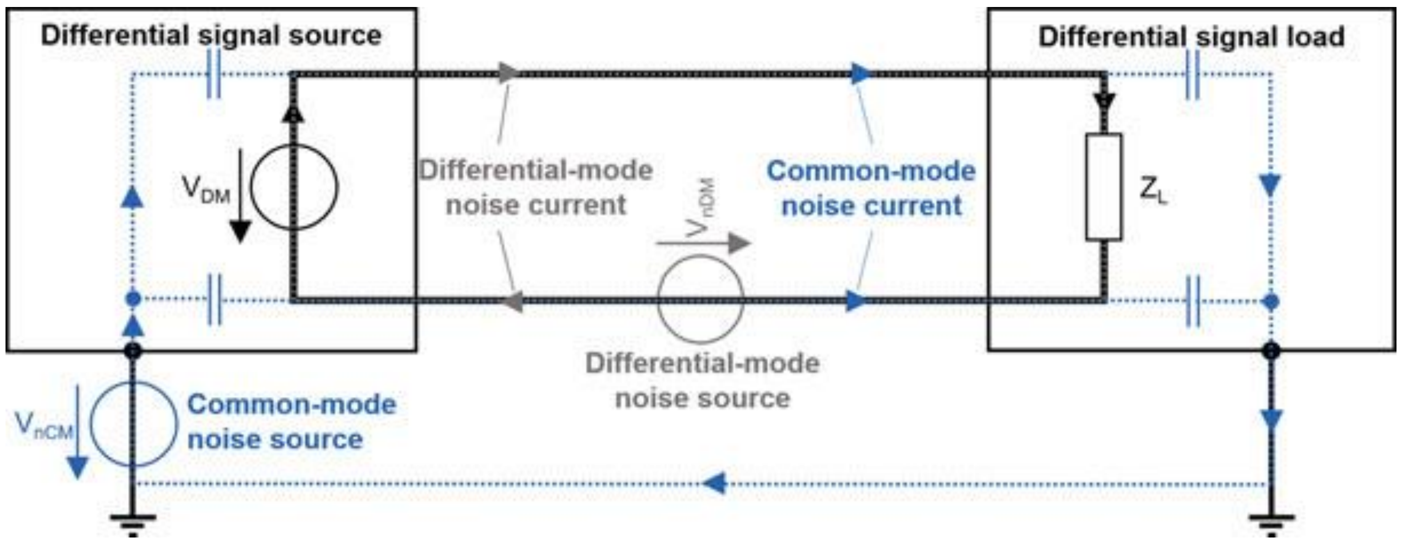
EMI suppression filters are one of the most common and effective methods for attenuating interference. Without EMI filters, the device might require much more extensive shielding and a complete redesign.



5. EMC SOLUTIONS

EMI Filters

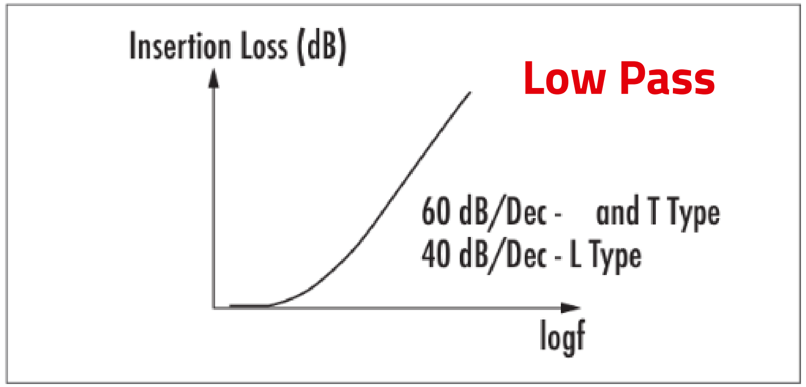
- EMI filters work by combining passive components such as inductors, capacitors, and resistors, which form filter networks to attenuate common-mode and differential-mode noise.
- These filter networks act on unwanted frequencies, typically generated by switching components or high-frequency noise sources, while allowing useful low-frequency signals or power supply current to pass through unaltered.

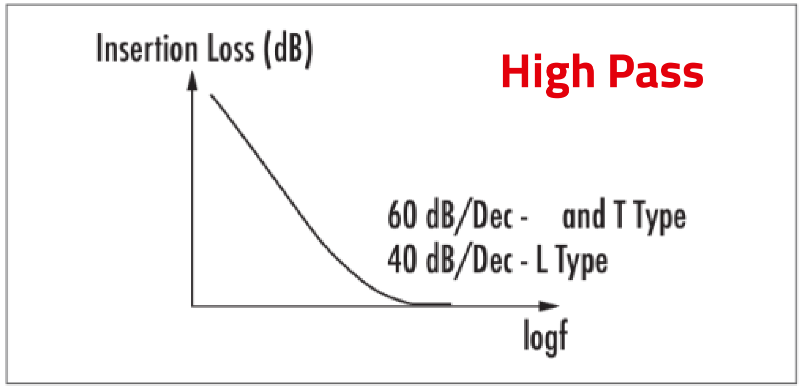


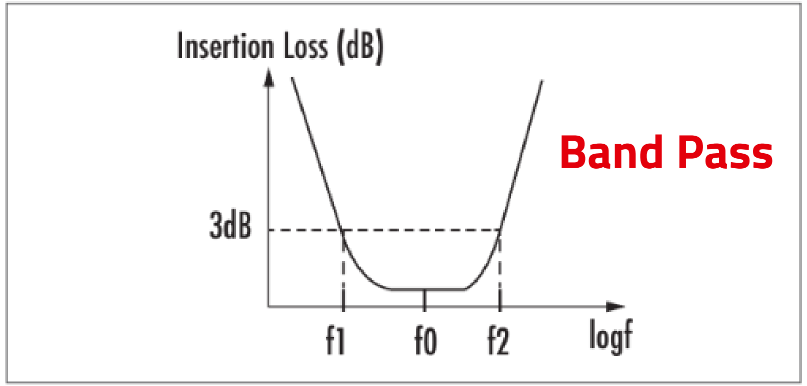
5. EMC SOLUTIONS

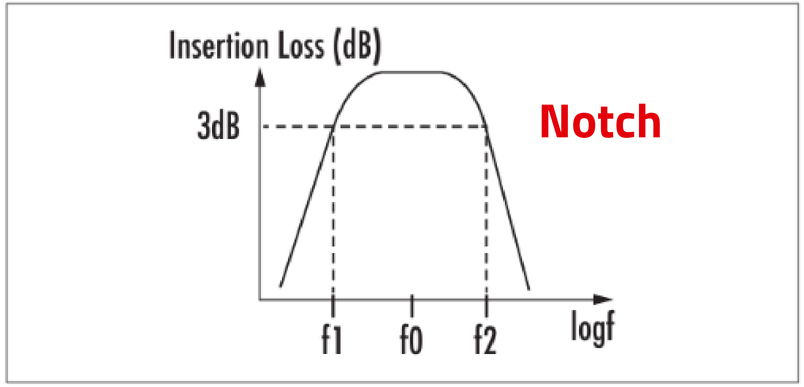
EMI Filters

- There are four general types of filter.







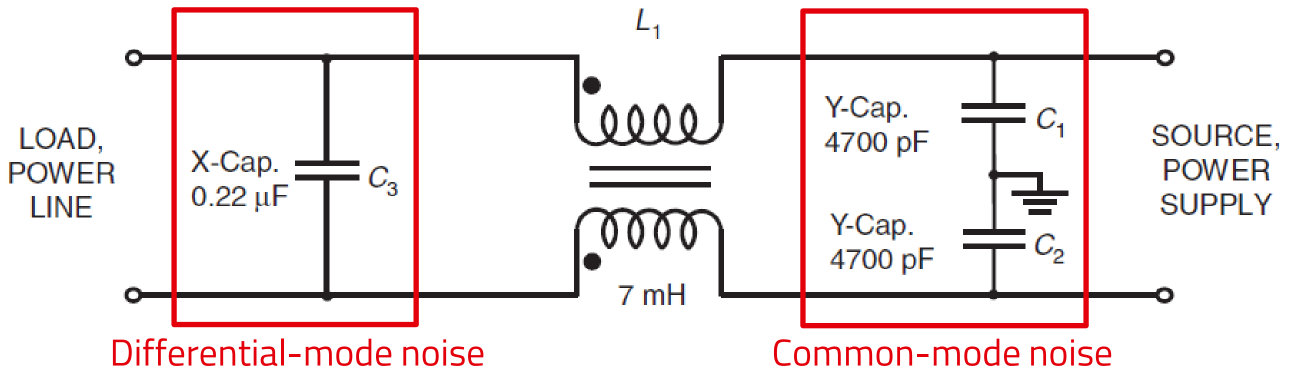


5. EMC SOLUTIONS

EMI Filters

Components of an EMI Filter:

- Capacitors:
  - Capacitors in EMI filters are used to shunt high-frequency noise to ground or between lines. **X capacitors** (between phase and neutral lines) and **Y capacitors** (between phase/neutral and ground) are common in EMI filters to eliminate differential-mode and common-mode noise.
- Resistors:
  - Resistors are sometimes incorporated into the design of EMI filters to dissipate noise energy and improve filter stability. **(Chip Ferrite).**



5. EMC SOLUTIONS

EMI Filters

Components of an EMI Filter:

- Inductors (coils):
  - These are used to block high-frequency signals. They work by creating a high impedance to noise signals, attenuating their passage.
  - In EMI filters, **common-mode chokes** are ferrite-core coils used to reduce common-mode noise, allowing low-frequency AC or DC current to pass through without problems.

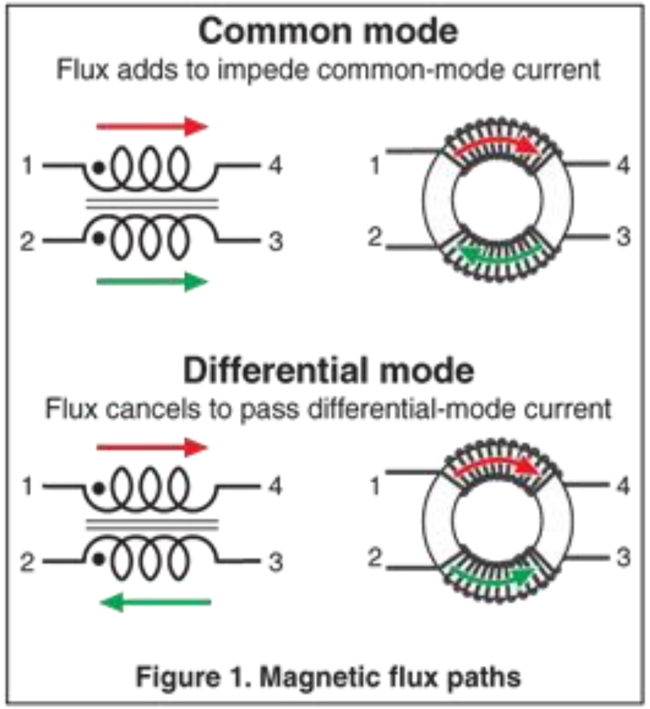
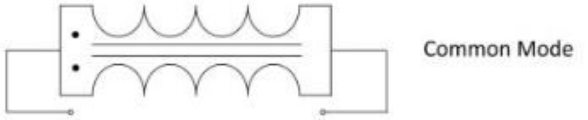


Figure 1. Magnetic flux paths



5. EMC SOLUTIONS

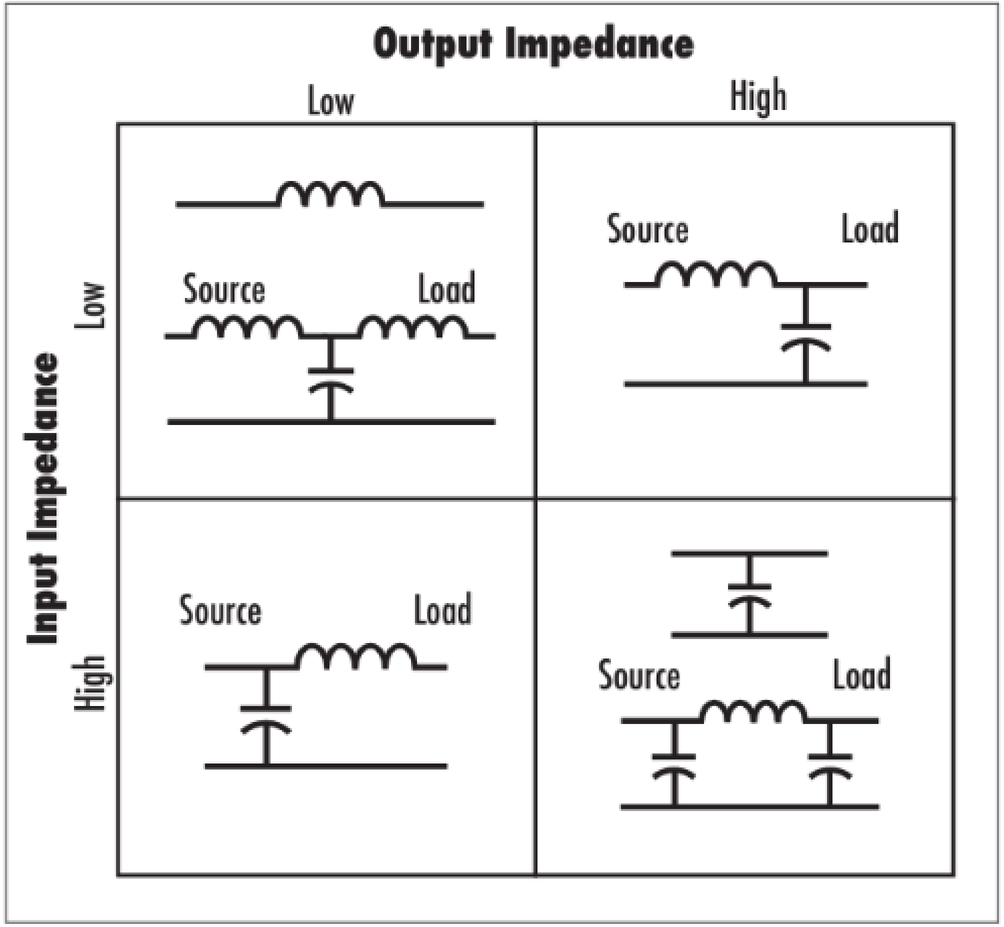
EMI Filters

There is a general rule that can be used to assist the designer:

- The first filter element closest to the source or load should be selected to provide the greatest possible impedance mismatch at the frequencies where the EMI is located.

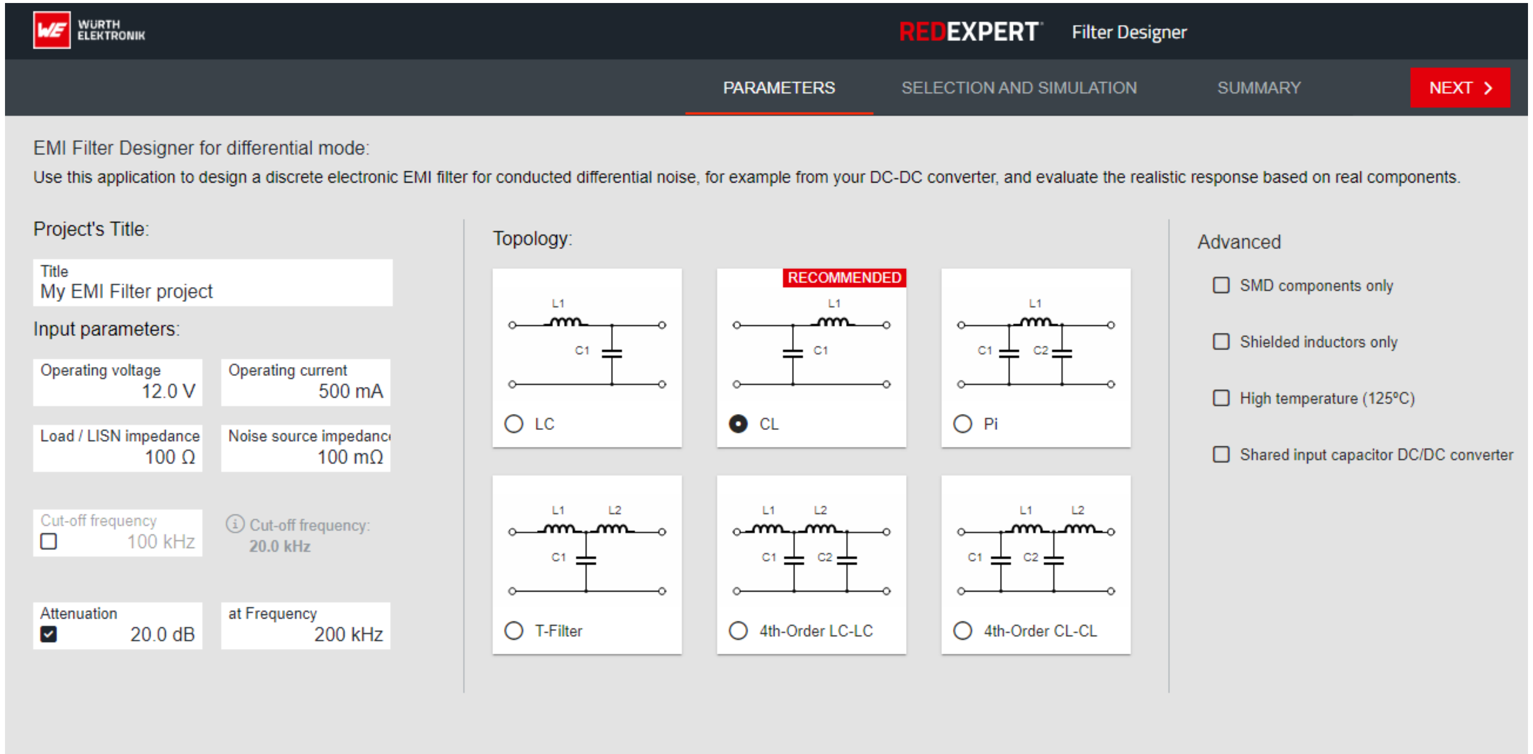
- Typically, this means that if the source or load impedance is low (<100 Ω), then the first filter element should be an inductive component. Conversely, if the source or load impedance is high (>100 Ω), the first filter element should be a capacitive component.

- This provides the designer with an extremely efficient design using the fewest possible stages or components.



5. EMC SOLUTIONS

EMI Filters



Commercial power-line filter

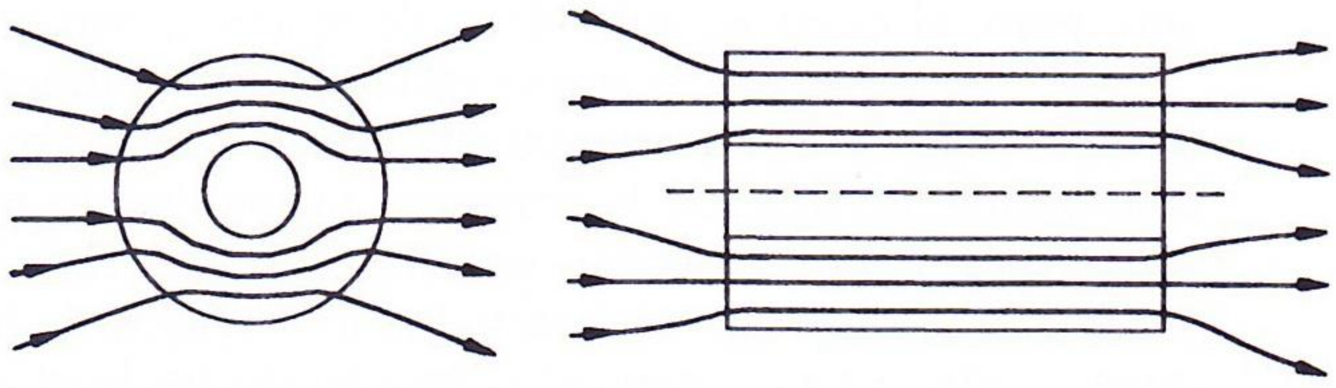
5. EMC SOLUTIONS

Cable Ferrites

It is the solution to shield the effects of the **magnetic field**. The material used to make ferrite has very **high permeability**. It is usually an alloy of **NiZn** or **MnZn**. Nanocrystalline compounds with very high permeability are recently being used

- When the sample is introduced, the external field is significantly distorted, becoming, at each point, the resultant of the initial magnetic field and the field created by the orientation of the magnetic domains.

- This results in the material concentrating the field lines, so that in regions outside and near the material, the resulting field is very weak.



5. EMC SOLUTIONS

Cable Ferrites. Applications.

Unwanted EMI sources in cables can appear in our system when connected to another device.

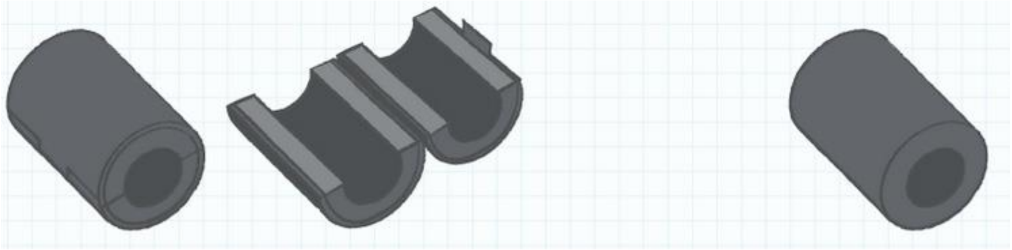
One of the most common techniques for reducing interference in cables is to apply an EMI suppressor, such as a sleeve ferrite core.

Therefore, this component is widely used to filter:
- EMI in power cables to reduce high-frequency oscillations generated by switching or parasitic resonances within a circuit.
- EMI in cables connecting peripheral devices: video cables or multi-conductor USB cables.

5. EMC SOLUTIONS

Cable Ferrites. Applications.

- In final radiated emissions tests, it is sometimes found that the internal filtering is insufficient to meet the specified emissions requirements.
- The DC output cable is not monitored for conducted emissions, but it can act as a reasonable antenna for radiated emissions.
- One solution to attenuate these radiated emissions that exceed the limits is to introduce an external ferrite core wrapped around the DC output cable to increase the line impedance for potential interference frequencies.



Split Bead   Sleeve Core

5. EMC SOLUTIONS

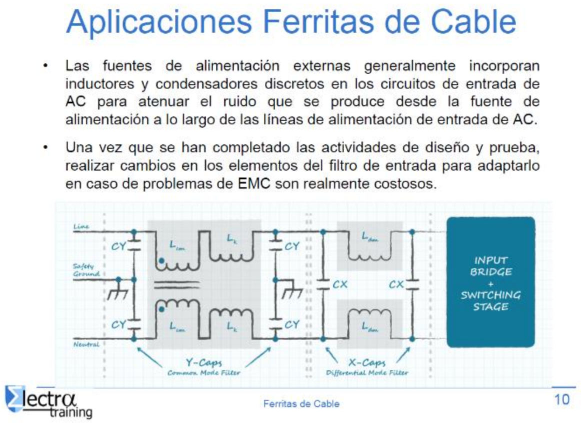
Cable Ferrites. Applications.

- A power supply is typically tested in isolation to meet conducted and radiated emission requirements.

- However, once the power supply is integrated into a complete system, the system may fail emissions tests.

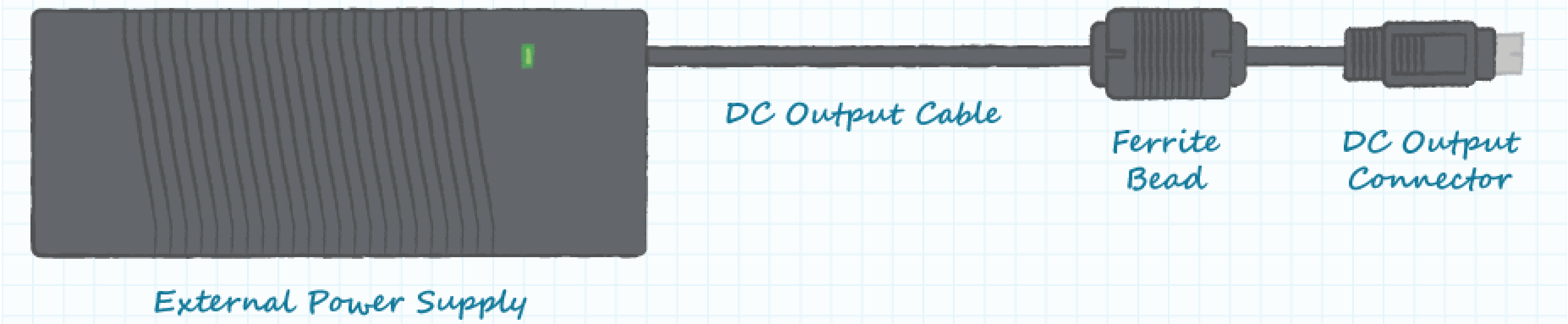
- One common reason for complete system failure is noise from the system load that propagates through the DC output power cable returning to the power supply, which acts as an antenna.

- Adding ferrite beads to the DC output cable is a low-cost solution that can reduce emissions to an acceptable level.



Aplicaciones Ferritas de Cable

- Las fuentes de alimentación externas generalmente incorporan inductores y condensadores discretos en los circuitos de entrada de AC para atenuar el ruido que se produce desde la fuente de alimentación a lo largo de las líneas de alimentación de entrada de AC.
- Una vez que se han completado las actividades de diseño y prueba, realizar cambios en los elementos del filtro de entrada para adaptarlo en caso de problemas de EMC son realmente costosos.



5. EMC SOLUTIONS

Cable Ferrites

Advantages
It does not require redesigning the electronics and, in general, the mechanical components. This is an important advantage because determining the source of EMI during the testing phase is not straightforward.

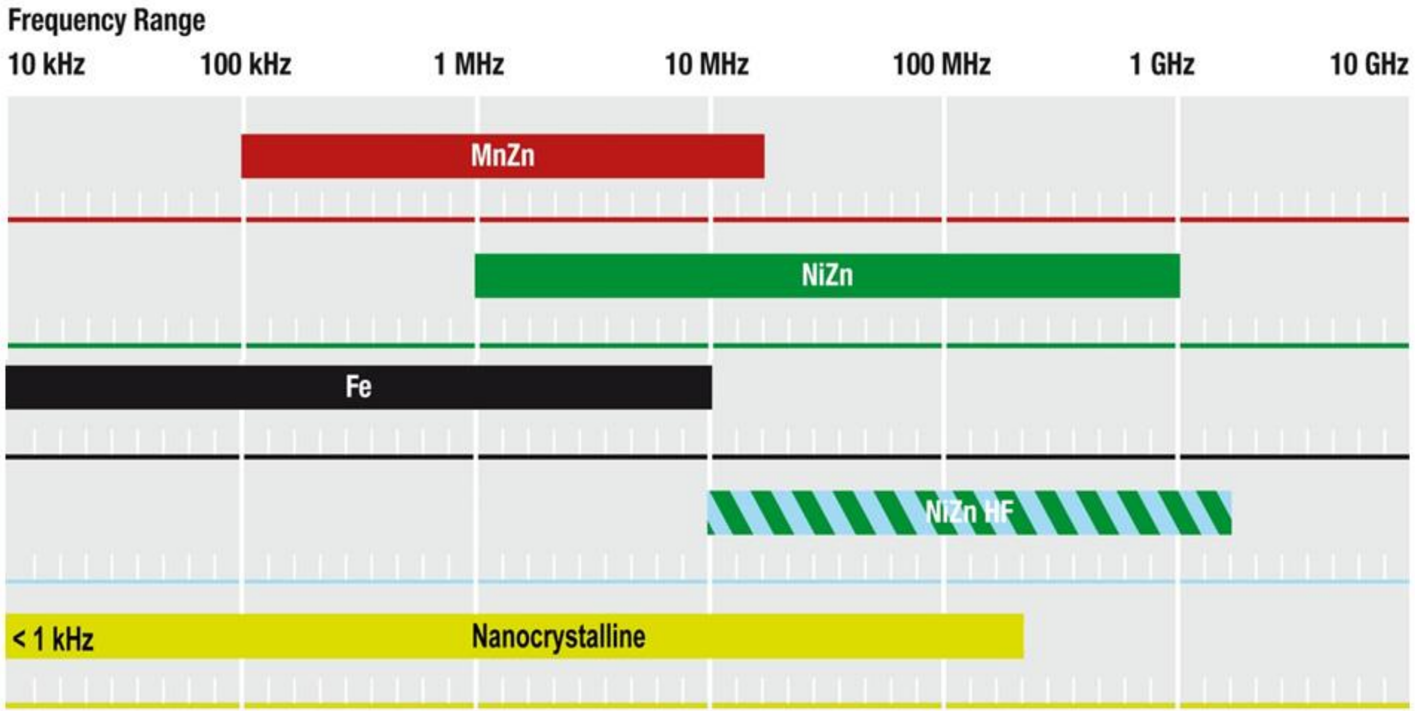
Disadvantages
The addition of an extra component results in an increase in the size and weight of the product, as well as the cost.

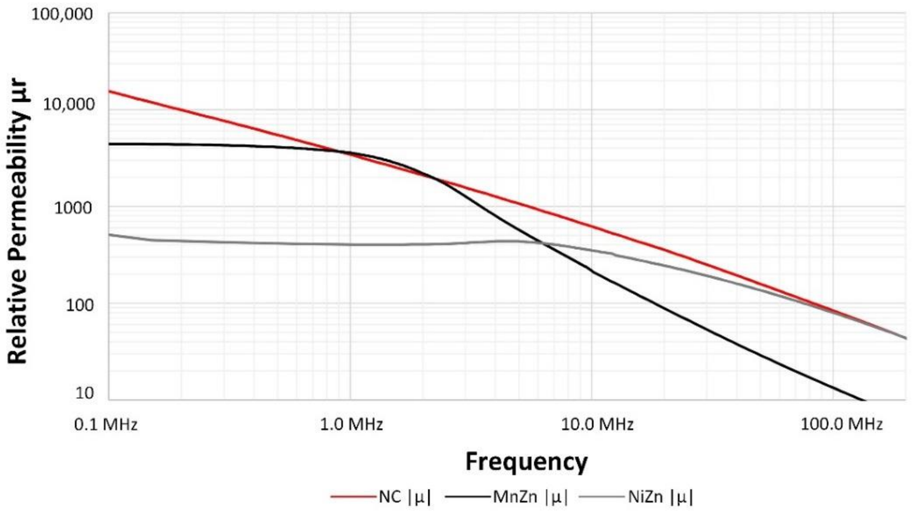
Optimization
Determine which material best suits the problem of our design and choose the ferrite cable with the lowest weight, dimensions, and cost.

5. EMC SOLUTIONS

Cable Ferrites. Selection.

It depends on the frequency



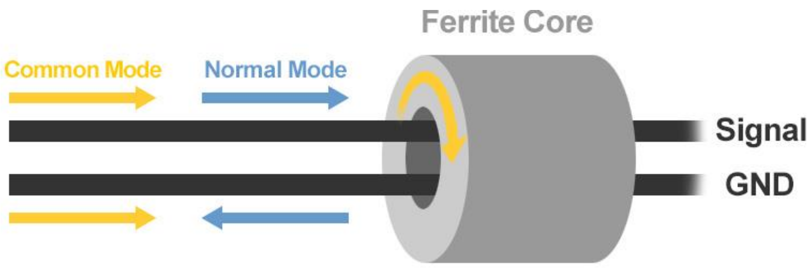


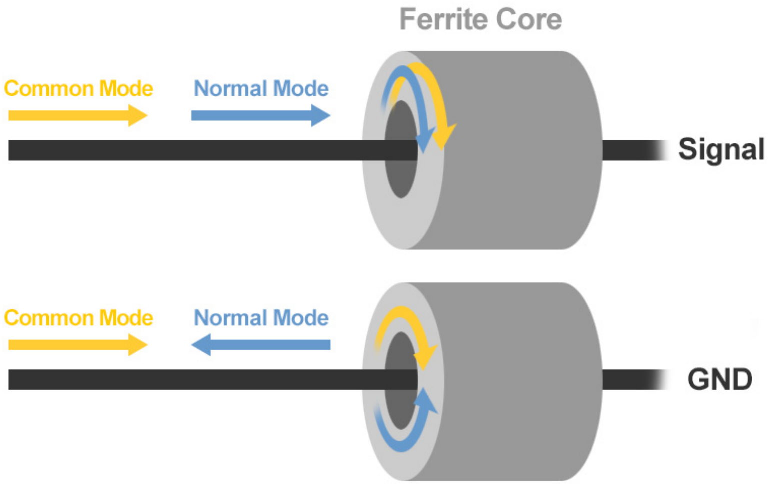
$$|Z| = N^2 \cdot \mu_0 * \sqrt{(\mu_r'')^2 + (\mu_r')^2} \cdot f \cdot l \cdot \ln(A)$$

5. EMC SOLUTIONS

Cable Ferrites. Tip.

How can you determine if a noise originates from common mode or differential mode?

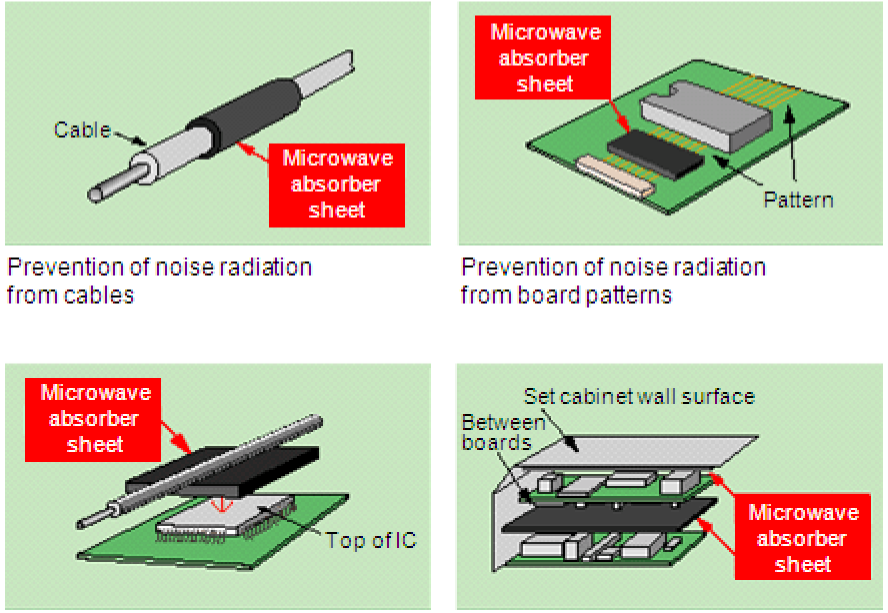




5. EMC SOLUTIONS

Flexible Absorber Sheets - Noise Suppression Sheet

The use of high-permeability absorbent material sheets, technically known as Flexible Absorber Sheet (FAS) or Noise Suppression Sheet (NSS), is a strategic solution in EMC engineering to mitigate interference without the need to mechanically redesign the equipment.



Prevention of noise radiation from cables

Prevention of noise radiation from board patterns

Suppression (electromagnetic shielding) of radiation noise induced in a cable by electromagnetic induction from a noise source (IC)

Prevention of noise induction between boards

5. EMC SOLUTIONS

Flexible Absorber Sheets - Noise Suppression Sheet

Absorption Attenuation Mechanism

Unlike conventional metallic shielding (such as copper or aluminum) that relies primarily on wave reflection, these materials are designed to absorb electromagnetic energy and transform it into heat.

The role of permeability: Their high relative permeability (μr) allows the material to interact strongly with magnetic fields, concentrating the field lines within it and preventing them from propagating to sensitive components or outside the equipment.

5. EMC SOLUTIONS

Flexible Absorber Sheets - Noise Suppression Sheet

Practical Design Solutions

These sheets solve specific problems where rigid shielding is not feasible or sufficient:

- **Direct Source Suppression**: They can be applied directly to integrated circuits (ICs), coils, or PCB traces identified as noise sources. This confines the noise at its source before it can radiate or couple to other structures.

- **Mitigation of Resonant Cavities**: In circuits enclosed in metal cases, waves can reflect internally, creating resonance peaks that degrade performance. Placing absorbent sheets on the internal walls of the enclosure helps to dampen these reflections and reduce the energy accumulated in the cavity.

- **Crosstalk Reduction**: These sheets are used to isolate areas of interference within a single PCB, preventing fast or noisy signals from coupling to sensitive analog traces.

- **Flexibility in confined spaces**: Being thin and flexible, these sheets allow for last-minute solutions (band-aid approach) in areas where there is no room for bulky shielding or additional discrete filters.

5. EMC SOLUTIONS

Flexible Absorber Sheets - Noise Suppression Sheet

Critical Selection Parameters

For the solution to be effective, the engineer must consider that performance depends on:

- Frequency dependence: Relative permeability varies with frequency; therefore, a material should be chosen whose absorption peak coincides with the range of the interfering noise.

- Geometry: The dimensions (length and width) and, above all, the thickness of the sheet determine the amount of magnetic flux it can handle before losing effectiveness.

These sheets act as a magnetic noise "sink," being especially useful for improving immunity and reducing emissions in high-density, compact designs.

5. EMC SOLUTIONS

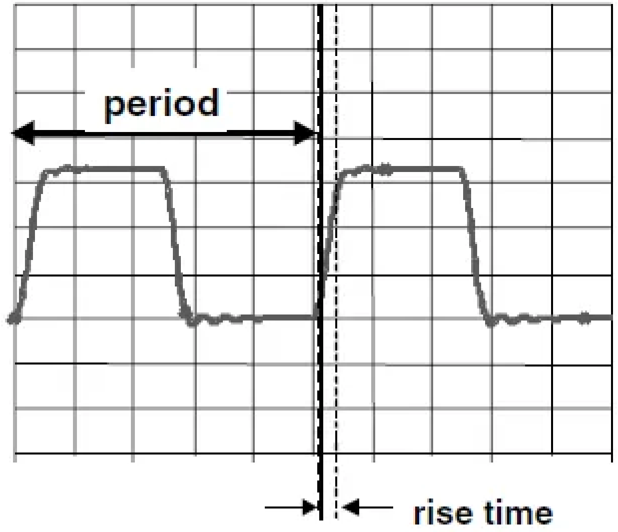
Shielding Cabinets

The main objective is to contain the radiation generated by high-speed digital electronics and prevent external fields from reaching sensitive circuits.

5. EMC SOLUTIONS

Shielding Cabinets

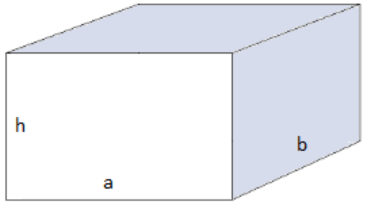
A clock with a relatively low speed, if it has very fast rising and falling edges, could generate harmonics at a very high frequency.



$$f_{clock} = 500\ MHz \qquad t_{rise} = 100\ ps$$

$$f_{knee} \approx \frac{0.35}{t_r} = 3.5\ GHz$$

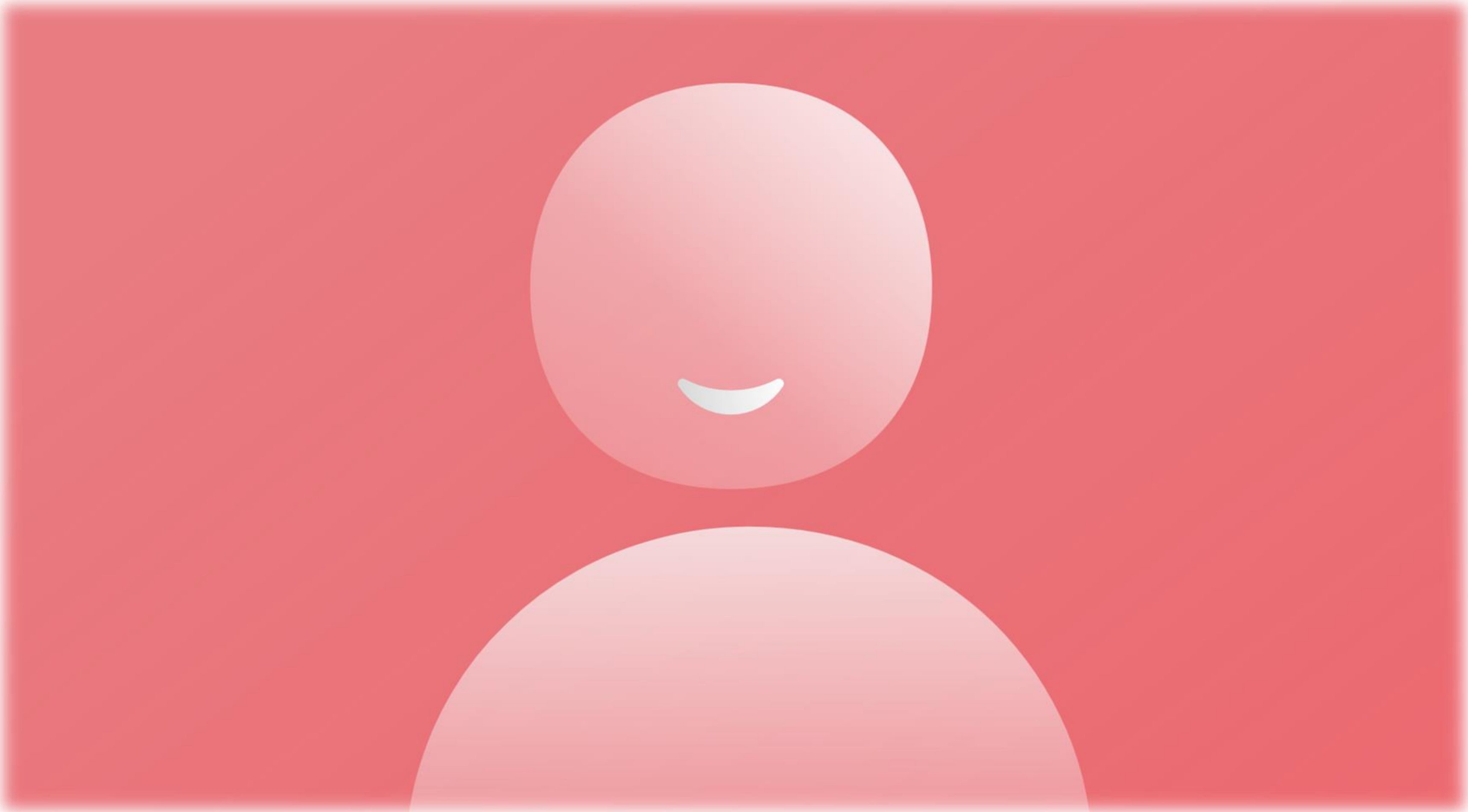
Cavity resonant:



$$f_{mnp} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

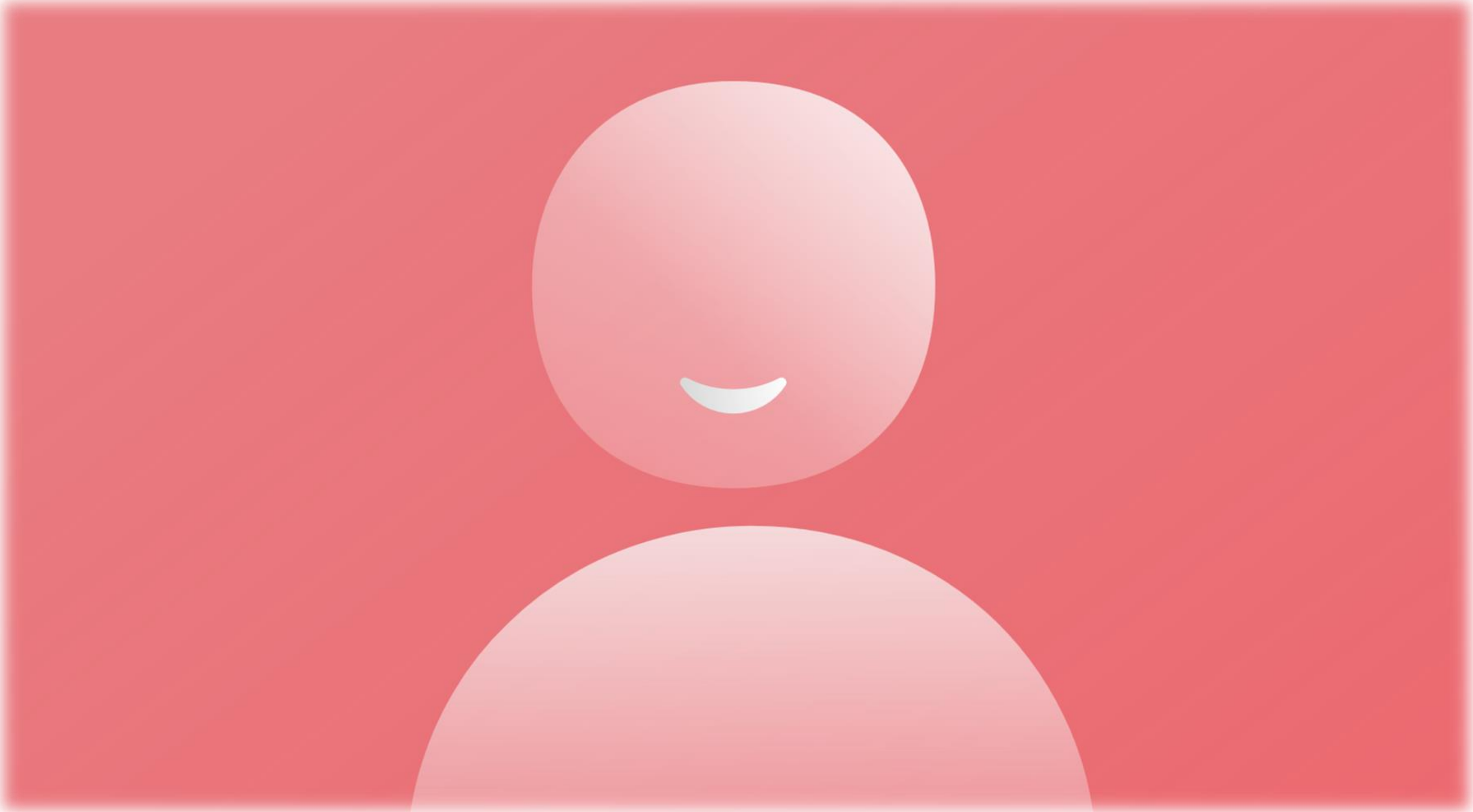
6. EXPERIMENTAL TEST

NFC kit

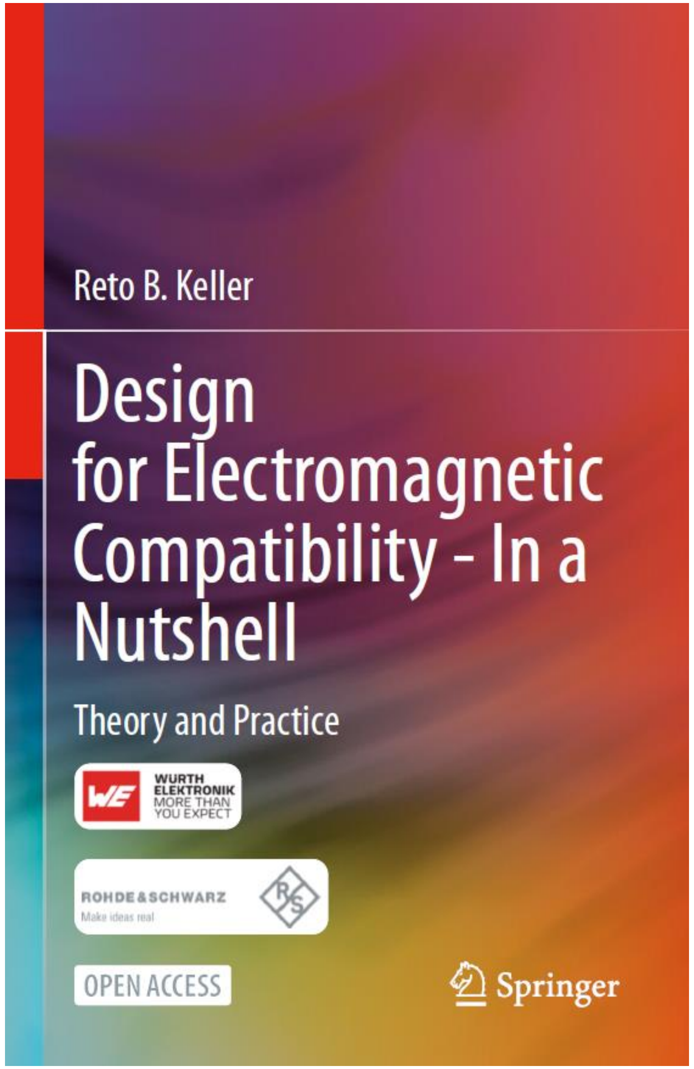


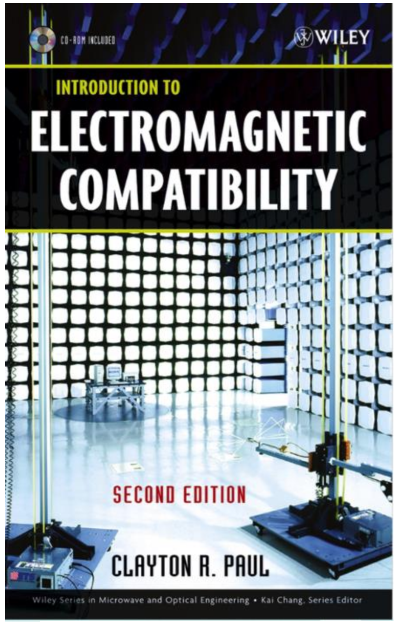
6. EXPERIMENTAL TEST

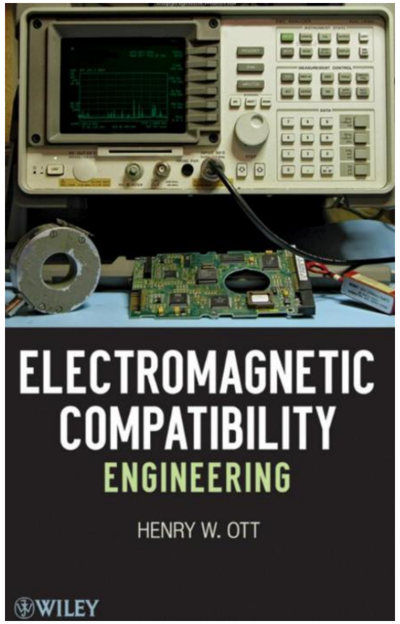
Sniffer

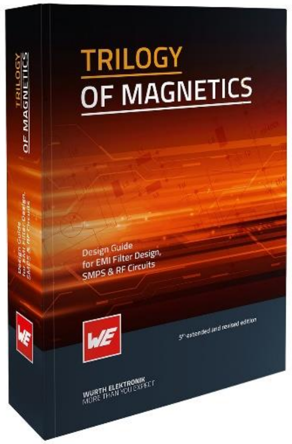


TO LEARN MORE









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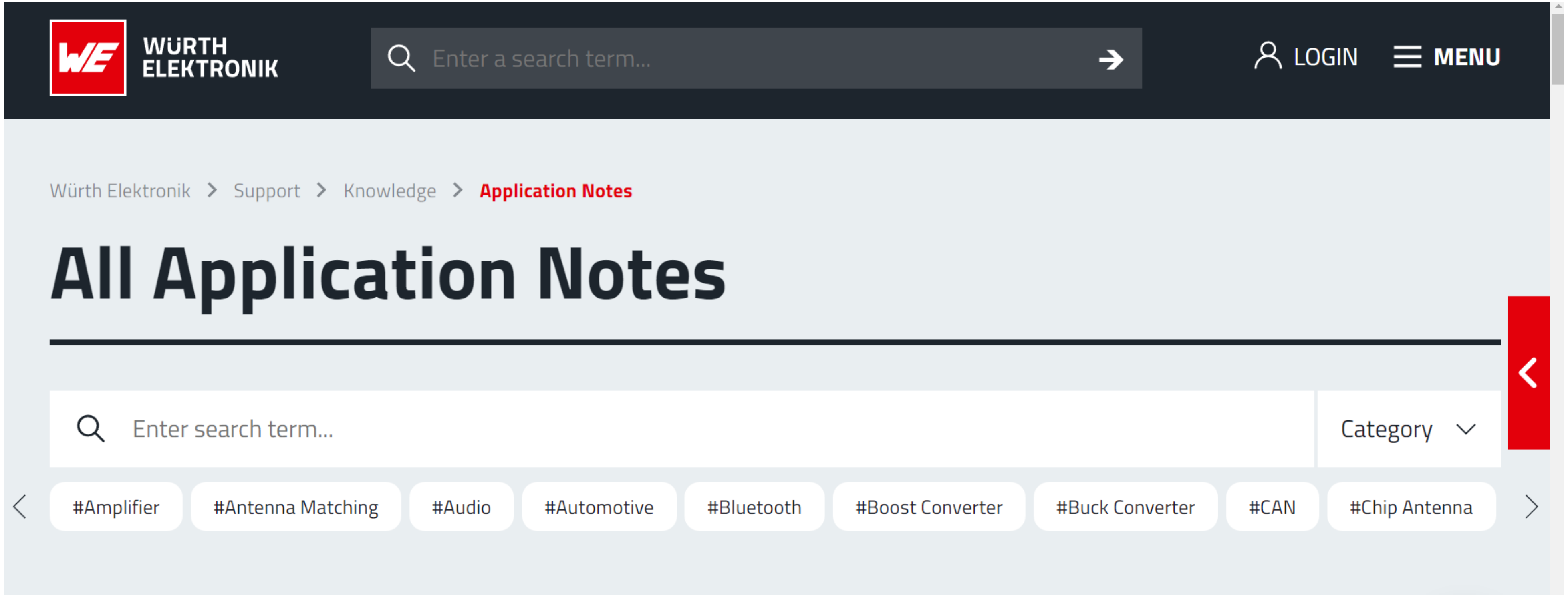

Presentation Feedback