EMC BASICS

Part 1

Now… this is what will happen to your designs in real life!

Agenda

- Technical terminology
- EMC Definitions
- Source, Path, Victim examples
- How is EMC made?
- What Is The Vehicle EMC Environment?
- ESD
- Material and Components Behavior
- Shielding and grounding concepts
- Test setups
- EMC Simulations

What Is EMC?

Introduction

- EMC → **Electromagnetic compatibility**
  - Definition: an electronic device’s ability to coexist with other devices without causing functional disturbances & not be disturbed by other devices
- EMI → Electromagnetic interference
  - Definition: Disruption of an electronic device’s function(s) due to conducted or radiated electromagnetic energy into the device
- RFI → Radio frequency interference
  - Definition: See EMI definition
- ESD → Electrostatic discharge
  - Definition: Sudden transfer of charge from one object to another

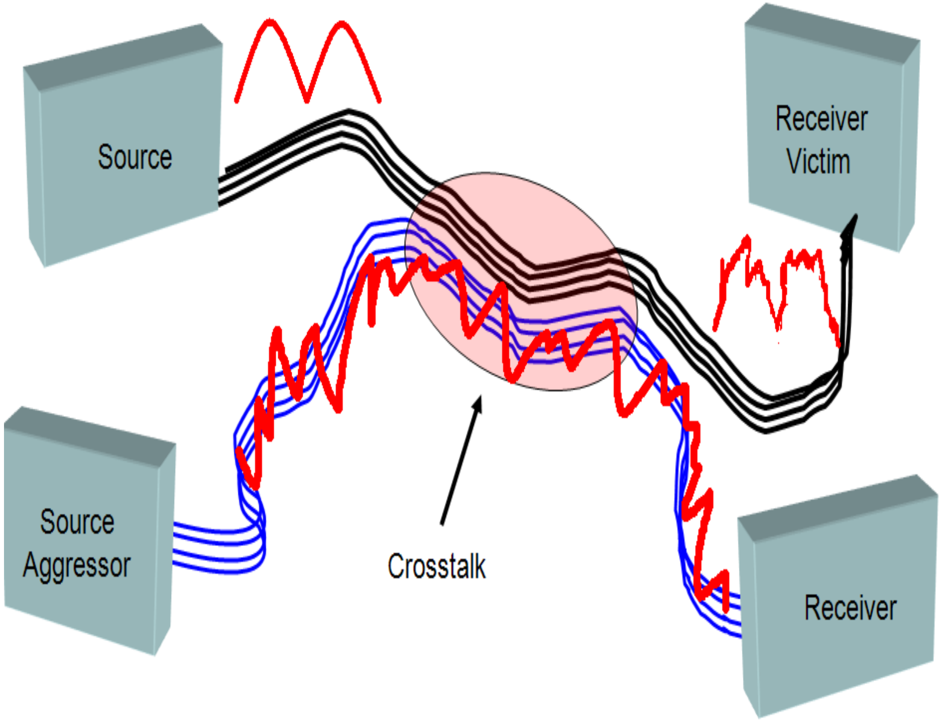
What makes an EMC problem?

- **What is EMC:**

Ever wonder why you are requested to switch off your electronics devices when you are taking a flight? This is one of the typical case of EMC of which your electronics devices may interfere with the electronics system in the aircraft.

- **EMC problem basics:**

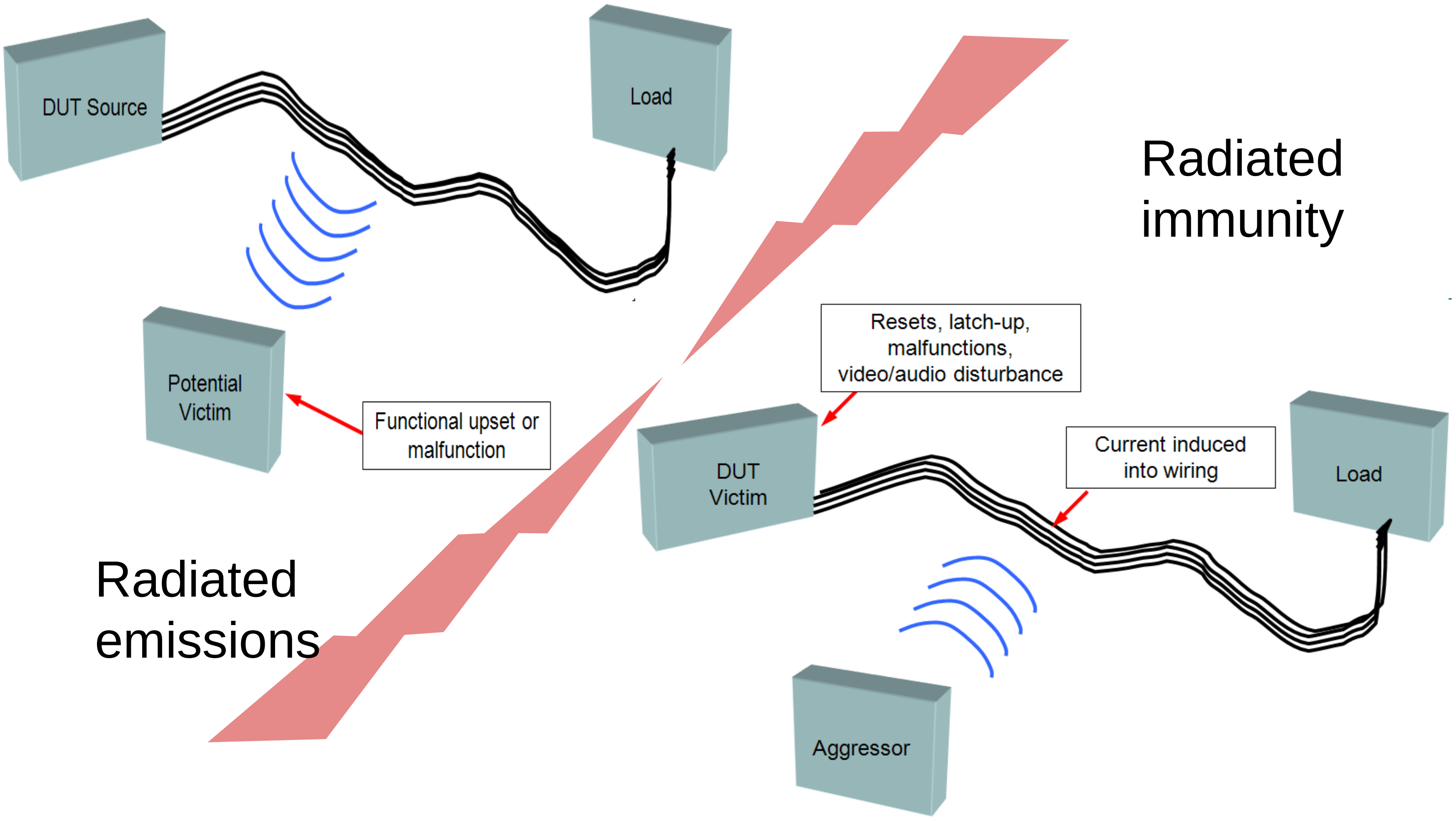
-Source of EM energy (Emitter; Source)
-Transfer of EM energy (Coupling path)
-Reception of EM energy (Receiver; Victim)



- **Coupling mechanisms:**

-Conducted coupling
-Capacitive coupling
-Inductive coupling
-Radiated coupling

What makes an EMC problem?



Radiated immunity

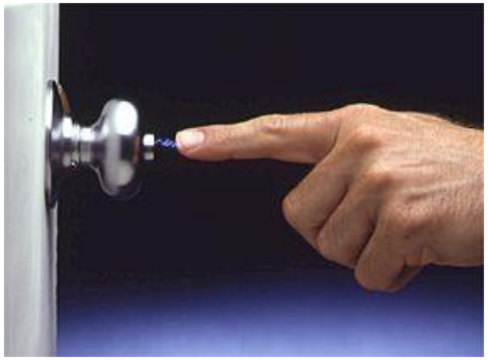
Resets, latch-up, malfunctions, video/audio disturbance

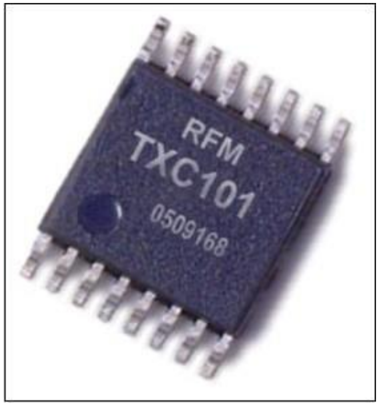
Current induced into wiring

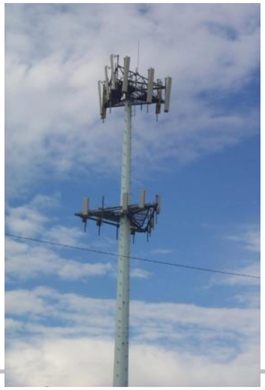
Functional upset or malfunction

Radiated emissions

Examples of Sources







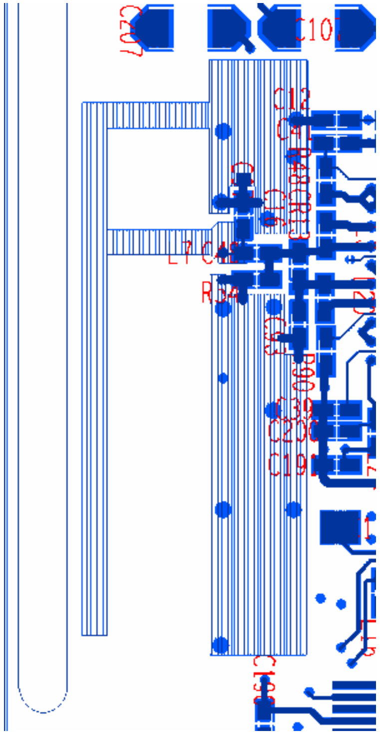
Sources

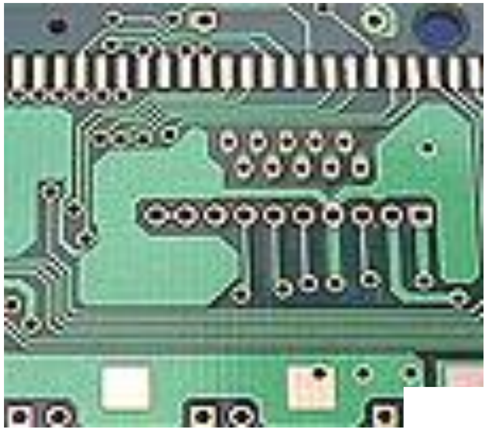
Electric and magnetic field Sources:

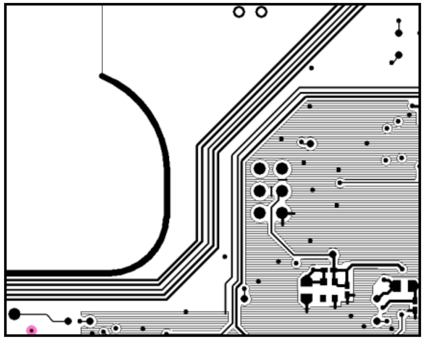
Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. **Magnetic fields** are created when electric current flows: the greater the current, the stronger the magnetic field.

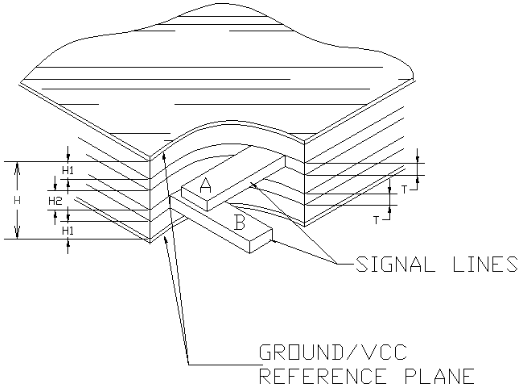
Electric fields	Magnetic fields
Electric fields arise from voltage (dv/dt) Their strength is measured in Volts per meter (V/m) An electric field can be present even when a device is switched off. Field strength decreases with distance from the source.	Magnetic fields arise from current (di/dt). Their strength is measured in amperes per meter (A/m). Magnetic fields exist as soon as a device is switched on and current flows. Field strength decreases with distance from the source.

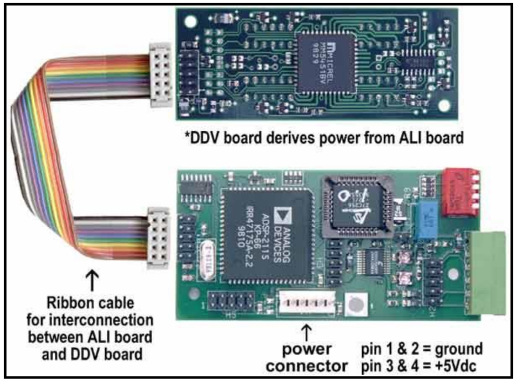
Examples of Paths











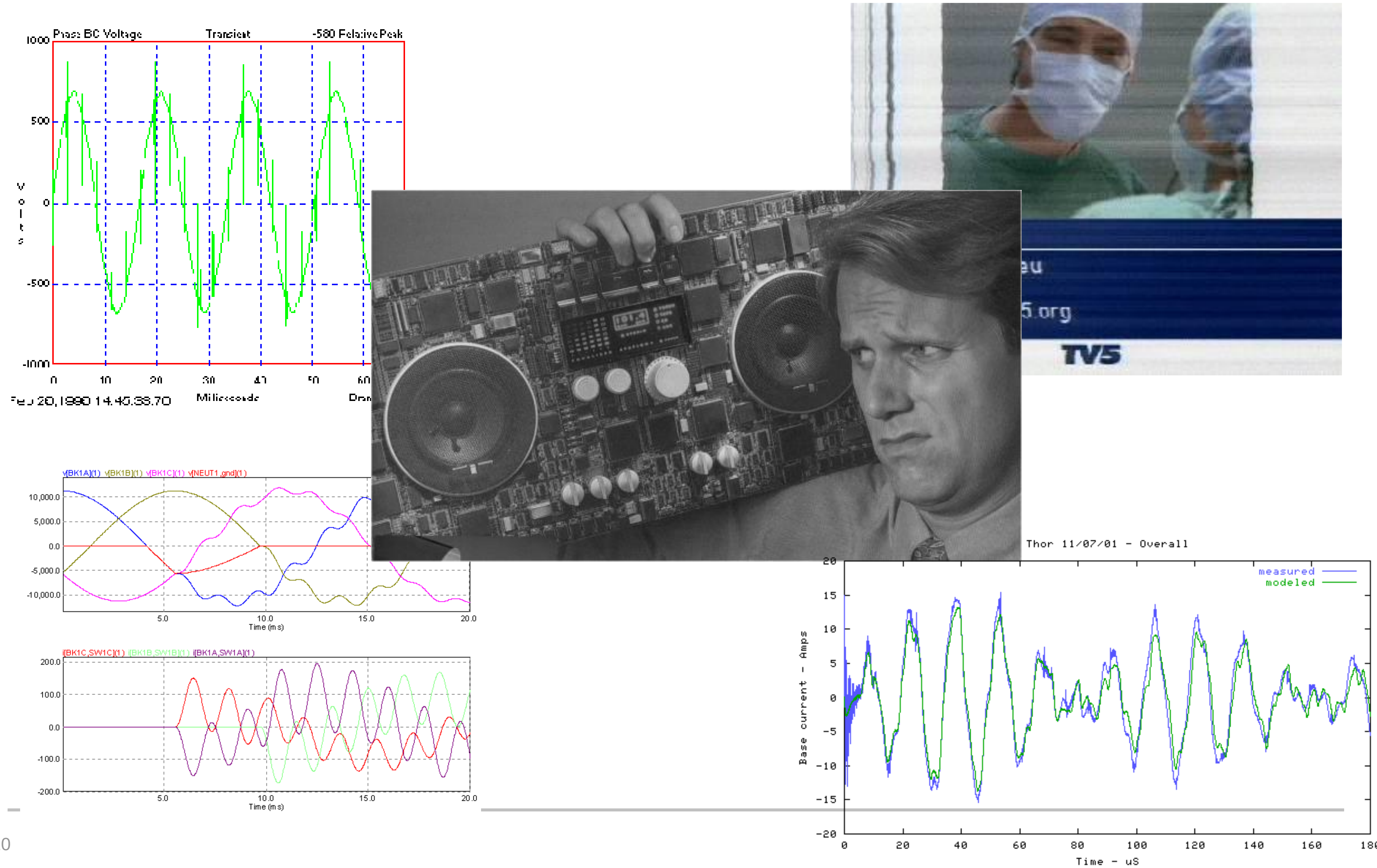
*DDV board derives power from ALI board

Ribbon cable for interconnection between ALI board and DDV board

power connector

pin 1 & 2 = ground
pin 3 & 4 = +5Vdc

Examples of Victims



EMC Fundamentals

How is EMC made?

- **The coupling path is frequency dependent**

– High frequencies are typically radiated
– Low frequencies are typically conducted
– The boundary is typically about 30 MHz

- **There are 5 aspects to understanding EMC**

– Frequency - Where in the spectrum is the problem observed?
– Amplitude - How strong is the energy source?
– Time - Is it continuous or not?
– Impedance - What is the Z of the source and receiver?
– Dimensions -What are the physical dimensions of the device which will allow emissions?
(RF currents will leave through openings which are fractions of a wavelength!)

EMC Fundamentals

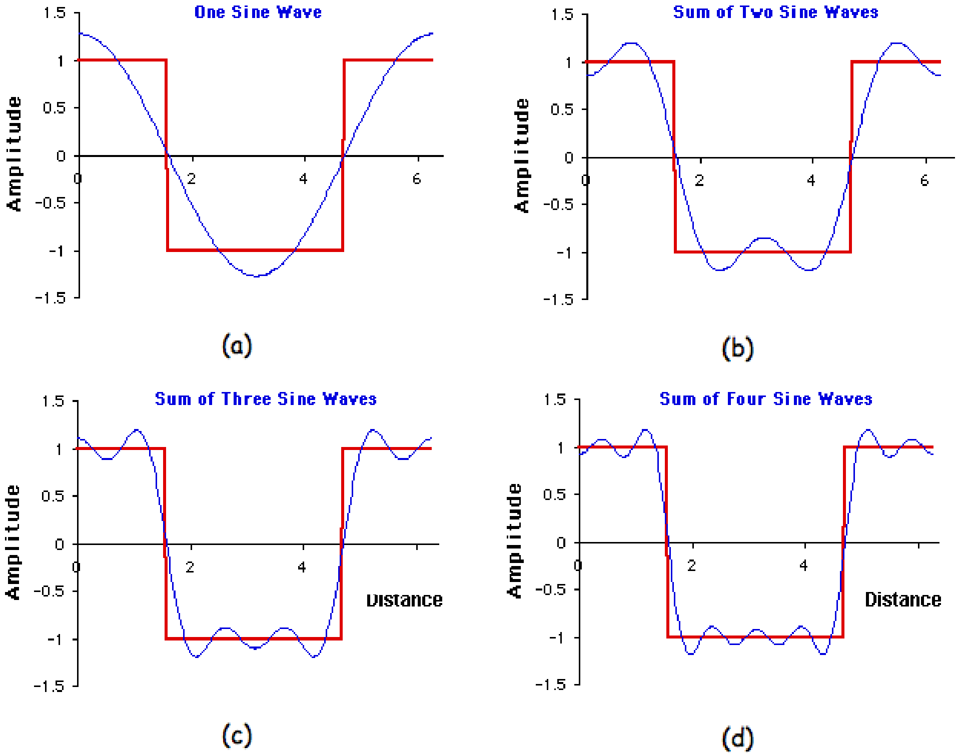
Coupling Clues

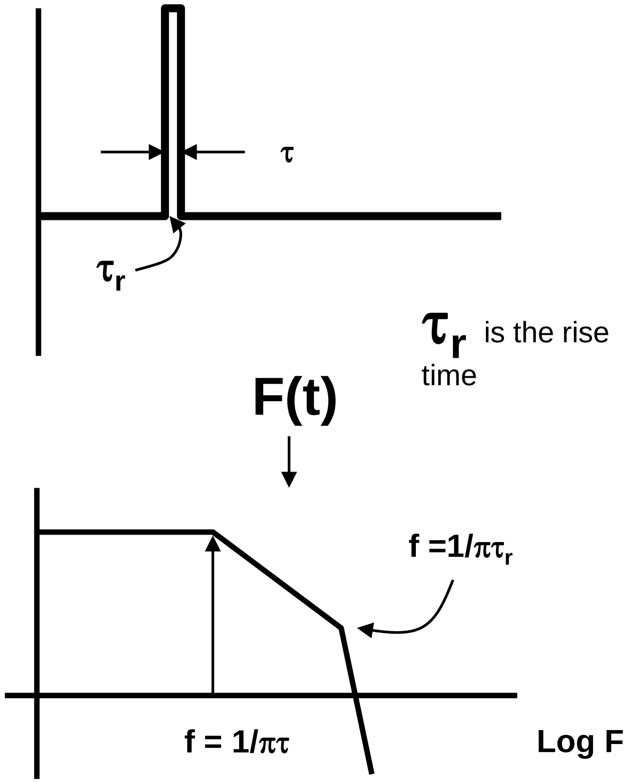
① **Conducted Coupling** (Common Impedance Coupling)	Low freq.(<10MHz), scaled voltage in victim
② **Capacitive Coupling** (Electric Field Coupling)	Large surfaces, large dV/dt, same phase, >377ohms
③ **Inductive Coupling** (Magnetic Field Coupling)	Large loops, large dI/dt, opposite phase, <377ohms
④ **Radiated Coupling** (EM/Plane wave/far field coupling)	Large separation distance, high freq., no DC offset

Think Harmonics!

- **Fourier transformation:**

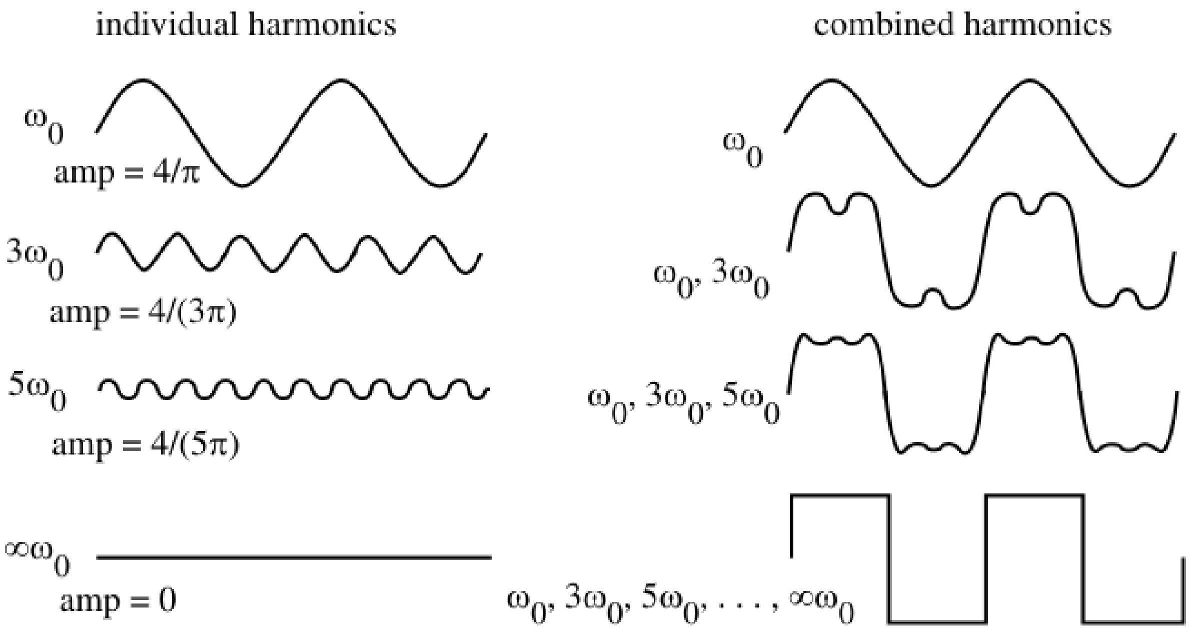
Signal rise and fall times are one of the main reason for EMI. The smaller these times are – the more issues we should expect.

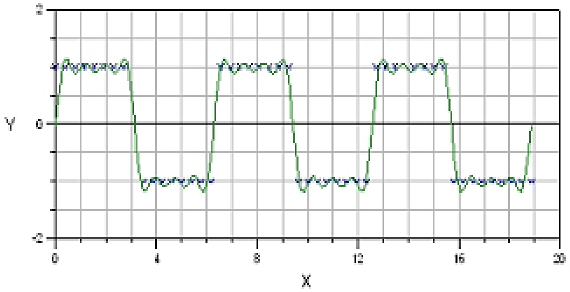


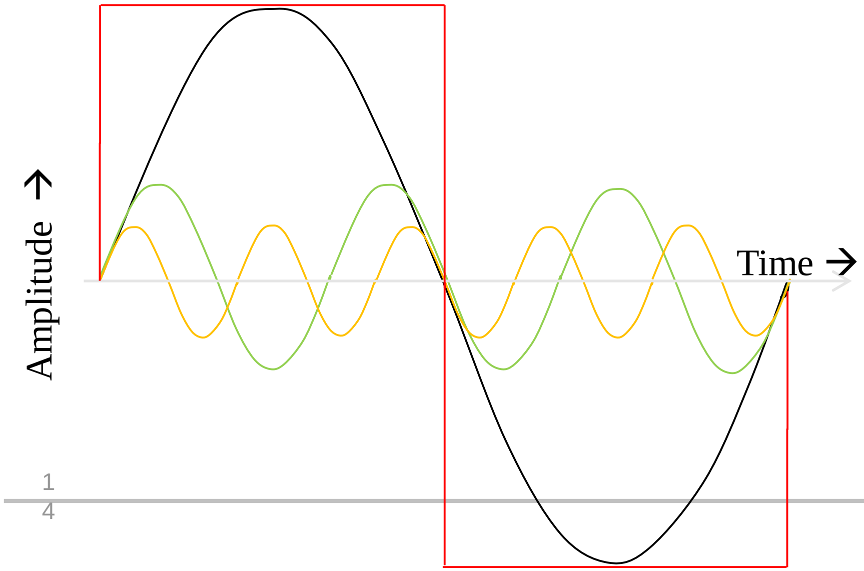


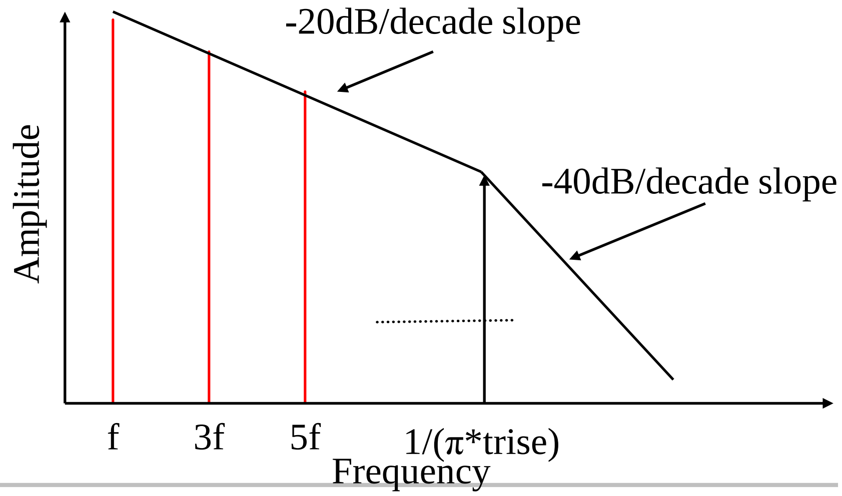
τ_r is the rise time

Clock Waveform Analysis







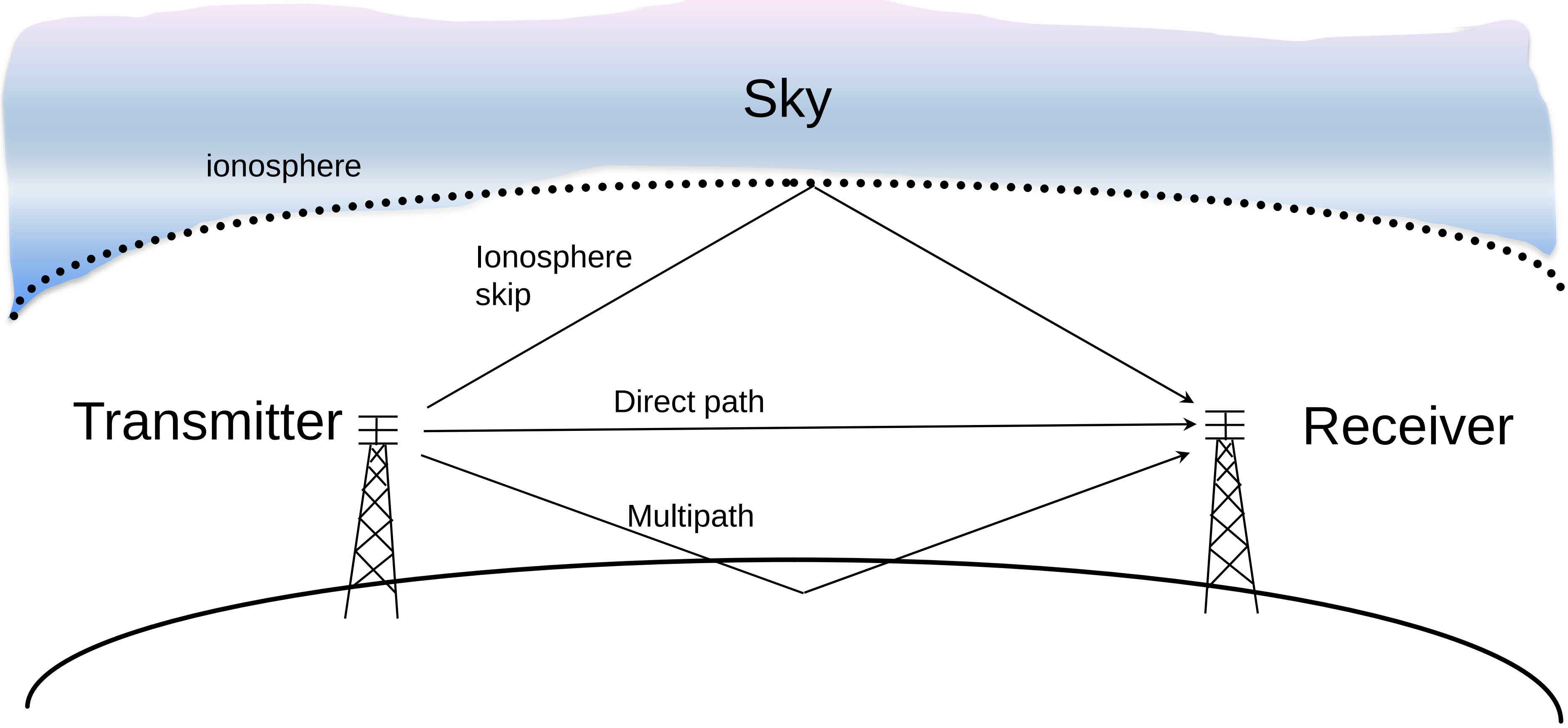


What is the vehicle EMC environment?

Why do we have EMC normative?

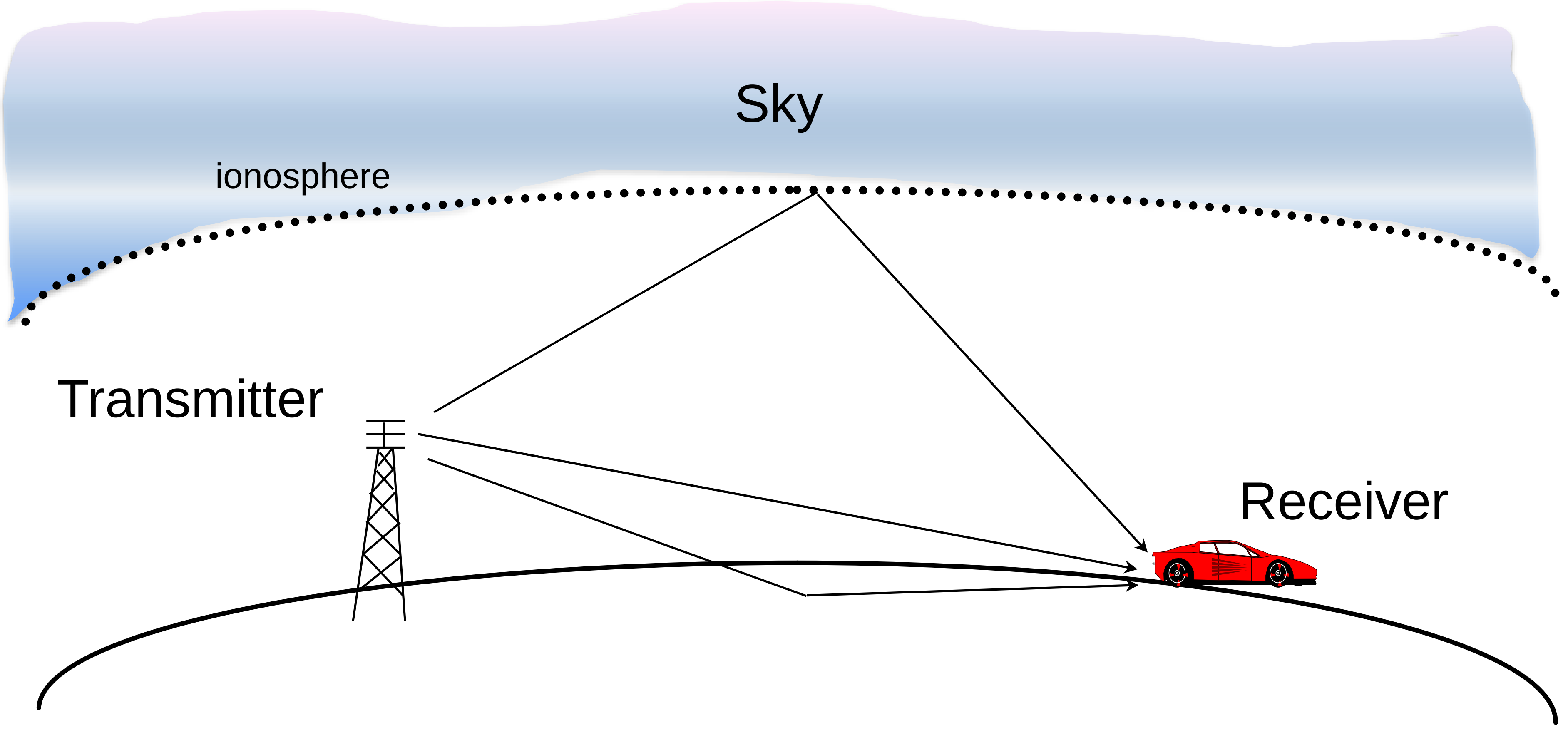
Introduction

Land Based Communications



Radio Propagation Paths

Vehicle Exposure



Radio Propagation Paths

Introduction

Intentional RF Transmitters

Introduction

Un-Intentional Transmitters Found In Vehicle Environment

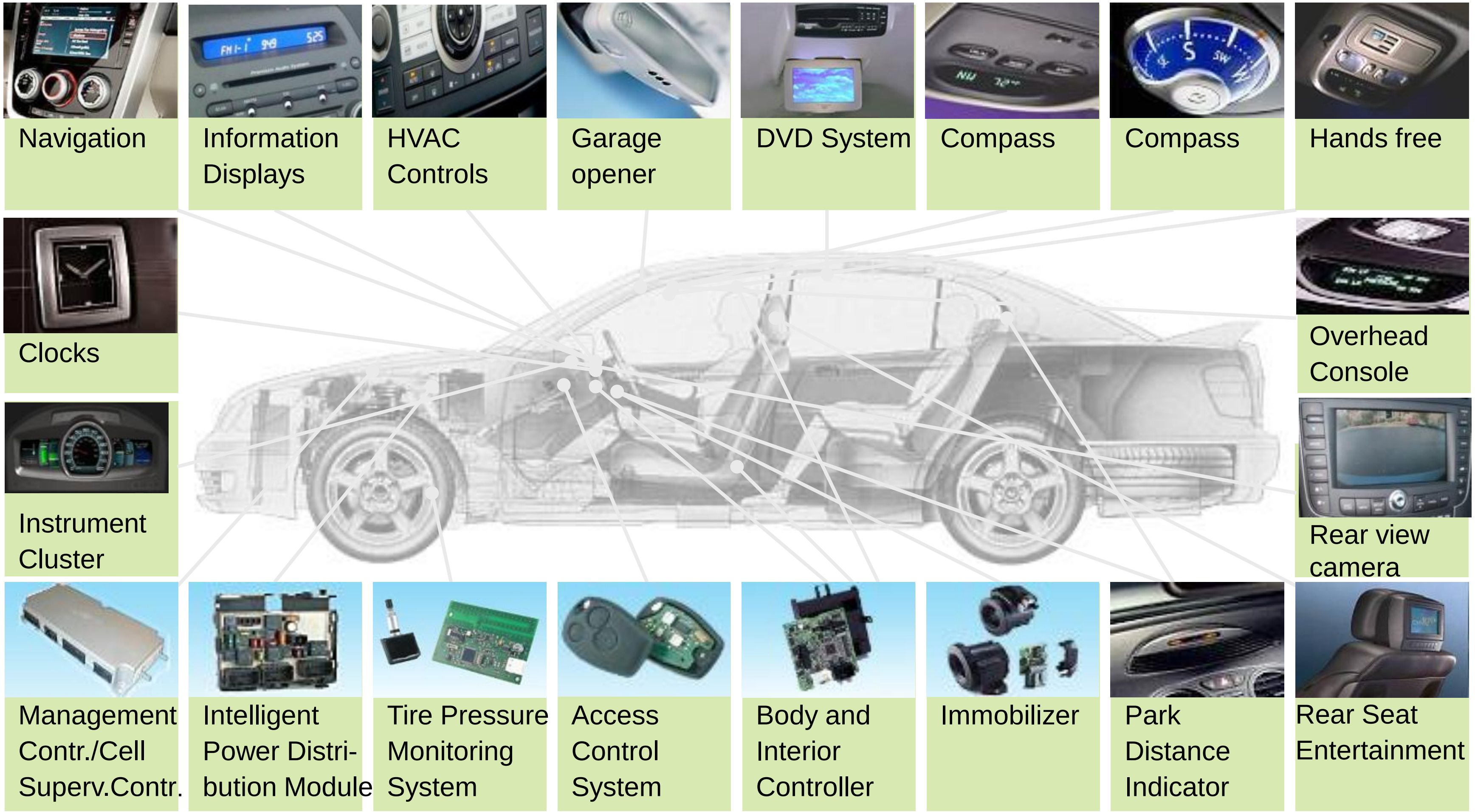
Introduction

Vehicle RF Receivers

Compass Locations

Introduction

On-board Electronics



Navigation

Information Displays

HVAC Controls

Garage opener

DVD System

Compass

Compass

Hands free

Clocks

Instrument Cluster

Overhead Console

Rear view camera

Management Contr./Cell Superv.Contr.

Intelligent Power Distribution Module

Tire Pressure Monitoring System

Access Control System

Body and Interior Controller

Immobilizer

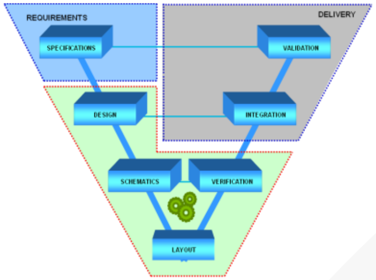
Park Distance Indicator

Rear Seat Entertainment

EMC COMPLIANCE
Global View

EMC Compliance

Overview



Visteon
Product Development

Component Level Tests

OEM Integration

Perform on-board receiver and full-vehicle validation

Regulatory (Government)

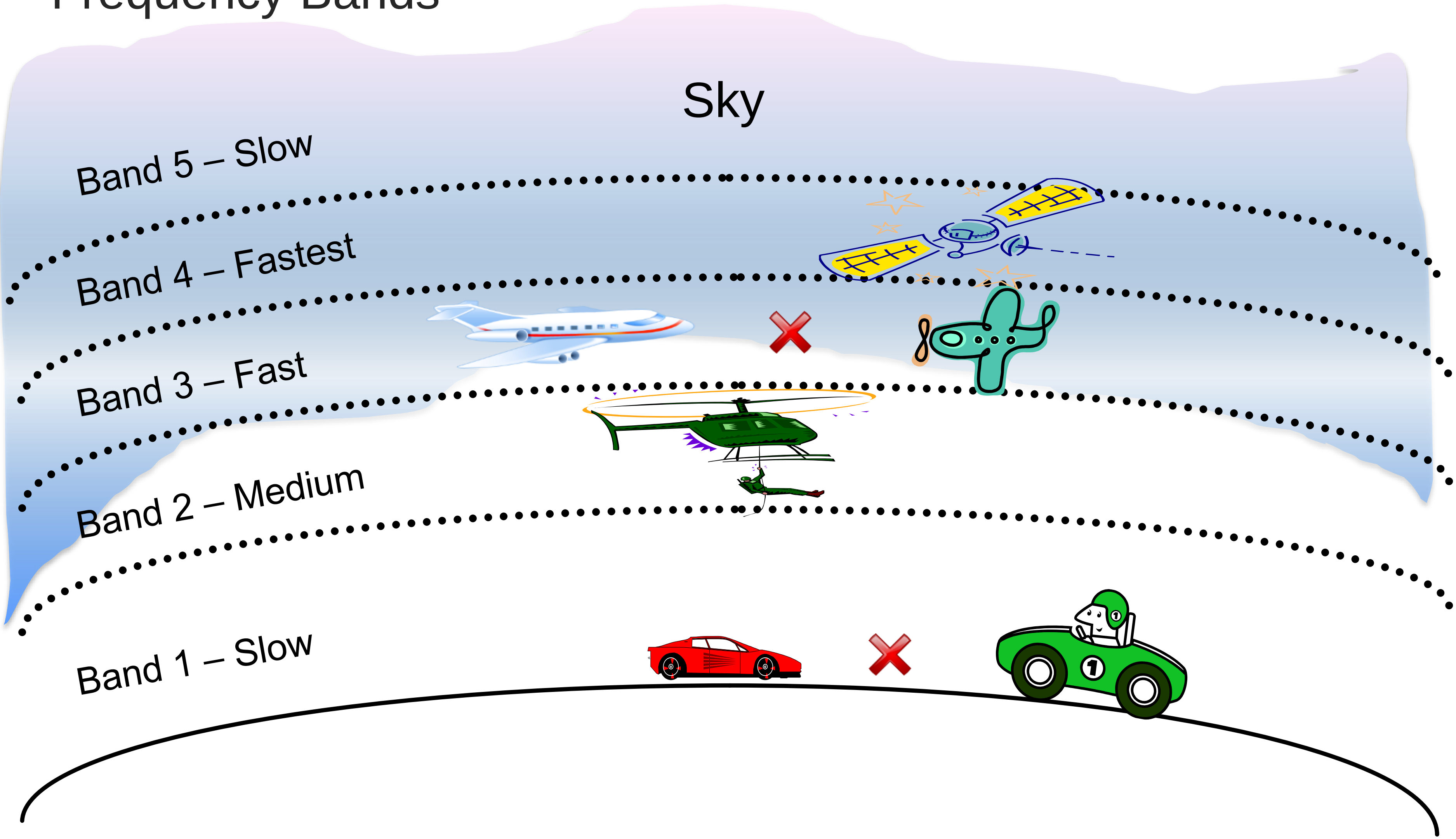
Obtain necessary certification prior to mass production

STANDARDS Australia

Industry Canada

EMC Compliance

Frequency Bands



Sky

Band 5 – Slow

Band 4 – Fastest

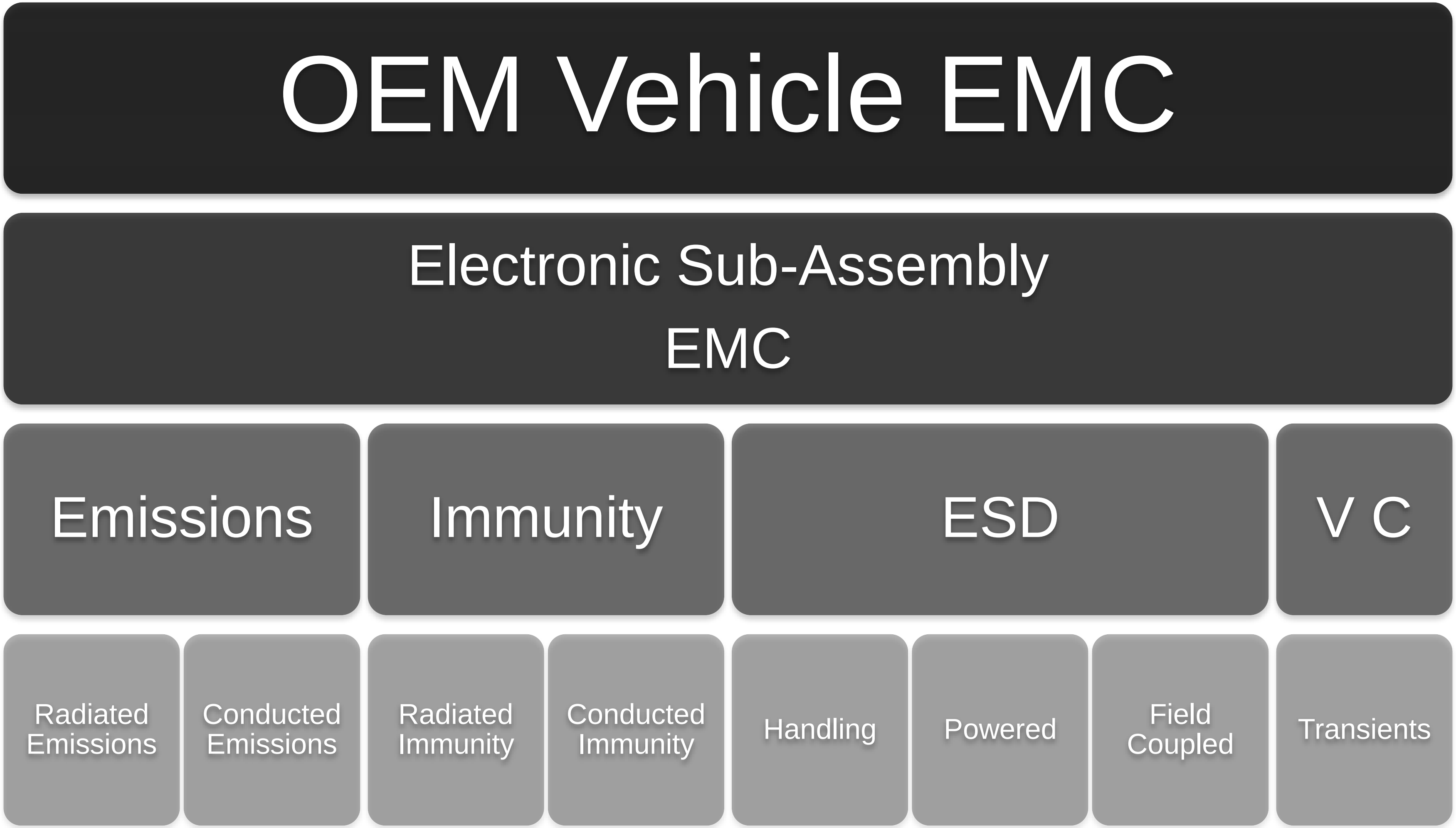
Band 3 – Fast

Band 2 – Medium

Band 1 – Slow

EMC Compliance

Hierarchy



OEM Vehicle EMC

Electronic Sub-Assembly
EMC

Emissions

Immunity

ESD

V C

Radiated Emissions

Conducted Emissions

Radiated Immunity

Conducted Immunity

Handling

Powered

Field Coupled

Transients

EMC Compliance

Vehicle EMC Validation

Vehicle level EMC testing by OEM

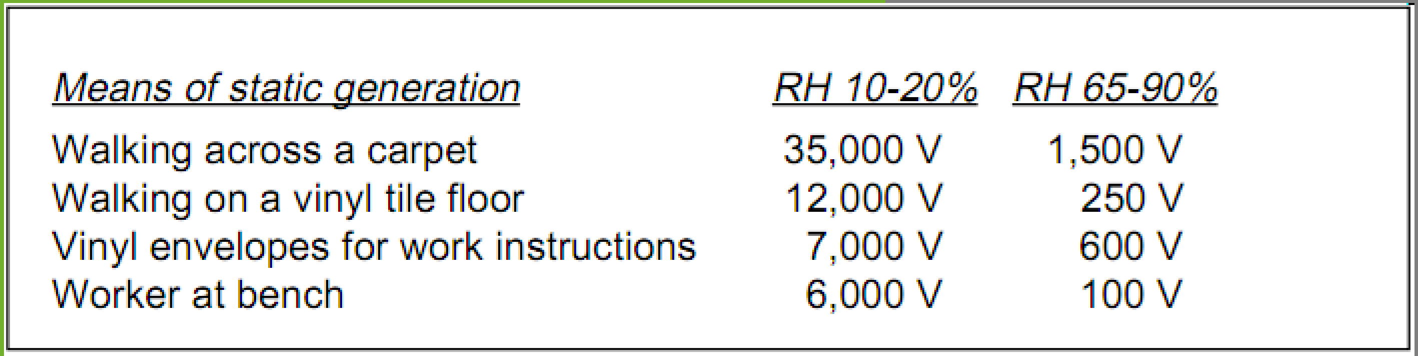
Radiated emissions
Radiated immunity
On-board transmitters
Off-board transmitters
ESD testing

Vehicle in drive mode

Rotate vehicle to test all sides

EMC Fundamentals

Electrostatic Discharge

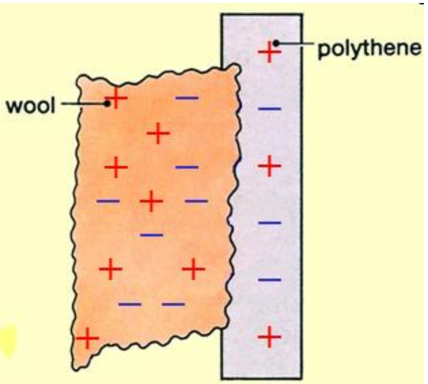


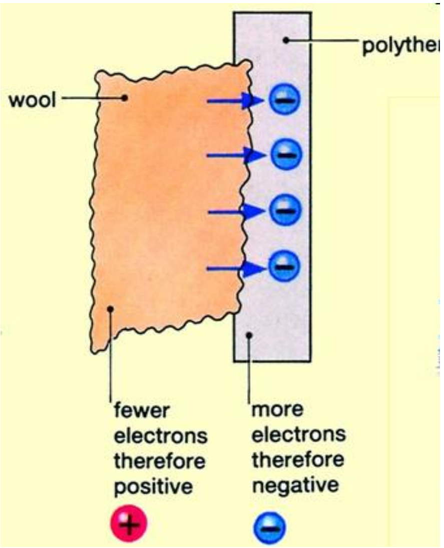
Means of static generation	*RH 10-20%*	*RH 65-90%*
Walking across a carpet	35,000 V	1,500 V
Walking on a vinyl tile floor	12,000 V	250 V
Vinyl envelopes for work instructions	7,000 V	600 V
Worker at bench	6,000 V	100 V

How is ESD made?

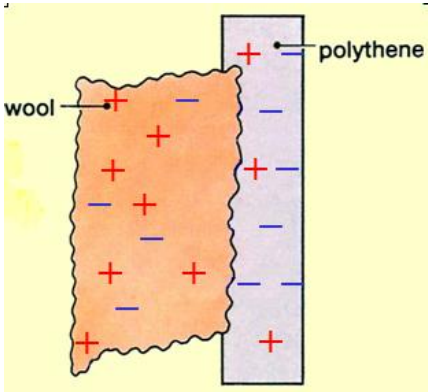
- **Electrostatic Charging:** The process of gaining electrons (negative charging) or losing electrons (positive charging). It is most important to know that it is only the negative electrons which can move. Positive charges (protons) cannot move.

“uncharged”



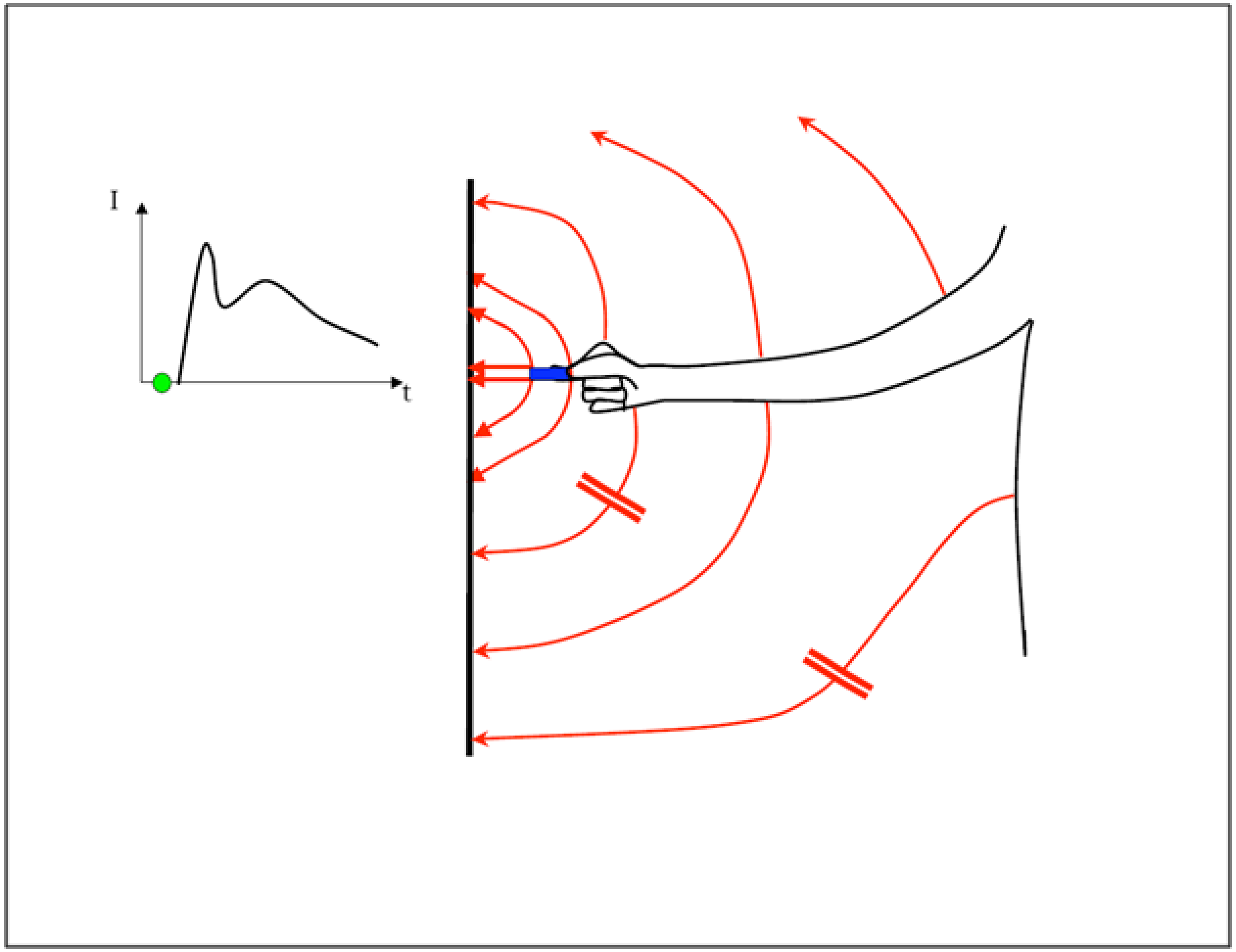


+ charged wool and – charged polythene

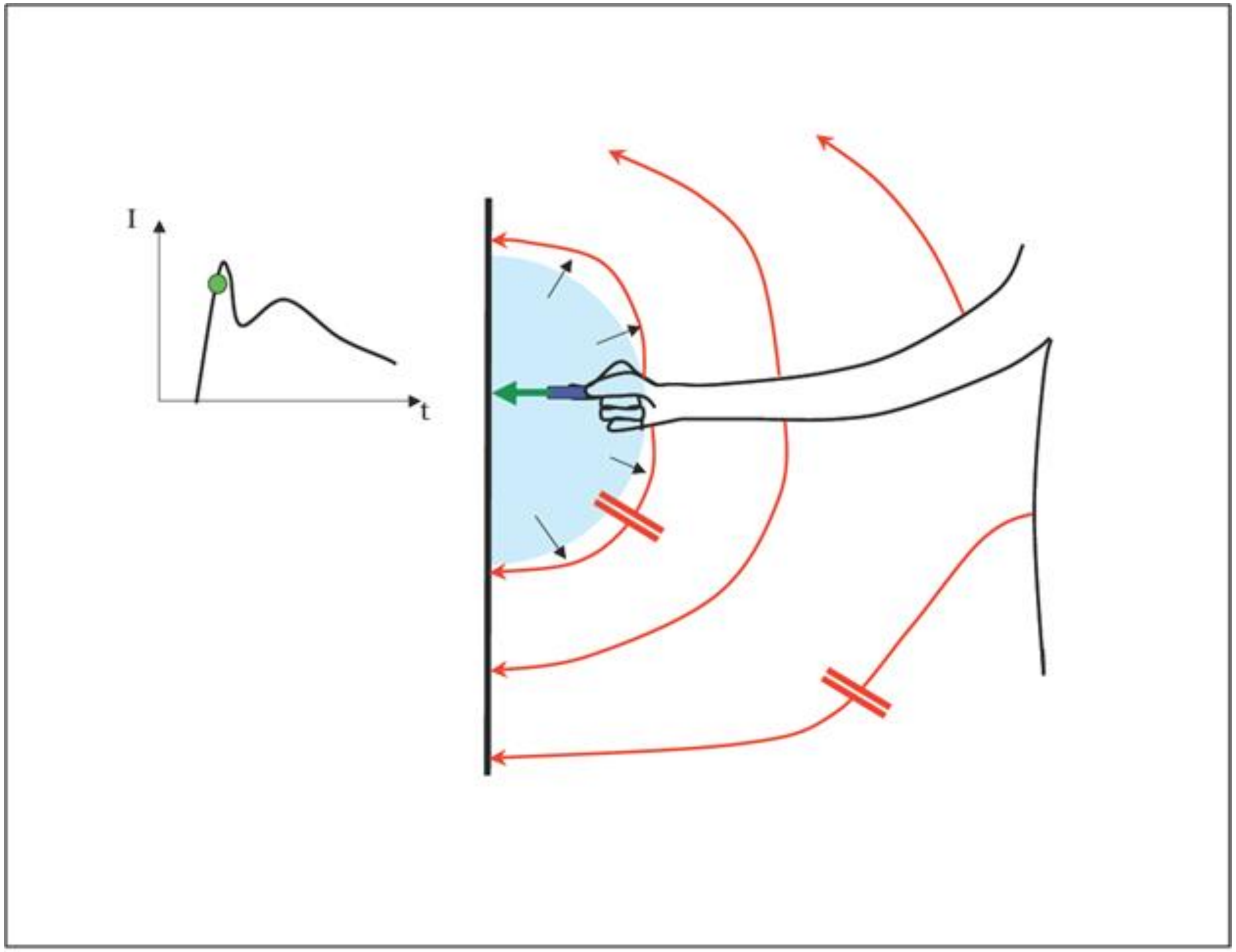


Both objects are now equally charged, with opposite charges because only electrons have moved!

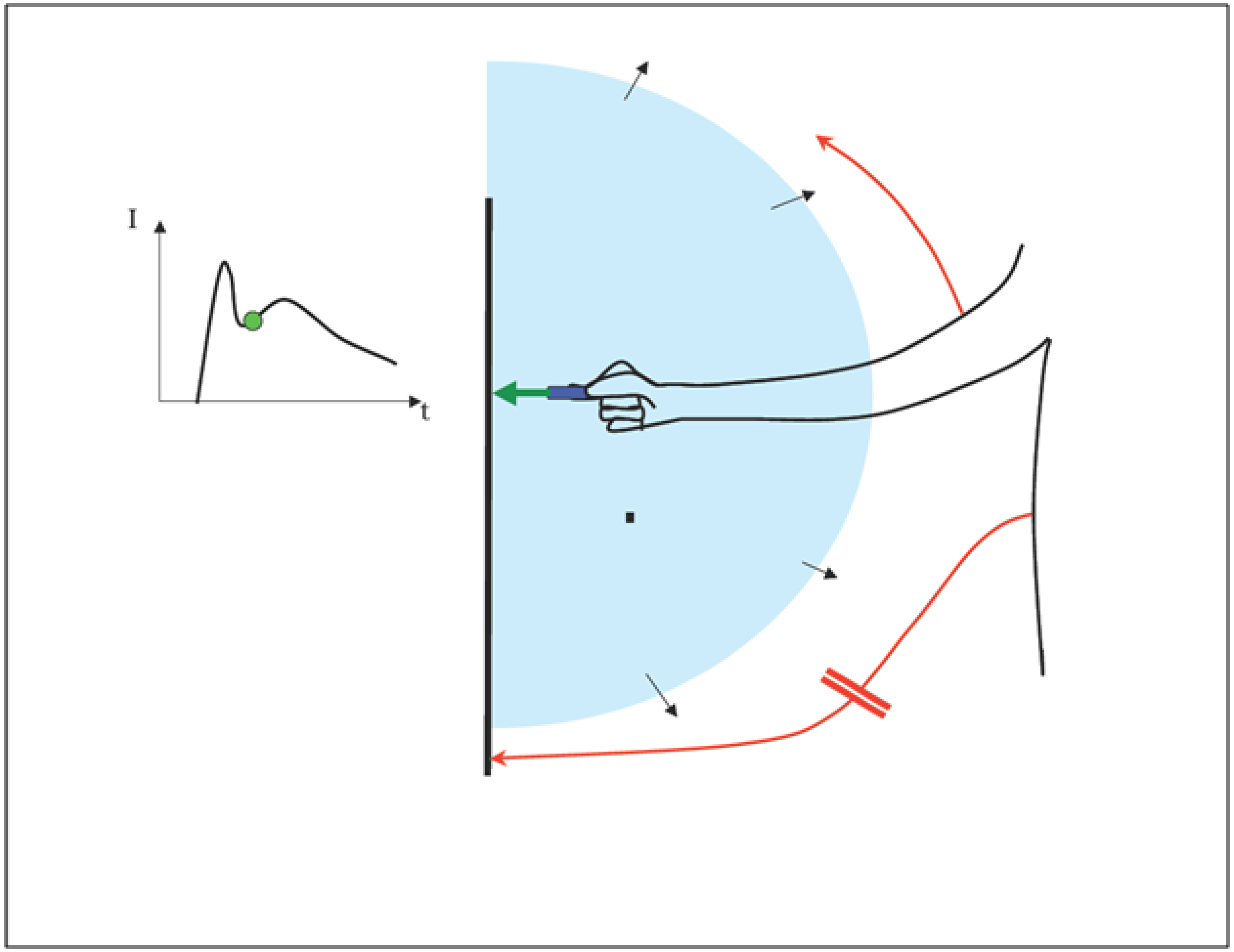
Human Body Model – I



Human Body Model – II



Human Body Model – III

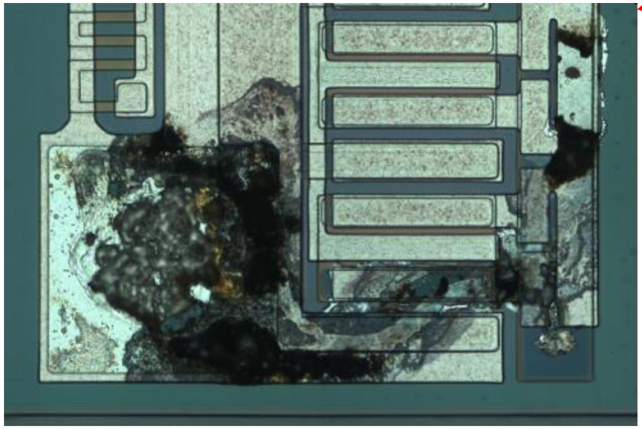


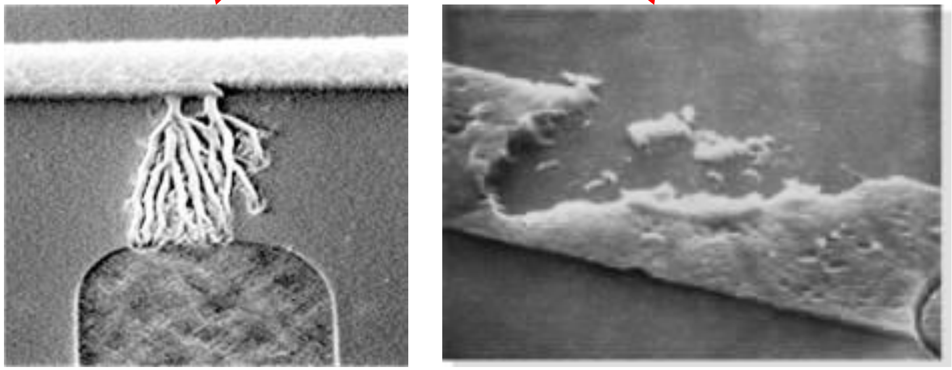
ESD Fundamentals

Effects of ESD on Electronic Equipment

- All ESD damage is not created equal. In fact, there are three different types of ESD damage:
  - A catastrophic failure
  - Latent defect
  - An upset failure

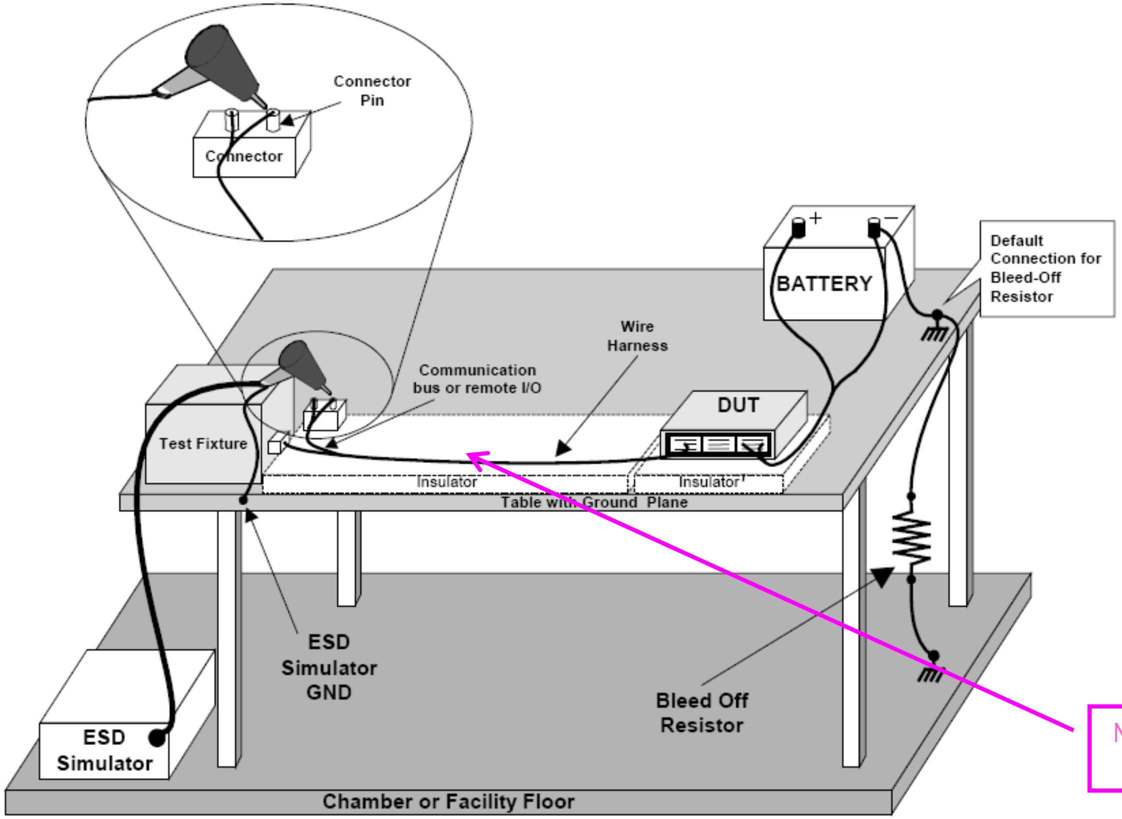
If the electrostatic discharge possesses sufficient energy, damage could occur in the device due to localized overheating.





Component Level EMC Tests

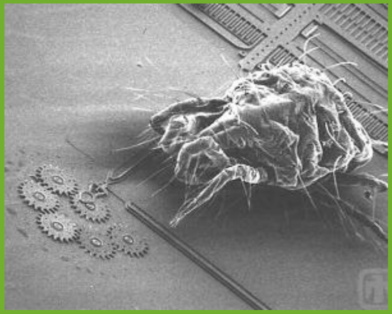
Electro Static Discharge (ESD) – Test Setup For Powered Case



Bleed Off resistor used to bleed charge from discharge points

Note that harness is isolated on from the ground plane as well as the DUT

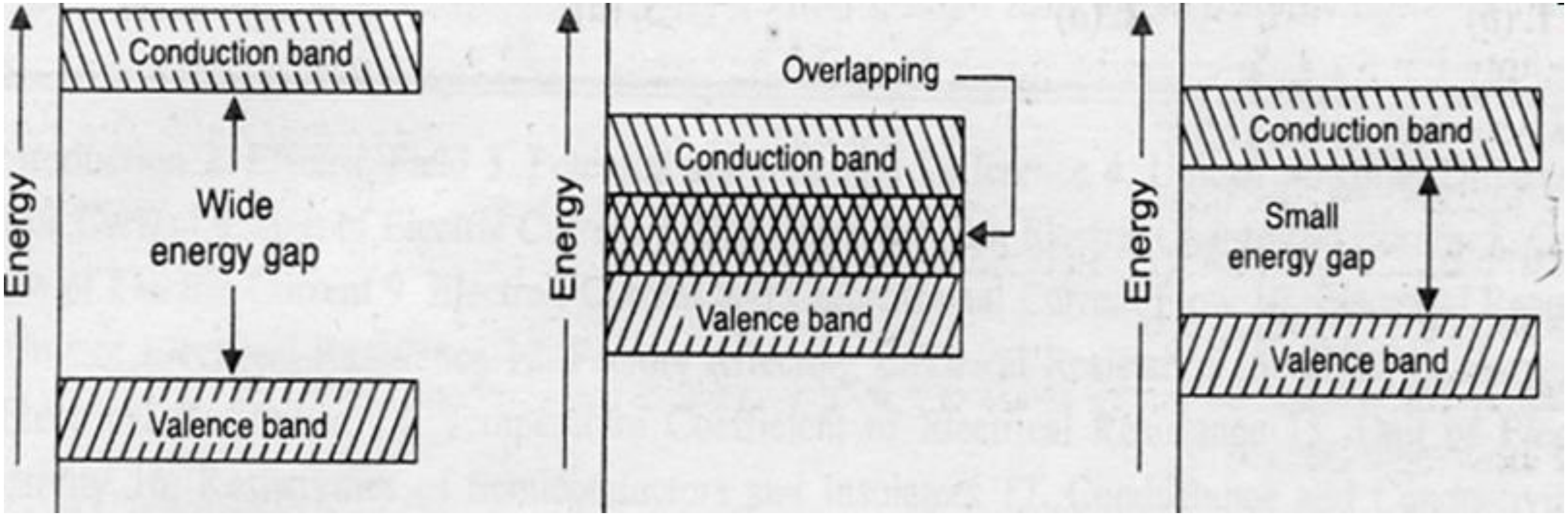
EMC Fundamentals



Material Behavior

Fundamentals (Material Behavior)

In a conductor, electric current can flow freely, in an insulator it cannot. But why?



a) Insulator

b) Conductor

c) Semiconductor

Fundamentals (Material Behavior – Conductors)

Metal = Conductor

By definition all metals are conductors of electricity. Some conduct better than others.

Material	Relative Conductivity
Silver	106
Copper	100
Gold	65
Aluminum	59
Lead	7

"Conductor" implies that the outer electrons of the atoms are loosely bound and free to move through the material. Metals are also generally good heat conductors.

Fundamentals (Material Behavior – Insulators)

Dielectric ≠ Insulator

Dielectrics are used to store the electric charges, while insulators are used to block the flow of electric charges (they more or less act like a wall).

While all dielectrics are insulators (they don't allow the flow of electric charges through them), all insulators aren't dielectric because they can't store charges unlike dielectrics.

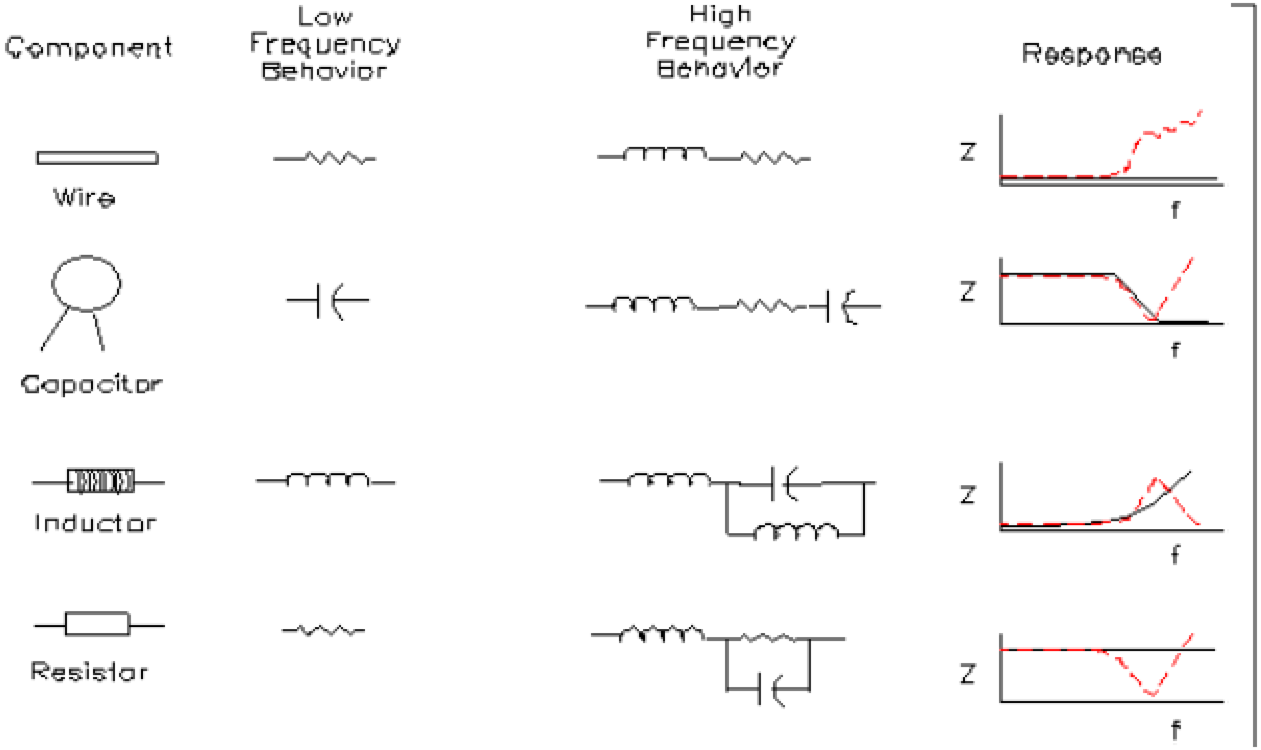
Material	**Volume resistivity (Ω/m)**
P.E.T. (Polyethylene)	10^{15}–10^{17}
Polythene (high density)	10^{14}–10^{15}
P.V.C.	5×10^{12}–10^{13}
Diamond	10^{10}–10^{11}
Rubber	10^{9}

EMC Fundamentals

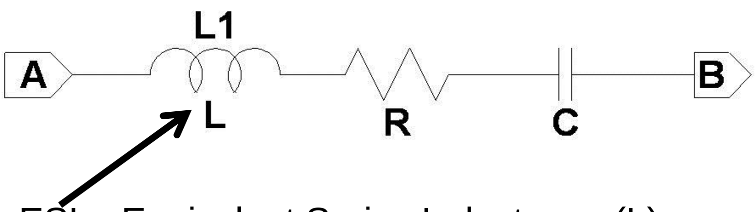
Component Behavior

Component Behavior

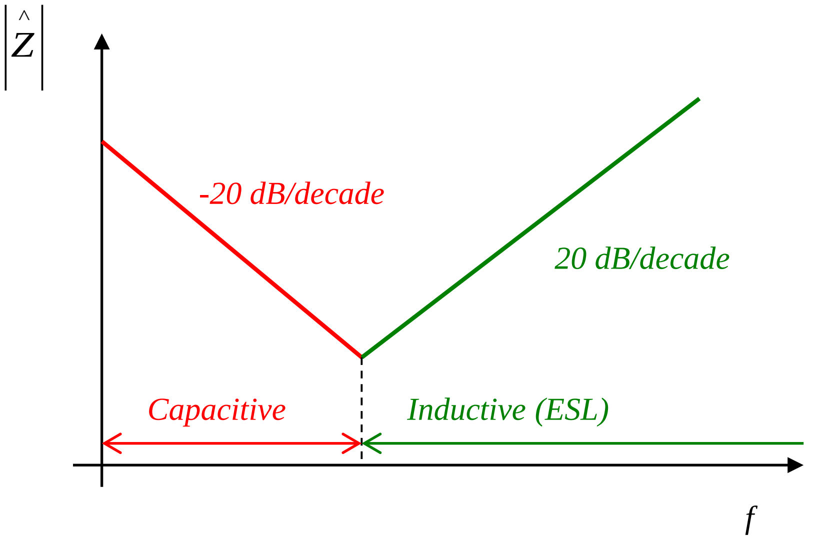
- All passive components have resistance, capacitance and inductance
- Component behavior is different at low and high frequencies



Component Behavior (Capacitors)



ESL - Equivalent Series Inductance (L)

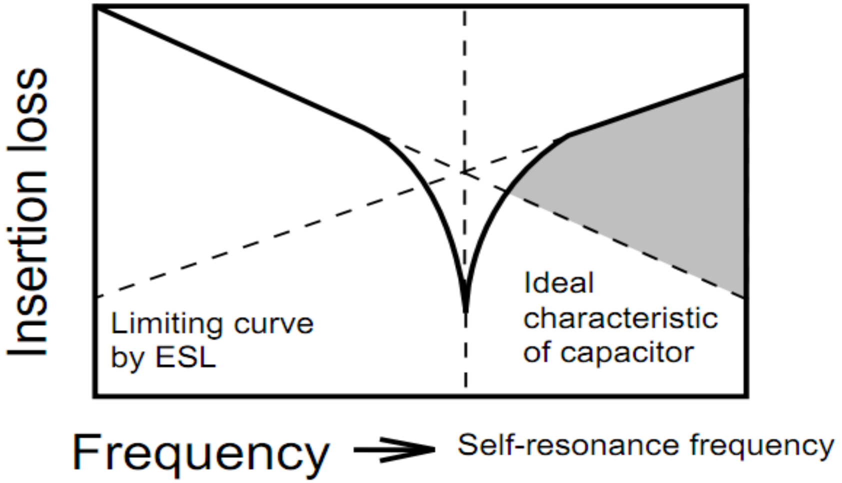


Self-resonance frequency:

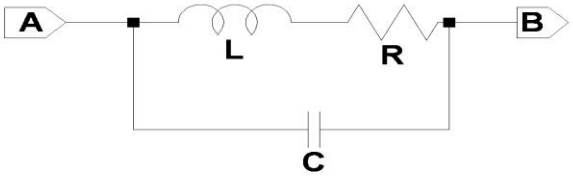
The frequency at which resonance occur due to the capacitor's own capacitance and ESL. It is the frequency at which the impedance of the capacitor becomes zero.

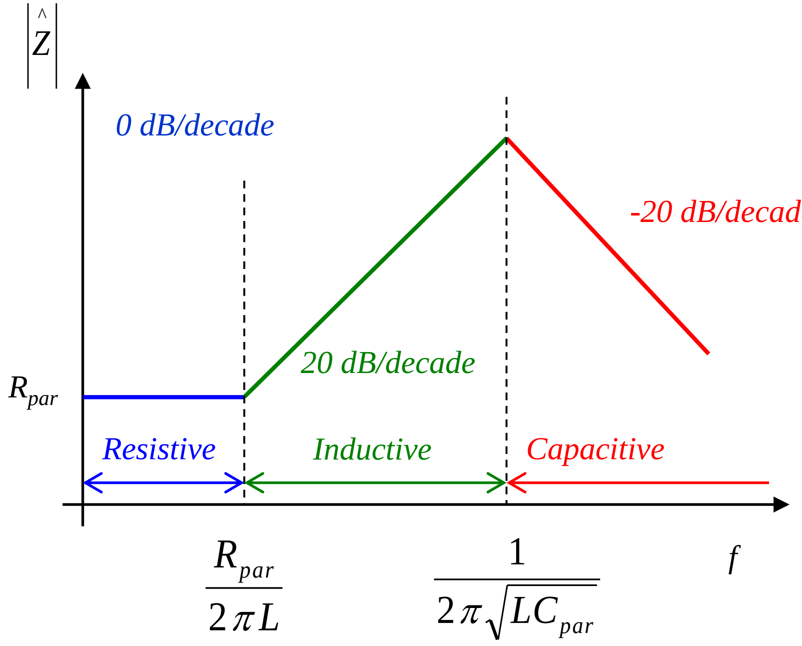
$$j2\pi fL + 1/j2\pi fC = 0$$

$$\frac{1}{2\pi\sqrt{L_{lead}C}}$$



Component Behavior (Inductors)

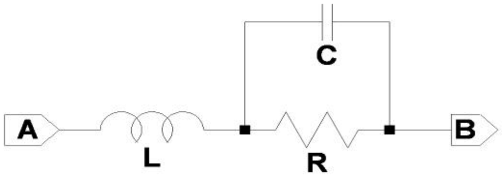


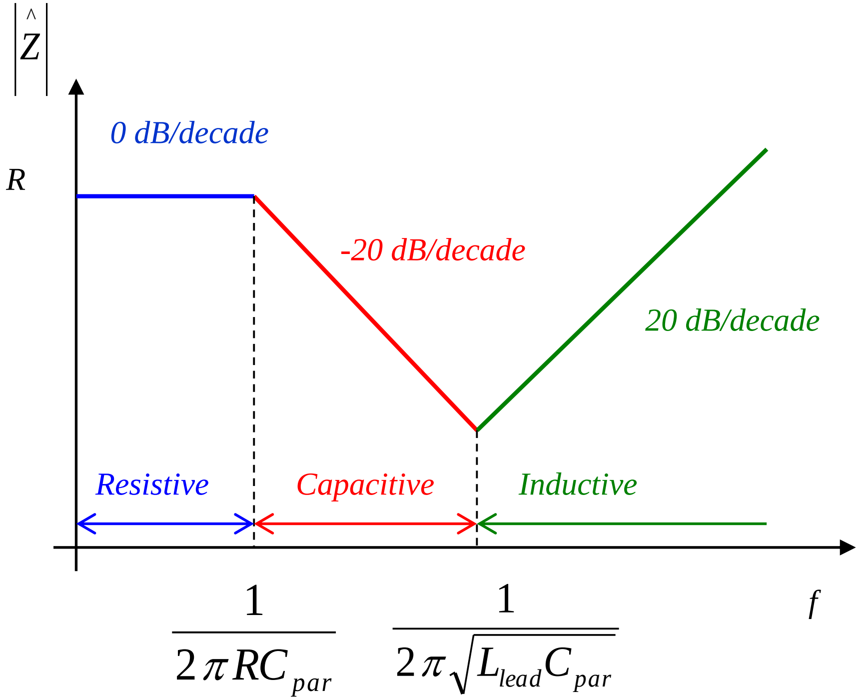


- As the frequency of operation increases, the ideal inductance L begins to dominate the impedance of the equivalent circuit near the frequency $\frac{R_{par}}{2\pi L}$

- As the frequency increases further, the impedance of the parasitic capacitance decreases until it's magnitude is equal to that of the ideal inductance. This occurs at the self resonant frequency $\frac{1}{2\pi\sqrt{LC_{par}}}$

Component Behavior (Resistor)





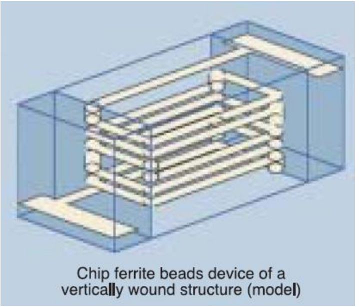
- As the frequency increases beyond this point, more current begins to flow through the conducting path provided by the parasitic capacitance than flows through the bulk resistance. In this regime, the lead inductance remains small (i.e., nearly a short circuit).

- As the frequency increases further, the impedance of the equivalent circuit decreases until the lead inductance and the parasitic capacitance cause the resistor to resonate. The equivalent circuit impedance is a minimum at the self resonant frequency of the resistor $\frac{1}{2\pi\sqrt{L_{lead}C_{par}}}$

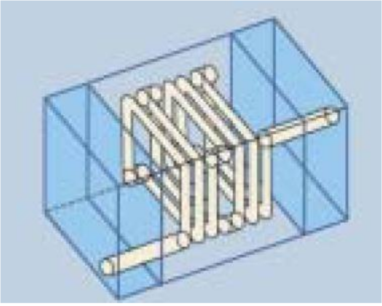
Note: Not as significant change vs frequency as compared to a capacitor impedance curve

Component Behavior (Ferrites)

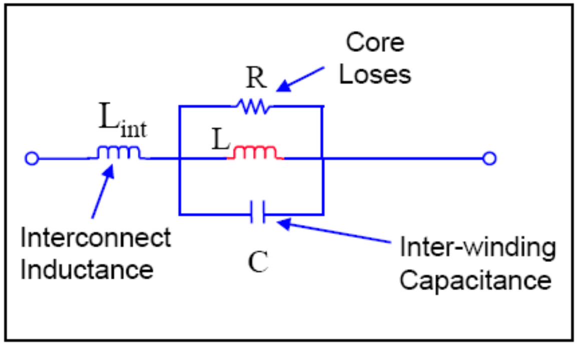
- Ferrites are composed of a metallic conductor which is wound horizontally or vertically inside a ferrite material core and connected to SMD pads



Chip ferrite beads device of a vertically wound structure (model)



- Equivalent circuit for a ferrite bead uses resistance to model the losses in the core material

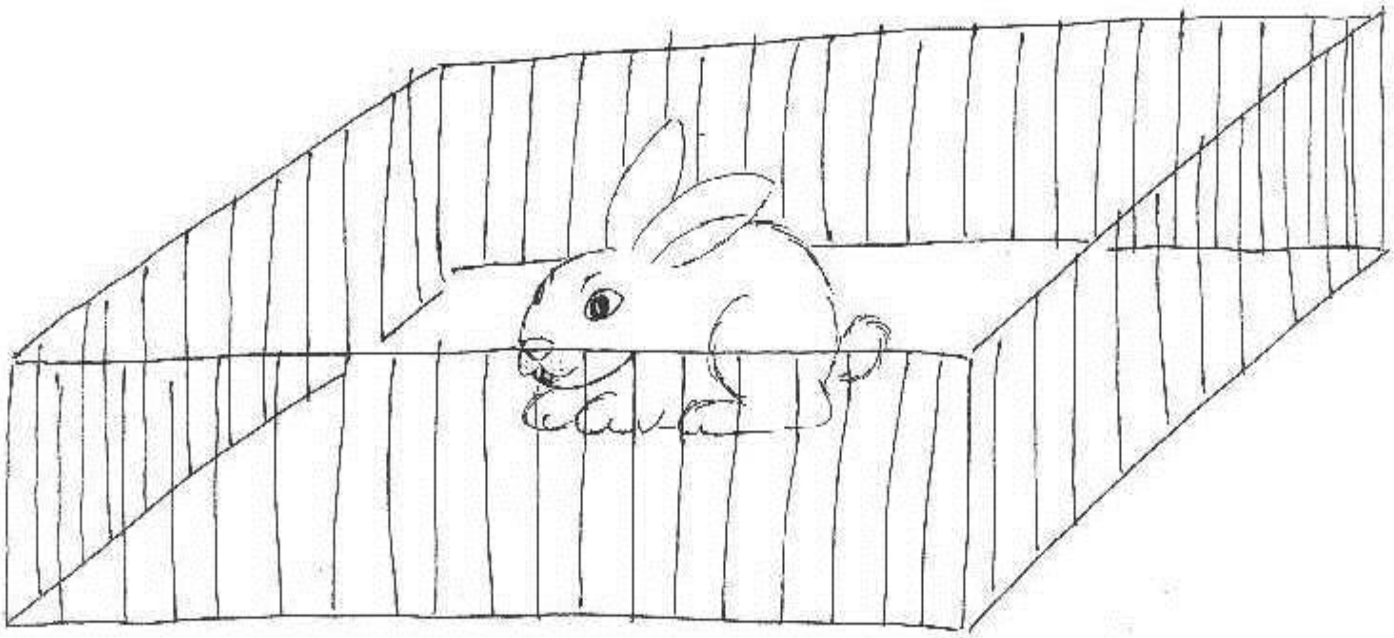


EMC Fundamentals

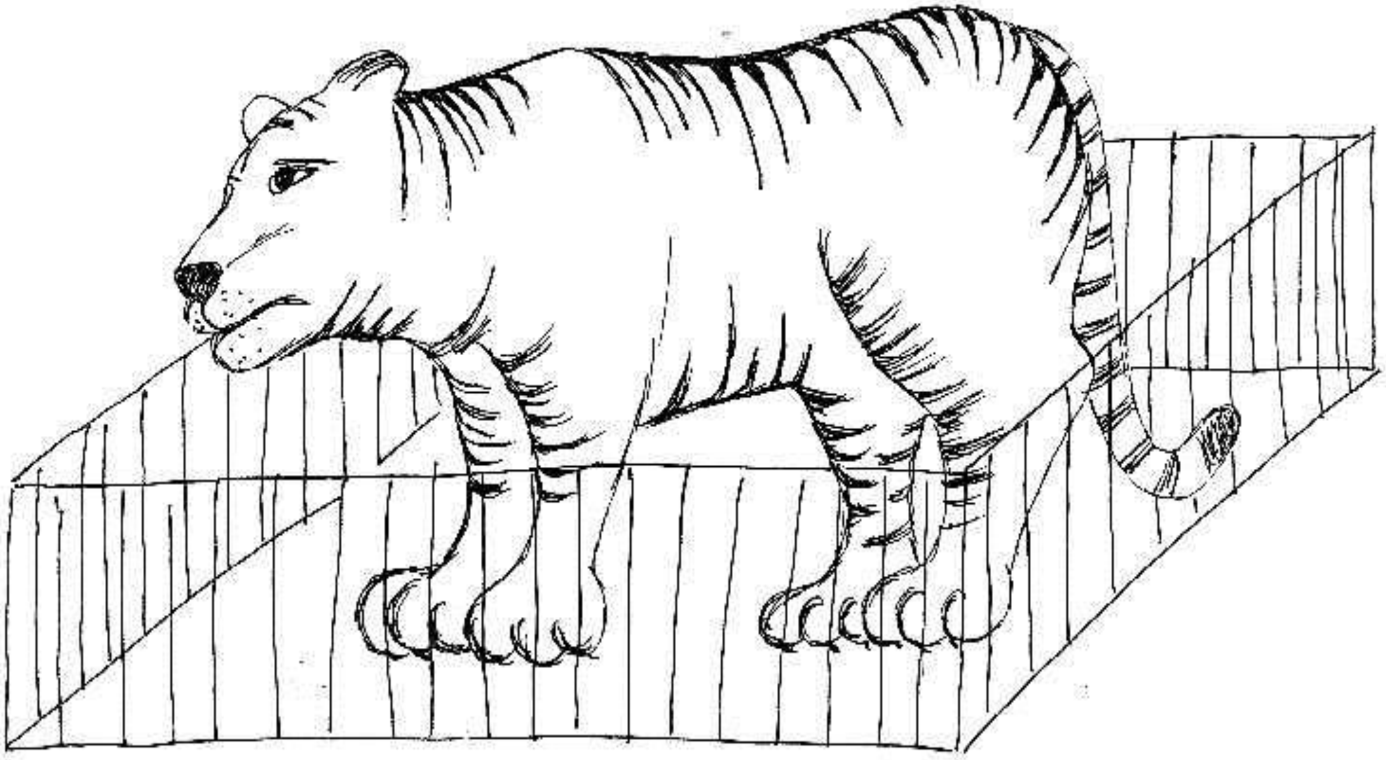
Shielding Concepts

Shielding (What is a shield?)

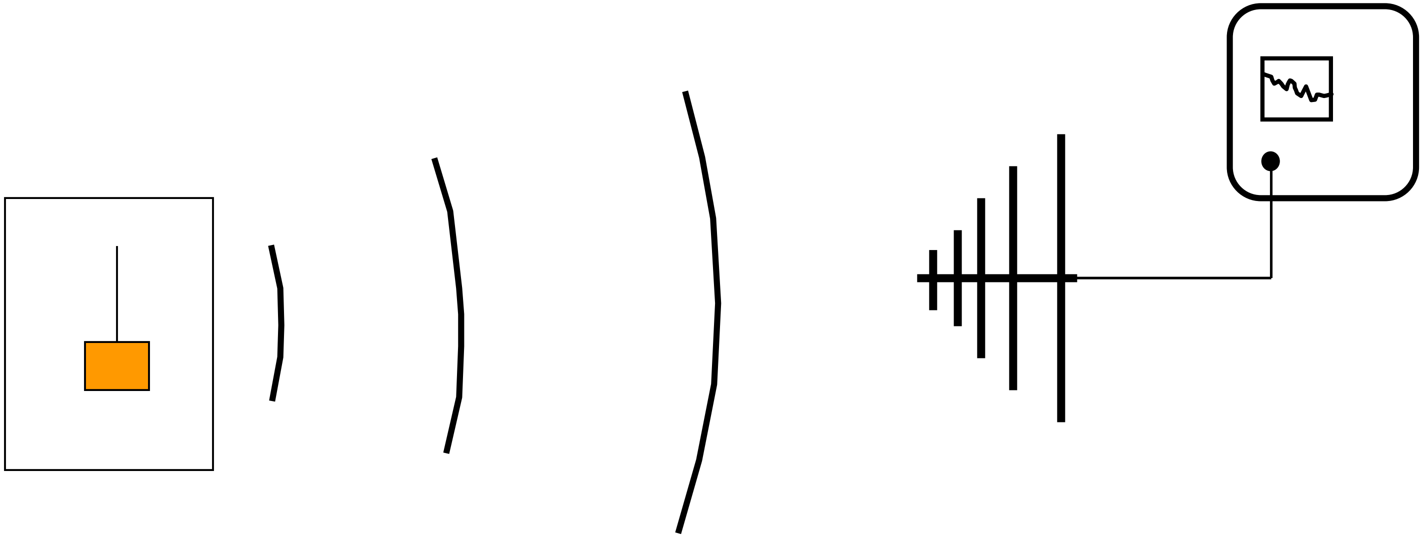
Shielding (What is a shield?)



Shielding (What is a shield?)

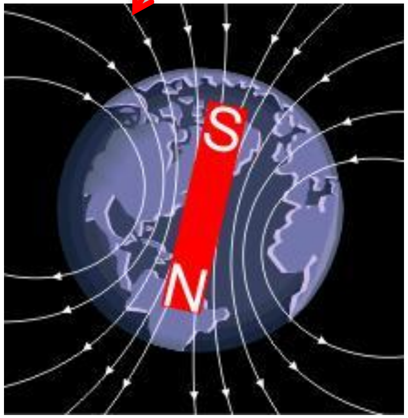


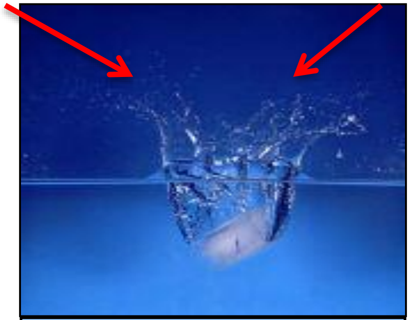
Shielding (Insertion Loss Measurement)



Shielding (Family of Fields)

- static fields
  - electro static fields
  - magneto static fields
- dynamic fields
  - quasi static fields
    - alternating electrical field
    - alternating magnetic field
  - electromagnetic waves





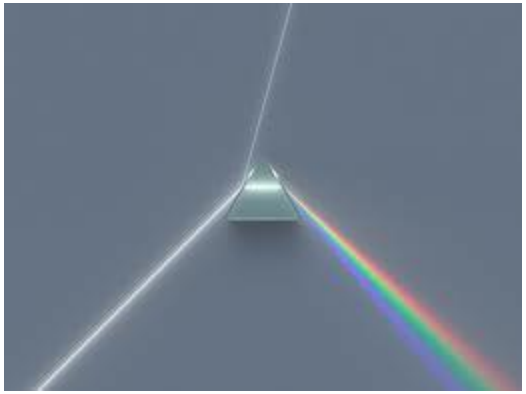
Near Field

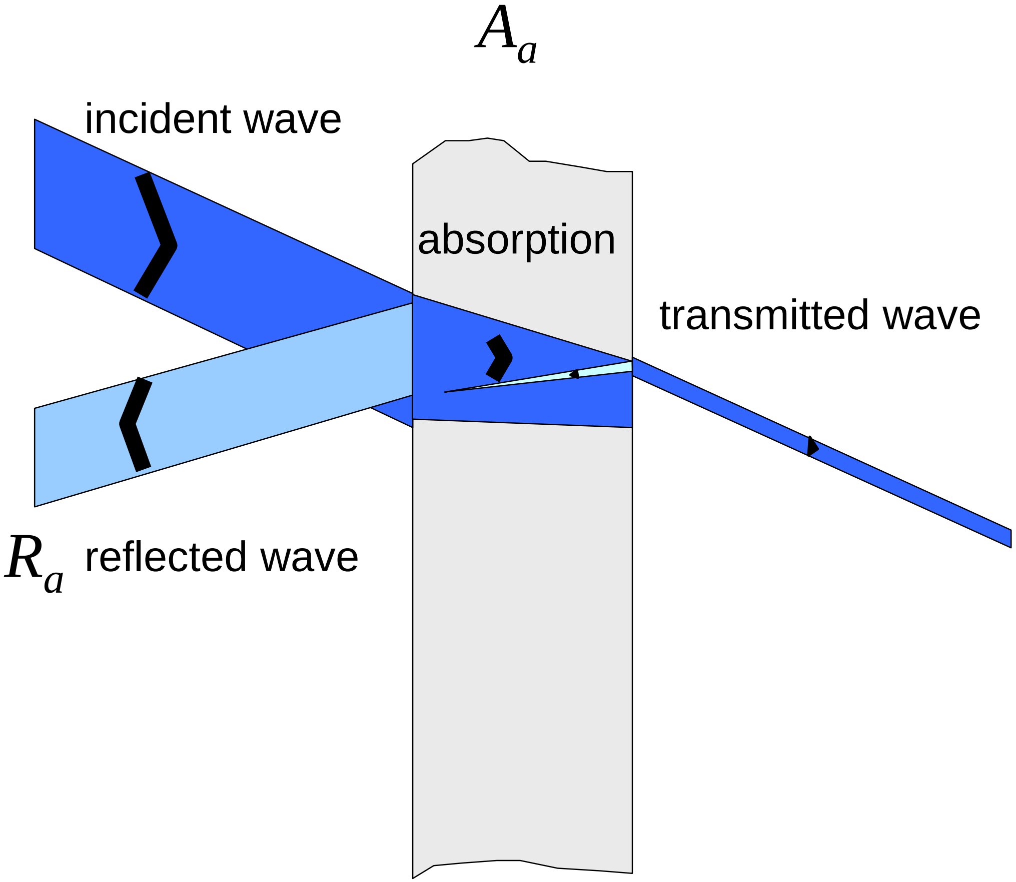
Far Field

Shielding (Properties)

Shielding Effectiveness:

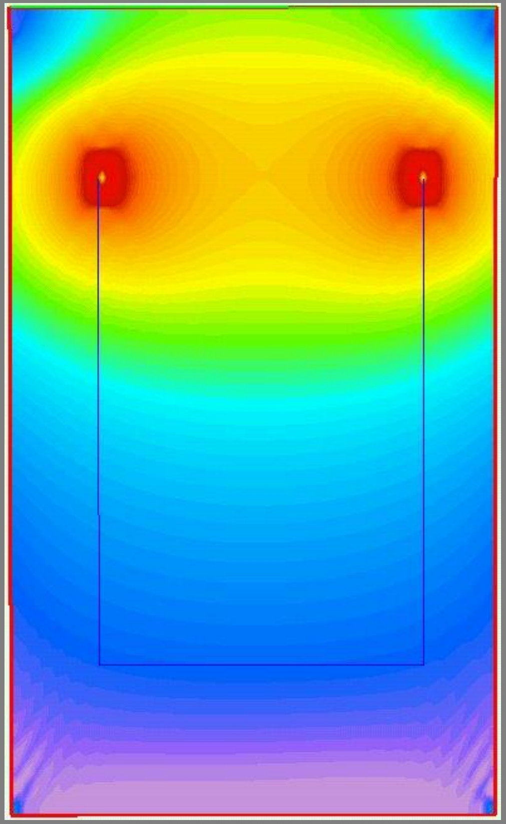
$$SE\big|_{dB} = R\big|_{dB} + A\big|_{dB}$$





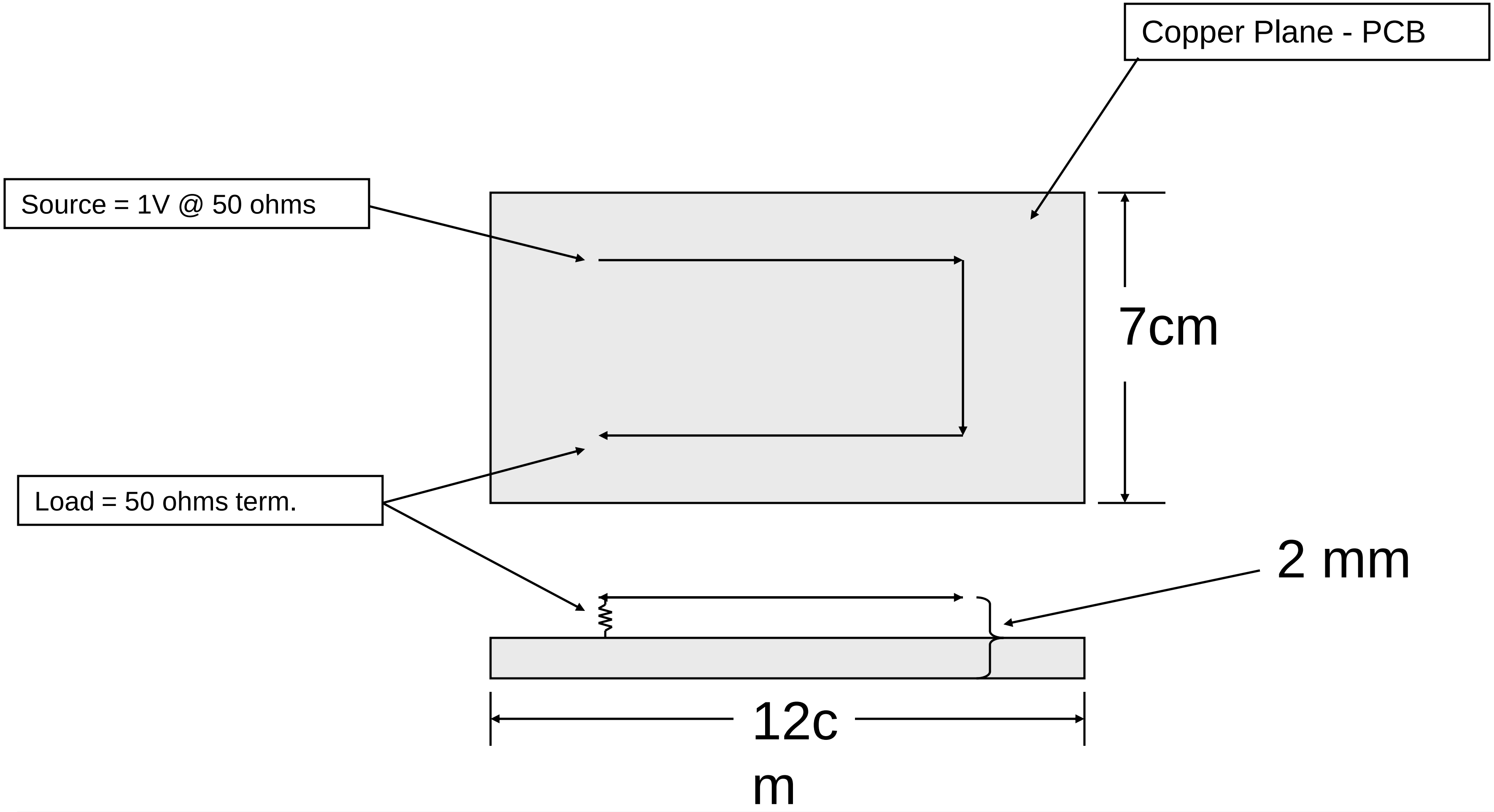
EMC Fundamentals

RF Current Return Path Concepts



Model Description (Simulation model)

- 3” x 5” coupon board



Copper Plane - PCB

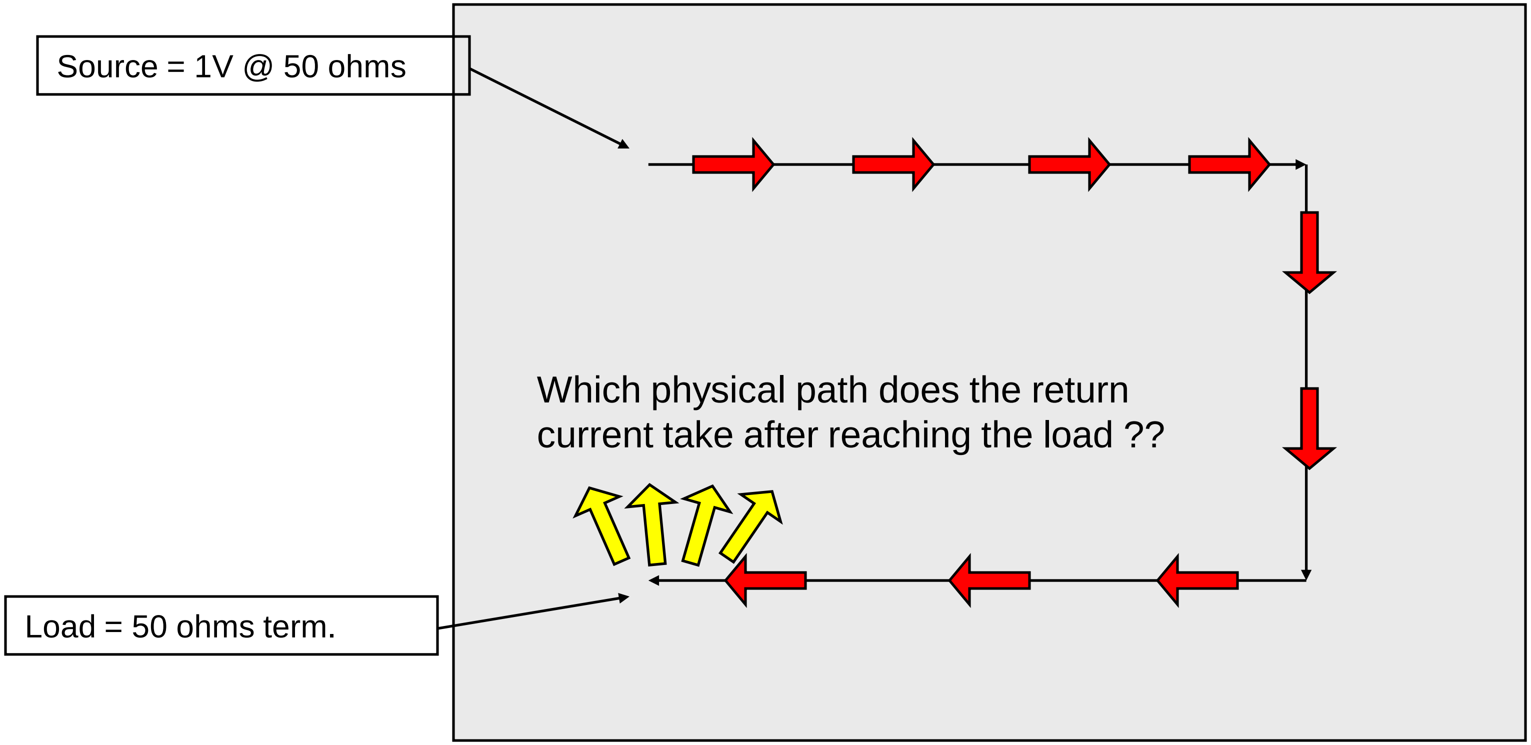
Source = 1V @ 50 ohms

Load = 50 ohms term.

Feed Current – To Load

🟥 = Source current to 50 ohm load termination

🟨 = Return current from 50 ohm load back to 50 ohm source



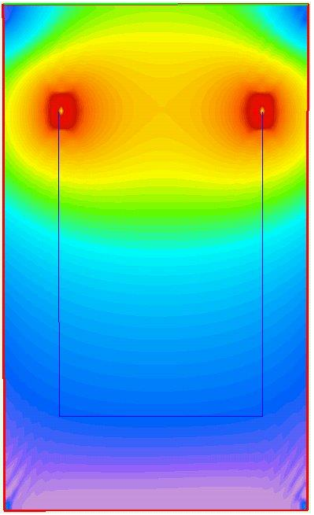
Source = 1V @ 50 ohms

Which physical path does the return current take after reaching the load ??

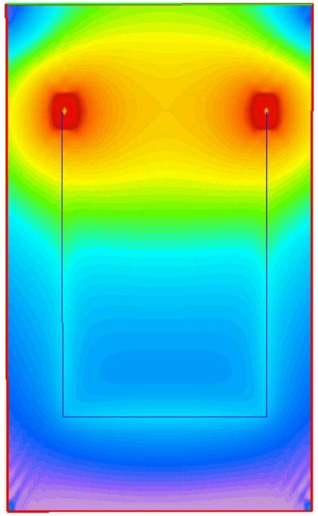
Load = 50 ohms term.

RF Return Current Over Frequency

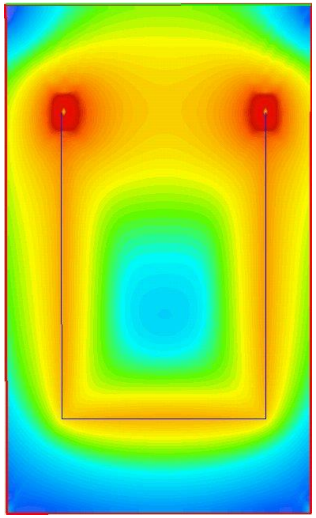
1kHz



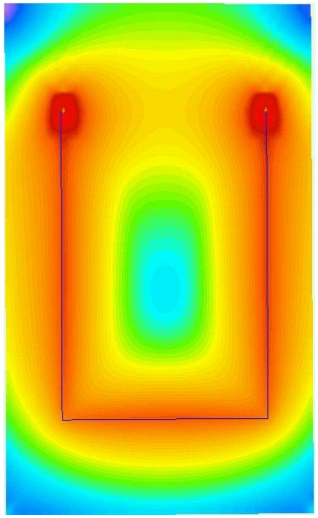
100kHz



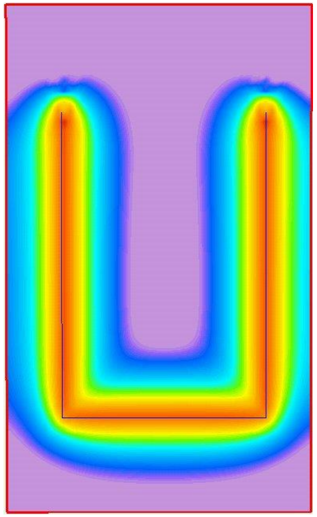
500kHz



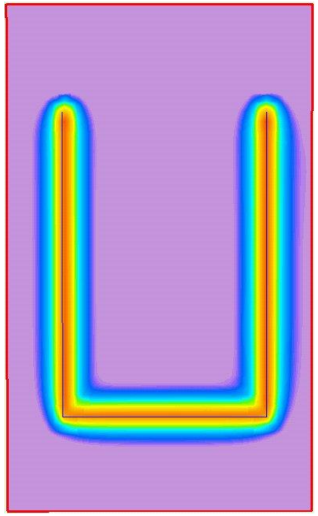
1MHz



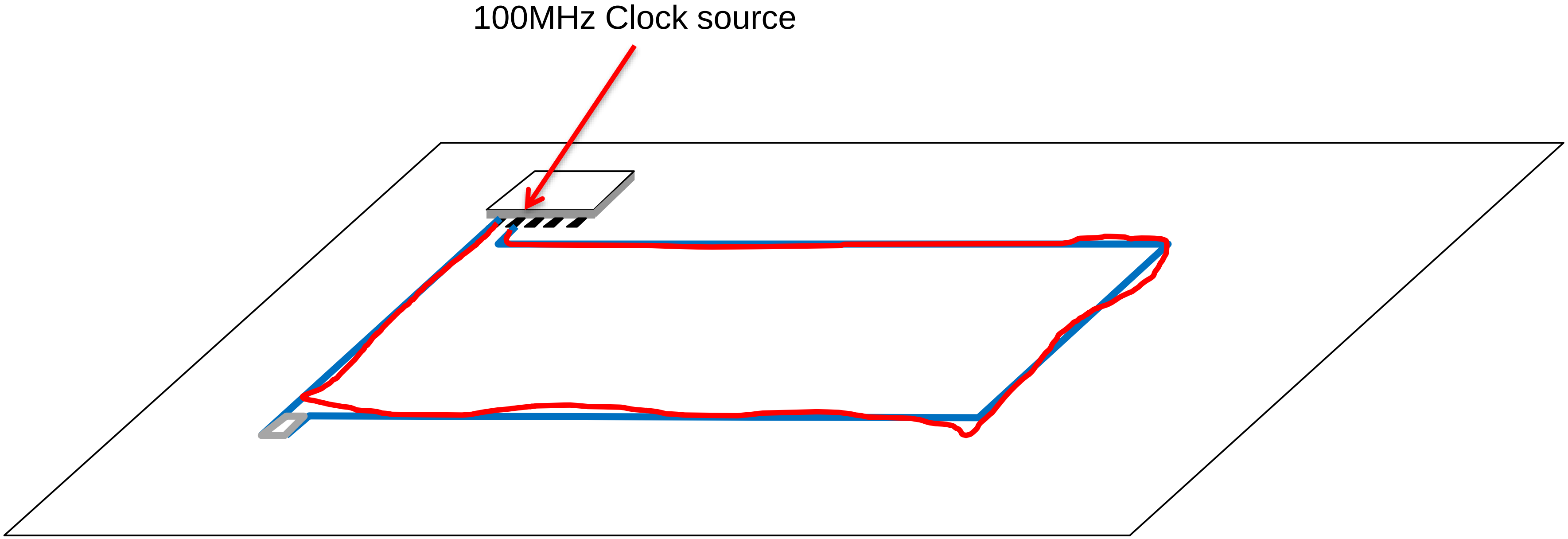
10MHz



100MHz

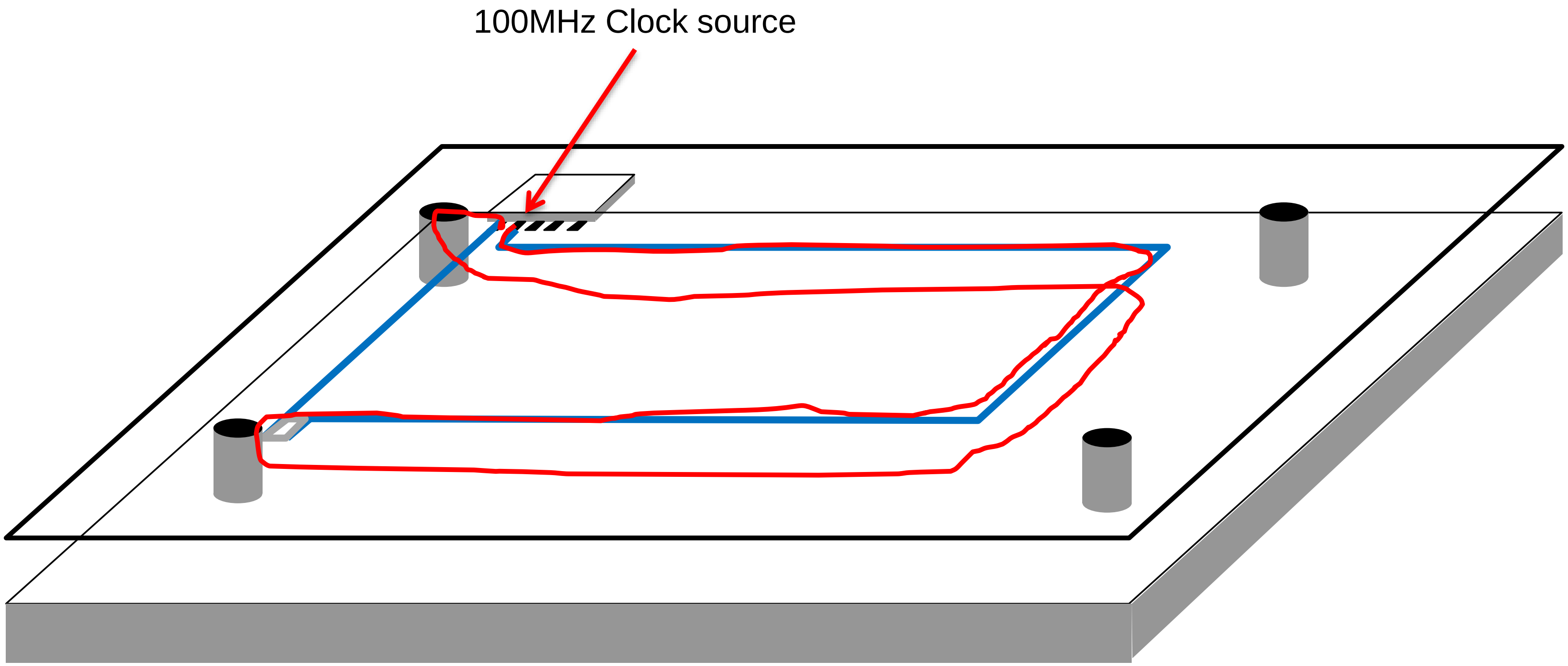


Grounding (Current Returns In The GND Plane)



Big loop → good magnetic source → increased EM emissions

Grounding (Current Returns In The Metal Sheet)



Longer path for current, but reduced loop area → decreased emissions

Grounding (Conclusion)

- Lots of very low inductive connections
- No isolating coating on the metal
- Avoid corrosion and oxidation → Good EMC performance over the whole lifetime
- Mechanical tolerances can lead to isolated connections
- Control of the return current paths

RI

RE

EMC COMPONENT LEVEL TESTS

ESD

BCI

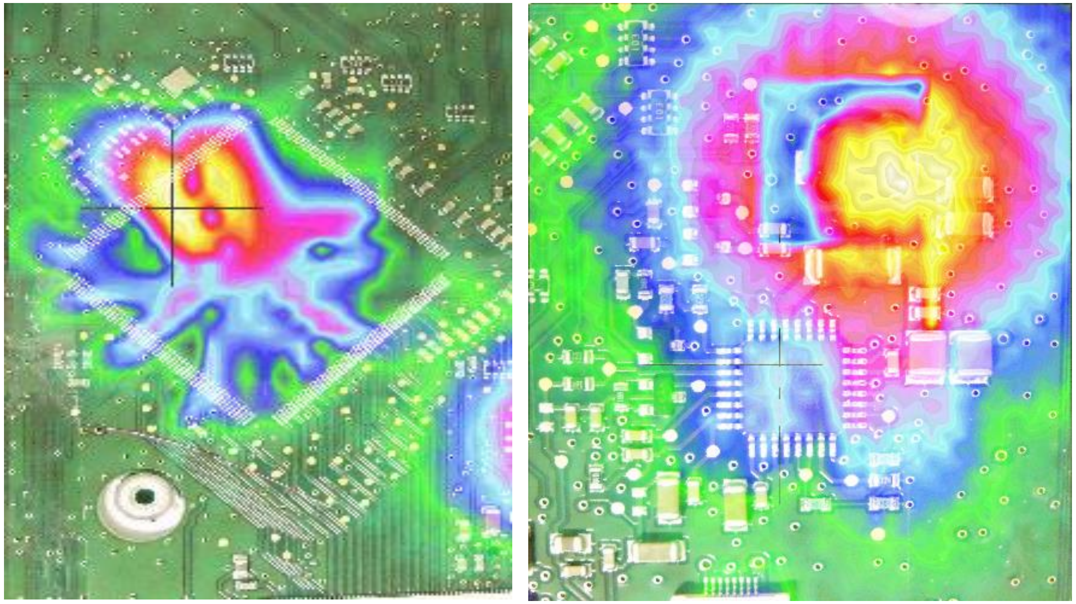
CE

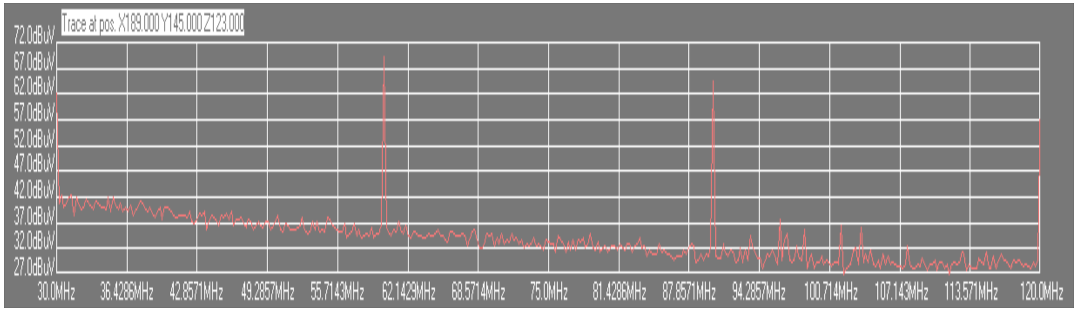
CI

Pre-compliance tests

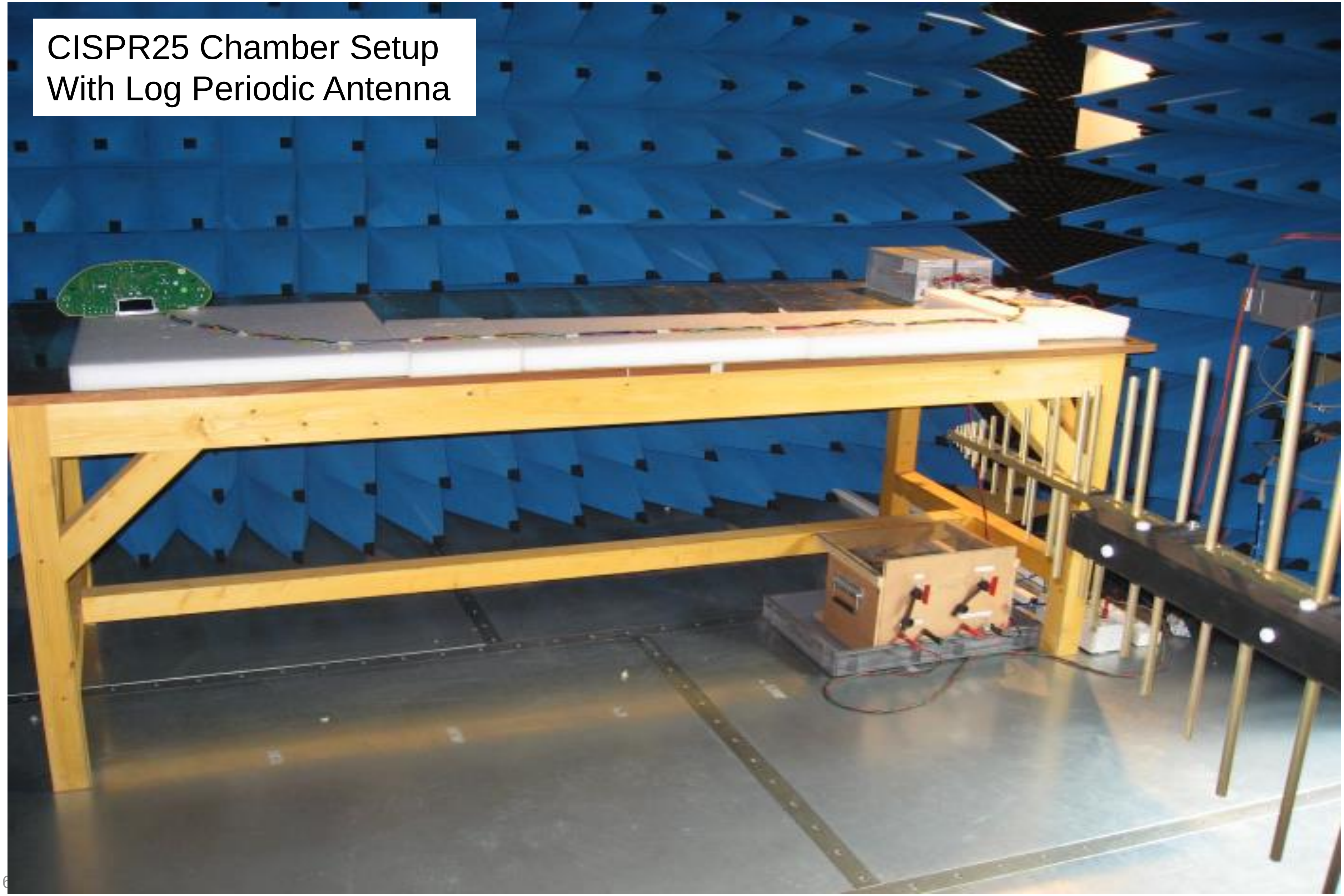
Pre-compliance tests are made during prototype development.

- Near Filed Scan – EMC Scanner



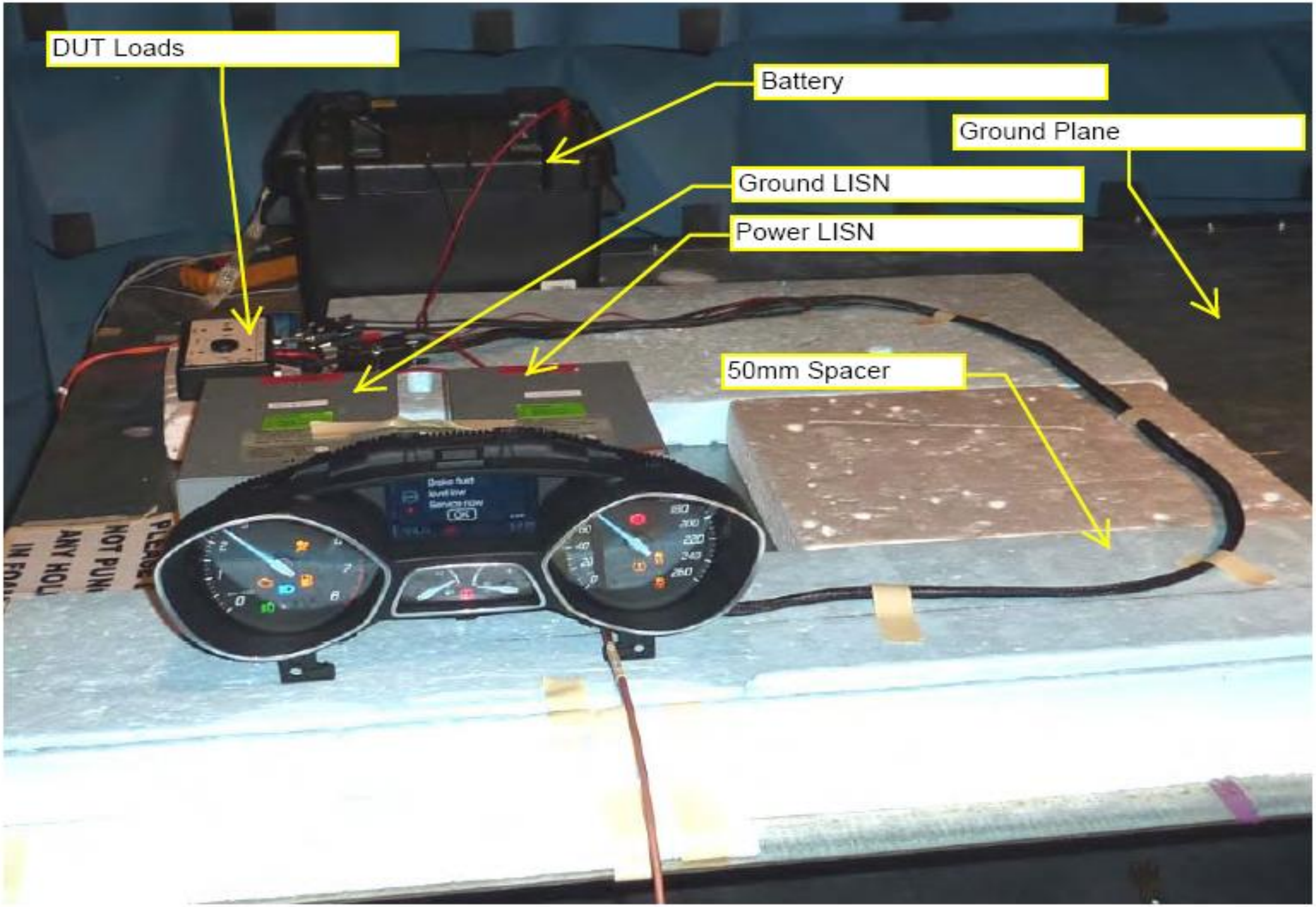


Radiated Emissions Measurements



CISPR25 Chamber Setup
With Log Periodic Antenna

Conducted Emissions Measurements

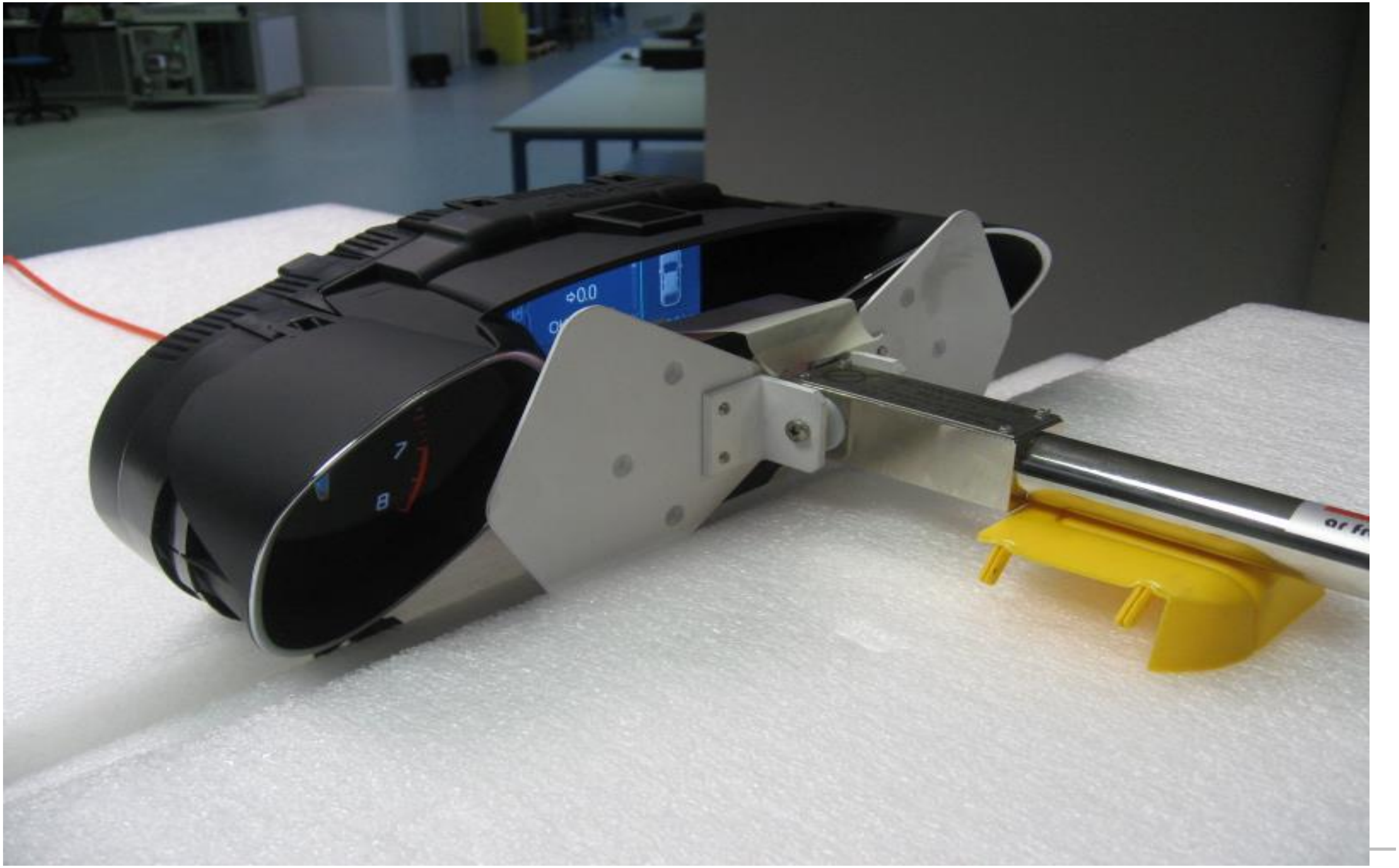


Basics of Immunity Problem

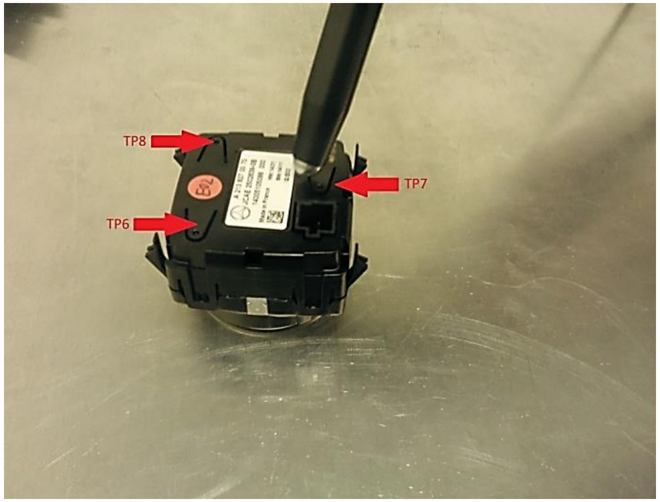
Bulk Current Injection Measurement

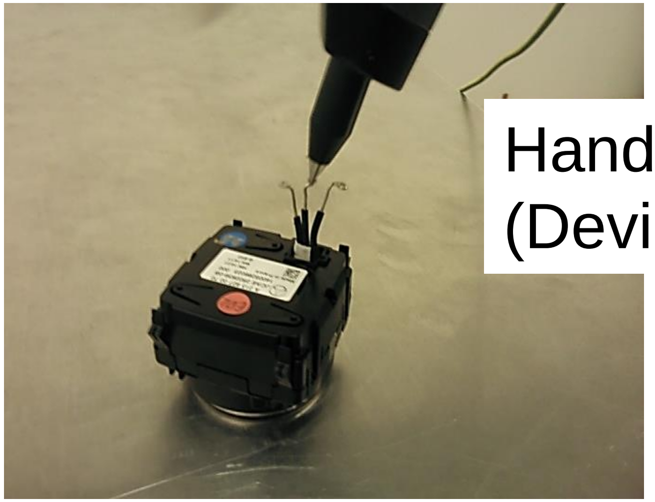
Basics of Immunity Problem

Near-Field Immunity Measurement – Cell Phone Simulator

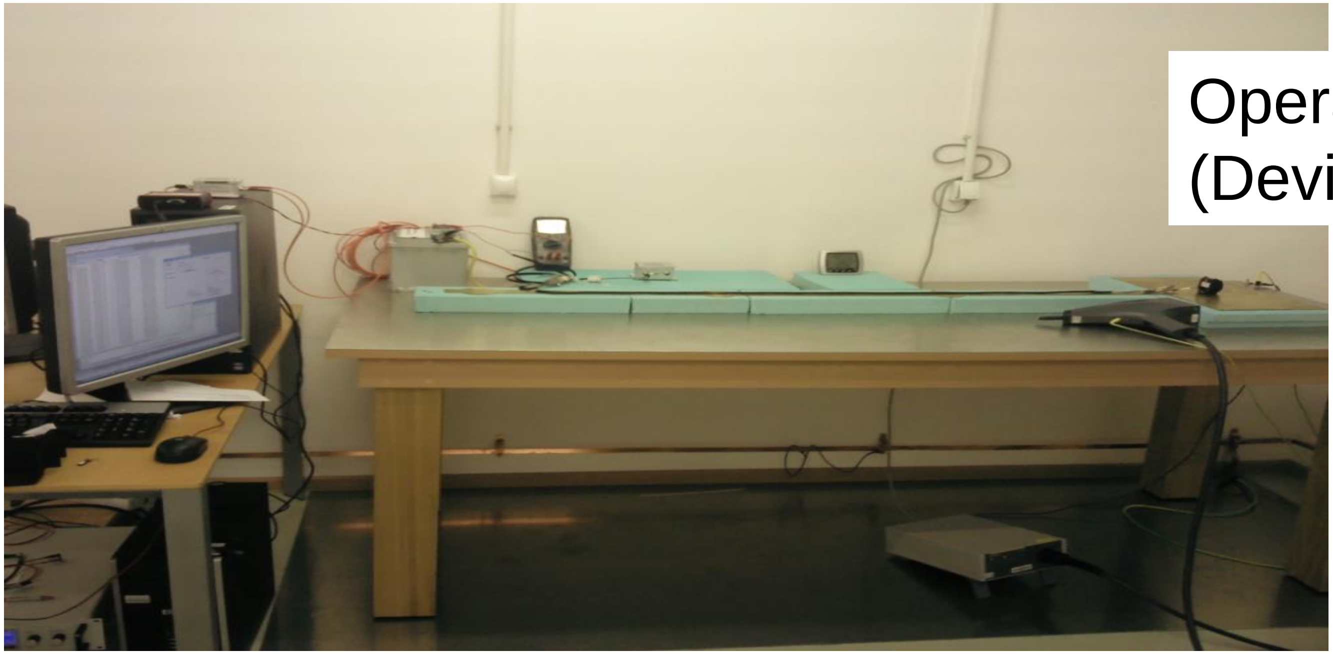


ESD Tests



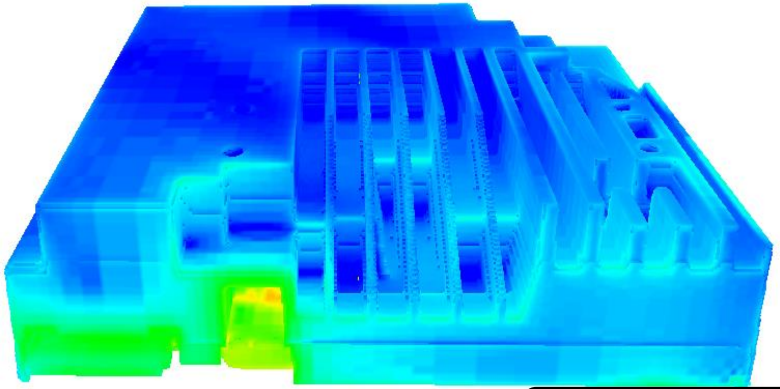


Handling Tests
(Device is OFF)

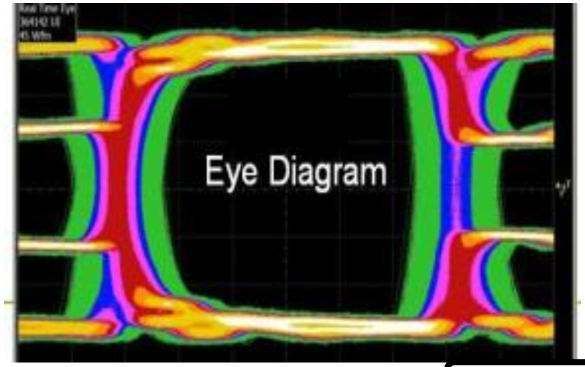


Operating Tests
(Device is ON)

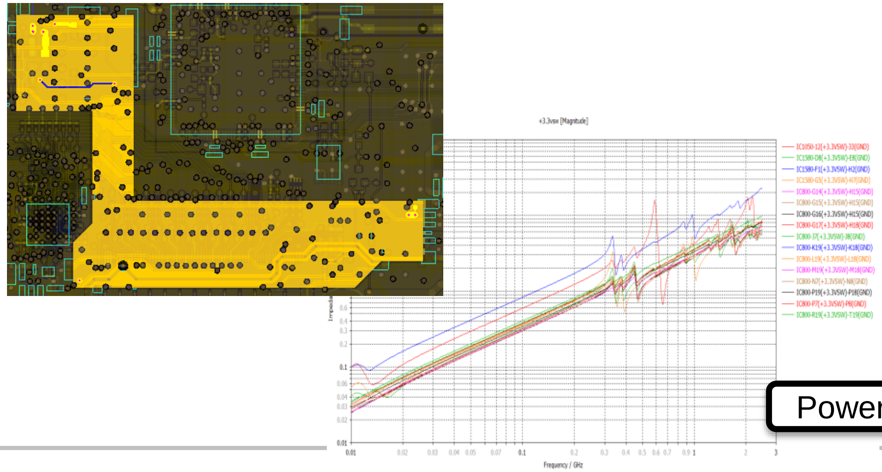
EMC SIMULATIONS



EMC



Signal Integrity

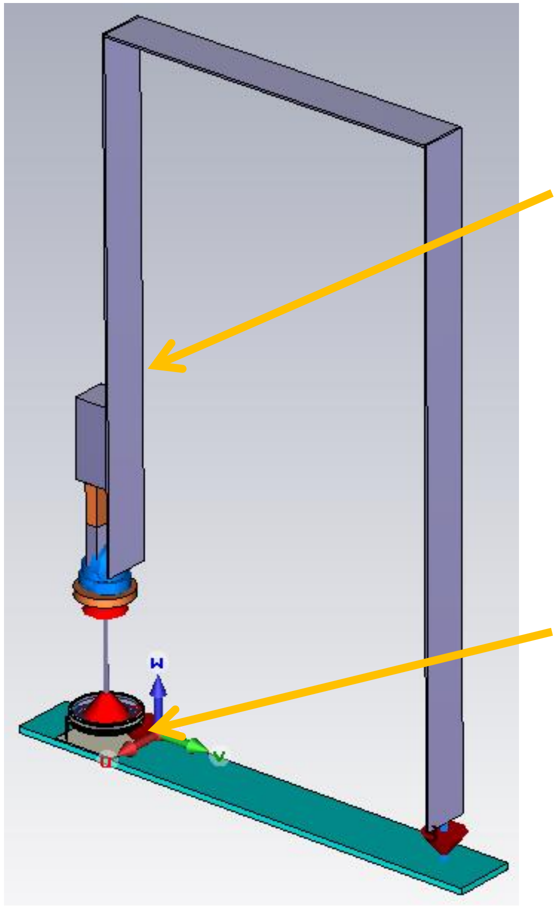


Power Integrity

EMC simulations

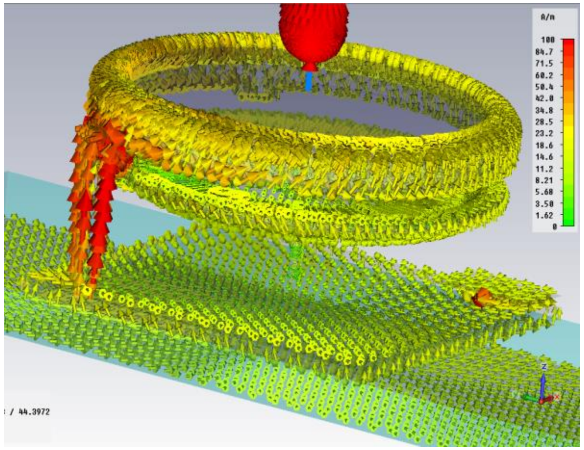
ESD Simulation

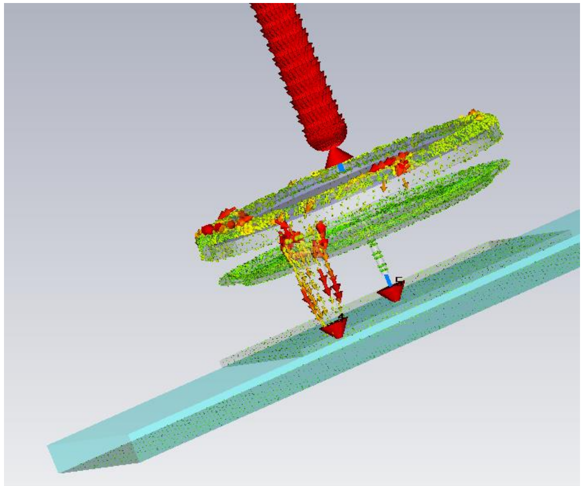
Simulation Results: Surface current



Model of the ESD Gun

Simulation model of the device

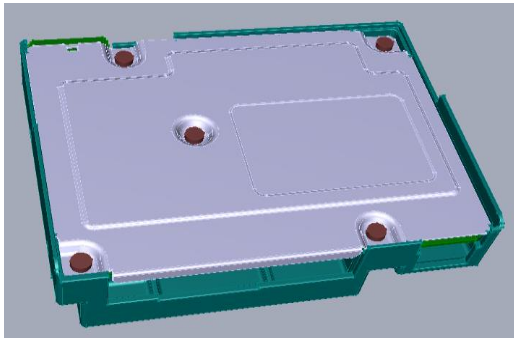




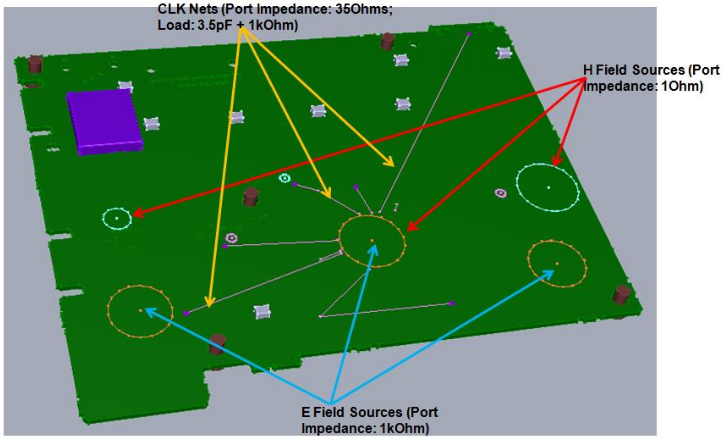
EMC simulations

Radiated Emissions Simulation

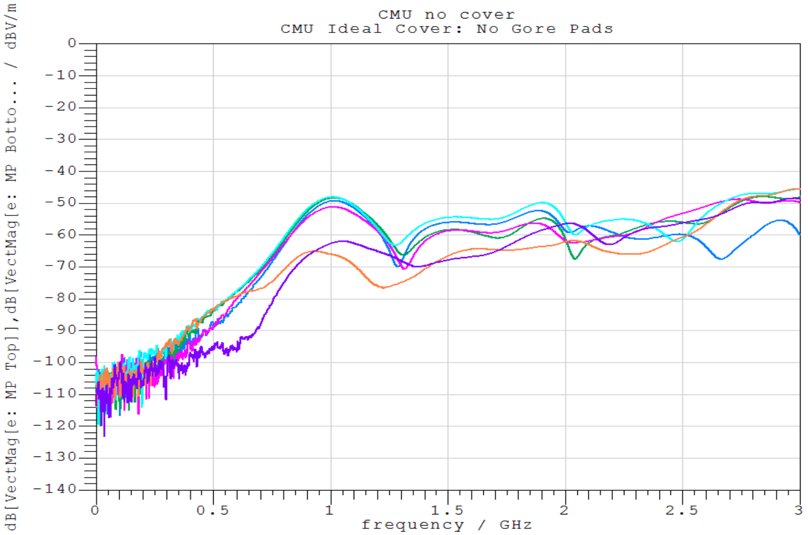
Model

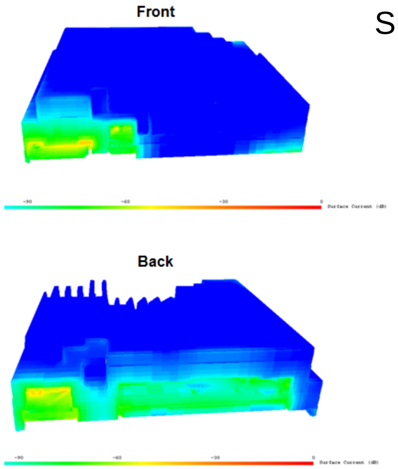


Model with defined sources

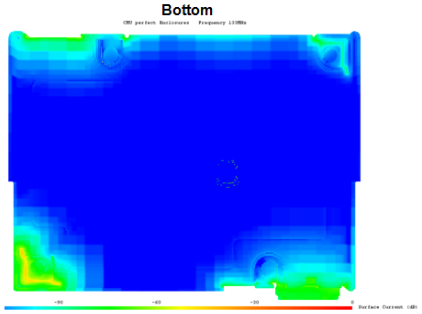


Results at monitoring points at 1m



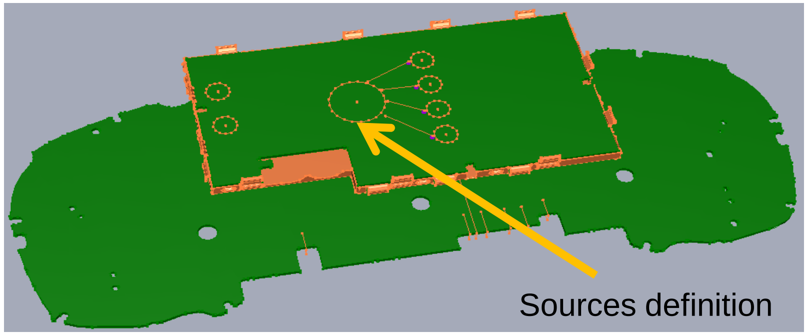


Surface Current

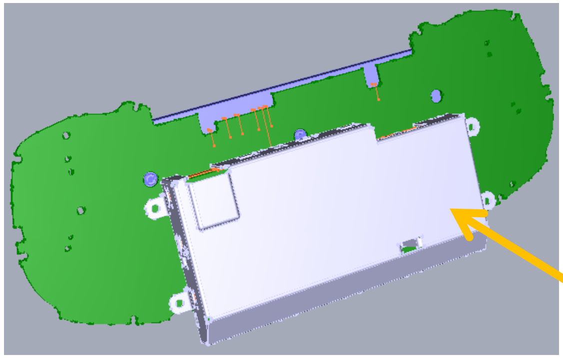


EMC simulations

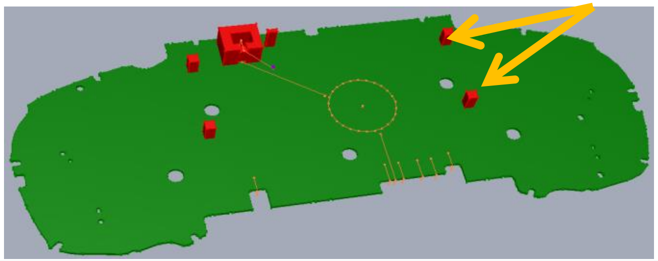
Shielding Effectiveness Simulation Model



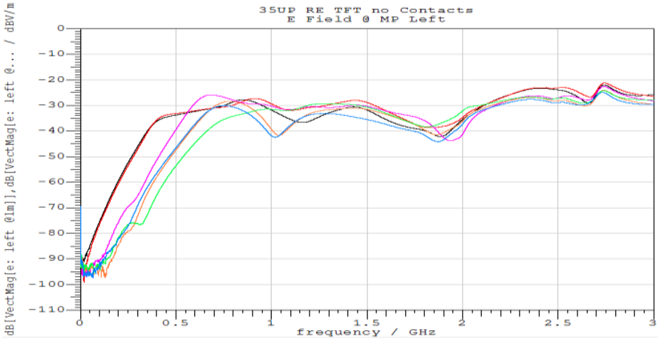
Sources definition



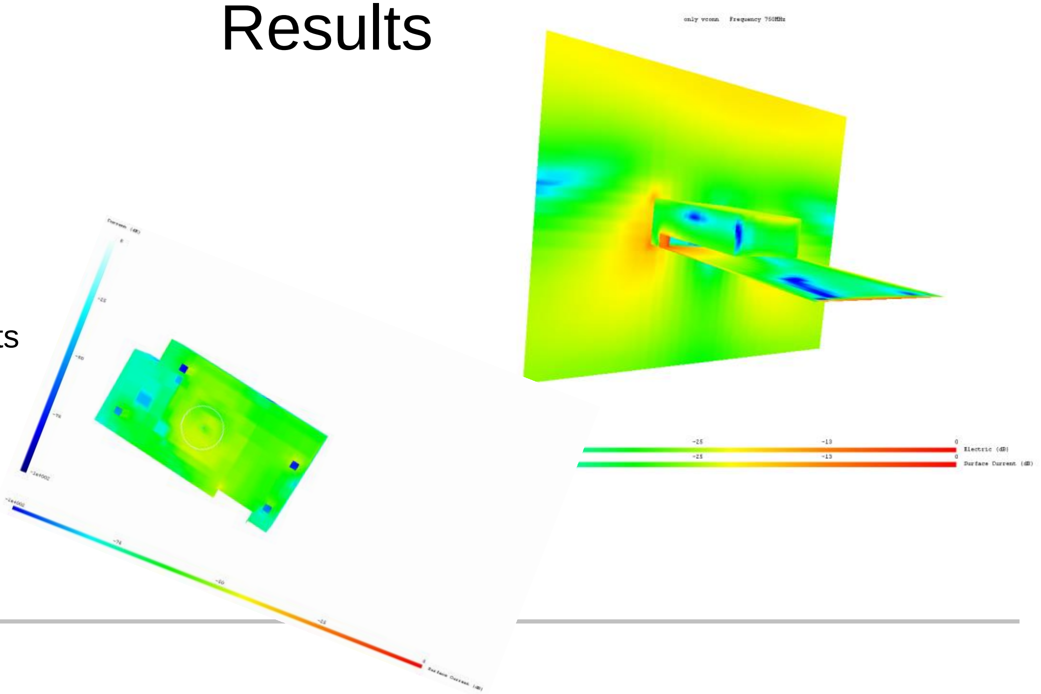
GND contacts



E-field Results



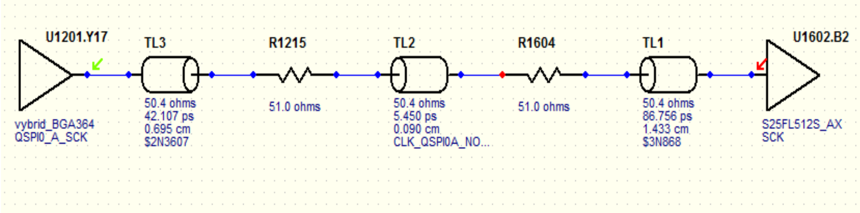
E-field and Surface Current Results



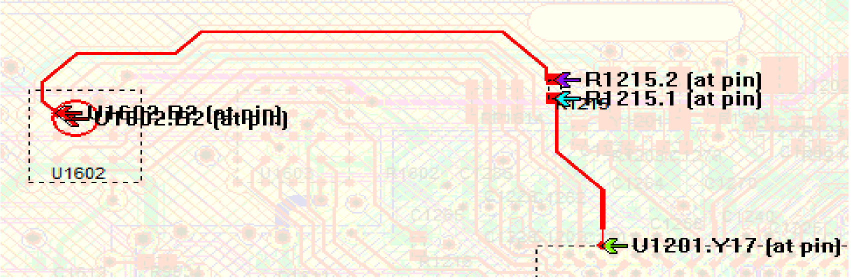
Signal Integrity Simulation

Example for selecting termination values

Trace built in Simulation tool

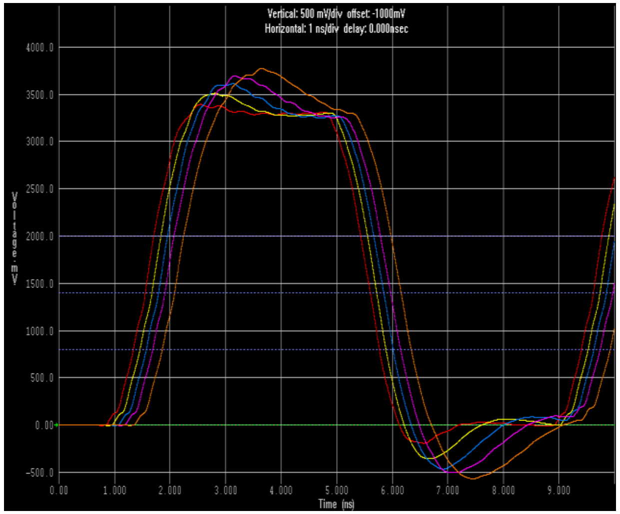


Trace from layout

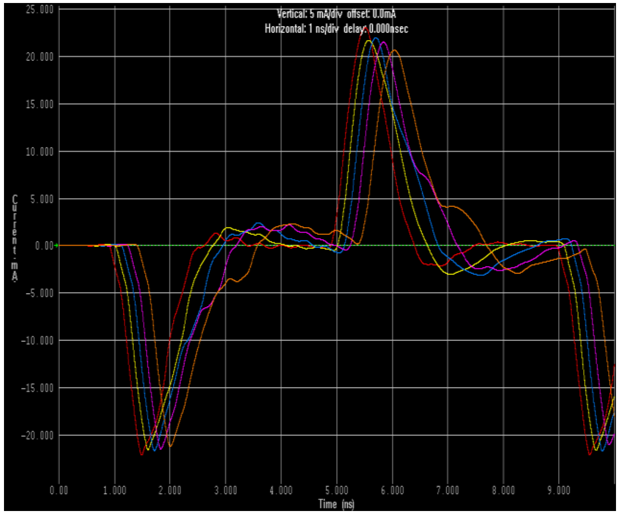


O-scope results

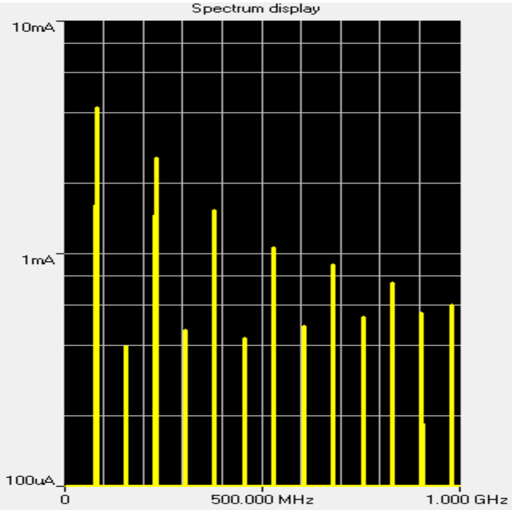
Voltage waveform



Current waveform



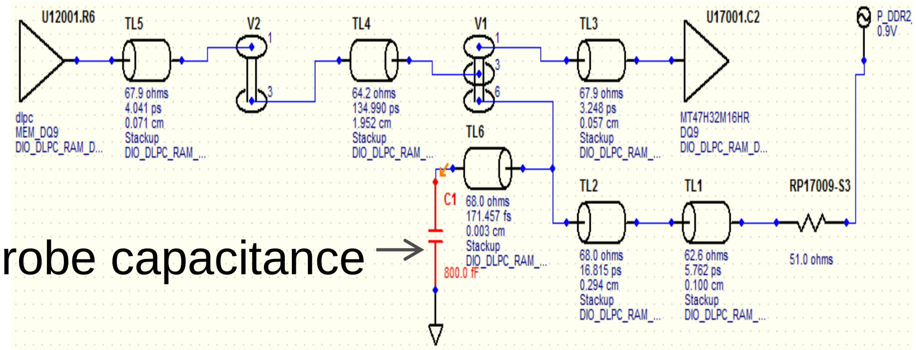
Freq. domain current



Signal Integrity Simulation

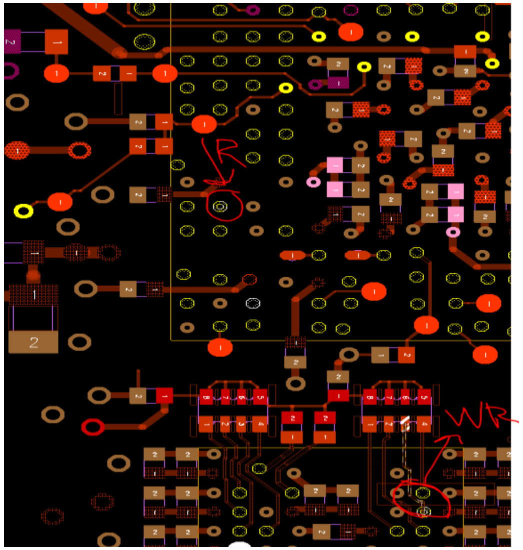
Correlation of the models is very important

Build model of the transmission line

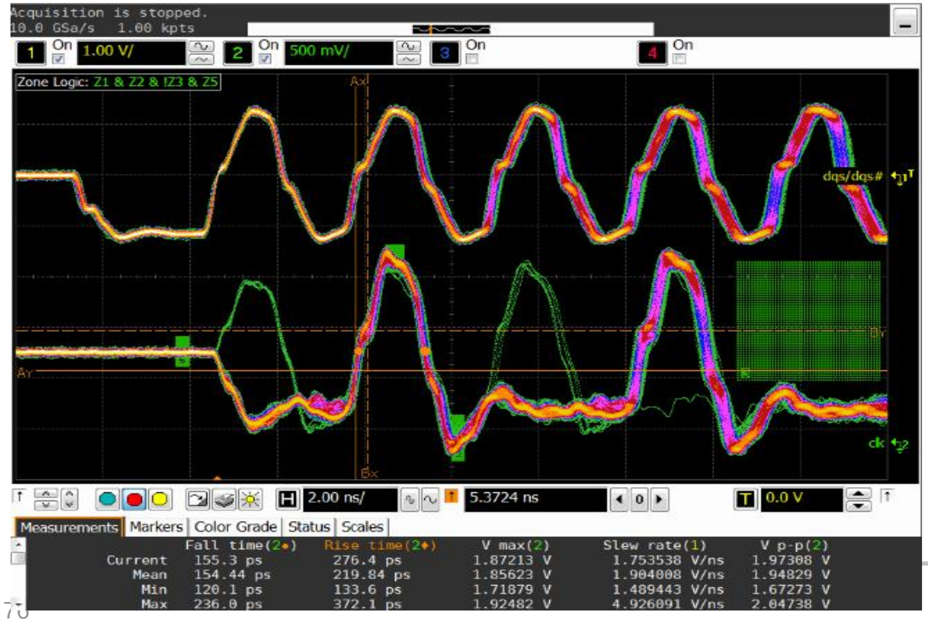


Probe capacitance →

Layout view



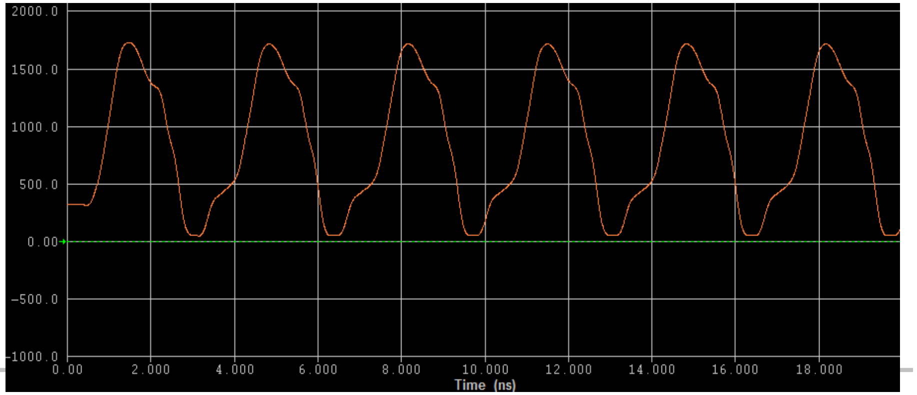
Measured signal



```
Acquisition is stopped.
10.0 GSa/s   1.00 kpts
```

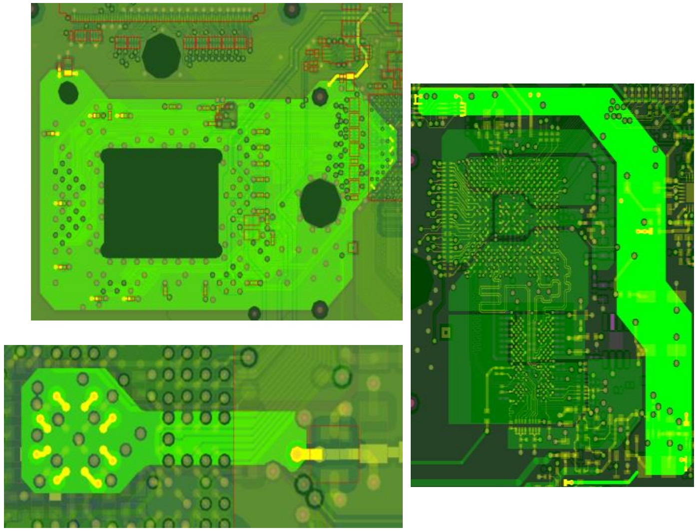
```
          Fall time(2•)  Rise time(2♦)  V max(2)     Slew rate(1)     V p-p(2)
Current    155.3 ps       276.4 ps      1.87213 V    1.753538 V/ns    1.97308 V
   Mean    154.44 ps      219.84 ps     1.85623 V    1.904008 V/ns    1.94829 V
    Min    120.1 ps       133.6 ps      1.71879 V    1.489443 V/ns    1.67273 V
    Max    236.0 ps       372.1 ps      1.92482 V    4.926091 V/ns    2.04738 V
```

Simulated signal

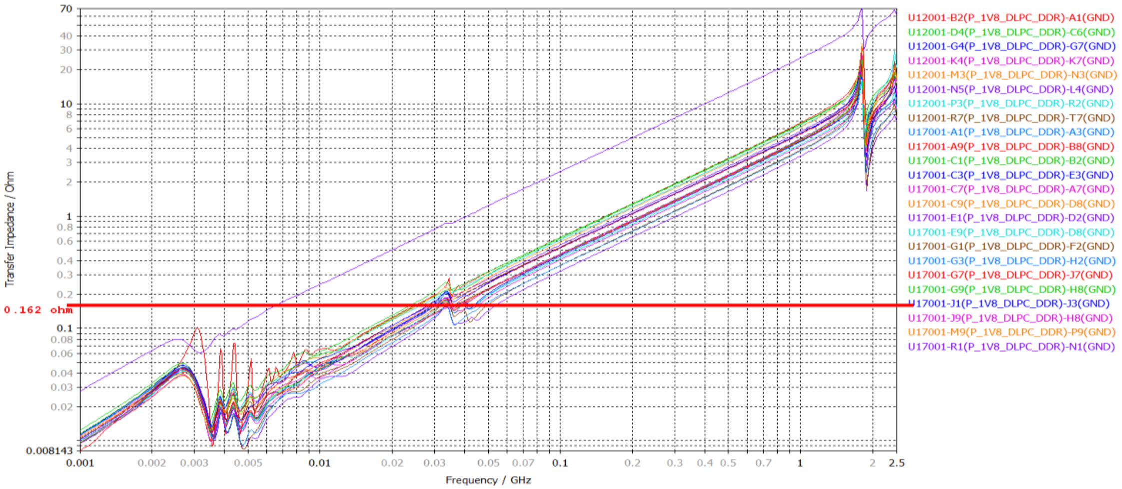


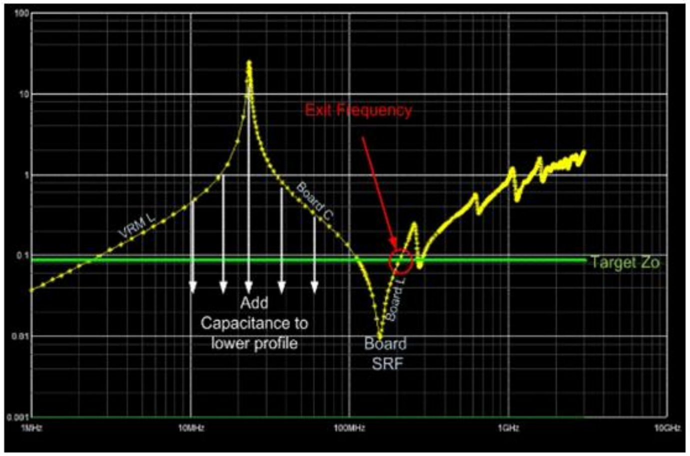
Power Integrity Simulation

Different type of power analyzes



Impedance over Frequency graph





Graph legend

Target Z0 = target impedance of power distribution network (PDN)

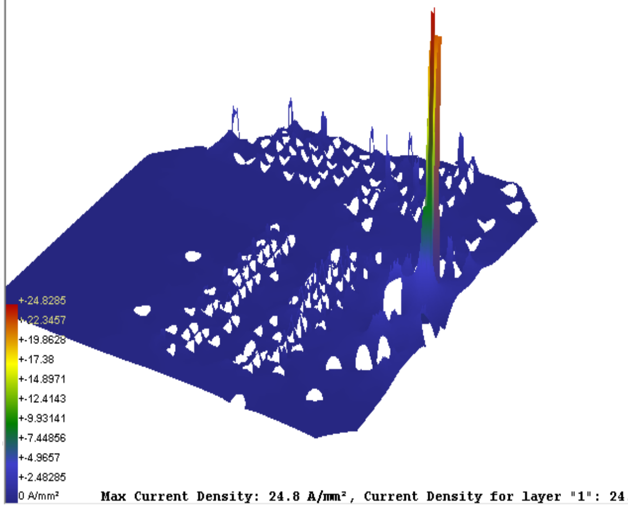
VRM L = voltage regulator models inductive part

Board C = PCB or plane capacitance

Board SRF = first self resonant frequency of PCB or plane

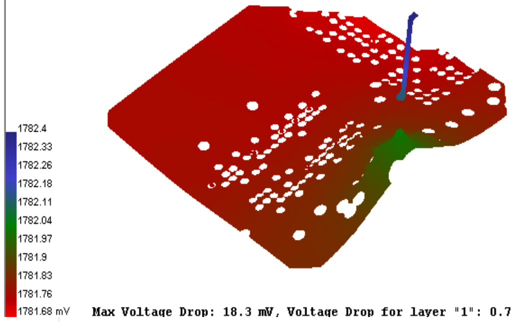
Exit frequency = frequency up to which PDN is capable to deliver energy below Z0

DC Current Density



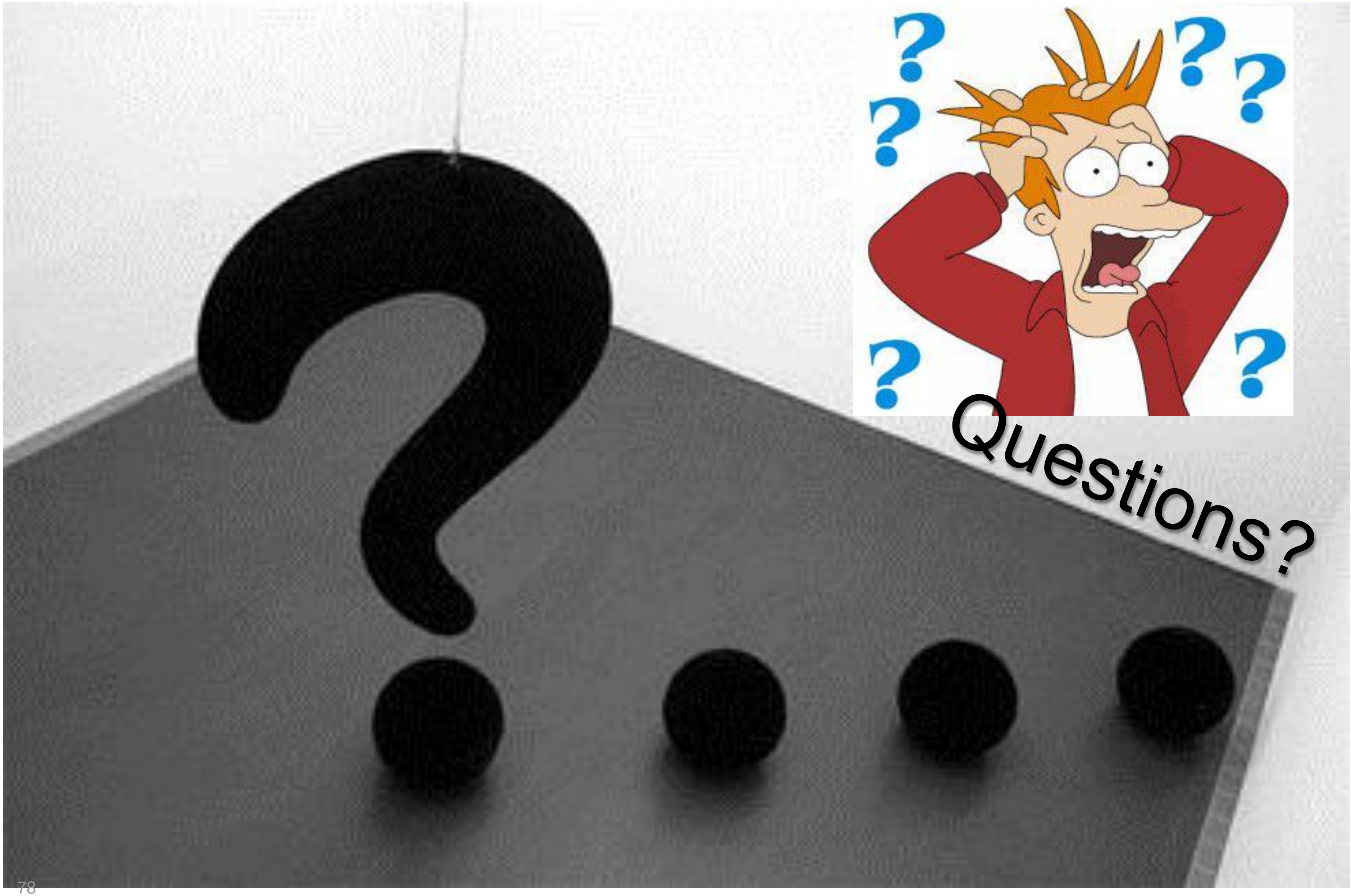
Max Current Density: 24.8 A/mm^2, Current Density for layer "1": 24.8 A/mm

DC Drop Voltage



Max Voltage Drop: 18.3 mV, Voltage Drop for layer "1": 0.7 mV

End of Part 1



Questions?