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E.M.I

Good engineering not voodoo

Peter.Wright Phd

2009

- Electro
- Magnetic
- Interference

- The Science of Electrical Packaging something ,so that nothing is disturbed by anything else.
- Harmony of multiple systems in the same location

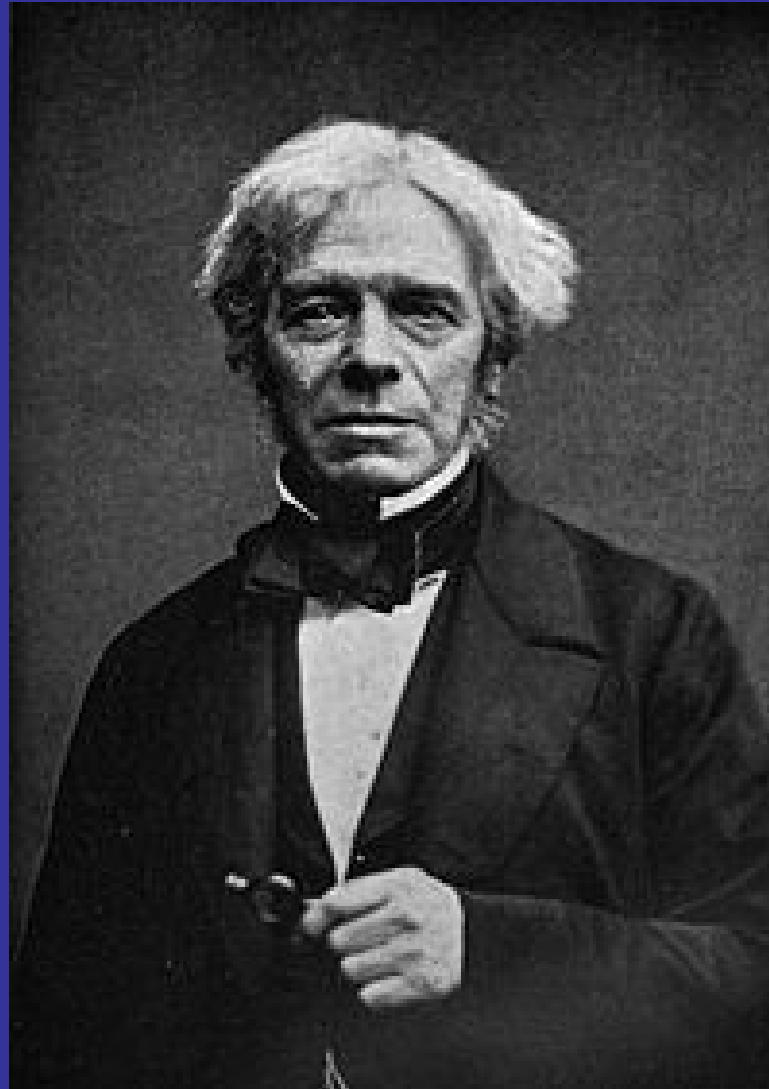
Two Directions

- Electrical waves leaving the unit and its cables with H and E Fields = Source of EMI to other equipment
- Electrical waves entering the unit from the outside = Electro magnetic Susceptibility

Where does the Physics of
EMI have its Roots



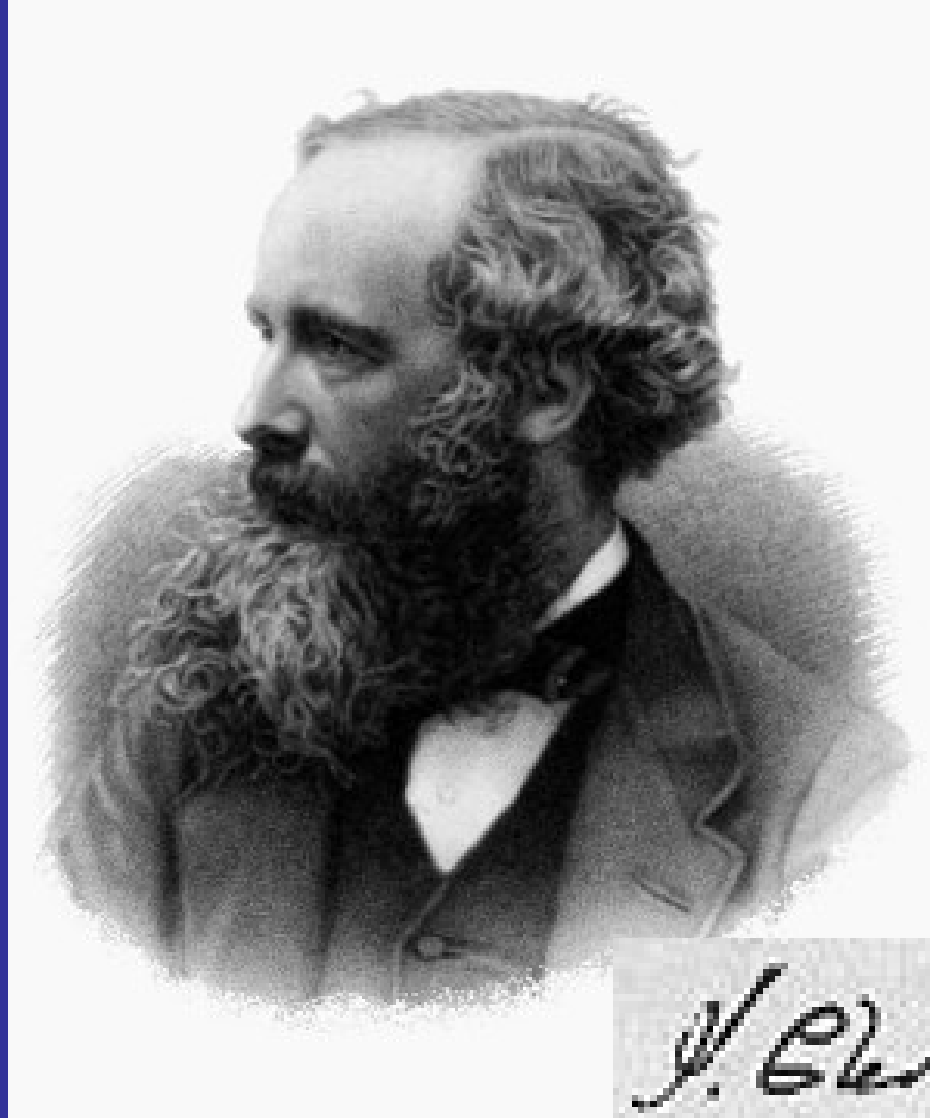
Michael Faraday



From London
1791-1867 (75)

A small image of a handwritten signature in cursive script, reading "M Faraday".

James Clark Maxwell

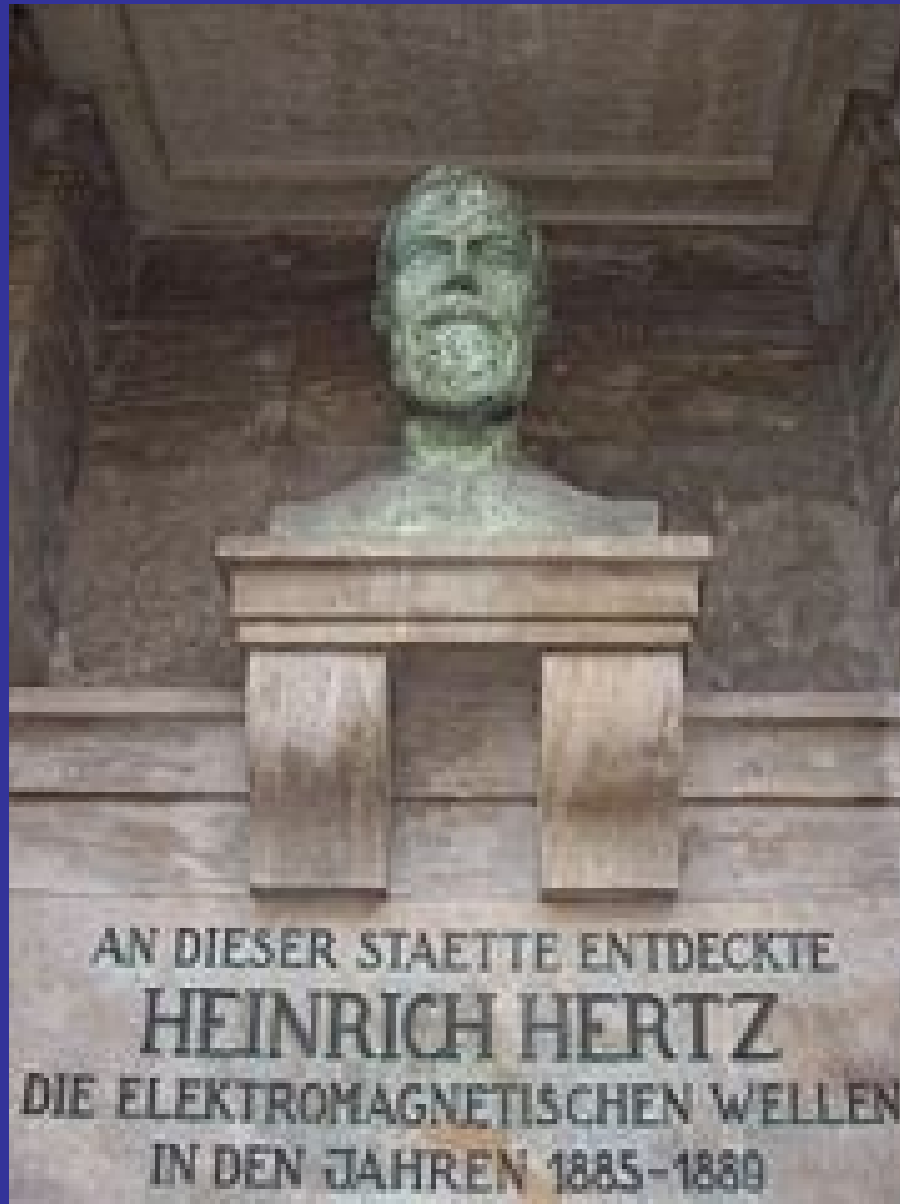


A Son of
Edinbrough

1831-1879 (48)

J. C. Maxwell

Heinrich Hertz



University of
Karlsruhe

Hamburg

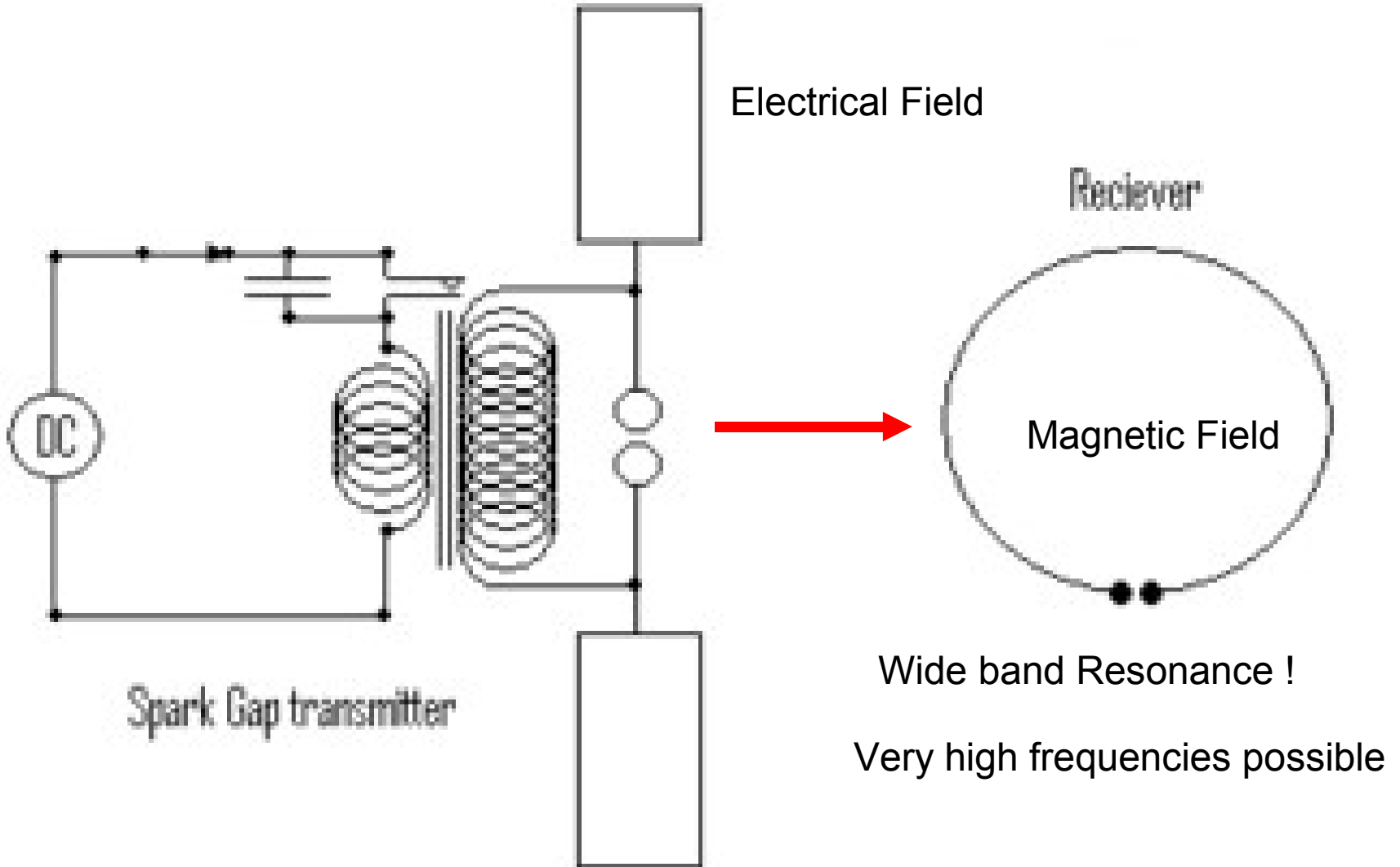
1857-1894 (36)

A handwritten signature of Heinrich Hertz, written in cursive script.

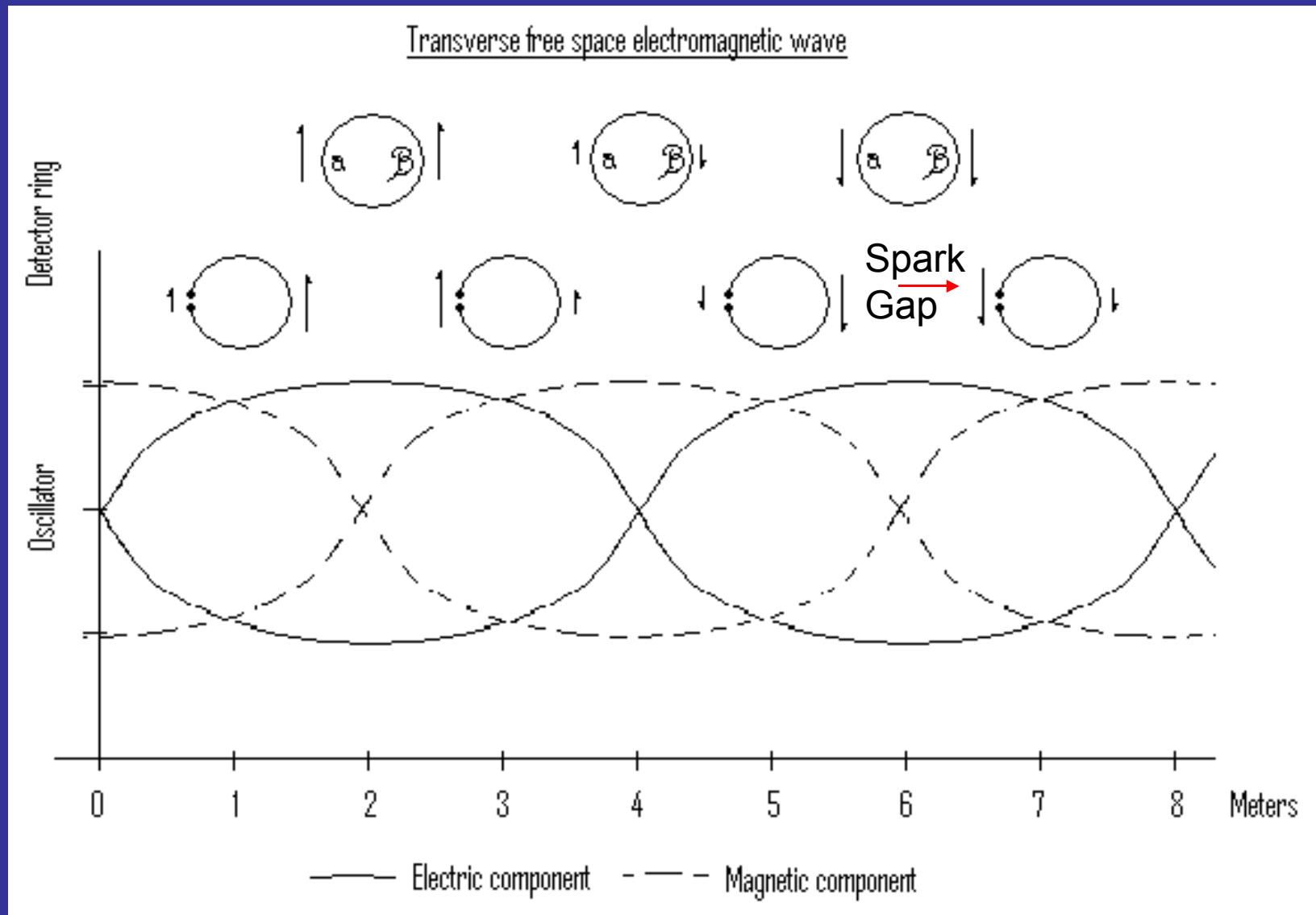
3 Physicists who told us Everything

- Why is EMI a problem today when it was understood in the 18th Century to a full.
-
- That's a dammed good Question the answer is no one stops to think and that's our problem otherwise nothing ! We call EMI the Product of bad engineering .

Generation of H and E Fields



E or Electric and H or Magnetic Waves



Every conductor generates EMI

- H and E Fields are generated by Inrush Current , switching of heavy loads , disconnection of heavy loads, commutation, Sine and Square waves, Arcing of high voltages, Static electricity, Short rise times
- An optimal Field is proportional to a perfect impedance

Electrical Disturbances

- Switching of high voltages
 - Switching at high speed or with high speed
 - Discharging of high voltages
 - Discharging with high resistance
 - Is related to Capacitance
 - EMI at higher frequencies
-
- The higher the voltage the higher the field
 - E Fields Capacitance

Magnetic Interference

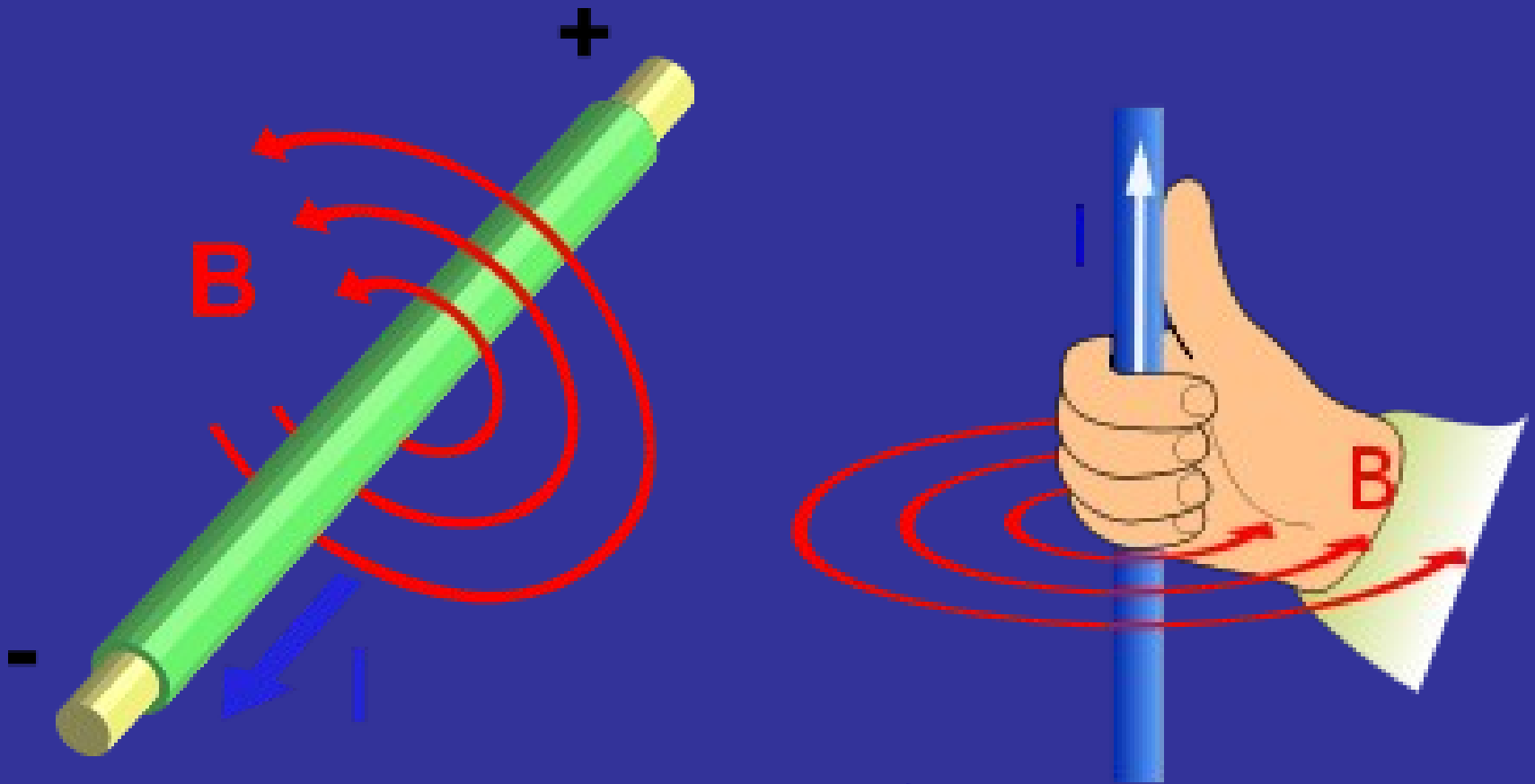
- Comes Adjacent to Electrical Interference
- Increases when loops are present
- Is helped by magnetic materials
- EMI at lower frequencies

- The higher the current the higher the field
- H Fields Inductive

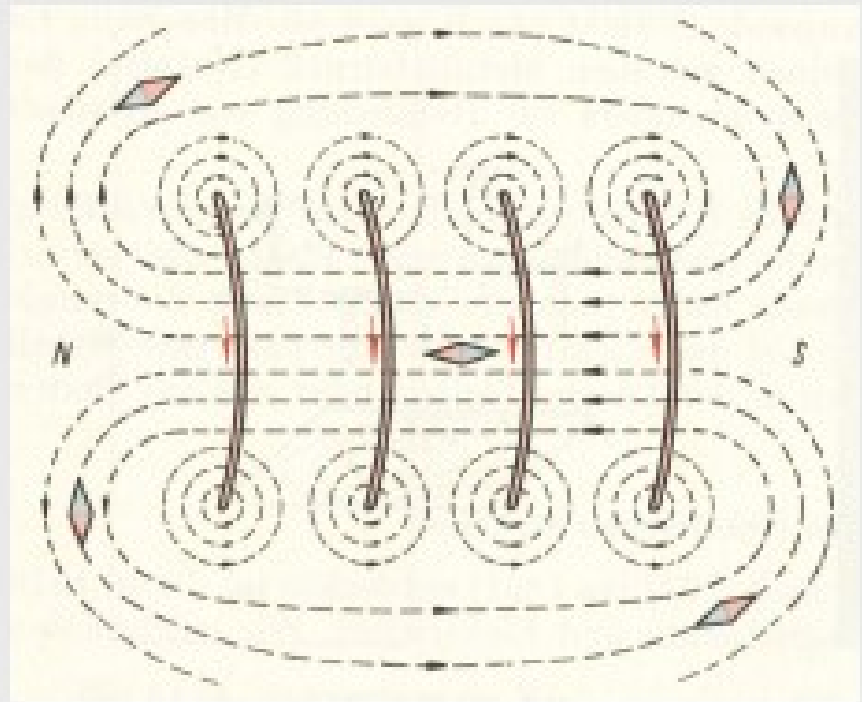
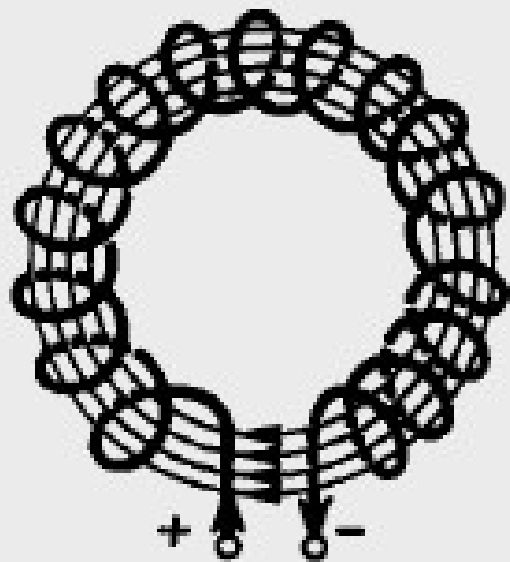
Electrical and Magnetic fields are
always together .

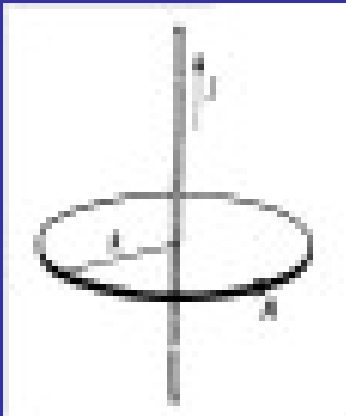
Kill one and you kill the other !

Electro Magnetics in General

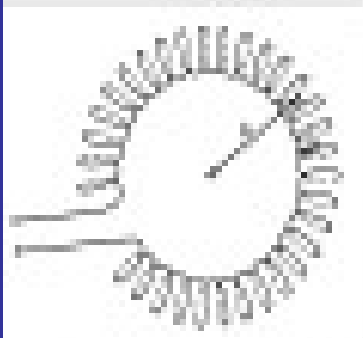
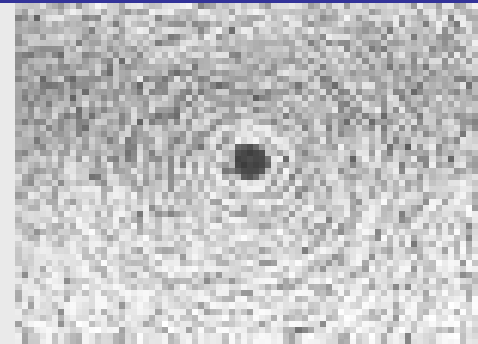


Remember school Physics?

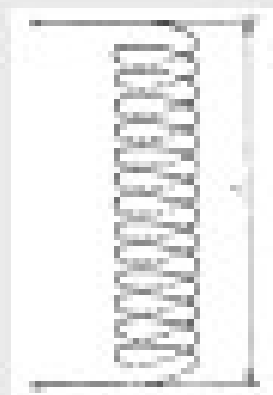
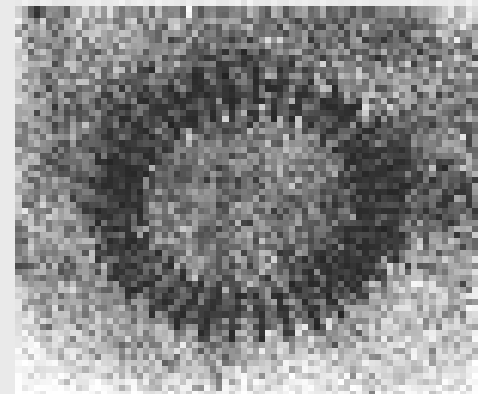




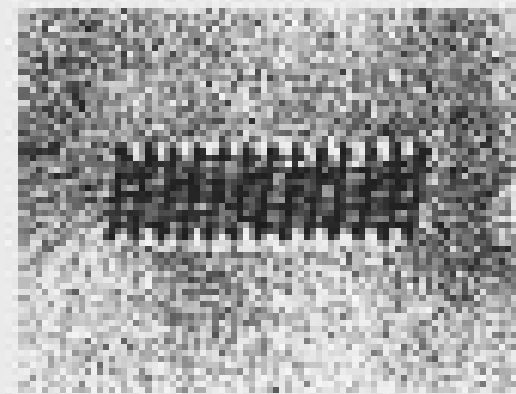
$$H = \frac{I}{2 \cdot \pi \cdot R}$$



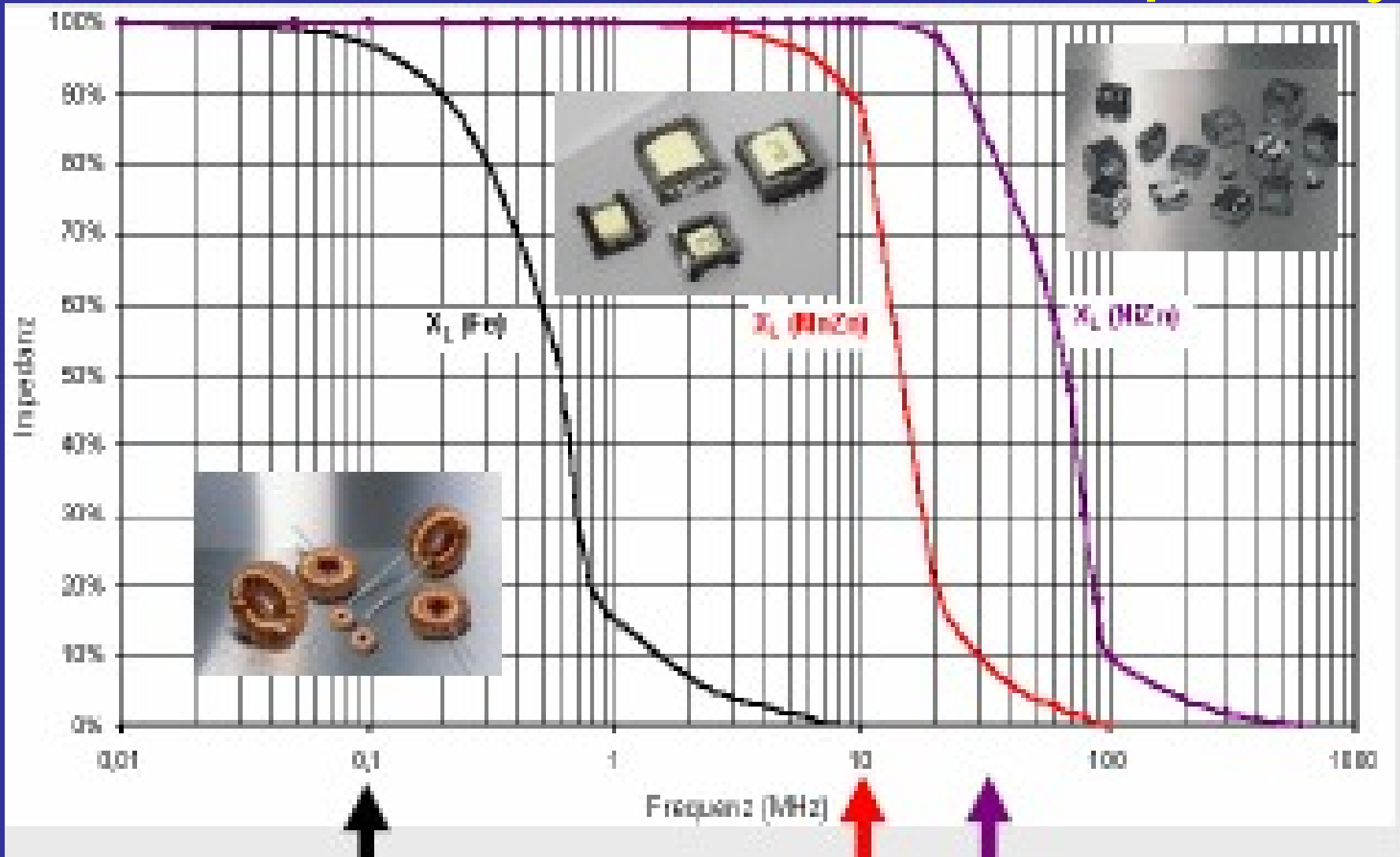
$$H = \frac{N \cdot I}{2 \cdot \pi \cdot R}$$



$$H = \frac{N \cdot I}{l}$$



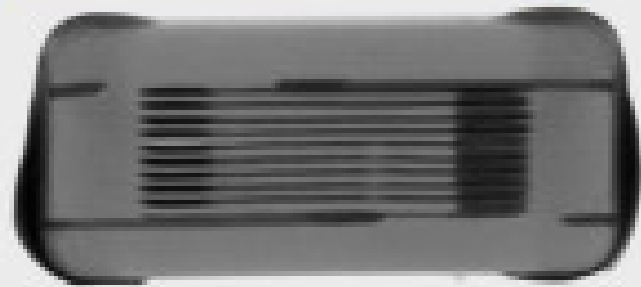
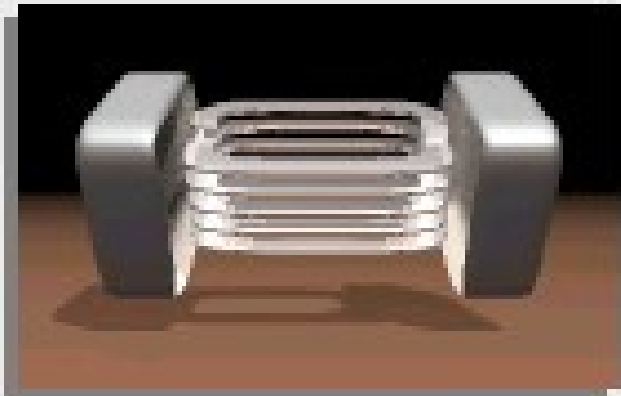
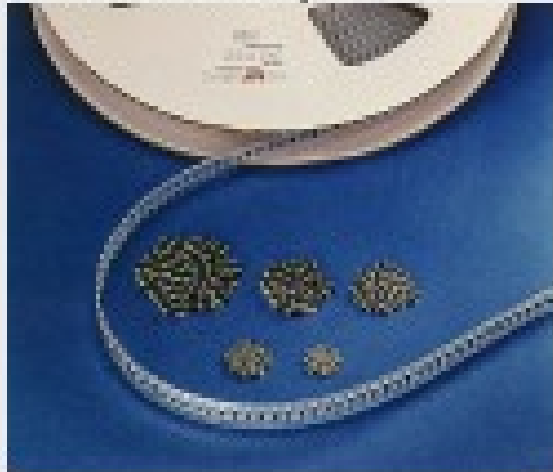
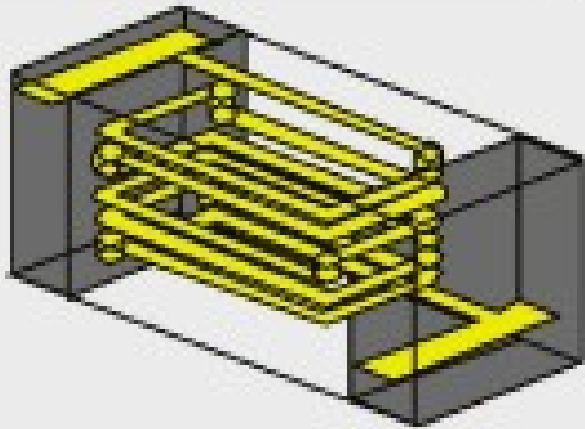
Which Material for What Frequency



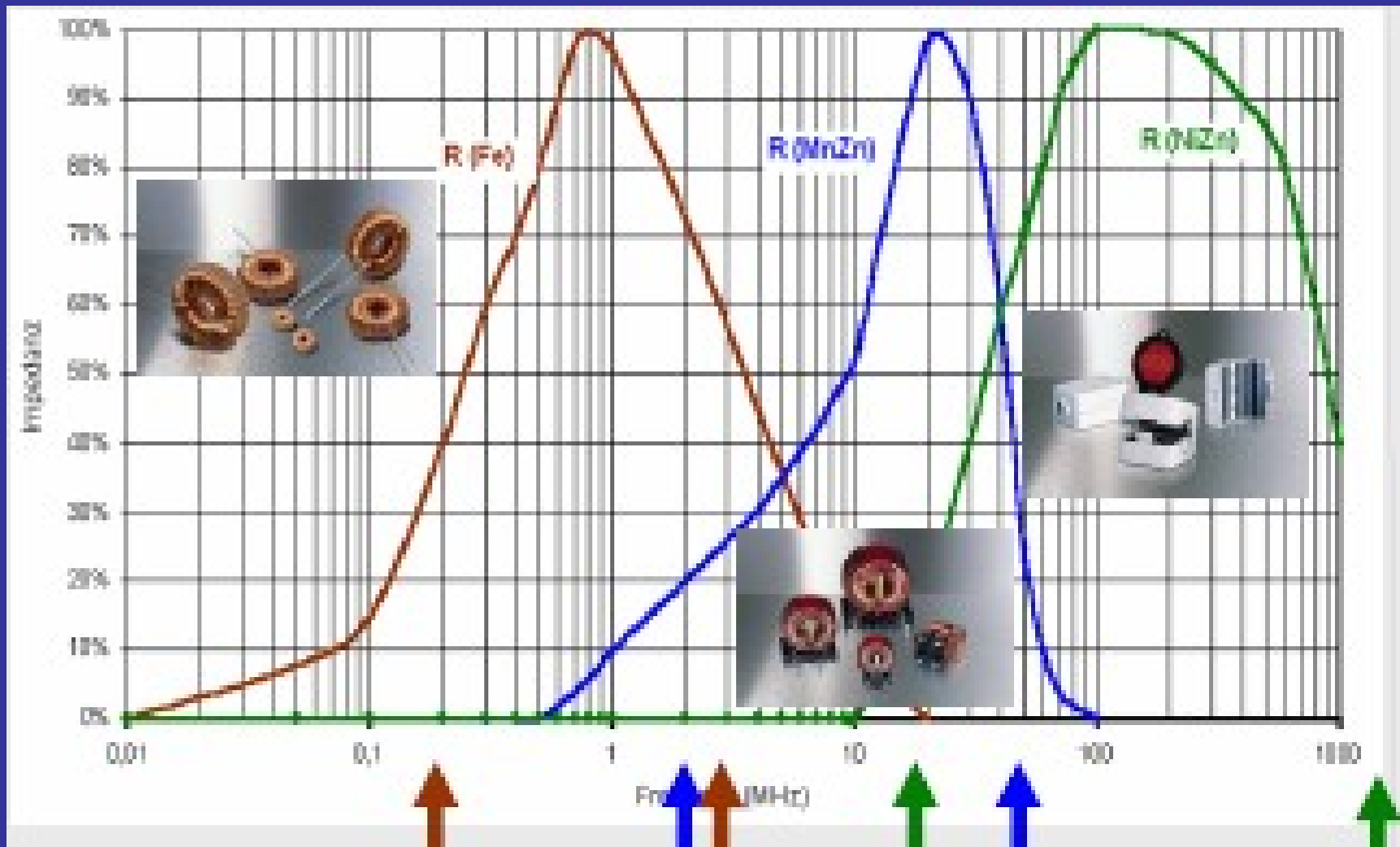
Iron, Mangan/Zink, Nickel/Zink

Use SMD Ferrites with Care they do not like inrush current !

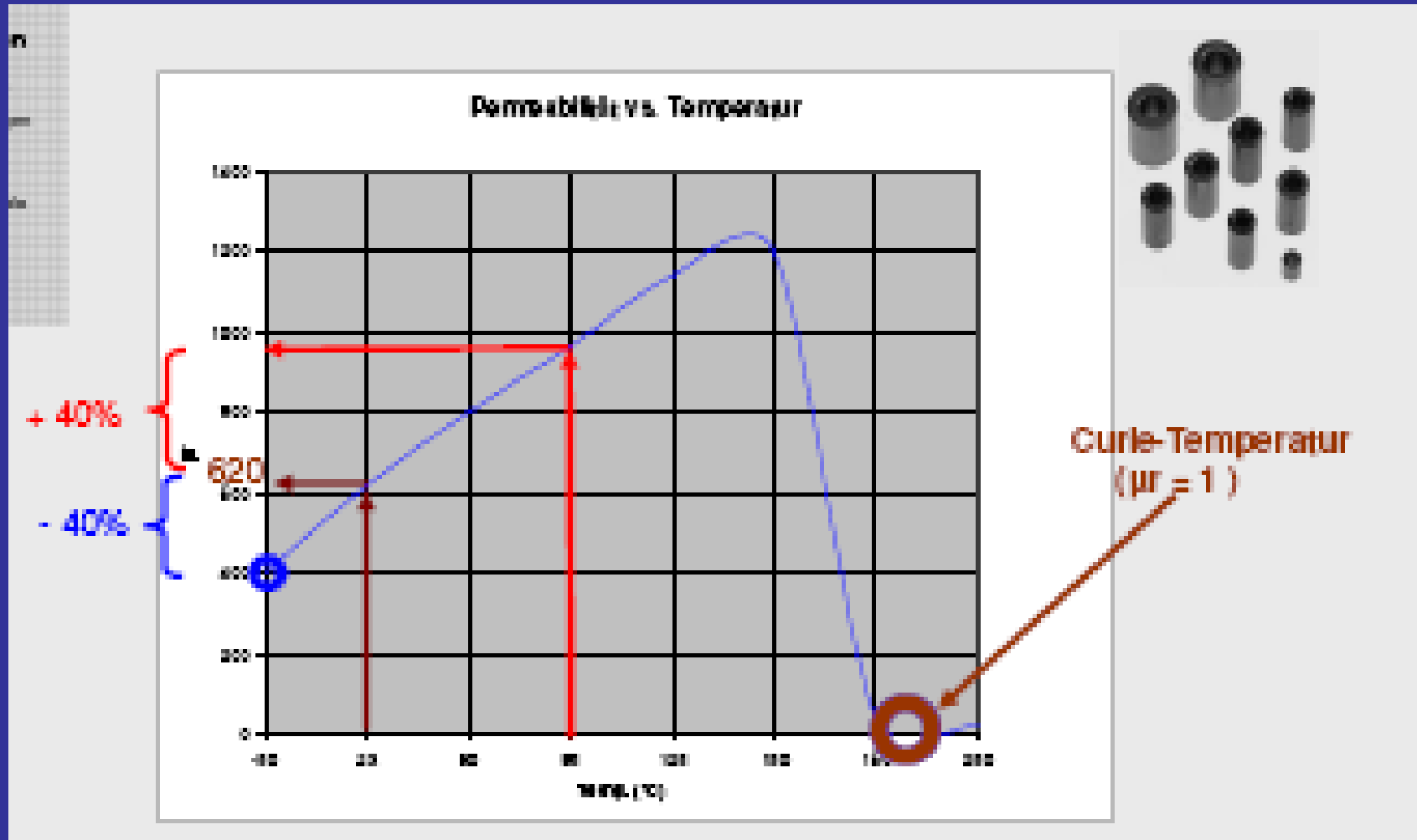
(Chip Bead Ferrite)



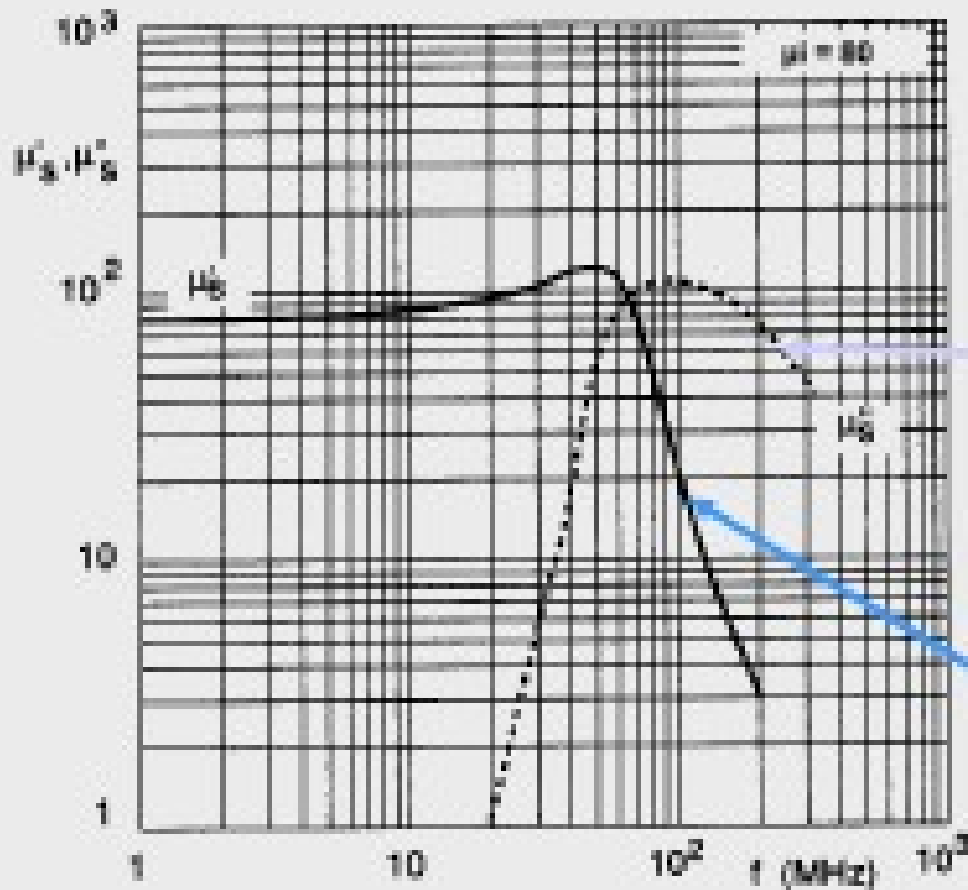
Which Choke Material should be used for what Frequency?



Beware of the Curie Temperature !



Frequency and Permeability



$$\underline{\mu} = \mu' - j\mu''$$

$$\underline{Z} = j\omega L_0 (\mu' - j\mu'') = R + jX$$

L_0 Induktivität ohne Kern

$R = \omega L_0 \mu''$
frequency dependent
core losses

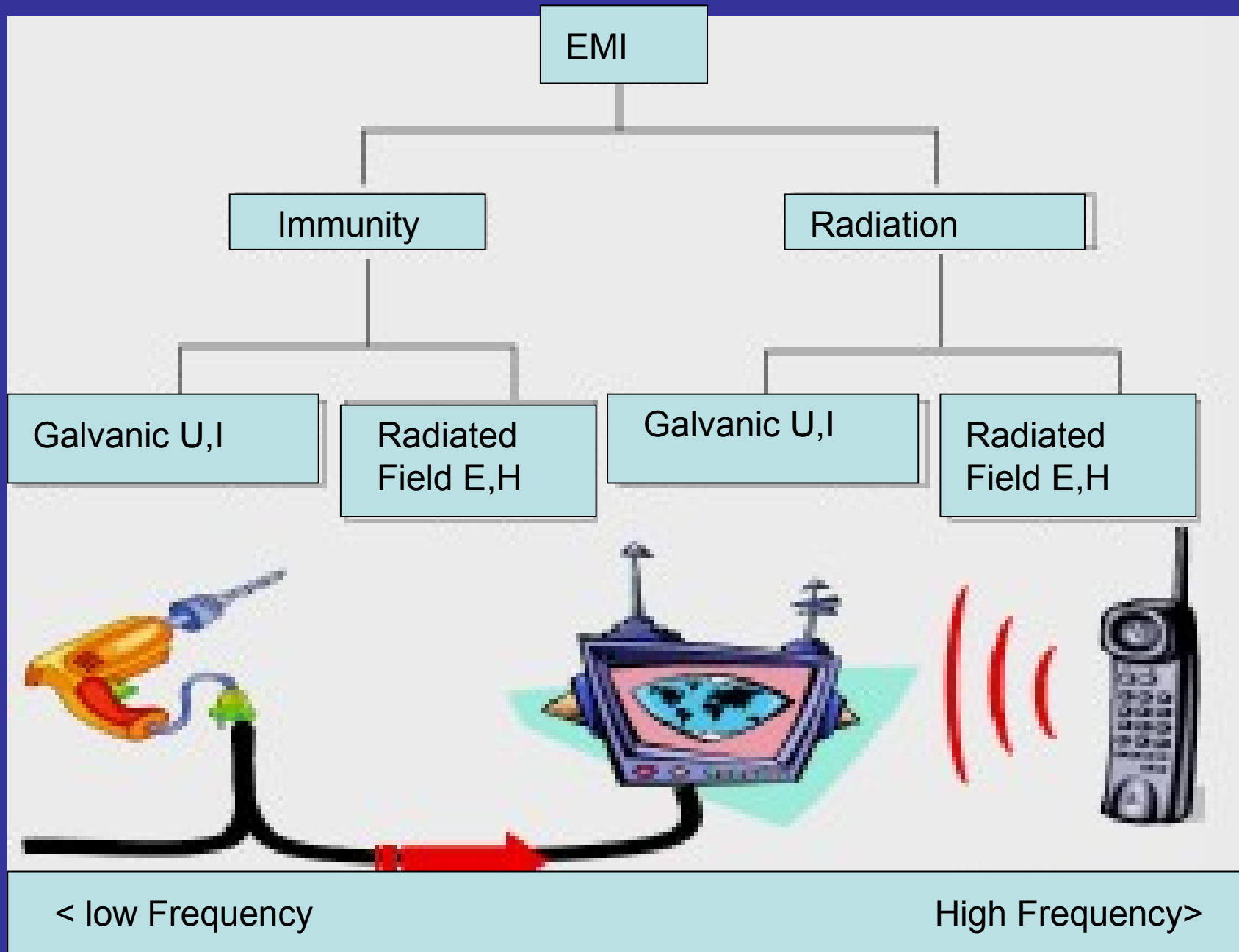
$X_L = j\omega L_0 \mu'$
frequency dependent
inductive portion

Important for Frequencies under 3 MHz you have to use Iron powder

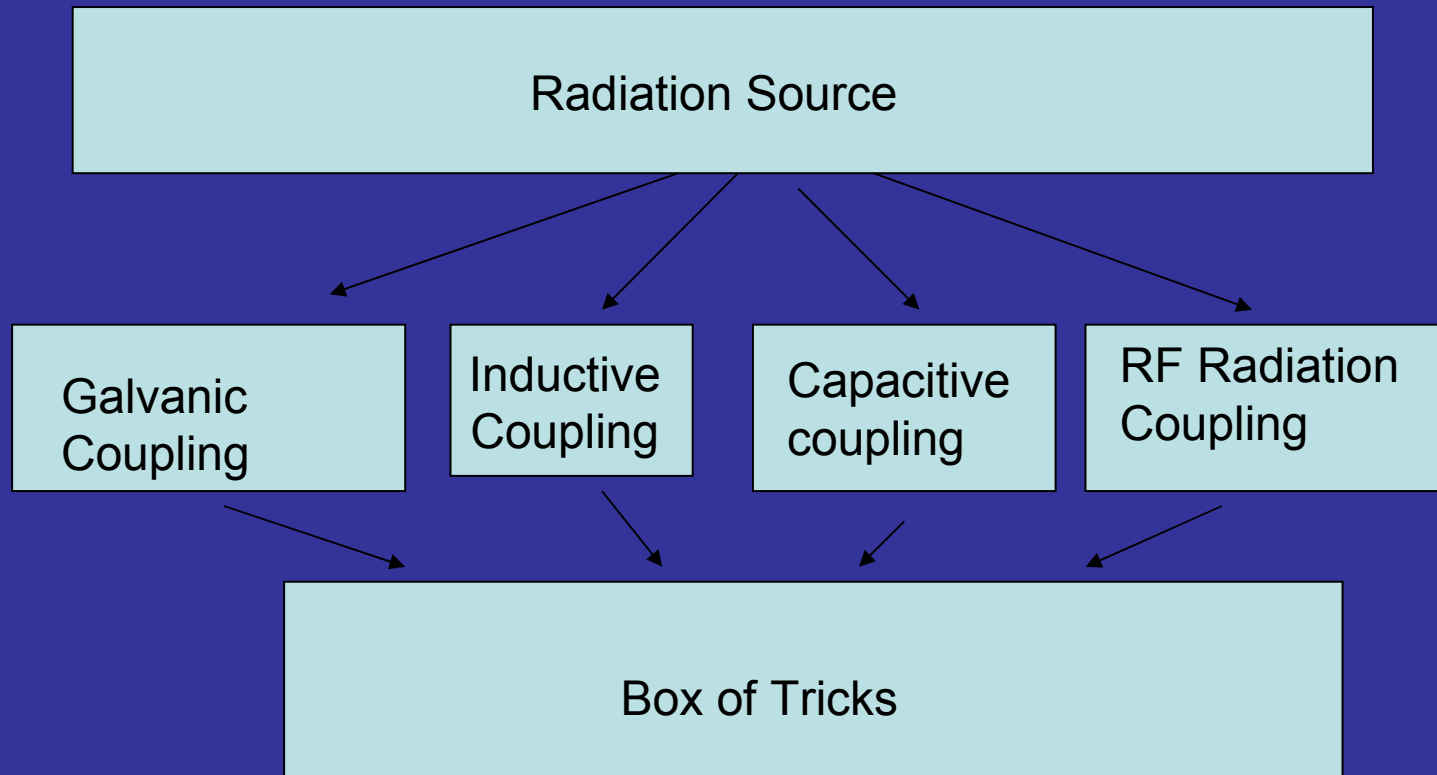
- The problem is with Iron powder that you can not cut it , this means that Clap “Ferrites” out of iron powder do not exist !
- This means that if you see a 2 half choke on a cable its not iron powder which means that the guy who selected it Hopes that interference is not below 3 MHz.
- That’s Funny in some applications for he who knows better !

Loss in core Material

- Inductivity, as lower as possible at the application frequency
- HF Choke as high as possible at the application frequency



EMI Methods of Transport



Short

Keep electrical cables

Long

2 Modes

- Common mode
- Differential Mode

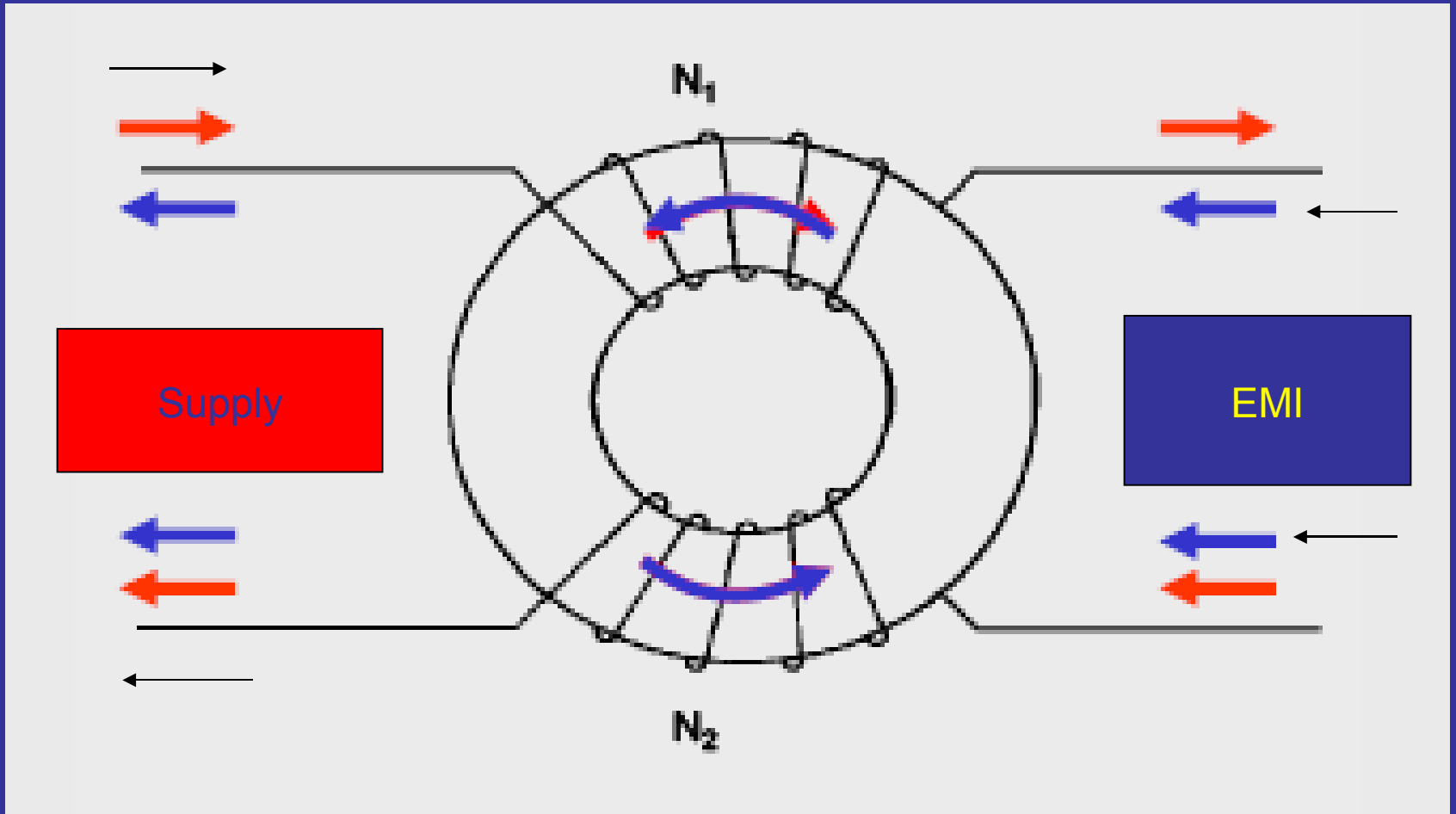
A Simple test

- Place a clamp ferrite onto the cable
- The EMI Measured level goes up or Down
=Differential mode
- Nothing happens = Common mode

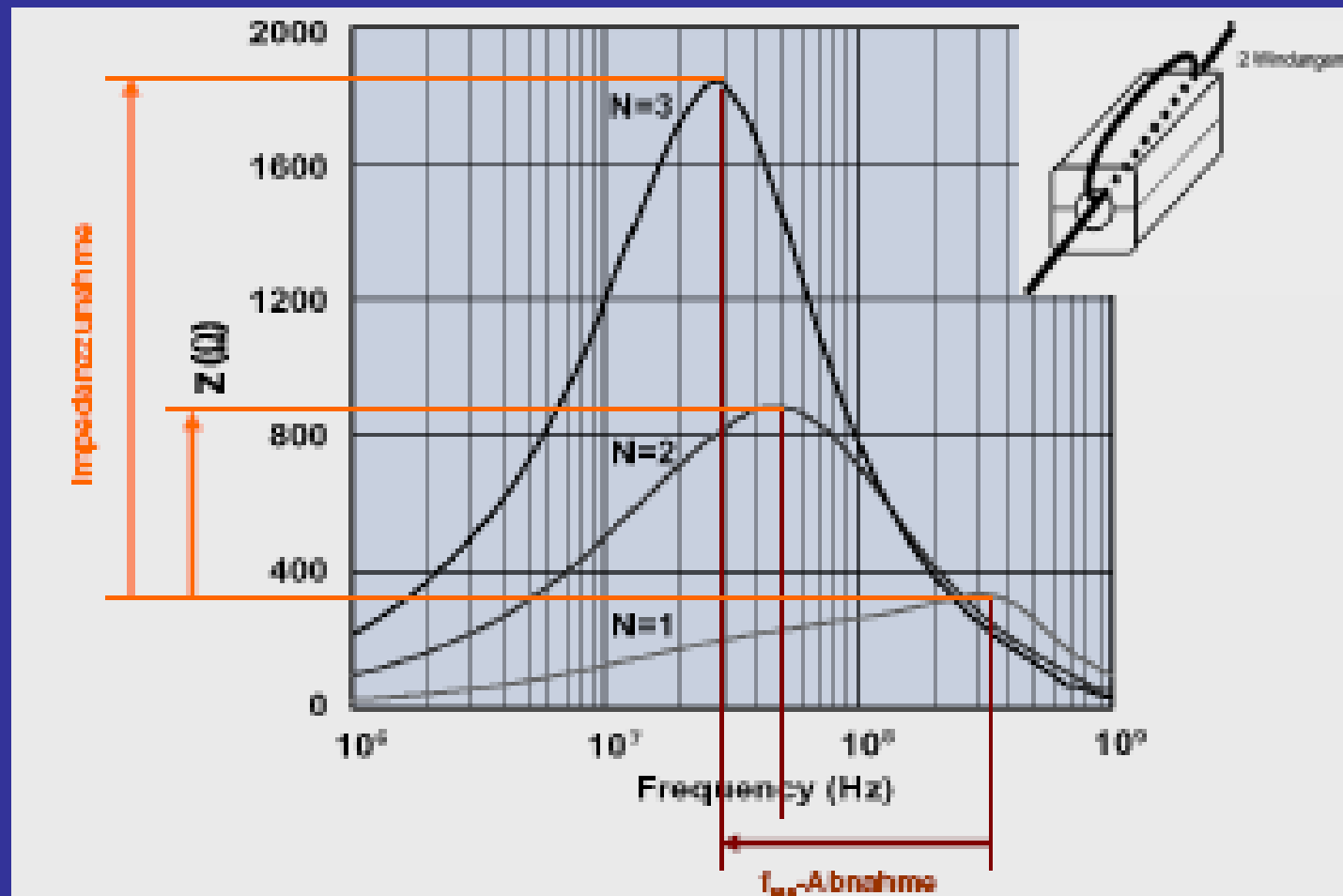
Who is normally guilty?

- The most common EMI is Differential mode this can be eliminated with PI Filters
- The Common mode is a bit harder you need to use a common mode choke with Bifilar windings , the Transient is converted to a magnetic field in the core

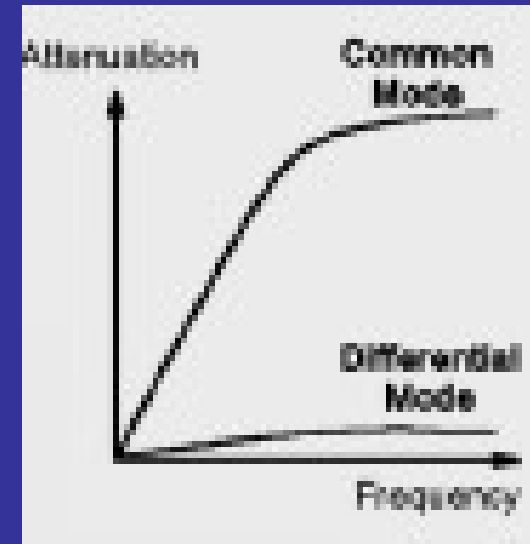
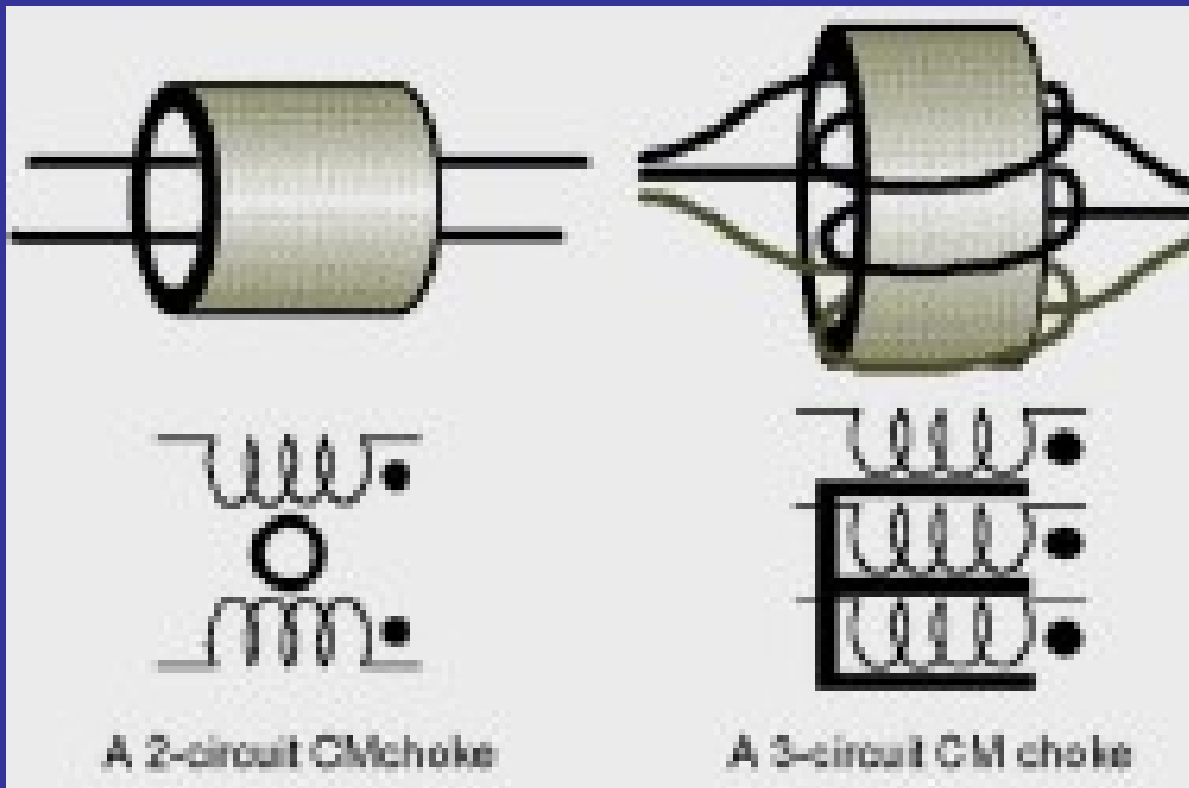
Why common mode?



The More Turns, the Higher the Impedance

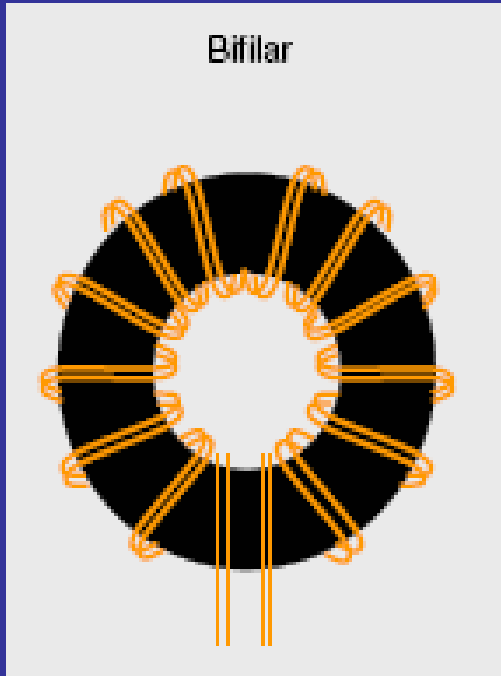


Do you see how a ferrite is also a common mode choke ?

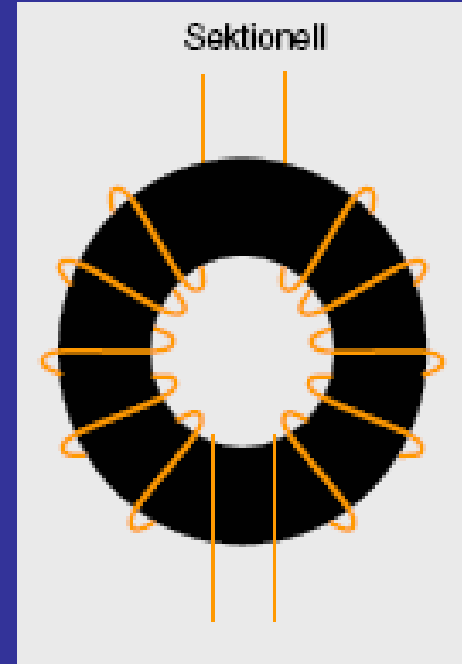


If you can not increase the number of turns you increase the number of ferrites !

How to wind a coil correctly

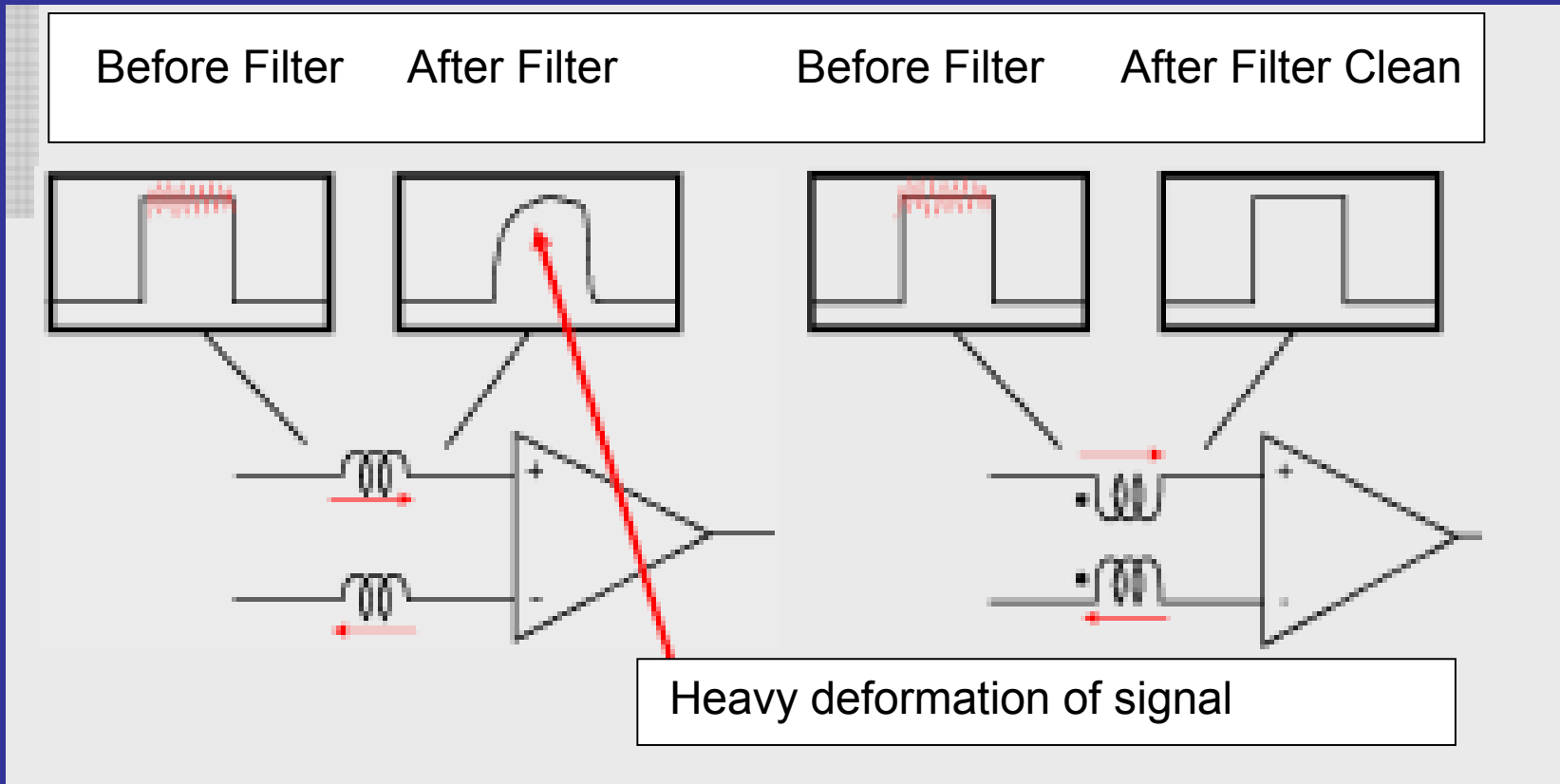


Almost right

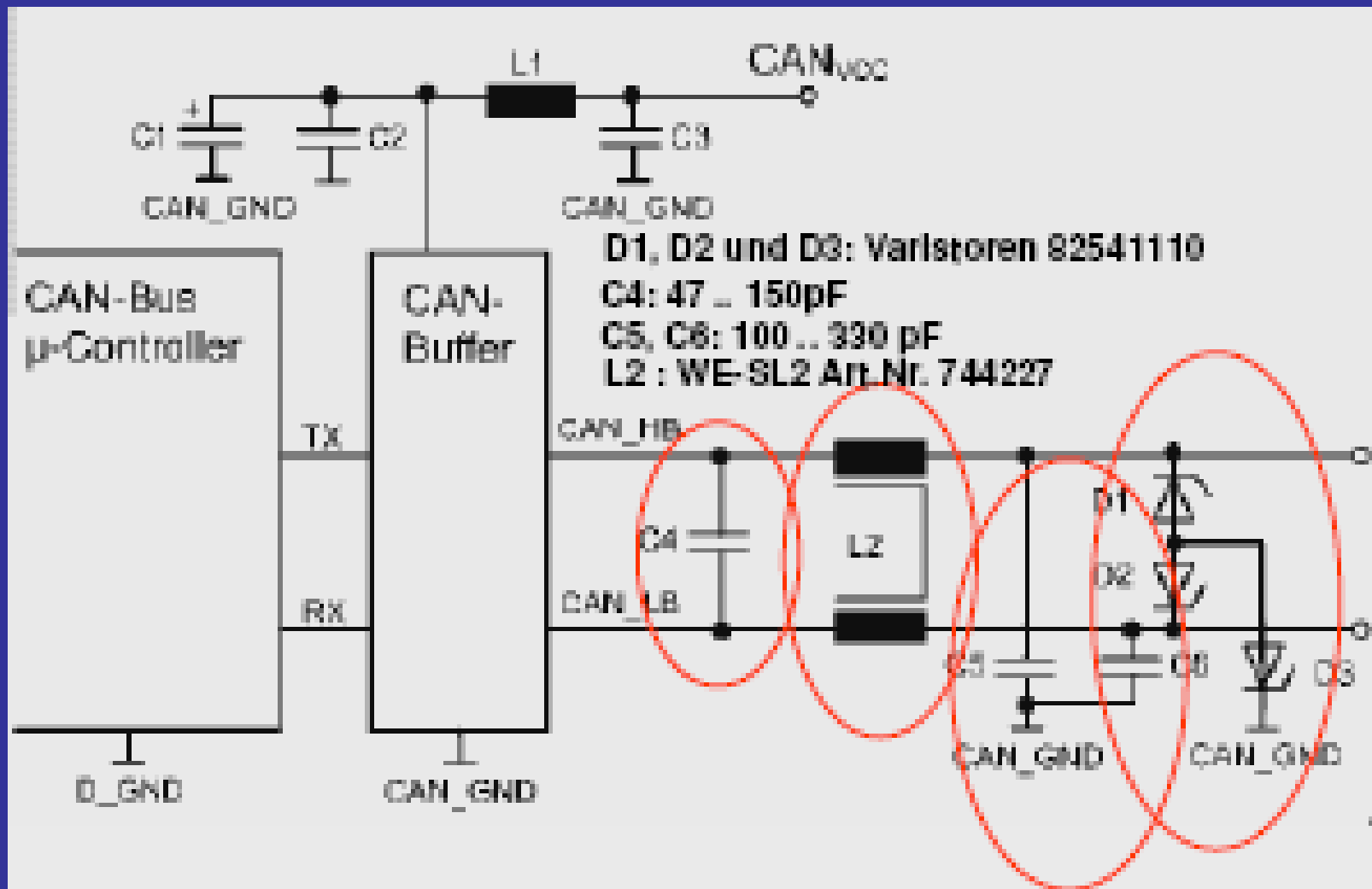


100% Right

What does a common mode choke Do to a bipolar signal ?



Use of Common Mode chokes as well as other modern EMI Suppression methods with complementary signals like RS422 RS485 , Can, Profibus, USB,



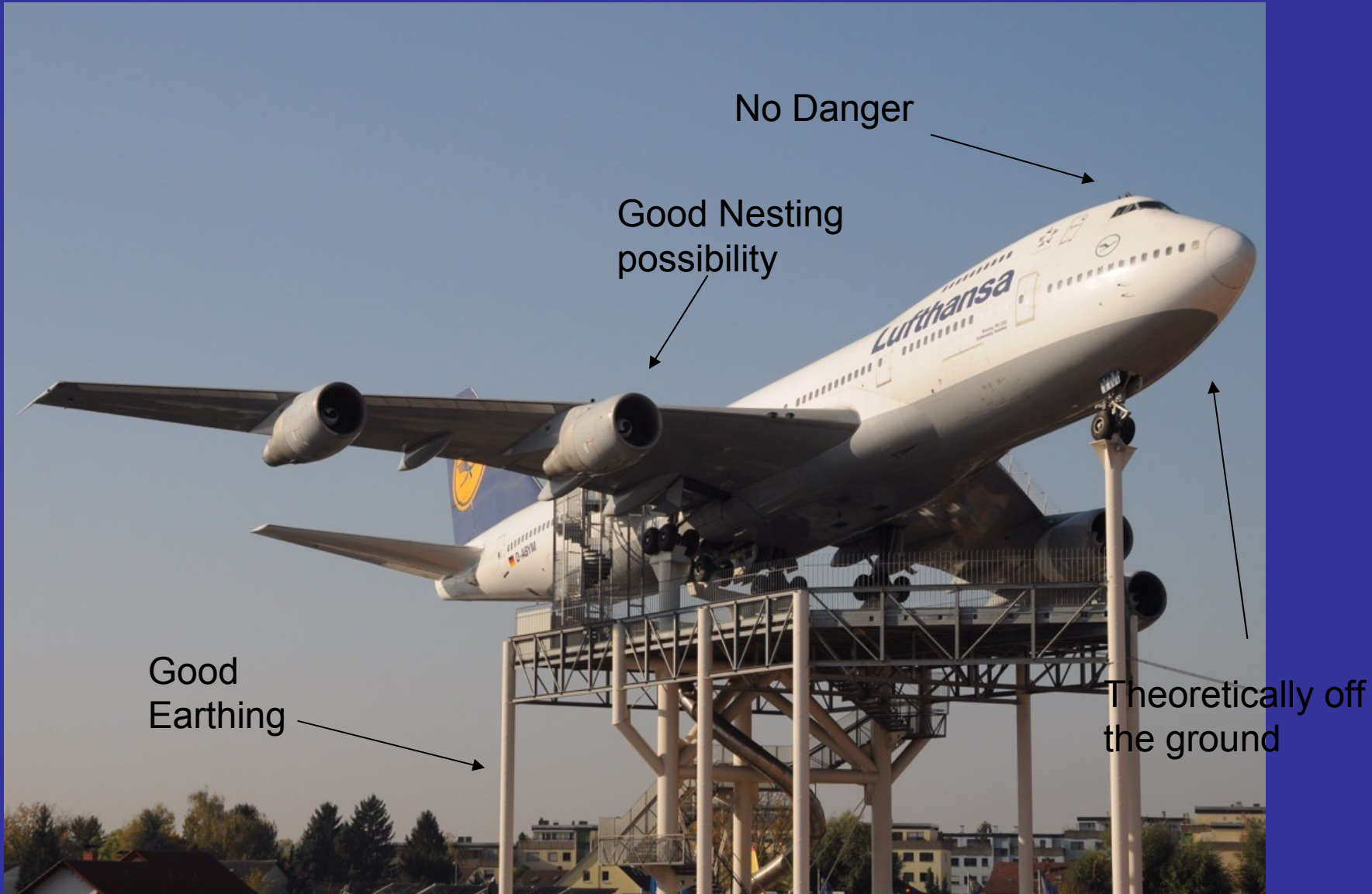
The Faraday Cage



A Moving Faraday Cage



An impractical Grounding concept



An unwanted Charge



!!! Rapid Discharge Generates EMI !!!

Ground Ref

Ground Ref

Ground Ref

Ground Ref

Ground Ref

Long Range Antenna to catch and Radiate EMI

EMI Generator

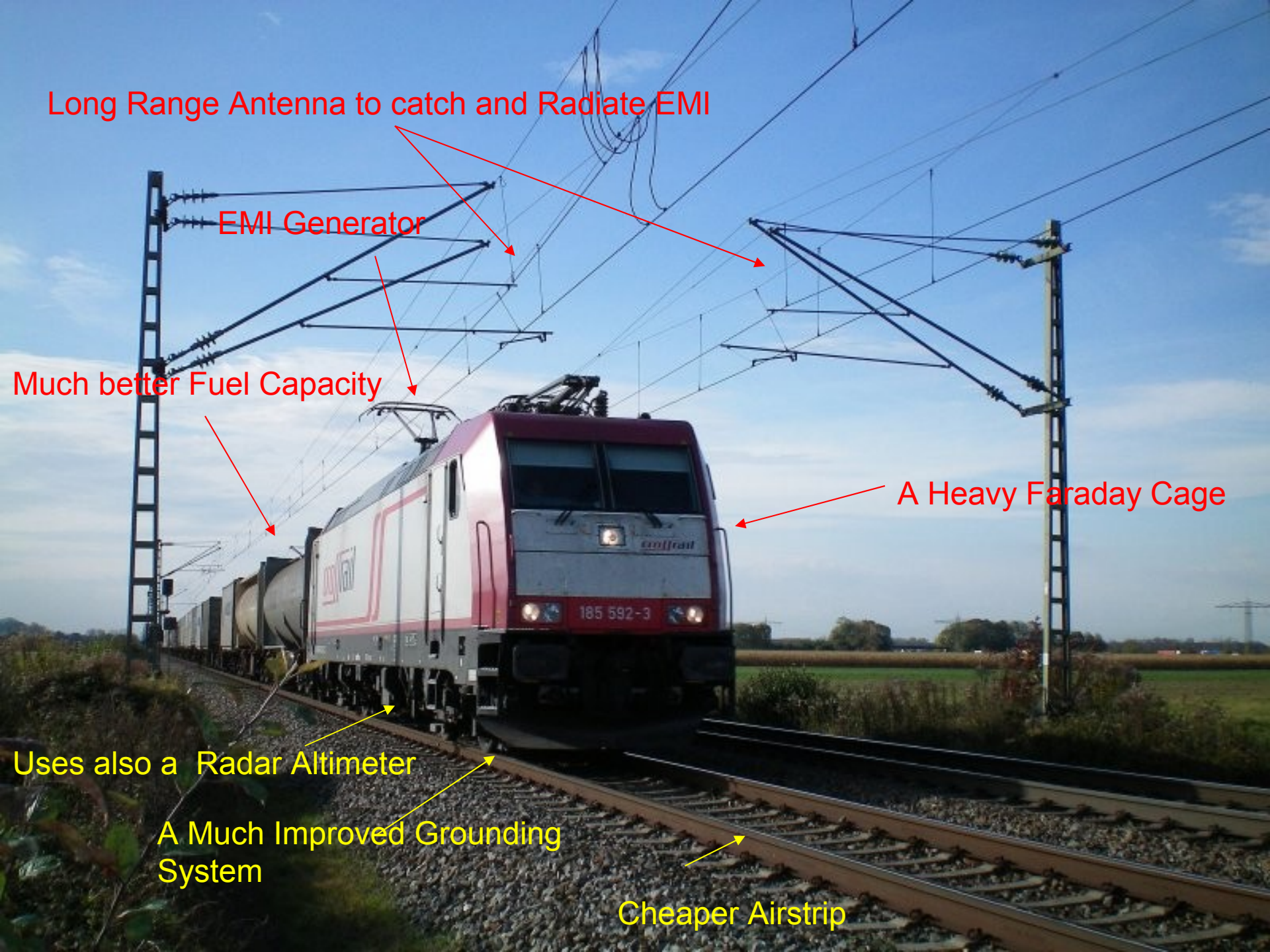
Much better Fuel Capacity

A Heavy Faraday Cage

Uses also a Radar Altimeter

A Much Improved Grounding System

Cheaper Airstrip



Factors

- 1 A faraday cage is only as good as its construction
- 2 Any cable entering it injects everything if not filtered
- 3 As Joints increase their resistance the performance of the cage in general drops
- 4 The conduction in Siemens of the metal used is proportional to the screening attenuation value obtainable.

Construction

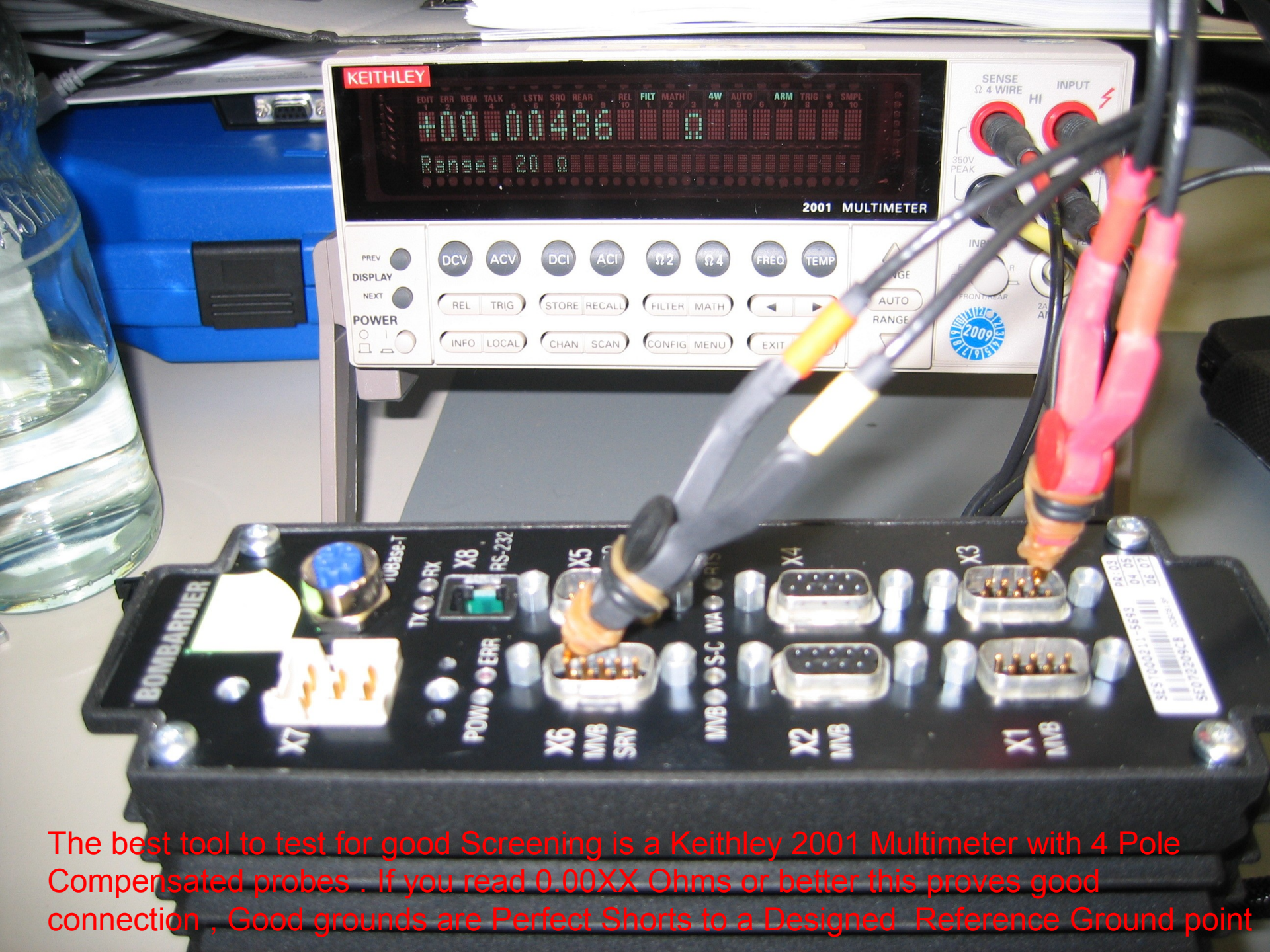
- The best way to manufacture a Faraday cage is to make a box out of silver plated copper and to silver solder each seam because Copper has a very good conductivity in Siemens and silver oxide Conducts and does not insulate
- If you Use Mesh you loose Attenuation via the contact resistance of each strand.
- Maximum Attenuation Frequency is dependant on hole or slit Length (Airbus A350) mesh gauge/ Current Capacity * Conductivity

Cables entering

- Every cable entering or leaving not filtered is a Wide band injection probe connected to a long antenna. All cables entering need either to come in via a dammed good screened cable or a filter or both!

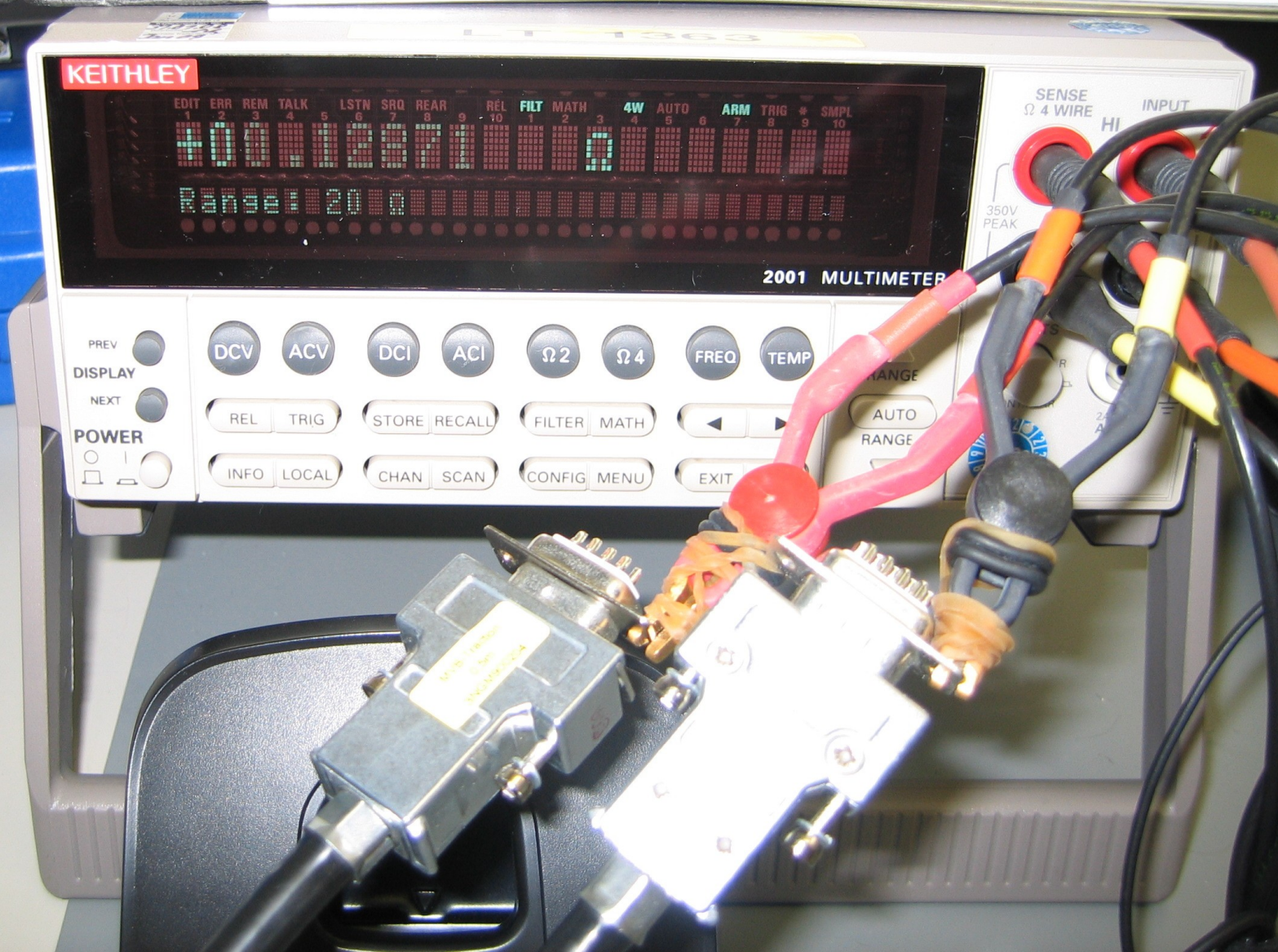
Joint Resistance

- When making a cage the electrical resistance as well as the air gap of the connection point between 2 plates is the most important factor effecting screening , no air gap means no slot antenna seeing outsidess EMI 0.000Ohms means no coil present seeing outside



The best tool to test for good Screening is a Keithley 2001 Multimeter with 4 Pole Compensated probes . If you read 0.00XX Ohms or better this proves good connection , Good grounds are Perfect Shorts to a Designed Reference Ground point

Electrical Testing of Cable Screening connection is also possible like this however you will have to know the art of Screening used by opening up the Braid or Foil or Both



Materials used

- It is the conductivity in Siemens of the materials used that ensure attenuation of a Faraday cage yesterday we used to use Milled brass boxes silver plated today we use Chromatised Aluminium one piece boxes with lids bolted every 15mm or Beryllium finger stock or other EMI Gasket materials

Avionic standards

Hundreds of screws and filters



Unused connectors with metal caps on !

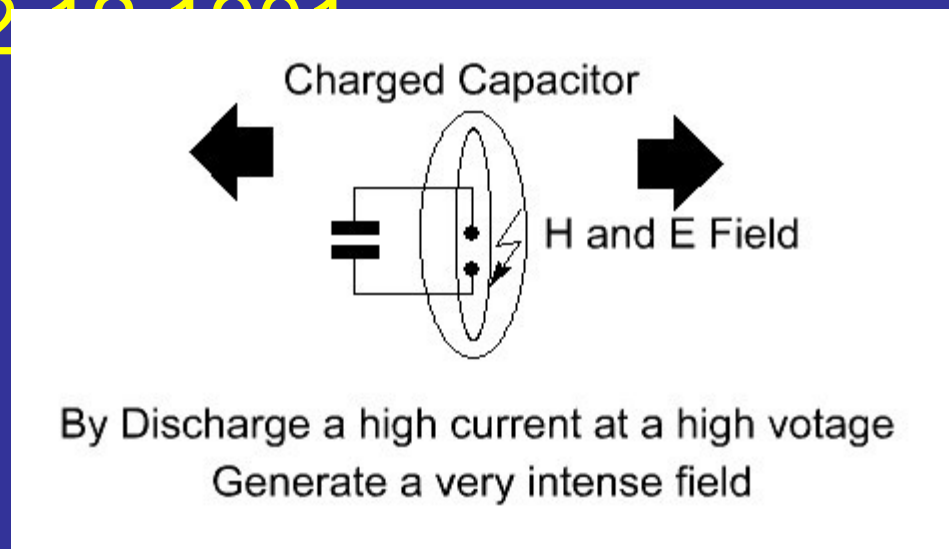


OK

Lets Start with Basics

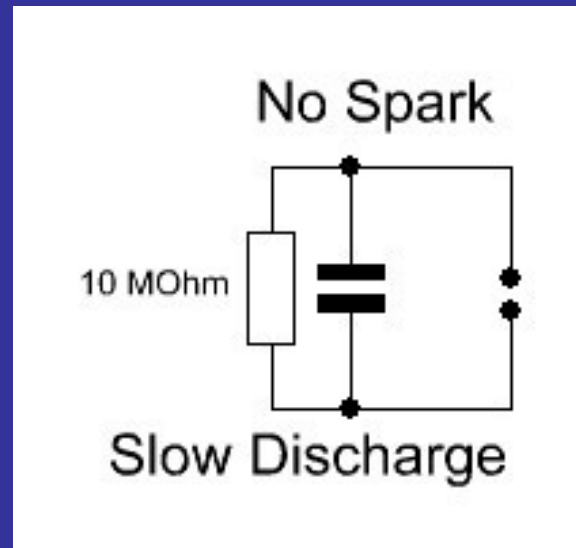
The EMI Pulse

- Mr Hertz generated EMI in a Lab
- Mr Marconi perfected it and communicated between Europe and the USA 12-10-1901



One key to stopping EMI is Slow Discharge

- This is the basis of ESD Safety in the electronic industry

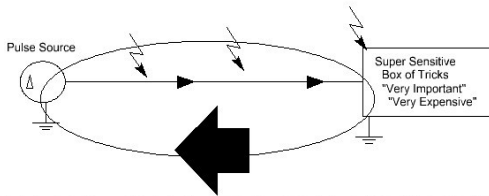


Unipolar and bipolar disturbances
are always present

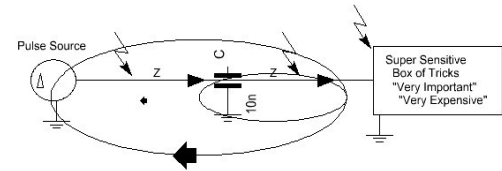
You have to suppress what is
harming you

EMI Filter Basics the LC Filter

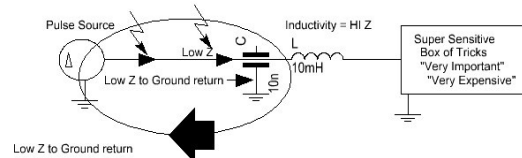
Using a high Impedance with an inductor or Ferrite to force a wave to go via a lower Impedance Capacitor to ground



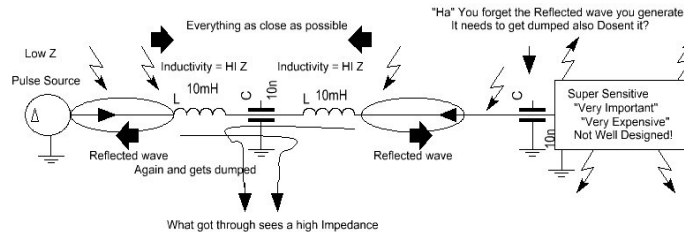
Current and voltage produce H and E Fields



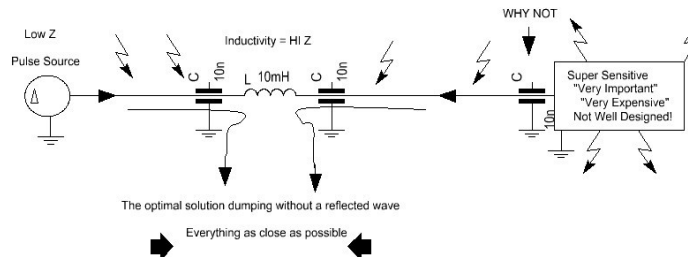
Where a ditching Capacitor is installed the impedance is still the same
So you do nothing



Where an inductor is present the impedance it presents is high so a capacitor may ditch EMI

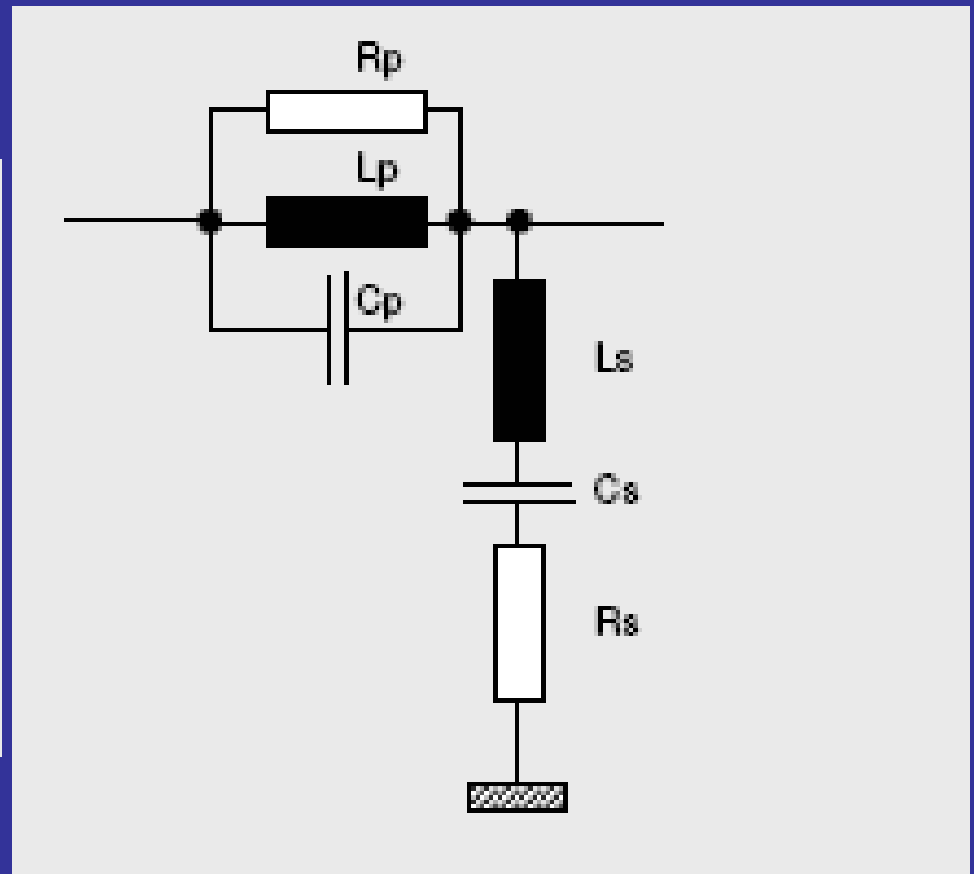
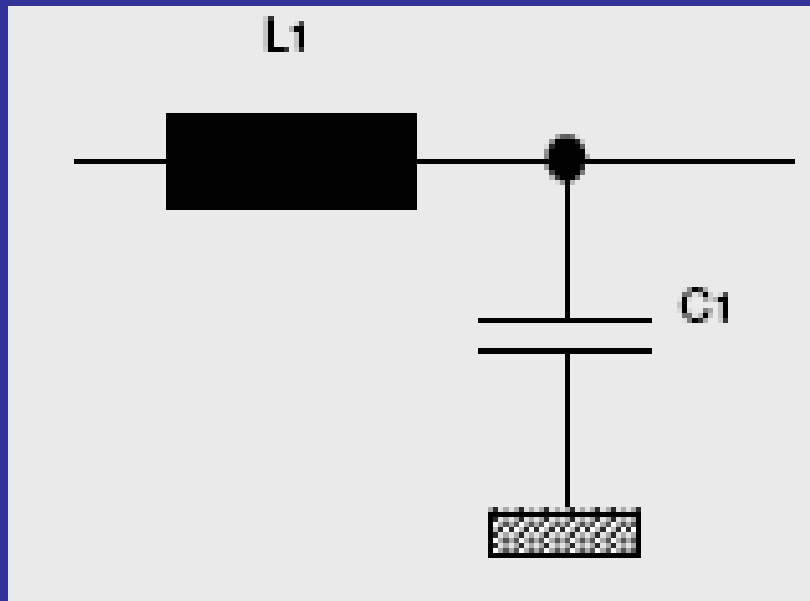


Here 2 coils or Ferrites do their job in cascade a reflected wave is however Generated
What gets through Gets however dumped , a good Solution



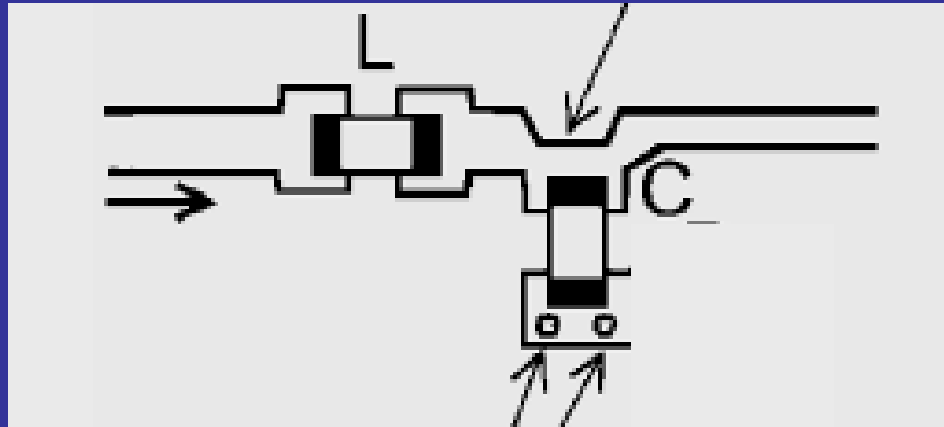
The Correct way of doing it with an engineers solution onboard with maybe a second inductor in cascade

Parasitic of wired components



EMI Ditching at Board level

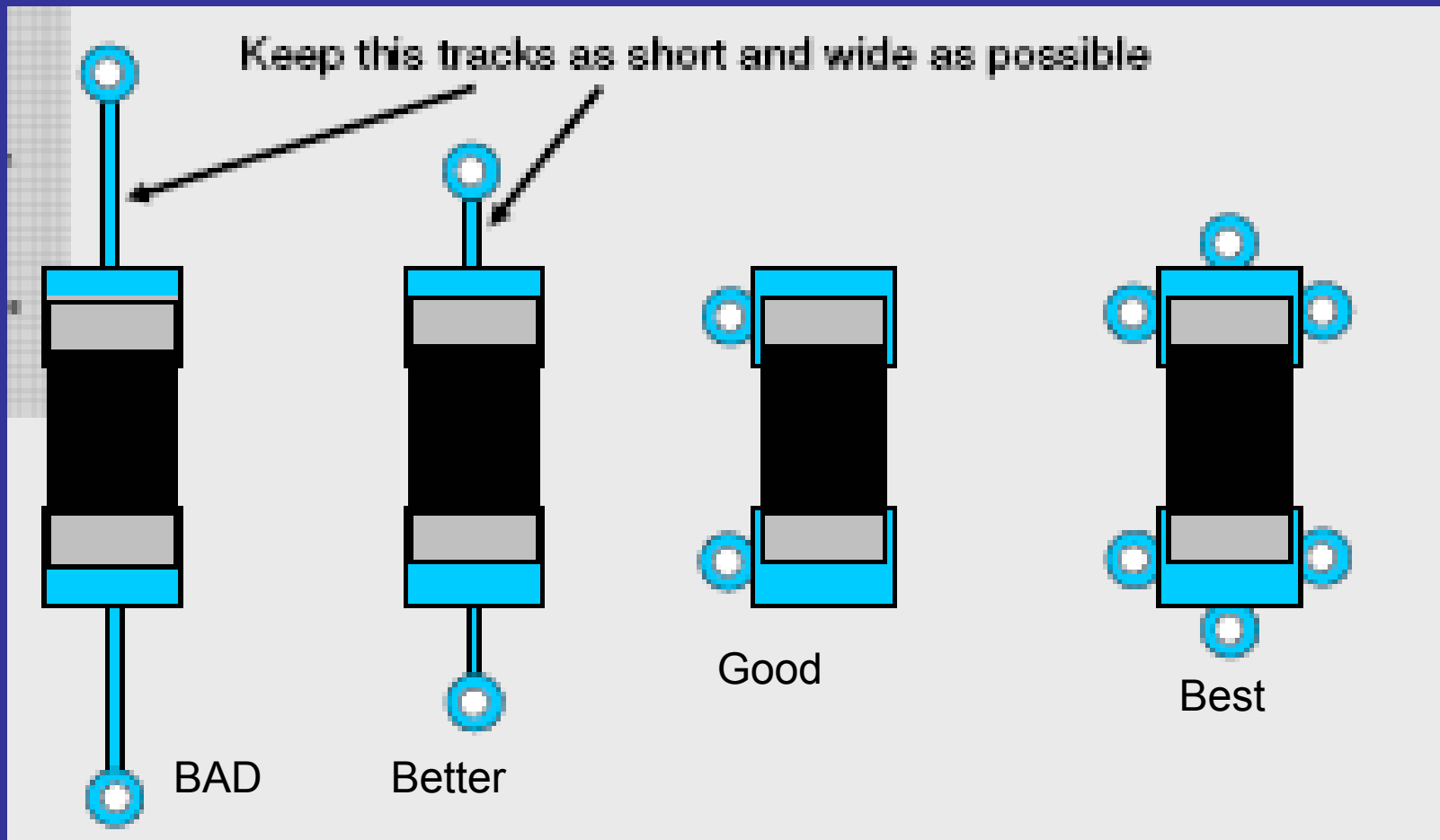
A “Ditch” in the artwork stops EMI by generating eddy currents and so time delay to assist the inductor



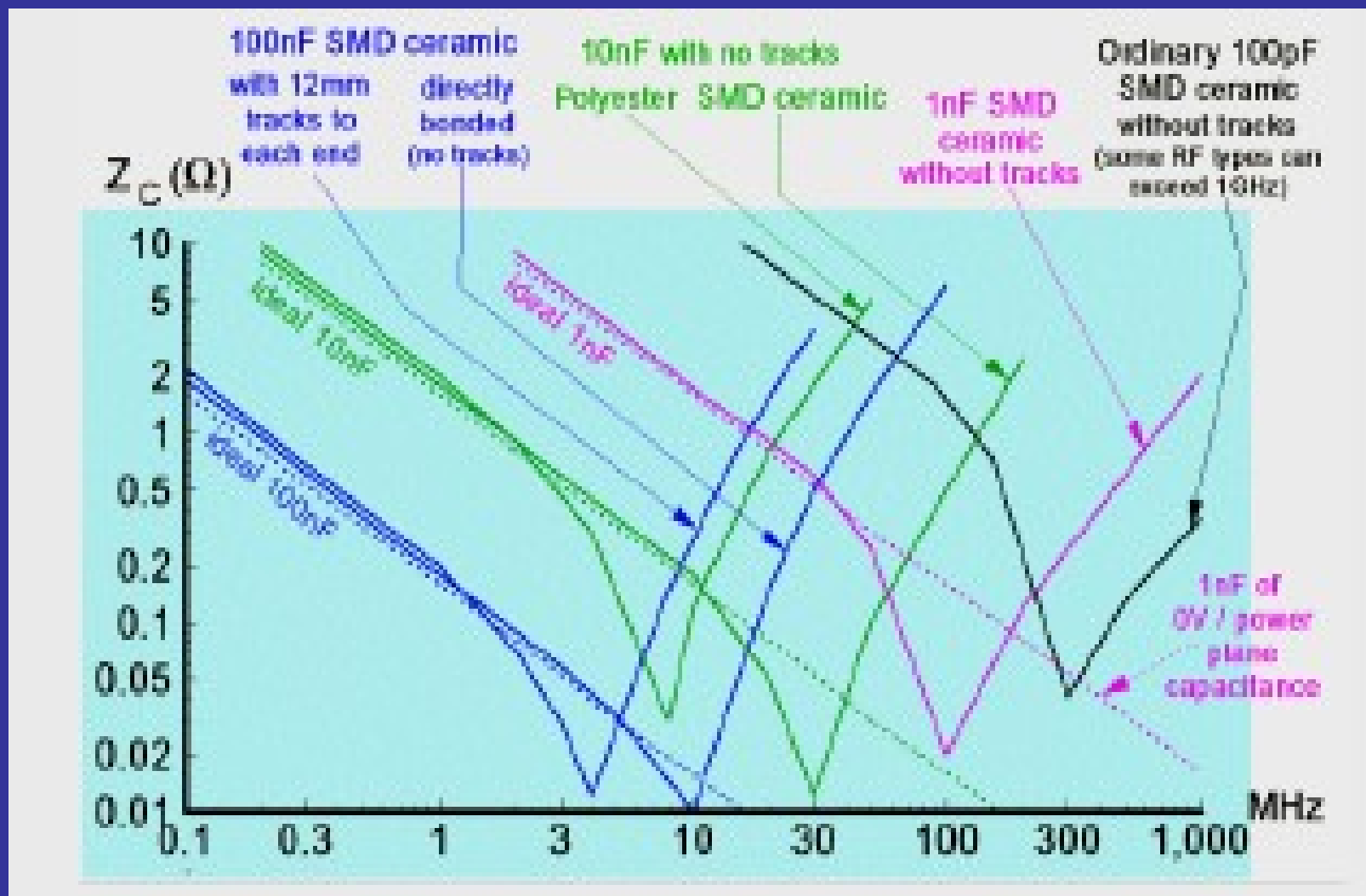
Multiple via holes close to pad

Real Voodoo Jewiew

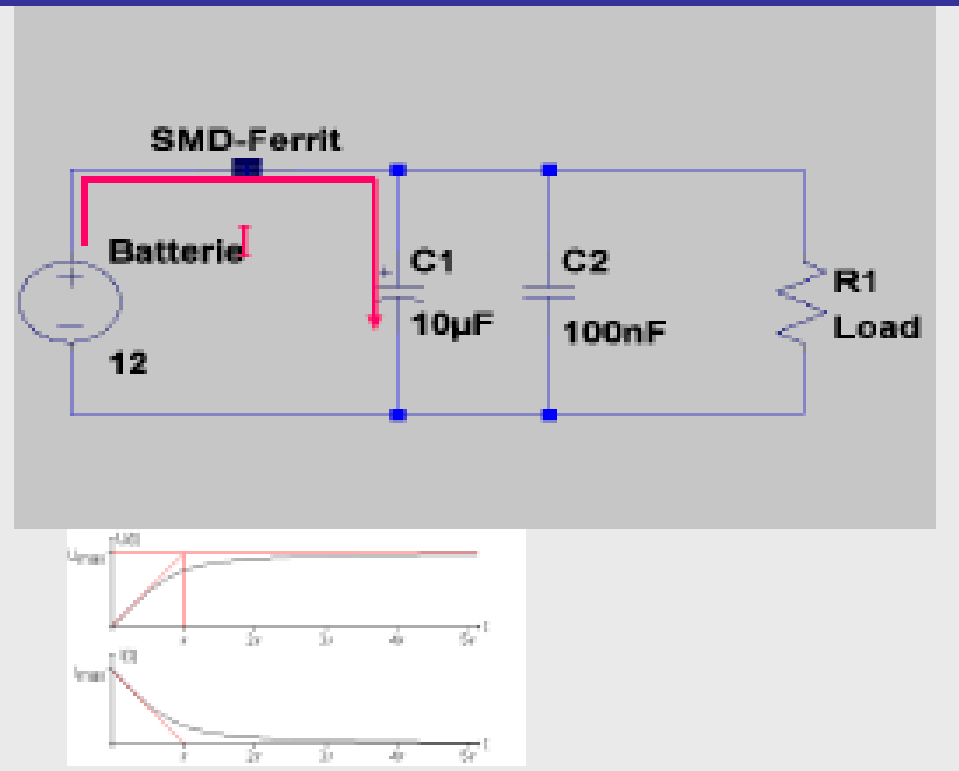
Via holes At Board level with Multilayer



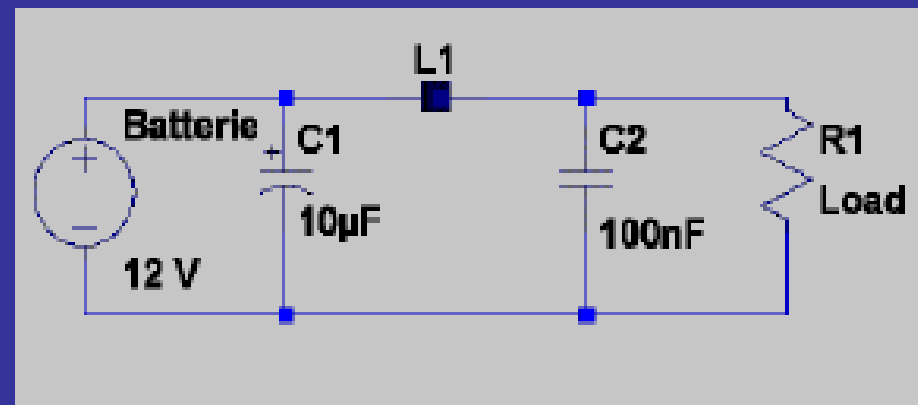
Impedance plot for Ceramic C,s



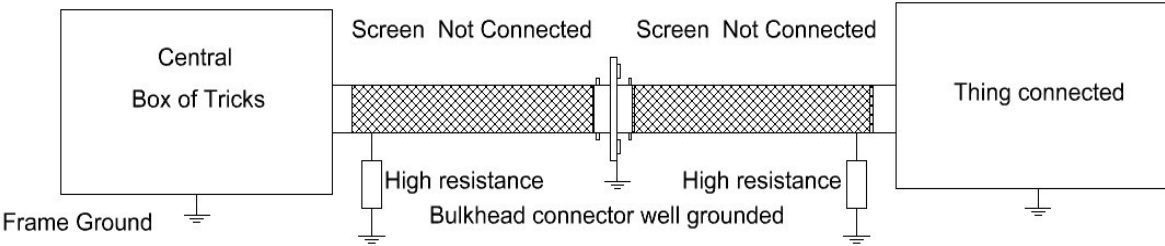
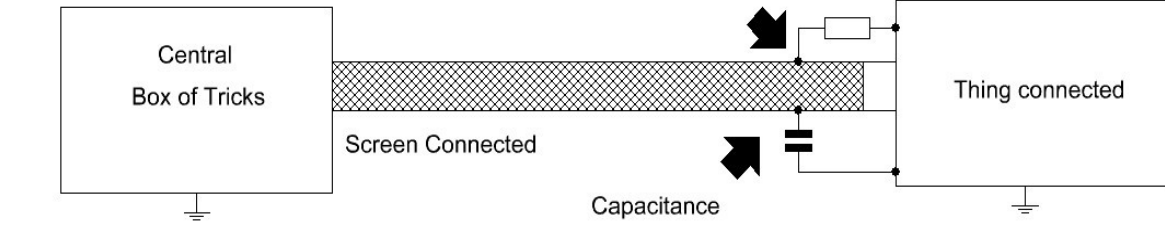
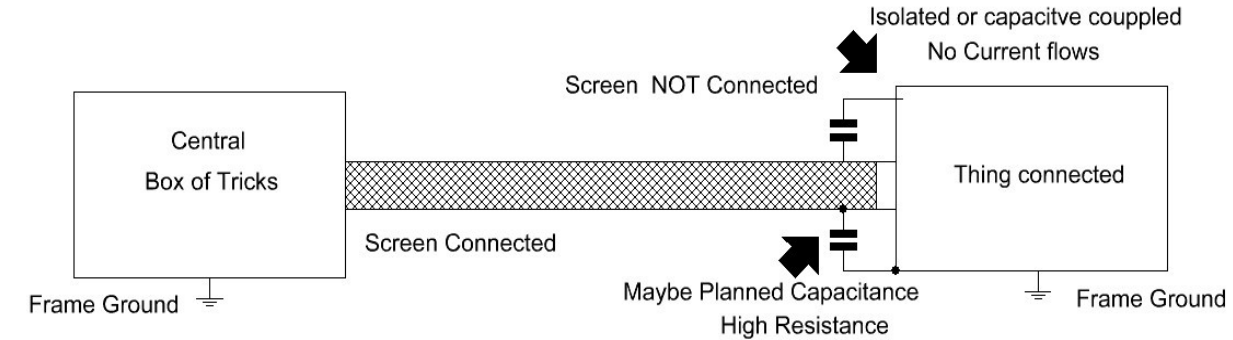
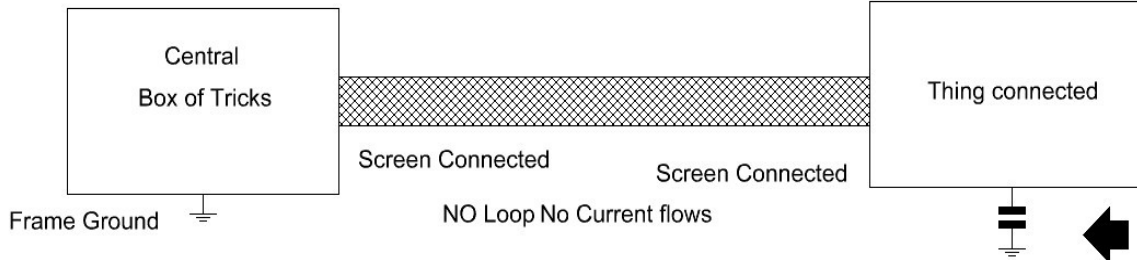
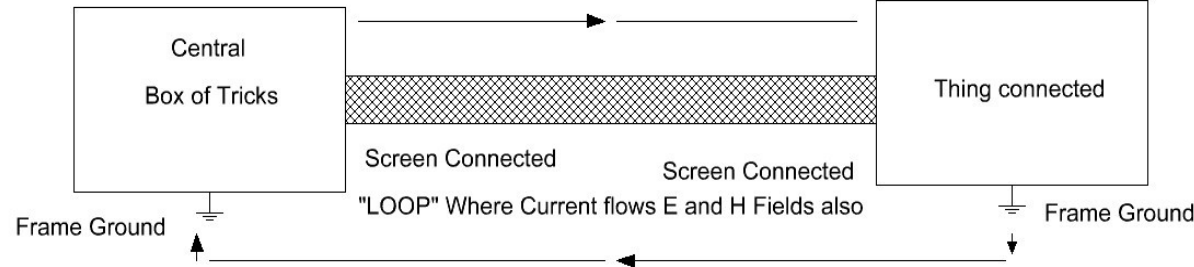
Typical design error



The Tank Capacitor is choked and is useless.



Correct way of using a choke



Methods of Isolating Avoiding Loops

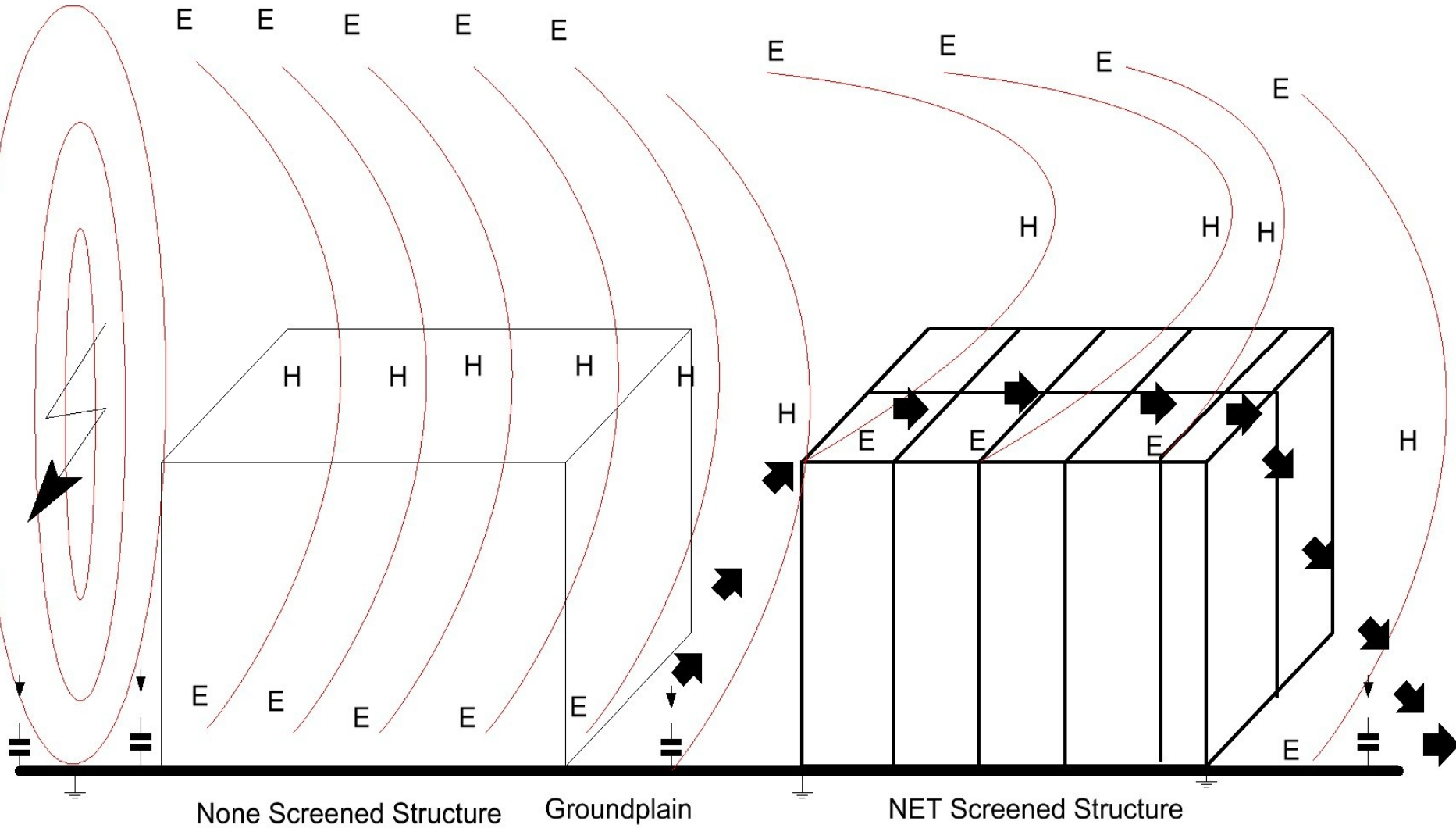
Where is ground ?

- The first test you should perform is to see if case and ground are connected, they should be isolated
- Only at the power supply may case ground and signal ground be connected
- Digital and analogue ground may be connected together in a unit if a filter is used as well as a tank Circuit.

First Level EMI Countermeasures Class A

H and E Field Follow the "Raised Ground Reference" 0

Spark



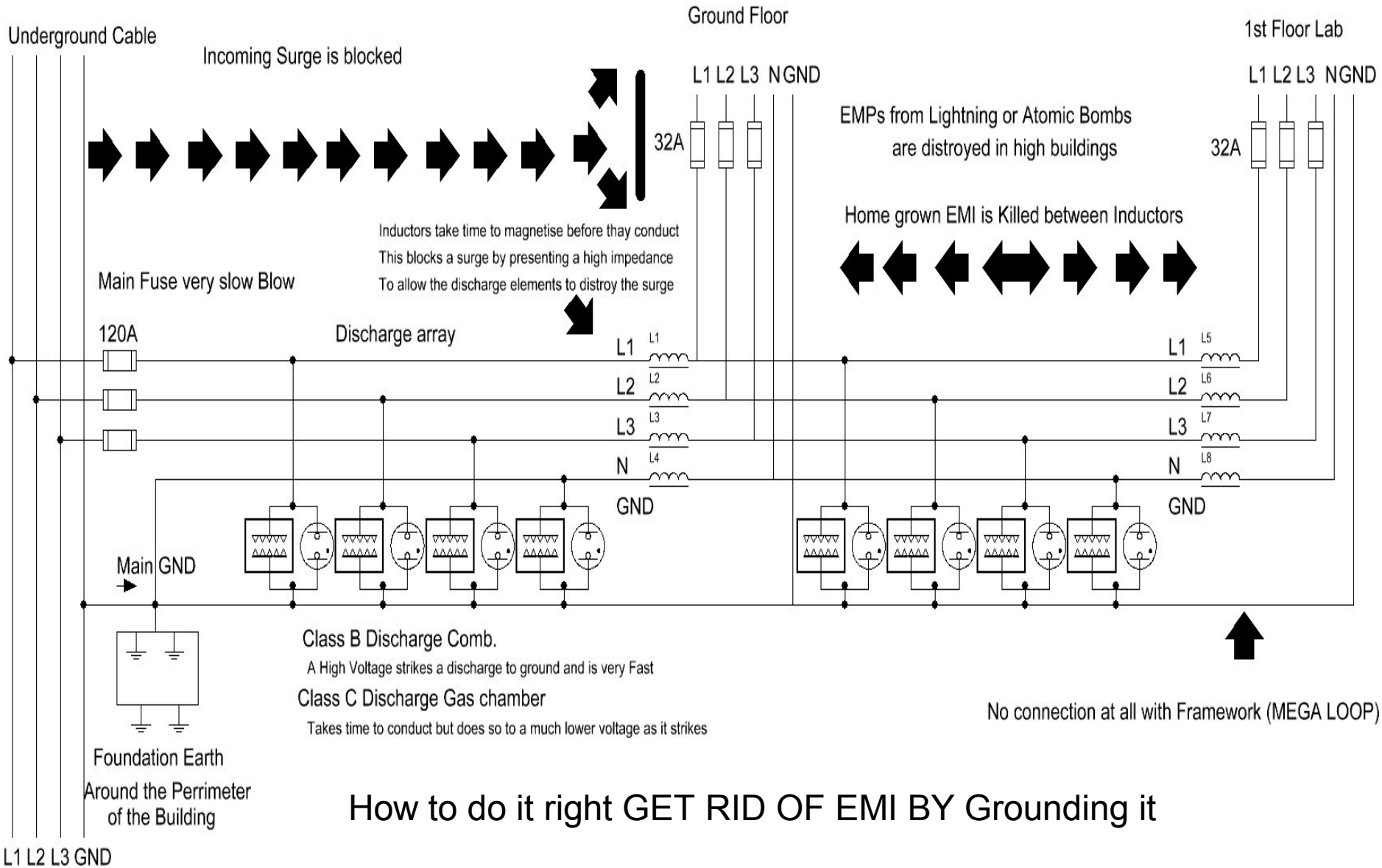
None Screened Structure

Groundplane

NET Screened Structure











How to do it right GET RID OF EMI BY Grounding it

Q4

Discharge units

<p>hager SPN 015 Type 2/8/C 230 V~ (50/60Hz) Imax : 40 kA In : 20 kA Up ≤ 1,25 kV Uc : 275 V~</p>	<p>hager SPN 015 Type 2/8/C 230 V~ (50/60Hz) Imax : 40 kA In : 20 kA Up ≤ 1,25 kV Uc : 275 V~</p>	<p>hager SPN 015 Type 2/8/C 230 V~ (50/60Hz) Imax : 40 kA In : 20 kA Up ≤ 1,25 kV Uc : 275 V~</p>	<p>hager SPN 015 Type 2/8/C 230 V~ (50/60Hz) Imax : 40 kA In : 20 kA Up ≤ 1,25 kV Uc : 275 V~</p>	<p>hager SP 937 Ln : 500 V~ In : 63 A / 40°C Ln : 15 µH Rgd : 2 mΩ</p> <p> N</p>
L1	L2	L3	N	

Coils

<p>hager SP 937 Ln : 500 V~ In : 63 A / 40°C Ln : 15 µH Rgd : 2 mΩ</p> <p> L1</p>	<p>hager SP 937 Ln : 500 V~ In : 63 A / 40°C Ln : 15 µH Rgd : 2 mΩ</p> <p> L2</p>	<p>hager SP 937 Ln : 500 V~ In : 63 A / 40°C Ln : 15 µH Rgd : 2 mΩ</p> <p> L3</p>
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Why was such technology
developed ?

Its good technology but why was
money for such development
made available ?



Soviet EMP Weapons Germany was the first target of the third world War
This is why Germany is the only country in Europe with Class A B and C
Discharge safety circuits in general use , they work also against lightning



And if you get Frightened here the Engineers solution for EMI Electro Smog free living , inside the attenuation screening is 240dB

So what has this got to do with Aircraft and Railway trains and cars

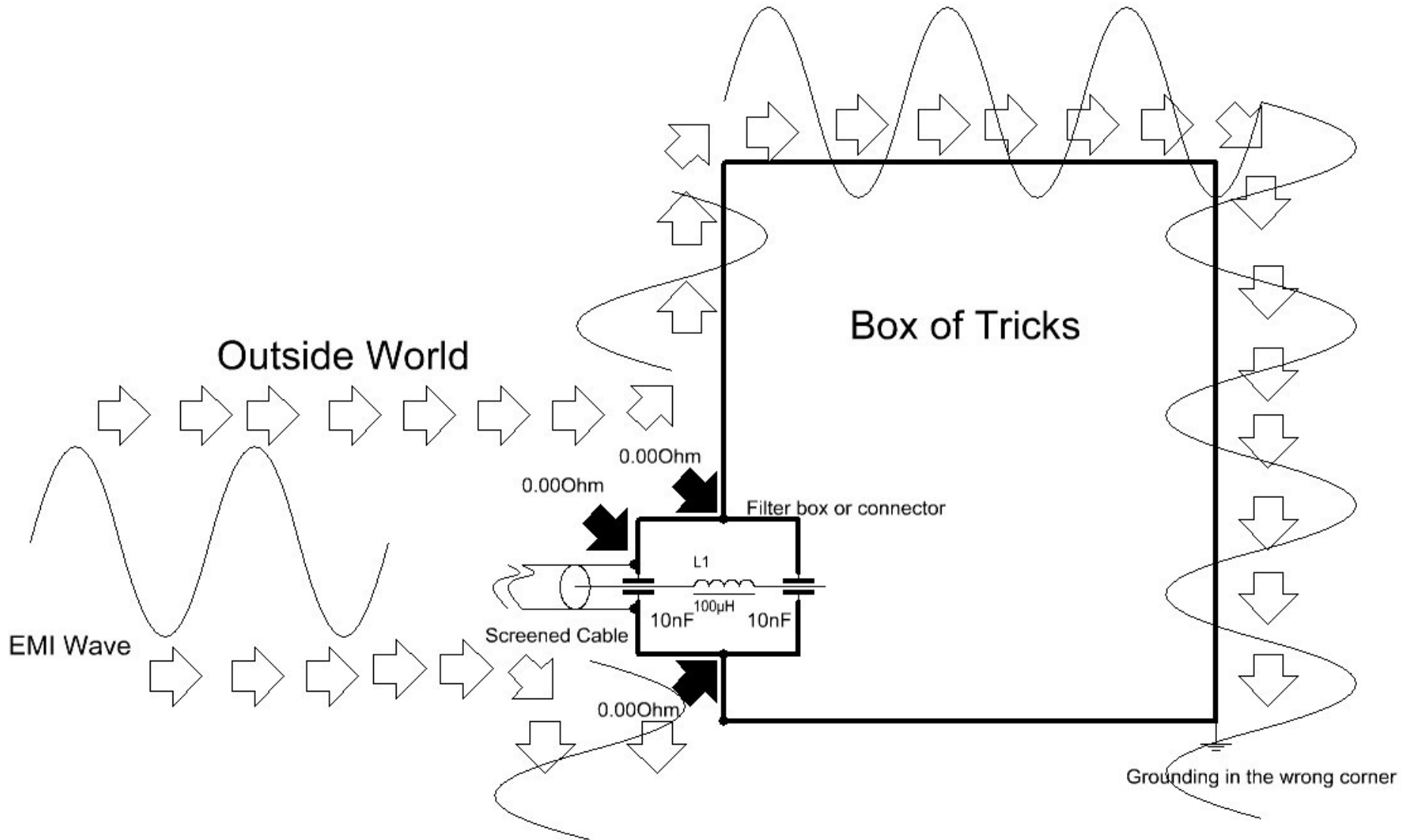
- The goal is Electro magnetic disturbance reduction up to removal of it completely.
- This allows a modern world to work faster higher baud speeds, safer systems, less errors and all that.
- It's a combination of everything and the understanding of physics that count.

But what about EMI in a cabinet

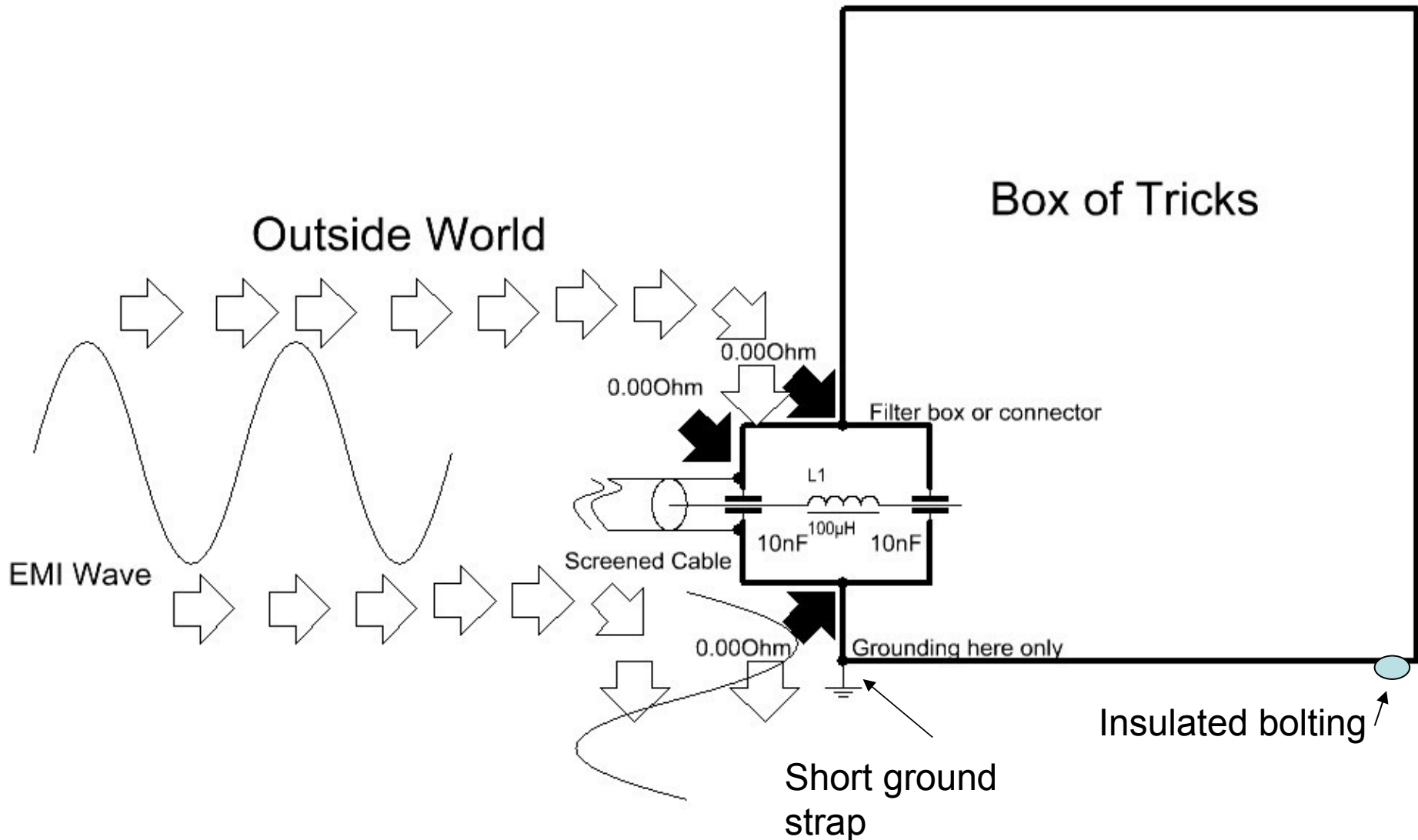
What are the problems here ?

- EMI Coming from Outside
- EMI from internal Harnessing
- EMI from Internal units
- EMI on a circuit board level.

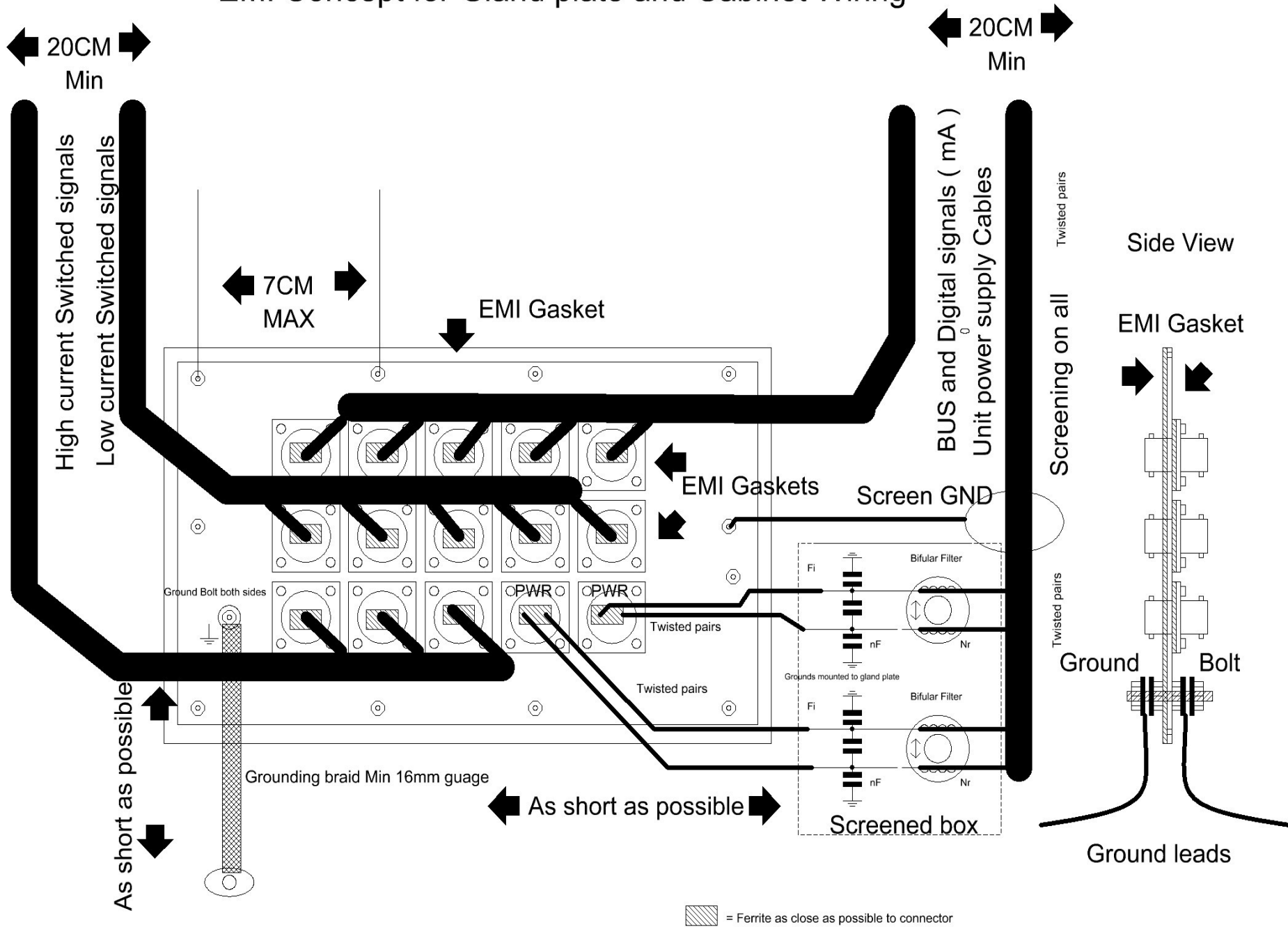
The wrong way to do it



The right way to do it !

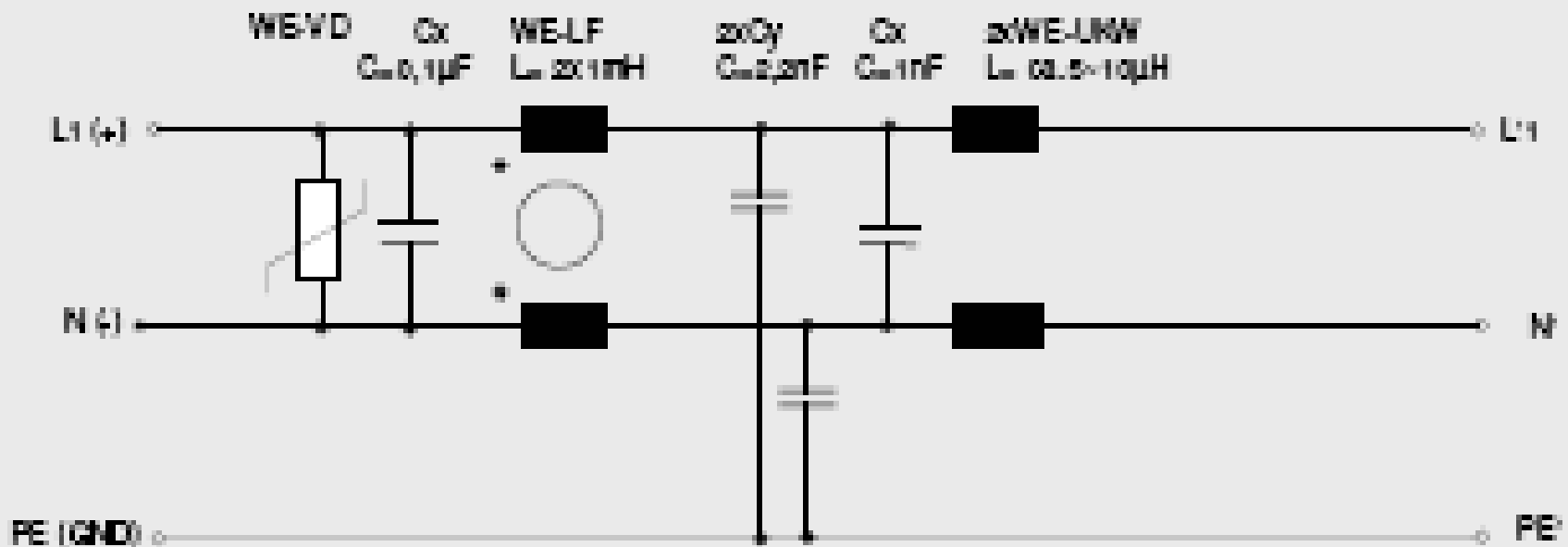


EMI Concept for Gland plate and Cabinet Wiring

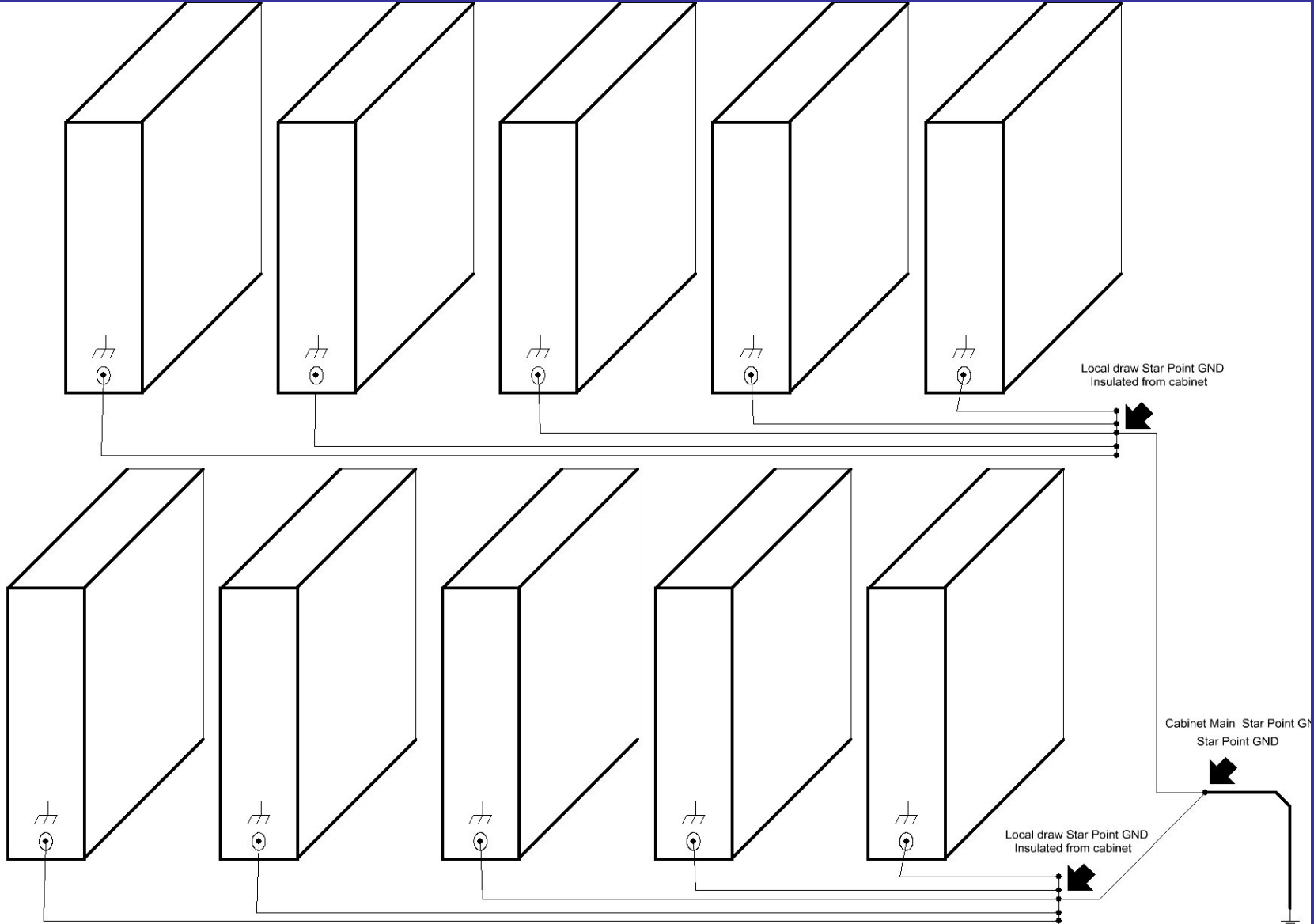


= Ferrite as close as possible to connector

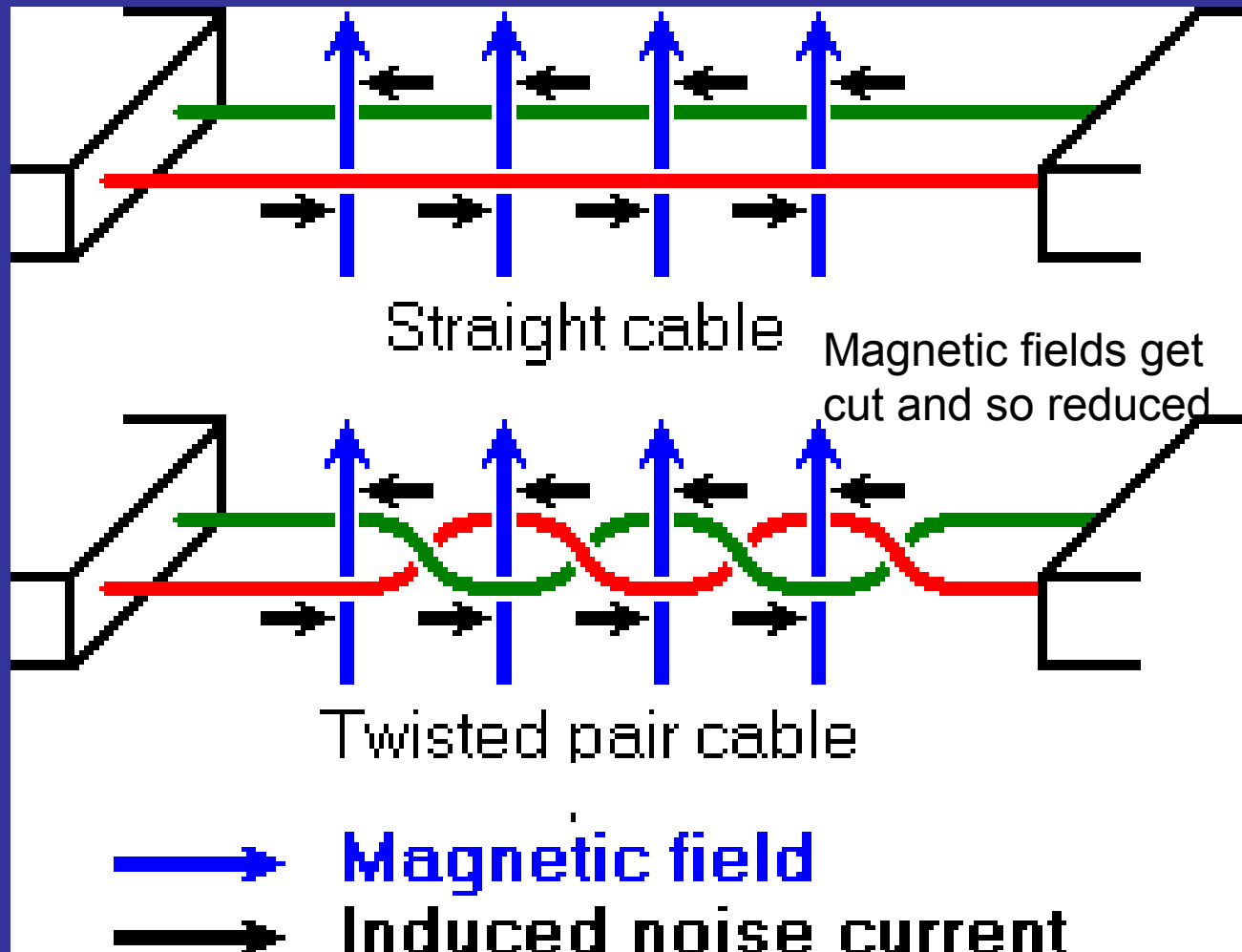
Use of Line Filter to Kill Galvanic EMI



The Star Grounding Principle



Parallel line / Twisted pair



The higher the number of twists per meter the higher is the data speed that you may transmit !
Also the smaller is the EMI Field or the susceptibility of your signal

Here a braid only cable has been opened , you can see the wires are roped instead of twisted in pairs ,

UKS
ENGINEERING

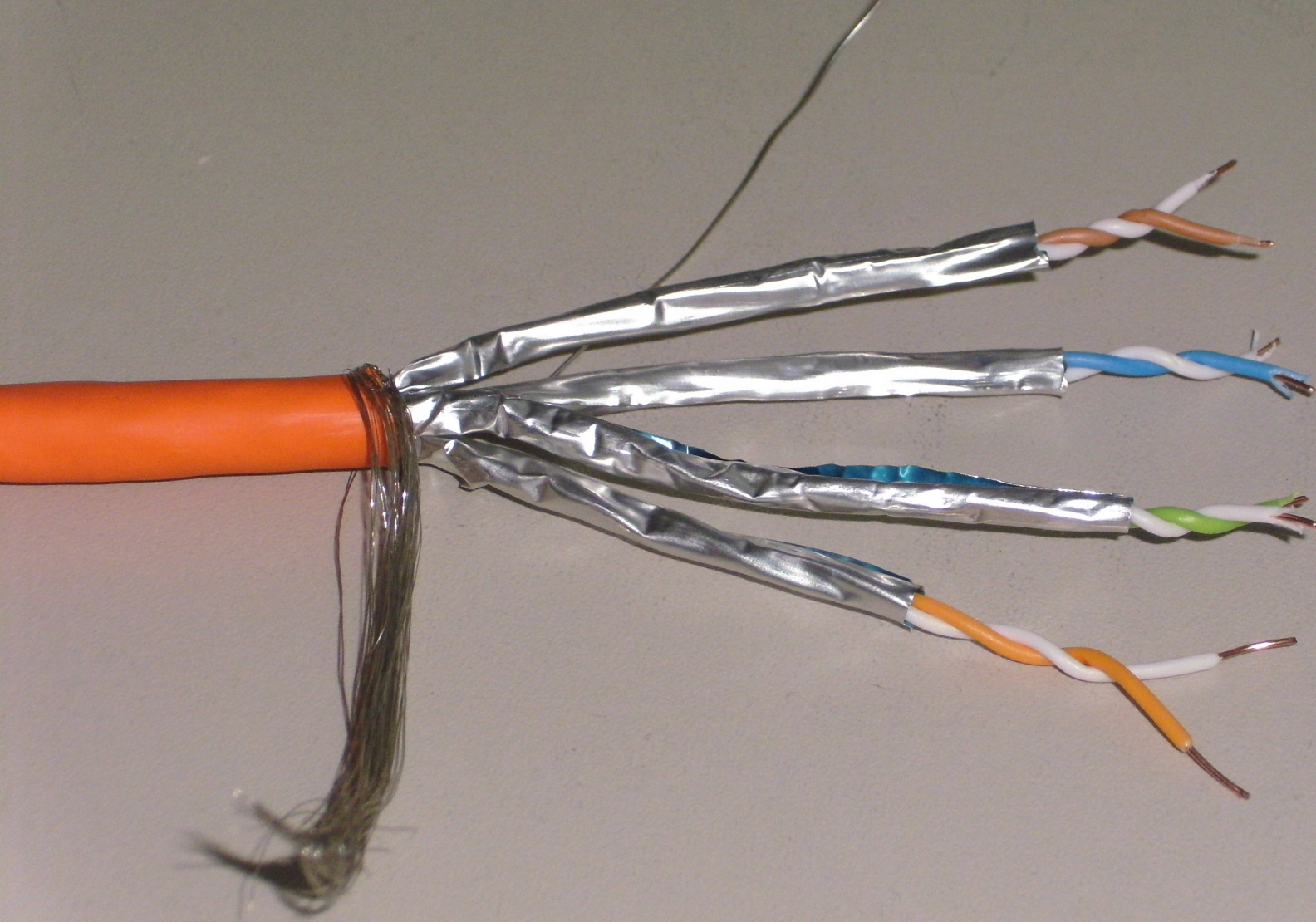
Serial: _____

Date: _____

Name: _____



Cat 7 Cable is tight twisted pairs individually screened with foil with a total screen braid and a PVC Mantel , Aluminium oxidizes copper is better



What is dB or dBm

- dB (Decibel) is a logarithmic value without a reference, +dB –dB this maybe used to express for instance the screening factor of a cabinet -40dB or the gain of an amplifier +12dB.
- dBm is linked to a defined power level the Miliwatt !
 $0\text{dBm} = 1\text{mW}$, $+10\text{dBm} = 10\text{mW}$
 $-10\text{mW} = 100\mu\text{W}$, $+40\text{dBm} = 10\text{W}$

A Few Definitions of Signal levels

- A level of -20 to -30 dBm is considered a healthy level of EMI where electronics function perfectly , a level of -30dBm($1\mu\text{W}$) is the target. Better than -20dBm is however the limit .and that's $10\mu\text{Watt}$
- If your electronics is living in a box at a higher level you are in trouble!

EMI Levels the Crossroads

- The EMI Counter measures you select are dependant on the maximum level in “REALITY” that the electronics will ever expect, If you go cheap here you will never get out of trouble because you will probably not be able to upgrade.
- What is the level where you Choose light cheap or heavy EMI Countermeasures in your concept ?

Measuring signal level

- To measure Signal level you need an H Field probe as well as an E field probe and a Spectrum Analyser together with a connection coaxial cable with a fully closed screen. At best everything in SMA !
- By using a Bulkhead SMA Connector its possible to drill a 6mm hole into any enclosure and so insert correctly a probe into the case , the connector must have a perfect connection to the case.

- The signal level is the **Signal Level**
 - *frequency span monitored as **Disturbance**
 - *Filter bandwidth of the **Analyser**
 - *Boltzmann's **Constant**

This value is the total power of your EMI
Noise floor .

Hi or Low level Concept

- If you have a signal level of higher than 1 W then you need good stuff like Beryllium copper finger material , boxed and grounded filters , maybe a combination off filters to hammer down a wider spectrum of EMI noise.
- If you are under 1W you can use the simple stuff like metal textile band EMI Gaskets, and ferrites

That's the simple rule of thumb



TEM Cell Testing of something Big ,
If the profit does not come to the mountain bring the mountain to the profit



This happen in real “Fully Fuelled”

And you thought your job was
Dangerous because you have to
wear an Orange Warning vest

NASA STS8

EMC Tests using a wide band horn



EMI is not a problem

Its Sound engineering from good engineers who understand to a full the Physics behind the problem.
Its as simple as that

The END