Engineering EMC

Definition
Standards
Some Examples
from: "Beheers uw stromen door verbreding van uw blik"

Environmental Competence Centre

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THALES

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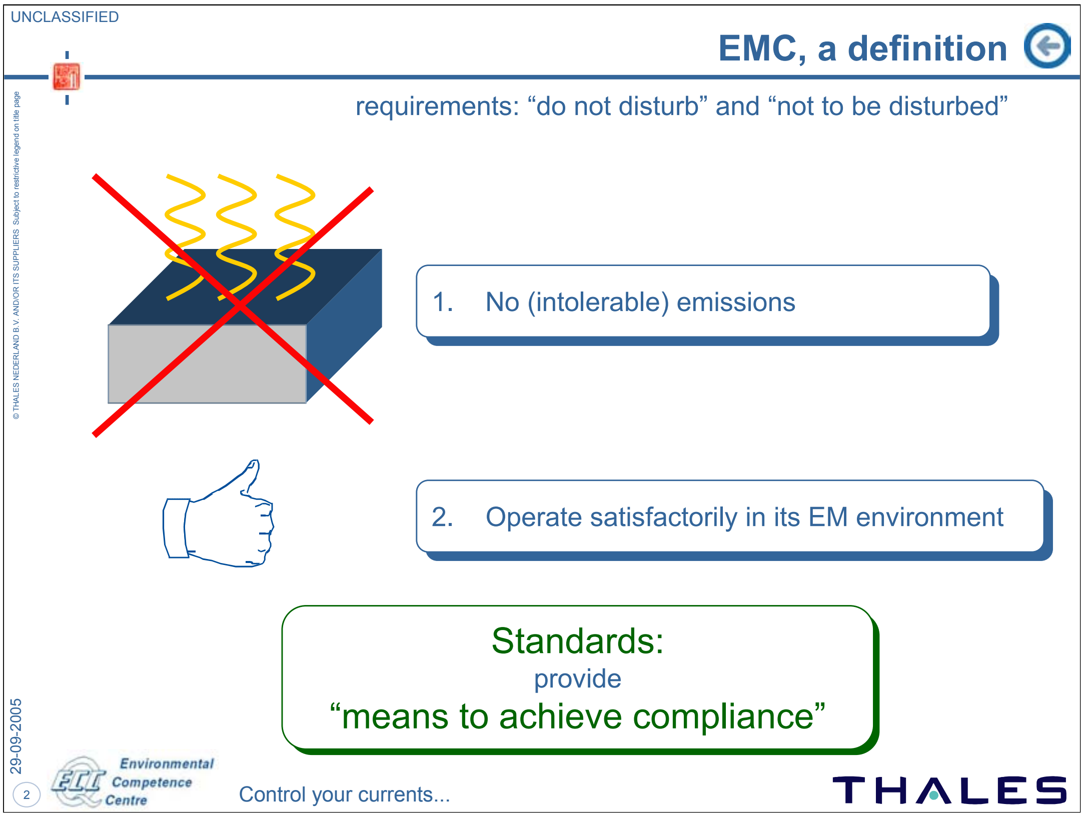


Recent technological developments have made electronics faster. Lay-outs and wiring schemes that could be used before no longer work and give rise to (unwanted) interference. The latter interference not only occurs between separated systems but also within a system between subassemblies or even components. The effects vary from reduced immunity to total loss of function. For this reason **“Electromagnetic Compatibility (EMC)”** [the ability to cooperate undisturbed] is a mandatory subject for anyone considering “electricity” or -rather- “electromagnetic phenomena” as his means to earn a living.

The boundaries between the profession called “EMC” and disciplines as analog or digital design are vague. As a criterion, we could consider EMC to cover those phenomena which are ignored but can no longer be disregarded. This means that the profession is “on the move”: as soon as everybody is aware of a certain aspect, the focus can be shifted to different topics.

The new council directive on the approximation of the laws of the Member States relating to electromagnetic compatibility of the European Economic Community (2004/108/EC) defines the essential requirements (Annex 1):

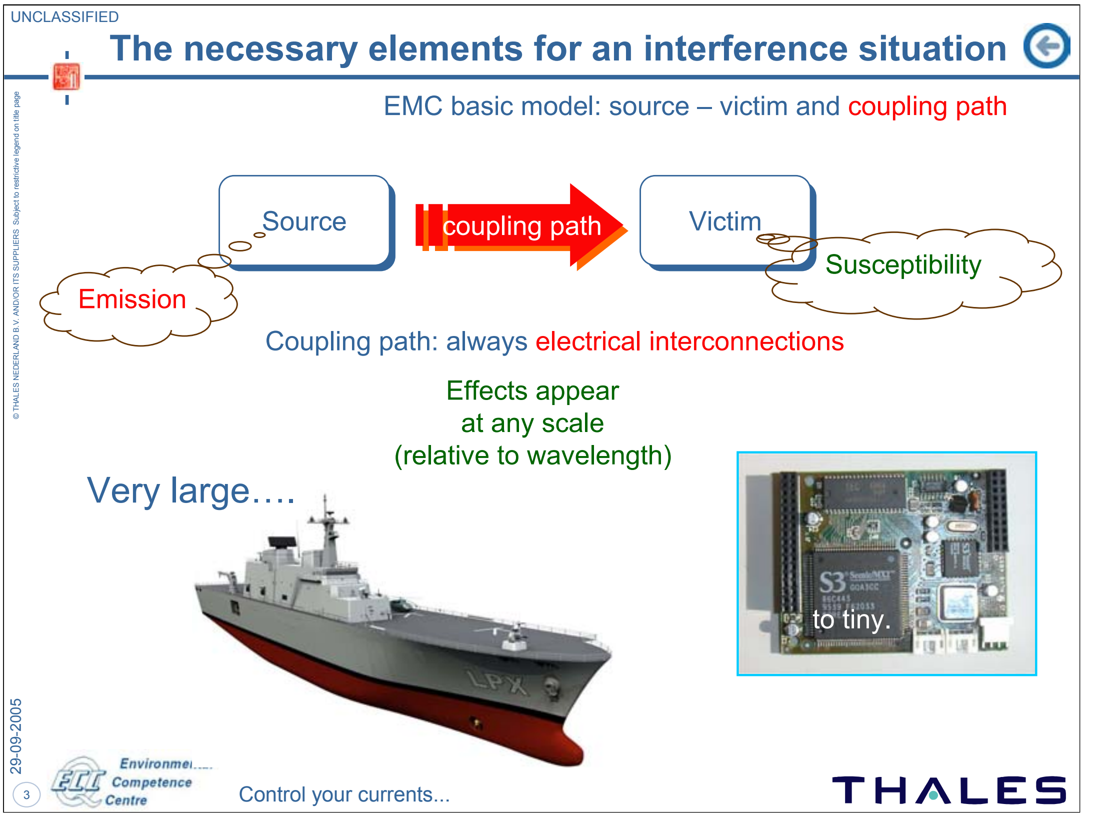
Equipment shall be so designed and manufactured having regard to the state of the art, as to ensure that:

“the electromagnetic disturbance it generates does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended”

and

“it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use”

This EC directive (with the associated CE marking) is not interested in the “quality” of the “apparatus” i.e. whether it is “useful”. This general approach also applies to military equipment although the levels and the way to determine these are different.



At the top of the sheet above a basic model is shown for any interference situation:

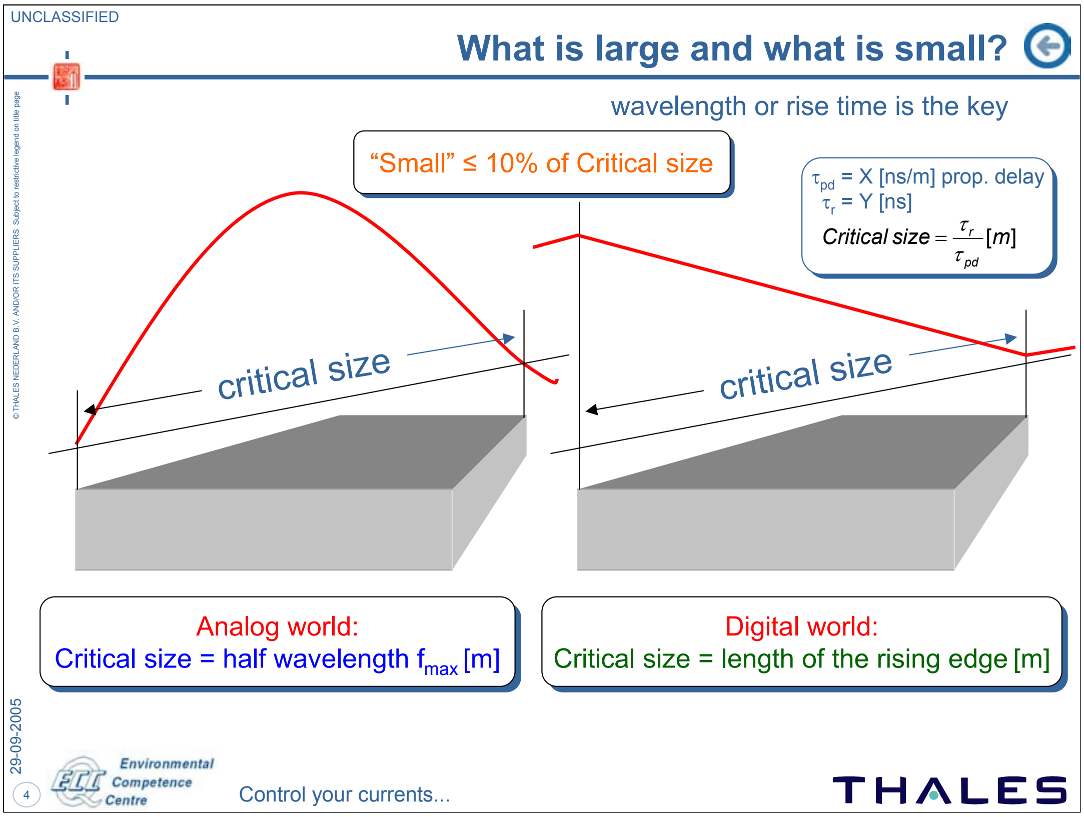
1. A source of interference
   e.g. A public radio transmitter, a switched mode power supply, a frequency controlled motor, a GSM telephone, lightning
2. A susceptible device (victim)
   e.g. a radio receiver, a pacemaker, an electric wheelchair (could be source too!), generally: low level analog circuitry
   note: "Susceptibility" is the military term, "immunity" is used in civil standards.
3. A coupling path
   e.g. The "air" i.e. electromagnetic fields emerging from interconnections, or conductors themselves. Always one or more electrical interconnections (cables) are involved at both ends!

Assuming that the source and the susceptible device are essential to some required function, the coupling path is left to be modified by the EMC engineer in order to mitigate the interference problem.

The basic form above can exist at various levels between:

- Systems
- Sub-systems or cabinets within a system
- Printed Circuit Boards
- Components

It will be shown and demonstrated during this workshop that the interconnections between devices are -always- part of the various coupling paths. Either as direct conductors for an interfering current or as antennae that convert currents into electromagnetic fields or fields back into currents.



The distinction between large and small can be made once the maximum frequency used in the system (or in the environment!) is known. For the analog situation, one half wavelength is considered a critical distance or size. beyond this distance, the signal has an opposite phase with respect to the situation nearby. At that point transmission line effects as propagation delay and reflection begin to seriously affect the performance of interconnections and measures to prevent those effects are necessary.

A similar effect occurs in digital systems. But the highest frequency is usually not known directly. Therefore we take a different approach to determine the critical size. For digital signals, the propagation delay τ_{pd} in [ns/m] in an interconnection is usually known. This is the inverse of the speed at which a transition moves over the line. The digital signal also has a rise time τ_r (or fall time τ_f: take the fastest for this analysis). The ratio of rise time versus propagation delay is the critical length.

A system that is small with respect to the critical size (or critical length in some texts) is preferable because it can be built with the least amount of extra measures. In the module "EMC measures" the current boundary is introduced. This provision can be used to separate a large system (with respect to the critical size) into smaller compartments which each are "small".

Example “Emission”

possible interference on radio communication

Issue: keep equipment noise below the limit line

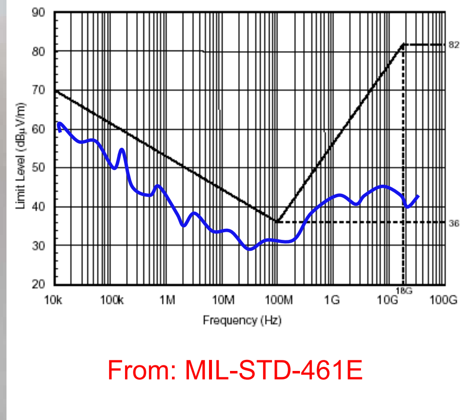
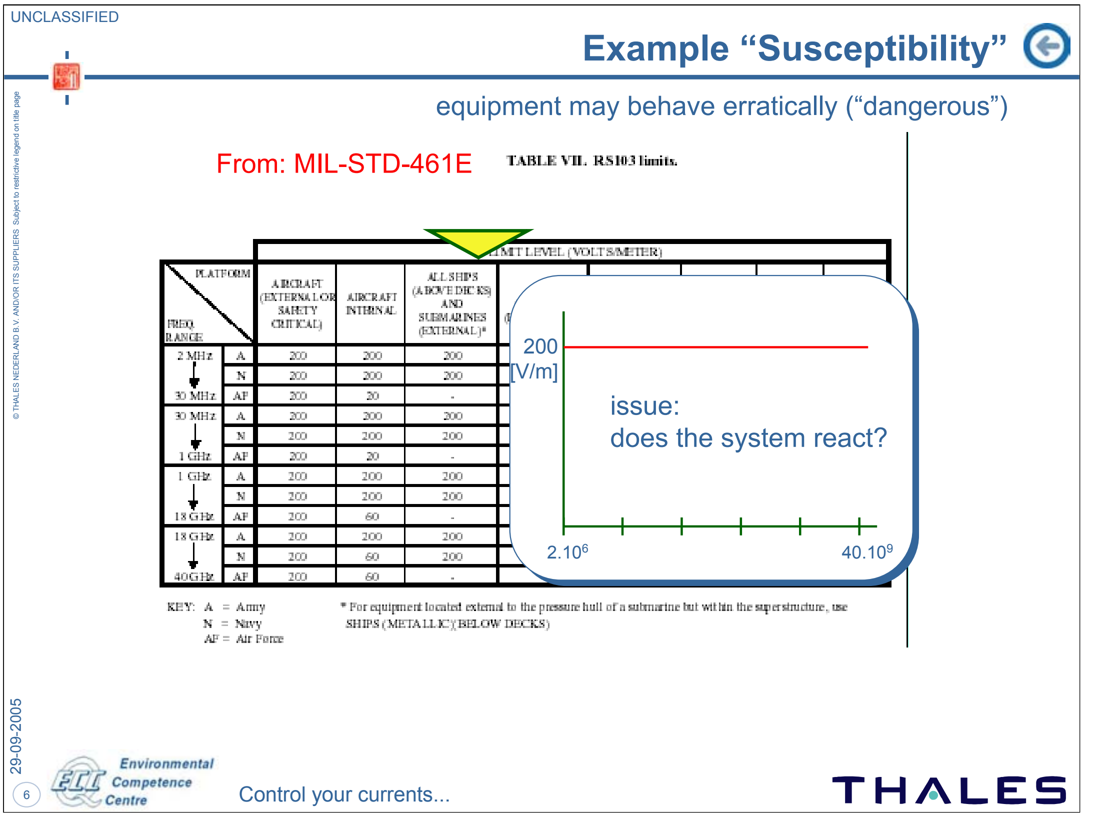


FIGURE RE102-1. RE102 limit for surface ship applications.

Why do we need regulations and standards? To keep “culprits” and “victims” separated reliably. It is not feasible to solve interference on a case by case basis. Standards set limits to emissions and define what level of susceptibility is reasonable. In this way equipment can be individually tested. Of course, differences in environment do exist. That means there are different limits and sometimes even different test procedures for domestic and industrial environments. Military equipment is usually exposed to more severe conditions during operation. Therefore the requirements for these systems are usually even tougher.

There are separate limits for emission and for susceptibility (immunity). The reason for this is the fact that emission limits are aimed at avoiding interference in telecommunications equipment (sensitive radio receivers etc.) while the susceptibility level is set according to the maximum threat expected to occur from e.g. transmitters (public service, mobile telephone, short wave communication etc.).



FREQ. RANGE / PLATFORM		AIRCRAFT (EXTERNAL OR SAFETY CRITICAL)	AIRCRAFT INTERNAL	ALL SHIPS (ABOVE DECKS) AND SUBMARINES (EXTERNAL)*
2 MHz – 30 MHz	A	200	200	200
	N	200	200	200
	AF	200	20	-
30 MHz – 1 GHz	A	200	200	200
	N	200	200	200
	AF	200	20	-
1 GHz – 18 GHz	A	200	200	200
	N	200	200	200
	AF	200	60	-
18 GHz – 40 GHz	A	200	200	200
	N	200	60	200
	AF	200	60	-

As the actual frequency of these external threats during the lifecycle of the equipment cannot be determined beforehand, the immunity (or susceptibility) should span the whole possible frequency range. A different issue is **margin**. A margin indicates the existing difference between the required level and the actual performance. Since the emission level can be actually measured, the emission margin can be established easily. This is not the case for susceptibility/immunity. To find out how much margin exists here, it would be necessary to generate an amount of interference which actually would cause the equipment to show degradation. This usually is not done.

note 1: a common mistake is to consider the difference between emission and susceptibility levels as "margin". Knowing that margins are normally in the order of 6 to 10 dB this could give rise to huge mistakes!

note 2: The decibel (dB) is a logarithmic measure for the ratio of two values. For voltages and currents we calculate "$20.{}^{10}\log$ (ratio)"

EMI phenomena can also be subdivided according to coupling mechanism which yields the following four combinations:

1. Radiated Emissions, **RE**, (fields)
2. Conducted Emissions, **CE**, (currents)
3. Radiated Susceptibility, **RS**, (fields)
4. Conducted Susceptibility **CS** (currents)

An interference problem can usually be assigned to one of these four cases. Solutions require the coupling path to be discovered and its weakest link to be improved.

EMC Mechanisms

Resistance, Capacitance and Inductance
Behaviour of interconnections and cables

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Control your currents...

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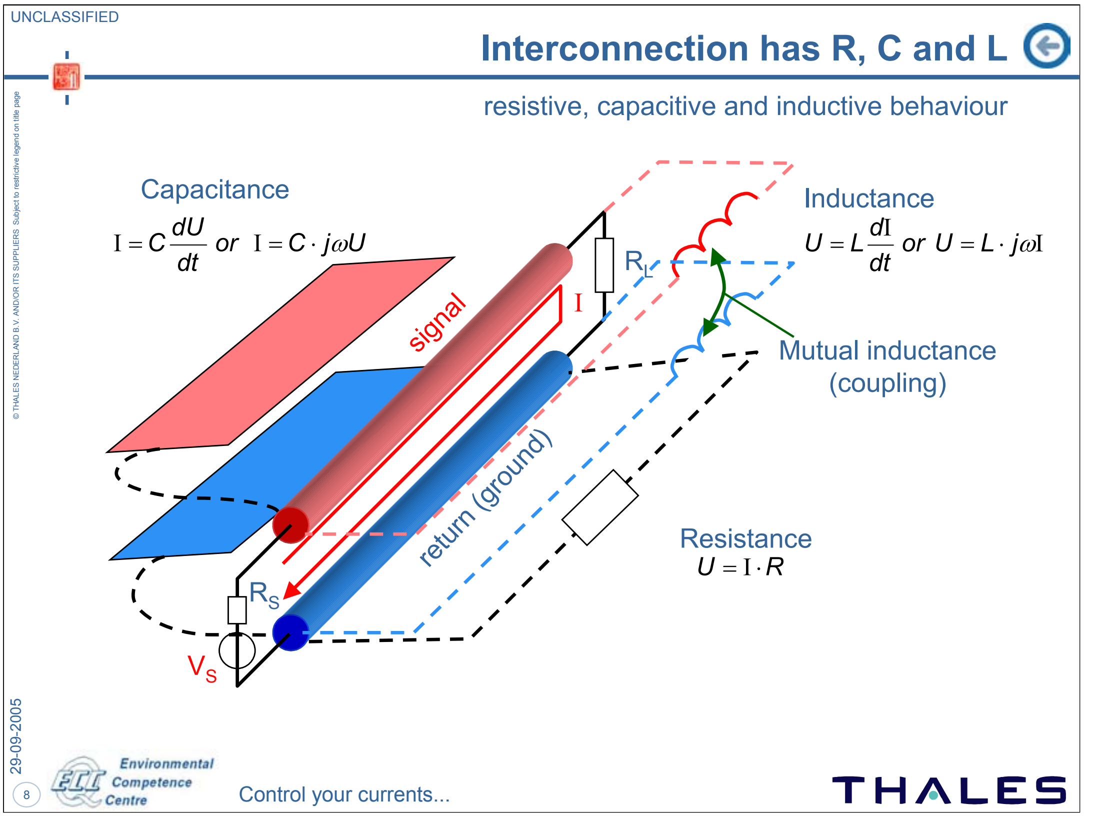


Interconnections determine the electromagnetic behaviour of our systems. Interference is generated or coupled into desired circuits by them. This behaviour can be described as impedance and manifests as:

1. Resistance. As soon as a current runs through a conductor, we can measure a voltage over some distance of the wire. The relation between current and voltage is linear and known as Ohm's Law.

2. Capacitance, which shows the effect of the electric field. For capacitance at least two conductors are necessary. The second conductor may be "the environment",

"the world". The only time we notice an effect of this capacitance is when the voltage of one of these conductors is changed with respect to the other (actually when electric charge is moved to or from the conductors). The higher the frequency of

this voltage change, the higher the resulting current. The relation between voltage and current for a capacitor linearly depends on the frequency. This is

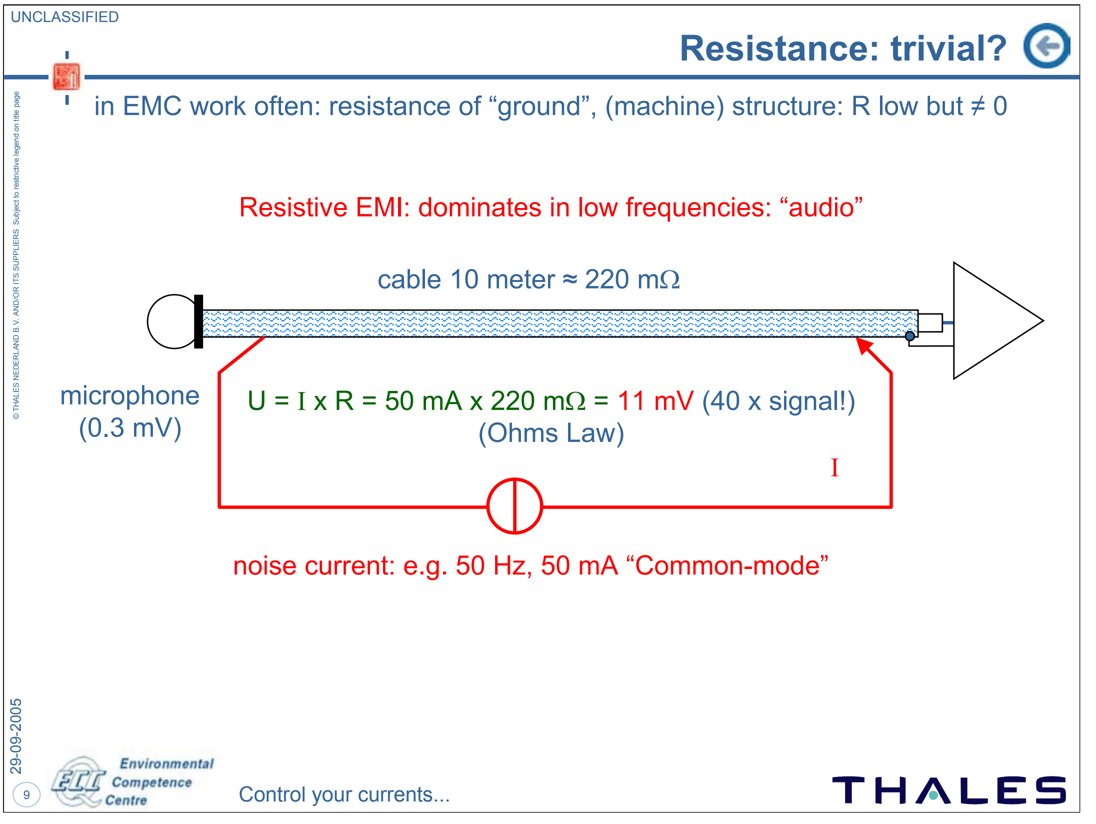
expressed in the formula by the factor "jω". ω is the angular frequency which relates to the frequency by a factor 2.π. The "j" is the complex operator, indicating

a 90° phase shift between current and voltage. Usually the phase of a signal is irrelevant for EMC purposes and can be disregarded. We are interested in the amplitude only.

3.(Self-)Inductance, showing the effect of the magnetic field. An inductance requires a closed current loop. Around this conductor a magnetic field develops.

This way a certain amount of magnetic flux appears within the loop. We could speak of the enclosed flux, or, the flux coupled to the loop. The flux lines are in themselves closed lines that circle the conductors and nowhere intersect with each other or with the conductor. The relation between current and voltage is, as for the capacitor, linearly dependent on the frequency. Current (i) and voltage (U) are exchanged

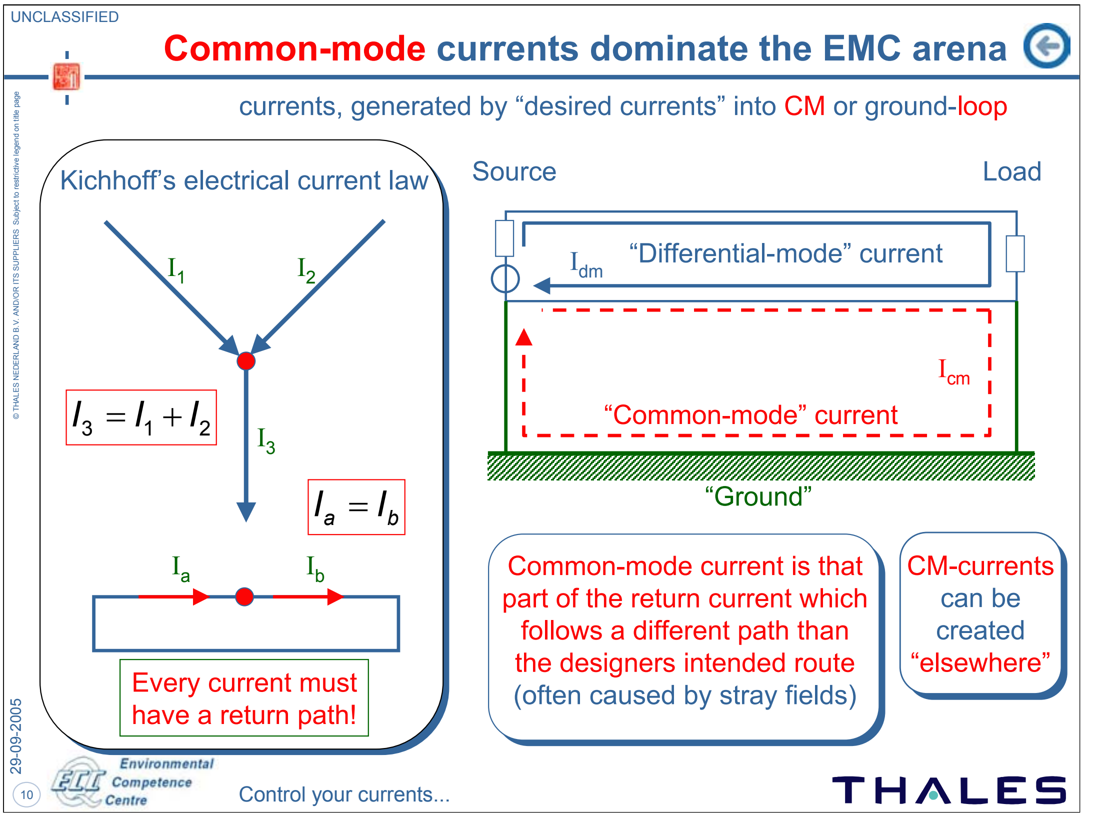
however in the formula. Inductance and Capacitance are thus shown to be complementary effects.



Above, an example of a “resistive” EMC effect is shown. It is an interconnection carrying a low level and low frequency analog signal: A microphone, delivering about 0.3 milli Volts of signal to an amplifier 10 meters removed. The assumption is that the cable screen has a DC resistance of 22 mΩ per meter, which gives the total cable screen a resistance of 220 mΩ.

If, for some reason a current flows over this screen e.g. some 50 Hz power current that happens to pass over this cable, the resulting voltage between beginning and end of the screen easily reaches levels much higher than the original intended signal.

This effect is well know in audio engineering. To avoid the effect the only option is to connect the screen to other ground conductors only at one point (single point grounding). The bottom line is that cable screens only start to work at higher frequencies, say, 10 to 20 kHz. Below those frequencies resistive effects dominate. Above them, inductive end capacitive effects gradually take over.



Kirchhoff’s electrical current law states that in each node in a network of conductors, the total amount of current flowing into the node must be zero. This is in agreement with the more general Maxwell’s law on the subject. The fact that this is valid for each node in a network implies that it is valid anywhere on a conductor. Nowhere we see a “charge build up”. When we extrapolate this, it is clear that each current anywhere in a network implies a return current.

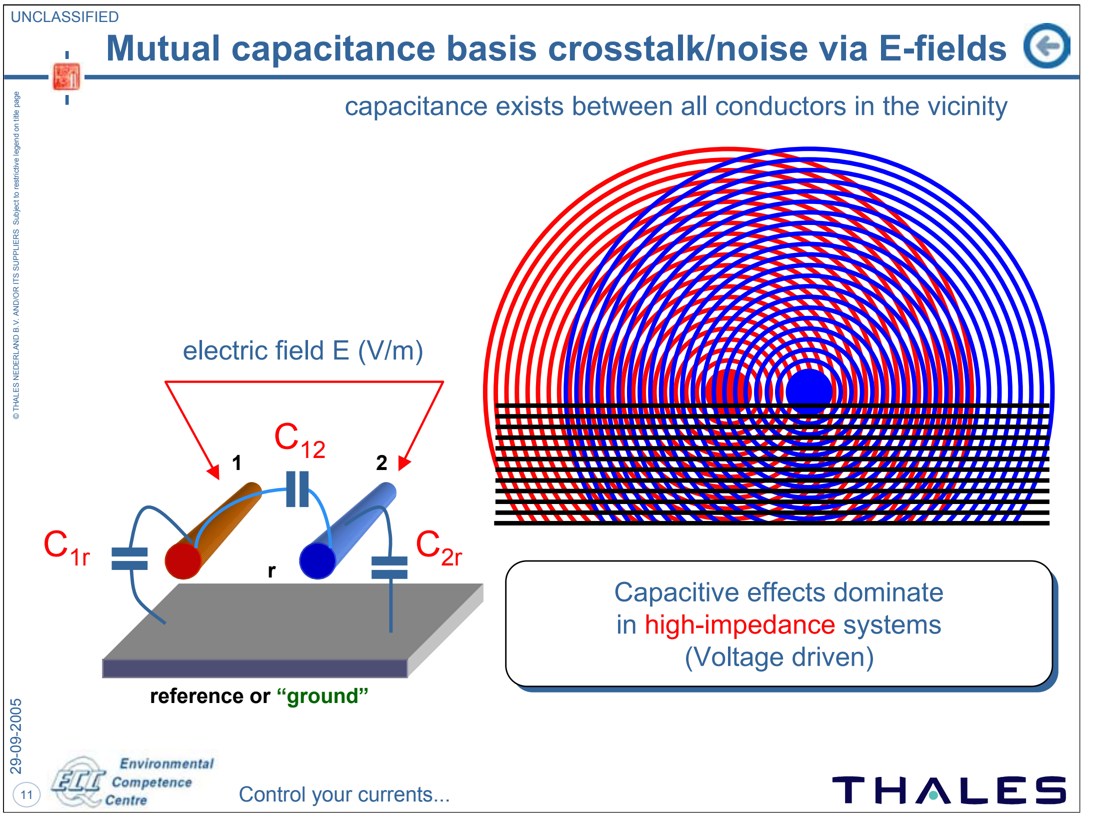
This is the primary reason for the presence of at least two conductors in any electrical circuit. If the current follows these two lines, intentionally created by the designer for this purpose, we will call this current a “differential mode” current: an equal current flowing in opposite directions in the two conductors.

Often, though, there are more paths for a return current than the return conductor conceived by the designer. There are usually other interconnections or connections to “ground” in a complete system.

Any current flowing in a different path than the intentional return conductor will not flow in the return conductor (Kirchhoff’s current law). Thus any current returning through ground or other conductors creates a net current in the original interconnection. This net current over an interconnection is called a “common-mode” current as it apparently travels over the two lines in the interconnection and finds a return elsewhere.

99% of al EMI problems are caused by common-mode currents!

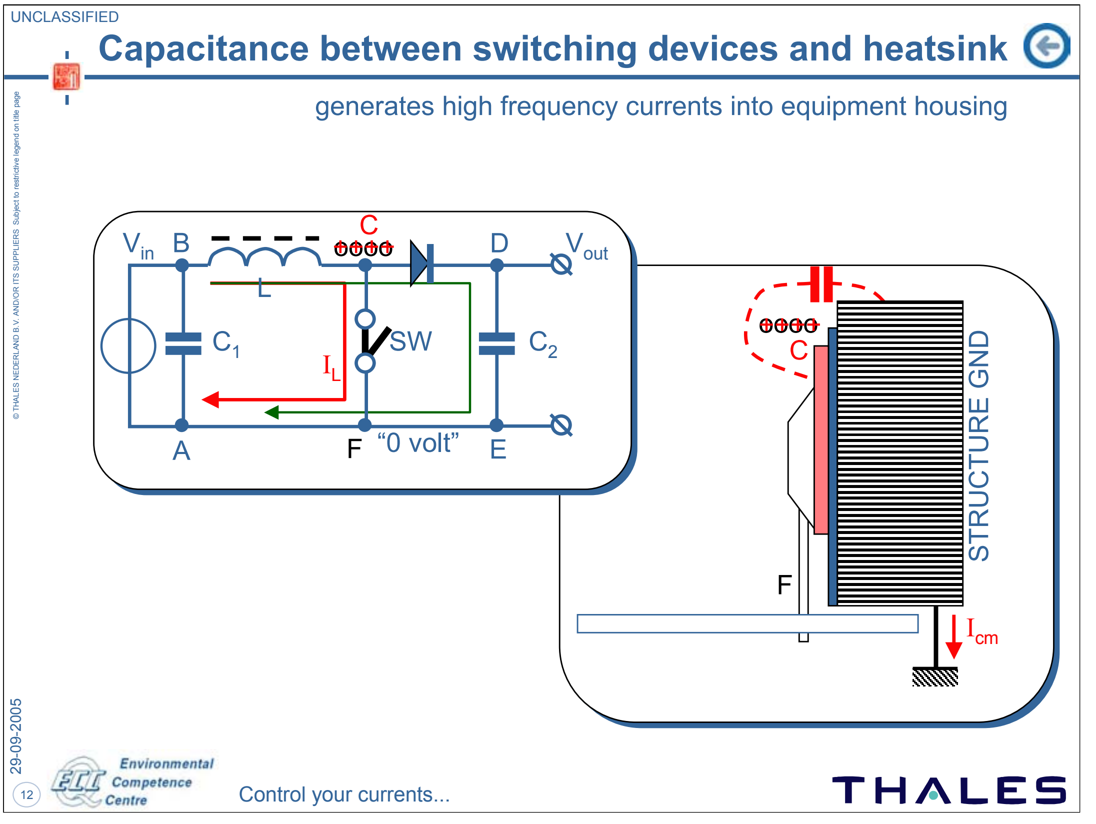
By the way, interconnections often create common-mode currents themselves. This also implies, that common-mode currents can be created elsewhere. These “noise” currents may in turn “enter” into the differential mode circuit of an interconnection. This is the mechanism for interference between cables in a system. It will be treated later under the label “Transfer-impedance”.



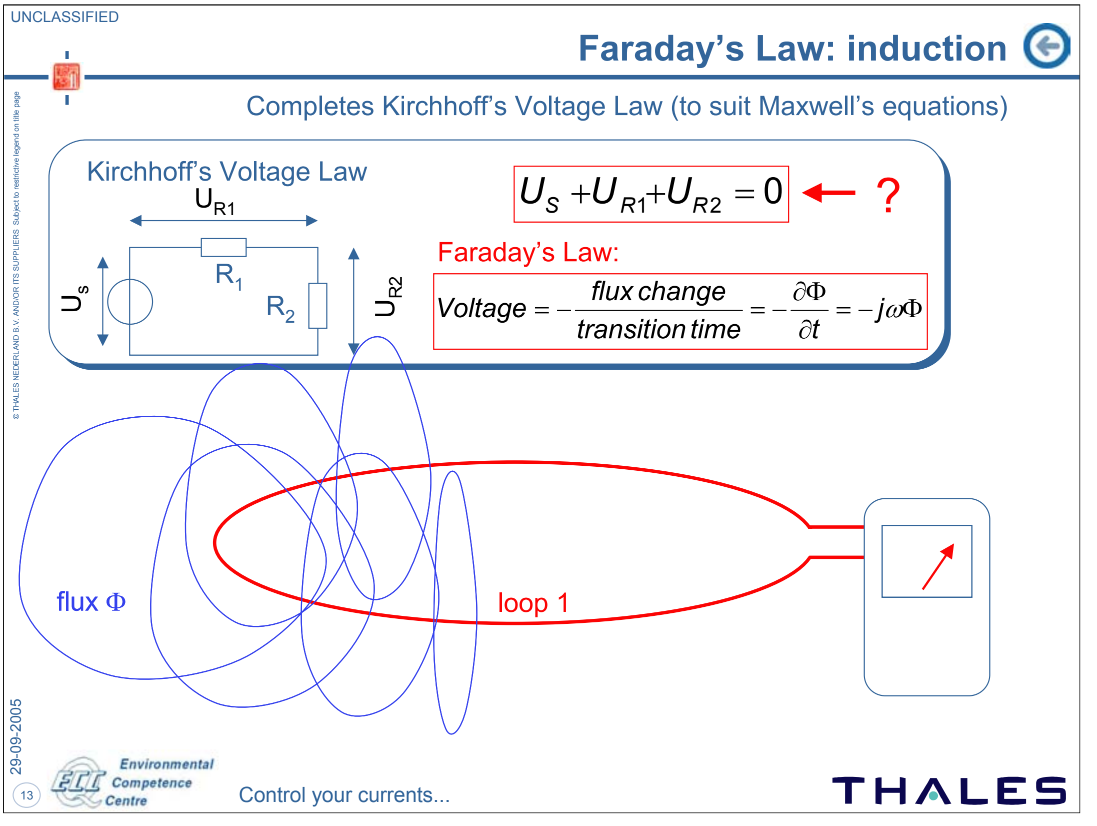
Between two conductors, an electric field indicates the presence of a voltage difference between them (and vice-versa). If the voltage level of one of the conductors changes e.g. with respect to a common reference or ground, the electric field "pulls" on the other conductor. Via other connections charge will flow to or from this second conductor to restore the natural balance (electric field – voltage).

The effect can be made visible by moving two sets of concentric circles within each other. The resulting "Moiré" effect shows the lines of electric force which start on one conductor and end on the other (at 90° angles). A set of parallel lines can mimic the effect of a nearby wide conducting plane.

Capacitance exists between all conductors in the vicinity. Possible capacitive crosstalk from conductor to the other can thus be modelled as the effect of a capacitive voltage divider.



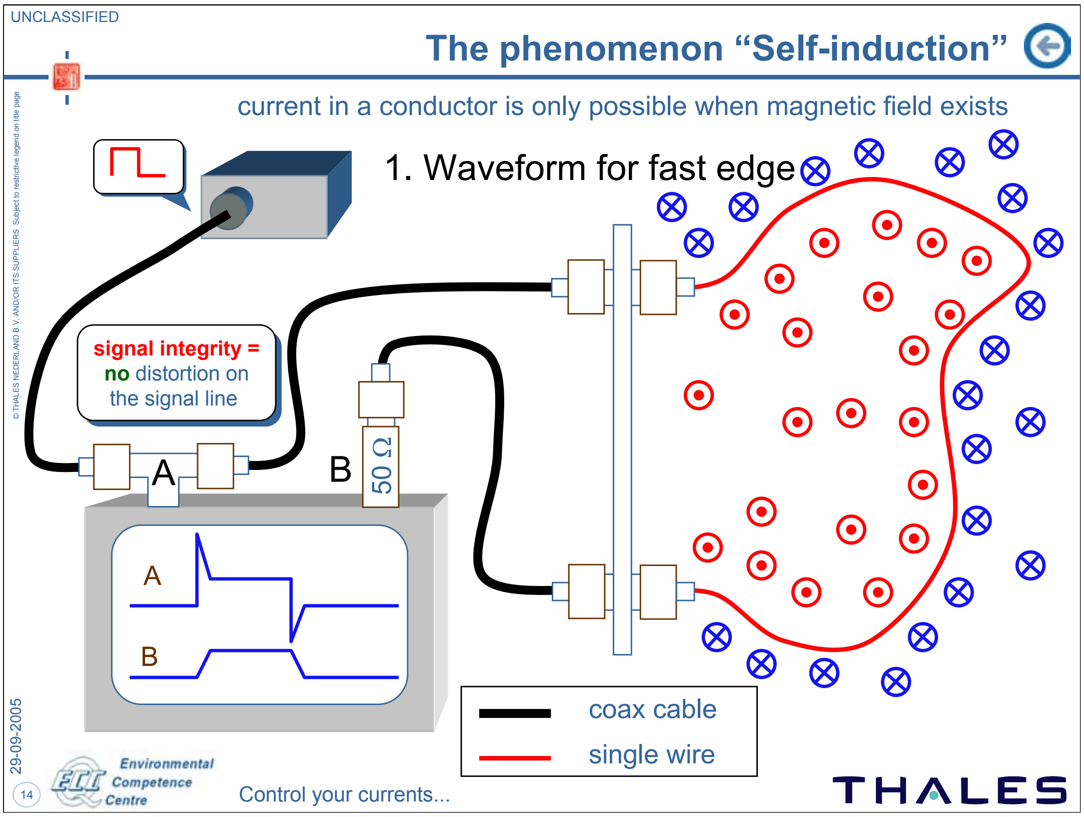
To clarify the fairly abstract demonstrations used until now, a practical example will be given. The diagram in the top left corner of the slide above shows a simplified schematic of a switched mode power supply. The collector (or drain) of the switching transistor (C) is at approximately the same voltage as the output, V_{out}, just before the "switch" is closed. Modern MOSFET switching devices are capable of switching speeds in the order of tens of nanoseconds. This means that point C in the schematic moves from V_{out} to zero in that time! If we mount the collector/drain tab of the transistor directly (with an insulating washer) to the heatsink or case, a capacitor is formed to that case. Due to the high speed large capacitive currents will flow to the heatsink/case.



Kirchhoff's voltage law is used extensively in network analysis and synthesis. It states that the sum of the voltages encountered in any loop in a network is zero. If everything went well, it was noted that this only was true for ideal components only: all fields would be stored inside capacitors and inductors and no fields would be generated by interconnections.

In the real world, however, fields outside the components do exist and create phenomena that cannot be explained by Kirchhoff's Voltage Law. When we look at Maxwell's equations, we can see that it is a simplification of the more general case, known as Faraday's law of induction. Faraday discovered that when the amount of magnetic flux in a loop is changed, a voltage is generated proportional to the rate of change.

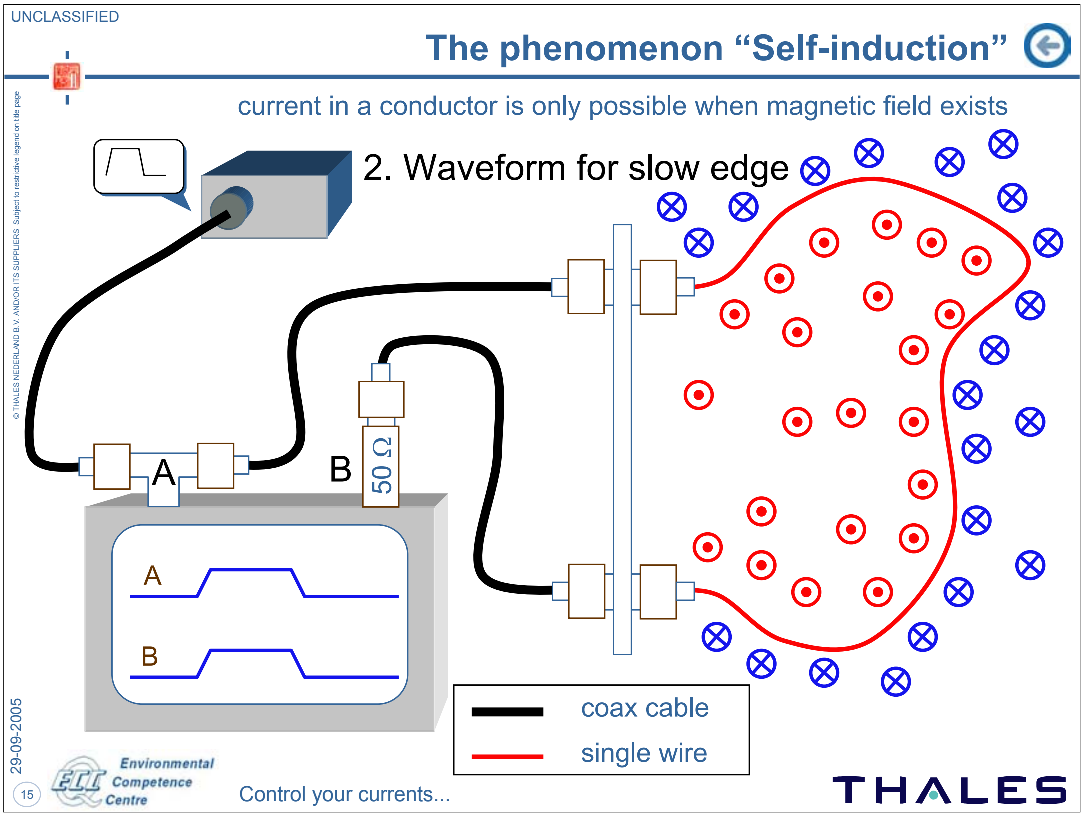
This is the voltage that prevented the current in our first experiment from immediately following the source voltage. Consequently, a spiking effect was noticed. The effect occurs in any conducting loop and is called "Self inductance".



The operation of a (self-)inductance can be visualized to some extent as follows: to build up a current in the loop forming the inductance, a magnetic field must be built up to match the current. Since there is a certain amount of energy stored in this field. "Effort" is needed to build the field and therefore *time* to accomplish the change. We can consider the current loop (single wire) as a coil consisting of one single turn. The value of the self-inductance (L, the ratio of the enclosed flux and the corresponding coil-current) is determined solely by the geometry or "lay-out" of the current loop.

Since time is needed to get current to flow, initially, there is no current! Consequently the voltage at channel A on our oscilloscope is equal to the oscillator "open circuit" voltage: approximately 5 Volts. The generator has an internal impedance of 50 Ω. Further, the wire loop is loaded with 50 Ω at channel B of the oscilloscope.

As soon as current starts to flow, the voltage at channel A (= generator output) goes down proportionally. At (almost) the same time, the voltage at channel B (= the load) starts to rise. Ultimately, a steady state value is reached midway (at 2.5 V), the result of the voltage divider formed by the generator output impedance and the load resistor, both 50 Ω.



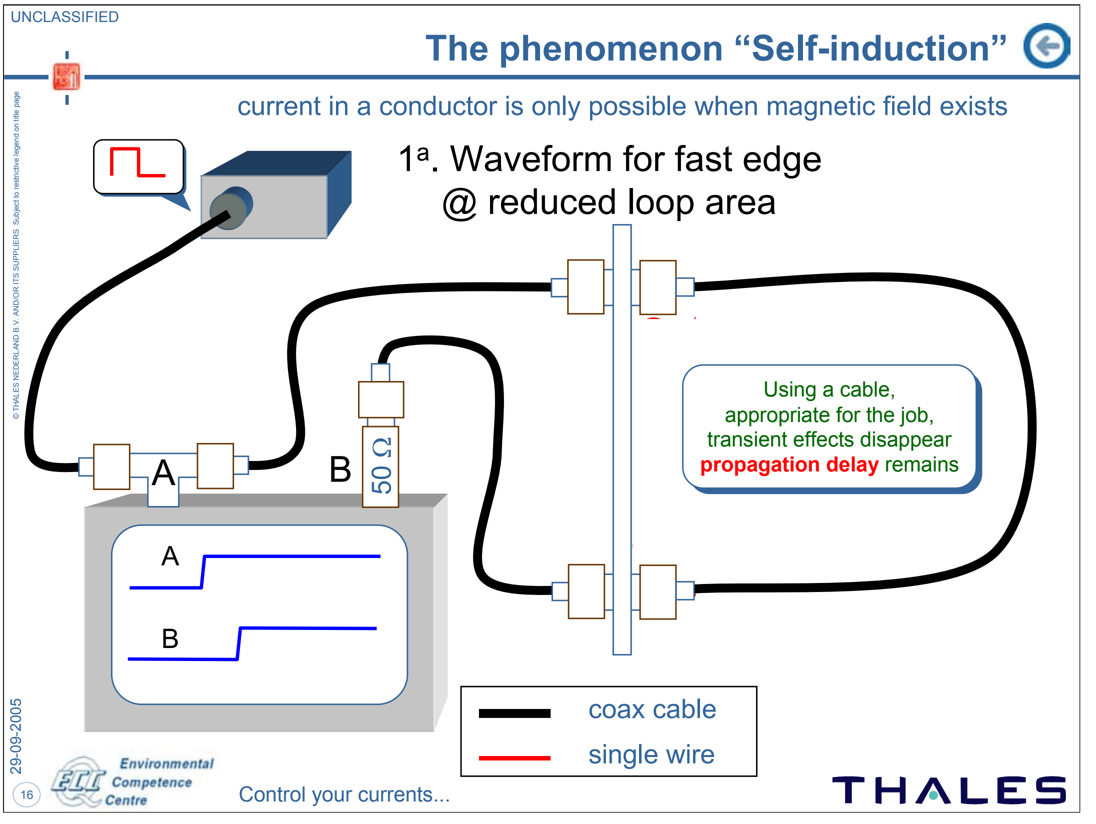
When we do this same experiment with a slower rise time edge, the phenomenon seen in the previous demonstration does not occur. The inductance is too small to create sufficient delay in the build up of current to show on the oscilloscope.

This proves that there is a relation between the amount of inductance and the signal rise time which causes this "inductive spiking effect".

Another way to explain the observation is:

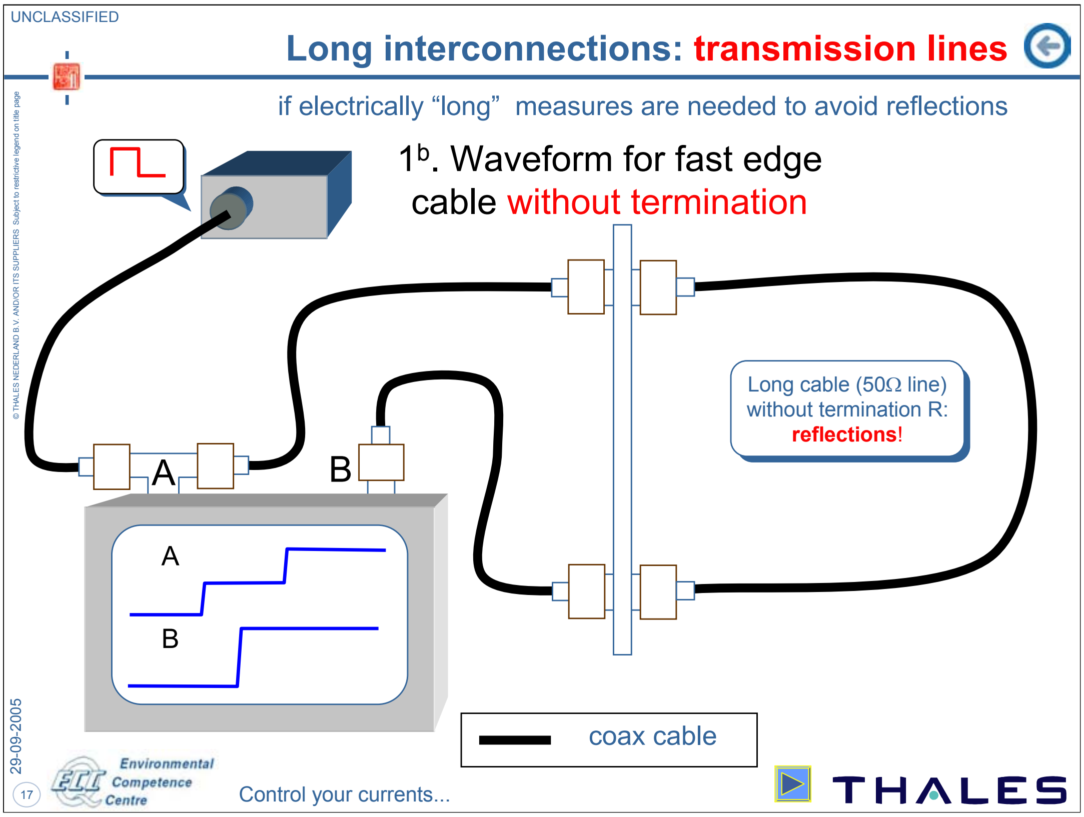
"the loop area and resulting induction in this interconnection is not large enough to cause any deformation in the transferred waveform"

We will see later that the spiking in the previous demonstration causes magnetic flux changes in the environment of the loop which can result in induced noise in other interconnections (I.e. crosstalk).



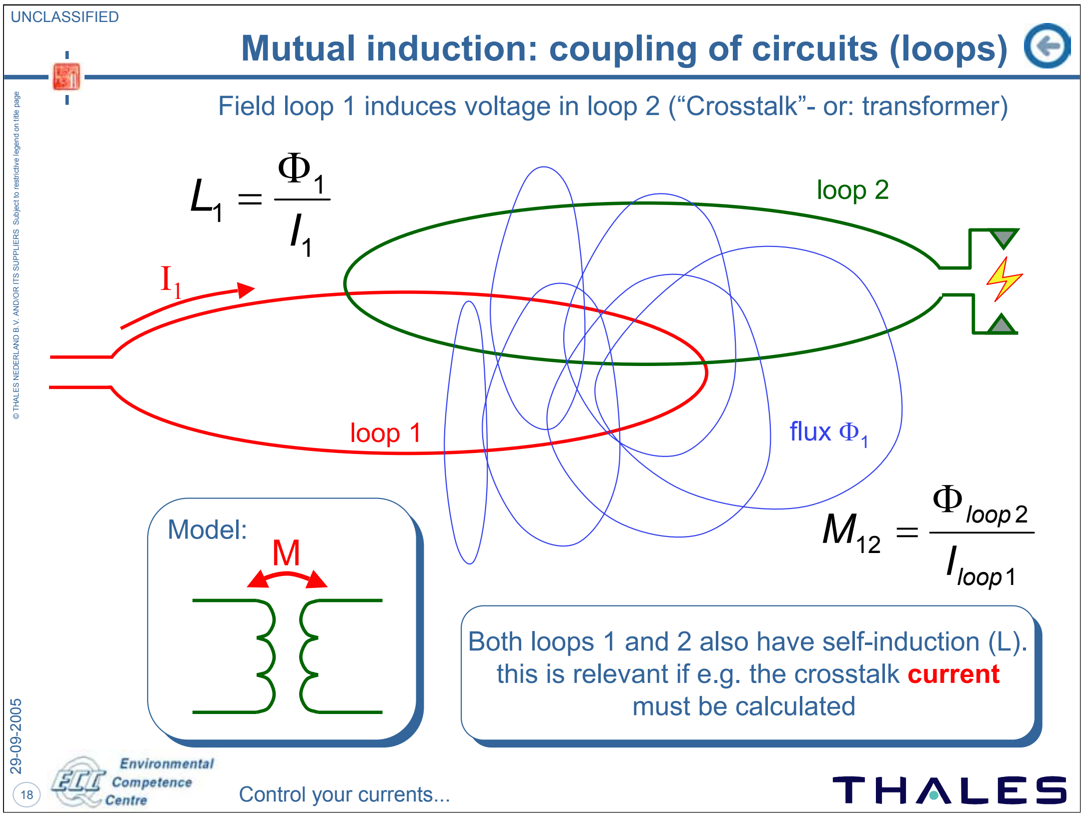
But, of course, we want to use fast edges. In that case we must conclude that single wires and/or large loops are inappropriate. Reducing the loop area by folding the wire is a good way to demonstrate the beneficial effect of a small loop.

The ultimate way to achieve a small loop is to keep signal and return wire together at all times. For that purpose the “cable” has been designed. A cable has a geometry which keeps the two (at least) lines together to reduce the loop area. This reduces the area which has to be filled with field lines (= energy) and, as an extra benefit, at the same time, reduces the fields (= noise) in its environment.



Good coaxial cables can transport fast edges practically without distortions as long as the cable geometry is constant. If cables are long with respect to the critical length, they behave as transmission lines. One prominent effect is propagation delay, the edge is transported at a finite speed. The other is: reflections. Any cable with a fixed geometry (constant cross-section and loss-less) behaves as a resistance to the propagated wave. That is, the voltage is accompanied by a corresponding current, a digital edge is a "package of energy" travelling over the line. If the impedance at the end of the line is different from the line impedance (50 Ω in the demonstrations), a reflection will occur.

In the picture above, the termination resistor at the end of the line (channel B) has been removed completely. That means, no energy can leave the line. The complete wave is returned! On channel A a staircase signal is visible. The initial step is the voltage divided value of the 50 Ω source on the 50 Ω line. Upon arrival at channel B, the energy is reflected back into the line. The current into channel B is about zero. Hence, the voltage doubles. This reflected wave arrives (after another line delay) at channel A. Here too, the double voltage is thereupon present. Arriving at the source, no reflection occurs as the source impedance equals the line impedance.

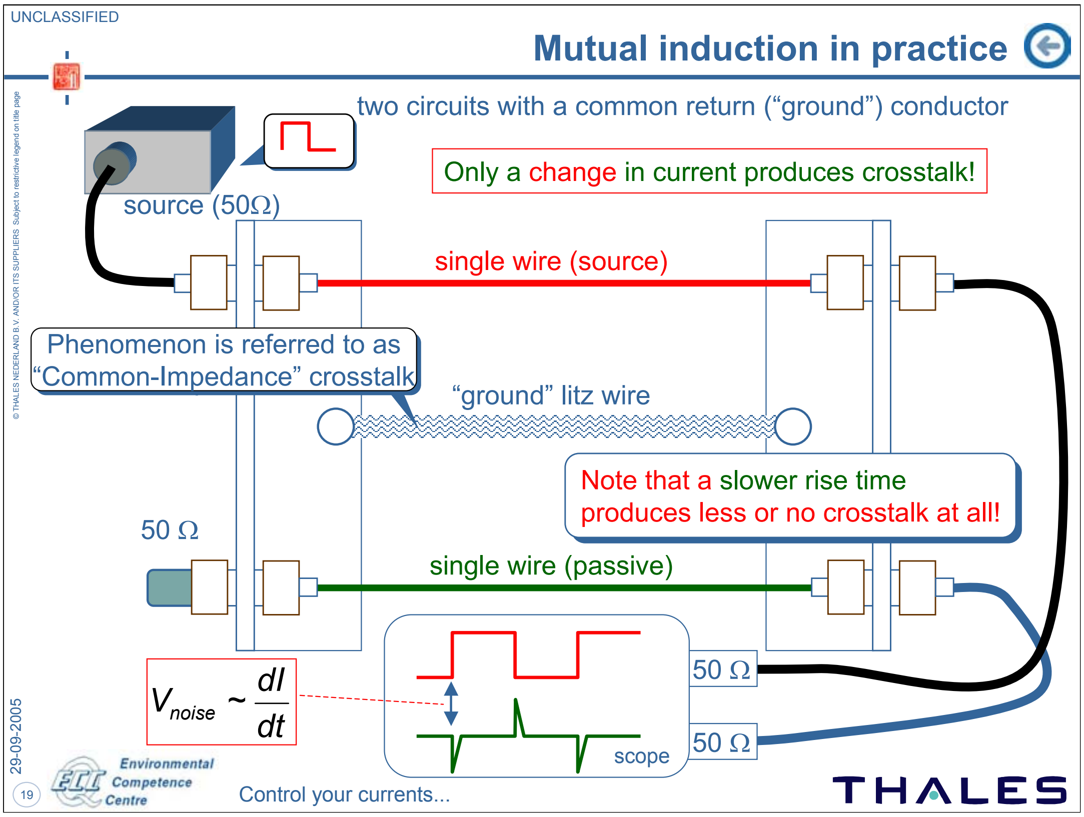


This induction of voltages not only occurs in the loop that carries the initial current but affects all other loops within reach of the magnetic flux generated by it. If a second loop is thus brought in the vicinity of the first one, a voltage is induced based on the rate of change of the amount of flux coupled into the second loop.

The mechanism is that of a transformer. Self induction is defined as the ratio of the amount of flux created by a certain current in a loop to this current.

In a similar manner "Mutual induction" is defined as the ratio of the amount of flux coupled into a loop to the current in the other loop that creates the flux.

The actual voltage generated in this second loop can be calculated using Faraday's law, discussed in a previous slide.



Mutual induction is the cause of many interference situations. One of these is pictured above. Two single wires share a common return conductor. The source wire (red line) together with the ground wire form the field generating loop. The passive wire (green line) together with this same ground wire form the loop which picks up this field to generate an interference voltage.

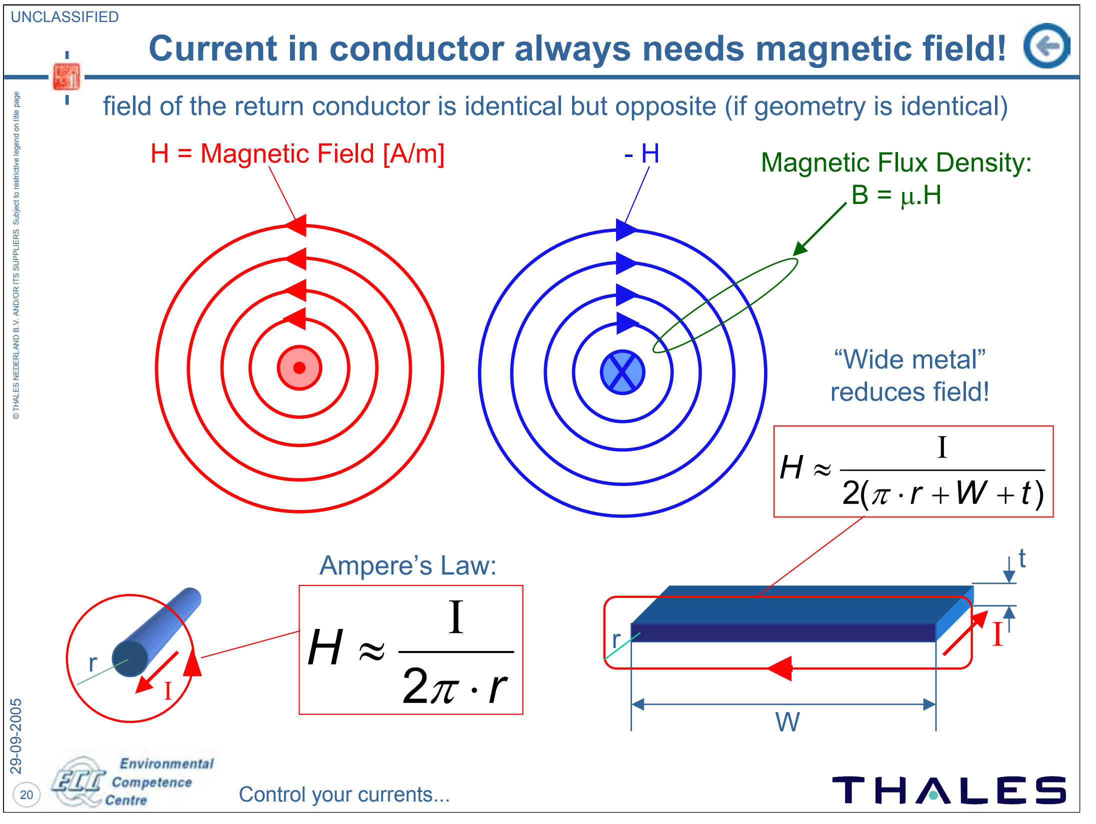
The problem in this situation is the common ground line which prevents the two loops from being separated. Given the signal in the source loop, the only way to reduce crosstalk is to reduce both loops (less coupled flux) and increase the distance (D) between the loops (magnetic field falls of with D^2). Given a common return wire, the separation is not possible and the only reduction comes from making both loops small: the red and the green wire must both be squeezed against the ground wire!

The lessons learned so far are:

- ❑ Acknowledge the presence of the effect (Faraday's law)
- ❑ Minimize loop areas
- ❑ If possible, separate the loops physically

If we reduce the edge rate, the crosstalk disappears, yielding another rule:

- ❑ Use the lowest possible frequencies



Any current needs a corresponding magnetic field to flow. Once a current flows, the value of the magnetic field can be estimated using Ampere's law (also a simplification of one of Maxwell's law). Estimated, since the law is only correct for very thin straight conductors of infinite length.

We have seen that all currents flow in loops which implies that there must be a return current of equal value. Assuming that this return current flows in an equivalent conductor at some distance from the original one, it follows that the magnetic field pattern must be identical but with opposite polarity or direction.

If we can position these two conductors close together, the fields will almost cancel each other. But, apparently, it is not possible to completely remove this field.

In a coaxial cable, this is possible. Apart from the shielding effects of the tube like return conductor, the coaxiality of the two conductors greatly reduces the external fields even at DC (frequency 0).

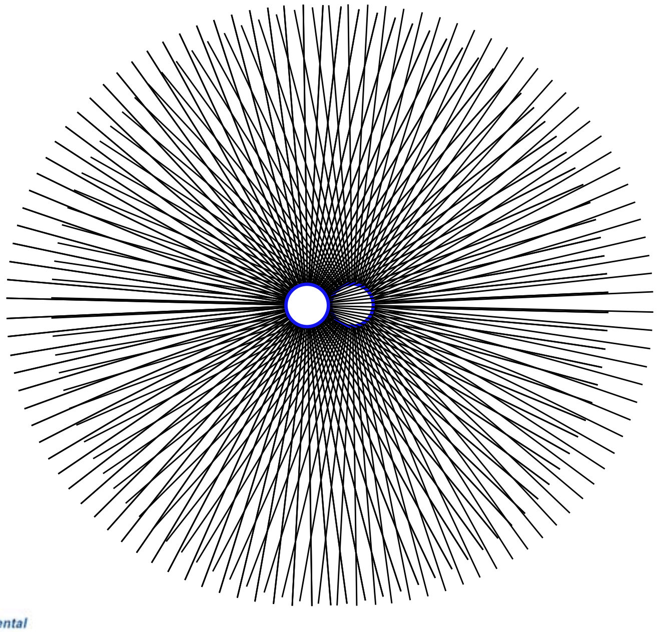
An estimate of the field in the vicinity of a conductor can be made using Ampere's law. It is shown above and valid for an infinitely long (infinitely thin) straight conductor. The equation also assumes the return conductor is so far away that its fields are negligible. Based on symmetry, the magnetic field at a distance, r, removed from the conductor can be calculated (on a concentric circular contour around the wire).

Another option to reduce magnetic field is a wide return conductor. A wide conductor inherently reduces the field as the contour around it at distance r has a much longer circumference. The current, I, is divided by this circumference to calculate the magnetic field, H.

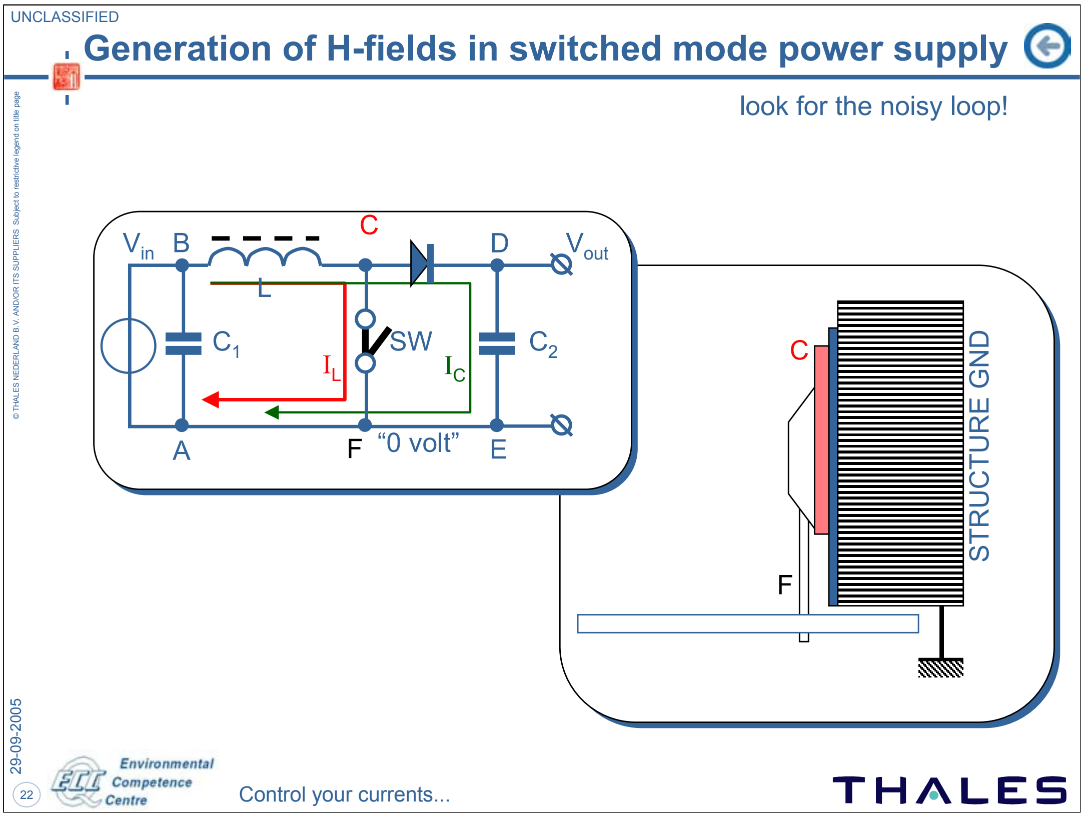
The story goes beyond this simple statement about the return current. In the next slides other effects are studied that help to reduce fields. They all boil down to the natural tendency of currents to flow with as little field as possible. If we, the designers of interconnections, provide the means, the current will automatically follow the path with the least amount of field ("the path of least inductance").

Current carrying conductor always exhibits H-field

field can be minimized by locating the return conductor as close as possible



Due to the symmetry of the fields in two equal conductors with equal currents of opposite polarity, it can be derived that the fields of both would cancel each other when the conductors are arranged concentric (not possible in practice). No field would remain. This can be appreciated from the animation in the slide above. Each wire is represented by an array of radial lines and these arrays are shifted on top of each other. The resulting visual effect (Moiré effect) gives an impression of the resulting vector sums of the magnetic fields from both conductors.



Let us look at the same switched mode power supply module. This time our focus is on magnetic field sources. To do that the principle of operation of the supply has to be examined. The circuit goes through the following cycles repeatedly:

a. The switch (-transistor) S closes and current starts to flow in the inductor L. Due to the large inductance the rate of change is limited.

b. When enough energy is "loaded" into the inductor, the switch opens. Energy stored in the inductor is now drained into the output capacitor. In this process, the voltage across the switch jumps from 0 to approximately V_{out} in tens of nanoseconds: generating a capacitive current into the heat sink (as discussed earlier).

c. The inductor releases its "magnetic charge" into the output capacitor. The current again changes *slowly* from the maximum value just before opening the switch to 0. The rate of change is limited as before by the value of the inductance L.

So, apparently, there are no fast current changes in this circuit! Not from the analysis above. But let us look a little closer:

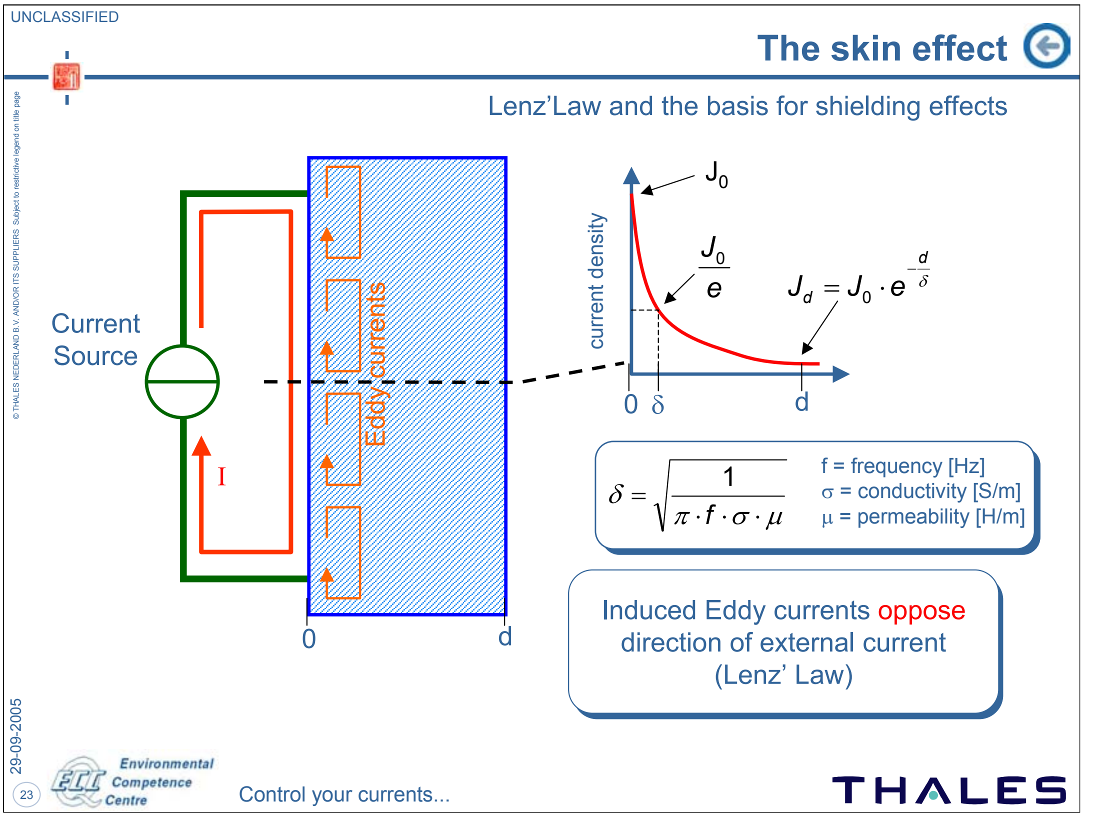
d. Initially, during "magnetic charge" build-up in the inductor, the current loop is ABCF in the diagram above. After opening the switch (tens of nanoseconds),

almost the same current flows in ABDE!

This means that the magnetic field in loop CDEF is switched on and off at a very fast rate! This is the **inductive crosstalk source** we have to be aware of! The best

way to reduce it is to make this loop CDEF very small.

This can be done by careful placement of the components and routing of the interconnections.



A further phenomenon that occurs in any conductor carrying alternating current is the Skin Effect. It can be explained using, again, Faraday's Law, with its minus sign

(the Lenz's Law extension). The steps are as follows:

1. A current loop is formed which injects a return current, I, initially, onto the left surface of the metal sheet shown above.

2.The field accompanying this return current will extend to the left into the air and to the right into the metal sheet.

3. With alternating current, the magnetic field around it alternates. This induces reactive currents in deeper layers of the sheet which oppose the direction of the original return current (the minus sign!).

4. As a result of this induction process, most of the energy flows at the surface, we could say: the current is "pushed to the surface"

5.The largest return current density can thus be found at the surface of the metal sheet, on the side of the signal conductor: "where the field is". The current

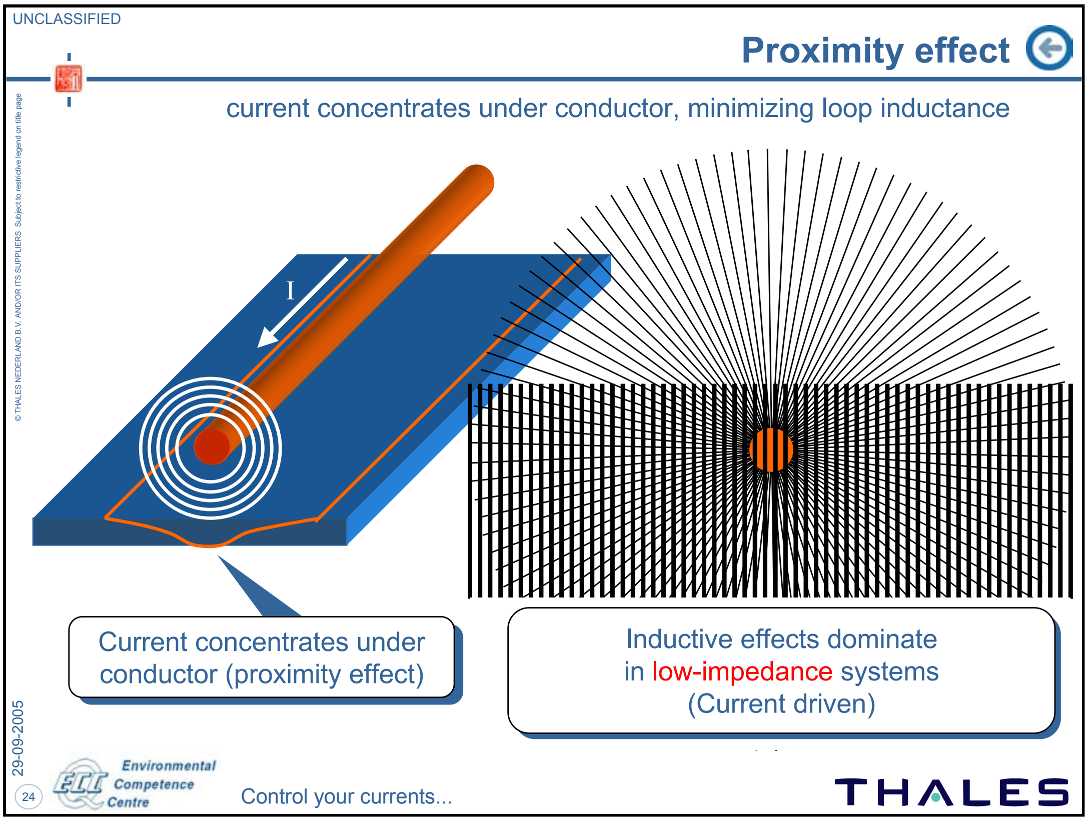
density is reduced *exponentially* at deeper layers of the metal sheet.

6.The field on the opposite side of the metal sheet is very small since the current density on that side is small.

The return current can be thought to run only in a thin skin of the metal surface. The depth of this skin can be defined as the depth at which the current density is reduced to 1/e of the surface value. This skin current carries 92% of the energy. Important side effects are:

7. Since the current density on the opposite side of the sheet is much reduced, the magnetic field strength is reduced to the same extent. This explains the shielding effect of metal shields.

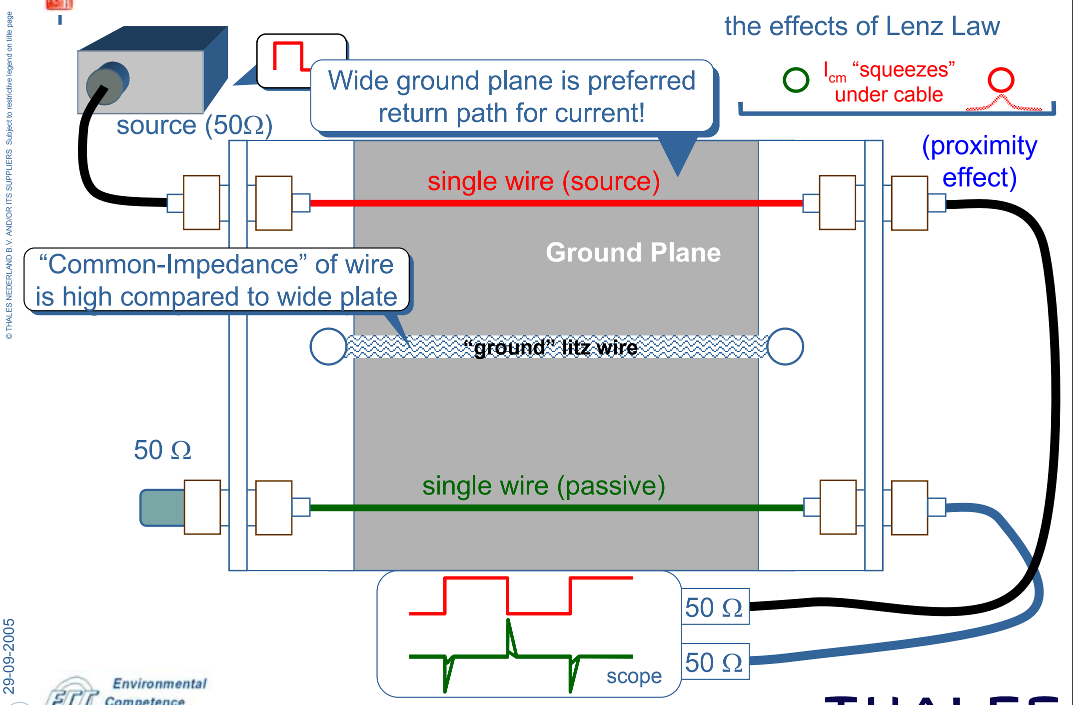
8. The effects increase with frequency. For frequencies above e few kiloherz, the skin depth in most conductors is reduced to microns: e.g. at *10 kHz* in *steel,* the depth δ = 93 μm.



Finally, the interaction of the magnetic fields of signal and return conductor “pull” the current in the return conductor under the position of the signal conductor (could be PCB trace) to enable the current to flow with as little field as possible to do the job. The skin effect keeps the field on the side of the signal conductor and even the current in the signal conductor will flow mainly on the bottom side of it. This is called the proximity effect.

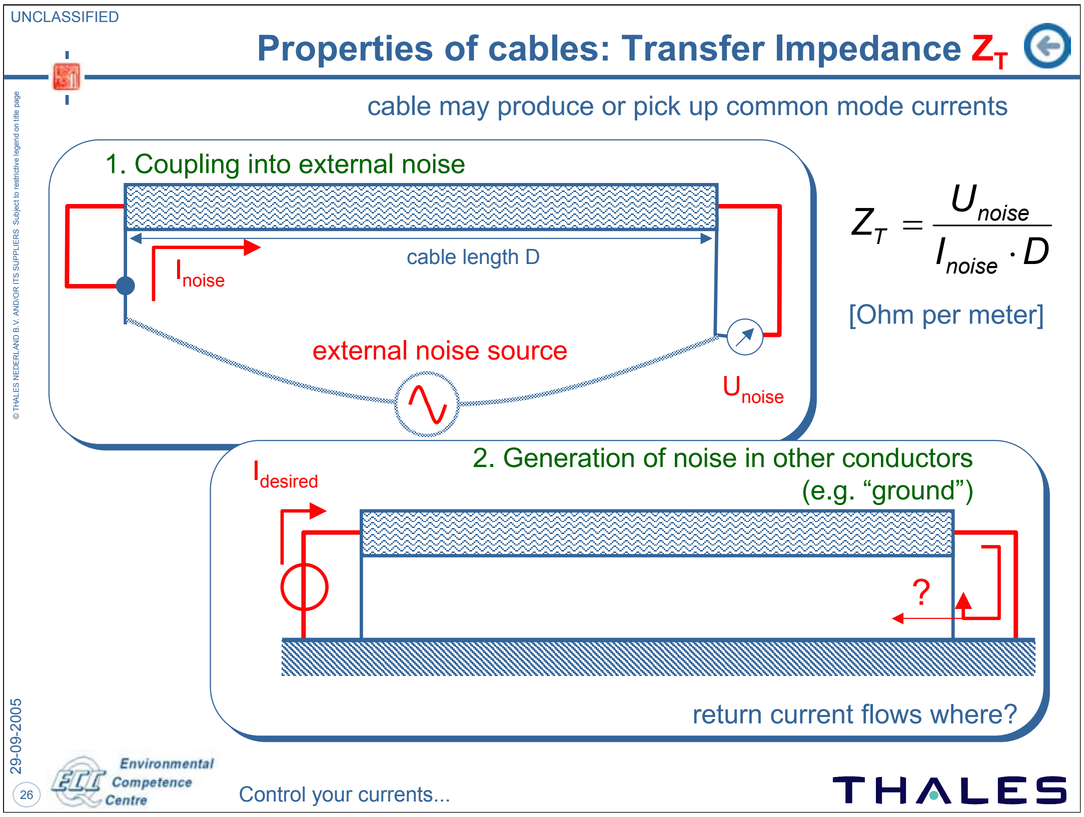
The effect works for any current be it differential or common-mode (the current does not know this distinction). Later on, when discussing metal conduits for complete cables, the effect is used for common-mode currents. In printed circuit boards the primary use is for differential mode currents. But, as the total fields around all conductors in a PCB are kept as small as possible, the common-mode currents through and around the board are also reduced by these wide metal planes.

Wide metal reduces common impedance efficiently



We can use the effects on magnetic fields of wide metal to reduce the crosstalk seen before. The problem with the relatively thin ground cable was the need to keep both the source and the victim wire close to the ground wire to reduce the two loops that caused the crosstalk in the first place. By doing this, the signal leads themselves were brought close together.

Using a wide metal plane solves the latter. Both wires can be laid as close to the ground plane as possible while at the same time at large distance from each other (the maximum determined by the width of the metal plane or strip).

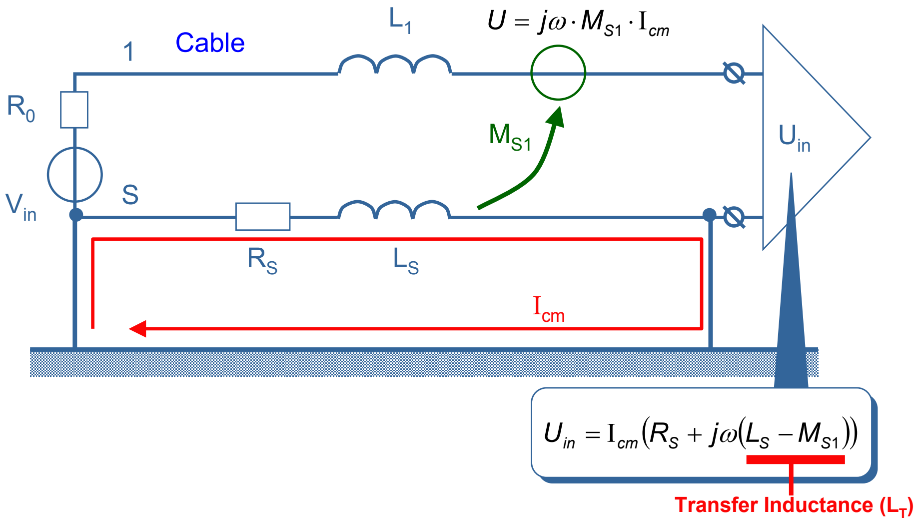


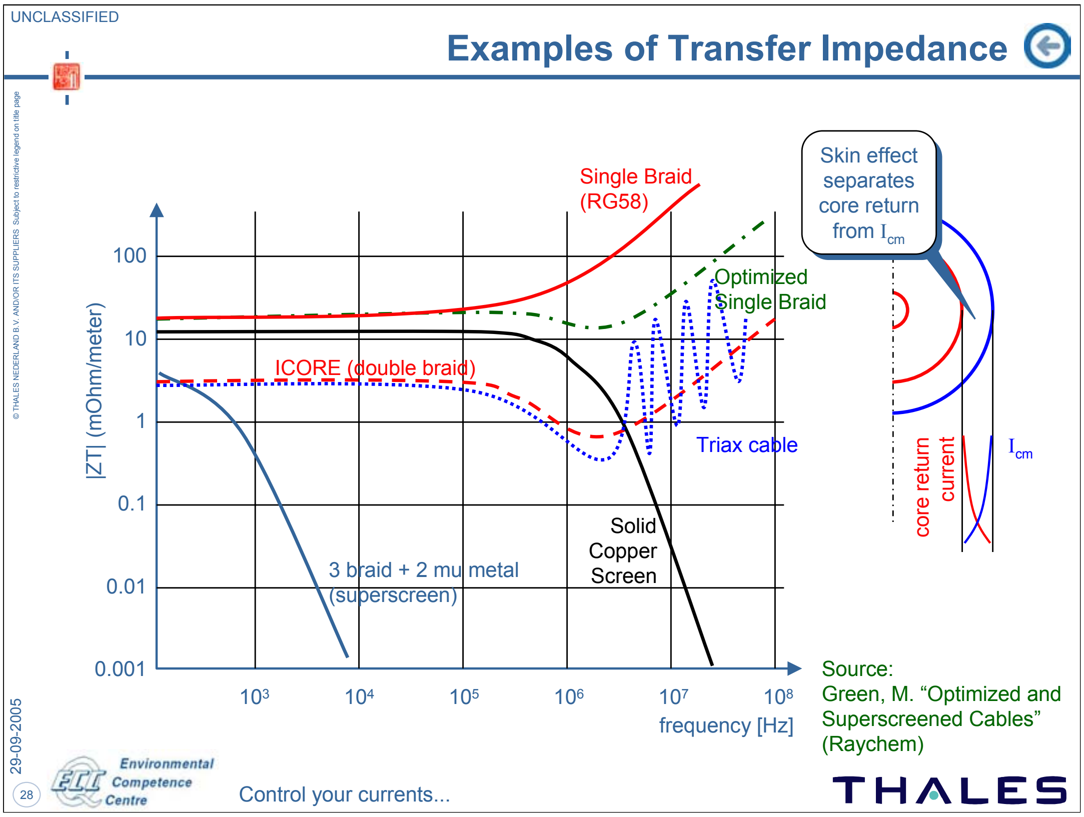
A combination of conductors intended to carry both signal and return current is a cable. In the light of the previous discussion, any cable can be expected to more or less create fields when a current is led through it. On the other hand, based on reciprocity, fields in the environment may be expected to create currents (and/or voltages) in the differential mode circuit of a cable. This property is called transfer impedance. One definition is the voltage at the end of one meter of cable while the other end is shorted, when one ampere of current is passed through the return conductor. The dimension consequently becomes: Ohms per meter. It is a frequency dependent property.

In a combination of several cables, some may generate common-mode currents while other, more sensitive lines, convert them back into voltages. These voltages are then added to the intended signals in these cables as noise. Interference is the result when these noise voltages become too high.

Mechanism of the transfer impedance

common-mode current flows in return impedance



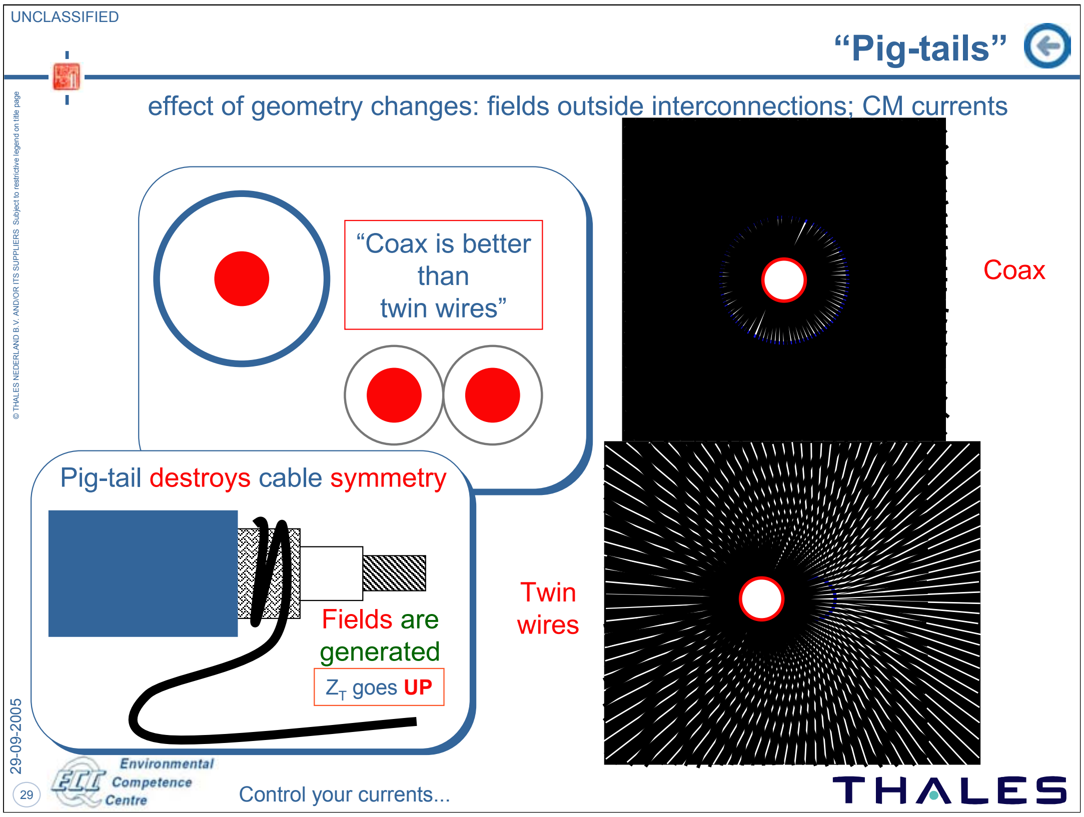


Some examples of Transfer impedances can be taken from a publication of M. Green (Report Wire and Cable Division, Raychem). The ICORE double braid has been added separately (because it is known at Thales). For all non-magnetic screens deviations from the DC resistance value occur around 1 MHz. Above that frequency other impedance effects take over. Braided cables are inherently leaking for very high frequencies because it is a more or less open structure. The transfer impedance hence goes up in these high ranges.

A special version of double braid is Triax Cable. Triax has two isolated braids. The inner braid is used together with the core as a protected coax cable. The outer braid is used as shield for external common-mode currents. An application within Thales is as base band (0- 4MHz) Radar Video cable. The inner coax screen is only connected at the source. At the load a floating amplifier with high common-mode rejection is used to avoid low frequency common mode currents on the inner screen which could interfere with the at times very small radar signals. The interconnection can be compared with a symmetric shielded twisted pair interconnection that uses balancing to cancel external noise. The only reason an inner coax is used, is the better behaviour of such coax at the high end of the base band (4 MHz).

For all shown cables except the Single Braid, there is a section around 1 MHz where the skin effect sets in. The skin effect improves (lower Z_T!) the transfer impedance. In case of a solid copper screen (e.g. semi rigid coax) the skin effect ultimately reduces the transfer impedance to "0" by completely separating the core return current (on the inside) from the noise current I_{cm}. In all other cases the -very small- openings in the braid(s) ultimately show an increase in the high frequencies (inductive effects).

A special type is the superscreen cable. This is a combination of several layers of braid combined with mu-metal foil. Due to the magnetic properties of the foil, the skin effect sets in at a very low frequency (below 1 kHz).

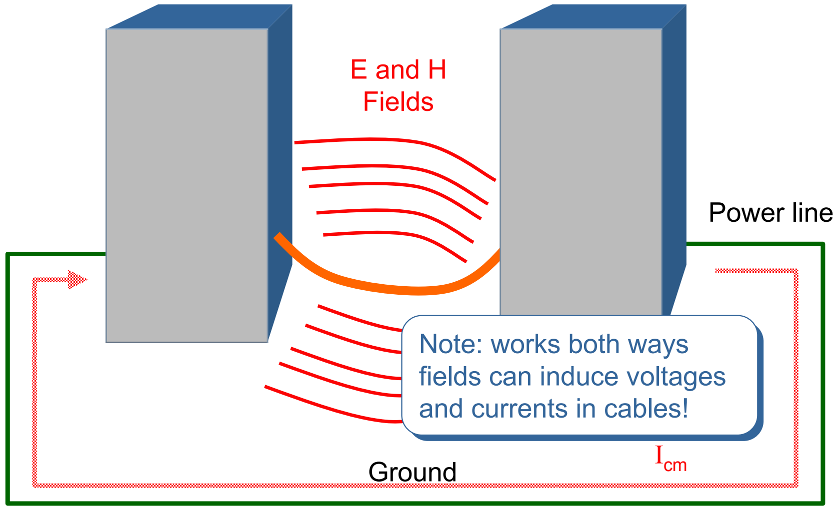


Transfer impedance occurs in any cable. The amount depends heavily on the cable geometry. Coaxial cables are superior in this respect to twin wire combinations.

If, however, a coaxial cable is terminated in a so called "pig-tail" in order to connect it to terminals in an instrumentation cabinet, this small geometry disturbance may largely deteriorate the transfer impedance of the cable. Deteriorate means: increased Z_T.

Fields “leaking” out of cables create CM-currents

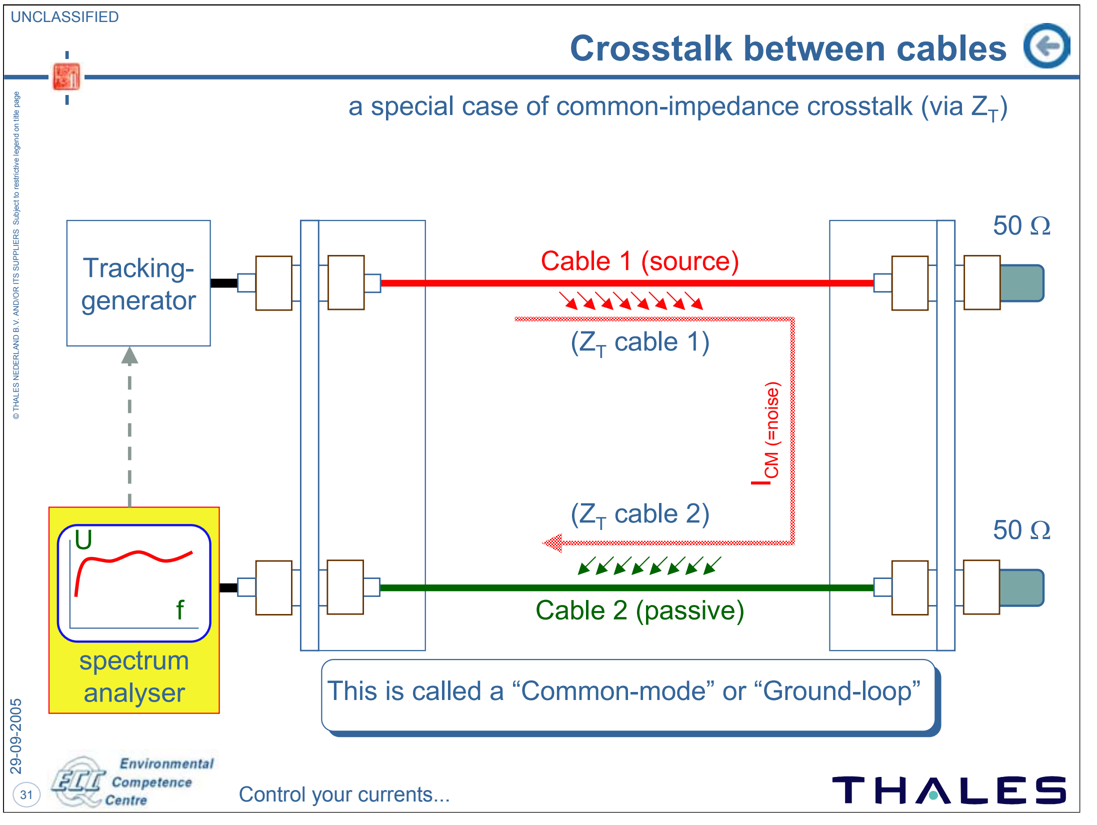
currents flow in connected conductors (cables and structural parts)



Since “ground” is the dominant conductor, the cm-loops are often referred to as “Ground loops”

Once a cable (+ connectors + pig-tails etc.) generates fields and hence common mode currents, these currents will find a path back to their source using connected cabling (and other conductors). Depending on the routing of these cables, large common mode loops can exist.

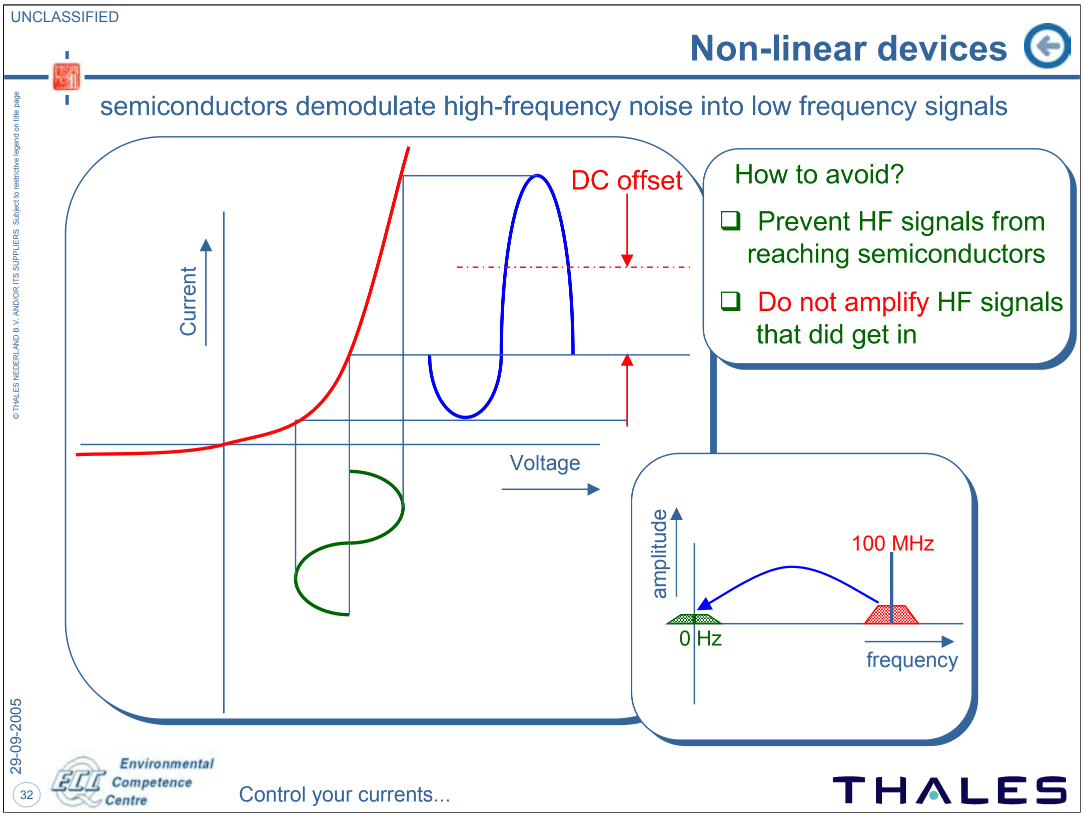
Since the dominant conductor is usually called “ground” or “structure”, these loops are known as “ground loops”.



The situation above is very common for installations: somewhere a cable exists which generates a lot of common-mode noise while elsewhere, in the same ground-loop a sensitive cable is present which will couple this cm-current as a voltage into its differential mode signal. Crosstalk will be the result.

The situation can be compared to the crosstalk demonstration on slides 11 and 17. There, the coupling mechanism is magnetic field and the proximity of two loops that could not be separated due to the common impedance formed by the ground/return conductor.

In the case above, the ground conductors are again coupling the two interconnections. This time we call it Transfer Impedance. But of course, Trasnfer Impedance is a property of the cable shield/return conductor. Resistive and inductive effects cause some of the intended signal of the “source” cable to leak as common-mode current. But it is just as valid to see this leak as a (magnetic) field leak which is the cause of the common-mode current in the ground loop formed by the cables and other conductors in the demonstration shown above.



Non-linearity is a natural property of semiconductors. They can demodulate high frequency signals. The slide depicts this process:

1. A high frequency signal reaches the non-linear device
2. The sinusoidal voltage is converted in a distorted sinusoidal current
3. This current contains a DC offset (called the quadratic detection term)
4. For an unmodulated HF signal, the DC offset may exist unnoticed
5. An amplitude modulated HF signal results in a varying DC level
6. This is a low frequency signal that usually falls within the operating band of the equipment
7. The “out of band” HF noise can thus create an “in band” low frequency signal

The non-linear behaviour cannot be prevented (it’s inherent).

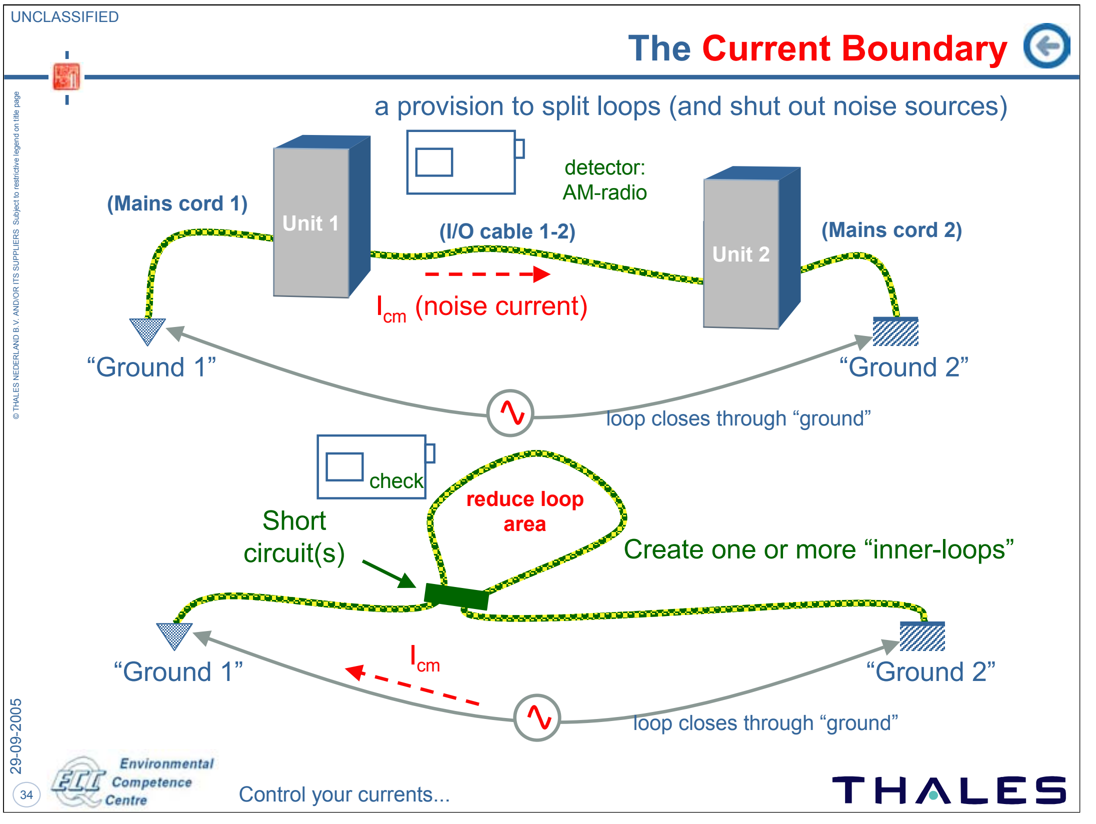
The designer should take measures to prevent HF signals from reaching the devices.

A further measure is not to amplify any HF signal that reaches an input.

Restrict the bandwidth of the design to a minimum.

EMC Measures

Grounding
Current Boundaries
Separate and Reduce (ground-) loops
Shielding



If two separate Protective Earth terminals in a building are connected, currents will flow. This happens because currents are present in the mains cabling including its PE wiring and the transfer impedance of mains cabling is high. By providing an extra current path with a ground cable, some of the PE currents will prefer to take this route. As detector for these currents an ordinary AM radio can be used tuned to approximately 1 MHz. This also shows that the currents through "earth" are not limited to 50 Hz! Mains connected equipment is responsible for those currents. If this happens in a single ground wire, it would also happen in the practical situation of two units, each with their mains cord plugged in, and an I/O cable connecting the two. What is the difference?

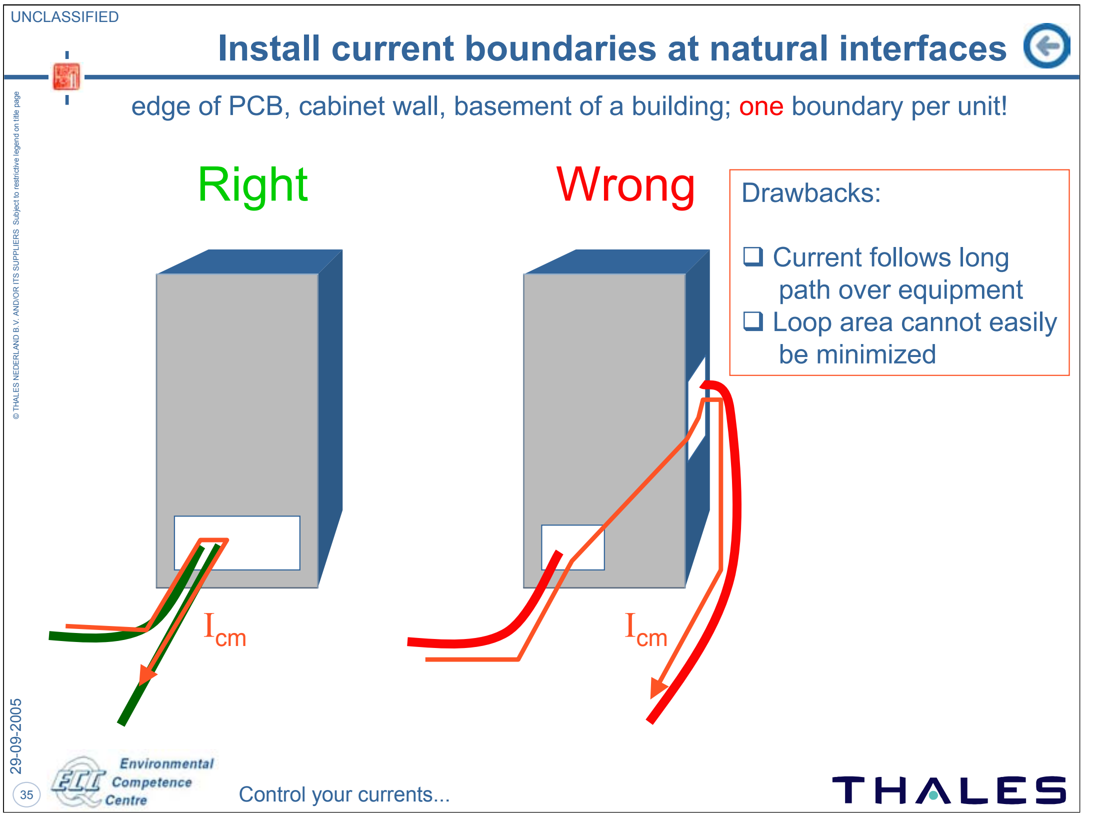
By making a minor lay-out change in our demonstration we can suppress most of the interference: we will form a loop in our ground wire (and actually provide an electrical connection at the resulting intersection) thereby creating a more "favourable" path for our interference current. In the inner-loop the current has gone down drastically (which can be shown with our radio).

We will call a provision that accomplishes this feat a "Current Boundary". In EMC text books, the term "Reference" is used. Traditionally, a reference is defined in terms of "voltages". This is a legacy from the times when "isolation" and single point grounds were adequate protection against interference. We would like to use the

definition "current boundary", because it is a provision to *split current loops into two or more separate loops*. The provision prevents noise currents either from entering our equipment (i.e. susceptibility problem) or from leaving it (emission) thus actually forming a boundary for noise currents.

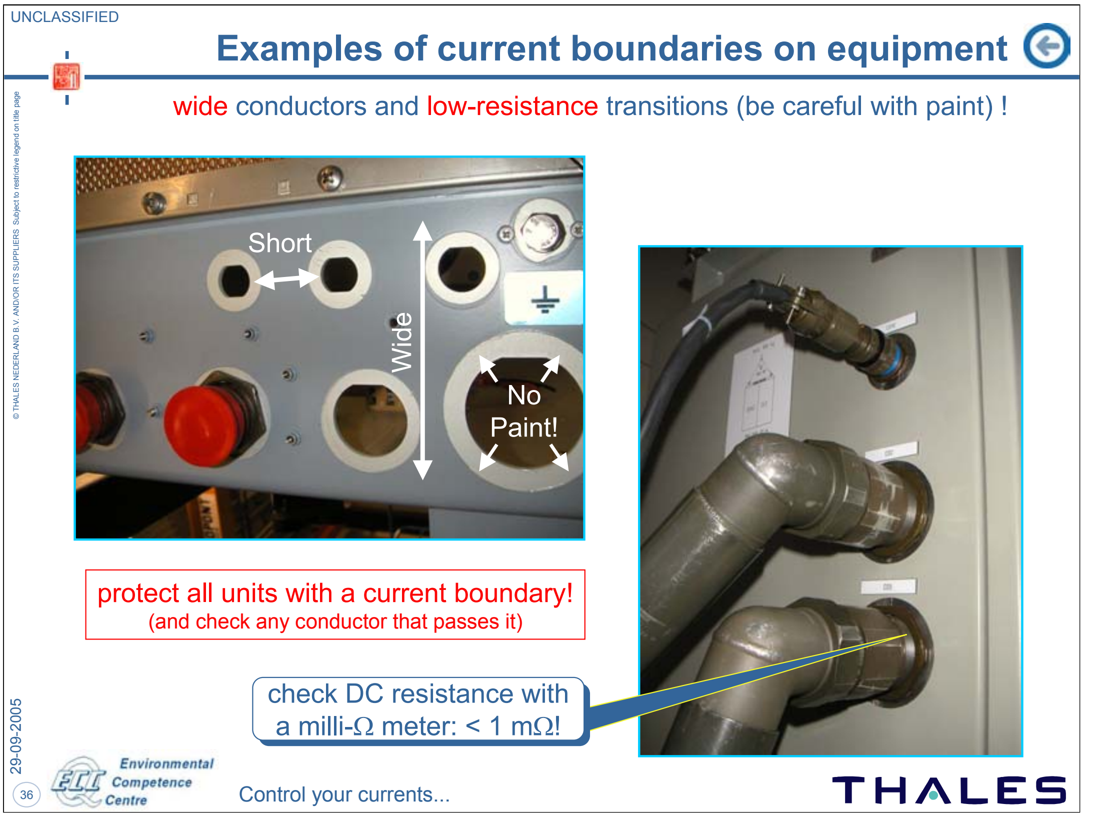
A very important "boundary" is the interface with the outside world. The example of lightning shows that current levels here can be very threatening to our electronics. We therefore urge our designers to give special attention to the boundary between their system (= responsibility) and "other systems", the outside world.

Note After the realization of the current boundary, we actually have separated our original loop into two separate loops. Of course, there is mutual inductance between them! Currents may still be induced in the inner loop by that mechanism. So, make sure to reduce your loop areas after inserting a boundary!



The drawing above shows a correct (left hand side) and an unfavourable (right hand side) implementation of such a current boundary. On the left, the cabinet has a provision called a connector- or (EMC) gland plate. It is a wide metal plane which makes sure that currents flowing in it will create the least amount of field. Further, the skin effect will keep these effects (currents, fields) on the side of the plate where they belong! For best results, the path over the equipment cabinet should be kept as small as possible (connectors or glands placed close together).

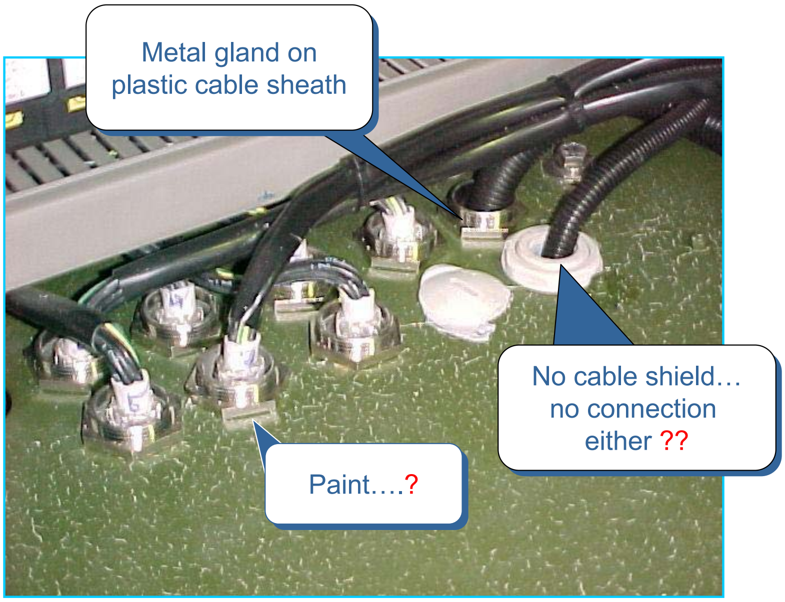
This is what went wrong on the right hand side. The external cables are connected at positions separated by a large distance and even on mechanically separate parts of the equipment cabinet. This means that the external noise current, I_{cm}, will have to follow this long path to get from one cable to the other. If the cabinet wall is not made out of one piece of metal, chances are, this current will have to take a detour through the inside of the cabinet to get from one plate to the other. This can happen if equipment body plates are isolated from each other e.g. by paint or foil. As long as the equipment wall between the two connectors is made of one piece of metal, the skin effect will most likely still be able to keep the external currents on the outside but making the external loop area small is difficult! large loops create larger fields in their environment.



Above some examples are shown of good current boundaries. Connectors are mounted on one wide, solid metal plane. The locations of the connectors are kept free of paint to ensure good electrical contact to the connector bodies. It is good construction practice to check this contact by measuring the resistance between connector plate or cabinet wall and connector shell using a milli Ohm meter. Good contact means less than 1 mΩ per transition.

What goes wrong on current boundaries…

mix of plastic and metal EMC glands signals errors



The picture above indicates that not every equipment builder has a clear vision about the do’s and don’ts of a current boundary. It seems that the choice to use a metal or plastic gland was based here on the presence of a cable screen! When looking at the picture, one wonders whether there is a galvanic connection between the glands and the metal plate.

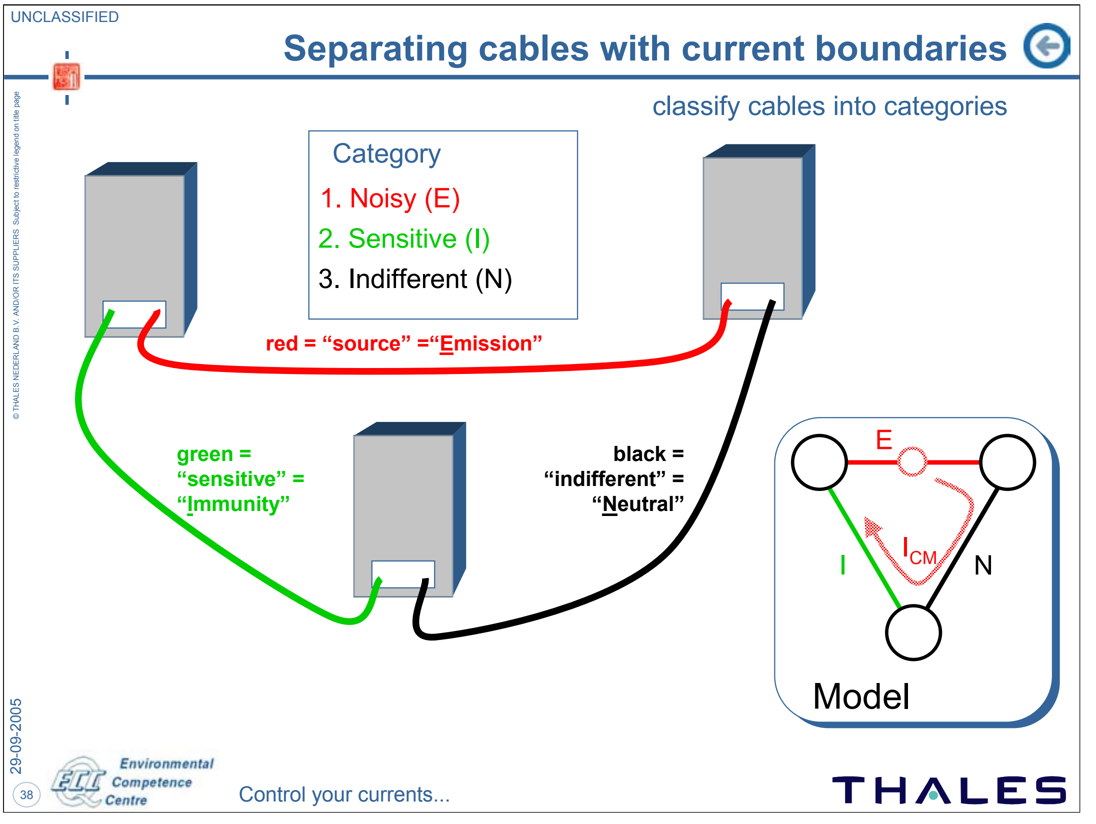
It is possible, however, that a metal plate current boundary has seven plastic glands and three metal glands “on purpose”. Probably, an interference problem was solved

there by providing metal glands only for those cables that actually carried the interfering currents. A clear case of “First Aid” measures then! If this had been the case in the situation above, one would, at least, have expected measures to assure good contact on the metal glands.

There is no law against such solutions. In practice, the actual cable lay-out determines where the currents will flow. Selective use of (more expensive) metal glands is theoretically possible.

But it is unsuitable as a design approach for an electro-magnetically sound system. Usually the actual cable layout is unknown during the design phase of a

machine. Or the layout varies for different customers. Using a uniform approach for all interconnections using adequate current boundaries, as described in this module, is best.



The connector plate is the first type of current boundary, placed at the interface between equipment and the outside world. “Equipment” can be interpreted as “cabinets” but could also be a rack or even a single Printed Circuit Board (PCB). At each of these levels current boundaries can be built, thus forming a system with “multipoint grounds” (each current boundary is a “common-mode” node in this system). But: what happens with the interconnections that create the common-mode currents in the first place?

We will now develop an approach for interference protection in any cable system. In such a system there are basically three types of cables:

❑ Cables with high differential mode currents and/or high frequencies which produce interference (Transfer impedance, **Emission** type)

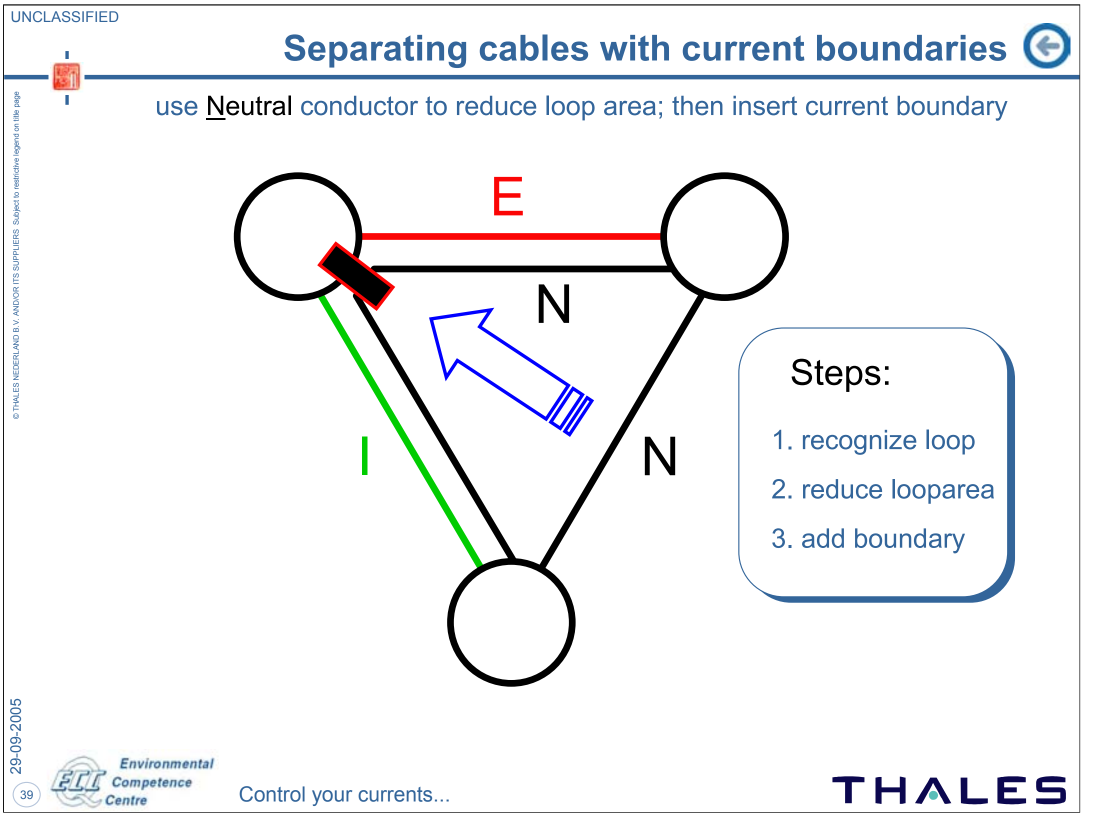
❑ Cables that transport low level signals that are sensitive to external common-mode currents (Transfer impedance, **Susceptibility** type)

❑ Cables and/or other conductors (e.g. structural mechanical parts) that are neither emitting nor susceptible but which can transport common-mode currents (**Indifferent** type).

Practical applications will have these types in various levels e.g. HSV-R-0096 has a distinction between Strongly Jamming, Jamming, Indifferent, Sensitive and Extremely Sensitive (and the idea is to separate all these categories, except indifferent, from each other).

For the purpose of this seminar it is sufficient to treat the three basic types. If we can separate emitting cables from sensitive ones, the separation of Strongly Jamming from Jamming cables can be done using the same principles.

Note: “Indifferent” can be a cable property. For low frequency applications a mains cable can be considered “indifferent”. For high frequency applications, no cable is considered “indifferent” because that could be interpreted as: “no measures needed”. The only indifferent conductors in high frequency work are wide structural metal parts that can be used to protect or shield cables and interconnections.



The model drawn above shown the general approach for separating “Jamming” (E) from “Sensitive” (I) interconnections. The trick is to use a “Neutral” or “Indifferent” conductor (in practical cases never a “cable”, always a structural metal part).

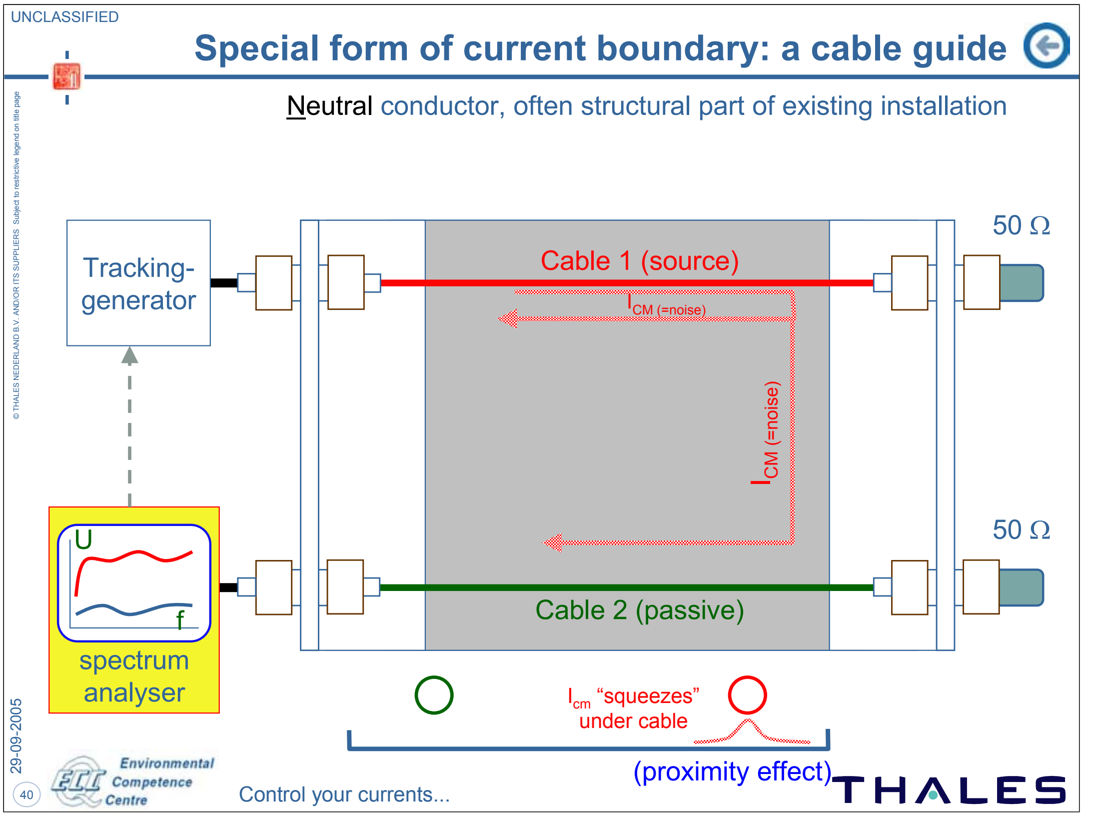
The steps to be followed are:

1. Find all common-mode (ground) loops

2. Reduce their loop area by extending the indifferent/neutral conductors close to the sensitive and jamming cables/interconnetions.

3. Connect the neutral/indifferent conductor (galvanically) at least to the current boundary that has both the jamming and the sensitive cable. In practice: connect the neutral conductor to all equipment current boundaries it passes.

The loop containing both the jamming and the sensitive cable are thus split into two loops, only containing neutral and either sensitive or jamming (but not both).



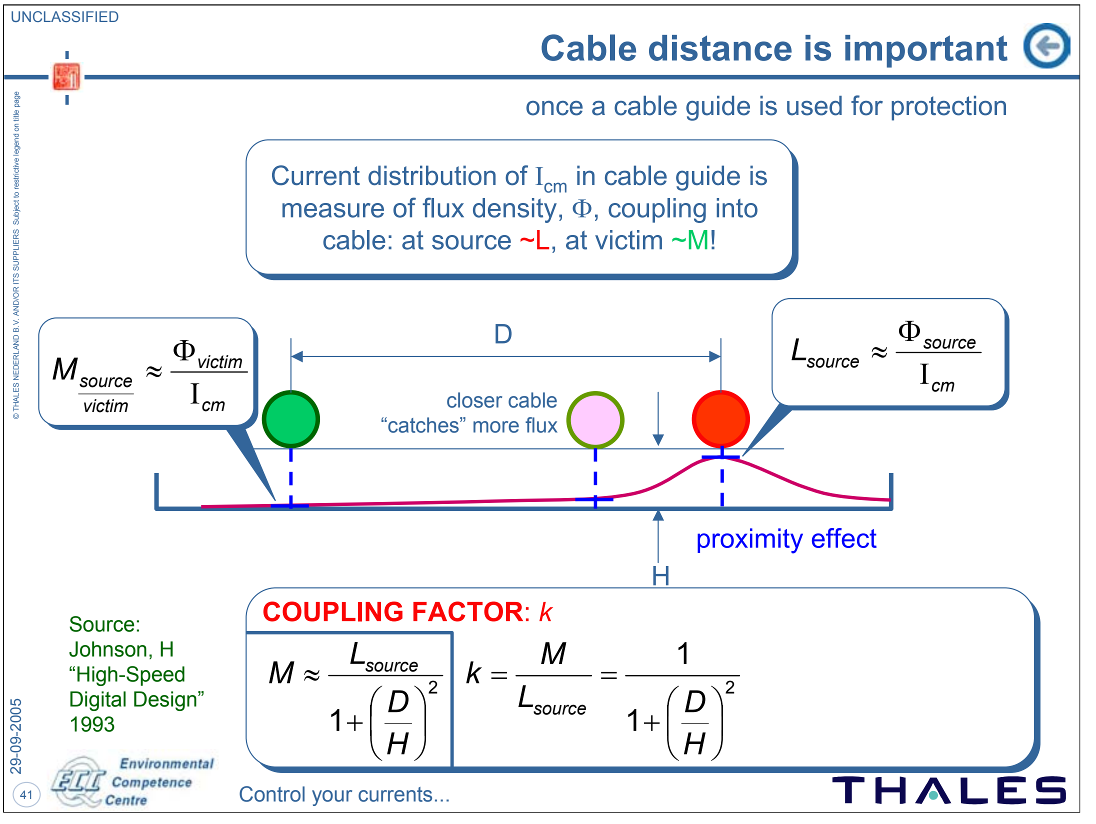
The approach set out in the previous slide leaves one situation unsolved:

The case where only a jamming and a sensitive cable are present between two cabinets or machines, as is the situation in the cable crosstalk demonstration shown above. Here too, the approach is to use a neutral/indifferent conductor to separate the two cables.

This could be a separate conductor (structure part) which is positioned close to each of the two cables and attached to the current boundaries of the equipment and/or machines on both ends. But is is more practical to use the wide metal plane approach already discussed in the module "EMC mechanisms".

This wide metal plane is available commercially as a metallic "cable guide". Apart from the mechanical and aesthetic functions, is can very well be used as neutral or indifferent conductor as long as it is electrically connected to the current boundaries (connector or gland plates) at both ends.

The separation of the Jamming and Sensitive loops is realized by the **proximity effect** discussed earlier. The concentration of current and thus field under the jamming cable removes fields and currents from the sensitive cable and, thereby, the source of the crosstalk! The effect is quantified in the following slide.



To get an impression of the magnitude of the crosstalk reduction, the distribution of the current (and thus the fields) over the cross section of the cable guide is needed.

Once the current density in the cable guide is known, the amount of magnetic flux present in the gap between cable and cable guide is also known. From the module "EMC mechanisms", we know that the amount of flux between a conductor and its return (if integrated over the area) determines the induction. If the conductor is the source of the noise (the red cable at the right side in the diagram), this is "self-induction", indicated by "L".

If the conductor is at the receiving end (e.g. the green cable at the left side of the diagram), then this flux (if integrated over the length of the cable) determines the mutual induction, "M", between the source and this cable.

The ratio, k, of this mutual induction, M, and self-induction, L, is a measure of the coupling that exists between the two cables.

The equation for this coupling factor, k, is given above. It relates the coupling to the dimensions "height above the plane", H, and "mutual distance", D, between the cables.

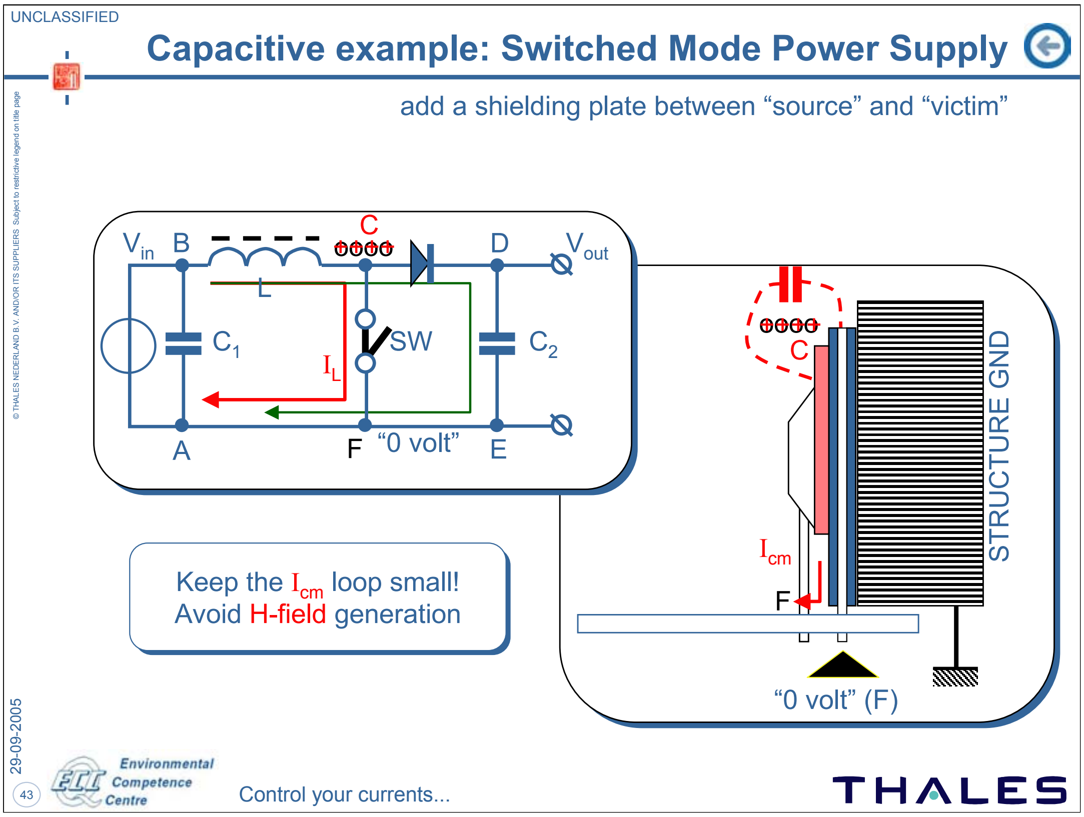
The "Attenuation", finally, provides a measure for the achievable reduction of noise due to the installation of a current boundary for a given cable system.

Cable categories

usually five or six categories, these taken from VG 95375-3

4	Extremely Sensitive not disturbing	0.1 µV to 500 mV 50 to 2000 Ω LF and HF	Receiving antenna cable Radar, TV and IR receive cables Hydrophone cables
3	Sensitive not disturbing	0.1 V to 15 V HF, wide band	Reference voltage Digital data transfer cable Frequency/phase dependent cable
2	Indifferent possibly disturbing	0.1 V to 120 V LF, narrow band	Power supply cables Lighting cables General control and signals
1	Disturbing not sensitive	DC 24 to 660 V AC 115 to 440 V 50, 60 and 400 Hz	Synchronization cables Video cables Strobe and marker cables
5	Extremely Disturbing not sensitive	10 to 1000 V HF, narrow band	Radio transmission cables Sonar transducer cables Pulse modulator cables

Depending on the standard used, different names are given to the identified cable categories. The set above is found in the German VG95375-3. This standard also specifies distances with respect to a ground plane. For cables, 10 m long, a maximum distance to the ground plane of no more than 10 cm is specified. For almost all combinations a mutual cable distance of 10 cm is required. (only between category 5 with respect to 4 and 3, 20 cm is given).



To avoid a capacitive current into the heatsink of the switched mode power supply discussed earlier, a (capacitive) screen is placed between the collector/drain tab and the heatsink/case. This tab is then connected to the *desired* return path

which, in this case, is to the ground or 0 Volt conductor or –plane on the printed circuit board. The geometry of the construction now makes this the "path of least inductance" so Lenz's law ensures this path is preferred.

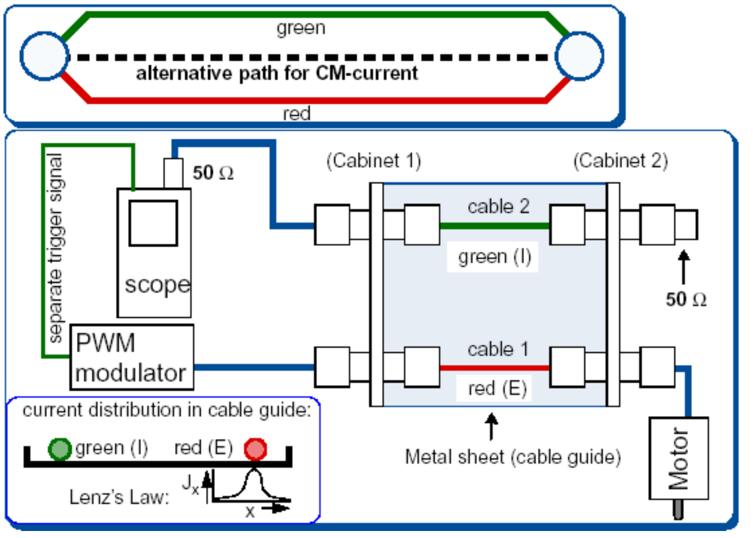
Note The capacitive screen is insulated from the heatsink for reasons of e.g. Low Voltage Safety. For EMC alone, it could be galvanically connected to the heatsink or case while the high-frequency current would still take the "easy path" back to ground! (as long as the connection is there).

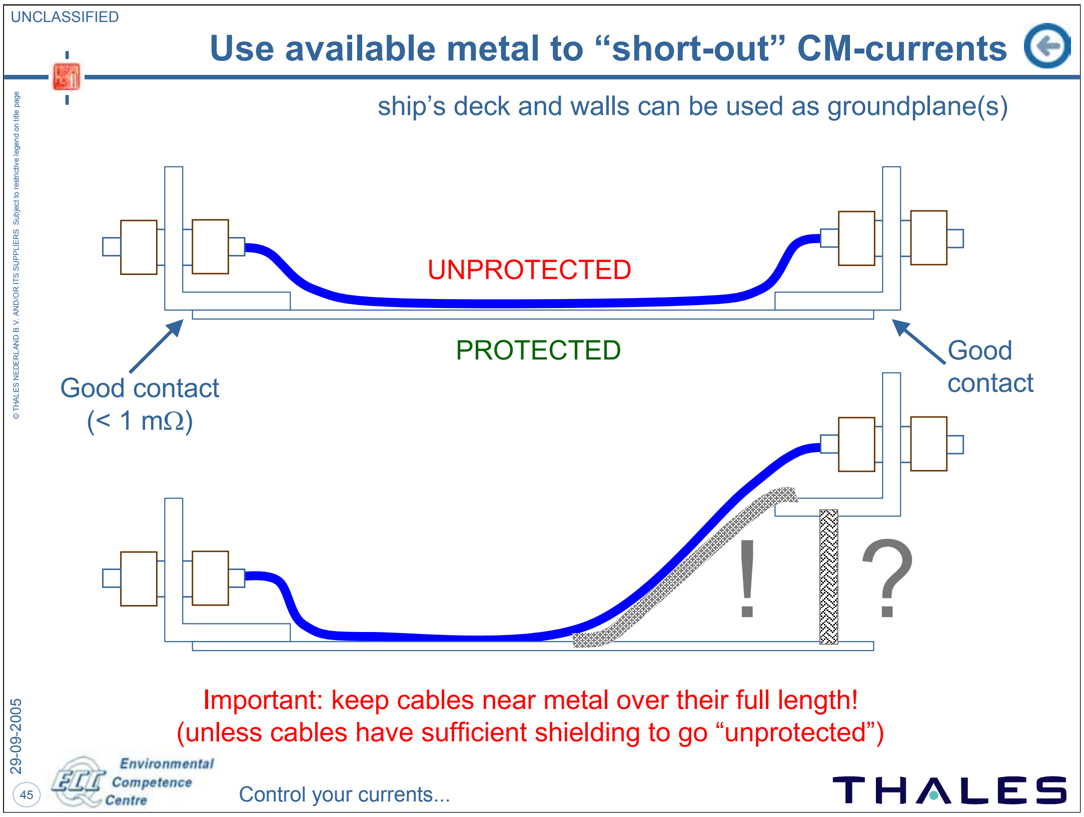
Reduction of crosstalk via Transfer Impedance

provide an alternative path for the (cm-) return current

Model:

Experiment XI



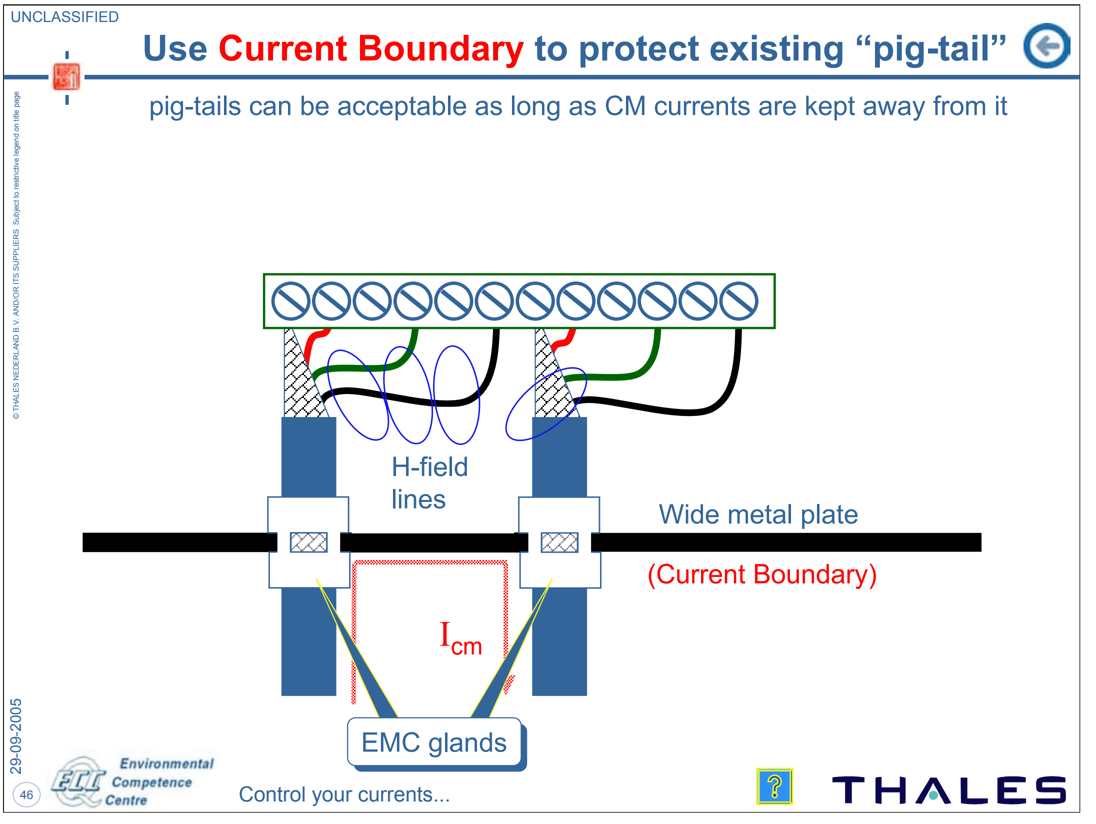


The "neutral" conductor, used as cable guide, can be any sheet or strip of metal available, as long as it is connected galvanically (< 1 mΩ per transition) to the equipment connector plates at either side.

Often, equipment has to be installed on shock mounts in order to protect it mechanically. In such cases, a "solid" connection cannot be made. If the cables are left unprotected, however, for some distance between e.g. the ships' deck and the connector plate, the cable guide function no longer works. Just "grounding" the equipment to the deck using a short, wide strap only provides some reduction in crosstalk. As shown in the drawing, a grounding strap as next to the question mark above is not enough. Not for EMC that is, it is O.K. for safety!

Why doesn't this work? Because the cable guide (the deck) can be considered as a protective shielding of the cable and the "opening" formed at the equipment on the right hand side is the equivalent of a Pig-Tail! (Here for common-mode currents).

To properly protect a cable, the cable guide or other conducting provision should follow the interconnection closely over its full length (no gaps).



The “Pig Tail” was identified as undesirable in interconnections in the module “EMC mechanisms”. Should pig-tails be avoided at all times?

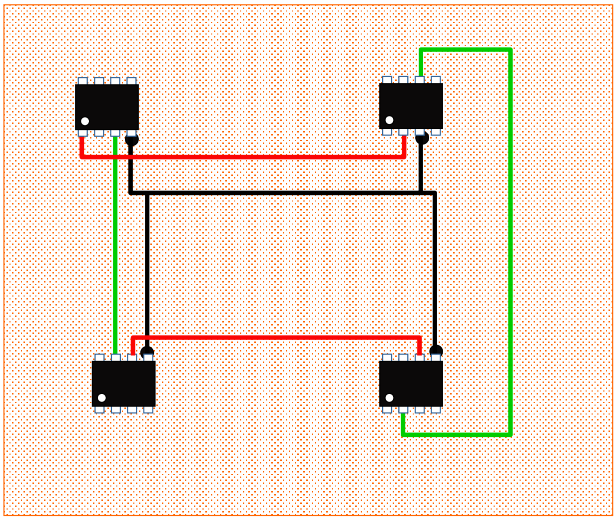
Sometimes, e.g. in installation cabinets, provisions are made using connection rails. The only way to connect a coax cable in those instances is using a pig-tail.

What can we do? Well, we can use a current boundary again! If left unprotected, common-mode currents flowing on the cabling in the field will couple into the pig-tails and generate interference. But, if we install a current boundary in the cabinet wall, these external common-mode currents will never reach the pig-tails! And, a pig-tail only becomes a problem if common mode current flows over it.

A different situation exists if these pigtails themselves also create interference (cm-) currents. In that case, crosstalk could occur within the instrumentation cabinet and the current boundary would only reduce the loop impedance! In such cases, the design decision to use the connection rail technology should be reconsidered, at least for these critical interconnections.

Application to small sized circuits e.g. PCB's

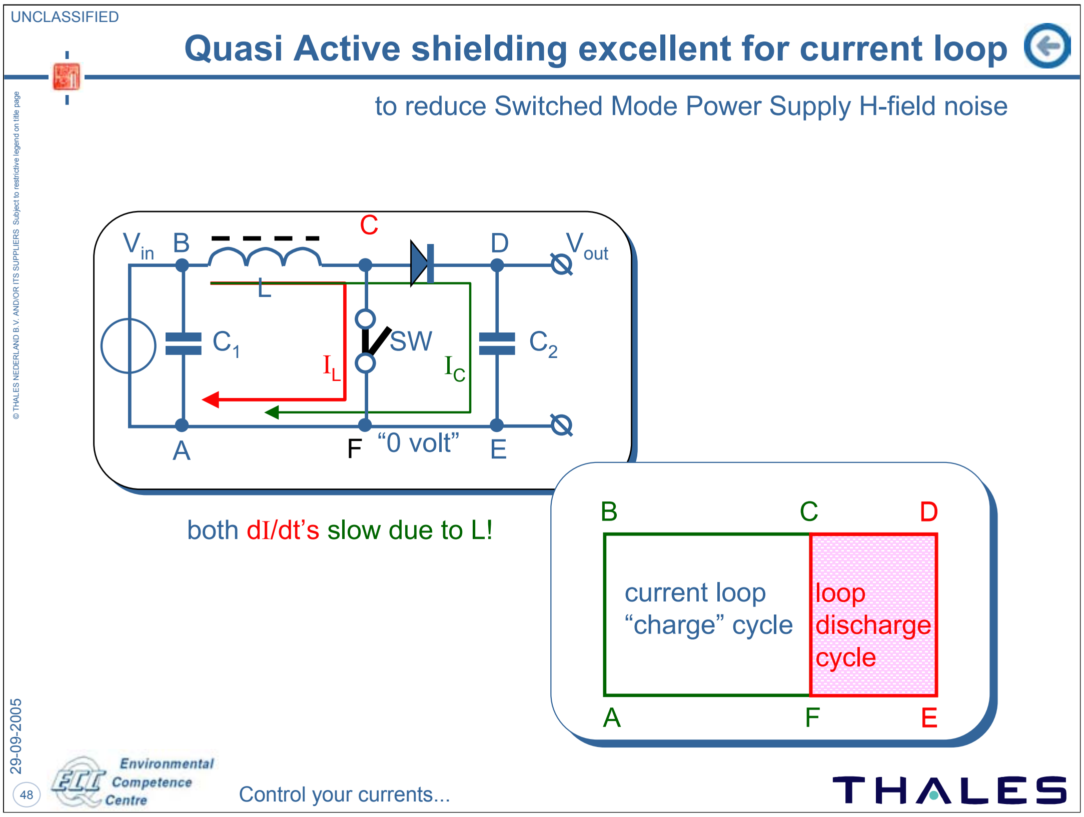
quasi active shielding using a ground plane



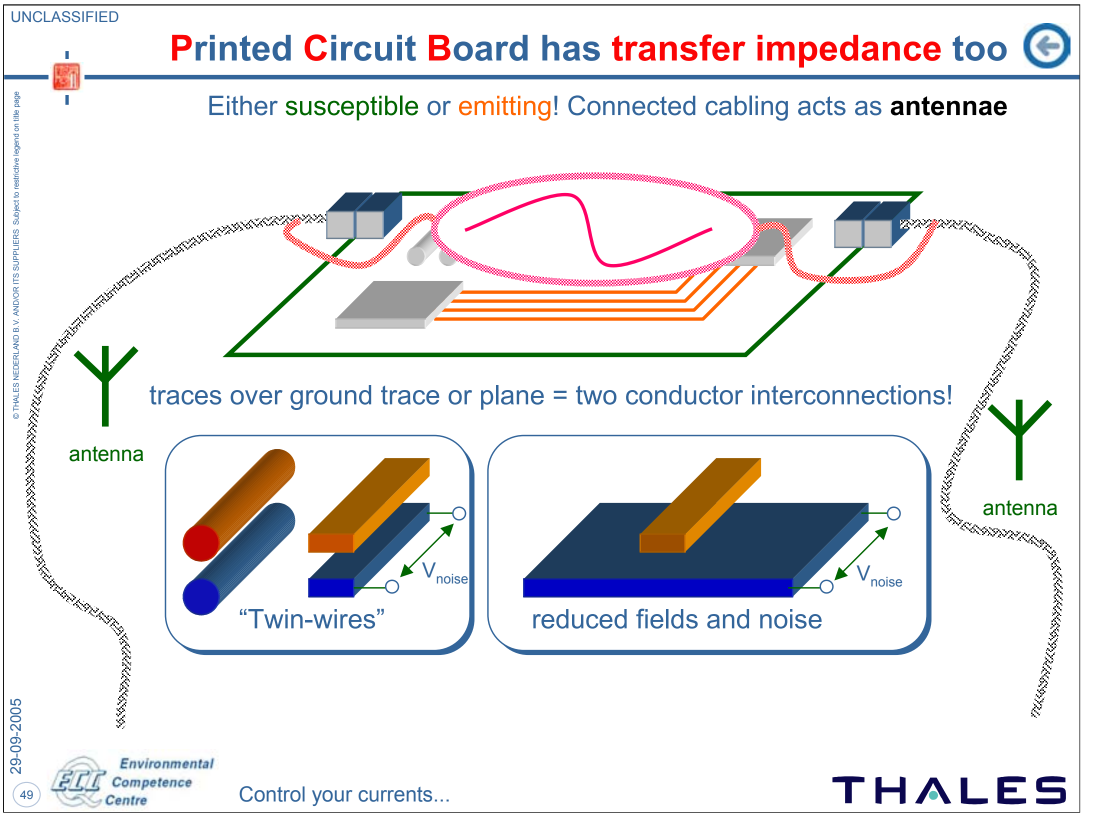
Here too, each return current flows under the signal trace!

The cable guide trick can be successfully applied at any level in a design. Printed Circuit Board interconnections face the same threats as wired versions: individual signals might interfere with each other. By replacing the common return conductor (system ground) by a wide metal plane, all return currents will flow close to the signal traces in this plane. **PROVIDED THE PLANE FOLLOWS THE SIGNALS OVER THEIR FULL LENGTH**! In the case of a printed circuit board with a ground plane, we are discussing differential mode currents now, instead of the common mode versions seen in the inter-cabinet cables.

But, the ground plane approach works for all currents! (The currents cannot distinguish between common and differential mode, only loops and loop area counts).



The inductive (magnetic field) noise created by loop CDEFC of our switched mode power supply example could be reduced by making this loop as small as possible. If this is not enough (component size determines loop area) it is possible to place a "ground plane" under this loop. Due to induction a current will flow under the interconnections/PCB traces in the plane, even if it is not connected to anything. This current produces a magnetic field which opposes the field of the loop we try to shield. This effectively reduces the loop area so less magnetic field will be emitted. This ground plane "trick" is called "quasi active screening".



Printed Circuit Boards (PCB's) are complex sets of interconnections. Each interconnection has some form of transfer impedance. By using a ground plane, the transfer impedance of each of these interconnections is reduced. The noise voltage, appearing over the length of the return conductor due to the differential mode current flowing in the interconnection, is lower if a plane is used instead of a conductor of equal size as the signal conductor.

Similarly, all interconnections in a Printed Circuit Board (PCB) together create a noise voltage over the common return conductor, I.e. the ground plane. This noise voltage appears at the connectors of this PCB and, inherently, depends on the location of these connectors, the currents and frequencies in the traces and the "solidity" of the ground plane (holes, splits etc.).

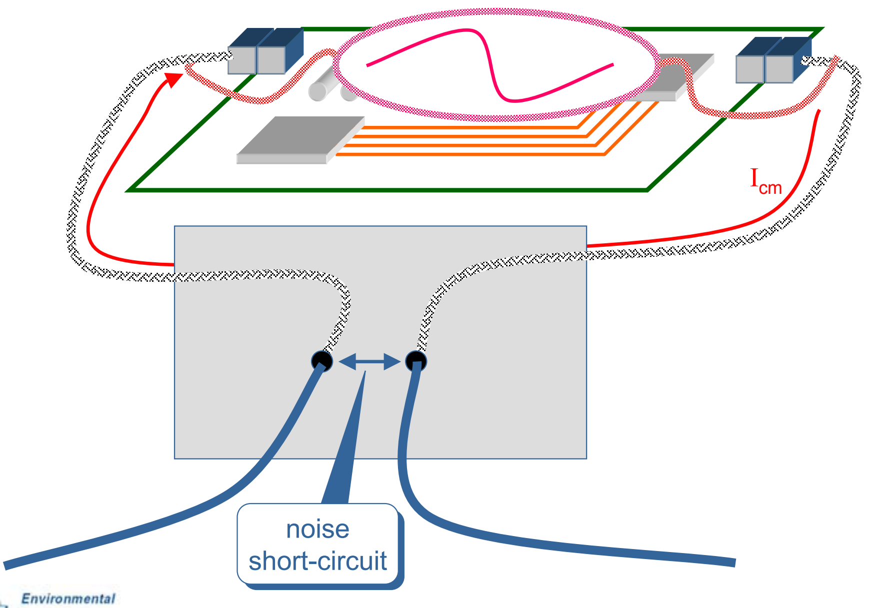
Once present, this noise voltage appears between anything attached to the PCB connectors, to the RETURN conductors, that is. This means the noise will most likely appear between the return conductors, screens of cables attached to the PCB.

These screens thereupon will act as antennae of the noise source (the PCB).

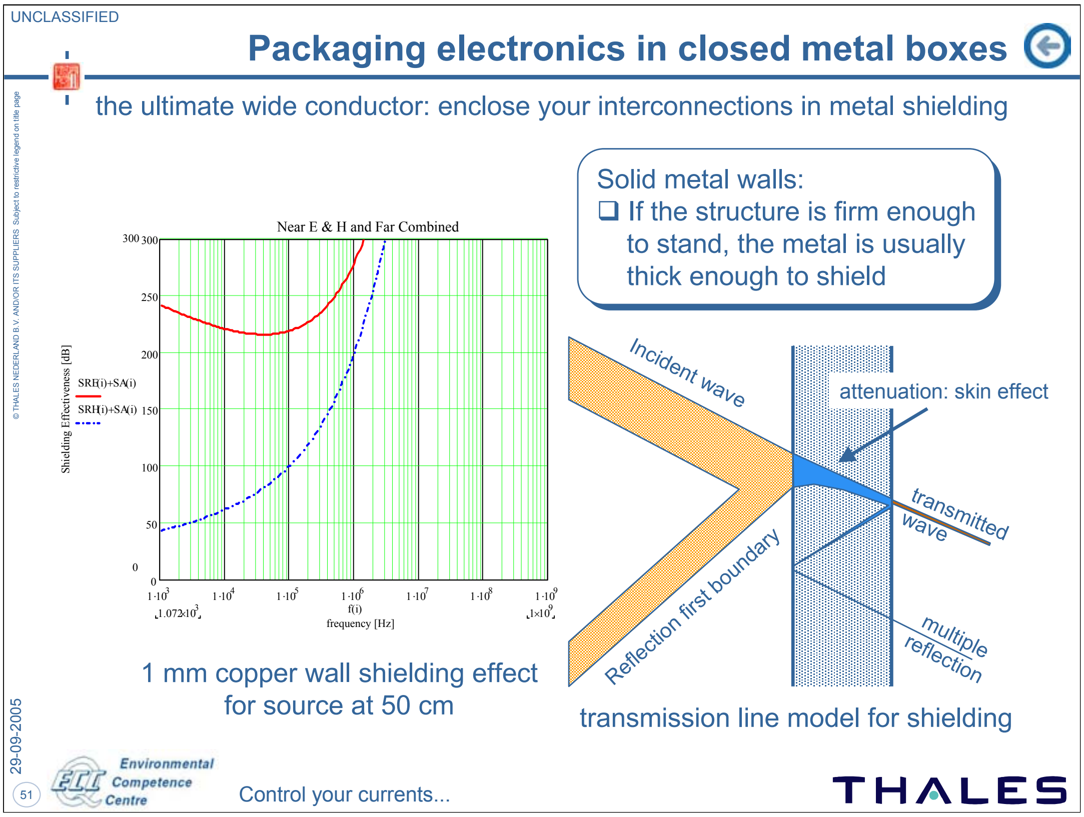
UNCLASSIFIED

Possible solution to PCB noise: add current boundary

separate inside (PCB) from outside (the world)



The only measure that can be taken to reduce the effect of this induced cable noise (apart from reducing the cable length) is the installation of a current boundary that keeps the noise inside e.g. the cabinet in which the PCB is mounted.



All measures up to this point have been aimed at improving interconnections themselves or adding ground planes or cable guides to improve the electro-magnetic (EM) behaviour of combinations of interconnections.

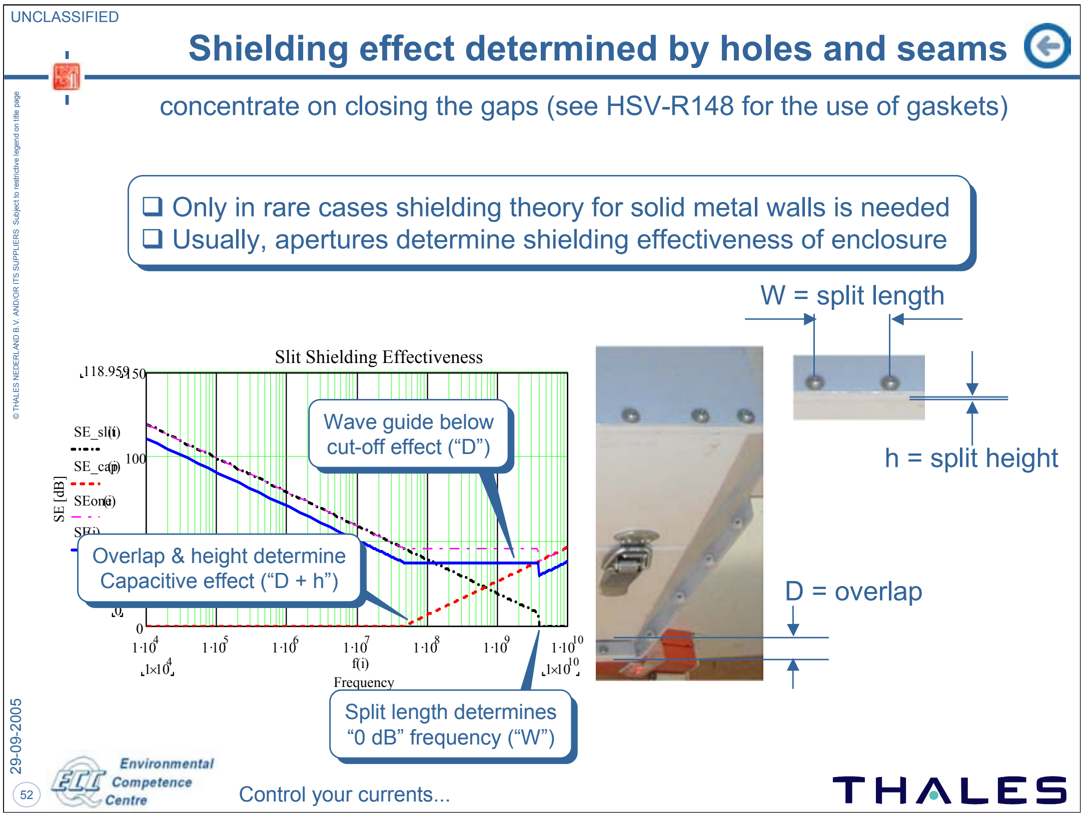
In a hostile electromagnetic environment, like the top side (deck) of a NAVY ship, measures usually have to be taken to protect equipment and the associated interconnections from the EM-fields in this environment. Equipment as a whole can be protected by placing it inside a metal box. If the box is completely closed ("gastight"), the shielding effect is determined solely by the metal wall properties.

Depending on the source of the interference and its distance, solid metal walls shield very well. As shown in the graph above, hundreds of decibels (100 dB is a factor of 100000) are easily attained. This allows the proposition that, when the metal enclosure is strong enough to withstand the mechanical stresses in the environment, it is good enough to shield the electromagnetic fields.

Several theories exist, on of these, the transmission line model, is shown in the drawing at the right hand side of the slide above.

An incident wave hits upon the enclosure. Part of it is reflected, some of it passes. The part that passes is attenuated in the metal based on the skin effect. The remaining wave, upon reaching the other side of the enclosure wall is reflected again while a small fraction enters the inside of the enclosure. The ratio of the incident wave to the amount that eventually passes the wall is called the shielding effectiveness. It is usually expressed in decibels: SE = 20 log ($E_{incident}/E_{transmitted}$).

In this example the ratio of the electric field component, (V/m), is used as measure. It is also possible to use the magnetic field component, (A/m), ratios or even the Power Densities, (W/m^2). In the latter case, "10 log" must be applied.



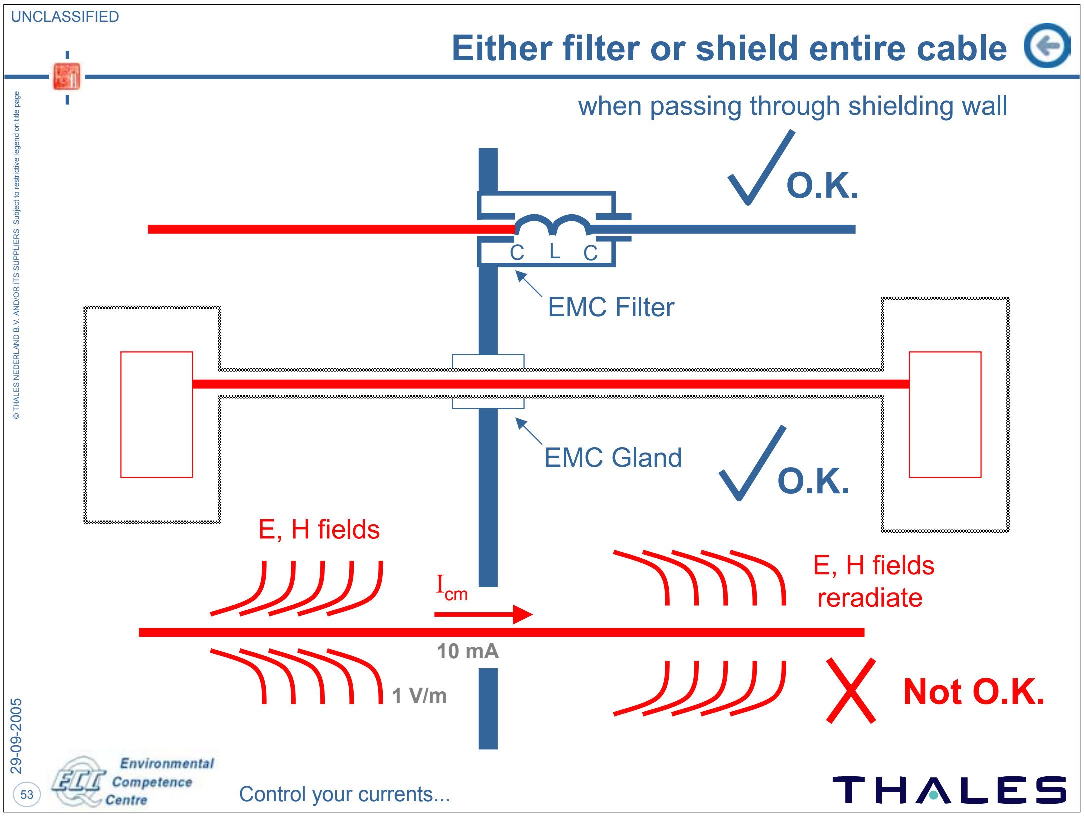
In all practical cases, the Shielding Effectiveness is determined by the apertures in an enclosure. This can be in the form of openings for the entry of light or air or fluids or in the form of splits and cracks in the enclosure wall due to the way it is constructed. Very common apertures are the edges of hatches and doors. The common approach is to make sure the door or hatch makes contact with the wall of the aperture it is supposed to close at many points. This can be using many bolts in case of a hatch or clamps in case of a door.

Following the shielding theory for apertures, the width of a remaining split determines the upper limit of the shielding effect in terms of frequency: a soon as the aperture length is one half wavelength, the wave is passed unattenuated. In the graph above this dimension is indicated as "W". Then there is possible overlap in the seam itself which acts as a capacitor. This capacitive effects attenuates high frequencies. In the graph these two effects are visible as slanted lines:

A decreasing SE value based on the effect of the split length, W; an increasing SE value based on the capacitive effect which is determined by the depth of the overlap and the height of the split. Both effects have a "0 dB" point (no shielding). For the designer of the enclosure it is important to keep the capacitive point well below the cut-off frequency determined by W.

Then there are some extra effects which can be used: height, H, depth, D, and width, W, together form a waveguide. Below its cut-off frequency (determined by W), it attenuates incoming waves. The construction therefore has received the name "Wave-guide Below Cut-Off (WBCO) and it is very effective.

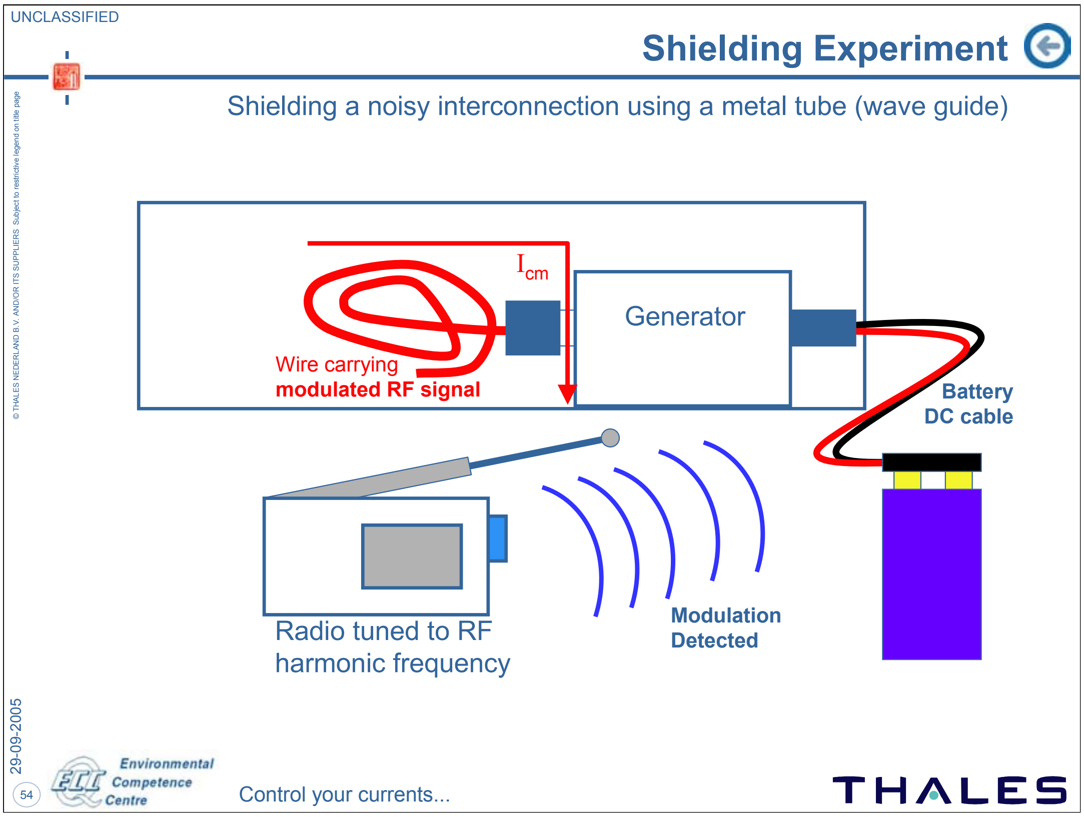
Note that there are other possibilities to reduce the gaps in shields. Gaskets can be used to fill the "open" areas between the contact points (distance "W"). These gaskets discussed (to some extent) in the Thales HSV-R148. The idea of gaskets is to reduce the gap length to a fraction of the critical half wavelength, especially in those cases where a smaller "W" is not feasible and the otherwise required overlap cannot be accommodated.



If cables are not screened, passage through a wall requires a filter. This is a device that only passes low frequencies and provides a low impedance to the wall for high frequencies.

If a conductor is passed through the wall in an insulated fashion, as shown in the bottom drawing above, EM fields will couple to the cable and convert into common-mode currents. These currents are passed through the wall and converted into fields again at the other side. Any shielding properties of the wall are thus seriously compromised.

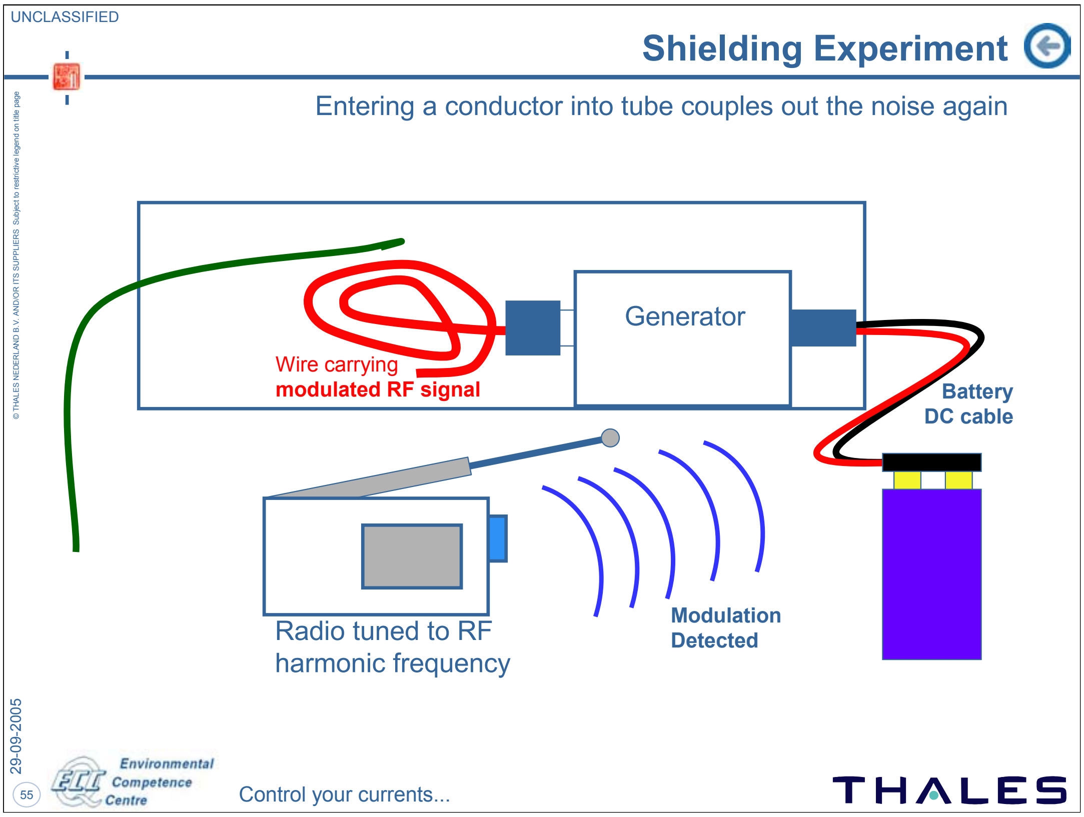
The numbers 1 [V/m] for the E-field level near the cable combined with the resulting 10 mA common-mode current are a “rule of thumb”. It can be used to estimate the effects.



The experiment depicted here can be done to gain insight into the operation of a shielding enclosure. An 8 cm wave guide is used together with a generator that emits an AM modulated high frequency signal (using a wire carrying the signal). This signal is audible on a radio receiver tuned to one of the RF harmonics (about 100 MHz).

If the generator and the attached wire or cable (the “Antenna”) is completely placed inside the wave guide, no sound is audible. This shows, that a shielding enclosure may have apertures as long as the size is considerable smaller than one half wavelength of the RF signal. In this case, the aperture size is about 8 [cm], while the wavelength is 3 [m].

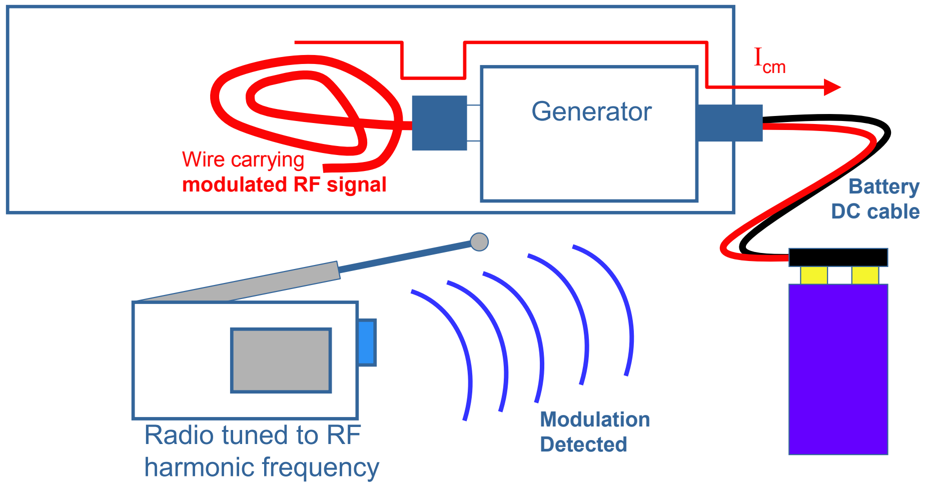
The battery cable may “hang out” as long as the generator case is galvanically connected to the shielding tube.



Any conductor inserted into the shielding aperture, however, produces an audible signal on the radio. And of course, as soon as the (antenna) wire itself is outside the wave guide, the signal is audible.

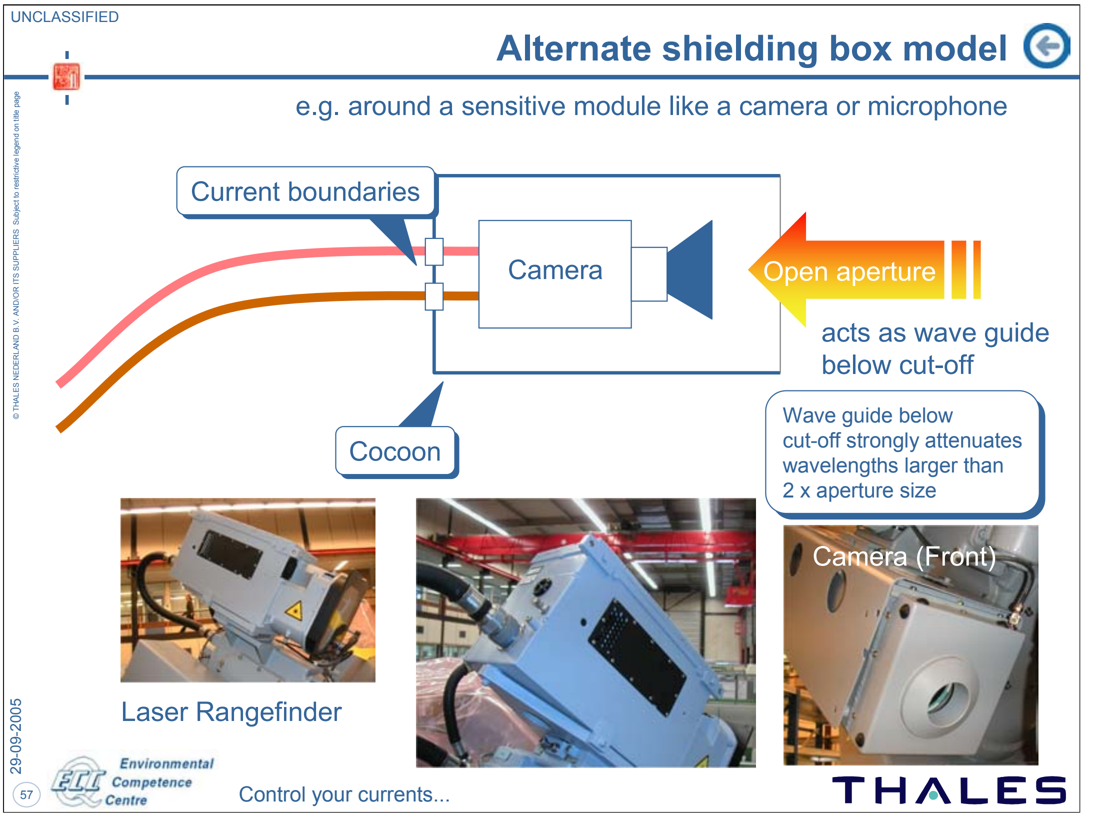
Shielding Experiment

Insulating generator case: battery cable now reradiates noise (antenna)



The battery, powering the generator, hangs outside the shielding metal. This normally is no problem since the signal in the battery wires is pure DC. The power input connector is filtered in the generator. But as soon as the contact between the generator and the wave guide is broken, the modulation is audible again on the radio. The common-mode current, I_{cm}, generated by the antenna wire can now freely flow over the battery cord and re-radiate as EM field.

This shows that any conductor leaving or entering the shielding enclosure should be connected to the shielding wall to avoid fields (currents) from inside to pass through the shield.



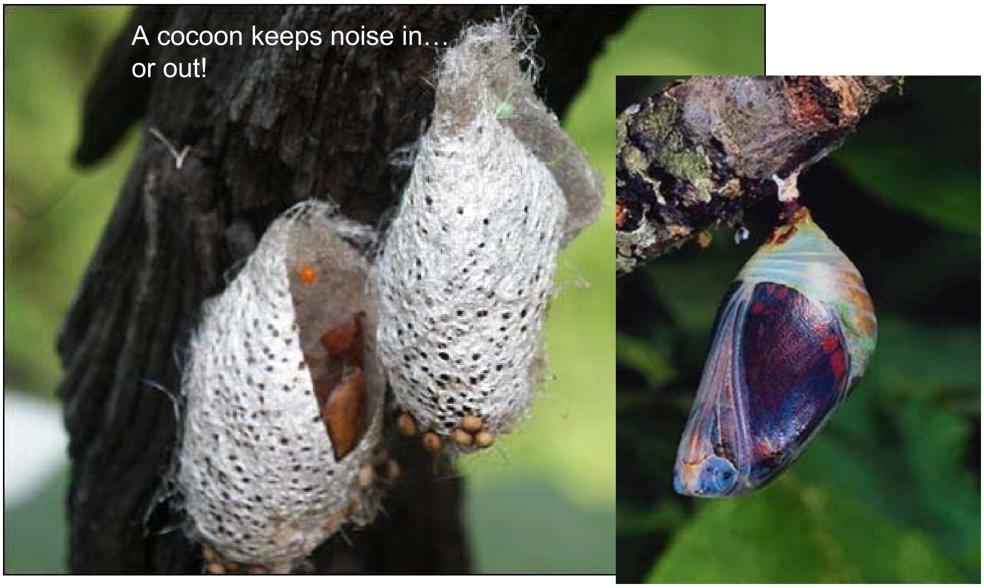
The presented shielding example has many practical examples. It shows that it is not always needed to completely enclose electronics in metal. It is sufficient to keep at least all the wiring inside and provide good current boundaries on the part of the wall where cables come in and out. Of course, these cables are shielded at least in the outside world (assuming a sensitive module). If not, the current boundary is a (low-pass) filter to keep the unwanted frequencies out.

The open end of the enclosure acts like a wave guide. It passes frequencies of which one half wavelength fits into or is smaller than the aperture. Lower frequencies are strongly attenuated.

On the bottom of the slide are some examples of this type of shielding enclosures.

Boxing in of sources or victims: Cocooning

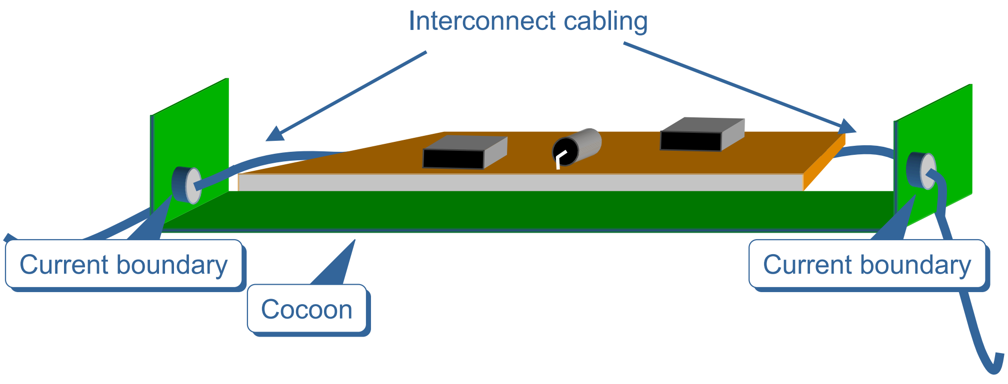
picture link (mind mapping) an easy way to remember the mechanism



It is helpful to think of this type of shielding enclosure as a cocoon. It protects the contents from threats in the outside world. Simultaneously, it protects the outside world from threats in the cocoon (if this would be the case).

The cocooning concept

approach to separating electronic modules (from conducted interference)



Another example of a construction which protects the contents against threats from outside (conducted interference). It is a metal frame which holds the electronics and has current boundaries on each cable exit. It is not so good against radiated interference but, as long as the printed circuit board is close to the metal case, it provides some protection (quasi-active shielding).

Remember: the generator enclosure is also a cocoon

so, cocooning can be applied recursively!

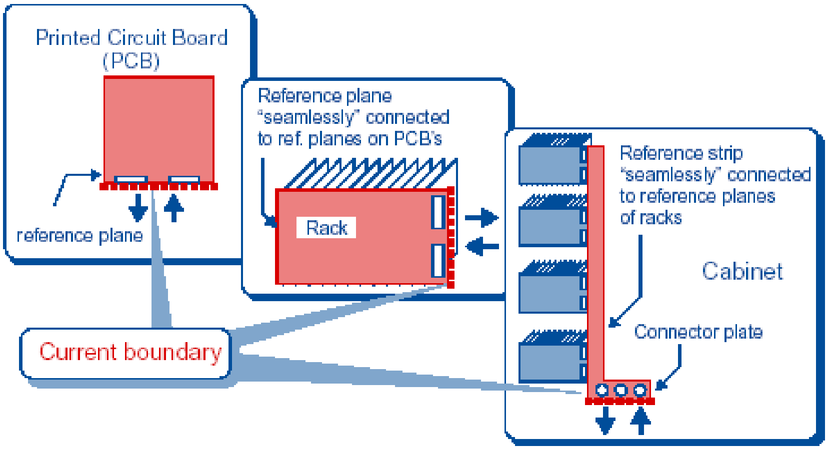
In EMC terms, sometimes referred to as: Multipoint Grounding…

Looking back at the example of the noise generator inside a piece of wave guide, it is obvious that the metal generator case in itself is already a cocoon. Due to the “noisy” wire on the output of the generator, another cocoon is placed around the set to seal it of from the outside world.

This shows that cocoons can be nested, like the well known Babushka dolls.

Multi point reference system

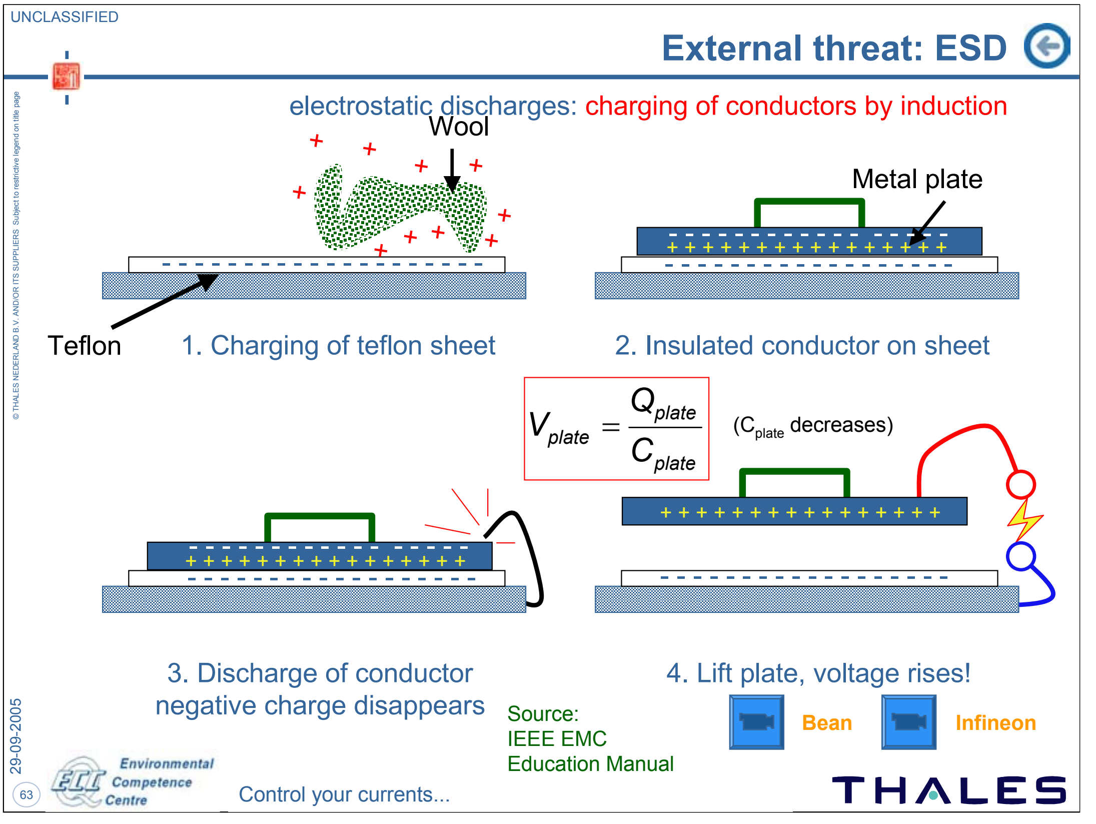
a hierarchy of current boundaries



Printed circuit boards inside racks inside cabinets is another example of nested cocooning. The repeated use of current boundaries prevent interference from travelling from one card towards another. Example: in order to reach a card in the lower card rack starting somewhere in the top rack, a noise signal will have to cross four (4) current boundaries. In terms of “separation”; if 20 dB (factor of 10) of “shielding” is assumed per current boundary, a total of 80 dB separation exists between the cards mentioned.

EMC Cases

ESD
Inductive load switching
Problems and Disasters



An interesting demonstration of the way conducting objects can be charged through influence from a charged insulator is given in the IEEE EMC Education Manual, available for free on the internet.

1. A Teflon plate is charged using a woollen or cotton cloth. The Teflon becomes negatively charged.

2. A metal plate with an insulating handle is placed on the charged Teflon. Electrons are pushed away from the Teflon plate, the bottom becomes positive, the top negative. In principle, no charge is lost, i.e. the plate as a whole is still neutral.

3. By touching the top of the plate with a conductor connected to the bottom plate, the negative charge is drained of, leaving only the negative charge in the Teflon plate and a positive charge in the metal plate. At this point, the top of the metal plate can be touched as the voltage (between top and bottom metal plates) has been reduced to zero by the discharge action. The positive charge on the bottom surface of the plate is still present together with the compensating negative charge in the Teflon.

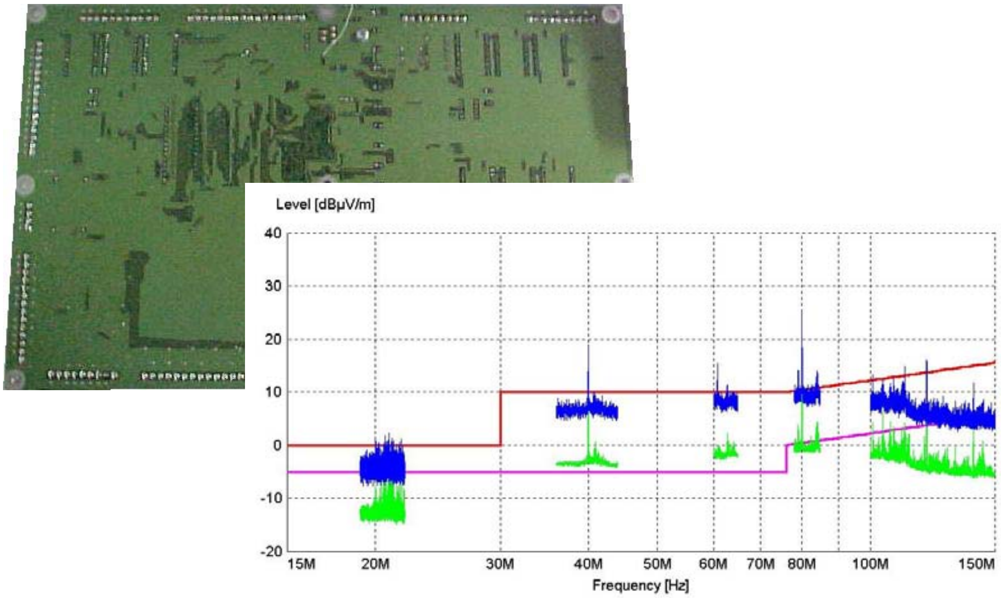
4. Upon lifting the metal plate the voltage is increased based on the equation

Q (charge) = C (capacitance) x V (voltage). C is decreased drastically by lifting the plate, Q remains virtually unchanged as the plate is isolated. A spark can now be drawn from the top plate.

This mechanism is also present when a test engineer (without wrist strap) discharges himself on the equipment cabinet before rising from his chair to work on the electronics.

Actual PCB (+ wiring) emissions

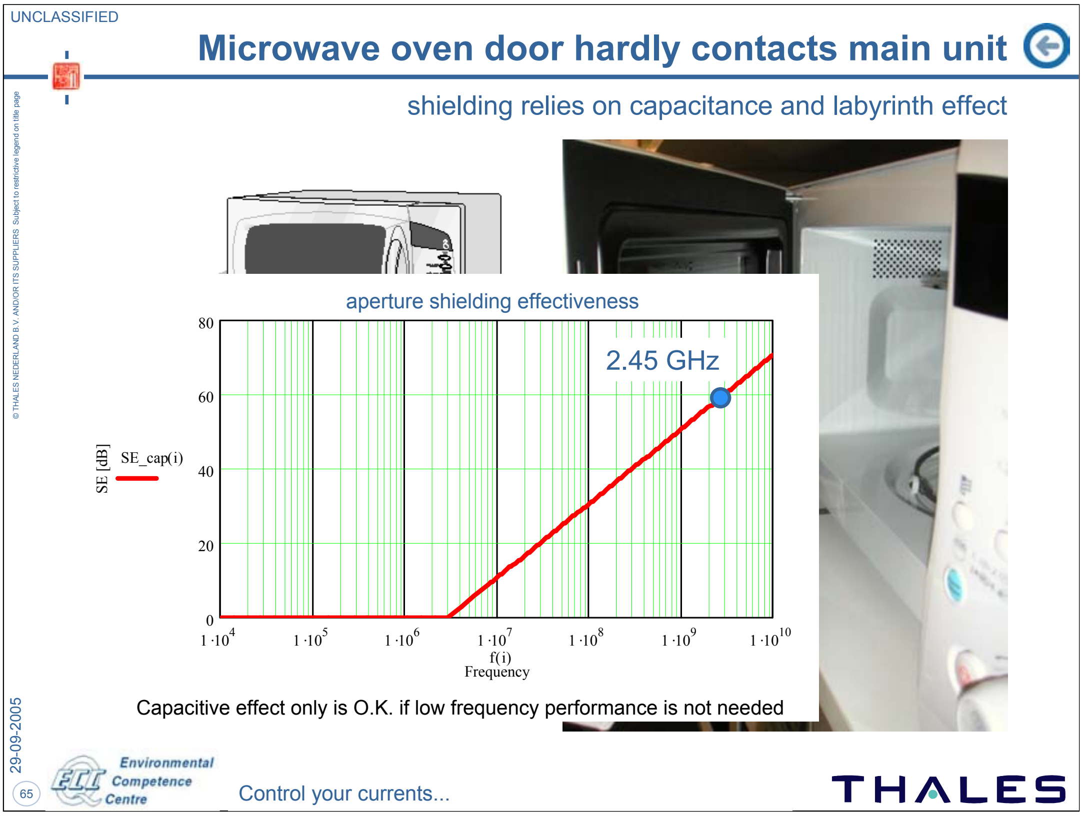
bi-layer technology: holes in ground plane around processor



Another example of a real EMI problem is a printed circuit board inside a large machine. The board was installed in a closed metal box but no filtering had been done. Further, wiring was connected to all edges of the board.

As a result, large limit violations up to 20 dB (factor of 10) were measured. What to do? Filtering all the individual wires was no option.

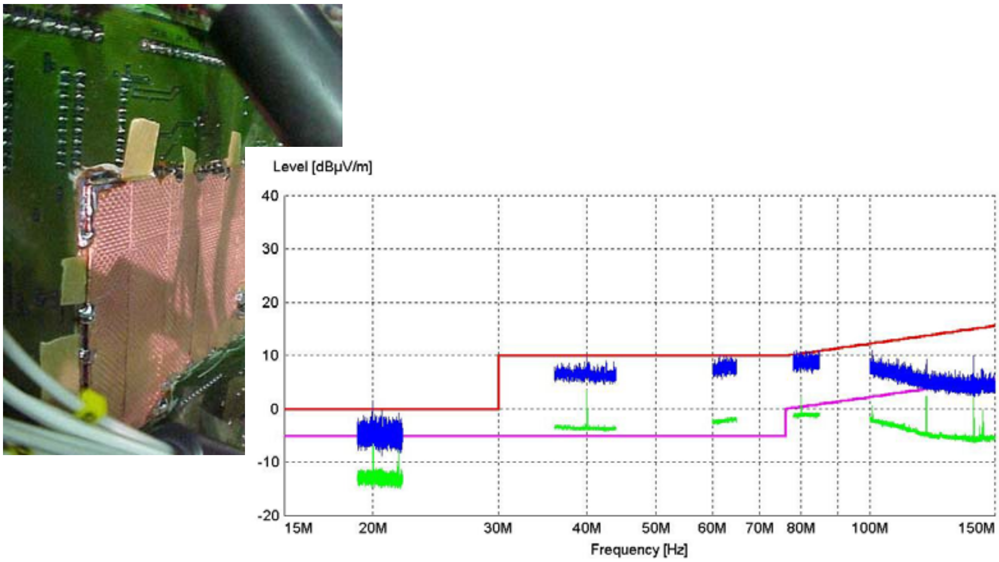
As can be seen from the picture of the board, the ground plane of this 2 layer design had been “broken” at several locations, mainly around the location of the processor.



Almost all microwave ovens do not have any conductive coupling between the door and the main unit. This means only the capacitive effect and possibly some labyrinth effect are available for shielding. But because there is only one (high) frequency to shield, this is a valid option!

Actual PCB (+ wiring) emissions

repair: cover “holes” in the ground plane (shield) using copper foil



As a measure, the area of the board with the large apertures in the ground plane was “repaired” using copper foil. Just closing the gaps in the ground plane solved all limit violations without the need for further measures.

Summary

Basic EMC rules

EMC: The Basic Rules

- ❑ Do not use high frequency signals (voltages and currents)

If you do use them:

- ❑ Do not transport them over large distances

If you do:

- ❑ Provide adequate current boundaries

Connector plates
EMC Glands
Metal cable guides