Abstract

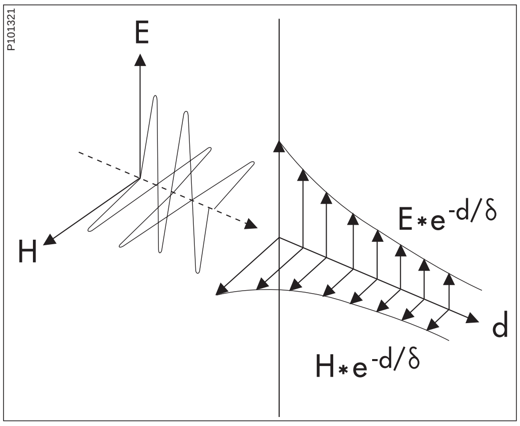

Fig. 1. Electromagnetic Field

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Shielding of Electric and Magnetic Fields by Metal Installation Trunking

Our electromagnetic environment consists of currents and voltages in cables and conductors and of radiated electromagnetic fields. There is a duality between the conducted and the radiated contributions to the electromagnetic environment. Conducted currents and voltages cause electromagnetic fields, and electromagnetic fields cause currents and voltages in conductors.

An electric field is present between two points having different potential. The field strength, measured in V/m, is: $E = U/d$, where U is the potential difference and d is the distance between the points. If the potential difference is constant we have a static electric field. In an electric cable we have mainly a 50 Hz electric field between phase conductor and neutral conductor.

A current flowing in a conductor creates a magnetic field around the conductor. The magnetic field has field strength H, measured in A/m, which is: $H = I/2\pi r$, where I is the current in the conductor and r is the distance from the conductor. A DC current creates a static magnetic field, while an alternating current creates a magnetic field with the same frequency as the current.

Close to the source of the electromagnetic fields, in wavelengths (λ), expressions like inductive and capacitive coupling or spherical waves are often used. At distances above $\lambda/2\pi$, in the far-field area, it is a plane wave with the wave impedance of free space, 377 Ω, as ratio between the electric and the magnetic fields. The electric field E is measured in V/m and the magnetic field H is measured in A/m. The magnetic flux density B is measured in T (Tesla) or, more common, in μT. The relation between magnetic flux density and magnetic field is:

$B = \mu\mu_0 H$, where μ_0 is the permeability of free space and μ is the relative permeability.

There is a great concern over how human beings are affected by electromagnetic fields. For short-term exposures EU Directive 2004/40/EG sets up limits to the field strengths that the working force may be exposed to. For the general public the Swedish Radiation Protection Authority has set up general advices in FS 2002:3 which state other, lower, limits for short-term exposures. The Directive and the advices are applicable for mean values at 6 minutes of exposure. The intention is mainly to prevent emergency damages, mainly through heat. The limits are expressed in current density, specific absorption rate (SAR) and radiation density respectively at different frequencies. Expressed in references values which are easier to measure the limits for exposure for the public are for example:

$B < 100\ \mu T$ at 50 Hz

$E < 41$ V/m at 900 MHz

For long-term exposure the limit for maximum acceptable magnetic flux density will be 0.4 μT as mean value for a year according to several Government Authorities. Swedish Government Authorities have formulated a “Principle of Prudent Avoidance” on how to prevent risks in connection with electromagnetic fields.

Installation Trunking and other Service Carriers made of metal can, just like other metal objects, reflect and absorb electric and electromagnetic fields. Use of metal Trunking and other Service Carriers can contribute to the reduction of electric and electromagnetic fields, and thereby to working in line with the “Principle of Prudent Avoidance”. The attenuation of low frequency electric fields and plane waves is excellent. For low frequency magnetic fields the effect is limited and additional methods must be used to achieve a good reduction of the field strengths.

Abstract

The Principle of Prudent Avoidance

There are advices and Directives concerning the maximum short-term exposure that the public and the work force may be exposed to. These advices and Directives intend to prevent emergency health risks and avoid damages, mainly through heat effects. For long-term exposure from comparatively weak electric and magnetic fields the risks are not well defined. Scientific research indicates an increased risk of cancer and other health problems as a result of long-term exposure even at low field strengths. In addition to the risk of cancer the concern has mainly been for pregnancy disturbances and electrical hypersensitivity.

The following Swedish Authorities jointly recommend “The Principle of Prudent Avoidance”:

The Work Environment Authority, The National Board of Housing, Building and Planning, The National Electrical Safety Board, The National Board of Health and Welfare and The Radiation Protection Authority.

If measures, which generally reduce exposure, can be taken at reasonable costs and other consequences it should be sought after to reduce fields which differ from what can be regarded as normal in the environment at hand. For new electrical installations and buildings, the planning should include design and positioning so that exposure is limited.

Shielding

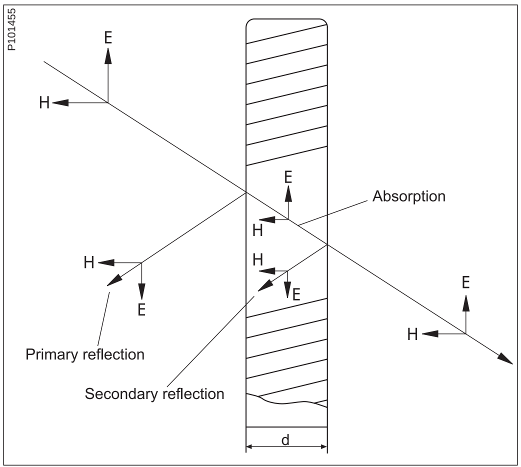

Fig. 2. Absorption and Reflection Attenuation

Shielding

The shielding effect from metallic materials is the result of two different phenomenon, reflection attenuation and absorption attenuation (Fig. 2). The following paragraphs on reflection attenuation and absorption attenuation are valid for a perfect shield having no openings, slots, holes or similar, and which is infinite or totally enclosed. The total attenuation expressed in dB is the sum of the reflection attenuation expressed in dB and the absorption attenuation expressed in dB.

Briefly on dB

The easiest way to state a ratio between two values is often to state is as the logarithm of the ratio. Logarithms and exponents are different ways to express the same ratio as when:

$p = b^x$ then $x = {}^{b}\log p$, i.e. x = the logarithm with base b of the number p.

The most common base is 10; it is so common that ${}^{10}\log a$ is usually written as just log a. When the logarithm with base e = 2.71828 is used, as it is in many mathematical formulas, it is usually written as ${}^{e}\log a = \ln a$ = natural logarithm of a.

When the ratio between two powers P1 and P2 is needed, it can be given as:

α = 10*log (P1/P2), which gives the ratio expressed in dB.

If the ratio between two voltages V1 and V2 is needed the corresponding expression is:

α = 20*log (V1/V2), in dB. The factor 20 instead of 10 comes from the fact that the power is proportional to the voltage square.

When working with logarithms it must be remembered that:

log (a*b) = log a + log b

log (a/b) = log a – log b

The effect of more than one shield can easily be calculated as the sum of the attenuation of each of the shields if the attenuation is expressed in dB. For voltage, current, electrical field strength and magnetic field strength 20 dB corresponds to a factor of 10, 40 dB means a factor of 100, 60 dB means a factor of 1000 and so on.

For power and power density 10 dB corresponds to a factor of 10, 20 dB means a factor of 100, 30 dB means a factor of 1000 and so on.

Absorption Attenuation

The part of the electromagnetic field which enters into a metal shield causes losses (eddy currents) in the material. The thicker the metal shield is and the higher the frequency of the electromagnetic field is the larger will the losses be and they are expressed an absorption attenuation. The thickness of the shield, d, is stated in skin depths δ, defined as:

$\delta = 1/(\pi\mu_r\mu_0\sigma f)^{½}$

where

σ = the conductivity of the material, e.g. $\sigma_{Cu} = 5.88*10^7$ (S) and $\sigma_{Al} = 3.45*10^7$ (S)

$\mu_0 = 4\pi*10^{-7}$ = the permeability of free space

μ_r = the relative permeability of the material; $\mu_r = 1$ for common, nonmagnetic material

f = frequency

$\omega = 2\pi f$ = angular frequency

The attenuation factor of absorption attenuation is $A = e^{-d/\delta}$.

At the distance $d = \delta$ into the shield $A = e^{-1}$ which gives an absorption attenuation of 8.69 dB. At this distance, one skin depth, the field strength is 0.37 *E_0, where E_0 is the field strength at the outer surface of the shield. At 50 Hz the skin depth of Cu is a little less than 1 cm and for Al a little more than 1 cm. An Al-shield with thickness 3δ must be approximately 3 cm thick. At the inside of the shield the field is then 0.05 * E_0, where E_0 is the field strength at the outer surface of the shield. The absorption attenuation is then 26 dB.

Shielding

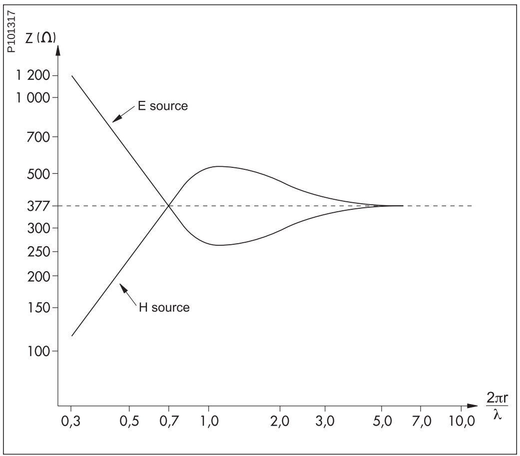

Fig 3. Wave impedance of fields from high and low impedance sources at different distances from the source

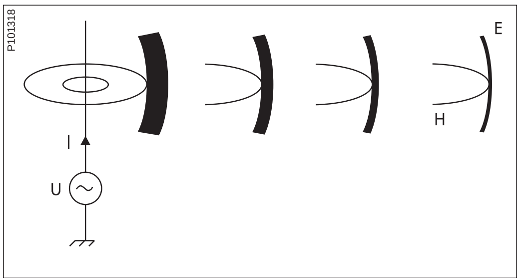

Fig 4. High impedance source sends out mostly E-field in the near zone

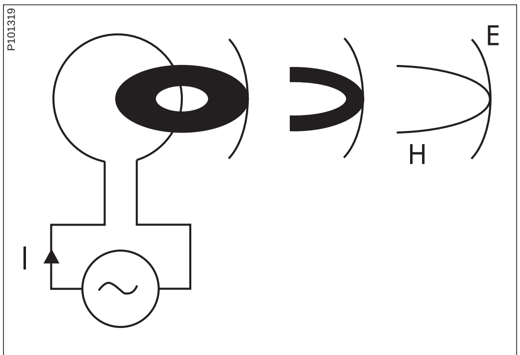

Fig 5. Low impedance source sends out mostly magnetic field in the near zone

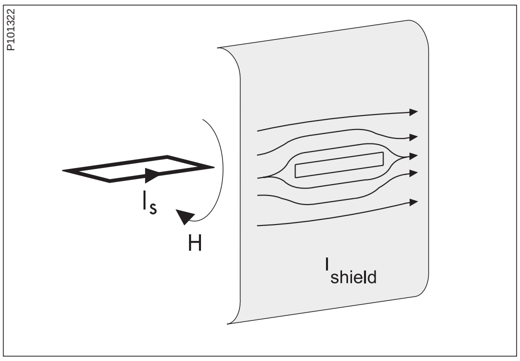

Fig 6. Minimum effect of the slot

Other values of d gives:

$A = 8.69 \cdot d/\delta$ dB

At higher frequencies the skin depth decreases rapidly. For example the skin depth is:

$\delta_{Cu,\ 500\ kHz}$ = 0.093 (mm) = 93 (μm)

$\delta_{Cu,\ 1MHz}$ = 0.066 (mm) = 66 (μm)

$\delta_{Cu,\ 10MHz}$ = 0.021 (mm) = 21 (μm).

Even a thin foil gives good absorption attenuation at these frequencies.

Reflection Attenuation

Reflection attenuation is a result of the mismatch between the impedance of the electromagnetic field, i.e. the ratio between the electric field and the magnetic field, and the impedance of the metal shield. At distances greater than $\lambda/2\pi$, in the far field zone, the impedance is that of free space, Z_0, which is 377 Ω (Fig. 3). The impedance of the metal shield is:

$Z_S = (\omega\mu_r\mu_0/\sigma)^{1/2}$

which for all metal materials and realistic frequencies is much less than 377 Ω. It causes a considerable mismatch and the reflection attenuation is:

$R = 4Z_0Z_S/(Z_0 + Z_S)^2$

The reflection attenuation decreases with increasing frequency; it becomes more and more difficult to reflect the fields when the frequency increases.

In the near zone, i.e. at distances less than $\lambda/2\pi$, the wave impedance depends both on the source impedance and the distance to the source. A source with high impedance, like a dipole antenna, mainly sends out electric field in the near zone. The impedance is high near the source, counted in distance $\lambda/2\pi$, but decreases with increasing distance (Fig. 4 and 5).

A source with low impedance, like a conductor carrying relatively high current, sends out mainly magnetic field in the near zone. The impedance is low near the source, counted in distance $\lambda/2\pi$, but increases with increasing distance. The further away from the source, the closer to 377 Ω will the wave impedance be.

The wavelength for 50 Hz is 6000 km, so the change from near zone field to far zone field is at about 1000 km distance. For all field strengths necessary to take into account one is always in the near zone and very close to the source. The wave impedance close to a low impedance source is very low, and the impedance of the metal shield is also very low. This gives good matching and the magnetic field passes right through the shield. This is the reason why it is so difficult to shield low frequency magnetic fields! For a high impedance source sending out low frequency electric fields there is a very large mismatch and a lot of the field is reflected. For low frequency electric fields the reflection attenuation gives the major contribution.

Realistic Shields

In the real world there are no infinite shields and no totally enclosed shields. Every realistic shield admits some kind of communication between the outer side and the inner side of the shield. It can be cable inlets, openings for displays and control switches etc., ventilation or just for installation inside the shield or passage through the shield. For a realistic shield the attenuation is mostly dependent on how well sealed the shield can be made, i.e. on how small all openings, holes and slots are in relation to the wavelength of the incoming field. The effect of slots etc. also depends on how they are positioned in relation to the direction of the incoming field. If the direction of the field is not known in a specific situation it is common to presume a worst case, i.e. that the field comes in the worst possible direction where the slot gives the worst possible result (Fig. 6 and 7).

A simplified but often very useful way to approximate the attenuation, shielding efficiency SE, from a shield with a slot of largest opening L is:

$SE = 20 \log (\lambda/2L)$ dB

Measured Shielding Effect

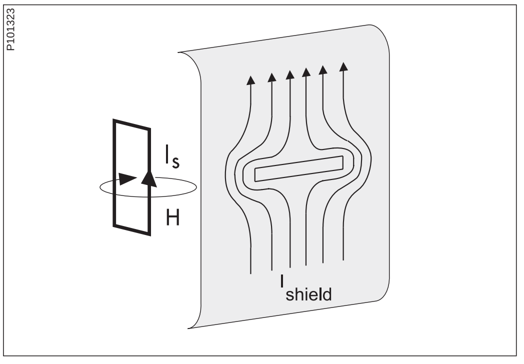

Fig 7. Maximum effect of the slot

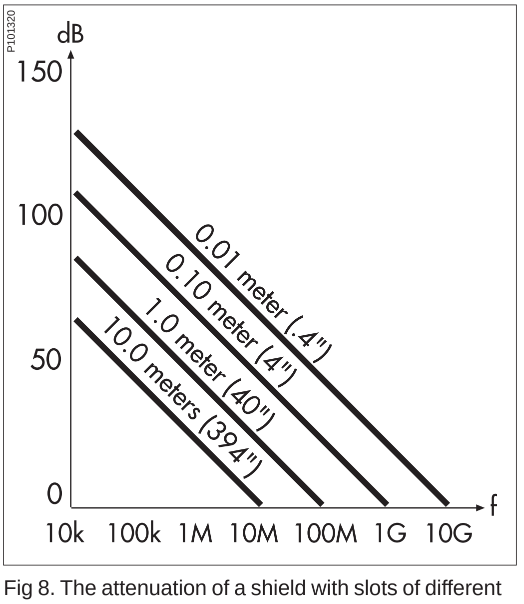

Fig 8. The attenuation of a shield with slots of different lengths

The formula means that when the slot has the length one half wavelength the attenuation is zero. A slot with length λ/30 gives an attenuation of approximately 23 dB. When the slot is very short in relation to the wavelength of the field the effect of the slot is limited (Fig. 8).

Examples of wavelengths at different frequencies are:

$\lambda_{50\ Hz}$ = 6000 (km)
$\lambda_{100\ kHz}$ = 3000 (m)
$\lambda_{10\ MHz}$ = 30 (m)
$\lambda_{100\ MHz}$ = 3 (m)
$\lambda_{1\ GHz}$ = 0.3 (m)

For a worst case the opening forces the current in the shield to make the largest possible detour. In the same way the effect is minimized when the opening affects the current in the shield as little as possible. If the opening is made electrically shorter by bridging it with conductive connections the effect is reduced correspondingly.

If several openings exist closer to each other than λ/2 they will together cause a lower attenuation compared to just one opening. A simplified formula gives the attenuation of a shield with n openings each with largest dimension L as

$SE = 20 \log (\lambda/2L) – 20 \log (n)^{1/2}$ dB

Shielding Provided by Installation Trunking

Metal installation Trunking such as INKA, TKA, DFK, TAS+ and FED will work as a static shield regardless of whether it is earthed or not and provide a certain, low attenuation. To make full use of the possible shielding characteristics both at low, medium and also at higher frequencies Trunking bases, Trunking fronts, Stop ends etc. shall be earthed with additional potential equalization conductors. If the earthing is made only to fully utilize the shielding characteristics, the earthing conductors are not allowed to be yellow-green. If on the other hand the earthing is also made for electrical safety reasons the earthing conductors must be yellow-green.

The shielding effect of the Trunking is reciprocal, i.e. it shields fields from disturbing cables in the Trunking so that the electromagnetic environment is minimally affected, and it shields sensitive transmission in cables inside the Trunking from disturbing fields from the environment.

The shielding effect can be expected to be very good for electric fields at low and medium frequencies and for electromagnetic fields at medium frequencies. At low frequencies the effect of slots and openings at Trunking fronts and service content is expected to be small as all openings are short in relation to the wavelength. The shielding effect for low frequency magnetic fields can be expected to be very limited.

Measured Shielding Effect of INKA and TAS+ Trunking

In a thesis work in year 2006 Claes Ring and Kristian Stafström from the University Collage of Borås measured the shielding characteristics of INKA and TAS+ Trunking at low and medium frequencies. The thesis work “Shielding Effectiveness of Cable Channels” was carried out at SP Technical Research Institute of Sweden in Borås and supervised by Mattias Engström of SP. Part of the work was to attempt to find a measurement method to establish the shielding characteristics at higher frequencies. These measurements were performed, but the results are partly hard to interpret as measurements on Trunking parts with a length which is not a very small part of a wavelength gives resonances and reflections which mask the shielding characteristics.

At low frequencies, mains 50 Hz up to the 5:th harmonic 250 Hz, both INKA Trunking made of Al and TAS+ Trunking made of steel attenuated the electric fields more than 60 dB, i.e. to less than 0.001 (one part in a thousand) of the fields without the metal Trunking. These measurements were performed on 2.5 m long Trunking parts with both Trunking base and Trunking front connected to earth.

Measured Shielding Effect

Even with an opening of 10.5 cm in the Trunking front, corresponding to an electrical outlet installed in the Trunking, the attenuation was above 41 dB. When the Trunking front was completely removed the attenuation was still better than 28 dB. The attenuation of magnetic fields was limited.

At medium frequencies measurements were made from 300 kHz up to 80 MHz. For frequencies when the Trunking length was no longer a negligible part of the wavelength the measurements showed resonances and reflections.

The measurements where made with a conductor in a PVC Trunking as transmitter, driven from a network analyser, and a conductor in a PVC Trunking as receiver to get a reference value for conductors without shielding Trunking. The measurement set-up was placed above an earth plane. The receiver was than replaced by a conductor in a metal Trunking. The difference between the received signals in the two measurements is due to attenuation in the metal Trunking.

To reduce the effect of reflections and resonances the measurements were also made with 1 m long Trunking parts and finally also on 0.3 m long Trunking parts. When the coupling to the earth plane was reduced by placing the Trunking vertically the effects of reflections and resonances was minimized.

The attenuation of earthed INKA and TAS+ Trunking was measured and was above 40 dB up to about 16 MHz.

For frequencies in the range 80 MHz up to 2 GHz the attenuation could not be measured with the used method. Reflections and resonances masked the attenuation.

Theoretically TAS+ Trunking, having contact ridges making contact between Trunking front and Trunking base at regular intervals and thereby giving shorter slots, should give better attenuation at high frequencies than INKA Trunking which have no contact ridges.

To summarize the Trunking gives very good attenuation of electric fields at 50 Hz and at 3:d and 5:th harmonic. At medium frequencies the Trunking gives good attenuation of electric and electromagnetic fields. At high frequencies the effect of slots and openings is expected to gradually reduce attenuation at increasing frequencies. The Trunking shall be earthed in all cases.

Measured Attenuation between Conductors in Different Chambers in the same INKA and TAS+ Trunking respectively

In the same way as for the other measurements at medium frequencies the attenuation between transmitting conductor in one chamber and receiving conductor in the other chamber was measured in INKA and TAS+ Trunking with 2 chambers. The Trunking length was 1 m and the Trunking was placed vertically above the earth plane. The attenuation was above 40 dB at frequencies up to about 10 MHz. A trunking with two chambers gives very good attenuation between cables installed in different chambers at low and medium frequencies.

At frequencies in the range 80 MHZ up to 2 GHz attenuation could not be measured with the used method. Reflections and resonances masked the attenuation completely.

Reduction of Low Frequency Magnetic Fields

As the wave impedance from a low impedance source is very low close to the source, and the impedance of a metal shield is also very low, we have a good matching and the magnetic field mainly passes right through the shield. If we try to use shielding to attenuate low frequency magnetic fields we need shields made of thick material, typically several cm in thickness, or made of special materials with very high permeability like μ–metal, Permalloy or Hypernom.

Reduction of Low Frequency Magnetic Fields

There is however another way to avoid low frequency magnetic fields and that is to very carefully make sure that all the current to a load and all the return current is conducted in phase conductor and neutral conductor placed very close to each other. If the currents are exactly equal and flow in opposite directions the net magnetic field is very small at distances which are large compared to the distance between the conductors. In 3-phase power feeds 5 conductor systems shall be used och in one phase systems separate neutral and PE conductors shall be used, to prevent any part of the return current from flowing through PE conductors or building structures.

An installation with 4 conductor system, i.e. with a common PEN conductor, creates several possible return paths for the current; stray currents are caused and it will be difficult to keep the magnetic flow density at low magnitudes. The situation can however be improved through installation of draining transformers, lowering the impedance in the return conductor and thereby reducing the stray currents.

Summary

Metal trunkings provide a very good shielding effect of electric and electromagnetic fields at low and medium frequencies. In this case it is important that all metal parts are earthed. For magnetic fields, the shielding effect is limited. At high frequencies there are no usable results with the current technique of measuring.