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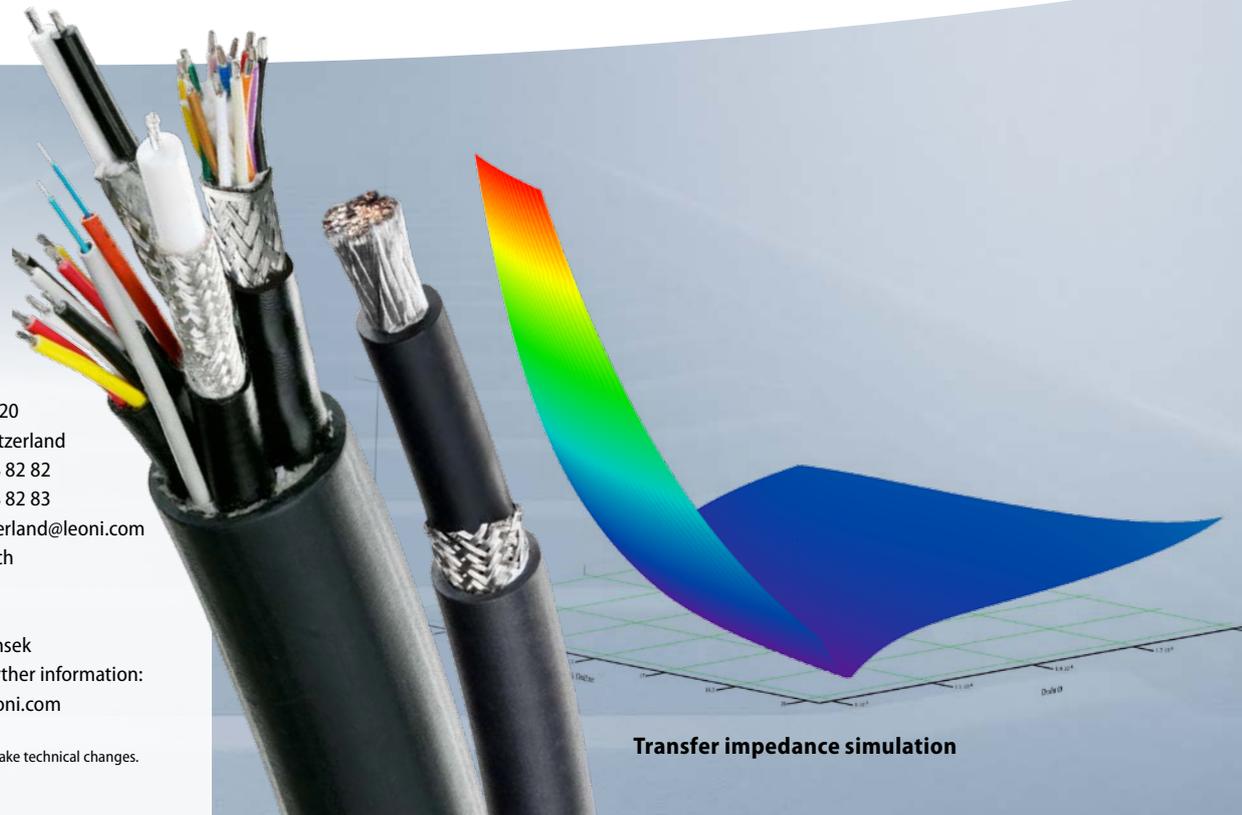
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Transfer impedance simulation

The art of creating EMC compatible cables

Those who are designing EMC-compatible cables, try to shield them optimally. They must consider complex coupling mechanisms. This is because it is expected that the cables will not be affected by external interference fields or that itself acts as a source of interference.

EMC shielded cables are very attractive or even indispensable for many applications. An EMC shielded cable is expected not to be affected by external interference fields nor to act as a source of interference. This requirement leads to the question: what exactly is an EMC compatible shield?

Nowadays, an economic EMC shield (braid) is mostly connected with a minimum coverage of 85%. For many consumers this provides sufficient EMC shielding, when combined with an aluminium foil (longitudinally wrapped or wound axially).

But because of the flexural stiffness, aluminium foil is not ideal for applications which require flexibility. The general statement concerning braided shields is that the shielding effect increases with a higher coverage. The complex coupling mechanisms involved, however, mean this statement is not true for products with braided shields above certain coverage.

The transfer impedance is a very important parameter of shielded cables. The source of interference is coupled with the interference sink via the transfer impedance. Today, the coupling mechanism and the measurement methods are very well described in many standards.
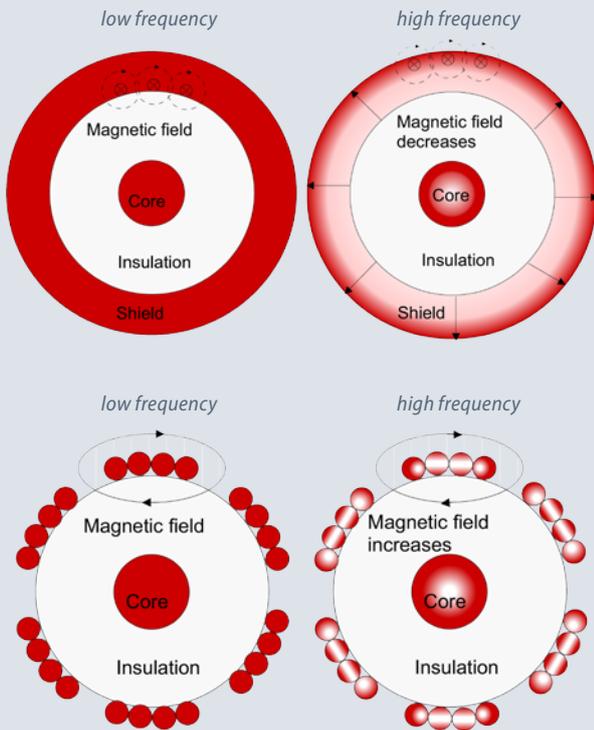
Fig. 1 (above): Shielding effect of a complete shielding
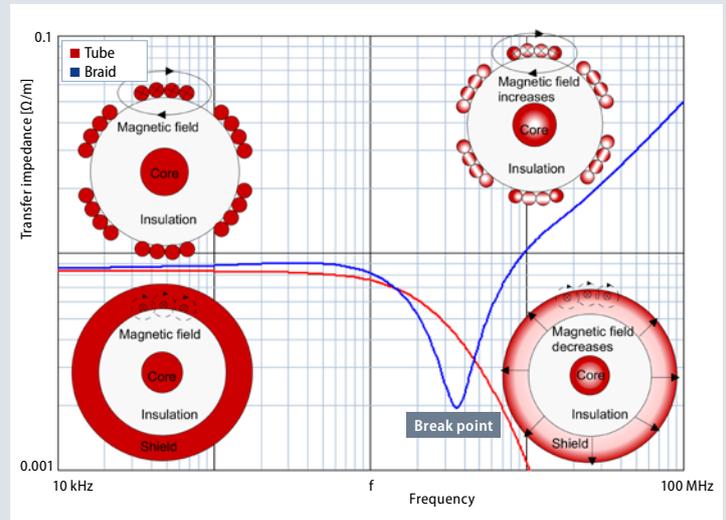Fig. 2 (below): Shielding effect of a braid

Fig. 3: Transfer impedance, complete shielding (tube) and braid

We first consider the topic complete shielding (solid metal tube) and then we will analyse the complex coupling in the case of a braid. When there is a DC voltage or there are low frequencies, the electrical current in the shield is distributed evenly and homogeneously as shown above (*Fig. 1, left)*. The inductive coupling is negligibly small compared with the conductive coupling. The source of interference and the interference sink have the same ground loop. It is not different from typical commonmode impedance coupling; this, however, applies only to low frequencies. In this case, the transfer impedance corresponds to the DC resistance of the shield.

Shielding and transfer impedance

At high frequencies there are further effects. Because of the skin effect, the current is displaced to the outside (*Fig. 1, right)*.
As a consequence, the current inside the shield gets smaller and the magnetic field which is generated by the shield current is reduced inversely proportionally to the frequency. Here, the skin effect has a positive impact in favour of an improved shielding. This phenomenon, however, appears only for cables which have a closed complete shielding. For braided shields the situation is even more complex. At low frequencies the current distribution is approximately homogeneous. Therefore, the coupling mechanism is exactly the same as for a complete shielding.

With increasing frequency, the braided shield can behave like a closed shield up to a certain frequency. (This does not apply to all braids) Then the fields emerge through the apertures (holes in the braid) so that external interference propagates (*Fig. 2)*. Now the transfer impendance increases proportionally to the frequency and the common mode impedance coupling is overlayed by the magnetic coupling. The situation is comparable with a typical frequency-dependent reactance.

In *Fig. 3*, typical frequency-dependent transfer impedance of braided and tubular shields are illustrated. The red curve shows the transfer impedance for a closed shielding. The blue curve represents the braided shield. Up to the break point, there are no major differences. However, such a break point does not appear at all braids. Most of the braids with 85 % coverage show only a moderate break point or none at all. After this point, i.e. at higher frequencies, the perceptible disturbance of the magnetic field begins.

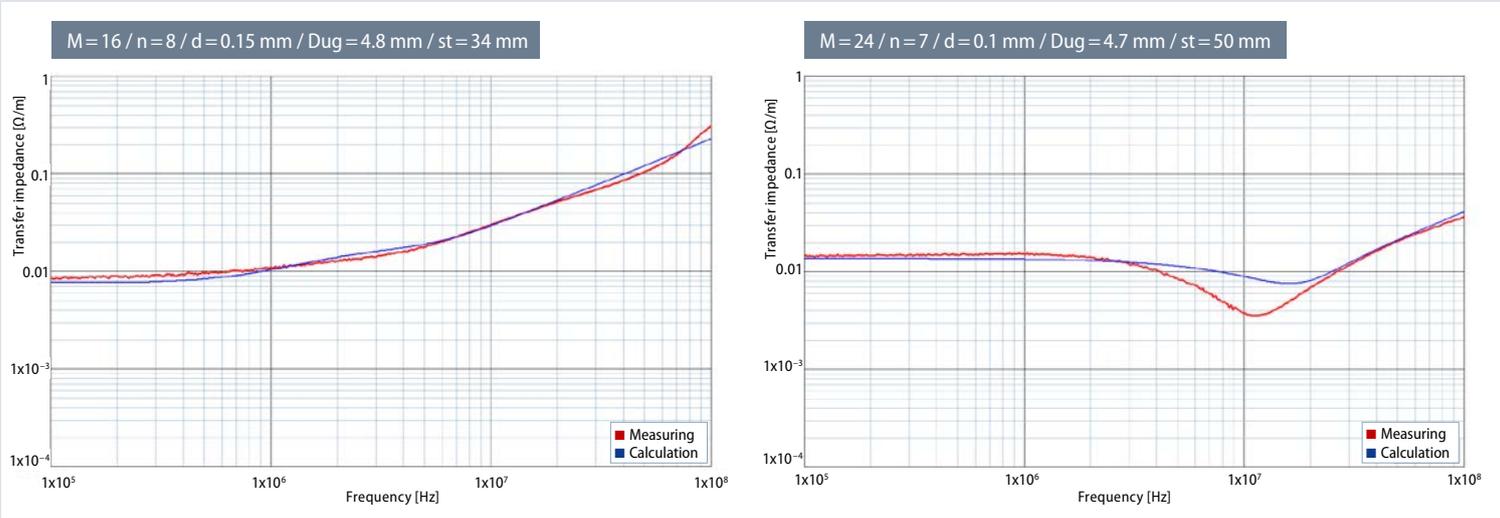The mathematical description of the transfer impedance is very complex.

M = 16 / n = 8 / d = 0.15 mm / Dug = 4.8 mm / st = 34 mm

M = 24 / n = 7 / d = 0.1 mm / Dug = 4.7 mm / st = 50 mm

Fig. 4: Transfer impedance, comparison with measurements

Several calculation models of the transfer impedance exist. An improved model is that of Thomas Kley (see formula). It is based on many empirical factors and reads:

$$Z_T = Z_R + i\omega L_T + (1 + i)\,\omega L_S \quad \text{(Kley, 1991)}[1]$$

Z_R Transfer impedance of the tube

L_T Coupling inductance

L_S Skin inductance

[1] "Optimierte Kabelschirme Theorie und Messung"
(Optimised cable shields. Theory and measurement. ETH doctoral thesis)
DISS. ETH Nr. 9354 Thomas Kley, page 55

Fig. 5: Comparison with transfer impedance

The simulation was compared at LEONI by means of several tests. The result in the case of round cables is astonishingly good. In *Fig. 4* the measurements and the calculations were compared. The measurement is carried out with the triaxial measuring method according to EN 50289-1-6 EN (Communication cables. Specifications for test methods. Electrical test methods. Electromagnetic performance).

So long as the cable is geometrically round and the braid is fully tightened, very good results are achieved. In practice, signal cables mostly are not round. The constructions with two, three and four wires are noncircular without bedding. The braiding process as well as the tension of individual braiding elements,
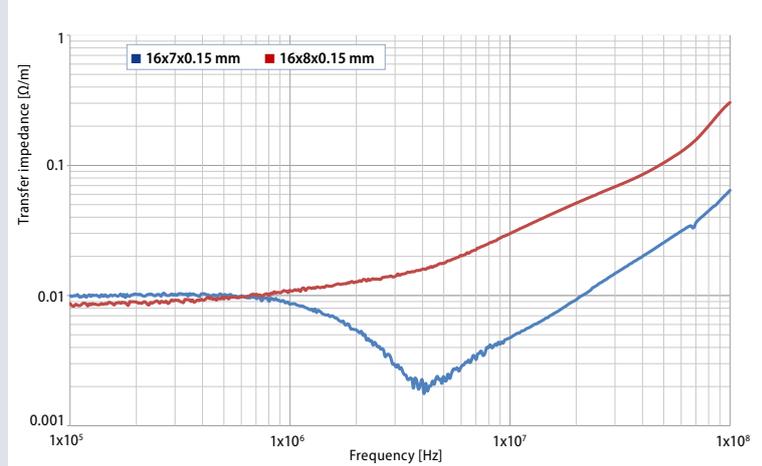
the precision of the lay length etc., have a great influence. For this reason, it is not easy to make a comparison with the real world.

The major difficulty lies in the calculation of the inductive component. The magnetic field of the shield is heavily influenced by the skin and proximity effects. On the other hand, this inductive part represents the predominant proportion of the transfer impedance at the higher frequency. Therefore, the main challenge is to calculate this inductive coupling. This depends on the parameters of the braid. More specifically, these are the wire diameter (d), the number of wires (n), the number of braiding elements (M), the lay length(st) and the diameter (Dug) under the braid.

All 5 parameters have influence on the coupling inductance. In this context, at first glance the surprising finding was that a higher braiding coverage is not always the better option. In *Fig. 5*, two braids with different designs are measured and compared. The only difference between the braids is the number of wires of each braiding element. The blue curve has one wire less than the red curve. All the other braiding parameters as well as the measuring method are identical.

Measured according to EN 50289-1-6

The result is surprising. At low frequencies, the DC resistance is negligibly higher because of the smaller shield cross-section. With increasing frequency, however, it can be recognised that despite a smaller cross-section and a smaller coverage lower transfer impedance appears and thus a noticeable better shielding effect is achieved. It can be seen how strongly the transfer impedance depends on the braid design. An additional wire can also act like an antenna and therefore evoke worse coupling behaviour as well as additional magnetic fields. This phenomenon can appear with different diameters and braid designs. In contrast to the transfer impedance, the shield attenuation is not very strongly influenced by the braid design. Only moderate differences up to approximately 100 MHz can be detected.

A technical improvement can only be implemented if the optimization can be realised from a production standpoint and is interesting from an economic standpoint. The optimization also has to respect the standards. In EN50306[1] and EN50264[2] certain braiding parameters such as braid angle, wire diameter and filling are specified for the railway sector. The braid angle has a significant role for flexible products. The angle must be within a certain range in order that during movements the braid does not break. With a greater lay length production time is reduced

and as a consequence the product gets cheaper and more economic. If the length of lay is too large, the braid becomes unstable and is not suitable from the point of view of EMC. According to Kley[3] the optimum angle for smallest possible couplings is between 30° and 40°. This range, however, is not quite the optimum for flexible applications. Depending on the intended application, LEONI can offer its customers different optimised solutions. The next parameter to be considered is the number of braiding elements which is very important for the number and the size of the apertures. With a higher number of braiding elements (M) the number of the apertures is increasing. On the other hand, however, the surface of these apertures gets smaller. This has a positive influence on the shield attenuation. Several small aperture areas are better than a few large aperture areas.

Another important feature is the selection of the wire diameter. In practice, it is mostly between 0.07 mm and 0.3 mm. Smaller wires can break more easily, but, on the other hand, have less weight. With a high number of thinner wires economic and EMC compatible braids can be produced. Each cable diameter needs to be specifically treated and designed.

In certain cases, the consumers demand physical braid cross-sections for internal calculations. The calculation of the electric resistance using the physical braid cross-section leads to an inaccurate shield resistance. The effective shield resistance can be 20% higher than the value which is theoretically calculated. For the calculation of the shield resistance, the electrical cross-section should be requested.

[1] EN 50306-3: Railway applications – Railway rolling stock cables having special fire performance; Thin wall – Part 3: Single core and multicore cables (pairs, triples and quads) screened and thin wall sheathed

[2] EN 50264-3: Railway applications – Railway rolling stock power and control cables having special fire performance – Part 3: Cables with crosslinked elastomeric insulation with reduced dimensions – Part 3: Multicore cables

[3] "Optimierte Kabelschirme Theorie und Messung" DISS. ETH Nr. 9354 Thomas Kley, page 77

Conclusion

An EMC compatible cable can only be designed if the requirements are known. The frequency range and the coupling boundaries have to be defined. The most important coupling parameters for the shield are the transfer impedance and the shield attenuation. Both parameters depend very strongly on the frequency. At lower frequencies (up to a few hundred kHz), interference couplings can be avoided by a shield resistance which is as low as possible. At high frequencies, all braiding parameters play an essential role due to complex coupling mechanisms. With the model developed by Kley, round symmetrical cables can be simulated very well for low and high frequencies and optimised.

For data cables and for Cat 5 up to Cat 7 cables the corresponding specifications are defined in certain EN or IEC standards. Most signal cables, with the exception of the railway sector, are not standardised, or only an optical coverage of 85 % is required. This coverage, when taken alone, makes little sense above all for bigger cables because their aperture surfaces are increasing with the same coverage.

The apertures can be covered with an aluminium foil if no continuous movement is required. As a result the shielding effect is massively improved. Due to its longstanding experience and verified simulation software, LEONI is capable to design the optimum shielding solution for all requirements.