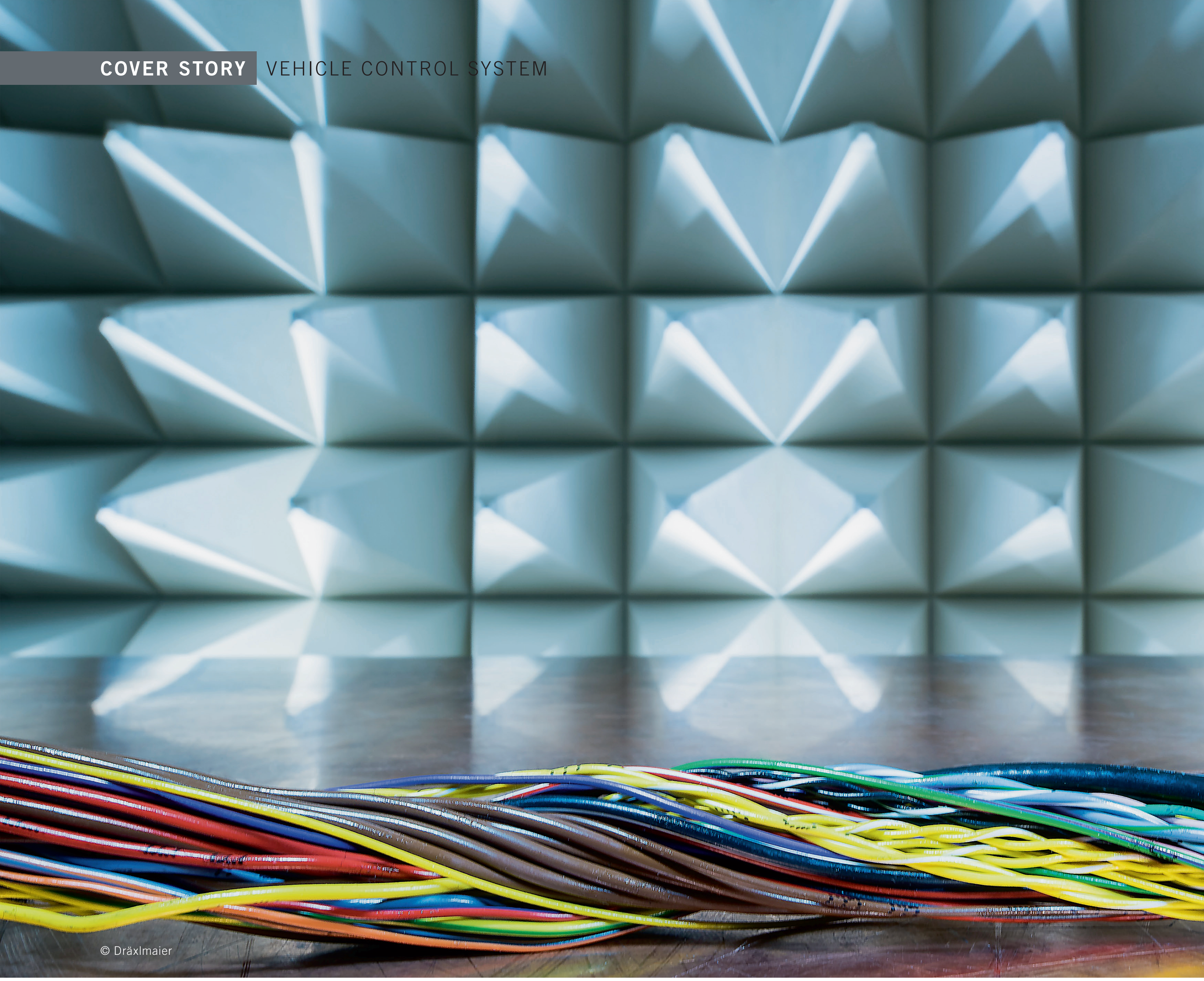

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INNOVATIONS IN VEHICLE DESIGN

Undeniably, autonomous driving will determine the future of the automobile. This is, among other things, down to the demand of customers for greater mobility, as well as the possibilities it offers for greater individuality. Due to the high degree of automation, security requirements will also increase, which is why vehicles will be developed increasingly within the framework of ISO 26262:2011.

Measures to improve the environmental performance are leading to changes in the automotive design: to reduce emissions, lightweight construction has become an even more important issue than it already was in the past. But this is a decisive factor as regards the on-board electrical sys-

Influences of EMC on the On-board Electrical System Configuration

Through the increased functional security requirements, as well as the use of new materials, on-board electrical system development faces new structural tasks. But what is the best way to face these? Dräxlmaier demonstrates possible solutions on the basis of current knowledge.

tem design: because the new materials used in coachwork construction are non-conductive and also no longer have shielding properties, they cannot positively affect the electromagnetic compatibility (EMC). The missing conductivity in particular leads to a weakness in the structural availability in regard to the earth distribution within the vehicle. New earthing concepts are therefore inevitable.

There will also be new challenges with regard to the effects on people. This subject is the focus of the ICNIRP (International Commission on Non-Ionizing Radiation Protection), which provides guidelines for permissible electromagnetic field propagation. The transition into legal regulations means these must be complied with in many places.

It can be said at this point, that the safety and the environmental compatibility of a vehicle stands in close relation to the EMC. The consideration of these factors is thus becoming more important for the entire design of on-board electrical systems, in particular with regard to the safety requirements in accordance with ISO 26262:2011 and the ICNIRP. This article will focus therefore on the propagation of electromagnetic fields, as well as the application of the ICNIRP guidelines.

Especially interesting in the context of these considerations are the dynamic loads, since they lead to currents, which in turn generate variable magnetic fields: electric coachwork functions, switched electrical heating loads and 48-V recuperation at peak currents over 600 A are a challenge for on-board electrical system developers in regard to both their current and their dynamics, as the resulting magnetic fields impact not only the vehicle's occupants, but also components such as control devices.

As already mentioned, the earth distribution will change due to the new composite materials. As a result, the behaviour of the current spread over the earth is increasingly difficult to predict. The formation of magnetic fields can thus occur in unexpected places in the vehicle.

What constructive approaches and protective measures must be considered in the on-board electrical systems of the future to successfully meet the new challenges?

ILLUSTRATION OF THE FIELD PROPAGATION

First, it is important to develop an understanding of the current behaviour and the concomitant electromagnetic characteristics. Although magnetic fields are not visible, simulations of the field propagation, however, are extremely helpful in visualizing and evaluating their effects.

The following observations of the model rely on a simplified representation to keep the simulation under control. A steel floor plate and an aluminium one, each with a thickness of 2 mm, are used. To represent how the current spreads, a supply line for a fictitious control unit (CU) was modelled, **FIGURE 1** (yellow). The supply is at the point (+). The control unit is connected to the plate that serves as an earth for the current feedback. The earth take-off is at the point (-). Now, the circuit is closed. Power sources, such as a battery or a generator, can be located between the points (+) and (-). The turquoise surface between A and B marks the intersection where different conductor arrangements are considered later with respect to their EMC. At any point, the magnetic flux density at the frequencies relevant to the ICNIRP

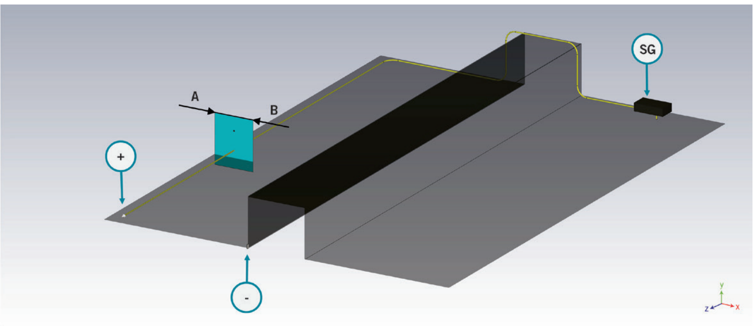

FIGURE 1 Schematic diagram of simulation set-up: (+) B+, (-) earth, (CU) control unit, section AB (level for further considerations) (© Dräxlmaier)

(1, 10, 100, 500, 1k, 2k, 4k, 10k Hz) are centrally calculated via the conductor arrangement, and at a distance of 50 mm to the top edge of the floor plate. The selected power level is always 100 A. The most important cases are depicted pictorially in the following.

But first a look at the current propagation: Here we see an interesting, but ultimately not surprising result: With increasing frequency, the current flowing back to the earth via the plate increasingly follows the route along the supply cable. This is clearly evident in **FIGURE 2** based on a current density focused increasingly below the cable. The different behaviour of steel and aluminium is interesting – in the latter case, the power links much faster to the wiring due the missing magnetic permeability as well as the better conductivity.

As already mentioned, the mix of materials used in modern vehicles poses additional challenges. To simulate this, imperfections with a resistance of 1 Ω were introduced into the aluminium plate. As can be seen in **FIGURE 3**, this causes the current to choose a route via the parts with a lower resistance, but it always strives to stay as close as possible below the actual cable. The magnetic fields propagate further between the feed and return lines, depending on how far apart the two pathways are from each other.

It can be easily derived from this, that any imperfection in the coachwork can lead to EMC problems, because it is precisely here that broad magnetic fields can form. This cannot be avoided, but can, however, be affected by constructive measures – unfortunately not always for the better.

EFFECTS OF CONDUCTOR SHAPE

Now the question arises, as to how to get such a situation under control. To do this, different conductor arrangements were checked at a frequency of 1 kHz, including a single round conductor, a double round conductor, a single rail, as well as a double rail. The conductors are each mounted on a base plate made of steel or aluminium.

One initial interesting aspect can be seen already from looking at a round conductor: aluminium has advantages over steel in the optimisation of EMC, because the magnetic field propagation is much more focused between the conductor and the plate. This was to be expected considering the previous power density observations. **FIGURE 4** shows that the field is still relatively large, however. If a single rail is used instead of a round conductor, the field spread can be reduced slightly. Thus, the construction design of the conductor plays an important role with regard to EMC. But what additional measures can be taken to curb the field and even bypass imperfections in the coachwork structure?

USING A DOUBLE RAIL

A possible parallel supply for B+ and earth is beneficial. Two structural possibilities were simulated in this regard: a design with double round conductors and with a double rail, **FIGURE 5**. Neither form requires earth feedback via the plate. In the case of the double round conductor, a clear reduction of the electromagnetic field can be seen, since this is largely locally focused on the two conductors. The best field properties, however, are shown by the double rail. With this design, the expansion of the field is extremely low, which is why it is also suitable for installation in the interior. The ICNIRP limit values are complied with.

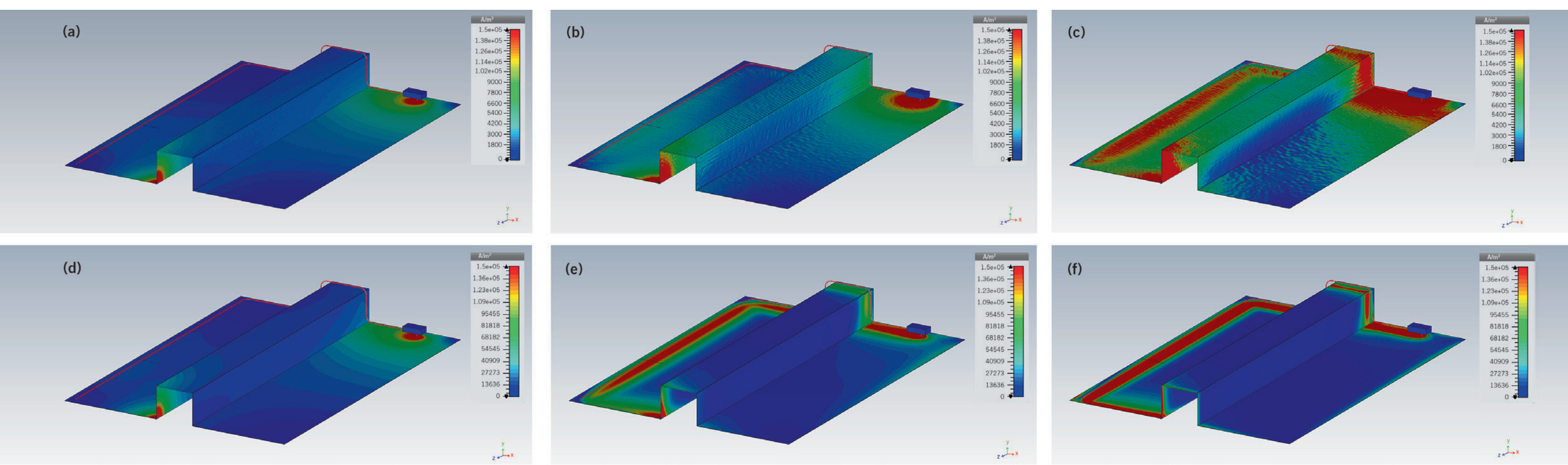

FIGURE 2 Current density 5/50/200 Hz (top steel/bottom aluminium) (© Dräxlmaier)

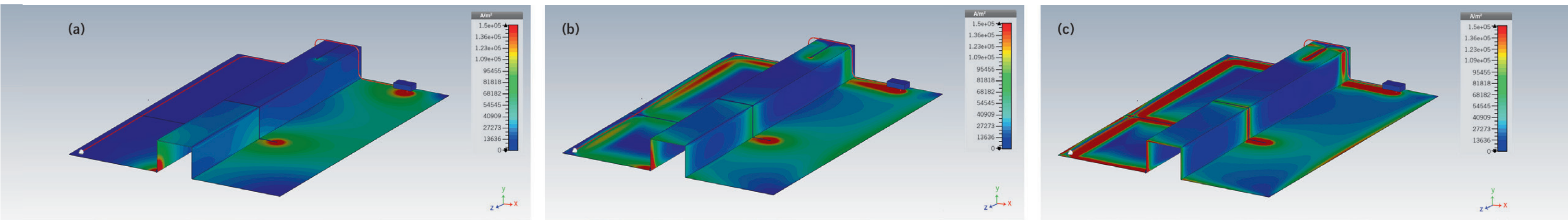

FIGURE 3 Current density 5/50/200 Hz in an aluminium plate with imperfections (© Dräxlmaier)

CONTENT OF THE ICNIRP GUIDELINES

There are structural ways to positively affect the flows and thus the magnetic fields which can act upon passengers and components inside the vehicle. This is significant not only for the function of the vehicle, but also for its occupants. Because stimuli are transmitted in the human body via electrical currents, magnetic fields can have an impact on the organism. The International Commission on Non-Ionizing Radiation Protection has therefore launched a policy that includes limit values: The "ICNIRP guidelines for limiting exposure to time-varyfing electric and magnetic fields (1 Hz to 100 kHz)" [1] qualitatively describe the possible effects of magnetic and electric fields in the frequency range up to 100 kHz and provide limits for those who are occupationally exposed to them, as well as for those who move within them in a private capacity. The latter includes, for example, the passengers of vehicles. The guidelines, which appeared for the first time in 1998 and were republished in 2010 with partially raised limits, are designed in particular for magnetic fields in industrial and public environments, were also, however, implemented in the automotive sector in the form of the stricter ICNIRP guidelines of 1998. **FIGURE 6** shows the ICNIRP limits for magnetic flux density B in Tesla as a function of frequency for both versions. Quasistatic magnetic fields are given a higher limit of 40 mT, which decreases with increasing frequency to 6.25 µT (ICRNIP 1998).

As already described above, the magnetic field effect originates in current-carrying wires in the automobile. As the load currents are typically very dynamic, many transient load transitions arise.

MEASUREMENT PROCESS IN THE AUTOMOTIVE ENVIRONMENT

Occurring magnetic fields are recorded in the automotive industry using a standardised instrument in the context of vehicle validation. This directly indicates the ratio of the measured value to the maximum allowable magnetic field strength according to ICNIRP (in percent). A disadvantage of this approach is that the measurements can only be performed on an already implemented vehicle concept. On the one hand this is very expensive, and on the other the construction as well as the preparation of the prototype take much time. In addition, the measurements themselves are very time consuming. First, the respective vehicle operating conditions must be set, then the measuring probe is placed in turn at each measurement point in the vehicle. Only then can one read off and document the measured value in percent of the ICNIRP limit value, while ensuring that the maximum measured value in the area of the measuring point is determined. In addition, it is necessary to document all maximum values. There are already 13 measuring points, from which two measurements have to be made every 30 s, on a single seat. In a four-seater vehicle, this leads to a pure measuring time of 52 min. As there are many more measuring points in a vehicle, however, this leads to a considerable amount of time for all necessary tests, as has already been said.

The objective must be to enable the preparation of an analytical statement in advance as to whether an on-board electrical system potentially leads to problems with regard to the emitted magnetic fields. In the process, these consist of a continuum of different frequency components. It is important for the understanding of the ICNIRP directive that the individual frequency components are incorporated in an additive fashion. The limit value is calculated in percent by means of a summation of the quotients from the respective frequency range and the applicable limit value.

Eq. 1 $$ICNIRP\% = \sum \frac{B(f)}{B_{limit(f)}} \, x \cos \varphi$$

This relationship is nothing other than an inverse Fourier transformation of magnetic flow components weighted

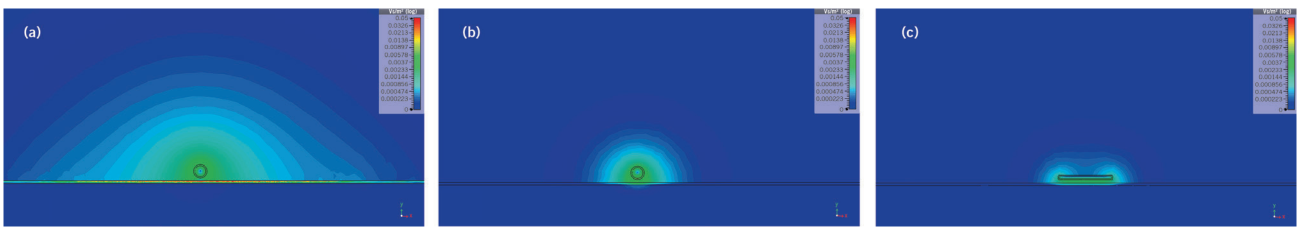

FIGURE 4 Field spread with round single conductors via one steel and aluminium sheet, as well as a single flat conductor via aluminium sheet at 1 kHz (l. to r.) (© Dräxlmaier)

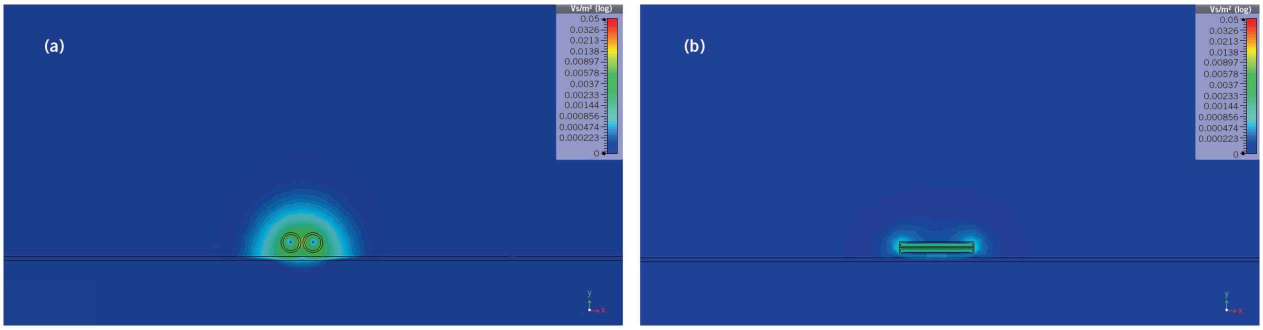

FIGURE 5 Field spread at 1 kHz with a double round conductor and a double rail on a sheet of aluminium (© Dräxlmaier)

with the limit value. If the transfer function I(f) after B(f), as well as the temporal profile of the current l(t) is known, the expected percentage of the limit value can be calculated.

COMPARISON OF THE ICNIRP LIMIT VALUES

An example here, once again, illustrates the differences between the two versions of ICNIRP from 1998 and 2010. In **FIGURE 7**, the percentage of the permissible magnetic field exposure (as a percentage of the maximum load) for the supply is applied to a load that has a short current peak at 0.55 seconds. The magnetic field exposure, measured using the Narda ELT 400 probe (ICNIRP 2010), is recorded in **FIGURE 7** as ICNIRP%(t) (green).

The exposure is, on average, three percent of the permitted exposure according to ICNIRP 2010 with transients up to nine percent of the permitted exposure. To derive the limits according to ICNIRP 1998, the signal is transformed into the corresponding frequency range, the limits are re-weighted and the result is transformed back again. The result is shown in the figure in blue. It is plain to see that the transients are considerably higher. If one makes a comparison with the ICNIRP% measured values that come directly from a 1998 probe, it is noticeable that the output data of this probe are again up to 30 % higher than the results from the conversion. This is an indication that the older ICNIRP standard measuring probe significantly increases noise.

CHARACTERISTICS OF THE MEASUREMENT

When using the ICNIRP in the automotive environment, several particularities must be observed. Thus an evaluation according to the ICNIRP 1998 standards shows a pronounced sensitivity with regard to current transients. Because the probe used for the ICNIRP measurement has a drag pointer max-hold function, short needle tips as shown in **FIGURE 7** in connection with a singular transients already cause a threshold exceedance (ICNIRP > 100%). If the limit value is permanently exceeded or caused only by a singular switching, transients cannot be differentiated. Also the result is very much dependent on the exposure scenario during measurement and, in particular, whether exposure transients randomly overlap.

It should be noted that the ICNIRP measurement with the limits of the 1998 standard is to be applied in the automotive environment. There are interpretation possibilities, however, regarding measurement scenarios and the actual impact of singular transients.

FLEXIBILITY THROUGH SIMULATION

Due to changes in vehicle design, in particular the use of lightweight structures to reduce emissions, electromagnetic compatibility has become a defining issue. Future on-board electrical system concepts are influenced by external factors more than ever before. Dynamic loads with new functions generate more electricity flows in the on-board electrical system, which is also constantly changing. As it is very time consuming to carry out measurements on an already implemented vehicle concept – but a meaningful consideration of the spread of the magnetic field is also necessary – simulations offer an alternative solution. An on-board electrical system can only be adjusted in the early stages of development if these are conducted in a timely manner. This not only saves costs compared to the later applicable possibility of an intensive measurement, but also gives developers a high degree of flexibility in the on-board electrical system design at the same time.

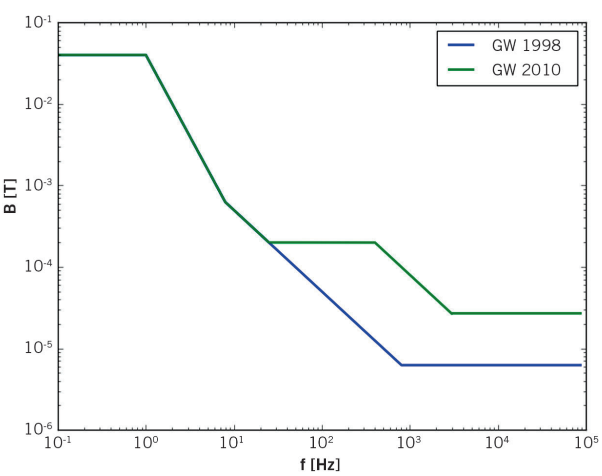

FIGURE 6 ICNIRP limits for magnetic flux density B in Tesla as a function of frequency for both versions of the directive (1998/2010) (© Dräxlmaier)

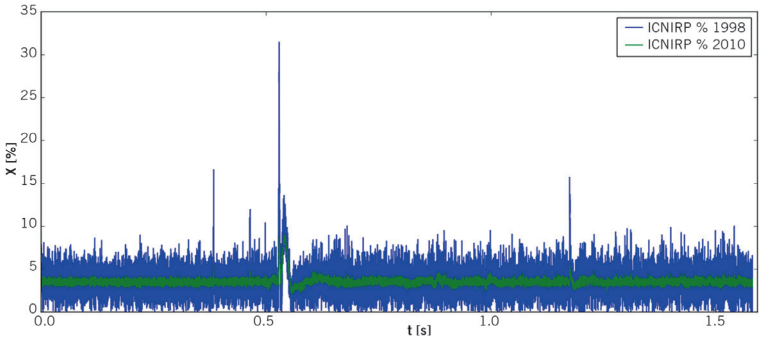

FIGURE 7 Comparison of measured values according to ICNIRP 1998 and 2010 (© Dräxlmaier)

THE HOLISTIC VIEW

The materials used, the body structure and the electrical system can never be considered alone. Rather they are closely related to each other – which could be illustrated on the basis of the examples mentioned. It makes a difference whether steel or aluminium is used, along with the position of imperfections in the coachwork and the position the harness was moved to. In addition, the structural design of the B+ supply as well as the earth concept are relevant. Also, the shape of the conductor is of importance because a single, preferably flat conductor already has advantage over a round conductor.

Another measure to curb the field and possibly even to bridge imperfections in the coachwork construction, involves a possible parallel supply for B+ and earth. Here, a flat rail routed in two layers – i.e. a double rail – is the best option. Their very good field properties deliver such a low field spread that this design is suited even in the context of the ICNIRP for interior installation. At this point, however, it should be noted that the correct application of the ICNIRP is very challenging and still the subject of discussions. It is therefore of particular importance that dealing with measurement results always also requires a plausibility check.

Now, the priority is to consolidate the findings. To do this, further studies and simulations must be initiated, which can then be checked using measurement setups. The approach of the Dräxlmaier Group, already from an early stage, has been to coordinate vehicle and on-board electrical system design with the automobile manufacturers, so that an optimized electromagnetic compatibility is available at the end of the process.

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[1] International Commission on Non-Ionizing Radiation Protection (ICNIRP) (Ed.): ICNIRP Guidelines for limiting exposure to time-varying electric and magnetic Fields (1 Hz–100 kHz). 2010. Online: http://www.icnirp.org/en/frequencies/low-frequency/index.html (accessed on 27/04/2017)