Flat Wire Weave as a Flexible Electromagnetic Shielding Solution

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The shielding of electromagnetic radiation is an essential task in the design of future cars, especially with regard to the electrification of the drivetrain and the development of autonomous vehicles. Kern-Liebers explains how the electromagnetic compatibility of such systems can be effectively improved, using a wire mesh with flat wires as an example. Very promising attenuation values of the electromagnetic shielding were achieved.

A wire weave with flat wires is very suitable for electromagnetic shielding. Especially with a small mesh size, the surface coverage of such a weave is comparatively high due to the involvement of the flat wire itself. A very good shielding effect from the short-wave to the microwave range can be demonstrated. Compared to conventional shielding plates, the weave shows advantages like high spatial flexibility and vapor permeability.

The weave is not to be seen as a competition to the shielding plate or similar constructions, rather it can be understood as an additional component of the shielding system. In this context, the processability of the weave as well as the connection technology to sheet metal, stamped or stamped bent parts play an essential role. Moreover this structure is of great importance in plastic composite parts.

ELECTROMAGNETIC SHIELDING IN CARS

Electromagnetic compatibility will gain increasing importance in the future due to the electrification of the drivetrain on the one hand and the sensors for autonomous driving on the other. For example, in power electronic modules between the electric motor and the battery, high electrical currents are converted in short times. With the switching frequencies of the power electronics in the range of a few kHz, this leads to strong electromagnetic emissions up to the GHz range. In case of an insufficient shielding, these can interfere with sensi-

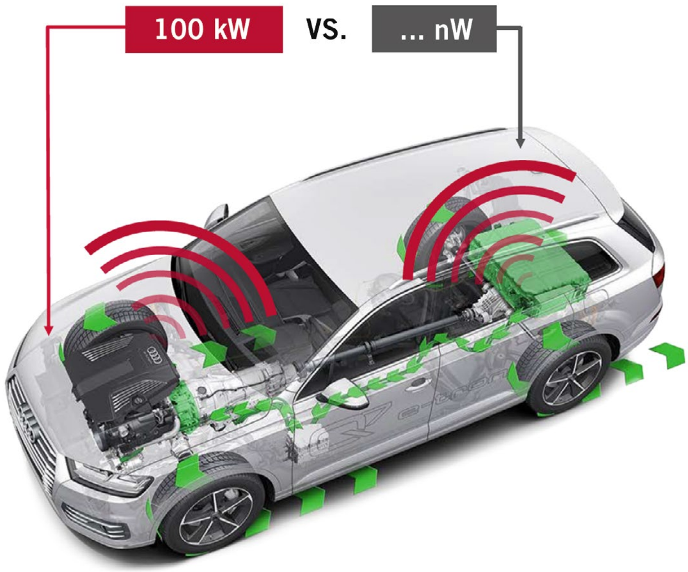

FIGURE 1 Switching of high currents in power electronics (graphic taken from [1]) (© Audi)

tive sensors or sensor signals. This could be of drastic consequences during autonomous or connected driving.

In addition, it is also possible that other automotive sub-systems like infotainment systems or control units are disturbed. This is directly relevant to the function or customer. But also the sensitive control and monitoring units of traction batteries in hybrid electric vehicle or battery electric vehicles have to work without interference in order to ensure the energy supply of the motor. This requires a proper EMC shielding and filter design. Audi describes this relationship in **FIGURE 1**.

HOLISTIC EMC CONCEPT

A proper EMC concept includes consideration of all structural levels of the car. This involves semiconductor devices as well as components and systems, like powertrain or battery, but also the integrated vehicle itself and finally the charging technology. Various considerations are necessary at these levels to ensure the electrical functions of the overall system. For example, at the semiconductor and component level, relevant aspects of EMC have to be taken into account in early stages of development and design.

At the component/system level, the use of filters and shieldings is a key issue of EMC compatibility. When considering the electrical system, EMC simulations are a suitable tool for the validation of the effectivity and interaction of individual schemes. At the overall level, the balance of all applied filtering and shielding measures is important, this depends on the vehicle topology [1]. Interference signals of the charging process are also relevant.

During inductive charging with typical frequencies in the range of 75 to 90 kHz, an alternating current is induced in the receiver coil. Consequently, an electronic rectification is necessary before the battery is charged. Furthermore, large amounts of electromagnetic emission are generated during the charging process. Therefore, a concept is needed to shield this emission, especially for the passenger compartment. Negative effects are also conceivable during conductive charging [1].

In addition to the switching frequencies of the semiconductor component for controlling the electrical machine, interference signals in the low-frequency range are also important. For example, those signals are generated in acceleration and braking processes. Typical frequencies in the range of 2 to 3 kHz are caused here [2].

SIGNIFICANCE OF ELECTROMAGNETIC SHIELDING

The importance of electromagnetic shielding for OEMs and their suppliers is demonstrated, for example, in the tendency to shield the entire high-voltage harness. This is required by the occurrence of high currents in the range of several 100 A at high-voltage levels between 48 and 800 V. Moreover, the increasing legal framework shows the high importance of EMC. In this context, it is obligatory to take the ICNIRP (International Commission on Non-Ionizing Radiation Protection) as well as the CISPR (Comité international spécial des perturbations radioélectriques – international special committee for radio interference) into account. The focus is on both the protection of the driver and the technological robustness with regard to electromagnetic interference [2, 3].

This article addresses possible solutions resulting from a novel flat wire weave that is characterized by the following features:
– good shielding properties due to high surface coverage
– small mesh size enables good vapor permeability
– Mechanical flexibility of the mesh allows flexible mounting in complicated installation situations.

FLAT-WIRE-BASED EMC WEAVES

The wire meshes can be made from flat wires of copper and aluminum, **FIGURE 2**. The flat wire is produced from round wire by means of flat rolling. In addition to pure metals, alloys are also conceivable. Copper alloys like bronzes and brasses play an important role. But low alloyed materials such as CuSn0.5 or CuMg1 are also relevant, as they exhibit good mechanical strength in

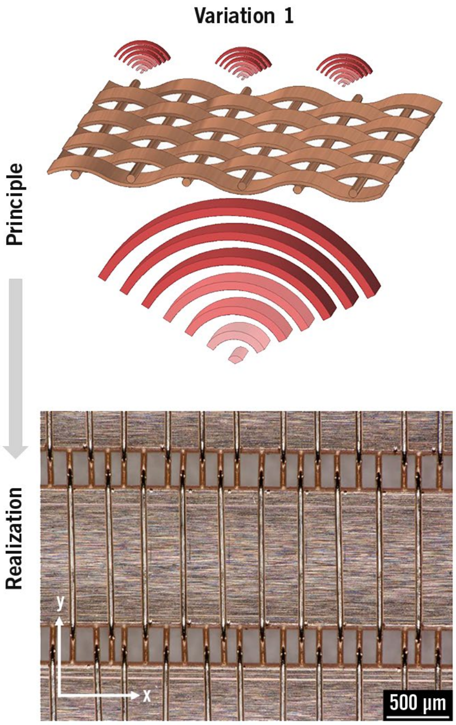

FIGURE 2 Principle of electromagnetic shielding based on a flat wire weave with two design options as well as an exemplary implementation (© Kern-Liebers)

addition to high conductivity. Important aluminum wire alloys are AlMgSi and AlMg3.

The weaves can be made with flat wire in one or two spatial directions. If the flat wire is used in only one direction, the warp wire is designed as a round wire. In this context, a wire diameter of 0.112 mm is well suited. The flat wire is used in the weft direction orthogonal to this. Alternatively, it is also possible to design the warp wires as flat wire. Various post-processing steps allow the shielding properties to be optimized.

With regard to the mesh size or hole density of a weave, it is necessary to consider the effect of the holes. The electromagnetic field after an electrically conductive wall is composed firstly of the damped field that would occur if there were no hole, and secondly of the field which is induced by the opening. The hole acts like a dipole with a polarizability. Rectangular holes with small edge radius show the lowest polarizability. The polarizability increases with the hole diameter. Therefore, weaves with a large number of small holes show better shielding effects than weaves with a small number of big weaves. Especially in the case of strongly inhomogeneous fields, a small mesh size is important for the shielding of the electric field component.

However, conductivity of the weave material as well as the quality and contact at the wire crossings dominate the shielding effect at frequencies between kHz and a few MHz. If there is no good connection, the effective mesh size is to be considered larger. Furthermore, the occurrence of slots must be avoided.

CHARACTERIZATION OF THE SHIELDING EFFECTIVITY OF THE FLAT WIRE WEAVE

In the following, an exemplarily measurement of a flat wire weave is described. In this case, the flat wires consist of pure copper Cu-ETP1 in the weft direction with a cross-section of (1.250 × 0.100) mm². The warp wires made of CuSn6 are round wires and have a diameter of 0.06 mm. The mesh size is about 100 µm in the x-direction and about 250 µm in the y-direction, **FIGURE 2**.

The shielding effectivity is determined using the practical principle of insertion loss [EN 50147-1 96]. The test specimen is inserted between the transmitter and receiver coil. A measurement without a specimen is performed as a reference.

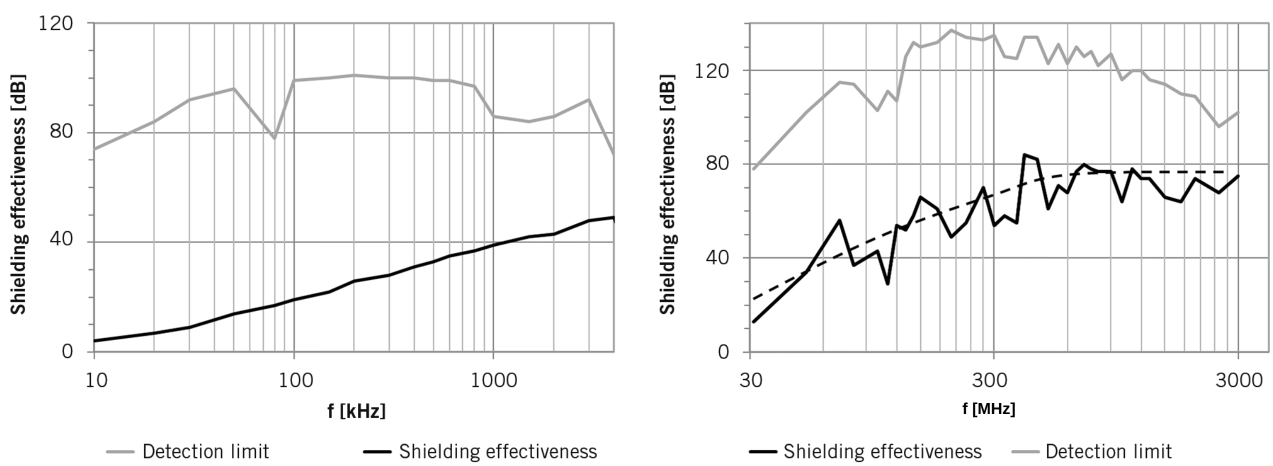

FIGURE 3 Measurement of the shielding effectivity of the flat wire weave: measurement for low frequencies with magnetic antennas (right); measurement of the electromagnetic shielding effectivity in the GHz range (the smoothed curve is shown as a dashed line) (left); the bright graph shows the detection limit; the measured shielding effectivity of the weave is shown as a dark line (© Kern-Liebers)

FIGURE 4 Illustration of a demonstrator with a shaped flat wire weave and a plastic mounting to show the manufacturing possibilities (© Haver & Boecker)

Consequently, the shielding effectiveness can be calculated [4].

For frequencies in the kHz range, the shielding effectiveness is measured using magnetic antennas, as shown in **FIGURE 3** (left). The result for electromagnetic fields in the high MHz as well as GHz range can also be seen in **FIGURE 3** (right). Considering the frequency range from 10 kHz to 4 MHz, an approximately linear magnetic shielding effectiveness up to 45 dB is obtained. The electrical shielding effectiveness in this range is not to be considered critical for this material due to the Faraday effect. Electromagnetic shielding effectiveness in the 30 MHz to 3 GHz range is 20 to 80 dB.

Weaves for electromagnetic shielding are already commercially available in a large number of variants made of round wire. These are inferior to the weave described here in terms of shielding effectivity. For example, the attenuation values there are generally around 60 db in the low MHz range.

OUTLOOK: FIELDS OF APPLICATION AND DESIGN OPPORTUNITIES

A particular advantage of the wire weave is its spatial flexibility. Thus, applications with geometrically complex installation situations are very suitable. This flexibility also allows good mounting and assembly. The wire weave offers advantages due to its geometric degrees of freedom.

In most cases, the weave is understood as part of a shielding system. Therefore, combinations of shaped weaves with metal sheets, stamped or stamped bent parts or (contact) springs are conceivable. In order to produce effective shielding systems, the development of suitable joining and connection technology is of central importance in order to supply customized solutions from a single source.

The combination with plastic (composite) parts is also an interesting possibility for covers and housings with a high shielding effectivity in the context of lightweight design. As shown in **FIGURE 4**, vapor and gas permeability could also be realized using windows. Consequently, similar sensor housings have high potential as safety elements, for example for applications in battery technology, **FIGURE 5**.

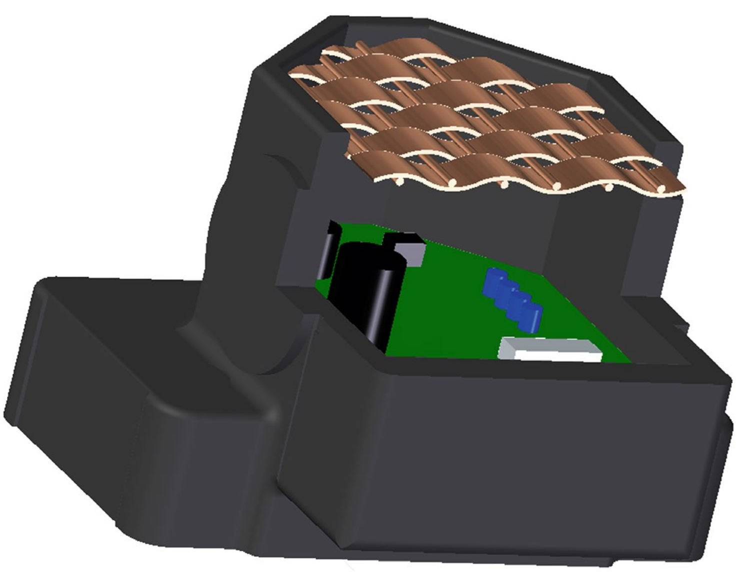

FIGURE 5 View of a sensor housing with an integrated vapor-permeable, inmoulded flat wire mesh; it is also conceivable to produce a complete plastic composite part, without a window to obtain optimum shielding properties (© Kern-Liebers)

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THANKS

The flat wire weaves are developed and manufactured in a strategic cooperation between Bruker-Spaleck GmbH (Kern-Liebers group) and Haver & Boecker OHG. The author would like to thank Dr. Hans Wolfsperger (W+R Schirmungstechnik) for performing the measurements and for the constructive discussions.