Messe Frankfurt Group

mesago

emv

12. – 14.03.2024
KÖLN

Proceedings EMV Kongress 2024

e-emv.com

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über https://portal.dnb.de abrufbar.

Diese Publikation ist als E-Book erhältlich.

Heyno Garbe (Hrsg.):

EMV 2024
Internationale Fachmesse und Kongress für Elektromagnetische Verträglichkeit

1. Auflage, 2024

Mesago Messe Frankfurt GmbH
Rotebühlstraße 83-85
70178 Stuttgart, Germany
www.mesago.de

Apprimus Verlag, Aachen, 2024
Wissenschaftsverlag des Instituts für Industriekommunikation und Fachmedien an der RWTH Aachen
Steinbachstr. 25
52074 Aachen, Germany
Internet: www.apprimus-verlag.de, E-Mail: info@apprimus-verlag.de

EMV Kongresskomitee 2024

Komiteevorsitz:

Prof. Dr.-Ing. Heyno Garbe	Leibniz Universität Hannover

Komiteemitglieder:

Dipl.-Ing. Jörg Bärenfänger	EMC Test NRW GmbH
Prof. Dr.-Ing. Stefan Dickmann	Helmut-Schmidt-Universität Hamburg
Prof. Dr.-Ing. Thomas Eibert	Technische Universität München
Prof. Dr. Achim Enders	Technische Universität Braunschweig
Prof. Dr.-Ing. Stephan Frei	Technische Universität Dortmund
Andreas Grielhuesl	IABG Industrieanlagen-Betriebsgesellschaft mbH
Prof. Dr. Frank Gronwald	Universität Siegen
Dr. Ralf Heinrich	AMETEK CTS Europe GmbH
Dr. Johann Heyen	Volkswagen AG
Prof. Dr.-Ing. Holger Hirsch	Universität Duisburg-Essen
Dipl.-Phys. Detlef Hoffmann	Webasto Roof & Components SE
Armin Hudetz	SGS Germany GmbH
Dr. Bernd Jäkel	Siemens AG
Dr.-Ing. Robert Kebel	AIRBUS Operations GmbH
Prof. Dr.-Ing. Klaus-Dieter Kruse	Sachverständigenbüro Fachgebiet EMV
Prof. Dr.-Ing. Marco Leone	Otto-von-Guericke-Universität Magdeburg
Dr.-Ing. Mathias Magdowski	Otto-von-Guericke-Universität Magdeburg
Dipl.-Ing. Christian Paulwitz	TDK Electronics AG
Prof. Dr.-Ing. Matthias Richter	Westsächsische Hochschule Zwickau
PD Dr.-Ing. Frank Sabath	Wehrwissenschaftliches Institut für Schutztechnologien - WIS-ABC Schutz
Dr.-Ing. Martin Sack	Karlsruher Institut für Technologie (KIT)
Prof. Dr.-Ing. Kerstin Siebert	Hochschule Ruhr-West
Prof. Dr.-Ing. Stefan Tenbohlen	Universität Stuttgart
Prof. Dr.-Ing. Jan Luiken ter Haseborg	Technische Universität Hamburg-Harburg
Prof. Dr.-Ing. Ralf Vick	Otto-von-Guericke-Universität Magdeburg
Dr. Markus Wehr	ARGE Rundfunk-Betriebstechnik

Active Reduction of Magnetic Fields in Vehicles

Oded Einat, SafeFields Technologies Ltd, Israel
Shaul Shulman, SafeFields Technologies Ltd, Israel
Dr. Uwe Reinhardt, IAV GmbH Germany
Dr. David Hamann; IAV GmbH, Germany
Jürgen Kunstmann, IceField Consult GmbH, Germany

1 Abstract

This paper presents an innovative solution for the challenging problem of suppressing low frequent magnetic fields generated by electrical driven powertrains. The solution is based on active field reduction by generating a counter phase magnetic field to suppress the original field. Main principles and technical challenges of such a system are described and discussed. To illustrate the achievable suppression levels, measurement results under different drive modes of two commercially available electrically powered vehicle models (from two different makers) are presented.

2 Introduction

The increasing level of magnetic field strength caused by implementation of frequency converter-controlled power drives at high current levels leads to challenges. Especially when magnetic sensitive technology (e.g. Hall sensors) are used in parallel, reduction of these magnetic fields may become evident.

In parallel, biological effects caused by long term exposition of human bodies in low frequency magnetic fields are being discussed. In the recent years, due to the rapid adoption of electrified transportation systems, more attention is being raised to potential passenger exposure to strong magnetic fields. Although more and more measurement procedures and emissions characterizations of powertrains are being explored and published (as described further below).

In this paper we will describe a solution for efficiently suppressing low frequent magnetic fields. Such solution can be enabler for the industry to adopt a much safer design approach for electrified driven transportation applications such as passenger cars, trucks, busses and trains.

3 The status quo of relevant standards and regulations for magnetic field exposure

In terms of distinct limits on exposure, only acute fields have been covered so far through IEEE [1] and ICNIRP [2] standards. These standards derive the limit recommendations from calculating the electrical excitation and currents induced in the body based on a model of the nervous system. Up to now, they do not address the impacts on diseases associated with chronic exposure.

Also, low magnetic field exposure becomes more relevant under technical regulation aspects. The magnetic field exposure is relevant for the type approval process in China. Additional regulations in other countries are supposed to follow.

Recently, there has been a great progress on standardizing of measuring of ULF-MF in vehicles. EU JRE report [3] and subsequently IEC standards [4] define a standard procedure of measuring vehicles, which allows comparison between models and deriving health safety scores. This can be used by technical authorities and government institutions to grade electrified vehicles according to the of risk level from magnetic field exposure. Such practice is already implemented in China, through the C-NCAP program [5].

4 General Shielding concepts for low frequency magnetic fields.

4.1 Passive Shielding

The conventional method to suppress electromagnetic emissions is the use of passive shielding. Functionally, it is based on redirecting magnetic field lines away from the space to be protected. This is obtained by employing high permeable soft magnetic materials [5,6]. These are magnetic materials with low coercivity (usually less than 1000A/m), which are easily magnetizable and de-magnetizable.

There are several kinds of soft magnetic materials, but only a few can be used for effective magnetic field shielding. Thus, iron-silicon alloys [7], while being relatively cheap do not have high enough magnetic permeability and result in massive shields with below mediocre shielding efficiency. Nickel-Iron alloys, especially those with high Nickel content, are the softest magnetic materials available with high relative permeability (~100.000) [7]. Their relatively low saturation magnetization (significantly lower than Fe-Si alloy's) is one of the disadvantages limiting their applications. Additionally, manufacturing of such compounds is highly complex due to the usage of sophisticated equipment, ultra clean raw materials requirements and unique processes technologies is adding up to highly expensive materials.

Another aspect of influencing shielding efficiency is the geometry of the shield. Shield geometries can be split into two groups: those that completely divide the space into source and shielded regions (e.g., infinite planar shields, infinite cylindrical shields, and spherical shields) so called ‘closed topologies’ and ‘open topologies’, that do not completely separate source and shielded regions [8,9]. While ‘closed topologies’ show good shielding efficiency, reaching dozens of dB at low frequencies (below 1kHz), magnetic field leakage in the ‘open topologies’ significantly diminishes their performance.

Based on this, application of passive magnetic shielding in vehicles is limited, first by the feasible geometries in a vehicle, predominantly in very ‘open topologies’ leading to poor shielding efficiency. And secondly by the high cost of the soft magnetic materials.

4.2 Active Field cancelation

An alternative and innovative approach to passive shielding is active shielding. Basically, it is a real-time digital signal processing (DSP) based dynamic field cancelation approach. It offers numerous technological advantages compared to passive shielding:

- Higher suppression ratios
- Flexible installation and placement, can be implemented nearly independently related to other vehicle specific design and development targets
- Can be “retrofitted”

Due to the flexibility of the design, A typical active cancelation system consists of an array of magnetic field measurement sensors, a real-time digital signal processing unit and active cancelation actuators, as described in figure1. The digital signal processing unit is calculating all magnetic field sensor input signals in real time. Based on the data, a specific phase inverted actuator signal will be generated with the same amplitude as the detected source signal (2). The processing in the time domain for the signal tracking and phase inversion must performed in real time, to avoid significant phase shifting between the generated and the original signal.

The size and shape of the sensors and the actuators are small enough so that installation and even retrofit installation in a vehicle can be carried out on a minimally invasive level.

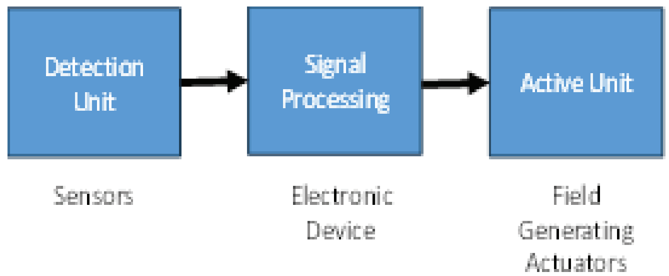

Figure 1: Active Cancelation System Components

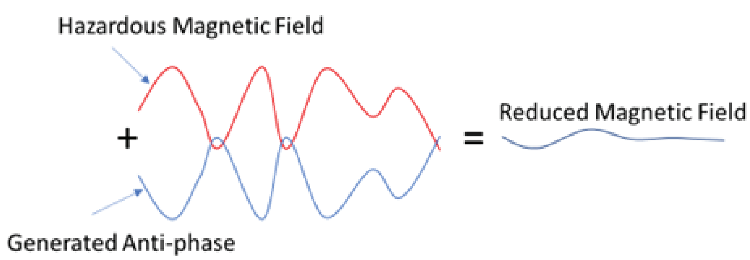

Figure 2: Active Cancelation Principle

5 Design challenges associated with Active Cancelation

The key performance indicators, which are associated with the development of an effective and robust active field cancelation system are as follows:

- Accuracy of field measurements
- Coverage of multiple radiation sources in the vehicle
- Latency / response time
- Dynamic range
- Frequency range of cancelation must cover all significant emissions
- Separating the original field at the input from the field resulting from the actuators
- Components accuracy tracking with variable conditions (temperature)
- Robustness against interfering signals

In general, the challenges can be divided in two subgroups:

- Spatial domain (to ensure that the relevant space is covered by the field cancelation)
- Time Domain (to ensure, that the generated phase inverted field can ‘follow’ the original field in negligible phase shift)

Time domain challenges are solved through by powerful real time signal processing design. Spatial fitting requires both design of the general concept and a specific adaptation of the shape and locations of the sensors and the actuators per specific vehicle architecture.

Achievable target specifications:

- BW to cover vehicle emissions, typically 20Hz to 20KHz
- Suppression ratio of >80%
- Power consumption less than 1% of total power consumption of vehicle
- Signal processing module size is small enough to be implemented minimally invasive (comparable to the size of a large smartphone)
- No interaction with the electronic system of the vehicle apart from 12V power supply

6 Test Procedure

Two commercially available vehicles models from two different makers (Major Brand OEMs) were chosen for the verification. We will refer to them as Vehicle A and Vehicle B.

First, a pattern of magnetic field level measurements was carried out under all relevant driving conditions.

A special developed algorithm allows the allocation of the maximum field level spots in the car. Then, the hardware is to be installed and sensors are placed in the vehicle, based on the collected data of the field distribution in the vehicle.

After proper installation of the hardware devices, initial parametrizing of the adaptive software must be carried out. The basic parametrization is derived from the analytical measurement (as mentioned above). Then, a final tuning is performed on a dyno or under real road condition. This needs to be an iterative development process to achieve optimal suppression performance results.

Measurements with the system on and off were performed to compare the effectiveness under all drive modes.

7 Test Results

The following pages show the results of two installed active field cancellation systems. Figure 3 shows the spatial field strength distribution in a passenger car cabin.

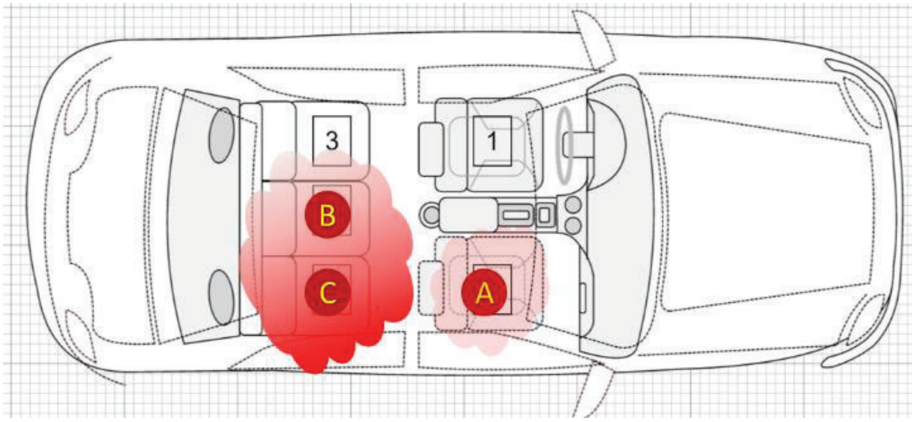

Figure 3: Spatial magnetic field strength distribution in the passenger cabin (Vehicle A)

After initial setup and optimization of the cancelation system, the magnetic field strength with and without cancelation system is shown in figure 4. The test shows different vehicle operational modes and was carried out in an EMC test site without ambient noise. All test cases show more than 80% reduction of the original magnetic field.

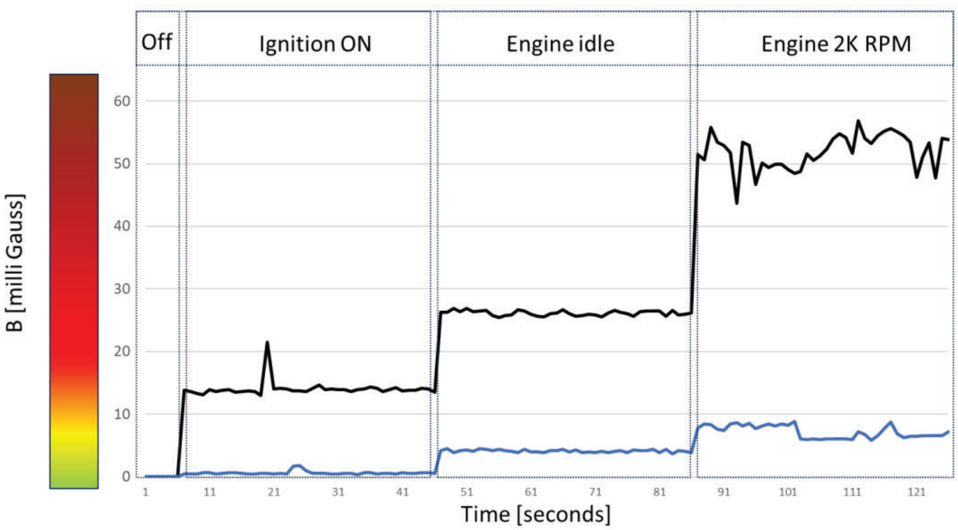

Figure 4: Vehicle A: Results with (blue) and without (black) active cancelation.
Measured at point C.

To verify the time domain capabilities the next figure shows a dynamic driving test. The vehicle was driven on an outside road and the system was turned on and off. 5a shows the results of the magnetic amplitude with system on und off. In 5b the time domain signal is recorded during the operation of the cancelation. The plot shows the original field as well as the phase inverted generated cancelation signal. It is clearly to be seen, that the response is fast enough to minimize the phase shift and optimize the cancelation performance.

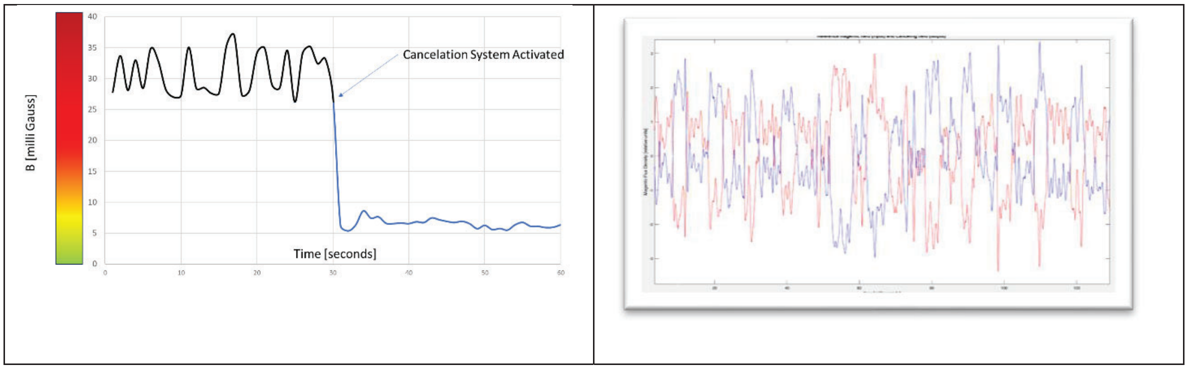

Figure 5 (a, left): Test Vehicle A Magnetic field before and after system activation during a slow driving segment
(b, right): Dynamic response of the system blue: magnetic field; red: active canceling field

A similar test was carried out for another vehicle B. In this vehicle a significant hotspot of emissions is at the back right rear seat. Figure 6 shows the cancelation performance in this “hot spot” of Vehicle B. The results during a driving segment are shown in Figure 7.

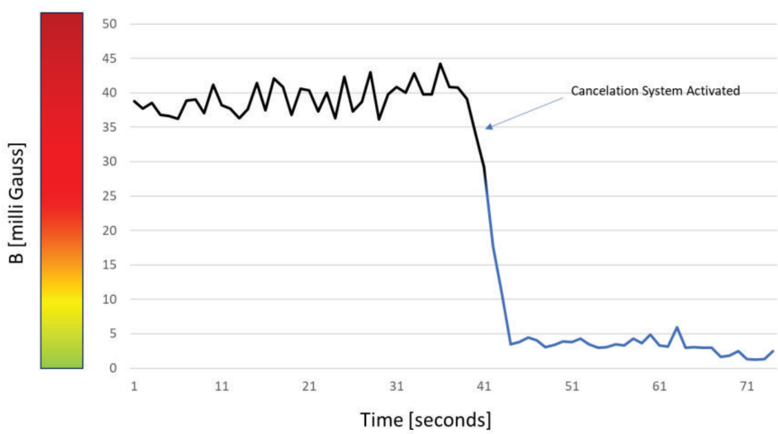

Figure 6: Vehicle B Magnetic field before and after system activation during a slow driving segment

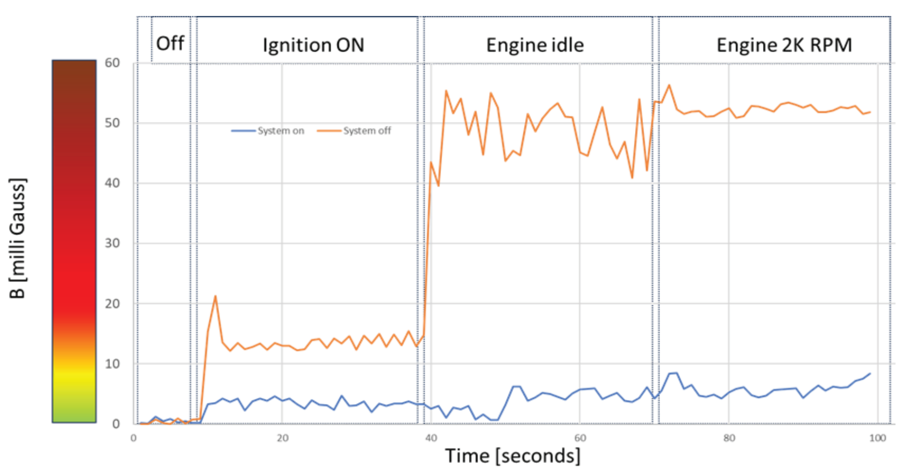

Figure 1: Vehicle B static modes with and without cancelation system activated

8 Conclusion

An innovative active reduction system for suppressing magnetic fields was presented. In the examples of the tested vehicles, more than 80% reduction of the initial magnetic field was achieved. Active cancelation provides an attractive alternative (and in many applications the only alternative) for shielding solution which requires highly effective, predictable and reproducible suppression levels in combination with lower cost, small size and less weight.

This technology enables flexible solutions for the upcoming demand of suppressing magnetic field strength exposure out of technological and biological reasons.

References

[1] IEEE, Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz, IEEE Std C95.1™-2019, 2019.

[2] ICNIRP guidelines, guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz), 2010.

[3] Trentadue, G., Zanni, M. and Martini, G., Assessment of low frequency magnetic fields in electrified vehicles, EUR 30198 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-18458-4, doi:10.2760/056116, JRC120312.

[4] IEC 62764-1, Measurement procedures of magnetic field levels generated by electronic and electrical equipment in the automotive environment with respect to human exposure – Part 1: Low-frequency magnetic fields

[5] China New Car Assesment Program, C-NCAP, https://www.c-ncap.org.cn/

[6] - A.J. Mager, "Magnetic Shields" IEEE trans. on magnetics, vol. mag-6, 1970

[7] - Rikitake, T. (1987). Magnetic and Electromagnetic Shielding. New York, NY: Springer-Verlag

[8] - B.D. Cullity, C.D. Graham, "Introduction to Magnetic Materials" IEEE, WILEY

[9] - S. Celozzi, R.Araneo, G.Lovat, "Electromagnetic Shielding", IEEE, WILEY