Possibilities and Potentials of Active EMI Cancellation for the Volume Reduction of DC/DC Converters in Automobiles

Möglichkeiten und Potenziale der aktiven (EMV-)Störungsunterdrückung zur Bauraumreduktion von DC/DC-Wandlern im Kfz

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Abstract

The electromagnetic compatibility (EMC) of power electronic systems is a severe issue since the switching of transistors causes high electromagnetic interferences (EMI). To reduce the EMI, usually passive filters are applied that tend to be bulky, heavy and expensive. Active noise cancellation is a promising approach to get rid of these problems. Existing methods, namely active EMI filters, suffer from unavoidable delay times since they inject a cancellation signal that origins from a measured signal. These delay times limit the suppressible frequency range and the achievable EMI reduction. To resolve this issue, synthesized cancellation signals are applied by the authors. Since the signal is artificial, there is no systematic delay and all bothersome effects, like phase-shifts or magnitude responses, can be compensated. It is only required that the cancellation signal can be synchronized with the power electronic device to maintain a destructive interference. This can be realized in most digital controlled systems. The method has already been successfully applied to automotive DC/DC converters and is currently being extended for the application to power factor correction circuits and motor inverters. In this contribution, the state of the art and the innovation are described, a demonstrator and measurement results are presented, and the potential field of application is evaluated.

Kurzfassung

Leistungselektronische Systeme können aufgrund der verwendeten schnellschaltenden Transistoren erhebliche Quellen für elektromagnetische Störungen darstellen. Zur Begrenzung dieser Störungen gegenüber der Umwelt werden üblicherweise passive Filter eingesetzt, welche jedoch häufig groß, schwer und teuer sind. Die aktive Störungsunterdrückung ist ein vielversprechender Ansatz zur Lösung dieser Probleme. Bereits existierende Methoden (aktive Filter) leiden unter unvermeidlichen Verzögerungszeiten, da diese das Gegenstörsignal direkt aus einem gemessenen Signal erzeugen. Diese systematische Verzögerungszeit sorgt dafür, dass Störungen und Gegenstörungen niemals gleichzeitig sind. Daher sind die erzielbare Störungsreduktion und der entstörbare Frequenzbereich systematisch eingeschränkt. Zur Lösung dieses

Problems können synthetisierte Gegenstörsignale eingesetzt werden. Da diese künstlich erzeugt wurden, besteht keine systematische Verzögerungszeit und alle problematischen Effekte, wie Phasendrehungen oder Betragsgänge, können kompensiert werden. Für die destruktive Interferenz zwischen den Signalen muss ein synchroner Betrieb zwischen Leistungselektronik und dem Entstörsystem gewährleistet werden, was jedoch in den meisten digitalen Systemen realisiert werden kann. Die Methode wurde bereits erfolgreich bei DC/DC-Wandlern in Automotive-Anwendungen eingesetzt und wird derzeit für weitere wichtige Systeme, wie Leistungsfaktorkorrekturen oder Antriebswechselrichter, erweitert. In diesem Beitrag wird der bisherige Stand der aktiven Filter beschrieben, und die Störungsunterdrückung mithilfe von synthetisierten Signalen wird vorgestellt. Es wird ein Demonstrator präsentiert und Messergebnisse werden diskutiert. Potenzielle Einsatzbereiche werden dargestellt.

1 Introduction

Power electronics is a key technology of the 21st century due to the possibility of very efficient energy conversion. Usually, power electronics achieve this efficiency by switching transistors that may be considerable sources of electromagnetic interferences (EMI). These interferences may harm the operation of other systems, such as communication or broadcasting services or susceptible sensors, which steadily gain more significance due to digitization. To ensure the functionality of sensitive systems in proximity to power electronic devices, electromagnetic compatibility (EMC) is a major enabler for electrification with power electronics.

2 State of the Art

2.1 Passive Filters

Passive line filters consisting of coils and capacitors are commonly applied to attenuate the conducted EMI of power electronic devices. Since the disturbances as well as the operating voltages and currents of the converters are typically quite high, filters tend to be bulky and heavy. In *Figure 1*, an automotive on-board charger is depicted.

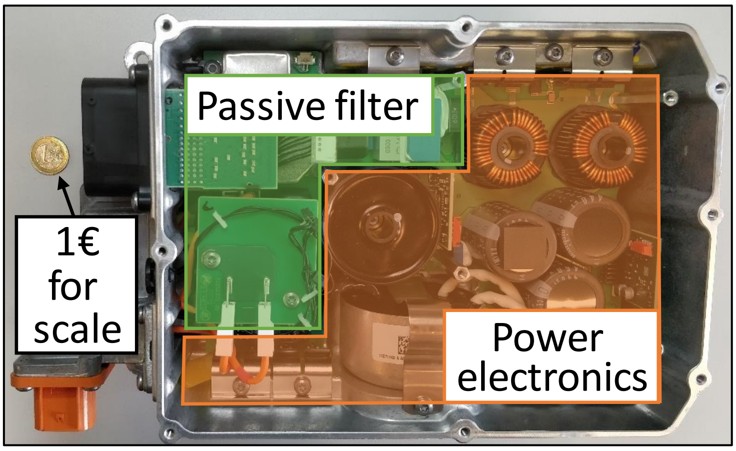

Figure 1: Exemplary on-board charger (3.6 kW)

Here, the passive filter takes up approximately one third of the electronics volume. In many applications, this can be a serious problem. In e.g. hybrid vehicles, there is not much volume for the power electronic systems since the combustion engine and its components take up basically all of the available space. In electric vehicles, there is more free space since there is no combustion engine anymore. Nevertheless, there are very high requirements regarding the vehicle's total mass to improve the driving range. So, there are many reasons to shrink the passive filter component.

2.2 Active EMI Filters

To resolve the mentioned issue, active EMI filters have been developed (*Figure 2*) [1]-[4]. In contrast to passive filters, active EMI filters inject cancellation signals that cause a destructive interference with the disturbances of the power electronics to reduce the EMI of the system. Active EMI filters consist of a small circuit for sensing the disturbances, an amplifier (e.g. operational amplifier) to generate the cancellation signal from the disturbances, and a small circuit for injecting the cancellation signal. The major limitation for active EMI filters is the inevitable delay time introduced by the analog (or recently also digital) circuitry. Due to this delay time, noise and anti-noise can never be exactly simultaneous. This effect systematically limits the achievable EMI reduction and the suppressible frequency range as analyzed exemplary for feedforward-types in [7].

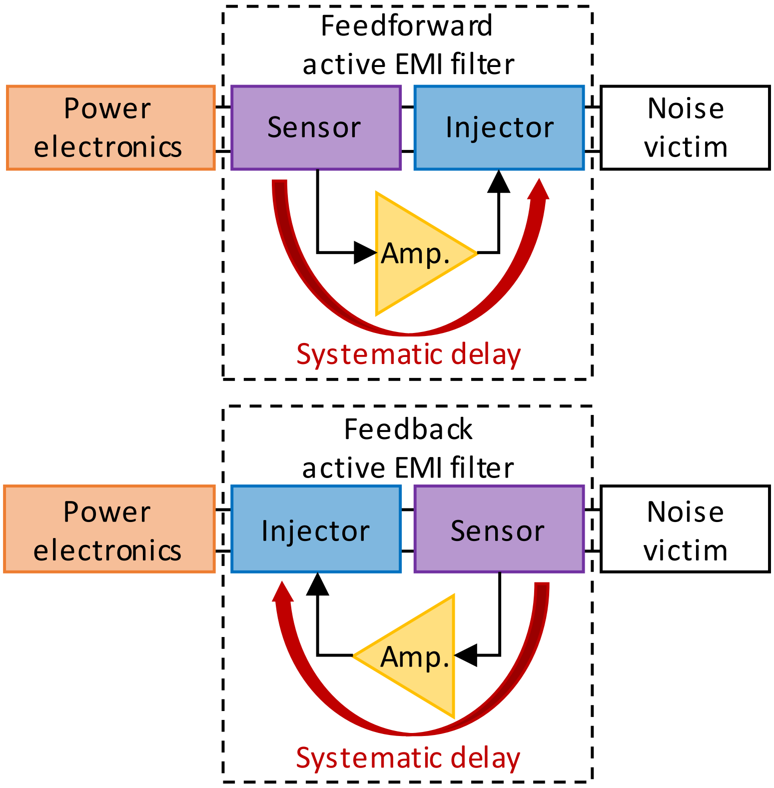

Figure 2: Fundamental topologies of active EMI filters (top: feedforward-type, bottom: feedback-type)

3 Innovation

3.1 Active Noise Suppression with Synthesized and Synchronized Cancellation Signals

To resolve the issue of a systematically delayed signal path, the cancellation signal can be artificially synthesized and applied in synchronicity with the disturbances (*Figure 3*) [5]-[8]. Remaining magnitude responses, phase-shifts and delays are compensated by the shape of the synthesized signal improving the cancellation's effectivity widely. For (quasi-)periodic disturbances, the signal can be easily constructed from harmonic sine waves. In the following, an adaptive approach is presented to find the right amplitudes and phases for the cancelling sine waves and, therefore, the overall cancellation signal.

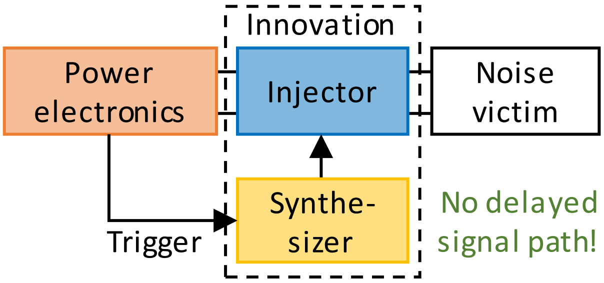

Figure 3: Concept of the innovation

3.2 Adapted Harmonics Cancellation

The fundamental concept of Adapted Harmonics Cancellation (AHC) is illustrated in *Figure 4*. The power electronic system is the source of the stationary disturbing harmonics that must be cancelled out. A DC/DC converter would be a typical example of a system that creates harmonic disturbances due to the periodic switching of the transistors. The cancellation signals can be generated by digital hardware (e.g. by an FPGA with analog-to-digital converters [ADCs] and digital-to-analog converters [DACs], *Figure 5*). The digital hardware comprises an optimizer and a synthesizer. For cancellation, the synthesizer generates a sine wave for each disturbing harmonic. The optimizer is used to find the right amplitudes and phases for cancellation. The synchronicity of the generated sine waves and the disturbing harmonics is maintained by a suitable synchronization signal. To link the power electronic system and the cancellation system, interfaces are necessary. A sensor consisting of an analog circuit and an ADC is used to measure the disturbances. An injector is applied to couple the cancelling waveforms into the power electronic system. This injector consists of an injecting circuit and a DAC. These components can be very small, especially in comparison to passive EMI filters.

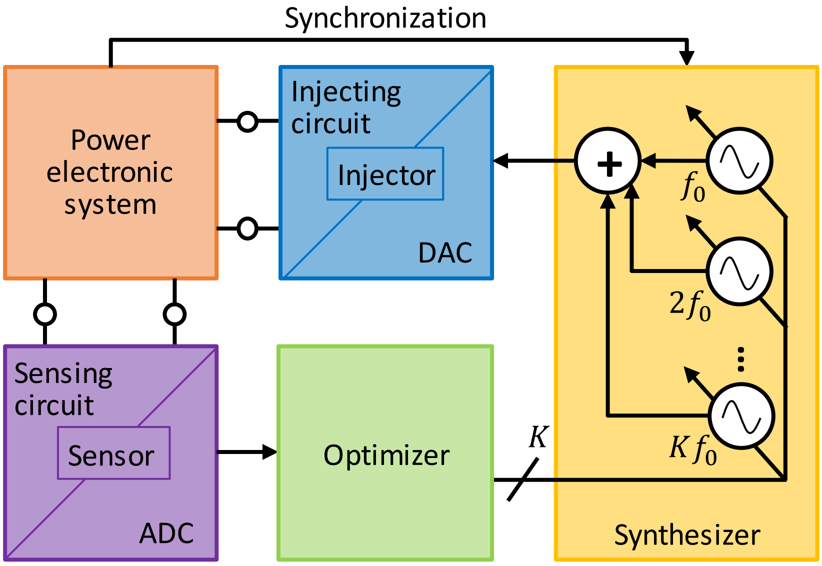

Figure 4: Concept of Adapted Harmonics Cancellation

Figure 5: FPGA evaluation system with high-speed DACs and ADCs (Red Pitaya STEMlab 125-14)

4 Demonstration

For demonstration, the disturbances of an automotive 48 V/12 V DC/DC are suppressed by a self-adapting algorithm that is implemented on the FPGA system Red Pitaya STEMlab 125-14. The Device Under Test (DUT) can be seen in *Figure 6*. In *Figure 7*, the disturbances at the artificial network are depicted. Obviously, the original disturbances are much higher than the class 5 limit of the standard CISPR 25 [9]. The resulting disturbances for a feedforward active EMI filter with a reasonable delay time of 10 ns are predicted with the formulas derived in [6] and [7]. Due to the systematic delay, the achievable reduction and the suppressible frequency range are severely limited for the active filter. Since there is no systematic delay between noise and anti-noise for the authors' proposed method, the noise suppression is widely improved. The complete frequency range from 150 kHz to 30 MHz is suppressed successfully and complies now with the standard. The fundamental wave at 300 kHz is reduced by nearly 60 dB, and even the 100th harmonic at 30 MHz is suppressed by approximately 40 dB. More details and further demonstrations can be found in [5]-[8].

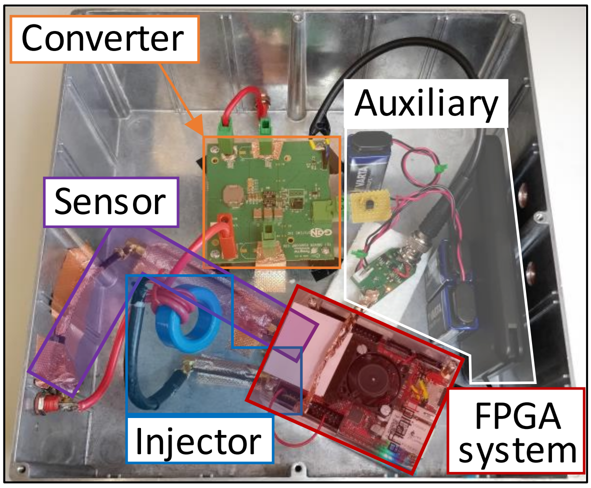

Figure 6: Realized DUT

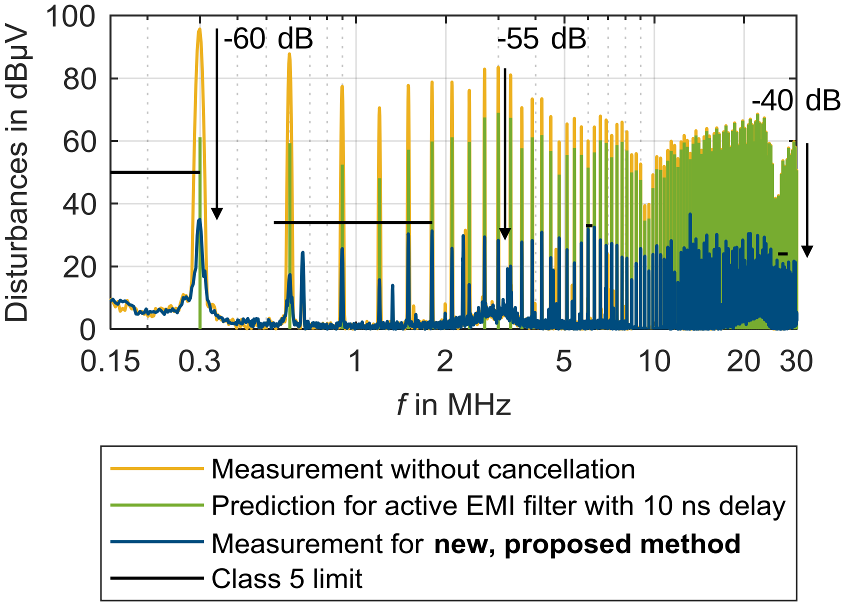

Figure 7: Measured disturbances at the artificial network

5 Potential Applications

Until now, the presented method of active EMI suppression with synthesized and synchronized cancellation signals has been successfully applied to stationary operating DC/DC converters. Currently, the method is extended for the application in non-stationary operating systems like power factor corrections or motor inverters which play a key role in power electronics. In these applications, the cancelling sine wave properties have to be adjusted continuously. By injecting exactly synchronous cancellation signals without any uncompensated delay, there is an extraordinary potential for the active EMI suppression in many power electronic systems.

6 Conclusion

In our research, a new method has been developed to eliminate disturbing voltages or currents by injecting synthesized and synchronized cancellation signals. In comparison to other known active methods, there is no systematic delay time that limits the achievable performance of the system. The effectivity of the method has already been shown for a DC/DC converter and is currently being extended for other important power electronic systems, namely power factor corrections and motor inverters. The authors expect a considerable reduction of the necessary passive filter effort that can lead to smaller and lighter power electronic systems.

7 References

[1] J. Walker, "Designing practical and effective active EMI filters," in Powercon 11 Proc., April 1984, Paper I-3.

[2] L. E. LaWhite, M. F. Schlecht, "Design of active ripple filters for power circuits operating in the 1-10 MHz range," IEEE Trans. Power Electron., vol. 3, no. 3, pp. 310-317, Jul. 1988.

[3] L. E. LaWhite, M. F. Schlecht, "Active filters for 1 MHz power circuits with strict input/output requirements," in 17th Annual IEEE Power Electronics Specialists Conf., Vancouver, Canada, 23-27 Jun. 1986, pp. 255-263.

[4] T. Farkas, M. F. Schlecht, "Viability of active EMI filters for utility applications," IEEE Trans. Power Electron., vol. 9, no. 3, pp. 328-337, May 1994.

[5] A. Bendicks, T. Dörlemann, S. Frei, N. Hees, M. Wiegand, "FPGA-basierte aktive Gegenkopplung der Schaltharmonischen von leistungselektronischen Systemen," in EMV Düsseldorf, Düsseldorf, Germany, 20-22 Feb. 2018, pp. 652-661.

[6] A. Bendicks, T. Dörlemann, S. Frei, N. Hees, M. Wiegand, "Development of an Adaptive EMI Cancellation Strategy for Stationary Clocked Systems," in EMC Europe, Amsterdam, Netherlands, 27 30 Aug. 2018.

[7] A. Bendicks, T. Dörlemann, S. Frei, N. Hees, M. Wiegand, "Active EMI Reduction of Stationary Clocked Systems by Adapted Harmonics Cancellation," IEEE Trans. EMC, to be published, Aug. 2018.

[8] A. Bendicks, S. Frei, "Broadband Noise Suppression of Stationary Clocked DC/DC Converters by Injecting Synthesized and Synchronized Cancellation Signals", IEEE Trans. Power Electron., to be published, Jan. 2019.

[9] CISPR 25 – Vehicles, Boats and Internal Combustion Engines – Radio Disturbance Characteristics – Limits and Methods of Measurement for the Protection of On-Board Receivers, Ed.4.0, 2015.