

# Evaluation of hybrid EMI filters to reduce the high level of conducted noise generated by the frequency inverter

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**Abstract.** This article presents an analysis of the applicability of hybrid EMI filters to reduce common mode noise. The effectiveness of filters was tested when attenuating the high level of EMI noise generated by the frequency inverter. The influence of the use of various magnetic cores in the hybrid EMI filter construction was investigated and the obtained insertion losses with passive filters were compared. The article concludes with the summary of both filtration techniques.

## 1 Introduction

The basis for the construction of hybrid EMI filters are active filters, which were described in detail and tested by the authors in previous publications [1, 2]. This article is focused to hybrid filters. The examined filters were tested when attenuating the high level of common mode noise generated by the frequency inverter. The environment of a high level of CM noise was simulated by connecting additional capacitors on the frequency inverter output. Research aimed at attenuation of the common mode noise, because the dimensions of EMI filters depend mainly on the size of the common mode choke [3].

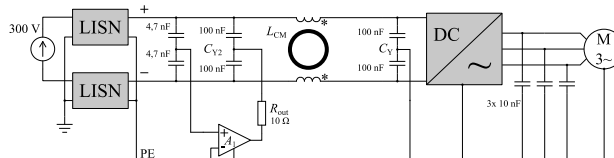
## 2 Hybrid EMI filters

According to the analysis carried out in the previous work [1], an active filter type III [4] (voltage detection and current cancelation) was chosen for the construction of a hybrid filter for common mode noise.

### 2.1. Evaluation of hybrid EMI filters

The active filter used in the construction of hybrid filter was described in the previous work of the authors [2]. The noise voltage is detected by 4.7 nF capacitors directly from the supply lines. Compensation signal for common mode noise is provided by capacitors with a capacity of 100 nF and an additional resistor  $R_{out}$ . This resistor is used to improve the stability of the active part of the filter. Figure 2 presents a schematic of a proposed by the authors measurement stand for testing hybrid filters.

The passive part of the hybrid filter was built using four different ferromagnetic cores, whose parameters are presented in Table 1.



**Fig. 1.** Schematic diagram of the proposed measuring stand for active EMI filters.

**Table 1.** Parameters of cores used for filter construction.

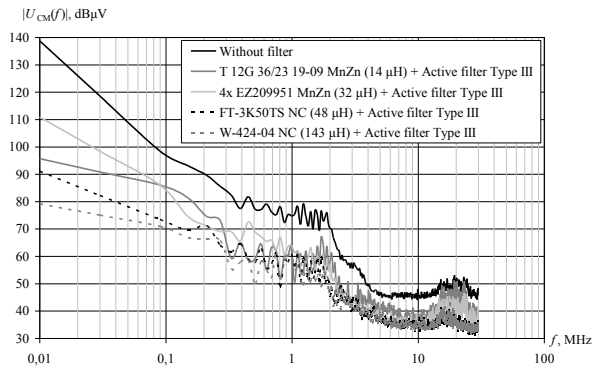
	Symbol	Core type	AL, nH	Weight, g
1	NCD, EZ209951	Ferrite MnZn	8000	77
2	KOLEKTOR, T 12G 36/23 19-09		14000	62
3	HITACHI, FT-3K50TS	Nanocryst. NC	48000	76
4	VAC, W 424-04		143000	70,5

The cores had similar geometric dimensions, however, they were made with different types of magnetic materials: powder (MgZn) and nanocrystalline (NC). Inductance of  $L_{CM}$  choke in the hybrid filter had same values such as core AL coefficient used in their construction, because only one turn was wound. The attenuation properties of the resulting filter depend only on the magnetic and geometric properties of the core [5].

A comparison of obtained CM noise spectra generated by the frequency inverter without filters and after suppressing them with hybrid filters are shown in Figure 2.

Differences in insertion loss modulus provided by hybrid filters, in the construction of which different cores are used, vary (depending on the frequency) from 1 dB to 30 dB. However, the insertion loss modulus of the tested sets (in relation to the level of CM noise generated by the frequency inverter without filters) was from 1 dB to 60 dB.

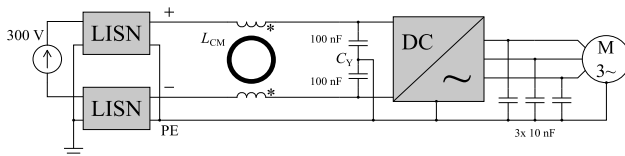
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**Fig. 2.** Obtained CM EMI spectra generated by a frequency inverter without a filter and with a hybrid filters with various core materials.

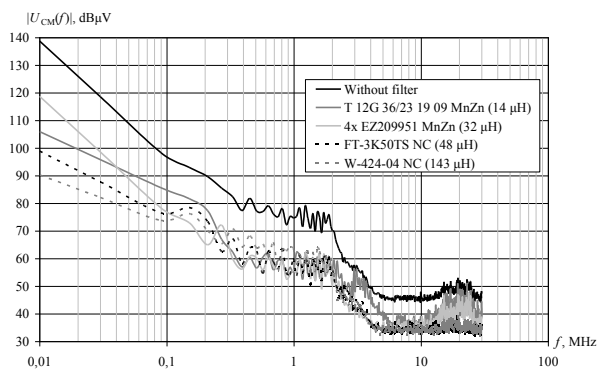
### 2.2 Measurements of passive filters

The cores used in construction of passive filters are the same as in the previously constructed active filters. The diagram of a measurement stand proposed by the authors is shown in Figure 3.



**Fig. 3.** Schematic diagram of the proposed measuring stand for passive filters.

Figure 4 presents obtained spectra of CM noise generated by the inverter after suppression with passive filters. The spectrum of CM noise without filter is also included.

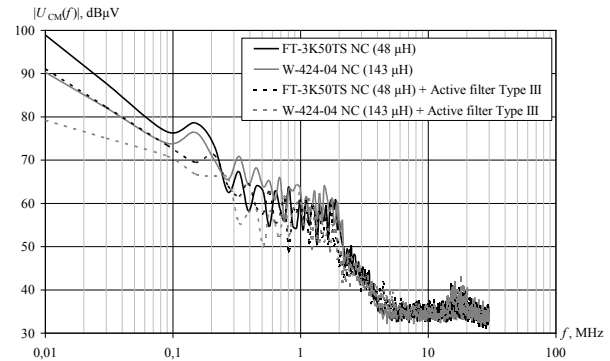


**Fig. 4.** Obtained CM EMI spectra generated by a frequency inverter without a filter and with a passive filters with various core materials.

The use of hybrid filters in the conditions of a large level of CM noise, compared to passive filters made using the same core materials, allows to increase the noise attenuation from approx. 5 dB to 10 dB in the frequency range from 10 kHz to 200 kHz for nanocrystalline cores. At powder cores, which have less magnetic permeability than nanocrystalline cores, the attenuation were worse.

### 3 Summary

Figure 5 presents a combination of selected spectra of CM noise generated by the frequency inverter with additional capacitors on the output after suppressing them with passive and hybrid filters.



**Fig. 5.** Obtained CM EMI spectra generated by a frequency inverter without a filter and with a passive and hybrid filters with various core materials.

Analyzing the obtained spectra, it should be noted that the use of a hybrid filter with  $L_{CM}$  choke inductance of 48  $\mu\text{H}$  gives similar results compared to a passive filter with  $L_{CM}$  choke inductance of 143  $\mu\text{H}$ . This similarity is noticeable in the frequency range from 10 kHz to 100 kHz. Above these frequencies, the hybrid filter has even greater attenuation of CM noise than the passive filter, ranging from 1 dB to 10 dB. Research in an environment with a high level of CM noise has shown that a nanocrystalline core with three times lower permeability can be used together with an active filter to obtain a better insertion loss than at the passive filter alone. At the same time, it allows to reduce the overall size, weight and price of the EMI filters because cores with lower permeability are cheaper and can be used with smaller dimensions (higher saturation current).

### References

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