UNIVERSITY
OF TRENTO

DIPARTIMENTO DI INGEGNERIA E SCIENZA DELL'INFORMAZIONE

38123 Povo – Trento (Italy), Via Sommarive 14
http://www.disi.unitn.it

AUTOMATIC DESIGN AND OPTIMIZATION OF AN EMI FILTER USING COMMERCIALLY-AVAILABLE COMPONENTS

R. Azaro, L. Ioriatti, M. Martinelli, and A. Massa

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Automatic design and optimization of an EMI filter using commercially-available components

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Designing customized EMI filters is a challenging task since the choice of the circuit topology as well as of the discrete values of the electric components, for satisfying multiple electrical requirements, is not trivial and no-standard guidelines are available. In this letter, an approach based on a particle swarm optimizer, used in conjunction with a circuital simulator, is described. By using equivalent models of commercial components, such a method allows the synthesis of reliable and ready-to-build filters. As an example, a filter prototype is realized and its efficiency assessed through numerical and experimental evaluations.

Introduction: Electromagnetic interference (EMI) is a relevant problem in electric and electronic systems. As a matter of fact, devices and installations have to meet international EMI standards concerned with conducted interferences. Towards this end, EMI filters are usually needed in order to reach a proper RF noise suppression. As far as electric and electronic industry is concerned, the problem of designing EMI filters is recast as that of determining the most economical circuit architecture that satisfies assigned constraints on insertion losses (common mode and differential mode) and able to withstanding low-frequency voltage and current ratings [1], as well. In such a framework, some non-negligible difficulties arise from the uncertainty on the knowledge of the frequency behavior of both the internal impedances modeling EMI sources and the loads connected to I/O ports of the filter. As a consequence, methods for the EMI filter design able to deal with several (and in some cases, conflicting) and realistic constraints, are not generally available. As a matter of fact, state-of-the-art techniques [2] are mainly based on worst-case methodologies or on empirical assumptions. Moreover, they often require experimental data and detailed physical descriptions of passive devices (not usually available from the components suppliers). On the other hand, research activities devoted to the synthesis of EMI filters [3][4][5] are mainly aimed at optimizing the values of the components of an *a-priori* defined circuit topology. In this letter, the design of a mono-phase AC filter is recast as an optimization problem solved by means of a Particle Swarm Optimizer (PSO) [6] that employs equivalent circuital models available from datasheets of commercial components.

EMI filter design and experimental measurements: By assuming an impedance value of 50 Ω for both the noise source and the load, the following project constraints have been assumed. An insertion loss behaviour in the 10 kHz – 30 MHz frequency range for the common mode and differential mode described by the masks shown in Fig. 3 and Fig. 4, respectively; a rated voltage equal to 230 Vac; a rated current of 0.1 A; a maximum leakage current and maximum loss differential current at 50 Hz equal to $I_l^{\max} = 0.5$ mA and $I_{dl}^{\max} = 10$ mA, respectively. In order to fit these requirements by optimizing the component values and the topology of the filter, a suitable cost function has been defined and optimized through a discrete version of the

PSO algorithm [7] integrated with a circuit architecture generator and a SPICE circuital simulator. More in detail, the circuital topology generator iteratively builds a population of tentative solutions by cascading up to 4 cells chosen among a set of elementary cells (see Figure 1) according to the PSO updating strategy. Concerning the components values, they are chosen among the discrete values listed in a database of commercially-available devices. Moreover, in order to carefully model the electric behaviour of the filter, some components simulating the parasitic phenomena inside [1] and between neighbouring devices [8][9] are integrated into the equivalent SPICE model of the circuit. For each trial solution, the corresponding electrical parameters [i.e., common mode (CMA) and differential mode (DMA) attenuations, leakage current, loss differential current] are computed by means of the SPICE simulator. The iterative process continues until an user-defined threshold of the cost function or a maximum number of iterations is reached.

Figure 2 shows the structure of the synthesized mono-phase AC filter whose components values are: $CX_1 = CX_2 = 47$ nF Class X1 275 Vac, $CY_1 = CY_2 = 3.3$ nF Class Y1 250 Vac, $LCM_1 = 100$ mH Common Mode Choke 0.35 A, and $R_1 = 1$ M Ω 1 W.

Experimental Validation: A prototype of the mono-phase AC filter has been built by using a photolithographic printing circuit technology and the CMA and DMA have been measured placing the filter prototype on a reference ground plane inside a shielded chamber. As far as the measurement is concerned, an EMI receiver equipped with a tracking generator that employs a couple of unbalanced-to-balanced RF transformers for differential measurements has been used. In Figs. 3 and 4, the behaviors of CMA and DMA are shown in order to assess the effectiveness of the design methodology as well as the agreement between simulated and measured data. Moreover, the values of the leakage current ($I_l = 0.456$ mA) and of the differential loss current ($I_{dl} = 6.66$ mA) comply with the specifications, as well.

Conclusion: The design and optimization of a mono-phase AC filter EMI filter has been described. The filter architecture has been synthesized through a PSO-based algorithm by optimizing the circuit topology and by choosing the values of commercially-available components for fitting a suitable set of electrical constraints. A filter prototype has been built and experimentally-verified for assessing the effectiveness of the proposed design procedure.

Acknowledgments

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Authors' affiliations:
R. Azaro, L. Ioriatti, M. Martinelli, and A. Massa
Department of Information and Communication Technology,
University of Trento, Via Sommarive 14, 38050 Trento – ITALY

Corresponding Author:
A. Massa
Department of Information and Communication Technology
University of Trento
Via Sommarive 14
38050 Trento
ITALY
E-mail: andrea.massa@ing.unitn.it

Figure captions:

Fig. 1 - Elementary cells circuital topology.

Fig. 2 - Optimized mono-phase AC EMI filter.

Fig. 3 - Comparison between measured and simulated Common Mode Insertion Loss values.

———— Simulated Data

- - - - - - - - Measured Data

· · · · · · · · · Requirements

Fig. 4 - Comparison between measured and simulated Differential Mode Insertion Loss values.

———— Simulated Data

- - - - - - - - Measured Data

· · · · · · · · · Requirements

Figure 1

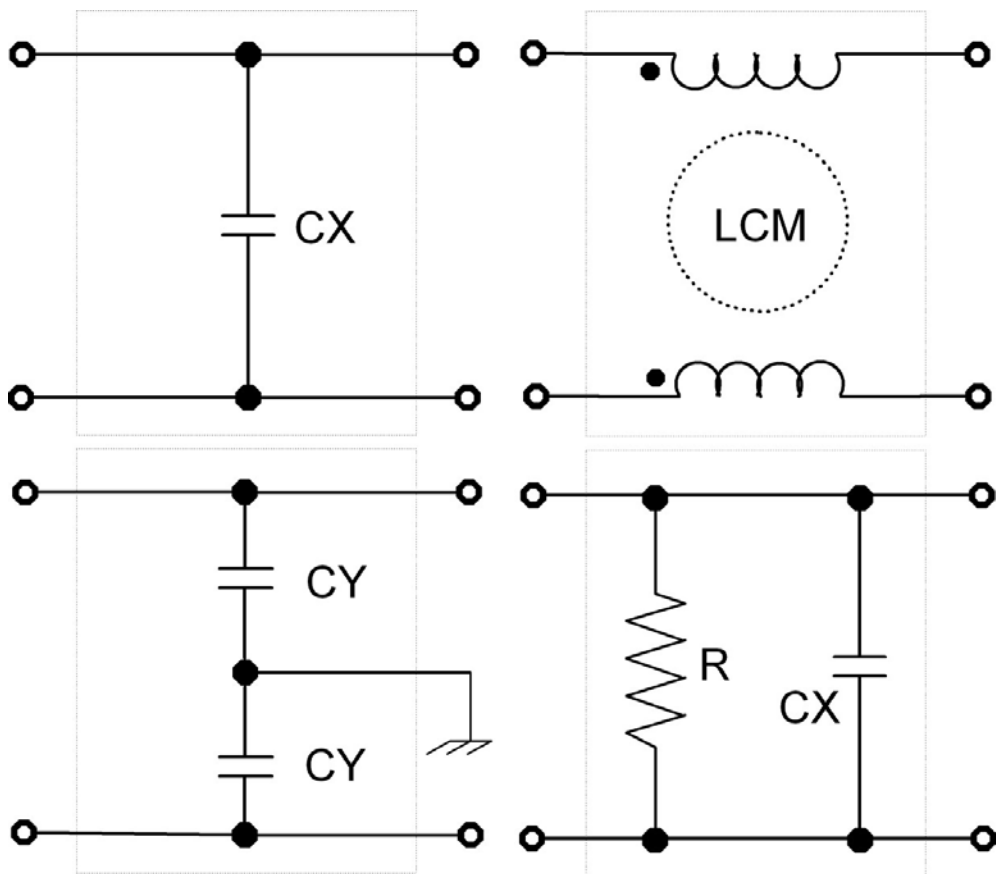


Figure 2

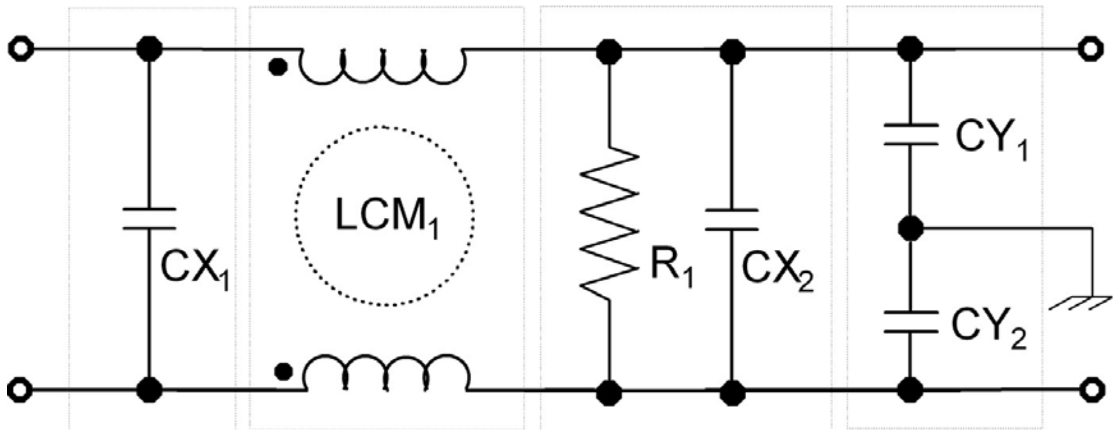
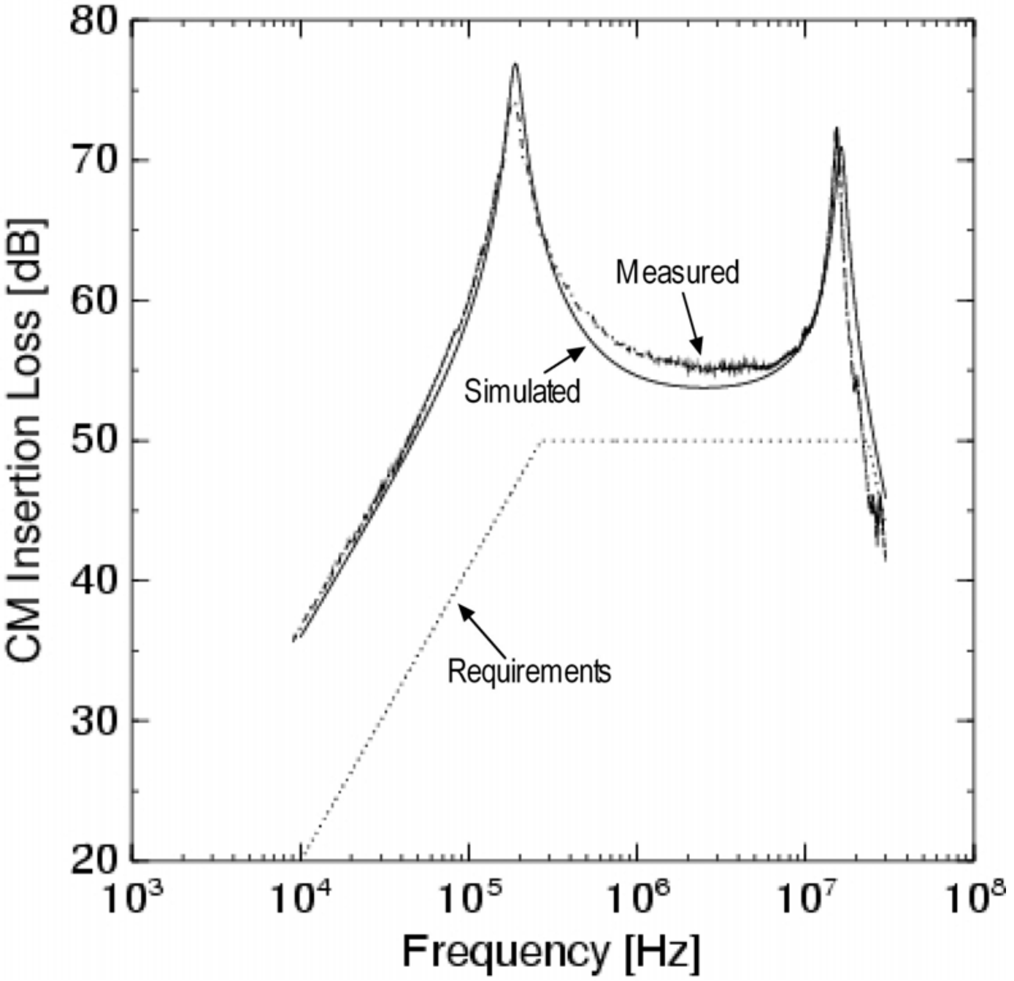
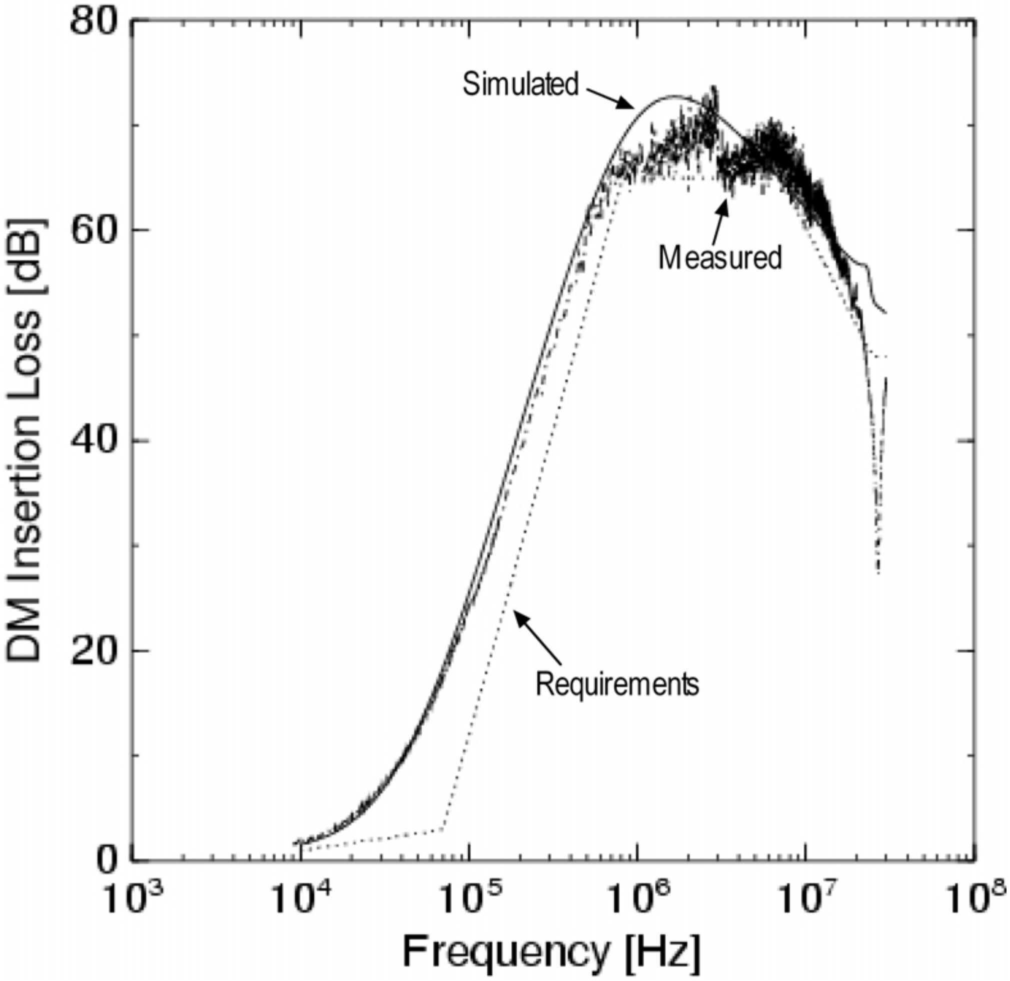


Figure 3



80
70
60
50
40
30
20
CM Insertion Loss [dB]
Measured
Simulated
Requirements
10^3
10^4
10^5
10^6
10^7
10^8
Frequency [Hz]

Figure 4



80
60
40
20
0
DM Insertion Loss [dB]
Simulated
Measured
Requirements
10^3
10^4
10^5
10^6
10^7
10^8
Frequency [Hz]