Teaching EMC using an EMC demonstration unit

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Abstract—When teaching electromagnetics, electromagnetic compatibility (EMC) and printed circuit board (PCB) design, it is important to bridge the gap between theory and practice. This paper describes several demonstrative real-life aspects of a developed up-to-date EMC demonstration unit and contrived lab exercises. The demonstration unit proves to be useful when demonstrating EMC practices to a large variety of people, whether they are technically skilled or not. The demonstration unit also allows to realise a project based teaching of future electronic design engineers.

I. INTRODUCTION

Electronic systems are integrating more and more functionalities in an ever confined volume. The use of increasing clock frequencies in combination with decreasing rise and fall times increases the emission of electromagnetic disturbances. At the same time, supply voltages and voltage margins are decreasing which tends to decrease the immunity of the electronic parts. Without appropriate precautions many electronic components and systems will suffer from electromagnetic interference (EMI) related problems. The electronic community develops a broad range of techniques to avoid or reduce EMI related problems i.e. to obtain electromagnetic compatibility (EMC). In order to tackle these problems, it is imperative that a large number of people, for example technicians; scientists; engineers, and their managers are aware of the EMI related problems and the EMC based solutions. Therefore, it is increasingly important to teach a basic understanding of EMC to a large variety of people, whether they are technically skilled or not. Practical demonstrations of good and bad EMC practices are often the most efficient way to teach a basic understanding of EMC, to demonstrate the importance of good EMC practices and to be sure the target group remembers these EMC practices. It is also important to teach a good knowledge of EMC to all electronic design engineers. Theory sessions must be accompanied by demonstrations of good and bad EMC practices to bridge the gap between theory and practice. Moreover, it is important all electronic design engineers gain practical experience concerning the major EMC practices. The idea to build a demonstration box to teach EMC practices is not new. An EMC demonstration box has been built by K. Armstrong in the 1990s to demonstrate good practice design issues in shielding and filtering [1]. The box

shows how to distinguish good EMC designs from bad EMC designs [2]. A newly developed up-to-date unit [3] allows easy demonstrations of the most basic EMC phenomena, good and bad EMC practices, the importance of EMC filter chassis bonding, the impact of good and not so well designed high-speed PCBs. Conducted emission and radiated emission phenomena, including near field and far field measurements, can be shown. In [3], merely technical aspects related with the development and the use of the new EMC demonstration unit have been discussed. In the present paper, merely the teaching aspects of the use of the EMC demonstration unit will be discussed. A distinction has been made between:

- teaching a basic understanding of EMC to a large variety of people, whether they are technically skilled or not,
- teaching a good knowledge of EMC to electronic design engineers.

II. THE EMC DEMONSTRATION UNIT

The EMC demonstration unit, having an internal spatial planning as visualised in Figure 1, allows the users:

- to study the shielding effectiveness of a metal enclosure and the impact of apertures, e.g. slots and holes, on the shielding effectiveness,
- to investigate the impact of seams of the lid of the metal enclosure and how the shielding effectiveness increases by using EMC gaskets,
- to study conducted and radiated emission levels due to a Switched Mode Power Supply (SMPS),
- to study the impact on the conducted emission levels of a SMPS when the IEC inlets are filtered and the importance of a proper bonding of such a filter,
- to study conducted and radiated emission levels due to different PCB designs containing e.g. an oscillator providing a Low-Voltage Differential Signal (LVDS) driving a twisted pair cable,
- to study the influence of shielded versus unshielded cables on both the radiated and conducted emission levels,
- to study the influence of matched and mismatched loads both for a shielded and an unshielded connector on the radiated and conducted emission levels.

Fig. 1. Internal spatial planning inside the demonstration unit

III. DEMONSTRATIONS BASED ON THE EMC DEMONSTRATION UNIT

A. Real-life demonstrations

The demonstration unit allows to teach a basic understanding of EMC to a large variety of people. During academic years 2015 - 2016 and 2016 - 2017, an important number of demonstrations have been performed:

- pupils studying at primary (6 to 12 years old) and secondary level (12 to 18 years old) and their accompanying family during a Flemish National Science Day,
- pupils studying at a secondary level (14 to 16 years old) during a scientific and programming summer camp,
- teachers teaching at technical secondary schools,
- electronics-ICT students studying a professionally oriented bachelor program,
- master students in engineering studying a more theoretically oriented five year engineering program,
- master students in engineering studying a more practically oriented four year engineering program (electronics ICT and electromechanical engineering students),
- a group of Belarusian engineering students comprising bachelor students, a master student and PhD students [4],
- a group of Belarusian professors active at the Belarusian State University (BSU), Grodno State University (GrSU), Gomel State University (GSU) and Belarusian State Technological University (BSTU),
- graduated engineers, active in the local industry, during an EMC seminar.

Whenever possible, the participants were asked to evaluate the EMC demonstrations based on the demonstration unit and the overall appreciation was really high as visualised in Table I. A self-defined questionnaire containing three positively defined statements have been offered to the participants. In order to obtain an adequate dispersion of the data, a five-point Likert scale was used in the questionnaire. The participants also had the opportunity to mention open statements. Finally, the questionnaire asked for a global evaluation using a scale from 1 to 10. The overall evaluations of the different types of participating groups are very similar which allows to combine

TABLE I
EVALUATION OF THE DEMONSTRATIONS PERFORMED USING THE EMC DEMONSTRATION BOX

Description	Five-point Likert scale				
	1	2	3	4	5
The research assistant is skilled, motivated and communicates clearly				47.6%	52.4%
The demonstration unit and the demonstration itself have a high quality and provide clear examples and applications				48.8%	51.2%
The demonstration is relevant in my personal educational program		5.0%	2.5%	65.0%	27.5%

the data. Table I gathers data of participating pupils and students (a total of 40 evaluations are available). The overall appreciation gives an average score of 8.0 of the scale ranging from 1 to 10.

A skilled and motivated research assistant is needed to give EMC demonstrations using the demonstration unit. This boundary condition is satisfied and the demonstrations itself are highly appreciated by all types of pupils and students. In general, the pupils and the students have the impression EMC is a relevant topic in their educational program (also students studying electromechanics share this opinion).

The number of participating teachers who participated the evaluation is limited (only three) but they also share the opinion of the pupils and students by giving an average global evaluation of 8.3.

The positive responses of the participants encourage the authors to realise further improvements on the demonstration unit and to maintain the number of demonstrations to large varieties of groups.

In order to spread the use of the demonstration unit, rebuilding and selling the demonstration unit allows all interested training centres, including but not limited to colleges, universities and engineering companies to use the unit. The amount of additional measurement devices, needed to perform the demonstrations, is limited to a spectrum analyser and a suitable probe to perform the near field measurements. The same spectrum analyser and a current clamp is needed to perform the conducted emission measurements. Both probes could come in the form of a very cheap DIY probe [5]–[8] while one of the currently cheapest spectrum analysers - or a cheap USB spectrum analyser - would already be adequate. An additional option could be an external display output, so that the measured values could be either projected or displayed on a larger screen during demonstrations improving visibility for a larger audience.

B. Demonstrations using multimedia

Although real-life demonstrations are stimulating and allow an informal contact with the demonstrator, it requires a considerable time investment to set-up, prepare, double check

and perform these demonstrations. As part of the Erasmus+ project "Improvement of master-level education" in the field of physical sciences in Belarusian universities [9] [4], the EMC demonstrations have been filmed and the movies are available in a Moodle and a Blackboard learning environment. Such a multimedia approach allows to reach a larger number of students without the need of the demonstration unit and EMC related measurement devices. This approach provides the students, wherever their location, the opportunity to watch the movies as many times as needed and no additional time-investment of a demonstrator is needed. Moreover, the students can afterwards be interactively questioned.

The movies also allow a public availability using social media like YouTube, Youku, Vimeo,... Such an approach provides educational information to a broad range of people, whether they are technically skilled or not, whether they are electronic design engineers or not, whether they are mechanical design engineers or not.

IV. TEACHING ELECTRONIC DESIGN ENGINEERS

Bridging the gap between theory and practice is always a challenge when teaching electronic circuit theory, EMC, PCB design issues and their interrelationship [3], [10], [11]. By combining the demonstration unit with the infrastructure available in an EMC research laboratory, interesting project based teaching opportunities appear. Although a slim version of this teaching approach seems applicable to mechanical design engineers (e.g. design of apertures, seams, ...), the approach mainly applies to electronic design engineering students.

A. Main goals of the project based teaching

When teaching specialised EMC courses to electronic design engineers, the demonstrations discussed in the previous paragraphs can usefully be provided. Both the use of real-life demonstrations and multimedia demonstrations remain important opportunities. By combining the demonstration unit with the infrastructure available in an EMC research laboratory, new opportunities appear to teach specialised EMC courses and to teach important learning outcomes like:

- specialised disciplinary knowledge and comprehension,
- problem analysis and solving,
- information gathering and processing,
- critical thinking,
- written communication skills.

During academic year 2016-2017, an EMC course for master students started with a theoretical teaching of EMC. To bridge the link between theory and practice, in the second half of the course, the students realised a project work aimed at bringing their acquired theory into practice, while gaining some familiarity with typical EMC set-ups and measurements. The lab exercises were developed to train students in three levels of expertise:

- 1) Performing basic measurements, interpreting and linking them to theoretical concepts.

Fig. 2. Radiated emissions according CISPR32 standard class B limit of the autorouted version of the driver PCB

- 2) Performing modifications to the demonstration unit, interpreting the change in results obtained from measurements by explaining the underlying theoretical principles.
- 3) Performing advanced experiments, testing their understanding of the theoretical concepts thereby building up scientifically justified reasoning.

The incorporated skills in the exercises are:

- obtaining familiarity with the reading of EMC normalisations by linking these normalisations with conducted emission measurements,
- obtaining familiarity with the reading of EMC normalisations by linking these normalisations with radiated emission measurements,
- comparing the emission levels when relying on different EMC practices,
- design of a Printed Circuit Board (PCB) using automatic routing and manual routing taking good EMC practices into account,
- comparing the emission levels of automatically and manually routed PCBs.

B. Practical implementation of the project based teaching

A first assignment included the design of a high-speed driver PCB containing a voltage regulator and a LVDS generator driving a twisted pair cable. The students were given a short practical hands-on lab in PCB EMC SI/PI signal integrity design inspired by [12], and were asked to layout two versions of the high-speed driver PCB:

- 1) with the aid of the autoroute function of the PCB design software.
- 2) by manually routing the traces keeping good EMC practices in mind as they learnt.

In both cases the PCB layer stack-up (FR4 material, double layer), the Bill Of Materials (BOM) and circuit schematic interconnecting those components were identical. Both PCBs were manufactured and their radiated emissions measured according the CISPR32 standard while mounted inside the demonstration unit.

From the measurements performed by the students, it is clear that the autorouted PCB fails against the CISPR32 standard, class B limit (see Figure 2) while the manually routed PCB, which implements good EMC practices, passes the CISPR32 standard class B limit (see Figure 3).

Fig. 3. Radiated emissions according CISPR32 standard class B limit of the manually routed version of the driver PCB

Fig. 4. Radiated emissions according CISPR32 standard class B limit in case of an interrupted volumetric shield

A second assignment given to the students included the comparison of the radiated emission levels against the same CISPR32 standard class B limit for the worst, i.e. the autorouted, high-speed driver PCB layout. Two cases are considered:

- 1) an interrupted volumetric shield, by having an unshielded connector at the load end.
- 2) a complete uninterrupted volumetric shield, by having a shielded connector at the load end.

In both cases the demonstration unit was covered with a solid lid. An EMC gasket was fit into the tongue-and-groove joint of the lid. The connector of the driver PCB was shielded, a shielded UTP cable was connecting a matched shielded load box to the unit. The load box is an aluminium enclosure containing a load PCB which allows to match or mismatch the output of the demonstration unit. In case of the interrupted volumetric shield, the connector of the load box was unshielded. In case of the uninterrupted volumetric shield, the connector of the load box was shielded. It is clear from the measurements performed by the students, that the emission levels are different in both cases. In the first case (see Figure 4) of an interrupted volumetric shield, the unit fails against the CISPR32 standard class B limit. In the second case (see Figure 5) of an uninterrupted volumetric shield, the unit passes the CISPR32 standard class B limit.

V. CONCLUSION

By designing and building an up-to-date EMC demonstration unit, opportunities arise to demonstrate major EMC phenomena, good and bad EMC practices, the importance of EMC filter chassis bonding and the impact of a good and a not so good high-speed PCB design to a large variety of people in an accessible way. The EMC demonstration unit also proved to be useful when teaching in-depth EMC related topics to electronic design engineers. When basic EMC research

Fig. 5. Radiated emissions according CISPR32 standard class B limit in case of a complete volumetric shield

laboratory equipment is available, the EMC demonstration unit allows to bridge theory courses into practice by project work performed by the students.

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