Virtual Instrumentation Approach for Teaching EMC Concepts

E. Lunca, A. Salceanu

Technical University of Iasi, Faculty of Electrical Engineering,
21-23 Professor Dimitrie Mangeron Boulevard, Iasi 700050, Romania, phone: +40-232-278683, e-mail:
elunca@ee.tuiasi.ro

Introduction

Today, many academic courses teaching engineering subjects incorporate virtual instrumentation tools, either in lectures or in laboratory sessions. Based on graphical programming techniques, the virtual instruments (VIs) offer scientific data visualization and advanced analysis capability with much lower costs comparing to the conventional laboratory practice. Moreover, the VIs are characterized by user-friendly interfaces and possibility of further improvements and developments, which may increase the student participation in the learning process.

In electrical engineering, the virtual instrumentation approaches have potential to enhance the content of a wide range of courses, complementing the theoretical lessons and promoting the experimental learning. Representative application fields include, but are not limited to: sensors and instrumentation [1, 2], electrical machines [3, 4], electric circuit analysis [3, 5], digital circuits [6, 7], digital signal processing [8–10], power electronics [3, 11] and automatic control systems [12]. Additionally, this paper demonstrates that, using a virtual instrumentation approach, it is also possible to enhance the Electromagnetic Compatibility education through the development of new teaching resources. Working with LabVIEW for many years and looking for new ways to make the EMC course in our faculty more engaging and enjoyable, we have introduced a set of computer-based instructional modules (VIs) concerning EMC concepts. Designed to be used in conjunction with conventional teaching resources, they aim to consolidate the EMC skills of the 3rd and 4th year undergraduate students. Some of these tools might also serve to other EMC purposes.

Present development

Because of the growing importance of the electromagnetic compatibility, universities worldwide are paying more attention in training future engineers with EMC knowledge. Therefore, a large number of electrical engineering degree programs have incorporated independent EMC courses, which are devoted to important EMC topics [13–17]: electromagnetic theory, signals and coupling modes, transmission lines, grounding and bonding, enclosure shielding, filtering techniques, PCB design for EMC compliance, standards and regulations, testing for EMC compliance, EMC diagnostic and troubleshooting, etc.

In our faculty, specific EMC chapters have been introduced since 1995, as part of other courses like Electronic Measurements [18]. In 2001, a one semester EMC course has been established at undergraduate level, to provide students of different specializations with fundamental knowledge in various areas of Electromagnetic Compatibility. At the moment, the course theory covers all the topics mentioned above, but it is still open to further improvements as dictated by the new developments and requirements in industry and technology.

Laboratory exercises are also an integral part of the EMC course. A number of specific experiments have been designed to expose the students to practical EMC aspects, ranging from simple demonstration of coupling phenomena, using commonly available lab equipment and components, to measurements and test methods defined in the European standards, which often require massive investments in specialized test equipment. For instance, towards the end of the course, the students are guided to EN 61000-4-2 Electrostatic Discharge Immunity Test, relating to equipment, systems, subsystems and peripherals, which may be affected by static electricity discharges due to environmental and installation conditions [19]. Even if, in such experiments, the use of sophisticated and expensive equipment, including the NSG 435 ESD simulator from Schaffner and a complete ESD waveform verification system consisting of Tektronix DPO7254 2.5 GHz digital oscilloscope, Faraday cage and Schaffner MD 101 current target, may seem extravagant, it certainly helps

students to better understand the way that the EMC testing is realized, as well as to become aware of the importance of EMC and its associated problems.
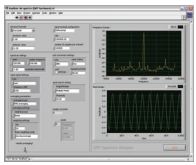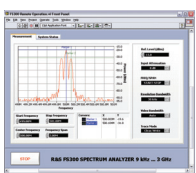
In order to make the EMC laboratory experience more attractive and challenging, we also adopted a virtual instrumentation approach based on LabVIEW – the de facto standard for graphical programming. Since this environment has thousands of functions created specifically for testing purposes and free instrument drivers for virtually any physical instrument, the first step was to develop a collection of hardware-based VIs aimed to illustrate different types of measurements and test techniques related to EMC problems.
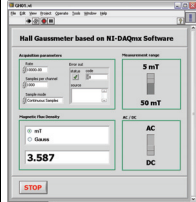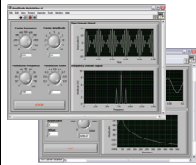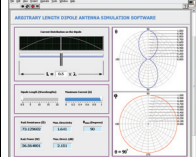
On the other hand, LabVIEW features powerful built-in simulation capabilities. Thus, the second step was to reinforce the theory by creating a series of live computer simulations intended to illustrate specific phenomena and systems described by mathematical models. But because LabVIEW integrates a variety of example VIs and configurable express VIs, which significantly reduce the complexity associated with adding analysis and signal processing algorithms into applications, our students are encouraged to develop their own simulation modules concerning EMC concepts.

Finally, since LabVIEW greatly simplifies the mathematical calculations, a suite of computation tools for RF and EMC have been developed to save time and validate results during the course activities. These tools may be distributed to students in form of executable files, to be utilized in their homework and future projects (only the prior installation of LabVIEW Run-Time Engine, a free downloadable program, is required).

Table 1 summarizes a number of representative developments. Detailed presentations for three of them will be realized, as case studies, in the subsequent sections of the paper.

Table 1. LabVIEW instructional modules for the EMC course

Experiment	Software interface	Short description
Hardware-based VIs		
Dealing with signal spectra. Zoom-FFT analysis		In this experiment, a high-speed data acquisition card and the Spectral Measurements Toolkit for LabVIEW are used by students to exercise with signal spectra and Zoom-FFT analysis. Simulation VIs are available too.
Understanding the superheterodyne spectrum analyzer		Designed to work in conjunction with Rohde & Schwarz FS 300, this intuitive VI allows students to become familiar with the basic operation of the superheterodyne spectrum analyzer.
Measuring radiated electromagnetic interferences		A more complex software that, besides programming the most important parameters of the FS300 spectrum analyzer and retrieving power data, computes and directly displays the electric and

Experiment	Software interface	Short description
Hardware-based VIs		
		magnetic field strength.
Measuring insertion loss, return loss, VSWR and frequency response		This software integrates a E4407B spectrum analyzer with tracking generator into an easy-to-use automatic test system that perform a series of RF measurements on EMI/RFI filters, antennas, amplifiers, etc.
Characterizing DC and low-frequency magnetic field sources		A virtual gaussmeter based on linear Hall sensor IC and PCMCIA data acquisition card for measuring DC and low-frequency magnetic fields up to 50 mT.
Simulation & Calculation VIs		
Exploring analog modulations (AM, FM)		Two simulation VIs based on mathematical models, which help students to understand the way in which the electromagnetic energy is transmitted.
Studying the behavior of the linear dipole antenna		A very intuitive simulation tool for teaching the radiation properties of the arbitrary length dipole antenna (far-field analysis).
Studying the behavior of the lossless transmission line		Comprehensive simulation software that solves the lossless transmission line equations and displays the voltage and current standing wave patterns along the line.
Understanding essentials in PCB impedance control		A LabVIEW program for determining the characteristic impedance and per-unit-length parameters for typical PCB trace geometries.
Common calculations & conversions		A suite of utility tools for performing various calculations during the EMC classes: RF conversion calculator, gain antenna calculator, coaxial line calculator, etc.

Case study 1: A hardware-based VI module

From a pedagogical perspective, introducing students to radiated EMI (electromagnetic interferences) measurement techniques represents one of the most relevant laboratory experiments for any EMC course. In such a context, the integration of LabVIEW with typical test equipment like spectrum analyzers and calibrated antennas may provide a complementary approach offering students the opportunity to focus on EMI analysis, rather

than recording voltage or power data manually, extracting antenna calibration factors from tables and graphs, and performing a large amount of calculations.

The graphical user interface (GUI) of a virtual instrument designed to assist the teaching of radiated EMI is shown in Fig. 1. Suggestively named RF-FieldVIEW, the developed LabVIEW program expands the functionality of a Rohde & Schwarz FS300 superheterodyne spectrum analyzer to automatically measure radiated emissions, in terms of electric and magnetic field-strength, over the frequency range from 9 kHz to 3 GHz.
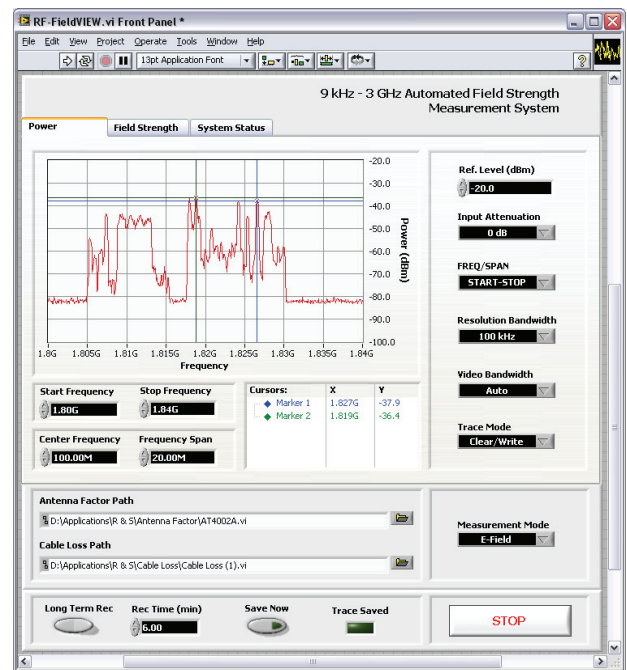
RF-FieldVIEW remotely communicates with FS300 through a USB connection, using the VXI Plug&Play style instrument driver. Its graphical interface is basically organized in the form of three tabs: "Power", for controlling the main parameters of the spectrum analyzer and offering a direct reading of power data, "Field Strength", for viewing and analyzing the correspondent E-field and H-field traces, and "Systems Status", which primarily indicates the errors that can occur during the system operation. Other options, such as those for selecting the measurement mode (*E* or *H*) and recording the measurement results, are always displayed under the tabs area.

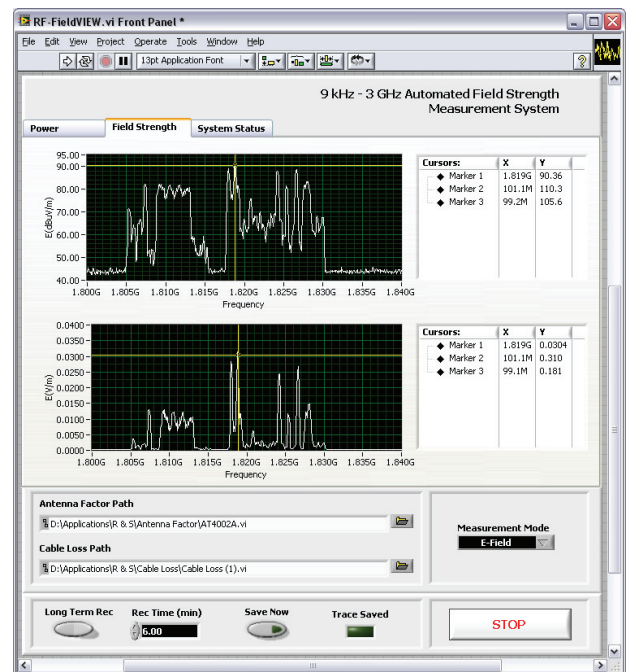The "Power" window is shown in Fig. 1.a. Intended to be simple and intuitive to use, it allows:

- Switching between the "start frequency – stop frequency" and the "center frequency – frequency span" modes;
- Setting the reference level and input attenuation;
- Selecting the resolution bandwidth, *RBW*, and video bandwidth, *VBW*;
- Applying one of the five trace functions (clear/write, view, max hold, min hold, average);
- Displaying the live power spectrum and activating markers on the trace.

The "Field Strength" window is presented in Fig. 1.b. According to the selected measurement mode, the electric field strength will be displayed in both dBμV/m and V/m, while the magnetic field strength will be displayed in both dBμA/m and A/m. As in the case of the power spectrum, the E-field and H-field traces may be evaluated in "real time" with markers, or, if desired, stored for off-line analysis.

It should be noted that, for converting the power delivered by a particular antenna to the equivalent field strength, it is necessary to account for the antenna factor (*AF*) across the entire frequency range explored, at a given time, by the spectrum analyzer. For this reason, the *AF* values are computed, utilizing interpolation techniques, by small sub-VIs that are dynamically called by the RF-FieldVIEW software when it starts. Similarly, the loss of the transmission line connecting the antenna to the analyzer, which also depends on frequency, is added to the measurement result by the same procedure. This means that, if a new antenna or transmission line has to be used, no code changes are needed. All we have to do is just to create simple subVIs that calculate these two parameters, and specify their location on computer using the front panel path controls.

a)

b)

Fig. 1. VI based on spectrum analyzer for measuring radiated emissions: a – "Power" window; b – "Field-strength" window

RF-FieldVIEW may be configured to function as a spectrum monitor, by recording time and date stamped field traces directly to the PC's hard disk. The period between records is user-programmable, but the live field traces can be saved at any moment. A dedicated LabVIEW program (Fig. 2) allows an easy investigation of all saved traces and, at the same time, provides an effective method for determining the resultant field strength by taking into account the records on three orthogonal directions, as suggested in [20]. Alternatively, the data can be imported into common evaluation programs, e.g. Microsoft Excel, for further processing and documentation.
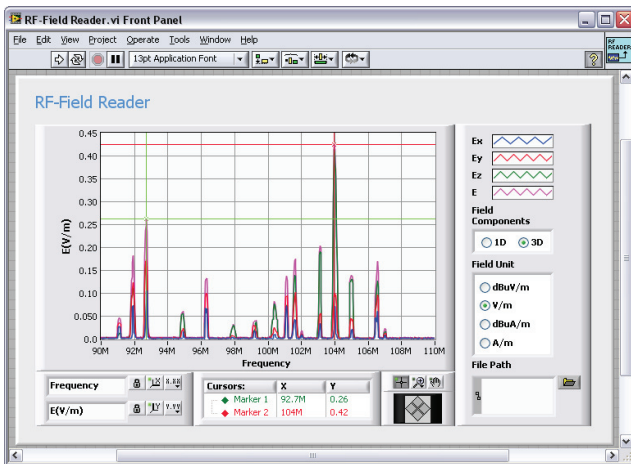
Fig. 2. Program for post-measurement analysis

The RF field strength measurement software not only produces more accurate, repeatable readings, but it also saves significant time, thanks to its flexibility in changing parameters and user-friendly operation. During the laboratory sessions, it has been used to characterize EMI from various RF emitters like TV/FM/AM broadcast stations, GSM base stations and wireless network applications (far-field measurements), as well as to quickly qualify the nature of radiant structures by performing relative measurements on both components of the field (near-field measurements).
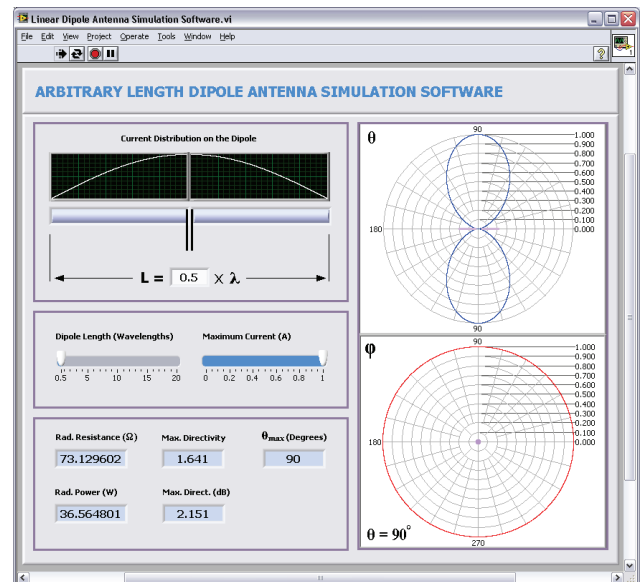
Case study 2: A LabVIEW simulation for EMC

A key feature of the LabVIEW environment, which can be extremely relevant for a whole range of EMC topics, consists in the wide variety of data visualization options, including Smith charts, polar plots, time-frequency graphs, etc. Combining such visual options with the advanced simulation capability allows developing very intuitive pedagogical tools that offer the opportunity to investigate complex concepts, as the behavior of transmission lines and electromagnetic radiation from antennas, in a fully dynamic fashion.

A LabVIEW simulation program, designed to assist the teaching of the radiation properties of the arbitrary length dipole antenna, is shown in Fig. 3. It enables students to monitor in real-time the changes in both the radiation pattern and some of the most important parameters of the dipole antenna, when varying its length or maximum (peak) current.
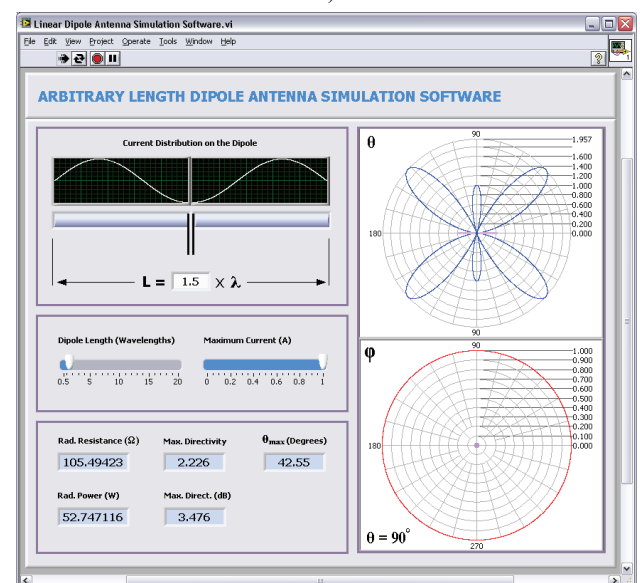
In order to determine the effect of the antenna length L (in terms of wavelength λ) on the radiation pattern, the program plots the normalized radiation intensity function. The field view area on the right side of the GUI consists of two polar coordinate systems that display the elevation pattern and azimuth pattern, respectively. When putting these graphs together, the students could have a 3D representation of how the energy is radiated from the antenna. For instance, if the dipole has a total length of 0.5λ, the resulting emission diagram is a slightly flattened torus; on contrary, if the total length increases to 1.5λ, a more complicated diagram results.

The software also displays the current distribution along the antenna. As it can be easily seen on the upper left

side of the GUI, we assume the hypothesis that the dipole is fed at the center and the current distribution on the dipole is symmetrical, with the current being zero at the ends of the two wires. As in the case of the radiation pattern, for studying how the current distribution changes along the antenna as a function of its length, the students may use either the numeric control under the physical representation of the dipole or the associated slider control, located just below this section of the GUI.
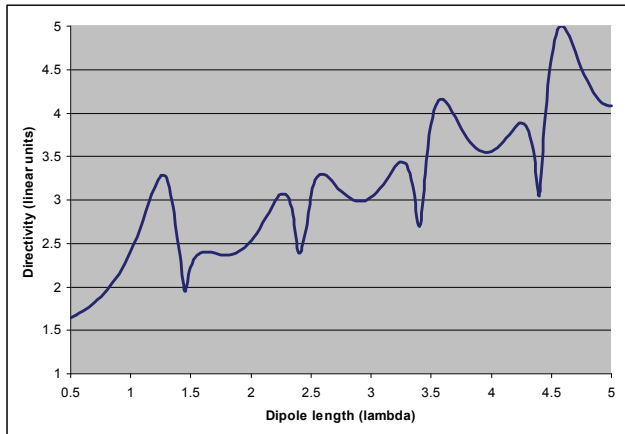

a)

b)

Fig. 3. LabVIEW simulation program for exploring the radiation properties of the dipole antenna: a – $L = 0.5\lambda$; b – $L = 1.5\lambda$

In addition, the program uses the numeric integration possibility of LabVIEW to calculate the radiated power, radiation resistance and maximum directivity, the last one being expressed in both logarithmic and linear units. Obviously, knowing the values of these parameters will allow students to carry out a more detailed investigation of the dipole antenna. For example, by representing the maximum directivity as a function of antenna length, they may observe that the directivity increases with the length

78

L, but, from approximately $L = 1.25\lambda$, the upward trend is no longer monotonic (Fig. 4). Another observation that can be made by students is that modifying the current amplitude has effect only on the radiated power.

Fig. 4. Example of analysis performed by students: plotting the dipole directivity as a function of the dipole length

Finally, the angle corresponding to the maximum directivity, θ_{max}, is also computed. If considering the half-wave dipole in Fig. 3.a, the maximum directivity occurs, as expected, at $\theta = 90°$; for the 1.5-wavelength dipole in Fig. 3.b, the direction of maximum radiation is at $\theta = 42°55'$. However, the angle $180° - \theta_{max}$ corresponds to the maximum directivity as well.

To verify that this simulation tool produces accurate results, comparisons to other sources have been performed. The radiation patterns obtained at various lengths of the dipole antenna are identical to the "reference" plots given in textbooks or to the patterns generated by some interactive Java applets [21, 22]. Likewise, the calculated values of the radiation resistance and directivity are consistent with the values specified in literature.
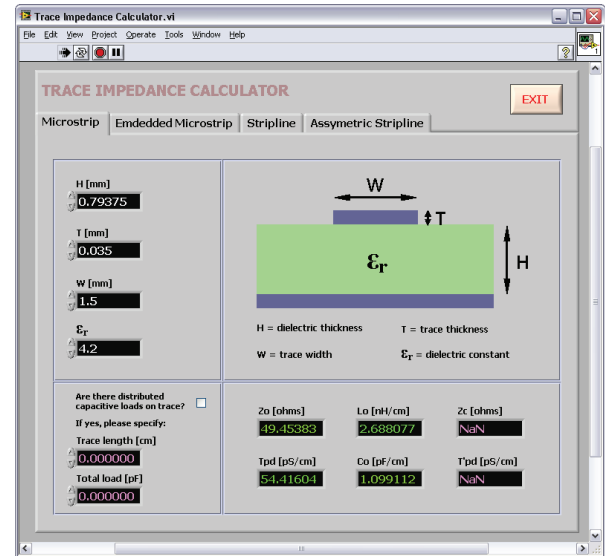
Case study 3: A calculation program for EMC

As stated earlier in this paper, LabVIEW may also simplify the mathematical calculations associated with various EMC issues. By incorporating specific equations, the LabVIEW virtual instruments can be used, for instance, to perform conversions between RF units, to predict emissions from wires and coupling to wires, and to determine the parameters of the transmission lines.

An example of such a program calculating electrical parameters for typical PCB trace geometries is given in Fig. 5. Its graphical user interface consists of four similar windows, each of them corresponding to a particular PCB trace geometry: microstrip, embedded microstrip, stripline and asymmetric stripline, respectively. Based on a collection of well-known approximation formulas, this VI may even serve as an engineering tool, but is not intended to be used for purposes requiring a high degree of accuracy.

For calculating the characteristic impedance Z_0 and per-unit-length parameters of the selected structure, including propagation delay T_{pd}, capacitance C_0 and inductance L_0, we only have to specify the values of the

geometrical parameters, in metric units. Additionally, if there are distributed capacitive loads on the trace, the program is able to determine the effective characteristic impedance Z_c and effective propagation delay T'_{pd}, by taking into account the average length of the traces attaching the loads and the average load capacitance. It should also be noted that, if the input data does not match the applicability conditions, the VI generates warning messages indicating the correction to be made. In the case of the microstrip line, for instance, such messages are reported if the dielectric constant ε_r is not situated between 1 and 15 or/and the ratio of the trace width W to the dielectric thickness H is not situated between 0.1 and 3.

Fig. 5. Virtual instrument for PCB impedance control

Conclusions

The paper presented here demonstrates that, considering a virtual instrumentation approach focused on LabVIEW, it is possible to enhance, with minimum cost implications, the conventional EMC learning environment. This powerful software allows creating both hardware-based experiments, generally dealing with EMC/EMI test and characterization techniques, and "realistic" computer simulations that enable students to interactively explore a wide variety of electromagnetic phenomena and specific systems.

Finally, it is worthwhile to remark that, during the EMC courses delivered by the authors, the developed LabVIEW tools generated an increased interest among students, which showed more involvement and desire to experiment. With highly-interactive interfaces and intuitive use, some of these modules may create the premises for an on-line experience, which, thanks to LabVIEW, is just a couple of mouse clicks away.

Acknowledgements

References

1. **Referowski L., Swisulski D.** Progress in Education of Electrical Measurements // Electronics and Electrical Engineering. – Kaunas: Technologija, 2006. – No. 3(67). – P. 25–30.
2. **Marozas V., Jurkonis R., Lukoševičius A.** Development of Virtual and Remote Lab Experimentation System for Electronics Engineering // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 7(87). – P. 41–44.
3. **Ertugrul N.** LabVIEW for Electric Circuits, Machines, Drives, and Laboratories. – Prentice Hall PTR, 2002. – 436 p.
4. **Martis C. S., et al.** Electrical Machines Virtual Laboratory: Grid Connection of a Synchronous Generator // 12th International Power Electronics and Motion Control Conference, 2006. – P. 1709–1714.
5. **Juška V., Chaziachmetovas A., Jaruševičius R.** Effectiveness and Quality of Education: Methodology, Organization and Technical Means // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 6(102). – P. 103–106.
6. **Paton B.** Fundamentals of Digital Electronics. – National Instruments, 1998. – 82 p.
7. **Swain N., Korrapati R.** Design and Development of Virtual Instrument (VI) Modules for an Introductory Digital Logic Course // IJME-INTERTECH International Conference, 2006. – P. 1–9.
8. **Kehtarnavaz N., Kim N.** Digital Signal Processing System-Level Design Using LabVIEW. – Elsevier, 2005. – 305 p.
9. **Fosalau C., Nita L., Antoniu M.** Virtual instrument for digital signal processing learning // Bulletin of the Polytechnic Institute of Iasi, 2004. – Vol. 50(54). – P. 820–825.
10. **Milici M. R., Mihai I., Milici L. D.** Aspects of Engineering Education in Signal Technology Using Virtual Instrumentation // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 113–116.
11. **Brenner E.** Virtual Instruments for the Circuit Analysis with Interactive Parameter Modification // International Journal of Online Engineering (iJOE), 2006. – Vol. 2. – No. 3. – P. 1–7.
12. **Temneanu C.** Contributions on the digital control of the industrial processes. – Iasi: Venus Publishing House, 2009. – 187 p.
13. **Apaydin G., Ari N.** EMC education at the University of Technology Zurich // Turkish Journal of Electrical Engineering & Computer Sciences, 2009. – Vol. 17. – No. 3. – P. 261–272.
14. **Song J., Voltmer D. R., Wheeler E.** A Required EMC Course for Computer Engineering Undergraduates // EMC 2005 International Symposium on Electromagnetic Compatibility, 2005. – P. 13–18.
15. **Zhao Y., See K. Y.** A practical approach to EMC education at the undergraduate level // IEEE Transactions on Education, 2004. – Vol. 47. – No. 4. – P. 425–429.
16. **Sevgi L.** EMC and BEM Engineering Education: Physics Based Modelling, Hands-On Training, and Challenges // IEEE Antennas and Propagation Magazine, 2004. – Vol. 46. – No. 2. – P. 140–145.
17. **Hellany A., Nagrial, M. H.** Project based engineering education: a case for teaching EMC/EMI // Asia-Pacific Conference on Applied Electromagnetics (APACE'2003), 2003. – P. 88–91.
18. **Antoniu M.** Electronic Measurements. Metrology, Analogue Measuring Instruments (1st ed). – Iasi: "Gh. Asachi" Publishing House, 1995. – 511 p.
19. **Lunca E., Salceanu A., Ursache S.** EMC Testing Education According to the ISO/IEC 17025 Quality System Requirements // Acta Electrotehnica, 2009. – Vol. 50. – No. 3. – P. 214–218.
20. **Müllner W., Neubauer G., Haider H.** Precise Power Flux Density Measurements at Base Stations // Compliance Engineering – Annual Reference Guide, 2002. – P. 72–77.
21. **Ulaby F. T.** Fundamentals of Applied Electromagnetics (5th ed.). – Prentice Hall, 2006. – 448 p.
22. **Linear dipole antenna.** Online: http://www.amanogawa.com/archive/DipoleAnt/DipoleAnt.html

E. Lunca, A. Salceanu. Virtual Instrumentation Approach for Teaching EMC Concepts // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 1(117). – P. 75–80.

This paper illustrates the possibility of using virtual instrumentation techniques for enhancing the conventional EMC learning environment. After a short introduction into the EMC curricula, the main considerations for adopting a LabVIEW approach to create EMC educational tools are given. Then, a number of virtual instruments (VIs) concerning various EMC concepts, utilized during the EMC courses delivered by the authors, are briefly introduced. Three of them – a hardware-based VI module for experimenting with radiated electromagnetic interferences, an interactive simulation for teaching the radiation properties of the dipole antenna and an example of calculation program for EMC, which computes electrical parameters for typical PCB transmission lines – are presented in detail as case studies. Ill. 5, bibl. 22, tabl. 1 (in English; abstracts in English and Lithuanian).

E. Lunca, A. Salceanu. Virtualios instrumentuotės metodas EMS pagrindams dėstyti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 1(117). – P. 75–80.

Iliustruojama galimybė naudoti virtualios instrumentuotės metodus gerinant tradicinę EMS mokymo aplinką. Po trumpo EMS programos pristatymo pateikti pagrindiniai apmąstymai, kaip adaptuoti LabVIEW, kuriant mokomuosius įrankius. Trumpai pristatyti virtualus instrumentai (VI), naudoti EMS kursuose. Trys iš jų – aparatinis VI modulis, skirtas elektromagnetinei interferencijai tirti, interaktyvi dipolės antenos spinduliavimo charakteristikų imitacija ir SMP perdavimo linijų EMS skaičiavimo pavyzdys yra pateikti detaliau. Il. 5, bibl. 22, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).