Turk J Elec Eng & Comp Sci, Vol.17, No.3, 2009, © TÜBİTAK
doi:10.3906/elk-0908-168

EMC education at the University of Technology Zurich

Gökhan APAYDIN, Niyazi ARI
Applied Research and Development, University of Technology Zurich, Technoparkstrasse 1,
8005 Zurich-SWITZERLAND
e-mail: gapaydin@hsz-t.ch, nari@hsz-t.ch

Abstract

This paper illustrates educational issues in electromagnetic compatibility (EMC) engineering in Switzerland and presents the contents of courses and practical materials for EMC education at the University of Technology Zurich. After giving the fundamentals of theoretical part, practical applications have been given to make students and engineers aware of EMC issues and its problems.

Key Words: *Electromagnetic compatibility; engineering education; EMC measurement.*

1. Introduction

Electromagnetic compatibility (EMC) is defined as the ability of a device, equipment, or system to function satisfactorily in its electromagnetic environment without producing intolerable electromagnetic disturbances to anything in that environment [1]. By this way, the device is not susceptible to electromagnetic signals from others and the emission of signals from device does not cause interference problems to others.

The term EMC has gained much attention because of the increase of electrical and electronic equipments and mobile devices in our environments. In the past years, international regulations forced equipment manufacturers to consider the electromagnetic compatibility of their products. If producers take EMC into account from the beginning, it can be possible to reduce cost and provide fast production over the long term. As such, some universities have started to train electronic engineers with good EMC design knowledge in their Bachelor or Master's programs; see Table 1 for examples. An EMC course gives students an opportunity to become exposed to EMC concepts and ability to design products which are more reliable and better suited to their environment. They are encouraged to transfer their experience in lecture to industry in future. In this way, producers do not need to spend their time for research and development to EMC issues as a result of finding talented engineers, which saves time and money while considering EMC concept for production.

Some universities have incorporated EMC courses for electrical engineers, presented in [2–9]. In this study, we discuss not only significant issues and concerns throughout the development but also the implementation process which provides students both of the technical knowledge and practical experience to solve EMC problems in industry. Other aspects of EMC's impact on today's technology have been evaluated in [10] and this article mainly addresses the necessary dedicated studies into electrical engineering technology programs. In [11] Kerry discussed six major challenges (technology convergence, frequency range, digital technology, EMC limits, network EMC, and EMC education) for the successful control of EMC [11], and also pointed out the significance of EMC education. In [12, 13], the educational challenges in electromagnetic compatibility, bio-electromagnetic engineering and related issues were indicated by pointing out the characteristic cases in EMC tests, measurements, modeling, and simulation. Finally, a practical approach to EMC education was addressed in [14] and presented as an example a printed circuit board design of a standard digital circuit with, and without, EMC consideration.

Table 1. A sample of universities offering EMC courses in their Bachelor or Master's programs.

Code	**University**	**Web address**
EEE401	Uni. of Sheffield, UK	http://www.shef.ac.uk/eee/
ECE407	Michigan State Uni. MI, USA	http://www.egr.msu.edu/ece/
ECE5480	Utah State Uni., UT, USA	http://www.ece.usu.edu/
ELE525	Syracuse Uni., NY, USA	http://lcs.syr.edu/academic/dept_electricalengcompsci/
ECE442	Mercer Uni., GA, USA	http://engineering.mercer.edu/undergraduate_pgms/ece/
ECE614	The Ohio State Uni. OH, USA	http://www.ece.osu.edu/
EE371	Missouri Uni. Sci.&Tech., MO,USA	http://emclab.mst.edu/index.html
-	Swiss Fed. Inst. Tech. Zurich, CH	http://www.ee.ethz.ch/
-	Ecole Poly. Fed. de Lausanne, CH	http://sti.epfl.ch/
ECSE450	McGill Uni., Montreal, CA	http://www.mcgill.ca/ece

The University of Technology Zurich organized some courses on topics related to EMC for engineers in industrial areas and for students in their engineering faculty, in 1986 [15]. Theoretical fundamentals were first introduced, followed by practical applications in order to make students and engineers aware of EMC and its typical problems. Table 2 outlines the EMC course at the University of Technology, Zurich.

Table 2. An outline of EMC course at the University of Technology Zurich.

No	Course Title	Hours/Week	Duration (Week)
1	Introduction	4	1
2	Theory	4	8
3	Practice	4	7
4	Projects, Diploma Thesis	4	16

2. Theory

In the theoretical part, the fundamental aspects of EMC are presented, such as emission, susceptibility, coupling, EMC standards, test and measurement methods, numerical and simulation modeling (solution approaches, analytical/ numerical methods), and design techniques (screening, grounding, shielding, and filtering).

At the University of Technology Zurich, the EMC course for undergraduates and graduates cover practical training on noise control of electronic devices in addition to research activities. Methods of noise reduction techniques are also taken into consideration. The content of the course is given in Table 3.

Table 3. Content of the EMC Course at the University of Technology Zurich.

Introduction to EMC: The aim of this part is to give the fundamentals of EMC	
• Basic EMC definitions • Interference examples • History	• Causes of EMC problems • EMC Regulations
Electromagnetic Theory:	
• Maxwell's Equations in time and frequency domain • Electromagnetic Waves • Analytical Solution Methods • Antennas • Waveguides	• Numerical Solution Methods (Finite Difference Method, Finite Element Method, Method of Moments, Monte Carlo Methods) • Symbolic Methods • Computer codes
Modeling of Coupling:	
• Capacitive Coupling • Inductive Coupling • Resistive Coupling	• Radiation • Computer codes and examples
Transmission Line and Multi-conductor Transmission Line (MTL):	
• Modeling of two-wire transmission line • Transmission line parameter • Theory of MTL • Reflection Coefficients • Transients	• Crosstalk • Field to Wire Coupling • Emission of Wires and Cables • Cable Shield Transfer Impedance and Admittance
Grounding and Bonding:	
• Basic Principles of Grounding for Safety • Various Grounding Techniques and their implementation • Correct Grounding for Shielding	• Practical Applications of techniques are introduced and discussed • Computer codes and circuit analysis codes
Filtering:	
• Overview of filtering for EMC • incorrect connection	• capacitive/inductive crosstalk between input and output
Shielding:	
• Shielding Effectiveness • Modeling • Multilayer	• Apertures • Computer codes
EMC Standards:	
• International Standards (International Electro-technical Commission)	• National Standards
EMC Tests:	
• EMC Test Plan • Instrumentation • Test-Set-Up • Anechoic Chamber	• Shielded Room, • Open Site Measurements • Radiated Emission and Susceptibility • Theoretical background and system analysis • Conducted Emission and Susceptibility
EMC Equipment Design:	
• Analyzing System • Subsystem	• Components • Computer codes

The EMC course is not standalone; it contains the electrical, electronic, and telecommunication engineering programs. Some parts include the use of proprietary software packages to illustrate EMC effects. The use of such software provides the ability to tackle a greater variety of problems and conduct more experiments than either analysis or conventional measurements would allow.

3. Practice

3.1. Case study: Applet for wire interconnects as radiators

Conducting wires generate electromagnetic fields and have coupling fields to other components and circuits. These fields can lead to malfunction or permanently damages. It is important to be able to quantify the emission of fields. In this study, the radiation of fields from a wire interconnects has been investigated. The modeling for emission was created via Java and Matlab GUI applets.

This work presents a model to determine radiation of transmission line with and without ground. The effect of ground is crucial for near field radiation. There exist many theoretical explanations about radiation of fields. The pattern of radiated fields is indicated as the near field and far field radiation. Understanding the radiation phenomena, the simulation of radiation pattern and the examples of numerical computation have been shown with and without ground plane. Its configuration and presence of conducting plane are also kept in mind.

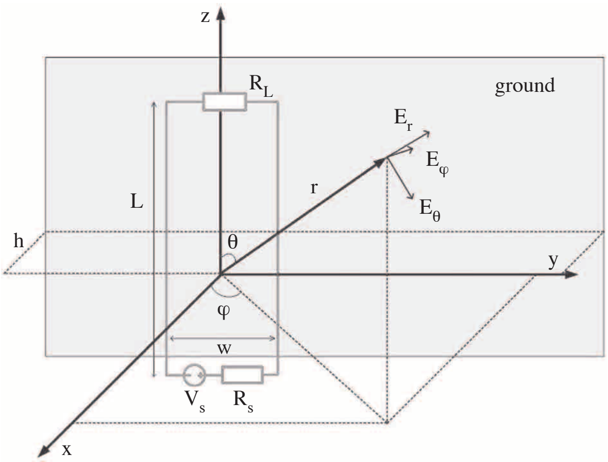


Figure 1. Modeling for a transmission line circuit.

The transmission line, shown in Figure 1, consists of a pair of parallel conducting wires with constant separation. According to this transmission line without ground plane, the radiation from each of the opposite currents are assumed the same and are summed. The circuit length L should be large, and the circuit width w is small to have limited radiation. The radiated electric field of the circuit in the xy plane is [16]

$$E = \frac{Z_0\,|I|\,wf}{rc}\cos\varphi\sin\left[\pi\left(\frac{Lf}{v_p}+\frac{wf}{v_p}-\frac{Lf}{c}\cos\varphi\right)\right]-\frac{Z_0\,|I|\,wf}{rc}\frac{\sin^2\varphi\sin\left[\pi Lf/c\left(\cos\varphi-c/v_p\right)\right]}{\cos\varphi-c/v_p} \quad (1)$$

where Z_0 is the characteristic impedance of free space, f is frequency, r is the observation distance, c is the speed of light, $|I|$ is the peak amplitude of the current, v_p is the propagation velocity, θ is the elevation angle, and φ is the azimuth angle. In the circuit, V_S is the voltage source, R_L and R_S are load resistance and source resistance, respectively. Considering the ground plane, the radiating images of currents are taken into consideration. h is the distance between the transmission line and the ground. There are two situations. If the transmission line is parallel to the ground, the image currents are in the same directions. If the transmission line is perpendicular to the ground, the image currents are in opposite directions. The radiated field over the ground is the sum of the circuit radiation and its image.

From theory, computer code has been written to simulate and determine radiation and is packaged as an applet. Field components are presented in Cartesian and polar coordinates.

A transmission line without ground plane, with wire diameter $d = 0.5$ mm, $w = 50$ mm, $f = 1$ MHz, $L = 1$ m, $r = 1$ m, $R_L = 50\ \ \Omega$, $R_S = 50\Omega$ and $V_S = 1$ V is computed using the applet composed. The results can be compared with [17–18]. Figures 2 and 3 show the simulation results for polar coordinates without and with ground, respectively. It is seen that E_φ and E_x components do not exist for $\varphi = 90°$. All the other components are plotted and compared with other coordinates easily. The second model is done for the transmission line with ground plane with $h = 5$ mm to show the ground effect.

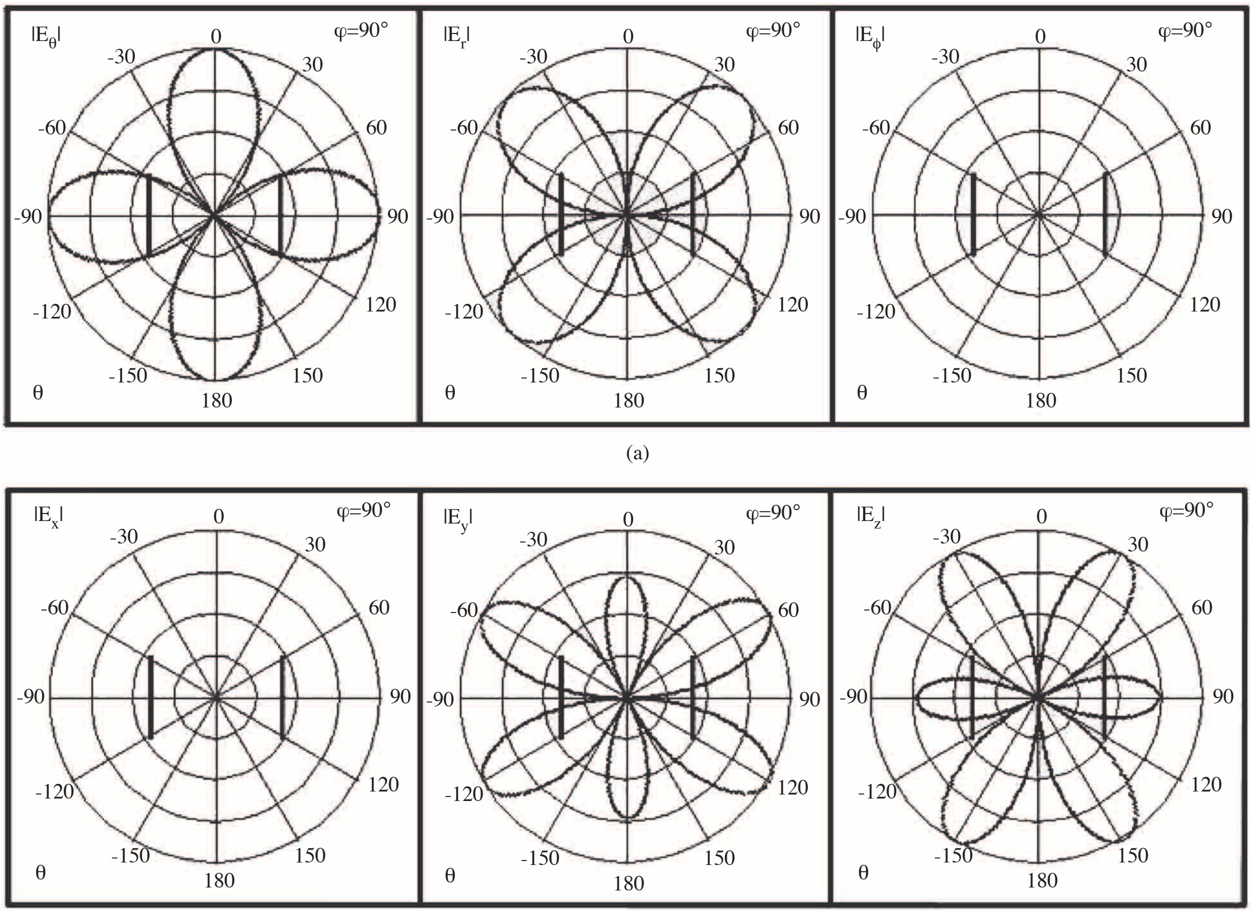
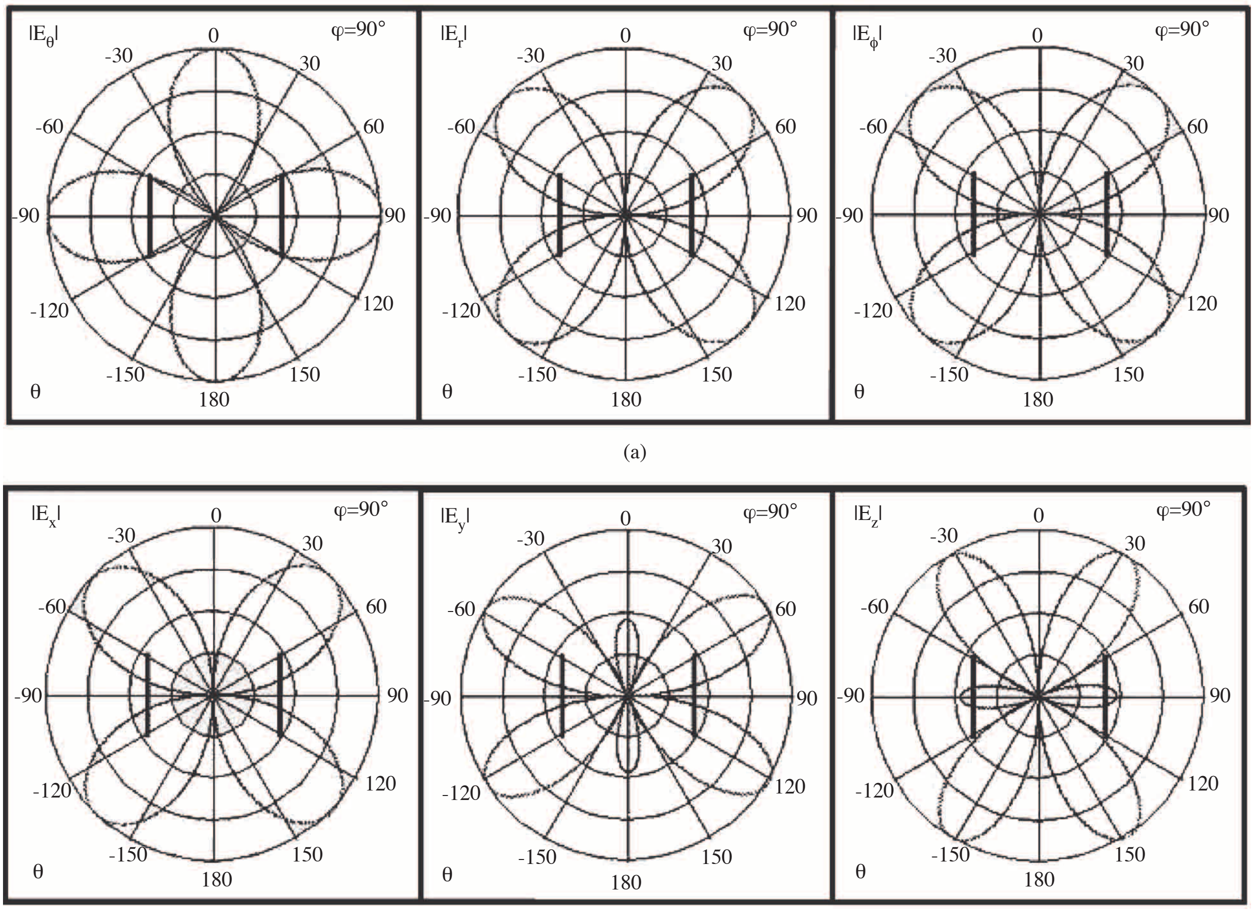


Figure 2. The (a) Polar and (b) Cartesian field components for $\varphi = 90°$.

If the same components of two models are compared, different radiation patterns can be easily distinguished. In this study, the general procedure to determine electromagnetic fields in Cartesian and Polar coordinates is indicated and the following results are achieved:

- Numerical experiments illustrate radiation effects from wire circuits.
- Using the program, it is possible to measure the contribution of each radiation components separately in Cartesian and Polar coordinates.

- Depending on θ and φ, the radiation could be computed for practical experiments.
- The computer codes are very simple and could be used via internet browser.
- The effect of ground plane to the radiation of fields from a wire interconnects can be seen easily.
- This applet can be used with new parameters and it can be improved to fit while considering new materials with different conductivities.



(a) (b)

Figure 3. The (a) Polar and (b) Cartesian field components for $\varphi = 90°$ with the ground plane.

3.2. Practical measurements

The EMC Langer system is split into two main functions, emission and immunity. The emission system finds disturbance of emitted sources on printed circuits by using rod or loop antennas and displaying them on the spectrum analyzer. With the immunity kit, it can be easily checked how resistant the measured product is. The system is small and portable. Therefore, it can be used for supporting projects during the development at the university and the products (printed circuits, sensors or integrated circuits) of the industry. The equipment and component details for EMC Langer System are as follows:

- Disturbance emission development system
- Traineeship set
- Optical fiber probe
- Disturbance immunity development system
- Near field probe set
- Spectrum analyzer
- Radiation meter.

The anechoic chamber (3 m standard test set-up) is designed to simulate free space environment. It is lined with absorbers to reduce the reflection of electromagnetic waves. Absorbing materials are covered on all surfaces including floor for full anechoic chamber. The ground plane effect can be considered without absorbing material on the floor, known as a semi-anechoic chamber. By the structure inside a building, the anechoic chamber achieves a constant accuracy of the measured values and is suspended no external influences. The equipment and component details of this system are as follows:

- Amplifiers, 30 W, 25–1000 MHz
- Signal generator HP8648D
- Antennas, Loop (1 kHz–30 MHz), BICONILOG (26 MHz–2 GHz)
- Spectrum analyzer, 9 kHz-1 GHz
- ESD / burst / surge generator, 0.2–18 kV
- Coupling networks, 3×25 A
- Probes, H-Field (300 kHz–1 GHz), E-Field (100 kHz–18 GHz)
- Current probe, 20 Hz–100 MHz, 20–300 MHz
- Near field probe, 100 kHz–1 GHz

3.3. Case study: EMC test

In this part, the EMC emission test [19–20] is conducted for a system board with and without top cover, as shown in Figure 4, as it operates transmitting data via USB and Ethernet [21]. Additional assemblies for this test are an USB stick connected by cable and power supply. Table 4 shows these interfaces and their properties.

Table 4. Properties of interfaces for the emission test.

Interface	Electrical properties	Mechanical properties	Maximum length (m)
Power supply	18VDC, 0.4ADC	Copper wire	-
Ethernet	Signal	Copper wire	< 30 m
USB	Signal	Copper wire	< 3 m
Serial	Signal	Copper wire	< 3 m

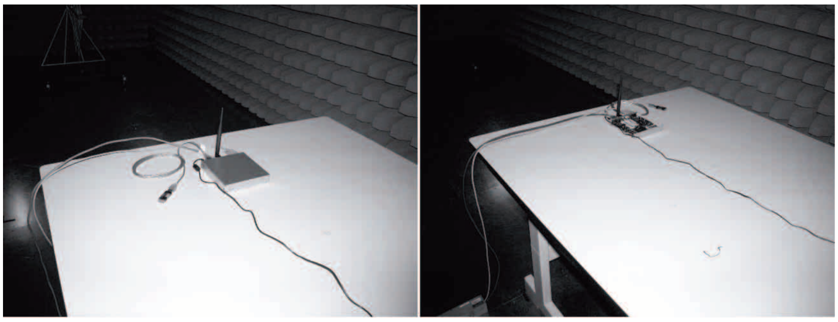


Figure 4. System board with and without top cover for emission test.

Testing for Class B EMI between 30 MHz and 1 GHz [19–20] was not conducted in an accredited domain due to a nonstandard measuring station. In the present work, the test was executed with the antenna at the following heights: with horizontal polarization from 1 to 2 m and with vertical polarization from 1 to 1.8 m in an anechoic chamber at a test distance of 3 m. The limits were converted to the test distance 3 m. The limit values are allowed when the unit under test is in the far field. Table 5 shows the expanded uncertainty with a confidence level of 95%. The system board passed the test with values below Class B EMI limits [19].

Table 5. The expanded uncertainty with a confidence level of 95%.

f (MHz)	Uncertainty (dB)	f (MHz)	Uncertainty (dB)
30	10.0	160	0.0
35	10.1	175	0.0
40	11.0	180	0.0
45	8.8	200	0.0
50	6.6	250	0.0
60	2.6	300	0.0
70	0.3	400	0.1
80	0.1	500	1.0
90	0.0	600	0.5
100	0.5	700	0.8
120	0.0	800	2.2
125	0.0	900	1.8
140	0.0	1000	1.8
150	0.0		

Unlike CE tests with the top cover, FCC tests are performed according to FCC Title 47 Section 15.32 [20], specifying procedures for CPU boards and computer power supplies open at the top and at least two sides. Same as before, this product is in conformity with the standards. And it does not exceed the limits by more than 6 dB for the test according to FCC. Figure 5 shows the test results with and without top cover.

4. Industrial cooperation

The University of Technology Zurich also offers complete EMC education, training, test, and consultancy for military, industrial, medical and automotive sectors in Switzerland. Near field measurements, emission and immunity tests of product by conduction or EM radiation are made in our laboratory.

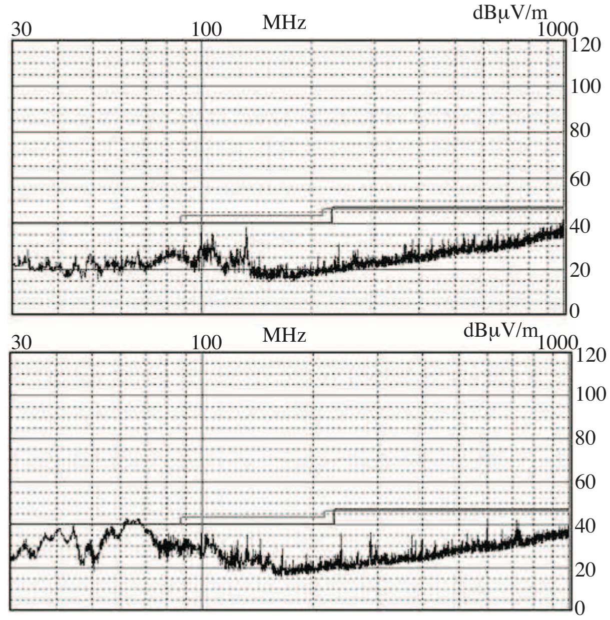


Figure 5. Test results with and without top cover.

5. Conclusion

This study illustrates educational issues (contents of courses and practical materials) at the University of Technology Zurich for EMC engineering. We presented a summary of the course outline, then the realized simulation applications.

Highly qualified EMC engineers are required not only to solve problems but also organize EMC management and EMC related products and systems development for practical applications in industry. It is necessary to provide that the university activities, in-house courses for the coordination between university and industry are significant for the education of engineering in EMC.

Finally, it must be considered that the EMC concept should be mentioned in other engineering course programs such as electronic design, antennas and microwave circuit design, transmission line theory, communication, microprocessor, printed circuit board design, etc. In this way, the students can understand the theoretical concepts with practical applications in an efficient way and they can use their knowledge to design electronic equipments in the industrial sector.

References

[1] J.J. Goedbloed, Electromagnetic Compatibility, Prentice Hall, Cambridge, 1992.

[2] R.M. Nelson, “Designing for EMC a case study for developing a course in electromagnetic compatibility”, IEEE Trans. On Education, Vol. 40, No. 4, pp. 283-286, Nov 1997.

[3] P.Y. Liau, Y.C. Chang, W. Chang-Yu, L. Dinan, “Introduction to the EMC education and activities in Taiwan”, IEEE Int. Sym. EMC, pp. 415-420, 24-28 Aug 1998.

[4] H. Lu, M. Zhu, "Undergraduate EMC education at Xidian University", IEEE Int. Sym. EMC, pp. 786-787, 17-21 May 1999.

[5] G.K. Deb, "Importance of EMC education", IEEE Proceedings of EM Inteference and Compatibility, pp. 160-170, 6-8 Dec 1999.

[6] J. Jarvik, K. Janson, V. Bolgov, P. Kroos, "EMC education and related problems at Tallinn Technical University", Compatibility in Power Electronics, pp. 1-3, 29 May-1 Jun 2007.

[7] N. Ari, J. Usonbek, B. Kanberoglu, "EMC education at university", Int. Conf. on Electronics and Computer, IKECCO'2005, pp. 51-56, 6-7 May 2005.

[8] N. Ari, EMC Education, Theory and Practice Workshop, Int. Conf. on Electronics and Computer, IKECCO'2005, 6-7 May 2005.

[9] N. Ari, EMC Education Workshop, Int. Conf. on Electronics and Computer, IKECCO'2006, 12-13 April 2006.

[10] A. Lozano-Nieto, W. Ofosu, "Electromagnetic compatibility, interference, and susceptibility in EET programs", Journal of Engineering Technology, Vol. 17, No. 2, pp. 32-36, 2000.

[11] P.J. Kerry, "EMC in the new millennium", Engineering Science and Education Journal, Vol. 10, No. 2, pp. 81-87, 2001.

[12] L. Sevgi, "EMC and BEM engineering education: physics-based modeling, hands-on training, and challenges-I", IEEE Antennas and Propagation Magazine, Vol. 45, No. 2, pp. 114-119, Apr 2003.

[13] L. Sevgi, "EMC and BEM engineering education: physics-based modeling, hands-on training, and challenges-II", IEEE Antennas and Propagation Magazine, Vol. 46, No. 2, pp. 140-145, Apr 2004.

[14] Z. Yang, K.Y. See, "A practical approach to EMC education at the undergraduate level", IEEE Transactions on Education, Vol. 47, No. 4, pp. 425-429, Nov 2004.

[15] N. Ari, EMC Education, Theory and Practice, Lecture notes at University of Technology Zurich, Switzerland, 1986.

[16] W.S. Bennett, Control and Measurements of Unintentional EM Radiation, Wiley, 1997.

[17] C. Christopoulos, Principles and Techniques of Electromagnetic Compatibility, CRC Press, Boca Raton, FL, 1995.

[18] U. Ravaioli, A.C. Cangellaris, J. Schutt-Aine, C. Christopoulos, "Interactive computer-aided electromagnetic education", Tutorial Session, XI International Symposium on Theoretical Electrical Engineering, Linz, 2002.

[19] EN 61000-6-3, Electromagnetic Compatibility (EMC)-Part 6-3: Generic Standards - Emission Standard for Residential, Commercial and Light Industrial Environments.

[20] FCC 47 CFR Part 15, Radio Frequency Devices.

[21] N. Ari, A. Stuker, D.E.08.14: EMC Test Report, University of Technology Zurich, 2008.

Appendix

Basic EMC concepts from international electro-technical commission 161.01

Electromagnetic environment is the totality of electromagnetic phenomena existing at a given location.

Electromagnetic noise is a time-varying electromagnetic phenomenon apparently not conveying information and which may be superimposed on or combined with a wanted signal.

Unwanted (undesired) signal is a signal that may impair the reception of a wanted signal.

Interfering signal is a signal that impairs the reception of a wanted signal.

Electromagnetic disturbance is any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter.

Electromagnetic interference (EMI) is degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance.

Electromagnetic Compatibility (EMC) is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Electromagnetic emission is the phenomenon by which electromagnetic energy emanates from a source.

Electromagnetic radiation is the phenomenon by which energy in the form of electromagnetic waves emanates from a source into space.

Radio environment is the electromagnetic environment in the radio frequency range.

Radio (frequency) noise is electromagnetic noise having components in the radio frequency range.

Radio (frequency) disturbance is electromagnetic disturbance having components in the radio frequency range.

Radio frequency interference (RFI) is degradation of the reception of a wanted signal caused by radio frequency disturbance.

Inter-system interference is electromagnetic interference in one system due to an electromagnetic disturbance produced by another system.

Intra-system interference is electromagnetic interference occurring in a system due to an electromagnetic disturbance produced within the same system.

Natural noise is electromagnetic noise having its source in natural phenomena and not generated by man-made devices.

Man-made noise is electromagnetic noise having its source in man-made devices.

Immunity (to a disturbance) is the ability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.

Electromagnetic susceptibility is the inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance.

Electrostatic discharge (ESD) is a transfer of electric charge between bodies of different electrostatic potential in proximity or through direct contact.

Emitter (of electromagnetic disturbance) is device, equipment or system which gives rise to voltages, currents or electromagnetic fields that can act as electromagnetic disturbances.

Susceptible device is device, equipment or system whose performance can be degraded by an electromagnetic disturbance.

EMC 161-02: Disturbance waveforms
EMC 161-03: Interference control related terms
EMC 161-04: Measurements
EMC Section 161-05: Equipment classification
EMC Section 161-06: Receiver and transmitter terms
EMC Section 161-07: Power controls and supply network impedances
EMC Section 161-08: Voltage changes and flicker