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Teaching Electromagnetic Compatibility and Component Parameter Tolerances

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Teaching Electromagnetic Compatibility and Effects Of Component Parameter Tolerances

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Abstract

This paper describes a graduate level course on Electromagnetic Compatibility where the effects of component parameter tolerances are covered by simulation and measurement. The component parameter changes could be critical not only to maintain desired circuit or system parameters, but they can affect electromagnetic compatibility of components, circuits and systems. They create interference problems between various circuits in the system. When the clock speed or communication speed exceed limits, the interference signals and their harmonics affect other circuits. In addition to the circuit analysis, the tolerances of some connecting cables were also considered in order to observe how the signal integrity could change and how this affected the circuit performance, sensitivity of circuits, component tolerances, signal integrity and effect of environmental changes on the overall system. A simple assessment of the effectiveness of the course is done at the end of the semester by student survey. The students commented that the course material was easy to understand due to the lab experiments and demonstrations in the class. Details of topics covered in our course, the circuit simulations done, measurements of interference signals under varying conditions, challenges faced and student feedback are also presented.

1. Introduction

The course of Electromagnetic Compatibility (EMC) has been taught for many years at our University. We improved the course with new topics, simulation and experiments. The industry projects that we did also helped us in improving course topics. The course outline and outcome are given in Appendix A. The course required a lot of background related to electromagnetics, communication circuits and systems, measurements and instrumentation. In addition, the parasitic components and distortion of signals are also considered and included in the discussion of circuits and systems. The EMC problems are of interest to automotive industry where CAN (Control Area Network) communication protocol is used for exchanging data between various control units [1, 4]. The signal integrity problems have appeared to be of greater interest. In the EMC course several examples of the signal integrity issues are discussed, including signal distortions due to the noise, jitter, parasitic circuit components and circuit component tolerances. Receiving incorrect information due to undesired interference and distortions, signal delays, multiple triggering, and missing pulses, are the effects of EMC problem. The circuit component tolerance effects are also related to connecting pathways, which often include transmission lines. In this case, the Time Domain Reflectometry (TDR) appears to be helpful to study transmission line effects [5]. The courses on Electromagnetic Compatibility are offered at quite a few US universities including: Michigan State University, Missouri University of Science and Technology, University of Illinois – Urbana, Chicago, North Dakota State University, University of California at Berkeley, National Louis University of Chicago, and Oakland University in Rochester, Michigan. Our course is unique since we add along with extensive simulations a number of measurement experiments very similar to real world conditions. These experiments are made suitable for automotive industry since most of our graduate students work at automotive industries.

Industrial research projects related to automotive and industrial electromagnetic compatibility problems, such as vehicle grounding, vehicle controller area networks (CAN), and shielded and unshielded twisted pair cables led to adding simulation and experiments similar to real world problems in Electromagnetic Compatibility course [6-10].

2. Selected Examples of Simulated Circuits to Demonstrate Interference Effects Caused by Noise and Parameter Tolerances

Some of the experiments and simulations exercises analyze the following:

1. Adding spikes to regular waves as input or as data on the transmission lines.
2. Effects of rise and fall times in pulses
3. Effects of small amplitude tolerances
4. Effects of ripples added to pulses
5. Signal integrity problems

The PSPICE simulations are used to study the changes of circuit parameters due to component tolerances and due to parasitic component effects appearing at higher frequencies.

The simulation with PSPICE based examples of some of the simulated circuits are shown here. Figures 1a to 1f show the circuit used to generate periodic pulse signals of one microsecond period, but of different pulse widths and of different rise and fall times and the signal spectrum.

The simulations demonstrate how the rise and fall time of the pulses can affect the spectra of pulse sequences of the same repetition frequency (1MHz). Four separate circuits are shown with pulse parameters. If there is a possibility of increasing the rise and fall times of the pulses, the high frequency spectral components could be reduced and potential for high frequency radiation could be limited. The last figure, related to Vsourc4 shows the smaller values of high frequency spectra than the ones presented in Figures 1b -1e. Figures 2 to 5 show various circuits simulated.

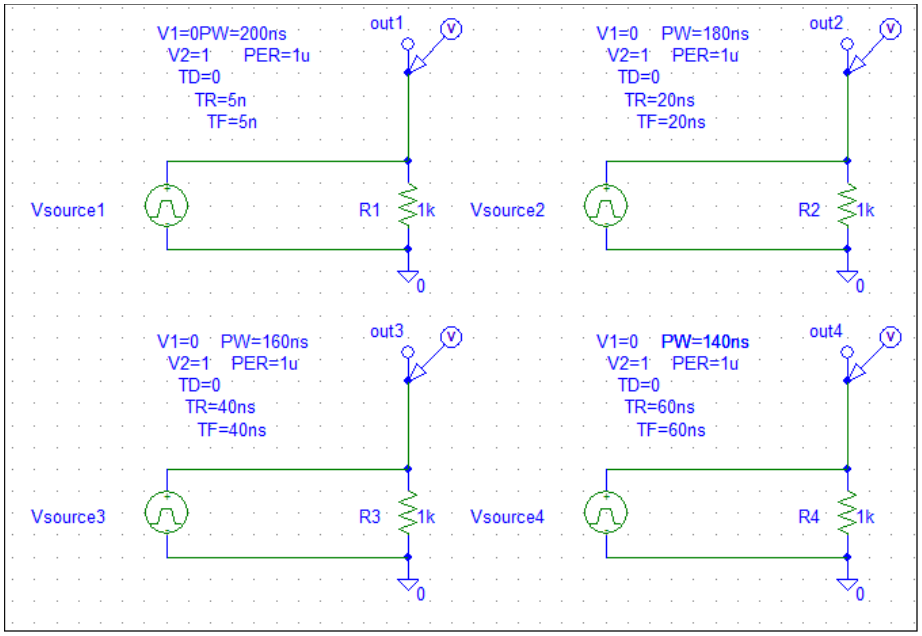

Fig.1a The circuit used to generate periodic pulse signals of one microsecond period, but of different pulse widths and of different rise and fall times

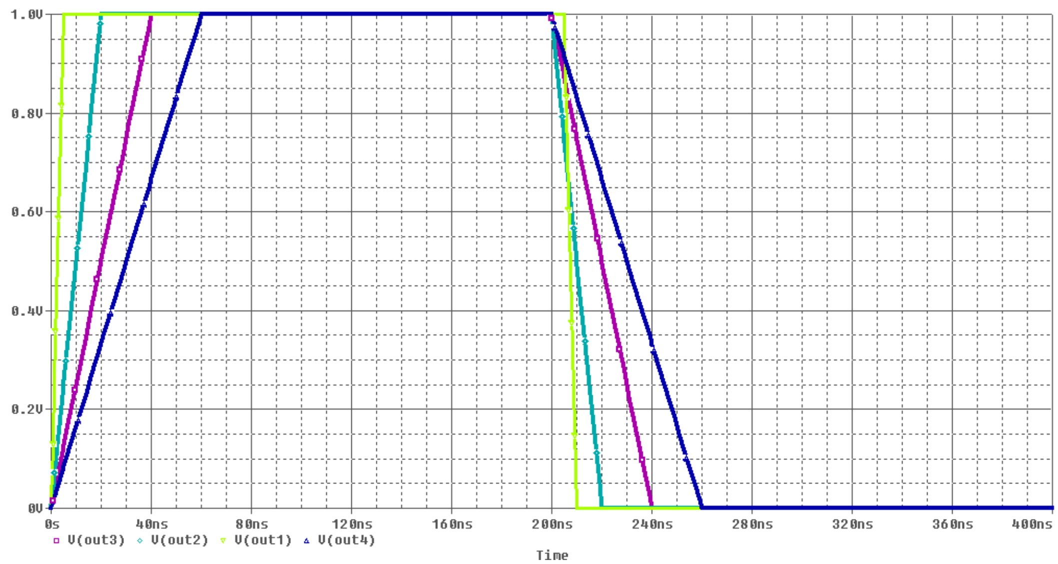

Fig.1b Pulses generated by the circuits shown in Fig.1a

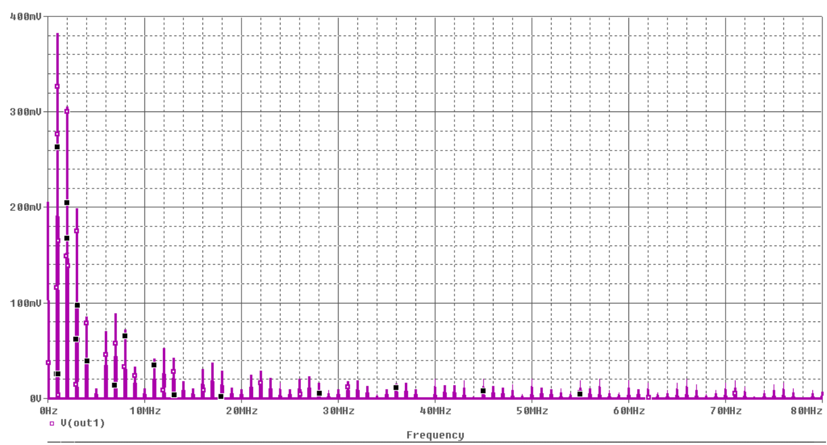

Fig.1c Spectrum of the signal of Vsource1

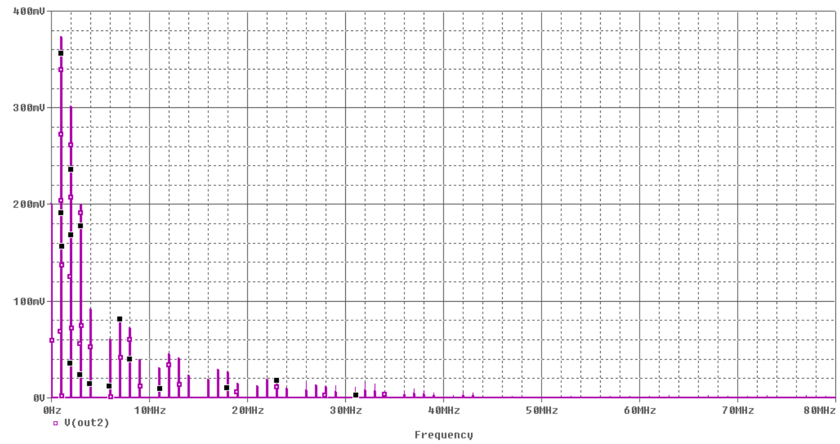

Fig.1d Spectrum of the signal of Vsource2

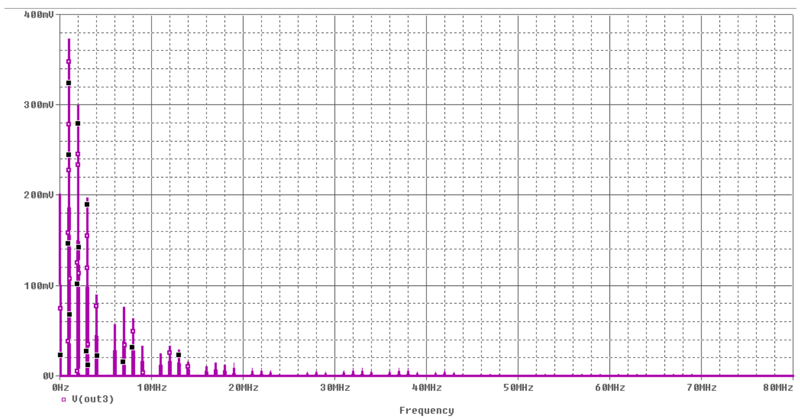

Fig.1e Spectrum of the signal of Vsource3

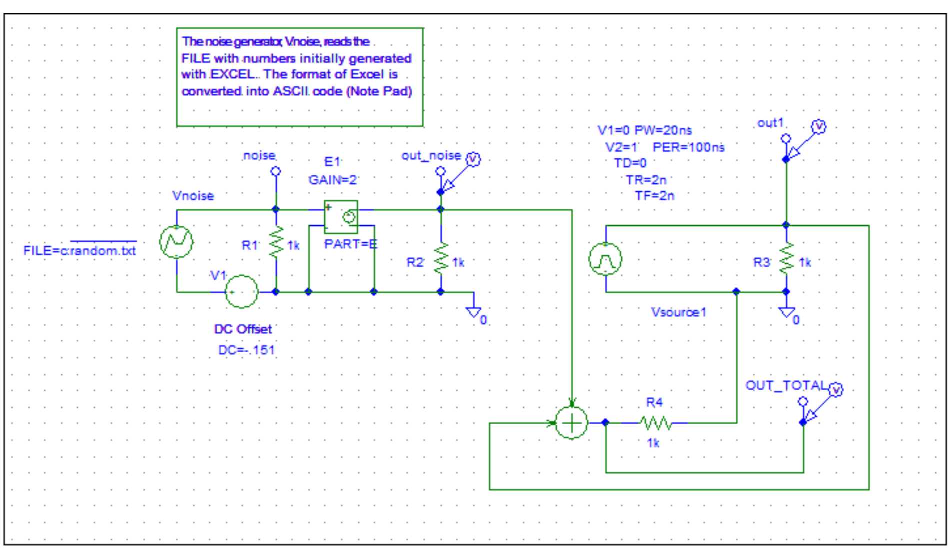

Fig.2a Circuit to simulate Noise Signal.

Circuits to simulate the noise signal, which could be tested and also added to desired signals to demonstrate effects of it on the circuit operation and on the signal distortions were modeled. Time-domain signal, signal distortions are studied.

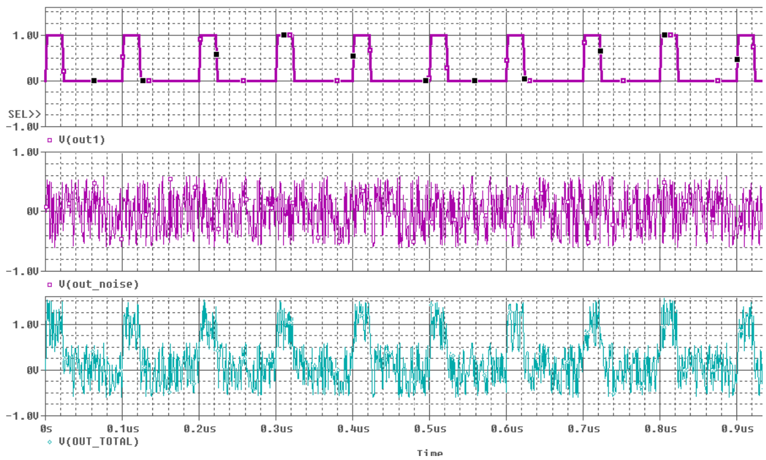

Fig.2b The pulses generated by adding different noise signal to the pulses

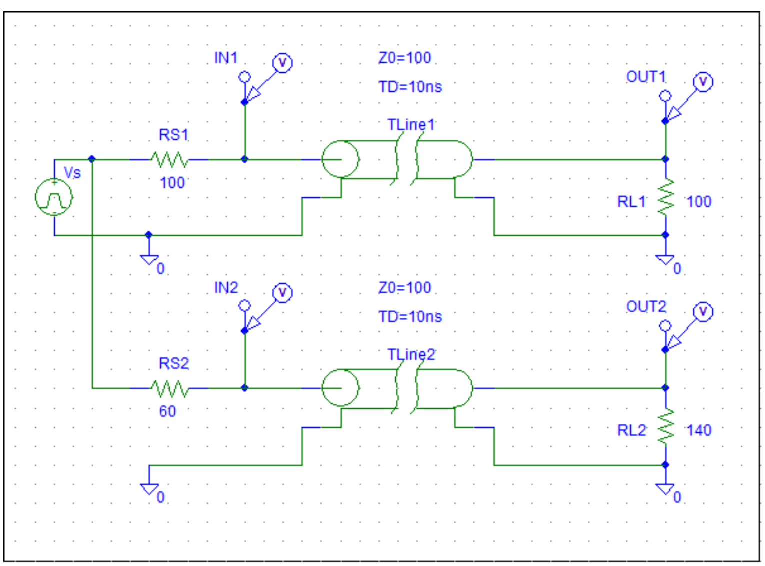

Fig.3 The circuits used to demonstrate the pulse reflections in transmission lines. Upper circuit is used to simulate and ideal case when the source and load resistances are matched to the characteristic impedance of the transmission line. The lower circuit has both resistances unmatched to the characteristic impedance of the transmission line. The harmonic signal

components of the signals of the unmatched circuit appeared to be of higher level than the signal harmonic components of the matched circuits.

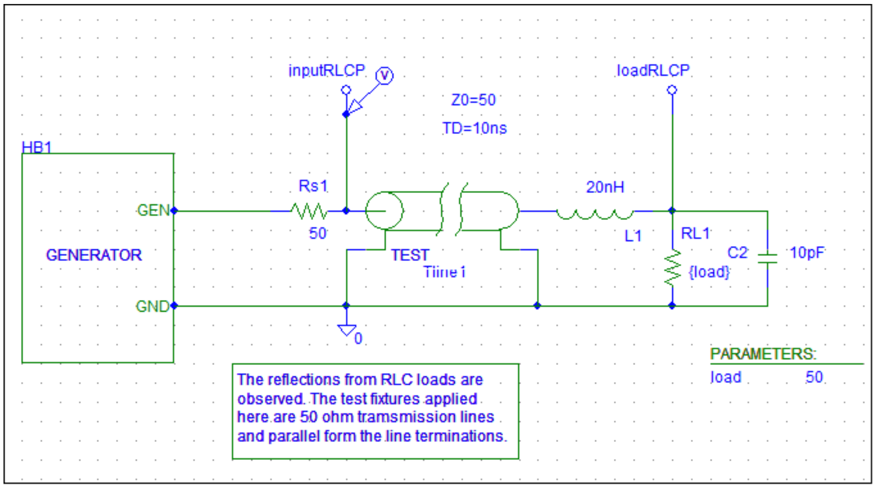

Fig.4 The circuit shown above demonstrates simplified version of the time domain reflectometer used to simulate the signals observed when different loads are connected to the output of the transmission line. The loads include resistors of several values and parasitic components

Fig.4b The signals for RL = 0.3 ohm (single step up, spike and step down) and RL = 100 kohms (two steps up and spike)

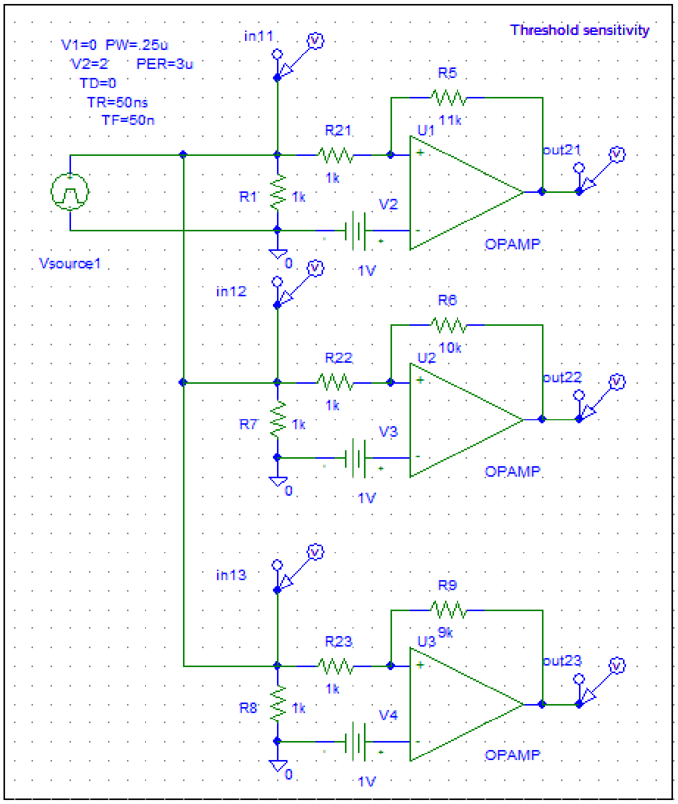

Fig.5a Comparator circuits with positive feedback loops. The feedback resistors R5=11K, R6=10K, and R9=9K are selected to show the threshold dependence upon tolerances of feedback resistors.

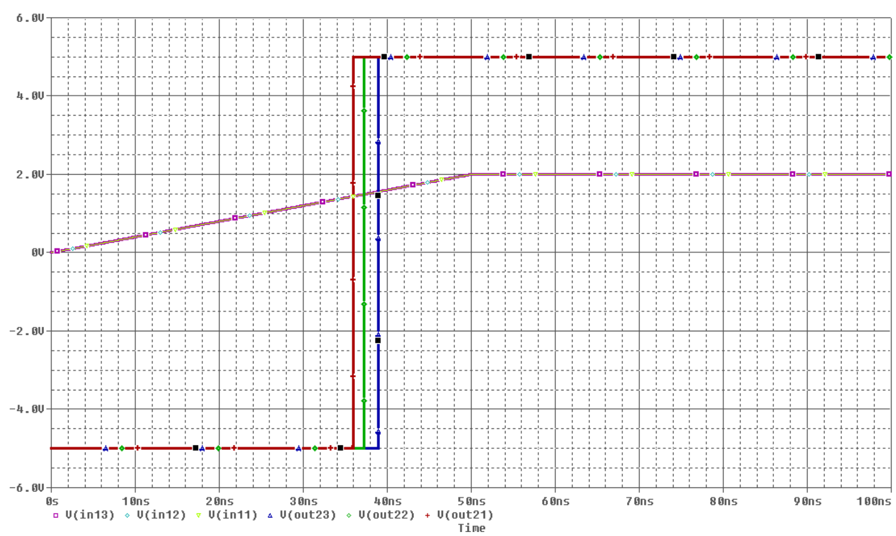

Fig.5b Image showing comparator threshold sensitivity. Leftmost – top circuit, rightmost – lowest circuit. Ten percent tolerance of upper resistors of comparator voltage dividers is considered. The differences in delays of about one nanosecond are caused by the

differences in the threshold levels. If the circuits activated by such steps operate in nanosecond ranges, the delays may affect their timing.

Meaurements

A practical demonstration was prepared to be shown during our EMC lecture – three ways: with UTP (unshielded twisted pair), STP (shielded twisted pair) and coaxial cable, coupled with single conducting wires used to inject interfering signals. They were set up to show how interfering signals can get from the single wire to transmission lines as common mode and differential mode signals. In addition, it could be observed how effective the process of shielding is when coaxial cable has various grounding connections. Interesting observation could be made when the interfering signals are observed on the shield of coax when both ends of the screen are grounded – to show effectiveness of shield grounding. The research led to some publications and to preparation of some experiments later demonstrated to students. Simulations used to supplement experimental results, and to make some predictions were later simplified and introduced to support lectures.

Figure 6 shows the equipment to demonstrate most of the above experiments. They include transmission line, pulse generator, a four-channel oscilloscope. The image on the scope shows various points along the line, and clearly reveals the pulse delay due to the length of the line.

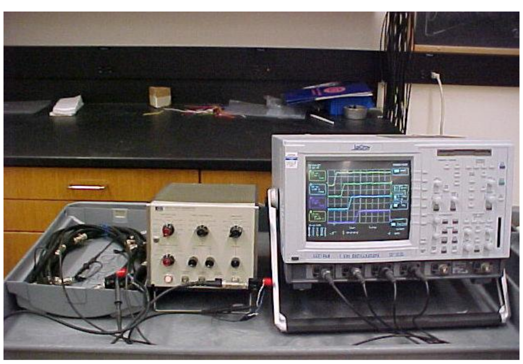

Fig. 6: The equipment necessary for the demonstration.

The measurement results of the twisted pair cables demonstrated helps in understanding the radiated emissions, crosstalk effects and shielding,

Another test circuit includes the single wire above the ground cable (GENERATOR WIRE), which is connected to the Spectrum Analyzer internal generator sweeper (to 1.5 GHz), and parallel twisted pair cable with four outputs (two NEAR END and two FAR END). The four output signals are measured and registered by means of the Spectrum Analyzer. The simple cable structures were chosen to limit the effects of potential installation problems related to grounding and existence of cable “tails”. The signals used to test include: sine waves, pseudo-random waves, fast pulses, and high voltage narrow pulses. Measurement results are presented in [10].

Student Participation in Experiments

We observe the following in graduate classes:

1. Most of our graduate students work for local industry,
2. Involving all students in the class in observing and in partial measurements and extension of measurements by simulations of some experiments provides a huge learning opportunity for students.

The students attending the EMC (Electromagnetic Compatibility) course have a chance to participate in demonstrations of experiments and they could also get familiar with all instruments to measure the most important parameters of the signals. In addition to measurements, the students use PSPICE software program to model the twisted-pair transmission lines and make some predictions.

The instructional approach in this course is unique since we show experiments when learning theory. The student evaluations clearly indicate improvements in meeting the course outcomes [Appendix A]. The comments in the course evaluations to the question on the above projects indicate that the students received a greater understanding of the topics like radiation, conduction and cross talk due to these experiments.

Students understand the differences between the performance of the shielded and unshielded twisted pair cables applied in automobiles and in industrial robots. The other experiments, included in this course demonstrate sinusoidal and pulse performance of coaxial cables, radiated emission tests, applications of Line Impedance Stabilization Network to test conducted emissions, and the test of the “spike” generator, which was also used to check the EMC performance of the twisted pair cables.

Our homework, and exam answers clearly show the full understanding by almost all the students due to the experiments.

Some students sent emails stating that they applied these demonstrations and theory learned from the course in their industry. At the end of the course, we do survey of the course content and delivery of the content of graduate courses by external evaluators/ experts. The external evaluators were very happy to see the addition of these experiments to clarify and show the application of the theory in these courses.

As per the alumni letters, the described projects and their interpretation are very helpful to the working graduate students, and they could apply some of the demonstrated ideas in their company. Some of the students joined electromagnetic compatibility laboratories with the knowledge reinforced by the experiments. The employer letters indicate that our alumni have used the knowledge gained from these experiments in the industry to rectify many of the problems in the design.

Thanks to the introduction of the experiments in the class, the enrollment in the course doubled from the previous years since the students find the course more interesting and useful. Some examples of experiments are presented in the References [2, 3, 5 to 8].

Conclusions and how the Students Benefit from this Approach

The experiments introduced in the course and simulation exercises have made the course material easy to understand and fun to learn the application of EMC theory. The course evaluations on the course outcomes received very good results.

The described project measurements and simulations are very helpful to our graduate students, who work for aviation and automotive industry. They could apply some of the demonstrated ideas in their company.

The student experiments show possible effects of tolerances of some parameters of pulse signals on the signal shapes, which could affect the signal spectra and increase the potential for undesired circuit reactions and for measurement errors. In addition, some effects of noise signals on the circuit performance have been shown.

Appendix A

ECE 546 Electromagnetic Compatibility Course Details

Textbook: C. R. Paul, *Introduction to Electromagnetic Compatibility*, J. Wiley, Recent Edition.

Topics:

- Overview of EMC
- EMC Requirements (i, j)
- Review of Electromagnetic Principles (a, e)
- Distributed and Lumped Components
- Signal Spectra and Spectrum Measurements (a, e, k)
- Intro to EMC Pre-compliance and Compliance Tests, Component and System Level Measurements (e, k)
- Radiated Emissions and Susceptibility (a, e)
- Conducted Emissions and Susceptibility (a, e)
- Crosstalk (a)
- Shielding and Guarding (a)
- Electrostatic Discharge (a)
- Introduction to System Design (a, e, i, j, k)
- Introduction to Signal Integrity (a)

Course Outcomes:

- The students obtain the following competencies:
- Understanding of the US and foreign EMC standards.
- Understanding of the time and frequency representations of signals.
- Ability to evaluate parameters of electronic components at high frequency.
- Ability to evaluate the design factors that contribute to conducted emissions, radiated emissions, and crosstalk.

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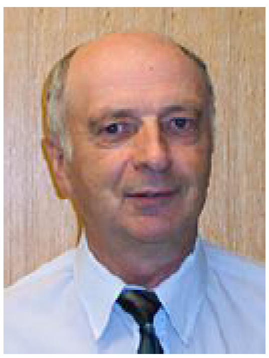
Biography

Subra Ganesan (ganesan@oakland.edu) is a Professor of Electrical and Computer Engineering at Oakland University and Director of Real Time Embedded DSP Systems Lab. He joined the university in 1984. After graduating from Indian Institute of Sciences Bangalore India, he served at universities in Germany, and Canada and Indian research laboratory as a scientist. He does research work in collaboration with TI, Free Scale, and a few automotive companies and US army. His research areas include DSP, Embedded Systems, Real Time Systems, Condition-based Maintenance, and Optimization.



Andrew Rusek (rusek@oakland.edu) is a Professor of Engineering at Oakland University in Rochester, Michigan. He received an M.S. in Electrical Engineering from Warsaw Technical University in 1962, and a PhD. in Electrical Engineering from the same university in 1972. His post-doctoral research involved sampling oscillography, and was completed at Aston University in Birmingham, England, in 1973-74. Dr. Rusek is very actively involved in the automotive industry with research in communication systems, high frequency electronics, and electromagnetic compatibility. He is the recipient of the 1995- 96 Oakland University Teaching Excellence Award