



EMC Education at the University of Michigan-Dearborn... the Excitement Continues!

Mark Steffka, Adjunct Lecturer, ECE Department, University of Michigan-Dearborn

The initial investment of a \$10,000 grant by the IEEE EMC Society in 1999 has continued to pay big dividends! Many of you may recall my article in the Winter 2003 issue of the EMC Society Newsletter where I described what had taken place in the four (4) years since the grant was received by the campus. Since then, a number of other significant and exciting events have occurred.

The first event was the opportunity to collaborate with Mr. Henry Ott on a planned “revision” of his *Noise Reduction Techniques in Electronic System*—which resulted in his new book *Electromagnetic Compatibility Engineering*. Two years of undergraduate students in my course ECE-319, “Introduction to Electromagnetic Compatibility,” were able to use Mr. Ott’s proposed manuscript for the new book and make suggestions as to items that they felt were important to be in the book, and they also developed many chapter problems to be solved. This resulted in a book that reflected the needs and interests of “real world students.”

The second event was the establishment of a formal EMC laboratory component to accompany the lecture portion of the class. As a result of my conversations with Dr. Flavio Canavero (Polytechnic Di Torino) about the EMC courses at

his university, I realized that the foundation for the laboratory experiments should be the IEEE Education Manual that was first published in 1987 by Mr. Henry Ott and Dr. Clayton Paul. Dr. Canavero and I discussed the possibility of developing the experiments in an “updated” fashion to reflect the chapters in the new textbook. When I told one of my former undergraduate students (now a graduate student), Chris Semanson, of my plans—he (surprisingly!) offered to take on the task of selecting the experiments to be done and linking them to the weekly class lectures. The results (as you can read in Chris’ article below) were amazing! The students really seemed to be excited to do the experiments, asked many insightful questions, and demonstrated an understanding of EMC that I had not seen with previous classes. This was a direct result of Chris’ hard work, dedication, and the assistance of Mr. Ott (for which Chris and I are very appreciative)!

It is hoped that Chris’ article will give other instructors (and students of EMC courses) insight into how they may be able to implement a similar learning process at their institutions.

On behalf of Chris and myself, we wish to express our deep appreciation to all that assisted us in this work.

Creating Practical Experiments on EMC

Lessons Learned from Henry Ott and the IEEE EMC Society’s Experiments Manual
By Chris Semanson, University of Michigan-Dearborn

Introduction

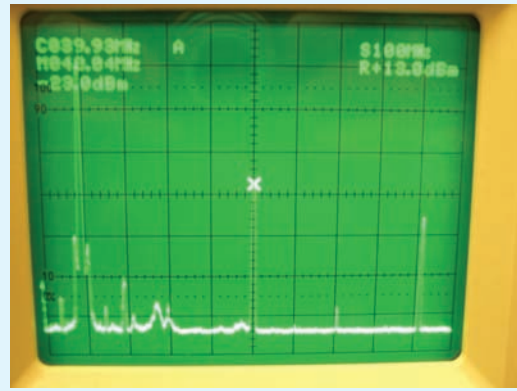
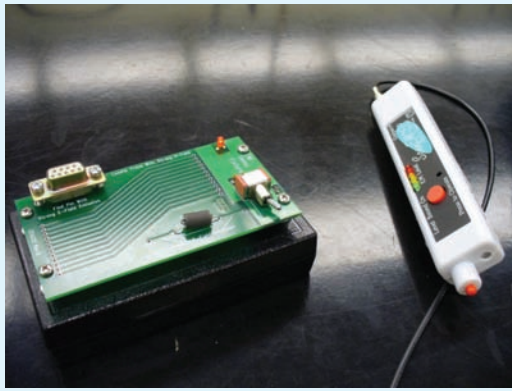
How many of us have worked with an individual who has tried to design a complicated audio filter on a twenty year old bread board, or thought that using wires for oscilloscope probes is all you need to measure a signal? This situation happens more than many would like to admit and is the reason why, when Mark Steffka, my instructor for the EMC course, had a situation where he needed some laboratory experiments designed, built and then taught, I was the first to volunteer.

Having no existing experiments to work from proved a problem which was easily solved by the use of a document produced by the IEEE EMC Society in the 80’s, which Henry Ott and a few others started. This document contains laboratory experiments designed to show people who have little to no understanding of concepts most Electromagnetic Compatibility engineers take for granted. The topics range from demon-

strating Maxwell’s equations in an easy to understand form, to what happens when you design a shielded enclosure poorly, to proper design with switching circuits. Even more impressive is how this document has withstood the test of time as only little tweaks were needed to bring this document into the current classroom setting. So, with this document in hand, I went about designing and building experiments that closely followed the new edition of Henry Ott’s book, *Electromagnetic Compatibility Engineering*, as reviewed in the Spring 2010 EMC Newsletter, Issue 225.

Lab One: Getting Familiar with Fields

The EMC Society laboratory experiments manual has twenty complete laboratory experiments, each covering a specific topic in EMC. However, none of them had before been done at this campus



Pictured above are the EMSCAN kit with probe and a spectrum analyzer output showing the operating frequency at 40 MHz.

to familiarize students with the basics of the subject. Therefore, the labs had to be designed, from scratch, to include the most basic of principles surrounding electromagnetic compatibility.

The first lab is split into two parts and assumes that the student has zero familiarity with spectrum analyzers, field probes and basic emissions concepts. Part one is designed to show how digital circuitry can radiate both electric and magnetic fields, and the spectrum analyzer along with an EMSCAN kit is used to show this. The focused topics include:

- How large loops, signal strength, and signal speed can affect the strength of the detected field
- Magnetic fields are very directional and can be harder to detect when compared to electric fields
- Large voltages, such as static discharges, can create large E fields

And finally, in order to familiarize the students with taking power spectral density measurements with the spectrum analyzer, a brief overview of the spectrum analyzer was given covering the following topics:

- How a spectrum analyzer differs from an oscilloscope
- What the horizontal axis represents
- Common normally occurring frequencies such as the FM spectrum and cell phone carrier frequencies

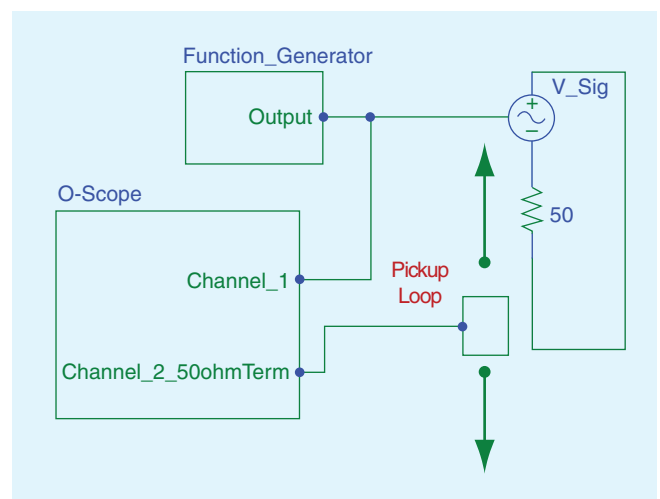
The student is tasked with operating a sample circuit board operating at a set frequency. The board has multiple labeled test points on it. These test points include different traces in which only some carry current while other points are hidden; it also includes a reference or ground plane, a DB-9 and a ferrite. The experiment includes using simple electric and magnetic field probes to probe around the board observing the effect on both the probes. The lab included a set of questions designed to emphasize how current carrying traces have both magnetic and electric fields associated with them. This proves to the student that that magnetic fields curl around the direction of current travel and from this, the direction of current flow can be discerned. This also shows how traces, while visibly hidden, can still radiate. Finally, the lab asks the student to connect the probes to the spectrum analyzer to measure the frequency content of the emissions coming from the board; through this the student is then able to deduce the frequency of the oscillator as well as the strength of the signal depending upon the orientation of the probe. Through this experiment, students learn that magnetic fields have significant directionality.

Part two of this experiment uses a spectrum analyzer, electric field probe, as well as a function generator to showcase how dif-

ferent signals have varying amounts of spectral content. The experiment asks the student to place a breakout connector on the function generator output, treating it like a small loop antenna. The student then will cycle through the square, triangle and sinusoidal signals and use the spectrum analyzer to measure the different amounts of spectral content generated. The student will find that the square wave has the most spectral content, while the sine wave has the least, and that it varies with the frequency of the signal being broadcasted. Finally, in an effort to showcase the effect of rise and fall time on the spectral content, the student is asked to test for conducted emissions in a switching circuit. The measured circuit is first a purely resistive circuit then it is contrasted with a resistor capacitor circuit, the capacitor slowing the rise and fall time of the switching signal down reduces the measured frequency content.

Lab Two: Induced Voltages and Pickups

In this experiment, the student will have their first experience with mutual inductance and how a sharp change in a signal can induce voltages in circuits not physically connected to each other. The variables that the students are allowed to change include the switching frequency, the signal, the angle that the neighboring loop has in relation to the main loop, and where the pickup loop is in relation to the noise source (a 50 ohm

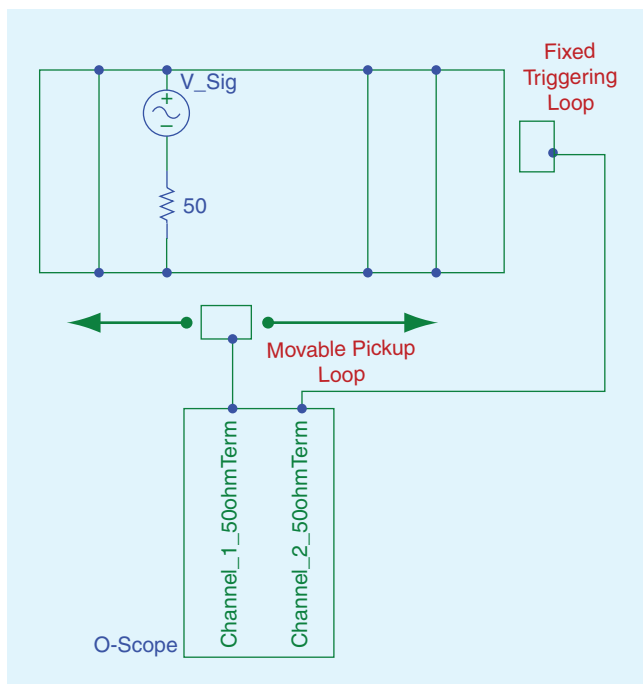
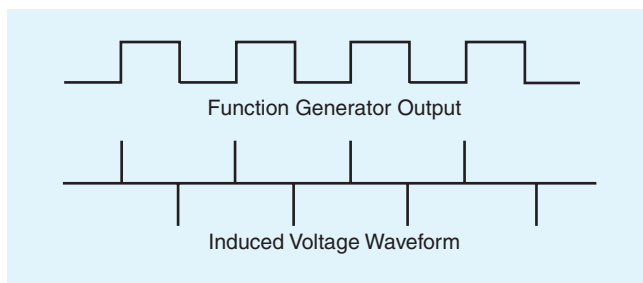


Pictured above is the schematic for part one of lab two.

resistance). In addition to introducing the mutual inductance concept, this experiment further demonstrates Faraday's law by asking the student to take a conducted measurement with an oscilloscope on a bare wire. The way this experiment is setup, voltage will appear across what looks to them as a bare wire, they are then asked to increase the frequency and watch the amplitude of the signal they're measuring change with frequency. The student is then asked to consider this effect as a function of the loop area, the probe, and/or a function of how the circuit is laid out.

The first part of this experiment uses a simple resistive circuit with a loop made of pickup wire with two turns. Using this, the student will probe the circuit looking for the 'noise source' shown in the figure below; the flux the current creates will pass through the pickup loop depending on its orientation and induce a voltage in that loop.

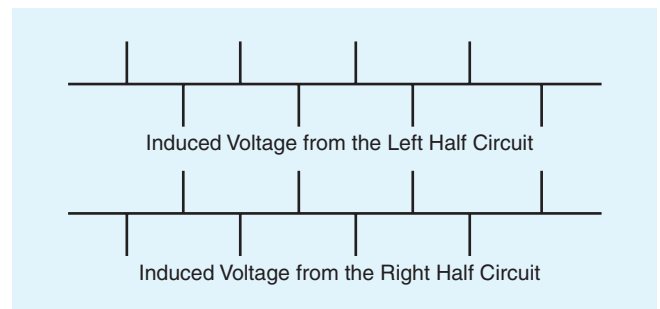
This is essentially Faraday's law of induction, where time varying flux through a loop will create a measurable induced electro-motive force. The student is then asked to not only draw or take a snapshot of the wave form, but note the percentage of voltage coupled to the pickup loop. Then they are asked to draw inferences to the possible implications of power electronic situations where it is more than just a switched five volt signal. What appears on the oscilloscope as below is a damped voltage spike which correlates directly to the rise and fall of the switching waveform.



Pictured above is the schematic for the second part of lab two.

The next part of the lab continues this concept, but demonstrates the 'curl' concept of magnetic fields about a current. This setup has a ladder reference plane with a single resistor to again act as a noise source. The student is asked to move the pickup loop to the left and to the right of the resistor and note how much voltage is coupled to the pickup loop.

As the moveable pickup loop is moved to either side of the 50 ohm resistance, the phase of the signal on the oscilloscope changes one hundred and eighty degrees, demonstrating that the curl changes with the direction of current in relation to the right hand rule. The student is also asked to move the pickup loop on the other side of the ladder plane to notice the same effect as the current converge as it returns to the signal generator. Finally, the student is then asked to find the place on the perimeter of the circuit where the induced signal is the smallest, and then is asked to infer why this is the case. As below, this location is at the junction where the main branch of current splits which causes the flux, due to the geometry of the circuit, to be almost nonexistent.



In order to mathematically explain what the student is seeing, the following equation is derived from Faraday's law. This equation states that the induced voltage is dependent upon the switching frequency, the area the flux flows through, the strength of the field as well as the angle the loop forms with the flux.

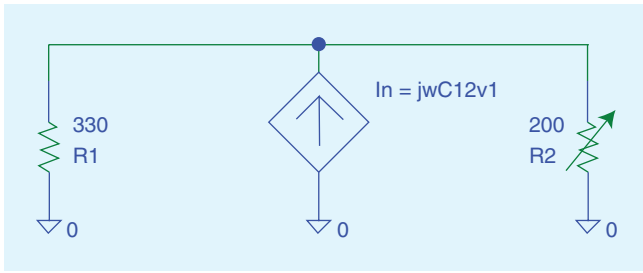
$$V_{\text{induced}} = j\omega \vec{B} \vec{A} \cos(\theta)$$

Faraday's law simplified

The student is then asked to apply this simple concept to real world circuits, and then explain why large loop areas in a circuit are a poor design, as well as why switching transients can be harmful in a high power circuit.

Lab Three: Effects of Impedance on Field Coupled Cross Talk

Up to this point in the lab curriculum, the concept of mutual inductance has been introduced, as well as how electromagnetic fields can be generated from a non dc signal. This lab takes these concepts and explains how impedance of a circuit can affect what type of coupling phenomenon is occurring. In both parts of this experiment, the student is asked to change the impedance in a neighboring two conductor circuit and witness the effect on the coupled signal depending on the setup of the circuit generating the cross talk. By graphing the percentage of signal coupled onto the secondary in each situation with respect to the resistance, students readily witness that impedance in closely coupled circuits play a large role in the type of coupling.



Equivalent circuit for Electric Field Coupling.

Part one of the lab places two circuits in close proximity in the configuration shown below. The signal generator is connected to a two conductor wire with an open circuit load to force the energy in the signal to voltage. The close proximity of the two conductors, and the high electric field content of one, allows for a very efficient capacitive coupling mechanism to exist. This capacitive coupling creates what can be viewed as a frequency controlled current source in the second conductor.

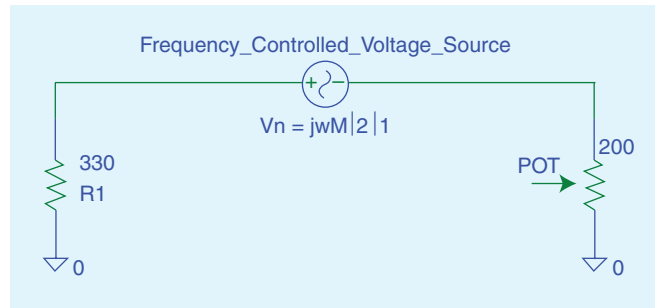
With this current source, the student can change the impedance of the circuit and then record the corresponding effects on the oscilloscope. They will find out that when the parallel impedance is at its greatest, the voltage drop across the impedances is also at its peak. After the students chart their findings, the equations governing the system are explained.

The student is then asked to explore different frequencies and waveforms to see their effects on the waveform coupled to the second inductor. Then, using the following equations, they are asked to find the stray capacitance the system has at a given frequency.

$$i = j\omega C_{12}V_1 \quad \frac{V_{rms_2}}{Z(\omega V_{rms_1})} = C_{12}$$

Current source equation and capacitance equation

In part two, the conductor carrying the signal is now shorted through a 10 ohm resistor; the low impedance load forces most of the energy in the circuit to current creating a large magnetic field. The close proximity of the two circuits, coupled with the magnetic field, allows an efficient mutual inductance coupling mechanism to form. This mutual inductance acts as a frequency dependant voltage source in the second conductor, and the students are again encouraged



Equivalent circuit for the frequency controlled voltage source created in the neighboring circuit.

to vary the impedance in the second circuit and record what it does to the coupled voltage.

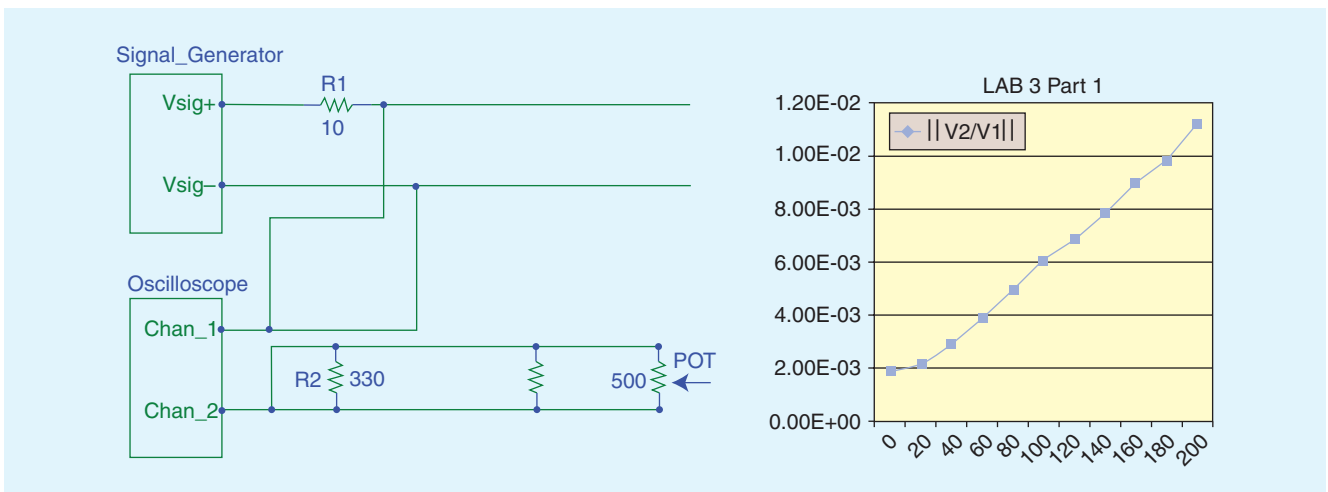
They will notice a stark contrast to the high impedance situation, and from that they can infer that large impedances couple electric fields well, while small impedances couple magnetic fields well through mutual inductance.

As a last exercise to show the stark contrast between the coupling mechanisms, the student is asked to place their hand between the circuits in both parts of the lab. The body's capacitance results in helping the coupling effect in the first lab, by increasing the signal strength appearing in the second conductor. The mutual inductance is not affected by placing a hand between the two circuits.

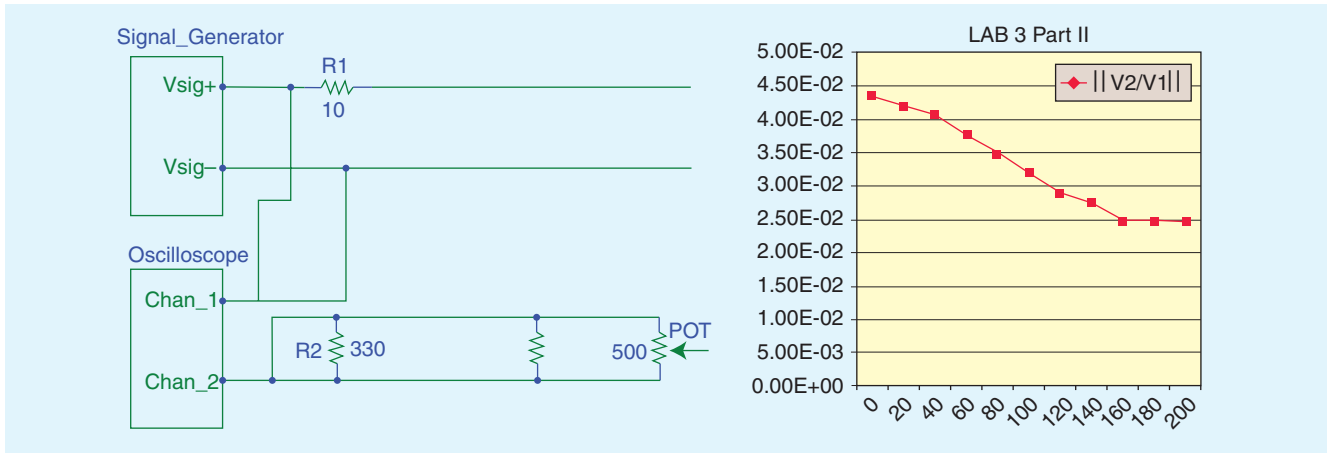
Lab Four: The Thinking Engineer's Guide to Proper Measurement

Poor placement of probes proves to be possibly problematic

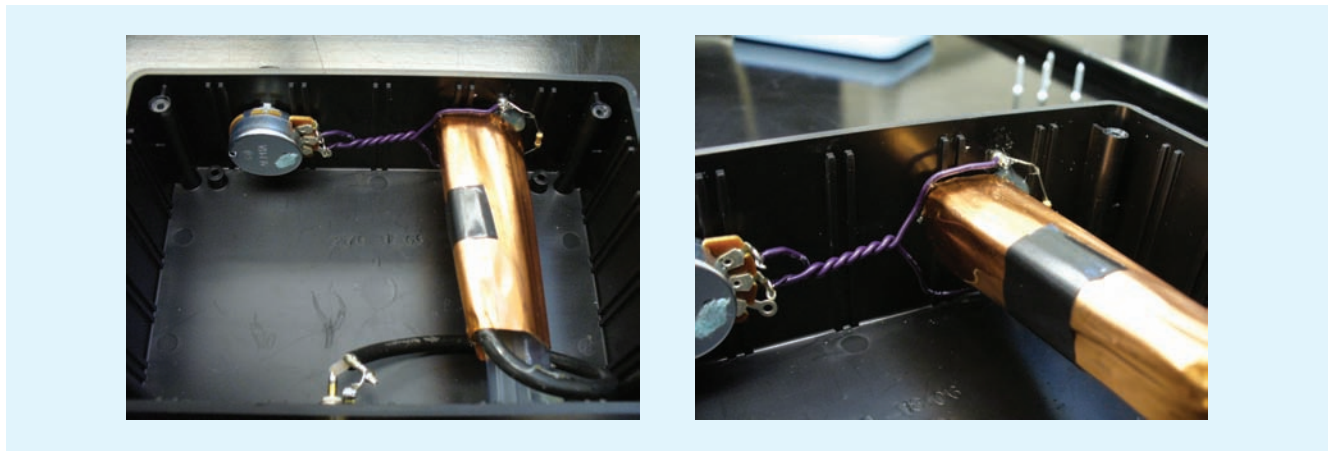
While the previous three labs dealt specifically with the theory of fields and their cause and effect, the next two labs focus on proper measurement and the effect of improper design of electronic circuitry. Many engineers act without care when taking measurements in a circuit, and they show this by placing the probe and its clip haphazardly in the circuit they're measuring and they trust their measurements. This lab puts sloppy measurements into the spotlight, and shows the student how



Pictured above left is the laboratory setup for the first part; on the right is the graph from a student showing the correlation between impedance and the coupled signal.



Pictured above left is the laboratory setup for the second part of the experiment; on the right is the graph from a student showing the correlation between impedance and the coupled signal.



Pictured above is the CurLE Box.

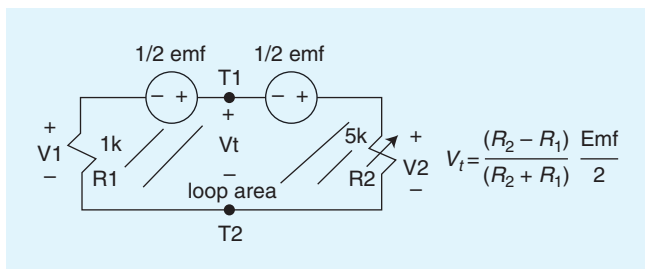
two probes connected to the same test points can get two drastically different measurements.

This lab requires the construction of the *CurLE* box, which houses a ferrite antenna which broadcasts a sine wave into a loop inducing a voltage of varying frequency; the loop is made up of wire with a resistance on one and a potentiometer on the other. Photos of the setup are shown below.

The flux generated by the ferrite rod is guided into the loop via the copper shield; soldered to the loop are two posts to which oscilloscope probes connect.

In the first part of the lab, just one oscilloscope probe is used to measure the induced voltage in the loop. The equivalent circuit diagram and equation governing this system is shown below.

After studying the equations, three possible scenarios may be obtained from this setup. The induced signal can either be of



Equivalent circuit diagram and equation governing this system.

the same phase as the input signal, it can be opposite phase, or it can be zero. This is all due to the tightly controlled geometry of the loop and how the voltage is induced in that loop.

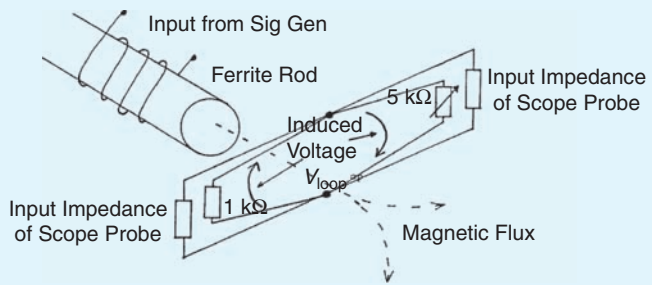
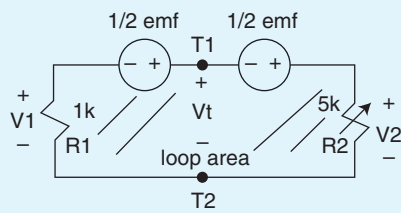
The second part of the lab, however, is more complex as the probe clip loop comes into play in the induced voltage. The equivalent circuit diagram is shown below.

The student, not aware that the ground clip will create another loop in which a signal can be induced, places the probes haphazardly opposing each other, creating two equal and opposite loops. The equations governing this part of the lab do not change much from the first part, except with the addition of two more induced voltage sources found in the ground clips.

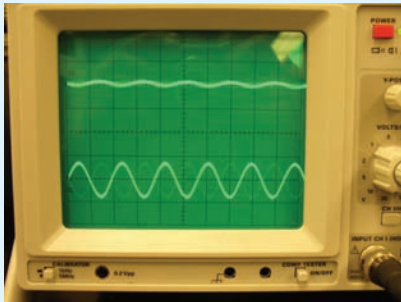
$$E_1 = V_t - V_{\text{probe}} \quad E_2 = V_t + V_{\text{probe}}$$

Paying close attention to the variable the students are allowed to control, and to the resistance of the loop, the student is again able to explore three distinct scenarios as below. Probe one is the top trace, while probe two is the bottom trace.

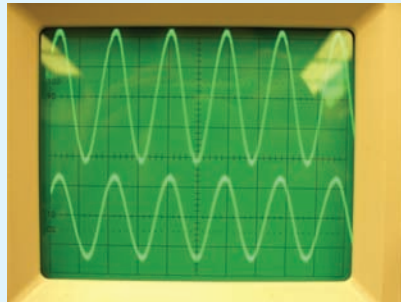
This initially confuses the student and some professors; their first reaction is to check the oscilloscope and probe for damage. However, after thirty minutes of exploring the geometry of the experiment, the individual realizes that changing the placement of the scope probe causes the voltages to go back into phase with each other. The final question of the lab is to ask the student why this is happening, and how this relates to measurements



Equivalent circuit diagram and equation governing the second part of the lab.



$R_2 > R_1$



$R_2 < R_1$

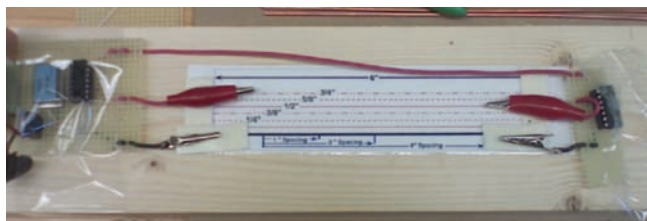


$R_2 = R_1$

taken in their other electronics classes. It is a very memorable way to demonstrate the need for keeping clip areas small, and to not letting scope probes sit haphazardly in the circuit.

Lab Five: Reference (Ground) Noise in Digital Logic

While the previous experiment showcased what happens when probes are haphazardly placed in a circuit, this experiment again revisits the concept of inductance and applies it to 'grounding' in digital logic. What's unique to this lab experiment is that the student has control over multiple variables, including the gauge of the return conductor, the conductor spacing and the probe spacing. In addition to changing these variables to see their effects, the students are asked to take measurements in both the frequency domain as well as the time domain across the bare wire return conductor. In the time domain, small voltage spikes appear, and the student feels that this is an acceptable noise level to deal with. Next a frequency domain measurement is taken, and the harmonic content of these small spikes is seen extending out much farther than the fundamental clock har-

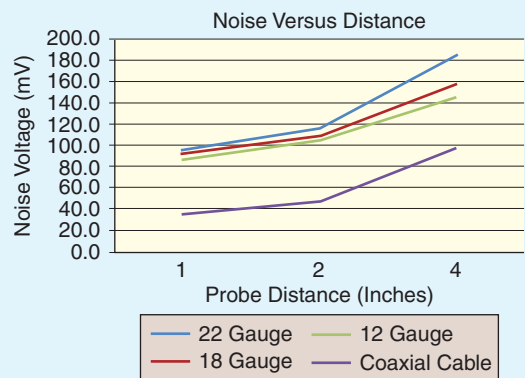


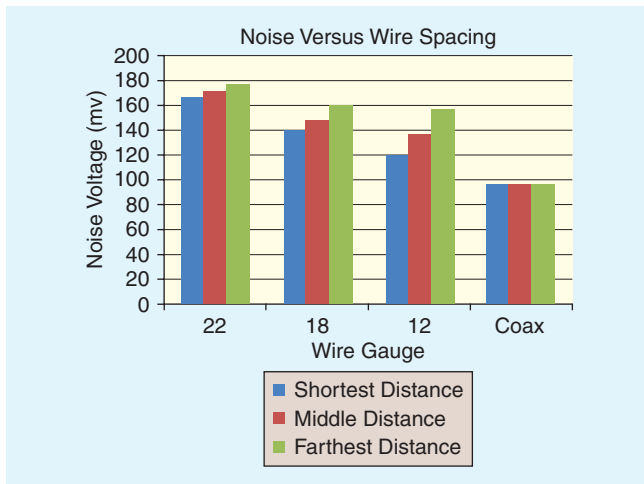
A picture of an early prototype of the lab—later versions had fixed conductors - but this still shows the control the student has over the separation of the probe, the gauge of the return conductor, as well as the spacing of the conductors.

monic with equal power; through comparing the two measurements, the student is able to get a more complete understanding of an induced voltage spike due to a clock or switching harmonic. The circuit being measured is a clock pulse being sent from one NAND gate to another to create a five volt pulse.

The first part of this lab asks the student to take measurements of all the different wire gauges at three different predefined spots for the probe and clip. The larger the clip distance, the more inductance the probe is measuring across and thus the larger the noise voltage measurement. This is an example of changing the self inductance of the return conductor; a table of results is shown below. The student, after collecting data, can easily assert that not only is probe clip distance very critical especially at larger gauges, but that coaxial cable is by far the best at resisting induced voltages.

Part two focuses on the mutual inductance the signal and return wires create. The experiment asks for the two wires to be placed very close together, and then a half inch from each other,





then one inch from each other. The student is asked to keep the probe clip constant at one inch to minimize noise generated by the self inductance of the conductor. Through these series of measurements, the students realize that the mutual inductance, previously thought to be a 'bad' thing, actually helps to reduce the noise voltage as the wires are placed farther and farther apart, the spikes on the return conductor became worse.

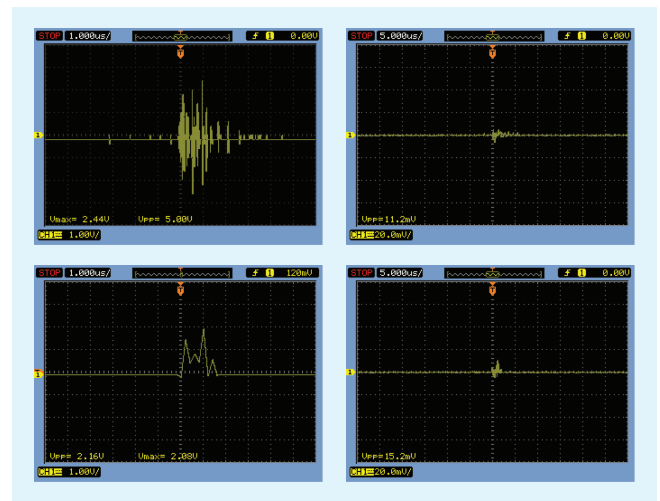
The student now realizes that the self inductance on both the signal and return conductor work to create the inductance in the circuit. They realize that the design goal is to balance loop areas and signal routing so that they're close enough to each other to maximize the mutual inductance, while choosing the minimum gauge needed for the current application so that the total inductance in the circuit is minimized. The total inductance equation governing this experiment is shown below.

$$L_{\text{total}} = -L_{\text{mutual}} + L_{\text{selfsignal}} + L_{\text{selfreturn}}$$

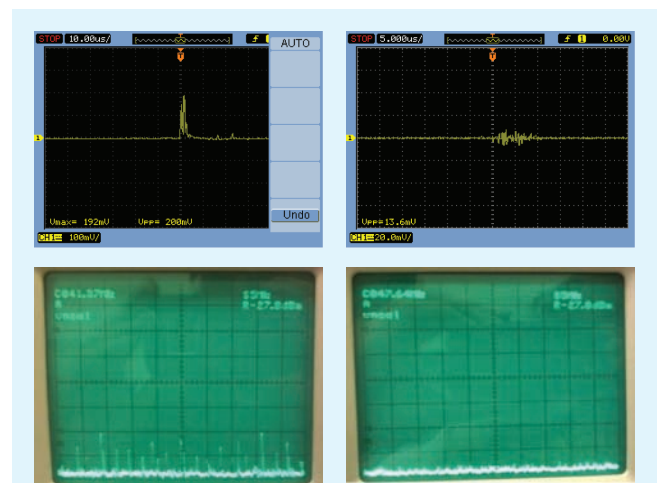
Lab Six: Reducing Noise on a DC Motor

The final lab needed to be a design project that encompassed both the theoretical topics covered in the lab section as well as the practices learned through the last two experiments. For this reason, a brush commutated DC motor (which is notorious for emitting large amounts of conducted and radiated emissions) was chosen as the central topic of the project. The students were first given a brief overview of how DC motors work (focusing on how the discontinuity of the contacts is the main generator of electromagnetic radiation). Then they were tasked with taking baseline common and differential mode current measurements, as well as radiated and conducted emissions measurements. After these measurements were taken, they were given access to copper and aluminum shielding, different passive filtering elements and were allowed to use whatever means necessary to reduce and document the reduction in emissions. No help was given from the instructor outside of soldering the leads to the motor (it was up to the students to determine the lead wire orientation), and the only requirement imposed was that the crank of the motor must be visible and the leads must be tied down (to prevent damage to the motor leads). A five minute presentation was required from each group of three describing their before and after results as well as their thought process.

Ideas ranged from the more common, twisting the lead wires and covering the motor in copper shielding, to the less common, building a line filter and paying close attention to how the lead wires are attached to the contacts of the motor. The first thing many students did was try to identify the type of noise emitted from the motor which was done by using RF current clamps, wands and high impedance probes. They connected these probes to measure both the spectral power density as well as the time varying amplitude of the conducted noise. Then, many started twisting the lead wires and noticed this has a substantial impact on the noise voltage, leading many to believe that the noise voltage was differential. However, since the noise was radiating back on both the power and reference lines, the common mode measurement was greater than the differential measurement in some cases. In the end, the most inventive solutions came in the form of a well molded copper shield in which paper was used to insulate the shield from the motor casing. This acted as a ground to prevent the motor from shorting,



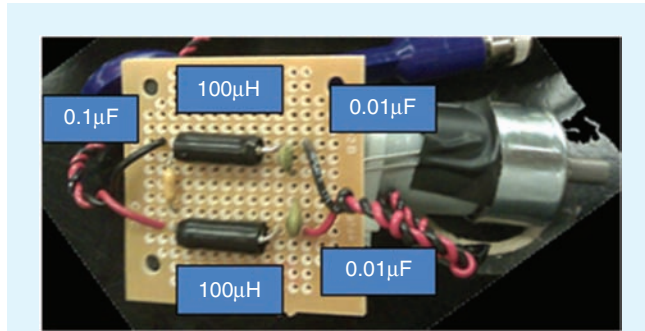
The left column has the before measurements, common mode on top, differential on bottom, while the right column has the after measurements.



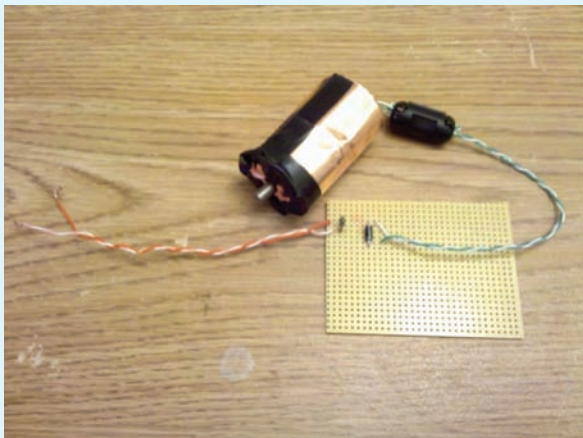
The left column has the before measurements, while the right column has the after measurements. Measuring in both the frequency and time domains gives the student a well-rounded idea of what they're dealing with.

as well as a full line filter and the use of a TVS diode. The key thing students learned was that adding certain components worked well, such as an inductor, but it also had the possibility of reducing motor current and could slow the motor down.

Below are some examples of the measurements obtained and a photo of a finished project.



Line filter implemented



Shielding cut to size, with ferrite and a small TVS diode

Conclusion

Each of these experiments took about two weeks of planning, from inception to implementation, and could not have been possible without the aid of the EMC Society's document. The most remarkable thing about this document is that it was put together by individuals in the 1980s and still has strong ties to present day electromagnetic compatibility topics. These lab experiments not only showed the students relevant examples of theoretical topics, but also that the problems electromagnetic compatibility engineers face have not changed but have gotten worse in the last twenty years. The way the experiments are rolled out with each one reinforcing something learned in the past, in addition to being tightly coupled with Henry Ott's new book, allows for not only a unique but easily reproducible learning experience.

Issue No. 196
Winter 2003 ISSN 1089-0785
Janet O'Neill, Editor

<http://www.emcs.org>

EMC

IEEE EMC Society Newsletter

INSIDE:

- Letter from the Editor 3
- President's Message 4
- Chapter Charter 5
- Practical Papers, Articles and Application Notes 21
- Education and Student Activities 37
- Personality Profile 38
- EMC Test Equipment Control Software 39
- 2003 IEEE International Symposium on EMC, Istanbul "Radiating Compatibility from the East" 41
- Introducing Members Newly Elected to the EMC Society Board of Directors 44
- Board of Directors Activities 46
- EMC Standards Activities 56
- EMC AHS 58
- Division IV Director's Report 62
- Call for Board Nominations 64
- EMC Europe 2002 66
- New EMC Society Members 69
- Three New Distinguished Lecturers 70
- Calendar 72

EMC Education at the University of Michigan – Dearborn

By Mark Steffka

What started out with a \$10,000 IEEE grant in 1999 in order to help incorporate EMC into the Electrical and Computer Engineering (ECE) courses at the University of Michigan – Dearborn, has grown into a key part of the undergraduate curriculum and the engineering continuing education programs! The accomplishments that have been achieved since the Winter 2000 term are significant and include:

- Establishment of two undergraduate courses: "ECE 319 – Introduction to EMC" and "ECE 420 – EMC Testing and Instrumentation".
- A United States National Science Foundation (NSF) grant to establish an on-campus EMC laboratory.
- Two courses conducted in "Automotive System EMC" (as part of the Engineering Professional Development Program).
- The total past and current enrollment in the undergraduate courses is now over 100 students and 30 engineers have taken the "Automotive System EMC" two-day course.

The IEEE grant was initially pursued by the ECE department chair, Dr. M. Shridhar, in response to a request he received to look at how the topic of EMC

You can see the enthusiasm the students have for EMC! Instructor Mark Steffka is shown with students Dale Sanders and Maureen McGinnis (left to right) in the University's new EMC Lab.

could be covered at the university level. In developing the rationale for the grant, Dr. Shridhar requested and received outstanding industry cooperation through the efforts of many EMC professionals located in the Southeast Michigan region, many of whom are members of the IEEE EMC SE Michigan Chapter. This cooperation resulted in the preparation of an outline of an EMC curriculum content, selection of appropriate reference materials (primarily textbooks), and the identification of a need for a laboratory facility to assist the students in their understanding. In order to introduce the topic to current students, the university then conducted a series of guest lectures on different aspects of EMC. These lectures were well received and indicated the potential viability of full-term course(s) in EMC at the campus.

In the Winter 2000 term the first course in the EMC sequence (ECE 319) was taught by Mr. Jim Muccio, a well-known EMC professional from the Detroit area. This course is an introduction to the EMC discipline, how it has evolved, its impact on product design practices, and what basic techniques are used to minimize EMC issues in components and systems.

Since the Fall 2000 term, the curriculum has been taught by Mr. Mark Steffka, an EMC Specialist at General Motors, and an Adjunct Lecturer in the UM-D ECE department. The course that was first offered for the Fall 2000 term was ECE 420 – which builds upon the fundamentals covered in ECE 319 and incorporates a study of test methods and instrumentation used in EMC. ECE 319 utilizes Henry Ott's text, "Noise Reduction Techniques in Electronic Systems" and the textbook for ECE 420 is Dr. Clayton Paul's book "Introduction to EMC". (Since the Winter 2001 term, Mr. Steffka has also been the instructor for ECE 319.)

continued on page 35

EMC activity at the University of Michigan-Dearborn has certainly grown since the Winter of 2003, thanks to the efforts of Adjunct Professor Mark Steffka (shown above left).

Biography



Christopher Semanson received his B.S.E. in Electrical and Computer Engineering from the University of Michigan-Dearborn (UM-D), where he is also currently completing his master's degree in Electrical Engineering. He is also working as a graduate studies research assistant in the UM-D Power Electronics Research Group. He has previously worked for Chrysler in Telematics, Active and Passive Safety, and Hybrid Systems.

In the Fall of 2009, he volunteered to take the IEEE EMC Society Education Manual, adapt it to complement Henry Ott's new Electromagnetic Compatibility book, and develop a number of laboratory experiments for the campus' undergraduate EMC course (as well as developing a design project). He also obtained a grant from the IEEE EMC Society to aid in his laboratory development work.

Currently, Chris is working on "State of Charge Estimation" in the Power Electronics group at Michigan-Dearborn. He plans to graduate in December, 2010, with an M.S. degree in Electrical Engineering. His wide range of technical interests includes embedded system design for power electronics, state of charge estimation, hardware layout, controls, and electromagnetic compatibility. He may be reached at phone 248-417-0218 or email chris.semanson@ieee.org.

(Editor's Note: Chris Semanson is currently evaluating various career options and is looking for an opportunity that can combine his interests and in-depth knowledge of EMC!)

EMC