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Lessons Learning from Developing and Teaching an Electromagnetic Compatibility (EMC) Course – From Concepts to Delivery

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Lessons Learned from Developing and Teaching an Electromagnetic Compatibility Course – From Concepts to Delivery

Abstract

The field of electromagnetic compatibility (EMC) is to ensure that electrical systems will function as intended in an electromagnetic environment. EMC is important in electronic design since all electronics in the market must comply with EMC regulations. The main goal of the EMC course is to provide students with a fundamental understanding of EMC principles to prepare them for future careers in industry and academia.

To enhance student engagement and interest, several new teaching practices were proposed and implemented during the fall 2022 semester. These practices included making real-world connections to the course materials, using concept maps to depict the connections between high-level concepts and lower-level facts, incorporating cartoon pictures into the classroom to add a sense of humor, and a gamified approach in the form of a Jeopardy-style game. These approaches are adopted to help students reinforce their knowledge and gain a stronger understanding of EMC concepts.

The emphasis of this paper will be on improving the EMC course curriculum through the integration of engaging and interactive instructional activities into traditional classroom settings. We first give a general overview of the course's development and contents, then present a detailed discussion of new teaching strategies. Finally, key findings from the course implementation process as well as student feedback are presented.

I. Introduction

Electronics are important in the modern world and play a significant role in various fields, including telecommunications, transportation, healthcare, military, etc. With the continuous development of new and innovative electronic devices, the concept of Electromagnetic Compatibility (EMC) has become increasingly important. The electromagnetic (EM) waves emitted by electronic systems may interfere with other electronic systems, resulting in performance degradation, system failure, and even hazardous situations. It is particularly critical in safety-critical applications, such as aerospace, medical equipment, and transportation systems, where the failure of an electronic system could have severe consequences. Almost all countries and nations mandate that electronic systems must comply with EMC international regulations and standards.

To address the growing importance of maintaining electronic system compatibility, the development of an EMC course becomes necessary. As a consultant for a student electric car competition team, the author often encountered a recurring design issue: electromagnetic interference (EMI) that prevented the car from functioning properly. It was not practical to simply apply EMC patches to the current prototype because it would increase costs, add complexity, and have a negative impact on the final product's reliability and compliance. As a result, it was critical that students learn how to identify and address EMC issues early in the design process. It'll provide long-term benefits in terms of cost-effectiveness, reliability, and compliance with the understanding of EMC design.

In this study, we present ongoing efforts to improve the EMC course curriculum through interactive and engaging instructional activities. The course's development and content will be outlined and discussed. To promote student engagement and motivation, several learner-centered approaches have been adopted in the EMC course. These include creating strong links between course materials and real-world scenarios, utilizing concept maps to clarify relationships between various concepts and theories, incorporating cartoon illustrations to add a sense of humor, and developing a Jeopardy-style game to further engage students in the learning process. These strategies are used to facilitate student learning and make the course more enjoyable and interactive.

Additionally, this paper will include an analysis of student feedback to gain a thorough understanding of their learning experience. The objective is to assess the effectiveness of the teaching strategies and the impact on the student's understanding and engagement with the EMC course.

II. Background

A. Overview of existing EMC courses

The field of EMC is a critical aspect of modern electronic design and plays a crucial role in ensuring the safe and reliable operation of advanced electronic systems. As a result, EMC courses are now an integral part of curricula in electrical engineering, computer engineering, and other related fields.

Existing EMC courses in universities and colleges cover a wide range of topics including an overview of the concepts and principles of EMC and EMI, design considerations, measurement, and methods for mitigating EMC problems. These courses give students a thorough understanding of the concepts and principles of EMC and prepare them for the challenges of electronic design and development.

There are online EMC courses and certification programs available in addition to traditional classroom-based EMC courses. These courses are typically topic-specific and are delivered via an online platform. Students can choose which topic to learn and can learn at their own pace or on a set schedule. While online courses may be more convenient for students interested in pursuing careers in EMC, they may have limitations such as limited feedback from instructors and pre-recorded content with no immediate feedback opportunities.

B. Course Objective

The EMC course is designed with three main objectives.

- Firstly, the course aims to provide a fundamental understanding of the concepts and principles of EMC, including EM sources, coupling mechanisms, emission, and immunity, as well as advanced topics such as grounding, filtering, shielding, electrostatic discharge (ESD), and system design for EMC compliance, etc.

- Secondly, the course aims to prepare students for the challenges they will face in the design of modern electronic systems. Industry and military standards such as FCC, CISBR, and MIL-STD-461 for conducted and radiated emission, and immunity.
- Thirdly, the course aims to provide students with critical thinking and problem-solving skill in the design of safe and reliable electronic systems. This includes the ability to *analyze and evaluate* EMC performance, *identify and implement* effective solutions to EMC issues, as well as *reduce and minimize* electromagnetic noise and coupling.

Overall, the EMC course aims to prepare students for succeed in the field of electrical engineering by teaching them how to design safe and reliable electronic systems that comply with EMC standards. The course is designed to be challenging, engaging, and relevant to the pressing needs of advanced electronic design and research.

C. Overview of Course Content

The content of this course is accredited as 3 credits for undergraduate students and 4 credits for graduate students. The course is organized into three components, basic EMC concepts, advanced topics, and system design topics with an equal amount of lecture time. The main textbook is ‘Introduction to EMC’ [1]. To address the section on EMC system design, which includes PCB design and layout, and EMC measurements, the book 'EMC Engineering' [2] is used as a reference.

i. Basic EMC topics

These topics serve as a foundation for EMC principles and concepts, including electromagnetic fields, transmission lines, EMI and antennas, non-ideal circuit components, and EMC regulations. The students will also gain an understanding of the latest industry standards and regulations related to EMC through discussions on these basic EMC subjects shown in Figure 1.

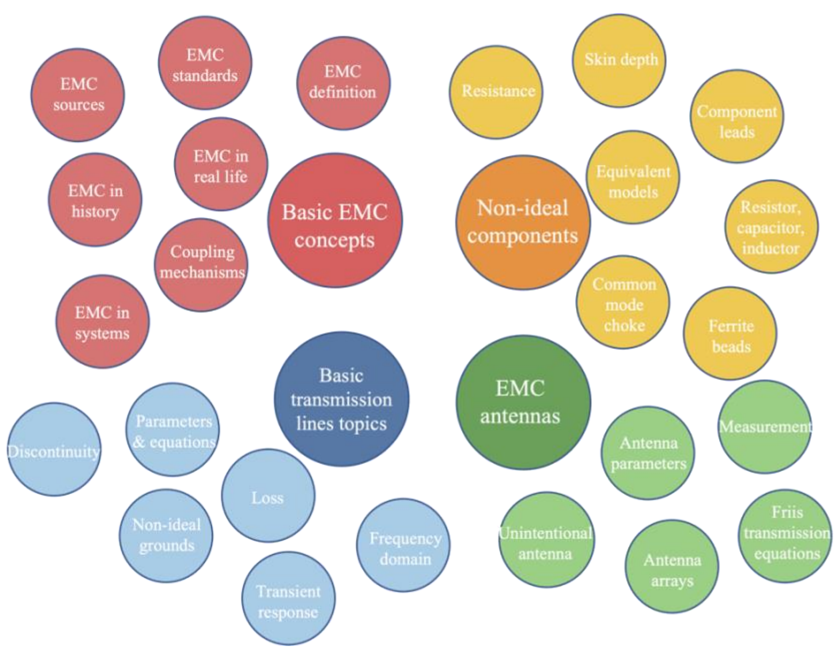


Figure 1 Unconstructed view of EMC basic topics.

ii. Advanced topics

These advanced topics dive deeper into EMC, covering topics such as advanced transmission line theory, radiated emissions and susceptibility, conducted emissions and susceptibility, and crosstalk. Most of the advanced concepts may be introduced for the first time to the students. Figure 2 illustrates the unconstructed version of advanced topics.

Figure 2 Unconstructed view of EMC advanced topics.

iii. System design topics

The system design EMC topics focus on the practical application of EMC principles in the design and development of electronic systems. This section covers system integration and design considerations for EMC compliance, as illustrated in Figure 3. The course materials are expected to be newly introduced to all students. As a conclusion of this section, a commercial SDRAM memory design is discussed in class. The main purpose of this section is to answer the following questions:

1) How to minimize electronic systems' potential to interfere with other electronic systems?
2) What can be done to maximize the system's immunity to electromagnetic emissions from other sources?
3) How to minimize the system's potential radiated emissions to prevent interference with itself?

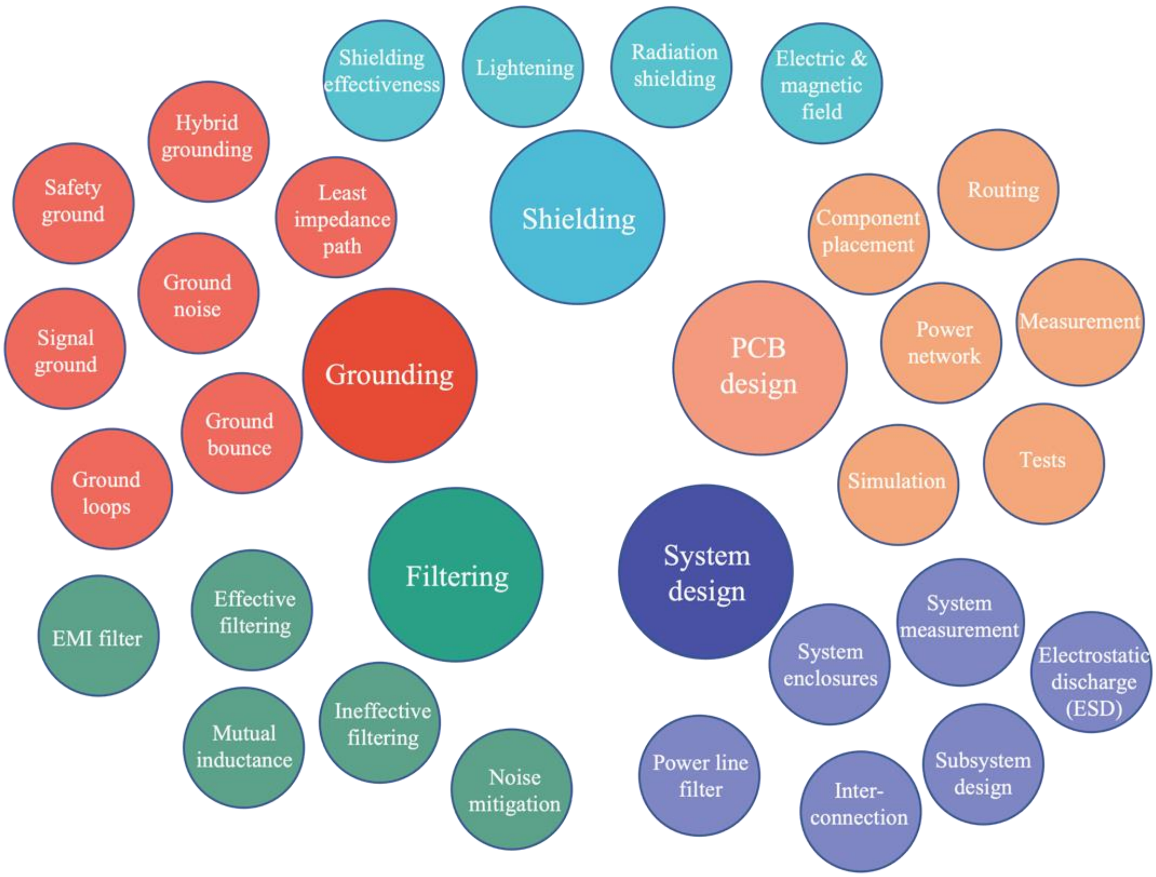


Figure 3 Unconstructed view of EMC system design topics.

These topics, basic, advanced, and system design, are covered in an equal amount of time over the course of one semester. Two midterms and one final exam are used to assess students' knowledge, allowing them to progress from simple to complex concepts.

D. Incorporation of industry best practices

Incorporating industry best practices into the EMC course is a new component that ensures students receive relevant and up-to-date education in the field. As the EMC industry is constantly evolving, an updated curriculum is required to ensure students receive the most up-to-date information. These best practices are incorporated throughout the course, which keeps the students interested and motivated. Students will gain practical knowledge of the EMC principles and the skillsets to design safe and reliable electronic systems. These new components include the latest EMC standards and regulations, trace design for printed circuit boards (PCBs), spectrum analyzer usage, latest EMC measurements and tests (Figure 4), interference between various antennas on aircraft and base stations (Figure 5), ribbon cable design, grounding system for data converter (Figure 6), ESD vs. PCB layout (Figure 7), and general guidelines for EMC system design.

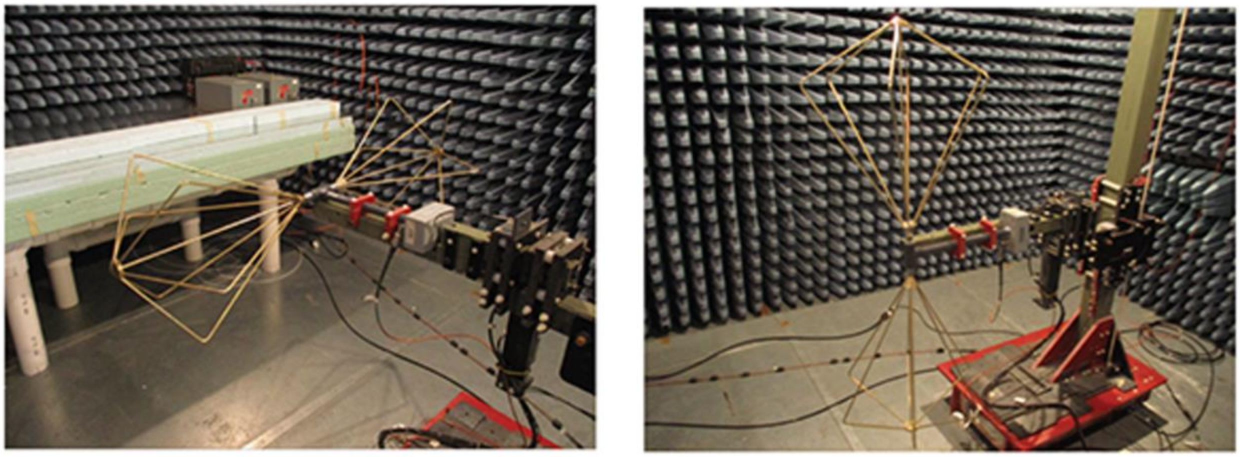
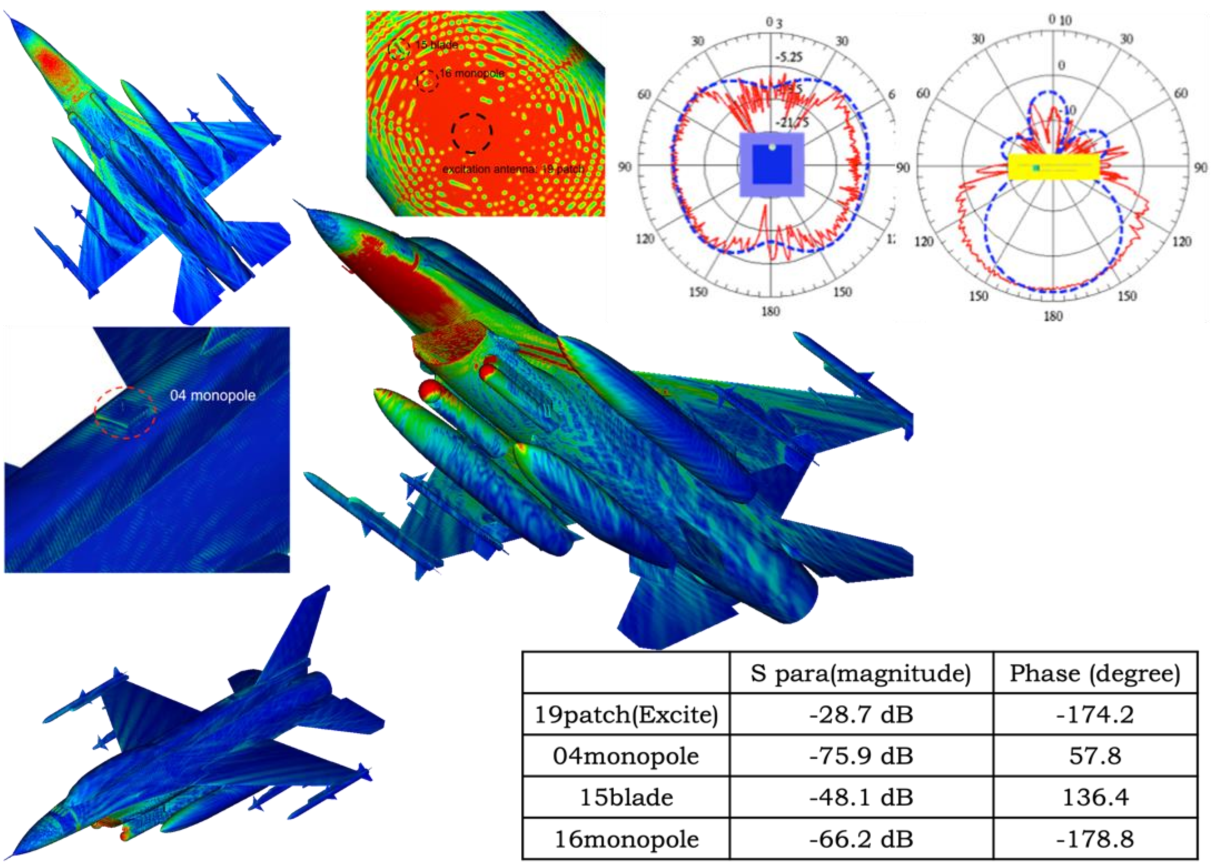


Figure 4 Biconical antenna in an anechoic chamber [3].



	S para(magnitude)	Phase (degree)
19patch(Excite)	-28.7 dB	-174.2
04monopole	-75.9 dB	57.8
15blade	-48.1 dB	136.4
16monopole	-66.2 dB	-178.8

Figure 5 Interference between various antennas on aircraft and base stations [4].

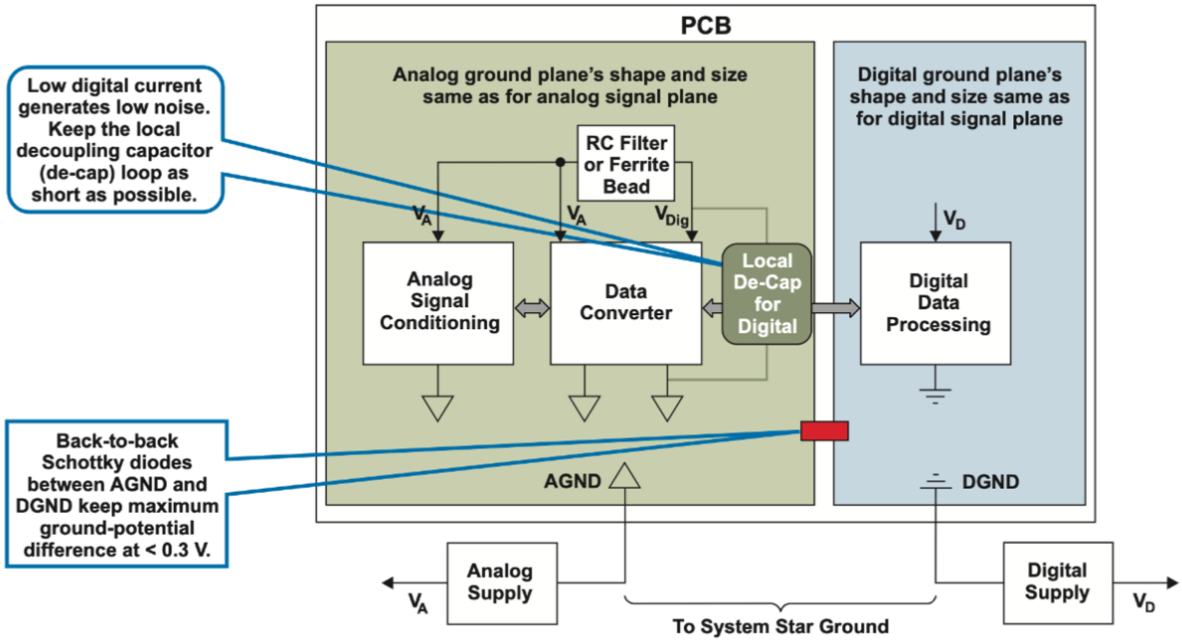
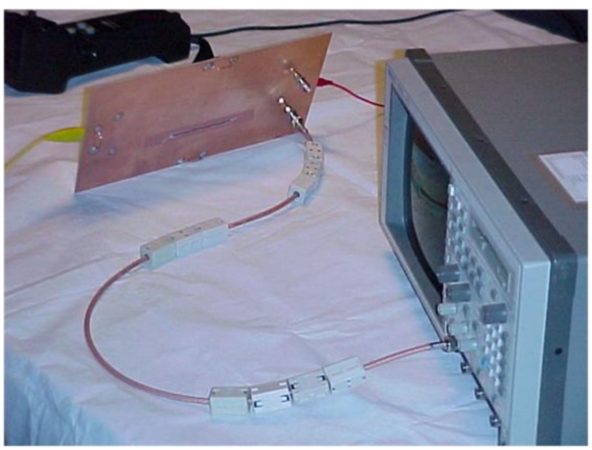
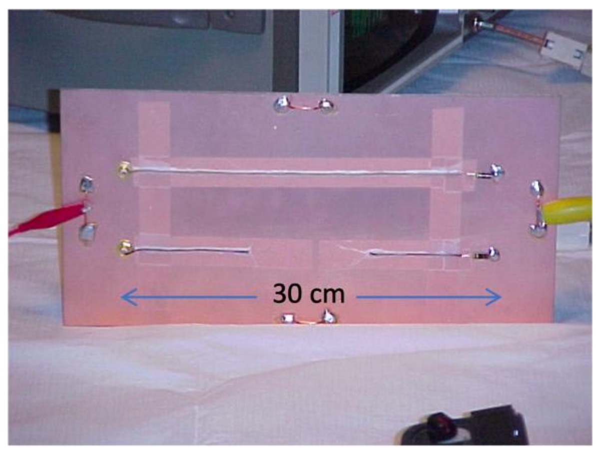


Figure 6 Grounding system design for data converter [5].



(a) Connection to Oscilloscope



(b) Test board with two test paths

Figure 7 ESD immunity vs. PCB layout [6].

Incorporating industry best practices into the EMC curriculum provides students with greater hands-on knowledge of recent industry and research developments. In this way, students will be better prepared to face the challenges of designing EMC-compliant electronic systems.

III. Implementation

A. Make use of real-world examples

EMC design is a multidisciplinary topic with a wide range of subfields, including electronics design, electromagnetics, antenna design, material science, physics, among others. Students tend to learn more effectively when the lecture content is linked to their prior knowledge. Real-world examples can be used to provoke discussions in class and encourage students to apply their problem-solving skills. This can be done by engaging students in a variety of activities, such as introducing realistic problems for discussion in class, encouraging students to research relevant problems outside the classroom, and allowing them to explore their own interests in problem-solving, etc. These approaches contribute to the creation of a dynamic and interactive learning environment that keeps students engaged and motivated.

For instance, in addition to discussing the consequences of not complying with electromagnetic compatibility rules, presenting realistic scenarios in class can help promote critical thinking and discussion. Following are a few examples of EMC applications in students' daily lives:

- EMI from cell phones: Interference between cell phones and TVs is one common example of interference. When a cell phone is used close to a TV, the signals emitted by the phone can interfere with the TV's picture or sound quality, causing the TV to have pixelation, picture noise, or loss of signal. It is due to the cell phone's radio frequency (RF) signals interfering with the TV's reception of the broadcast signals.

- Microwave shielding: Metal films are used to form a Faraday cage around microwaves to stop EM leakage. However, it is recommended to maintain a safe distance from a microwave source to minimize exposure to the EM fields, which may have potential health implications.

- Apple ‘Antennagate’: When iPhone 4 was released, customers found out that holding it in the left hand will causing network connection problems. It was due to a gap in the two antenna bands on the left lower corner of the phone.

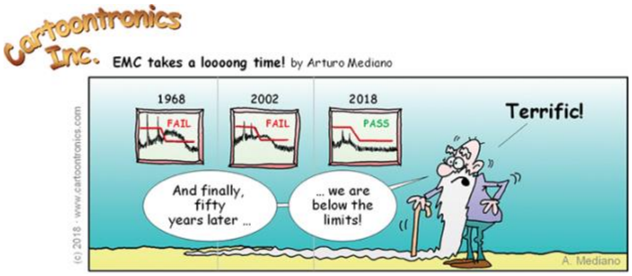
- Low-frequency EM field: Due to the possible health effects of exposure to EM fields, living close to high-voltage power lines has been a concern for many people. The EM fields generated by high-voltage power lines are mainly at extremely low-frequency (ELF). The possible negative effects of exposure to ELF fields (with the potential increased risk of certain health issues, such as childhood leukemia) on health are continuously discussed among scientists. Students are guided to research this topic and discuss the facts in class.

- Electronic safety: ESD is the transfer of electrons and a sudden electrical discharge between two objects. This can happen when a person walks on a Nylon carpet and touches a metal object. The sudden discharge can cause damage to sensitive electronic devices, such as smartphones, laptops, and memory devices. To prevent ESD, it is recommended to use anti-static materials, such as wrist straps, and to avoid touching sensitive electronic devices with bare hands or metal objects.

These examples help students understand the importance of EMC in their daily lives. Overall, incorporating real-life examples in an EMC course can help students retain information and understand the importance of EMC in electronic design in an engaging and interesting way.

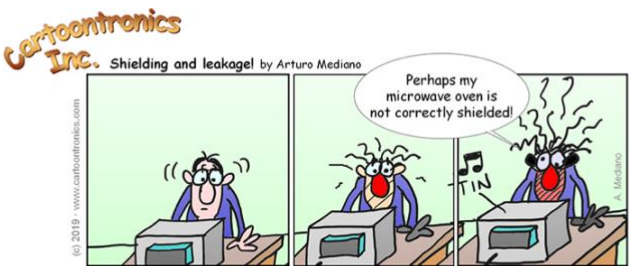
B. A sense of humor

Using cartoon pictures to teach the EMC class can add a sense of humor to the course and make the subject more appealing to students. This can be especially useful when students are losing focus during extended class periods. Cartoons can help to simplify complex concepts and make them easier to understand, particularly for students with limited prior knowledge of EMC. By including cartoons in the middle of the class, students' attention can be re-directed and their learning process reignited, leading to a more memorable and effective educational experience. Figure 8 shows several examples of cartoons used in class.

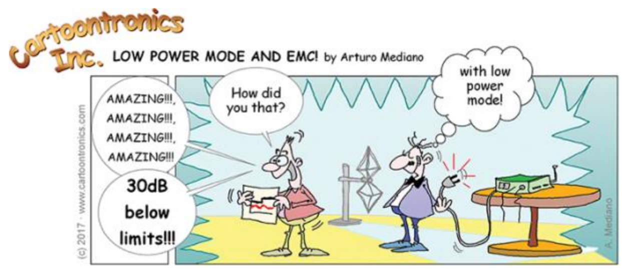


(a) EMC takes a long time.

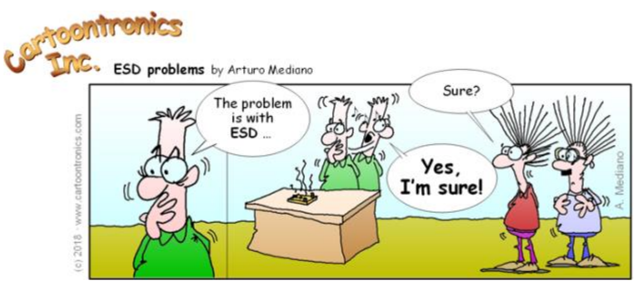
(b) Holes in GND planes.



(c) Shielding and leakage.



(d) Low power mode and EMC.



(e) ESD problems.

(f) A wrong EMC 'solution'.

Figure 8 Examples of Cartoons illustrating EMC concepts [7].

In summary, using cartoons in lectures allows students to better connect the topic to everyday events and retain the information. Humor can also be used in lectures to encourage student participation and break up the monotony of traditional lectures.

C. Concept map

Since EMC is a multidisciplinary topic, students frequently find it challenging to organize and understand different concepts and their interrelationships. Concept mapping was developed by Joseph D. Novak and Alberto J. Cañas in the 1970s [8]. Concept mapping is now a popular tool in education for enhancing teaching and learning across a range of subject areas, including science, math, social studies, and literature. Several studies have explored the benefits and challenges of using concept maps in college education. [9] explores the effectiveness of concept maps as a learning tool in medical education. The study suggests that concept mapping is an effective tool for enhancing knowledge retention, critical thinking, and clinical reasoning among medical students. In [10], the authors highlight the challenges that students face in organizing and applying their knowledge to different engineering situations. Two maps are developed as a useful pedagogical tool that can help students structure their learning and facilitate understanding, retrieval, and problem-solving. In [11], the authors utilized concept maps for assessing student learning in an introductory solid mechanics course for engineering majors. The analysis of concept maps created by students was used to identify how they assimilated the course material. It was found that while students generally drew the expected connections, there were instances of isolated or wrongly associated topics.

Concept maps are particularly useful in fields that involve complex information or multiple interrelated concepts. Utilizing a clear concept map in the EMC course is a great teaching tool because it helps students to see the big picture and understand the meaningful connections between all higher-level concepts and lower-level facts. It was used in the fall 2022 semester to help students learn and understand complex EMC concepts. The first approach used in class is introducing a concept map to students to help them navigate between lectures. The concept map starts with the fundamental EMC principle, known as the source-coupling path-victim model, and branches out to different types of sources, victims, and coupling mechanisms. Each branch is further divided into more specific subtopics. Since it gives students a clear and structured framework with the hierarchical nature of concepts, it allows students to quickly identify the key topics, as well as the connections within them. The use of concept mapping can also benefit students with diverse learning styles, as it offers a visual representation of information. Additionally, it serves as a useful tool for students to summarize and review course material prior to exams.

The second approach used in class is to let students develop their own concept maps to promote active learning. It allows students to actively participate in the learning process. One example of a concept map created by a student is shown Figure 9. It illustrates a thorough understanding of various subjects as well as the relationship and hierarchy between concepts.

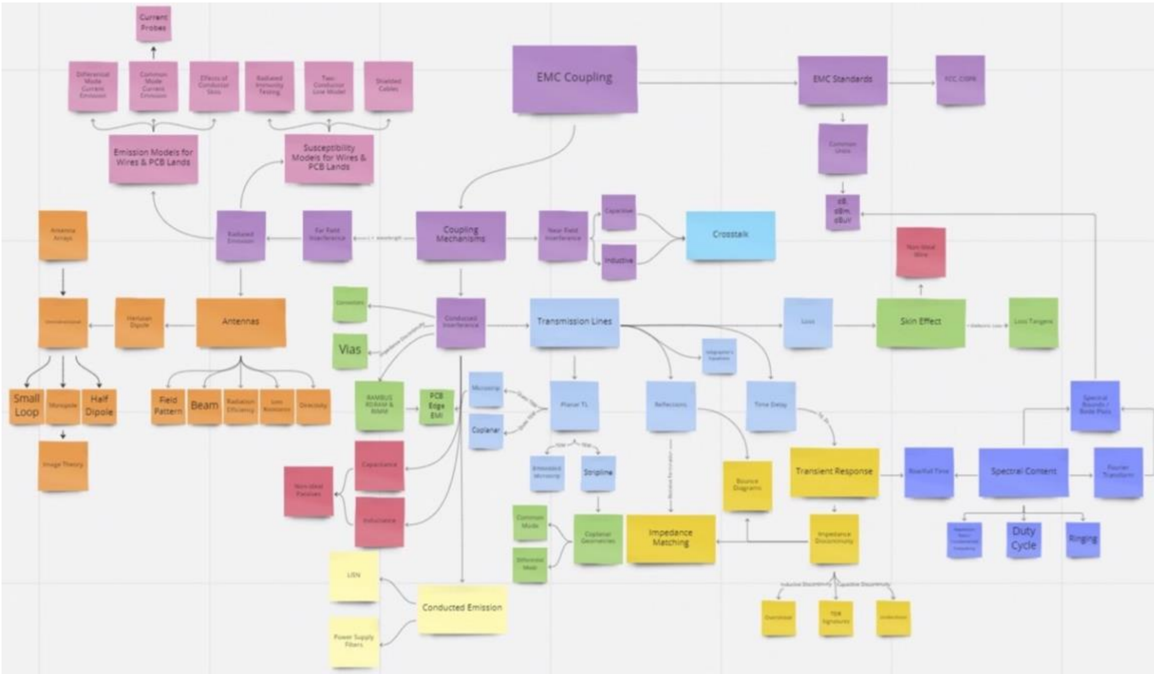
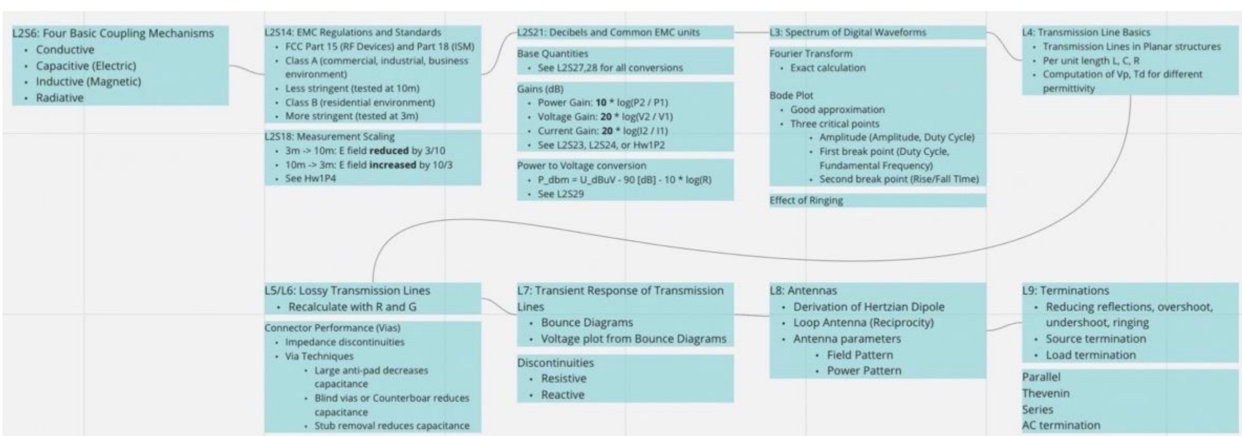
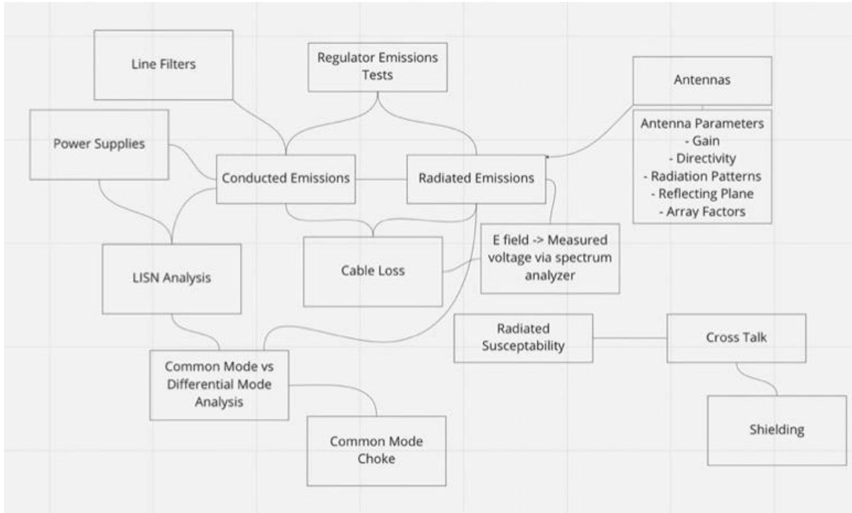


Figure 9 One example of a concept map created by a student.

The students were also asked to revise their concept maps and discuss them with their peers. This active learning technique is effective in improving students' comprehension of EMC concepts and promoting a deeper understanding of the material. Figure 10 depicts a concept map before and after revision by the same student. The initial map only contains a list of topics covered by each lecture. The revised version, however, demonstrated a better understanding of the connections between the topics. During the process of building the concept maps throughout the semester, the students develop the EMC idea in the big picture, use it to simplify complex problems into smaller and easier ones, and further guide their study for review and preparation for exams.



(a) The initial concept map created by one student



(b) Modified concept map by the same student

Figure 10 Examples of concept maps before and after revision.

D. Gamification

Integrating gamification into the classroom is becoming more and more common in today's education. Gamification has several benefits, including increasing student motivation and engagement, improved learning outcomes, customized learning paces, and a better team learning experience. When incorporating gamification in the classroom, instructors need to define learning objectives, know their students and their learning styles, identify learning outcomes, and study various gamification tools. For example, [12] developed a gamification strategy proposed by Werbach and Hunter, which is based on dynamics, mechanics, and components. The authors used digital tools to manage the points and badges, including Genial.ly, Kahoot, YouTube, MindMeister, Quizizz, Mentimeter, and Edmodo for four different engineering courses. However, the study in [12] tells a different experience of using Moodle plugins to implement badges, experience points, leaderboards, and quizzes with automated feedback in five engineering courses over two semesters. The results indicate that students found immediate feedback and the ability to make repeated attempts at similar questions helpful for their learning, but the game-like elements were only minimally helpful for their motivation. The study suggests that incorporating more meaningful goals and challenges tied to extra credit may increase student motivation.

For the fall 2022 semester, a Jeopardy game was developed toward the end of the semester in the EMC course, as seen in Figure 11. This type of game can be an effective teaching method in the EMC course to engage students and encourage teamwork. In the game, teams of students answer questions on various EMC topics, such as EMC regulations, EM theory, transmission lines, EMC coupling mechanism, and system EMC design. The questions range from basic, to advanced, as well as system design topics. By participating in this interactive and competitive activity, students are able to reinforce their knowledge and build a deeper understanding of EMC concepts. The use of games in the classroom can also create a fun and relaxed learning environment, which can help students feel more motivated and engaged. The Jeopardy game serves as a complementary approach to traditional lecture-based instruction and makes the learning experience more enjoyable and memorable.

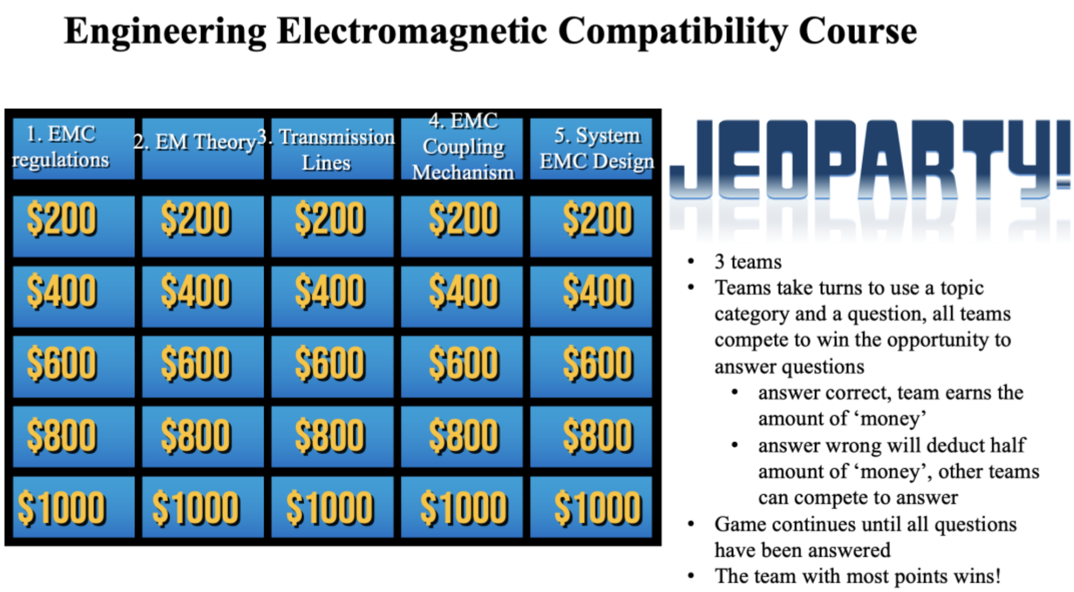


Figure 11 Jeopardy game about EMC concepts and design considerations.

IV. Course Evaluation and feedback from students

There were 10 students enrolled in the course in the fall 2022 semester, both from undergraduate and graduate programs. The graduate students have different backgrounds, from antenna design, circuit design, lithography, bioengineering, and physics.

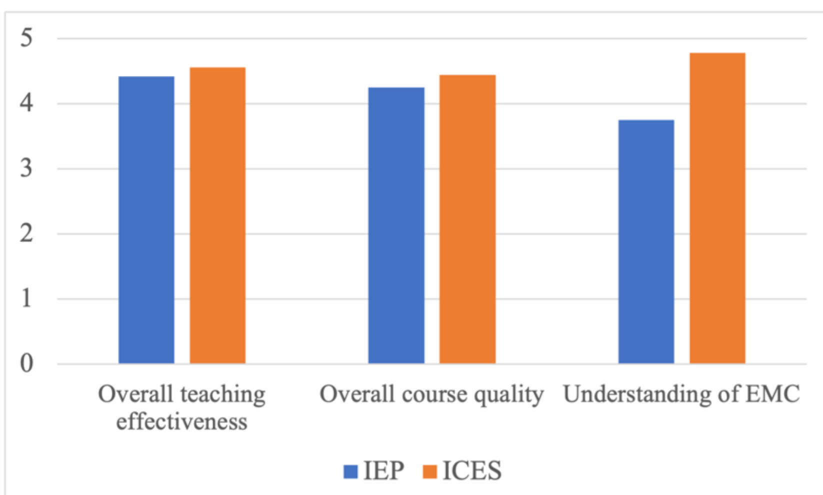


Figure 12 Overall course EMC concepts and design considerations.

The course evaluation and student feedback are important aspects of the development and improvement of the EMC course. The early informal feedback (IEP) survey and course evaluation survey (Instructor course evaluation system, ICES) were sent to the students in the middle of the semester and after the semester, respectively. During the survey, students were requested to answer (with a five-point scale: 1-very poor, 2-poor, 3-satisactory, 4-good, and 5-very good) anonymous questionnaires. According to the ICES results, the EMC course received 4.44 points with a standard deviation of 0.73. As shown in Figure 12, both overall teaching effectiveness and course quality show a 3% increase from mid-semester to the end of the semester. The students felt much more confident in their knowledge of the EMC topics, with an increase from 3.75 to 4.78 from midterm toward the end of the semester.

The following results summarize the student response in various aspects:

- Students agreed that in-class discussions engage them to learn better with 4.42 points on a five-point scale. No students disagreed with that.
- Students felt the pace of the course was just right with 2.58 on the five-point scale of 1– too slow, 2 – slow, 3 – not too fast or slow, 4 – fast, and 5 – too fast. The standard derivation is 0.52. One student commented that '*class pacing can feel fast at times, maybe more time going in-depth on some of the more fundamental concepts or more going through examples step by step in writing*'. This shows that students in general felt the pace is good but sometimes it's good to slow down for some specific topics, especially for students who maybe lack of engineering background.
- Students thought they have social connections among the students and from the instructor with 4.08 points. No student felt isolated.
- Students agreed that the real-world examples discussed in class helped them to understand the topic better with 4.67 points. No students disagreed with that. One student wrote this regarding the real-world examples in the survey, '*talk more about the real-world examples. I have limited design experience as a student, so more design examples, EMC design rules, and before and after EMC fix comparisons are going to help me with understanding.*' This demonstrates the need to connect theories/concepts to real-world applications and examples.
- Students believed the comic pictures in lecture slides helped them learn better with 4.43 points. However, one student stood out among the rest by strongly disagreeing with the statement. It shows that students have different learning preferences. Some students prefer visual aids such as diagrams, videos, or animations, while others may prefer audio aids such as lecture recordings or podcasts. Cartoon pictures can be used in the EMC course to incorporate a mix of teaching methods, including a combination of lectures, hands-on activities, and visual aids.
- Students thought general course organization is excellent with 4.67 points. No student disagreed with this.
- Students felt the course materials are useful and helpful with 4.6 points. No student disagreed with this.

Several of the student comments are included below:

- *Very informative and interesting course!*

- *The lectures are informative and interesting.*
- *The course was very helpful in expanding on several topics in EE that I have been working with so far.*
- *Make connections between multiple classes in ECE and apply them to real examples and designs.*
- *It is a very relevant topic, important for our projects and career.*
- *Comic pictures in the slides are best (Definitely!)*
- *Collaboration in class is great even though the class size is small.*
- *I like how the material in the course has direct applications, unlike most of the other theory courses I have been taking so far.*
- *It's a good course.*
- *The instructor is highly willing to teach, which is fantastic.*

Based on the survey, there are also some key areas for improvement.

- The lecture notes might be organized in a better way with more prominent figures. Some figures in the slides are taken from the textbook, which is either old or too small to see.
- It also helps to cite the textbook in addition to organizing the topics by chapters.
- Since EMC has many topics, transitioning from one topic to another one can also be improved.

V. Conclusion

In this paper, the course development and implementation of an EMC course were discussed. The EMC course was cross-listed for both senior-level undergraduate students and graduate students. The 16-week-long semester was divided into three general topic areas: fundamental topics, advanced topics, and system design topics. The course material includes many real-world applications and examples, making the content more engaging and relevant to students' research areas and daily lives. Cartoon pictures of EMC problems were used to better pace the class and help the students regain their focus during a long lecture. The utilization of concept maps enabled students to better understand the interrelationships between complex concepts, through visual representation. The Jeopardy game received enthusiastic responses from the students at the end of the semester. This game format helps to engage students, encourage teamwork, and provide an interactive and competitive learning experience. Student surveys were conducted throughout the semester. The course evaluation was highly positive. The students strongly agreed that the course prepared them better for future engineering careers.

The future scope of the EMC course development is critical to ensure that the course remains relevant and effective. The course should be updated to incorporate new technologies and practices, expand hands-on exercises and projects, collaborate with industry partners, and incorporate online learning. By continuously updating and improving the course, instructors and administrators can ensure that it remains relevant and effective for future generations of electronic design experts.

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