Integrating Electromagnetic Compatibility Studies into Multidisciplinary Engineering Curricula: A Critical Need for Modern Education

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Abstract

India's National Education Policy (NEP) 2020, along with a global shift toward sustainable development and international cooperation, is reshaping the landscape of engineering education. To prepare students for the complex world they will enter, curricula must evolve to address both technical advancements and societal needs. One critical area that deserves immediate attention is Electromagnetic Compatibility (EMC)—a fundamental aspect in designing reliable and resilient electrical and electronic systems that impact our daily lives. As devices become more compact and high-frequency, and as technologies such as wireless communication and high-speed data transfer become integral to everyday experiences, the challenges of Electromagnetic Interference (EMI) and EMC become personal and universal. Yet, despite their clear industrial relevance, EMC topics are rarely given center stage in undergraduate engineering programs. This paper makes a case for weaving EMC concepts throughout undergraduate Electrical and Electronics Engineering (EEE) and related technology courses, in keeping with the vision of NEP2020. EMC knowledge is not just about meeting regulatory standards like CISPR, FCC, and IEC—it's about ensuring that the technology we depend on functions reliably and safely. This paper explores how EMC can be brought to life through interdisciplinary teaching, hands-on projects, and the creation of a dedicated course accessible even to non-EE majors. By sharing real-world examples and lessons from project-based learning, we hope to inspire a more human-centered, practical, and future-ready approach to engineering education.

Keywords: Electro-Magnetic interference (EMI), Electro-Magnetic compatibility (EMC), multidisciplinary, NEP2020 compliances, project-based learning

1. Introduction:

Modern engineering education is undergoing a transformation, especially within India's NEP 2020 framework, to better reflect the interconnectedness of technology, society, and the environment. Today's students need more than just technical knowledge—they need the ability to think globally, collaborate across disciplines, and adapt to rapid change. As our electronic systems shrink in size but grow in complexity, the importance of electromagnetic compatibility (EMC) and interference (EMI) becomes more than a technical issue; it becomes a matter of everyday reliability, user safety, and social responsibility.

The rise of tools like Artificial Intelligence (AI) and Machine Learning (ML) for predictive modeling in EMC, together with ever-evolving regulations, makes this subject relevant and urgent. Building bridges between academia and industry—through guest lectures, collaborative projects, and internships—helps keep the curriculum dynamic and meaningful. Real-world examples, current research, and industry best practices will anchor the course, ensuring that students not only gain theoretical knowledge but also develop practical skills and a strong professional network. In this way, EMC education becomes a vibrant, learner-centered journey rather than a static set of rules.

Today's industries demand engineers who are not only specialized in their core fields but also possess awareness and skills that intersect across multiple disciplines. For instance, an embedded systems engineer must understand not just software and digital hardware, but also how EMI affects signal integrity and power supply performance. Similarly, a robotics engineer working on motor drivers or wireless modules must ensure EMC compliance to avoid malfunctions. The integration of EMI/EMC studies provides the foundational understanding required to design such robust, interference-resilient systems. This paper positions EMI/EMC studies not as peripheral electives but as core components of modern engineering education.

2. The Technological Context for EMC Education

Technological advancement has pushed systems toward faster data transmission and broader bandwidths. Simultaneously, electronic devices such as switching power supplies, variable frequency drives, mobile phones, computers, and IoT devices are becoming omnipresent. These devices can be both sources and victims of electromagnetic interference. In real-world applications, failure to account for EMC often leads to malfunction, increased product development cycles, and additional certification costs.

A strong foundation in EMI/EMC principles is essential for ensuring that these devices:

- Operate reliably in their electromagnetic environment,
- Do not interfere with the operation of other equipment, and
- Comply with national and international regulatory standards.

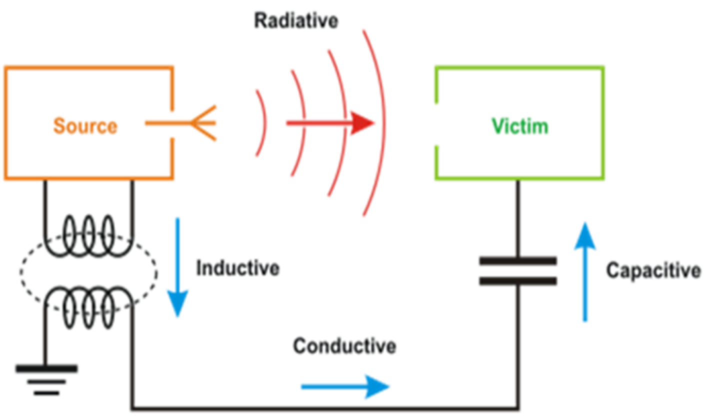

Fig.1 Typical Scenario of Electromagnetic interference Source and Coupling

Electronic design is no longer cod to just functionality; it now extends to operational reliability in diverse electromagnetic environments. Regulatory bodies such as the FCC, CISPR, and BIS in India mandate EMC compliance for most categories of electronics. Without proper EMC design, devices may fail certification, delaying market entry and increasing development costs. Moreover, non-compliance can lead to customer dissatisfaction, brand damage, and safety risks. Therefore, understanding EMI coupling mechanisms as shown in Fig.1, designing effective filters, grounding and shielding strategies, and following layout best practices are no longer advanced topics but baseline competencies expected from graduate engineers.

This scenario places an urgent need for academic institutions to align their teaching content with industry expectations. While subjects like communication systems, signal processing, and power electronics are regularly updated to reflect technological advances, EMC education remains neglected or sparsely touched upon in these syllabi. Thus, academic reforms that prioritize EMC education are critical to bridging the gap between education and employability.

3. EMC: A Multidisciplinary Educational Gap

Modern electronics and electrical engineering demand expertise in a variety of core areas including circuit analysis, signal processing, control systems, and electromagnetics. However, despite its cross-cutting nature, EMC is seldom taught as part of the standard undergraduate syllabus. As a result, new graduates often enter the workforce lacking essential EMC knowledge, learning on the job through trial-and-error, leading to:

a. Increased design costs,
b. Delayed product development cycles,
c. Reduced competitiveness for companies.
d. Low credentials for other products also

This educational gap is especially pronounced in emerging areas like automotive electronics, industrial automation, defense electronics, and medical devices, where system reliability and certification are non-negotiable. Engineers lacking EMC training may create designs that emit or are vulnerable to interference, resulting in expensive redesigns. On the other hand, companies end up investing heavily in post-hire training and debugging, which could have been minimized with proper academic exposure. Moreover, the general perception among students that electromagnetics is a difficult and abstract subject often leads to reduced engagement. Introducing EMC through practical, project-based activities can counter this disengagement by showing real-life applications. EMC projects can involve measurements with spectrum analyzers, layout simulations, and filter design experiments—each helping reinforce abstract theory with tangible outcomes. This dual-pronged approach enhances both theoretical understanding and practical design skills.

3.1. Justification for Curriculum Integration

Given its broad applicability, EMC should be introduced not just as a standalone course but also as an integrated theme across various subjects. Key arguments for curriculum integration include:

(i) Reinforcement of electromagnetics through real-world applications,

(ii) Increased student interest via practical and industry-relevant examples,

(iii) Better preparedness for EMI/EMC compliance in future design roles.

Integration strategies can include embedding EMC case studies in power electronics, introducing layout best practices in digital design, or adding filtering assignments in analog circuits courses. By doing this, students begin to internalize EMC principles as part of good design practice rather than isolated knowledge. Additionally, this integration encourages interdisciplinary collaboration, for instance between electrical and mechanical students in casing and shielding designs, or with computer engineers in firmware-based EMI mitigation.

Furthermore, by normalizing EMC as a design constraint across all courses, students develop a systems-level view of engineering. This aligns well with current trends toward system engineering, model-based design, and digital twins, all of which require interdisciplinary thinking. Institutions can further support this integration by offering certifications, elective modules, and industry-led guest lectures in EMC to keep content updated and relevant. The integration can be achieved through:

I. Projects and case studies involving EMC challenges,

II. Simulations of EMI effects and filtering techniques,

III. Laboratory sessions with tools like spectrum analyzers, LISNs, and EMI probes.

IV. Anechoic chamber based experiments on radiated susceptability

There are limited facilities available for anechoic chambers, NABL accredited labs and knowledge of required standards to comply before any product is launched in the market. This shortcoming leads to poor quality equipment and performance. In defence and critical sector, standards are met under strict supervision of experts, but those expertise is also home grown, thus the need of such course at undergraduate level itself will create awareness and sensitisation during design level itself. These data can further be trained in machine learning tools to reduce experiments later. It can help in generating vast data sets on vulnerability threshold of wide range of circuitry/gadgets with respect to power or field and frequency.

3.2. Proposed EMC Course Outline

The new course should outline the fundamental concepts of EMC, including types of EMI, EMC standards (CISPR, IEC), and the basic principles of electromagnetic theory relevant to EMC. Methodologies for embedding EMC principles in existing core courses (e.g., circuit analysis, signal processing, wireless communication) will be easier than treating EMC as a standalone subject using books or reports as listed in references [1-6]. This integration facilitates early and continuous exposure to EMC concepts. To address the curricular gap, a foundational course on EMC should be developed for upper-level undergraduates and interested non-EE majors. A suggested course outline could include:

Module	Topic
1	Fundamentals of Electromagnetic Fields
2	EMI Sources and Coupling Mechanisms
3	EMC Standards and Compliance Requirements
4	Shielding, Grounding, and Filtering Techniques
5	EMC in PCB and System Design
6	Measurement Techniques and Instrumentation
7	EMC Case Studies in Consumer and Industrial Electronics
8	Mini-Projects and Simulation-Based Assignments

This course should emphasize hands-on learning, using simulation tools like CST, HFSS, Altium Designer or SPICE, and promote interdisciplinary collaborations. Each module should involve both theoretical and hands-on components. For example, measurement modules could have lab sessions with signal generators, LISNs, and spectrum analyzers. Layout modules could use simulation software and comparison with built in standards of CISPR, FCC, IEC etc. Table-1 indicates a few standards applicable to various industrial products for complainces.The course should also include team-based projects for such product to test and verify such as EMC testing of a home appliance or designing a compliant IoT device, encouraging teamwork and problem-solving.

Table 1: A few industrial products and relevant standards for Qualification

Lightening products	Industry, Scientific and Medical (ISM) Products	Automotive Products
CE Marking - EU /30, EU/RED/53 Emission – CISPR 15 CE, RE, Harmonics, Flicker Immunity ESD, RS, EFT, Surge, CS, PFMF, Voltage Dips	CE Marking - EU /30, EU/RED/53 Emission – CISPR 11 CE, RE, Harmonics, Flicker Immunity ESD, RS, EFT, Surge, CS, PFMF, Voltage Dips	CE Marking - EC 10 / AIS 140 – AIS 004-3 Emission – CISPR 25 / ESA CISPR 12 CE, RE, Harmonics, Flicker Immunity ESD, RS, EFT (Pulse), Surge, CS

Assessment methods could include quizzes, lab reports, compliance audits, and a final project presentation. Guest lectures from industry professionals and certification opportunities from bodies like IEEE EMC Society or inter/intra university competition on EMI troubleshooting can further enhance the value of the course.

4. Cross-Disciplinary Relevance

While EMC is rooted in electrical and electronics engineering, it is increasingly relevant to students from mechanical, computer science, instrumentation, and even biomedical disciplines. Topics such as electromagnetic shielding, PCB layout design, or signal integrity are essential in robotics, autonomous systems, medical electronics, and embedded systems. Therefore, the proposed course should be designed with flexibility to accommodate students from varied engineering backgrounds. The structure of a dedicated EMC course, covering topics like emission and susceptibility, coupling mechanisms, and design for EMC. This course could serve as a capstone, integrating knowledge from various disciplines. Potential challenges in adding EMC to the present engineering curriculum include time constraints and prerequisite knowledge. For that suggested solution is modular course design emphasizing cross-disciplinary faculties [7]. The devices used in different sector need different standards to be qualified as listed in Table-1, before implementation for consistent performance.

In mechanical engineering, understanding EMI shielding materials and structural impacts of grounding techniques can be crucial. In biomedical applications, where safety and precision are critical, EMC becomes a compliance necessity. Computer science students working on embedded firmware or high-speed interfaces benefit from understanding how code and clocking can affect

EMI. This breadth of relevance justifies the inclusion of EMC principles not only in electrical engineering curricula but also as electives or modules within broader multidisciplinary programs.

Additionally, the growing trend of multidisciplinary capstone projects presents an excellent opportunity to embed EMC considerations from project conception to delivery. This helps students think beyond isolated components and promotes system-level awareness—a skill highly valued in the industry.

5. Lessons from Project-Based Learning

The importance of practical experience will be more visible, through labs, projects, and the use of simulation tools (e.g., ANSYS HFSS, CST Studio Suite) in understanding EMC challenges and solutions. Propose of incorporating case studies and real-world examples in teaching to illustrate the application of EMC principles in various industries e.g., automotive, aerospace, consumer electronics. In project-driven environments, students who engaged in real EMC problems developed deeper conceptual clarity and industry-relevant skills. Projects included typically:

- Designing EMI filters for power supplies,
- Investigating crosstalk in PCB traces,
- Simulating the effect of shielding materials.

Project-based learning not only enhanced understanding but also sparked innovation and critical thinking. For instance, teams experimenting with 3D printed enclosures explored the EMC impact of different polymer blends. Another group designed an open-source LISN for educational labs. These projects fostered creativity, collaborative learning, and a maker mindset—attributes that align with the NEP 2020 vision for higher education. Moreover, the feedback from students involved in such projects indicated increased confidence in handling real-world EMI/EMC challenges. The iterative design process—build, test, fail, and redesign—mirrors actual engineering workflows, preparing students for professional roles in R&D, product development, and compliance engineering. These experiences highlighted:

A. The pedagogical value of hands-on EMC education,
B. The effectiveness of simulation tools in reinforcing theory,
C. The ability of interdisciplinary teams to tackle complex system-level EMC challenges.

The education of 21st century students has to be learner's centric and future need based. Such skill will empower them to look for career as independent circuit or system designer, problem solver and team person as and when needed. This pedagogy of teaching and peerogogy of learning will ensure in-depth understanding of the subject EMC, importance of the EMI issues and application across the disciplines for reliable performance of system or devices.

6. Conclusion

Electromagnetic Compatibility is no longer an optional subject in the age of interconnected and high-speed electronics. Its inclusion in the engineering curriculum is essential to develop industry-ready graduates who can design robust, compliant, and competitive systems. This paper calls for both the integration of EMI/EMC topics across undergraduate engineering courses and the establishment of a dedicated introductory course. Through multidisciplinary collaboration on hands on learning of various systems and devices, future engineers can be equipped with the necessary tools to navigate the increasingly complex electromagnetic environment of modern technology.

By fostering EMC literacy early in engineering education, institutions can contribute to national goals such as Digital India, Make in India, and global competitiveness. As devices become smarter and more connected, EMC knowledge will become a foundational pillar of engineering excellence, safety, and sustainability

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