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The Fundamentals of EMC (EMC 101)

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Abstract

Electromagnetic Interference (EMI) is an ever present threat to the electrical and electronic systems in our world today. Protection from EMI and ensuring that the new generations of devices do not become inadvertent threats is the main goal of Electromagnetic Compatibility (EMC). This article will explore the fundamentals of EMC and EMI, providing definitions and understanding to this increasingly important concept.

Keywords

Electromagnetic Compatibility (EMC) — Electromagnetic Interference (EMI) — RF Coupling — RF Shielding — Global EMC

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What's the Difference ...?

Electrical devices convert electrical energy into other forms of energy, such as heat, light or sound. An electric hotplate is a good example of an electrical device as it converts electrical energy into heat for cooking.

Electronic devices, such as microprocessors, diodes, and integrated circuits (to name a few), control the flow of electrons to complete a task. Electronic devices play a critical role in modern computer systems and mobile phones.

Introduction

In today's increasingly connected world, preventing disturbance from electromagnetic sources (EM) is becoming more important. Electromagnetic compatibility (EMC) focuses on preventing these disturbances through careful design, ensuring that the device does not suffer from (susceptibility) or radiate (emit) EM signals which could inhibit the operation of other devices. But before EMC can be discussed further, the concept of electromagnetic interference, EMI, needs to be understood since it is the very thing that EMC works to prevent.

1. Electromagnetic Interference (EMI)

Electromagnetic interference (EMI), sometimes known as radio frequency interference (RFI), is unwanted noise or inhibition along an electrical path or circuit caused by an outside source. It can cause the electrical or electronic device that it affects to malfunction, operate inefficiently or even stop working completely.

Electromagnetic interference (EMI) occurs because of the close relationship between electricity and magnetism. All electrical flow, such as the current found in electrical power, produces a magnetic field. Similarly, any moving magnetic field produces an electrical current. These

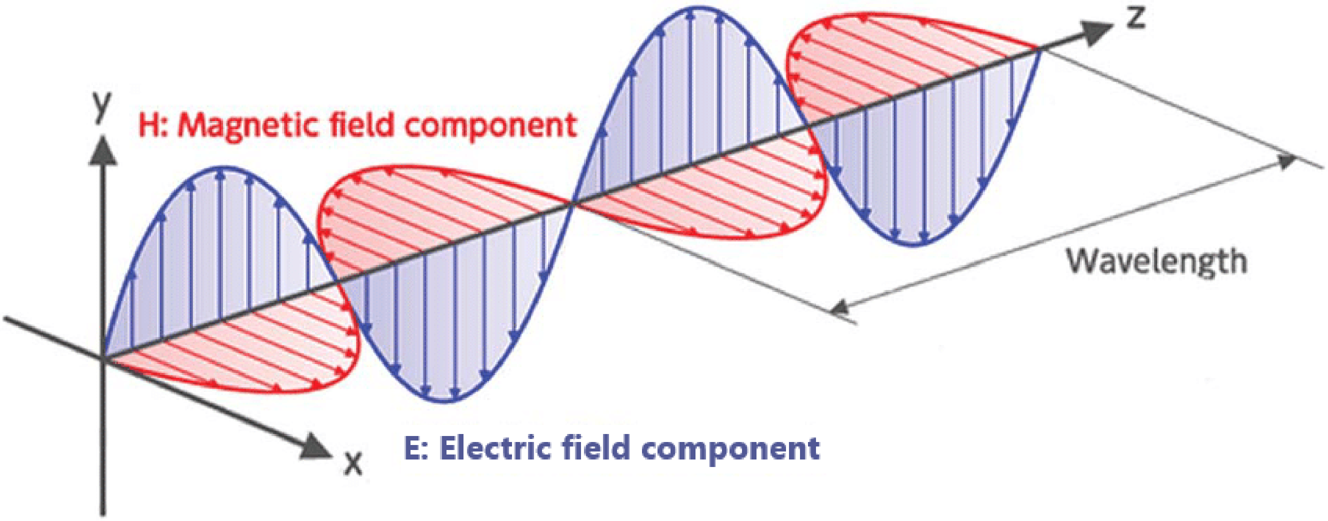

Figure 1. A schematic diagram of an electromagnetic wave propagating along the z-axis, showing the electric (E-field) component, the magnetic (H-field) component and wavelength, λ [1].

fields and currents can pass through conductors as well as propagate through the air, allowing them to be harnessed for electrical power as well as data transmission, for example via mobile phone and Wi-Fi signals.

Did You Know . . .?
It is the intrinsic link between electric and magnetic fields that allows electric motors and generators to work. The current flow through the wires of a motor causes a magnetic field around the wires, which then is repelled / attracted by the surrounding magnet, causing the motor to spin.

Electric and magnetic fields, for the reasons mentioned above, are part of the same phenomenon, an electromagnetic (EM) wave, shown in figure 1. EM waves have a wavelength (the physical distance between identical points in adjacent cycles of a wave, e.g. between two peaks), λ, and frequency (how many cycles the wave completes per second), f, associated with them. All EM waves travel at the speed of light (c), so these quantities are linked by:

$$\lambda = \frac{c}{f} \tag{1}$$

The wavelength of an EM wave dictates the scale of the conductors it can interact with, with the frequency determining what purpose the EM wave is used for, e.g. visible light has a frequency of 400 - 790 THz, which is detectable by the human eye and thus these EM waves are used for vision. As an example, a Wi-Fi signal is often emitted at around 2.4 GHz, which corresponds to a physical size of the order of 12 cm. This can be detected by an antenna that is $\approx 30mm$. Higher frequencies have even shorter wavelengths. Consequently, distant radio sources and high powered electrical sources can impact devices far away, causing EMI.

All electrical conductors can operate as radio antennas. As electronics become smaller and more sensitive, devices become miniaturised (reducing the spacing between components), and signal frequencies become higher, our technology is becoming increasingly susceptible to EMI.

1.1 Sources

There are a wide range of sources that can cause EMI, and with the world becoming increasingly connected, the list of sources will continue to grow. Sources of EMI can be loosely split into two categories, human-made or natural. Human-made sources can then be further subdivided depending on their origin and it is common for human made sources to be categorised into industrial or residential/domestic.

Industrial sources of EMI can affect devices

Figure 2. An image of some of the natural causes of Electromagnetic Interference (EMI). The Aurorae Borealis and Australis (L), Lightning Strikes (C) and Solar Flares (R) are some of the most visually stunning and exciting phenomena in the universe and are all manifestations of EMI [2].

across a large distance owing to the significant power being used in this technology. Even helpful sources of electromagnetic emissions, such as signals from cellular towers and satellite communication networks, can cause interference to certain devices if they are not adequately shielded. High voltage power lines, industrial electric motors and generators, TV and radio broadcast transmitters and even medical imaging systems can all be sources of EMI.

Residential sources of EMI are commonly electronic devices in the home, especially those that operate with a wireless signal, such as mobile phones, laptops, smart speakers, fluorescent lightbulbs and microwave ovens. Often they do not cause significant damage, but given the multitude of these devices found in our homes, there is the potential of more widespread disruption.

Natural sources are some of the most spectacular phenomena in the universe. Solar flares, lightning and the Aurorae Borealis and Australis - the Northern and Southern Lights - (see figure 2) are all naturally occurring examples of EMI. Less spectacular, but still hazardous to electrical and electronic devices are thunderstorms, static electricity and atmospheric electrical storms.

1.2 Risks

EMI poses risks to both human health and electrical and electronic devices. According to the World Health Organisation, [3], the effects of exposure to electromagnetic fields are only a risk if the human body is exposed to very high EM fields for a prolonged period of time. The daily levels of exposure to EM fields in the home show no obvious detrimental effects to health. There is no evidence to conclude that exposure to low level EM fields is harmful to human health.

Did You Know ...?

Mobile phones are only allowed to be used on aeroplanes in flight mode. The reason for this is that planes use RF signals emitted from beacons on the ground to track their progress and maintain their course. There are concerns that interference caused by the polling and signals from mobile phones on board could confuse the GPS and navigation systems on board the plane and cause it to go off course. There are also concerns that these same signals could interfere with the operation of some of the critical systems on the plane, inhibiting their normal operation.

To electronic devices, though, exposure to EM fields can be a different story. The most visible effects of EMI can cause devices to malfunction, fail, stop working altogether and even experience damage. The unwanted power that is present in the system, in the form of stray voltages or currents, in the most extreme cases can cause overload, potentially causing physical damage to the system. Other manifestations of EMI include distortion and reduced intelligibility on communications systems, range and angle errors in navigation systems and difficulties with range and tracking using radar systems.

Another, more subtle, consequence of EMI, is the risk of data being compromised and eavesdropping. In these cases, it is not so much the EMI causing the system to misbehave, more the system emitting EMI that is the threat. As current passes through electronic components and wires, EM waves are generated, which can be detected by other devices if not adequately shielded. The result is that sensitive or confidential data can be stolen from devices and even viewed in real time without the need for a physical connection.

2. Electromagnetic Compatibility (EMC)

Electromagnetic compatibility, in it's most distilled form is the prevention of EMI. More commonly known as EMC, it fundamentally focuses on ensuring that all electrical and electronic devices and systems operate as they are designed to, without being inhibited by other EM sources.

EMC ensures that each device or system:

1. Does not interfere with their environment (emissions)
2. Does not have its operation disrupted by the environment (immunity)
3. Does not interfere with itself or its own operation (signal integrity) [4]

The manner in which an electronic device or system may interfere with itself or surroundings will depend on how the EM waves propagate from the source, a process known as coupling.

2.1 Coupling

One definition is that interference is the unwanted transference of energy from a source to a receiver (victim) via some coupling path. These coupling paths can take the form of physical transmission (or power) lines or radiated signals. The victim device is the device whose normal operation is affected by the interference and the source is the system that emits the interference. Any device that uses electricity can be an unintentional source or victim.

The transference of this unwanted energy occurs via a coupling path. The most common coupling paths are inductive coupling, capacitive coupling, conducted emissions and radiated emissions, as depicted in figure 3.

- **Conducted Emissions** are transmitted away from the source along a physical path from the source to the victim device. Often this takes the form of power transmission lines.
- **Radiated Emissions** come in two forms, *narrowband EMI*, which only affects a specific radio frequency, and *broadband EMI* affecting a larger portion of the EM spectrum. Narrowband EMI usually originates from some form of radio transmitter, whereas broadband EMI commonly is caused by malfunctioning or poorly designed equipment. Radiated EMI emissions are the likely cause if the source and victim are far apart, though source and victim can also be close together. Radiated emissions propagate through the air from the source to the victim device. The victim device does not need an antenna to pick up the radiated EM wave, as every conductor has the potential to be an antenna.
- **Capacitive Coupling** most commonly occurs on circuit boards or groups of closely packed wires. When two conductors are parallel to each other, very close together, and store a charge between them. This coupling is a manifestation of the EM phenomenon of capacitance, where a potential difference is created between the two sides of the capacitor (in this case the two conductors) and when the potential difference is large enough, the charge can transfer from one conductor to the other.
- **Inductive Coupling** is caused by the magnetic field of a conductor and is a manifestation of electromagnetic inductance. The magnetic field of one conductor (caused for example by the flow of charge in a power cable) induces an unwanted current in a nearby conductor. This is quite often heard as the hum when a power cable and audio equipment are in close proximity. Another example of this is switching noise.

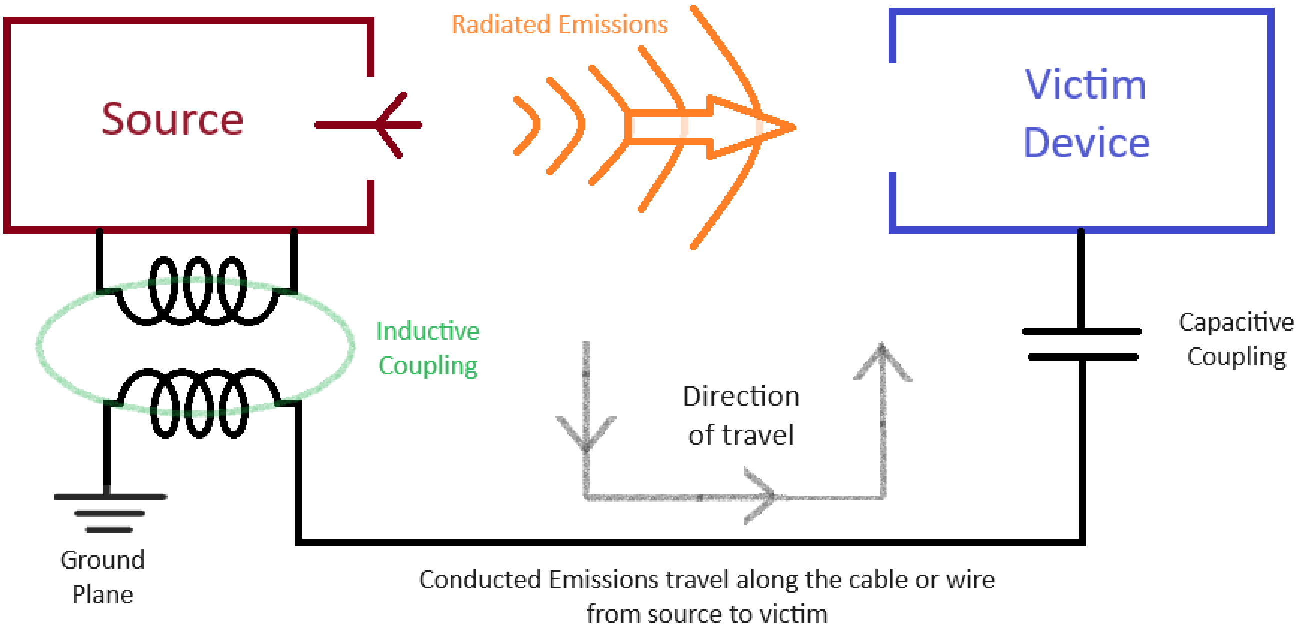

Figure 3. A diagram illustrating some of the possible coupling paths of Electromagnetic Interference (EMI)

2.2 Testing and Regulations

The cornerstone of EMC is good testing and regulation practices. The regulations and standards identify and standardise testing practices as well as define minimum thresholds of EMC and shielding that must be met. EMC testing focuses on 3 main areas:

1. **Emissions** - Testing ensures that stray EMI and EM signals emitted by a device do not cause high levels of unwanted noise in the environment. This does not include emissions that are there by design, such as from a WiFi router, since these can be accounted for by noting their frequency. This is in an effort to minimise the risk of EMI to other devices.
2. **Immunity** - Immunity testing involves bombarding the equipment or device under test with EM signals to ensure that there are no adverse effects if EMI is incident on the device.
3. **Signal Integrity** - Signal integrity is most common in electronic devices with printed circuit boards (PCBs) and wires that are closely spaced. It focuses on ensuring that these paths do not interfere with each other, and can often be ensured in the early design stages through detailed and thorough simulation.

Regulations . . .
Depending on the application of the electronic device or system, there are a number of different standards that it could be tested against. These, along with their associated testing procedures, are set and reviewed at regular intervals by committees of field experts and industry leaders. The more difficult to achieve standards, such as TEMPEST, are often costly, and often excessive for everyday, so less strict, but still worthwhile, standards are also offered, The tests still need to be performed by an accredited tester though.

The vast majority of EMI issues can be prevented using adequate RF shielding. Good EMC design should use RF shielding to protect from both emitted and incident EMI, be it shielding the wires, device or encasing the equipment in a shielded enclosure.

An RF shield is made of materials with high electrical conductivity, such as metals. When an EM field is incident on a complete shield, the free electrons in the material immediately reconfigure themselves to generate a secondary, opposing EM

Figure 4. An image of a Faraday cage protecting people from a high voltage discharge from a Tesla coil. Source: sciencefacts.net.

field. The shielding material must surround the potential victim, mirroring a complete circuit, for the EM field to be cancelled out inside the enclosure.

A Faraday cage is one example of an RF shield. It is often used to demonstrate the concept of shielding from electromagnetic fields in quite spectacular fashion (see figure 4). It demonstrates that, with adequate electrical conductivity, even high voltages can be prevented from passing through.

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Some Useful Terminology

In the world of Electromagnetics and EMC there are a number of abbreviations and terms that can often cause confusion or misunderstanding. Some of the more common terms and phrases are presented in the mini glossary below:

DUT **D**evice **U**nder **T**est - The electronic / electrical apparatus being tested for emissions and/or susceptibility in the chamber. In other words, the household appliance or gadget that is being checked to make sure that it is safe before being distributed around the world.

EMC - **E**lectro**m**agnetic **C**ompatibility.

EMI - **E**lectro**m**agnetic **I**nterference.

EUT **E**quipment **U**nder **T**est - Another expression for DUT (see above) more commonly reserved for larger items or systems.

PCB - Printed Circuit Board.

RF **R**adio **F**requency - The part of the electromagnetic spectrum that lies between 3 kHz and 300 GHz.

Source - The device that is emitting the noise / interference that is causing the malfunction of another device.

Susceptibility - The tendency of an electrical / electronic device (the victim) to malfunction or break down in the presence of EMI.

Victim - The device (receiver) that is interfered with. In other words, the device whose normal operation is impacted by EMI.