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Study on Electromagnetic Interference (EMI) and Electromagnetic compatibility (EMC): Sources and Design Concept for Mitigation of EMI/EMC

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Abstract:

Electronics is preoccupied with the advancement of modern technology. Electrical and electronic technology is extremely significant in the twenty-first century, from household appliances to military. Electromagnetic emissions are increasing as the use of electrical and electronic instruments and devices grows. As a result, the problem of electromagnetic interference is becoming increasingly significant. When it comes to regulatory testing of electronic components and consumer goods, the words electromagnetic interference (EMI) and electromagnetic compatibility (EMC) are frequently used interchangeably. They are easily confused since they are connected in so many ways.EMI, on the other hand, is an electromagnetic or electrostatic disturbance that causes a malfunction or an unwanted response in one or more electronic systems, equipments, devices, circuits, and so on. As a result, electromagnetic interference is a major concern for both maintainers and users. As a result, the idea of EMC is the capacity of equipment and systems to work as intended in their intended operational electromagnetic environment without degradation or malfunction. It is an analytical work that evaluates EMI/EMC in general, as well as the sources and techniques for mitigating the EMI problem and the PCB design concept.

Key Words: Interference, RFI, EMI, EMC, PCB, bonding, shielding, filtering

Introduction

Electromagnetic interference, often known as radio frequency interference (RFI), is a type of disturbance that occurs in an electrical circuit as a result of electromagnetic conduction or electromagnetic radiation released from an external source. The growth of mobile electronic systems, wireless communication systems, and computer networks has exacerbated EMI issues.[1] **The interference induced by electrical and magnetic fields is known as EMI. When an electronic or electrical device's electromagnetic field interferes with another device, EMI interference occurs. EMI interference occurs only when both the electrical and magnetic fields are present. When two or more signals travel in parallel, they create an electric and magnetic field and emit electromagnetic waves. The electromagnetic waves of one signal may interfere with those of other signals, and vice versa.**[2]This is known as Electromagnetic Interference (EMI).[3]Such a disturbance may damage the performance of the circuit or perhaps cause it to fail. These consequences can range from an increase in mistake rate to total data loss in the case of a data path.[4] Man-made and natural sources also generate shifting electrical currents and voltages that can cause EMI, such as ignition systems, mobile phone cellular networks, lightning, solar flares, and auroras or northern/southern lights.[5]AM radios are frequently affected by EMI. It can also affect mobile phones, FM radios, and televisions, as well as radio astronomy and atmospheric science observations.[6]EMI can be purposely employed to jam radio signals, as in electronic warfare.[7]

Electromagnetic compatibility (EMC) refers to a system's capacity to function as intended, without malfunction or unacceptable deterioration of performance owing to EMI in its operating environment. As a result of EMI, any electrical, electromechanical, or electronic equipment must not impair the operation of any other equipment or system, and vice versa.[8] To minimize or suppress electromagnetic interference (EMI) in electronics, a few basic system components are routinely utilized. It is critical to understand what these components are, what they perform, how they work best, and when they are unsuccessful. Capacitors, Common Mode Chokes, Diodes, EMI Filters, Ferrites, Inductors, Resistors, and other system components are utilized to minimize EMI.[9]The harmful consequences of interference from both intentional and inadvertent transmissions have been felt from the early days of radio communications, and the need to control the radio frequency spectrum became apparent.[10]

A meeting of the International Electro-technical Commission (IEC) in Paris in 1933 suggested the formation of the International Special Committee on Radio Interference (CISPR) to deal with the emerging problem of EMI.[11]For instance, CISPR 22 is analogous to European standard EN 55022. This is the standard that is frequently cited in all European EMC standards, describing measurement methods, measurement equipment, limit lines, and interpretation of limit line application, ranging from household appliances to medical devices.[12]Following that, CISPR published technical documents on measuring and testing procedures, as well as suggested emission and immunity limits. These have evolved over the years and serve as the foundation for many of the world's EMC standards today.[13]

Ships, submarines, and aircraft are now merely platforms for a plethora of highly sensitive and complicated electronic weapons and communication systems. Interference from electromagnetic sources has been a concern onboard vessel due to the near proximity of equipment such as converters, power panels, microprocessors, radar antennas, and so on.[14]There are also kilometers of cables and similar radiators and emitters. Coupling between different antennas and conductors contributes to a variety of unwanted and uncontrolled electromagnetic fields. Because of these complications, EMI can no longer be overlooked in ensuring the success of any mission or operation. In general, equipment defined with compatibility regulations such as US Standard Federal Communications Commission (FCC), US Military Standard MIL-STD-461E, and CISPR[15] should be installed on a marine/naval platform under development [16], etc. However, occasionally the compatibility of that marine/naval platform's equipment is never tested during its whole life cycle. Furthermore, vessels are repaired, components are replaced, shielding is added, changes are made, and many linkages and junctions are exposed to the elements. Earthing efficiency also decreases over time. As a result, attaining EMC is a major concern onboard ship. EMC must be achieved onboard naval ships and marine platforms through design, production, maintenance, training/awareness, and the use of military standard/EMC standard equipment. It is an analytical paper on EMI/EMC and control methods.There is a wealth of material and literature on EMI/EMC available in libraries and on the internet. Few studies on accessible documentation and procedures on EMI/EMC have been conducted. This study goes into the history of EMC and shipboard EMI sources. As we all know, EMI has negative consequences, thus my main focus will be on sources, negative effects of EMI, problem mitigation, circuit/PCB design concept, and so on. It is an analytical article that evaluates EMI/EMC in general, the sources and techniques for mitigating the EMI problem, and the optimum PCB design concept to handle the concerns.

History and Chronological Development of EMC/EMC

In the late 1880s, the German physicist Heinrich Hertz conducted experiments that demonstrated the concept of radio wave transmission. As shown in Figure 1, Hertz created a spark in a small gap between two metal rods that were attached at the other end to metal plates. The spark excitation produced an oscillating current on the rods, resulting in electromagnetic radiation at the antenna's resonance frequency. The presence of a spark in the gap indicated the presence of a timevaryingfield, and the maximum spark gap length supplied a measurement of the strength of the received field.Guglielmo Marconi, a radio pioneer, invented the wireless telegraph in 1859. This was the first communication gadget that sent data using radio waves. The significance of this invention was not recognized by the general public at the time, as it is today. The United States Military, on the other hand, saw immense promise in its usage as a communication device for their ships. In 1899, the United States Navy began employing wireless telegraphs and met one of the first recognized EMC difficulties. Because the transmitters were all tuned to the same operating frequency, no discernible information could be received when more than one transmitter was operational at the same time. This is known as Radio Frequency Interference (RFI).[17]

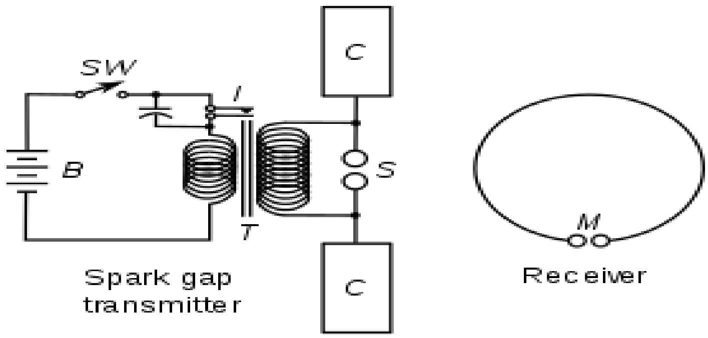

Fig 1: Early antennas constructed by Heinrich Hertz[18]

In 1904, US President Theodore Roosevelt issued an executive order authorizing the Department of Commerce to regulate all private radio stations and the Navy to supervise all government stations as well as all radio stations during wartime. To decrease the risk for RFI, different types of radio transmitters were granted different frequency allocations and were frequently only allowed to operate at specific hours. By 1906, various spark-quenching methods and tuning circuits were being used to dramatically limit the bandwidth of wireless transmitters and receivers. Later, in 1912, the vacuum tube oscillator was invented, and in 1918, the super heterodyne receiver was invented, allowing for truly narrow band transmission and receiving.These advancements also enabled the transmission of reasonably intelligible human speech, paving the path for commercial radio broadcasts. The golden age of radio was from approximately 1925 until 1950. Radio's popularity skyrocketed throughout this time period. As the number of radios increased, so did electromagnetic compatibility issues. Because the restrictions controlling intentional or unintentional interference with a commercial radio broadcast were low and more people had access to radio equipment, RFI was a prevalent problem. To address this issue, the Federal Communications Commission (FCC) was founded in 1934 as an independent body of the United States Government.

In fact, the EMI area was quietly recognized in 1933 by a sub-committee of the IEC in Paris called CISPR in an effort to better comprehend the long-term issues that could come from radio frequency technology. Radio's popularity had exploded since its founding in 1820 by Morse, Henry, and Vail, becoming a must-have household appliance during the Depression, but intentional and unintentional RF transmissions began affecting other electrical systems, and as a result, awareness of EMI began to grow within the electronics community.[19]However, in 1934, CISPR began developing and disseminating guidelines for recommended allowed emissions and immunity limits for electronic devices, which have since evolved into the majority of the world's EMC rules. Throughout the 1960s, 1970s, and 1980s, researchers became increasingly concerned about electromagnetic interference. The United States military produced Mil Standard 461A in 1967, which specified testing and verification criteria for electronic devices used in military applications, as well as emission and susceptibility limits for new military electronic equipment. Furthermore, the FCC in the United States placed regulatory restrictions on electromagnetic emissions from all digital equipment in 1979. These laws have evolved through time as systems have become faster, smaller, and more powerful, with a higher proclivity to interfere with the operations of other electrical systems. Top avionics and aerospace engineers studied EMI concerns to obtain a better knowledge of how noise is generated and how new systems might be constructed to decrease transmitting noise while also being able to endure certain degrees of noise from other sources.

As the number of radio receivers in houses increased, the general public was exposed to a slew of new EMC issues. Unintentional electromagnetic radiation sources including thunderstorms, gasoline engines, and electric appliances frequently caused more interference than intended radio transmitters. Intra-system interference was also becoming a source of worry. Automobiles, elevators, tractors, and airplanes all had radios installed. To make their products work, the designers and makers of these systems discovered that better grounding, shielding, and filtering techniques were required.[20]During World War II, new types of radio transmitters and receivers were created for military purposes. Radio signals were utilized for more than just communication; they were also used to find ships and planes (RADAR) and to jam hostile radio transmissions. Because of the urgency of warfare, no extensive testing was performed, and as a result, the equipment produced major EMC problems on ships and planes. The Navy issued the first RFI standard towards the end of the war, and EMC became a recognized engineering expertise. The Armour Research Foundation Conference on Radio Frequency Interference made its debut in 1954. The Electromagnetic Compatibility Society of the Institute of Electrical and Electronics Engineers (IEEE) still operates today as a result of this conference.[21]

Electronic equipment and systems were an increasingly significant aspect of society, and especially national defense, during the 1960s. For example, a typical aircraft carrier would include 35 radio transmitters, 56 radio receivers, 5 radars, 7 navigational aid systems, and well over 100 antennas. As a result, the issue of electromagnetic compatibility received increased attention. Outside of the military, an increased reliance on computers, satellites, telephones, radio, and television raised severe concerns about potential sensitivity to electromagnetic phenomena. The microprocessor was invented in the 1970s, and compact, low cost, low power semiconductor devices proliferated. Circuits that used these transistors were far more sensitive.[22]As a result, increased emphasis was placed on resolving a growing number of electromagnetic susceptibility issues that arose with these circuits. Electromagnetic susceptibility issues rose to prominence in the 1970s. Electrostatic discharge (ESD) is perhaps the most well-known of them.

Another electromagnetic susceptibility issue that gained prominence in the 1970s was known as EMP, or Electromagnetic Pulse. The military knew that a highaltitude nuclear weapon detonation would emit an exceptionally powerful pulse of electromagnetic radiation across a large area. This pulse has the potential to damage or deactivate vital electronic systems. To address this worry, a major effort was launched to create shielding and surge protection techniques that would protect essential systems in this extremely harsh environment.[23]The rising use of semiconductor devices has resulted in the formation of a third electromagnetic susceptibility concern, power line transient susceptibility (PLT). Another significant development that happened in the 1960s and 1970s was the progressive replacement of the term RFI with the more broad term EMI, or Electromagnetic Interference. Between 1980 and 1982, the FCC standards governing EMI from computing devices were phased in. The European Union developed EMC restrictions in the 1990s that went much beyond the FCC requirements. The European Union created regulations for these devices' electromagnetic immunity and defined processes for testing electronic systems' susceptibility to radiated electromagnetic fields, conducted power and signal line noise, and electrostatic discharge. [24]

Initially, most corporations chose quick, unwieldy shielded enclosure systems, nothing more than minimally effective Faraday cages, to handle the EMI problem. More savvy researchers from corporations seeking better long-term solutions to minimize the susceptibility of their sensitive electronic products to EMI used a more specialized, concentrated approach, integrating superior electronic designs and layouts, shielding and filtering when needed. This was accomplished by developing a variety of professional certification levels, including the Military Standard, to ensure electrical system compatibility in terms of radiated and conducted emissions and susceptibility. With the introduction of these standards, experts were able to easily find electrical systems that could be easily integrated into their own assemblies without worry of EMI difficulties.Today, as a result of tougher rules incorporated into the ever-expanding area of electronics, all equipment, particularly sensitive reconnaissance, medical, and avionics equipment, is significantly safer from the possibility of catastrophic failure owing to noisy EMI.[25]Again, while EMC laws are tremendously beneficial in expediting the creative process and general design safety, they do not immediately remedy systems that were designed without consideration for extraneous radio frequency fluctuations. Many modern systems are nevertheless vulnerable to EMI because they generate or receive interference in a variety of ways that might lead to failure. These issues are often addressed by a combination of electromagnetic fluctuation shielding devices and the use of filtering to eliminate unwanted and potentially hazardous radiation as EMI.[26]EMI noise concerns are approached more as a doctor approaches a patient than most forms of remedial engineering solution testing. The first phases are associated with gathering information or identifying obvious signs of the problem. During the assessment phase, we may consider using a Spectrum Analyzer with a near field probe to sniff around the outside and insides of the system to assist you identify where the noise is coming from, similar to how a doctor might take X-rays of an injury. Once we have a good assessment or diagnosis of the problem, we may begin treating it with simple remedies and work our way up to more sophisticated and expensive solutions or cures.

Sources of EMI

The electromagnetic spectrum is becoming more congested. Following that, the explanations are detailed; why electromagnetic interference occurs and how it impacts the system. The presence of an electrical field contributes to the levels of electrical and electromagnetic noise and interference in the surrounding environment. The growing demand for and reliance on electromagnetic transmission systems for information technology applications has resulted in the development of innovative communications capabilities such as cordless communication devices, wireless networking, and satellite communication systems. As the number of these devices grows, so does electromagnetic radiation within the electromagnetic spectrum segments in which these systems function.These emissions could disrupt the normal operation of electronic communication lines and systems. Environmental interference (El) refers to electromagnetic energy that interferes with the regular functioning or performance of electronic devices. El's source can be environmental (naturally occurring), inadvertent, or purposeful. Regardless of the source, the consequences of El can be severe; nevertheless, engineering design and other factors can be employed to limit the impact and disruption of El on electronic, communication, and information systems. [27]EMI is caused by undesired emissions that are either conducted (voltages or currents) or radiated (electric or magnetic fields). Three basic factors must exist for EMI to occur: an electrical noise (EMI) source, a coupling path, and a victim receptor. The path of coupling from a source to a receptor can be conducted (electric current), inductively coupled (magnetic field), capacitive coupled (electric field), or radiated (electromagnetic field).[28]

The shipboard RF environment, on the other hand, is a complicated blend of radiated electromagnetic radiation generated by various sources. For marine platforms, there are numerous onboard EMI contributors. There are deliberate or desirable RF energy radiators onboard, such as transmitters, radars, EW jammers, IFF transponders, and tactical air navigation (TACAN) homing beacons[29] etc.Radiators of RF energy that are not onboard but on some external platform serve as extraneous emitters. They generate incoming useful RF transmissions such as communications, navigation data, TDL, IFF, and so on from friendly external sources, extraneous RF transmissions or radar transmissions from nearby ships, and unwanted deliberate RF transmissions such as energy surveillance and jamming, and so on. They include natural RF sources such as lightning, cosmic and atmospheric noise, and so on.[30]Man-made sources of EM energy include unintended sources such as electrical machinery and components.

The rapid development of portable flexible electronic devices necessitates the creation of a multifunctional composite film with outstanding thermal management capability, high electromagnetic interference (EMI) shielding, and strong fire safety performance.[31]

EMI Problem and Its Effect

To diagnose an EMI problem, it is critical to establish the coupling path of EMI in addition to recognizing the sources. Typically, the source is recognized by studying the type of interference that is plugging the receiver. The coupling path, which connects the source to the victim via a radiated channel, a conducted path, or a mix of the two, is the most frequently missed component. An interference state does not exist in the absence of the coupling connection; so, breaking this path is required to achieve EMC. These phenomena are described further below.

- Conducted Emissions (CE): It is described as the flow of electromagnetic energy out of a device, equipment, or system (source) via the conducted path, i.e. via leads (wires or cables) emanating from the source. These emissions can affect the devices, equipment, and systems that are linked to these leads. To prevent EMI, the levels of these emissions should be limited in some way.
- Radiated Emissions (RE): This is the flow of electromagnetic radiation from a device, equipment, system (source), and so on. The radiated path can be through antennas, cables functioning as radiating elements, or apertures in the source's units, cabinets, or housing. These emissions can affect devices, equipment, and systems in the vicinity/path of these radiations. To prevent EMI, the levels of these emissions should be limited in some way.
- Conducted Susceptibility (CS): Conducted Susceptibility (CS) is the vulnerability or weakness of a device, equipment, or system (victim) to existing emissions via the conducted channel, i.e. conducted emissions generated by a source to which they are connected. This parameter describes the victim's Electromagnetic Vulnerability (EMV). To avoid the debilitating effects of EMI, the victim should be sufficiently 'hardened' electromagnetically.
- Radiated Susceptibility (RS): Radiated susceptibility (RS) is the ability of a device, equipment, or system (victim) to be influenced by existing emissions via the radiated path, i.e. radiated emissions emitted by some source in the area or path of which these devices, equipment, or systems exist. This parameter describes the victim's Electromagnetic Vulnerability (EMV). To avoid the debilitating effects of EMI, the victim should be sufficiently 'hardened' electromagnetically.

Medical equipment-generated electromagnetic interference can interfere with implanted cardiac devices such as pacemakers and implantable cardioverter-defibrillators. The most typical interaction is with electrosurgery in the operating room. Close communication between the cardiac-device specialist and the anesthesiology/surgical team to design a patient-specific approach that accounts for aspects such as device type, surgery type, and whether the patient is pacemaker dependent can often reduce the likelihood of complications. Although magnetic resonance imaging should not be used in patients with implanted cardiac devices in general, various published guidelines provide strategies and recommendations for risk management if magnetic resonance imaging is essential and no other diagnostic options are available.[32] EMI can be induced by both natural and man-made factors. EMI can be reduced by using high-quality electronics, electrical shielding, and contemporary error correction. When a mobile phone is placed near powered audio equipment or speakers, it produces a noise or series of beeps, which is an example of EMI. Because of the strong link between electricity and magnetic, EMI occurs. Every electrical flow generates a little magnetic field. A moving magnetic field, on the other hand, generates an electrical current. These principles enable electric motors and generators to function. Furthermore, all electrical conductors can function as radio antennas.[33]

High-powered electrical and radio sources might cause unintended effects in distant equipment. Electronics grow increasingly susceptible to these effects as they become smaller, faster, more densely packed, and more sensitive, resulting in EMI.[34]There are some natural sources that can generate powerful enough electric fields to impact electronic devices. Strong electrostatic discharges and magnetic pulses can be produced by lightning. Solar storms and solar flares produce highly charged particles, which can disrupt satellite and terrestrial communications. Bitflips in electronics have been linked to cosmic radiation.[35]

Human-made EMI can come from a variety of sources. Unwanted EMI can be caused by high-power radios and electrical sources. Consumer products that fail or are poorly designed might produce EMI in other devices. Using an electromagnetic pulse to deliberately generate EMI defects in victim equipment is another conceivable aggressive tactic.[36]Floodlights, for example, were highly popular on boats that had to work at night, and when the first LED light bulbs were introduced, they were viewed as a method to save money. Many fishing boats have switched from light bulbs to LEDs to conserve electricity. However, a few months later, accidents occurred because it was discovered that these LED lights were not very excellent in terms of EMC (Electromagnetic Compatibility) and messed up the navigation equipment, particularly the VHF channels.[37]In 1967, a military aircraft was revealed to ship radar, causing it to accidentally fire its ammo, striking another armed aircraft on the ship's outer deck. This was an EMI accident, as examinations revealed that a defective cable shield termination on the first aircraft created emissions that interfered with the radar and hence the aircraft's performance, causing it to misfire.[38]A small collision happened outside of United Kingdom (UK) waters between a supply vessel servicing a semi-submersible offshore oil and gas installation. The interplay of radio waves from a portable VHF radio and the joystick control caused the vessel to undergo a sudden power surge. This caused the joystick to perform orders that the operator had not requested, resulting in contact between the vessel and the installation. The encounter resulted in minimal harm.[39]Another example is when a US Navy vessel was at full power while sailing and then experienced an unexpected power outage. High frequency (HF) transmissions were discovered to cause an oil pressure sensor to mistakenly detect a low level. The incorrect indication generated a shutdown signal in the automated power control system before engineers could intervene.[40]The British ship H.M.S. Sheffield sank with high fatalities during the Falkland War after being damaged by an Exocet missile. Despite possessing the most sophisticated anti-missile defense system available, the Sheffield's system caused electromagnetic interference to radio communications to and among the ship's Harrier fighters. The missile defense was withdrawn due to EMI as the Harriers took off and landed, allowing communications with the planes and providing a window of opportunity for the Exocet missile.[41]

In 1987, an uncommanded stabilator movement occurred on an Army Sikorsky UH-60 Blackhawk helicopter as it flew past a radio broadcast tower in West Germany. There have also been reports of erroneous warning light readings and bogus cockpit warnings. Subsequent analysis and testing revealed that EMI from high intensity radiated fields (HIRF) was affecting the stabilator system. The fly control system on the Blackhawk is traditional mechanically connected with hydraulic help. The stabilator system, on the other hand, uses digital signals transmitted from the aircraft to automatically modify its position in relation to control and flight parameters.[42]These digital signals are extremely vulnerable to HIRF. Five Blackhawk helicopters crashed between 1981 and 1987, killing or injuring everyone on board. The chopper flew too close to radio transmitters in each crash. Long-term solutions included increasing shielding of vulnerable circuits and implementing an automatic control reset backup.[43]A Korean news website revealed in October 2011 that the S&T Daewoo K11 weapon burst after one of its 20mm grenades was discharged prematurely. The soldier manning the pistol had injuries to his hands and face. The Korean Defense Ministry identified the issue as electromagnetic interference from the Fire Control System. Because of a design flaw, the transmitter that transfers the trigger signal to the ammo fuse was not correctly repaired. When the shooter pressed the trigger just before shooting, it connected with an incorrectly positioned transmitter and sent the improper signal to the 20mm ammo fuse. In the barrel, it triggered a 20mm round explosion.[44]

High-intensity RF fields can harm humans, fuel, and ordnance. Hazards of Electromagnetic Radiation to Personnel (HERP), Hazards of Electromagnetic Radiation to Ordnance (HERO), and Hazards of Electromagnetic Radiation to Fuel (HERF). Electromagnetic energy interacts with human tissues to cause biologically damaging effects. The extent of damage is determined by elements such as intensity, frequency, high energy photons, polarization, time of exposure, and so on.[45]The following table shows how machineries and equipment onboard can be hazardous to human bodies according to their radiation level:

Frequency MHZ	Wavelength (cm)	Site of major tissue effects	Major biological effects
100	Above 200	Not established- Probably whole body	General warming of exposed areas (used in Diathermy)
150-1200	200 - 25	Internal Body Organs	Damage to Internal Organs from Overheating
1000-3300	30 - 10	Lens of the Eye	Lens of the Eye particularly susceptible and tissue heating
3300-10000	10 - 3	Top layers of the Skin, Lens of Eye	Skin heating with the Sensation of warmth
10-100 GHZ	Less than 8	Skin	Skin surface acts as reflector or absorber with heating effects
Damaging levels vary with frequency, ambient temperatures, and individuals. Safety criteria establish levels above 10 MW / cm^2 at any frequency as being unsafe.			

Table 1- Biological effects of microwave damaging levels [46]

The required efforts must be done to control the biological dangers posed by electromagnetic radiation.[47]Personnel management, equipment design, necessary limitations, and radiation fences are examples of these actions. Elevate radar antennas above work zones and include suitable interlocks on antenna elevation and azimuth controls to prevent antennas from being pointed at populated areas, such as deck level. When maintaining radar sets and it is not essential to radiate at the antenna, it is preferable to utilize a dummy load in place of the antenna. Enclose an antenna with a fence at a distance where antenna electromagnetic radiation exposure is safe for individuals who are not exposed. Extensive usage of warning signs in potentially hazardous locations.[48]High-intensity electromagnetic fields are produced by modern radio and radar transmitting equipment. Such fields can cause sensitive electric explosive devices (EEDs) in ordnance systems to be activated prematurely. Electromagnetic radiation can enter ordnance items by a hole or crack in their skin, or it can be carried into them through the use of firing leads, wires, screw drivers, fingers, and other devices.[49]In general, ordnance systems that have been shown to be susceptible to radio frequency energy are particularly vulnerable during assembly, disassembly, loading, and unloading, among other things.

The main threat from electromagnetic radiation to fuels exists when aircrafts are refueled on the decks of aircraft carriers near high powered radiating transmitting antennas. There are also risks when certain low vapor pressure fuels are transported in sealed trucks subjected to liquid agitation, which causes an electric charge build-up in the fuel and subsequent electrostatic discharge inside the tank, potentially resulting in an explosion if the internal mixture of fuel vapor and air is suitable.[50]The following special precautions should be observed to prevent or minimize the inadvertent ignition of fuels by electromagnetic energy:

- Fuel servicing equipment should be used and maintained properly to reduce the danger of spills.
- Radiating devices shall be installed such that they do not illuminate the area where fueling is in progress.
- Radar and other transmitting equipment should not be used when fueling or defueling.[51]

EMI Mitigation Techniques

To minimize or suppress electromagnetic interference (EMI) in electronics, a few basic system components are routinely utilized. It is critical to understand what these components are, what they perform, how they work best, and when they are unsuccessful. Capacitors, Common Mode Chokes, Diodes, EMI Filters, Ferrites, Inductors, Resistors, and other system components are utilized to minimize EMI.[52]However, ship and equipment design cannot always predict, mitigate, and prevent all potential interference conditions. As a result, EMI reduction techniques are critical for avoiding electromagnetic interferences. Bonding, grounding, shielding, and filtering are four important approaches. These four strategies are explained further below.

- **Bonding:** Bonding is the process of establishing a low impedance route for the flow of electric current between two metal objects. Bonds that are properly planned and executed minimize potential differences between locations in an electronic system's fault protection, signal referencing, shielding, and lightning protection networks. A good bond's job is to enhance the area for current flow, hence lowering bond resistance.[53] Bond DC resistance should never be greater than 2.5 milliohms and should be in the micro-ohm range. Bonding can be divided into two types. Direct bonding is the process of forming an electrical path between interconnected elements without the use of an auxiliary conductor. Bus bar splices, lightning down conductor-earth electrode connections, equipment front panel-rack mating, and connector shell-panel installation are all examples of direct bonding. Direct bonding is frequently impossible due to the way the equipment is operated or where it is located. Bond straps or cables are frequently used as indirect bonding to prevent static charge buildup and to link metal items to lightning down conductors to prevent flashover. However, the electrical bonding method can also classify as follows.

- Class ‘A’: A bond formed by physically connecting two metallic surfaces via the welding or brazing process.
- Class ‘B’: A bond of 0.1 ohm or less is formed between an equipment housing, case, or cabinet and ground potential as a result of its installation or the preparation of the mounting surface.
- Class ‘C’: A bond formed by connecting two metallic surfaces with a metallic bond strap. Class 'C' bond straps are further classified based on their application and are classified into four types: type I, type II, type III, and type IV.

➢ **Grounding:** Grounding is another well-known method of reducing electromagnetic interferences. Grounding is the process of establishing the necessary low impedance or low resistance path between an item or equipment and ground potential using the methods indicated. It ensures personnel safety and prevents shock hazards or death if an equipment produces a high potential due to illumination, a high external transient, or a power defect to the case, for example.[54] It provides a reference for signals used to communicate between equipment. There are three types of grounding which are as follows.

- Floating Signal Ground: This sort of signal ground system is electrically insulated from the hull of a ship. As a result, noise currents in the hull ground system are not conductively connected to the signal circuits. The floating ground system concept is frequently used in equipment cabinets to keep noise currents from connecting directly to signal circuits. It is impossible to construct a totally floating system aboard a ship, and even if perfect isolation is achieved, such a system is difficult to maintain.

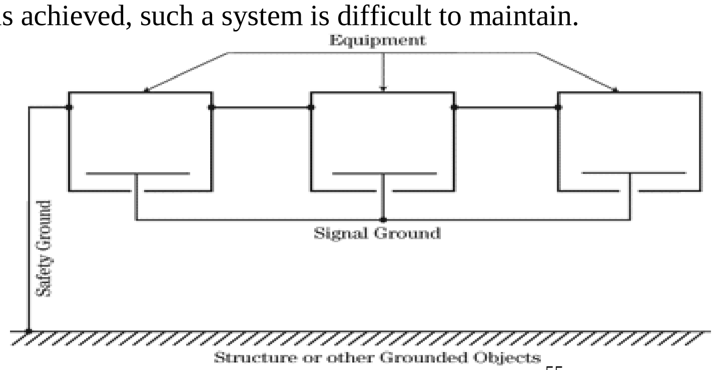

Figure 2: Floating Signal Ground[55]

- Single Point Ground: The signal circuits are referenced to a single point in this configuration, which is then connected to the hull. The ideal single-point signal ground network has distinct ground conductors extending from one point on the hull ground to the return side of each of the ship's multiple circuits. This type of ground network necessitated a massive number of conductors and is not generally economically viable. Various degrees of approximation to single-point grounding are used in place of the ideal. One significant benefit of the single-point configuration is that it aids in the control of conductivity-coupled interference. The requirement for a long conductor is a significant disadvantage of the single point ground layout.

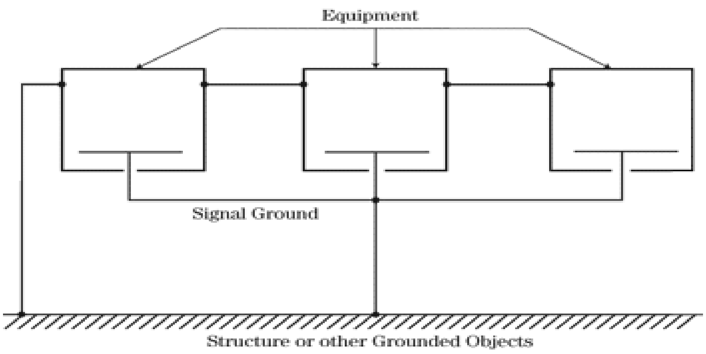

Figure 3: Single-Point Signal Ground[56]

- Multiple Point Ground: The multiple point ground uses numerous conductive routes from the hull to the ship's various electronic systems or subsystems. Circuits and networks within each subsystem are linked to this ground network. As shown in Figure 4, there are several parallel paths in a ship between any two points in the ground network. However, multiple-point grounding has a significant drawback. Power currents and other high amplitude, low frequency currents passing through the hull can conductively couple into signal circuits, causing intolerable interference in low frequency circuits.

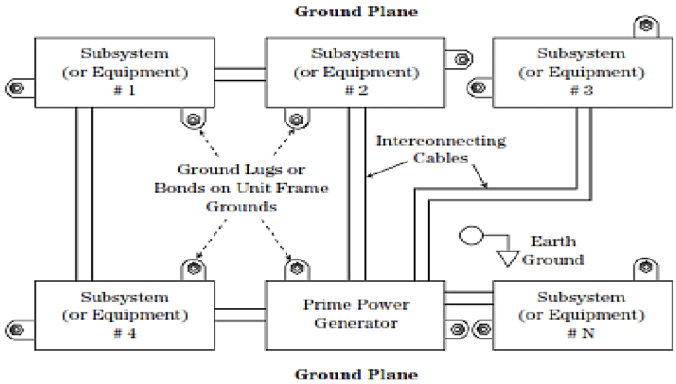

Fig 4: Multiple-Point Ground Configuration[57]

- **Shielding:** Shielding is a method of decoupling that limits equipment interaction. Shielding is considered once the isolation methods have been completed. Only those components that need shielding should be included in the shield. Shielded enclosures, when properly built and constructed, can be a very effective technique of attenuating radiated emissions and shielding products from external sources of interference. Shielding confines EMI to a narrow location. It also keeps EMI from entering a particular region. Shielding effectiveness is determined by the sum of reflection and penetration losses.Penetration loss and reflection loss for magnetic fields become minimal at frequencies as low as 60 Hz, hence a very thick metallic barrier may be required to shield against magnetic fields at lower frequencies. Magnetic materials are more effective as low-frequency shields because they have high permeability at low frequencies and thus high penetration loss.[58]Increases in penetration loss are acquired at the expense of a decrease in reflection loss. In this situation, a correction factor (B) must be introduced to account for the effect of subsequent re-reflections. The total shielding effectiveness(S) becomes:

  S = A + R + B. Where, S = Shielding Effectiveness; A = Penetration or absorption loss in dB of the shield; R = Total reflection loss in dB from both surfaces of the shield; B = Positive or negative correction factor when A < 10.

  Again, wave energy that penetrates the shielding has a penetration loss that is proportional to the type and thickness of the shielding material. Reflection losses are not affected by shielding thickness. As a result, a thin layer of high conductivity material works well as an electromagnetic shield. For low impedance electromagnetic waves, this reflection loss cannot be depended on, therefore the only option for building a shield for low impedance waves is to prove for the greatest penetration loss. The penetration loss, also known as absorption loss, can be defined as follows:

  $A = 3.34(10^{-3t}\sqrt{f\mu_r \sigma_r})$ Where, A= Absorption loss in decibels; t = shield thickness in miles; f = frequency in hertz; μ_r= permeability relative to μ_0 andσ_r = conductivity relative to copper. So, the relative permeability (μ_r) of "magnetic shielding" materials ranges from 102 to 106, whereas their μ_r ranges from 102 to 10-1. Thus, in ELF and VLF frequencies, a nickel iron alloys (80% nickel and 20% iron), such as metal, Hypercom, and Co-Netic is the ideal shielding material because permeability maximizes absorption function at a given frequency.

- **Filtering:** Filters are circuit components that are designed to pass currents at specific frequencies while attenuating currents at other frequencies. They make use of the response characteristics of series and parallel inductance and capacitance combinations. These reactances reduce interference by connecting a high impedance to the interference currents and/or shunting interference currents to ground via a low impedance.[59] The filters can be classified under the following categories.

- Low Pass Filter: This permits electrical energy with frequency components ranging from DC to a certain frequency (the cut off frequency) to pass with little or no attenuation, but electrical energy with frequencies above this is rejected with at least 6db per octave additional attenuation.
- High Pass Filter: It admits energy beyond the cut off frequency but rejects it significantly below this frequency.
- Band Pass Filter: This receives radiation within a set band or spectrum but rejects it drastically outside of the band.
- Band Stop Filter: These filters block electrical energy within a certain band while accepting or passing it outside of the band.

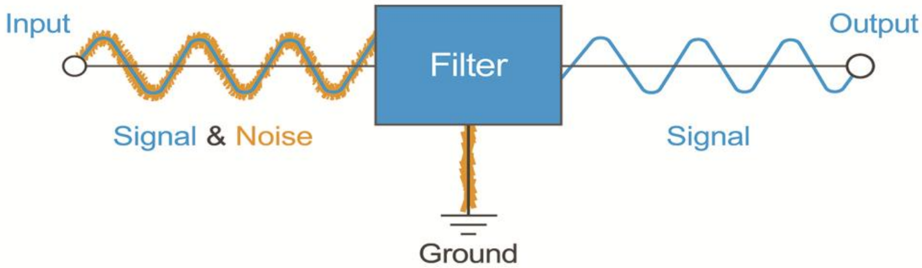

Fig 5: EMI filtering for high reliability[60]

Achieve EMC Capabilities

The capacity of an electronic system to perform adequately within an electromagnetic environment without generating unacceptable EMI in surrounding devices/systems is referred to as EMC. EMC guarantees that the system performs as planned in accordance with the established safety precautions.[61] The electromagnetic interference induced by various sources, as well as their coupling channels, is a critical topic that must be addressed and reduced. As a result, the concept of EMC emerges. According to Faraday's law, the magnetic field generated by a coil is directly proportional to the coil's area and current. $E = di/dt \propto$ Coil Area Current flowing through the coil, as we know. The first thing that becomes crucial is lowering the coil/loop area. The magnetic flux diminishes as the loop area shrinks. The question now is, how can we accomplish it? If we have a trace on the top PCB layer, we can lessen the loop by putting a ground plane just beneath the trace/signal.When we do this, the current flows through the trace that follows the device before returning through the ground plane. The PCB thickness is roughly 3 mils (3000th part of an inch), hence the area is very small. Because it decreases the overall area to be traversed, placing the ground plane immediately below the trace reduces EMI. The second step is to reduce the rate of change of current since higher current creates more emissions. As a result, lowering the current can likewise lower the EMI. Maintaining low rise times, even while your PCB is working at high frequencies, can also aid with EMI mitigation.[62]A correctly constructed system will always have matching impedances from the source to the transmission line to the load. It maximizes power transfer while minimizing reflections. Transmission line reflections enhance harmonics, which increases radiated emissions. Ringing and overrun in digital signals are caused by mismatched impedances, resulting in increased radiated emissions. Properly matched impedances are essential since they minimize the device's radiated emissions.

It is now a revolutionary technique for locating electromagnetic interference (EMI) sources using the time-reversal (TR) cavity concept. To locate EMI sources, the equipment under test (EUT) is put in a rectangular metallic cavity of appropriate dimensions based on the frequency band and EUT size, and fitted with a simple monopole or dipole antenna. It is very possible to find EMI sources using only one sensor by taking advantage of the concentrating features of a TR cavity. To find the focused time slice in which the highest electric field defines the position of the EMI source, the entropy criterion is used.To demonstrate the capability of such a system, both 2D and 3D numerical simulation schemes are now used. The accuracy of numerical simulations is evaluated using frequency domain measurements. In comparison to traditional EMI tests in anechoic chambers and scanning methods, this current technology is a simpler and more cost-effective test method that requires only one sensor, such as a monopole or dipole antenna.[63]

The rapid growth of fifth-generation mobile communication technology and wearable electronic gadgets has drawn worldwide attention to electromagnetic interference and radiation pollution generated by electromagnetic waves. As a result, the design and development of highly efficient EMI shielding materials is critical.[64]The three-dimensional graphene oxide (GO) with regular honeycomb structure (GH) is first created in this work using a sacrificial template and freeze-drying procedures.[65]The amino functionalized FeNi alloy particles (f-FeNi) are then placed onto the GH skeleton and reduced in-situ to form the rGH@FeNi aerogel.[66]Again, vacuum-assisted epoxy resin impregnation results in rGH@FeNi/epoxy EMI shielding composites with a regular honeycomb structure.[67]The rGH@FeNi/epoxy composites exhibit a high EMI shielding effectiveness (EMI SE) of 46 dB, which is 5.8 times greater than that (8 dB) for rGO/FeNi/epoxy composites with the same rGO/FeNi mass fraction. These composites benefit from the construction of a regular honeycomb structure and electromagnetic synergistic effect.[68]The rGH@FeNi/epoxy composites show exceptional mechanical properties with a storage modulus of 8296.2 MPa, as well as great thermal stability, with heat-resistance index and maximum decomposition rate temperatures of 179.1 and 389.0 °C, respectively.[69]

Two issues are addressed by electromagnetic compatibility (EMC).[70] First, a device's capacity to control its radio frequency emissions so that it does not interfere with other surrounding devices (such as radio receivers). Second, a device's capacity to function normally in the face of electrical and electromagnetic interference, as well as other electrical risks. Furthermore, EMI implementation would be impossible without maintaining proper EM hygiene onboard ships. Furthermore, EMC should be achieved by design, production, maintenance, and military standard equipment. The following approaches lead to possible solutions for achieving EMC from the aforementioned views, particularly for ships, marine platforms, and aircraft.

- EMC through Design: EMC issues should be handled from the ship/equipment design stage. For ships, this includes determining the best position for radars, radio equipment, planned equipment sites, likely cable routes, and so on.
- EMC through Production During the various stages of ship construction and equipment installation, constant attention should be paid to the shipbuilding yards. Furthermore, EMC compliance certificates can be obtained when purchasing devices or machinery from an OEM. Before commissioning a ship or equipment, and after all HATs have been completed, a top deck visual survey, a below deck visual survey, a ground discontinuity test, radiation hazard measurement, and so on should be performed.
- EMC through Maintenance: To ensure that the ship has an EMI-free operational cycle, ship employees can follow an EMC work package that can be implemented both during and after the refit. Furthermore, we can concentrate on retrofitting equipment and machinery that is very important during Ship Midlife Upgrades (MLUs). To avoid any problems, the following steps can be followed during maintenance period:

- Examine the EMC specifications supplied by the equipment maker.
- Ensure that the EMC certification is related to the specific location of the installation.
- If in doubt, seek test reports from the manufacturer to demonstrate conformity.

- Training and Awareness: Aside from academic and practical work, all workers should be trained on a regular basis through courses. Additionally, seminars and one/two day workshops can be held at regular intervals at various commands, dockyards, and schools to educate specific target groups on EMI/EMC. In addition, an EMC center can be constructed. The center's goal should be to ensure, maintain, and monitor EMI/EMC training and activities.
- Military Standards: The electromagnetic environment onboard ships is far more sophisticated than that of a commercial product. To avoid EMI effects, all machines must adhere to specific EMC standards. In general, equipment specified with EMC standard compatibility standards such as US Standard Federal Communications Commission (FCC), US Military Standard MIL-STD-461E: 1999, European Standard International Special Committee on Radio Interference (CISPR), and so on should be installed on a vessel under construction.
- Check off List: Onboard naval platforms, many types of electrical and electronic equipment, such as navigational, communication, and EW equipment/systems, are used. This equipment produces EMI, which degrades the performance of numerous systems. As a result, it is vital to raise awareness among both maintainers and users in order to reduce EMI and develop EMC. As a result, regular EMI/EMC auditing is essential.

EMI/EMC auditing specifies the check lists, limits, and constraints that must be followed in order to eliminate EMI in the ship's hull and structure, communication system, radar system, and EW system.

Regular monitoring of the check list, limitations and constraints of the ship's hull and structure, communication system, radar system, and EW system in terms of EMI/EMC may improve the equipment's performance.

Basic PCB Design and Assembling

A printed circuit board (PCB), also known as a printed wiring board (PWB), is a media used to connect or 'wire' components of a circuit together. Electrical and electronic circuits were wired point-to-point on a chassis prior to the development of printed circuit boards.[71]The chassis was often a sheet metal frame or pan, sometimes with a wooden bottom. The methodologies utilized in current printed circuit boards were developed in the early twentieth century. Albert Hanson, a German inventor, disclosed flat foil conductors laminated to an insulating board in numerous layers in 1903. In 1904 Thomas Edison experimented with chemical plating methods for plating conductors onto linen paper.[72] While working in the UK about 1936, Austrian engineer Paul Eisler devised the printed circuit as part of a radio set.[73]In 1941, German magnetic influence naval mines employed a multi-layer printed circuit.[74]Around 1943, the United States began to mass-produce proximity fuses for use in World War II.[75] The invention was commercialized in the United States in 1948. Printed circuits were not widely used in consumer electronics until the mid-1950s, when the United States Army developed the Auto-Sembly process. Because of recent improvements in 3D printing, various novel ways in PCB manufacturing have emerged.[76]3D printed electronics (PEs) can be used to print products layer by layer, followed by printing with a liquid ink including electronic functions.

HDI (High Density Interconnect) technology enables a denser design on the PCB, potentially resulting in smaller PCBs with more traces and/or components in a given area. As a result, the pathways between components may be reduced in length. HDI technology is most commonly used in computer and mobile phone components, as well as medical and military communication equipment.[77]A 4-layer HDI microvia PCB has the same quality as an 8-layer through-hole PCB, hence HDI technology can save money.[78]Currently, a printed circuit board (PCB) is a laminated sandwich structure made of conductive and insulating layers, with conductive layers having artwork patterns made of traces, planes, and other features (similar to wires on a flat surface) etched from one or more copper sheet layers laminated onto and/or between sheet layers of a non-conductive substrate.[79] To electrically connect and mechanically secure electrical components to it, conductive pads on the outer layers can be formed to accommodate the component's terminals.[80]Printed circuit boards are found in almost all electronic devices. Wire wrap and point-to-point fabrication were formerly popular but are now rarely utilized as alternatives to PCBs.[81]PCBs necessitate more design work to lay out the circuit, but manufacturing and assembly can be automated. Much of the layout process can be automated using electronic design automation software.[82]Because components are placed and wired in a single operation, mass-producing circuits with PCBs is less expensive and faster than alternative wiring methods. A large number of PCBs can be manufactured at the same time, and the layout only needs to be done once. PCBs can also be produced manually in small quantities, albeit with diminished benefits.[83]PCBs can be single-sided (one copper layer), double-sided (two copper layers on both sides of one substrate layer), or multi-layer (alternating copper exterior and inner layers). Because circuit traces on the inner layers would otherwise take up surface space between components, multi-layer PCBs allow for substantially higher component density.[84]The adoption of surface mount technology coincided with the rise in popularity of multilayer PCBs with more than two, and notably more than four, copper planes.[85]However, multilayer PCBs make circuit repair, analysis, and field modification far more complicated and often impractical.[86]The global market for bare PCBs surpassed $60.2 billion in 2014 and is expected to reach $79 billion by 2024. [8788]

Through Hole Technology Mounting (THT) refers to the process of mounting components with leads on a PCB utilizing plated through holes. Prior to the invention of Surface Mount Technology (SMT), all components were mounted to the PCB via leads that passed through component holes in the board. THT technology dominated the industry until the late 1980s. Today, most components are mounted using SMT, also known as Surface Mount Devices (SMD), which is more efficient, cost effective, and suitable for denser boards. Based on this, you may conclude that THT devices are now obsolete and no longer employed, because SMT is more efficient, cost effective, and adaptable to denser boards.THT, on the other hand, has certain advantages that keep it relevant. THT bonds are significantly stronger than SMT bonds, making THT the optimum solution for components that will be subjected to mechanical and environmental stress, as well as high heat. THT components are extremely easy to alter while prototyping, making them ideal for testing and hobby users. There are also drawbacks. Through hole components are much larger, and the component is on one side of the PCB while the solder junction is on the other, so space is used on both sides. Because the holes must be drilled through all of the PCB layers, THT limits the available routing area on inner layers.[89]

THT assembly is less dependable and more expensive than SMT because it is not automated and relies on the expertise of the operators. We shortened the leads to the appropriate size before installing the TH components. Some components must be placed at a specific distance from the board. To arrange the components at the proper height, we use'spacers' made of plastic or metal. Soldering, screwing, or snap-fitting are used to secure the spacers. Some components are installed from the side rather than the top of the boards. Edge mounted connections are what they're called. Edge mounted connections are most commonly employed in high frequency applications. They require considerable consideration in both design and installation.

Some applications require hybrid technology components to combine the benefits of SMD and THT. The most frequent are USB connectors, which must be installed on thick boards with limited free space, making SMT technology ideal, but require good mechanical stability, which is only possible with TH leads. As stated in earlier episode, we employ pin in paste technique to mount such components. SMT was created to reduce production costs while making the best use of board space.[90]Surface mount technology has enabled manufacturers to produce smaller-sized sophisticated circuit boards. Surface mount technique has both advantages and problems.[91]Surface-mount technology was invented in the 1960s and became popular in the 1980s. They were employed in the majority of high-end PCB assembly by the 1990s. Metal tabs or end caps that could be affixed directly to the board surface were added to traditional electronic components. This replaced traditional wire leads that had to pass through drilled holes.[92]SMT permitted component insertion on both sides of the board and resulted in considerably smaller components. Surface mounting allows for greater automation, lowering labor costs and increasing manufacturing rates, resulting in more advanced board development.[93]Electrical components can be installed on the board surface using SMT without any drilling. Surface mount components are preferred in most electronic applications because they are compact and may be put on either side of a printed circuit.[94]They are appropriate for applications requiring larger routing densities. These components are smaller than through-hole components and have smaller leads or no leads at all.

There are only a few significant differences between THT and SMT. SMT eliminates the board space limitation imposed by the through-hole mounting production process. Manufacturing costs for through-hole components are higher than for SMT components. When compared to through-hole technology, SMT demands advanced design and production expertise.[95]When compared to through-hole components, SMT components can have a larger pin count. However, unlike through-hole technology, SMT allows for assembly automation, allowing for higher production quantities at lower costs than through-hole production. When opposed to through-hole mounting, SMT components are more compact, resulting in higher component density. While surface mount reduces production costs, the capital investment for apparatus is greater than that required for through-hole technology.[96]Through-hole mounting is better suited to the manufacture of big and bulky components subjected to periodic mechanical pressures, as well as high-voltage and high-power components. Because of its smaller size and fewer holes, SMT allows for faster circuit speeds. SMT has numerous advantages over traditional THT. SMT helps microelectronics by allowing more components on the board to be positioned closer together. As a result, designs become lighter and more compact.[97]When compared to through-hole technology, the setup process for SMT production is faster. This is because components are attached with solder paste rather than drilled holes.

SMT saves time and effort in labor-intensive tasks. Components can be arranged on both sides of the circuit board, allowing for more component density and more connections per component.[98]Higher-density traces can be accommodated on the same layer due to the package's compact size. Molten solder's surface tension pulls components into alignment with solder pads, instantly correcting small placement issues. These, unlike through holes, do not expand in size throughout the process. As a result, we can lower the inter-packaging space. Because of their tiny size and low lead inductance, SMT boards are easily magnetically compatible. SMT connections have lower resistance and inductance. It reduces the unwanted impacts of RF waves and improves high-frequency performance. Because of their compactness, more parts can readily fit on the board, resulting in shorter signal routes. This improves the signal's integrity. Heat dissipation is also lower than with through-hole components.[99]SMT lowers the cost of board and material handling. SMT allows us to regulate the manufacturing process. This was chosen in particular for high-volume PCB fabrication.[100]SMT has certain disadvantages as follows.

- When components are subjected to mechanical stress, using surface mounting as the sole means of attachment to the PCB is unreliable. This is because component connectors are required to link with external devices that are periodically removed and reattached.
- Thermal cycles during operations may cause solder connections for SMDs to be destroyed.
- For component-level repair and manual prototype assembly, you would need highly trained or expert-level operators as well as pricey tools. Because of the smaller diameters and lead spaces, this is the case.[101]
- Most SMT component packages cannot be put in sockets that allow for the simple installation and replacement of defective components.
- Because you use less solder for solder joints in SMT, the dependability of solder joints becomes an issue. Here, void buildup could result in solder joint failures.
- SMDs are often smaller than through-hole components, resulting in less surface area available for identifying part IDs and component values. This makes identifying components difficult during prototyping and PCB maintenance.[102]
- When exposed to high temperatures, solder can melt. As a result, SMT cannot be used in high heat dissipation electrical load circuits.
- This technique necessitates higher installation costs for PCBs. This is due to the high cost of most SMT equipment, such as the hot air rework station pick and place machine, solder paste screen printer, and reflow oven.
- Miniaturization and a wide range of solder joints can complicate the operation and inspection.[103]
  Because of the compact size, there is a greater possibility of solder overflow, which can result in short circuits and solder bridges.

The bulk of goods developed nowadays use surface mount technology. However, SMT is not appropriate in all situations. SMT has considered very useful and successful for the following cases.

- You need to fit a high component density.
- A compact or small product is required.[104]
- Regardless of component density, your end product must be streamlined and light.
- The requirement indicates the device's high-speed/frequency operation.
- You must use automated technology to create vast volumes.[105]
- Your product should make very little (if any) noise.
- SMT component placement guidelines.

Here are some recommendations for SMD placement to maintain good signal and power integrity for your board.

- Keep the components as close together as possible to reduce routing distance.
- While placing the components, adhere to the signal path as shown on the schematic.[106]
- Never put sensitive signal components in the return path. As a result, signal integrity difficulties arise.[107]Signal Integrity (SI) refers to a signal's ability to propagate without distortion. The quality of the signal travelling over a transmission line is referred to as signal integrity. It measures the amount of signal degradation that occurs as the signal travels from the driver to the receiver.
- Place bypass capacitors closer to the power pins of high-speed devices. This lowers parasitic inductance.
- Arrange the SMDs for power supply circuits together. This will allow you to create shorter routing while also lowering inductance in the connections.[108]
- To save money on stencils and assembly, try to keep SMT components on one side of the board.[109]
- Maintain the minimum distance between test points and SMT components as stated by the manufacturer. This spacing may vary depending on the height of the component.

To make the assembly process easier, make sure that all component names, polarities, orientations, and positions are accurately marked in the assembly drawing. The footprints in the drawings should correspond to the actual parts. If you are considering consigned assembly, check with your manufacturer for their kitting guidelines. Make the necessary changes to your BOM. To install components onto the board, solder reflow and wave soldering are commonly utilized.[110] Depending on the nature of the components, the designer can choose one of these methods for SMT.

- **Wave soldering is typically utilized for through-hole components since the solder flows through the holes to establish a connection. Most surface-mount components can also be soldered using wave soldering.**[111]

- **Solder reflow: This is the recommended method in SMT. In this case, the solder on one pin melts and reflows faster than the solder on the other. The sole drawback is that it produces a tomb-stoning effect, in which the component rips away from the non-melted pad. Surface mount components like as resistors, capacitors, and inductors are prone to this effect.**[112]

The efficient layout of traces on a PCB is a sophisticated technique that takes a great deal of patience. This work has been greatly simplified by the availability of PCB layout software, but still remains difficult. A circuit is often designed by an electronics or electrical engineer, and the PCB is designed by a layout specialist. PCB design requires specialist knowledge. There are several strategies and guidelines for designing a PCB that is simple to build while remaining tiny and economical.[113]These are the typical PCB layout processes for most clients, allowing the customer full flexibility to make adjustments to accommodate routine engineering changes that occur during the design process. The engineering teams' efforts to design and build a successful product are maximized by using this structured method.[114] There are 4 steps to build an efficient PCB stack-up.[115]

- To ensure manufacturability, we must prepare our design needs.
- To construct your stack-up, we will need to employ PCB layout design tools.
- Before finalizing the layer stack, we should understand the production tolerances.
- In high-volume production, we should repeat the same manufacturing procedure.[116]

However, there are 5 design ideas to build our PCB stack-up with good signal integrity. Such as:

- We must choose the proper dielectric substance.[117]
- We must determine the optimal number of signal layers.
- We must determine the number of ground and power layers required.
- We have to preserve consistent impedance throughout the high-speed traces.
- To decrease EMI, we must avoid placing adjacent signal layers.[118]

EMI in Integrated Circuits,RF Immunity and RFI

Integrated circuits are common sources of EMI. However, in order to radiate considerably, those must frequently couple their energy to larger objects such as heatsinks, circuit board planes, and wires.[119]Again, important methods of reducing EMI on integrated circuits include the use of bypass or decoupling capacitors on each active device connected across the power supply as close to the device as possible, rise time control of high-speed signals using series resistors, and IC power supply pin filtering.[120]Shielding is typically used as a last resort when other strategies have failed due to the additional cost of shielding components such as conductive gaskets.[121]The radiation efficiency is determined by the height above the ground plane or power plane, as well as the length of the conductor in relation to the wavelength of the signal component, such as fundamental frequency, harmonic, or transient such as overshoot, undershoot, or ringing, among others.[122]Lower frequency radiation, such as 133 MHz, is virtually entirely via I/O cables; RF noise enters the power planes and is attached to the line drivers via the VCC and GND pins. The RF is then linked to the cable as common-mode noise through the line driver.[123]Shielding has little effect, even with differential pairs, because the noise is common-mode.[124]The RF energy is capacitively connected from the signal pair to the shield, which then radiates.[125]A braid-breaker or choke can be used to limit the common-mode signal.[126]

Traces get electrically longer and higher above the plane at higher frequencies, often above 500 MHz. At these frequencies, two strategies are used: wave shaping with series resistors and embedding the traces between the two planes. If all of these precautions still result in excessive EMI, shielding such as RF gaskets and copper or conductive tape can be utilized.[127]The majority of digital equipment is housed in metal or conductive-coated plastic casings. Any unshielded semiconductor, such as an integrated circuit, will operate as a detector for radio frequencies often present in the home, such as mobile phones.[128]A detector of this type may demodulate high-frequency mobile phone carriers such as GSM850 and GSM1900, as well as low-frequency carriers such as 217 Hz.[129] This demodulation produces an undesirable audible buzz in audio devices such as microphone amplifiers, speaker amplifiers, vehicle radios, telephones, and so on.[130]Bypassing EMI or enhancing RF immunity can be aided by the use of onboard EMI filters or unique designing techniques. Some integrated circuits, such as LMV831-LMV834[131], MAX9724[132], are developed with integrated RF filters or a specific design that aids in the reduction of high-frequency carrier demodulation. Designers frequently need to conduct RF immunity studies on items that will be employed in a system. These tests are frequently performed in an anechoic laboratory with a controlled RF environment, where the test vectors generate an RF field similar to that created in the real world.[133]

Interference in radio astronomy, often known as radio-frequency interference (RFI), is any source of transmission inside the measured frequency band that is not the celestial sources themselves.[134]RFI is a big hazard for radio astronomy since transmitters on and around the Earth can be several times louder than the astronomical signal of interest.[135]

RFI is also used to describe natural sources of interference, such as lightning and the Sun. Another method for dealing with RFI is to create a radio quiet zone (RQZ).[136]The radio astronomy zone (RQZ) is a well-defined area surrounding receivers that has particular restrictions in place to limit RFI in favor of radio astronomy observations within the zone. The United States National Radio Quiet Zone (NRQZ), created in 1958, was the first RQZ for radio astronomy.[137]Prior to the emergence of Wi-Fi, the Terminal Doppler Weather Radar was one of the most important applications of the 5 GHz spectrum.[138] The decision to use 5 GHz spectrum for Wi-Fi was made during the World Radiocommunication Conference in 2003, although meteorological authorities were not consulted.[139] Following that, lax deployment and misconfiguration of DFS caused major interruption in weather radar operations in a number of nations around the world.[140]For more than a month, Hungary's weather radar system was declared inoperable. Because of the severity of the interference, South African meteorological services abandoned C band operation and switched their radar network to S band.[141]Transmissions on adjacent bands to those utilized by passive remote sensing, such as weather satellites, have resulted in substantial interference.[142] There is worry that the implementation of poorly controlled 5G may result in serious interference difficulties.[143]Significant interference can have a significant economic and public safety impact on numerical weather forecast performance.[144] These worries prompted US Secretary of Commerce Wilbur Ross and NASA Administrator Jim Bridenstine to request the FCC in February 2019[145] to stop a proposed spectrum auction, which was denied.[146]

Design Concept and Guidelines for EMI and EMC Reduction in a PCB

It is critical to design a board with little or no electromagnetic interference. These optimal design techniques may shorten and narrow the potential signal return routes, reducing undesirable EM emissions. The multi-layer stack-up will be crucial, especially in high-power and digital applications.[147]It is critical to design a board with little or no electromagnetic interference. These optimal design techniques may shorten and narrow the potential signal return routes, reducing undesirable EM emissions. The multi-layer stack-up will be crucial, especially in high-power and digital applications.[148]It is critical to design a board with little or no electromagnetic interference. These optimal design techniques may shorten and narrow the potential signal return routes, reducing undesirable EM emissions. The multi-layer stack-up will be crucial, especially in high-power and digital applications.[149]When these traces meet at any curve or cross, they combine to produce a fully radiating antenna. The following are some popular outline design rules.

- Trace separation is required. Clocks, video, audio, and reset signals, for example, must all be segregated from other traces. According to the usual rule, the distance between the traces should be 3W, where 'W' is the width of the trace. This technique aids in the reduction of crosstalk and coupling between adjacent traces on the same PCB layer. The exception to this rule is differential traces. Crosstalk must be avoided in the HDI substrate.[150]
- We should avoid right angles and instead do a 45° turn. When a trace encounters a 90° curve, the capacitance increases, causing the characteristic impedance value to alter, resulting in reflections. Sharp bends can be avoided by replacing them with 45° curves.
- Differential traces must be routed carefully. By increasing the coupling factor, common mode noise is maintained. Let's take two wires placed close to one another as an example. These two traces will each experience the same level of disturbance from any intervening external noise. The difference would be 0.5 V if trace 1 had 1 V and trace 2 had 1.5 V. Since the outside noise on both traces is the same, let's suppose 0.1 V. As a result, trace 1 will increase to 1.1 V and trace 2 to 1.6 V. And the difference, which is 0.5 V, remains the same when you calculate it. Therefore, the noise will actually stop.As a result, high-speed signals are best routed as differential pairs. More information on high-speed PCB routing is required.[151]
- We must master the use of vias. Vias are utilized for signal routing in multi-layer PCBs. A smart designer understands that each through has its own capacitance and inductance effect. In reality, as much as possible, vias should be avoided, and important traces should be routed on the same layer. The parasitic capacitance and inductance in the vias induce an impedance mismatch between the through and the trace, resulting in reflections.[152]When vias cannot be avoided, it is critical that ground vias be located close to signal vias. This

ensures that the signals are referred to linked grounds, reducing changes in characteristic impedance and consequently reflections. When vias cannot be avoided in differential pairs, the identical number of vias should be placed in both traces. In differential traces, we must avoid vias.

- Stubs must be avoided in sensitive and high-frequency traces. Stubs generate reflections and have the possibility to add fractional wavelength antennas to the circuit. To understand how through stubs contribute to reflections, we must examine relevant literature and articles. This page is on the impacts of through stubs.[153]
- For clock lines, we must employ guard and shunt traces. Decoupling capacitors are critical in clock circuits for minimizing noise propagation along the supply rails.[154] Guard and shunt traces are used to protect clock lines from EMI sources, which may otherwise cause difficulties elsewhere in the circuit.

A ground with a low inductance value is essential for reducing EMC concerns during PCB design. Increasing the ground area of a PCB reduces the system's ground inductance and, as a result, EM emission and crosstalk. When it comes to connecting signals to the ground in the best possible way, we have several options. To choose the best PCB design method, we must first establish the acceptable limit. The PCB components should not be connected to the ground points at random. The steps of design approach have been described below.

- We must employ the complete ground plane and ground grids. When the signal returns to the source from the load, use the full ground plane because it has the lowest inductance value. Although a dedicated PCB layer is required for a ground, this may not always be possible in a two-layer PCB. In such cases, designers employ ground grids, the inductance of which is proportional to the distance between the grids.
- We must avoid long return paths. Faraday's law states that the way a signal returns via the system ground makes all the difference. When a signal travels a longer distance, it develops a ground loop, which acts as a radiating antenna. A short return path has lower impedance and so performs better in terms of EMC. Longer return pathways cause more mutual coupling, leading in crosstalk. As a result, keep the return paths as short and the loop area as little as possible. The existing return path must be followed precisely. It is advised that the device grounds be connected directly to the ground plane. This will reduce the number of ground loops.
- To isolate the noisy surroundings, we must employ Faraday's cage/guard ring. By placing the ground on the edge of the PCB, a Faraday cage is formed. The goal is to avoid routing any signal beyond of this limit. This approach limits the emission/interference to a specified limit.
- High-speed circuits should be placed closer to the ground, whereas low-speed circuits should be placed closer to the power plane. The copper fill portions must be grounded. Floating copper areas should be grounded at all times. Otherwise, it may operate as an antenna, resulting in EMC problems.
- We need to look into multi-power requirements. When a circuit has multiple power supplies, it is ideal to keep them isolated by a ground plane. However, multi-ground planes are not possible in single-layer PCBs. This issue can be remedied by running separate power and ground tracks for each source. It will help prevent noise coupling between power sources.
- We need to be careful with split apertures. Split apertures that are long holes and wide vias in power and ground planes create a non-uniform area. This non-uniformity increases the impedance in power and ground planes. We need to learn how grounding controls EMI and noise in PCB from contemporary literature and publications.[155]

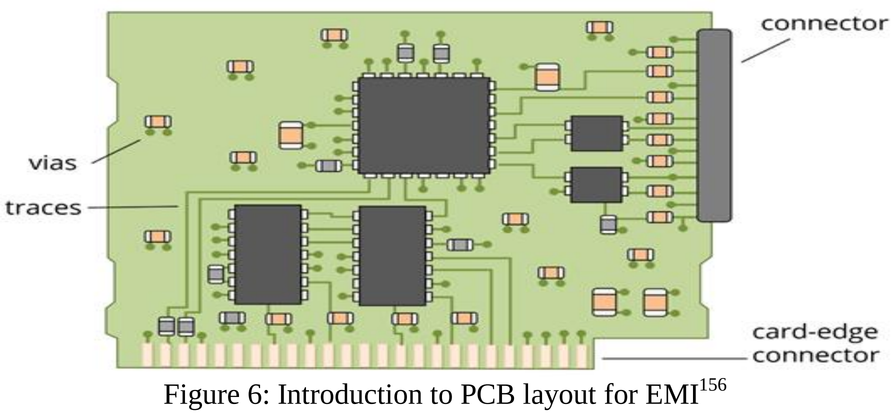

Figure 6: Introduction to PCB layout for EMI[156]

Shielding is a mechanical approach that prevents EMI in a system by using conductive/magnetic (or both) materials. A mechanical shield is a closed conductive container connected to the ground that absorbs and reflects some of the radiation emitted by loop antennas. It can be used to cover the entire system or just a portion of it, depending on the situation. EMI/EMC shielding shields the signal transmission from outside noise and prevents data loss.Cables that transmit analog and digital signals, on the other hand, cause major EMI problems. This is due to their parasitic capacitance and inductance components. EMI can be avoided by insulating these cables and connecting them to ground at both ends. The EMC performance of a PCB is also affected by the layer arrangement. When using two or more layers of a board, one full layer should be used as a ground plane. The layer beneath the ground layer should be used as a power plane on a four-layer board.

For the four-layer board, the preferred layer stack is signal 1, ground, power, and signal 2. The impedance-matched traces should be as far away from signal1 as practicable.Ground grids should be employed if a two-layer board is used and a whole layer of ground is not possible.[157]To maintain the supply clean, ground traces should run in parallel with power traces if a separate power plane is not employed. When there are more than four layers, it is recommended to utilize PCB layers' arrangement like signal layer→ ground/power layer → signal layer → ground/power layer → signal layer → ground/power layer → signal layer. That is, alternating signal and ground layers are used. Furthermore, the number of layers should be even. Some of the greatest PCB grounding solutions for avoiding EMI include dedicated ground planes, ground vias, and galvanic isolation.[158]

PCB components must be grouped according to the signals they operate on for an EMC-friendly design, such as analog, digital, power supply, low-speed, high-speed signals, and so on.[159]Each component group's signal tracks should remain inside their prescribed area. When a signal must pass from one subsystem to another, it is best to utilize a filter. When ICs operate, however, they switch current at a high frequency, resulting in switching noise in the power rails/traces linked to the IC. If not managed, this noise will result in radiated emissions and therefore EMI.[160]The decoupling capacitors are placed close to the IC power pins to reduce power rail noise. Again, the capacitors are grounded directly to the ground planes. Power noise can be reduced by using power planes instead of power traces. When a circuit operates at high speeds, however, impedance matching between the source and destination becomes crucial. Signal reflection and high-frequency ringing will occur if the impedance is not correctly matched and managed. Excess RF energy produced by ringing and reflection will radiate/couple to other sections of the circuit, causing EMI issues. Signal termination solutions can help to mitigate these negative impacts.[161] The impedance of traces also depends on the PCB materials used on the board.

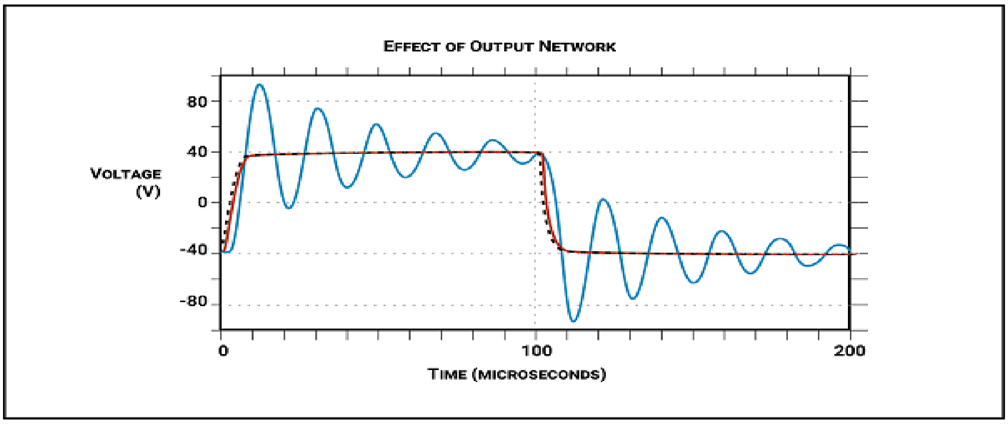

Figure 7: Adequate termination strategy helps in ringing reduction to PCB design of EMI/EMC[162]

Testing and Meeting EMI/EMC Standards

EMC compatibility is determined by three factors: it should not interact with other systems, it should not be sensitive to emissions from other systems, and it should not interfere with itself. Various modeling techniques are used to measure electromagnetic emissions in an electrical system. Computer simulation is frequently recognized as the fundamental method in EMC investigation. To provide an accurate measurement of critical parameters, the computer simulation employs an integration technique. To test electromagnetic emission in an electronic system, several stages are taken.

- To measure the frequency response of the common-mode current during high voltage applications, finite difference time domain modeling is used.
- The common-mode current is calculated by taking into account elements like current-mode antenna impedance and the distributed circuit constant.
  The common-mode current is affected by the electric connection between the power plane and the ground plane.

The goal of EMC/EMI standards is to keep the co-located electrical and electronic systems compatible for trouble-free operation. All products, systems, and installations are subject to CISPR standards. It may establish allowed limitations for both conducted and radiated emissions, as well as categorize them as residential, commercial, light industrial, or industrial. To meet EMC requirements, the equipment must be evaluated for conducted and radiated emissions, as well as sensitivity to conducted and radiated emissions. An electronic circuit is made up of multiple electronic components that are placed in a specific order.[163]

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Figure 8: EMC/EMI Testing Labs and its function[165]

EMC/EMI testing is an important phase in the design and manufacture of electronic equipment. Various regulatory authorities, like the FDA, FCC, and ISO, have established particular restrictions on the emissions that an electronic device can emit.[166]These EMC laws improve the reliability and safety of electrical and electronic equipment by ensuring that the device does not interfere with the functioning of other equipment or fails to operate as intended owing to interference from other emissions. Failure to pass EMC compliance testing may lead to fines and product recalls. Investing in tools that may detect potential EMC/EMI concerns prior to EMC testing is thus worthwhile. EMC is a vital component in the testing stage. It analyzes a product's capacity to work as intended inside its intended environment, known as immunity testing, as well as a device's potential to cause harmful interference to other devices running in its vicinity, known as emissions testing.[167]Immunity testing determines how a device reacts to various types of electromagnetic disturbances or events, whereas emissions testing determines the amount of electromagnetic energy (conducted and radiated) produced by the device. Both are critical factors that the designer must address during the design process. If not adequately handled, the resulting electromagnetic incompatibility can have a severe impact on the surrounding environment, contributing to product failures, safety protocol violations, data losses, and other issues. To avoid a failed EMC compliance test, use basic design rules during the design and manufacturing stages.[168]To minimize costly EMC testing failures, a list of the most common reasons why designs fail EMC testing, as well as how to avoid them through correct design principles, is provided below.

- **Need to Avoid Interrupting the Signal Return Plane**. Under normal conditions, a split, gap, or cut in the signal return or ground plane is rarely required for any board. Including these pauses may cause more issues than solutions. The most serious of these issues is the additional time and effort required to create methods to control the flow of low-frequency currents. Seek more assistance or advice if we are very certain that our board requires a split, gap, or cut in the signal return plane to prevent low-frequency coupling difficulties. An expert can review our work, provide comments, and assist us in developing solutions to help us close the gap efficiently.[169] It's important to remember that what worked for another design may not work the same way in yours.

- **Should not Place High-Speed Circuitry between Connectors**. This simple rule is often overlooked by designers. Bypassing this detail can lead to bloated designs that require more shielding and filtering than is necessary. The positioning of connectors on the PCB is critical because the cabling connecting to these connectors acts as very effective antennas, particularly at frequencies below two to three hundred MHz.
  While PCB traces can operate as antennas, their electrical effects are often minor in comparison to the wavelength at these frequencies. As a result, PCB traces are ineffective radiators. Cable lengths at these frequencies are often substantially closer to the ideal wavelengths, making them far more efficient radiators. When these connectors are positioned along a single edge of a board, the voltage between them is usually not a problem.[170]When high-speed circuitry is positioned between the connections, higher potential differences can arise, resulting in RF currents on the shield and/or conductors of the cable. As a result, the cable radiates, potentially causing the product to exceed emissions restrictions.
- **Need to Ensure Auxiliary Equipment is Compliant**. Manufacturers are required to connect auxiliary equipment to all I/O ports during emissions testing using commercially accessible connections. This guarantees that all ports on the device are used, exhibiting the gadget's complete capabilities. This is often a worst-case scenario, forcing the gadget to emit maximum quantities of emissions. This stage is critical to the testing process, but using the wrong supplementary equipment might lead to serious problems. For instance, if we utilize a non-compliant device, such as a low-quality USB flash drive, the emissions test results may be distorted. This is not due to our device, but rather to non-compliant auxiliary equipment.
- **Need to Find Proper LCD Displays**. An LCD display, like any other component, can have an impact on a product's radiated emissions performance. This is primarily due to the fact that not all LCDs are manufactured in the same manner. Even if they appear identical, one LCD may emit far more noise than another due to design variances. Handling this issue is highly dependent on the LCD display used in the device. In most circumstances, getting samples from different manufacturers and evaluating multiple screens at once is a practical way to go. This allows the tester to pre-scan each display to identify which is optimal for minimizing emissions.This method, on the other hand, is considerably less practicable with larger, more expensive LCD displays. It is significantly more difficult with custom LCD displays, as many custom orders may be required. The easiest way to prevent this issue is to purchase from a reputable manufacturer who can back up their emissions levels. Additionally, reducing emissions by building around displays might provide significant outcomes.[171]If the LCD is connected to the rest of the device by a flex cable or DIP connector, for example, adding a signal filter to our design could be just as effective.
- **Need to Prepare for ESD Testing**. ESD testing, commonly known as electrostatic discharge testing, is a fundamental criterion for general CE certification. This testing procedure determines how your product will react if it is subjected to a powerful electrostatic discharge. The technique typically involves the administration of two to eight-kV ESD pulses to the product's exposed metallic surfaces (contact discharge) as well as insulated surfaces (air discharge).[172] ESD testing can cause serious damage to the product.

- **Need to pinpoint ESD testing locations.** These are sections of the gadget that can be touched without the need for special equipment or the disassembly of the product. One aspect of this procedure is exploratory testing on the casing, in which the tester touches all outside portions of the product's chassis. Other popular testing spots for non-conductive chassis include connections, screw heads, keypads and buttons, chassis seams, displays, and areas where internal PCBs and components come close to the chassis.[173]
- **Need to identify ESD testing levels.** Discharges are often applied at steadily rising voltage levels, ranging from two to four kilovolts for contact discharge and two to eight kilovolts for air discharge. These levels will differ depending on your product and planned installation scenario. To determine the specific test values to be used for your product, consult with your test laboratory or refer to the applicable standards for your product.[174]
- **Need to choose an appropriate suppressor.** ESD protection for your circuit board can be found. Remember that this protection must be adequate for the test levels that will be applied to your product. Spark gaps, resistors, capacitors, varistors, and TVS diodes are all effective suppressors. A varistor is an electronic component that protects against surges and has an electrical resistance that fluctuates with applied voltage. However, they must fit adequately within our product without generating further issues.[175]
- **Need to apply suppressors to the proper locations.** When you have the protective components, make sure they are as close to the issue region as possible. This reduces the series inductance introduced by any routing between the discharge site and the suppressor.[176]

- **Should think about the discharge path.** Consider the discharge path for applied ESD carefully. For safety concerns, the chassis ground is often segregated from the main board ground in many systems. A common way is to connect your circuit board's chassis ground to the main power input. This allows discharges to dissipate without interfering with the remainder of the circuitry.[177]

➢ **Need to Manage Signal Transition Times**. The amplitude of well-formed digital signals at lower harmonic frequencies is significantly greater than that of higher harmonics.
Slowing the transition periods of digital signals can help to lower higher harmonics even more.[178] However, increasing the transition time too much can begin to degrade the signal integrity. Finding the ‘sweet spot’ is key.

- **Should control the slew-rate with a logic family.** This is frequently the most efficient solution for applications, especially when combined with a matching termination.
- **Need to place a resistor or ferrite in series with the device’s output.** Controlling a circuit's rise time provides more control while often costing less than the other choices discussed. Ferrite is also effective but more expensive.
- **Need to put a capacitor in parallel with the device’s output.** Capacitors have the ability to boost the amount of high-frequency current drawn by the source device. This is usually the least useful option for transition time control, but it does work in some cases.[179]

➢ **Should Minimize Loop Areas**.The insertion of loop areas associated with high-frequency currents is one of the simplest and most prevalent mistakes committed in circuit board design. This is frequently the result of designer error, especially if the designer is unaware of where the currents flow. Signal currents will always return to their origin. As a result, current pathways are invariably loops.[180]**Signal currents, on the other hand, follow the path with the lowest impedance. For high-frequency currents, this is the path with the lowest inductance. This is the path of least resistance for lower frequency currents.**

➢ **Need to Reduce RF Noise on Cables**. Cables are prone to emitting RF noise, which can raise a product's overall emissions and cause it to fail radiated emissions tests. If our completed design appears to have problems with radiated emissions, the first step we should take to try to solve the problem is to disconnect as many wires as feasible. If the emission goes away, we'll know that the noise was coming from one of the disconnected cables. Use a simple elimination method by reconnecting the connections one at a time until the problem emission reappears.Multiple cables may be the root of the problem in some circumstances, making it more difficult to identify and manage the problematic wires. While these steps should be followed to address these difficulties after they occur, it is preferable to prevent any unintentional RF energy as much as possible throughout the design process. Designers achieve this by reducing signal slew rates.[181]There are hundreds of ways to mitigate the effects of these signals on emissions, but they can be avoided with a few simple design practices. The first of these design practices involves adding in-line ferrite beads to your power supply and static I/O signals. These inline beads function as noise suppression beads, specifically designed to absorb RF energy and convert it to heat.

➢ **Need to Select the Right Power Adapter**. A noisy power supply or power converter can add a lot of noise to your equipment, reducing the gadget's emissions performance during testing. As a result, it's critical to choose a power adapter appropriate for our device's emissions class. An emissions class is essentially a rating that describes our device's intended function. Class A devices, for example, are intended for use in corporate, industrial, and commercial settings, whereas class B devices can be utilized in both of these settings as well as in domestic settings. Class B regulations are substantially tighter than class A requirements, with much lower emission level restrictions. Because of the differences in needs, it is critical to grasp our device's class and choose an adequate power supply.

- **Accommodating for the power adapter.** Power adapters are often tested with DC resistive loads, which differ significantly from dynamic loads. This means that when connected to a dynamic load with a broader current supply spectrum, the adapter's emission characteristics may alter. This discrepancy in current attributes may result in higher emissions than stated. To mitigate the effects of this discrepancy, your power circuitry may need to be specifically designed to handle a broader current supply range.
- **Investing in better adapters.** When it comes to compliance testing, many manufacturers will twist the truth. This is especially frequent among makers of lower-quality or lower-cost products, as it lowers their bottom line while increasing profits. As a result, it doesn't hurt to invest a little more time and money in a high-quality adapter from a reputable manufacturer.

- **Requesting a test report from the manufacturer.** It's never a bad idea to double-check the equipment you're buying, especially if it's from a new company. Many manufacturers will supply test records to back up their equipment claims.[182]

- **Need to Use Shielding for Over Sensitive Circuitry**. Because EMC immunity tests can interfere with delicate analog circuitry, they should be shielded with a well-grounded conductive shield.[183]The energy in an RF field can create tiny currents, which can disrupt the operation of our circuits, particularly sensors and other sensitive components. We can avoid most of these negative impacts during CE testing by wrapping an electrical shield around any of these sensitive sections.[184]
- **Need to Find a Trusted Expert in EMC**. Over half of all consumer items fail EMC compliance tests, which is why in-house testing is such a vital component of the production process. Pre-compliance testing not only allows any organization to uncover and correct compliance concerns before to a formal test, but it also saves money by removing the need for several tests, rescheduling fees, and personnel costs. When bringing a product to market, EMC testing is crucial. Knowing how much noise a device makes and emits, as well as how it will respond to noise from an external source, is a crucial aspect of quality control for consumer goods.[185]

As a result, all electronic equipment generate electromagnetic noise, which has the potential to create EMI. Inadequate noise immunity can impair a product's capacity to function in specific situations, and noise emission might possibly interfere with other devices in its vicinity. This is known as EMC. EMC compliance testing of products destined for the consumer market has several significant advantages.[186] When developing a product, designers must evaluate numerous engineering possibilities. A product's design and construction take a significant amount of time and work, from component selection through casing decisions. The designer is most concerned with how well their product will perform in the final testing stage.[187]You can avoid or reduce the sources of EMI in embedded systems by following some EMI best practices, which will help you design and test your embedded system more effectively and quickly. It is critical, for example, to do EMI analysis and simulation early in the design process. Furthermore, modular design and function separation can assist separate and protect distinct sections of an embedded system from EMI. You should also adhere to the instructions and recommendations of the applicable EMI standards and laws. Quality components and materials with low EMI properties should be used as well. Finally, to guarantee consistency and traceability, it is critical to document and analyze your EMI design and testing results.[188]

Conclusion

EMI is described as electromagnetic energy that interferes with the operation of an electronic equipment. EMC, on the other hand, is a measure of a device's capacity to function as intended in its shared operating environment while not interfering with the ability of other equipment in the same environment to function as intended. Embedded systems can operate in surroundings that are extremely hypersensitive and noisy, which can contribute to EMI issues. It consists of any undesired, spurious, conducted, or radiated electrical impulses that might degrade equipment performance. As a result, all components must meet criteria in order to assure EMC, and there are numerous design solutions available to prevent EMI.During an embedded system's development life cycle, the product must be developed to comply with the EMC requirements described above, and the product must be tested for EMC for improved performance. Experiencing electromagnetic interference throughout various missions can be extremely unpleasant. The EMI case examples given above clearly demonstrate how a mission's success can be endangered in certain conditions. Nearly every electronic system onboard a naval platform is vulnerable to electromagnetic interference (EMI) caused by another device onboard.This has been a recurring concern for modern fleets as modern ships have been outfitted with a greater number of antennas and more sensitive electronics. Pre-compliance EMC testing is widely acknowledged as one of the most effective methods of identifying EMC concerns early in the product development cycle. Outside of the United States, several ISO, IEC, CISPR, and other standards establish allowable EMI and overall EMC limitations. Compliance with these standards is optional in some businesses and markets.

The most effective strategy to eliminate EMI sources in embedded systems is to use EMI mitigation strategies during the design and development process. Circuit design, component selection, layout optimization, shielding, filtering, grounding, or isolation are all examples of EMI mitigation approaches. EMI mitigation strategies can help us improve your embedded system's signal integrity, noise immunity, and power quality while also lowering emissions and sensitivity to EMI. Furthermore, such difficulties can be overcome with the proper equipment. As EMI difficulties become increasingly widespread, modern fleets and maritime platforms are focusing more on EMC requirements. EMC standards help to ensure that EMI mitigation procedures like as bonding, grounding, shielding, and filtering are used on a regular basis.Furthermore, the EMC standard aids in the reduction and control of EMI concerns. Aircraft, marine, and naval ships/platforms may begin applying the above-mentioned lessons, best PCB design and production, frame or hull and structural system imperatives, communication system, radar system, and EW System to accomplish desired EMC. EMC can also be achieved by design, manufacturing, maintenance, training, and awareness initiatives. This understanding will result in beneficial improvements in workforce in terms of the use of technological devices, equipment, and maintenance.

However, as electronic devices become smaller, faster, and more complicated, EMC engineers encounter new obstacles on a daily basis.New trends indicate that EMC is becoming more important around the world. Countries are being subjected to global standards, and test requirements are increasing. Designing with EMC in mind is becoming the standard rather than a vexing afterthought. As a result, appropriate PCB design, high-quality goods, and industry-leading support or after-sales service are critical to the success of EMC concerns.

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