BASICS OF ELECTROMAGNETIC COMPATIBILITY OF INTEGRATED CIRCUITS

A MODELLING APPROACH USING IC-EMC

Alexandre BOYER
Etienne SICARD
INSA de Toulouse

To Anouck and Victor

To J. J. Whalen

ACKNOWLEDGEMENTS

We wish to warmly acknowledge all our former PhD students who developed numerous case studies presented in this book: Bertrand Vrignon, Enrique Lamoureux, Cécile Labussière, Samuel Akue Boulingui, Céline Dupoux, Mickael Deobarro, Amadou Cisse Ndoye, Bihong Li, He Huang, Laurent Guibert, Veljko Tomasevic and Chaimae Ghfiri. We would also like to thank Sonia Ben Dhia and Sebastien Serpaud for their positive support and constructive remarks about our IC-EMC tool, together with all our colleagues in the area of electromagnetic compatibility of integrated circuits who inspired us through fruitful discussions and collaborative research.

We are also grateful to Delphine Libby-Claybrough and Marie-Agnès Detourbe for their English editing assistance. We would furthermore like to acknowledge the publishing opportunity provided by the editors of the Engineering Book Series of “Presses Universitaires du Midi”, Jean-Marie Dilhac and Thierry Monteil. Our thanks too to all the research project leaders who co-funded our research, contributed to the development of the IC-EMC tool and supported the writing of this book (MEDEA, EPEA, SEISME, ANR, IRT Saint-Exupéry and MECA).

We also wish to thank our wives for their patience and for encouraging us to complete this work despite the time it meant spending away from them. Last, but not least, we would like to acknowledge the support received from European programme Erasmus+ Knowledge Alliance - MicroElectronics Cloud Alliance in order to publish this book.

April 2017

Alexandre Boyer
Etienne Sicard

Contents

chapter I

INTRODUCTION TO THE ELECTROMAGNETIC COMPATIBILITY OF INTEGRATED CIRCUITS

Before addressing integrated circuits (ICs), this chapter defines the notions of electromagnetic interference and electromagnetic environment, with a brief overview of the sources of electromagnetic disturbances which can affect the operation of electrical, electronic and radio equipment. Some examples of real cases of failures induced by electromagnetic disturbances are then presented to highlight the risks for the safe operation of electronic systems and the need for electromagnetic compatibility (EMC). The notions of emission, immunity, susceptibility and coupling path are defined. As EMC is extremely important for safety reasons, it is a legal requirement in most countries. This chapter briefly describes aspects of EMC regulations in Europe and the USA. Although EMC is not a legal requirement for integrated circuits, this introduction explains why EMC has become a serious concern for both IC manufacturers and end users. Finally, the book's scope and organisation are presented.

1. ELECTROMAGNETIC INTERFERENCE

> Electromagnetic interference (EMI) is the disturbance of an electrical or electronic device's operation (e.g. error, loss of performance or degraded operation) caused by electromagnetic fields produced by an external source.

EMI can be induced by natural or man-made sources, as explained in part 2. Incoming disturbing signals or electromagnetic (EM) noise are coupled to the victim equipment through one or more of the following three mechanisms:

- the disturbing signals are conducted from the source to the victim over a power supply network, for example. This is known as conducted coupling;
- the disturbing signals are induced on the victim by the nearby presence of the source. This coupling mechanism, related to electric field and/or magnetic field coupling, is known as crosstalk;
- the source produces EM radiation which is coupled to the victim through what is known as radiated coupling.

When the disturbing signal spectrum lies in the radio frequency (RF) range, i.e. the practical frequency range of radiocommunications from 30 kHz up to 10 GHz, EMI is also called radio frequency interference (RFI).

We are all familiar with EMI. A classic example is the disturbance of radio reception, such as the interference to old analogue TV receivers by nearby electrical devices. More recently, digital video broadcasting - terrestrial (DVB-T) receivers are still sensitive to EM disturbance. For instance, cases of interference with a DVB-T receiver by a 4G Long-Term Evolution (LTE) base station operating in the 800 MHz band are reported regularly [Pol15]. Another familiar example of EMI is a mobile phone or WiFi signal captured and demodulated by a speaker system.

2. Electromagnetic environment

The electromagnetic environment covers all the electromagnetic phenomena in a given location. The EM environment can produce EMI. Characterising the electromagnetic environment means determining the sources of electromagnetic noise, their time or frequency domain properties and their typical amplitudes. Figure 1- 1 summarises the usual EMI sources.

> Electromagnetic noise sources can be classified in two different categories:
> 1. natural noise sources
> 2. man-made noise

Natural noise sources are related to natural phenomena such as radiation from the Sun, galaxy, atmosphere or lightning. Even though man-made noise may be related to EM noise produced naturally by man, such as electrostatic discharge (ESD), it mainly covers noise created by the electrical and electronic devices, equipment and systems manufactured by humans.

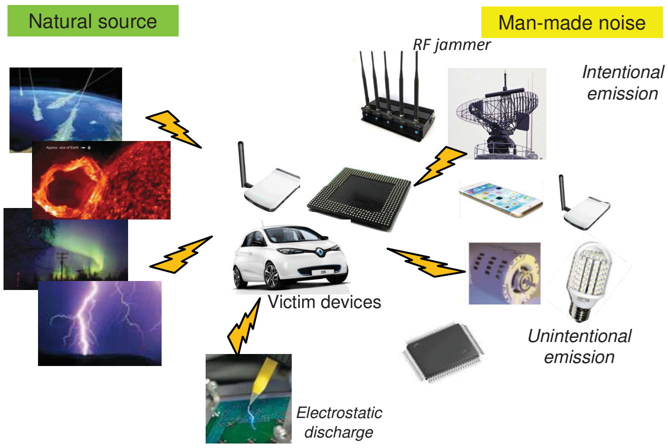

Figure 1- 1: Electromagnetic environment - Common EMI sources

Man-made noise sources can be divided into several sub-categories. EM noise sources can be built specifically to generate EM radiation and induce EMI on victim devices. Such intentional radio jamming occurs mostly in the context of electronic warfare or criminal actions [Bee14]. Conversely, wireless communication systems or radars are not designed to create EMI, but use EM radiation to transmit signals or perform measurements. They may, however, produce spurious signals affecting victim devices and causing unwanted disturbance of their nominal operation. Most radio systems produce modulated harmonic disturbances. The occupied frequency range is quite narrow, which is why we talk about narrowband interference sources. To regulate the use of radio spectrum resources and mitigate the risk of EMI due to RF communications, radio spectrum management has been developed worldwide since the 1930s.

However, most electrical and electronic equipment produces unintentional EM noise due to the transient current produced. This includes electric motors and their drivers, switches, relays, power converters, digital devices, LED bulbs and LCD panels for example. This kind of equipment has essentially pulse waveforms that occupy a broad frequency range. Since their spectrum is spread over several decades, we talk about broadband interference sources. Solving EM problems due to this type of source is a complicated task because the mitigation techniques have to be efficient over wide frequency ranges. Figure 1- 2 presents the spectrum of the broadband EM noise produced by two different electronic devices. The upper spectrum shows the noise produced by a switched-mode power supply conducted along the power supply cable harness. Although the switching frequency is equal to 230 kHz, a large number of harmonics occupy a wide frequency range up to nearly 100 MHz. The lower spectrum is that of the current flowing through the ground pins of a microcontroller. The embedded program induces a regular cycle with a frequency of 6 MHz. Multiple harmonics of this fundamental frequency are clearly visible up to 1 GHz. In both cases, even though the high order harmonics of the conducted emission are of a small amplitude, they should not be neglected as they may contribute to radiated electromagnetic emissions.

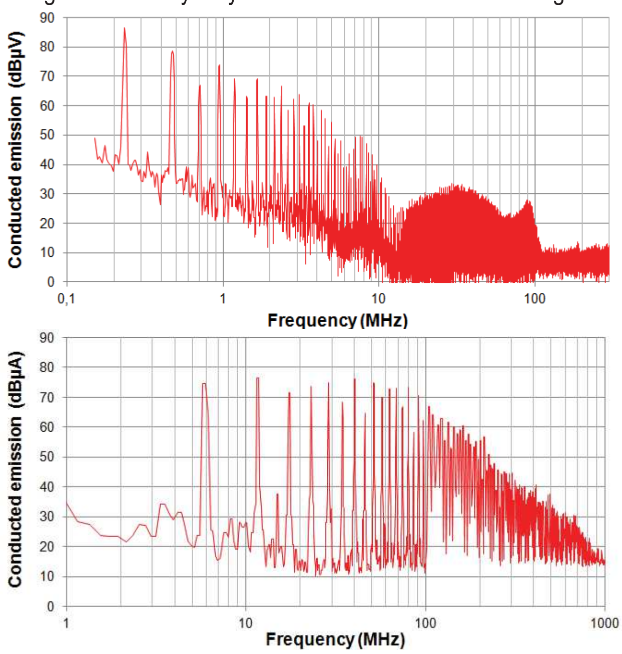

Figure 1- 2: Broadband interference sources: conducted emission produced by a switching-mode power supply (top) and a microcontroller (bottom)

It is difficult to evaluate what may be considered a "usual" ambient electromagnetic field. It can be very high close to RF power sources such as a radar, TV broadcast transmitter, electrically-powered machinery or a cell phone base station. For instance, the maximum electric field for the latter being able to reach 20 V/m 10 m from the base station. Surveys such as [Lar88] about the peak electric field above airports showed that it can reach between 15 V/m and 1 kV/m over the range 10 kHz - 40 GHz. Similarly, it is reported in [Vas15] that the low-frequency magnetic field 20 cm from the 70 kW power train of an electric vehicle may reach 150 A/m, leading to serious concern about EMC and human exposure to EM fields.

Far from identified noise sources, different models have been developed to evaluate the ambient EM field due to natural and man-made noise in different types of environment, such as those reported in ITU-R 372-11 [ITU-R]. Figure 1- 3 presents the ambient man-made radiated noise predicted by this recommendation for different environmental categories. The receiver antenna is considered to be a half-wave dipole and the receiver bandwidth is set to 10 kHz. Man-made noise tends to decrease with frequency and is obviously greater in densely populated areas.

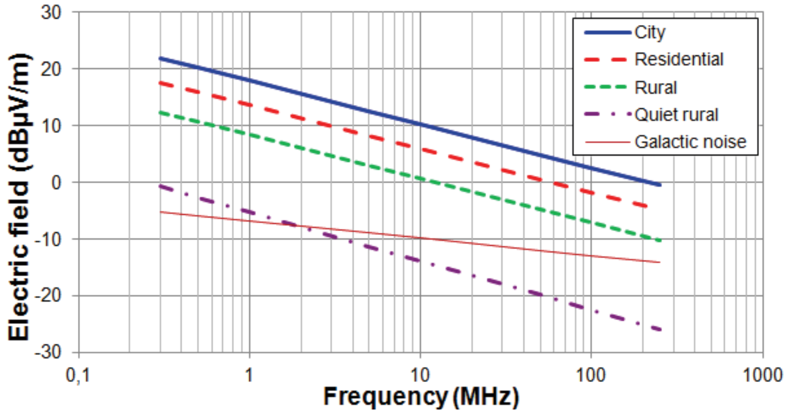

Figure 1- 3: Ambient radiated fields due to man-made noise predicted by ITU-R 372-11 (the receiver bandwidth is equal to 10 kHz and the receiving antenna is a half-wave dipole)

However, this estimation of man-made noise is now obsolete, since the values were extracted from measurements taken in the 1970s. Man-made noise is considered to be Gaussian in nature, although it is actually more pulse-like. Moreover, the predicted levels are usually underestimated because of the multiplication of noise sources since that period (with a sharp increase in wireless communication systems and digital devices). Recent surveys such as those reported in [Lef10] clearly show that EM noise is 20 to 40 dB higher in a semi-enclosed environment such as a production plant, office or vehicle environment, than that estimated by ITU-R 372-8 models. In urban and suburban environments, these surveys indicate that the electric field peak value may reach 1 to 20 V/m.

3. ELECTROMAGNETIC RISKS FOR ELECTRONIC SYSTEMS

This part reports some spectacular cases and surveys of EM interference for various types of application. The resulting loss of performance and risks for consumers justify a consideration of EMI during system design and the need for rigorous EMC characterisation.

3.1 ~ Effect of electromagnetic disturbance on radiocommunication systems

Radio receivers are sensitive to any noise within or near their receiving bandwidth, since noise cannot be completely filtered out. It is produced by nearby radio transmitters which produce in-band or adjacent band interference. One familiar example is the interference of IEEE 802.11 (WiFi) systems in domestic and professional environments. WiFi uses an unlicensed ISM band between 2400 and 2500 MHz, which is shared with numerous radio or electronic systems such as Bluetooth, Zigbee devices, cordless phones, cameras and microwave ovens, resulting in potential in-band interference, as illustrated in Figure 1- 4. It is reported in [Cis08] that if one or more of these devices are placed within eight metres of a WiFi terminal, the performance of the WiFi network may be affected.

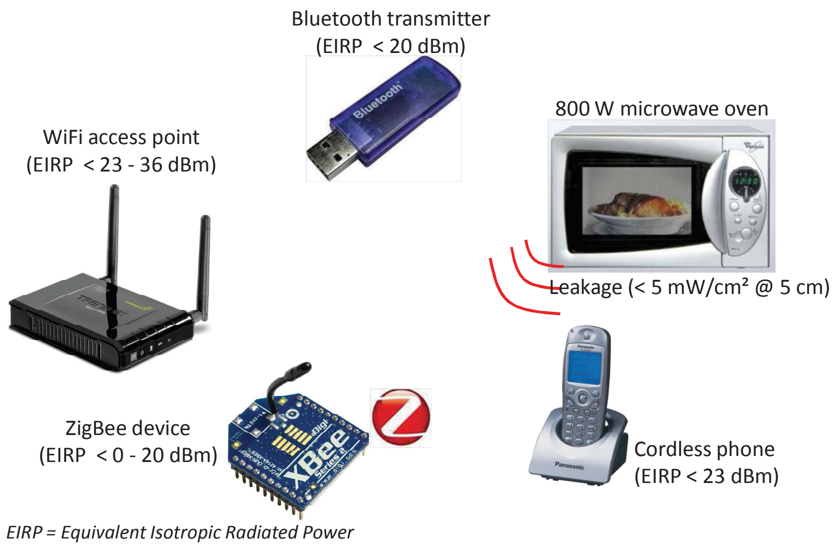

Figure 1- 4: Devices radiating energy at 2.4 GHz so likely sources of interference (the indicated maximum radiated power varies according to applicable regulations)

Radio interference may also be produced by broadband noise sources. For example, the noise created by lightning can severely degrade communications in HF band. An interesting case of radio interference due to man-made broadband noise is also reported in [Lef10]. The disturbance of a DVB-T receiver in a house situated near a railway track is described, and the interference scenario reproduced in a laboratory. The high impulse noise generated by the passage of a train interferes with the TV signal at 850 MHz. Another recent example concerns LED lights that may interfere with DVB-T reception [ACMA16]. In order to ensure low power consumption and a long life, LED lights are controlled by switching circuits that produce broadband noise covering a large spectrum from some tens of kHz up to hundreds of MHz [Mat14].

3.2 ~ Effect of electromagnetic disturbance on medical devices

EMI can have dramatic consequences when they concern medical devices. A tragic example is given in [Boe04], where radiated interference induced the involuntary ignition of a wheelchair, which was nonetheless certified by the manufacturer. EMI problems in medical devices are not insignificant events. The US Food and Drug Administration (FDA) reports all EMI cases linked to medical devices. They can be found in the MAUDE database (Manufacturer and User Facility Device Experience) [MAU]. Table 1- 1 sums up the cases reported by the FDA (whether proven or suspected) and the number of subsequent deaths. EMI affects equipment such as heart monitors, infusion pumps, pacemakers and respirators. These figures show an increase in EMI issues no doubt due to both the increase in portable medical devices and a noisier EM environment in hospitals.

Period	Reported cases	Number of deaths
1979 - 1993	91	6
1994 - 2005	405	6
2005 - 2015	4993	22

Table 1- 1: EMI problems affecting medical devices reported by the FDA [MAU]

3.3 ~ Effect of electromagnetic disturbance on military systems

The history of EMI affecting military electronic systems goes back a long way, starting with the military use of radio. There are stringent requirements on the protection of military equipment from RFI, but military history is nevertheless punctuated with several catastrophic events due to EMI. Two famous cases are presented here [NAS95]. The first one concerns the US aircraft carrier USS Forrestal. The coupling of a radiated disturbance produced by a radar on board the carrier with a plane coming in to land accidentally triggered the aircraft's weapon system. A missile was launched on a gas tank and a munitions stock, killing 134 sailors. The accident resulted in major damage requiring seven months of repairs. Investigations showed that the origin of the problem was a damaged shield termination on the aircraft, which should have prevented RFI coupling. After this major accident, the US Army's system level EMC requirements were revised.

In the second example, EMI indirectly led to a disaster. During the Falklands War, the British ship HMS Sheffield was hit by an Argentinean Exocet missile and subsequently sank. This situation should never have occurred because the Sheffield was equipped with the best antimissile defence system available in the early 80s. However, this system created EMI affecting the telecommunication systems of the Harrier jets assigned to the ship. In order to allow communication with jets on take-off, the antimissile defence system was disengaged. Unfortunately, Argentinian aircraft took advantage of this unforeseen situation and launched a missile. The explosion killed 30 crew members and injured another 24. The ship sank one week later.

3.4 ~ Effect of electromagnetic disturbance on aeronautical systems

Anyone who takes a plane regularly knows that electronic devices with a wireless function must be switched off during the flight. This safety precaution aims to reduce the risk of interference with the aircraft's radio systems. It is understandable when we see the numerous EMC-related incidents due to passengers' electronic devices recorded in the last 30 years, as shown in Table 1- 2 [NAS95]. Since 2002, the United States' Federal Aviation Administration (FAA) has reported 12 proven cases of failure due to EMI induced by electronic devices brought on board by passengers [ASRS12].

Suspected cause	Navigation aids	Communications	Radio navigation (VOR)
Cell phone	7	2	4
Laptop computer	5	0	2
Radio	3	1	0
GPS	0	0	1
Electronic game	1	0	2
CD player	0	1	1
Heart monitor	0	1	0
Television	1	0	0

Table 1- 2: EMI problems caused by a passenger's electronic device reported by the FAA (1986-2012)

3.5 ~ Effect of electromagnetic disturbance on automobile systems

Like aeronautical systems, automobile systems are safety critical, since any incident may lead to dramatic consequences for drivers, passengers and their entourage. That is why EMI is a serious concern for automobile manufacturers and their equipment suppliers. Manufacturers regularly recall vehicles to fix problems, which is an extremely costly operation harmful to their reputation. Although manufacturers do not communicate the exact nature of these problems, some are related to EMI [INT14]. One famous example of EMI is the effect on the first Anti-lock Braking System (ABS) by Mercedes-Benz in the 1980s. Some customers reported severe braking problems along a certain section of a German motorway. Engineers rapidly identified the source of interference—a nearby radio transmitter—and the short-term solution was to build a mesh screen along the roadside to reduce EMI [Nas95].

More recently, in 2015, we can cite the recall of 2.12 million cars by Chrysler, Toyota and Honda because of accidental airbag deployments that led to 81 injuries without car crashes [Com15]. The origin of these deployments was a noise problem generated by a component of the airbag control unit.

4. WHAT IS EMC?

4.1 ~ Definition

Electromagnetic compatibility (EMC) is a fundamental constraint that all electrical or electronic equipment must meet to ensure the simultaneous and safe operation of all nearby electrical or electronic devices in a given electromagnetic environment.

> EMC is the ability of a component, equipment or system to operate satisfactorily in a given electromagnetic environment without causing any harmful electromagnetic disturbance to systems placed in this environment

By definition, EMC covers two complementary aspects: electromagnetic emission and susceptibility to electromagnetic interference.

4.2 ~ Electromagnetic emission

In [IEC10], we find the following definition:

> Electromagnetic emission is the phenomenon by which electromagnetic energy emanates from a source and is released into its environment.

Except for wireless applications, electromagnetic emission is an unwanted phenomenon, and is also called radio frequency interference (RFI). For the purposes of simplification, this book will refer to emission.

Emission is caused by charge transfers within or between electrical or electronic devices. These transfers result in the circulation of transient currents. Switching devices such as digital ICs, bus drivers, RF circuits, switched-mode power supplies or motor drivers are typical sources of EM emissions. Transient current can circulate along circuit interconnects, PCB traces, connectors or cable harness. This conducted emission may lead not only to excessive voltage fluctuations, but also EM radiation or radiated emission.

Emission issues are illustrated in Figure 1- 5. In a vehicle, the main emission sources are the ignition system, the electric motors and actuators, and the digital circuits in the Electronic Control Units or bus drivers. The conducted emissions propagated by cable harnesses lead to radiation. The emissions may jeopardize the correct behaviour of other equipment in the car (e.g. safety functions), RF links or passengers' personal devices.

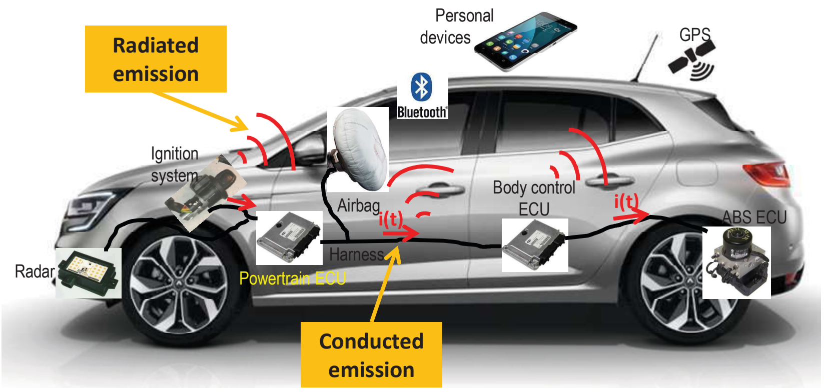

Figure 1- 5: Illustration of electromagnetic emission issues in the car industry

4.3 ~ Susceptibility and Immunity

Susceptibility and immunity are two opposite notions describing the same phenomenon. In [IEC10], they are defined as:

> Susceptibility qualifies the sensitivity of an electrical or electronic device, equipment or system—referred to as a victim—to malfunction or fail in the presence of electromagnetic disturbance.

> Immunity is the ability of an electrical or electronic device, equipment or system to perform without error, loss of performance or degradation in the presence of an electromagnetic disturbance.

Susceptibility due to the coupling of a radiated disturbance is known as radiated susceptibility. In the case of conducted coupling, we talk about conducted susceptibility. The coupling of EM disturbances can cause temporary malfunctions such as binary errors, voltage drifts, clock jitter, unwanted resets, RF blocking… or even permanent damage to the electronic equipment (including metal shorts, oxide breakdown or latch-ups).

Susceptibility to RFI is illustrated in Figure 1- 6 in the case of a radar wave illuminating an aircraft. This situation is very common in the vicinity of airports. A Giga-watt pulse is received by the plane, which captures energy that may flow to the equipment, the printed circuit board (PCB) and finally to the component, leading to a loss of performance, degradation or even failure.

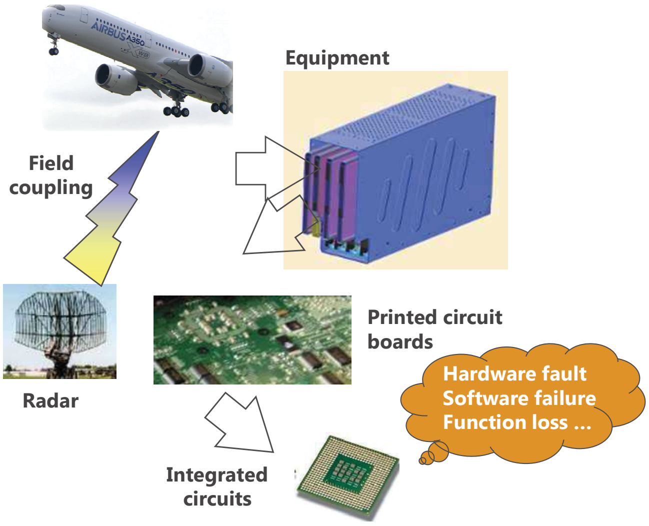

Figure 1- 6: Illustration of electromagnetic emission issues in an aeronautical context

4.4 ~ Noise path

An EMC problem arises when equipment producing significant EM emission is placed in proximity to equipment that is sensitive to RFI, such that EM disturbances can be coupled efficiently from the source to the victim, according to one or other of the coupling mechanisms presented in part 1. The basic approach to analysing an EMC problem is the concept of a noise path, illustrated in Figure 1- 7. The construction of a noise path relies on identifying the RFI source, the victim and how the disturbance is carried from the source to the victim. The identification of each part of this path—and especially the coupling path—is not always easy.

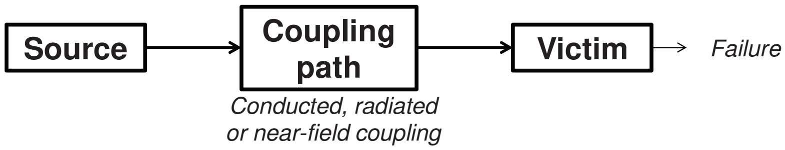

Figure 1- 7: Noise path: a chain linking the source, coupling path and victim

Mitigating an EMC problem consists in intervening to modify one or more of the three parts of this noise path:

- reducing electromagnetic emission directly at the source
- cutting off noise on the coupling path before it reaches the victim
- making the victim more robust against electromagnetic disturbances

A traditional approach to mitigating EMC problems consists in acting on the coupling path through filtering, shielding and proper grounding. Unfortunately, EMC problems are usually addressed at equipment and system level, i.e. on a nearly finished version. It can be more efficient to act directly on the source or victim. Reducing emissions and increasing the robustness of circuits decreases the occurrence of EMC problems and limits the number of filtering components or shielding required. This point will be addressed in part 6.

5. EMC REGULATIONS

Most countries worldwide have legal requirements on EMC for electronic and electrical devices intended for consumers, in order to protect citizens against the consequences of abnormal operation due to EMI and limit the "electromagnetic pollution" of the radio spectrum. EMC regulations state that electronic products must operate correctly in nominal EM environments and must not produce EM disturbance that can interfere with other equipment.
Therefore, the main concern for the manufacturers of electronic and electrical devices is the EMC certification of their products to prove their compliance with current EMC regulations, the declaration of conformity and conformity logo being affixed on the certified products (Figure 1- 8). Many countries have similar EMC requirements, but due to differences in the regulation process, measurement techniques and limits, EMC certification in one country is not systematically valid in another. For example, the CE conformity mark has no legal significance in the USA. Products certified for the European market cannot be placed on the US market without going through the FCC certification process.
This part briefly describes the EMC regulations for consumer electronics in Europe and the USA. More information can be found in books such as [Wil07]. Not all industries (such as the automobile, aeronautical or defence industries) are subject to the same EMC regulations. Historically, these industries took EMC into consideration before EMC regulations were introduced on consumer electronics, so they have kept their own EMC certification processes, which are usually more stringent than the EMC requirements for consumer products.

Conformity mark	Validity area	Logo
Conformité Européenne	European Economic Area	CE
Federal Communications Commission	USA	FC
Voluntary Council for Control of Interference	Japan	VCI
China Compulsory Certificate	China	CCC
Australian Communications Authority (ACA)	Australia / New Zealand	
GOST (State Committee for Quality Control and Standardization)	Former USSR countries	PCT
Korea Communications Commission	South Korea	KC
Bureau of Standards, Metrology and Inspection	Taiwan	

Figure 1- 8: Different EMC conformity markings and their area of validity

5.1 ~ EMC legislation in Europe

In the European Union, all consumer products must comply with the directives that are applicable to them in order to obtain the CE mark and be sold on the European market. A directive is a list of objectives defined by the European Commission and dedicated to one economic sector or industry. It aims to define a common framework for the marketing of safe and environmentally responsible products on the European market. Electrical and electronic devices must comply with several directives to be marketed in Europe, such as the Low Voltage Directive (2006/95/EC) for safety regulations or the RoHS Directive (2002/95/EC) for hazardous substances.

Since 1996, all electrical and electronic products must comply with European EMC Directive 89/336/EEC before they can be placed on the European market. This directive was repealed in 2007 by Directive 2004/108/EC [Eur04] and will be replaced in 2016 by new EMC Directive 2014/30/EU. The EMC Directive applies to all “apparatus,” "components" and "sub-assemblies" able to disturb the EM environment or susceptible to EM disturbances, except:

- fixed installations such as industrial plants, power plants or airport facilities. However, the component parts must meet the requirements of the EMC Directive;
- radio and telecommunication terminal equipment, which is subject to R&TTE Directive 1999/5/EC, which integrates EMC requirements. The Radio Equipment Directive 2014/53/EU has replaces the R&TTE Directive for radio equipments since 2016;
- electro-medical equipment, which is subject to the Medical Device Directive (93/42/EEC), which also integrates EMC requirements;
- aeronautical and automobile equipment that comply with specific regulations.

> The EMC Directive requires that any "electrical apparatus", "components" or "sub-assemblies" placed on the European market must avoid generating electromagnetic disturbance able to interfere with radio or telecommunication equipment, and more generally the operation of any equipment. Reciprocally, it must be sufficiently immune to electromagnetic disturbance for its operation to remain unaffected.

According to [Eur04], "apparatus" means any finished appliance commercially available as a single functional unit, while "components" or "sub-assemblies" are intended to be incorporated in the "apparatus" by end users (e.g. a USB stick or graphics board). Manufacturers of "electrical apparatus", "components" or "sub-assemblies" must confirm that this directive has been applied by delivering a declaration of conformity and affixing the CE mark to their product. Moreover, a technical report on the EMC compliance tests carried out must remain available for ten years after production.

Are electronic components covered by the European EMC Directive?

Although the EMC Directive mentions "components", electronic components such as integrated circuits are not covered by the EMC Directive. Indeed, an individual electronic component is not a functional unit for the end user. They are not marketed independently like finished "apparatus" because they have to be assembled in a final product. However, the manufacturer of the final product must check that the electronic components themselves do not produce unacceptable EM interference and are not vulnerable to EM disturbances.

The EMC Directive recommends using reference norms known as harmonised standards, tailored to the product and its operating environment, in order to verify the supposed conformity to the EMC Directive. Harmonised standards define the emission and immunity limits and test methods. Harmonised standards for EMC emanate from three sources: the International Electrotechnical Committee (IEC), the International Special Committee on Radio Interference (CISPR) and the European Telecommunications Standards Institute (ETSI). There are three types of harmonised standards:

- **Basic standards** define the general rules for test measurements, result analyses, test reports and the characterisation of test equipment. They are often used by the other harmonised standards.
- **Generic standards** define general tests and EMC limits for equipment, whether in a residential or industrial environment.
- **Product standards** define tests and EMC limits for a specific product family in a specific environment.

Obviously, manufacturers have to identify the most suitable product standard. If no product standard is really suitable, generic standards are applied. They give the minimum requirements for CE marking. Table 1- 3 lists some examples of commonly-used harmonised standards.

Type	Name	Title
Basic standard	EN 61000-4-X (1 ≤X≤33)	EMC – Testing and measurement techniques
Generic standard	EN 61000-6-1/2	Generic immunity standard for residential/ industrial environments
	EN 61000-6-3/4	Generic emission standard for residential/ industrial environments
Product standard	EN 55011	Industrial, scientific and medical equipment
	EN 55013	Broadcast receivers and associated equipment
	EN 55014	Household appliances, electrical tools and similar apparatus
	EN 55015	Electrical lighting and similar apparatus
	EN 55022	Information technology equipment
	EN 60601-1-2	Medical electrical equipment - General requirements for basic safety and essential performance - Electromagnetic disturbances - Requirements and tests

	EN 330220	EMC and radio spectrum matters; Short Range Devices, 25-1000 MHz
	EN 330330	EMC and radio spectrum matters; Short Range Devices, 9 kHz-25 MHz

Table 1- 3: List of commonly-used harmonised standards for CE marking

5.2 ~ EMC legislation in the USA

Since 1975, conducted and radiated electromagnetic emissions for electrical and electronic devices (initially only computer and digital devices) have been regulated by Part 15 of Title 47 (Telecommunication - Radio Frequency Devices) of the Code of Federal Regulations drafted by the Federal Communications Commission (FCC) in order to protect radio and telecommunications [FCC47]. This Code covers the technical specifications, administrative requirements and other conditions relating to the marketing of FCC Part 15 devices. FCC certification is required for devices classified as 15 (information technology equipment, TV receivers, switched-mode power supplies, low power emitters, unlicensed personal communication devices etc.). Regulations also exist for industrial, scientific and medical devices that generate electromagnetic emission, i.e. class 18 devices, which are regulated by Part 18 of Title 47 of the Code of Federal Regulations. FCC regulations have defined limits for conducted and radiated emissions according to the product application and classified according to two types:

- Class A: commercial, industrial and business applications
- Class B: residential applications

As in Europe, the automobile, aerospace and military industries are exempt from FCC requirements, but depend on other authorities (namely the Society of Automotive Engineers, the FAA and the Department of Defence). It should be noted that FCC regulations do not consider immunity because they do not threaten radio or telecommunication systems. However, many manufacturers create their own standards for immunity testing and limits. As in the European Union, electronic components are not covered by FCC regulations.

5.3 ~ Special EMC legislation

Some industries, such as the aerospace, avionics, automobile or military sectors, have their own EMC requirements. They are not subject to EMC regulations for commercial products such as the European EMC Directive or FCC Title 15. Table 1- 4 gives some common EMC-related standards used in these industrial domains.

Field of Application	Standards
Automobile	ISO 7637, ISO 11451/11452, CISPR 25, SAE J1113
Aeronautical	RTCA DO-160-G, EUROCAE ED-14
Military	MIL-STD-461E

Table 1- 4: Examples of EMC standards for automobile, aeronautical and military electrical/electronic applications

5.4 ~ Evolution of EMC regulations

EMC regulations have been adopted everywhere and the electrical and electronic industries are aware of EMC problems. Moreover, all the theoretical background on electromagnetism, electricity and electronics is well-known. So why are EMC problems not yet resolved, and why are EMC experts still working on new recommendations, new measurement standards and new modelling tools? We admit that EMC problems are difficult to solve due to the complexity of EM phenomena, but over time, the expertise of EMC engineers and electronics designers should have expanded and the characterisation and modelling methods become more and more efficient.

The answer is that EMC cannot become a static engineering discipline as long as technologies continue to evolve. As new technologies are introduced, so the EM environment changes: new interference sources appear, with new waveforms and spectral contents. Let us look, for example, at developments in the area of radiocommunications. Most of today's EMC standards were defined with analogue modulation receivers in mind, but nowadays, most radio systems use complex digital modulation schemes. Besides, electrical and electronic equipment occupies an increasingly important place in our society. It is only possible to develop the Internet of Things, to wear medical devices or use self-driving cars if their safe and reliable operation is ensured whatever the EM environment and nearby electronic equipment.

The problem is that the coexistence of all these new technologies cannot be guaranteed as long as they have not been developed and placed in close proximity. This is why EMC regulations and standards have to be regularly updated to gear them to the new EMC issues that arise due to on-going technological developments.

6. THE EMC OF ICS

For many stakeholders in the electronics industry, there are no EMC concerns at such a fundamental level as ICs since EMC problems are traditionally addressed at PCB, equipment or system levels. Moreover, ICs are not subject to EMC regulations such as the European EMC Directive. However, ICs are not EMC-proof. Although they are not finished "apparatus", they are electrical devices after all. Actually, semiconductor devices are often both the source and the victim of EM interference [Ben06]. Various EM noise coupling mechanisms can apply to integrated circuits, including wired connections such as the supply lines, coupling of the package leads to electric or magnetic fields, or even the coupling of the field directly to the silicon chip (Figure 1- 9). Also represented in the figure are couplings through cables and PCB traces. Thus, EMC at PCB level depends on the emission and susceptibility of the ICs mounted on it.

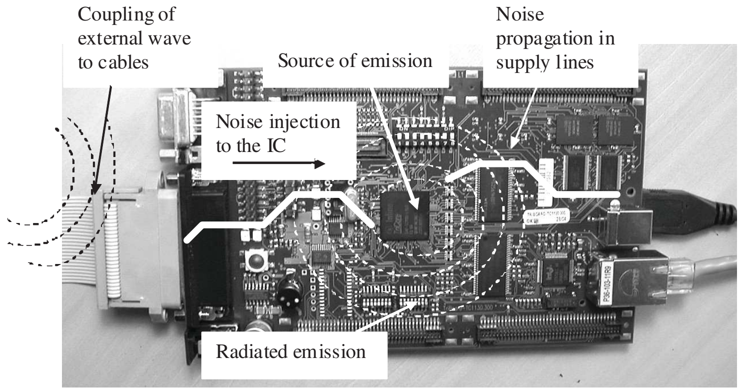

Figure 1- 9: Conducted emission, radiated emission and susceptibility of an integrated circuit

The following example illustrates the role of an IC malfunction due to EMI in an accident at system level [MIR11]. In December 2011 in Nanaimo, British Columbia, the bow propulsion pitch control on the Coastal Inspiration ferry failed to respond as the vessel was approaching the ferry terminal. The vessel accidentally struck the dock, leading to major damage to the vessel and ferry terminal, and minor injuries to seven passengers and nine crew members. The origin of the accident was a bow propeller which did not respond to the speed reduction command as the vessel was approaching the berth. A protective system against overload was activated. The power of the bow propeller is continuously monitored by a protective module to prevent the electrical generator from overloading and shutting down. An isolation amplifier was placed between the propulsion system and the protective module to protect it against noise and interference. Investigations demonstrated that this amplifier was responsible for the failure. Although it responded correctly in normal conditions, it did not deliver the correct voltage when an external magnetic field was applied, making it impossible to adjust the speed correctly. This accident could probably have been avoided if a more EMI-resistant amplifier had been used.

6-1 ~ Why address EMC at IC level?

The purpose of this part is not to convince the reader that EMC problems can be fully solved at IC level. EMC closely depends on PCB routing, external filtering, equipment and system grounding, shielding etc. Addressing EMC at circuit level allows an effective reduction in noise sources and failures due to external RFI. It can provide efficient solutions for facilitating EMC mitigation at PCB or equipment level, and can also reduce EMC compliance costs by removing certain protective devices against EMC. Moreover, it reduces the time needed to develop mitigation solutions at PCB level, which have to be redesigned for each new specification.

For example, let us suppose that for a given application, two ICs are available. They are pin-to-pin compatible and have nearly the same performance, except that one produces less EM emission or is less vulnerable to RFI. For EMC-critical applications, a circuit that is robust to EMI is a real advantage for the application designer since it may help save time and money in mitigating EMC issues. It is important enough to make EMC one of the constraints of IC specifications. EMC is taken seriously into account since it is the third cause of IC redesign, just after functional and power consumption issues.