DESIGN GUIDELINES FOR A ROBUST ELECTROMAGNETIC COMPATIBILITY OPERATION OF APLICATION SPECIFIC MICROELECTRONIC SYSTEMS

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Key words: Electromagnetic compatibility, EMC, EMI, ASIC, GTEM,

Abstract: Proper operation of microelectronic systems is often influenced by electromagnetic interference. While the geometry and power supply voltage of the microelectronic structures are decreasing, the demand for emission robust integrated circuits is increasing. Designing the integrated circuit for electromagnetic compatibility is therefore necessary, to achieve the desired functional performance, as well as to meet legal requirements. Example here can be automotive market, where several strict regulations must be fulfilled. It is a good practice, to incorporate known guidelines and use simulation tools for electromagnetic compatibility from the beginning of the project. Later redesign of the microelectronic system, to fulfill the electromagnetic compatibility test, is very expensive and can cause serious product delays and consecutive market loss. Conversely, incorporating all the best electromagnetic immunity practice at the beginning, can lead to the product being over engineered and expensive to produce. In this article several electromagnetic compatibility design guidelines and practical solutions for microelectronic systems are presented.

Priporočila za načrtovanje elektromagnetno robustnih mikroelektronskih sistemov po naročilu

Kjučne besede: Elektromagnetna združljivost, EMC, EMI, ASIC, GTEM,

Izvleček: Na pravilno delovanje mikroelektronskih sistemov pogosto vplivajo elektromagnetne motnje. Z zmanjševanjem velikosti mikroelektronskih struktur in njihovih napajalnih napetosti, so se povečale zahteve za elektromagnetno robustnost integriranih vezij. Upoštevanje elektromagnetne združljivosti, je torej potrebno tako zaradi pravilnega delovanja vezja, kot tudi zaradi upoštevanja predpisanih zakonov elektromagnetne združljivosti. Dober primer je tržišče avtomobilske elektronike, kjer je potrebno striktno upoštevati strogo zakonodajo. Priporočila in rezultate simulacijskih orodij za elektromagnetno združljivost je smiselno upoštevati že od samega začetka projekta. Popravljanje končanih, elektromagnetno nezdružljivih mikroelektronskih sistemov je drago opravilo. Običajno povzroči tudi veliko zamudo izdelka in posledično izgubo tržišča. Po drugi strani pa lahko preveč striktno upoštevanje vseh faktorjev glede elektromagnetne združljivosti po nepotrebnem podraži izdelek. V članku smo navedli priporočila in praktične rešitve za elektromagnetno združljivost mikroelektronskih sistemov.

1 Introduction

The technique of electromagnetic compatibility (EMC) is very important engineering process, to ensure that various electrical devices may operate simultaneously without interfering with each other. EMC is mostly influenced by internal or external electromagnetic emissions that are usually caused by pulsing electrical current. The transition time of such pulse is very important. It determines the spectral image of possible electromagnetic interference (EMI), which may disturb the normal operation of another device or microelectronic system. Fast transition time generates wider spectral image that can more easily cause electromagnetic interference at certain frequencies. This phenomenon may degrade the quality of analog signals or corrupt digital signals. Some claim, that only fifteen percents of devices that have not been designed for EMC, are likely to pass EMC testing for the first time.

We can say, that device is electromagnetically compatible, when it is capable to satisfy all the operating specifications in electromagnetic environment and meet all legal requirements about electromagnetic emissions. More precisely, microelectronic system is electromagnetically compatible with its environment, when it satisfies the following criteria:

- It does not cause EMI to other systems.
- It is not sensitive to EMI from other systems
- It does not cause EMI to itself.

Various EMC standards for different applications specify levels and test methods to minimize these problems. EMI occurs, if the received amount of energy is strong enough, to cause the receptor to behave in erratic way. Electromagnetic energy can be transferred via different coupling modes:

- Radiated coupling (electromagnetic field)
- Inductive coupling (magnetic field)
- Capacitive coupling (electric field)
- Conductive coupling (electric current)

Figure 1 presents such system with emitter, coupling path and receiver. The sensitivity to electromagnetic interference of the receiver is also quite important.

Therefore the first step to reduce the amount of transferred electromagnetic energy would be to suppress the emis-

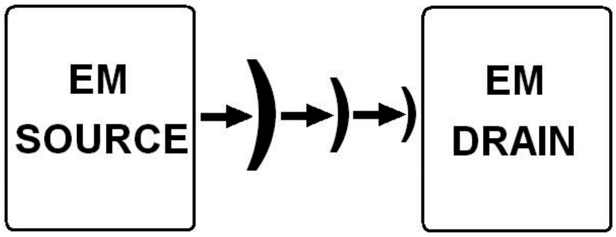


Fig. 1: EMC radiated coupling path with emitter and receiver

sion at its source. Further improvement of the problem, is to make the coupling path as inefficient as possible and the next step is, to make the receptor less susceptible to EMC. Minimizing the cost factor of the selected solution is also quite important. For example, to shield low cost systems with simple and effective conductive enclosure is usually too expensive.

EMC Directive in general is that electrical devices shall be so designed and manufactured, having regard to the state of the art and as to ensure that the electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or any other equipment cannot operate as intended and it has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.

The European Union's harmonized EMC Standards provide guidelines and limits for testing and include descriptions of test layout and methods, as well as defined maximum permissible limits of electro-magnetic emission and immunity levels.

2 Methods for better EMC compatibility of the integrated circuits

When designing an application specific integrated circuit (ASIC), we must consider several aspects of EMC. The most common trouble spots are EMI influence on power supply lines and input connections. Here we treat digital and analog input pins differently. Output emissions can be most efficiently suppressed by pulse shaping.

2.1 EMC and power supply lines

Power supply usually delivers to an integrated circuit some kind of AC signal, superimposed on the DC power line. Such AC signals can reach up to 100Vpp. Influence on power supply is presented on Figure 2. It is needless to say, how the difference in power supply for 1 or 2 volts affects modern low power and low voltage microelectronic systems.

The solution here is to properly increase the decoupling on the Vdd. High frequencies and transient currents can flow through a capacitor, in this case in preference to the

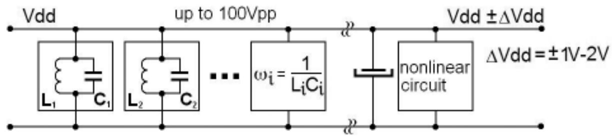


Fig. 2: EMC and power supply lines

harder path through the decoupled circuit, but DC cannot go through the capacitor, so continues on to the decoupled circuit. Some additional LC filters on power supply lines are also helpful. The best way to avoid this problem is to design the ASIC in a way that minimizes the influence of alterations in power supply voltage. In other words, we must guarantee by design as high as possible power supply rejection ratio (PSRR) at high frequencies.

2.2 EMI influence on digital input pins and solution

Figure 3 presents similar situation on digital input pin. Electromagnetic interference can easily generate additional ones and zeroes. Beside digital communication protocol automatic error correction, the solution of the problem is presented on figure 4. Each digital input pin should have some protective structures that will rectify at much higher voltages. For example, this solution is typical for automotive IC market.

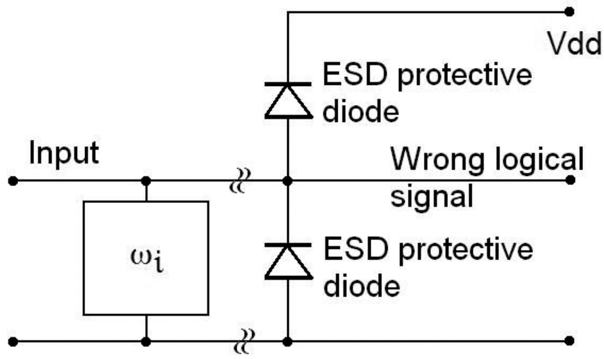


Fig. 3: EMI influence on digital input pin and solution

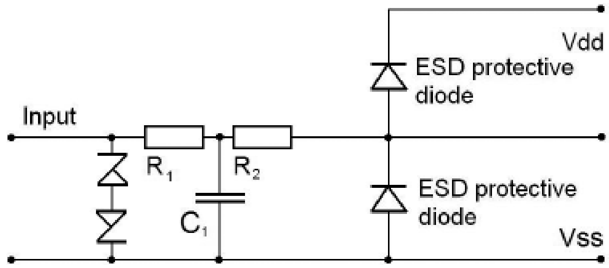


Fig. 4: Solution of EMI influence on digital input pin

2.3 EMI influence on analog input pins and solution

The biggest problems for EMC are analog input pins. If possible, the problem should be solved by an external LC filter. Figure 5 presents the solution for analog input pins. The protective structure is quite similar to that for the digital input pins. The difference is that here the integrated filter consist from LC and RC part.

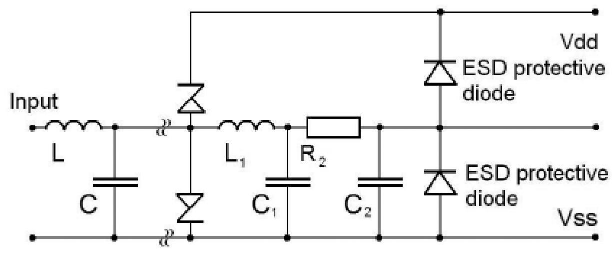


Fig. 5: EMI influence on analog input pins and solution

2.4 Methods to decrease electromagnetic emissions

The straight edge of the digital pulse (if perfectly vertical = zero rise time) represents a sinewave of almost infinitely high frequency. The faster the digital signal gets, wider is the slot of the frequency spectrum it occupies. Unfortunately such digital signals will radiate and cause interference in pretty much the same way, as may some intentional analog wave transmitters. The solution is presented on figure 6. By increasing the rise and fall time, such emissions can be drastically improved. It is also a good idea to keep the clock frequency as low as possible and rather to use some parallelism for speeding up the circuit.

$$t_r = t_f = \frac{C \cdot Vdd}{I_s} \tag{1}$$

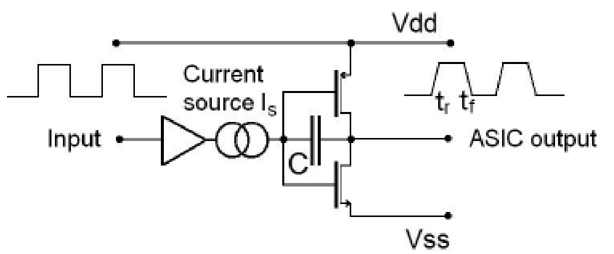


Fig. 6: Decreasing EMI with signal shaping

Another method to decrease the influence of the electromagnetic emission is in proper partitioning and positioning of the integrated circuit components. The topology of the ASIC and of the corresponding printed circuit environment should consider some of the following rules:

- Reduce the serial inductance to avoid resonance (package)
- Place Vdd and Vss supply as close as possible (use Vdd and Vss pad pairs)
- Use a grid of power supply network on chip
- Decoupling capacitance should be used for each active part of the circuit
- Identify and isolate noisy blocks – use separate supplies

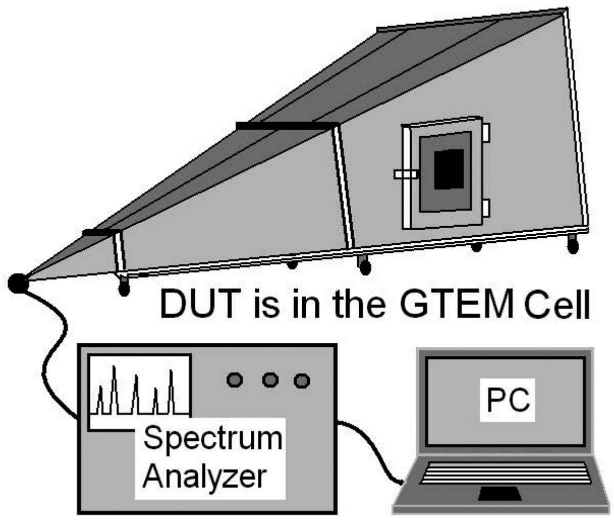


Fig. 7: GTEM cell with typical RF emissions test setup

- High frequency interconnections should be as short as possible
- Very sensitive analog or digital lines should be short
- Sensitive interconnections should be shielded – with ground wires or other layers if possible
- It is better to use two capacitors than one with the same nominal value
- High frequency interconnections should be away from the input and output structures

2.5 Measuring methods

Almost all EMC measuring methods require some generation of low and high frequency, high density electromagnetic field. Some tests require immunity of up to 300V/m. Testing should be done in an environment that allows measurements without disruption from external environment. For both, electromagnetic emission and immunity debugging purpose it is quite important to have a reflection and radio frequency free area for proper accommodating our device under test (DUT).

For small components there are several EMC compliance test cells with field strength sensor available on the market. They are basically divided in TEM (Transverse Electro Magnetic) and GTEM (Gigahertz Transverse Electro Magnetic) cells.

TEM cell is a small enclosure, to be used in normal laboratory environment for emission and immunity analysis. They are relatively inexpensive and do not require a high power amplifier; the drawback is that they can not operate at very low frequencies. By increasing its size, the lower frequency limit can be extended.

GTEM cell is larger. The tapered point and anechoic absorbers at the larger side of the pyramid shape, allow GTEM cell to operate well into the gigahertz range. Figure 7 presents GTEM cell with typical RF emissions test setup and figure 8 presents GTEM cell with typical RF immunity

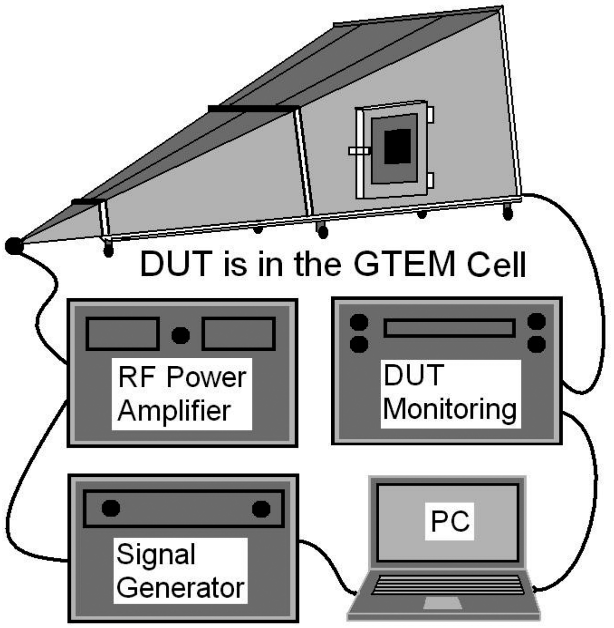


Fig. 8: GTEM cell with typical RF immunity test setup

test setup. A small, from 30W to 100W power amplifier with bandwidth from approximately 100 MHz to 1GHz will do the basic job. It boosts the spot frequency signals to achieve the required field strength. Tested device is exposed to each field for a fixed amount of time. Operation within specifications is checked and procedure is repeated for another, different DUT orientation within the test cell.

For emission compliance, the equivalence between testing in GTEM cell and testing in open area test site (OATS) has been formerly endorsed. On the other hand, the RF immunity testing in GTEM cell can be more or less used only as a pre-compliance verification. Final RF immunity verification should be done in an anechoic chamber. Better is the pre-compliance verification, shorter is the time in expensive anechoic chamber.

Alternatively, the radiated immunity can also be tested in somehow cheaper reverberation chambers. Entire truck or bus can be proofed for EMC in such chambers. They usually have a rotating tuner on the ceiling. Technically they are like a big microwave oven. RF energy is injected into a corner of the chamber and allowed to reflect off the walls, ceiling, floor and rotating tuner. At each reflection the wave loses a little of its magnitude. Consequently the reflected waves arrive at our measuring point inside the chamber with different magnitudes. The revolving tuner also changes the path lengths and the number of reflections of the waves. From few Hz to several GHz can be generated. The larger are the dimensions of the reverberation chamber the lower is the chamber's minimum operating frequency. The maximum useable frequency seems to be related only to the maximum power available to drive the chamber. Figure 9 presents such chamber.

However, measuring a field in a reverberation chamber looks more like measuring a noise and it doesn't give the operator any information about the direction and polarization. In the reverberation chamber we can measure only the total radiated power and not the electric field at a specified distance, as required by most test standards.

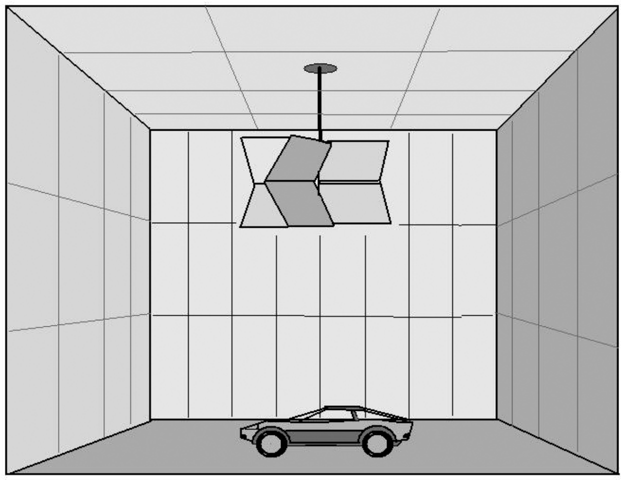


Fig. 9: Reverberation chamber with tuner on the ceiling

The full compliance EMC testing can be usually done in anechoic chambers. The materials used on the walls and ceiling of an anechoic chamber are such that there is a little, or no reflection of electromagnetic waves. This is accomplished by the geometry and the absorptive nature of these materials. They usually have a rotating platform for DUT. Such anechoic chambers are quite expensive and EMC measurements may take a considerable amount of time. So it is a good idea, to do some pre-compliance EMC measurements with ordinary laboratory equipment, when it is possible.

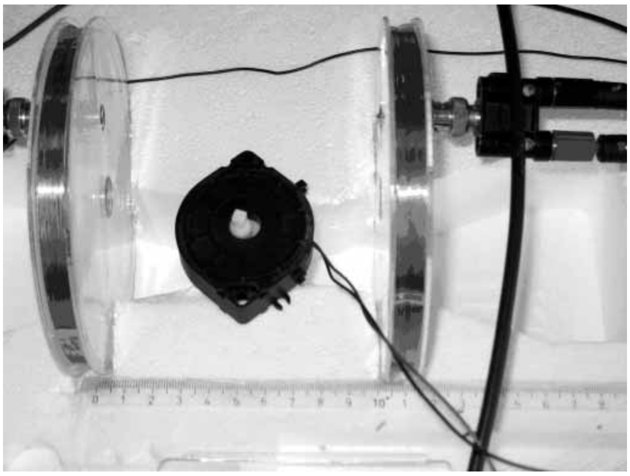
3 Examples of EMC measurements and solutions

3.1 Example of pre-compliance testing for EMC of automotive airbag sensor

Sensor for automotive airbag was developed in Laboratory of Microelectronics at University of Ljubljana. As guideline for measurements we used EMC standard MIL-STD-461E (5.18.4 RS 101 alt. test procedure AC Helmholtz coil). Sensor was measured in magnetic field that was generated by two opposite coils. Sensor was rotated in six different positions. Two such positions with the coils for the magnetic field generation are presented on figure 10. Frequency was varied from 50Hz to 10 kHz. Sensor passed the later EMC measurements successfully.

3.2 EMC solution for automotive steering wheel sensor

Automotive steering wheel sensor was also developed in Laboratory of Microelectronics at University of Ljubljana. The principle of sensor operation is to determine the automotive steering wheel position on the maximum interfer-



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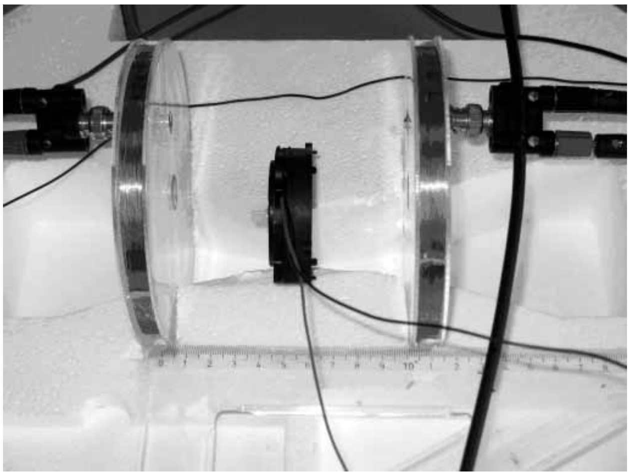

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Fig. 10: Example of different sensor positions while doing pre-compliance measurements of automotive airbag sensor for EMC

ence basis. The EMC problem here was that sensor was very susceptible to electromagnetic interference. Employment of shielding for the entire sensor did not satisfy the EMC, as well as extensive blocking of input and output pins. The problem was solved by modifying the sensor in a way, that sensor actually detects, when the electromagnetic interference happens on its momentarily operating frequency. Then it automatically switches to another frequency and continues an undisturbed operation. Figure 11 presents such disassembled, steering wheel sensor.

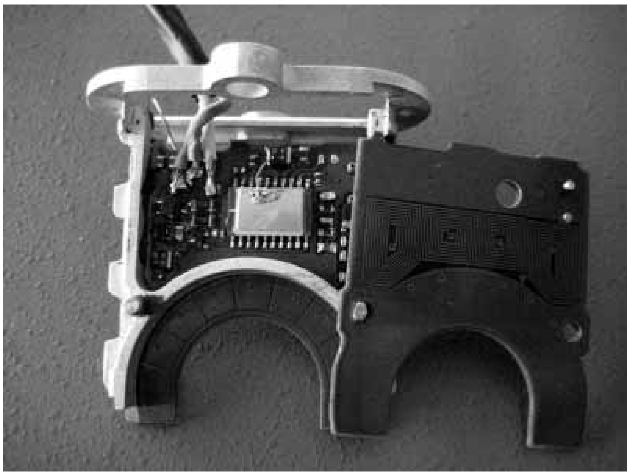

Fig. 11: Automotive steering wheel sensor with capability of switching operating frequencies to avoid EMI

4 Conclusions

The situation about EMC is getting worse, since we are using more and more wireless electrical equipment. That equipment operates at higher and higher frequencies and data rates. For example, the basic clock frequency of the common personal computer nowadays is higher than the transmission frequency used by cellular phones. Scaling down the integrated circuits and decreasing operating voltages to reduce power consumption makes modern electronic much more vulnerable to interference. Lower is the supply voltage, less tolerance we have for transients. And not at least, more and more digital transmission signals are cleverly packaged to fit as many separate channels as possible in the available spectrum. Such signals are usually hopelessly complicated mesh of the fundamental frequency, a load of harmonics, switching transients, sidebands and music from the local radio transmitter. Beside that, also heavy equipment is drawing large currents and strong electrical motors in particular, may cause transients that can propagate very far over the power supply network. Fortunately all kind of modern data communications protocols include at least some type of error checking and correction. Few lost bits in home DVD player may not cause a serious problem, yet few lost bits in medical or military equipment may be catastrophic.

The problem is also with standards compliance. It is often left up to the manufacturer to choose the most appropriate standard and the selected one may not be the most stringent one available, to match the electromagnetic environment of the product. So, like every other aspect of EMC, the standards compliance is no guarantee that the product will actually work in all circumstances. Therefore we may say in the end, that we have some good design guidelines, but there is no way of knowing exactly what will happen in real life of the product. However, it is possible in theory to design the product that will not make or accept any interference from other products, but it will be bulky, expensive and hard to sell. On the other hand, if we design cheap and for electromagnetic interferences sensitive electronic devices, nobody would buy them either. So designing for electromagnetic compatibility may be extremely convoluted, unpredictable and difficult business, and above all, it is always a subject of compromise. Furthermore always keep in mind that a user, manufacturer or even a provider of electrical device that caused material loses or any other harm to a third party due to electromagnetic compatibility, may be prosecuted.

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Prispelo (Arrived): 26.06.2008 Sprejeto (Accepted): 15.09.2008