SGS-THOMSON MICROELECTRONICS

**APPLICATION NOTE**

# EMC GUIDE-LINES FOR MICROCONTROLLER - BASED APPLICATIONS

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## INTRODUCTION

EMC must be taken into account at the very beginning of a project; the cost of correcting an EMC problem of an application encountered at the start of the production can be far greater that the cost of detailed EMC study during the development phase.

The use of microcontroller-based systems is increasingly pervasive, especially in such areas as consumer, industrial and automotive applications, where the drive for cost reduction is the common trend. This emphasis on cost reduction and the increasing complexity of such systems requires the manufacturers of the semiconductor components to develop highly integrated, single chip, high operating frequency microcontroller using the highest density technology possible. Unfortunately, for semiconductor structures, the higher the density and the faster the operation, intrinsically the higher the level of electrical noise generated, and the more sensitive to spikes induced from external noise. Therefore the PCB layout, the software and the system must now apply EMC "hardening" techniques in their design.

This note aims to provide guide-lines to the designer of microcontroller-based applications such that the optimum level of EMC performance can be achieved.

For general information about EMC, please refer to AN898.

# 1 EMC DEFINITIONS

Electro Magnetic Compatibility is the capacity of a piece of equipment to work properly in its normal environment, and not to create electrical perturbations that would interfere with other equipment.

Electro Magnetic Susceptibility (EMS) is the level of resistance to the electrical perturbations; electro magnetic fields and conducted electrical noise. Electro Magnetic Interference (EMI) is the level of conducted/radiated electrical noise sourced by the equipment.

There exists several norms addressing the EMS or EMI, and for every type of application area. These norms apply to the finished equipment. Up-to-now, there is no official norm applicable to the subsystem or electronic components. Nevertheless, EMC tests must be performed on the sub-systems in order to evaluate and optimise for EMC.

## 1.1 EMC NORMS

**Table 1. Emission**

| NORM | EQUIVALENT I NTERNATIONAL NORM | DESCRIPTION |
|---|---|---|
| EN50081-1 | | Generic emissions standards - Residential |
| EN50081-2 | | Generic emissions standards - Industrial |
| EN55011 | CISPR 11 | For industrial, scientific and medical equipment |
| EN55013 | CISPR 13 | For broadcast receivers |
| EN 55014 | CISPR 14 | For household appliances/tools |
| EN 55022 | CISPR 22 | For data processing equipment |
| | SAE 1752/3 | American Measurements Procedure for suscepti-bility |

**Table 2. Susceptibility**

| NORM | EQUIVALENT INTERNATIONAL NORM | DESCRIPTION |
|---|---|---|
| EN50082-1 | | Generic immunity standards - Residential |
| EN50082-2 | | Generic immunity standards - Industrial |
| EN50140 | IEC 1000-4-3<br>(old nb: IEC 801-3) | RFI (radiated test)<br>(80Mhz - 1 Ghz at 1 to 10 V/m) |
| EN50141 | IEC 1000-4-6<br>(old nb: IEC 801-6) | Induced RF fields (conducted test)<br>(150Khz - 80Mhz at 1 to 10V (80% AM, 1 Khz)) |
| EN50142 | IEC 1000-4-5<br>(old nb: IEC 801-5) | Surge |
| EN????<br>(still undecid-ed) | IEC 1000-4-4<br>(old nb: IEC 801-4) | EFT / Burst<br>(250V - 2kV I/O lines; 0.5 - 4kV AC/DC mains) |

# 2 ACTORS WITHIN EMC

Every part of a microcontroller-based application is relevant to specific EMC optimization according to its role reference to EMI.

## 2.1 SOURCES OF NOISE

Coming from the environment around the microcontroller the EMI sources are electrostatic discharges, mains, switching of high currents or voltages, RF generators,...

Coming from the microcontroller, the main noise contributors are:

– oscillator: continuous RF source

– system clock circuitry: RF divider followed by big amplifiers which drive long lines inside the component

– transitions of the outputs: the relative weight depends on the frequency of the transitions, and on the transition duration: shorter are the transitions, richer is the frequency spectrum

– bus(es) of data/addresses: for some microcontrollers a part of the memory space is external, implying continuous transitions on several lines.

### 2.2 CARRIERS OF THE NOISE

EMI can be transferred by electromagnetic waves, conduction, and inductive/capacitive coupling. Obviously, EMI needs to reach the conductors to disturb the components. It means that the loops, the long length and the large area of the conductors are vulnerabilities and make the PCB the principal subject of EMC improvements.

### 2.3 VICTIMS OF THE NOISE

In a microcontroller-based system, the core process is intrinsically sequential and must rely on valid data. A non EMC-guarded program, when disturbed one time is not able to resume a normal operation.

From the electrical point of view, the major vulnerabilities are:

– system-clock integrity

– memory cells - not only memory blocks, but as well, registers and memory cells supporting the state machine of the processor

– important signal like RESET, INTERRUPT, HANDSHAKING STROBE.

## 3 WINNING COMPLIANCE WITH EMC

Knowing the actors, the game to improve EMC consists of decreasing emissions of the sources, increasing immunity of the possible victims and weakening the capacity of the medias to transfer the noise.

### 3.1 PRINTED CIRCUIT BOARD

The technical considerations lead to a choice of a multi-layer PCB with a layer 100% dedicated to the ground and another one to $V_{DD}$ supply; this choice makes for a good decoupling, plus a good shielding effect. For a lot of applications, the economical constraint does not allow such a board: assuming this to be the case, the most important feature is to save a good structure for:

1. the GROUND

2. the POWER SUPPLY

#### 3.1.1 Components positioning

A preliminary layout of the PCB must separate the different circuits according to their EMI contribution, to reducing the cross-coupling on the PCB: noisy / high current circuits, low-voltage circuits, and digital components.

### 3.1.2 Ground and power line ($V_{SS}$, $V_{DD}$)

The GROUND should be distributed individually to every block (noisy, low level sensitive, digital,...) with a single point to gather all the ground returns. Loops must be avoided or have a minimum area. Then the power line should be implemented close to the ground line to minimize the area of the supply loop: acting as an antenna, the supply loop is the main emitter and receiver of EMI.

All the free area of the PCB must be filled with additional ground to create a kind of shielding (moreover for a single layer PCB).

### 3.1.3 Decouplings

The standard decoupling of a microcontroller is a pool capacitor 100 µF typically (to avoid aluminium electrolytic capacitor: poor HF performance), and in parallel, a high frequency capacitor 0.1 µF. These capacitors must be as close as possible the pins $V_{SS}/V_{DD}$ of the component to reduce the effective loop area.

As a general rule, the decoupling of all the sensitive or noisy signals improves the EMC performance; there exist 2 types of decoupling:

- capacitors close to the components. One must take care of the inductive characteristic which exists for all the capacitors beyond a certain frequency, if possible, parallelized capacitor with decreasing values (0.1, 0.01,... µF) should be used
- inductances. They are often ignored; nevertheless, for example, ferrite beads are excellent: good dissipation of the EMI energy, no DC voltage loss (not the case for simple resistors).

### 3.1.4 Oscillator

Almost all the microcontrollers have an oscillator coupled to an external crystal or ceramic resonator. On the PCB, the traces to EXTAL/XTAL/$V_{SS}$ (for external capacitors) must be as short as possible. Some resonators include these capacitors and allow the shortest traces.

The RC option is potentially sensitive to spikes which can create too short clock period, the resonator option is preferable.

### 3.1.5 Other signals

Consideration of EMC should lead the designer to pay attention to:

- noisy signal (clock...)
- sensitive signal (high impedance...)

plus

- signals for which a temporary disturbance affects the running process permanently (the case for interrupt, hanshaking strobe/not the case for LED command).

A surrounding ground trace for these signal yields benefit for EMC, together with short length, no proximity of noisy and sensitive traces (cross talk effect).

For digital signals, the best possible electrical margin must be reached for the 2 logical states and slow schmitt triggers are recommended to eliminate parasitic states.

## 3.2 PROGRAMMING, EMC HARDENED SOFTWARE

### 3.2.1 Parallel processes

With a programmable system, an obvious possible EMS weakness arises from an unique process relying on valid memorized data: at first, the unique process must be split into parallel and independent processes, as many as possible. This is particularly important for the guarding functions like watchdog, refresh routine, initializing routine. Additionally such a split is useful during the EMC debug to locate a weakness.

### 3.2.2 Watchdog

The watchdog is a circuit which must be updated inside a maximum time slot, other. The best system is to have the watchdog independent of the CPU (not built with a soft routine). For example, SGS-THOMSON's ST62 microcontrollers have a watchdog integrated in the component, and able to run independently of the CPU.

The routine to update the watchdog must be treated as a critical process, to reduce the chance to update the watchdog when the process has left the normal execution.

### 3.2.3 Free memory

In many cases, the internal program space is not used 100%: this creates a free area where normally, the application program must never take instructions. The area must be used as a trap which leads to a Reset routine: the method consists in filling this area with NOPs followed by "JUMP to Reset routine".

### 3.2.4 Hardening the software

Several other tricks improve the EMC performance:

- periodic self-check of the data integrity (checkum...)
- around the execution of a critical task, redundancy of data and check to detect a runaway condition
- to create a kind of milestone (i.e. trace point) throughout the program and to check with a "status register" that the step n is following the step n-1.
- periodic up-dating of the control/data registers; this is particularly useful for the I/O registers which are in the first line to face EMI.

Every detected runaway condition must lead to the initialization routine.

## 3.3 SYSTEM ARCHITECTURE

At the very beginning of a project, some starting decisions have to meet the EMC optimization requirements.

### 3.3.1 Location of the PCB in the application

The proximity of wires carrying the mains and switched on/off several times must be prohibited, the same for very high voltage lines or very high current lines.

Sometimes, "natural" shielding may exist in the application, it should be used wisely.

### 3.3.2 SMC or conventional through hole components

The SMC allows a higher density giving shorter traces on the PCB. For the microcontrollers, the SMC packages like SO, QFP reduce the length of the signal lines and allow a small loop of the power line.

### 3.3.3 Choice of the microcontroller

It is useless and dangerous for EMC to adopt a microcontroller with a high clock rate if this feature is not requested by the real-time constraints of the application. In case of a requested high system-clock frequency, some microcontrollers (like the ST9 family of SGS-THOMSON) have an internal PLL to build a system clock frequency higher than the frequency of the oscillator with an external resonator (EMI reduction). Hardware watchdog implemented in the microcontroller is a requested feature to meet the EMC.

Some component suppliers like SGS-THOMSON have included EMC constraints in the design of their products, and characterize their products regarding EMC. It is preferable to use components EMC characterized rather than unknown.

### 3.3.4 Unused features

All the microcontrollers are conceived for a variety of applications and it is common for a particular application not to use 100% of the resources.

For EMC, unused clock/counter or input/outputs should not be left free: input/output should be stuck to "0" or "1" and unused function should be "frozen" or disabled.

## 3.4 MEASURING THE EMC PERFORMANCE

EMC measurement has to be split into two aspects: EME (Electromagnetic Emission) and EMS (ElectroMagnetic Susceptibility).

The two aspects are different by the measurement method, the problem found and the solutions.

If an MCU application passes the susceptibility test, it does not mean that it passes the emission's one. It's the same for the several immunity tests or emission tests. So both EMS and EME tests must be performed.

SGS-THOMSON has setup EMC tests for its microcontroller components. The same method can be used for the microcontroller applications. There follows a short description of the approach.

**EMC test in SGS-THOMSON**

The method is derived from IEC (norms) and VDE/SAE recommendations.

Firstly, an EMC test board is designed for each microcontroller: this board reproduces the typical environment of the microcontroller in an application.

To ensure reproducible tests, the pin loading is standardized according to SAE 1751.

**Table 3. EMC tests**

| | |
|---|---|
| Power digital | Typically 100µF electrolytic<br>Typically 100 µF ceramic |
| Input | GND or 10K pull up if cannot GND |
| Output | 50pF to GND |
| El-directional | Configure as output 50 pF to GND |

### 3.4.1 Emission tests

There are two types of emission tests: conducted and radiated. Conducted tests are more reproducible because they do not depend too much on the PCB.

#### 3.4.1.1 Radiated tests

To isolate the component's EMC behaviour, the board follows SAE 1752.

The board is placed on a metallic box in order to mask all the other components.

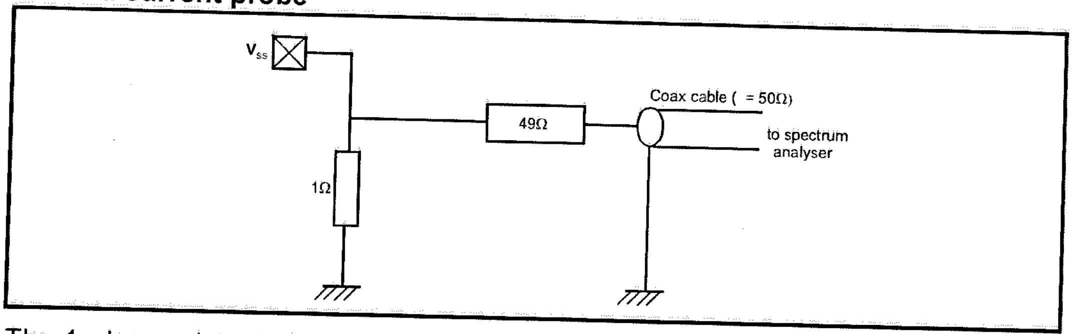
The measurements are performed in a Faraday cage with the antenna placed at 3 meters. The results are taken by a spectrum analyser.

#### 3.4.1.2 Conducted tests

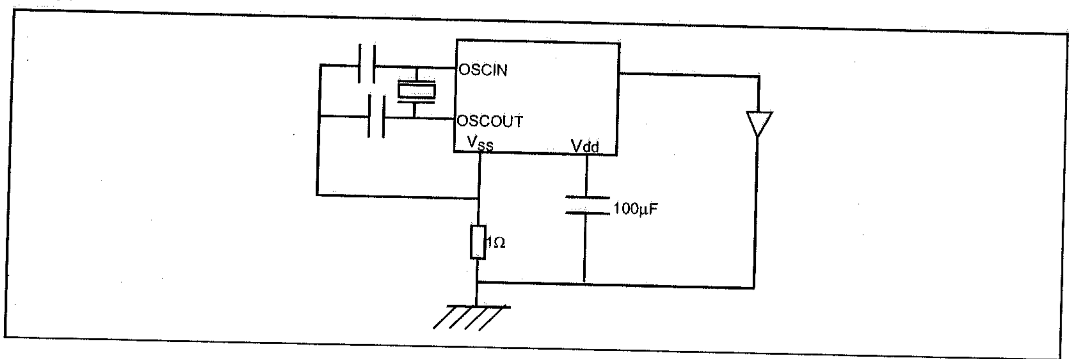
The origin of the noise radiated by the microcontroller is the supply current and the output signal. So the most significant conducted emission measurements consist in the analysis of that signals with a spectrum analyser.

Two probes are used to extract the signal and adapt the impedance to the spectrum analyser input.

**Ground current probe**




The 1 ohm resistor is inserted into the main GND wire, this means between power supply, decoupling capacitor and pin load on one side and IC GND plus oscillator load.

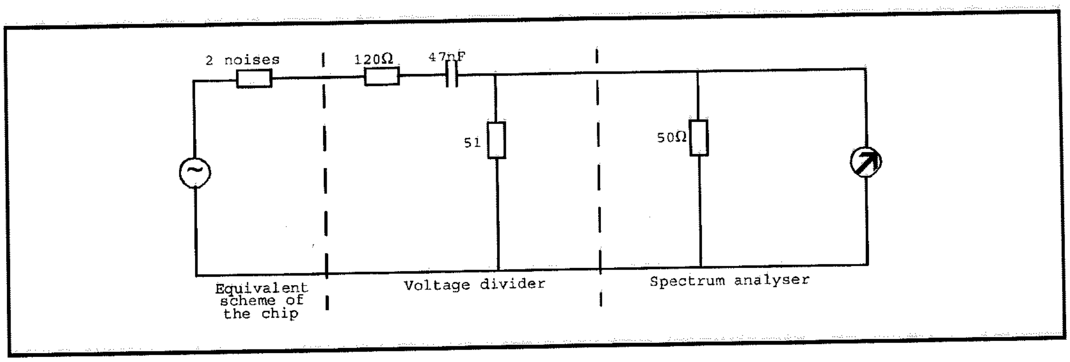



A good correlation can be found between radiated measurement and ground current measurement.

The 1 ohm probe has very good frequency characteristics up to 1 GHz. Because of low signal level, an amplifier is used.

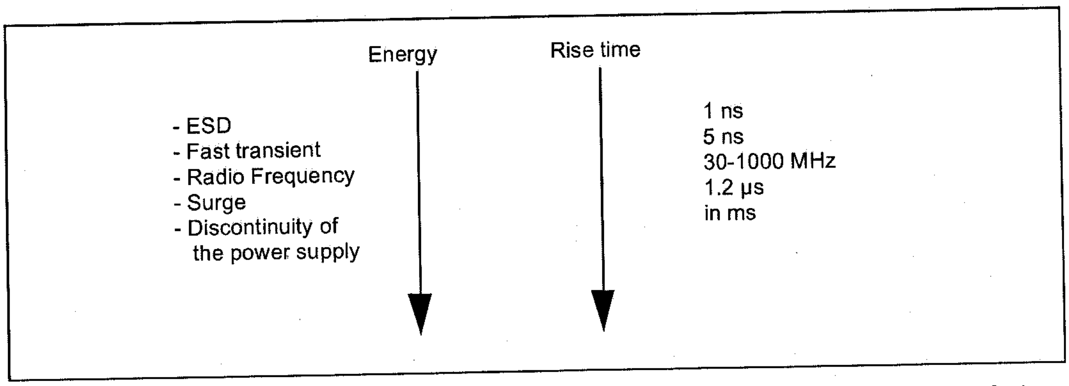
**Output pin probe**

The HF resistivity of wires on application boards are typically in the range of 100-300 ohms. Therefore the chip can be seen as a noise generator connected to a 150 ohm antenna system. These definitions are taken from IEC 1000-4-6. To convert the 150 ohm board load to 50 ohms, a voltage divider is used.




### 3.4.2 Immunity test

There exist an infinity of perturbations, but the main types of perturbation can be classified according to their spectrum.




Discontinuity of the power supply has no sense because there is no storage of electrical energy in a microcontroller.

Surge test has no effect on microcontroller as long as the supply voltage is correct because the rising time is too important compared with the clock period.

SGS-THOMSON focuses it efforts on the ESD, fast transients.

#### 3.4.2.1 ESD (according to IEC 1000-4-2)

The ElectroStatic Discharge (ESD) tests are very important to ensure that the application is not perturbed by the high static voltage produced by the human body.

There is two types of test: air-discharge with a spherical tip and contact discharge with conical tip.

Using contact discharge, the tips are placed on the pins. The ESD voltage is in the range 0 - 8 KV.

For air-discharge, the product is placed on a ground plane separated by 10 cm of insulator.

The discharges are made on the ground plane.

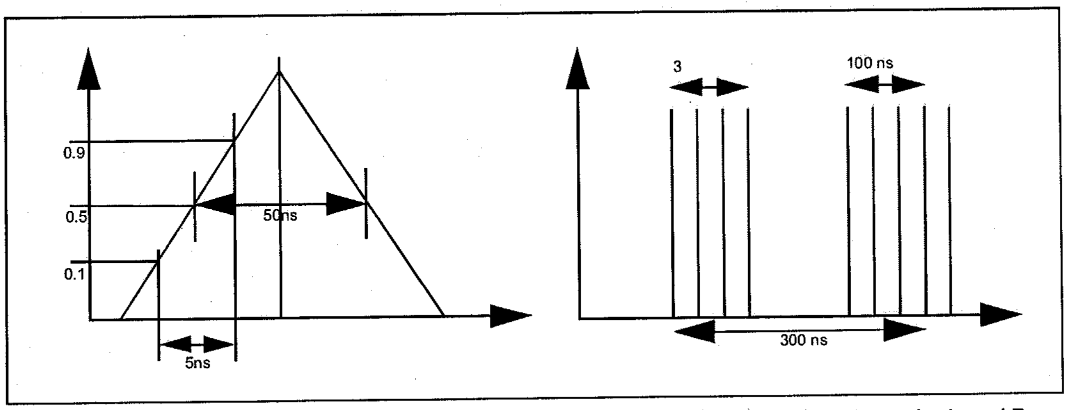
A statistical method gives more reproducible results.

### 3.4.2.2 Fast transient

This test consists in coupling these perturbations to the power supply or to the I/O of the MCU. Fast transients are generated by switches or relay.

**Description of the perturbations**

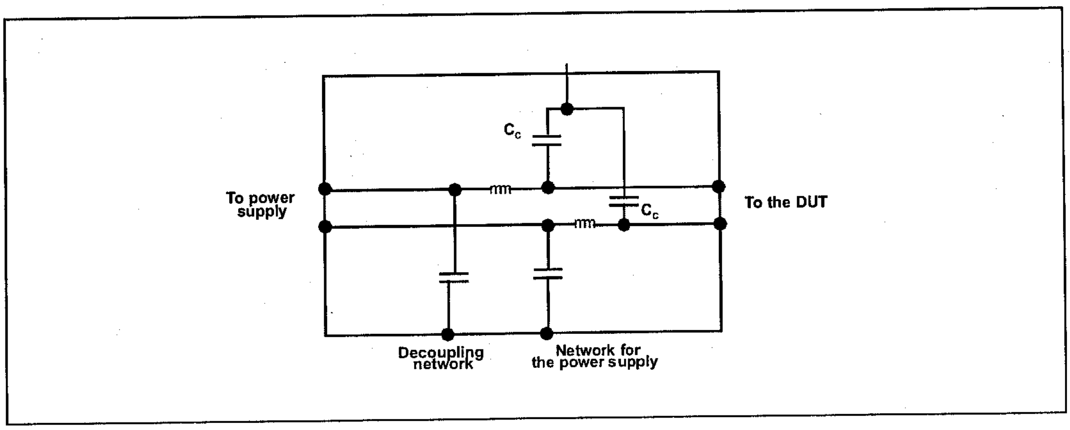
The fast transients are described on the IEC.1000-4-4.




The spike frequency is 5 KHz. The generator produces bursts of spikes during 15ms every 300ms.

**Coupling network**

The fast transients are coupled to the DUT with the capacitors $C_C$. Use of an attenuator is necessary because the burst generators are too powerful for direct application to the components.



The fast transients are coupled to the I/O with a small capacitor.

**Test description (according to IEC 1000-4-4)**

The measurements are performed on a ground plane.

The generator is connected to ground plane with short wire.

The HT wire is 10 cm from the ground plane.

The DUT is on the insulator 10 cm from the ground plane.

The first method consists of increasing the generator voltage until the micro fails. If this method demonstrates reproducibility problems (the voltage is less important than the moment the spike occurs) a statistical method must be used.

#### 3.4.2.3 Radio-frequency

The radio-frequency is a sine wave modulated with a 1 KHz signal. The frequency range is 150 KHz - 1 GHz. In general, it results from electromagnetic radiation. Both radiated and conducted test (respectively described by SAE and VDE) are used by ST. The first gives a global description of the MCU whereas the second gives a description of each pin.

The radiated test are performed in a screened room. The product is completely isolated by using special board according to SAE 1752 (see paragraph radiated test).

This test is described by the IEC 1000-4-3.

The conducted test uses a coupling network similar to fast transients one.

For each frequency, the voltage is increased until the MCU fails in order to characterise the voltage-frequency space of safe operation.

### 3.4.3 Interpretation of the results

The goals of the described EMC measurements is a guide for the application Engineer during EMC debug phase and for the prequalification EMC test; these measurements are not certified tests which are in charge of specialized laboratories: therefore there is no absolute acceptance levels (which, anyway, depend on the application area), the process consists in detecting too high speaks (EME) and too high sensitive frequencies and in fixing these defects.

## 4 CONCLUSION

It is hoped that This application note will convince the designers of microcontroller application to think of EMC at the very beginning of the project.

Most of the presented EMC improvements are already known but they have to be applied. There is no unique action to meet EMC, each technique yields a small improvement, only the comprehensive application of the technique mentioned can lead to good EMC compliance. SGS-THOMSON, who has built an EMC expertise for his microcontrollers makes available his expertise for his customers.