ATEE - 2004

SOME PRECAUTIONARY MEASURES TO REDUCE EMI AND RF EMISSIONS IN EMBEDDED SYSTEMS

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Abstract

A new embedded system project must agree with some rules of design. In addition to functional specifications, the project must fulfil the requirements of the electromagnetic compatibility for conformity with the regulations imposed by standards. This paper presents some suggestions to reduce EMI and RF emissions in applications as embedded systems with microprocessors or microcontrollers. The considerations and the practical exemples that follows are inspired from our works with the microprocessor Rabbit 3000.

Keywords: *EMI and RF emissions, electromagnetic compatibility, embedded systems*

1. INTRODUCTION

The EMI and RF emissions produced by the "unintentional radio-frequency devices" are subject of a series of regulations and requirements for electromagnetic compatibility. The national organizations mandated for elaboration and application of the rules concerning EC are the Federal Communications Commission (FCC) in the United States and a similarly regulatory authority in the European Union (EC – European Commission).

To demonstrate compliance with regulations, radiated and conducted emissions are measured at a standard distance, 3 or 10m. The field strength is measured using a calibrated antenna and a filter with a bandwitth of 120kHz connected to a spectrum analyser. The peak power is measured by using a „quasi peak" detector in the spectrum analyzer. The quasi peak detector has a charge time constant of 1ms and a discharge time constant of 550ms. In this manner the peak radiated signal strength is measured. The tests required by the FCC and the EC are practically identical. The radiated emissions for microprocessor based systems that do not have a clock spectrum spreader will generally be pure tones at harmonics of the clock speed which makes it unnecessary to use a special filter or quasi-peak detection.

The equipment needed to perform these tests may costs disaines of thousands dollars. The necessity of legal requirement to perform the tests depends on the type of equipment and its intended use.

By example, FCC regulations divide equipment into two classes. In addition, there are certain types of equipment such as test equipment, industrial equipment, automotive-related equipment and medical equipment there are not subject to regulation. The two classes are:

Class A: Digital equipment meant for office use. The FCC limits are 50dB μV/m at 3m (50dB relative to 1 μV/m) or 300 μV/m. The CE limits are: 30÷230MHz/40dB μV/m at 10m; 230MHz-1Ghz/47dB μV/m at 10m.

Class B: Digital equipment meant for home use. The FCC limits are 40dB μV/m 100 μV/m. The CE limits are: 30÷230MHz/30dB μV/m at 10m; 230MHz-1Ghz/37dB μV/m at 10m.

Radiation is generated by the high-frequency current which flows in printed-circuit boards and attached cables. Various national standards regulate the levels of radiation from computing devices. The usual test is to place the device to be tested at a set distance from a calibrated antenna, and then to measure the radiation received by the antenna with a spectrum analyzer. The maximum field strength allowed is measured in μV/m at a given frequency. The maximum field intensity allowed is specified in terms of μV/m for radiation in 120 kHz width bands. Generally the limits are in the range of 100-300μV/m measured at a distance of 3m. This is express in dB relative to 1μV/m (0 dB corresponds to 1 μV/m, and 40 dB corresponds to 100 μV/m).Unintentional radiation is generated in two distinct way:

- differential-mode radiation from current loops (increases proportional to the square of frequency). Differential-mode radiation can be calculated from the following formula:

$$E = 8.6 \cdot 10^{-9} f^2 A l \tag{1}$$

where: E is the electric field as measured in FCC tests at 3m (in -3dB μV/m), f is the frequency in MHz, A is the area of the loop in mm^2 and I is the current in μA for a 120 KHz bandwidth.

- common-mode radiations from antennas. Common-mode radiation is the radiation emitted by an antenna such as a wire attached to a voltage source. The formula for common – mode radiation is:

$$E = 0{,}4 f L l \tag{2}$$

Where E is the electric field at 3m (in μV/m at 3m), f is the frequency in MHz, L is the length of the antenna in m and I is the current in the antenna in μA.

An antenna is often formed by a cable attached to a printed-circuit board (PCB).

2. METHODS FOR EMI AND RF CONTROL

2.1. Rules for the design of μP architecture to reduce EMI radiation

- The power supply for the processor is on separate pins from power supply for I-O buffers associated with the processor and various peripheral devices. The microprocessor silicon die may have two separately powered parts: the core, which is the logic in the center part of the die, and the I/O ring, which is located on the edges of the die and consists of the buffers that interface with the package I/O pins. The core logic is very fast with rise time of order of 100ps. The I/O ring buffers drive large currents whose rise times are much slower, around a few nanoseconds. Separate power pins supply power to the core and to the I/O ring of the microprocessor. Most of the high-frequency noise originates in the microprocessor core. This noise then escapes the microprocessor package via the power pins and ground pins. EMI reducing id done by adding decoupling capacitors between the power and ground pins of the microprocessor itself.
- A spectrum spreader in the clock circuit can be enabled to spread the spectrum of the clock by varying the clock frequency in a regular pattern.
- The built in clock doubler. The external oscillator circuitry operate at ½ of internal clock frequency.
- Avoiding to route the system clock outside the microprocessor package, although a pin is provided for this purpose in the unusual circumstances where it might be necessary. The high speed clock on PCB traces is a major cause of EMI.
- Clock system variation, in accord with momentary action of the system.

2.2. The method of Clock Spectrum Spreader

The spectrum spreader modulates the clock so as to spread out the spectrum of the clock and its harmonics. Since the standard tests use a 120 kHz bandwidth to measure EMI, spreading the energy of a given harmonic over a wider bandwidth will decrease the amount of EMI measured for a given harmonic. The spectrum spreader not only reduces the EMI measured in standard tests, but it will also often reduce the interference created for radio and television reception.

When the spectrum spreader is engaged, the frequency is modulated, and individual clock cycles may be shortened or lengthened by an amount that depends on whether the clock doubler is engaged and whether the spectrum spreader is set to the normal or strong setting. The frequency modulation amplitude and the change in a clock cycle length is greater at lower voltages or higher temperature since it is sensitive to process parameters. The spectrum spreader also introduces a time offset in the system clock edge and an equal offset in edges generated relative to the system clock. A feedback system limits the worst case time error of any signal edge derived from the system clock to plus or minus 20ns for the normal setting and plus or minus 40ns for the strong setting at 3.3V. The maximum time offset is inversely proportional to operating voltage. The time error will not usually interfere with communications channels, except perhaps at the extreme upper data rates.

2.3. PCB layout considerations to reduce EMI radiation

Even though processor may have powerful anti-EMI features, it is still important that PCB layout be done taking into account proper precautions against EMI. The higher the clock frequency, the worse the EMI. Expect the EMI amplitude to increase by 6 dB for each doubling of clock frequency.

- The one of the most important board layout goal is to minimize power-ground noise. As practical matter, power-ground noise is main driven of radiated emissions.
- Usually the main source of this noise is the processor. Minimizing power-ground noise is accomplished by blocking the escape of the noise from the processor – and into the power and ground planes, and by designing a power-ground system that has low impedance over a board range of frequencies.
- Noise may be blocked from exiting the processor package by using suitable decoupling capacitors connected directly to the package pins. The goal of a low-impedance power-ground system is realized by minimizing the spacing between the power and ground planes by using low-impedance decoupling capacitors connected with low-impedance connections to the power planes.

Decoupling capacitors around microprocessor. To prevent high-frequency noise produced within processor from escaping through the power and ground system of the PCB, each pair of core power and ground pins should be decoupled from the PCB by a pair of capacitor. Since the capacitors and the connecting traces form a "filter", it is important that the vias to the ground and power planes are placed after the "filter".

Besides the core power pins, the I/O ring's power and ground pins should also be decoupled to prevent noise generated in the I/O ring from escaping and to provide a low/impedance source of switching current.

Decoupling capacitors around memory chip. Memory chip can be decoupled. If the memory chip is fast or has adjacent ground and power pins, then both ground and power can be isolated from the power planes in the same manner as the processor.

Decoupling capacitors between PCB power and ground plans. An important recommendation is to realize if it is possible, not a 2-layer PCB, but a minimum of a 4-layer PCB with a separate ground and power planes.

A manufacturing goal is to provide for minimal separation between the power and ground planes so as to maximize power-ground capacitance.

The power and ground planes should be connected by decoupling capacitors that are in addition to capacitors used to decouple the processor and the memory chips. Since decoupling capacitors are relatively ineffective at frequencies above 100 MHz, a number of small capacitors (2nF, 10nF and 100nF) in parallel must be used. The more cables and other devices there are connected to the board, the more important the decoupling is between the power and the ground planes.

Decoupling cables attached to the PCB. Cables connected to the PCB board serve as antennas if they have high-frequency noise coupled to them. The noise can be coupled to the shield of a cable, to all wires of twisted pairs or cable bundles, or to a single wire. The noise can get on the cable by capacitive coupling from the ground and power planes, via the driver power supply, or by passing circuitry.

Clock and oscillator considerations. It is not recommended to use in application system the clock output of the processor. To minimize EMI, avoid using this pin as a clock output. However, in the cases that require a clock, a series resistor can be placed in the clock line to slow down the rise and fall times, which will reduce radiated emissions at higher harmonics of the frequency. The clock line must keep as short as possible and away from other traces.

3. CONCLUSIONS

The design recommendations for an embedded system are summarized below. Most of this suggestion involve no extra expense; so there is no reason not to implement them in a new project:

- if the processor has a spectrum spreader, this must be enabled unless is a serious reason not to;
- filter the processor package power-supply pins with a pair of decoupling capacitors;
- use a 4-layer PCB with the VCC and the ground planes on the inner layers, separated by no more than 0.05mm;
- add 2nF, 10nF and 100nF decoupling capacitors to the power planes;
- decouple the power-supply input lines and filter incoming power with 10μF, 10nF, 100nF capacitors;
- decouple memory chips;
- don't connect cable shields directly to the ground plane, a ferrite is a good option;
- cut away ground and power planes near connectors to avoid common-mode coupling to attached cables;
- avoid slots in the ground or power planes;
- don't run clocks on the board, but it is absolutely necessary, place them near the ground plane and modify rise times by using a series resistor.
- filter the cable drivers' power supply.

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