Analysis of EME Produced by a Microcontroller Operations

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Abstract

This paper deals with the characterization of integrated circuits electromagnetic emissions. The TEM cell method is employed in order to identify primary emissions sources of complex digital devices. An 8-bit microcontroller, realized by a 0.8 μm HCMOS process is considered. It is composed of several building blocks like the central processing unit, the analog to digital converter and the EPROM memory. Emission measurements are performed by operating a specific program code stored in the microcontroller memory and emissions due to each building block are identified.

1. Introduction

The central processing unit (CPU) of a microcontroller (μC) performs sequences of elementary operations at high frequency, while its input-output (I/O) circuits realize communications with peripheral units. CPU and I/O operations are synchronous to a clock signal, hence steep currents are absorbed from the power supply. Such currents represent one of the primary sources of a μC electromagnetic emissions (EME) since they drive antennas composed of printed circuit board (PCB) traces and connecting cables. In addition, μC operations induce direct EM radiation by package lead-frame, bonding interconnections and circuits integrated on silicon.

The reduction of PCB emissions can be obtained by lowering the efficiency of antenna composed of traces and cables [1, 2, 3]. Such an operation is often difficult and expensive. On the other hand, the same result can be obtained by controlling the primary sources of emission, i.e currents absorbed from the power supply. Most of a μC building blocks absorb pulsed current from the power supply circuits and some of these currents are dominant in respect with the others. Contributions of each block to the overall radiated emissions can be quantified by operating the test method described in [4]. Such a technique consists in the measurement of radiated near EM field close to the device under test (DUT). In particular, an electric field probe scans the DUT surface and the electric field is picked up in several points.

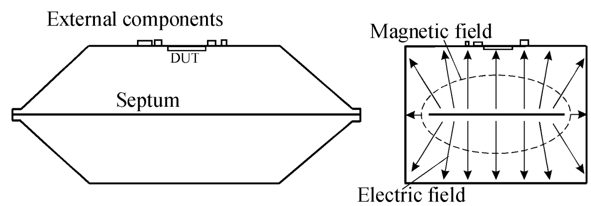

Figure 1. Longitudinal and transversal section of a TEM cell

This method is effective only if μC building blocks are spatially separated on the device layout. However, modern tools of layout place and route, manage the overall μC layout and the identification of a specific building block is not more possible. On the other hand, international standards [5, 6] propose the measurement of an IC radiated emission by operating the TEM cell method.

In this work the TEM cell method is employed in evaluating specific contribution of some μC building block to the overall radiated emissions. A μC is programmed by a specific code composed of several modules [7]. Each program module is a continuous loop of instructions by which operations of a specific μC building block are excited.

2. The TEM cell method

The TEM cell method makes it possible the measurements of ICs direct radiation [8]. TEM cell is a transmission line with characteristic impedance of $50\ \Omega$ which is realized by gradually expanding the size of a coaxial transmission line (see Fig. 1)[9].

If the TEM cell is terminated in its characteristic impedance and operated below the cutoff frequency a propagating TEM field can be generated within it. Under these conditions EM field in the TEM cell approximates a plane wave which is well suitable for emission and immunity testing. A TEM cell built in compliance with [5], shows an upper aperture with dimensions suitable for the PCB where the DUT is inserted. The DUT is placed on the layer that works as a part of the TEM cell walls, and it is connected to the other layer by vias. The ground layer realizes a good con-

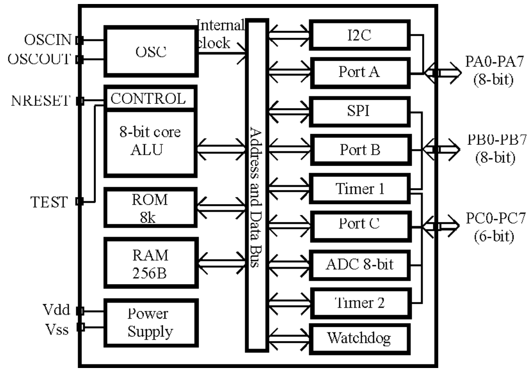

Figure 2. Block diagram of device under test

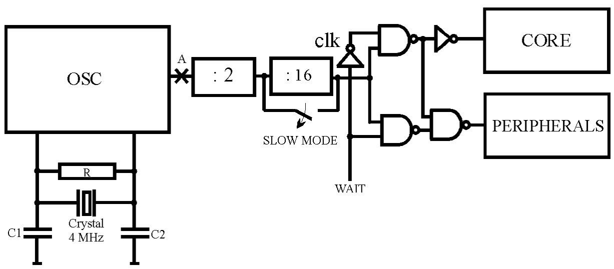

Figure 3. Clock block diagram

tact to the TEM cell wall, all around the border of aperture. The multilayer test board has been realized in compliance with [5].

3. Device under test

In this work an 8-bit μC is considered [10]. It is realized by a 0.8 μm HCMOS process, and encapsulated in a dual in line (DIP) package. It presents only a couple of power supply pins.

Such a device operates on 8-bit addresses and data. It is composed of a clock circuit, a CPU, an 8-Kbyte EPROM memory, a 256 RAM memory, an 8-bit analog to digital converter (ADC), a programmable watchdog counter, and other peripheral circuits (see Fig. 2) [10].

The CPU instruction set is composed of 63 base instructions with 17 different addressing modes that operate on 6 internal register [11]. The clock signal is obtained by a Pierce oscillator (Fig. 3) and distributed all over the μC. Some instructions modify the clock signal frequency and its distribution to the internal blocks. In facts, the signal produced by the clock circuit is divided by 32 if the SLOW MODE timing is selected otherwise, it is divided by 2 (NORMAL MODE timing).

4. Sofware code

The μC executes instructions of the programming code stored in the EPROM memory. The code has been written in order to operate one single block at time. In particular it is composed of the following six modules :

- WAIT : μC executes the *Wait For Interrupt* instruction. The clock signal is distributed to all building blocks except for the CPU (Fig. 3) ;
- MEM : CPU executes writing operations in the RAM memory ;
- CORE : in this routine some instructions like increment, decrement, complement, sum and multiplication are executed ;
- CORES : the same operations of the previous module are executed in the SLOW MODE timing ;
- WDOG : in this module the watchdog counter is excited ;
- ADC : the code enables the analog to digital converter. The result of the conversion is saved in a special register.

Instructions of each module are executed in a continuous loop and I/O circuits are set as input (see Appendix). Each module of the program can be selected by an interrupt signal. In practice, pure operations of a one single block cannot be obtained, since the CPU executes timing and control of the μC activities.

5. Measurement results

EME of a μC programmed by the code described in the previous section has been evaluated. The code has been stored in the μC EPROM and emission measurements have been performed by using the test setup shown in Fig. 4. Such a test bench is composed of a 1 GHz TEM cell connected to a low noise 24 dB preamplifier (HP 87405A) and a spectrum analyzer (HP 8594EM). The test bench is controlled by a personal computer.

Measurements have been performed in the frequency range 10 MHz - 1 GHz and in such a range the noise floor observed was lower than -10 dBμV.

Figs. 5 - 8 show emission spectra related to MEM, CORE, WDOG, ADC program modules. Emission spectra are composed of two different ranges. The first one concerns the frequency range 10 - 150 MHz while the second one covers range 300 MHz - 1 GHz. On the basis of such experimental results it can be observed that operations of each module induce variations in the emission spectrum only in the range 300 MHz - 1 GHz. Furthermore, amplitude of spectral lines in the range 10 - 150 MHz spectral does not depend on the operations of the selected module.

Such a result is confirmed by the emission spectrum related to the WAIT module operations. The Wait For Interrupt instruction stops operations in the CPU and peripherals, but the clock signal is distributed all over the integrated circuits. In the frequency range 10 - 150 MHz amplitudes of spectral lines (see Fig. 9) are comparable with

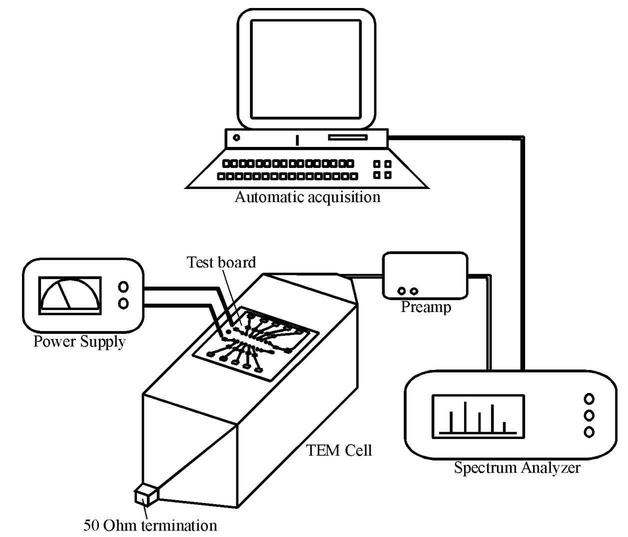

Figure 4. TEM cell setup

those of Figs. 5 - 8 . In such a condition, emissions are due to operations of the clock signal oscillator and current consumption of the clock tree components. The weight of radiated emission due to operations of the clock signal oscillator has been evaluated on some test devices. The original μC has been modified by cutting the clock tree at the oscillator output (see point A in Fig. 3), and emission measurements have been performed (see Fig. 10). On balance, it has been shown that radiated emissions up to 70 MHz are due to operations of the clock oscillator. The comparison of radiated emissions spectra shown in Figs. 9 and 10 highlights the contribution of the clock tree distribution circuits to the radiated emissions.

Furthermore, emission spectra of Figs. 6 and 11 respectively related to CORE and CORES modules show a strong reduction of radiated emissions in the frequency range 300 MHz - 1 GHz. In facts, the SLOW MODE timing implies a frequency reduction of the pulsed current absorbed from core and peripherals circuits and the consequent reduction of radiated emissions. Therefore, the selection of the SLOW MODE timing does not influence amplitudes of spectral lines related to the clock circuits oscillator operations.

6. Conclusions

In this work the TEM cell method is operated in evaluating specific contribution of some μC building block to the overall radiated emissions. A μC is programmed by a specific code composed of several modules. Each program module is a continuous loop of instructions by which operations of a specific μC building block are excited.

Experimental results have shown that operations of each program module induce variation in the emission spectrum only in the frequency range 300 MHz - 1 GHz. Further investigations have shown that the amplitude of spectral lines in the range 1 - 150 MHz does not depend on the operation of the selected module. In particular, it has been highlighted that radiated emission up to 70 MHz are due to clock oscillator operations.

7. Appendix

```
MEMORY MODULE

MEMTEST     CALL WRITEMEM
            JRT MEMTEST
.WRITEMEM_R
            CLR X
            LD A,#$FF
LOOPA       LD (LOW,X), A
            INC X
            CP X, FINE
            JRNE LOOPA
            CLR X
            CLR A
LOOPB       LD (HIGH,X), A
            INC X
            CP X, FINE
            JRNE LOOPB
```

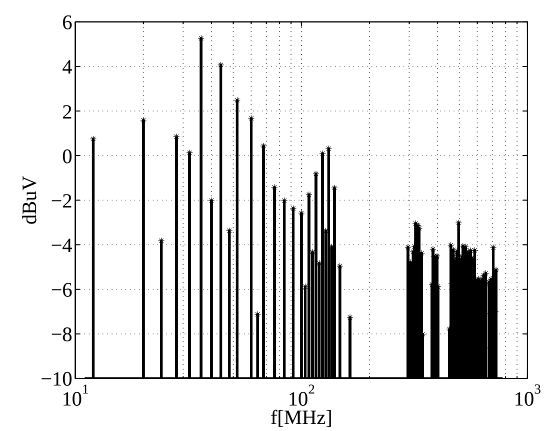

Figure 5. Spectrum of μC in MEM routine

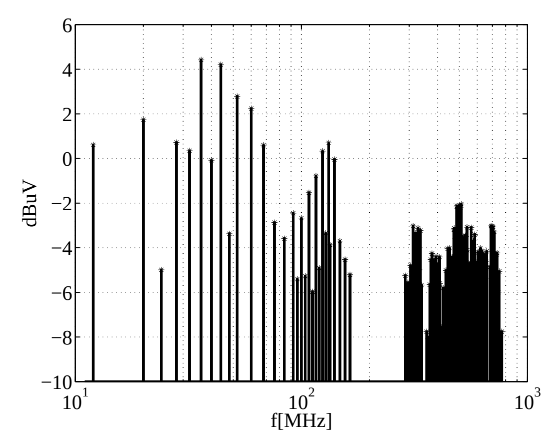

Figure 6. Spectrum of μC in CORE routine

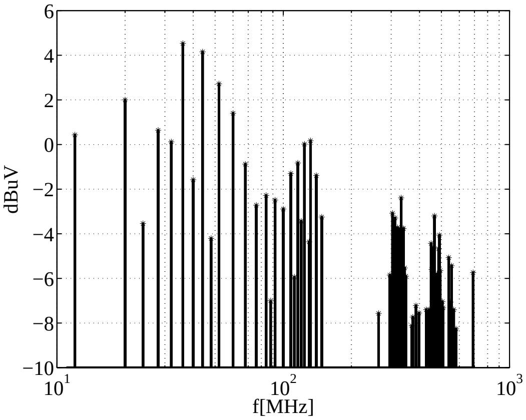

Figure 7. Spectrum of μC in WDOG routine

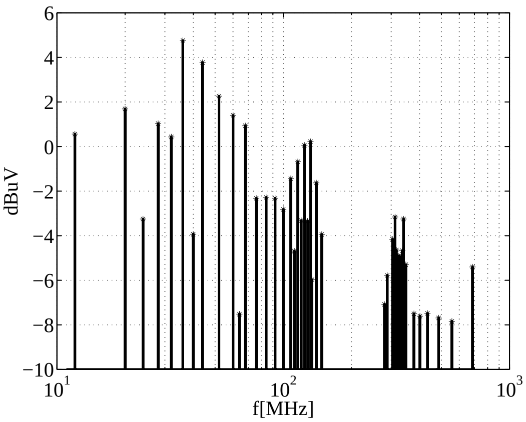

Figure 8. Spectrum of μC in ADC routine

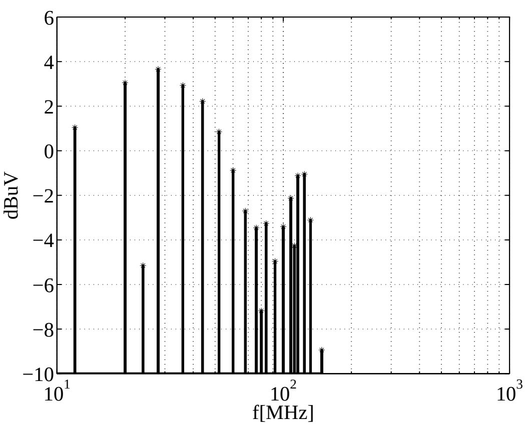

Figure 9. Spectrum of μC in WAIT routine

```
            CLR X
LOOPC       LD (LOW,X), A
            INC X
            CP X, FINE
            JRNE LOOPC
            CLR X
            LD A,#$FF
LOOPD       LD (HIGH,X), A
```

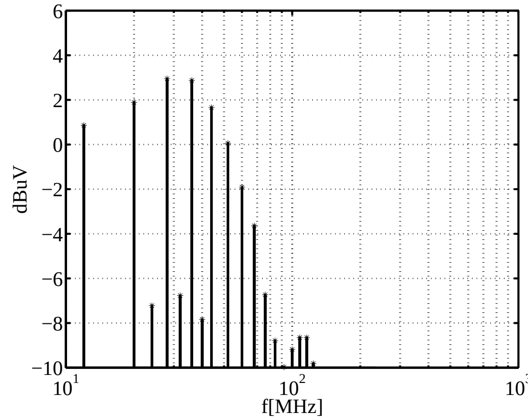

Figure 10. Spectrum of modified μC

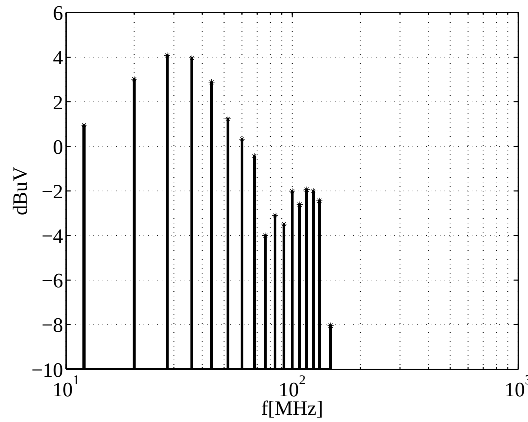

Figure 11. Spectrum of μC in CORES routine

```
            INC X
            CP X, FINE
            JRNE LOOPD
            RET

CORE AND CORES MODULE

CORETEST    CALL CORE_R
            JRA CORETEST
.CORE_R
            CPL A
            ADC A,#$FF
            LD X,#$AA
MULOOP      LD A,#$01
            MUL X,A
            CPL A
            LD X,A
            JRPL A,#$FF
            INC A
            CLR A
            DEC A
            RET

WDOG MODULE
```

```
WDOGTEST    CALL WDOG_R
            JRT WDOGTEST
.WDOG_R
            LD A,#$7F
            LD WDGCR,A
            BTJT WDGCR,#0,*
            BTJF WDGCR,#0,*
            LD A,#$7C
            CALLR WDWAIT
            LD A,#$78
            CALLR WDWAIT
            LD A,#$70
            CALLR WDWAIT
            LD A,#$60
            CALLR WDWAIT
            LD A,#$40
            CALLR WDWAIT
            LD A,#$00
            CALLR WDWAIT
            RET
.WDWAIT_R
            LD WDGCR,A
            BTJF WDGCR,#0,*
            RET

ADC MODULE

ADTEST      LD A,#$25
            LD ADCCSR,A
WAITCONV    BTJF ADCCSR,#COCO,WAITCONV
            JRA ADTEST
```

8. Acknowledgements

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