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CONDUCTED EMISSION MEASUREMENT OF A CELL PHONE PROCESSOR MODULE

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Abstract—This paper discusses a conducted emission measurement of a cell phone integrated circuit. The industry standard measurement method is used to compare the measurement result to the defined limit line. A data analysis method- short time fast Fourier transform (STFFT) is presented to help to analyze the result. The data consistency and repeatability is also analyzed.

1. INTRODUCTION

Billions of cell phones have been purchased every year in the world. The cell phones need to pass the conduction emission test to ensure that they won't cause any problem to other equipments. The main emission source in the cell phone is the processor. It contains both analogue and digital components which emit emission greatly. The emission can cause problem to the cell phone itself and also other nearby equipments, one of the main emission method is called conducted emission. The conducted emission normally cause problem to the other components on the cell phone, or coupled to the charge cable to other equipments which share the same power. Thus, the conducted emission test of the processor is necessary. There are several measurement methods to do the conducted emission measurement of integrated circuit [1, 2]. Two popular methods are defined by IEC 61967 part4 [3] and BISS paper [4] respectively.

The previous work [5] on the conducted emission test only focuses on the measurement itself, and compares the result to the defined limit line. The analysis of the data is not sufficient. This paper talks the difference between the two measurement methods through

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simulation and analyzes the measurement result using several data analysis method, such as STFFT [6]. The data consistency and measurement repeatability are also analyzed.

This paper is organized as follows: two test bench setups are compared in Section 2, while the conducted emission measurement result is presented in Section 3. The data analysis method is shown in Section 4. The data consistency and repeatability is done in Section 5.

2. METHODOLOGY COMPARISON AND TEST SETUP

2.1. Measurement Methodology

The conducted emission method is closely related to the methods described in IEC 61967 part 4 [3] and the BISS paper [4]. The direct coupling method is shown in Figure 1. The 150 Ohm coupling circuit is a voltage divider with reverse match, not only a matching network, as the output impedance of the IC, which is unknown, is not matched to anything.

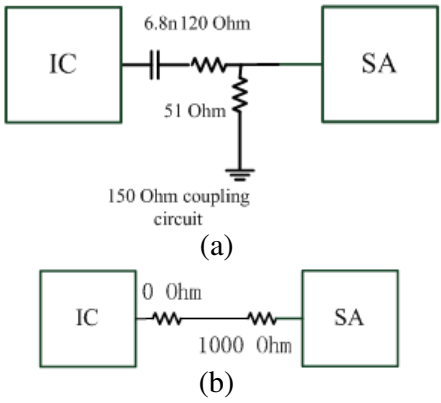

Figure 1. (a) 150 Ohm coupling method, (b) 1 k Ohm coupling method.

Using 150 Ohm was selected as a load condition for the test method for the following reasons: If the resistor value is low: It has strong loading effect, the function of IC may not be given, and also it changes of signal voltages, but it has good RF response, no problem with parasitic components.

If the resistor value is high: It has little effect on the signal, but it may cause bad signal to noise ratio due to high divider ratio and possibly reduced upper frequency due to parasitic components.

2.2. Test Setup

The test setup is shown in Figure 2, the setup is composed of a spectrum analyzer (HP 4396A), an amplifier (ZX60-33LN+), and a test board with the processor module. The 06.2 version board is changed to adapt to the 150 Ohm coupling method. As the processor module is a cell phone module, an antenna and a SIM card are installed to enable the functionality of the module. The diagram of the test setup is shown in Figure 3. According to the BISS paper's requirements in conducted emission test, the settings of spectrum analyzer are shown below: Frequency: 30 MHz–1 GHz, RBW: 100 kHz, Detector: Peak, Display: Max hold.

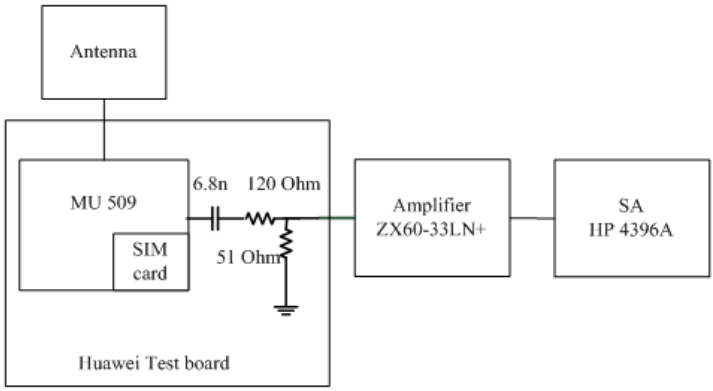

Figure 2. Diagram of the test setup.

2.3. Simulation Model and Results

First, the simulation model is used to describe the attenuation relationship between the 150 Ohm coupling method and the 1 k Ohm coupling method.

As shown in Figure 3(a), Vsrc1 is used as the internal emission source, and Vsrc2 is used as a potential noise between the PCB ground and the module ground. From the measurement result, the internal emission source is thought to be much larger than the noise between the PCB ground and module ground. C_1 is used as the input impedance of the reset port. A value of 5 pF seems reasonable for an input of an IC. If other ports would be modeled other impedance would need to be used, such as 50 Ohm for terminated single ended ports, 100 Ohm for some differential input ports and lower values like 20 Ohm (or Input/Output Buffer Information Specification (IBIS) models [7, 8]) for output ports.

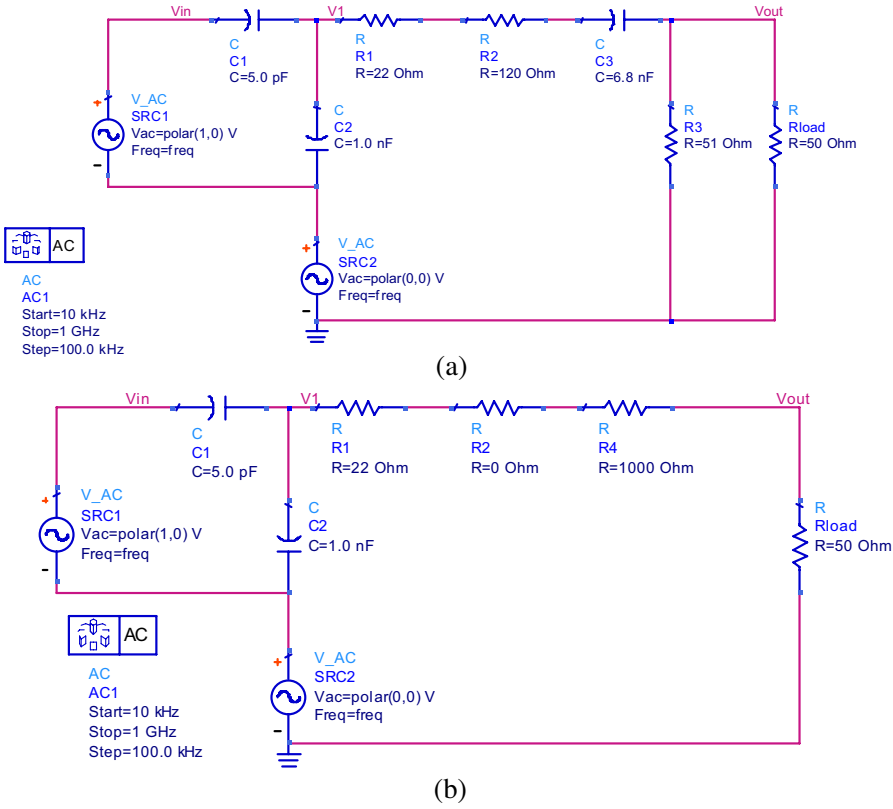

Figure 3. (a) Spice model of the 150 Ohm coupling method, (b) spice model of the 1 k Ohm coupling method.

The resistor R_1 and the capacitor C_2 are inside the module at the reset port. R_2, R_3 and C_3 form the coupling circuit of the 150 Ohm method. As shown in Figure 3(b), a similar Pspice model [9] is used to model the 1 k Ohm coupling method. The simulation result of the attenuation relationship between the two coupling methods is shown in Figure 4. There is a 10 dB difference between the two methods. The amplitude of the source is chosen by taking the measurement result as the reference; however, it needs to be pointed out that the magnitude of the source does not influence the difference between the two coupling methods. The measurement spectrum using the 150 Ohm coupling method is about 40 to 50 dBuV, while the measurement spectrum of 1 k Ohm coupling is about 30 to 40 dBuV.

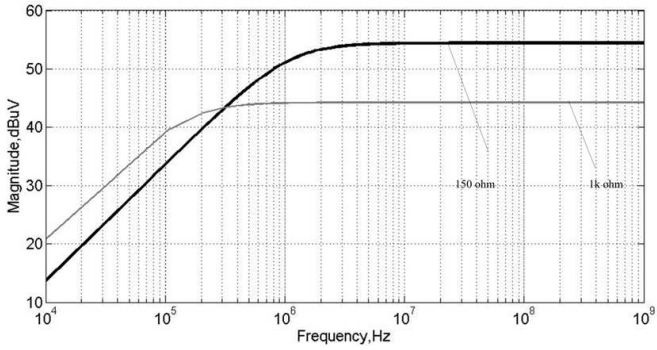

Figure 4. Attenuation relationship between 150 Ohm and 1 k Ohm coupling methods.

The voltage across C_2 can be represented by:

$$\begin{aligned} Z_1 &= \frac{1}{j\omega C_1} \\ Z_2 &= \frac{1}{j\omega C_2} // (R_load // R_3 + R_1 + R_2 + \frac{1}{j\omega C_3}) \\ V_1 &= \frac{Z_2}{Z_1 + Z_2} V_{in} \end{aligned} \tag{1}$$

where the capacitors are the components in the 150 ohm coupling circuit and the voltages are marked on the circuit.

In high frequency (for example, higher than 10 MHz), compared with the impedance of the serial resistors (R_1, R_2 and R_3) the impedance of C_2 is very low.

The voltage can be represented by:

$$V_1 = \frac{\frac{1}{C2}}{\frac{1}{C1} + \frac{1}{C2}} * V_{in} \tag{2}$$

V_1 has no frequency response.

The voltage across the R_load in 150 Ohm method can be represented by

$$V_{out} = \frac{R_load // R_3}{R_load // R_3 + R_1 + R_2 + \frac{1}{j\omega C_3}} * V_1 \tag{3}$$

where the resistors and capacitors are the component in the 150 ohm coupling circuit and the voltages are marked in the circuit.

Compared with the impedance of resistors, the impedance of capacitor C_3 in 150 ohm method is very small in high frequency. Thus,

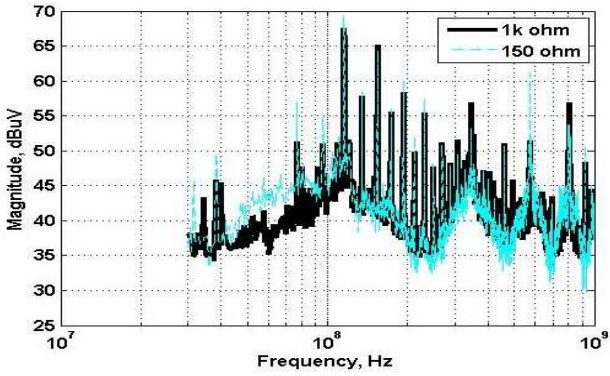

Figure 5. Measurement result of the two coupling methods, 10 dB have been added to the 1 k ohm method data to illustrate the 10 dB differences caused by the different coupling networks.

the voltage across the resistor *R_load* is dominated by the coupling resistors which have no frequency response. The simulation result in high frequency is also flat, as shown in Figure 5.

In low frequency (for example 10 kHz), compared with the impedance of resistors, impedance of C_2 is large. The voltage across resistor *R_load* decreases as the frequency decreases, and because of the large impedance of capacitor C_3, the voltage across the resistor *R_load* in 150 ohm method decreases faster than the 1 k ohm method does.

Also, because of the lack consideration of parasitic parameters of components, the simulation result may have small difference relative to measurement result at high frequencies.

3. MEASUREMENT

3.1. Conducted Emission on Reset Port

The conducted emission of the reset port using two difference coupling methods is shown in Figure 5. For illustration reasons, 10 dB are added to the data from the 1 k Ohm method. As predicted in the simulation part, the waveforms of the two coupling methods are almost same, except the only small differences at high frequency, which may be caused by signal to noise limitations or by varying operating conditions of the tested module.

To analyze which signal is time dependent and which signal is time independent, a variety of data analysis methods can be used. One of them is STFFT [6].

Table 1. The difference frequencies of peaks.

First peak	Second peak	Third peak	Fourth peak	Fifth peak
115.2 MHz	135.2 MHz	152.8 MHz	172.7 MHz	191.6 MHz
Sixth peak	Seventh peak	Eighth peak	Ninth peak	Tenth peak
211.7 MHz	230.0 MHz	249.8 MHz	269.0 MHz	288.6 MHz

The difference frequency between two peaks is obtained by using the maker function of the spectrum analyzer. As shown in Table 1, the difference frequency is about 19.2 MHz, which is the clock frequency of the IC. The frequencies of the peaks are thought to be the harmonic frequencies of the clock.

The rise and the fall time of the clock, and the coupling path's frequency response determine the observed spectral density of the clock harmonics.

This harmonic content of the conducted emissions are narrow band signals and are time independent.

3.2. Comparison Relative to the BISS Levels

The BISS paper gives different limit values for global ports and local ports, as shown in Figures 6 and 7. The BISS paper defines the ports as such:

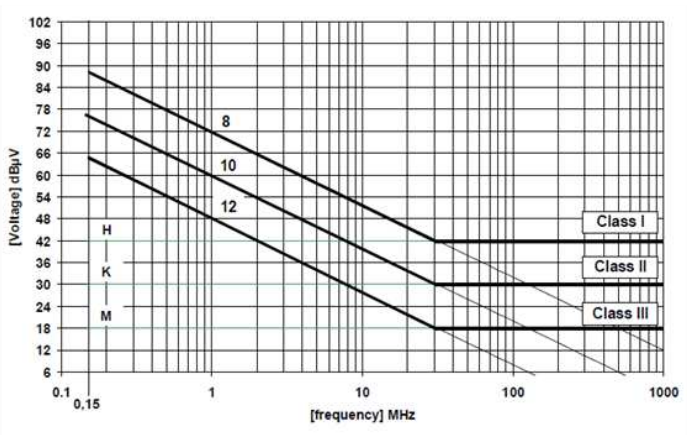

Figure 6. Limit line for global ports.

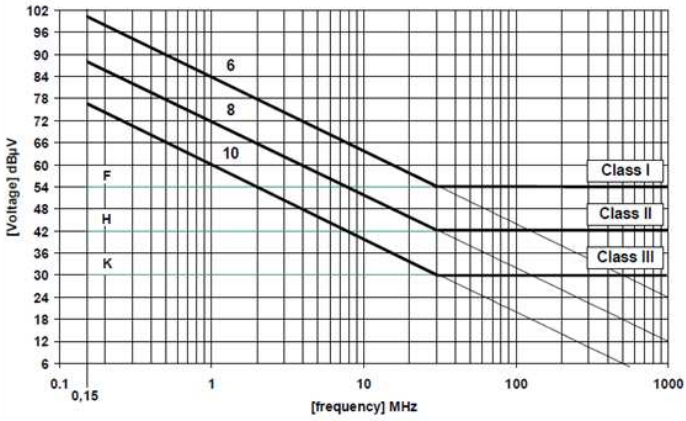

Figure 7. Limit line for local ports.

3.2.1. Global Pin

A 'global' pin carries a signal or power, which enters or leaves the application board.

3.2.2. Local Pin

A 'local' pin carries a signal or power, which does not leave the application board. It remains on the application PCB as a signal between two components with or without additional EMC components.

According to the definition of BISS paper, the reset port is local port.

The difference between local and global ports is 12 dB, the difference between two adjacent classes is 12 dB.

The measurement results compared with BISS limit values are shown in Figure 8.

4. SHORT TIME FFT

A powerful tool for the analysis of time dependent signals is the STFFT. The STFFT requires capturing real time data. Being interested in data up to 1 GHz, a sampling rate of 5 GS/sec and 2 Meg sample points allows capturing 400 µs of data. A low pass filter with a stop frequency of 1.2 GHz is used to avoid aliasing [6]. The test setup to do STFFT is shown in Figure 9.

The emission on reset port using STFFT is shown in Figure 10.

A better time resolution requires a shorter window length, whereas a better frequency resolution needs more data which requires longer

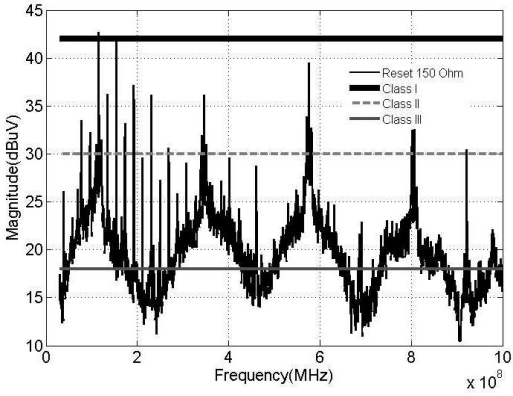

Figure 8. Reset port compared with BISS limit.

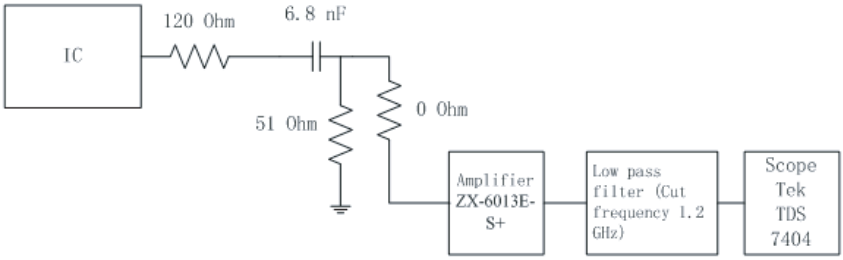

Figure 9. A test setup to do STFFT.

window length. As shown in Figure 10, the longer window gives a better frequency resolution.

The analysis of emission on 115.2 MHz using STFFT is shown in Figure 11. The 115.2 MHz emission is a narrowband signal combined with wide band time dependent signals.

5. DATA CONSISTENCY AND MEASUREMENT REPEATABILITY

5.1. Data Consistency

Multiple factors can contribute to variations in the data:

- Different operating conditions on the same board.
- Board to board variations.
- Test setup variations.

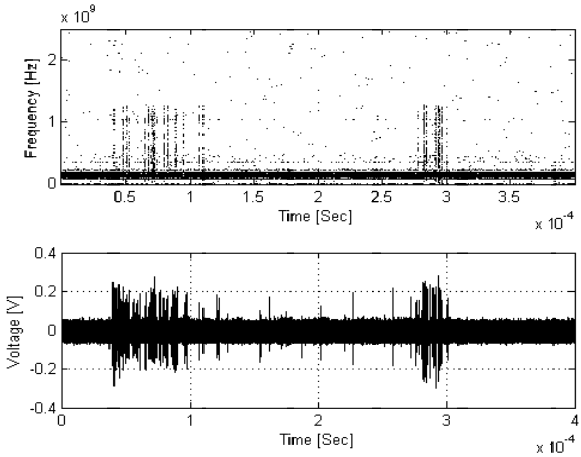

Figure 10. STFFT of reset port (NFFT 5000 points, Noverlap 1250).

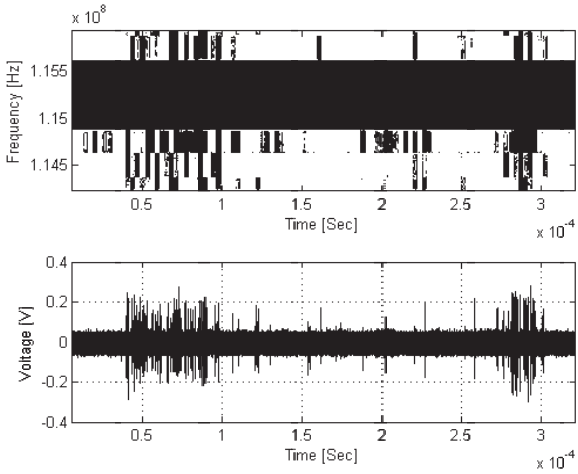

Figure 11. Analysis of 115.4 MHz emission using STFFT (zoom in, NFFT 20 k points, Noverlap 5000).

Repeated measurements and careful observation of the operating conditions allowed us to consider these parameters as well controlled. The last parameter in question is the board to board variation.

Comparison of different boards is shown below. The conducted emission of the reset port on two different boards (04.1, 04.2) using the 150 ohm method are shown in Figure 12.

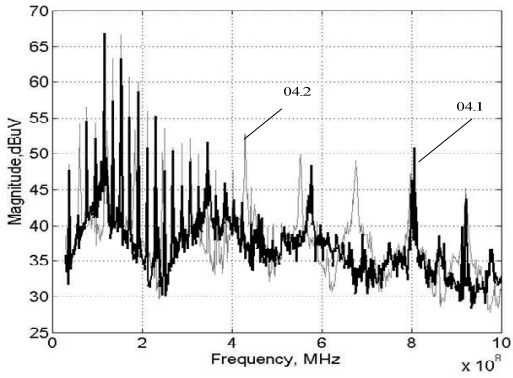

Figure 12. Conducted emission from the reset port on three different boards.

As shown in Figure 12, there are differences in the high frequency range among the test boards. As analyzed before, the emission on the reset port can be divided into two parts, the narrowband signals which are low frequency emissions caused by clock harmonics and wide band signals which are time dependent signal. With the same operation condition and same test setup, the narrowband signal won't change except that the internal source of the emission disappears or the coupling path changes. The variation of the boards may change the coupling path, but not obvious in this measurement as the variation of narrowband emission among the different boards is small. The obvious variation of wideband emission could be explained by software processes in the board, as we had observed that very long times in peak hold mode are needed before the spectrum stabilizes at its maximal value.

5.2. Measurement Repeatability

The measurement of different phases on reset port of 04.2 version test board is shown in Figure 13.

This measurement is to test the effect of software activity in conducted emission. As shown in Figure 13, in searching status, which is a temporary status, the emission is about 6 dB higher than the register status (It is a steady status, all the measurements above are in this status) in high frequency (600-1 GHz), but in low frequency(30 MHz–200 MHz), the emission on both status are almost same.

As discussed before, there are two types conducted emission

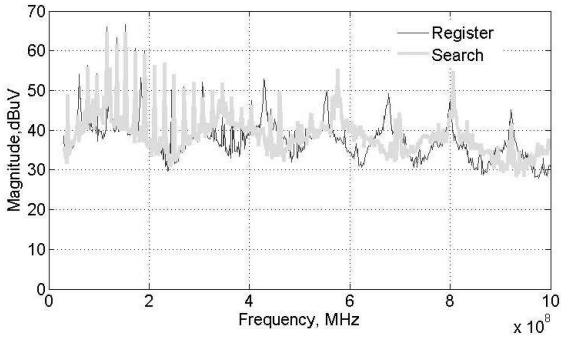

Figure 13. Measurement of different status on reset port.

content. One is the narrow band and time independent emission which is the harmonic frequency of clock. As shown in Figure 13, these narrow band signals aren't changed obviously. It illustrates that the narrowband signal aren't changed by the activity of software. The other is wideband signal. In searching status, the emission is about 6 dB higher than the register status in high frequency (600-1 GHz). The activity of software affects the wideband emission.

6. CONCLUSIONS

Conducted emission data has been extracted from the test board. Two different coupling networks have been used and compared. Both allow coupling the signal. After subtracting a coupling network related 10 dB difference both methods show similar results.

The conducted emission result of the module is good when compared with BISS limits, the BISS limits is an automotive limits whose noise sensitivity is often many dB worse than in FCC testing due to intra-system disturbances, like to the AM radio, FM radio etc..

For frequency part, there are narrow band signals which are clock harmonic frequency, amplitude modulation signal, and wide band time dependent signal.

The activity of software influences the wideband emission.

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