Characterization of the RF Emissions from a Family of Microprocessors Using a 1 GHz TEM Cell

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Abstract: This paper examines the radiated RF emissions from a family of microprocessors expanding on our previous investigations into this area [1]. The procedure used was SAE J1752-3 [2], which specifies a radiated emissions measurement system using a 1 GHz TEM cell with the IC under test on a standardized test board that is a part of the wall above the septum of the TEM cell. This procedure provides a controlled test environment and has been developed to characterize high speed VLSI ICs and survey the variation of RF emissions due to changes in IC process and package parameters. Our investigation involved evaluating the effects on radiated RF emissions from the microprocessors due to processor type, operating software, die mask level, die fab site, die fab date code and fab process variation. The intent is to build a database that will facilitate an assessment of the impact of process changes on the RF emissions from microprocessors.

INTRODUCTION

The area of RF emissions from microprocessors is of increased interest as clock rates and rise times become faster resulting in increased emissions potential. We were aware that process variation could play a significant role in microprocessor emissions and set out to investigate some of these effects. Our intent in this study was to characterize the RF emissions from a family of microprocessors and evaluate the effect of process variations on emissions using a 1 GHz TEM cell. We chose a Motorola family of microprocessors to evaluate due to the availability of hardware. The processors we evaluated were the HC11 and HC12 8-bit controllers and the HC16 16-bit controller. Our primary focus was on the HC16. We looked at the HC16 as a stand alone processor and with an ASIC and collage IC as a chip set. We were able to obtain and evaluate a sampling of micros from different mask levels, different integrated circuit fab locations, different date codes and over a range of four process parametrics. These parametrics were the p-channel and n-channel threshold voltage and the width and length of the transistor.

DESCRIPTION OF SETUP

We used a 1 GHz Fischer TEM cell with a 32 dB Sonoma preamp and an HP 8568B spectrum analyzer to measure the RF emissions using the procedure described in SAE J1752-3. The spectrum analyzer was set to 10 kHz resolution bandwidth, 30 kHz video bandwidth and 150 seconds sweep time to cover the 1 MHz to 1 GHz frequency span. One thousand data points were captured over this frequency span. The 150 second scan time allows 150 milliseconds per frequency step and was chosen to be longer than the expected software code execution time at each frequency [3]. The ambient noise floor was approximately -120 dBm. The test boards were four inch square with an internal ground plane and the microprocessor mounted on the side of the board facing into the TEM cell. Initially, we evaluated the four possible orientations of the test board relative to the TEM cell. For symmetrical test boards we observed that two orthogonal orientations were sufficient to characterize the IC. Typically, we used the North and East orientations. The 1 GHz TEM cell was placed in a shielded room in order to control the ambient and connected to the preamp through a few feet of heliax and RG214 coax.. The data was captured using a 200 MHz Pentium PC running Lab View 4.0 software and imported into Excel 5.0 for processing and display..

GENERAL OBSERVATIONS

Below approximately 150 MHz, individual spectral lines were affected by rotation of the processor test board and above this frequency the effects were due more to statistical variations but could be as much as 10 dB. This is illustrated in Figure 1 where a North and an East orientation (90° rotation) of the microprocessor test board relative to the TEM cell for a 3G26 HC16 microprocessor are plotted. This data is filtered using a 16 point moving average to reduce the spectral clutter. This frequency and orientation relationship may be due to the dominance of the magnetic coupling mechanism at the lower

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frequencies and the dominance of the electric field at higher frequencies [4] & [5].

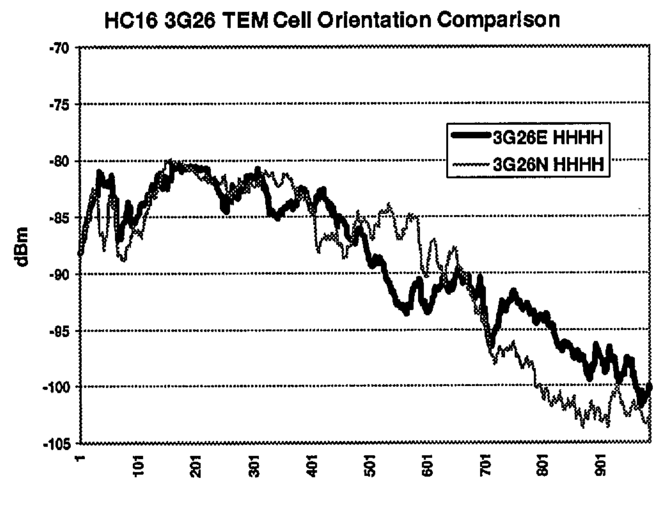

Figure 1

We observed generally increased emissions when the micro I/O was busy as a result of the additional current loops generated. We were able to demonstrate overall measurement repeatability of ± 0.5 dB. We found that the spectra of the processors varied considerably with the more complex micros, as expected, having greater emissions and higher frequency content, as shown in Figure 2.

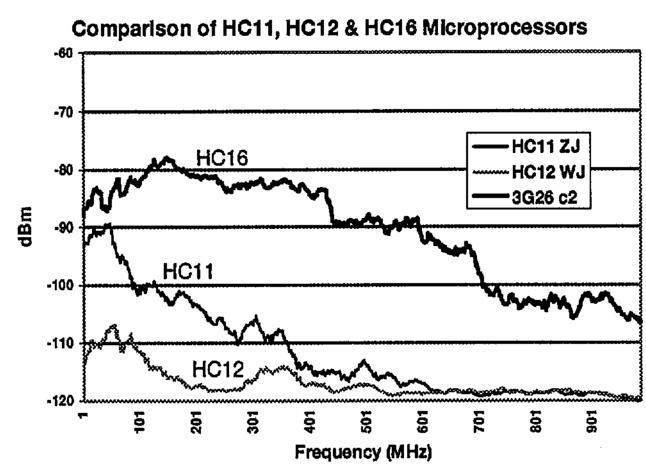

Figure 2

This comparison also uses smoothed data. The HC16 smoothed spectra displayed here is from die level 3G and Fab 26 (Phoenix). The HC16, 16-bit micros had spectra that was not limited to our 1 GHz upper scan frequency. As a result of this observation, we are investigating upgrading our capability using a 2 GHz Fischer TEM cell in order to more completely evaluate these faster micros. It is our hypothesis that the spectra of RF emissions from the microprocessor, driven by the clock rate and software controlled activity, is strongly affected by the microprocessor internal rise time and, to a lesser extent, by the external I/O rise time. The I/O rise time is easily measured and is usually in the range of a few nanoseconds which would correlate to a breakpoint in the spectra in the 50 MHz to 150 MHz range. Note that for the HC11 and HC12 this first break point is under 100 MHz. Our measured I/O rise time for the HC11 and HC12 is of the order of 13 nanoseconds. The break frequency corresponding to this rise time is 76.9 MHz which agrees with the measured data. For the HC16, we measured I/O rise times in the range of 4.0 to 6.7 nanoseconds. This would correspond to a break frequency in the range of 149 to 250 MHz which also is in agreement with the measured data. The internal rise time is related to die process parameters and is not so easily measured. The spectra for the HC16 presents a second breakpoint at approximately 600 MHz. We suggest that this corresponds to an internal rise time of 500 picoseconds. This value has been confirmed as representative for the HC16. As a general pattern, the RF emissions spectra exhibited two breakpoints. The lower frequency break seems to correlate with I/O rise time and the higher frequency break we believe is a function of the internal rise time of the microprocessor.
The Muccioli-Catherwood paper [6] investigated the effects of variations in internal IC architecture on internal rise time. They concluded that gate capacitance has a significant effect on the overall emission spectrum. The HC16 spectra has a peak value around 150 MHz and is off only 10 dB from this value at 600 MHz whereas the spectra from the HC11 and HC12 is in the noise floor at 600 MHz. This suggests that the internal rise time of the HC16 is significantly faster than that of the HC11 and HC12. Interestingly, the HC12 and HC16 use the same 0.65μm process and were from the same fab facility, however, the HC16 is running a faster internal clock. The HC12 exhibits a significantly lower spectral signature than the HC11, as shown in Figure 3. These two micros were running the same production software code. It is our understanding that the HC12 was specifically designed as low noise microprocessor.

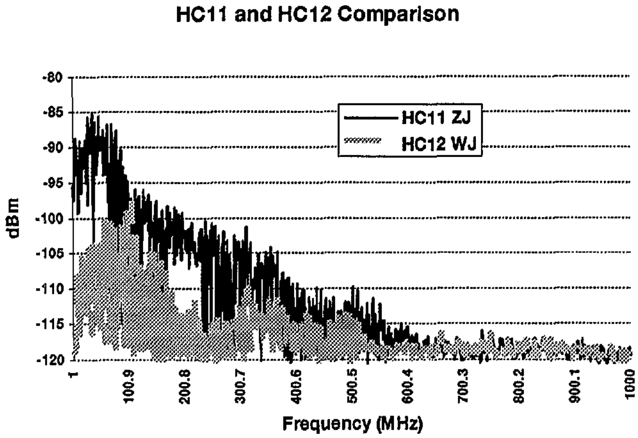

Figure 3

VARIATION DUE TO PROCESS PARAMETRICS

We were able to obtain a set of microprocessors assembled from dies that represented the four corners of the process. Figure 4 represents a statistical analysis of the spectra from the eight microprocessors representing the four process corners for two fab sources.

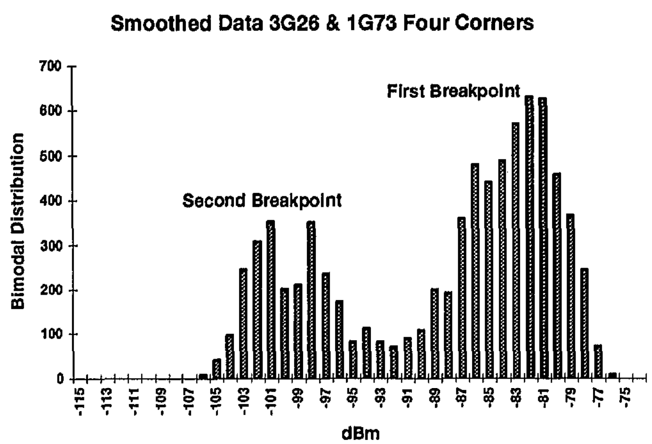

Figure 4

The two statistical distributions indicate the prominence of the breakpoints due to I/O rise time and internal rise time on the spectral output. A comparison of the spectral output distribution of means for the micros is presented in Figures 5 and 6. The following coding is used for the process parameters: a series of four characters identifies the range of process parametrics for that sample, the first place is the p-channel threshold voltage, the second is the n-channel threshold voltage, the third is the transistor width and the fourth is the transistor length. The symbols used are H for high, L for low and C for center distribution. For example, HHHH indicates all the parameters are high distribution. The four corners of the process that we were able to evaluate for the Phoenix fab were: LLLL (C1), LHHH (C2), HHHH (C3) and HLHH (C4). For the Scotland fab these four corners were: LLLL (C1), LHCC (C2), HHCC (C3) and HLCC (C4). For the 3G26 (Phoenix fab), the micro marked as corner 2 exhibits increased RF emissions relative to the others. For the 1G73 (Scotland fab), the corner 3 sample had the highest spectral output. In Figure 6, this data is compared for 1 to 200 MHz. Here the highest spectral output is for 3G26 corner 3.

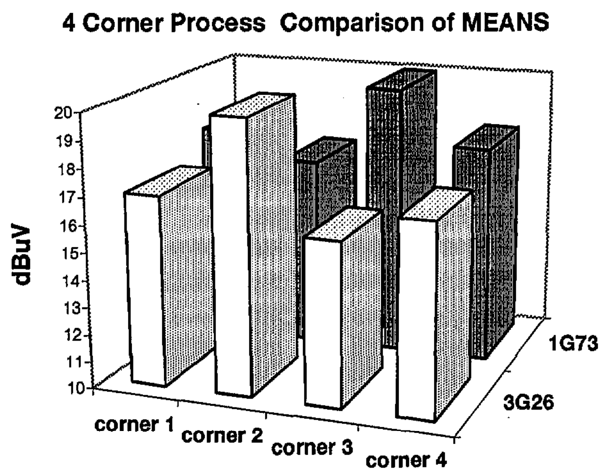

Figure 5

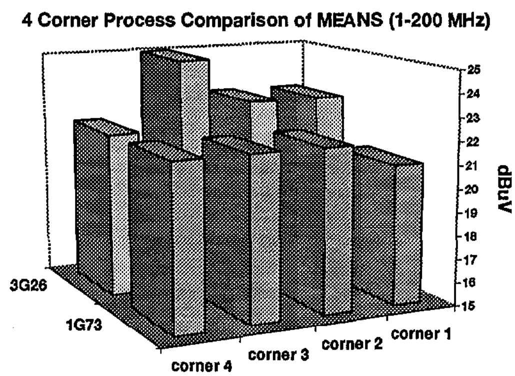

Figure 6

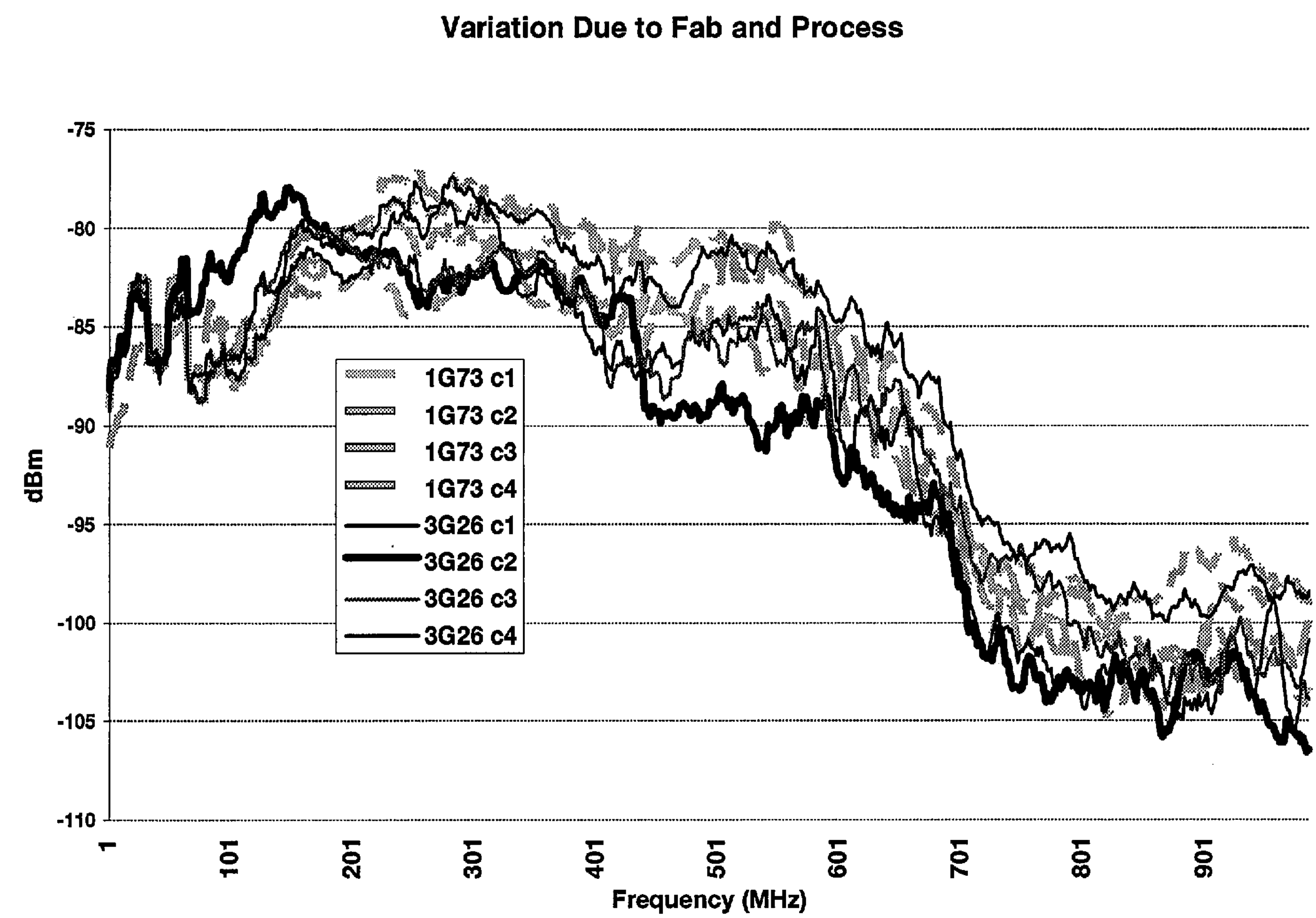

Figure 7

Figure 7 presents spectral data, filtered using a 16 point moving average, for the eight micros representing the four process corners from two different fabs. The differences here can be as much as 20 dB! The plot indicated by the dark line is for 3G26 corner 2. This microprocessor exhibits higher emissions below 200 MHz but significantly lower emissions from 200 MHz to 1 GHz. We believe that this micro has a slower internal rise time than the others from this lot.

VARIATION DUE TO DIE LEVEL, SOURCE and TIME

When comparing micros of the same die level and from the same fab but with date codes separated by 30 weeks, the differences were not significant. Comparison of different fabs producing the same die level did indicate varying spectra confirming that process variations from fab to fab can effect the RF emissions from the microprocessor. Also die level differences for the same microprocessor resulted in different spectral output.

CONCLUSIONS

IC process variations, particularly those that impact on internal rise time, can have a significant effect on the RF emissions from a microprocessor. We observed significant variations in the RF spectra due to IC die level and IC fab location and process. The micros with sub nanosecond internal rise times can be expected to have measurable spectra above 1 GHz. Conversely, if this internal rise time is not known, it can be estimated from the spectral output. Our results indicated that below approximately 150 MHz, individual spectral lines were affected by rotation of the processor test board and above this frequency the effects were due more to statistical variations but could be as much as 10 dB. A possible inference is that the processor can be considered as an array of radiated dipoles with a resultant vector direction at lower frequencies, but at the higher frequencies, the dipole arrays are essentially stochastic. The measurements also indicate that as the processor becomes more complex and is executing a more complex program, the scan rates used must change accordingly in order to fully capture maximum radiated peaks [3]. We confirmed that the measurements made using the 1 GHz Fischer TEM cell were repeatable and consistent within ± 0.5 dB. Our analysis of the effect of known variables on IC radiated emissions is continuing. The area of internal IC architecture and its effects on radiated emissions is a subject for future study. The use of the 1 GHz or (2 GHz) TEM cell in conjunction with a near field scanner should allow a correlation of measured radiated emission levels with an identified internal IC structure. The 20 dB of emissions variation that we observed due to process variation, and the repeatability of the TEM cell measurement procedure, make a convincing case for the use of this technique to provide a signature analysis of a microprocessor and then use this signature as a benchmark when the effects of process variations are being evaluated

ACKNOWLEDGMENTS

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