Experimental Study of IC EMI Reduction Using Spread-Spectrum Clocks

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ABSTRACT

In this study, a spread spectrum technique was employed to modulate clocks so as to reduce the electromagnetic interference (EMI) owing to clocking circuits, which have been considered as major sources of EMI from an IC. A TI-offered evaluation board containing a TI CDCE906 clock synthesizer with a built-in FM triangular modulating function was used as a spread-spectrum clock generator (SSCG). A TEM cell was used to evaluate the radiated emission from a spiral antenna excited by the SSCG. With the clock frequency-modulated and the rise/fall time extended, measured results revealed that the emission levels of the spiral antenna can be greatly reduced.

Keywords: electromagnetic Interference (EMI), spread-spectrum technology, spread-spectrum clock

使用展頻時脈降低 IC EMI 之實驗研究

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摘　要

時脈(Clock)電路為積體電路的主要電磁干擾（EMI）來源，本文利用展頻技術來調變時脈，期能有效抑制來自於時脈系統的電磁干擾（EMI）。本研究以內建 FM 三角波調變函數之德州儀器公司的 TI CDCE906 時脈合成器當作展頻時脈產生器(Spread-Spectrum Clock Generator; SSCG)，並以橫向電磁波室（TEM cell）來評估展頻時脈產生器激發螺旋天線的輻射放射。當一般時脈被頻頻率調變且其上升/下降時間被延長時，量測結果證實螺旋天線的放射準位確實能被大大地降低。

關鍵詞：電磁干擾，展頻技術，展頻時脈

文稿收件日期 99.4.14; 文稿修正後接受日期 99.9.2; *通訊作者
Manuscript received April 14, 2010; revised September 2, 2010; * Corresponding author

I. INTRODUCTION

Because of the increase in clock frequencies and signal speeds of electronic products, electromagnetic interference (EMI) problems due to an integrated circuit (IC) nowadays are more serious than ever before. These problems can be alleviated if the clock frequency can be appropriately reduced. However, this strategy may not be practical in most circumstances. Instead, in order to meet EMI regulations, one may reshape the spectrum of a clock by increasing the rise/fall time of or by frequency modulating the clock, or both [1]-[3].

In this experimental study, a TI-offered evaluation board containing a TI CDCE906 clock synthesizer was employed as a spread-spectrum clock generator (SSCG) for frequency modulating an un-modulated reference clock (URC) so that each harmonic of the URC is spread into a wider frequency band. Because of that, the overall power spectral density (PSD) of the spread-spectrum clock (SSC) is lower than that of its referenced counterpart (i.e., the URC), and hence the radiated emission (RE) level can be reduced. It was also observed experimentally that, upon extending the rise/fall time of the SSC, the peak RE level around each harmonic is significantly reduced.

II. SPREAD SPECTRUM ISSUE

A normal clock is a periodic pulse train or an infinite series of time-period-shifted identical pulse functions. Its Fourier transform or spectrum is an infinite series of clock-frequency-shifted impulse functions in the frequency domain. Ideally, each harmonic of the clock occupies only an infinitesimal frequency band in the frequency domain. If each harmonic of the clock can be spread in the frequency domain into a wider frequency band, the overall PSD of the clock can be reduced, and hence EMI regulations can be met more easily. Let denote the frequency of the URC. If a frequency modulation (FM) is applied to the URC by using a single-tone modulating signal having a modulating frequency of the time-domain representation of the modulated fundamental harmonic of the URC can be written as [4]

$$A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)] = A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos[2\pi (f_c + n f_m) t] \quad (1)$$

where A_c is the amplitude of the fundamental harmonic of the URC, β is the modulation index, and J_n is the Bessel function of the first kind of the nth order. The bandwidth of the modulated fundamental harmonic expressed by (1), according to Carson's rule, is estimated to be $2(\beta+1) f_m$. Similarly, the bandwidth of the modulated nth harmonic can be estimated to be $2(n\beta+1) f_m$. Since the bandwidth of each harmonic after single-tone frequency modulating the URC has increased from zero to a finite value, we can refer to the modulated clock as an SSC. Note that the higher order the harmonic, the wider the spread frequency band around that harmonic. Hence, one can expect an overall trend that the degree of reduction in the RE level is more pronounced for the higher-order harmonic than for the lower-order one. However, this trend cannot continue without bound since eventually adjacent harmonic bands associated with the SSC will overlap as the order of the harmonic is increased. The order of the harmonic, denoted by N_{overlap}, for which its band starts to overlap with that of its next higher-order harmonic can be computed to be [5], [6]

$$N_{\text{overlap}} = \text{Int}\left\{ \frac{1}{\delta}\left(\frac{1}{2} - \frac{f_m}{f_c}\right) - \frac{1}{2} \right\} + 1 \quad (2)$$

where $\text{Int}\{\}$ is the operator that takes the integer part of its argument, and δ is the spreading ratio defined by $\delta = \beta f_m / f_c$.

III. MEASURED RESULTS

RE measurement is commonly performed in an open area test site (OATS) or a semi-anechoic chamber. However, OATSs are not easy to find and semi-anechoic chambers are expensive. In the scenario where only relative RE levels are concerned, commercially available and cheap TEM cells can play a very important role [6], [7]. Fig. 1 shows the experimental setup for measuring the RE from the SSC generated from the SSCG (i.e., TI CDCE906 clock-synthesizer evaluation board). Instead of a

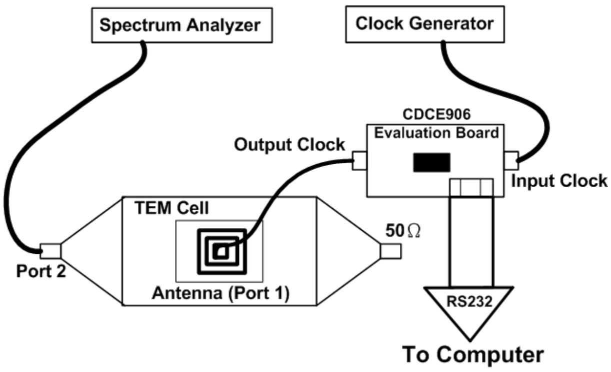

Fig.1. Experiment setup for measuring the RE of the spiral antenna excited by the CDCE906 output clock.

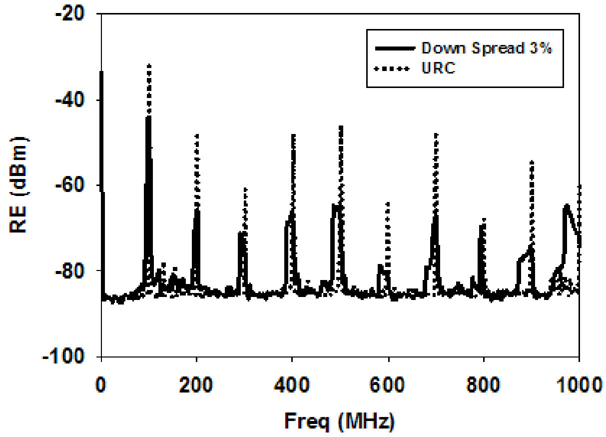

Fig.2. Radiated emissions from the antenna excited by the down-spread SSC with δ = 3% and the corresponding URC (or SSC with δ = 0); f_c = 100 MHz.

semi-anechoic chamber, a TEM cell was used for RE measurement [8], [9]. The SSCG input accepts signals from a clock generator output and the SSCG output is connected to a spiral antenna, which is placed at the aperture of a TEM cell. The RE is then measured through the output port of the TEM cell using an Agilent E7405A spectrum analyzer.

In the experiment, the frequency range of the spectrum analyzer was set to be from 100 kHz to 1 GHz, with a resolution bandwidth of 30 kHz. The TI CDCE906 evaluation board needs only one input clock but can provide up to six output clocks, each with a frequency possibly different from that of the input signal. If not modulated, the output clock is just a URC. If modulated, the output SSC can be classified into two categories: center spread and down spread. One can choose three different spreading ratios (defined by $\delta = \beta f_m / f_c$), i.e., ±0.1%, ±0.25%, and ±0.4%, from center-spread SSCs, and four (1%, 1.5%, 2%, and 3%) from down-spread SSCs. In the experiment, the SSCG input clock was chosen to be 10 MHz, the output clocks were set at 100 MHz (hence, f_c = 100 MHz). The RE from a down-spread 100 MHz SSC with a spreading ratio of 3% was measured and compared with that from the URC, as shown in Fig. 2. The measured spectrum indicates that the down-spread SSC has wider frequency bands around all harmonics of the URC. Moreover, the peak RE level of the down-spread SSC around each harmonic is indeed lower than that of the URC.

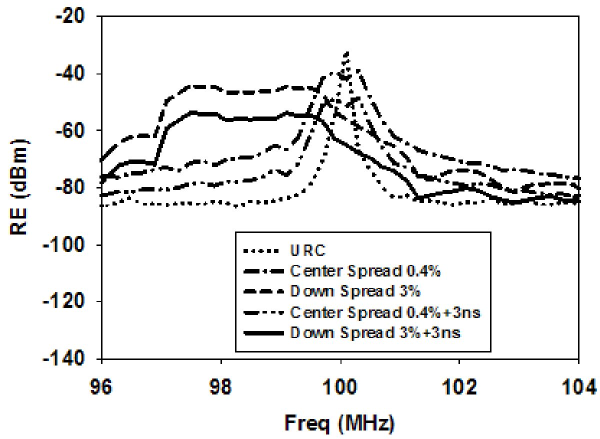

Fig.3. RE of spread SSCs with two different spreading schemes and with or without a 3 ns longer rise/fall time at fundamental frequency 100 MHz.

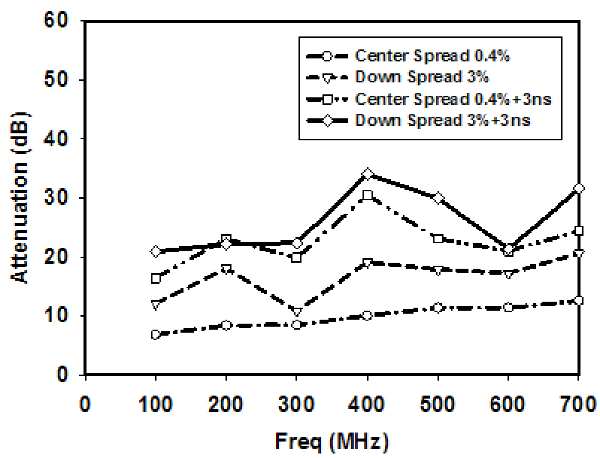

Fig.4. Attenuation values of the δ = 3% down-spread and the δ = ±0.4% center-spread schemes, both with and without an additional rise/fall time of 3 ns; f_c = 100 MHz.

Since the TI CDCE906 evaluation board also provides the capability of varying the rise/fall time of the SSC, we will also demonstrate that longer rise/fall time of the SSC will further enhance the attenuation property. Fig. 3 shows the RE of spread SSCs with two different spreading schemes and with or without 3-ns longer rise/fall time for the fundamental frequency (i.e., 100 MHz). The RE from the corresponding URC is also shown for comparison. Refer to the difference between the peak RE of the URC and that of an SSC around each harmonic as attenuation. The RE of the down-spread SSC with a spreading ratio of 3% and with an additional rise/fall time of 3 ns appears to provide a larger attenuation than the others. Fig. 4 shows the attenuation values of RE level for the first seven harmonics of these SSCs, including the down-spread scheme with δ = 3%, center-spread scheme with δ = ±0.4%, down-spread scheme with δ = 3% and with 3-ns longer rise/fall time, and center-spread scheme with δ = ±0.4% and with 3-ns longer rise/fall time). Without additional rise/fall time, the ±0.4% center-spread scheme can provide an attenuation of only 6.8–12.6 dB, whereas the 3% down-spread scheme 10.9–20.5 dB. If an additional rise/fall time is added to the SSCs, the ±0.4% center-spread scheme can provide an attenuation of 16.5–30.5 dB, whereas the 3% down-spread scheme 20.9–34.0 dB. The attenuation of the down-spread SSC appears to be larger than that of the center-spread SSC.

One might tend to conclude that the down-spread scheme is more effective than the center-spread one in reducing the RE, and hence is a better spread-spectrum scheme. However, we must remember that the spreading ratio adopted in the down-spread scheme is much larger than that adopted in the center-spread one. The attenuation of the SSC with an additional rise/fall time of 3 ns appears to be larger than that without. This dictates that extending the rise/fall time is indeed very effective in reducing the EMI level.

IV. CONCLUSIONS

In this study, reduction in IC EMI through SSCs in conjunction with possibly additional rise/fall time has been experimentally studied. The SSC and the additional rise/fall time were provided by a TI CDCE906 clock-synthesizer evaluation board. Both down- and center-spread schemes were employed and the measured results were compared. Without additional rise/fall time, SSCs can lead to an attenuation of RE level up to 20.5 dB. With an additional rise/fall time of 3 ns, an extra attenuation of 13.5 dB can be achieved. We hence conclude that an SSC with longer rise/fall time is preferred as long as the extra rise/fall time can be tolerated. If not, the SSC alone can also effectively reduce the IC EMI level.

ACKNOWLEDGMENT

The authors thank the National Science Council, Taiwan, ROC, for financial support under Grant NSC-98-2221-E-224-011-MY2.

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