Experimental Study of IC EMI Reduction by Spreading Clock-Signal Spectrum

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***Abstract*—Clock circuits have been considered as major sources of EMI from an IC. Hence, the reduction of EMI from clock circuits has been an active research topic in recent years. In this study, a spread spectrum technique was employed to modulate clock signals so as to reduce the EMI level. A TI-offered evaluation board containing a TI CDCE906 clock synthesizer with a built-in FM triangular modulating function was used as the spread spectrum clock generator (SSCG). The output spectrum-spread clock (SSC) was in turn fed into a PIC18F4420 microchip test board. With the clock signal frequency modulated and the rise/fall time extended, measured results revealed that the emission levels of the microchip test board can be greatly reduced.**

Key words: Spread spectrum technology, Electromagnetic Interference (EMI), Spectrum-spread clock.

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 signal by increasing the rise/fall time of or by frequency modulating the clock signal [1]-[3].

Lin and Chen were the first two who employed a modulation scheme on a clock signal to reduce the EMI level due to an IC [1]. Nowadays, some ICs have already had built-in user-controlled spread-spectrum functions. 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 spectrum level (or spectral power-density level) of the spectrum-spread clock (SSC) is lower than that of its referenced counterpart (i.e., URC), and hence the EMI level can be reduced. It was also observed experimentally that, upon extending the rise/fall time of the SSC, the peak power-density level around each harmonic is significantly reduced.

II. SPREAD SPECTRUM ISSUE

A normal clock signal 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. That is to say, each harmonic of the clock signal occupies only an infinitesimal frequency band in the frequency domain. If each harmonic of the clock signal can be spread in the frequency domain into a wider frequency band, the overall spectral power-density level of the clock can be reduced, and hence EMI regulations can be met more easily. Let f_c 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 f_m, the time-domain representation of the fundamental harmonic can be written as [4]

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

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 modulated nth harmonic can be estimated to be $2(n\beta+1) f_m$. Since the bandwidth of each harmonic after the single-tone FM of 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 spectral power-density 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]

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

where δ is the spreading ratio defined by $\delta = \beta f_m / f_c$.

III. Measurement Results

Fig. 1 shows the experimental setup for measuring the radiated emission (RE) from the SSC generated from the SSCG (i.e., TI CDCE906 clock-synthesizer evaluation board). 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 [6-8]. The RE is then measured through the output port of the TEM cell using an Agilent N1996A spectrum analyzer. The photograph of part of the physical setup is shown in Fig. 2.

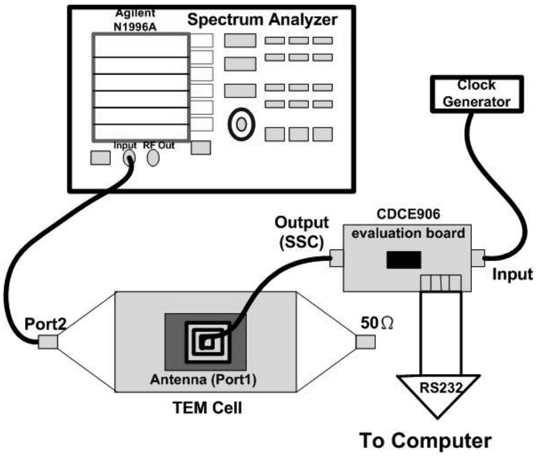

Fig. 1 Experiment setup for measuring the RE from the spiral antenna excited by the CDCE906 output clock.

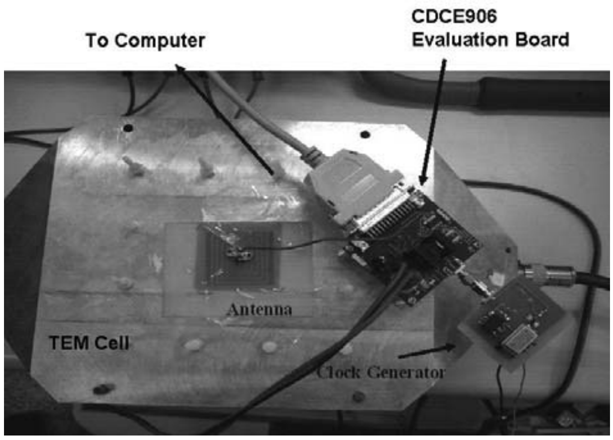

Fig. 2 Photograph of part of the physical setup for measuring the RE from the spiral antenna excited by the CDCE906 output clock.

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 100 kHz. The TI CDCE906 evaluation board needs only one input signal but can provide up to six output clock signals, each with a frequency possibly different from that of the input signal. If not modulated, the output clock signal 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, i.e., $\pm 0.1\%$, $\pm 0.25\%$, and $\pm 0.4\%$, from center spread SSCs, and four (1%, 1.5%, 2%, and 3%) from down spread SSCs. In the experiment, the SSCG input signal was chosen to be 10 MHz, the output signal was set at 10 or 100 MHz (hence, f_c = 10 or 100 MHz, respectively), and the modulating frequency was fixed at 40 kHz. A down (center) spread 100-MHz SSC with a spreading ratio of 3% ($\pm 0.4\%$) output from the SSCG was measured and compared with the URC, as shown in Fig. 3 (Fig. 4). The measured spectra indicate that both SSCs have wider frequency bands around all harmonics of the URC. Moreover, The peak spectral power-density levels of these two SSCs around each harmonic are indeed lower than that of the URC. Refer to the difference between the peak spectral power-density level of an SSC and that of the URC around each harmonic as attenuation. Fig. 5 shows the attenuation values for the first 10 harmonics of these two SSCs. The attenuation for 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 scheme in reducing the RE, and hence is a better spectrum-spreading 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. In a word, the $\pm 0.4\%$ center spread scheme can provide an attenuation of 3-11 dB, whereas the 3% down spread 7-12 dB.

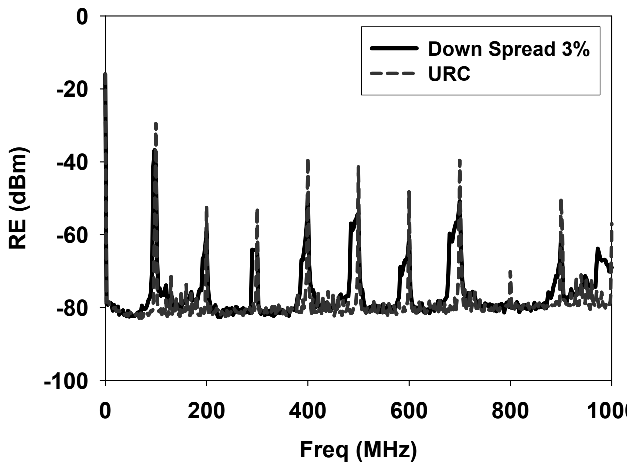

Fig. 3. Radiated emissions from the antenna excited by the down spread SSC with δ = 3% and the corresponding URC (or SSC with δ = 0); f_c = 100 MHz.

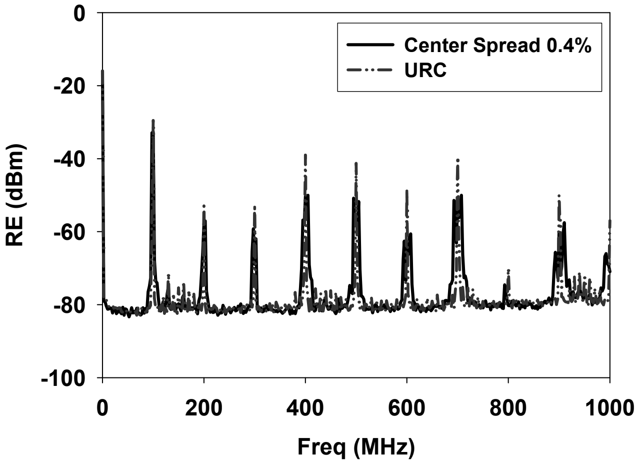

Fig. 4 Radiated emissions from the antenna excited by the center spread SSC with δ = ±0.4% and the corresponding URC (or SSC with δ = 0); f_c = 100 MHz.

Since the TI CDCE906 evaluation board also provides the capability of varying the rise/fall time of the SSC, we will also demonstrate that a longer rise/fall time of the SSC will further enhance the attenuation property. Shown in Fig. 6 are measured REs from the spiral antenna excited by 10-MHz URCs around their 17th harmonics for four different values of the additional rise/fall time, i.e., 0, 1, 2, and 3 ns. Observe that the longer the additional rise/fall time, the narrower the frequency band of the 17th harmonic and the weaker the measured RE. This dictates that extending the rise/fall time is indeed very effective in reducing the EMI level.

Next, the SSC output from the SSCG is now connected to a PIC18F4420 microchip test board, instead of the spiral antenna. The photograph of part of the physical setup is shown in Fig. 7. Presented in Fig. 8 (Fig. 9) are the measured RE from the whole test board fed by a URC and that fed by a ±0.4% center (3% down) spread SSC with an additional rise/fall time of 3 ns, both having an f_c of 10 MHz. Here, the spectrum analyzer was setup in exactly the same way as when the SSC is fed into the spiral antenna. Note that the curves shown in Figs. 8 and 9 are the envelopes of the spectra (i.e., these curves trace out the peak spectral power densities around all harmonics), instead of the original spectra; if the original spectra are plotted, these two figures would look very crowded. The measured results show that the both SSCs in conjunction with an additional rise/fall time of 3 ns can greatly enhance the attenuation. Observe that the ±0.4% center spread scheme with extended rise/fall time can provide attenuation of up to 16 dB, whereas the 3% down spread up to 22 dB. In comparison with Figs. 3 and 4, we can see that the extended rise/fall time plays a very significant role in IC EMI reduction.

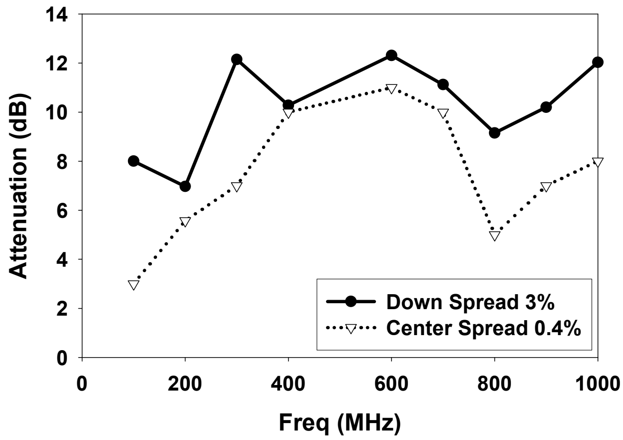

Fig. 5 Attenuation values of the down spread scheme (with δ = 3%) and the center spread scheme (with δ = ±0.4%); f_c = 100 MHz.

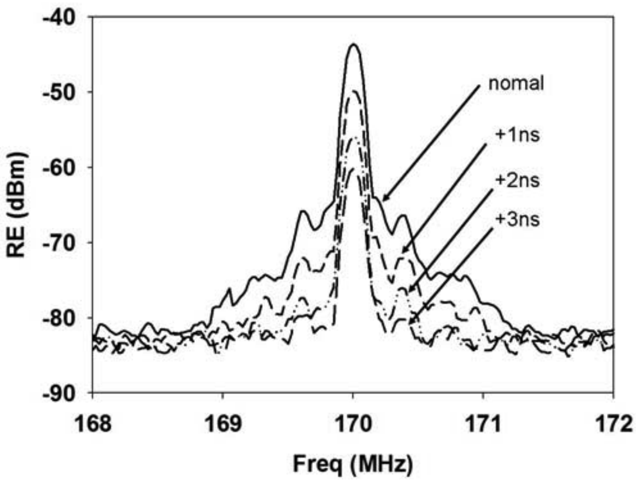

Fig. 6 Measured REs from the spiral antenna excited by the URCs for four different additional values of the rise/fall time; f_c = 10 MHz.

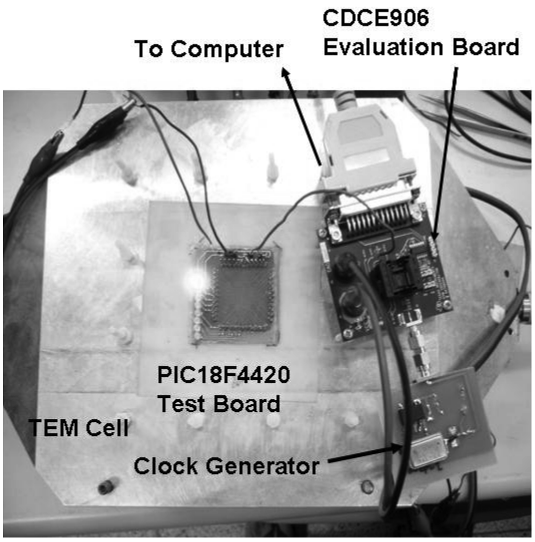

Fig. 7. Photograph of part of the physical setup for measuring the RE from the PIC18F4420 microchip test board clocked by the CDCE906 output signal.

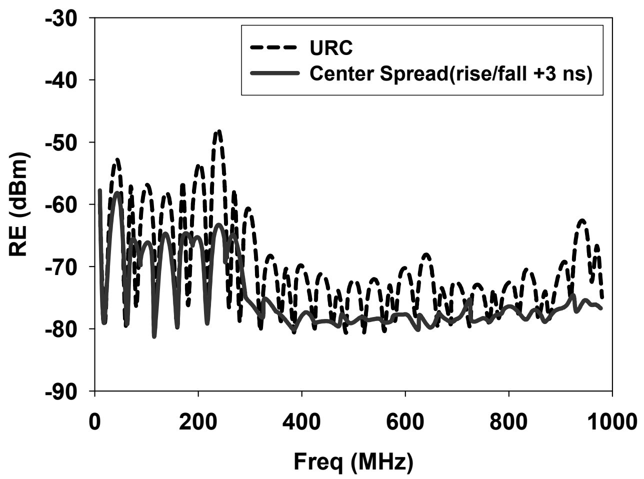

Fig. 8 Measured REs from the microchip test board clocked by the URC and by the ±0.4% center spread SSC with an additional rise/fall time of 3 ns; f_c = 10 MHz .

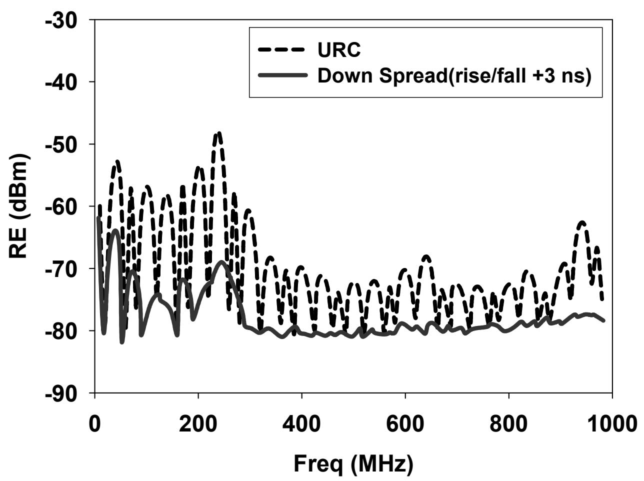

Fig. 9. Measured REs from the microchip test board clocked by the URC and by the 3% down center spread SSC with an additional rise/fall time of 3 ns; f_c = 10 MHz .

IV. CONCLUSION

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 spread and center spread schemes were employed and the measured results were compared. For the spiral antenna excited by SSCs, the obtained attenuation ranges from 3 to 12 dB. For the PIC18F4420 microchip test board clocked by SSCs with an additional rise/fall time of 3 ns, the attenuation was upgraded up to 22 dB. We hence conclude that whenever the rise/fall time is not critical, a longer rise/fall time is preferred. If that is not the case, SSCs alone can also effectively reduce the IC EMI level.

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