Buletinul Ştiinţific al Universităţii "Politehnica" din Timişoara

Seria ELECTRONICĂ şi TELECOMUNICAŢII
TRANSACTIONS on ELECTRONICS and COMMUNICATIONS

Tom 49(63), Fascicola 2, 2004

Accurate Sinewaves Implemented With a 16-bit Fixed-Point Digital Signal Processor

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Abstract – In this paper the performances of two methods in the implementation of a sinewave with a 16-bit fixed-point digital signal processor (DSP)-TMS320C5x are evaluated and compared. The methods used are the recurrence formula method and the look-up-table (LUT) method. By each method the sinewaves are generated by simulation and with the TMS320C5x Starter Kit (DSK) board. The performances of the methods are appreciated by means of the dynamic parameters of the sinewaves implemented: signal-to-noise and distortion ratio (SINAD) and total harmonic distortion (THD). The accuracy of the frequency of the sinewaves implemented is also determinate.

Keywords: implementation of the sinewave, digital signal processor, accurate estimate of the sinewave dynamic parameters.

I. INTRODUCTION

The sinewaves are the easiest to generate in practice at the frequencies with adequate accuracy. From these reasons the sinewaves are used in many applications, such as communication, instrumentation and control. The sinewaves can be implemented with analog or digital circuitry. Due to its advantages concerning the accuracy, speed and the easiest in establishing the parameters the microprocessors and the digital signal processors (DSP) are mostly employed for implementing the digital sinewave generators [1]-[3].

The objective of this paper is the determination and the comparison of the performances of two methods in the implementation of a sinewave with a 16-bit fixed-point DSP-TMS320C5x. The methods are ones of the most used in the implementation of a digital sinewave: the recurrence formula method [1], [4] and the look-up-table (LUT) method [3].

Using each method the sinewaves are generated by simulation and by means of the TMS320C5x Starter Kit (DSK) board. The accuracy of the sinewave implemented was determinate by its dynamic parameters: signal-to-noise and distortion ratio (SINAD) and total harmonic distortion (THD). Moreover, the accuracy of the frequency of the sinewave implemented is determinate.

II. THE METHODS USED FOR IMPLEMENTING THE SINEWAVES

A discrete-time sinewave can be implemented by the following two methods:

A. *The recurrence formula method*

We consider a continual-time sinewave $x(t)$ characterized by amplitude A and frequency f_{in}. After the sampling with frequency f_s ($f_s > 2 f_{in}$) the discrete-time sinewave $x[n]$ is obtained. $x[n]$ is given by

$$x[n] = A\sin\left(2\pi\frac{f_{in}}{f_s}n\right), \qquad n = 0, 1, 2, \ldots \qquad (1)$$

Based upon (1), after some simple algebra, the following recurrence relationship is achieved

$$x[n] = 2ax[n-1] - x[n-2] \qquad n = 2, 3, 4, \ldots \qquad (2)$$

where: $a = \cos\left(2\pi\frac{f_{in}}{f_s}\right)$;

$x[0] = 0$ (from (1));

$x[1] = A\sin\left(2\pi\frac{f_{in}}{f_s}\right)$ (from (1)).

Thus, from (2) it follows that the discrete-time sinewave $x[n]$ can be implemented by means of a recurrence formula.

B. *The look-up-table (LUT) method*

If N samples of the $x[n]$ (n = 0, 1, 2, ..., N-1) are acquired, then the relationship between the frequencies f_{in} and f_s is given by

$$\frac{f_{in}}{f_s} = \frac{J + \delta}{N} \qquad (3)$$

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where J is the number of sinewave cycles (J is an integer) and $0 \le \delta < 1$.

For $\delta = 0$ the sampling process is coherent with the sinewave and (3) represents the coherent sampling relationship between the frequencies f_{in} and f_s. In this case, based upon (1), $x[n]$ is periodically with the period N, i.e. $x[n] = x[n + N]$. So, $x[n]$ is completely represented by its first N samples ($n = 0, 1, 2, \ldots, N-1$).

The LUT method consists in the following two steps:

step 1: The first N samples of $x[n]$ ($n = 0, 1, 2, \ldots, N-1$) are stored in a memory (table).

step 2: The sinewave is generated by stepping the table, wrapping around at the end of the table whenever $n \ge N$, i.e. the following sequence is obtained

$$x[n \text{ modulo } N], \qquad n = 0, 1, 2, \ldots \tag{4}$$

[illegible]

when this quotient is computed as an integer.

For $\delta \ne 0$ the sampling process is not coherent with the sinewave. In this case for implementing the sinewave by LUT method an algorithm is proposed. This algorithm consists in the following steps:

step 1: A memory with a capacity K samples is considered. The values kf_{in}/f_s ($k = 0, 1, 2, \ldots, K$) are computed. The k value for which kf_{in}/f_s is the nearest closely to an integer number is determinate. This value $k = M$ ($M \le K$) and $q = \text{round}(Mf_{in}/f_s)$, where round($b$) is the most closely integer to b.

step 2: The frequency $\tilde{f}_{in} = qf_s / M$ is computed.

step 3: The first M samples of $\tilde{x}[n] = A\sin(2\pi \tilde{f}_{in} n/f_s)$, $n = 0, 1, \ldots, M-1$, are stored in the memory.

step 4: The sinewave $\tilde{x}[n]$ is generated by stepping through the table, wrapping around at the end of the table whenever $n \ge N$, i.e. the following sequence is obtained

$$\tilde{x}[n \text{ modulo } M], \qquad n = 0, 1, 2, \ldots \tag{5}$$

The errors between $x[n]$ and $\tilde{x}[n]$ are very small if K is high ($K \ge 4096$ samples).

III. SIMULATION RESULTS

By each method the sinewaves are simulated using the simulator *sim5x.exe* given by Texas Instruments [5]. The samples of the sinewaves were obtained by means of programs written in C.

The dynamic performances SINAD and THD of the sinewaves were determinate by the algorithm proposed in [6]. The frequencies of the sinewaves were estimated by the interpolated fast Fourier transform (interpolated FFT) algorithm [7]. The Blackman-Harris −191dB window [8] was employed for estimating the dynamic performances and the frequencies of the sinewaves.

Fig. 1 shows the performances of the sinewaves implemented by the recurrence formula method at some frequencies. The samples of the sinewaves were generated with 15.625 kHz sampling frequency. The sampling frequency of the acquisition process was equal to 15.625 kHz. Were acquired $N = 1024$ samples.

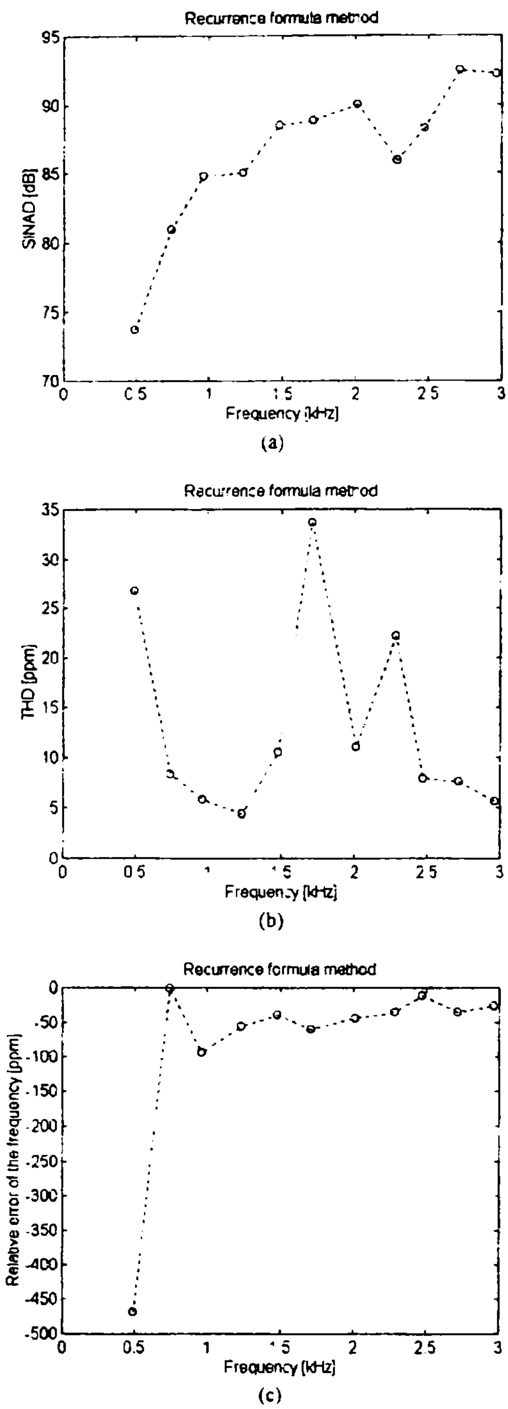

Fig. 1. The performances of the sinewaves implemented by the recurrence formula method.

In Fig. 2 are presented the performances of the sinewaves generated by the LUT method with the algorithm proposed at the same frequencies as for the sinewaves implemented by the recurrence formula method. The samples of the sinewaves were generated with 15.625 kHz sampling frequency. The memory capacity was $K = 7$ K samples. The sampling frequency of the acquisition process was equal to

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15.625 kHz and the number of samples acquired was $N = 1024$.

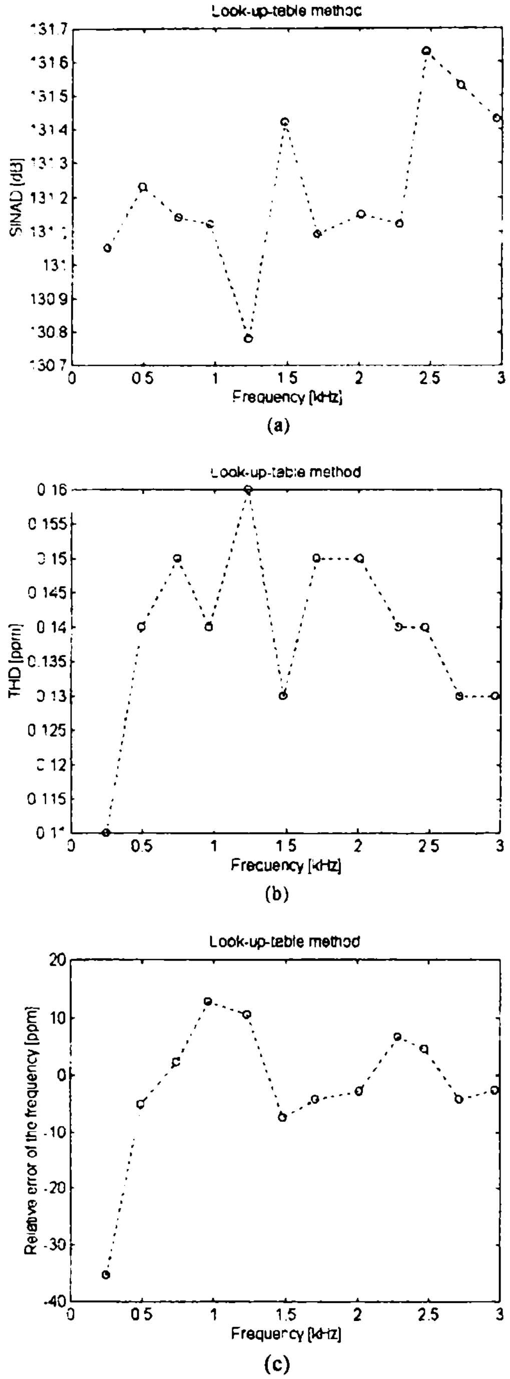

Fig. 2. The performances of the sinewaves implemented by the LUT method with the algorithm proposed.

From Figs. 1 and 2 it follows that the performances of the sinewaves implemented by the LUT method with the algorithm proposed are much higher than the ones obtained by using the recurrence formula method. These results are achieved because the samples of the sinewaves are obtained in the case of using the recurrence formula method, in comparison with the ones obtained by using the LUT method, after some operations with fixed-point arithmetic, which are affected by errors. However, the recurrence formula method leads, also, to very accurate results.

IV. EXPERIMENTAL RESULTS

The experimental results were carried out by means of the TMS320C5X DSK board [9]. The TMS320C5X DSK is a low-cost, simple, stand-alone application board equipped with the TMS320C50 DSP. DSK contains an analog interface circuit (AIC)-TLC32040, which provides the necessary conversion between the analogue and digital domain. For this purpose it incorporates a band-pass antialiasing input filter, a 14-bit analog-to-digital converter (ADC), a serial port by which AIC communicate with TMS320C50, a 14-bit digital-to-analog converter (DAC) and a low-pass output reconstruction filter. DSK is connected to a PC via a RS232 interface.

The acquisition system was also a TMS320C5X board. The experimental setup is presented in Fig. 3.

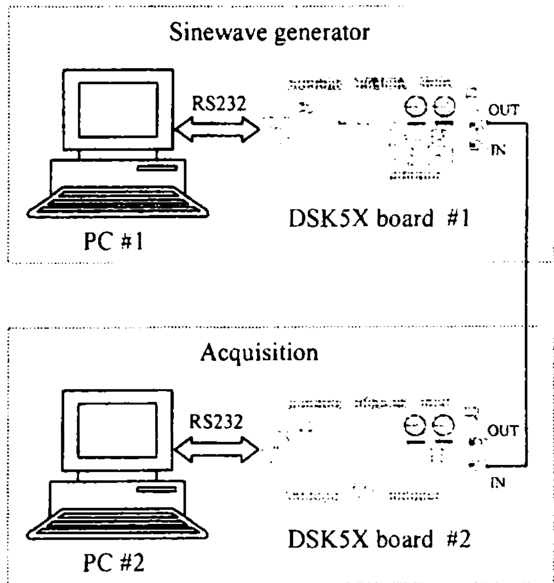

Fig. 3. The experimental setup.

The same algorithms as in simulation estimated the dynamic performances and the frequencies of the sinewaves.

Fig. 4 shows the performances of the sinewaves implemented by the recurrence formula method at the same frequencies as in simulation. The samples of the sinewaves were generated with 15.625 kHz sampling frequency. There were used two sampling frequencies $f_s = 7.95$ kHz and $f_s = 15.625$ kHz and were acquired $N = 1024$ samples.

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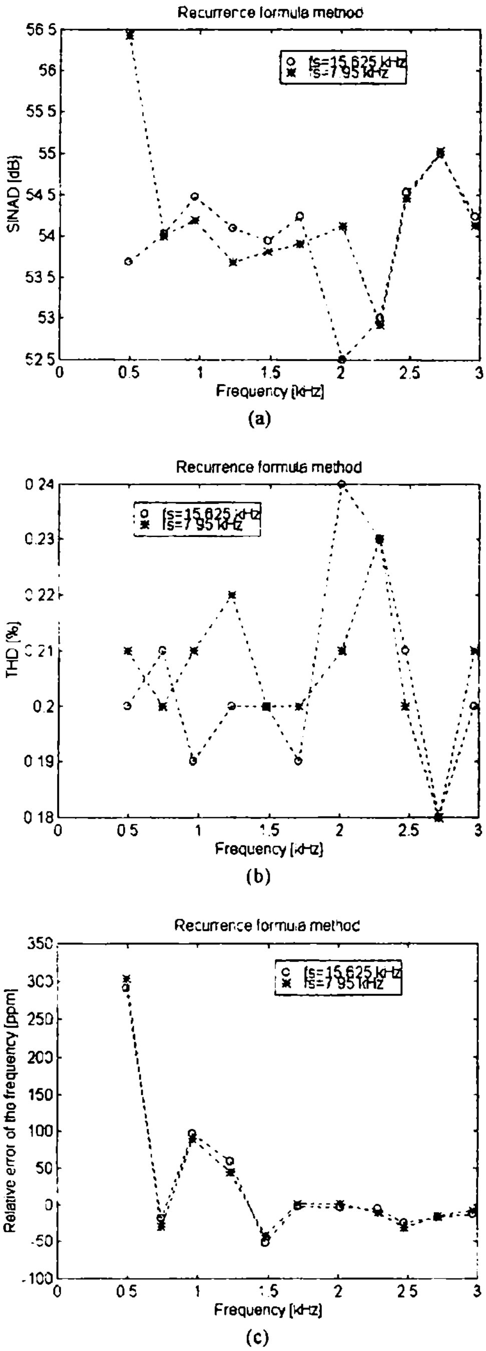

Fig. 4. The performances of the sinewaves implemented by the recurrence formula method at two sampling frequency of the acquisition process: f_s = 7.95 kHz (star) and f_s = 15.625 kHz (circle).

Fig. 5 presents the performances of the sinewaves generated by the LUT method with the algorithm proposed at the same frequencies as in simulation. There were used, also, two sampling frequencies of the acquisition process f_s = 7.95 kHz and f_s = 15.625kHz and were acquired N = 1024 samples.

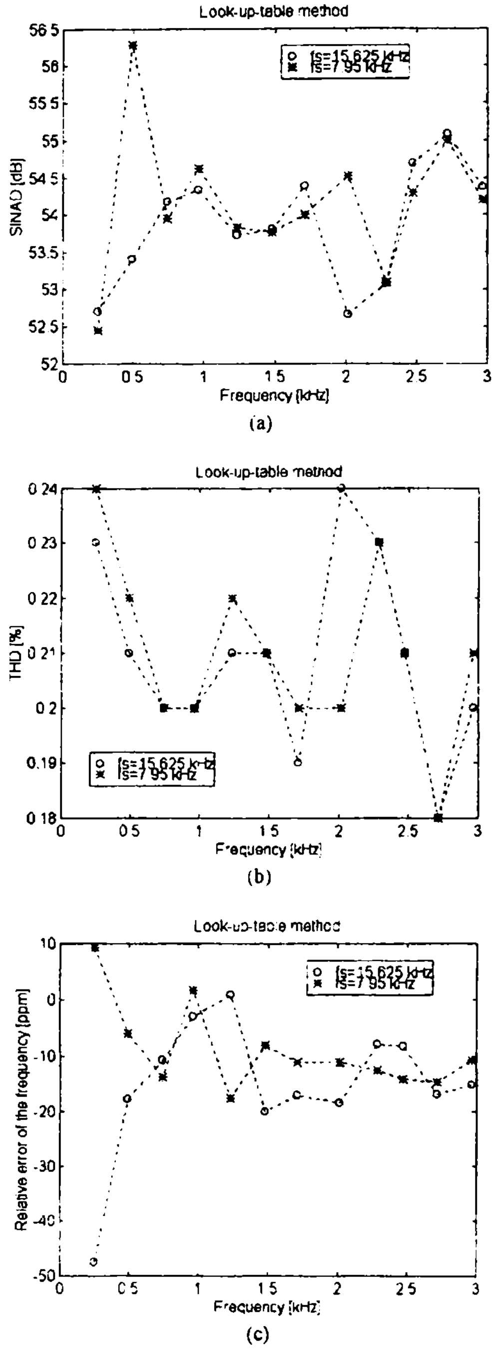

Fig. 5. The performances of the sinewaves implemented by the LUT method at two sampling frequency of the acquisition process: f_s = 7.95 kHz (star) and f_s = 15.625 kHz (circle).

By comparison the performances SINAD and THD of the sinewaves implemented with TMS320C5X DSK board at the acquisition sampling frequency f_s = 15.625 kHz with the ones obtained from simulated sinewaves it follows that the performances are severely degraded because of the poor performances of the low-pass output reconstruction filter of the AIC [9]. Due to the behavior of the AIC output filter the dynamic performances of the sinewaves implemented by both methods are very close. However, the dynamic performances of the sinewaves are, in many cases, superior to the ones obtained with the analog sinewave oscillators.

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From Figs. 4(c) and 5(c) it follows that the sinewaves frequencies are more accurate at small frequencies when the LUT method with the proposed algorithm is employed than when the recurrence formula method is used.

Another important conclusion drawn from Figs. 4 and 5 is that the performances of the sinewaves are not affected by the value of the sampling frequency of the acquisition process.

V. CONCLUSION

This paper was focused on the evaluation and the comparison of the performances of the sinewaves implemented with a 16-bit fixed point DSP-TMS320C5X by two methods. These methods were ones of the most used in the implementation of a digital sinewave: the recurrence formula method and the LUT method. In the case in which the acquisition sampling process is noncoherent with the sinewave for implementing the sinewave by LUT method an algorithm is proposed.

The simulation results indicate that the performances of the sinewaves implemented by the LUT method with the algorithm proposed are much higher than the ones obtained by using the recurrence formula method. The experimental results were carried out by means of the TMS320C5X DSK board. Unfortunately, the dynamic performances of the sinewaves implemented by this board are severely degraded by comparison with the simulated ones because of the poor performances of the low-pass output filter of the AIC of the DSK board. However, the dynamic performances obtained are, in many cases, superior than the ones provides by the analog sinewave oscillators. From the experimental results, it follows that the sinewaves frequencies are more accurate, at smaller frequencies, when the LUT method with the proposed algorithm is used.

ACKNOWLEDGEMENT

The results reported here were partially obtained in the framework of the CNCSIS Grant AT 32940 number 1, dedicated to the analog-to-digital converters dynamic testing in multi-tone mode.

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