Quality Assessment of a Square Wave as a Function of Levels Accuracy

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***Abstract*-** In this paper the influence of levels inaccuracy on the quality of a square wave is evaluated. This is done by means of the signal-to-noise ratio (SNR) of the square wave. An algorithm for estimating the SNR of a square wave is proposed. Simulations carried out confirm that the proposed algorithm leads to very accurate results. Some experimental results obtained based upon the proposed algorithm are also presented.

I. Introduction

Many practical applications use square waves obtained from signal generators. The quality of a square wave is determined, in principal, by: the levels accuracy, the rise and fall times value and the stability of its parameters (levels, frequency and duty cycle).

The levels of a square wave are affected by additive noise, jitter, ringing due to the filter, harmonic and spurious components, etc. [1], [2]. Thus, it is very useful, especially in very high accuracy measurement applications to know how these errors affect the quality of the square wave. The objective of this paper is to evaluate the influence of the levels inaccuracy on the quality of the square wave. This is determined by means of the signal-to-noise ratio (SNR) of the square wave. An algorithm for estimating this parameter is proposed. The performances of the proposed algorithm are analyzed by simulation. Moreover, some experimental results obtained with the proposed algorithm are presented. The experiments were obtained by means of a test system, specially developed for this purpose.

II. SNR estimation algorithm

We consider an analog square wave $x(t)$ characterized by levels a and b ($a > b$), duty cycle k and frequency f_{in}. The signal is digitized by means of a waveform recorder at a sampling frequency f_s. The digitized square wave obtained is $y(m)$, $m = 0, 1, 2, \ldots$ The SNR of the signal $y(m)$ is given by

$$SNR = 10\log\left(\frac{Y_{rms}^2}{\sigma^2}\right) = 10\log\left(\frac{(a-b)^2 k(1-k)}{\sigma^2}\right) \qquad [dB] \tag{1}$$

where: Y_{rms} is the rms value of the square wave ($Y_{rms} = (a-b)\sqrt{k(1-k)}$);

σ is the standard deviation of the square wave noise.

The square wave noise includes all the errors which affect the levels: additive noise, jitter, ringing due to the filter, harmonic and spurious components, etc. We assume that the waveform recorder errors are negligible in comparison with the square wave noise and so, do not affect the SNR of the square wave.

The algorithm proposed for estimating the SNR consists in the following steps:

1) M samples $y(0), y(1), \ldots, y(M - 1)$ are acquired.

2) The modulo-time plot of the acquired signal is computed [3]. From this, signals y_1 and y_2 which contain the samples corresponding to the high level and to the low level are determined. The lengths M_1 and M_2 of signals y_1 and y_2 are also determined.

3) From the samples of the signal y_1 the high level estimate value $\tilde{a}$ is determined by the least squares fitting algorithm ($\tilde{a}$ is equal to the mean value of y_1). Also, by using the same procedure the low level estimate value $\tilde{b}$ is determined ($\tilde{b}$ is equal to the mean value of y_2). The duty cycle of the square wave is estimated by the expression $\tilde{k} = M_1 / (M_1 + M_2)$.

4) The variance of the noise is estimated by the variance $\tilde{\sigma}^2$ of the differences between the samples acquired and the samples corresponding to the best - square fit.

5) The SNR is estimated by the expression

$$SNR_{est} = 10\log\left(\frac{\left(\tilde{a}-\tilde{b}\right)^2 \tilde{k}\left(1-\tilde{k}\right)}{\tilde{\sigma}^2}\right) \qquad [dB]. \tag{2}$$

The performances of the proposed algorithm are studied by simulation. The digitized square wave used in simulation was:

$$y(m) = x(m) + h(m) + e_n(m), \qquad m = 0, 1, 2, \ldots, M-1 \tag{3}$$

where: $x(m)$ is the simulated square wave input signal of f_{in} frequency with a = 2V, b = -1.5 V and $k = 0.5$;

$h(m) = h_2(m) + h_3(m)$, in which $h_2(m)$ is a simulated second harmonic component of $x(m)$ with levels u and $-3u/4$, duty cycle equal to 0.5and $h_3(m)$ is a simulated third harmonic component of $x(m)$ with levels $u/2$ and $-3u/8$, duty cycle equal to 0.5; u is determined as a function of SNR;

$e_n(m)$ is the simulated normal noise with zero mean and standard deviation σ.

The analog-to-digital converter (ADC) of the waveform recorder has a 12-bit resolution and a full-scale range FSR = 5V. The waveform recorder errors do not affect the values of the signal $y(m)$.

The relationship between the frequency f_{in} and the sampling frequency f_s of the waveform recorder is $f_{in} = (J + \delta)\cdot f_s/M$, where J is the number of recorded square wave cycles (J is an integer, J = 83) and δ is the fractional part of the recorded cycles, $0 \le \delta < 1$. A number of M = 2048 samples are acquired with a sampling frequency of 48.08 kHz.

Fig. 1 shows the absolute error of the SNR (ΔSNR = SNR$_{est}$ – SNR) as a function of δ and of the rms value H_{rms} of $h(m)$ (in dB relative to the Y_{rms}). δ scan was made in [0, 1) with an increment of 0.05. SNR scan was made in [30, 50] [dB] with an increment of 2 dB. The standard deviation of the noise was σ = 4q, in which q is the code width value of the ADC of the waveform recorder.

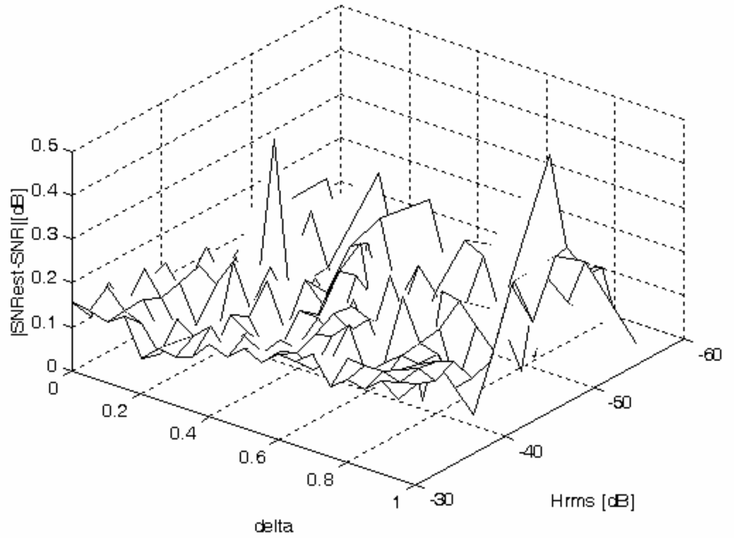


Figure 1. The modulus of the absolute error ΔSNR as a function of δ and of the rms value H_{rms} of $h(m)$.

Fig. 2 presents the absolute error ΔSNR as a function of δ and of σ value (expressed in code width value of ADC). δ scan was made in [0, 1) with an increment of 0.05. σ scan was made in [3, 13] [LSB] with an increment of 1 LSB. u was equal to 3q.

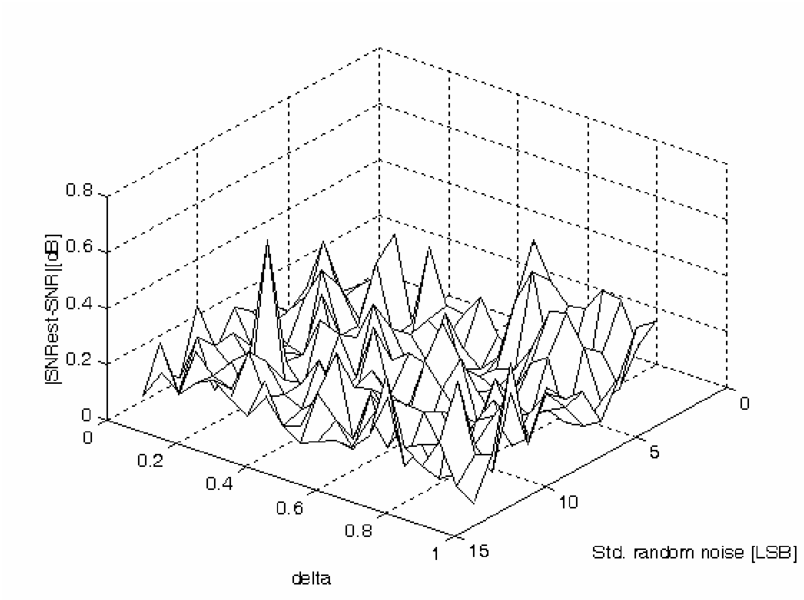


Figure 2. The modulus of the absolute error ΔSNR as a function of δ and of the σ value.

From Figs. 1 and 2 it follows that the proposed algorithm leads to very accurate estimates of the SNR of the square waves for all δ values.

III. Experimental results

Some experimental results obtained by means of the proposed algorithm are given for square waves implemented with the TMS320C5X DSK board [4] and obtained from an HM8130 signal generator [5]. The block diagram of the experimental setup is presented in Fig. 3.

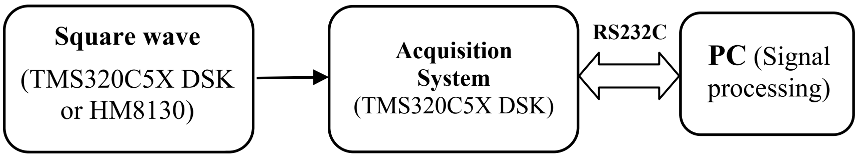


Figure 3. Block diagram of the experimental setup.

The acquisition system is based on the TMS320C5X DSK board containing a 16-bit fixed-point digital signal processor – TMS320C50. The data acquired is transmitted to the PC via RS232C interface. The program for characterization of the square waves was written in Matlab.

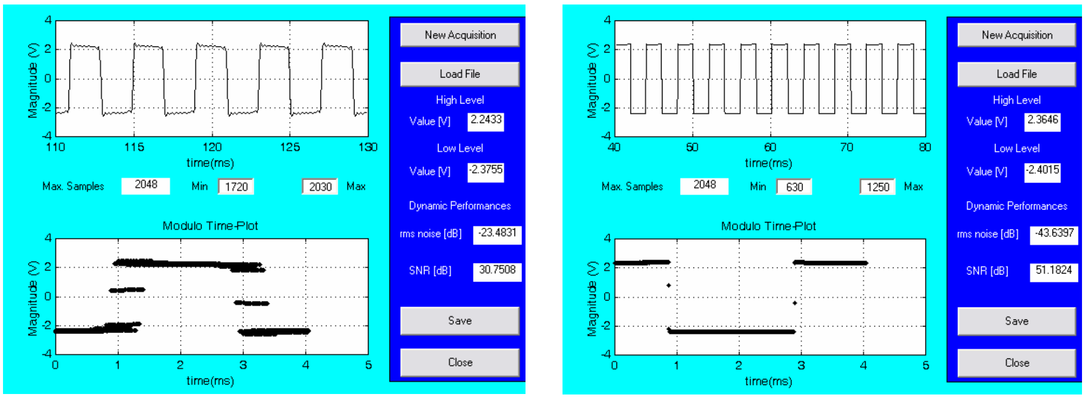
Figs. 4 and 5 show the output graphical page available after the characterization of two square waves implemented with another DSK5X board [6] (Figs. 4(a) and 5(a)) and obtained from HM8130 (Figs. 4(b) and 5(b)). The square waves have 2.5 V and -2.5 V levels, 0.5 duty cycle and frequencies 247 Hz (Fig. 4) and 987 Hz (Fig. 5). M = 2048 samples were acquired with a sampling frequency of 15.625 kHz.

In the graphical page the upper graphic shows the acquired data as a function of time and the bottom graphic presents the modulo-time plot of the signal acquired. Also, in the graphical page are presented the estimated values of the levels of the acquired square wave, the rms value of the noise and the SNR value.

From Figs. 4 and 5 it follows that, for a given frequency, the square wave obtained from HM8130 generator has higher SNR (smaller rms noise) values than the square wave implemented with DSK5X board and so, better quality. The poor SNR of the square waves implemented with the DSK5X board is caused by ringing due to the low-pass TLC32040 filter of the DSK5X board.

Also, from the results presented in Figs. 4 and 5 it follows that the SNR decreases (rms noise increases) when the frequency increases.

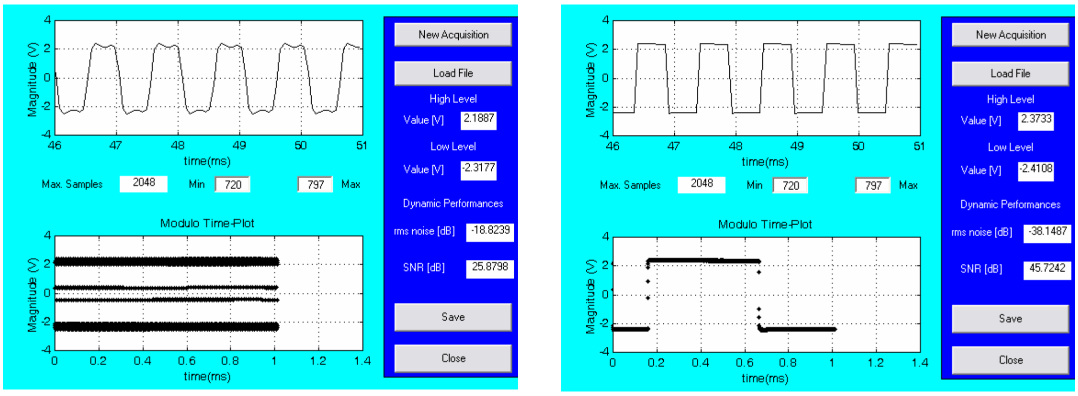
From the modulo-time plot of the square waves implemented by DSK5X board it can be seen that these square waves are affected by jitter.



(a)
Max. Samples 2048
Min 1720
2030 Max
High Level Value [V] 2.2433
Low Level Value [V] -2.3755
rms noise [dB] -23.4831
SNR [dB] 30.7508

(b)
Max. Samples 2048
Min 630
1250 Max
High Level Value [V] 2.3646
Low Level Value [V] -2.4015
rms noise [dB] -43.6397
SNR [dB] 51.1824

Figure 4. The experimental results of the square waves of 247 Hz frequency provided by:
(a) DSK5X board; (b) HM8130 function generator.



(a)
Max. Samples 2048
Min 720
797 Max
High Level Value [V] 2.1887
Low Level Value [V] -2.3177
rms noise [dB] -18.8239
SNR [dB] 25.8798

(b)
Max. Samples 2048
Min 720
797 Max
High Level Value [V] 2.3733
Low Level Value [V] -2.4108
rms noise [dB] -38.1487
SNR [dB] 45.7242

Figure 5. The experimental results of the square waves of 987 Hz frequency provided by:
(a) DSK5X board; (b) HM8130 function generator.

IV. Conclusion

The paper was focused on the estimation of the SNR of a square wave. This parameter is a measure of the influence of the level inaccuracy on the quality of a square wave. An algorithm by which the SNR is estimated with high accuracy was presented. Moreover, some experimental results obtained by means of the proposed algorithm are given.

References

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