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DIGITAL EQUIVALENTS OF ANALOG TECHNIQUES FOR OPTIMAL SUMMATION

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Optimal summation is a well-known concept of pulse signal processing. It can be reduced to the accumulation of radio-frequency pulses taken from various taps of the delay line [1]. The archaic nature of such hardware implementation technology is commonly recognized. The purpose of the present paper is the consideration of digital equivalents of optimal summation procedures which are adequate in terms of the improved capabilities of computer technology.

In the case of a radio-frequency pulse with a non-modulated carrier the kind of processing under consideration can be implemented in two somewhat different ways. The first option suggests that the analog-to-digital conversion of signal is implemented on a regular basis after an integer number of half-periods of intrapulse oscillations, while the accumulation of samples is performed in the mode of a sliding window according to the expression

$$F(S_1) = \sum_{S=S_1}^{S_1+N-1} U_s \cdot (-1)^{(S-S_1)k} \tag{1}$$

where $k = 2\,\omega_c / \omega_d$, $F(S_1)$ is the sliding window response corresponding to the S_1-th sample; ω_c is the frequency of signal filling; ω_d is the sampling frequency; S is the ordinal number of the ADC digital code; U_s is the voltage of the digitized signal at the s-th time instant, N - is the sliding window duration in sampling periods (it is usually equal to the signal duration).

The second option features the formation of even number of samples of U_s during the period of intrapulse oscillations. In this case the procedure of type (1) can be also used by introducing the rarefaction inside the sliding window and maintaining the slide increment equal to the ADC cycle period. As a result, the specified expression assumes the form

$$F(S_1) = \sum_{S=S_1;\,p}^{S_1+N-p} U_s \cdot (-1)^{\frac{S-S_1}{p}} \tag{2}$$

where the rarefaction interval of voltage samples is determined by the formula $p = \dfrac{\omega_d}{2\omega_c} = 1, 2, 3, \ldots$

In this case the summation of sampled values of U_s irrespective of sampling frequency is performed after a half-period of intrapulse oscillations with sign inversion while passing from one half-period to another. Such processing is accompanied by the power performance losses which increase with the rise of ratio p. Therefore, in the case of the second option it is preferable to abandon the data flow rarefaction and move to the summation according to the expression

$$F(S_1) = \sum_{S=S_1;\,R}^{S_1+N-R} \left(\sum_{r=S}^{S+R-1} U_r \right) \cdot (-1)^{\frac{S-S_1}{R}} \tag{3}$$

where R is the number of ADC samples during the signal half-period length.

The accumulation of samples both within the limits of the half-period and during the generation of the resulting response of the sliding window, if needed, can be performed using weight coefficients. It is advisable to specify values of the weight coefficients inversely proportional to the noise correlation function or directly proportional to the discrete function of the radio-frequency pulse envelope. In the last case expressions (1)–(3) can be rewritten in the form

$$F(S_1) = \sum_{S=S_1}^{S_1+N-1} K(S-S_1) \cdot U_s \cdot (-1)^{(S-S_1)K},$$

$$F(S_1) = \sum_{S=S_1;p}^{S_1+N-p} K(S-S_1) \cdot U_s \cdot (-1)^{\frac{S-S_1}{p}},$$

$$F(S_1) = \sum_{S=S_1;R}^{S_1+N-R} K(S-S_1) \cdot \left(\sum_{r=S}^{S+R-1} U_r \right) \cdot (-1)^{\frac{S-S_1}{R}}$$

where $K(S-S_1)$ is the envelope discrete function normalized to its maximum, moreover, in the last case we can use the average value of this function evaluated for the carrier half-period.

In problems related to the delay time measurement when the position of the response maximum of the sliding window is to be determined, it is expedient to generate the absolute values or squares of functions $F(S_1)$ rather than their proper values. In this case, the rule of selecting the detection threshold should be respectively modified.

Similar digital equivalents of optimal summation procedures are also available for complex signals. In the case of LFM pulse to prevent the significant power losses, the ADC cycle duration should be specified less than the minimum half-period duration of intrapulse oscillations. In addition, it is desirable that this difference is big enough. Then, similar to a simple radio-frequency pulse, the summation within the limits of the sliding window can be performed both with and without the rarefaction of samples.

In the first case, the rarefaction step should be non-uniform, determined by the linear dependence in accordance with frequency deviation, while the slide increment remains equal to one period of the ADC cycle. The compressed response is generated in the process of displacement of such a processing window along an array of samples. In the second case, at the same slide increment the summation of samples U_s is performed independently in each of half-periods of intrapulse oscillations, while the overall response of the sliding window is formed by accumulating the obtained half-period sums with inversion of their signs while moving from one half-period to another.

The survey of digital equivalents of analog methods for optimal summation would not be complete without due regard for the estimation accuracy of time position of radio-frequency pulses. It is important that from this viewpoint the optimal summation in general and presented options of its implementation, in particular, are a kind of phenomenon since they enable us to determine the delay time of radio-frequency signal when its initial phase is unknown with the accuracy proportional to the intrapulse oscillation frequency rather than to the pulse spectrum width [2]. These options being the optimal filtration procedures by their nature are invariant to the signal initial phase as any optimal filters. They generate their response in the form of the correlation radio function [3]. Other approaches including those synthesized on the basis of the maximum likelihood method [4] in the case of the random initial phase result in generation of the correlation envelope even in the case of radio-frequency digitizing. An exclusion may present only the maximum seeking procedure for the function such as

$$F(S_1) = \left[\sum_{S=S_1}^{S_1+N-1} U_s \cos(\omega \, \Delta t (S-S_1) + \phi_c) \right]^2$$

when the search is made for the number of the first of signal samples, corresponding to the specified initial phase ϕ_c rather than the initial instant of signal.

Owing to mismatch of the signal model and the real measurement of the radio-frequency pulse voltage, the estimate of the signal initial time position is shifted which is intrinsic to all procedures of optimal summation. Nevertheless, if the accumulation window duration is selected correctly, this estimate shift does not exceed a half-period of intrapulse oscillations and can be reduced to a negligible level by using signal digitizing directly at the carrier frequency.

Thus, the evident simplicity of hardware implementation of the measurement procedures discussed in combination with the possibility of achieving extraordinary high accuracy for estimating the signal delay time make them attractive for practical application.

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