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ESTIMATION OF SHAPE OF NARROW HIGH-POWER PULSES

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A method for estimating the shape of narrow powerful pulses in the case of narrow-band measuring channel is suggested.

As a rule, measurement of pulse signal shape by digital methods is performed with an accuracy of the sampling period of the analog-digital converter (ADC), provided that within the duration of the pulses to be estimated we form a rather representative set of digital samples. This approach does not allow us to estimate the shape of narrow signals' outline, especially if their duration is less than two sampling periods. Analysis of the operation speed of commercial ADC devices, either available or at the design stage, points to the fact that in the near future the application of traditional methods for estimation of pulse envelope shape will, as before, come up against substantial limitations on the duration of signals analyzed. The purpose of this paper consists in resolving this problem as applied to video signals of large power.

In traditional measurement procedures the necessary condition for resolving the estimation problem is the expansion of the analyzer's passband when the signal duration decreases. Contrary to this usual approach, in our measurements we use a narrow-band analog processing channel with a priori known pulse response, and perform at its output an analog-to-digital conversion with ordinary speed. The requirement of high power of the pulses analyzed stems from our quest to obtain a protracted response of the narrow-band channel with the energetics sufficient for resolving the measurement task.

We shall use an approximation of the analyzed pulse signal in the form of superimposed rectangular delta-pulses following one after another with intervals that are as small as desired, when the intervals are selected depending on the required accuracy of the envelope's shape estimation. As distinct from [2], these delta-pulses are discretely arranged in time, which permits us to represent the resulting response of the narrow-band channel to their totality not in the integral form but as a sum

$$U_s = \sum_{m=1}^{M} a_m \cdot g(md + sT) \qquad (1)$$

where $g(md+sT)$ is the discrete pulse response of the narrow-band channel, which is assumed to be known with an accuracy of the interval d between the delta-pulses approximating the analyzed signal (assumed to be regular); a_m is the amplitude of the mth delta-pulse; M is the number of delta-pulses within the signal duration; s is the ordinal number of ADC sample obtained at the narrow-band channel output; $T = kd$ is the ADC sampling period exceeding k times the repetition period d of the delta-pulses.

It should be noted that the substantial decrease in the magnitude of the approximation step d is limited for the most part by the signal-to-noise ratio and by the pulse response variation law.

Consider a set of s samples of voltages (1). The shift of the first sample from the starting point of the resulting pulse response of the narrow-band channel will be denoted as variable z. The totality of these voltages (with no regard for noise) makes it possible to set a system of S equations

$$U_s = \sum_{m=1}^{M} a_m \cdot g(z + md + sT) \qquad (2)$$

where the variables z and a_m are unknown, and estimation of values a_m is equivalent to restoration of the shape of the input pulse envelope.

In order to reduce the number of variables, it is expedient to pass in (2) to normalized amplitudes, for example, such as $\beta_m = a_m/a_1$, where a_1 is the amplitude of the first delta-action and $m = 1, \ldots M$. This measure is justified also from the viewpoint of subsequent use of the signal shape estimation in the procedures of measurement of delay time described in [3–5], which have to deal with the envelope discrete function. Obviously, the normalized amplitude of the first delta-pulse $\beta_1 = 1$.

Thus, with noise not taken into account, for an M-component approximation of the analyzed signal we have to determine M unknowns, namely, $M - 1$ values of the normalized amplitudes β_m of the second and subsequent delta-signals and, simultaneously, the shift z.

After setting up a sample of $s \geq M$ readings of ADC, it remains to resolve equation system (2) in terms of the above unknown values β_m $(M \geq m \geq 2)$ and z. Here we may employ either deterministic of statistical methods, for example, the least-square method (LSM) — by analogy with the approach considered in [5].

When the samplings of ADC readings are large, the problem of precise estimation of signal shape becomes rather complicated. Yet its treatment is feasible since we do not have to perform the calculations on a real time basis.

In addition to the delta-pulse approximation, we could consider some other analytical version of the variations of the narrow pulse outline. It is known, for example, that improvement of automatic control systems can be attained by a method of synthesis based on piecewise approximation of the input drive — with the use of linear functions of the $U(t) = U + \sigma t$ type [6].

A similar approach can be employed in the case under consideration. However, we must remember that instead of an unknown amplitude of partial pulse inputs there appears another variable to be estimated, namely, the rate of inclination of the linear function of the mth fragment of the input pulse σ_m. Thus, in order to set up a normal system of equations to estimate the shape of an ultra-short video signal, we need at least a two-channel measurer, and the estimation procedure itself will become more awkward. Moreover, one should remember that the use of piecewise linear representation, as in the case of estimating the narrow pulse outline based on the delta-pulse approximation, permits us to pass, with the aid of z-transform, to an operator description of the standard system response to an unknown input excitation [6]. The respective equation system for estimating the envelope variation law may be treated in the operator form, which is sometimes much simpler. Moreover, the apparatus of piecewise linear functions often permits us to work with responses of the narrow-band standard channel, which in the analytical sense are more convenient than the pulse responses corresponding to rectangular delta-pulse inputs.

In order to minimize the computational expenditures, the search of input excitation approximations, which are acceptable in terms of the resulting response, can be (as it is made in [6]) extended to the classes of piecewise quadratic, piecewise trigonometric, or some other piecewise nonlinear approximations. The respective approaches require detailed theoretical investigation — as well as the well-known problem of synthesis of standard narrow-band measurers by a prescribed appearance of their pulse response. The main accent must be made on the use of such analytical representations of pulse responses, which could substantially facilitate the estimation of parameters of the partial pulses approximating the signal to be analyzed.

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