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METHOD OF THE COHERENT-INCOHERENT PROCESSING OF RADIO PULSES

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Proposed is the unification of the results of incoherent and coherent reception of radio pulses based on the comparison operation.

Two extreme cases are known in the theory of optimal reception of radio signals when the law of changing the phase of the carrying phase is known or its estimate is absent. They are referred to, respectively, as coherent and incoherent reception [1]. Intermediate options are also possible. These options represent their combination [1]. The objective of the present article is the consideration of the method of unifying the results of the coherent and incoherent procedures reduced to the combination of such based on logical operations of comparison.

Given sufficiently large signal-to-noise ratios the efficiency of the coherent and incoherent methods coincides [2]. The applications with such levels may include, for instance, ultrasonic tomography, whose specificity in technical complexity of implementing large accumulations of echo-pulses. Therefore during visualization echo-grams tend to achieve the excess of the noise levels even in the case of single sounding. Referring to signal digital processing and treating incoherent buildup as nonsign summation it is possible to find strict proof of the possibility of the coincidence of its results with coherent processing. According to [3] for any numbers, the inequality is valid

$$\left| \sum_{i=1}^{N} a_i \right| \le \sum_{i=1}^{N} |a_i| \tag{1}$$

which given the identical signs of all summands is transformed into an identity. It is this case which is of interest.

Since the left-hand part (1) is one of the options of the coherent sum it remains for us only to specify conditions of its coincidence with the right-hand part by value. In the case of pulse signals and weak noises the identity of digital responses of coherent and incoherent build-ups occurs only in the case of a summation window, which do not exceed the duration of a radio pulse. In the case of partial or complete non-coincidence of them over time the result of the incoherent sum exceeds the value of the coherent build-up whereby noise is averaged. To verify this, one can refer to the results of a physical experiment represented in Fig. 1, where the values of the nonsign (incoherent) sum of ADC samples and coherent weight processing (curve *1*) matched the carrying frequency of the radio pulse (curve *2*) presented in Fig. 1. The experiment was carried out on a specially developed test bench, whose functional diagram is shown in Fig. 2. The device [4] was used as a shaper of radio pulses. This device conducts cutting out from a continuous harmonic oscillation of a train of radio pulses with the length and repetition period assigned by a PC. The frequency of the signal filling was 15 MHz, while the ADC clock frequency was 12 MHz, which satisfies the condition of digitization of voltages through the odd number of the carrying frequency quarter periods.

As for the algorithm of incoherent buildup implemented, it can be represented in the form:

$$U_{s_1}^{n} = \sum_{s=s_1}^{s_1+N-1} |U_s|, \quad s_1 = \text{var} \tag{2}$$

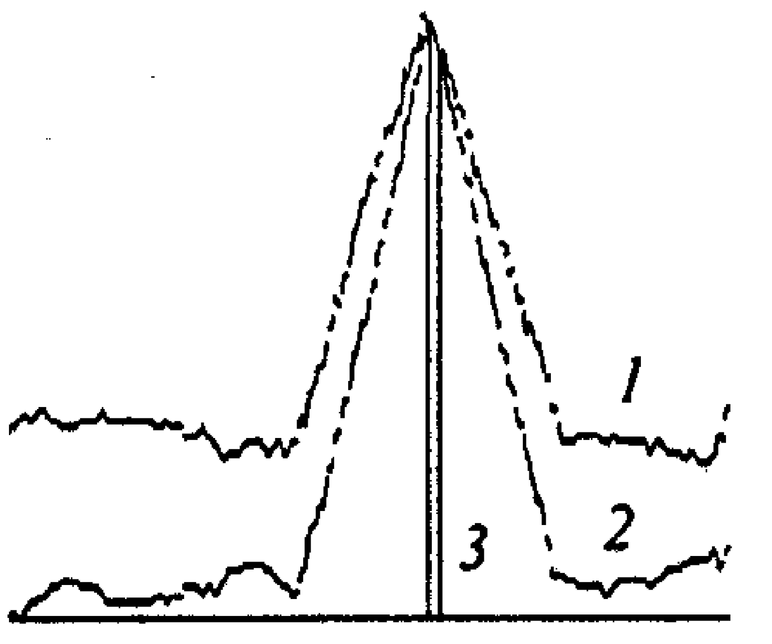

Fig. 1

where s is the ordeal number of the ADC sample; s_1 is the first of the samples within the limits of the summation window; N is time length of the window in the ADC samples equal to the radio pulse length; $|U_s|$ is the modulo of the ADC output voltage at the sth time instant; $U^n_{s_1}$ is the response of incoherent buildup corresponding to the s_1th window.

In the same notations the procedure of coherent buildup will be written down in the following way:

$$U^c_{s_1} = \left| \sum_{s=s_1}^{s_1+N-1} U_s \cos\frac{\pi}{2}(s - s_1) \right| + \left| \sum_{s=s_1}^{s_1+N-1} U_s \sin\frac{\pi}{2}(s - s_1) \right| \tag{3}$$

where $U^c_{s_1}$ is the response of the coherent summation in the s_1th window.

Analyzing inequality (1) and curves *1, 2* (Fig. 1) it is not difficult to arrive at the main idea of the approach being suggested: digitization of the signal should be implemented through the odd number of the quarters of the carrying frequency period, the results of coherent and incoherent summation should be compared between themselves, and in the case of coincidence by value, it should proceed without alteration, to processing, otherwise the comparison operation output code should be reset. Figure 1 shows the result of such unification of the responses $U^n_{s_1}$ and $U^c_{s_1}$ in curve *3*.

The case illustrated is characterized by the fact that both even and odd trains of ADC samples, by number, exceed the noise level. However, such a situation does not occur always. Given other initial phases of the signal, for instance, close to zero or $\frac{\pi}{2}$, the part of signal samples can be compared by value with the noise level. As a result even with comparison in time of the summation window and the radio pulse the responses of the coherent and incoherent buildups will be different, which will lead, when analyzing values (2) and (3), to complete loss of the signal. To avoid this the suggested idea of the method should be modified, replacing the comparison of sums (2) and (3) with the similar testing of the values

$$\sum_{s=s_1}^{s_1+N-1} \left| U_s \cos\frac{\pi}{2}(s - s_1) \right|, \quad \left| \sum_{s=s_1}^{s_1+N-1} U_s \cos\frac{\pi}{2}(s - s_1) \right| \tag{4}$$

and

$$\sum_{s=s_1}^{s_1+N-1} \left| U_s \sin\frac{\pi}{2}(s - s_1) \right|, \quad \left| \sum_{s=s_1}^{s_1+N-1} U_s \sin\frac{\pi}{2}(s - s_1) \right|, \tag{5}$$

respectively. Although such bifurcation of the algorithm is accompanied with losses in the signal energy, the loss which occurs, nevertheless, is compensated by a possibility of operation with radio pulses having the random initial phase. In this case the sum of totals of two specified comparisons or the larger among the values that were sampled in (4) and (5) can be

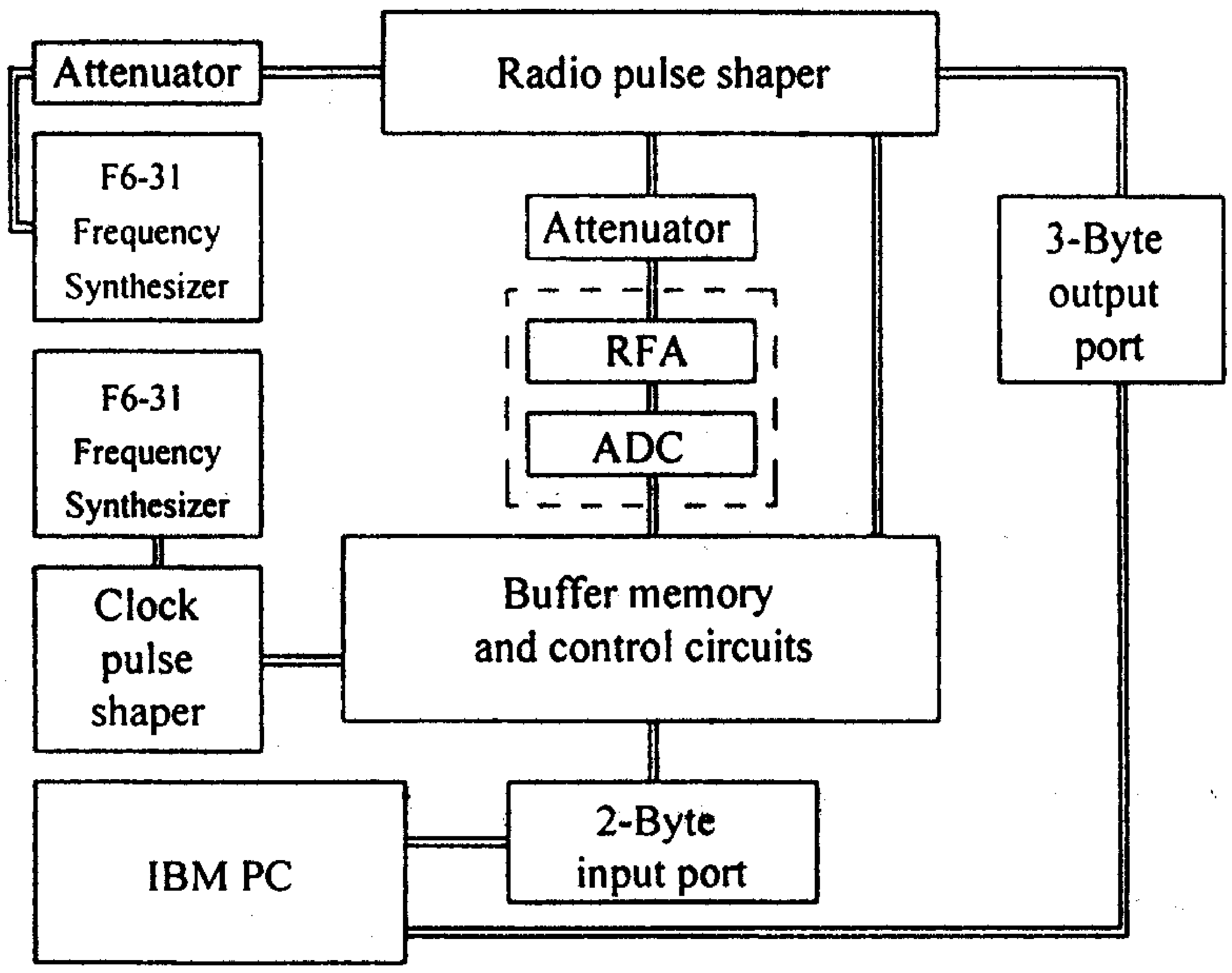

Fig. 2

considered as a final result. For many applications the last variant will be more preferential since it is not accompanied by the sharp jumps of the resultant response with the coincidence of the values of buildups both in procedures (4) and in (5).

With the presence of Doppler shifts in the frequency of filling the echo-signals the response of the coherent sum prior to its comparison with the result of incoherent processing should be increased by the value of the correction compensating a possible signal suppression caused by the deviation of its filling frequency from the central frequency for the coherent filter. The correction value should be assigned proceeding from the maximum possible Doppler frequency. Thus the proposed approach implements either detection without any thresholds, or operates, as in the last case, the deterministic threshold irrespective of noise variance. This is its distinctive feature.

To extend the possibilities of the method proposed with weak signals, it will be also sensible to introduce a statistical threshold within whose limits the responses of incoherent and coherent sums could differ. However, this question together with the investigation of detection characteristics themselves typical of this method require a separate research.

As for hardware implementation of the method it should be noted that a technical design of a device for ADC sampling without using signs described in [5] and a coherent integrator set out in the description of the invention in [6] can be used as a basis.

A prototype of a similar coherent integrator made on IC, series 1533, was tested at the frequency of ADC digitization equal to 32 MHz. In this case owing to parallelizing processing using algorithms (4) and (5) the frequency of data updating on adders 1533 IP3 in the circuit with transfer was 16 MHz. It is important to underline that uniting the coherent [6] and incoherent [5] integrators into a common circuit it is necessary to use common RAM, submodules of addressing and control.

In conclusion it remains to note that comparison of the values of the coherent and incoherent sums can be realized in the form of comparison of their relations $U^c_{s_1} / U^n_{s_1}$ with unity. In this case similarly to [7] for mapping the processing results one should use functional transforms

$$F_{s_1} = \left[1 - \frac{U^c_{s_1}}{U^n_{s_1}}\right]^{-1}, \quad \tilde{F}_{s_1} = \left[1 - \frac{U^c_{s_1}}{U^n_{s_1} - P}\right]^{-1} \tag{6}$$

or their information analogs

$$F_{s_1} = \left[U^n_{s_1} - U^c_{s_1}\right]^{-1}, \quad \tilde{F}_{s_1} = \left[U^n_{s_1} - P - U^c_{s_1}\right]^{-1} \tag{7}$$

where P is the threshold taking into account the mismatch of the values $U^n_{s_1}$ and $U^c_{s_1}$, for instance, at the expense of the Doppler shift of the signal frequency. Such reception makes it possible to maintain good visually perceived resolution

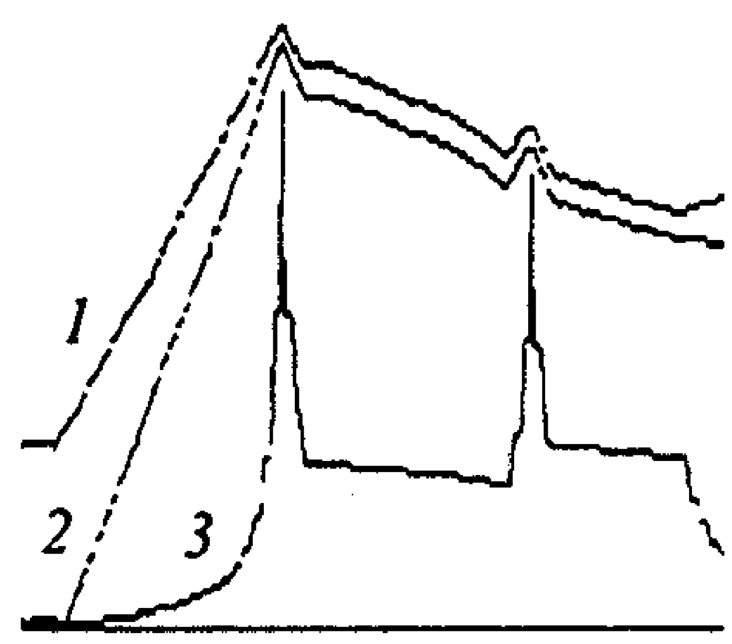

Fig. 3

during delay time, ruling out, at the same time, an omission of group signals in many unfavorable situations of their mutual overlapping. As an example (curve *3*), we provide an illustration of processing $\widetilde{F}_{s_1}$ (6) for the case of two closely running radio pulses and in this case curves *1* and *2* correspond to responses $U^{n}_{s_1}$ and $U^{c}_{s_1}$.

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