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Signal Shaping with Adjustable Parameters for Measuring Instruments

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***Abstract*—The article presents the results of studies of the pulse and harmonic signals shapers that is a part of measuring instruments with adjustable parameters. A method is proposed for shaping pulse signals via a harmonic signal as a reference, associated with the use of a stroboscopic sample-and-hold circuit. For shaping of the output signal the relative method of setting the amplitude has been used, which (though lacking speed) allows to get rid of the error components due to the irregularity of the frequency response and the mismatch in the output node. In this case, the output signal and its nominal level are measured in the same sectional plane of the output node. A shaper of harmonic and pulse signals, which implements the phase readout method based on a stroboscopic converter with feedback, is characterized by a significant reduction in the effect of broadband interference on the transformation accuracy. The use of a two-channel shaper structure is proposed. If channels are identical, the structure made it possible to minimize the error due to the amplitude and time instability of stroboscopic pulses. In the shaper the gating is performed at the extreme points, and in each channel, the gating of extreme value of only one sign, which is different from the extreme sign in the other channel. A number of studies have been carried out related to the estimation of the amplitude-frequency error due to the responsiveness of nonlinear elements in ring mixers in stroboscopic sample-and-hold circuits. The influence of operating conditions and mixer parts on its parameters is studied. The verification of the obtained results of theoretical research has been carried out via numerical modeling and experimentally. The influence of the parameters of the mixer parts on the accuracy of the stroboscopic sample-and-hold circuit has been evaluated**

Keywords— parameters control, phase readout, stroboscopic transformation, broadband signal, stroboscopic sample-and-hold circuit, pulse shape

I. Introduction

Shapers of signals of various shapes and with adjustable parameters are used in a variety of devices. Nowadays, they are widely used in measurement instruments such as amplitude generator-calibrators, time-slot generators and phase calibrators. Known methods for shaping the pulse waveforms use various methods and circuit solutions. Current switches, analog multiplexing with separate timing parameters and electronic components with charge accumulation are used most often for construction of wide-band, high-speed shapers [1].

During electronic products testing, an important problem is to ensure the undistorted transmission of test signals to a large-scale or very large-scale integrated circuit. It is necessary to accurately account for the amplitude and dynamic errors introduced by the transmission path in the VHF-UHF range.

The development of high-speed integrated electronics has set a series of problems concerning the development shapers of signals operating in the frequency band of 1-3 GHz and the picosecond time range [2]. Their stimulating impulse effects determine the process of dynamic functional control of electronic devices. Basic requirement for the shapers of signals is the range and accuracy of the assignment of static and dynamic parameters of the signals.

II. Theory

A. Problem Definition

The oscillator channel of the systems designed for testing large-scale and very large-scale integrated circuits is a complex device that is also a source (generator) of both periodic and irregular pulse signals. The pulse parameters at the channel output must be set with the specified accuracy.

The main parameters of pulse generator channels include: pulse duration, pulse amplitude, pulse repetition frequency (period), time shift of the output pulse relative to the sync pulse, and the time shift of the pulses of the second and subsequent channels relative to the output pulse of the first channel (synchronizing channel). During the pulse generators checking, the error in setting the pulse duration, distortion parameters, the error in setting the time shift and the error in setting the pulse amplitude (timing error) are determined.

Timing errors can be divided into two groups [3]: errors of system elements and errors arising in the course of system operation or program execution. The first group includes level offset of the test sequence generator, comparator and driver, also formatter delay, jitter and non-linearity of the test sequence generator. The second group includes skews between driver and comparator pins, ambiguous gating and skews caused by two threshold levels (high- and low-level comparator).

B. Priority Decision

The speed of the shapers is not high enough due to the long dispersion time of the switches of the transistors that are a part of them. The tabular procedure synthesis (when the signal realizations are programmatically calculated and written into memory with subsequent cyclic reading on a digital-to-analog converter (DAC)) is not fast enough and capable of operating in the VHF-UHF ranges. Broadband signal amplitude control devices [4], having a bandwidth from 1 MHz to 7 GHz, have a low maximum input voltage (up to 0.15 V). Adjusting the amplitude by an electronically

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controlled pin-diode attenuator leads to a large error due to the voltage standing-wave ratio that reaches a value of 2.

Evaluation of the classical method of pulse shaping by summing three linearly varying signals shows that at a clock frequency of 50 MHz and the limit of the spectrum width at 1 %, the bandwidth of the signal transmission paths and the adder should reach 5 GHz [5].

In the frequency range of more than 30 MHz the accuracy of setting the amplitude in a wide dynamic range (DR) deteriorates significantly — the error reaches 20–40 % in the frequency range of 1–3 GHz at the amplitudes of up to 0.1 V [1].

Thus the pulse amplitude shaping and adjustment is possible in various ways, but the scope of their application is limited by the maximum frequency, required short amplitude settling time, small discrete and large dynamic range (DR) of adjustment.

III. Research

A. Generator of Harmonic and Pulse Signals

We propose using devices based on phase methods and frequency conversion. Such shapers can serve as precision-controlled units as the parts the corresponding measuring instruments. In this plan, a generator of harmonic and pulse signals is proposed (Figure 1), which implements the phase readout method. Shaping of a pulse signal using a harmonic signal as a reference is associated with the use of a stroboscopic sample-and-hold circuit (SSaHC) based on a strobe converter with feedback (FSC), when the servo feedback eliminates the falloff of the pulse flat top during storage [6-8].

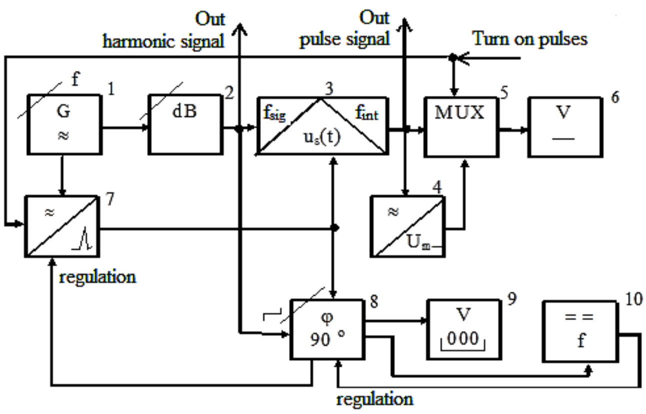

Fig. 1. Harmonic and pulse signals shaper.

The structure works in two stages. First, the nominal voltage level U_n of the output signal of the reference generator 1 is set using the attenuator 2 according to the voltmeter 6. At the same time, the maximum voltage is set by adjusting the automatic phase control (APC) 8. In this case, the amplitude of the input signal is read into the strobe converter with feedback SPOS 3, and the APC system 8 operates at an angle of 90 °. Phase-locked loop 10 provides operation in the frequency range.

By changing the position of the strobe pulse by the PPL system 8 relative to the harmonic signal at the output of the attenuator 2, at the output of the device we receive a pulse signal, the amplitude of which is defined as $U_n sin\varphi$ (indicated by indicator 9). This provides a high speed and wide frequency range, receiving pulses of both polarities, and adjusting the pulse duration with a step equal to the period of the harmonic signal. The use of the relative method of setting the amplitude, with a decrease in the speed of action, allows to get rid of the components of the error caused by the unevenness of the amplitude-frequency characteristic (AFC) and the mismatch in the output node [9]. The output signal and its nominal level are measured in the same sectional plane at the output.

B. Two-Channel Structure

Main disadvantage of devices with DC information processing is the temperature instability of the operating point of the SSaHC mixer [10]. Therefore, it is advisable to use a two-channel structure (Figure 2). If the channels are identical, the structure will minimize the error caused by the amplitude and time instability of strobe pulses [11]. In the shaper, gating is performed at the extreme points and in each channel the extreme value of only one sign is gated, which differs from the extreme sign in the other channel. The stored signal values are fed to the subtraction stage and the DC voltmeter measures the voltage:

$$U_V = [(U_{mOUT} - \Delta u) - (-U_{mOUT} - \Delta u)]/2 = U_{mOUT} \tag{1}$$

where U_{mOUT} is the voltage at the SSaHC output equal to the signal peak value at the shaper output; Δu is the drift of the SSaHC output voltage.

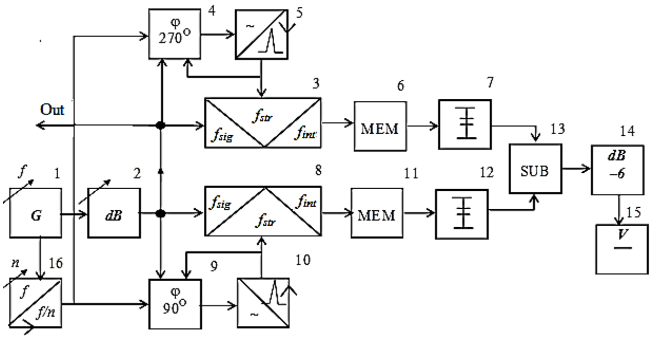

Fig. 2. Broadband shaper of harmonic signals.

Depending on the required accuracy of setting the output signal amplitude, a specific DC voltmeter could be used. The high accuracy of the 90 ° and 270 ° APC systems (nodes 9 and 4) and the high-quality formation of strobe pulses (nodes 5 and 10) are due to the operation at a fixed frequency due to a divider with variable division ratio (DVDR) 16 [12].

IV. Research Results

A. Pneumatic muscles holder

Let us assess the influence of the parameters of the mixer elements on the accuracy of the SSaHC. The integrated circuit of the mixer allows to fully charge the storage capacitor C_H, since the charge time constant is much less than the duration of the sampling pulses. Let us consider the influence of operating conditions and mixer elements on its parameters. We will use the following expression for the bandwidth [13]:

$$f = f_H \Bigg/ \left[\frac{1 + (1 + C/C_H)\sqrt{2}(\tau_C/\tau_H)}{1 + \sqrt{(3\tau_C/\tau_H)}} \right], \tag{2}$$

where C is the barrier capacitance of the bridge switch diode; τ_C is the duration of the strobe pulse according to the key opening level; $f_H = 1 / (2\pi\tau_H)$ – bandwidth at an ideal strobe pulse cumulative.

The study was carried out with the integrated circuit 04ПП002 [14]. The results showed that the bandwidth is inversely proportional to τ_H and is equal to 3 GHz (with C_H = 0.5 pF), depending on the output resistance path R_{out} and the resistance of the diode base R_d in the bridge switch. Value of C limits the accuracy of the SSaHC due to the redistribution of the capacitor charge C_n – an increase in C by 10 % leads to a similar increase in the fixation error.

Simulation in MATCAD showed that increasing C from 0.075 pF to 0.75 pF leads to the bandwidth decrease by 3 %. The data correspond to the duration of the strobe pulse of τ_c = 10 ps according to the opening level of the bridge key (Figure 3).

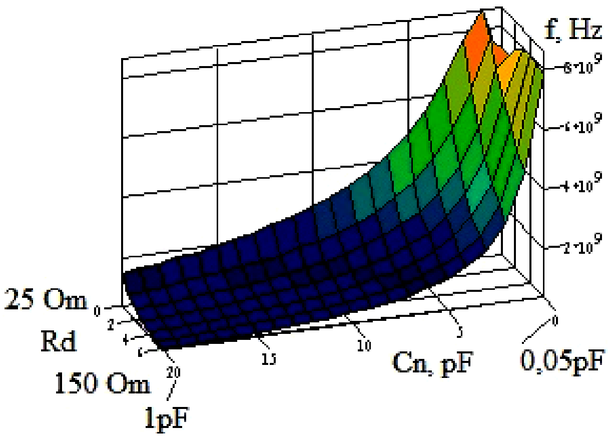

Fig. 3. Dependence of the bandwidth on the change in the storage capacitor C_n and the resistance of the diode base R_d.

The value of the transmission coefficient of the SaHC K_p and the error in the frequency range depend on the value C, the input capacity of the buffer stage and the bit switch [15]. The range of possible K_p values is in the range of 0.4–0.95 (Figure 4). The calculation is based on the following expression:

$$K_p = \left(\frac{R_{in}}{2R_{out} + R_d + R_{in}}\right) \Big/ \left(\frac{C_n}{C_n + 2C_d + 2C}\right), \qquad (3)$$

where R_{in} – signal source resistance; C_d – discharge circuit capacity.

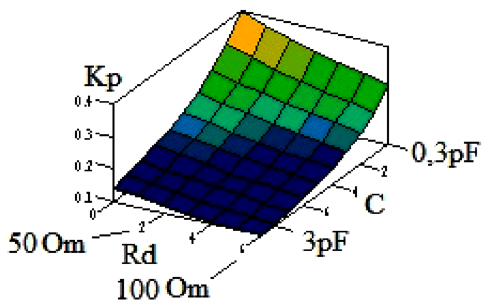

Fig. 4. Dependence of the transmission coefficient of the K_P and the error in the frequency range on the value of C, the input capacitance of the buffer stage and the bit key.

Noise The SSaHC noise (white noise) is determined by the resistance of the diode base and the output resistance of the path according to the expression depending on the spectral density of the transistor flicker noise, and the upper and lower frequencies of the amplitude-frequency characteristic of the amplifier of the stored signals [16]. The average value of the square of the effective noise voltage, reduced to the input of the SSaHC, is determined by:

$$\overline{U}^2_{noise} = \frac{kT}{C_n\left(\frac{R_{in}}{2R_{out} + R_d + R_{in}}\right)^2} + \frac{A}{\left[\left(\frac{R_{in}}{2R_{out} + R_d + R_{in}}\right)\left(\frac{C_n}{C_n + 2C_d + 2C}\right)\right]^2 \ln\frac{f_H}{f_L}}, \qquad (4)$$

where A – parameter that determines the spectral density of the flicker noise of the transistor ($A \approx 5 \cdot 10^{-11}$ V²); f_H, f_L – upper and lower frequencies of the amplifier of the stored signals. The simulation data are shown in Figure 5.

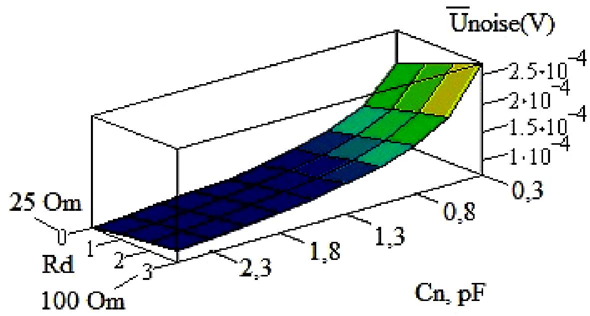

Fig. 5. Dependence of the mean value of the square of the effective noise voltage, reduced to the input of the SSaHC, on the resistance of the diode base and the output resistance.

V. Conclusion

Based on the results of the study of methods for generating signals for measuring instruments, a method for designing the signal shaper, that utilize phase methods and frequency conversion, is proposed. A shaper of harmonic and pulse signals with the use of a stroboscopic sample-and-hold circuit (SSaHC), which implements the phase readout method, is proposed. The use of a stroboscopic sample-and-hold circuit based on a strobe converter with feedback (FSC) determines the shaping of a pulse signal using a harmonic signal as a reference.

Estimates of the SSaHC characteristics are the result of many factors, the mathematical models of which can be determined (as well as the coefficients of influence on the total error). An assessment of the influence of the mixer elements parameters on the accuracy of the SSaHC is carried out. The influence of operating conditions and components of the mixer on its parameters is considered. When the dependence of the transmission coefficient on the frequency has been found, an assumption was made that the distortion of strobe pulses does not occur in the frequency range. Errors caused by the nonlinearity of the amplitude characteristic and the imperfection of stroboscopic signals are revealed and it has been determined that they are in fact broadband interference. It has been investigated that the use of a two-channel structure of the shaper (with identical channels) makes it possible to minimize the error due to the amplitude and time instability of strobe pulses.

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