

Scheme features of radio pulse gating for radar measurements

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Abstract. The model of a radio pulse stroboscopic converter consisting of a mixer and a narrowband filter tuned to the difference frequency of the carrier signals is considered. We demonstrate that the measurement of the phase structure of the input signals can be made at low frequency by amplitude methods by changing the phase both in the channel of the gating radio pulses and in the low frequency channel. The radio-pulse gating scheme goes into a phase-sensitive mode when the system clock frequency is synchronized with the second harmonic of the difference frequency, however, in this case, a parasitic phase modulation occurs in the converted signal, which does not depend on the transformation coefficient of the spectrum and is determined only by the duty cycle of the input signal. To eliminate parasitic modulation, which distorts the envelope of the output signal of the converter in a phase-sensitive mode, it is proposed to use an auto-shift circuit with a falling “slow” sawtooth voltage when generating gating radio pulses.

1 Introduction

The study of both the envelope form and the phase structure of the periodic sequence of coherent radio pulses is an important task of radar and pulse reflectometry. Usually, stroboscopic methods of transformation of a time scale are used, which allow matching the frequency range of broadband radio signals with the capabilities of measuring equipment [1]. Stroboscopic conversion is carried out by selecting signal samples $x(t)$ using short strobe pulses $a(t)$, the period (T_1) of which differs from the period of the signal under study (T) by the value of the reading step $\Delta T = T_1 - T \ll T, T_1$. In this case, the converted signal $y(t)$ is adequate to the input one, stretched in time $x(t/N)$, where $N = T/\Delta T \gg 1$. The time quantization inherent in these methods is well combined with the principle of digital filtering, which stimulates the use of stroboscopic methods in digital processing systems of broadband signals [2]. The combination of stroboscopic transformation with the numerical processing of information on computers significantly expands the field of application of these methods [3,4].

The main limitation of the use of stroboscopic processing methods is the requirement of periodicity of the studied signals on the observation interval, however, this condition is satisfied for most practical problems. The potential possibilities of stroboscopic transformation methods are most fully realized in oscillographic technology. Figure 1

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shows the parameters of analog and stroboscopic oscilloscopes of some domestic and foreign companies. The figure demonstrates that the corresponding product $S \cdot \Delta f$ for the stroboscopic devices is 10^2 – 10^4 times higher than that of conventional analog ones and devices with a traveling wave tube (TWT).

The task of converting a periodic sequence of microwave signals of nanosecond duration $x(t) = \cos[\omega_0 t + \theta(t)]$ into a low-frequency signal on a time scale is very important for pulse reflectometry and radar. Such a conversion can be carried out using coherent gating radio pulses $a(t) = A_1(t) \cdot \cos[\omega_1 + \varphi(t)]$ with high-frequency filling at the carrier frequency $\omega_1 = \omega_0 - \Omega$ ($\Omega \ll \omega_0, \omega_1$). The necessary periodicity of the converted signal can be easily ensured in short-range detection systems.

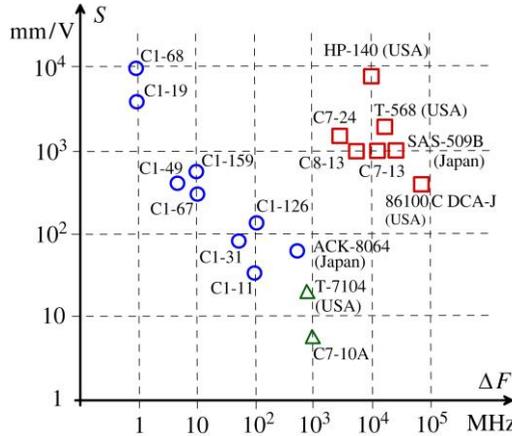


Fig. 1. Sensitivity (S) and frequency band (Δf) of some oscilloscope instruments: analog ones (O), TWT devices (Δ), stroboscopic ones (\square).

The linear mathematical model is widely used for theoretical analysis of the stroboscopic converter operation [1,3]. Such a model consists of a multiplier of the input and gate signals and a narrow-band filter BPF_{Ω} , which selects one of the spectral components of the conversion results. Figure 2 shows the mathematical model based on a differential frequency correlator.

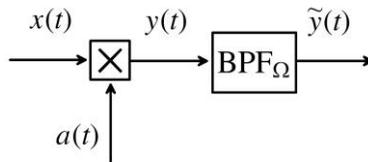


Fig. 2. Mathematical model of the radio pulse stroboscopic converter.

We study the mode of operation of a radio pulse gating scheme, in which the system clock frequency is synchronized with the second harmonic of the intermediate frequency. Complex models of $x(t)$ and $a(t)$ signals take into account the envelope delay relative to high-frequency filling:

$$\dot{x}(t) = \sum_{k=0}^N \dot{A}(t - kT - \tau_0) \exp(j\omega_0 t), \quad \dot{a}(t) = \sum_{k=0}^N \dot{A}_1(t - kT_1 - \tau_0) \exp(j\omega_1 t), \quad (1)$$

where $\dot{A}(t), \dot{A}_1(t)$ are the envelopes of $x(t)$ and $a(t)$, respectively, ω_0, ω_1 are carrier frequencies of input $x(t)$ and gating $a(t)$ radio signals, respectively, $\omega_0 - \omega_1 = \Omega \ll \omega_0, \omega_1$, T, T_1 are repetition periods of input and gating signals, respectively, N is spectral transformation coefficient ($N \gg 1$), τ_0 is the envelope delay relative to the high-frequency filling.

2 Phase-sensitive mode of radio pulse gating

The filter selects spectral components with frequencies Ω and $2\pi/T_1 - \Omega$ from the signal $y(t)$ and we have the following expression for the output signal of the converter in the asymptotic limit ($N \rightarrow \infty$):

$$\tilde{y}(t) \sim A(t/N) \cos[\theta(t/N) + \Omega\tau_0 - \varphi_0] \times \cos(\pi t/T_1), \quad (2)$$

where \tilde{A}_1 is the envelope area, φ_0 is the middle phase of the gating radio pulse [5], $\theta(t)$ is intrapulse phase modulation of the input signal. The transformation of the phase structure of the signal $\tilde{y}(t)$ into a change in amplitude occurs during synchronization of the clock frequency $2\pi/T$ due to the second harmonic of the difference frequency Ω . Formula (2) shows that countervailing phase measurements of transformed values of $\theta(t/N)$ by reducing to zero the signal envelope (2) can be performed either by selecting the phase values φ_0 (at the carrier frequency) or by selecting the delay τ_0 for low intermediate frequency Ω .

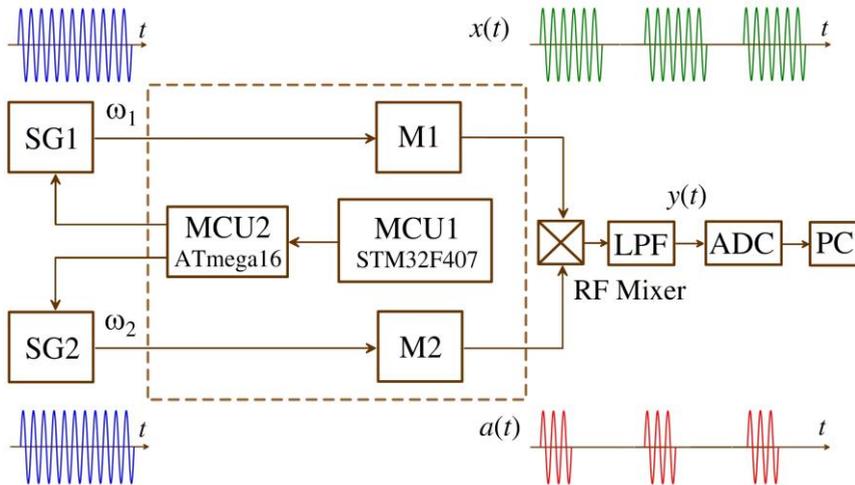


Fig. 3. Layout of radio pulse stroboscopic converter.

3 Model of radio pulse stroboscopic converter

Figure 3 shows the functional diagram of the experimental layout [6], which we use to simulate the operation of a radio pulse stroboscopic converter. We use the following designations: SG is Signal Generator, STM32F407 and K1 (ATmega16) are Micro Controller Units, M1 and M2 are multiplexors, RF Mixer is Radio Frequency Mixer, LPF is Low Pass Filter, ADC is Analog to Digital Converter, PC is Personal Computer. The practical implementation of the phase-sensitive mode in our model assumes that the system clock frequency $F_T = 1/T$ is formed by doubling the difference frequency of the carrier one ($F_\Omega = \Omega/2\pi$), since it remains unchanged when changeover of the spectral transformation coefficient N . However, in this case, a parasitic phase modulation with phase deviation $\Delta\varphi = \pi/Q$ appears in the complex envelope of the converted signal $y(t)$, which does not depend on the spectral transformation coefficient N and is determined only by the signal duty cycle $q = 1/Q = \tau_u/T$ (τ_u is pulse duration). Figure 4 shows the results of a semi-natural simulation of a phase-sensitive operating mode for $F_T = \pi/\Omega$, $\theta = 0$, $\varphi_0 = 0$.

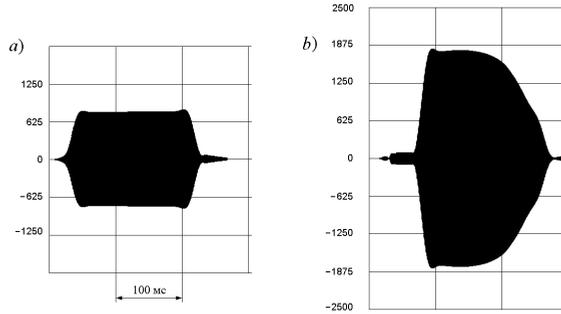


Fig. 4. The signal at the output of the layout of the radio pulse converter for $F_T > 2F_\Omega$ (a) and in phase-sensitive mode (b) at $F_T = 2F_\Omega$ (the scale is indicated in the ADC readings).

3 Conclusion

The operation model of a radio-pulse stroboscopic converter in a phase-sensitive mode for phase measurements of broadband radio signals by amplitude methods is constructed. Intra-pulsed phase modulation of nanosecond-duration signals can be measured by the compensation method, both by changing the phase of the carrier in the channel of the strobe radio pulse and by using the envelope delay with respect to high-frequency filling. Our method was tested using semi-natural modelling on an experimental layout and numerical simulations. The radio pulse gating scheme in the phase-sensitive mode requires synchronizing not the clock frequency of the system, but the repetition frequency of the gating radio pulse. We propose an auto-shift circuit with a falling “slow” sawtooth voltage to eliminate parasitic phase modulation.

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