PARAMETRON PHASEMETER

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Considerable attention is being paid to expanding the dynamic range of phase meters in connection with the development of rf measurement apparatus. Of considerable interest here, especially in the cases of weak signals, comparable to the noise level, is the method of comparison in pairs of the quantized phase samples obtained simultaneously during phase quantization of two input signals by, e.g., parametrons.

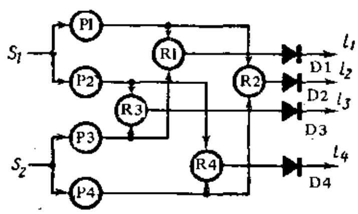

Fig. 1. Block diagram of the phase meter. P) Parametrons; R) hybrid rings; D) detectors. The pumping circuits for parametrons are not shown.

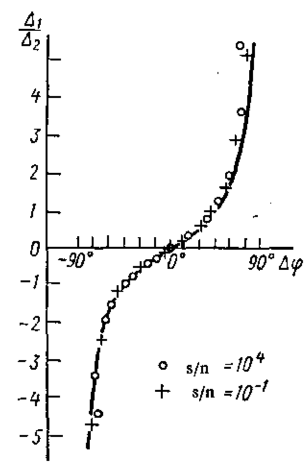

Fig. 2. Experimental tangential characteristic of a 1-MHz phase meter.

Figure 1 shows the block diagram of an appratus which performs this operation for two synchronous signals $S_i = a_i \cos(\omega_s t + \varphi_{0i})$ where $i = 1, 2$; a_i are the signal-to-noise (s/n) ratios; ω_s is the signal frequency; and φ_{0i} are the initial phases of the signals. Each of the input signals is split into two orthogonal quantization channels. The quantizers are balanced capacitive parametrons, which achieve nearly ideal amplitude limitation of the output signals. The parametrons are fed from a common pumping oscillator at $\omega_p = 2\omega_0$ (ω_0 is the subharmonic frequency).

To obtain quadrature quantization channels, the phase of the pumping voltages for parametrons 1 and 3 is shifted with respect to that for parametrons 2 and 4 by π radians. The parametrons operate in the soft mode with synchronous periodic triggering at frequency $\omega_s \sim \omega_0 \cdot 10^{-2}$; under these conditions, the parametrons are well shielded and are not coupled with any type of input.

The statistics of the excitation of stationary phases of the parametron carries information about the distribution function for the phase of the input signal. With s/m << << 1, the probabilities for the excitation of oscillations having phases of 0 and π in parametrons 1 and 3 are

$$p_k(0, \pi) \simeq \frac{1}{2} \pm \frac{a_i}{\sqrt{2\pi}} \cos \Theta_i, \qquad (1)$$

where $\Theta_i = \varphi_{0i} + \Delta\omega t$, $\Delta\omega = (\omega_s - \omega_0)$ is the detuning frequency, and $k = 1, 3$ indicates the parametron. For the quadrature channels (2 and 4) with stationary phases of $\pi/2$ and $3\pi/2$, we have

$$P_k(\pi/2;\ 3\pi/2) \simeq \frac{1}{2} \pm \frac{a_i}{\sqrt{2\pi}} \sin \Theta_i, \quad (k = 2, 4). \qquad (2)$$

The quantized phase samples (the output signals of the parametrons) are compared by hybrid rings, whose output signals are rectified. When the phases of the samples at the rectifier output coincide, a video pulse appears(conditional probability 1), and when these phases do not coincide, the visual pulse does not appear (conditional probability 0). (When samples of the mutually orthogonal channels are compared, the phase in one of the channels is shifted by $\pi/2$.) The discrete samples, consisting of zeros and units, are treated by digital computers.

In the case of independent quantization channels, the probabilities for the coincidenc and noncoincidence of the phases of the samples being compared, i.e., the probabilities for the appearance of "0's or 1's" at the outputs of detectors D_j, are found for the corresponding j = 1, 2, 3, and 4 from Eqs. (1) and (2):

$$P_1(0,1) = \frac{1}{2} \mp A\cos\Theta_1\cos\Theta_2; \quad P_2(0,1) = \frac{1}{2} \mp A\cos\Theta_1\sin\Theta_2,$$
$$P_3(0,1) = \frac{1}{2} \mp A\sin\Theta_1\cos\Theta_2; \quad P_4(0,1) = \frac{1}{2} \mp A\sin\Theta_1\sin\Theta_2, \tag{3}$$

where $A = a_1 a_2/\pi$.

From (3) we can find relations for the phase difference $\Delta\varphi = \varphi_{01} - \varphi_{02}$ and the parameter A (signal detection):

$$\operatorname{tg}\Delta\varphi = [P_3(1) - P_2(1)]/[P_1(1) - P_4(0)] = \Delta_1/\Delta_2, \quad (-\pi/2 \leqslant \Delta\varphi \leqslant \pi/2), \tag{4}$$

$$\operatorname{tg}(\Delta\varphi/2) = (\sqrt{1+\Delta_2/\Delta_1} + 1)^{-1}, \quad (-\pi \leqslant \Delta\varphi \leqslant \pi), \tag{4*}$$

$$A^2 = \Delta_1^2 + \Delta_2^2. \tag{5}$$

In Eqs. (4) and (5), Δ_1 and Δ_2 are constant only for fixed $\Delta\omega$, $\Delta\varphi$, and A, but they can also be used with AM and FM signals, if it is taken into account that with AM signals Expression (5) is time-dependent. The frequency and zero crossing of the detuning are found by a spectral analysis of the periodic alternating function for $\Delta\omega$ found from (3):

$$\operatorname{tg}(2\Delta\omega t + \psi_0) = [P_3(1) - P_2(0)]/[P_1(1) - P_4(1)] = \Delta_3(t)/\Delta_4(t), \tag{6}$$

where t is the time, and $\psi_0 = \varphi_{01} + \varphi_{02}$ is the initial phase.

Experimentally with multiple figuring of the parametrons, it is not the probabilities themselves which are measured, but the relative frequencies of coincidences and noncoincidences of the phases of the quantized samples: $h_j(0) = m_j/l$, $h_j(1) = n_j/l$. Here m is the number of "0's" in a sample of length l obtained during the time T, n is the number of "1's" in this sample, and we have $l = \omega_s T/2\pi$. The accuracy of the measurements of $\Delta\varphi$ and A in an analysis of samples on the basis of Eqs. (4) and (5) depends on the accumulation time, the triggering frequency, and the parametron sensitivity. This parametron sensitivity is governed primarily by the quality of the balancing, for which the criterion is $P_k(0,1) = 1/2$ with $S_i = 0$.

This method can be used in the quantization of both continuous and rf pulsed signals. With asynchronous signals, (4) becomes

$$\operatorname{tg}(\Delta\omega_s t + \Delta\varphi) = \Delta_1(t)/\Delta_2(t), \tag{7}$$

where $\Delta\varphi$ is the initial phase difference, t is the time, and $\Delta\omega_s = \omega_{s1} - \omega_{s2}$ is the detuning.

Experimental studies carried out with rf and microwave mockups (1 MHz and 2.7 GHz) showed that the phase meters operate reliably over a wide range of s/n values, $\sim 10^4 - 10^{-1}$.

The sensitivyt of theparametrons is $\sim 10^{-16} - 10^{-17}$ W. Figure 2 shows the experimental tangential characteristic of the 1-MHz phase meter.

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