MEASURING INSTRUMENT FOR SHORT-TERM FREQUENCY INSTABILITY

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The frequency fluctuations of a laser can be measured with a high degree of resolution in short time intervals by using high-frequency filtering on the phase noise from the output of a phase detector [1]. However this method is unsuitable for substantial absolute magnitudes of the fluctuations.

In [2] a method is proposed for measuring the characteristics of short-term frequency instability that simplifies the measuring process and the treatment of results, broadens the possibilities of the measuring apparatus, and improves the accuracy in short time intervals.

A simplified block diagram of the circuit for the instrument that was developed is shown in Fig. 1. A discussion is given for a version of the instrument that is designed to measure the instability of the frequency difference between the radiations of two lasers.

The instrument operates in the following manner. The frequencies of the radiations from a laser under study and a reference laser (not shown in Fig. 1) are mixed in a photodetector. By adjusting the frequency of the laser under study the frequency of the heterodyne signal is made equal to 1 MHz. This is then amplified by an amplifier 1 and fed to a frequency discriminator (FD) 2 of the counting type that converts the frequency fluctuations into voltage fluctuations.

The analog voltage is filtered by a band-pass filter 3 having parameters such that the effective value of the noise voltage at its output is proportional to the mean-square variation of the frequency or to the square root of the Allan variance.

The band-pass filter used in [2] for this purpose is a parallel LC oscillatory circuit tuned to a frequency $f_r = 1/\pi\tau$, where τ is the desired measuring-time interval, and the quality factor $Q = 1$. The measuring-time interval is established by switching in a band-pass filter that has appropriate frequency tuning.

The output voltage of the filter is measured by a meter 4 for the effective value as in [3]: This includes an amplifier, a linear detector, a square-law device, an averager, a circuit to obtain the square root, and indicators. The indicators provided in the instrument are a microammeter and a voltage–frequency converter whose output goes to an electronic counting frequency meter for the digital indication of the measured results.

The instrument measures the mean square variation of the frequency or the square root of the Allan variance in a range from $3 \cdot 10^2$ to $3 \cdot 10^4$ Hz with a resultant error between 6 and 22% for measuring-time intervals of 10^{-4}, 10^{-3}, 10^{-2}, and 10^{-1} sec.

The measuring error of the method depends on the kind of noise from the generator under study and, for the band-pass filter parameters selected, varies from 6% with frequency flicker noise to 16% for white phase noise. With white frequency noise the error of the method is zero.

The resultant error also includes errors due to the imperfection of the amplifier's amplitude–frequency response and the nonlinearity of the FD characteristic in the operating frequency band (no more than 0.5%), errors due to variations of the transfer constants for the different measuring ranges (2%), errors of the effective-voltage meter (no more than 3%), and the error due to the self noise of the meter.

The instrument has an output for connecting a low-frequency spectrum analyzer with which it is possible to measure characteristics of the spectral noise density at the output of the frequency discriminator and to determine the type of noise from the generator under study.

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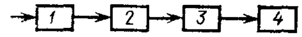

Fig. 1

TABLE 1

τ, sec	10^{-4}	10^{-3}	10^{-2}	10^{-1}
Δf_N, Hz	4	30	30	8

The measuring error in this case can be reduced to 6% because for each kind of noise the error of the method is known. The error of the instrument defined by the self noise does not exceed the values given in Table 1.

As seen from Table 1 the advantages of the method are most in evidence for short measuring-time intervals. The signal voltage for a difference frequency of 1 MHz at the instrument's input should not be less than 150 μV.

Besides the short-term instability meter the instrument's housing includes a long-term frequency instability meter which uses as a frequency discriminator a type Ch3-38 electronic counting frequency meter. It also contains a code—current converter that converts the signal from the output of the frequency meter and a type N390 ammeter—voltmeter that registers dc and ac. The long-term frequency drifts are recorded on the chart of a recording instrument. The amount of the drifts is determined with a special ruler. The measured drifts range from $3 \cdot 10^3$ to $3 \cdot 10^7$ Hz.

The signal voltage of the difference frequency at the input of the broad-band amplifier needed for normal operation of the instrument must be no less than 150 μV. The measuring error does not exceed 5%.

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ACCURACY OF TIME INTERVAL MEASUREMENT BY PULSE COUNTING

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Evaluation of the accuracy of time interval measurements by the pulse counting method is quite important in measurement engineering and has been discussed in many works [1-3, etc.].

A method of analyzing errors in time interval measurements which is based on the use of characteristic functions has been proposed in [3]. The method is useful when the spread of the measured intervals (as a result, e.g., of noise) is significantly greater than the count pulse period (quantum). Yet, in most practical cases the spread of the measured time interval is of the same order as the quantum or even less.

Here we describe a method for analyzing the quantization error of any time interval distribution functions (for any relation between the quantum and the measured time interval spread). The method is based on direct application of quantization error distribution functions.

Let us denote the duration of the measured time interval by t, the count pulse period by T, the pulse duration by θ, and the displacement of the start of the measured pulse interval with respect to the leading edge of the count pulse by τ. Let θ_0 denote the operating time-threshold of the gates. A pulse is counted when the portion of the pulse that falls within the measured interval $(\tau, \tau + t)$ exceeds θ_0. The following obvious inequalities

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