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# THERMAL MEASUREMENTS

## AN AMPLIFIER OF THE SIGNAL FROM A CONVERTER OF THE TEMPERATURE OSCILLATIONS OF THE SURFACE OF AN OBJECT

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*The operating principle and circuit of a low-frequency ac amplifier with a program-controlled transfer constant and a comparatively short regulation time are considered.*
***Keywords:*** *ac amplifier, amplitude-frequency characteristic, phase-frequency characteristic, analog-to-digital converter.*

The temperature wave method has become widely used when investigating the thermal properties of condensed materials at high temperatures [1, 2]. In this method, the thermal characteristics are estimated from the parameters of the temperature oscillations of the surface of the object being investigated. In using this equipment, we have employed as sensors, which convert the temperature oscillations into an electric signal, either high-temperature thermocouples or photoelectric converters (photodiodes). The amplitude of the electrical signal oscillations, depending on the type of sensor and the temperature range, is 1–1000 μV, and the range of operating frequencies is 1–100 Hz. The signals are processed in digital form in a computer. In order to use the capabilities of the analog-to-digital converter (ADC) to the greatest extent, an input linear normalizing ac amplifier with a variable transfer constant is required. The amplifier must be sufficiently broadband in order to introduce only small phase distortions into the signal, since the phase is an important parameter, on the basis of which the thermal diffusivity of the material being investigated is calculated. The gain is also important since it can be used to calculate the amplitude of the input electric signal, necessary to estimate the heat capacity. It should be borne in mind that, in addition to the useful signal, the ADC also receives electrical noise of different origins and considerable interference in the form of harmonics of the power supply frequency. The interference arises from the operation of the heater – an electrical resistance furnace, by means of which the average temperature of the object being investigated is measured. Hence, the equipment must include a regulated amplifier, in which interference at frequencies of 50 Hz and 100 Hz is rejected.

One can use as such an amplifier a tracking system which provides automatic gain control (AGC) [3]. In this case, naturally, this system is obviously closed through the computer. However, taking into account the fact that the AGC system must function at frequencies of the signal being investigated of a few hertz, the duration of a transient may amount to several minutes. For this reason, the speed at which measurements can be made falls, which is extremely undesirable. The purpose

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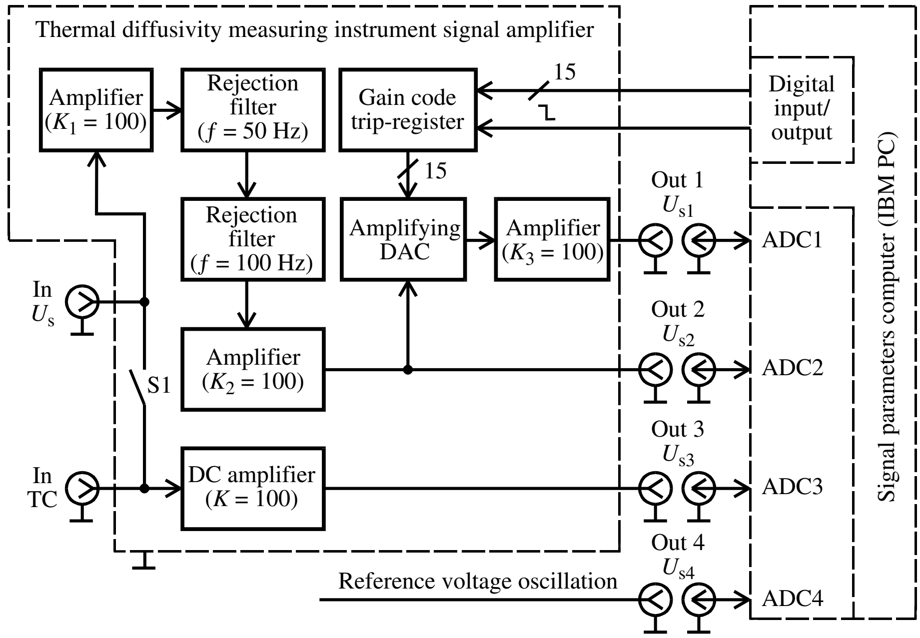


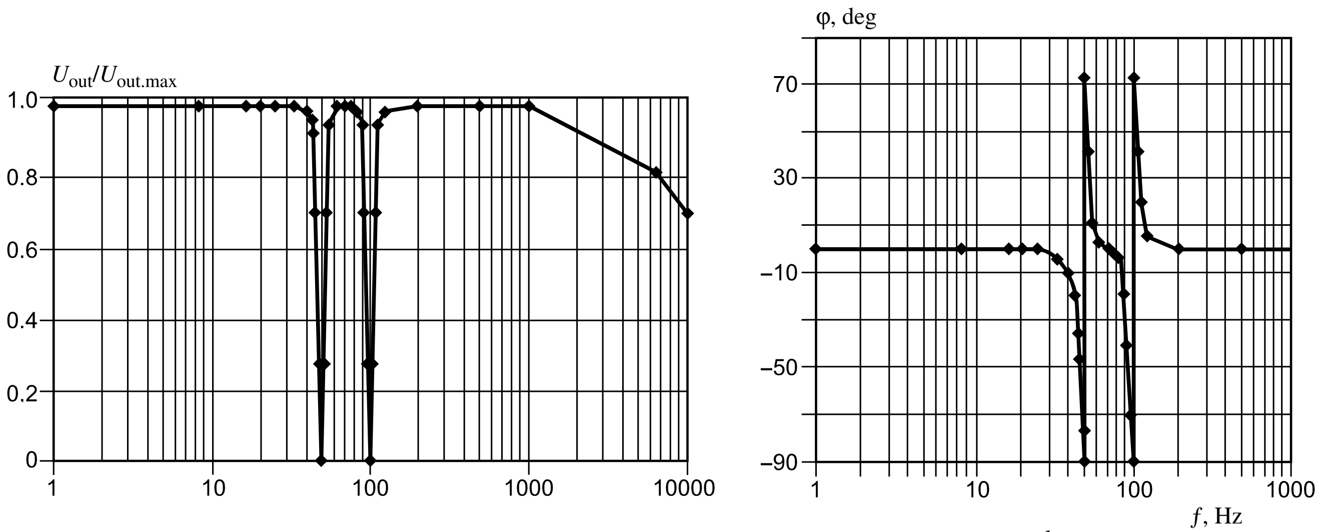

Fig. 1. Block diagram of the amplifier.

of the present paper is to describe the design of an ac amplifier, operating in a frequency band from fractions of a hertz to a few kilohertz with an operationally variable gain and a dynamic range of 60 dB, which includes rejector filters at frequencies of 50 Hz and 100 Hz.

A block diagram of an amplifier, which illustrates the principle of fairly rapid regulation of its transfer constant, is shown in Fig. 1. The ac unit consists of the first amplifier (gain $K_1$ = 100), 50 Hz and 100 Hz *rejection filters*, a second amplifier ($K_2$ = 100), a multiplying digital-to-analog converter (DAC), a third amplifier ($K_3$ = 100) and a gain code *trip register*. There is also a dc amplifier (DCA) with a transfer constant $K$ = 100 and a passband of a few hertz, by means of which an estimate is obtained of the mean temperature of the object being investigated from the mean signal voltage, obtained from the thermocouple sensor. In addition, the DCA performs the function of a decoupler of the input circuit from possible interference, produced by ADC3. The signals from the amplifiers are applied through an ADC to a *computer* (an IBM PC) which calculates the signal parameters.

The signals from the sensors are fed to the input of the system. If a photodiode is used as the temperature oscillation sensor, its signal is applied to the terminal In.$U_s$. The switch S1 in this mode of operation is open. The signal from the thermocouple then passes through the terminal In.TC only to the DCA and then to ADC3, for calculating the average temperature of the object. If the temperature oscillation sensor is a thermocouple, the photodiode is disconnected, the switch S1 is closed and the signal from the thermocouple is applied to both amplifiers.

Consider the operation of the ac amplifier. The rejector filters, incorporated into it, suppress concentrated interference, so that, for any actually occurring useful signals, the first and second stages of the amplifier operate linearly. The regulation process can be conveniently divided into three stages. In the first stage, using ADC2, over 10 periods of the useful signal, the mean square value of the voltage $U_{s2}$ at the output of the second amplifier is estimated. The information on the oscillation period is fed to the computer through ADC4 from the reference voltage generator [4], which generates harmonic oscillations, the frequency of which is equal to the frequency of the temperature wave, i.e., the frequency of the useful signal. In the second stage, using the value of $U_{s2}$, the program calculates the gain of the last amplifier unit, and, more accurately, the transfer constant of the DAC so that at the output of the third section of the amplifier the mean square value of the output voltage is at a level of 4.0 V. The formula $K_{DAC} = 0.04/U_{s2}$ is used for the calculation. The value of the transfer constant of the whole amplifier obtained is then used to calculate the thermal parameters of the object being investigated. At the




*a* *b*

Fig. 2. Amplitude-frequency characteristic (*a*) and phase-frequency characteristic (*b*) of the amplifier.

third stage, the result of the calculation is fed, in digital form in parallel code (two bytes), through an interface printed circuit to the trip-register amplifier, connected before the DAC. Using this code, the required transfer constant of the DAC is established, which remains constant until the process of recording the useful signal in the computer memory is completed. "Freezing" of the transfer constant while the useful signal is being converted into digital form is necessary in order to eliminate distortions due to a change in $K_{DAC}$.

As a result of these measures, the dynamic range of the ADC1 of the interface printed circuit plate is used practically completely. However, the signal parameters may change during the measurement procedure. Hence, if, when recording the useful signal, it is found that the voltage at the input of the ADC1 has exceeded the permissible value or has become extremely low, the regulation process is carried out once again. The thresholds for taking a decision on whether it is necessary to change the transfer constant is either the presence of a certain number of signal limits at the output of the third amplifier (which can be judged from the reading of ADC1), or a value of this signal that is insufficient to generate the leading digits of ADC1.

The linear circuits (see Fig. 1) are constructed using OR-27 integrated analog microcircuits [5], which possess high transfer constant stability and a low level of inherent interference. An isolating capacitor is connected at the input of the ac amplifier. The time constant of the input circuit is 8 sec.

The rejector filters (see Fig. 1) are constructed in the form of a double T-bridge using amplifiers with a limited transfer constant [6]. The transfer functions of the filters take the form of Butterworth polynomials. Highly stable K73 capacitors with an allowable deviation of the electric capacitance from the nominal value of 0.5% are used in the filters. This guarantees stability of the phase-frequency characteristic (PFC) of the amplifier. The phase delay, produced by the amplifier, is measured for each frequency of the temperature wave in a special calibrated experiment and then is assumed to remain unchanged. In Fig. 2, we show the normalized amplitude-frequency characteristic (AFC) and the phase-frequency characteristic (PFC) of the overall amplifier.

The trip register (memory circuit) is based on KR1533IR23 microcircuits. Code is recorded in the register when a negative pulse edge appears (a logical "0") in the leading code bit, proceeding from the interface printed circuit. The duration of the transient in the amplifier, due to a discrete change in its gain, is approximately 10 sec. The regulating components of the attenuator are K572PA1 ten-digit DACs.

**Conclusions.** The characteristics of the amplifier described were determined experimentally. Its passband at the 0.707 level lies in the range from 0.01 Hz to 10 kHz, where the interpeak value of the noise voltage, reduced to the amplifier input, is 1.5 μV, while the additional signal phase shift introduced at the operating limits of the frequency band does not exceed 0.5°. The regulating circuit enables the transfer constant to be measured digitally in the $10^4$–$10^6$ range, its instability amounts to 0.1%, and the instability of the phase characteristic is 0.1°. The time taken to establish (regulate) the transfer constant does not exceed 30 sec.

Hence, the amplifier described possesses the qualities required to measure the thermal properties of materials by the temperature wave method. The amplifier can also be used as part of other measuring devices for solving a wide range of engineering and scientific problems.

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