A CIRCUIT FOR CONTROLLING A MULTIELEMENT THERMAL RECEIVER BASED ON VO₂ FILMS

A. S. Oleinik

The basic electric circuit for controlling a multielement receiver based on VO₂ films, which carries out sequential switching of the elements of the heat-sensitive layer of the receiver and a linear transformation of the resistance of each element into the corresponding value of the voltage of the recorded signal in real time, is presented. Estimates of the error of measurements made by the receiver in the internal-memory mode are given.

Key words: semiconductor–metal phase transition, thermal receiver, resistance–voltage converter, heat-sensitive layer.

The development of new thermal receivers capable of measuring low and medium radiation powers with a radiation pulse length of the order of 1 psec is a pressing problem. A receiver, the operating principle of which is based on a semiconductor–metal phase transition in VO₂ films [1], is very promising. A semiconductor–metal phase transition occurs in polycrystalline films based on VO₂ when they are heated in the 46–86°C temperature range, which occurs in a time of about $10^{-11}$ sec and is accompanied by a sudden change in the resistivity $\rho$ (Fig. 1). The time taken for films of VO₂, 100–120 nm thick, in which the width of the thermal hysteresis loop of the resistivity is equal to 15–17°C, to heat up to the semiconductor–metal phase transition temperature due to the action of incident thermal radiation, is of the order of 1 psec. The internal memory mode is ensured by thermostatic control of the VO₂ film in the middle of the loop, in which case the forward branch of the hysteresis will have a quasi-linear form.

A multielement receiver based on VO₂ films has recently been developed [1], which is designed to measure the spatial energy characteristics of large beams of laser radiation. The receiver consists of a dielectric substrate with a heat-sensitive layer based on a VO₂ film in the form of a 24-element square array (2.5 × 2.5 mm²), which takes the form of a circle on the receiving area. The distance between the elements is equal to the dimension of an element. Contact areas are deposited on the opposite side of each element, which are connected to the printed conductors of the circuit by a current separator of Al. On the opposite side of substrate, under the elements of the heat-sensitive layer, there is a heater based on an NiCr film, which covers the whole surface occupied by the elements. On the free part of the surface of the substrate there is a copper–nickel film thermocouple. The outputs of the elements of the heat-sensitive layer are connected to the inputs of switches, and the outputs of the heater and the thermocouple are connected to a heat-regulator.

The purpose of the present research was to develop a circuit for controlling a multi-element thermal receiver, capable of measuring the spatial energy characteristics of large beams of laser radiation in real time.

The use as a sensitive layer in multielement receivers of materials with a reversible memory, for example, films based on vanadium dioxide, enables the electronic circuit for switching and synchronizing these signals to be simplified, and it also increases the threshold characteristic of the receiving system, which, in this case, will be expressed as the square root of the receiver area.
Heating of the heat-sensitive layer containing \( 1, \ldots, N \) elements occurs proportional to the spatial distribution of the energy density or the power of the radiation being measured, in which case a change occurs in the resistance of each element, and the resistance pattern formed is preserved for an unlimited time, so long as the heat-sensitive layer is maintained under thermostatically controlled conditions. A thermal receiver based on VO\(_2\) films is matched with a resistance–voltage converter based on a high-speed operational amplifier DA\(_1\) (Fig. 2), at the output of which a signal is generated proportional to the radiation being measured. The resistance–voltage converter contains an amplifier DA\(_1\) and two symmetrical linear stabilizers, consisting of stabilitrons VD\(_1\) and VD\(_2\), resistors R\(_1\) and R\(_2\) and power amplifiers VT\(_1\) and VT\(_2\). A standard voltage \( U_s \) is generated by the RP\(_1\) and R\(_3\) network, which is applied directly to the noninverting input 2 of the operational amplifier. The resistance R\(_4\) is chosen to be equal to the average maximum value of the resistance of the heat-sensitive layer of the receiver under thermostatically controlled conditions and is equal to 120 kΩ. The potentiometer RP\(_1\) served to set the reference voltage \( U_{s,R} \), which is equal to 10 V. The elements of the heat-sensitive layer of the receiver when interrogated are connected alternately in the feedback of operational amplifier DA\(_1\). The transfer function of the resistance–voltage converter has the form \( U_{out} = U_s(1 - (RP_2 + R)/R_4) \), where \( R \) is the current value of the resistance of an element of the heat-sensitive layer, and \( RP_2 \) is the resistance of the potentiometer, the purpose of which is to provide partial compensation of the spread in the elements of the heat-sensitive layer. Operational amplifier DA\(_1\) operates in the subtraction mode and, at a temperature corresponding to the lower limit of the temperature interval, equal to 70°C (the temperature at which the layer of VO\(_2\) is maintained), \( U_{out} = 0 \), and at a temperature of the heat-sensitive layer VO\(_2\) equal to the upper limit of the temperature range (83°C), \( U_{out} = U_s \).

The use of operational amplifier DA\(_1\) in the subtraction mode, unlike the traditional use in the amplification mode, enables us, for relatively low apparatus costs, to ensure that the output signal varies linearly over the whole range of \( U_s = 10 \) V.

Fig. 1. Temperature dependence of the surface resistivity of a layer of VO\(_2\) 100 nm thick.