Simulation of a Measuring Generator with a Prescribed Electrical Power Based on a Controlled Voltage Source and an Analog Voltage Multiplier

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***Abstract*—Measuring generators with a prescribed electrical power is a relatively new type of devices. Their application is especially promising in the field of medicine, electrochemistry, and a number of other areas where you have to deal with heat-dependent objects, whose parameters may change due to non-standardized electrical energy introduced into them during the measurement. Generators based on signal division have been fairly well researched, in contrast to structures based on signal multiplication. This article presents the study results of a prescribed electrical power generator based on the multiplication of signals and a voltage-controlled voltage source. The data obtained by computer simulation are consistent with the results of the generator circuit practical implementation. The generator can be implemented using only four IC's and provides the maintaining full-scale error of a prescribed electric power less than 15% in the range of load resistance variation from 50 to 1000 kOhm.**

Keywords—integrated circuit modeling, electric variables control, electrical resistance measurement.

I. Introduction

In various technological systems and in technological processes control, it is required to obtain objective information, reproducible during repeated measurements, on the electrical parameters of the objects under study. One of the tasks in such systems is the measurement of electrical resistance or conductivity. In measurement of electrical resistance or conductivity can not avoid exposure to the object under study electrical energy. The measurement of electrical resistance is usually carried out in the mode of prescribed electrical current or voltage. The electrical energy introduced into the object, in these cases, depends on its parameters (electrical resistance) and, accordingly, the state of the objects will change in different ways. This does not take into account that dissipated in the object energy in the form of Joule heat depends on the object parameters, so, the object heat and energy dependence are ignored. Measuring transducers operating in different modes will show different values of the measured parameter for the same object. Due to these phenomena, the obtained measurement results will have low accuracy, repeatability and reproducibility, which is confirmed by experiment. [1-3].

Methods for measuring electrical resistance were compared using the example of determining the acupuncture point electrical resistance in three modes:

• prescribed voltage +5 V;

• prescribed current +50 μA;

• prescribed electric power of 60 μW.

The obtained measurement results showed that the obtained data convergence during measurements in the prescribed electric power mode is 40% better than in the prescribed current mode and by more than an order of magnitude compared to the prescribed voltage mode.

The resulting uncertainty in the energy measurement mode complicates the task of obtaining the high metrological characteristics of measuring transducers and measurements reproducibility. When creating equipment for technological and medical installations (galvanic treatment, electrophoresis, etc.), a certainty of the energy mode is also necessary. Therefore, to obtain results that are reproducible with repeated measurements, it is necessary the certain temperature of the object and a constant value of electrical power which dissipates in it.

To obtain the mode in which a nonlinear heat-dependent object parameters are estimated, it was proposed to use measuring circuits that provide the power constant value which is dissipated in the load resistance (within the operating range). A theory for constructing original functional units - measuring generators with a prescribed electrical power has been developed. Measuring generators with a prescribed electrical power are called electronic devices that provide a constant value of electrical power dissipated by a load with random resistance connected to their output, with an error not exceeding a predetermined value. The research results in such devices field of are given in [4-8].

In general, the structures of measuring generators with a prescribed electrical power can be divided into two groups according to the output devices type:

• with controlled voltage sources;

• with controlled current sources.

The measuring generators with prescribed electrical power structures with controlled voltage and current sources and witn dividing analog signals are shown in Fig. 1. Generators with controlled voltage sources are usually used for relatively large load resistances (units - hundreds of kΩ), and generators with controlled current sources for relatively low resistances (less than kΩ). This is due to low load resistances (for example, a resistance of 1 Ohm at an electric power of 100 μW) at which the output current of IC exceeds the output short-circuit current (the typical value for conventional operational amplifiers, such as used in the generator under study LM741, no more than 10 mA).

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However, there are already models of operational amplifiers such as the LM7171 with an output current of 100 mA, allowing to work with low load resistances.

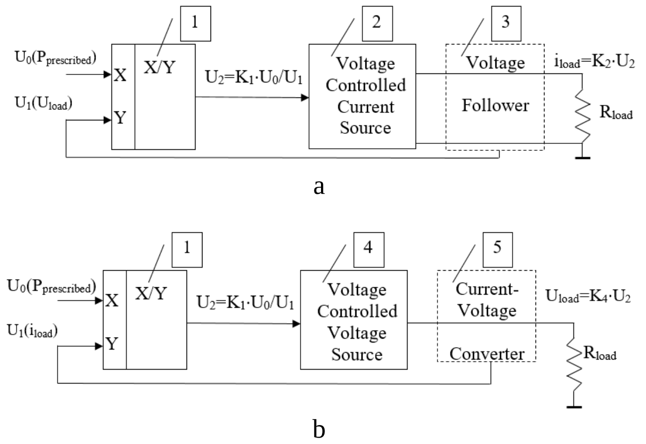

Fig. 1 The measuring generators with a prescribed electrical power structures with controlled voltage and current sources and dividing analog signals

The equations shown in the Fig. 1 explain the principles of these generators. Fig. 1 indicates:

- U_0 ($P_{prescribed}$) - voltage supplied to the IC input X of the analog signal divider and setting the value of the impact electric power;
- U_1 is the voltage supplied to the IC X input of the analog signal divider and characterizing the voltage across the load U_{load} or the current in the load i_{load};
- U_2 - voltage at the IC output of the analog signal divider;
- K_1 - conversion factor of the analog signal divider IC;
- K_2 - conversion factor of Voltage Controlled Current Source;
- K_4 - conversion factor of Voltage Controlled Voltage Source;
- R_{load} - load resistance.

When the load resistance changes, the current or voltage feedback signal makes it possible to correct the value of the impact electric power (within the operating range of electrical resistances) by changing the output voltage of the signal dividing device.

Generators based on signal division have been studied quite well, which cannot be said about structures based on signal multiplication. The modeling purpose was to identify the optimal circuit solutions and conversion factors for individual functional units and analog measuring generators with a prescribed electrical power as a system.

II. Materials and Methods

The simulation was carried out using the Micro-Cap 12 software [9]. Standard models of electronic components included in the standard program libraries were used for modelling. Some of the models were downloaded from the website of the Analog Devices manufacturer [10].

The technical characteristics of the measuring generators with a prescribed electrical power with a controlled voltage source and with signal multiplication were investigated, its structure is shown in Fig. 2. It includes an analog voltage multiplier 1, a reference-voltage source 2, a subtractor 3, a controlled voltage source 4, a voltage follower on a load resistance 5 and a current-voltage converter 6. The power value is set by the reference voltage source. A signal proportional to the voltage across the load resistance Z_n is fed to the analog voltage multiplier X input, and a signal proportional to the current is applied to the Y input. The signals multiplying result will be proportional to the value of the electrical power dissipated by the load resistance. The signal from the multiplier output is compared with the signal of the reference voltage source on the subtractor 3. This operation result is fed to the controlled voltage source input 4.

Generator blocks have the following conversion factors:

• voltage multiplier: 0.1;

• subtractive device: 60;

• controlled voltage source: 1;

• voltage follower on load resistance: 1;

• current-voltage converter: 60 000.

III. Results

In practical implementation the measuring generators with a prescribed electrical power was made on the basis of an AD734 – IC analog four-quadrant signal multiplier/divider (Analog Devices). The AD734 IC was chosen as having the highest output voltage among this group of devices at a supply voltage of ± 15 V. Such IC are widely used against the background of digital electronics rapid development [10-11].

It should be noted that the proposed options for digital generators of a prescribed electric power [8] are still inferior to analog ones in terms of speed.

The generator has the following characteristics for the range of change in load resistance:

• electrical power in load resistance 140 μW;

• operating range of load resistances 50-1000 kOhm;

• electric power value maintaining error for the prescribed range of load resistances is less than 15%.

The full-scale error of maintaining the prescribed electric power value at the load was determined by the maximum value for the following load resistance values - 50, 100, 270, 680, 1000 kOhm.

The measuring generator with a prescribed electrical power circuit operation was simulated in the MicroCap software package. The IC's perform the functions of the following circuit blocks: AD734 - voltage multiplier, AD620 - current-voltage converter, LM741 - subtractor and controlled voltage source [12], LM741 - voltage follower across the load resistance.

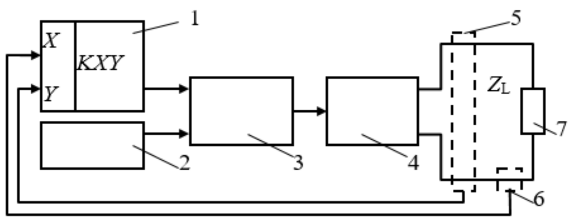

Fig. 2 The structure of measuring generator with a prescribed electrical power with a controlled voltage source and signal multiplication

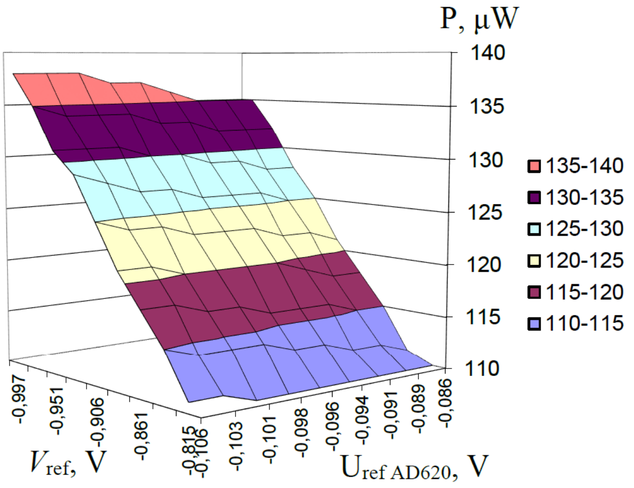

Fig. 3 Dependence of the generator output electric power – P on the change in the reference voltage – V_{ref} and the IC bias voltage U_{ref} of the current- voltage converter for a load resistance of 1 MΩ.

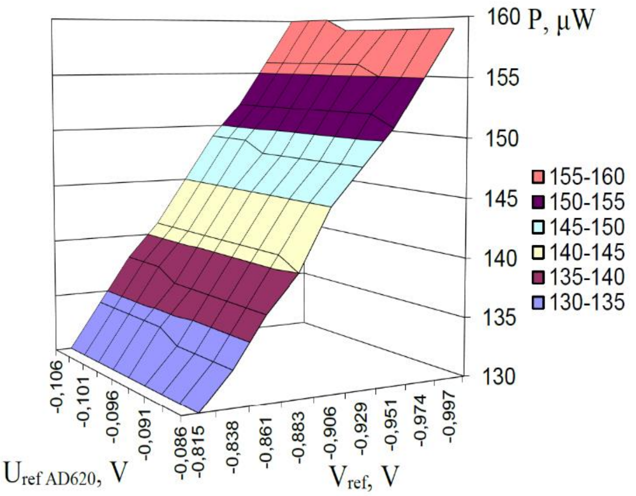

Fig. 4 Dependence of the generator output electric power P on the change in the reference voltage V_{ref} and the IC bias voltage U_{ref} of the current-voltage converter for a load resistance of 50 kΩ

The diagrams in Fig. 3, 4 show the obtained dependences of the generator output electric power value – P on the change in the reference voltage – V_{ref} and the bias voltage U_{ref} of the instrumental operational amplifier IC (AD620), which implements a current-voltage converter in this generator at the operating range boundaries for load resistances (50 kΩ and 1 MΩ).

As practice and simulation results show, a change in the offset voltage of the AD620 instrumental operational amplifier U_{ref} within ± 10% does not significantly affect the error in maintaining the measuring generator output electric power:

- for a load resistance of 50 kOhm - a change in the output electrical power within ± 1 μW;
- for a load resistance of 1 MΩ - change in the output electric power within ± 1.5 μW.

A change in the reference voltage responsible the prescribed generator power value V_{ref} within ± 10% has the following consequences:

- for a load resistance of 50 kOhm - change in the output electric power within ± 15%;
- for a load resistance of 1 megohm - a change in the output electric power within ± 12%.

IV. DISCUSSION

Based on the simulation results of an analog measuring generator it was found that:

- the error in providing the prescribed electric power for the range of load resistances of 50kOhm-1MOhm does not exceed 15%, which is in good agreement with the data obtained in the practical implementation of the circuit. The structure is built on the principle of a static automatic control system and therefore the error of such a system in a steady state in the general is not equal to zero;
- the value of the prescribed electric power when implementing a current-voltage converter using a differential amplifier (AD620) is significantly influenced by the offset voltage of this operational amplifier - when U_{ref} changes by 10%, the power value changes by 5%. This complicates the configuration of this device and requires a stable voltage reference;
- the implementation of the current-voltage converter using a differential amplifier imposes a limitation on the load resistance minimum values. This due to resistor, connected in series with the load, which sets the current-to-voltage conversion ratio. It is impractical to reduce the value of the current conversion factor to less than 100 Ohm (i.e., the minimum load resistance is limited to values of the 10 kOhm order). Also, a large current-to-voltage conversion factor (60,000) does not allow working with low load resistances for a power of 140 μW, because with a decrease in resistance, the load current increases and the voltage at the output of the converter will exceed the input voltage limit of the multiplier (10 V) already at a load resistance of 5 kΩ;
- it is recommended to reduce the current-voltage converter conversion factor to a value of 10000, because this will expand the range of generator load operating resistances without deteriorating other technical characteristics.

CONCLUSION

The prototyping and simulation showed that the considered version of an analog measuring generator with a prescribed electrical power based on a controlled voltage source and signal multiplication is efficient and can be implemented in practice using only four IC's. The full-scale error of maintaining a prescribed electric power in the range of load resistance variation from 50 to 1000 kOhm does not exceed 15%. The range of load operating electrical resistances can be expanded towards to small values (5÷10 kOhm) with a decrease in the conversion coefficient of the current-voltage converter.

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