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EXTENSION OF VOLTAGE RANGE FOR POWER AND ENERGY CALIBRATIONS

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Abstract

A special purpose ac voltage divider system having voltage ratios of 600 V, 480 V, 360 V, and 240 V to 120 V has been developed to extend the voltage range of primary electric power calibrations from 120 volts to 600 volts at power frequencies of 50 and 60 Hz. The system consists of a special two-stage resistive divider compensated with an active circuit, thereby reducing the error contributions to below 1 μV/V. The developmental goal to realize ac voltage scaling within 5 μV/V uncertainty in a device verifiable with dc resistance ratio measurements has been attained.

Summary

Introduction

At the National Institute of Standards and Technology (NIST), the primary realization of the quantity of ac electric power, the watt, is accomplished by means of a "power bridge [1]." The bridge is optimized for operation at 120 V and 5 A. Calibrations at other voltages and currents are possible using scaling transformers within the power bridge.

To further extend the voltage range to 600 volts, it was decided to investigate an amplifier-compensated resistive divider technique, similar to that successfully applied to high-voltage capacitive dividers [2]. The goal is to develop a multi-ratio divider for voltage ratios to 600V/120V having an uncertainty within 5 μV/V and easy ratio verification with dc measurements.

Operating Principle

The basic circuit is a two-stage divider similar to that of the cited reference [2], and the conceptual circuit of such a divider is shown in Fig. 1.

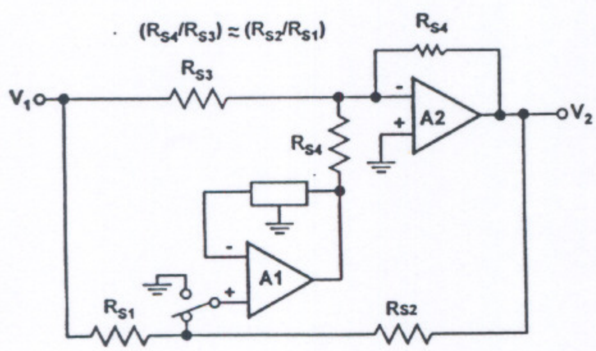

Fig. 1. Circuit illustrating operating principle.

High voltage operational amplifier A2 together with resistors R_{S3} and R_{S4} in the feedback form the first stage of the divider having the approximate voltage ratio given by

$$(V_2/V_1) \approx -(R_{S4}/R_{S3}).$$

The error of the first stage is due to the finite gain of the feedback loop. To compensate for this error, the input and output voltages are compared by the precision divider formed by R_{S1} and R_{S2} and any deviation of the voltage ratio $-(V_2/V_1)$ from the resistance ratio (R_{S2}/R_{S1}) is sensed and reduced by the feedback loop that includes A1.

For the purpose of analysis, first consider A1 with its input grounded. The voltage ratio becomes

$$(V_2/V_1) = (R_{S4}/R_{S3})[1 + 1/(G_2H_2)]^{-1}, \quad (1)$$

where $G_2H_2 \gg 1$ is the loop gain of A2. Certain simplifications are introduced in equation (1):

$$(R_{S4}/R_{S3}) = (R_{S2}/R_{S1})(1 - e_1), \text{ and}$$
$$1/G_2H_2 = e_2,$$

where e_1 and e_2 are small error terms. Substituting the above simplifications in eq. (1), the following simplified version is obtained

$$(V_2/V_1) = -(R_{S2}/R_{S1})(1 - e_1 - e_2). \quad (2)$$

Eq. 2 is valid for the condition where A1 is still inoperative with grounded input. The error voltage at the junction of the resistors R_{S1} and R_{S2} is given by

$$V_2\,(e_1 + e_2)[R_{S1}/(R_{S1} + R_{S2})].$$

When the amplifier A1 is switched in the circuit, this error voltage is reduced by a factor

$$1/(1 + G_1H_1) \approx 1/G_1H_1,$$

where G_1H_1 is the gain of the feedback loop which includes A1. Consequently, the error contribution in V_2 is reduced by the same factor. The voltage ratio with both amplifiers operational becomes

$$(V_2/V_1) = -(R_{S2}/R_{S1})[1 - (e_1 + e_2)/G_1H_1] \quad (3)$$

The loop gains are affected by the input resistances, R_{S1} and R_{S3}, that are used for a particular ratio. The worst case condition arises when $(V_2/V_1) = 0.5$ yielding: $|e_1| \leq 1 \times 10^{-4}$, $|e_2| \leq 5 \times 10^{-4}$, $|1/(G_1H_1)| \leq 1.25 \times 10^{-3}$, and indicating that the proportional error due to imperfect amplifiers is 0.75×10^{-6} or smaller. These calculated design results are substantiated by the measured data.

Detailed Circuit

The detailed circuit is shown in Fig. 2. Some of the details illustrate additional developmental challenges that had to be met to achieve the performance goals.

(1) The circuit is installed on two printed circuit boards, one for each of the amplifiers, with a shielded partition between the two to eliminate internal capacitance

feedback between the input and the output.

(2) The precision resistor networks, R_{S1}, R_{S2}, and R_{S3} are installed in separate shielded enclosures with coaxial terminals to achieve three-terminal characteristics. The resistor networks can be compensated by parallel capacitors to reduce phase angle within ± 5 μrad.

(3) The load on the divider, a two-stage transformer, acting as a resistance of a few ohms at dc, an inductive reactance at operating frequencies, and a capacitive reactance at high frequencies, presented dynamic stability problems requiring RC compensating networks at the summing point of both amplifiers and in the local feedback around A1.

(4) Two-stage output is devised with approximate and accurate stages for supplying the two-stage transformer thus reducing the amplifier error.

Test Results

Thorough diagnostic measurements were performed at 50 and 60 Hz to ensure the operation of the electronics as outlined in the Operating Principle section. With an output voltage of 120 V, the error voltage between R_{S1} and R_{S2} in all cases is below 60 μV.

Precision and system-based measurements consisted of dc resistance, ac resistance ratio, and divider voltage ratio. The results of the first two are consistent within $\pm 2 \times 10^{-6}$, dc resistance and divider voltage ratios are consistent within $\pm 3 \times 10^{-6}$. All the precision measurements are still in a preliminary stage and subject to revision. However, the test data at this time indicate that the accuracy goal has been achieved.

Acknowledgments

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References

[1] N. Oldham and O. Petersons, "Calibration of standard wattmeters using a capacitance bridge and a digital generator," *IEEE Trans. Instrum. Meas.*, vol. IM-34, pp. 521-524, Dec. 1985.

[2] O. Petersons and S.P. Mehta, "An active voltage divider and phase shifter," *IEEE Trans. Instrum. Meas.*, vol. IM-36, pp. 362-368, June 1987.

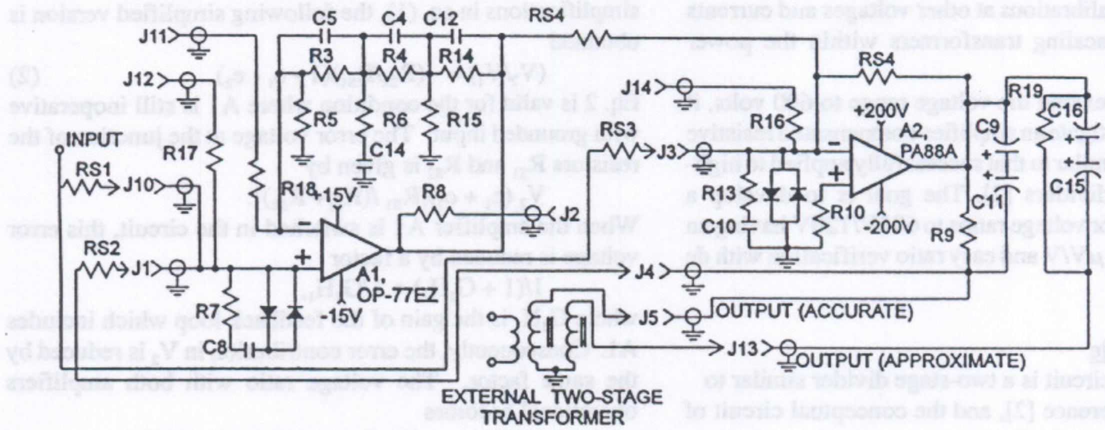

Fig. 2. Detailed circuit diagram.