Decrease uncertainty of measuring small differential signal against large common-mode signal

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Abstract. Comparators capable of comparing two alternating signals of the similar frequency within a wide dynamic range of frequencies and voltages are lock-in amplifiers with a differential input. The paper presents the methods and means are suggested for reducing the measurements uncertainty conditioned by the finite value of the common-mode rejection ratio in lock-in amplifier with a differential input.

1 Introduction

A comparison of the alternating voltage values is the classical problem of instrumentation [1-2]. A method of measurements by comparison against an actual measure is commonly used providing a comparison of the value to be measured $u_x(t)$ and the value of calibration signal $u_0(t)$ reproduced by measure. The practical implementation of this method including bridge and differentiation circuits requires the availability of high-sensitivity comparators possessing a resolution that, in large part, defines the uncertainty of measurements [3-8].

Comparators capable of comparing two alternating signals of the similar frequency within a wide dynamic range of frequencies and voltages are lock-in amplifiers with a differential input [9-11]. These devices are intended for the identification of a small differential signal of voltage to be compared (up to nanovolt units) against a large common-mode signal at a signal/noise ratio of -100 dB and high impedance (up to tens and hundreds of megaohms) at measurement inputs [12-13].

In this work, the methods and means are suggested for reducing the measurements uncertainty conditioned by the finite value of the common-mode rejection ratio in lock-in amplifier with a differential input.

2 Tracking power supply for differential signal extraction

The output voltage of the simplest lock-in amplifiers with a differential input can be obtained from:

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$$\Delta U \approx \frac{1}{E}\left(\lim_{T\to\infty}\frac{1}{T}\int_0^T \left[u_x(t) - u_0(t) + \frac{u_x(t)+u_0(t)}{2K_{\mathrm{RR}}(f)} \right] u_{\mathrm{ref}}(t)dt \right), \tag{1}$$

where E is the denominator of synchronous detector, V;

$u_0(t)$, $u_x(t)$ are input voltages to be compared, V;

$u_{\mathrm{ref}}(t)$ is the reference voltage, V;

K_{RR} is the common-mode rejection ratio.

From (1), measurement of the voltage difference ΔU of $u_0(t)$ and $u_x(t)$) is accompanied by the uncertainty that depends upon the phase shift φ between input signals and the finite value of the common-mode rejection ratio K_{RR} of the comparator circuit (subtractor). Also, it depends on incoherence of reference $u_{\mathrm{ref}}(t)$ and detected voltages at the inputs of the synchronous detector that is characterized by the phase shift φ_{ref}. The requirements for the common-mode rejection ratio must be improved, in particular, when checking and calibrating the scaling measurement transducers at (1-10 nV) maximum resolution of the lock-in amplifier within the medium frequency range at the higher level of 10√2 V of compared voltage dynamic range.

The increase of the common-mode rejection can be implemented by the addition of the voltage follower to the circuit as shown in Figure 1 that provides the tracking power supply of the instrumentation amplifier.

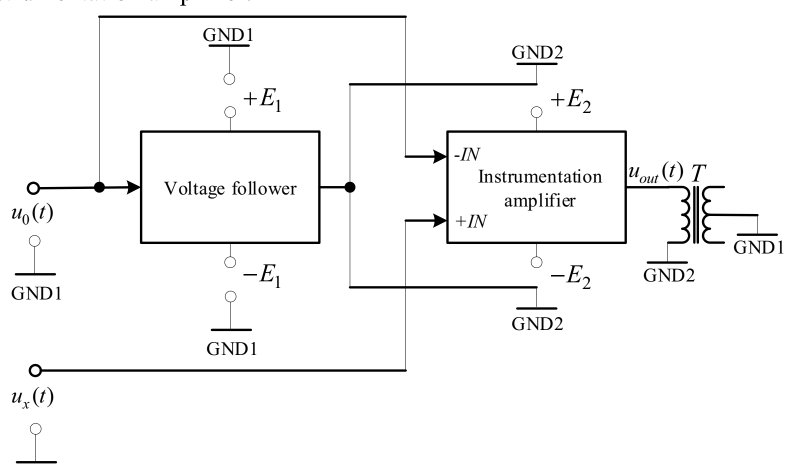

Fig. 1. Voltage follower-added circuit for formation of the tracking power supply.

For this circuit, the efficient common-mode rejection ratio will be increased and comes to

$$K_{\mathrm{RR.ef}}(f) = \frac{K_{\mathrm{RR}}(f)}{1 - K_{\mathrm{f}}(f)}, \tag{2}$$

where K_{f} is the transmission factor of the voltage follower.

The common-mode rejection down to 160–180 dB can be achieved within the frequency range of practically inertialess circuits, at easily reachable values of 0,999-0,9999 of the follower transmission as shown in Figure 2. These values provide the stability of the voltage follower transmission factor at different signal sources.

These dependencies prove a certain drawback of this technique used in the wide frequency range: the transmission factor module of the voltage follower and instrumentation amplifier decreases with the increase of frequency resulting in the common-mode rejection ratio of the whole circuit. Therefore, the high rejection of the common-mode signal is observed only in the narrow band of frequencies.

It should be noted that tracking power supply circuit with the use of voltage follower provides also a jump of the input impedance of measuring channels in the wide frequency range, especially u_x channel of the instrumentation amplifier.

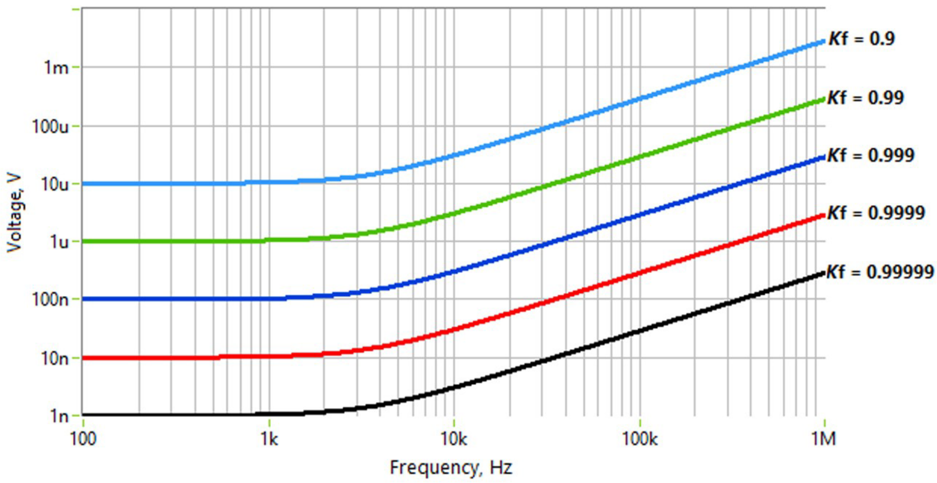

Fig. 2. Output voltage and frequency dependences of PGA207 instrumentation amplifier at different K_f values at common-mode 10 V and zero phase shift of the follower.

3 Sample and hold circuit

In order to achieve the required common-mode rejection, additional the sample and hold circuit can be used in the lock-in amplifier as shown in Figure 3.

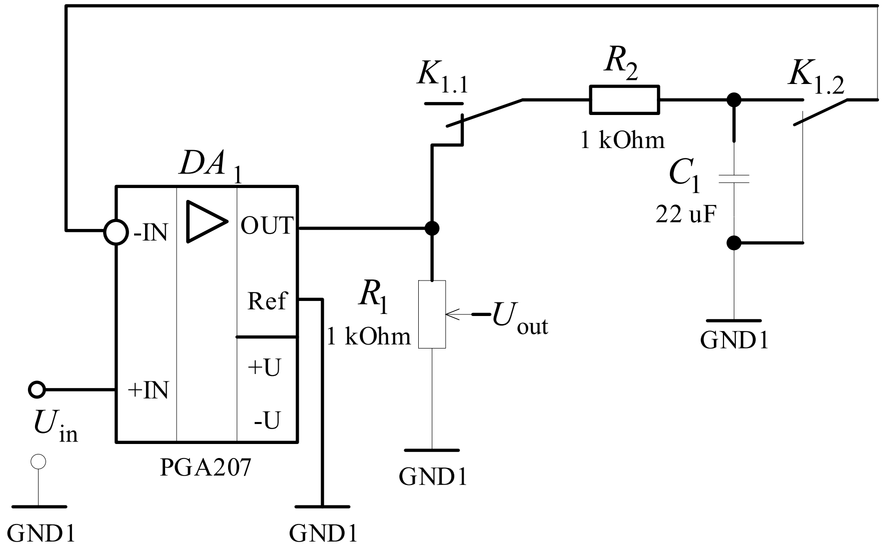

Fig. 3. Sample and hold circuit in PGA207.

With this view, the switch K_1 (e.g. reed switch RES-55) is installed in the connection circuit of the instrumentation amplifier to supply measurement inputs of voltage $u_0(t)$. The discharge common-mode voltage processed by synchronous detector and low-pass filter is stored by condenser C_1 of the sample and hold circuit.

In the mode of measuring the differential signal, voltages $u_0(t)$ and $u_x(t)$ transmit to the measurements inputs of the instrumentation amplifier by switch K_1. At the same time, in the sample and hold circuit the voltage stored in the capacitor is subtracted from the input voltage.

4 Conclusions

The suggested procedures oriented towards the decrease of uncertainty of measuring the small differential signal against a large common-mode signal, meet the requirements of the up-to-date instrumentation.

The technical implementation suggested for the tracking symmetrical power supply for the instrumentation amplifier is based on the voltage follower that allows increasing the common-mode rejection ratio up to 160-180 dB, comparing voltages up to $10\sqrt{2}$ V within the 100 kHz frequency range.

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