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:
\[
\Delta U \approx \frac{1}{E} \left\{ \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} u_s(t) - u_0(t) + \frac{u_r(t) + u_0(t)}{2K_{RR}(f)} u_{\text{ref}}(t) \, dt \right\}, \tag{1}
\]

where \( E \) is the denominator of synchronous detector, V; \( u_0(t), u_s(t) \) are input voltages to be compared, V; \( u_{\text{ref}}(t) \) is the reference voltage, V; \( K_{RR} \) is the common-mode rejection ratio.

From (1), measurement of the voltage difference \( \Delta U \) of \( u_0(t) \) and \( u_s(t) \) is accompanied by the uncertainty that depends upon the phase shift \( \phi \) 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 \( u_{\text{ref}}(t) \) and detected voltages at the inputs of the synchronous detector that is characterized by the phase shift \( \phi_{\text{ref}} \). 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\( \sqrt{2} \) 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.

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

\[
K_{RR,\text{ef}}(f) = \frac{K_{RR}(f)}{1 - K_f(f)}, \tag{2}
\]

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.](image)

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.](image)
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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References

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