Null detectors intended for comparing two voltages are being widely used in various automatic measuring and testing devices, and especially in digital measuring instruments.

A null detector has two inputs and one output. We examine below null detectors whose output signal indicates which of the two compared voltages $U_1$ and $U_2$ is the larger. Such null detectors have two stable positions which can be called arbitrarily "0" and "1".

The output signals which represent "0" and "1" can consist either of ac voltage levels or pulses.

Many advantageous properties of differential circuits have led to their wide application in null detectors. The null-detector circuit with an input differential amplifier and two isolated inputs is shown in Fig.1. This circuit is highly noiseproof with respect to inphase interference at its inputs, and it is adequately stable. The high input impedance of the amplifier is an additional advantage which provides good matching of the null detector to the sources of the compared signals. Differential amplifier $A$ serves to subtract voltages $U_1$ and $U_2$ and amplify the signal, thus reducing the null detector's threshold of sensitivity. The trigger circuit $TC$ which is connected to the amplifier output can consist of triggers or various electronic generator circuits with controlled oscillations. This circuit either generates pulses (condition "1") or stops oscillating (condition "0") depending on the value of the compared voltages.

Several works have been published recently on the theory of differential circuits [1-3]. It is interesting to investigate null-detector errors due to the asymmetry and nonlinearity of differential amplifiers.

The amplifier output voltage is equal to

$$U_{out} = k_1U_1 - k_2U_2,$$

where $k_1$ and $k_2$ are amplification factors with respect to inputs $U_1$ and $U_2$. Let us transform (1) and represent it in the following form

$$U_{out} = \frac{k_1 + k_2}{2} (U_1 - U_2) + (k_1 - k_2) \frac{(U_1 + U_2)}{2}$$

Quantity $U_1 - U_2$ represents the difference $\Delta U_{in}$ between the compared voltages, i.e., $\Delta U_{in} = U_1 - U_2$. Half the sum of voltages $U_1$ and $U_2$ represents the mean level $U_0$ of the compared signals, i.e., $U_0 = (U_1 + U_2)/2$.

Let us adopt the notations:

$$k_0 = \frac{k_1 + k_2}{2} \text{ and } k_1 = k_1 - k_2.$$

Factor $k_0$ which is measured when the amplifier input is fed with equal voltages in opposite phases represents the mean gain. Factor $k_1 = k_1 - k_2$, which is measured when the inputs are fed with equal voltages whose phases coincide at a given point, represents the amplifier asymmetry. If the amplifier is symmetrical $k_1 = 0$ i.e., $k_1 = k_2$. 

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**Fig. 1**

Null detector with a differential amplifier.
With the above notations (2) becomes

\[ U_{\text{out}} = k_0 \Delta U_{\text{in}} + k_1 U_0. \]  

(3)

Let us denote by \( \pm \Delta U_{\text{nd}} \) the limiting values of voltages for which the trigger circuit \( \text{TC} \) passes from one stable condition to the other. The zone of insensitivity of the null-detector trigger circuit will therefore be \( 2 \Delta U_{\text{nd}} \).

By equating the amplifier output voltage \( U_{\text{out}} \) to the null-detector trigger-circuit input voltage \( \pm \Delta U_{\text{nd}} \), for which the circuit operates we obtain

\[ \pm \Delta U_{\text{out}} = k_0 \Delta U_{\text{in}} + k_1 U_0. \]  

(4)

From (4) we can find the input voltage difference for which the null detector operates

\[ \Delta U_{\text{in}} = \pm \frac{\Delta U_{\text{nd}}}{k_0} - \frac{k_1}{k_0} U_0. \]  

(5)

The ratio of factors \( k_0 \) and \( k_1 \), which represents the capacity of a differential circuit to pick out the useful signal, is normally known in the theory of differential circuits [1] as rejection factor \( D \)

\[ D = \frac{k_0}{k_1} = \frac{k_1 + k_2}{2 (k_1 - k_2)}. \]  

(6)

By using rejection factor \( D \) in (5) it becomes possible to find the relationship of the null detector's threshold of sensitivity \( \Delta U_{\text{in}} \) to the compared voltages level \( U_0 \) and the circuit parameters.

\[ \Delta U_{\text{in}} = \pm \frac{\Delta U_{\text{nd}}}{k_0} \frac{U_0}{D}. \]  

(7)

Expression (7) represents a null detector with a differential amplifier. Term \( \pm \Delta U_{\text{nd}}/k_0 \) represents the null detector's threshold of sensitivity referred to the amplifier input. This threshold drops with a rise in gain of the amplifier. Term \( U_0/D \) determines the zero displacement for changes of the compared signals level due to the asymmetry of the differential amplifier. The higher the rejection factor \( D \) the smaller will be the zero shift for a given level \( U \) of compared voltages.

Figure 2 shows the characteristic of null detectors with different differential amplifiers designed according to (7). If the differential amplifier is linear (\( k=\text{const} \)), the null detector's zone of insensitivity remains constant (Fig. 2a). In the presence of asymmetry in a linear amplifier (\( k_1 \neq k_2 \)) the zone of insensitivity remains constant for different levels of compared signals, but a zero shift appears which has a linear relationship to the input signals level (Fig. 2b). In certain instances a regular zero shift can be allowed for by appropriate calibration. Asymmetry in a differential amplifier always leads to a reduction in its stability and noise rejection, especially in the case of variable external factors (supply voltages, temperature, etc.).

An amplifier's nonlinearity can be dealt with by substituting in (7) for the coefficients their functions which depend on the level of the compared signals, i.e., \( k_0=f(U_0) \) and \( D=f(U_0) \).

If the null detector incorporates a nonlinear amplifier which maintains symmetry (\( k_1 = k_2 \)) over the entire range of compared signals, the zone of insensitivity of such a detector will change according to the level of the compared voltages, but there will be no zero shift (Fig. 2c).