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# ZERO BIPOLAR MEASURING CIRCUIT

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**Abstract** – In the paper, results of substantiating analysis of the possibility application the frequent-independent two-terminals as zero measuring circuit are shown. It allows to determine not only reactive parameters, but also active resistances. Sensitivities of such measuring circuit are determined. Meter functional diagram and its usage are described.

**Keywords:** frequency independent two-terminal network, conditions of frequency independent, measuring circuit

Methods of comparison with a measure have gained recognition and spreading in measuring equipment. Zero measuring circuits are emphasized due to precise metrological characteristics in electrical measurements in this realm. The amount of such circuit kinds is rather limited only by electric bridges and equalizers. During this year there was published the principle substantiation of the third kind of the zero measuring circuit – measuring circuit as a frequency independent two-terminal network [1], but it allows measuring only reactive parameters: capacity and inductance.

Naturally, zero measuring circuits are not ideal and have drawbacks. In particular, bridge circuits of alternating current require special coupling accessories with electronic units. Bridges are formed according to a diagram of a four-terminal network and have two outlets for an output, but only one of four outlets can be earthed. If a generator of feeding signals and a transformer of unbalanced signals from a bridge circuit are earthed, then coupling units are required. As such equipment transformers and differential-amplifier stages are widely used. Each of them has its own drawbacks.

According to the above mentioned the aim of the paper is investigation and definition of perspective for use variants of new type of zero measuring circuit, which actually represents potentially frequency independent two-terminal network. To the problems of investigations belongs the substantiation of measuring possibility with the use of zero measuring circuit as potentially frequency independent two-terminal network of not only reactive parameters, but resistive resistance, and also decrease or elimination of drawbacks, connected with use of coupling devices of zero measuring circuits, having current spreading.

The following issues determine the principle possibility of use potentially frequency independent two-terminal network as a zero measuring circuit. While carrying out conditions of frequency independence the equivalent resistance of frequency independent two-terminal networks is resistive (has no reactive constituent) and has a definite value [2,3]. In the circuits of such two-terminal networks there are reactive elements, but, e.g., in resistive circuits with their participation at commutation there is no transitional process [4]. The elements of outer relatively frequency independent two-terminal networks of circuits, and values of their parameters do not effect upon the property of these two-terminal networks and do not require changing their conditions of frequency independence [4]. Proceeding from the conditions mentioned above, if after disconnection from the power source of constant voltage of resistive power circuit with the frequency independent two-terminal network in the coming time interval of the transitional process the electric signal is out (voltage value is equal to zero), then the conditions of frequency independence are fulfilled and from them one starts counting out of the sought parameter. If in the mentioned coming time interval there is an electric signal, then by means of the adjustment of the parameter chosen its voltage value should be reduced to zero and in such a way carry out the frequency independence condition.

First, in reactive elements of frequency independent two-terminal network one should accumulate electric power from the source of constant voltage. After power source disconnection power is disseminated, but at the observance of conditions for frequency independence the voltage value is equal to zero at the outlets of the two-terminal network, as at the equivalent resistor. The mathematical expressions of conditions for the frequency independence represent difference [1-4]. If they equal zero, then these conditions are performed. If conditions are not carried out, then differences have positive or negative values that can be reflected respectively through signal polarity upon potentially frequency independent two-terminal network in the time interval of the transitional process. It determines a direction of value changing for the chosen adjustable parameter to reduce to zero a value of signal voltage at two-terminal network.

For example, in Fig. 1 the potentially frequency independent two-terminal network is shown, which can be used as a zero measuring circuit. This variant of the two-terminal network allows inclusion in it parametric sensors of all three types: resistive, capacitance and inductive. At the closed state of the key s in reactive elements of the circuit considered there is electric power. At key disconnection voltage in the two-terminal network is determined through the following expressions

$$u = E(\exp p_1 t + \exp p_2 t)(r_1 - R_1)R/2r_1(R + R_1) - E(\exp p_1 t - \exp p_2 t)\{CR^2(r_1^2 - R_1^2) - 2[CR^2 r_1^2 - l(R + R_1 + r_1)^2]\}/\{2r_1(R + R_1) \times [C^2R^2(r_1 + R_1)^2 - 4lC(R + R_1 + r_1)^2]^{-1/2}\}, \quad (1)$$

$$p_{1,2} = \{-CR(r_1 + R_1) \pm [C^2R^2(r_1 + R_1)^2 - 4lC(R + R_1 + r_1)^2]^{1/2}\}/[2lC(R + R_1 + r_1)] \quad (2)$$

For the formula (1) such a form of writing down is chosen in order to emphasize conditions of frequency independence and a cumbersome expression write down within some lines. Conditions of frequency independence of two-terminal network (Fig.1)

$$r_1 - R_1 = 0, \qquad CR^2 r_1^2 - l(R + R_1 + r_1)^2 = 0, \quad (3)$$

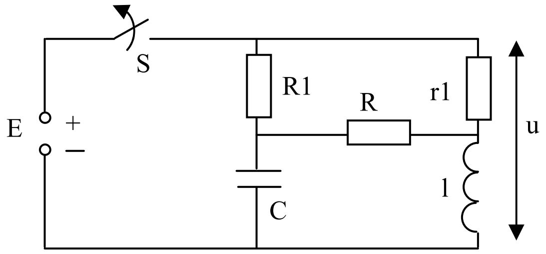


Fig. 1

equivalent resistance at their fulfillment –

$$Z_э = R_э = R_1(R + R_1)/(R + 2R_1). \quad (4)$$

From expressions (1) – (3) it is possible to conclusion that at the beginning the first condition of frequency independence in (3) and the second – in the course of measuring are to be fulfilled. Hence, it is possible to consider a parameter of the resistive character R to be measurable, and parameter of capacitance C or inductive l character to be adjustable. Also it is possible to consider parameter of the capacitance character C to be measurable, and those of R or l to be adjustable and, finally, parameter l to be measurable and those of R or C to be adjustable.

Provided the first condition of frequency independence (3) is fulfilled the second one will be written as

$$CR^2R_1^2 - l(R + 2R_1)^2 = 0. \quad (5)$$

and expressions (1), (2) will assume

$$u = E\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2}(\exp p_1 t + \exp p_2 t)/2CR_1(R + R_1), \quad (6)$$

$$p_{1,2} = \frac{-CRR_1 \pm \{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2}}{lC(R + 2R_1)}. \quad (7)$$

In this case the formula (6) has two exponential functions with the opposite signs and equal amplitudes in absolute value. From (7) an inequality is following:

$$|p_1| < |p_2|. \quad (8)$$

Provided inequality is fulfilled

$$CR^2R_1^2 > l(R + 2R_1)^2, \quad (9)$$

the positive exponent is damping with less velocity (8) than the exponent with the negative sign, and has damping up to zero voltage splash of the positive polarity. By the regulation of the parameters R, C or L the voltage value splash it's possible to reduce to zero and due to it to fulfill the second condition of frequency independence (5). It becomes the source of counting the unknown parameters.

Absolute sensitivities of the observed measuring circuit are defined by the comparatively cumbersome expressions by positive resistance, capacity and inductance:

$$S_R = E(\exp p_1 t - \exp p_2 t)[CRR_1^2 - l(R + 2R_1)]/2R_1(R + R_1)\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2} + Et(\exp p_1 t + \exp p_2 t)\{(R + 2R_1)[CRR_1^2 - l(R + 2R_1)] - [CR^2R_1^2 - l(R + 2R_1)^2]\}/2lCR_1(R + R_1)(R + 2R_1)^2 - E(\exp p_1 t - \exp p_2 t)\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2}[2tR_1^2(R + R_1) + l(R + R_1)^2]/2lCR_1(R + R_1)^2(R + 2R_1)^2, \quad (10)$$

$$S_C = E(\exp p_1 t - \exp p_2 t)[2CR^2R_1^2 - l(R + 2R_1)^2]/4CR_1(R + R_1)\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2} + Et(\exp p_1 t + \exp p_2 t) \times R^2R_1/2lC(R + R_1)(R + 2R_1) - E(\exp p_1 t - \exp p_2 t)\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2}/2C^2R_1(R + R_1), \quad (11)$$

$$S_l = -E(R + 2R_1)^2(\exp p_1 t - \exp p_2 t)/4R_1(R + R_1)\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2} - Et(\exp p_1 t + \exp p_2 t)[2CR^2R_1^2 - l(R + R_1)^2]/4l^2CR_1(R + R_1)(R + 2R_1) + ERt(\exp p_1 t - \exp p_2 t)\{C[CR^2R_1^2 - l(R + 2R_1)^2]\}^{1/2}/4l^2C(R + R_1)(R + 2R_1). \quad (12)$$

Relatively big voltage values from the output of zero measuring circuits are transformed and indicated in the electric circuits relatively simply. Some difficulties may appear in the measuring and other electron devices at the little voltage signals values. In the contemporary practice it was settled that the analysis of the zero measuring circuits is carried out towards "the worst variant', i.e. for very little voltage output signals values [5, 6]. Taking into account (5) and (6) for two-terminal network (Fig. 1) it corresponds to

$$CR^2R_1^2 \to l(R+2R_1)^2\ , \tag{13}$$

then, according to (7)

$$p_1 \to p_2. \tag{14}$$

The sensitivities are also defined in the area of little output voltage values. According to (13) and (14) expressions for the absolute sensitivities (10) - (12) deliberately reduced in the presented form. In particular, in the formula (10) the first item represents the nondescript 0/0, the third item contains two indefinitely small multipliers multiplication. Exposing the nondescript and without taking into account the item, containing indefinitely small values multiplication in comparison with other items, it's possible to reduce expression for the sensitivity by the resistance to:

$$\begin{aligned} S_R = {} & Et(\exp p_1t + \exp p_2t)\{(R+2R_1)[CRR_1^2 - \\ & - l(R+2R_1)] - CR^2R_1^2 + l(R+2R_1)^2\}\{(R+R_1)\times \\ & \times[CR^2R_1^2 - l(R+2R_1)] + CRR_1^2(2R+R_1) - \\ & - l(R+2R_1)(2R+3R_1)\}/2lCR_1(R+R_1)(R+ \\ & + 2R_1)^2[CRR_1^2(2R+R_1) - l(R+2R_1)(2R+3R_1)]. \end{aligned} \tag{15}$$

Equal transformations are reduced to the suitable variants of the sensitivity by capacity and inductance

$$\begin{aligned} S_C = {} & Et(\exp p_1t - \exp p_2t)\{l(R+2R_1)^2 \times \\ & \times[2CR^2R_1^2 - l(R+2R_1)^2] + CR^2R_1^2[3CR^2R_1^2 - \\ & - 2l(R+2R_1)^2]\}/4lC^2R_1(R+R_1)(R+2R_1)\times \\ & \times[3CR^2R_1^2 - 2l(R+2R_1)^2], \end{aligned} \tag{16}$$

$$\begin{aligned} S_l = {} & -Et(\exp p_1t + \exp p_2t)[2CR^2R_1^2 - \\ & - l(R+2R_1)^2]/2l^2CR_1(R+R_1)(R+2R_1). \end{aligned} \tag{17}$$

Let's switch to the opposite inequality in comparison with earlier reduced inequality (9)

$$CR^2R_1^2 < l(R+2R_1)^2\ . \tag{18}$$

Having fulfilled this inequality, the roots in the formulas (6) and (7) are imaginary. Using Euler's formula, we'll get expression for the voltage on the potentially frequency-independent two-terminal network equal to the inequality (18):

$$\begin{aligned} u = {} & -E\{l(R+2R_1)^2 - CR^2R_1^2\}^{1/2}\sin\omega t \times \\ & \times\exp pt/(R+R_1)RC^{1/2}\ , \end{aligned} \tag{19}$$

where

$$\omega = \{C[l(R+2R_1)^2 - CR^2R_1^2]\}^{1/2}/lC(R+2R_1), \tag{20}$$

$$p = -RR_1/l(R+2R_1). \tag{21}$$

Let's make comparison of the items by the absolute value at time t of the sinusoidal function in (19) and exponential function. We will provide the fulfillment the inequality in strong power

$$\{C[l(R+2R_1)^2 - CR^2R_1^2]\}^{1/2} << CRR_1\ . \tag{22}$$

To fulfill this, the resistances R, R1 and r1 shouldn't strive for zero and have final values. By choosing the values of these resistances it may be possible to carry out inequality (22). It is realized very simply as by fulfilling the condition (13) the left part of the inequality (22) is striving for zero.

Exponential function in (19) reduces comparatively quickly like index function. Then, taking into account the inequality (22) in time-interval during which exponential function and voltage (19) practically damp to zero, only initial part of sinusoidal function goes in, and we have sinus of very little angles known as equal to the angle itself. As a result, the voltage (19) on the examined two-terminal network will be reduced to

$$u = -\frac{Et[l(R+2R_1)^2 - CR^2R_1^2]}{lC(R+R_1)(R+2R_1)}\exp pt, \tag{23}$$

Now it becomes evident that the signal on two-terminal network represents the splash of negative polarity voltage damping to zero. In case the inequality (19) is changed into opposite (18), the polarity of the signal (6), (23) will change as well on the potentially frequency-independent two-terminal network.

Provided the inequality (19) is fulfilled the absolute sensitivities of the examined circuit by the resistance, capacities and inductances are defined by this expression:

$$\begin{aligned} S_R = {} & Et\{[l(R+2R_1)^2 - CR^2R_1^2][tR_1^2(R+R_1) + \\ & + l(R+2R_1)(2R+3R_1)] - 2l(R+R_1)(R+ \\ & + 2R_1)^2[l(R+2R_1) - CRR_1^2]\}\exp pt/l^2C(R+ \\ & + R_1)^2(R+2R_1)^3, \end{aligned} \tag{24}$$

$$S_C = Et(R+2R_1)\exp pt/C^2R_1(R+R_1), \tag{25}$$

$$S_l = -EtRR_1\{ t[l(R+2R_1)^2 - CR^2R_1^2] + \\ + lCRR_1(R+2R_1)\} \exp pt / l^3 CR_1(R+R_1) \times \\ \times (R+2R_1)^2, \tag{26}$$

Having fulfilled the condition of frequency independence the given formulas (15) - (17) and (24) - (26) by different parameters become equal by two and are defined by the expressions:

$$S_R = -\frac{2Et[l(R+2R_1) - CRR_1^2]}{lCR_1(R+R_1)(R+2R_1)} \exp pt, \tag{27}$$

$$S_l = -\frac{EtR^2R_1}{l^2CR_1(R+R_1)(R+2R_1)} \exp pt, \tag{28}$$

and the expression (11) coincide with the formula (25). For this parameter as sensitivity the signs "plus" and "minus" don't have significant meaning, its absolute value plays the main role. The expression sign for the sensitivity only defines the voltage increase and related parameter increase have equal and different signs. The absolute sensitivities (25), (27), (28) depend on time. When the carrying information about two-terminal network impulse is finished the sensitivities values between impulses are equal to zero. They have the maximum value at time period

$$t_0 = l(R+2R_1)/RR_1, \tag{29}$$

The least number of parameters in resistance independent two-terminal network is four [2-4], and that's why such two-terminal networks have the simplest mathematical description. But they still let measuring the parameters of capacity and inductive character but can't define the parameters of the resistance character. With the increase of the parameters in resistance independent two-terminal networks [3] according to the given variant (fig. 1) the cumbersome form of the mathematical description formula is quickly increasing. Instead of this variant another resistance independent two-terminal network can be chosen from [3, 4].

According to the fulfilled analysis for the use of potentially resistance independent two-terminal network as a means of zero measuring circuit at first it should be connected with the source of constant power for the gathering the electric energy in the reactive elements. After that it is required that two-terminal measuring circuit should be switched off and connected to the increasing and indication signal circuit from the measuring circuit. The structural scheme, presented on the figure 2 realizes these grounds. It contains two-terminal electric circuit TEC in the form of potentially resistance independent two-terminal network, voltage source VS, governed electron keys S1 and S2, governing scheme GS, amplifier A, and zero-indicator ZI.

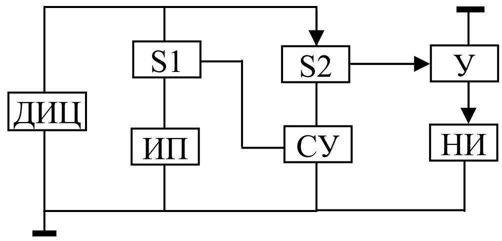


Fig. 2

Under the pressure of the governing impulses GI the key S1 is locked, and S2 is disconnected, and great amount of energy is accumulated in the reactive elements L and C of the measuring circuit. Then, GI disconnects the key S1. There is a sense to give a short pause during which the laying from the commutation may finish between the moment of disconnection time of the governing key S1 and the time moment of disconnection of the key S2. In the time interval of the locked condition of the key S2 there should be a time moment t0 (29) that is equal to the biggest values of the absolute sensitivities by measuring and regulating parameters at small voltage values in two-terminal network output (13).

During the locked condition of the regulated key S2 the signal carrying the information about potentially frequency-independent two-terminal network condition is sent to the transformation and indication schemes. The voltage of this signal may be of positive or negative polarity that corresponds two variants of non-fulfillment frequency independence conditions (9) or (18). At fulfillment the conditions of frequency resistance (3), (5) this voltage signal value is equal to zero. The amplifier A increases sensitivity of the detector by measuring and regulated parameters. To eliminate the negative impact of zero drift of the analogous schemes one can introduce transitional circuits with dividing condensers into cascade connections.

The duration of the locked condition of key S1 may be restricted

$$t_{S1} = (3 \div 5)/p_{\min}, \tag{30}$$

where $p_{\min}$ is the least value of multiplier at time t in the degree mark of the exponential function in (6). In the regarded variant this minimal value P1. The locked condition duration S1 is bigger than the defined one (30), and it leads to waste of energy. At less value of this duration the reactive elements of two-terminal network measuring circuit will accumulate considerably small amount of energy according to the maximum possible at the given value of energy source constant voltage E, that will lead to the sensitivity loss (25), (27), (29).

In the analogous part on the basis of zero measuring circuits, like those examined earlier, there is no sense in using the (high-voltage) elementary base of electronic schemes that has higher cost. Taking into account this fact and the formulas (29) from the lower part the duration of the locked condition of key S2 should be restricted

$$t_{S2} > 1\,мкс \text{ и } t_{S2} > t_0 \quad (31)$$

The second inequality says that time moment $t_0$ correspondent to the absolute resistance biggest value lays inside the time interval of the locked condition of the governed key S2.

The given or chosen according to quick repetition period $T_n$ of the impulses with two-terminal network measuring circuit restricts from the upper part the duration of the locked condition of the key S2

$$t_{S2} < T_n - t_{S1} - t_n, \quad (32)$$

where $t_n$ is the duration of pause between time moment of key S1 disconnection and time moment of key S2 locking. It should correspond to the inequality

$$t_n < t_0. \quad (33)$$

In the mathematical description of impulse with the measuring circuit (6) and (23) the exponents are striving at zero, and impulse is finished. After its finishing there is no necessity to continue the locked condition of the key S2. Counting this the duration of the locked condition can be defined as

$$t_{S2} = (2 \div 3)/p_{\min} - t_n, \quad (34)$$

The measuring procedure for the examined two-terminal network circuit and, for example, for the bridge measuring circuit is equal. At first these circuits bring to one condition when their output voltage values are equal. Then the account of sought parameters is taken either from equilibrium conditions for the set bridge circuit or from frequency independence for zero measuring circuit in state of frequency independent two-terminal network. These two measuring circuits contain regulated pattern elements, their choice represents some kind of compromise between the class of exactness and cost.

The principle difference of the examined zero measuring circuit in a form of potentially frequency independent two-terminal network between other zero measuring circuits is that the first is built by the scheme of two-terminal network electrical circuits, but not by the scheme of four-terminal network. More than that the signal from such circuit carrying condition information appears after the stop of power supply voltage of the measuring circuit action. In the existed zero measuring circuits the output and feeding signals act simultaneously. Two-terminal network circuit doesn't need special conjugation devices with electron blocks like other zero measuring circuits without transformers. It is free of drawbacks connected with the use of measuring conjugation devices (differential amplifier, transformer). For the examined zero measuring circuit in a state of the conjugation device with electron blocks it is appropriate to use ordinary first cascade of the amplifier (non-differential), for example, non-inversion amplifying cascade on operational amplifier. Having fulfilled the frequency independence conditions voltage influences the input of the first electron cascade which value is equal to zero. Under this condition input resistance, input capacity and their non-stability don't bring a lot of mistakes into the measurements. If these conditions are not fulfilled then the input parameters slightly alter the amplitude of voltage signal from the measuring circuit time moment related to its amplitude. Slight alterations are explained by that fact that input capacity of many operational amplifiers is too small, and input resistance at non-inverse switch of the operational amplifier is big. Like other measuring circuits two-terminal network circuits admit non-stability of feeding voltage, also pulsation of this voltage is admitted.

So, the results of the analysis are drawn, and the possibility of non-traditional use of frequency independent two-terminal networks as a means of zero two-terminal measuring circuit is explained. The examined version of such measuring circuit let measuring not only the reactive parameters, but as well parameter data units in the capacity of resistance. The structural scheme of the measuring unit on the basis of two-terminal network of the measuring circuit and structural scheme on its base are explained. Sensitivities of the observed variant of two-terminal network are detected.

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