Remote complex resistance measurement

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***Abstract*— In the proposed work we investigate the possibility of measuring a complex resistance remote by several meters, in particular the parallel connection of an active resistance and a capacitor. The measurement is made at a frequency of one megahertz. Since the unknown complex resistance is connected to the measuring equipment by a radio-frequency cable, the theory of long lines is used in deriving the formula. Examples of practical application of the algorithm for measuring human skin resistance are given.**

Keywords—remote measurement, human skin resistance, long line

I. INTRODUCTION

This Artificial Intelligence (AI) is based on analyzing data from multiple sensors and developing a response to developer-defined thresholds given by these sensors. The task of such AI may be pollution control, level control of bulk or liquid substances, measuring operations in production, or conducting research work. For example, one of such sensors at an intermediate stage of research work can be, for example, a measuring electrode, attached to the human body during measurements of signal passing through the human body [1,2,3]. In the general case the location of sensors does not necessarily have to be close to the measuring equipment. Information from remote sensors can come either by wires (or cables) or via wireless technology (e.g., Wi-Fi, Bluetooth, LORA, laser, etc.). The specific choice is determined cost, length of removal and connection method. As a rule, temporary sensors that are several units of meters away are easier to connect by cable. They are long lines. When measuring at high frequencies, the lines introduce errors determined by both their length and their parameters. This is due to the fact that the line, which is a circuit with distributed parameters, at a load other than the wave impedance, has a complex input resistance, which is different for each load. It is possible to compensate the arising error by measuring with special meters - vector analyzers. However, the latter have a high cost and cumbersome. Therefore, the problem arises of finding an algorithm for numerical calculation, which excludes the error.

II. FINDING A SOLUTION FOR DETERMINING THE REMOTE COMPLEX RESISTANCE .

A schematic diagram of the measurement is shown in Fig. 1. The voltage of the harmonic signal with frequency f and amplitude voltage E_g is fed from the generator with internal resistance R_g through an auxiliary short long line (line 0) with wave impedance R_0 and physical length L_0 . The load of this line is the input resistance Z_{OS} of the measuring oscilloscope and the input of the long removal line (line 1), the physical length L of which is chosen for practical reasons of connection with the remote unknown and the complex resistance we are interested in Z_C , representing a parallel connection of the active resistance R_C and the capacitor C_C . The input resistance Z_{OS} is also a parallel connection of the active resistance R_{OS} and the capacitor C_{OS} . In order to make a measurement of the complex resistance, it is necessary to know the phase changes occurring when a harmonic signal is applied to the complex resistance relative to the zero at the oscillator output . This can be done with the same oscilloscope when the oscilloscope is synchronized by the generator E_g . As experience has shown, such a phase measurement has a significant error and is associated with some difficulties. The application of special technologies, for example, correlation, require the use of oscilloscopes with 10 Gigahertz and higher sampling frequency. In the proposed work we investigate another approach - making two measurements of the amplitude of voltages at two values of the input resistance of the meter. During the measurement we have the possibility to connect an additional calibration active resistance R_K in parallel to the input resistance of the oscilloscope.

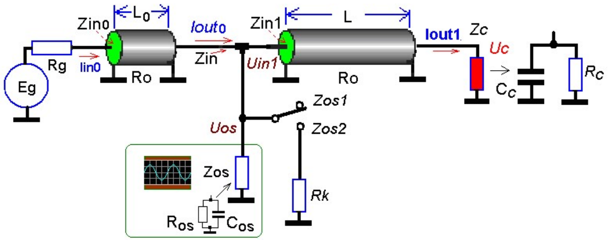

Fig.1 Schematic diagram of measurement of remote complex resistance.

We calculate using the classical theory of long lines [4,5]. Knowing the load of line 1, find its input resistance Z_{in1} . It is equal to:

$$Z_{in1} = \frac{Z_C + jR_0 \tan(\beta L)}{1 + j\dfrac{Z_C}{R_0}\tan(\beta L)} \text{ , where} \tag{1}$$

β - is the phase factor of the used long lines, which have a deceleration factor v_f and is equal to $\beta = \dfrac{2\pi f}{cv_f}$, where c is the speed of light. The load of line 0 will be the parallel connection of the input resistance of line1 and the input resistance of the oscilloscope: $Z_{in} = \dfrac{Z_{in1}Z_{OS}}{Z_{in1} + Z_{OS}}$.

Now we know the load for line 0 and therefore we can find the input resistance of this line:

$$Z_{in0} = \frac{Z_{in} + jR_0 \tan(\beta L_0)}{1 + j\dfrac{Z_{in}}{R_0}\tan(\beta L_0)} \text{ .} \tag{2}$$

Then we find the input current of line 0: $I_{in0} = \dfrac{E_g}{R_g + Z_{in0}}$, knowing which we find the output current of this line:

$$I_{out0} = \frac{I_{in0} R_0}{R_0 \cos(\beta L_0) + jZ_{in} \sin(\beta L_0)}. \qquad (3)$$

The voltage at the input of line 1 is v_f $U_{in1} = I_{out0} Z_{in}$. This voltage is the same on the oscilloscope $U_{OS} = U_{in1}$. Having two different values of resistance Z_{OS}, we will have two different voltages at the oscilloscope input whose measured amplitude moduli are equal U_{X1} and U_{X2}. Based on all the above data, we can make a system of two equations:

$$eq_1 = |(E_g g_1 (Z_c a + jR_0 b)) / ((j(Z_c ad + R_g bc) R_0^2 + R_0 (jg_1 (ad + bc) + \ldots$$
$$acs) + Z_{OS1} sj(ad + bc) + Z_c g_1 (ac - bd) + R_g g_1 (ac - bd) - \ldots$$
$$R_0^3 bd)| = U_{X1};$$
$$eq_2 = |(E_g g_2 (Z_c a + jR_0 b)) / ((j(Z_c ad + R_g bc) R_0^2 + R_0 (jg_2 (ad + bc) + \ldots$$
$$+acs) + Z_{OS2} sj(ad + bc) + Z_c g_1 (ac - bd) + R_g g_1 (ac - bd) - \ldots$$
$$R_0^3 bd)| = U_{X2}.$$

where:

$$a = \cos(\beta L),\ b = \sin(\beta L),\ c = \cos(\beta L_0),\ d = \sin(\beta L_0),$$
$$g_1 = R_0 Z_{OS1},\ g_2 = R_0 Z_{OS2},\ s = R_g Z_c,$$
$$Z_{OS1} = \frac{R_{OS} \dfrac{1}{j2\pi f C_{OS}}}{R_{OS} + \dfrac{1}{j2\pi f C_{OS}}},\ Z_{OS2} = \frac{Z_{OS1} R_k}{Z_{OS1} + R_k},\ Z_C = \frac{R_C \dfrac{1}{j2\pi f C_C}}{R_C + \dfrac{1}{j2\pi f C_C}}.$$

The system, due to the two measurements giving two voltages U_{X1}, U_{X2}, has two equations. Therefore we can determine at once the nominal values of the two elements, it R_C, C_C, which saves us from the problem of finding the phase shift. Due to the fact that the system equations are complex transcendental, there is no symbolic solution. Therefore, their solution was carried out numerically.

III CHECKING THE ALGORITHM

The complexity of the equations of the system requires verification of its solution. Suppose that the components of the remote resistance Z_c are: $R_c = 915\,ohm,\ C_c = 154\,pF$. Let the input parameters be as follows:

$E_g = 1000\,mV,\ R_g = 50\,ohm,\ R_0 = 50\,ohm,\ v_f = 0.6667,$
$c = 3e8\,m/c,\ f = 1e6\,Hz.,\ R_{OS} = 1e6\,ohm,\ C_{OS} = 13\,pF,$
$R_k = 50\,ohm,\ L_0 = 0.505m,\ L = 3.005m.$

Theoretical calculations gave the following values of measurements: $U_{X1} = 938.13110\,mV,\ U_{X2} = 485.20649\,mV.$ $U_{X1} = 938.13110\,mV,\ U_{X2} = 485.20649\,mV.$ Substituting them into the system we get $R_c = 915.00035\,ohm,\ C_c = 154.00049\,pF$. Thus, the equations are correct. Similar results can be obtained graphically (Fig. 2). But here the accuracy determined by the place of intersection of two curves will depend on the subjective evaluation of the operator.

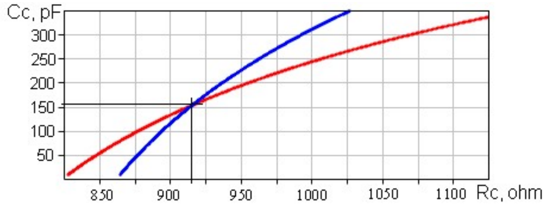

Fig.2 Graphical solution of the search for the remote complex resistance.

IV MEASUREMENT OF IMPEDANCE OF HUMAN BODY SKIN.

When measuring on the human body, it is of interest to measure the skin input impedance at the point where the sensor is attached. This impedance is not a constant value and depends on many factors (psychophysical state and age of the person, moisture and thickness of the skin, the area and material of the sensor plates, etc.). To minimize the influence of the sensor (gold-plated plates with an area of 1 cm^2 and a base between them 2 cm were used) and to reduce the resistance between them and the skin, a special electrically conductive LEM gel was applied to the skin before the measurement. According to studies on this subject, the equivalent electrical circuit of the skin is a parallel connection of a resistance and a capacitor [6]. In order to provide some freedom to both the test person and the operator with his apparatus, the connection to the sensor was made with a 3-meter cable. For the example, the measurement was made at the point shown in Fig. 3. The measuring equipment and input parameters are the same as those used above.

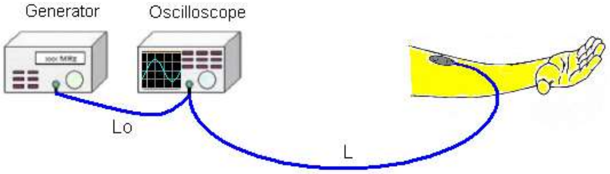

Fig.3 Scene of measuring the complex resistance of the human body skin.

The measurements gave the following figures: $U_{X1} = 816\,mV,\ U_{X2} = 452\,mV.$ Based on these data, the components of the skin resistance at this point are $R_c = 265\,ohm,\ C_c = 528\,pF$. The modulus of the resulting complex resistance at frequency 1 MHz equals $|Z_c| = 197.7\,ohm$. This value is within the range of values obtained with a specialized device for measuring the skin resistance modulus.

V CONCLUSION

To measure the remote complex resistance representing the parallel connection of the capacitor and the active resistance, a numerical calculation algorithm was obtained. The latter allows to exclude the phase measurement during the measurements.

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