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The Study of Electrical Resonance in a Physics Course

Aleksei Gavrilov
Department of Cybernetics
Division of Physics,
Tallinn University of Technology.
Tallinn, Ehitajate tee 5, Estonia
e-mail: aleksei.gavrilov@taltech.ee

***Abstract*—The article describes a device for demonstrating electrical series and parallel resonance. The device is structurally simple and small-sized. It allows you quickly familiarize students visually with the features of these phenomena using a document projector.**

Keywords*—*physics course; demonstration of experiment; electrical resonance

I. INTRODUCTION

The phenomenon of electrical resonance [1] plays an important role in electrical engineering, radio electronics, etc. Therefore, when studying this issue in a physics course, special attention must be paid to it. In our opinion, it is important not only to consider this phenomenon theoretically, but also to visually demonstrate it to the audience. Moreover, it is desirable that the demonstration experience would not take much space and would not require much time for preparation. In this paper we describe a device that demonstrates on a large screen the features of serial and parallel resonance in RCL circuits. As in works [2,3] devoted to demonstration experiments in physics, this small-sized device is intended to be jointly used with a document camera and a projector.

II. DEVICE DESIGN

The electrical circuit of the device is shown in Fig.1 (end of article). It is powered from a DC adapter with a voltage of 12V. The current consumed in this case is not more than 50mA. For direct power supply of the DA1, DA2 chips and the VT1 transistor a voltage of 10 V, stabilized by a Zener VD1 diode is used.

The sinusoidal voltage generator is assembled on an XR2206 chip. The signal from the output of the chip is fed to a buffer amplifier with a voltage gain of 1. This buffer is assembled on ½ of the operational amplifier TS922 and is also powered by a unipolar voltage of 10V. The value of the alternating voltage at its output can be set within certain limits using the trimmer resistor R3 in the circuit of the sinusoidal signal generator. In the original design, this value is 1.8V of effective voltage.

The frequency of signal can be changed using the potentiometer regulator R6, which has an indicative scale. With the values of the resistor R5 and potentiometer R6, shown on the electrical circuit, the frequency can be set within 2….20 kHz.

The signal from the buffer output is fed to switch SA2, consisting of four switches (SA2.1….SA2.4). Using this switch, you can select various configurations of the RCL circuit (in Fig.1 it is R16 C8 L1). These configurations 1…5 are shown in Fig.2.

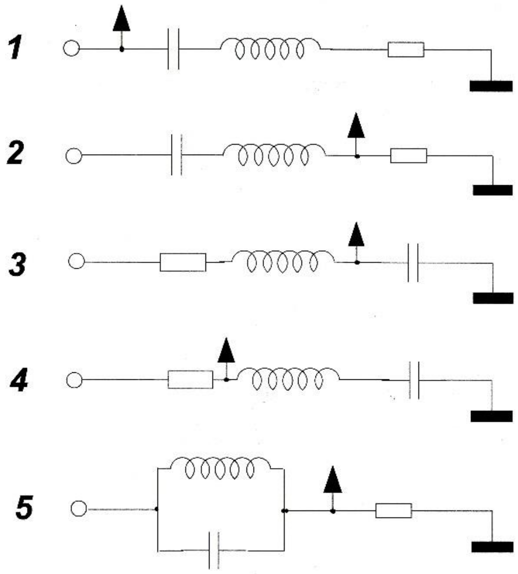

Fig.2. Different configurations of the RCL circuit depending on the position of the switch SA2.

In position 1 of the switch, all elements are interconnected in series and a voltmeter measures the voltage U_0 applied to the entire RCL circuit. This alternating voltage between the left point of the circuit and ground remains constant and independent of the signal frequency at all positions (1….5) of the switch. We also note here that at all positions of the switch SA2, the voltage from the circuit elements is also measured relative to ground.

In position 2 of the switch, the voltmeter measures the alternating voltage from the resistor. In position 3 it measures from the capacitor and in position 4 measures from a capacitor and inductor connected in series. As can be seen from Fig.2, in positions 1….4 of the switch, all the elements of the RCL circuit are interconnected in series.

In contrast, in position 5, the inductor and capacitor are connected in parallel (i.e., form an oscillating circuit). The resistor is now connected in series with this oscillating circuit.

The alternating voltage from the elements of the RCL circuit is measured with a voltmeter, which is assembled on 2SK170 field-effect transistor according to the source follower circuit. The voltage from this transistor is supplied to the rectifier, assembled on BAT85 Schottky diodes. The rectified voltage is measured with a microammeter PA1. In original design, this microammeter of magnetoelectric type has a scale of 100 μA and internal resistance of 1.75 kΩ. The sensitivity of this microammeter can be adjusted using a trimmer resistor R14.

The name of measuring units (μA) was removed from the microammeter and only the scale of divisions was left. It is used as an AC voltmeter with relative units from zero to 100. Herewith the small nonlinearity of the scale is not significant for our purposes.

In the process of adjusting the device using a resistor R3, a voltage of 1.8 V is set at the output of the buffer. Next, by setting the switch SA2 into position 1, we set the microammeter arrow to the middle position on the scale using the resistor R14 (in our case, at point 50). With this, the adjustment of the device is finished (of course, on the assumption that the values of the RCL circuit correspond to those shown in Fig.1). The dimensions of the device are 18 x 18 x 7 cm, and its appearance is shown in Fig.3.

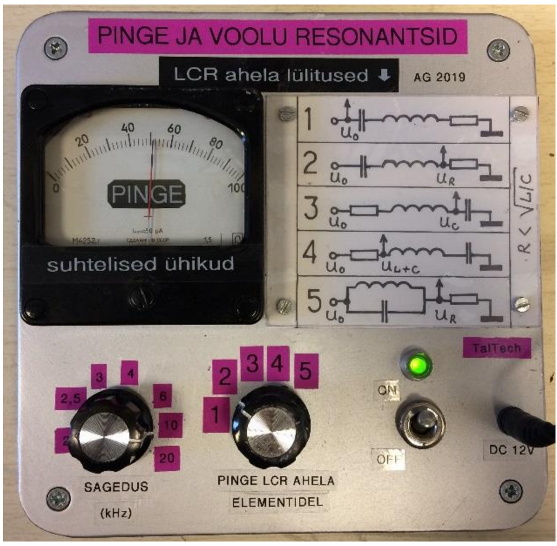

Fig.3. Appearance of the device for observing electrical resonance.

III. DEMONSTRATION OF THE ELECTRICAL RESONANCE

The demonstration process starts at position 1 of the switch SA2. We demonstrate the value of the alternating voltage U_0 supplied at all positions of the switch to the RCL circuit. Changing the frequency throughout the entire scale, we show that this voltage does not depend on it.

Next, in position 2 of the switch, changing the frequency of the signal, we find the maximum voltage at the resistor. It can be seen then the value of this voltage almost coincides with the value of the voltage U_0. That is, almost all the voltage applied to the RCL circuit, at this frequency is applied to the resistor. This means that the current through this circuit is maximum at this frequency, that is, we have achieved the state of series electrical resonance. This angular resonance frequency ω_0 is equal to [1]:

$$\omega_0 = (L C)^{-1/2}$$

Next, without changing the found frequency, let's put the switch in position 3. In this position, the voltage across the capacitor is measured. We see that this voltage is greater than the previous voltage across the resistor (which was approximately equal to the input voltage U_0 on the RCL circuit).

Here it is necessary to clarify the following:

The so-called wave impedance ρ of the entire RCL circuit is defined as follows [4]:

$$\rho = (L/C)^{1/2}$$

In our original design, with the given values $L = 27$ mH and $C=8.2$ nF, the wave impedance $\rho \approx 1.8$ kΩ.

The concept of quality Q is also used in the theory of RCL circuits [1]:

$$Q = \omega_0 L / R = \rho / R ,$$

where R is resistance of the resistor in the RCL circuit.

The current I_0 in the circuit at series resonance is:

$$I_0 = U_0/R$$

Then the voltage across the capacitor will be:

$$U_c = I_0/\omega_0 C = I_0\rho = U_0\rho/R = U_0 Q.$$

Thus, if R is less than the wave impedance ρ (or Q is greater than one), then at series resonance U_c will be more than U_0. In principle, it can exceed the input voltage U_0 by hundreds of times.

In our case, the resistance R of the resistor is approximately 1.2 kΩ, and then $\rho/R \approx 1.5$.

We have set the position of the arrow of the voltmeter, corresponding to a voltage of U_0, in the middle of the scale (at point 50). Then the voltmeter, when measuring U_c at series resonance, will show about 75 (that is, it will not go beyond the scale). The resistance of the resistor, as we see, is selected so that the sensitivity of the voltmeter during measurements would not need to be changed (and at the same time it would be possible to show that the voltage on the capacitor in certain cases can exceed the input voltage on the RCL circuit).

Without changing the set frequency of the series resonance, in position 4 of the switch we measure the voltage across the capacitor and inductor, which are connected in series. We know from theory that in series resonance, the voltage across the capacitor and inductance coil are equal in absolute value and opposite in phase [1,4]. In position 4 we just see that the total voltage is almost zero. And this can only be when the voltage across the inductor is equal to the voltage across the capacitor and is in the opposite phase.

In the last position 5 of the switch, a parallel electrical resonance is demonstrated. We show that at a frequency ω_0 the voltage across resistor is minimal and almost equal to zero. Respectively, the current in the circuit is minimal. Almost all voltage U_0 is applied to a capacitor and inductor connected in parallel (to the oscillating circuit). The impedance of such a circuit at the resonant frequency of ω_o is maximum.

IV. CONCLUSION

In conclusion, we can say that the described device for demonstrating electric resonance is simple in design, has a small size and allows you to visually familiarize students with the features of this phenomenon in a short time. The design of the device also allows for various changes in the circuit. So, it is not critical to the selected values of most of its elements. For example, the supply voltage can be approximately doubled. Another operational amplifier, field effect transistor, microammeter, other Schottky diodes, etc. can be used. Of course, in this case additional adjustment may be required.

In our opinion, the use of such a demonstration device helps to better understand the features of electrical series and parallel resonance in RCL circuits.

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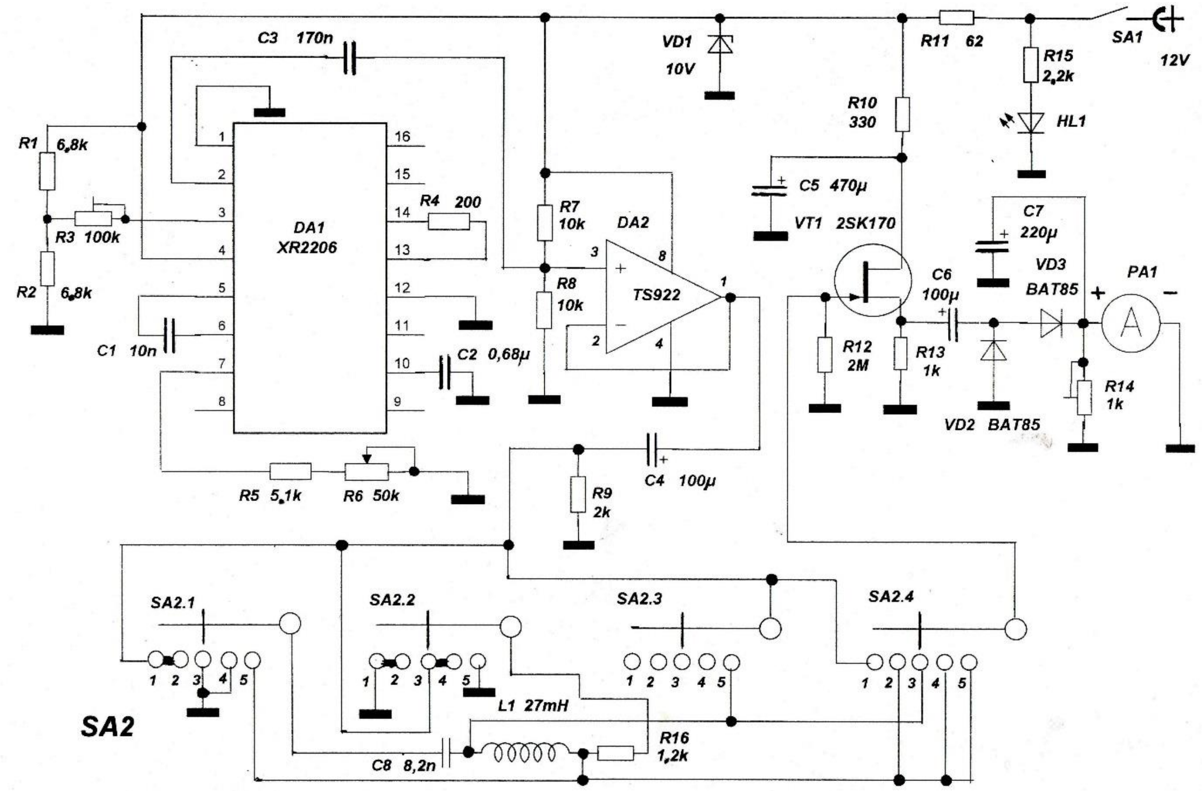

Fig.1. Electrical circuit of the device (switch SA2 is in position 3).