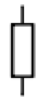
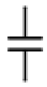
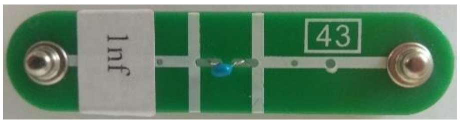
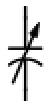
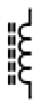
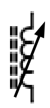
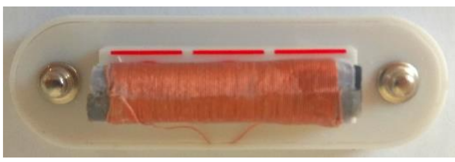
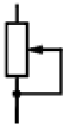
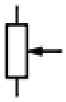
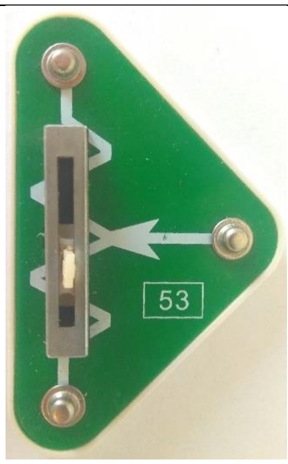
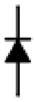
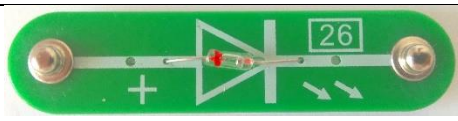
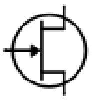
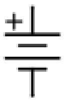
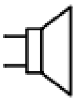
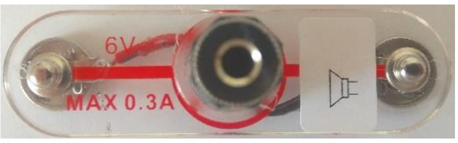
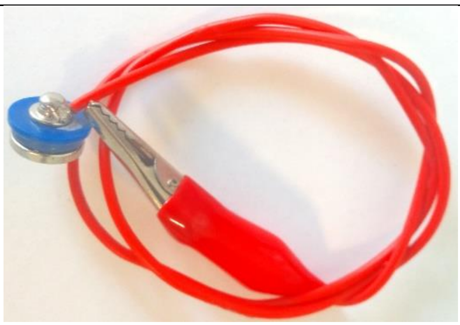
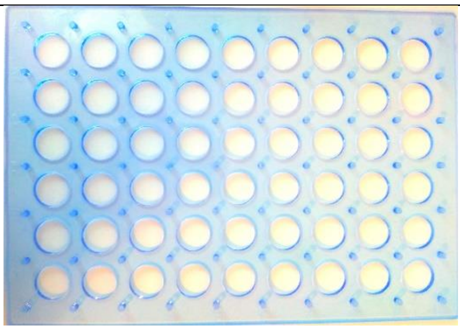
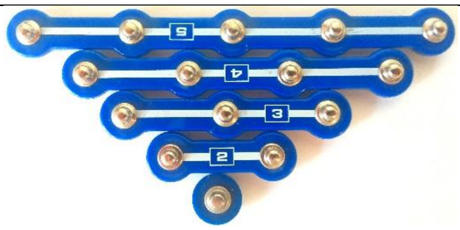
Wireless Communication

Equipment and Instruments

An oscilloscope, a signal generator, an *LCR*-meter, electronic components (see the table below), a container for components, and a Scotch tape.

Component	**Electronic Symbol**	**Photo**	**Comments**
Resistor			Values: 1 kΩ – 2 pcs. 10 kΩ – 1 pc. 100 kΩ – 1 pc. 1 MΩ – 1 pc.
Capacitor			Values: 39 pF – 1 pc. 1000 pF – 2 pcs. 0,1 μF – 2 pcs. 0,02 μF – 1 pc.
Variable Capacitor			2 pcs. To change capacitance, turn the dial.
Inductor			1 pc.
Variable Inductor			1 pc. To change inductance, move the core.

Variable Resistor			2 pcs.
Potentiometer			1 pc.
Diode			2 pcs.
Transistor			4 pcs. One of the four transistors has an extra disconnected terminal.
Battery Compartment			4 pcs.

Headphones		 	1 pc.
Wire			1 pc.
Circuit Board			3 pcs.
Jumpers			A set.

Multiple and fraction prefixes used in the assignment.

mega		M	10^{6}		micro		μ	10^{-6}
kilo		k	10^{3}		nano		n	10^{-9}
milli		m	10^{-3}		pico		p	10^{-12}

In this assignment you will study the principles of radio transmission and reception and then use them in practice to transmit and receive radio waves. To design a radio electronic device, it is necessary to have a basic knowledge of alternating electric current. One also needs to have basic ideas about linear elements of electric circuits (such as a resistor, capacitor, and inductor) and about nonlinear ones (such as a diode and transistor). The first part of the assignment is devoted to the study of these two classes of elements.

Part 1. Theory.

Chapter 1. Alternating Current and RC-circuit.

An alternating current (AC) is a current which amplitude varies with time. If an alternating current is periodic, with a period T, it can be specified by the frequency $\nu = 1/T$. A direct current (DC) can be considered as an alternating current of zero frequency (its magnitude does not vary). The most frequent and simple case is of an alternating current which time dependence is specified by a harmonic function:

$$i(t) = I\cos(\omega t + \varphi_i)\,. \tag{1}$$

Here $i(t)$ is an instantaneous value of the current, I is its amplitude (the maximum value), ω is the angular frequency related to the cycle frequency ν as $\omega = 2\pi\nu$. The quantity $\varphi = \omega t + \varphi_i$ is called the phase of the current, and φ_i is the initial phase (the phase at t=0).

Suppose an AC harmonic voltage,

$$u(t) = U\cos(\omega t + \varphi_u)\,, \tag{2}$$

is applied to a circuit. Here $u(t)$ is an instantaneous value of the voltage, U is the amplitude, and φ_u is the initial phase. If the circuit contains only the elements for which the amplitudes of current and voltage are linearly related (such elements are called linear), an alternating current in the circuit also varies harmonically. These circuits are also referred to as linear.

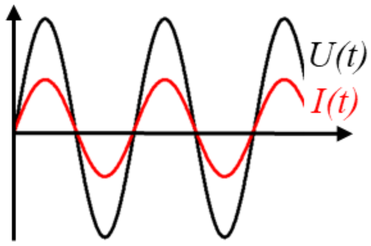
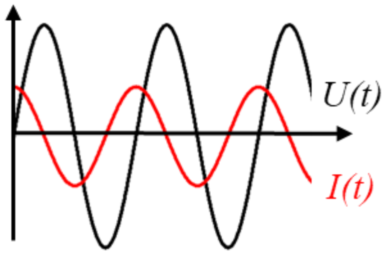
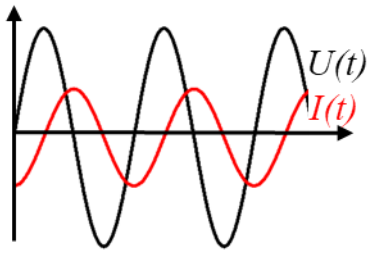
Any linear circuit with two terminals can be represented by a single equivalent linear element. Let the voltage (2) be applied across such an element, then the current (1) will flow through the element. The proportionality factor between the amplitudes of voltage and current of the element is called the *magnitude of impedance Z*:

$$Z = \frac{U}{I} \tag{3}$$

The phase shift between the initial phases of voltage and current is called the impedance phase:

$$\varphi = \varphi_u - \varphi_i \,. \tag{4}$$

The simplest linear elements are a resistor R, a capacitor C, and an inductor L. The magnitude and phase of the impedances of these elements are listed in the table.

<table>
<tr><th>Element</th><th>Time dependence of current and voltage</th><th>Z</th><th>φ</th></tr>
<tr><td>Resistor</td><td></td><td>R</td><td>0</td></tr>
<tr><td>Capacitor</td><td></td><td>$\dfrac{1}{\omega C}$</td><td>$-\dfrac{\pi}{2}$</td></tr>
<tr><td>Inductor</td><td></td><td>ωL</td><td>$\dfrac{\pi}{2}$</td></tr>
</table>

In order to calculate characteristics of an AC circuit assembled of several linear elements, it is necessary to know the rules of adding the impedances of the elements connected in series and in parallel. A circuit assembled of individual elements can be replaced by an equivalent element which impedance is calculated according to these rules.

Let us evaluate the equivalent impedance of two elements connected in series. In this case the same current flows through the elements and the voltage across the circuit equals the sum of the voltages across each element. Let the initial phase of the current be equal to zero. Then the current i and the voltage u across the equivalent element are given by the following equations:

$$\begin{aligned} i &= I\cos\omega t, \\ u &= u_1 + u_2 = Z_1 I\cos(\omega t + \varphi_1) + Z_2 I\cos(\omega t + \varphi_2), \end{aligned} \tag{5}$$

where $u_{1,2}$ are voltages across the first and the second elements, $Z_{1,2}$ are magnitudes of the element impedances, and $\varphi_{1,2}$ are initial phases of the voltages across the elements.

The formula for u can be reduced to

$$u = I\sqrt{Z_1^2 + Z_2^2 + 2Z_1Z_2\cos(\varphi_1 - \varphi_2)}\cos\left[\omega t + \mathrm{arctg}\left(\frac{Z_1\sin\varphi_1 + Z_2\sin\varphi_2}{Z_1\cos\varphi_1 + Z_2\cos\varphi_2}\right)\right].$$

Thus, the magnitude and phase of the element, which is equivalent to two elements connected in series, are

$$\begin{aligned} Z &= I\sqrt{Z_1^2 + Z_2^2 + 2Z_1Z_2\cos(\varphi_1 - \varphi_2)}, \\ \varphi &= \mathrm{arctg}\left(\frac{Z_1\sin\varphi_1 + Z_2\sin\varphi_2}{Z_1\cos\varphi_1 + Z_2\cos\varphi_2}\right). \end{aligned} \tag{6}$$

Task 1.1.1.

The diagram in Fig.1 shows the *RC*-circuit assembled of a resistor R and an ideal capacitor C. Derive and write down analytical formulae for the ratio of the input and output voltages $\dfrac{U_{\text{out}}}{U_{\text{in}}}$ and for the phase shift between the input and output voltages.

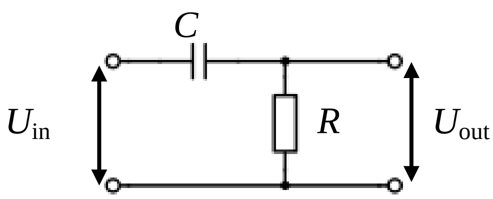


Fig. 1. *RC*-circuit.

Here and below:

- **the amplitude of AC signal at an oscilloscope channel is defined as the difference between the maximum and minimum of the signal. The corresponding function on the oscilloscope interface is «$V_{p\text{-}p}$»;**
- **for those experimental dependencies which ARE NOT supposed to be fitted with a linear function, it would be enough to obtain 12 experimental points uniformly distributed over the range under study;**
- **for those experimental dependencies which ARE supposed to be fitted with a linear function, it would be enough to obtain 7 experimental points uniformly distributed over the range under study.**

Task 1.1.2.

Assemble the circuit shown in Fig.2 (use two 1 nF capacitors to obtain the 2 nF capacitance).

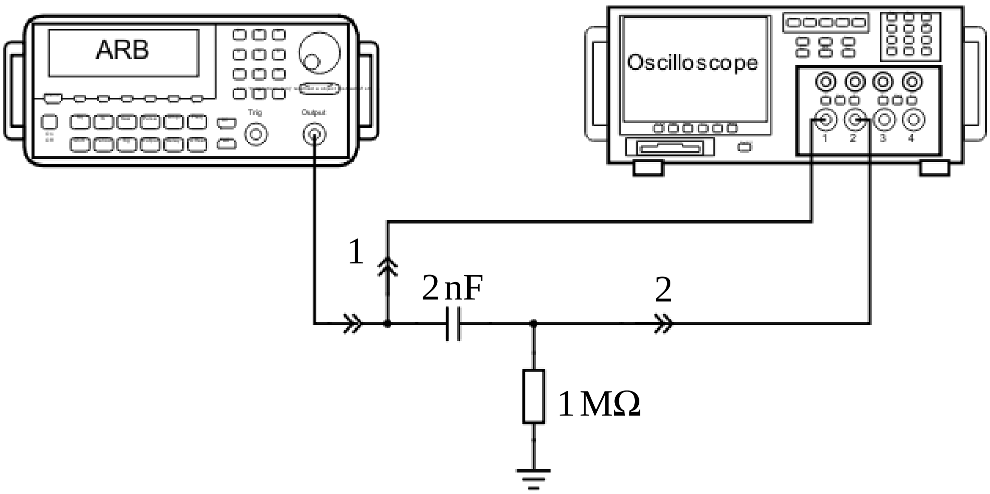


Fig. 2. Setup for the study of RC-circuit.

Connect the signal generator and the oscilloscope to the circuit according to the diagram. Do not forget to connect a grounding contact (the «crocodile» clip) of an oscilloscope probe to the circuit common point. Hereinafter, «input» and «output» arrows on a diagram correspond to the generator output and an oscilloscope channel input, respectively. The oscilloscope channels will be numbered by «1» and «2».

Set the input amplitude of the generator harmonic signal to 10V. Measure the ratio $\frac{U_{out}}{U_{in}}$ of amplitudes of the voltages across the first and the second oscilloscope channels versus a generator frequency f in the range from 50 to 500 Hz. Measure the ratio of the phase shift $\Delta\varphi$ between the first and the second channel versus the frequency in the same frequency range.

A possible experimental setup for the study of *RC*-circuit is shown in Fig.2a.

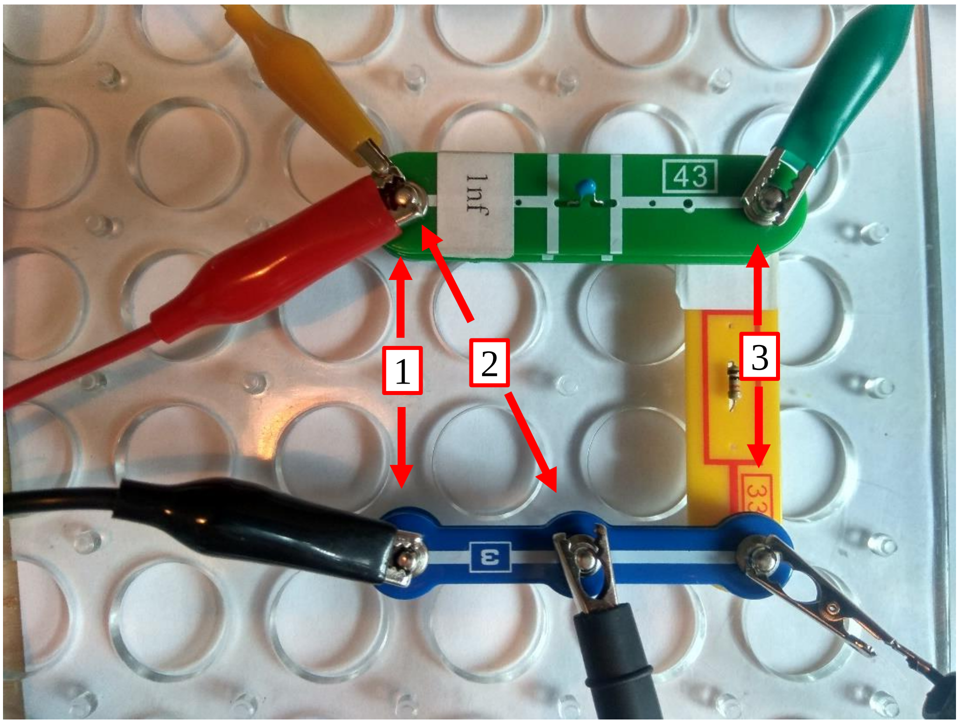


Fig. 2a. A possible experimental setup for the study of *RC*-circuit. Generator probes (1), probes of the oscilloscope first channel (2), probes of the oscilloscope second channel (3).

Task 1.1.3.

Using the formulae derived in 1.1.1, plot the dependencies obtained in 1.1.2 by reducing them to linear form. Determine the value of *RC* by using the dependence of the ratio of amplitudes on frequency.

Task 1.1.4.

The value of *RC*, determined in 1.1.3 does not agree with the value calculated from the values of $R = 1$ MΩ and $C = 2$ nF. Indicate the circuit element responsible for this disagreement (either in English, or in Russian, or by drawing a simple diagram). Specify the value of the element in the appropriate units. What instrument can be used to verify your assumption?

Task 1.1.5.

Calculate theoretically the magnitude of the equivalent impedance of a resistor *R* and a capacitor *C* connected in parallel. Sketch the dependence of the impedance magnitude on frequency. To which values the impedance magnitude tends at small ($f \to 0$) and at large ($f \to \infty$) frequencies?

Chapter 2. LC-circuit.

Task 1.2.1.

Evaluate a theoretical dependence of the impedance magnitude of an element composed of an ideal capacitor C and an ideal conductor L connected in parallel on frequency. Sketch the obtained dependence. Indicate the frequency f_r corresponding to a peak of this dependence. Let us call this frequency the «resonance frequency» of the *LC*-circuit (inductor and capacitor connected in parallel).

A real inductor coil is different from an ideal inductor by the presence of a non-zero internal resistance (the resistance to a DC current). An equivalent element corresponding to a real inductor coil can be represented by an ideal inductor and a resistor, which resistance equals to the internal resistance of the coil, connected in series.

Task 1.2.2.

Sketch a dependence of the impedance magnitude of an *LC*-circuit with a real inductor on frequency.

We are not going to measure the impedance of an *LC*-circuit, rather we will study a related phenomenon. A varying external magnetic field induces a variable EMF in the coil of the frequency equal to that of the external field. In this case, it is said that the coil operates as a magnetic field antenna. By connecting a capacitor to the coil, one obtains a selective magnetic field antenna which is the most sensitive to the external magnetic field of the frequency to which the *LC*-circuit is tuned to.

Task 1.2.3.

Assemble a circuit according to the diagram shown in Fig.3. The coils must be installed in adjacent sockets of the circuit board and be parallel to each other.

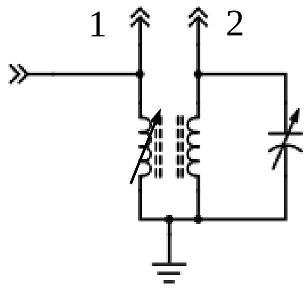


Fig. 3. Setup for the study of *LC*-circuit with inductive coupling.

Turn the dial of the variable capacitor all the way counterclockwise. Set the amplitude of the signal generator approximately to 1V. The coil connected to the generator will generate a magnetic field in the space inside and outside itself. The coil connected in parallel with the variable capacitor will operate as a selective magnetic field antenna.

Obtain the experimental dependence of the ratio of amplitudes $\frac{U_{\text{out}}}{U_{\text{in}}}$ at the channels 2 and 1 of the oscilloscope versus a frequency f of the signal generator. Plot the dependence. Choose the frequency range and the incremental step so that a characteristic width of the resonance peak were approximately a quarter of the frequency range and the peak were in the middle of the range.

Task 1.2.4.

Using the *LCR*-meter to measure the coil inductance and a capacitance of the capacitor with its turning dial fixed. Calculate a theoretical value of the resonance frequency f_{theor} of the *LC*-circuit under study. Determine a real resonance frequency f_{graph} from the diagram plotted in 1.2.3. Specify, whether the calculated and measured values are the same.

Task 1.2.5.

Measure the dependence of resonance frequency f_r on a capacitance C of the variable capacitor. Choose a function for the resonance value so that it would be linearly depended on the capacitance C. Write down an analytical expression for this function. Plot this function. Specify, by what amount the plot is shifted along the capacitance axis. Which circuit element has this capacitance? (Write, either in English, or in Russian, or draw a simple diagram.)

Task 1.2.6.

Use the *LCR*-meter to measure the capacitance of this element. At what frequency does the *LCR*-meter measure this capacitance? (This frequency is called the operating frequency of the *LCR*-meter.)

Chapter 3. Nonlinear Elements.

A rigorous definition of a nonlinear electronic element is complicated, so let us describe the features of nonlinear elements, which are the most essential for our purpose, in terms of their functionality.

A nonlinear element is an element for which instantaneous values of current and voltage are nonlinearly related. This condition is fulfilled in the «low-frequency» range of AC current. What is understood by a «low frequency» is determined by the self-capacitance and inductance of an element. In our experiment the self-capacitance and inductance are so small that the studied range of frequencies belongs to the low frequency range, i.e. there is no lag between the instantaneous values of current and voltage due to the proper capacitance and inductance of a nonlinear element. A function relating instantaneous values of current and voltage of a nonlinear element is called the current-voltage characteristic (an *I*-*V* curve) of the element.

Thus, from the phase relation perspective, a nonlinear element in an electrical circuit behaves like a resistor although it has a nonlinear *I*-*V* curve.

One of the most commonly used nonlinear elements is a semiconductor diode. Its main function is to pass electric current in one direction and block the current in the opposite direction. The typical *I*-*V* curve of a diode is shown in Fig.4. The branch corresponding to a negative voltage across the diode tends to a small current of a magnitude I_s. The current I_s is called the *saturation current*.

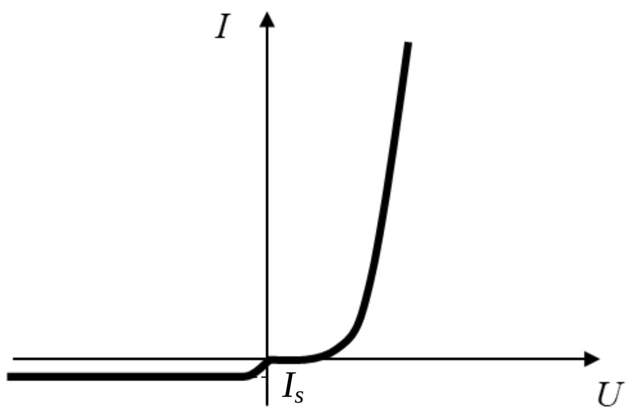


Fig. 4. Diode *I*-*V*-curve.

A circuit combining linear and nonlinear elements can be described by an equivalent current-voltage characteristic.

Task 1.3.1.

Let us employ one of the classical methods of measurement of the equivalent current-voltage characteristic of a nonlinear element and a resistor connected in series. To do this, assemble the circuit shown in Fig.5. Set the frequency of the signal generator to 1 kHz and the amplitude approximately to 1.5V. Set both oscilloscope channels to the «DC» mode and adjust the channel sweeps so that to see several signal cycles on the display. Sketch the signals at the first and the second channels (time dependence of the voltages $U_1(t)$ and $U_2(t)$).

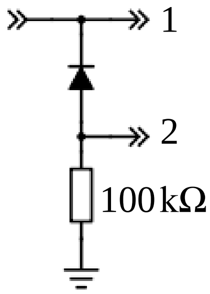


Fig. 5. Setup for measurement of the equivalent current-voltage characteristic of diode and resistor connected in series.

In the «Display» tab, set the oscilloscope to the XY mode. The voltage U_2 across the resistor will be displayed on the vertical axis, it is proportional to the current flowing through the resistor and the diode. The voltage U_1 across the in-series connection of diode and resistor will be displayed on the horizontal axis. Thus, the *I-V* curve of the in-series connection of the diode and resistor will be displayed on the oscilloscope screen. Sketch the displayed dependence of $U_2(U_1)$. Determine the saturation current of the diode.

Task 1.3.2.

Switch the oscilloscope display mode to YT.

The circuit shown in Fig.5 allows the current to flow only in one direction. Increase gradually the frequency of the signal generator to the maximum. Change the oscilloscope time sweep so that several cycles of the signal were displayed each time. Sketch two typical waveforms (the dependencies of U_2 on t) at the maximum frequency of the signal generator and at a frequency less than the maximum by two orders of magnitude (the amplitude of the input signal at these two frequencies must be the same). Notice the ratio of the variable and constant component of the signal.

The observed pattern of the output signal at a large frequency is related to the oscilloscope capacitance. The typical type of discharge of the oscilloscope channel capacitor via a resistor of 100 kΩ at large frequencies significantly exceeds the period of a generator signal. Thus, at large frequencies the circuit operates as a rectifier, i.e. converts AC current to DC current.

Task 1.3.3.

Connect in parallel a capacitor of 1 nF to the resistor. How does this change the typical frequency at which the signal begins to rectify? At the frequency of 500 kHz, measure the dependence of the DC (rectified) voltage $\langle U_2 \rangle$ at the second oscilloscope channel on the amplitude U_1 of AC voltage of the signal generator. Sketch the dependence of the output voltage of the rectifier on the amplitude of the rectifier input voltage and determine the angular slope of this function.

Since the constant voltage at the circuit output (at the second oscilloscope channel) varies with the voltage amplitude supplied by the signal generator, the circuit can be regarded as a detector, i.e. it uniquely «converts» the amplitude of an AC signal to the magnitude of a DC one. Let us apply a high-frequency signal varying at a low frequency (amplitude modulated signal) to such a circuit. The amplitude variation frequency of the amplitude of a high-frequency signal is called the modulation frequency. At the circuit output one obtains a signal with the frequency equal to the modulation frequency. Such a process is called detection in radio engineering (see Fig.6).

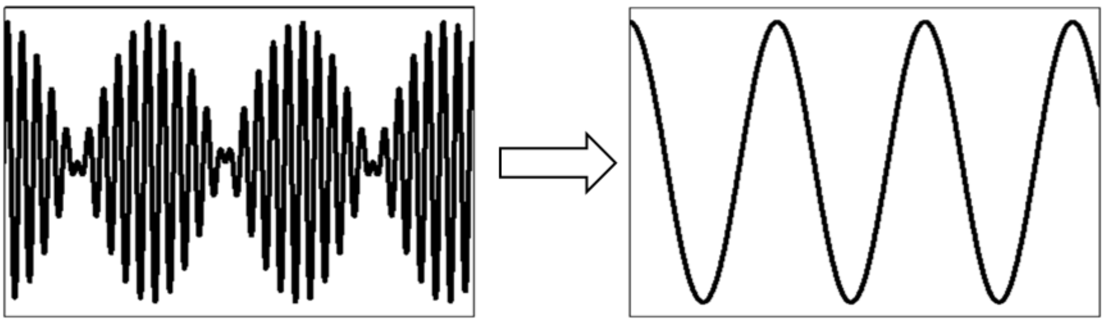


Fig. 6. Detection of amplitude-modulated signal.

The next nonlinear element to be considered is called «field-effect transistor» (hereinafter, transistor). This element has three terminals (see Fig.7) called drain (D), source (S), and gate (G).

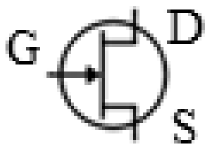


Fig. 7. Transistor: D – drain, S – source, G – gate.

The current-voltage characteristic $I(U)$ between the drain and the source depends on a voltage U_g between the gate and the drain. A form of the *I-V* curve does not change under variation of U_g but the saturation current of the transistor does (see Fig.8).

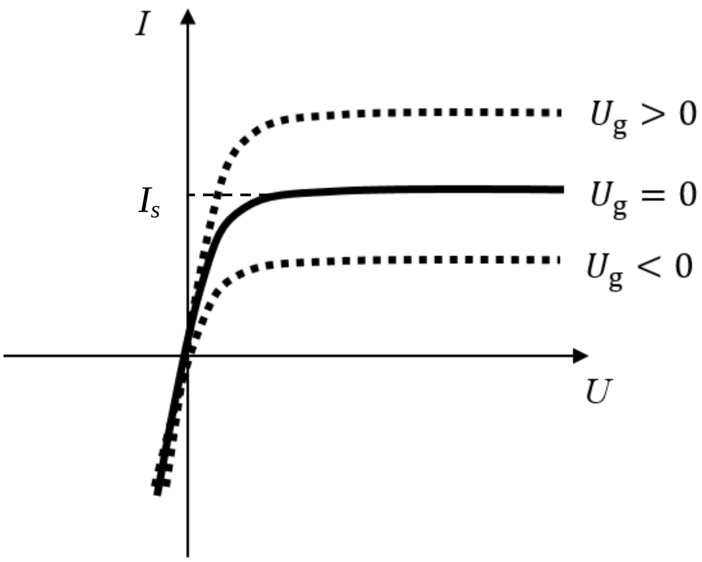


Fig. 8. Transistor I-V curves versus a voltage across the gate and the source.

A transistor can be used to build a voltage amplifier. Amplifier is an element which serves to enhance the amplitude of a signal. To design a transistor based amplifier, let us find out first the voltage across a transistor connected in series with a resistor to a DC source. To do this, notice that the net voltage across the transistor U_t and the resistor IR equals a constant voltage U_s of the source:

$$U_t + IR = U_s . \qquad (7)$$

Therefore, the transistor voltage can be calculated as

$$U_t = U_s - IR . \qquad (8)$$

The most obvious solution of this equation is provided by the graphical method (see Fig.9).

As seen, the straight line defined for a certain resistor value by Eq. (8) intersects the transistor *I-V* curve in the current saturation domain. The saturation current depends on the voltage across the gate and the source. Therefore, the current flowing through the resistor and the voltage across it vary under a variation of the gate voltage. Given a correctly chosen resistor, the change of resistor voltage can exceed the change of gate voltage. Let us illustrate this statement (see Fig.10).

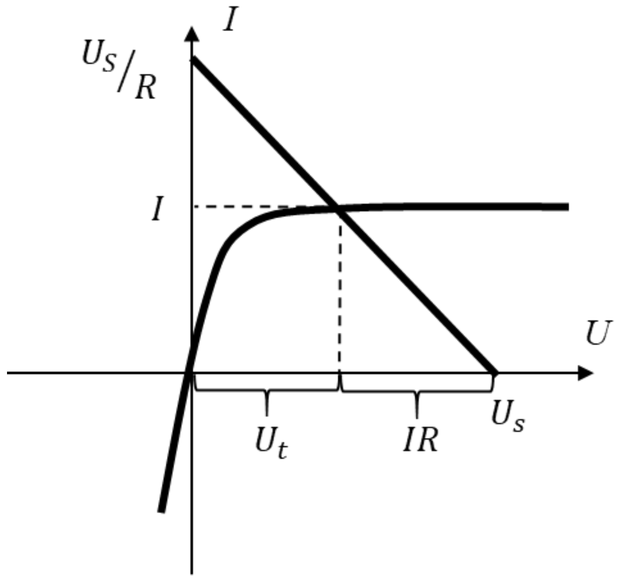


Fig. 9. Graphical solution of Eq. (8).

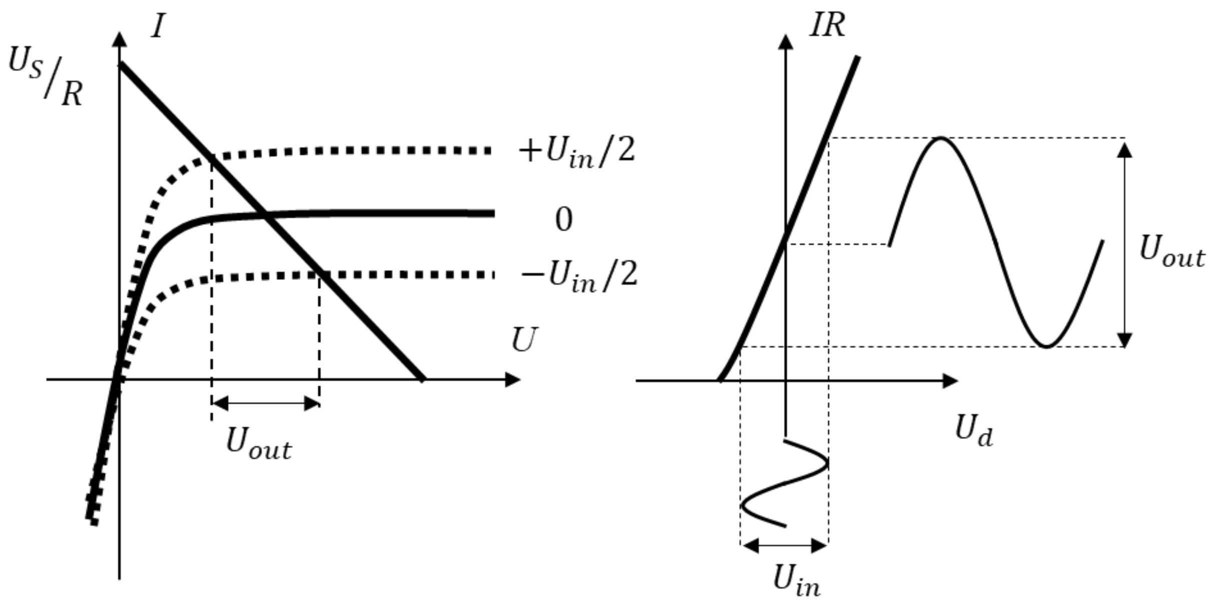


Fig. 10. Operation of voltage amplifier.

Task 1.3.4.

Assemble the circuit shown in Fig.11. Set the voltage of the signal generator to 50 mV and the frequency to 500 kHz. By varying a resistance of the variable resistor, obtain the maximum amplitude of the AC signal at the second oscilloscope channel. Measure and write down the range of resistances of the variable resistor corresponding to the maximum voltage at the amplifier output.

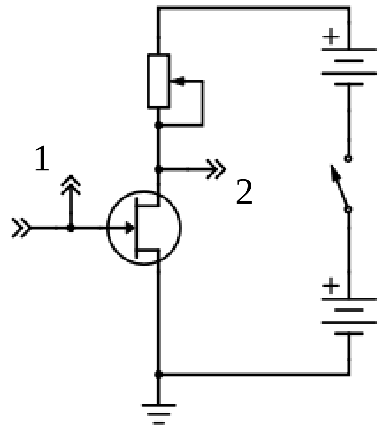


Fig. 11. Circuit diagram of amplifier.

Measure a dependence of the voltage amplitude U_2 at the second oscilloscope channel on the voltage amplitude U_1 at the signal generator. Plot this dependence. Determine the amplifier gain, i.e. the ratio of the amplitude of output voltage to the amplitude of input voltage on the linear part of the plot. Starting with what amplitude of the input signal the output signal becomes non-harmonic (the amplifier goes into non-linear mode)?

In the task 1.3.4. we considered the simplest amplifier which was not selective in the signal frequency. However, in some cases it is convenient to use the amplifier which amplifies only a signal of certain frequency. Such an amplifier is called the *resonance amplifier*. To this end, one replaces a resistor in the drain circuit with an *LC*-circuit and installs a resistor in the source circuit to protect the transistor from overheating.

Task 1.3.5.

Assemble the circuit shown in Fig.12. Use the resistor of 500 Ω (connect two resistors of 1 kΩ to obtain the required value). Set the amplitude of the input voltage of the amplifier to 50 mV (at the signal generator). Turn the dial of the variable capacitor all the way clockwise. Determine the frequency corresponding to the maximum amplifier gain. What is the phase shift between the input and output signal of the amplifier at the resonance frequency?

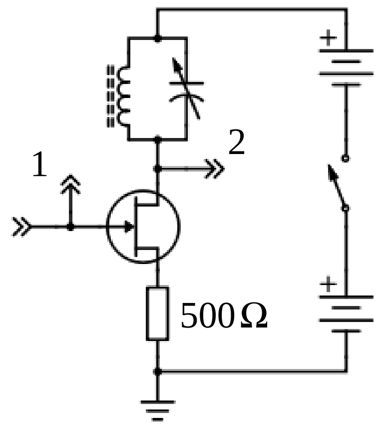


Fig. 12. Circuit diagram of resonance amplifier.

Task 1.3.6.

Measure the dependence of the amplitude of output signal of the resonance amplifier on the amplitude of input signal at the maximum gain. Plot this dependence. Determine the angular slope of the initial linear part of the plot. Compare the value of the slope with that one determined in 1.3.4. (do not write on the answer sheet). The measured value will be used in the next task.

The input voltage is applied to the amplifier by the signal generator. However, one can induce an EMF of induction in the coil of *LC*-circuit by placing another coil nearby, so the input voltage can be applied by means of this coil without using the signal generator. Using this simple method one can build his/her own generator, i.e. a device, in which an AC current is autonomously generated (without an external agent). Hereinafter we refer to the built generator as the «**HF oscillator**» (high-frequency oscillator).

Task 1.3.7.

Wind several turns of wire around the coil of *LC*-circuit. In so doing, you have made a transformer with the secondary winding consisting of several turns. Measure the voltage across the winding by means of the oscilloscope with the signal generator turned on. Choose the number of turns of the secondary winding so that the ratio of the voltage amplitude across the primary winding of *LC*-circuit to the voltage amplitude across the secondary winding were approximately two thirds of the amplifier gain measured in 1.3.6. Write the chosen number of turns on the answer sheet. Connect the secondary winding instead of the signal generator to the circuit (see Fig.13).

Respect polarity, i.e. the phase shift of the signals on the secondary and first windings must correspond to the phase shift measured in 1.3.5. Attach the secondary winding to the coil with the Scotch tape.

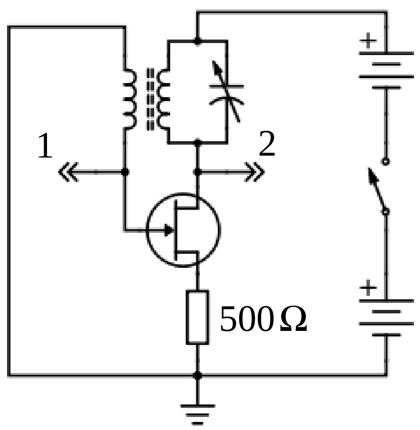


Fig. 13. Circuit diagram of HF oscillator.

The designed HF oscillator creates the so-called carrier frequency at which a radio signal will be transmitted. However, to transmit a sound, it is necessary to ensure the amplitude modulation of the carrier frequency by an audio frequency (see Fig.6, on the left).

To achieve the modulation, it is necessary to vary a parameter of the HF oscillator at a desired frequency. In the case at hand, the working point of the HF oscillator will be varied, i.e. a voltage U_g across the gate and the source.

Task 1.3.8.

An average voltage at the gate of the HF oscillator shown in Fig.13 equals 0 V (relative to the ground). However, by adding a voltage divider and a capacitor of 0,1 μF to the circuit, it is possible to vary the average gate voltage in a certain range (see Fig.14).

Assemble the circuit shown in Fig.14. Measure and plot the dependence of the amplitude at the output of HF oscillator on the average voltage at the transistor gate. At what average voltage at the gate does the generation disappear?

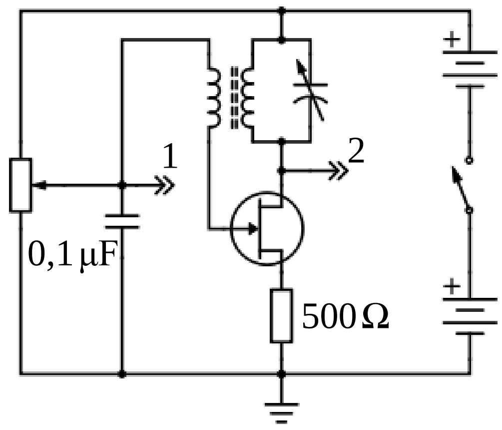


Fig. 14. HF oscillator with tunable working point.

Task 1.3.9.

Set a voltage at the transistor gate (the working point) equal to one half of the voltage at which the HF oscillator stops working (it was found in 1.3.8.). Connect the signal generator to one of the capacitor plates as shown in Fig.15. Set the frequency of signal generator to 1 kHz. Adjust the signal amplitude to achieve the maximum of modulation amplitude while making sure that the generation remains stable.

Sketch the signal waveform at the transistor gate and at the output of the HF oscillator.

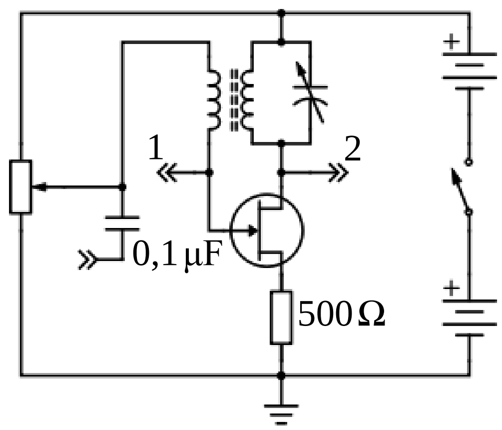


Fig. 15. HF oscillator with amplitude modulation.

Chapter 4. Dividing Elements.

It is evident from 1.3.4., that the signal at the amplifier output consists both of an AC and DC components, i.e. it contains a component of zero frequency. After the amplifier, a signal can be further processed by various circuits, but only the AC component should be applied to their inputs. To get rid of the DC component, it is necessary to use an *RC*-filter which operation principle was studied in 1.1.1. In addition to the DC component of a signal, there could be a 50 Hz pickup from the household electrical wiring, so the parameters of *RC*-filter are chosen to pass a useful signal and to block a signal at a frequency below 50 Hz.

Task 1.4.1.

Use a resistor of 10 kΩ and a capacitor from the given set to assemble the *RC*-filter that would reduce a signal amplitude at 50 Hz, at least, by a factor of 10 and at the same time would pass a signal at a frequency of 500 kHz as best as possible. Write down the capacitor value.

Assemble the *RC*-filter using the chosen capacitor. Apply a 50 Hz signal from the signal generator to the filter input. Shift the average value at the signal generator output by pulling and turning the knob «DC-offset». Make sure the filter does not pass the DC component of a signal and reduces the 50 Hz signal (do not forget to set the «DC» measurement mode of the oscilloscope channels). Set the signal generator frequency to 500 kHz. Make sure the filter passes the signal at this frequency and keeps cutting out the DC component.

Task 1.4.2.

Assemble the circuit shown in Fig.16. Apply a 500 kHz signal with an amplitude of 5V from the signal generator to the circuit input. Sketch the signal waveforms at the circuit input and output (the second signal shows how the diode voltage varies). The sketch must make clear a difference between the signals. Notice the average signal at the output (do not write on the answer sheet). Does the output signal of this circuit depend on the average signal at the input (at the signal generator)? To change the average signal on the generator, pull the knob «DC-OFFSET». Do not forget to return the knob into the initial position after completing the task.

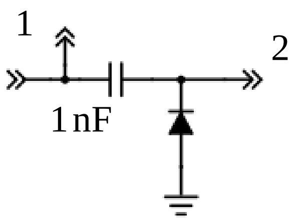


Fig. 16. Dividing capacitor with diode.

Task 1.4.3.

Connect the detector circuit from 1.3.3. to the output of the circuit considered in the previous task (see the diagram in Fig.17). Set the signal generator frequency to 500 kHz.

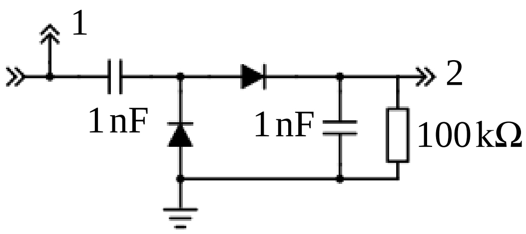


Fig. 17. Detector with two diodes.

Measure and plot the dependence of a constant voltage $\langle U_2 \rangle$ at the circuit output (the voltage across the resistor) on the amplitude of a voltage U_1 at the circuit input. Plot the average voltage at the circuit output versus the amplitude of the voltage at the detector input and determine the angular slope of this function. Determine the ratio of the slope measured in this task to the slope measured in 1.3.3.

Part 2. Practice.

Chapter 1. Construction of Receiver.

In this part of the assignment you will assemble and adjust a direct amplification receiver. It is designed for reception, detection, and conversion into sound of an amplitude-modulated (AM) signal of high frequency. The block diagram of such a receiver is shown in Fig.18.

Of all radio signals and noise the *LC*-circuit of the receiver 1 «selects» a HF signal of a certain frequency. The selected signal is applied to the high frequency amplifier 2, processed by the detector 3, and amplified by the low frequency amplifier 4. The amplified low frequency signal is applied to a speaker or headphone 5 which makes the radio transmitted message audible.

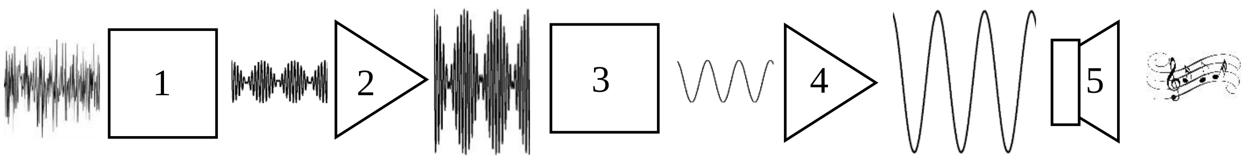


Fig. 18. Block diagram of direct amplification receiver.
receiver *LC*-circuit (1); high frequency amplifier (2); detector (3);
low frequency amplifier (4); speaker (5).

To assemble the receiver, two rectangular circuit boards are required. Arrange them so that their short sides touch each other. Install two battery compartments on the edge of the right board. Connect the compartments with a switch by respecting the polarity. Install two contact buses along the long sides of the boards and connect them to the positive and negative terminals of the battery (see Fig.19). The bus connected to the negative terminal will be used to connect to the oscilloscope ground.

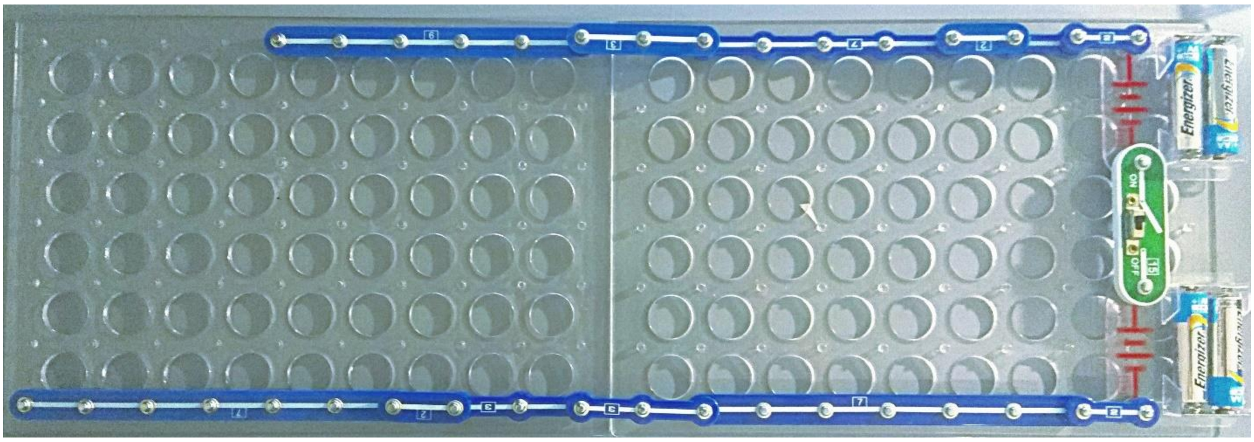


Fig. 19. Preliminary arrangement of two circuit boards for receiver assemblage.

<u>*Task 2.1.1.*</u>

Set the frequency of the HF oscillator (assembled according to Fig.15) to the minimum. Set to zero the amplitude of the output signal of the signal generator, thereby switching off modulation of the signal of the HF oscillator.

Assemble a parallel *LC*-circuit on the prepared doubled circuit board and place it near the HF oscillator (see Fig.20). By changing the capacitance in the *LC*-circuit, set the resonance frequency of the *LC*-circuit equal to the frequency of the HF oscillator. Use the oscilloscope to measure the amplitude of the signal in the *LC*-circuit.

If the signal level at the oscilloscope input is too low to ensure the stable measurements, try to place the HF oscillator so that the HF inductor and that of the *LC*-circuit were closer to each other.

Fig. 20. Setting up *LC*-circuit.

Task 2.1.2.

A HF signal coming from the *LC*-circuit is too weak to be amplified by a single amplifier considered in 1.3.4. Hence, we will connect the amplifiers in series. Each of the amplifiers will be referred to as an amplification stage (or stage, for short).

Connect the *LC*-circuit to the first amplification stage (see Fig.21). By varying a resistance of the variable resistor, adjust the maximum gain of the first stage. Measure the gain of the first stage. Use both oscilloscope channels for simultaneous measurement of the signal at the input and output of the amplifier.

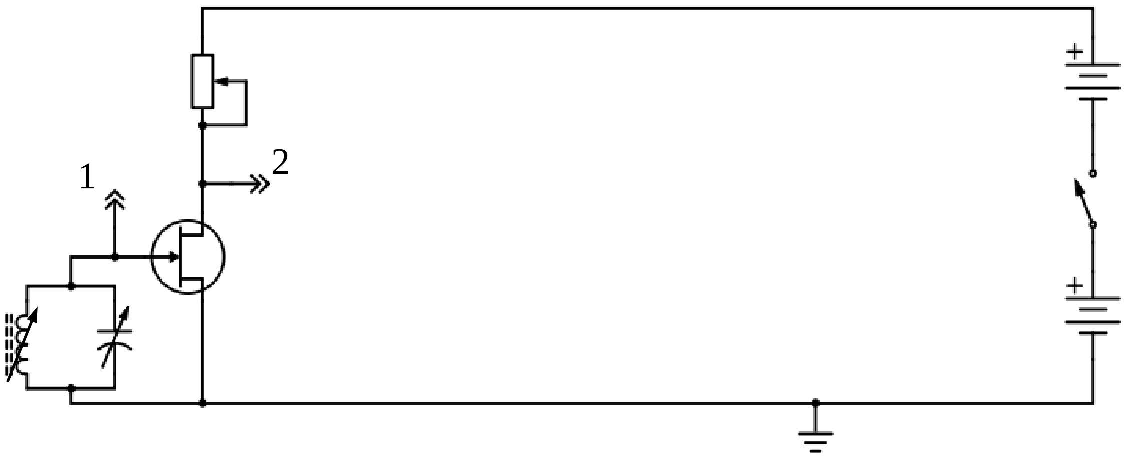


Fig. 21. Setting up the first amplification stage.

Task 2.1.3.

Set the low frequency filter at the output of the first amplification stage (see Fig.22). Choose the capacitor value according to the results obtained in 1.4.1.

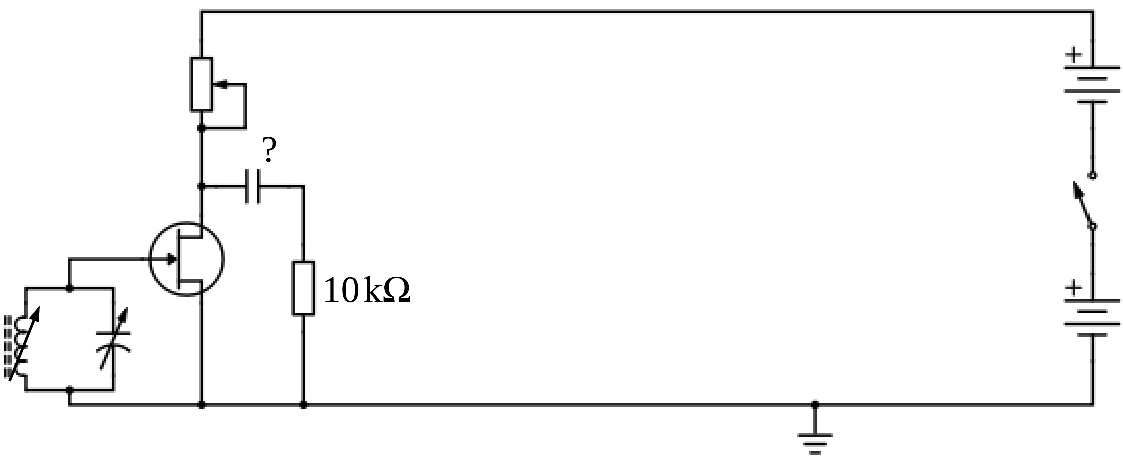


Fig. 22. Setting up low frequency filter.

Task 2.1.4.

Connect the second amplification stage to the output of the low frequency filter as shown in Fig.23. Use a capacitor of 39 pF to create a negative feedback of the second stage in order to avoid self-excitation of the resulted amplifier. Adjust the gain of the second stage to the maximum by varying a resistance of the variable resistor.

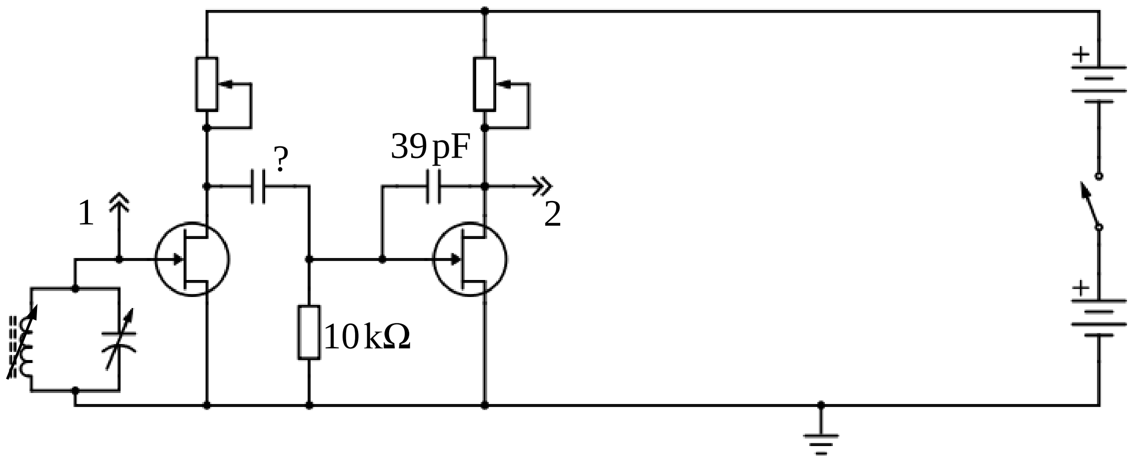


Fig. 23. Setting up the second amplification stage.

Measure the net gain K of the two-stage amplifier, i.e. measure the ratio of the signal amplitude at the second stage output to the signal amplitude on the LC-circuit. Use two oscilloscope channels for the simultaneous measurement of the signals at the input of the first stage and at the amplifier output.

Write down an equation relating the net gain K and the gains K_1 and K_2 of the stages. Evaluate the gain K_2 of the second stage of the amplifier.

Task 2.1.5.

Set the amplitude of the signal generator so that the modulation amplitude was at the maximum while the generation remained stable.

Connect the detector with two diodes studied in 1.4.3 (hereinafter, the detector) to the output of the second stage, see Fig.24. Set the frequency of amplitude modulation of the HF oscillator to 1 kHz. Sketch 3-4 cycles of the signal measured by the oscilloscope at the detector output. Set the frequency of amplitude modulation of the HF oscillator to 5 kHz. Sketch 3-4 cycles of the signal measured by the oscilloscope at the detector output. Try to emphasize a difference in these signals.

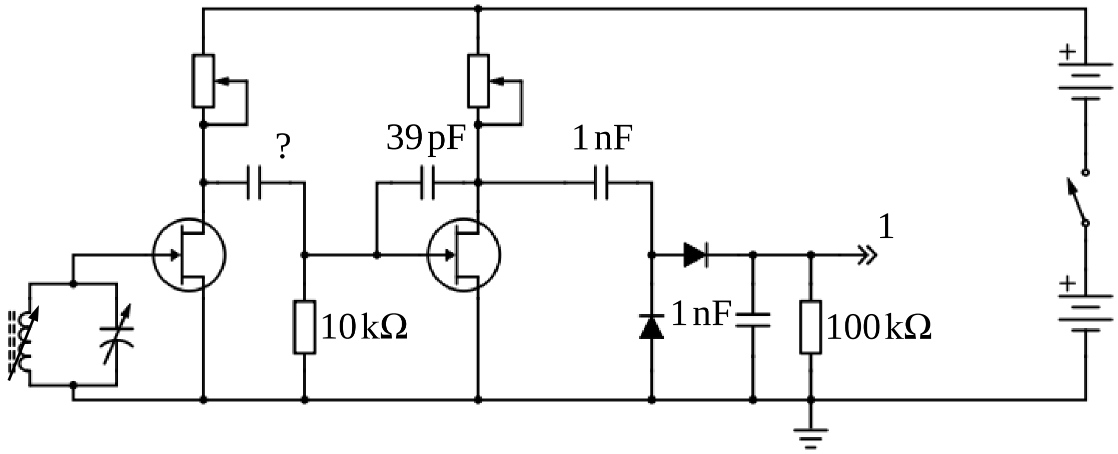


Fig. 24. Setting up detector with two diodes.

<u>*Task 2.1.6.*</u>

Insert the headphones in the corresponding socket. Measure their resistance with the *LCR*-meter.

Connect the low frequency (LF) amplifier to the detector output as shown in Fig.25. Sketch a waveform of the signal at the output of LF amplifier. Disconnect the 0,1 μF capacitor in the circuit of the transistor drain of the LF amplifier and sketch the obtained waveform of the signal at the output of LF amplifier. Show clearly the difference in the signals on the drawing. Calculate the magnitude of the impedance of the headphone and the capacitor at an audio frequency of 1 kHz and at 500 kHz (close to the carrier frequency).

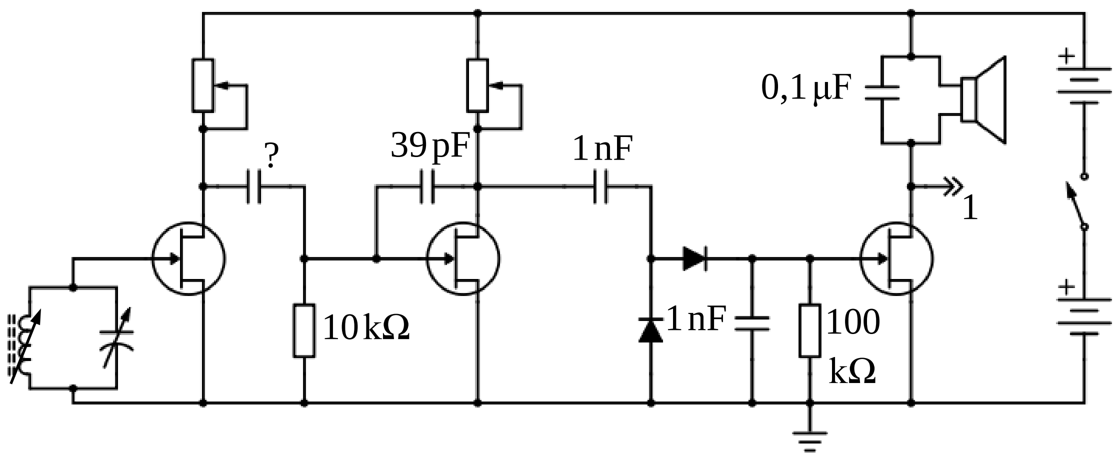


Fig. 25. Setting up low frequency amplifier and headphones of the receiver.

Chapter 2. Reception of Broadcasted Signal.

Now you have to receive the signal of the radio station working in your classroom. The carrier frequency of the station exceeds 2 MHz. To receive a signal from the station, it is necessary to change the range in which a resonant frequency of the *LC*-circuit can be adjusted.

Task 2.2.1.

In a few English words or by means of a simple drawing, explain how the adjustment range of the resonant frequency of the *LC*-circuit can be changed. Specify, what should be exactly done to the elements of the *LC*-circuit.

Task 2.2.2.

The household wiring in this room and the electrical appliances connected to the wiring make a good antenna for the broadcasted signal. Connect oscilloscope probes to the *LC*-circuit to increase the signal at the receiver input circuit. Measure the carrier frequency of the broadcasted signal and its audio frequency (the modulation frequency).

Task 2.2.3.

The broadcasted audio signal is a single word transmitted in Morse code. It is a special language consisting of short and long signals which allow one to transmit radio messages. Each symbol of English alphabet is represented by a sequence of short and long signals called the «dots» and the «dashes».

The correspondence between the letters of English alphabet and the signals of Morse code is shown in Fig.26. Every «dot» and/or «dash» are separated by a short interval of silence (no sound). A silence interval is short inside a letter, it is longer between letters, and the longest interval is between words.

Write the broadcasted message using the «dots» and the «dashes» on the answer sheet. Decipher the message and write the word in English letters.

A	• —	J	• — — —	S	• • •
B	— • • •	K	— • —	T	—
C	— • — •	L	• — • •	U	• • —
D	— • •	M	— —	V	• • • —
E	•	N	— •	W	• — —
F	• • — •	O	— — —	X	— • • —
G	— — •	P	• — — •	Y	— • — —
H	• • • •	Q	— — • —	Z	— — • •
I	• •	R	• — •		

Fig. 26. Morse code.