MARITIME UNIVERSITY OF SZCZECIN

ORGANIZATIONAL UNIT:
DEPARTMENT OF MARINE COMMUNICATION TECHNOLOGIES

INSTRUCTION

ELECTRICAL ENGEENERING AND ELECTRONICS
Laboratory
Exercise No 2: RLC circuits

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2. RLC circuits

2.1. The purpose and scope of the exercise

The aim of the exercise is to master knowledge in the field of construction and application of basic electrical circuits including differentiating and integrating systems as well as series and parallel resonance systems.

Issues:

1. Basic electrical components.
2. Basic laws of the theory of electric circuits.
3. Principles of performing measurements with an oscilloscope.
4. Structure, characteristics and basic relationships of differentiating systems.
5. Structure, characteristics and basic relationships of integral circuits.
6. The use of differentiating and integrating systems.
7. Structure, characteristics and basic dependencies of the serial resonant circuit.
8. Structure, characteristics and basic relations of a parallel resonant circuit.
9. The use of resonant circuits.

Control questions

1. Discuss the construction, operation and use of differentiating systems.
2. Discuss the construction, operation and use of integrating circuits.
3. Describe the phenomenon of series resonance.
4. Describe the phenomenon of parallel resonance.
5. What is the frequency characteristics?
6. What is the bandwidth of the resonance circuit (characteristics)?
7. What is the effect of Q-factor on the shape of the frequency response?
8. Give the basic relations regarding the resonant circuit series.
9. Give the basic relations regarding the parallel resonant circuit.

2.2. Description of the measurement system

A set of instruments:

1. A generator of sinusoidal waveforms.
2. Two-channel oscilloscope.
3. The resonant circuit board.

The resonant circuit board consists of two parts. In the upper one there is a series resonance circuit, in the lower one a parallel resonance system. The board contains only one *L* coil switched to one of the resonance circuits to the "L" terminals. A sinusoidal signal from the generator is connected to the "WE" sockets. The oscilloscope is connected to the "WY" sockets. The current flowing in the circuit is observed by the voltage drop across the measuring resistor R_p, which is of little importance to the circuit's operation. Each of the circuits has the ability to switch on one of the three resistors to change the goodness of the circuit and one of the three capacitors to change the resonant frequency.

2.3. The course of the exercise

2.3.1. Serial resonance measurements

Connect the oscilloscope to the serial resonance output (terminals R_p) on the resonant circuit board. Connect the inductance to the "L" terminals. A sinusoidal signal with an amplitude of U = 10 V and a preliminary frequency f = 1 kHz should be given for the input of the system.

a. Connect the capacitance C_1 and the resistance R_1 to the circuit. Find the resonance frequency (the amplitude of the output voltage is the largest) and write it to the table. Measure the three frequency characteristics of the resonant circuit, sequentially, when three resistances R_1, R_2, R_3 are connected in increments of 0.1 kHz.
b. Connect the capacitance C_2 and the resistance R_1 to the circuit. Find the resonance frequency (the amplitude of the output voltage is the largest) and write it to the table. Measure the three frequency characteristics of the resonant circuit, sequentially, when three resistances R_1, R_2, R_3 are connected in increments of 0.1 kHz.
c. Connect the capacitance C_3 and the resistance R_1 to the circuit. Find the resonance frequency (the amplitude of the output voltage is the largest) and write it to the table. Measure the three frequency characteristics of the resonant circuit, sequentially, when three resistances R_1, R_2, R_3 are connected in increments of 0.1 kHz.

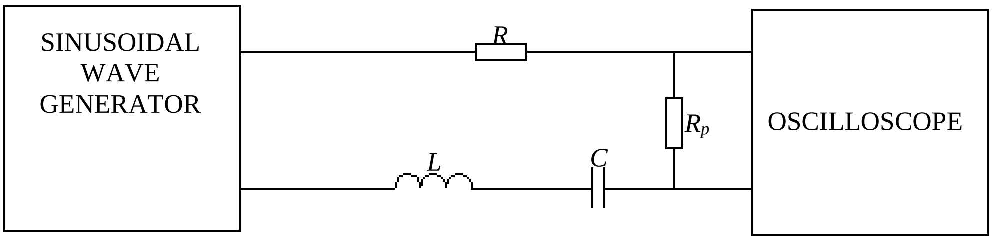

Fig. 2.3.1. Measurement system for series resonance testing

2.3.2. Parallel resonance measurements

Connect the oscilloscope to the parallel resonance output (terminals R_p) on the resonant circuit board. Connect the inductance to the "L" terminals. A sinusoidal signal with an amplitude of U = 10 V and a preliminary frequency f = 1 kHz should be given for the input of the system.

a. Connect the capacitance C_1 and the resistance R_1 to the circuit. Find the resonance frequency (the amplitude of the output voltage is the largest) and write it to the table. Measure the three frequency characteristics of the resonant circuit, sequentially, when three resistances R_1, R_2, R_3 are connected in increments of 0.5 kHz.
b. Connect the capacitance C_2 and the resistance R_1 to the circuit. Find the resonance frequency (the amplitude of the output voltage is the largest) and write it to the table. Measure the three frequency characteristics of the resonant circuit, sequentially, when three resistances R_1, R_2, R_3 are connected in increments of 0.5 kHz.
c. Connect the capacitance C_3 and the resistance R_1 to the circuit. Find the resonance frequency (the amplitude of the output voltage is the largest) and write it to the table. Measure the three frequency characteristics of the resonant circuit, sequentially, when three resistances R_1, R_2, R_3 are connected in increments of 0.5 kHz.

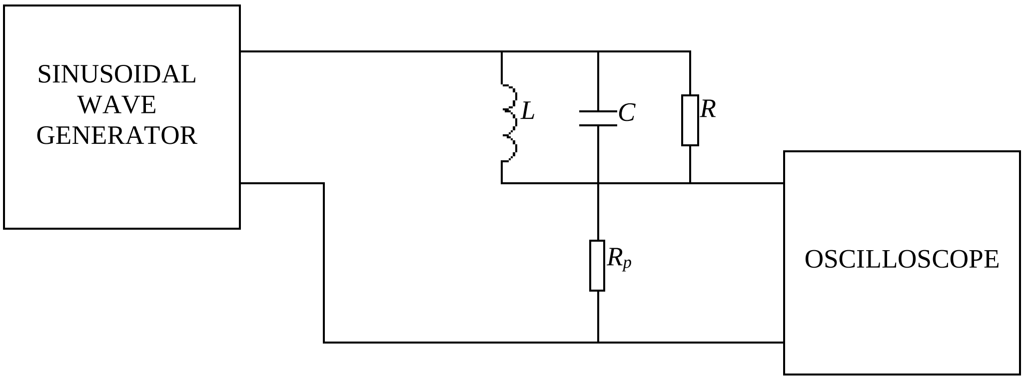

Fig. 2.3.2. Measurement system for parallel resonance testing

2.4. Conditions for assessment of the exercise

The condition for assessment of the exercise is:

- to write a short test at the beginning of the class with a positive result;
- to do the exercise;
- preparing a report according to the instructions below;
- positive assessment of the report on the next class;

The report should include:

- a measuring card with calculated currents assuming that the measuring resistor R_p in the series resonance system is 10 Ω and in the parallel resonance system R_p = 470 Ω;
- characteristics of current as a function of frequency for series resonance systems with marked frequency f_d and f_g of the bandwidth;
- characteristics of current as a function of frequency for paralel resonance;
- calculated Q-factors (goodness - *dobroć* in Polish), according to equation:

$$Q = \frac{f_{rez}}{B}$$

- calculated inductance L, according to equation :

$$L = \frac{1}{4 \cdot \pi^2 \cdot f_{rez}^2 \cdot C}$$

- own conclusions and observations.

2.5. Theoretical basics

2.5.1. Elements of the electrical circuit

Each electrical circuit, in which, along with elements typical of direct current, i.e. elements representing the real electrical resistance *R*, there are typical elements of AC circuits, i.e. *C* or *L* inductances, have impedance *Z.* This impedance otherwise called complex resistance is expressed in relationship:

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

The reverse of the impedance is called the admittance of *Y*. The impedance consists in a general case of two parts: real and imaginary. The real part, called resistance or active resistance, denoted *R*, represents the resistance occurring for both alternating and constant currents; its value in both cases is the same. In the case of a resistance with a direct or alternating current flow, the current is always converted into thermal energy. The unit of both impedance and resistance is ohm [Ω]. The reverse of the resistance is called the active conductivity or conductance and we denote G, the unit of admittance and conductance is siemens [S]. The imaginary part of the impedance forms a passive resistance called reactance, determined by *X*. There is no heat release in the reactance, and the current flowing through the reactance causes energy to accumulate in the electromagnetic field. The existence in the reactance circuit causes a phase shift between the current and voltage waveforms. We distinguish capacitive reactance X_C, i.e. capacitive resistance of alternating current and inductive reactance X_L, i.e. resistive resistance inductance for alternating current. The value of the impedance determines the dependence:

$$Z = \sqrt{R^2 + X^2}$$

where:

$$X = X_C - X_L = \frac{1}{2\pi fC} - 2\pi fL$$

From the given dependence on the *X* reactance results the following conclusions:

- for direct current, (f = 0), the ideal capacity represents the resistance $R = \infty$ i.e. it prevents the flow of direct current,
- for alternating current the capacitance reactance decreases when the current frequency increases, for very high frequencies capacitive reactance tends to zero,
- for direct current, the ideal inductance is zero resistance, i.e. $R = 0$,
- for alternating current, inductive reactance increases with increasing frequency.

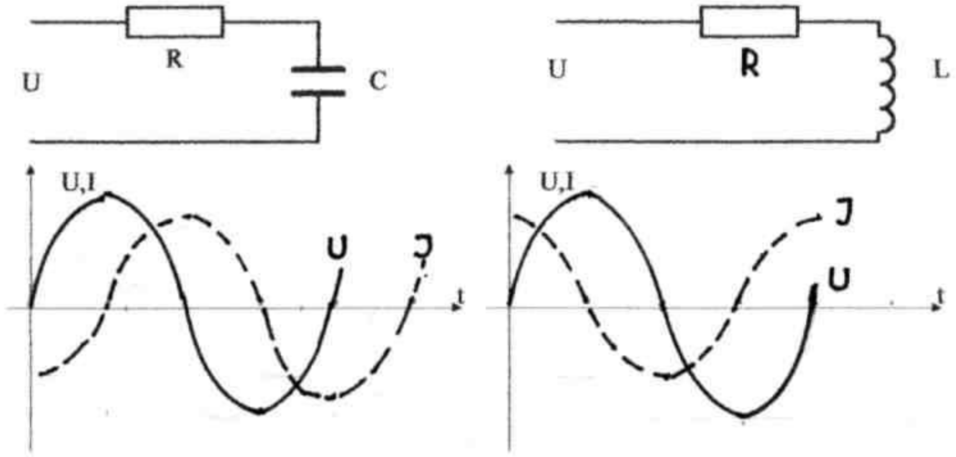

Fig.2.5.1. Current and voltage waveforms for circuits with capacitance and inductance

The existence in the reactance circuit causes a phase shift between the current and voltage waveforms. In the case of capacity as a result of this shift, the current is ahead of the voltage by 90°.

In the case of inductances, the voltage overruns the current by 90°. In the case when the circuit occurs simultaneously and inductance and capacity, the shift takes the intermediate values within ± 90°. Appropriate waveforms are shown in Fig. 2.5.1.

Elements of electrical circuits can be divided into two groups: active and passive elements. Active elements are elements that increase the energy of the supplied signal (lamps, transistors, integrated circuits), and passive elements are elements that do not increase the signal's energy. These include, above all, the so-called RLC elements, but also LEDs, switches and tp.

A resistor or resistor is called an element with a fixed resistance or variable (adjustable). Resistors with adjustable resistance are often called potentiometers. Each resistor has three basic parameters:

- the nominal resistance *R* given in [Ω], [kΩ], or [MΩ]
- tolerance in percent (generally 5, 10 or 20%)
- the value of the allowable power (generally 0.1, 0.25, 0.5, 1, or 2 W).

A capacitor is a passive element with a defined fixed or regulated capacity. The capacitor consists of two conductive covers insulated from each other by a dielectric. Depending on the design and type of dielectric, it is distinguished among others capacitors: air, paper, polystyrene, ceramic, mica, electrolytic etc. Each capacitor is characterized by three basic parameters:

- the value of the capacity, marked *C* given most often in [μF], [nF], or [pF],
- tolerance in percent (generally 10, 20 or 50%),
- maximum working voltage given in [V].

The coil is a passive element with a defined constant or regulated inductance. The coil is made by winding the wire on the insulator body. If there is no ferromagnetic core inside the body, the coil is called air. Insertion of the core from a ferromagnetic material causes a significant increase in the inductance of the coil. Inductance *L* is the basic parameter of the coil. It is determined in henr [H] or smaller units [μH] or [mH]. Coils should have as little resistance as possible. High resistance adversely affects the goodness of the coil, and thus the *Q*-factor (goodness, *dobroć* in Polish) of the resonant circuit.

2.5.2. Integrating and differentiating circuits

The integrating circuit is a linear circuit containing the capacitance and resistance or inductance and resistance combined as shown in Figure 2.

The figure also shows the influence of the time constant on the shape of the output waveform. The dashed line represents the input signal and the solid line the output signal from the system. From the drawing it is clear that the time constant $\tau = RC$ or $\tau = L/R$ is larger, the more the shape of the output signal deviates from the shape of the input signal. The integration circuit can be considered as a low-pass filter that transmits the components of the low-frequency signal and damps the components with higher frequencies. The figure 2.5.2 shows that with a large time constant the leading edge of the rectangular signal is converted to a linearly increasing waveform, so we have to do with integrating the input signal.

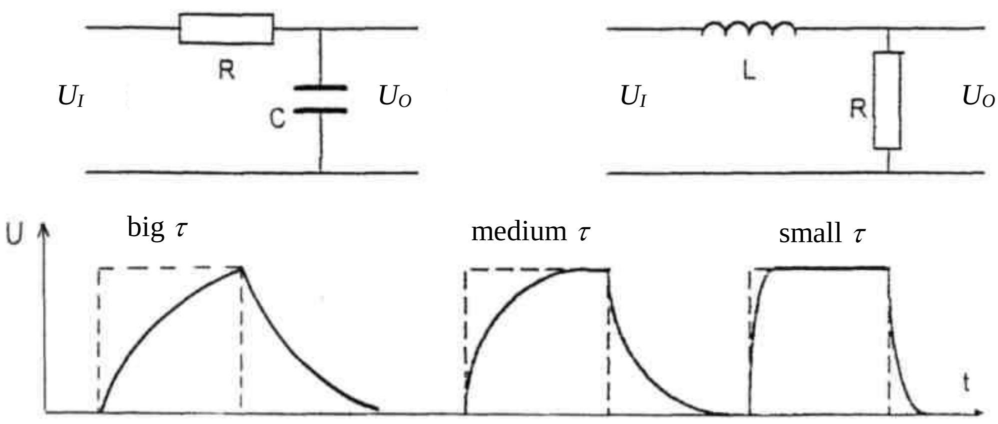

Fig. 2.5.2. Integrating circuits

The differentiating circuit is a linear circuit containing the capacitance and resistance or inductance and resistance combined in the manner shown in the figure below:

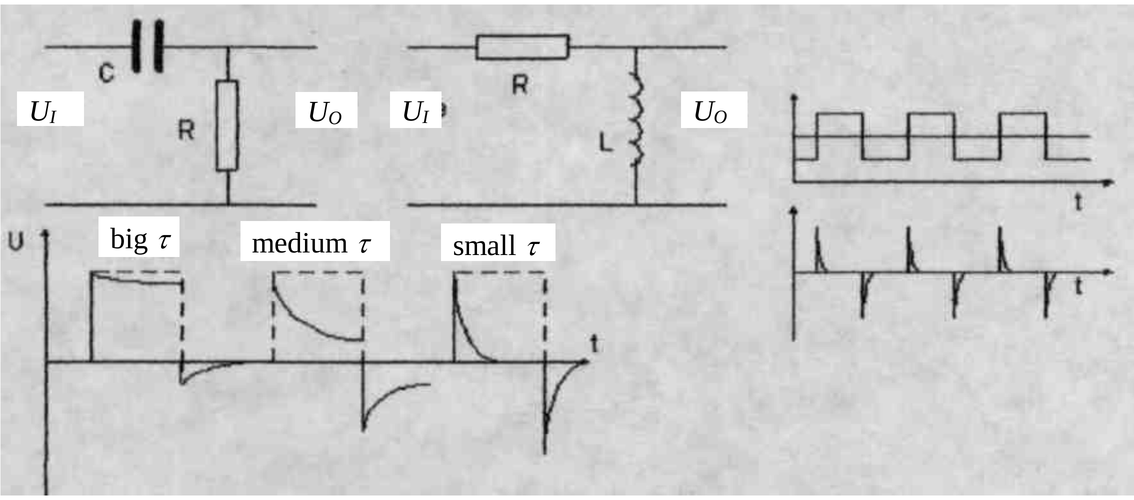

Fig. 2.5.3 Differentiating circuits. Direct current damping

As with integral circuits, the differentiating circuits change the shape of the signal. This time, however, the smaller the time constant $\tau = RC$ or $\tau = L/R$ the more the shape of the output signal differs from the shape of the input signal. The differentiator system can be seen as a filter that transmits the signal components at higher frequencies and suppresses components at low frequencies, i.e. as a high pass filter. It can be noticed that with a relatively small time constant, the derivative causes the rectangular signal to be converted into a series of positive pulses and positive and negative pulses, thus the input signal is differentiated from the mathematical point of view. According to the differentiation rules (derivative of the constant value is equal to zero), the output signal never contains a constant component even though it was present in the input signal. This statement is true only for *RC* systems. Physically this is caused by the presence of a series capacitor at the input of the differentiator. In practice, *RL* differentiating circuits are relatively rarely used.

2.5.3. Serial resonance circuits

The resonant circuit is called an electrical circuit that simultaneously contains the capacity *C* and inductance *L*.

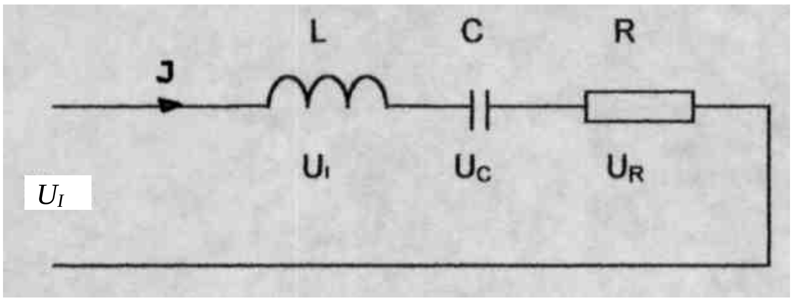

Fig. 2.5.4 . Series resonant circuit

If the capacitance and inductance are connected in series in relation to the power source, we are talking about a series resonance circuit. Each actual resonant circuit, in addition to the capacitance and inductance, also has a certain resistance R called a loss resistance. It consists of the resistance of the wire from which the coil is made, the losses in the core of the coil, converted into resistance, the losses in the capacitor converted into resistance, and the resistance of the connecting wires. Generally, the lower the resistance of the losses, the better the resonant circuit. The parameter determining the quality of the resonant circuit is its goodness. *Q*-factor is the ratio of capacitive or inductive reactance in resonance to loss resistance:

$$Q = \frac{X_{C0}}{R} = \frac{X_{L0}}{R}$$

The *Q*-factor of the circuit depends only on its parameters. Goodness values for resonant circuits range from a few to a few hundred. After appropriate transformations, we get:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

The impedance of the serial *RLC* circuit is equal to:

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$$

The condition of resonance is the equality of capacitive and inductive reactance:

$$X_C = X_L$$

Since both capacitive and inductive capacitance depend on the frequency there is only one frequency f_0 for which this condition is met:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

As it results from the above dependencies, the impedance of the circuit in the resonance reaches the minimum:

$$Z_0 = R$$

The current flowing in the circuit, in resonance, reaches the maximum value and is equal:

$$I_0 = \frac{U_{WE}}{Z_0} = \frac{U_{WE}}{R}$$

The voltages on the coil and capacitor in the resonance are many times higher than the input voltage, reach their maximum and amount respectively:

$$U_{L0} = I_0 X_{L0} = \frac{U_{WE}}{R} X_{L0} = U_{WE} Q$$

$$U_{C0} = I_0 X_{C0} = \frac{U_{WE}}{R} X_{C0} = U_{WE} Q$$

As can be seen from the above relationships, these resonance voltages are equal. However, they are shifted in phase by 180 °, so their sum is equal to zero.

The characteristic of the resonant circuit is the dependence of the current in the circuit on the frequency. A similar shape has the dependence of the voltage on the coil or capacitor from the frequency. You can also find the dependence of the circuit impedance on the frequency. The latter characteristic is a simple reversal of the current characteristic. The exact shape of the characteristic, its height and width depends on the goodness of the circuit. Based on the characteristics, the frequency response of the circuit can be determined.

It can be proved that the frequency bandwidth depends primarily on the *Q*-factor of the resonant circuit and amounts to:

$$B = f_g - f_d = \frac{f_0}{Q}$$

A similar shape to the current characteristic has a characteristic showing the course of the voltage on the coil or capacitor as a function of frequency. This results in the possibility of using a serial resonant circuit to select signals at a specific frequency, e.g. to select stations in a radio receiver.

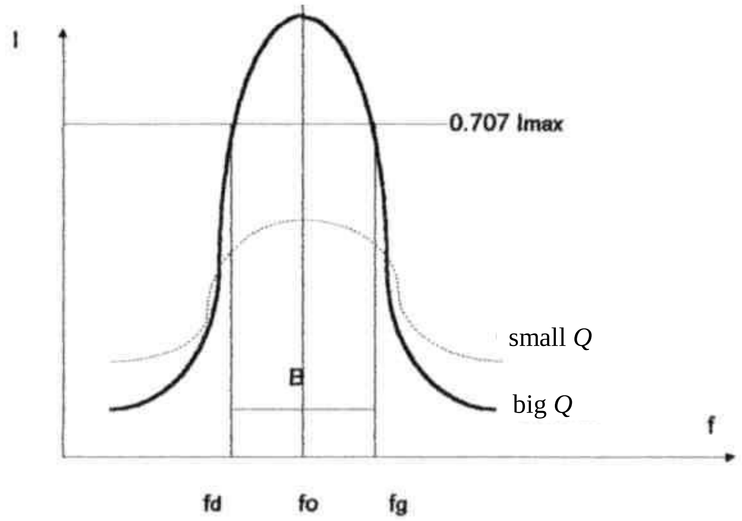

Fig. 2.5.5 Chart of the serial resonant circuit

If to the input of the resonant circuit we will connect voltage from the antenna, containing signals coming from many radio stations, with different frequencies and then by changing the capacitor's capacitance we will lead the circuit to resonance at the station frequency we want to listen to at the given moment *Q* times higher than the remaining station signal voltages. With sufficiently good kindness, it is possible to obtain such a large difference in voltages that practically only the selected station will be heard.

2.5.4. Parallel resonance circuit

The parallel resonance circuit is created by connecting the capacitance *C* and inductance *L* in parallel to the voltage source. The actual circuit, like the series resonant circuit, also has a loss resistance *R*. Note that if the resistance is presented as a parallel opacitor, the low resistance value represents large losses and high resistance small losses. Therefore, the definition of *Q*-factor for a parallel resonance circuit with a parallel loss presentation is as:

$$Q = \frac{R}{X_{L0}} = \frac{R}{X_{C0}}$$

The resonance condition and resonant frequency are the same as for the series resonance circuit.

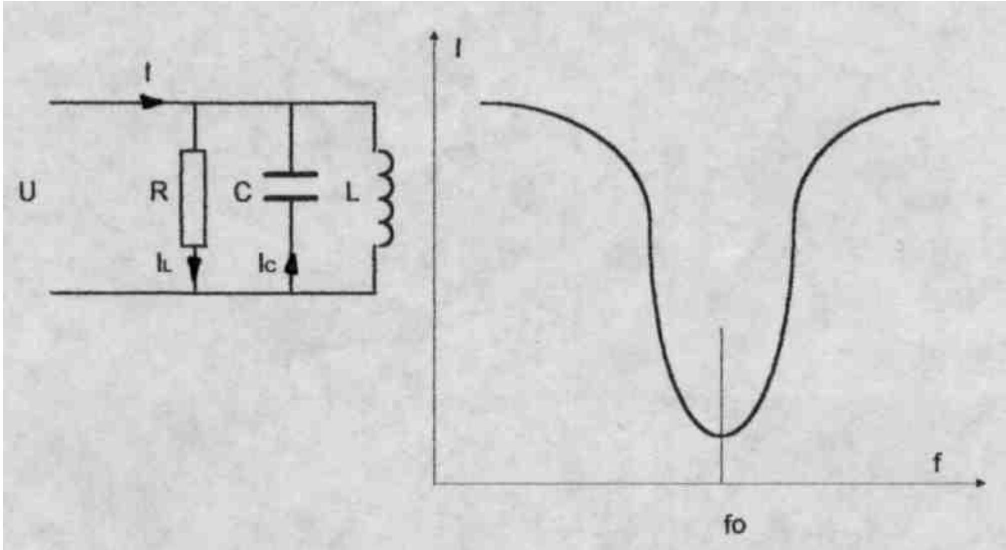

Fig. 2.5.6. Parallel resonant circuit and its characteristics

The parallel resonance circuit in resonance has the following properties:

- the circuit impedance reaches maximum $Z = R$
- the current reaches the minimum $I = \frac{U}{R}$
- the coil and capacitor currents are equal $I_C = I_L$,

The feature of the parallel resonant circuit is the tendency to generate vibrations. In an ideal resonance circuit, ie in a circuit without losses, after stimulation, a current circulating on the principle of energy exchange of the electric field in the capacitor and electromagnetic in the coil would flow in the loop consisting of the capacitance and inductance. There would be undefining electric vibrations with a frequency equal to natural frequency of the circuit (resonant frequency f_0). The circuit would not take electricity from the source. In the real circuit also vibrations will be generated, however, as a result of losses on resistance, these will be fading.

Parallel resonant circuits are mainly used for the construction of *LC* type generators and for the construction of selective (resonant) amplifiers. In the case of resonant amplifiers, it is used in resonance that the circuit has maximum resistance. Because the gain of the amplifier is proportional to the resistance in the collector of the transistor, so inserting a parallel resonant circuit instead of a resistor in this place will cause the amplifier to have maximum amplification for the resonant frequency.