

New properties of the reactive elements of the radio-technical chains

F. F. Mende

B. Verkin Institute for Low Temperature Physics and Engineering NAS
Ukraine, Kharkov, Ukraine.

E-mail: mende_fedor@mail.ru

The article describes the new features of reactive elements of radio circuits. It is shown that reactive elements such as the capacitance and inductance may possess properties of resistance, depending on time. A new method to obtain the wave equation of long lines, allowing the possibility to solve the problem of distribution, which can not be solved by telegraph equations. It is shown that stretches long lines have macroscopic quantum properties.

Keywords: reactive elements, capacitance, inductance, long line, Maxwell equations, vector potential.

1. Introduction

To the laws of self-induction should be carried those laws, which describe the reaction of such elements of radio-technical chains as capacity, inductance and resistance with the galvanic connection to them of the sources of current or voltage [1-4]. These laws are the basis of the theory of electrical chains. The results of this theory can be postponed also by the electrodynamics of material media, since. such media can be represented in the form equivalent diagrams with the use of such elements [5].

The motion of charges in any chain, which force them to change their position, is connected with the energy consumption from the power sources. The processes of interaction of the power sources with such structures are regulated by the laws of self-induction.

To the self-induction let us carry also that case, when its parameters can change with the presence of the connected power source or the energy accumulated in the system. This self-induction we will call parametric [2]. Subsequently we will use these concepts: as current generator and the voltage generator. By ideal voltage generator we will understand such source, which ensures on any load the lumped voltage, internal resistance in this generator equal to zero. By ideal current generator we will understand such source, which ensures in any load the assigned current, internal resistance in this generator equally to infinity. The ideal current generators and voltage in nature there does not exist, since both the current generators and the voltage generators have their internal resistance, which limits their possibilities.

If we to one or the other network element connect the current generator or voltage, then opposition to a change in its initial state is the response reaction of this element and this opposition is always equal to the applied action, which corresponds to third Newton's law.

2. Self-induction of the reactive elements

If the capacity C is charged to a potential difference U , then the charge Q , accumulated in it, is determined by the relationship

$$Q_{C,U} = CU \quad (2.1).$$

The charge $Q_{C,U}$, depending on of capacitance value and from a voltage drop across it, we will call still the flow of electrical self-induction.

When speech goes about a change in the charge, determined by relationship (2.1), that this value it can change with the method of changing the potential

difference with a constant capacity, either with a change in capacity itself with a constant potential difference, or and that and other parameter simultaneously.

If capacitance value or voltage drop across it depend on time, then the current strength is determined by the relationship:

$$I = \frac{dQ_{C,U}}{dt} = C \frac{dU}{dt} + U \frac{dC}{dt}.$$

This expression determines the law of electrical self-induction. Thus, current in the circuit, which contains capacitor, can be obtained by two methods, changing voltage across capacitor with its constant capacity either changing capacity itself with constant voltage across capacitor, or to produce change in both parameters simultaneously.

For the case, when the capacity C_1 is constant, we obtain known expression for the current, which flows through the capacity:

$$I = C_1 \frac{dU}{dt}, \quad (2.2)$$

when changes capacity, and at it is supported the constant voltage U_1 , we have:

$$I = U_1 \frac{dC}{dt}. \quad (2.3)$$

This case to relate to the parametric electrical self-induction, since the presence of current is connected with a change in this parameter as capacity.

Let us examine the consequences, which escape from relationship (11.2).

if we to the capacity connect the direct-current generator of I_0 , then voltage on it will change according to the law:

$$U = \frac{I_0 t}{C_1}. \quad (2.4)$$

Thus, the capacity, connected to the source of direct current, presents for it the effective resistance

$$R = \frac{t}{C_1} \quad (2.5)$$

which linearly depends on time. The it should be noted that obtained result is completely obvious; however, such properties of capacity, which customary to assume by reactive element they were for the first time noted in the work [6].

This is understandable from a physical point of view, since in order to charge capacity, source must expend energy.

The power, expended in this case by source, is determined by the relationship:

$$P(t) = \frac{I_0^2 t}{C_1} . \quad (2.6)$$

The energy, accumulated by capacity in the time t , we will obtain, after integrating relationship (2.6) with respect to the time:

$$W_c = \frac{I_0^2 t^2}{2C_1} .$$

Substituting here the value of current from relationship (11.4), we obtain the dependence of the value of the accumulated in the capacity energy from the instantaneous value of voltage on it:

$$W_c = \frac{1}{2} C_1 U^2 .$$

Using for the case examined a concept of the flow of the electrical induction

$$\Phi_U = C_1 U = Q(U) \quad (2.7)$$

and using relationship (2.2), we obtain:

$$I_0 = \frac{d\Phi_U}{dt} = \frac{dQ(U)}{dt} \quad (2.8)$$

i.e., if we to a constant capacity connect the source of direct current, then the current strength will be equal to the derivative of the flow of capacitive induction on the time.

Now we will support at the capacity constant voltage U_1 , and change capacity itself, then

$$I = U_1 \frac{dC}{dt} . \quad (2.9)$$

It is evident that the value

$$R_c = \left(\frac{dC}{dt} \right)^{-1}, \quad (2.10)$$

plays the role of the effective resistance [6]. This result is also physically intelligible, since, with an increase in the capacitance increases the energy accumulated in it, and thus, capacity extracts in the voltage source energy, presenting for it resistive load. The power, expended in this case by source, is determined by the relationship:

$$P(t) = \frac{dC}{dt} U_1^2 \quad (2.11)$$

From relationship (2.11) is evident that depending on the sign of derivative the expendable power can have different signs. When the derived positive, expendable power goes for the accomplishment of external work. If derived negative, then external source accomplishes work, charging capacity.

Again, introducing concept the flow of the electrical induction

$$\Phi_c = CU_1 = Q(C),$$

we obtain

$$I = \frac{\partial \Phi_c}{\partial t} \quad (2.12)$$

Relationships (2.8) and (2.12) indicate that regardless of the fact, how changes the flow of electrical self-induction (charge), its time derivative is always equal to current.

Let us examine one additional process, which earlier the laws of induction did not include, however, it falls under for our extended determination of this concept. From relationship (2.7) it is evident that if the charge, left constant (we will call this regime the regime of the frozen electric flux), then voltage on the capacity can be changed by its change. In this case the relationship will be carried out:

$$CU = C_0U_0 = const ,$$

where C and U are instantaneous values, and C_0 and U_0 are initial values of these parameters, which occur with turning off from the capacity of the power source. The voltage on the capacity and the energy, accumulated in it, will be in this case determined by the relationships:

$$U = \frac{C_0U_0}{C} , \quad (2.13)$$

$$W_c = \frac{1}{2} \frac{(C_0U_0)^2}{C} .$$

It is natural that this process of self-induction can be connected only with a change in capacity itself, and therefore it falls under for the determination of parametric self-induction.

Thus, are located three relationships (2.8), (2.12) and (2.13), which determine the processes of electrical self-induction. We will call their rules of the electric flux. Relationship (2.8) determines the electrical self-induction, during which there are no changes in the capacity, and therefore this self-induction can be named simply electrical self-induction. Relationships (2.3) and (2.9-2.11) assume the presence of changes in the capacity; therefore the processes, which correspond by these relationships, we will call electrical parametric self-induction.

Let us now move on to the examination of the processes, proceeding in the inductance. Let us introduce the concept of the flow of the current self-induction

$$\Phi_{L,I} = LI .$$

If inductance is shortened outed, and made from the material, which does not have effective resistance, for example from the superconductor, then

$$\Phi_{L,I} = L_1I_1 = const ,$$

where L_1 and I_1 are initial values of these parameters, which are located at the moment of the short circuit of inductance with the presence in it of current.

This regime we will call the regime of the frozen flow [1-3]. In this case the relationship is fulfilled:

$$I = \frac{I_1 L_1}{L}, \quad (2.14)$$

where I and L are the instantaneous values of the corresponding parameters.

In flow regime examined of current induction remains constant, however, in connection with the fact that current in the inductance it can change with its change, this process falls under for the determination of parametric self-induction. The energy, accumulated in the inductance, in this case will be determined by the relationship

$$W_L = \frac{1}{2} \frac{(L_1 I_1)^2}{L} = \frac{1}{2} \frac{(const)^2}{L}.$$

Voltage on the inductance is equal to the derivative of the flow of current induction on the time:

$$U = \frac{d\Phi_{L,I}}{dt} = L \frac{dI}{dt} + I \frac{dL}{dt}.$$

let us examine the case, when the inductance of is constant.

$$U = L_1 \frac{dI}{dt}, \quad (2.15)$$

Designating $\Phi_I = L_1 I$, we obtain $U = \frac{d\Phi_I}{dt}$.

After integrating expression (2.15) on the time, we will obtain:

$$I = \frac{Ut}{L_1}. \quad (2.16)$$

Thus, the capacity, connected to the source of voltage, presents for it the effective resistance

$$R = \frac{L_1}{t}, \quad (2.17)$$

which decreases inversely proportional to time.

The power, expended in this case by source, is determined by the relationship:

$$P(t) = \frac{U^2 t}{L_1}. \quad (2.18)$$

This power linearly depends on time. After integrating relationship (2.18) on the time, we will obtain the energy, accumulated in the inductance

$$W_L = \frac{1}{2} \frac{U^2 t^2}{L_1}. \quad (2.19)$$

After substituting into expression (2.19) the value of voltage from relationship (2.16), we obtain:

$$W_L = \frac{1}{2} L_1 I^2.$$

This energy can be returned from the inductance into the external circuit, if we open inductance from the power source and to connect effective resistance to it.

Now let us examine the case, when the current I_1 , which flows through the inductance, is constant, and inductance itself can change. In this case is fulfilled the relationship

$$U = I_1 \frac{dL}{dt}. \quad (2.20)$$

Thus, the value

$$R(t) = \frac{dL}{dt} \quad (2.21)$$

plays the role of the effective resistance [6]. As in the case the electric flux, effective resistance can be (depending on the sign of derivative) both positive and negative. This means that the inductance can how derive energy from without, so also return it into the external circuits.

Introducing the designation $\Phi_L = LI_1$ and, taking into account (2.20), we obtain:

$$U = \frac{d\Phi_L}{dt}. \quad (2.22)$$

The relationship (2.14), (2.19) and (2.22) we will call the rules of current self-induction, or the flow rules of current self-induction. From relationships (2.19) and (2.22) it is evident that, as in the case with the electric flux, the method of changing the flow does not influence eventual result, and its time derivative is always equal to the applied potential difference. Relationship (2.19) determines the current self-induction, during which there are no changes in the inductance, and therefore it can be named simply current self-induction. Relationships (2.20,2.21) assume the presence of changes in the inductance; therefore we will call such processes current parametric self-induction.

3. New method of obtaining the wave equation

The processes, examined in two previous paragraphs, concern chains with the lumped parameters, when the distribution of potential differences and currents in the elements examined can be considered uniform. However, there are chains, for example the long lines, into which potential differences and currents are not three-dimensional uniform. These processes are described by the wave equations, which can be obtained from Maxwell equations or with the aid of the telegraphic equations, but physics of phenomenon itself in these processes to us is not clear.

We will use the results, obtained in the previous paragraph, for examining the processes, proceeding in the long lines, in which the capacity and inductance are the distributed parameters. We will consider that the linear capacity and the inductance of line is equal C_0 and L_0 respectively. If we to this line connect the dc power supply U_1 , then its front will be extended in the line some by the speed v , and the moving coordinate of this front will be determined by the relationship $z = vt$. In this case the total quantity of the charged capacity and the value of the summary

inductance, along which it flows current, calculated from the beginning lines to the location of the front of voltage, will change according to the law [1]:

$$C(t) = zC_0 = vt C_0,$$

$$L(t) = zL_0 = vt L_0.$$

The source of voltage U_1 will in this case charge the being increased capacity of line, for which from the source to the charged line in accordance with relationship (2.9) must leak the current:

$$I_1 = U_1 \frac{dC(t)}{dt} = vU_1 C_0. \quad (3.1)$$

This current there will be the leak through the conductors of line, that possess inductance. But, since the inductance of line in connection with the motion of the front of voltage, also increases, in accordance with relationship (2.20), on it will be observed a voltage drop:

$$U = I_1 \frac{dL(t)}{dt} = vI_1 L_0 = v^2 U_1 C_0 L_0.$$

But a voltage drop across the conductors of line in the absolute value is equal to the voltage, applied to its entrance; therefore in the last expression should be placed $U = U_1$. We immediately find taking this into account that the rate of the motion of the front of voltage with the assigned linear parameters and when, on, the incoming line of constant voltage U_1 is present, must compose

$$v = \frac{1}{\sqrt{L_0 C_0}}. \quad (3.2)$$

This expression corresponds to the signal velocity in line itself. Consequently, if we to the infinitely long line connect the voltage source, then in it will occur the expansion of electrical pour on and the currents, which fill line with energy, and the speed of the front of constant voltage and current will be equal to the velocity of propagation of electromagnetic vibrations in this line. This wave can be named electrocurrent wave. It is interesting to note that the obtained result does not depend

on the form of the function U , i.e., to the line can be connected both the dc power supply and the source, whose voltage changes according to any law. In all these cases the value of the local value of voltage on incoming line will be extended along it with the speed, which follows from relationship (3.2). This result could be, until now, obtained only by the method of solution of wave equation, but in this case he indicates the physical cause for this propagation, and it gives the physical picture of process itself. Examination shows that very process of propagation is connected with the energy processes of the filling of line with electrical and current energy. This process occurs in such a way that the wave front, being extended with the speed v , leaves after itself the line, charged to a potential difference U_1 , which corresponds to the filling of line with electrostatic electric field energy. However, in the section of line from the voltage source also to the wave front flows the current I_1 , which corresponds to the filling of line in this section with energy, which is connected with the motion of the charges along the conductors of line, which possess inductance.

The current strength in the line can be obtained, after substituting the values of the velocity of propagation of the wave front, determined by relationship (3.2), into relationship (3.1). After making this substitution, we will obtain

$$I_1 = U_1 \sqrt{\frac{C_0}{L_0}},$$

where $Z = \sqrt{\frac{L_0}{C_0}}$ is line characteristic.

In this case

$$U_1 = I \frac{dL}{dt} = \frac{d\Phi_L}{dt}.$$

So accurately

$$I_1 = U_1 \frac{dC}{dt} = \frac{d\Phi_C}{dt}.$$

It is evident that the flow rules both for the electrical and for the current self-induction are observed also in this case.

Thus, the processes of the propagation of a potential difference along the conductors of long line and current in it are connected and mutually supplementing each other, and to exist without each other they do not can. This process can be called electrocurrent spontaneous parametric self-induction. This name connected with the fact that flow expansion they occur arbitrarily and characterizes the rate of the process of the filling of line with energy. From the aforesaid the connection between the energy processes and the velocity of propagation of the wave fronts in the long lines becomes clear. Since with the emission of electromagnetic waves the free space is also transmission line, similar laws must characterize propagation in this space.

Let us examine the case, when the spiral, which presents long solenoid, is undertaken as one of the conductors of long line. Obviously, in this case the velocity of propagation of the front of voltage in this line will decrease, since the linear inductance of line will increase. This propagation will accompany the process of the propagation not only of external with respect to the solenoid pour on and currents, but both the process of the propagation of magnetic flux inside the solenoid itself and the velocity of propagation of this flow will be equal to the velocity of propagation of electromagnetic wave in line itself.

Knowing current and voltage in the line, it is possible to calculate the specific energy, concluded in the linear capacity and the inductance of line. These energies will be determined by the relationships:

$$W_C = \frac{1}{2} C_0 U_1^2, \quad (3.3)$$

$$W_L = \frac{1}{2} L_0 I_1^2. \quad (3.4)$$

In this case $W_C = W_L$.

Now let us discuss a question about the duration of the front of electrocurrent wave and about which space will occupy this front in line itself. Answer to the first question is determined by the properties of the very voltage source, since. local derivative $\frac{\partial U}{\partial t}$ at incoming line depends on transient processes in the source itself and in that device, with the aid of which this source is connected to the line. If the process of establishing the voltage on incoming line will last some time Δt , then in the line it will engage section with the length $v\Delta t$. If we to the line exert the voltage, which is changed with the time according to the law $U(t)$, then the same value of function will be observed at any point of the line at a distance of z rel.un. of beginning with the delay $t = \frac{z}{v}$. Thus, the function of

$$U(t, z) = U\left(t - \frac{z}{v}\right) \quad (3.5)$$

can be named propagation function, since. it establishes the connection between the local temporary and three-dimensional values of function in the line. Long line is the device, which converts local derivative voltages on the time on incoming line into the gradients in line itself. On the basis propagation function (3.5) it is possible to establish the connection between the local and gradients in the long line. It is obvious that

$$\frac{\partial U(z)}{\partial z} = \frac{1}{v} \frac{\partial U(t)}{\partial t}.$$

Is important to note that very process of propagation in this case is obliged to the natural expansion of electric field and current in the line, and it is subordinated to the rules of parametric self-induction.

In the second place, for solving the wave equations of the long lines of

$$\begin{aligned}\frac{\partial^2 U}{\partial z^2} &= \frac{1}{v^2} \frac{\partial^2 U}{\partial t^2} \\ \frac{\partial^2 I}{\partial z^2} &= \frac{1}{v^2} \frac{\partial^2 I}{\partial t^2},\end{aligned}\tag{3.6}$$

obtained from the telegraphic equations

$$\begin{aligned}\frac{\partial U}{\partial z} &= -L \frac{\partial I}{\partial t} \\ \frac{\partial I}{\partial z} &= -C \frac{\partial U}{\partial t},\end{aligned}$$

the knowledge second derivative voltages and currents is required [7].

But what is to be done, if to incoming line is supplied voltage, whose second derivative is equal to zero (case, when the voltage of source it does change according to the linear law)? Answer to this question equation (3.6) they do not give. The utilized method gives answer also to this question.

With the examination of processes in the long line figured such concepts as linear capacity and inductance, and also currents and voltage in the line. However, in the electrodynamics, based on Maxwell equations, there are no such concepts as capacity and inductance, and there are concepts of the electrical and magnetic permeability of medium [8]. In the carried out examination such concepts as electrical and magnetic fields also was absent. Let us show how to pass from such categories as linear inductance and capacity, current and voltage in the line to such concepts as dielectric and magnetic constant, and also electrical and magnetic field. For this let us take the simplest construction of line, located in the vacuum, as shown in Fig. 1.

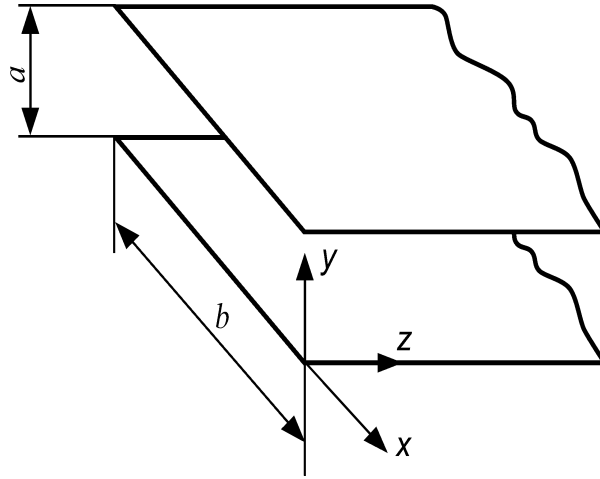


Fig. 1. The two-wire circuit, which consists of two ideally conducting planes.

We will consider that $b \gg a$ and edge effects it is possible not to consider. Then the following connection will exist between the linear parameters of line and the magnetic and dielectric constants:

$$L_0 = \mu_0 \frac{a}{b}, \quad (3.7)$$

$$C_0 = \varepsilon_0 \frac{b}{a}, \quad (3.8)$$

where μ_0 and ε_0 are dielectric and magnetic constant of vacuum.

The phase speed in this line will be determined by the relationship:

$$v = \frac{1}{\sqrt{L_0 C_0}} = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = c,$$

where c is velocity of propagation of light in the vacuum.

The wave drag of the line examined will be equal

$$Z = \frac{a}{b} \sqrt{\frac{\mu_0}{\varepsilon_0}} = \frac{a}{b} Z_0,$$

where $Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ is wave drag of free space.

With the observance of the condition of $a = b$ we obtain the equality $L_0 = \mu_0$.

This means that magnetic permeability of μ_0 plays the role of the longitudinal specific inductance of vacuum. In this case is observed also the equality $C_0 = \epsilon_0$. This means that the dielectric constant ϵ_0 plays the role of the transverse specific capacity of vacuum. In this interpretation both μ_0 and ϵ_0 acquire clear physical sense and, just as in the long line, ensure the process of the propagation of electromagnetic wave in the free space.

The examination of electromagnetic wave in the long line can be considered as filling of space, which is been located between its conductors, special form of material, which present the electrical and magnetic fields. Mathematically it is possible to consider that these fields themselves possess specific energy and with their aid it is possible to transfer energy by the transmission lines. But if we examine the processes, which take place with the emission of electromagnetic waves with the aid of any antenna, then it it is possible to examine also as the filling of free space with this form of material. However, pour on geometric form and currents in this case it will be more complexly, since they will always be present both transverse and longitudinal component pour on. This approach excludes the need for application, for describing the propagation of electromagnetic waves, this substance as ether.

If we to the examined line of infinite length, or of line of that loaded with wave drag, connect the dc power supply U , then the field strength in the line will comprise:

$$E_y = \frac{U}{a},$$

and the current, which flows into the line from the power source, will be determined by the relationship:

$$I = \frac{U}{Z} = \frac{aE_y}{Z}. \quad (3.9)$$

Magnetic field in the line will be equal to the specific current, flowing in the line

$$H_x = \frac{I}{b} = \frac{aE_y}{bZ}.$$

substituting here the value Z , we obtain

$$H_x = \frac{E_y}{Z_0}. \quad (3.10)$$

The same connection between the electrical and magnetic field exists also for the case of the transverse electromagnetic waves, which are extended in the free space.

Comparing expressions for the energies, it is easy to see that the specific energy can be expressed through the electrical and magnetic fields

$$\frac{1}{2}\mu_0 H_x^2 = \frac{1}{2}\epsilon_0 E_y^2. \quad (3.11)$$

This means that the specific energy, accumulated in the magnetic and electric field in this line is identical. If the values of these energies are multiplied by the volumes, occupied by fields, then the obtained values coincide with expressions (3.3-3.4).

Thus, it is possible to make the conclusion that in the line examined are propagated the same transverse plane waves, as in the free space. Moreover this conclusion is obtained not by the method of solution of Maxwell equations, but by the way of examining the dynamic processes, which are related to the discharge of parametric self-induction. The special feature of this line will be the fact that in it, in contrast to the free space, the stationary magnetic and electric fields can be extended, but this case cannot be examined by the method of solution of Maxwell equations.

The special feature of this line is the fact that with the flow in the line of direct current the distribution of electrical and magnetic pour on in it it is uniform. It is not difficult to show that the force, which acts on the conductors of this line, is equal to zero. This follows from relationship (3.11), in which its right and leftist of part present the force gradients, applied to the planes of line. But electrical and magnetic forces have different signs; therefore they compensate each other. This conclusion concerns the transmission lines of any other configuration.

If we to the line exert the voltage, which is changed in the course of time according to any law $U(t) = aE_y(t)$, the like of analogy (3.5) it is possible to write down

$$E_y(z) = E_y\left(t - \frac{z}{c}\right). \quad (3.12)$$

Analogous relationship will be also pour on for the magnetic.

Is obvious that the work $I(t)U(t)$ represents the power P , transferred through the cross section of line in the direction z . If in this relationship current and voltage was replaced through the tensions of magnetic and electrical pour on, then we will obtain $P = abE_yH_x$. The work E_yH_x represents the absolute value of Poynting vector, which represents the specific power, transferred through the cross section of the line of single area. Certainly, all these relationships can be written down also in the vector form.

Thus, all conclusions, obtained on the basis of the examination of processes in the long line by two methods, coincide. Therefore subsequently, without risking to commit the errors of fundamental nature, it is possible for describing the processes in the long lines successfully to use such parameters as the distributed inductance and capacity. Certainly, in this case one should understand that C_0 and this L_0 some integral characteristics, which do not consider structure pour on. It should be noted that from a practical point of view, the application of the parameters C_0 and L_0 has important significance, since can be approximately solved the tasks, which with the aid of Maxwell equations cannot be solved. This, for example, the case, when spirals are the conductors of transmission line.

4. Macroscopic quantization in the sections of the long lines

Farady established the law of induction, carrying out experiments on the solenoids, including turning off in them current, or moving with respect to the solenoids the turns of the wire, to which was connected the galvanometer. Its point of view, which is considered accurate and today, was reduced to the fact that with the connection to the solenoid of the dc power supply U , then current in all its turns increases according to the linear law of

$$I = \frac{Ut}{L}, \quad (4.1)$$

where L is inductance of solenoid.

Consequently, magnetic field with this interpretation for entire elongation of solenoid will increase synchronous. However, so whether this in reality? In order to be dismantled at this, let us examine a question about how swelling current in the shortened out section of long line will.

If line (Fig. 2) to short out at a distance z_1 , then summary the inductance of line will compose the value $L_{\Sigma} = z_1 L_0 = z_1 \frac{a}{b} \mu_0$. If we connect to the line dc power supply, in it will begin to be extended the wave of the voltage $I = \frac{U}{Z}$ and current U as shown in Fig. 2 The wave of voltage in its right part has the transition section z_2 , which is named the front of the wave of voltage. This section corresponds to the transit time $\tau = \frac{z_2}{c}$, for which the voltage of the source, connected to the line, attains its nominal value.

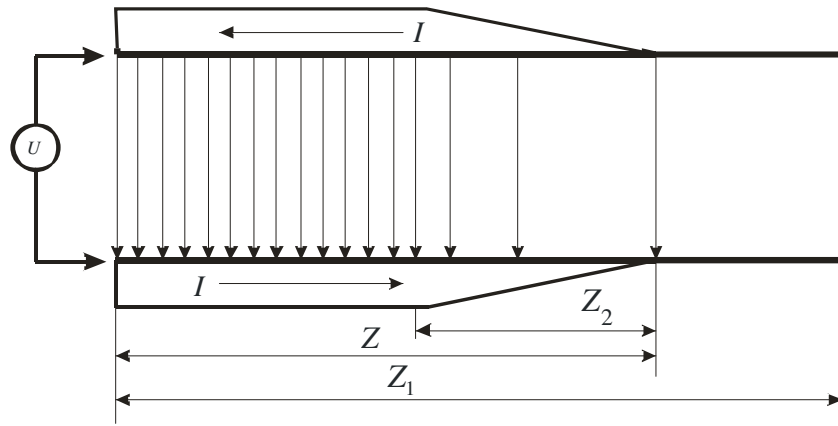


Fig. 2. Propagation of the current wave and voltage in the long line.

Specifically, in this transition section proceeds the acceleration of the charges from the zero speed in its beginning, to the values necessary for creating the rated current in the line, whose value is determined by the relationship $I = \frac{U}{Z}$. To this section is

applied the voltage of the power source. In this case it is accepted that during the voltage transient increases according to the linear law (although in the general case it can increase according to any other law). It is accepted also that the time of this transient process is considerably less than the time, for which the front of voltage passes along the line to one side. The interval z_2 corresponds to the transient process, which is connected with the inertia properties of the device, which connects the voltage source to the line. It is assumed that z_1 is considerably greater than z_2 .

At the moment of the time, when on the cross connection in the end of the line appears the front of the voltage of , appears the wave with the voltage of reflected, which runs in the opposite direction. Since current in the wave reflected is equal to voltage with the negative sign and it moves in the opposite direction, then the

summed current, created by this wave will be equal $-\left(-\frac{U}{Z}\right) = \frac{U}{Z}$, i.e., it there will

be leak in the same direction as the current of the incident wave. Thus, the wave

reflected, moving in the opposite direction, will leave after itself current, equal $\frac{2U}{Z}$, and zero voltage. When the front of voltage to return at the beginning to line, it brings with itself the state of the doubled initial current and zero voltage. Source will again send into the front line of the voltage U and current $\frac{U}{Z}$. This current will be formed with the current $\frac{2U}{Z}$, and summed current in the line will compose $\frac{3U}{Z}$. Current will further increase by steps, adding each sequential time to its previous value the value $\frac{2U}{Z}$. If this process reflected in the time, thus will appear, as shown in Fig. (3) In this figure the time

$$T = \frac{z_1}{c} = z_1 \sqrt{L_0 C_0} = z_1 \sqrt{\mu_0 \epsilon_0}$$

it is equal to the time, for which the front of voltage passes along the line to one side of beginning to the shortened out section.

The special feature of this process is that that the selection of energy from the voltage source will not be subordinated to linear law, but it will have spasmodic nature. The power, selected in the range of time from zero to $2T$, will be equal $\frac{U^2}{Z}$. But in each subsequent interval of the time, equal $2T$, it will grow already to the value $\frac{2U^2}{Z}$.

Thus, the growth of current bears completely not linear, but spasmodic nature, and it is more expressed, the greater the length of line. The process indicated occurs with any length of line. With the small length of gallop they follow through the small time intervals and the dependence of current on the time approximately it is possible to consider it linear that also is characteristic for the elements with the lumped parameters.

Should be focused attention on the fact that, the power, selected by the shortened out line in the source of voltage (Fig. 3), it is not linear function, but after the time equal $2T$ abruptly it increases by $\frac{2U^2}{Z}$, the first of gallops corresponding to the selected power $\frac{U^2}{Z}$.

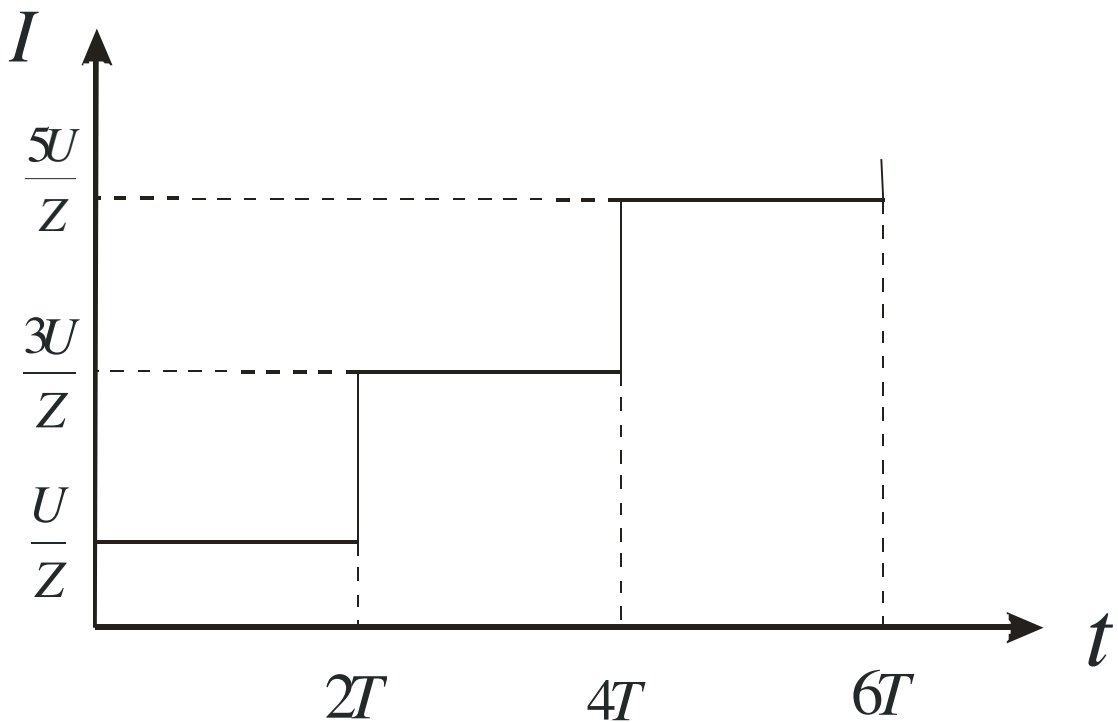


Fig. 3. Dependences of input current on the time in shortened out line.

Consequently, the shortened out line extracts energy in the voltage source not by continuous means, but by portions (edgings). This first portion would $U^2 C_0 z_1$, and each subsequent portion is equal $2U^2 C_0 z_1$.

Is not difficult to show that the magnetic flux in this case changes according to the linear law (Fig. 4). Actually, during the forward stroke, to the moment of

reaching by the wave of the shortened out section, flow will increase in the linear law, and up to the moment T it will reach the value $\Phi_B = \frac{z_1}{c}U$.

When, after being reflected from the shortened out section, the front of voltage will begin to move in the opposite direction, then flow will continue to grow according to the linear law, and up to the moment of the arrival of the front of voltage at the voltage source it will conversely reach the value $\Phi_B = \frac{2z_1}{c}U$.

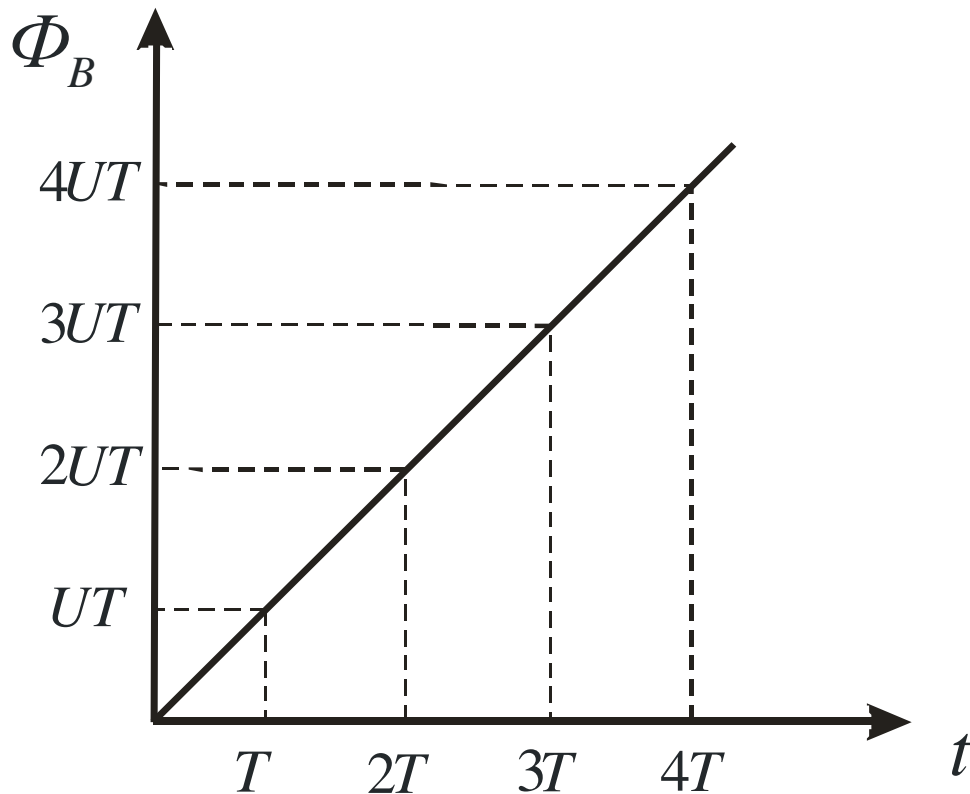


Fig. 4. Dependence of magnetic flux on the time in the shortened out line.

Thus, with the connection of the shortened out line to the voltage source is carried out the law of induction $U = \frac{d\Phi_B}{dt}$.

The electric flux in the line will also change, but according to another law (Fig. 5).

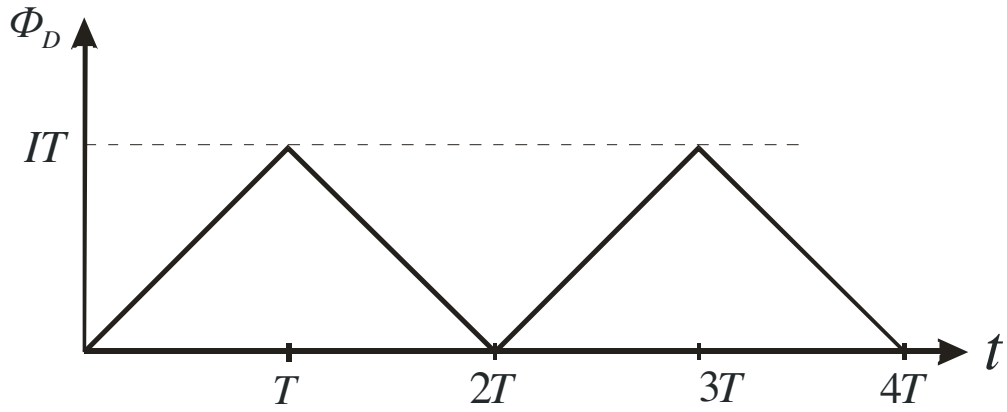


Fig. 5. Dependence of the electric flux on the time for the shortened out line.

In contrast to the magnetic flux it will change periodically, first, growing, then, diminishing, according to the linear law. When wave moves in the positive direction, simultaneously grows magnetic and electric flux. In this case, both in the magnetic and in the electric field stored energy grows. When wave begins to move in the opposite direction, then electric field begins to disappear, and its energy passes into the magnetic energy of reverse current wave. After the front of the wave of voltage reaches incoming line, magnetic field and current in it doubles, and electric field disappears. Further cycle is repeated. Consequently, the process of the growth of magnetic flux in that shortened out by long line, in the required order accompanies the process of an alternation in the flow of electrical induction, as a result of which between the planes of line periodically it appears and it disappears electric field.

Let us assume that line is made from superconductor and loss-free. Then after replacing at the specific moment the voltage generator with the superconductive cross connection, it is possible to freeze current in the line. The moment, when in the line electric field completely is absent is favorable moment for this procedure.

Then in the line is frozen the flow $\Phi_B = \frac{2Nz_1}{c}U$, to which will correspond the

current $I = \frac{2NU}{Z}$.

This phenomenon is an example of the macroscopic quantization of flow in the macroscopic structures, which have the specific sizes. The same quantization of flow occurs also in the microscopic structures, which the atoms are.

From the point of view of chains with the lumped parameters, growth of current in the solenoid with the connection to it of the voltage source occur according to the linear law, moreover in all its turns simultaneously. But so whether this? For explaining this question let us replace the upper plane of the two-wire circuit (Fig. 6) by long solenoid. If we to this line connect the voltage source, then the process of the growth of current in it will in no way differ from that examined. The linear inductance of line will be now in essence determined by the linear inductance of solenoid and the velocity of propagation and current wave, and the wave of the voltage (voltage now it will be applied between the solenoid and the lower conductor of line) it will be less than in the preceding case.

When in the line examined wave will reach the point with the coordinate z_1 , then magnetic field fill only the part of the solenoid, located between the power source and the point z_1 . When wave reaches its end, then magnetic field fill entire solenoid. The magnetic field in the solenoid will be doubled with the back stroke of wave, and process will begin first. Thus, internal magnetic flux in any cross section of solenoid will increase not smoothly, but irregularly, and the period of these jumps will be determined by transit time by the wave of this shortened out section of solenoid.

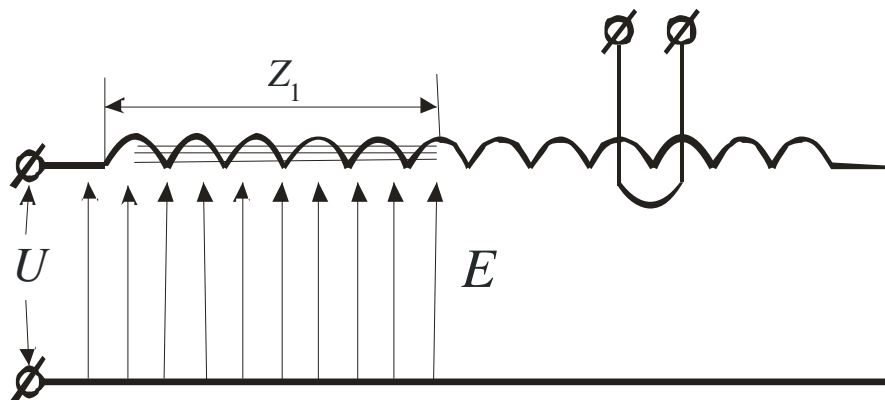


Fig. 6 . The diagram of the propagation of magnetic and electrical pour on in the long solenoid.

Let us place now that the solenoid in the specific place is envelopped by turn. This process is such to mechanical dressing of the covering turn to the end of the solenoid with the only difference that in this case magnetic flux, being moved inside the solenoid, itself it pierces its covering turn. Moreover the speed of the motion of the front of magnetic flux in this case is incommensurably more than during mechanical dressing. But both processes have identical nature. By these processes is explained the phenomenon of the mutual induction between the solenoid and the covering turn. The pulse separation is small with the small length of solenoid; therefore they, merging, is formed almost constant voltage. Voltage in the turn will be induced only at the moment of the intersection with the magnetic flux of the solenoid of the environments of the cross section, envelopped by turn. In the environments of the covering turn will at this moment appear both the vector potential and the magnetic field. And, precisely, the intersection of the covering turn with the magnetic fields of the scattering (the same, as at the end of the solenoid with the direct current) leads to the induction in it emf. This moment will begin both with the straight line and with the back stroke of wave; moreover the polarity of the voltage pulses, induced in the turn, in both cases will be one and the same. The frequency of these pulses will depend on the length of solenoid, and it will be the greater, the shorter the solenoid. Consequently, the average value of the induced voltage will be grow with the decrease of the length of solenoid, i.e., its quantity of turns, that also determines the transformation ratio of this transformer.

After examining the process of the growth of currents pour on in the long solenoid, let us return to the problem of the presence of the circulation of vector potential around the long solenoid. Let us give the existing point of view on this question, represented in the work [9]. The value of vector potential in the space, which surrounds solenoid, is found from the relationship

$$A(r) = \frac{nIr_0^2}{2\epsilon_0 c^2 r}, \quad (4.2)$$

where n is quantity of turns, which falls per unit of the length of solenoid, I is the current, which flows through the solenoid, r_0 is diameter of solenoid, r is distance from the axis of solenoid to the observation point. It is assumed during the record of this relationship that $r \geq r_0$.

The inductance of solenoid is determined by the expression

$$L = \frac{n^2 \pi r_0^2 z_0}{\epsilon_0 c^2}, \quad (4.3)$$

where z_0 is length of solenoid.

If we to the solenoid connect the dc power supply of U , then taking into account relationships (4.1,4.3), we obtain

$$A(r,t) = \frac{Ut}{2\pi Nr},$$

where N is total number of turns in the solenoid, and since

$$E = -\mu_0 \frac{\partial A}{\partial t},$$

that the tension of electric field in the environment of solenoid at the moment of the connection to it of dc power supply will comprise

$$E(r) = \frac{\mu_0 U}{2\pi Nr}.$$

The tension of electric field in accordance with the version in question appears at the moment of connection to the solenoid of the power source instantly for entire its

elongation. If the solenoid lacks resistance, then the tension of electric field will be constant during entire period of the time of connection to the solenoid of dc power supply. What here do appear contradictions? First, electric fields possess energy, and instantly they cannot appear. The second contradiction escapes from the first and consists in the fact that, since the electric fields possess energy, this energy must be included in the general energy, accumulated in the solenoid. But only magnetic fields inside the solenoid are considered with the calculation of this energy.

Thus, very process of inducing the electrical pour on around the long solenoid it occurs in no way in the manner that this represented in the existing literature [9], when it is considered that the circulation of magnetic vector potential for entire its elongation grows simultaneously, that also leads to the induction emf. in the covering turn.

from the aforesaid it is possible to conclude that the point of view about the appearance of electrical pour on inductions around the solenoid in that place, where the rotor of vector potential is equal to zero, it does not correspond to reality, and very process of the formation of vector potential outside the solenoid and magnetic pour on inside it does not correspond to those ideas, which exist today. The rotor of vector potential outside the solenoid is equal to zero, and this field possesses no energy; therefore to reveal it in the static behavior is impossible.

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