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SIMPLE SIMULATION OF LONG-DISTANCE LINE

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This paper illustrates the application of one component of MS Office package – Excel – in circuit theory on the simulation of the long-distance line in harmonic steady state and describes the special program for its analysis and graphic illustration of the results. In the first order it is shown how the theoretical expressions of the voltage and current wave on the long-distance line are modifying for this program, further it is shown how to access that basic functions of Excel to work with complex numbers and finally the program is described and illustrated. The special states (short connection or disconnection on the long-distance line output) and special events (lossless line and non-misleading line) analysis is also possible.

So this program enables full computer processing of long distance line analysis including graphics illustration of results.

Key words: Theory of electrical engineering, Circuits with distributed parameters, Long-distance line, Excel

Introduction. The simulation is a medium, which is currently very often used for the modeling and solving various kinds of problems. Also in the theory of electrical engineering are developed simulating programs for scientific [1], [2] as well as pedagogic part [3] of this theory.

In the pedagogic part of theory of electrical engineering, i.e. electric circuit analysis some kind of circuits are suitable for developing the general mathematic prescription for which is easy to make a computer program for their solving inclusive of its graphic representation, the other kind of circuits is not suitable for such a general mathematic prescription, but graphic illustration of the results are also very useful.

For the easy availability of such materials for wide rang of the students we use usual computer technique and software – operating system Windows and package Office, exactly one component of package Office – Excel although the efficiency of basic Office programs is underestimated very often. At first were developed computer programs for analysis of three-phase circuits with the appliance of connection format Y and connection format D [3] and the computer program for analysis of long-distance line now. These programs are components of electronic study materials, so that student is able to simulate many cases of solving problem and to compare received results.

Long-distance line analysis. The common description of long-distance line in the harmonic steady state is by two complex equations for complexors of voltage and current wave along the long line $\dot{U}(t,x)$ and $\dot{I}(t,x)$, which solution by the means of output voltage and current value $\dot{U}_2(t)$ and $\dot{I}_2(t)$ is [4]:

$$\dot{U}(t,x)=\frac{1}{2}\left(\dot{U}_2(t)+\dot{I}_2(t)\dot{Z}_{\text{v}}\right)\mathrm{e}^{\dot{\gamma}(l-x)}+ +\frac{1}{2}\left(\dot{U}_2(t)-\dot{I}_2(t)\dot{Z}_{\text{v}}\right)\mathrm{e}^{-\dot{\gamma}(l-x)} \quad (1)$$

and
$$\dot{I}(t,x)=\frac{1}{2}\left(\dot{I}_2(t)+\frac{\dot{U}_2(t)}{\dot{Z}_{\text{v}}}\right)\mathrm{e}^{\dot{\gamma}(l-x)}+ +\frac{1}{2}\left(\dot{I}_2(t)-\frac{\dot{U}_2(t)}{\dot{Z}_{\text{v}}}\right)\mathrm{e}^{-\dot{\gamma}(l-x)}, \quad (2)$$

where $\dot{\gamma}$ is the complex constant of wave propagation and $\dot{Z}_{\text{v}}$ is the complex wave impedance.

Let us write these equations in the form

$$\dot{U}(t,x)=\dot{K}_1(t)\mathrm{e}^{\dot{\gamma}(l-x)}+\dot{K}_2(t)\mathrm{e}^{-\dot{\gamma}(l-x)} \quad (3)$$

and

$$\dot{I}(t,x)=\dot{K}_3(t)\mathrm{e}^{\dot{\gamma}(l-x)}+\dot{K}_4(t)\mathrm{e}^{-\dot{\gamma}(l-x)}, \quad (4)$$

where

$$\dot{K}_1(t)=\frac{1}{2}\left(\dot{U}_2(t)+\dot{I}_2(t)\dot{Z}_{\text{v}}\right)=K_1(t)\mathrm{e}^{\mathrm{j}\varphi_{K1}}; \quad (5)$$

$$\dot{K}_2(t)=\frac{1}{2}\left(\dot{U}_2(t)-\dot{I}_2(t)\dot{Z}_{\text{v}}\right)=K_2(t)\mathrm{e}^{\mathrm{j}\varphi_{K2}}; \quad (6)$$

$$\dot{K}_3(t)=\frac{1}{2}\left(\dot{I}_2(t)+\frac{\dot{U}_2(t)}{\dot{Z}_{\text{v}}}\right)=K_3(t)\mathrm{e}^{\mathrm{j}\varphi_{K3}}; \quad (7)$$

$$\dot{K}_4(t)=\frac{1}{2}\left(\dot{I}_2(t)-\frac{\dot{U}_2(t)}{\dot{Z}_{\text{v}}}\right)=K_4(t)\mathrm{e}^{\mathrm{j}\varphi_{K4}}. \quad (8)$$

Then the *t* and *x* dependence of voltage and current wave along the long line for the sine resp. cosine time dependence of given electrical quantity will be:

$$u(t,x)=K_1\mathrm{e}^{\beta(l-x)}\sin\left(\omega t+\alpha(l-x)+\varphi_{K1}\right)+ +K_2\mathrm{e}^{-\beta(l-x)}\sin\left(\omega t-\alpha(l-x)+\varphi_{K2}\right) \quad (9a)$$

and

$$i(t,x)=K_3\mathrm{e}^{\beta(l-x)}\sin\left(\omega t+\alpha(l-x)+\varphi_{K3}\right)+ +K_4\mathrm{e}^{-\beta(l-x)}\sin\left(\omega t-\alpha(l-x)+\varphi_{K4}\right), \quad (10a)$$

resp.

$$u(t,x)=K_1\mathrm{e}^{\beta(l-x)}\cos\left(\omega t+\alpha(l-x)+\varphi_{K1}\right)+$$

$$+K_2 e^{-\beta(l-x)} \cos\left(\omega t - \alpha(l-x)\right) + \varphi_{K2}\Big) \qquad (9b)$$

and

$$i(t,x) = K_3 e^{\beta(l-x)} \cos\left(\omega t + \alpha(l-x)\right) + \varphi_{K3}\Big) +$$

$$+K_4 e^{-\beta(l-x)} \cos\left(\omega t - \alpha(l-x)\right) + \varphi_{K4}\Big). \qquad (10b)$$

If the input voltage $u_1(t)$ by correspondent complexor $\dot{U}_1(t)$ is given, we have:

$$\dot{U}_2(t) = \frac{2\dot{U}_1(t)}{\dot{K}_5(t)e^{\dot{\gamma}l} + \dot{K}_6(t)e^{-\dot{\gamma}l}}; \qquad (11a)$$

$$\dot{I}_2(t) = \frac{\dot{U}_2(t)}{\dot{Z}_2}; \qquad (11b)$$

$$\dot{I}_1(t) = \dot{K}_3(t)e^{\dot{\gamma}l} + \dot{K}_4(t)e^{-\dot{\gamma}l}, \qquad (11c)$$

where $\dot{K}_5(t) = 1 + \frac{\dot{Z}_v}{\dot{Z}_2}$, $\dot{K}_6(t) = 1 - \frac{\dot{Z}_v}{\dot{Z}_2}$.

If the input current $i_1(t)$ by correspondent complexor $\dot{I}_1(t)$ is given, we get:

$$\dot{I}_2(t) = \frac{2\dot{I}_1(t)}{\dot{K}_7(t)e^{\dot{\gamma}l} + \dot{K}_8(t)e^{-\dot{\gamma}l}}; \qquad (12a)$$

$$\dot{U}_2(t) = \dot{I}_2(t)\dot{Z}_2; \qquad (12b)$$

$$\dot{U}_1(t) = \dot{K}_1(t)e^{\dot{\gamma}l} + \dot{K}_2(t)e^{-\dot{\gamma}l}, \qquad (12c)$$

where $\dot{K}_7(t) = 1 + \frac{\dot{Z}_2}{\dot{Z}_v}$, $\dot{K}_8(t) = 1 - \frac{\dot{Z}_2}{\dot{Z}_v}$.

Further, if the output voltage $u_2(t)$ by correspondent complexor $\dot{U}_2(t)$ is given, we have:

$$\dot{I}_2(t) = \frac{\dot{U}_2(t)}{\dot{Z}_2}; \qquad (13a)$$

$$\dot{U}_1(t) = \dot{K}_1(t)e^{\dot{\gamma}l} + \dot{K}_2(t)e^{-\dot{\gamma}l}; \qquad (13b)$$

$$\dot{I}_1(t) = \dot{K}_3(t)e^{\dot{\gamma}l} + \dot{K}_4(t)e^{-\dot{\gamma}l}, \qquad (13c)$$

and at least if output current $i_2(t)$ by correspondent complexor $\dot{I}_2(t)$ is given, it is:

$$\dot{U}_2(t) = \dot{I}_2(t)\dot{Z}_2; \qquad (14a)$$

$$\dot{U}_1(t) = \dot{K}_1(t)e^{\dot{\gamma}l} + \dot{K}_2(t)e^{-\dot{\gamma}l}; \qquad (14b)$$

$$\dot{I}_1(t) = \dot{K}_3(t)e^{\dot{\gamma}l} + \dot{K}_4(t)e^{-\dot{\gamma}l}. \qquad (14c)$$

Program description. In the first order it is necessary to access that the basic functions of Excel will work with complex numbers (CN). For the Excel 2003 it means to activate Analytic Tools in the panel Tools – Accessories [5], which enables to use functions:

COMPLEX – returns CN in the algebraic form,

IMREAL – returns the real part of CN,

IMAGINARY – returns the imaginary part of CN,

IMSUM – returns the sum of two or more CN,

IMSUB – returns the subtraction of two CN,

IMPRODUCT – returns the product of two or more CN,

IMDIV – returns the ratio of two CN,

IMARGUMENT – returns the phase of CN,

IMABS – returns the module of CN

Presented program consists of five basic parts: *Setting, Analysis for given $u_1(t)$* – sheet $u_1(t)$, *Analysis for given $i_1(t)$* – sheet $i_1(t)$, *Analysis for given $u_2(t)$* – sheet $u_2(t)$, *Analysis for given $i_2(t)$* – sheet $i_2(t)$.

*Setting***.** This part is dedicated for the basic long line parameters setting, namely either primary (R_0, L_0, G_0, C_0) or secondary ($\dot{\gamma}$, $\dot{Z}_v$) and the long line length l (all of them in the basic unit km) , angular frequency w and output impedance $\dot{Z}_2$. If the primary parameters are set, this program part will calculate the secondary ones, if the secondary parameters are given, this calculation will not be made (fig. 1). Further, in this part the time period T and wave length L are calculated for the verification that the basic requirement of long line modeling by the means of given theory ($l \approx L$) is met.

	A	B	C	D	E	F
13	Z2 =		Mod[Z2] =	200	Arg[Z2] =	0
14	l =	300				
15	w =	6,00E+03				
16	Ro =	4				
17	Lo =	3,00E-03				
18	Go =	4,00E-05				
19	Co =	8,00E-08				
24	Zv:		Mod[Zv] =	195,658	Arg[Zv] =	-3,883
25	g:		Mod[g] =	0,094	Arg[g] =	81,354

Figure1 – Selected parts of program part Setting

All the *following parts* of presented program named $u_1(t)$, $i_1(t)$, $u_2(t)$, $i_2(t)$ are dedicated for the calculations of voltage and current wave along the long line (t and x dependence of $u(t, x)$ and $i(t, x)$) as well as graphic presentation of the results for the selected x value for time dependence and selected t value for the x dependence and it is made separately for each possibility of given electric quantity ($u_1(t)$, $i_1(t)$, $u_2(t)$, $i_2(t)$). Although the t and x dependence of voltage and current wave along the long line are described in the same form ((9a), (10a) resp. (9b), (10b)), it must be mentioned that in the description of complexors $\dot{K}_1(t), \dot{K}_2(t), \dot{K}_3(t), \dot{K}_4(t)$ the different values of complexors $\dot{U}_2(t)$ and $\dot{I}_2(t)$ are used, in dependence of given electric parameter (11a ÷ 14c), so that complexors $\dot{K}_1(t), \dot{K}_2(t), \dot{K}_3(t), \dot{K}_4(t)$ are different for every one of given electrical parameter and it is necessary to make separate part of the program for each possibility of given electric parameter.

Each part gives two kinds of results – complexor of input and output voltage and current values and voltage and current wave graphic illustration of t dependence, for selected x value and x dependence for selected t value.

Results. The several simulations were selected as an illustration of achieved results. For given value $u_1(t)$ with sine time dependence:

– calculation of input and output voltage and current complexors values is shown on the fig.2,

– voltage and current wave graphic illustration of t dependence for $x = l/2$ is given on the fig. 3.a and fig. 3.b,

– voltage and current wave graphic illustration of x dependence for $t = T/2$ are illustrated on the fig. 4.a and fig. 4.d.

	A	B	C	D	E
1	Setting:				
2	*U*1:	Mod[*U*1] =	141,41	Arg[*U*1] =	30
3	*t* dependence for *x* =	150			
4	*x* dependence for *t* =	5,24E-04			
5	Constants:				
6	*U*2:				
7	Mod[*U*2] =	2,062			
8	Arg[*U*2] =	-125,46			
9	*I*2:				
10	Mod[*I*2] =	0,01			
11	Arg[*I*2] =	-125,46			
12	*I*1:				
13	Mod[*I*1] =	0,723			
14	Arg[*I*1] =	33,882			

Figure 2 – $\dot{U}_2(t)$, $\dot{I}_2(t)$, $\dot{I}_1(t)$ calculations for given $u_1(t)$

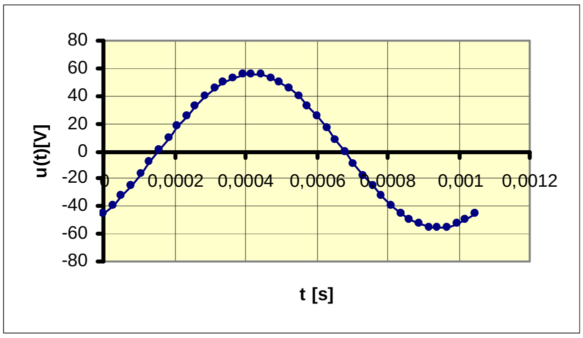


Figure 3, a – Voltage wave *t* dependence for $x = l/2$

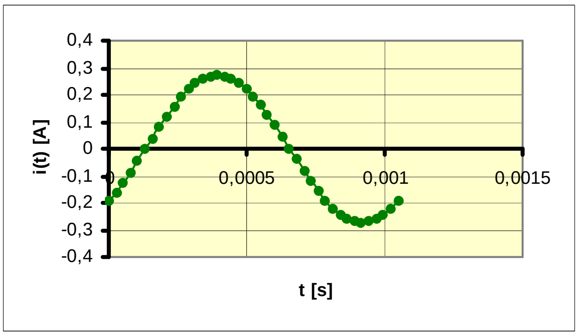


Figure3, b – Current wave *t* dependence for $x = l/2$

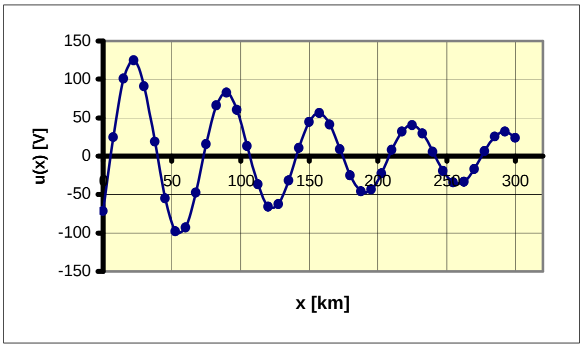


Figure 4, a – Voltage wave *x*-dependence for $t = T/2$

Presented program allow displaying *direct part* and *back part* of both voltage and current wave separately. For the voltage wave on the fig. 4.a is the direct part shown on the fig. 4.b and back part on the fig. 4.c.

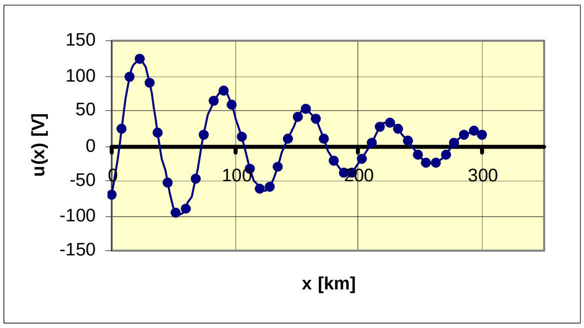


Figure 4, b – Direct part of the voltage wave

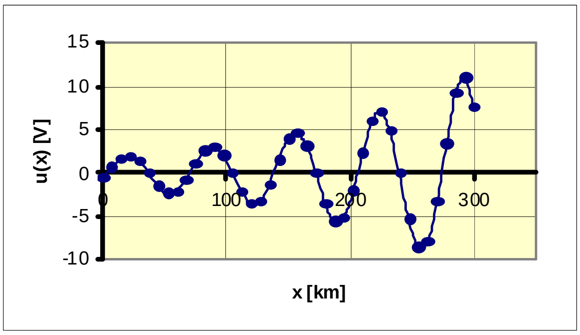


Figure 4, c – Back part of the voltage wave

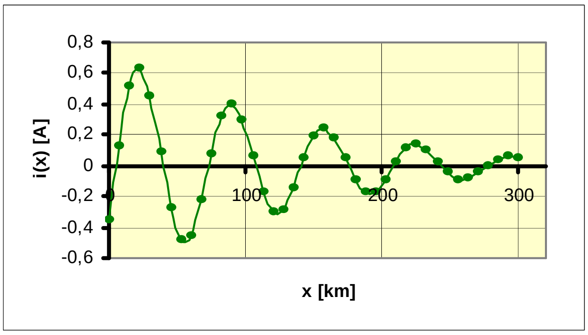


Figure 4, d – Current wave *x* dependence for $t = T/2$

The special long line states analysis - *short connection* as well as *disconnection* on the output is also possible. The illustration of voltage and current wave *x* dependence for $t = T/2$ for the *short connected long line*.

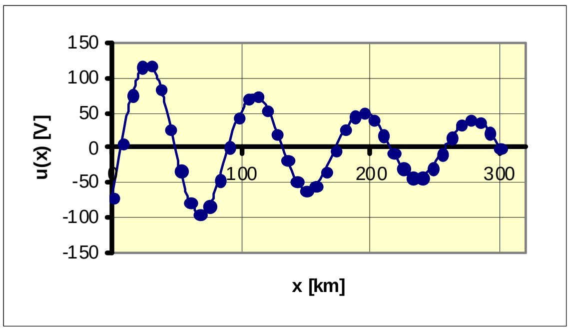


Figure 5, a – Voltage wave *x* dependence of the short connected long line for $t = T/2$

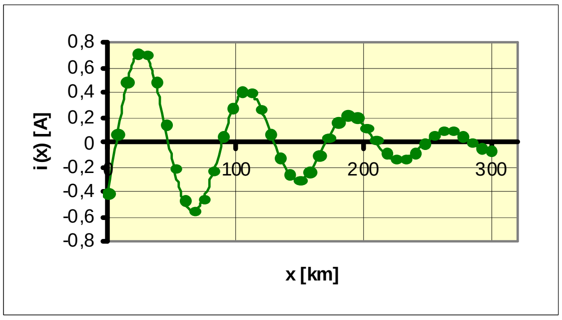


Figure 5, b – Current wave *x* dependence of the short connected long line for $t = T/2$

Voltage and current wave *x* dependence for $t = T/2$ for the *disconnected long line* are on the fig. 6.a and fig. 6.b.

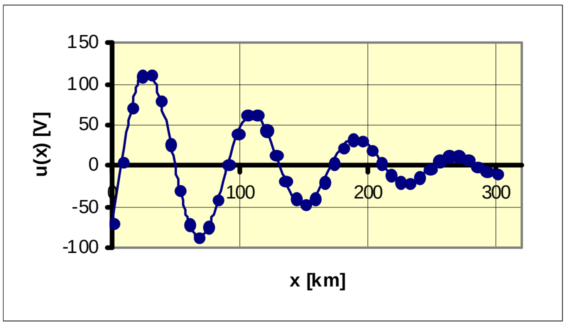


Figure 6, a – Voltage wave *x* dependence of the disconnected long line for $t = T/2$

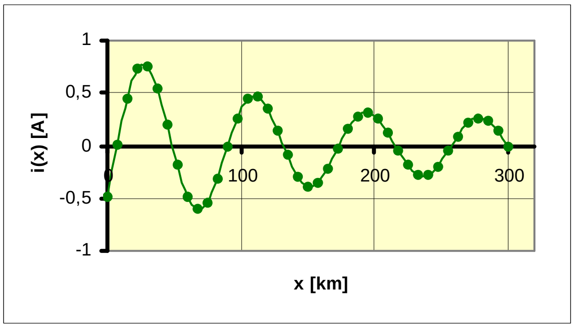


Figure 6, b – Current wave *x* dependence of the disconnected long line for $t = T/2$

Special interesting cases of long line are *adapted long line* as well as *lossless long line*, which may be simulated by presented program too.

There is no back part of voltage wave, as well as no back part of the current wave on the *adapted long line* as is illustrated on the fig. 7.a for the voltage wave and fig. 7.b for the current wave, where the pink part in these illustrations represent the back part of voltage respectively current wave.

For the *lossless long line* there is no attenuation nor of the voltage wave nor of the current wave as may be seen on the fig.8.a for the voltage wave and on the fig. 8.b for the current wave.

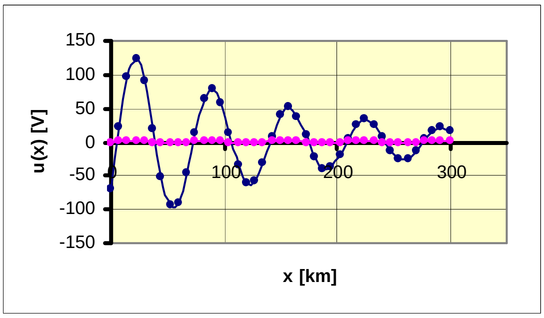


Figure 7, a – Voltage wave *x* dependence of adapted long line for $t = T/2$

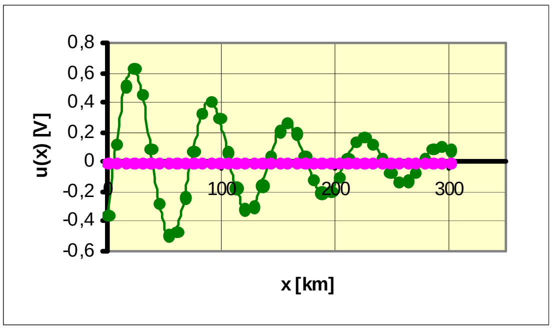


Figure 7, b – Current wave *x* dependence of adapted long line for $t = T/2$

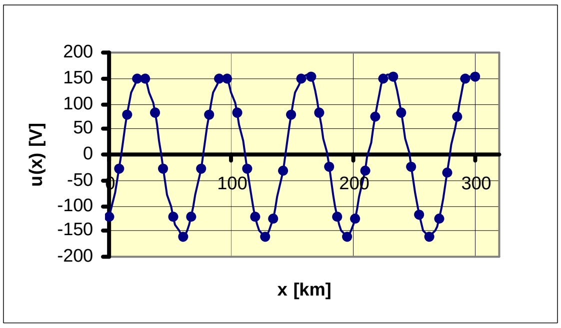


Figure 8, a – Current wave *x* dependence of lossless long line for $t = T/2$

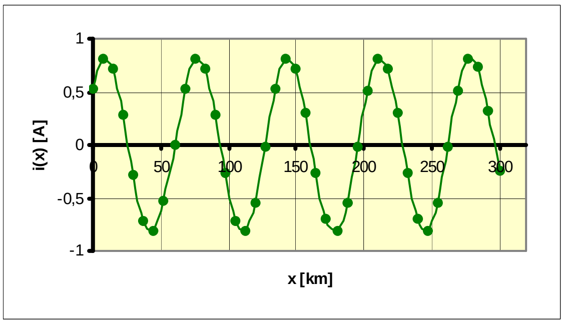


Figure 8, b – Current wave *x* dependence of the lossless long line for $t = T/2$

These several samples illustrate simulation potential of presented program. Another very interesting possibility its exploitation is application on the microwave circuits analysis. The sizes of these circuits are small, but the frequency of input signals is high, so that wave lengths of the electromagnetic wave on the microwave circuit load is comparable with the circuits sizes and the basic requirement of long line modeling by the means of given theory ($l \approx L$) is met. According to this theory the lead of microwave circuits may be considered as lossless, because always will be R_0 wL_0 and G_0 wC_0, so that complex wave impedance $\dot{Z}_v$ will be real.

The application of presented theory and its software processing on the microwave circuits is represented by the part Setting on the fig. 9.a and by the graphic illustration of voltage wave on the fig. 9.b and current wave on the fig. 9.c.

	A	B	C	D	E	F
13	Z2 =		Mod[Z2] =	200	Arg[Z2] =	60
14	l =	3,50E-02				
15	w =	1,00E+11				
16	Ro =	1,00E-03				
17	Lo =	3,00E-06				
18	Go =	4,00E-09				
19	Co =	8,00E-12				
24	Zv:		Mod[Zv] =	612,372	Arg[Zv] =	4,77465E-08
25	g:		Mod[g] =	489,898	Arg[g] =	89,99999976

Figure 9, a – Selected parts of program part Setting for microwave circuits

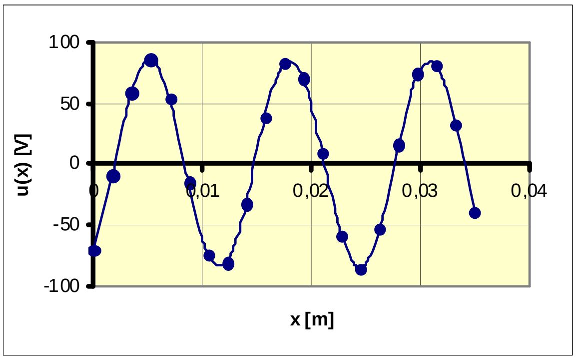
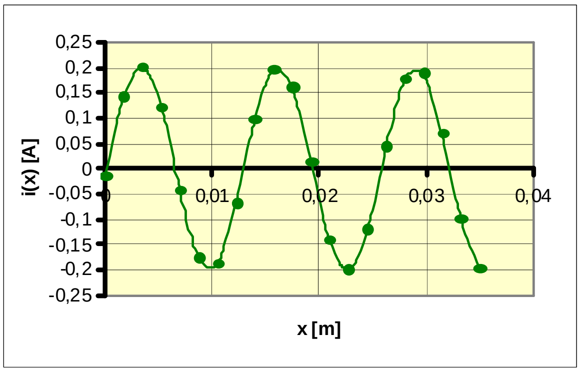


Figure 9, b – Voltage wave *x* dependence on microwave



load for $t = T/2$

Figure 9, c – Current wave *x* dependence on microwave load for $t = T/2$

Conclusions. This paper illustrates a simple modification of the telegraphic equations for their computer processing as well as their solution by the means of application one component of OFFICE package - Excel – and suggest other possibilities of application this theory and program in circuit theory as well as describe the special program for this kind of circuits, which are modeling by the circuit with distributed parameters, such as the long-distance line or microwave circuits loads in harmonic steady state. In the first order it is shown how the theoretical expressions of the voltage and current complexors are modifying for this program, next is shown how to access that the basic functions of Excel will work with complex numbers and finally the program is described and illustrated. Presented program grant to do the full analysis of long-distance line including short connection or disconnection on the long line output (impedance of short connection is suggested to be simulated by number 10^{-20} and impedance of disconnection by number 10^{20}) as well as adapted long line and special events as lossless line and non-misleading line. Further, the program modification for microwave circuits load as well as selected program results illustration is referred too.

Our goal is to prepare studying materials for Theory of electrical engineering with the possibility of simple and fast simulation many cases of solving problem and to compare received results, so that student is able to obtain more explicit representation of solved problem. Computer programs for analysis of three-phase circuits with the appliance of connection format Y and connection format D [3] has been developed still, as well as simple programs on the graphical representation of mathematic form results, obtained as the solution for circuits with unbalanced supply and circuits in non-stationary state, which are more representative then mathematic formula.

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ПРОСТОЕ МОДЕЛИРОВАНИЕ ПРОТЯЖЕННОЙ ЛИНИИ

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Продемонстрировано применение одного из компонентов пакета программ MS Office - Excel - в теории электрических цепей при моделировании протяженной линии в гармонически устойчивом состоянии и описана специальная программа для анализа и графического представления результатов. Представлено преобразование теоретических выражений, описывающих напряжение и ток протяженной линии, показана процедура получения доступа к функции Excel для работы с комплексными числами, представлены описание и иллюстрации программы. Также возможно исследование аварийных и специальных режимов (короткое замыкание или разрыв протяженной линии, линия без потерь и линия без помех).

Ключевые слова: теоретические основы электротехники, цепи с распределенными параметрами, протяженная линия, Excel.

ПРОСТЕ МОДЕЛЮВАННЯ ПРОТЯЖНОЇ ЛІНІЇ

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Продемонстровано застосування одного з компонентів пакету програм MS Office - Excel - в теорії електричних ланцюгів під час моделювання протяжної лінії в гармонічно стійкому стані та описана спеціальна програма для аналізу й графічного подання результатів. Представлено перетворення теоретичних виразів, що описують напругу й струм протяжної лінії, показана процедура одержання доступу до функції Excel для роботи з комплексними числами, надані опис і ілюстрації програми. Також можливе дослідження аварійних і спеціальних режимів (коротке замикання або розрив протяжної лінії, лінія без втрат і лінія без перешкод).

Ключові слова: теоретичні основи електротехніки, ланцюги з розподіленими параметрами, протяжна лінія, Excel.