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APPLICATION OF THE MULTISIM PROGRAM IN ANALYSIS OF THE TRANSMISSION LINES

Summary: The paper describes the possibilities of Multisim program in the analysis of transmission lines. It also presents examples of lossless and lossy transmission line simulation in steady-state and transient conditions, which have been carried out by means of this program. Results of circuit simulation in Multisim program are consistent with results of simulation in PSpice program.

Keywords: transmission lines, transmission line parameters, lossy transmission line, lossless line, computer programs

ZASTOSOWANIE PROGRAMU MULTISIM W ANALIZIE LINII DŁUGICH

Streszczenie. W artykule przedstawiono możliwości programu Multisim w kontekście jego zastosowania w analizie linii długich. Przedstawiono przykłady symulacji linii długiej (stratnej i bezstratnej) w stanie ustalonym i nieustalonym. Stwierdzono zgodność wyników otrzymanych w wyniku symulacji obwodów w programie Multisim z wynikami uzyskanymi w rezultacie symulacji tych samych obwodów za pomocą programu PSpice.

Słowa kluczowe: linie długie, parametry linii długiej, linia stratna, linia bezstratna, programy komputerowe

1. INTRODUCTION

Nowadays numerous computer programs for analysis of electric circuits are available. For many years they have been used in education and research, helping both the beginners and advanced researchers. It is difficult to imagine how to exist today without taking advantage of these programs. Computer programs offer extensive element libraries, which are used in setting up investigated circuits. The diversity of available analysis makes it possible to investigate any given circuit from different standpoints. The results obtained via computer simulations are accessible as text (numerical values of determined quantities, e.g. current or voltage) and graphics (e.g. waveforms in time domain).

In computer analysis of transmission line we often utilize those computer programs, which offer ready-made models of transmission lines. Usually at the stage of setting up the circuit, user has to input specified parameters of the line, in accordance with e.g. the text and data provided in some problem. These may be, for instance:

1) line parameters per unit length (R_0, L_0, C_0, G_0) and line length (l), or

2) characteristic impedance of the line (Z_C) and transmission delay (τ) (of the wave from one end of the line to another), or

3) characteristic impedance of the line (Z_C), frequency of the sine waveform (f) and normalized line length at a given frequency (this relative line length is equal to the ratio of line length to wave length).

The choice of parameter set (1, 2 or 3) by the user depends also on the possibilities provided by a given computer program. The Multisim program discussed in this paper provides three models of transmission line (Fig.1), and all three sets of parameters may be declared for those models.

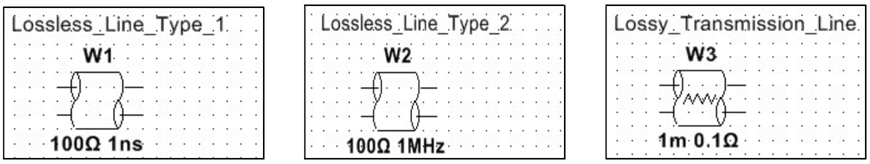

Fig.1. Models of transmission line in Multisim program
Rys.1. Modele linii długiej zawarte w programie Multisim

2. MULTISIM PROGRAM

Multisim program [2] is a virtual tool which makes it possible to set up electronic and electric circuit models and to simulate their operation. This is facilitated by the extensive library of element models contained in the program. This is a very powerful program which is used for computer analysis of analog and digital circuits [3]; its possibilities are very diverse (Fig.2).

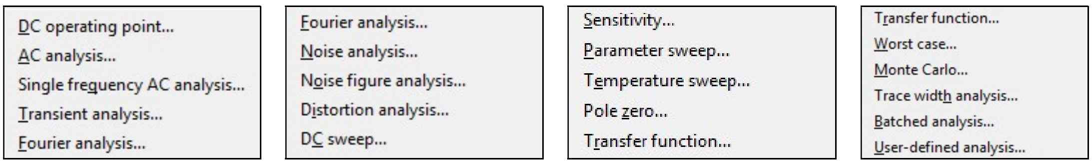

Fig.2. Types of analysis available in Multisim program
Rys.2. Rodzaje analiz dostępnych w programie Multisim

When program is started, a workspace window pops up; there in the circuit window circuits are created on the basis of elements selected from the appropriate component toolbar (getting these elements is achieved by dragging them into the workspace). Elements which can be used in circuits created by the user are divided into groups containing: supply sources, passive elements, diodes, transistors, operating amplifiers, TTL elements, CMOS elements, digital integrated circuits, displays and indicators; mechanical elements and radio elements [6].

The work is intuitive and should not pose any difficulty even to beginners. When elements are connected into a required circuit, "measurement instruments" can be connected there too (e.g. voltmeter, ammeter, generator, oscilloscope). Then suitable type of analysis is chosen (Fig.2), parameters are set, computer simulation is run and results are obtained. These may be subjected to analysis.

3. MODELS OF TRANSMISSION LINES PROVIDED BY MULTISIM PROGRAM

It has been mentioned that transmission line models are available in Multisim program (see Fig.1). In the lossless line model *Lossless_Line_Type_1* the user may declare characteristic impedance of the line (Z0) and transmission delay (time of propagating the wave from one end of the line to the other - TD). In the second model of lossless line *Lossless_Line_Type_2* we may declare: characteristic impedance of the line (Z0), frequency of sine waveform (F) and normalized line length at a given frequency (NL). The parameters per unit length and length of the line may be declared in the model of lossy transmission line *Lossy_Transmission_Line*. Two of the specified models have been used in calculation problems presented in current paper.

Format of command recalling the model of the lossless transmission line (*Lossless_Line_Type_1, Lossless_Line_Type_2*) is given as follows [1]:

```
Txxx nodeP1+  nodeP1-  nodeP2+  nodeP2- Z0=z0 <TD=td> <F=freq <NL=nl>
<IC=v1 <,i1 <,v2 <,i2>>>> <REL=rel> <ABS=abs>

Txxx nodeP1+  nodeP1-  nodeP2+  nodeP2- Z0=z0 <TD=td> <F=freq <NL=nl>
<V1=v1> <I1=i1> <V2=v2> <I2=i2> <REL=rel> <ABS=abs>
```

Brackets < > denote optional parameters. Moreover:

`nodeP1+`, `nodeP1-` – mark the input nodes of the line,

`nodeP2+`, `nodeP2-` – mark the output nodes of the line,

`Z0` – characteristic impedance,

`TD` – transmission delay (time of wave propagation from one end of the line to another),

`F` – frequency of the sine waveform, where $\lambda = l/\mathrm{NL}$,

`NL` – normalized length of line at a given frequency F ($\mathrm{NL} = l/\lambda$).

The remaining parameters (e.g. REL, ABS etc.) have been described in [1].

Examples:
```
Tbezstratna 1 0 2 0 Z0=100
Tbezstratna 1 0 2 0 Z0=100 TD=1u
```

Format of command recalling the model of lossy transmission line (*Lossy_Transmission_Line)* in Multisim program is given as follows:

```
Oxxx node1 node2 node3 node4 ModelName <IC=v1 <,i1 <,v2 <,i2>>>>

Oxxx node1 node2 node3 node4 ModelName <V1=v1> <I1=i1> <V2=v2> <I2=i2>

.MODEL ModelName LTRA ( <NOCONTROL> <STEPLIMIT/NOSTEPLIMIT>
+ <LININTERP/QUADINTERP/MIXEDINTERP> <Other_Model_Parameters…> )
```

The parameters mentioned above (e.g. NOCONTROL, STEPLIMIT etc.), as well as many other model parameters have been described in [1].

Example:
```
Ostratna 3 0 4 0 NazwaModelu
.MODEL NazwaModelu LTRA (LEN=1000 R=10 L=4e-006 C=4.7e-012 G=8e-010)
```

In the above notation:

`3, 0` – denote input nodes of the line,

`4, 0` – denote the output nodes of the line,

`LEN` – length of the line (l),

`R` – resistance per unit length,

`L` – inductance per unit length,

`G` – conductance per unit length,

`C` – capacitance per unit length.

4. CALCULATION EXAMPLE I

Transmission line shown in Fig. 3 is characterized by following quantities: length $l = 100$ km and parameters per unit length: $R_0 = 10.2$ Ω/km, $L_0 = 4.2$ mH/km, $C_0 = 4.7$ nF/km, $G_0 = 0.8$ µS/km. It is loaded by a two-terminal series network RC with resistor $R_2 = 100$ Ω, capacitor $C_2 = 2.2$ µF. It is supplied with ac voltage $u(t)=200\sin(6280t+30^{o})$ V. Calculate voltage $\underline{U}_2$ at the right end of the line and currents $\underline{I}_1$ (left end of the line) and $\underline{I}_2$ (right end of the line) [4].

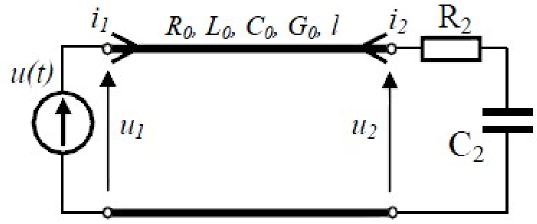

Fig.3. Lossy transmission line loaded with series RC two-terminal network [4]
Rys.3. Linia długa stratna obciążona dwójnikiem szeregowym RC [4]

Analytical solution. Impedance per unit length:

$$\underline{Z}_0 = R_0 + \mathrm{j}\omega L_0 = 10.2 + \mathrm{j}6280 \cdot 4.2 \cdot 10^{-3} = (10.2 + \mathrm{j}26.389)\frac{\Omega}{\mathrm{km}} \tag{1}$$

Admittance per unit length:

$$\underline{Y}_0 = G_0 + \mathrm{j}\omega C_0 = 0.8 \cdot 10^{-6} + \mathrm{j}6280 \cdot 4.7 \cdot 10^{-9} = (0.8 \cdot 10^{-6} + \mathrm{j}2.953 \cdot 10^{-5})\frac{\mathrm{S}}{\mathrm{km}} \tag{2}$$

Propagation constant:

$$\underline{\gamma} = \sqrt{\underline{Z}_0 \cdot \underline{Y}_0} = \sqrt{(10.2 + \mathrm{j}26.389) \cdot (0.8 \cdot 10^{-6} + \mathrm{j}2.953 \cdot 10^{-5})} = (5.686 \cdot 10^{-3} + \mathrm{j}0.028)\frac{1}{\mathrm{km}} \tag{3}$$

Wave impedance of the line:

$$\underline{Z}_C = \sqrt{\frac{\underline{Z}_0}{\underline{Y}_0}} = \sqrt{\frac{10.2 + \mathrm{j}26.389}{0.8 \cdot 10^{-6} + \mathrm{j}2.953 \cdot 10^{-5}}} = (964.367 - \mathrm{j}166.408)\,\Omega \tag{4}$$

Load impedance:

$$\underline{Z}_2 = R_2 - \mathrm{j}\frac{1}{\omega C_2} = 150 - \mathrm{j}\frac{1}{6280 \cdot 2.2 \cdot 10^{-6}} = (150 - \mathrm{j}72.343)\,\Omega \tag{5}$$

Input impedance of the line:

$$\underline{Z}_{we} = \frac{\underline{Z}_2 \cdot \cosh(\underline{\gamma} \cdot l) + \underline{Z}_C \cdot \sinh(\underline{\gamma} \cdot l)}{\underline{Z}_2 \cdot \sinh(\underline{\gamma} \cdot l) + \underline{Z}_C \cdot \cosh(\underline{\gamma} \cdot l)} \cdot \underline{Z}_C = (583.599 - \mathrm{j}333.657)\,\Omega \tag{6}$$

Input line current:

$$\underline{I}_1 = \frac{\underline{U}_1}{\underline{Z}_{we}} = \frac{141.42 \cdot e^{\mathrm{j}30^\circ}}{583.599 - \mathrm{j}333.657} = (0.106 + \mathrm{j}0.182) = 0.21 \cdot e^{\mathrm{j}59.758^\circ}\,\mathrm{A} \tag{7}$$

Output line current:

$$\underline{I}_2 = \frac{\underline{U}_1}{\underline{Z}_2 \cdot \cosh(\underline{\gamma} \cdot l) + \underline{Z}_C \cdot \sinh(\underline{\gamma} \cdot l)} = (-0.055 - \mathrm{j}0.169) = 0.178 \cdot e^{-\mathrm{j}107.91^\circ}\,\mathrm{A} \tag{8}$$

Output line voltage:

$$\underline{U}_2 = \underline{Z}_2 \cdot \underline{I}_2 = (150 - \text{j}72.343) \cdot (-0.055 - \text{j}0.169) = 21.926 \cdot e^{-\text{j}143.794^\circ} \text{V} \tag{9}$$

Numerical solution. Line parameters per unit length and length of the line may be declared in the model of lossy transmission line (line W3 in Fig.1). The circuit set up in Multisim program is shown in Fig.4. Two additional voltage sources (V2, V3) with voltage magnitute of 0 V have been connected in order to determine values of current at the left and right ends of the line (these are currents flowing through these extra sources).

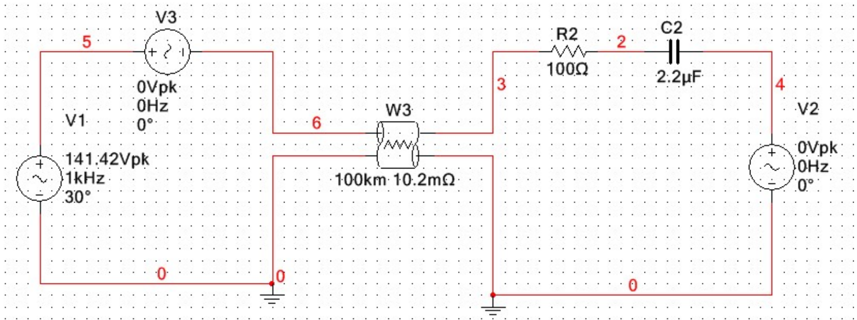

Fig.4. Circuit I in Multisim program
Rys.4. Rozważany obwód I w programie Multisim

When *AC Analysis* parameters have been determined and simulation has been run, absolute values (modules) of right-end and left-end voltages and currents together with their phase shifts are obtained. These results are presented in Tables 1 and 2. In addition, results obtained with the help of PSpice software (batch file *.cir, Fig.5) have also been presented for verification purposes together with results of analytical solution. The consistence of the results has been ascertained.

Table 1.

Voltage values at left (U_1) and right end (U_2) of transmission line

Results	**U_1**		**U_2**	
	Module [V]	Phase angle [°]	Module [V]	Phase angle [°]
Multisim program	141.42	30	21.929	-143.794
PSpice program	1.414E+02	3.000E+01	2.193E+01	-1.438E+02
Analytical solution	1.414E+02	30	21.929	-143.794

Table 2.

Current values at left (I_1) and right end (I_2) of transmission line

Results	**I_1**		**I_2**	
	Module [A]	Phase angle [°]	Module [A]	Phase angle [°]
Multisim program	0.210369	59.75757	0.177673	-107.91
PSpice program	2.104E-01	5.976E+01	1.777E-01	-1.079E+02
Analytical solution	0.21	59.758	0.178	-107.91

```
V_VU    $N_0033 0 DC 0V AC 141.42 30
V_VD1   $N_0033 $N_0003 DC 0V AC 0 0
T_T1    $N_0003 0 $N_0002 0 LEN=100 R=10.2 L=4.2m G=0.8u C=4.7n
V_VD2   $N_0002 $N_0022 DC 0V AC 0 0
R_R2    $N_0022 $N_0001  100
C_C2    $N_0001 0 2.2u
.OP
.ac LIN 1 1k 1k
.print ac VM(V_VU) VP(V_VU) VR(V_VU) VI(V_VU)
+VM([$N_0002],[0]) VP([$N_0002],[0])
+VR([$N_0002],[0]) VI([$N_0002],[0])
+IM(V_VU) IP(V_VU) IR(V_VU) II(V_VU)
+IM(R_R2) IP(R_R2) IR(R_R2) II(R_R2)
+IM(V_VD1) IP(V_VD1) IR(V_VD1) II(V_VD1)
+IM(V_VD2) IP(V_VD2) IR(V_VD2) II(V_VD2)
.end
```

Fig.5. Batch file (*.cir) for PSpice program used in computer simulation of circuit shown in Fig. 3
Rys.5. Plik wsadowy (*.cir) do programu PSpice służący do rozwiązania rozważanego obwodu

5. CALCULATION EXAMPLE II

Lossless transmission line characterized by length of $l = 300$ m, wave impedance $Z_C = 75\ \Omega$ and propagation constant $\tau = 1\mu s$, is supplied with dc voltage $E = 150$ V starting at time instant $t = 0$. Calculate current and voltage signals along the line in transient state. Assume that: $R_1 = Z_C$ and $R_2 = Z_C/3$ [5].

The circuit set up in Multisim program is shown in Fig.6. The supply source VE is a PWL Voltage type source; its value is determined by line segments connecting points (co-ordinates: time and voltage) declared by the user. The transmission line W1 is a lossless line (*Lossless_Line_Type_1*); characteristic impedance of the line is declared as ZO = 75 Ω and transmission delay (of the wave from one end of the line to another) is declared as TD=1μs. The input resistor R_1 makes it possible to model the non-zero internal resistance of the supply source (in this case it has been assumed that $R_1 = Z_C = 75\ \Omega$), while resistor R_2, in accordance with the problem data, is equal to $R_2 = Z_C/3 = 75/3 = 25\ \Omega$.

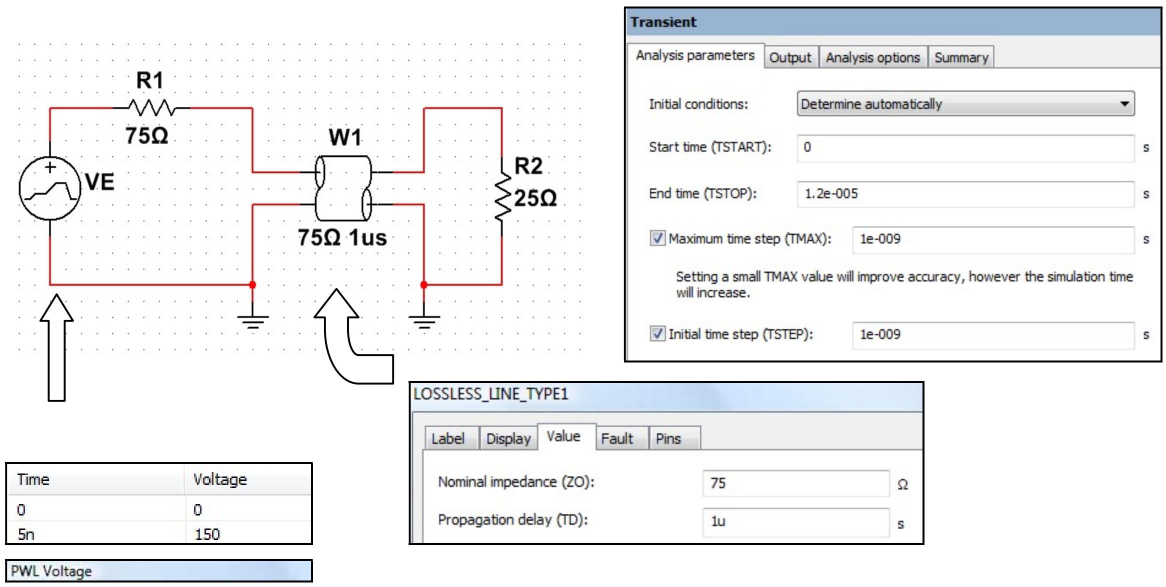

Fig.6. Circuit with lossless transmission line and parameters for transient state analysis
Rys.6. Obwód z linią długą bezstratną wraz z parametrami do analizy w stanie nieustalonym

When *Transient Analysis* parameters have been set (the declared parameters of this analysis are shown in Fig.6) and computer simulation has been run, the current and voltage waveforms at the right and left end of the line are obtained. The selected results are shown in Fig.7.

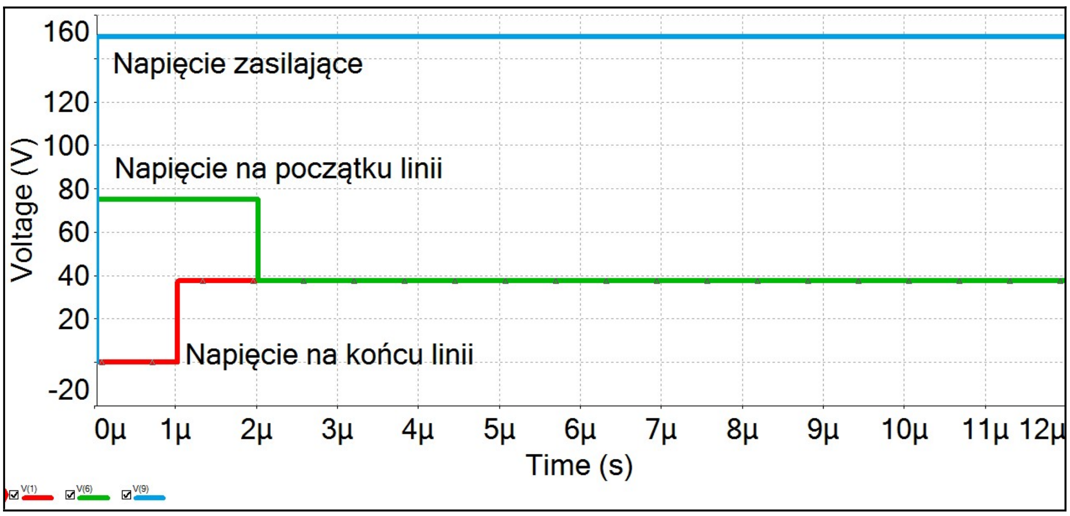

Fig.7. The waveforms of the supply voltage and voltages at the left and right end of transmission line
Rys.7. Przebiegi napięć: zasilającego oraz na początku i na końcu linii długiej

The investigated circuit may of course be subjected to different types of tests, e.g. analysis may be conducted for different modes of line operation (no-load, short-circuit, impedance matching, loading with resistance R_2 of arbitrary value – the specified modes may be obtained by appropriate declaration of resistor R_2 value) or impact of resistance R_1 and/or R_2 on voltage and current waveforms at left end and right end of the line may be determined as well as current and voltage waveforms at points in the line other than $x = 0$ (left end) and $x = 300$ m (right end). Example of such calculations is given below.

In order to visualise transient waveforms not only at the ends of the discussed line (length 300 m and $\tau = 1\mu s$), but also for other points e.g. $x = 75$ m, $x = 150$ m, $x = 225$ m, four lines should be connected together in cascade (Fig.8). These lines are characterized by identical wave impedances and transmission delays equal to $\tau/4 = 0.25$ μs. The fourth line is loaded with resistance $R_2 = Z_C/3 = 75/3 = 25\ \Omega$. Time analysis is declared and computer simulation is run. When simulation is done, voltage and current waveforms are accessible through graphical postprocessor (Grapher View), they may be visualized and analyzed. The selected results of computer simulation are shown in Figs. 9 and 10.

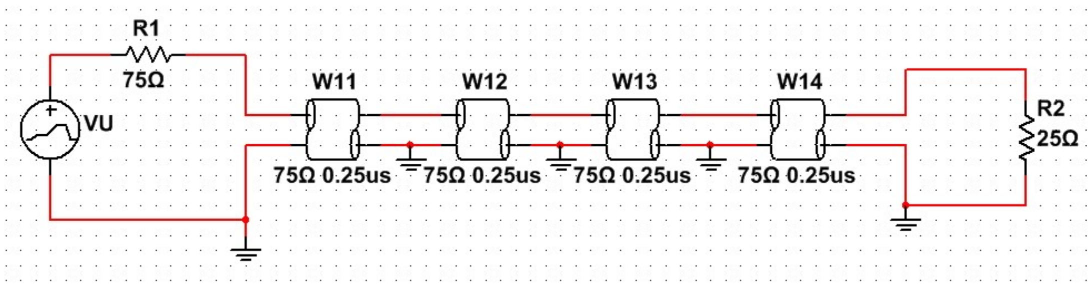

Fig.8. Circuit II (second version) in Multisim program
Rys.8. Rozważany obwód II (druga wersja) w programie Multisim

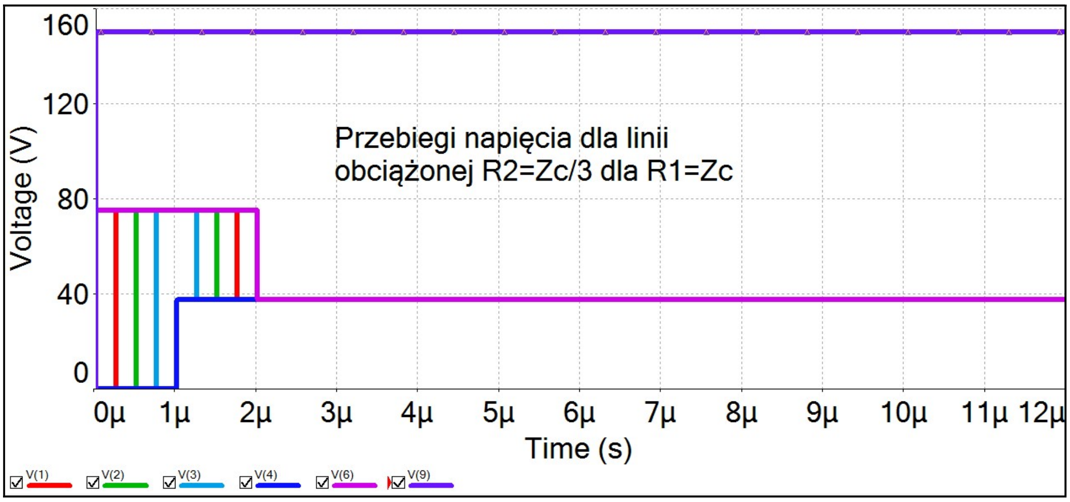

Fig.9. The voltage waveforms for lossless transmission line, $R_1 = Z_C$, resistor load $R_2 = Z_C/3$
Rys.9. Przebiegi napięcia dla linii obciążonej $R_2 = Z_C/3$ dla $R_1 = Z_C$

a) b)

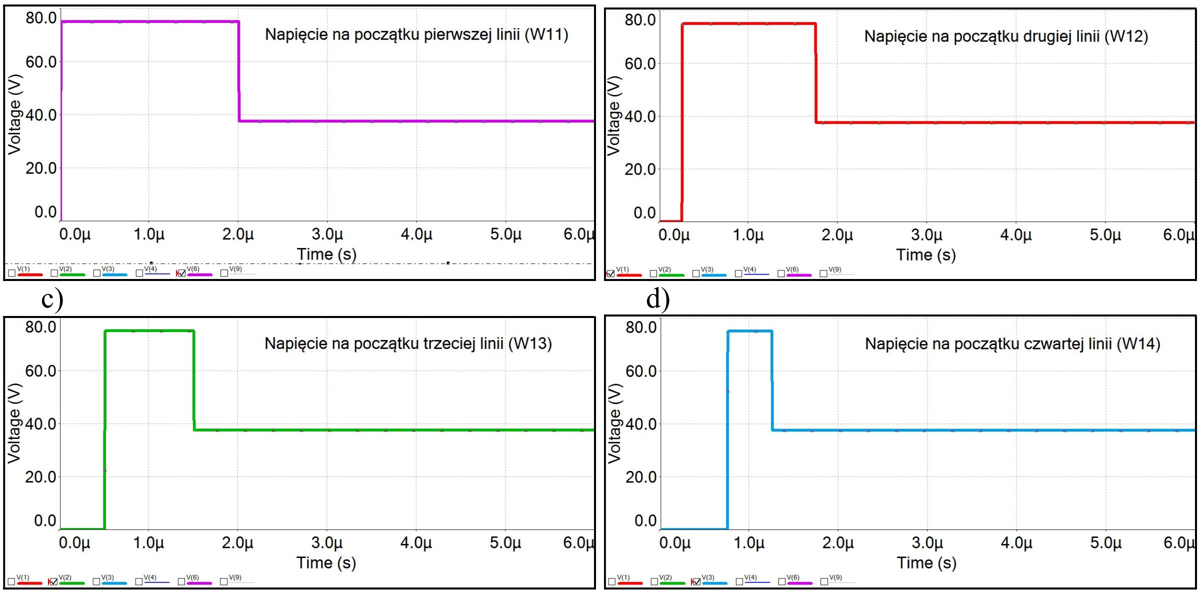

Fig.10. Voltage waveforms in lossless line (circuit shown in Fig.8), resistor load $R_2 = Z_C/3$ for $x = 0$ (a), $x = 75$ m (b), $x = 150$ m (c) and $x = 225$ m (d)
Rys.10. Przebiegi napięcia w linii bezstratnej w obwodzie z rys.8 obciążonej rezystancją $R_2 = Z_C/3$ dla $x = 0$ (a), dla $x = 75$ m (b), dla $x = 150$ m (c) oraz dla $x = 225$ m (d)

The voltage waveforms for the internal resistance of the supply source equal to the wave resistance of the transmission line ($R_1 = Z_C = 75\ \Omega$) are shown in Fig.9 and 10. On account of impedance matching at the input, when time $\tau = 1$ µs is elapsed, the output voltage and current are steady. The analytical solution of calculation example II (Laplace transform has been used in calculations) illustrated with graphs obtained from Mathcad software as well as PSpice software may be found in reference [5], pages 323-336. The circuit model of lossless line in transient state is also presented in that publication together with set of relationships describing the performance of lossless line loaded with resistance in transient state. This model consists of controlled sources. Since the example discussed here is a lossless line, transient state calculations may be run using circuit model of transmission line instead of Laplace transform.

6. CONCLUSION

Examples of using Multisim program for analysis of transmission line in transient and steady states have been presented in this paper. Library of Multisim program contains three models of transmission line: two models for lossless line and model of lossy line. The calculation examples illustrate use of two models of transmission line (lossy line model and one model of lossless model) in the circuit supplied from sinusoidal ac source (calculation example I) and circuit supplied from PWL-type source, where character of this source is determined by line segments connecting points declared by the user (calculation example II).

Computer simulation of the presented circuits with PSpice software has confirmed the correctness of simulation in Multisim program; the obtained results are consistent.

The results obtained by computer simulation of circuits in Multisim program, may be e.g. recorded in file using Microsoft Excel format. The diverse possibilities offered by Multisim program indicate that different tasks may be successfully carried out here, both for educational purposes and research. The program is useful to beginners, but it is also attractive to advanced users who might have been using e.g. PSpice or LTspice software for many years.

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