



Simulation study of the quadripole via using integrated environments for the design and analysis

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Abstract: The research of the quadripole entirely in programming environments is presented in the paper. A program is developed to calculate the frequency characteristics of the quadripole in the programming environment Matlab. Their work is simulated in the programming environment Multisim. An analysis and a comparison of theoretically and experimentally obtained frequency responses are made. The program which is presented in the paper will be used in the educational process in the Electrical Engineering course, included in the curriculum of the "Electricity technology" or "Computer and Communication Systems" specialties for the Bachelor educational degree.

Keywords: quadripole; frequency responses; Matlab; Multisim

I. Introduction

The programming environments and the developed virtual labs are used in the training of students ever more widely. They allow to visualize processes in the studied circuits and also to alleviate mathematical data processing. The research via simulation allows the learner to gain experience and confidence before he is realized in practice [1].

The quadripoles are subject of study in the course of Electrical Engineering. The mathematical apparatus for calculating the frequency responses of the quadripoles is complicated, it requires a good knowledge of complex numbers. It significantly simplifies if using Matlab software. The simulation of quadripole work in programme environment allows for verification of results.

In the theoretical construction of the frequency responses the programming environment Matlab is used, and at the simulation research the programming environments Simulink of National Instruments are used.

II. Main parameters and frequency responses of the quadripole

In general terms, as it is known, a quadripole can be displayed as shown in Figure 1 [2,3]. In determining the main parameters of the quadripole directions of currents and voltages will be used, as shown in the figure.

Figure 1: The quadripole



The ability of the linear quadripole to pass signals from its input to its output is characterized as full of so-called transfer function of quadripole. It is presented as the ratio of any of the output parameters $\dot{U}_2$ or $\dot{I}_2$ to any of the input $\dot{U}_1$ or $\dot{I}_1$. There are distinguished four basic transfer functions, which are represented in the complex or the operator type:

1. Voltage transfer function (transmission coefficient):

$$(1) \quad k_U(j\omega) = \frac{\dot{U}_2}{\dot{U}_1}; k_U(p) = \frac{U_2(p)}{U_1(p)}$$

Current transfer function (transmission coefficient):

$$(2) \quad k_I(j\omega) = \frac{\dot{I}_2}{\dot{I}_1}; k_I(p) = \frac{I_2(p)}{I_1(p)}$$

2. Transmission impedance (mutual impedance):

$$(3) \quad Z_{tr}(j\omega) = Z_{12}(j\omega) = \frac{\dot{U}_2}{\dot{I}_1}; Z_{12}(p) = \frac{U_2(p)}{I_1(p)}$$

3. Transmission conductivity:

$$(4) \quad Y_{tr}(j\omega) = Y_{12}(j\omega) = \frac{\dot{I}_2}{\dot{U}_1}; Y_{12}(p) = \frac{I_2(p)}{U_1(p)}$$

Often for the four types of transfer functions a common symbol $T(j\omega)$, respectively $T(p)$ is used. The nature of the transfer function depends on the parameters of the quadripole, the values and nature of the internal resistance of the power source and the load.

$$(5) \quad k_U(p) = \frac{Z_T(p)y_{21}(p)}{1 - Z_T(p)y_{22}(p)}$$

or

$$(6) \quad k_U(p) = \frac{-y_{21}(p)}{y_{22}(p)} \Big|_{I_2=0} = \frac{z_{21}(p)}{z_{11}(p)} \Big|_{I_2=0};$$

$$(7) \quad Y_{21}(p) = \frac{y_{21}(p)}{1 + Z_T(p)y_{22}(p)};$$

$$(8) \quad Z_{21}(p) = \frac{Z_T(p)z_{21}(p)}{Z_T(p) + z_{22}(p)}.$$

The transfer function voltage is used most widely in practice

A.) Analytical expression of the transfer function

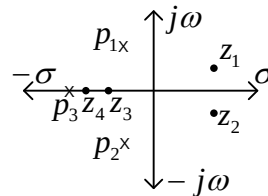
$$(9) \quad T(p) = \frac{Q(p)}{P(p)} = \frac{a_m \cdot p^m + a_{m-1} \cdot p^{m-1} + \dots + a_1 \cdot p + a_0}{b_n \cdot p^n + b_{n-1} \cdot p^{n-1} + \dots + b_1 \cdot p + b_0}.$$

Here a_i from $k_U(p)$ and $k_I(p)$ may have positive or negative values.

The roots of the polynomial in the numerator $Q(p)$ are called zeros, while those in the denominator polynomial $P(p)$ - poles.

B.) Pole-zero diagram. The image of zeros and poles in the complex plane is called pole-zero diagram (Figure 2). Usually zeros are represented by circles and the poles - by „x”. When the poles and zeros are real, they lie on the σ axis when imaginary - the $j\omega$ axis; complex - in the complex plane out of the coordinate axes. The zeros can lie on the left and right half of the complex plane..

Figure 2: A pole-zero diagram



The poles of the sustainable quadripole lay only at the left half-plane.

Depending on the location of the zeros of the quadripoles they can be divided into two major groups: minimum phase (all zeros are only on the left half-plane) and no minimum phase (part of the zeros lay in the right half-plane).

C.) Frequency responses (characteristics)

$$(10) \quad T(j\omega) = T_1(\omega) + jT_2(\omega) = T(\omega) \cdot e^{j\varphi(\omega)},$$

where

$T(\omega)$ - amplitude-frequency response (AFR), generally refers to voltage transfer function $k_U(p)$;

$\varphi(\omega)$ - phase-frequency response (FFR).

There has strict conformity (unambiguous connection) between $k_U(\omega)$ and $\varphi(\omega)$ for each frequency value. At the minimum phase quadripole there is no such uniformity and there is a possibility to change FFR without affecting the AFR at the no minimum phase quadripole.

The values of the frequency response for different frequencies can be represented as numbers representing the ratio between the two amplitudes when these variations are not distinguished significantly. For large differences a logarithmic measure is introduced:

$$(12) \quad \begin{aligned} k_U &= 20 \lg \frac{U_2}{U_1}, dB \\ k_U &= 20 \ln \frac{U_2}{U_1}, Np \end{aligned}$$

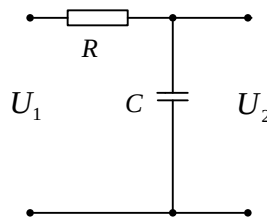
as $1Np = 8,686dB; 1dB = 0,115Np$.

D.) Polar diagram. The Curve that describes the tip of the vector of the transfer function in the complex Gauss plain at a frequency change or any of the circuit elements. The length of the straight line drawn from the origin to a point at the curve, which corresponds to a frequency in the selected scale, represents exactly the value of the module $T(\omega)$. The angle between this segment and the real axis - the phase angle $\varphi(\omega)$ of the transfer function for this frequency.

III. Calculating and draw the frequency responses of the quadripole in programming environment Matlab

The quadripole, which will be researched, is shown in Figure 3. The values of the his elements are: $R = 100\Omega$ and $C = 27\mu F$. It is necessary draw AFP, FFR and pole-zero diagram of the transfer function voltage. For this purpose it is necessary to write the expression to the coefficient of transmission voltage.

Figure 3: The quadripole, which will be researched



The expression (1) is used and it is applied to the scheme, shown on Figure 3. The obtained result is:

$$(13) \quad k_U(p) = \frac{U_2(p)}{U_1(p)} = \frac{Z_C}{Z_C + R} \Big|_{I_2=0} = \frac{1/pC}{1/pC + R} = \frac{1}{1 + pRC}$$

This transfer function is of the first order and has only one pole $p = -1/RC$.

The programme, which is called *quadripole.m*, is developed in the programming environment Matlab. It makes the necessary calculations and on their basis the frequency characteristics and pole-zero diagram are drawn:

```
1. clear;
2. disp('*****')
3. disp('The program to plot the frequency responses of the quadripole')
4. disp('*****')
5. %introduce the parameters of quadripole
6. R=input('Enter the value of the resistor in Ohms : R=');
7. C=input('Enter the value of the capacitor in Farads using square brackets C=');
8. %To draw the theoretically frequency responses
9. Q=input('Enter the coefficients in the numerator using square brackets: Q=');
10. P=input('Enter the coefficients in the denominator using square brackets: P=');
11. w=0:100:10000;
12. Q1=input('Enter the polynomial in the numerator Q1=');
13. P1=input('Enter the denominator polynomial P1=');

14. figure(1)
15. zplane(Q,P),%Draw pole-zero diagram
16. grid
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17. title('Pole-zero diagram')
18. Y=Q1./P1;
19. figure(2)
20. Y1=abs(Y);
21. plot(w,Y1),grid
22. title('Amplitude-frequency response')
23. xlabel('w,rad')
24. ylabel('Module of the coefficient of transmission voltage')
25. figure(3)
26. Y2=angle(Y);
27. anglegdeg=Y2*180/pi;
28. plot(w,anglegdeg),grid
29. title('Phase-frequency response')
30. xlabel('w,rad')
31. ylabel('Phase of the transmission coefficient of a voltage')
32. K1=real(Y);
33. K2=imag(Y);
34. figure(4)
35. plot(K1,K2),
36. grid
37. title('Polar diagram')
38. xlabel('Real part of the coefficient of transmission voltage')
39. ylabel('Imaginary part of the coefficient of transmission voltage')
40. %To draw the experimental amplitude-frequency response
41. figure(5)
42. fsim=input('Enter the frequency in Hz using square brackets: f=')
43. Uin=input('Enter the input voltage in V using square brackets: Uin=')
44. Uout=input('Enter the output voltage in V using square brackets: Uout=')
45. wsim=fsim.*(2*pi);
46. Ksim=Uout./Uin;
47. figure(5)
48. plot(wsim,Ksim),grid
49. title('Experimental amplitude-frequency response')
50. %To compare the theoretically and the experimentally built
51. %amplitude-frequency responses
52. figure(6)
53. plot(w,Y1,'r',wsim,Ksim,'b'),grid
54. legend('Theoretical amplitude-frequency response','Experimental amplitude-frequency response')
55. xlabel('w,rad')
56. ylabel('Module of the coefficient of transmission voltage')

```

The program is universal and can be used for any circuit. For this purpose it is necessary to establish the parameters of the scheme. If the circuit contains more than one resistor or capacitor, lines 6 and 7 must be repeated by placing indexes of different dimensions. At presence of inductance a line must be added where to introduce its value in Henry, too.

The parameters or the expressions which are written at lines 9, 10, 12 and 13 are also specific to each scheme. They depend on the resulting expression (13)=

In this case at the starting of the program and the introduction of the desired data the following is obtained on the screen:

The program to plot the frequency responses of the quadripole

Enter the value of the resistor in Ohms : R=100;

*Enter the value of the capacitor in Farads using square brackets C=27*10^-6*

Enter the coefficients in the numerator using square brackets: Q=[1];

*Enter the coefficients in the denominator using square brackets: P=[R*C 1];*

Enter the polynomial in the numerator Q1=1

*Enter the denominator polynomial P1=((R*C).*(i*w))+1;*

The resulting frequency response is shown in figure. 4, 5, 6 and 7.

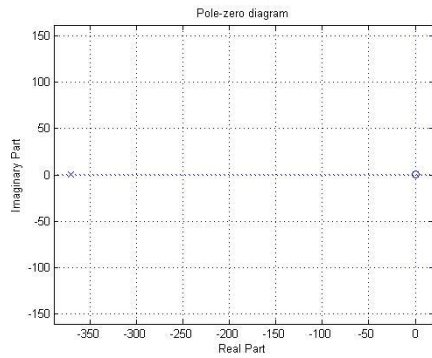


Figure 4: A pole-zero diagram

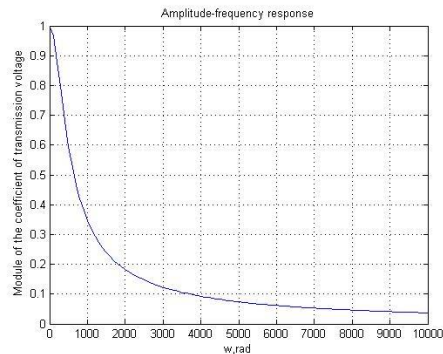


Figure 5: An amplitude-frequency response

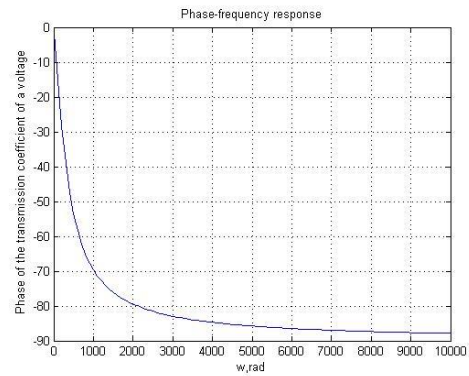


Figure 6: A phase-frequency response

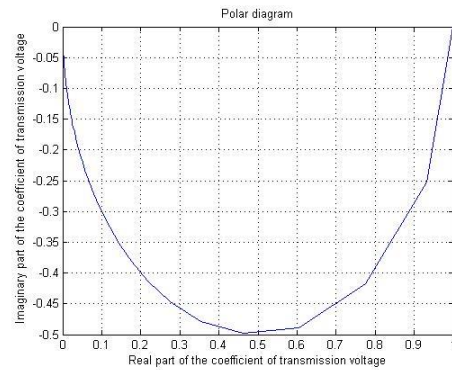


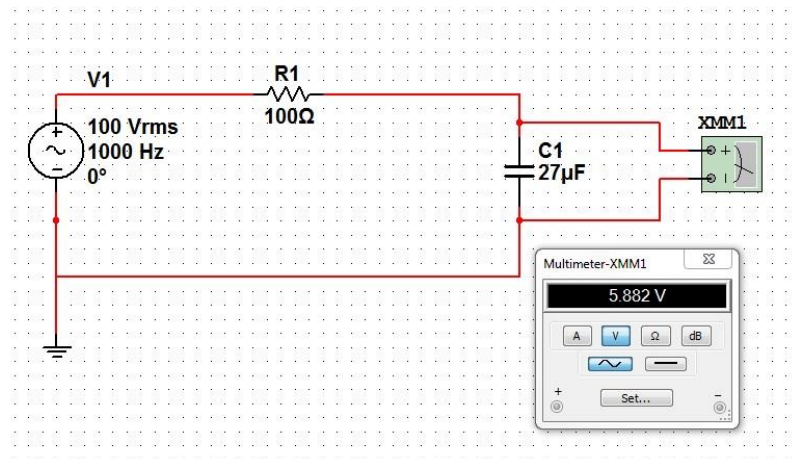
Figure 7: A polar diagram

IV. Verification of the theoretical data by simulation work of the scheme in programming environment Simulink of National Instruments.

For this purpose, the research scheme is implemented in programming environment Simulink of the NI as shown in Figure 8. The readings on the voltmeter at different frequencies are recorded. Then experimental frequency response is drawn, using the program *quadripole.m*. These are lines from 40 to 49. On the desktop in Matlab is obtained the following:

Enter the frequency in Hz using square brackets: $f=[10\ 20\ 40\ 60\ 80\ 100\ 150\ 250\ 300\ 400\ 500\ 1000]$;
Enter the input voltage in V using square brackets: $U_{in}=[100\ 100\ 100\ 100\ 100\ 100\ 100\ 100\ 100\ 100\ 100\ 100]$;
Enter the output voltage in V using square brackets: $U_{out}=[98.566\ 94.672\ 82.747\ 70.081\ 59.319\ 50.78\ 36.575\ 22.949\ 19.28\ 14.578\ 11.707\ 5.882]$

Figure 8: The Research scheme in programming environment Simulink



The experimental amplitude-frequency response is given in Figure 9.

V. Comparative analysis of theoretical and experimental data

Program *quadripole.m*, which is developed in Matlab (lines 50-56) allows a comparative analysis of theoretical and experimental data. For this purpose, both frequency responses are plotted of a common coordinate system as shown in Figure 10.

Figure 10 shows the full matching of the both characteristics (theoretical and experimental).

Figure 9: The experimental amplitude-frequency response

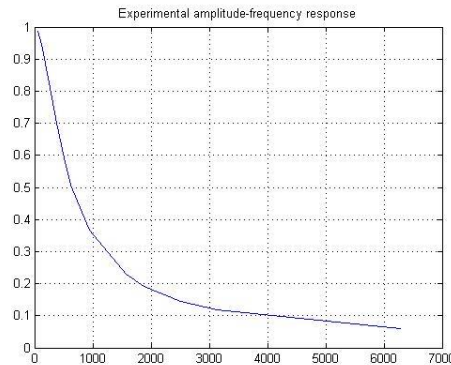
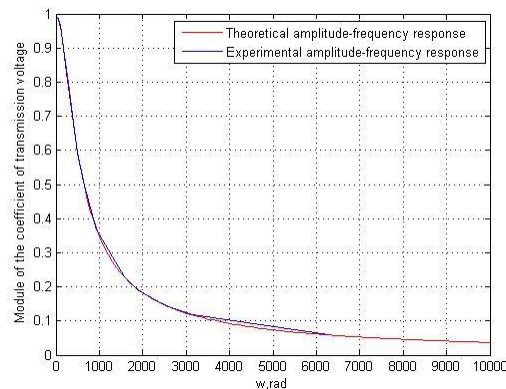


Figure 10: The Comparative analysis of theoretical and experimental amplitude-frequency responses



VI. Conclusion

Scheme of any quadripole may be theoretically researched by using the program developed in programming environment Matlab. The program *quadripole.m* is universal and easy to use. The learners must know the basic laws of electrical engineering and transformations in electrical circuits to find an expression for the coefficient of transmission voltage. The remaining conversions and calculations are performed by the developed program. The results are verified by simulation of the operation of the concerned circuit. The analysis of theoretical and experimental data shows complete coincidence.

The use of the proposed program increases the interest to the Electrical Engineering course, and avoids complex mathematical transformations.

VII. References

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