LTP - A TUTORIAL PROGRAM FOR ANALYSIS OF LINEAR TWO - PORTS

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Abstract

The paper describes basic possibilities offered by the program LTP (Linear Two-Ports) in teaching electrial networks theory. At the same time the most important algorithms used in the program are briefly described. The program LTP analyses immittance and transfer functions of two-ports in the domain of complex variable p, in the frequency domain and in the time domain. The results can be obtained in symbolic, semisymbolic and numerical form (with optional graphical representation of the numerical results). The program is user friendly and can be used easily by anyone.

Keywords:

Network analysis, Linear two-ports, CAD

1. Introduction

Teaching electrical networks is very demanding from the point of view of the necessary theoretical background required from the students. In spite of the basic analytical methods being simple in principle the concrete realisation of these methods in case of even modestly complicated networks can be rather tedious. It is therefore convenient to let the computer formulate and solve the network equations and process the results in graphical form. The time saved in this way can be usefully utilised for analysing the results or for experimenting with the network configuration or with parameters of the elements.

The program LTP developed at the Institute of Theoretical and Experimental Electrical Engineering, Faculty of Electrical Engineering, Brno Technical University, Czechoslovakia, is able to solve many practical problems. The user does not need to know anything about programming and is able to work with the program in the very first session. When creating the program its authors did not attempt to compete with well known and perfect but much more demanding programs as e.g. SPICE, SADYS/DYNAST or TINA (to name only programs that are familiar to specialists in Eastern Europe). In spite of this the program has several qualities that distinguish it from many others.

2. Properties of the program

The program LTP offers the following choice of possibilities:

- It analyses linear (linearised) networks the models of which are composed of resistors, capacitors, inductors (including inductors with mutual magnetic coupling), 4 types of controlled sources and ideal operational amplifiers.
- The network to be analysed may be described by means of its electrical schematic diagram (formed easily on the CRT) or by a simple table that defines its configuration. The input data may be prepared in advance and stored as files on disk.
- The analysed network is treated as a two-port. The program calculates its port- or transfer functions defined by just one signal (voltage or current) source and just one output sensor (voltmeter or ammeter).
- The network function in question can be expressed in form of rational fraction

$$F(p) = \frac{Q_m(p)}{P_n(p)} = \frac{b_m p^m + \ldots + b_1 p + b_0}{a_n p^n + \ldots + a_1 p + a_0} \quad , \qquad (1)$$

  either in symbolic or semisymbolic form. In symbolic form the coefficients of both polynomials are written as sums of products of parameters of network elements. The semisymbolic form of the results offers numerical values of these coefficients or numerical values of poles and zeroes of $F(p)$. The program further eliminates poles and zeroes that cancel each other and keeps the polynomial orders m and n as low as possible.
- The analysis is based on modified node voltage method [1]. The program formulates equations for independent node voltages plus equations for selected currents. In principle the method is applicable for linear networks with linear elements of any kind as e.g. gyrators, immittance inverters and converters, conveyors etc.
- The program further calculates complex values of $F(p)$ for $p = j\omega$ in a selected range of frequencies and plots

the graphs of frequency characteristics: modulus $F(\omega)$ in decibels, argument $\varphi(\omega)$ in degrees and group delay $tg(\omega) = -d\varphi(\omega)/d$ in seconds. Another possible form of the frequency characteristic is the hodograph, i.e. the dependence of imaginary part of $F(j\omega)$ on real part with ω as parameter of the curve.

- Finally the program analyses the impulse response

$$g(t) = L^{-1}[F(p)] \quad (2)$$

and the step response

$$h(t) = L^{-1}[F(p)/p] \quad . \quad (3)$$

The procedure is based on semisymbolic partial fraction expansion of $F(p)$ and $F(p)/p$ [2] and corresponding inversion of individual fractions leading to semisymbolic formulae for time waveforms.

- The initial electrical scheme with table of parameters, symbolic and semisymbolic forms of the network function or the partial fractions and time waveforms and all the graphical results can be optionaly printed on a 9-pin or 24-pin printer.
- The program is written in Pascal for IBM PC (XT, AT, 386 or 486) or compatible with graphical card Hercules (mono), EGA or VGA (mono or color). The program itself occupies about 150 kilobytes of memory and needs approximately another 200 kilobytes for data storage. The program works interactively and leads the user systematically in every step of operation.

3. Program structure

The work with the program will become clear from the following description of its principal blocks:

Block 1.

Select the name of the problem and the way of defining the two-port to be solved:

- Electrical schematic diagram: Build or modify the scheme, choose the identifiers and parameters of all elements. Store in the file NAME.SCH. Go to Block 2.
- Description of the electrical scheme: Formulate or modify the scheme description, choose the identifiers and parameters of all elements. Store in the file NAME.POP. Go to Block 3.
- Rational fraction $F(p) = Q(p)/P(p)$: Define or modify the orders and coefficients of the polynomials in $F(p)$. Store in the file NAME.RAC. Go to Block 5.

Block 2.

Check formal correctness of the scheme (connectivity, existence of just one source and just one sensor). On base of the graphic schematic diagram formulate the description of the two-port. Store in the file NAME.POP.

Block 3.

Determine the number of independent nodes and number of added unknown currents. Reduce inner nodes of series connections of elements with added currents (each reduction causes that the number of unknown quantities drops by 2).
Create a table describing the circuit matrix.
Find the symbolic expressions for cofactors of this matrix.
Formulate all existing (i.e. different from zero) products and classify them according to the power of p. Eliminate the products that cancel each other.
Find the polynomial LCD(p) that is the largest common divisor of the polynomials in the numerator and denominator of the fraction. Reduce the fraction if possible.
Store the results in the file NAME.SYM, display and/or print.

Block 4.

Calculate numerical values for the coefficients of polynomials in the numerator and denominator. Store the results in the file NAME.RAC, display and/or print.

Block 5.

Choose next steps in the analysis:

- Calculate zeros and poles: Calculate roots of the polynomials, display and/or print. Go back to the beginning of Block 5.
- Calculate and display the frequncy-domain characteristics: Go to Block 6.
- Calculate and display the time-domain characteristics: Go to Block 7.
- End of analysis? Choose one of the following possibilities:
  - Go back to the Block 1 and modify the actual allocation.
  - Go back to the Block 1 and create a new allocation.
  - Finish the work with the program.

Block 6.

Choose the type (logarithmic, linear) of frequency variation and the frequency (or angular frequency) range.
Choose the type of frequency responses to be analysed: Modulus and argument in degrees, modulus and group delay or hodograph.
Calculate corresponding values and store them. Display and optionally print the graphs.
Go to Block 5.

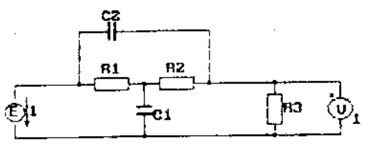
Block 7.

Choose the type of time-domain responses (impulse response $g(t)$, step response $h(t)$ or both responses simultaneously) and the time interval for the calculation.
If the order of numerator is not lower then that of denominator perform the division and separate the terms that will result in Dirac impulses of first and higher orders.
Express the fractional part of $F(p)$ and $F(p)/p$ in semisymbolic form as sum of partial fractions. Derive semisymbolic expressions for responses $g(t)$ and $h(t)$ as sums of inverse Laplace transforms of these fractions.
Substitute for time t to get numerical values of responses and store them for graphical representation.
Display and optionally print the graphs. Go to Block 5.

4. Example

The network to be solved is a bridged-T RC network loaded at the output with resistor R3 the value of which is comparable with internal resistances R1 and R2. The placement of input voltage source E1 and voltmeter V1 shows that the network function to be analysed is voltage transfer factor $K_u(p)$. Some results copied from the printer are shown in the following tables.

F4 - Bridged-T Network




```
R3    2.000000000E+0004   Rzat
R2    5.000000000E+0003   R2
C1    1.000000000E-0007   C
C2    5.000000000E-0009   C2
R1    2.000000000E+0003   R

Ku(p)

Numerator
+p^0*(+Rzat)
+p^1*(+C2*R2*Rzat +C2*R*Rzat)
+p^2*(+C*C2*R*R2*Rzat)

Denominator
+p^0*(+Rzat +R2 +R)
+p^1*(+C*R*Rzat +C*R*R2 +C2*R2*Rzat +C2*R*Rzat)
+p^2*(+C*C2*R*R2*Rzat)


Ku(p)

Numerator
 2.0000000E+0004*p^0
 7.0000000E-0001*p^1
 1.0000000E-0004*p^2
Denominator
 2.7000000E+0004*p^0
 5.7000000E+0000*p^1
 1.0000000E-0004*p^2

Multipl. Coefficient
 1.0000000E+0000
Numerator
 2.0000000E+0008*p^0
 7.0000000E+0003*p^1
 1.0000000E+0000*p^2
Denominator
 2.7000000E+0008*p^0
 5.7000000E+0004*p^1
 1.0000000E+0000*p^2
```

The table under the scheme contains parameter values of all the network elements. Then there follow symbolic expressions for the coefficients of polynomials and numerical values of these coefficients and roots of both polynomials.

Characteristics in frequency domain are represented by the modulus in dB and phase in degrees. Under the graphs there is a table of numerical values of all important data corresponding to f=2238.72 Hz, i.e. to the minimum value of the modulus. The table contains real and imaginary parts of $F(j\omega)$, modulus both in absolute value and in dB, angular frequncy ω, phase *fi* in degrees, group delay in seconds and slope of the modulus characteristic in dB/decade.

In time domain we calculate both impulse and step responses. Since the order of both polynomials in $F(p)$ are equal the impulse response $g(t)$ contains a Dirac impulse delta^1. The presence of this impulse is indicated in the formula for $g(t)$ but the impulse is not seen in the graph.

5. Conclusion

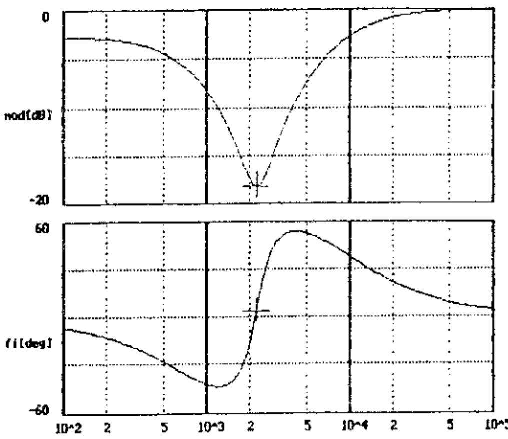
The program LTP can be used to analyse network functions of linear paasive or active two-ports in the domain of complex variable p, in frequency domain and in ti

```
Zeros
-3.500000E+0003   +j*(-1.370219E+0004)
-3.500000E+0003   +j*( 1.370219E+0004)

Poles
-5.213738E+0003   +j*( 0.000000E+0000)
-5.178626E+0004   +j*( 0.000000E+0000)
```

Freq. Domain Characteristics

Ku(p) Voltage Transfer Factor




```
f: 2.23872E+03[Hz]     mod: 1.22342E-01                 ome: 1.40663E+04[]
Re[F]: 1.22059E-01     mod:-1.82487E+01[dB]             fi = 3.897[deg]
Im[F]: 8.31404E-03     sa = 9.31402E+00[dB/dek]         tg =-2.41504E-04[s

 Network Function is Not a Proper Fraction:
After Division We Get:
 1.00000E+0000*p^0

 Partial Fractions of F(p)
 4.09441E+0003/(p-(-5.21374E+0003))
-5.40944E+0004/(p-(-5.17863E+0004))
```

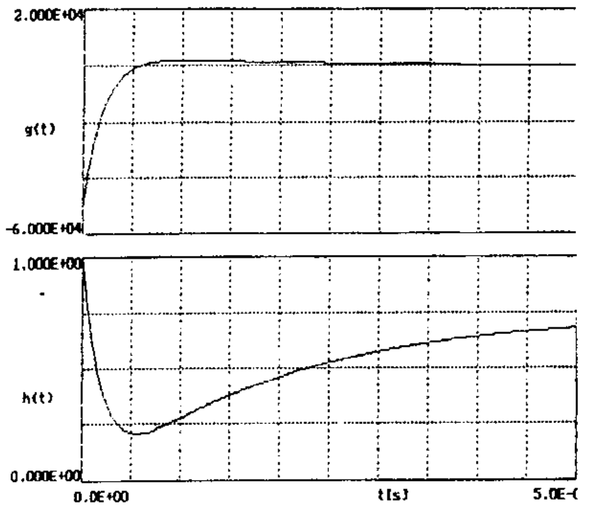
```
 g(t)=
 1.00000E+0000*delta^1
 4.09441E+0003*exp(-5.21374E+0003*t)
-5.40944E+0004*exp(-5.17863E+0004*t)

 Partial Fractions of F(p)/p
 7.40741E-0001/(p)
-7.85311E-0001/(p-(-5.21374E+0003))
 1.04457E+0000/(p-(-5.17863E+0004))

 h(t)=
 7.40741E-0001
-7.85311E-0001*exp(-5.21374E+0003*t)
 1.04457E+0000*exp(-5.17863E+0004*t)
```

Time Domain Characteristics

Xu(p) Voltage Transfer Factor



me domain. It offers a comfortable and interactive contact with the user but does not require any long and demanding trainig. These properties predestine the program not only for the use in teaching theory of linear circuits in undergraduate courses but also as a handy tool for everyone who wants to verify his results or to experiment with various schemes or element parameters.

6. References

[1] Chung-Wen Ho - Ruehli, A. E. - Brennan, P. A.: The Modified Nodal Approach to Network Analysis, IEEE Trans. on Circuits and Systems CAS-22, No. 6, June 1975, pp. 504-509.

[2] Chin, F. Y. - Steiglitz, K.: An O(N^2) Algorithm for Partial Fraction Expansion, IEEE Trans. on Circuits and Systems CAS-24, Jan. 1977, pp. 42-45.

About author

Juraj Valsa was born in Záměl, Czechoslovakia, in 1933. He received the M.E. degree in radioengineering at the Military Technical Academy in Brno in 1956 and the Ph.D. degree in 1965. He is currently a professor at the Department of Theoretical and Experimental Electrical Engineering of the VUT Brno. In pedagogical and research activities he is interested mainly in mathematical modeling and simulation of systems with rotating electrical machines and methods of CAD of linear and nonlinear electrical and electronic circuits and systems.
During academic year 1993-94 he is on academic leave at University of Waterloo, Canada.