4

Analysis of linear systems with LISA

Overview

LISA allows the analysis of linear systems with input $u(t)$ and output $y(t)$ given in form of a transfer function with dead time

System model

$$G(s) = \frac{Y(s)}{U(s)} = \frac{b_m s^m + b_{m-1} s^{m-1} + \ldots + b_1 s + b_0}{s^n + a_{n-1} s^{n-1} + \ldots + a_1 s + a_0} e^{-Ts} .$$

or in form of a block list, i. e. a serial combination of linear standard transfer elements. If the system is specified via block list the corresponding total transfer function is calculated internally. For more details see chapter *Basics*.

System analysis covers the following tasks:

- Calculation of step response

  The response of the system to a input step function

$$u(t) = \begin{cases} 0 & \textit{für } t < 0 \\ 1 & \textit{für } t \geq 0 \end{cases}$$

  is calculated. Simulation length and number of simulation steps can be chosen by the user. The simulation is executed by using the matrix exponential method [3].

- Frequency response representation in form of a Bode plot

  The frequency response

$$G(\mathrm{j}\omega) = \frac{Y(\mathrm{j}\omega)}{U(\mathrm{j}\omega)} = \frac{b_m (\mathrm{j}\omega)^m + b_{m-1} (\mathrm{j}\omega)^{m-1} + \ldots + b_1 (\mathrm{j}\omega) + b_0}{(\mathrm{j}\omega)^n + a_{n-1} (\mathrm{j}\omega)^{n-1} + \ldots + a_1 (\mathrm{j}\omega) + a_0} e^{-\mathrm{j}\omega T}$$

  is calculated over a user-defined frequency range and representend in form of amplitude (gain) response $|G(\mathrm{j}\omega)|_{\mathrm{dB}}$ and phase response $\angle G(\mathrm{j}\omega)$ over a logarithmic frequency axis.

- Frequency response representation in form of a Nyquist plot

  In this case the frequency response is separated into a real part $\mathrm{Re}\{G(\mathrm{j}\omega)\}$ and an imaginary part $\mathrm{Im}\{G(\mathrm{j}\omega)\}$ and drawn over the complex plane. If desired the plot can be parameterized by using the frequency ω as a curve parameter.

- Root locus representation

  For this representation the course of the eigenvalues of the closed-loop system in dependance of the gain of a P-controller is calculated and drawn over the complex plane.

- Calculation of poles and zeros

  The poles (eigenvalues) and zeros of $G(s)$ are calculated by using the algorithm of Lagrange.

LISA offers a Multi-Document interface; thus one system can simultaneously be represented in different forms, with different scaling etc.

Program options

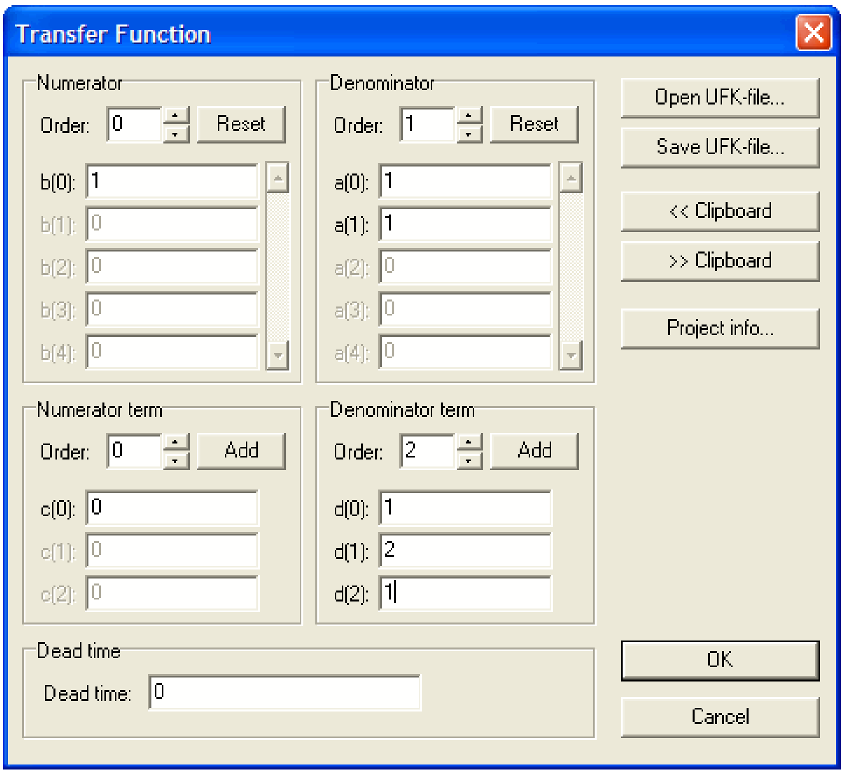
Specifying the system

After starting LISA automatically a first (still empty) document window appears. The system to be analyzed can be specified directly as a transfer function or in form of a block list which is transformed to a total transfer function internally. The menu options FILE | OPEN SYSTEM FILE..., FILE | SAVE SYSTEM FILE (AS) resp. FILE | EDIT TRANSFER FUNCTION... or FILE | EDIT BLOCK LIST... from the FILE submenu can be used for these purposes; alternatively the corresponding toolbar button may be used. The corresponding system model is represented within the document window which is the active one at that moment. If you intend to open a new document window select the FILE | NEW WINDOW menu option first.

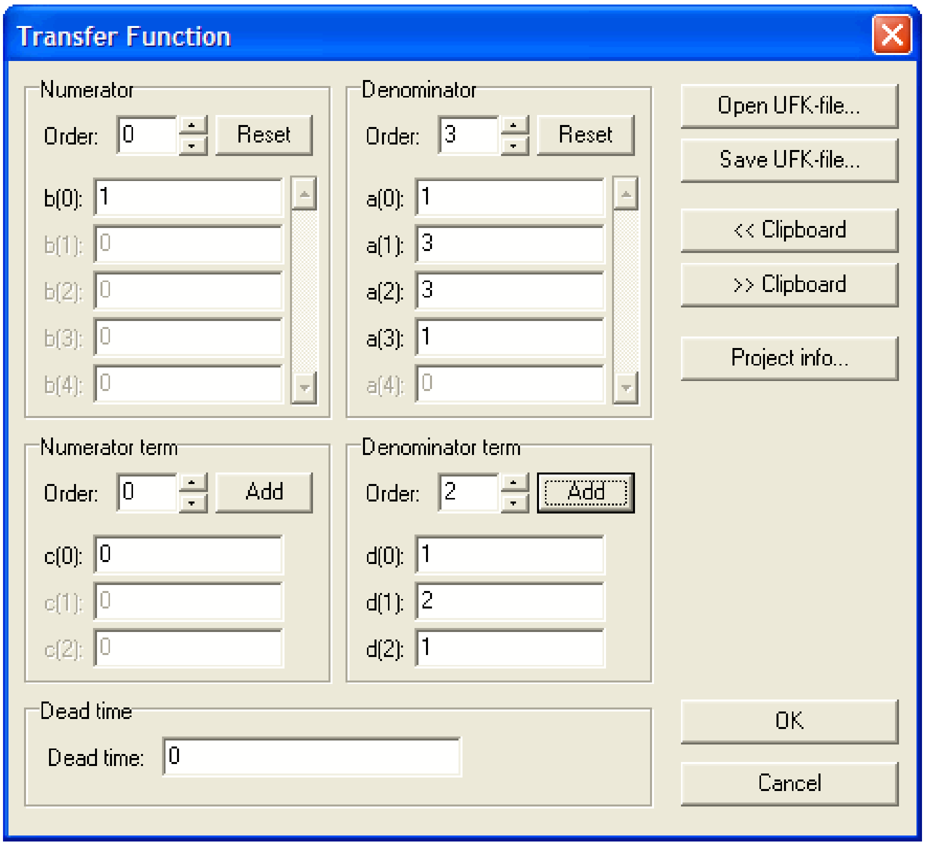
The screenshot below shows the corresponding dialog. This dialog offers the following options:

- Modification of the transfer function's coefficients and dead time
- Copy and/or Paste from/to Windows clipboard
- Save and load to/from a UFK file
- Display and modification of the project information

The numerator and denominator polynom of the transfer function can be entered directly by their coefficients. In addition to that it's also possible to enter the polynoms termwise, that means as a product of single numerator resp. denominator terms of order 0 up to 2. Therefore the single terms have to be entered in the lower half of the dialog box; after clicking the *Add* button, the term is then added to the already existing polynom. By clicking the *Reset* button, the numerator resp. denominator polynom can be reset to 1 at any time. The following screenshots explain the procedure. If a root locus representation is selected the dead time is automatically set to 0 internally.

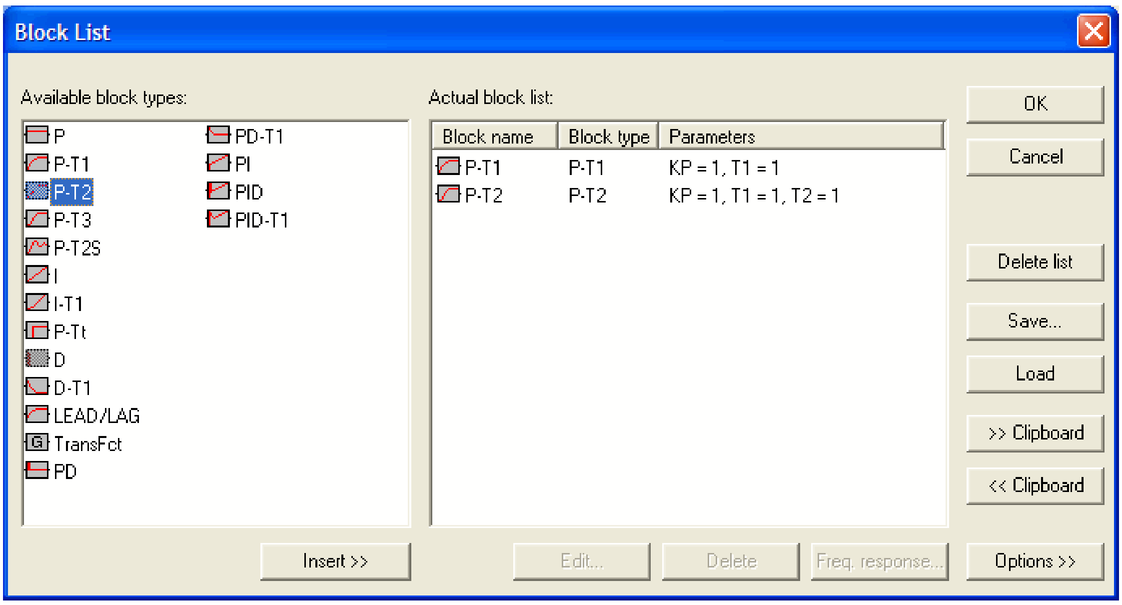


Example for the factorized specification of a denominator term of second order...



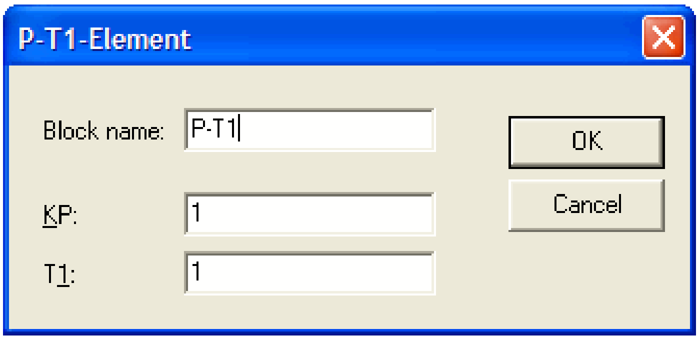
... and dialog box after adding it to the already existing denominator

If the system model is specified in form of a block list the following dialog appears.



Dialog for modification of a block list

The left dialog area contains a list view with all available block types; a block can be inserted into the block list by a double click or by selecting the block first and pressing the *Insert >>* button afterwards. The right area of the dialog shows the current block list in which all blocks are displayed with their block name, block type and parameters. By a double click on a block of the current block list this block can be edited (see screenshot below). Pressing the *Freq. response* button opens a separate window displaying the Bode plot of the selected block. The buttons located at the right dialog margin allow saving and loading of block list files (extension BL) or data transfer from/to the Windows clipboard.

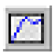


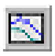
Example: Dialog for editing a P-T1-block

After closing the block list dialog the current block list is automatically transformed to the corresponding total transfer function. If desired this total transfer function can be modified later - however this is not recommended. Because the block list representation is the more flexible one it will be better to modify the system always in its block list representation if it was first specified in this form.

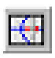
Display modes and how to save results

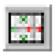
A new graphic window by default has the mode *step response*. To change the mode, use the DISPLAY-submenu or one of the following toolbar buttons:

 Step response

 Bode plot

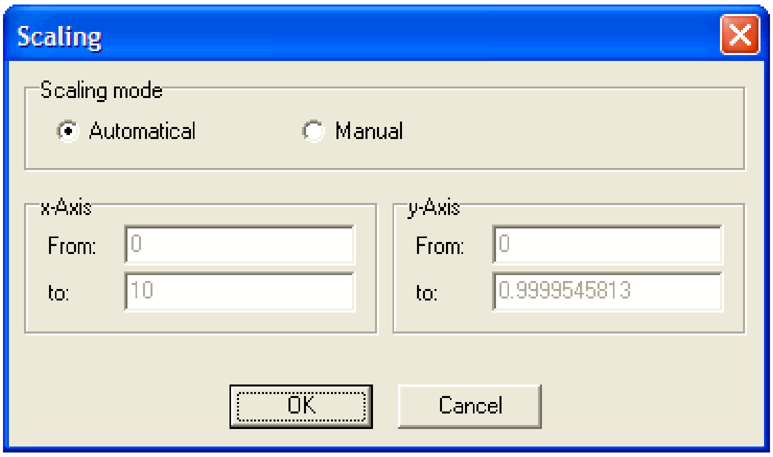
 Nyquist plot

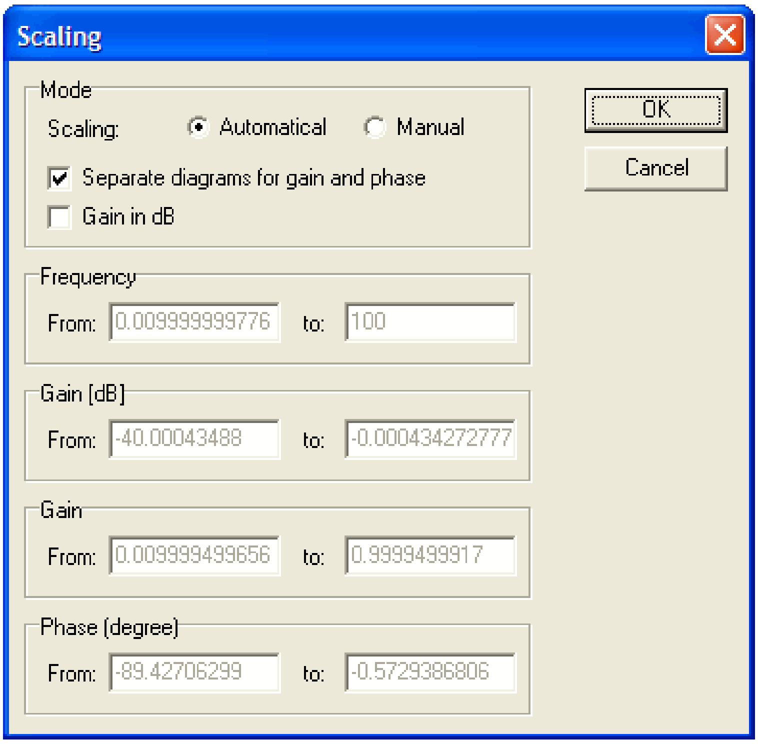
 Root locus

 Poles/Zeros

Step responses, Bode plots and Nyquist plots can be saved in SIM, BD resp. OK files; choose the SAVE | SAVE... menu option or the button  of the toolbar.

The scaling of the diagram axes can be specified via the SCALING | SCALING... menu option, some other display mode depending parameters via the PARAMETERS | PARAMETERS... option (see screenshots below).





Dialogs for scaling linear (top) resp. logarithmic diagrams (bottom)

The PARAMETERS | PARAMETERS... menu option allows the specification of the time resp. frequency domain parameters for the calculations.

Time domain parameters are

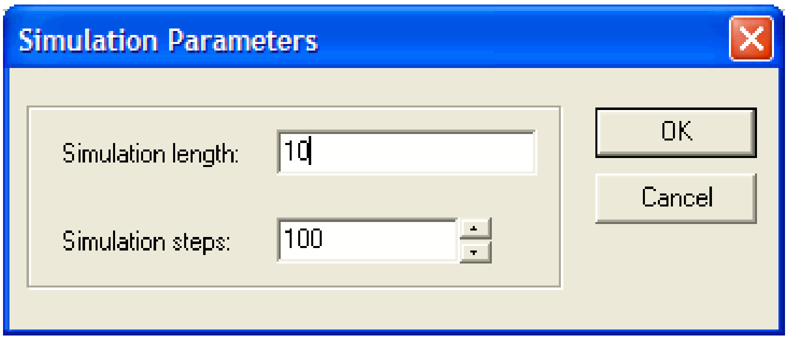
- The simulation length T_{Sim}..
- The number of simulation steps n. This should be specified in such a way that the resulting step size

$$\Delta T = \frac{T_{\mathrm{Sim}}}{n-1}$$

  is less than 10% of the smallest time constant of the system to get simulation results with sufficient precision.

Defaults:

Simulation length:	10
Simulation steps:	100



Dialog for simulation parameters

For Bode or Nyquist plot the following parameters have to be specified:

- The smallest calculated frequency $\omega_{\min}$
- The number of frequency decades to be calculated
- The number of values calculated for each decade. This number is a lower bound; if the curve seems to be not smooth enough for a specific frequency range, the value is increased by LISA automatically (see below).
- The angle $\Delta\Phi$ which specifies the maximum allowed change of phase between two frequencies before additional intermediate points are cal-

culated (see above). If the curves are not smooth enough, you can decrease this parameter.

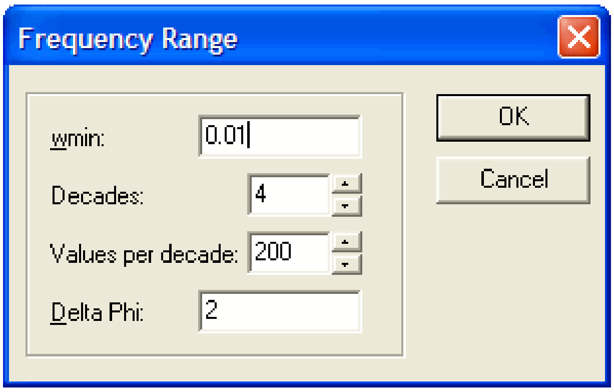
Defaults:

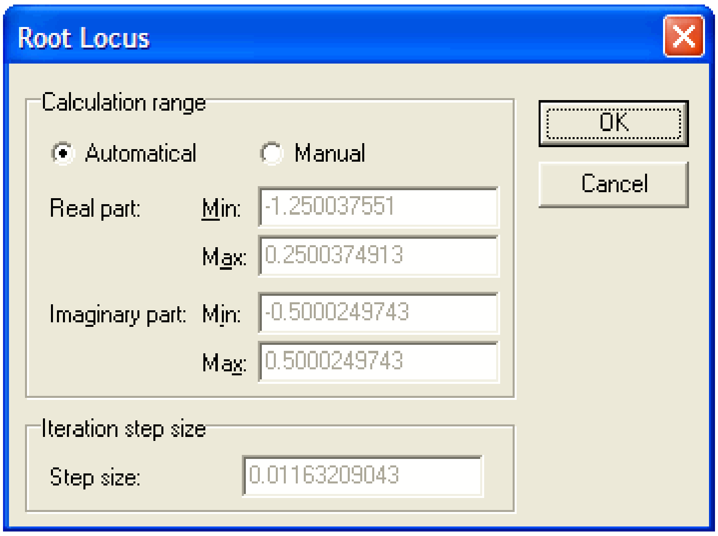
$\omega_{\min}$:	0.01
Decades:	4
Values/Decade:	20
$\Delta\Phi$:	5

In the root locus mode the following parameters have to be specified:

- The calculation range for the real and the imaginary part. In the automatical mode these are determined in dependance of the poles and zeros of the system.

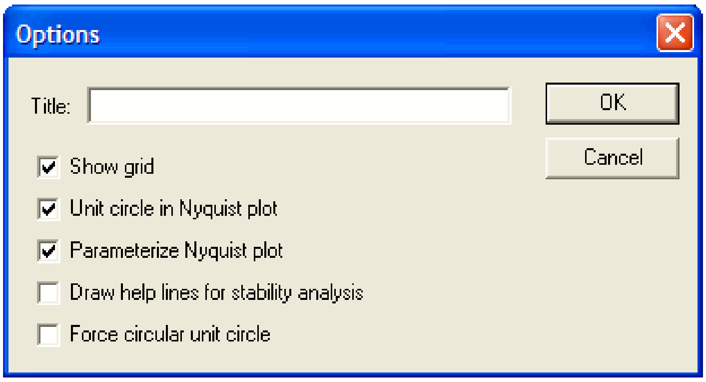
- The iteration step size for the calculation. This value is also set by default in dependance of the system's poles and zeros. If the system has poles and/or zeros that are located very near to each other, it may be useful to decrease this value to get better results.



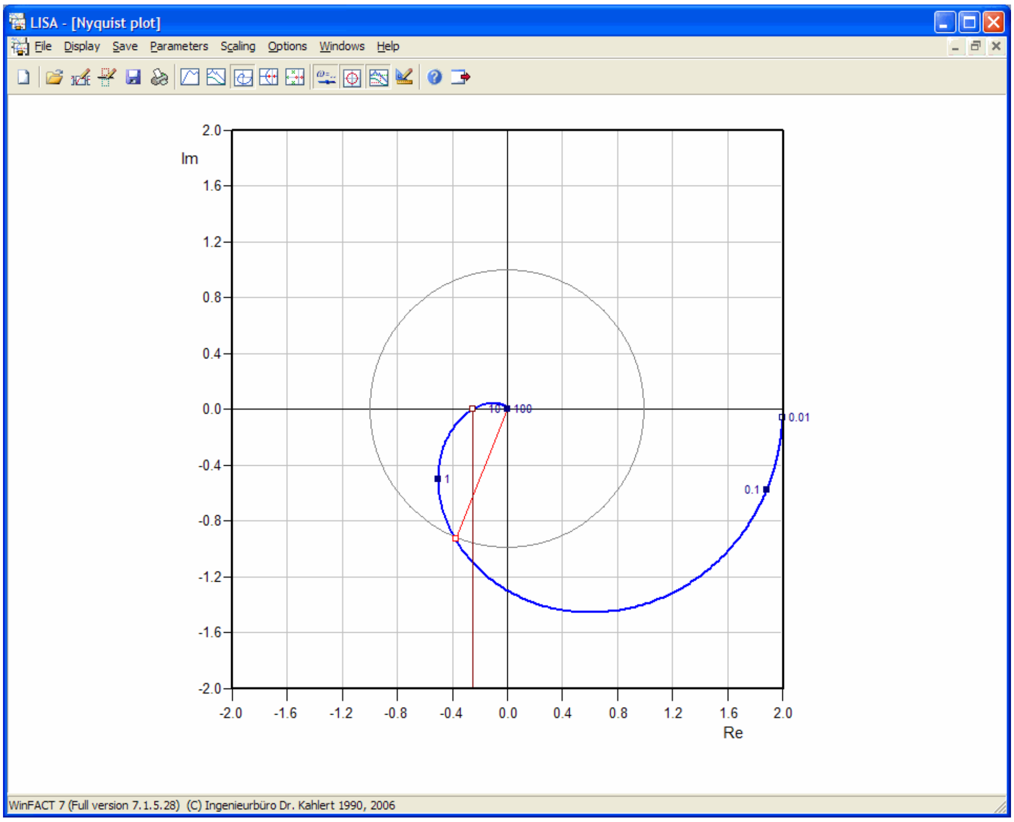


Dialogs for frequency range parameters (top) and root locus parameters (bottom)

The OPTIONS | OPTIONS... menu item allows the specification of a title for each document window, the activation/deactivation of diagram grids as well as unit circles and curve parameterization for Nyquist plots. Furthermore Bode and Nyquist plots can be supplied with help lines for the stability analysis of systems based on phase and amplitude margin. For Nyquist plots a special diagram mode can be forced with a unit circle that's really "circular" independent from display resolution and window size (see screenshot below).



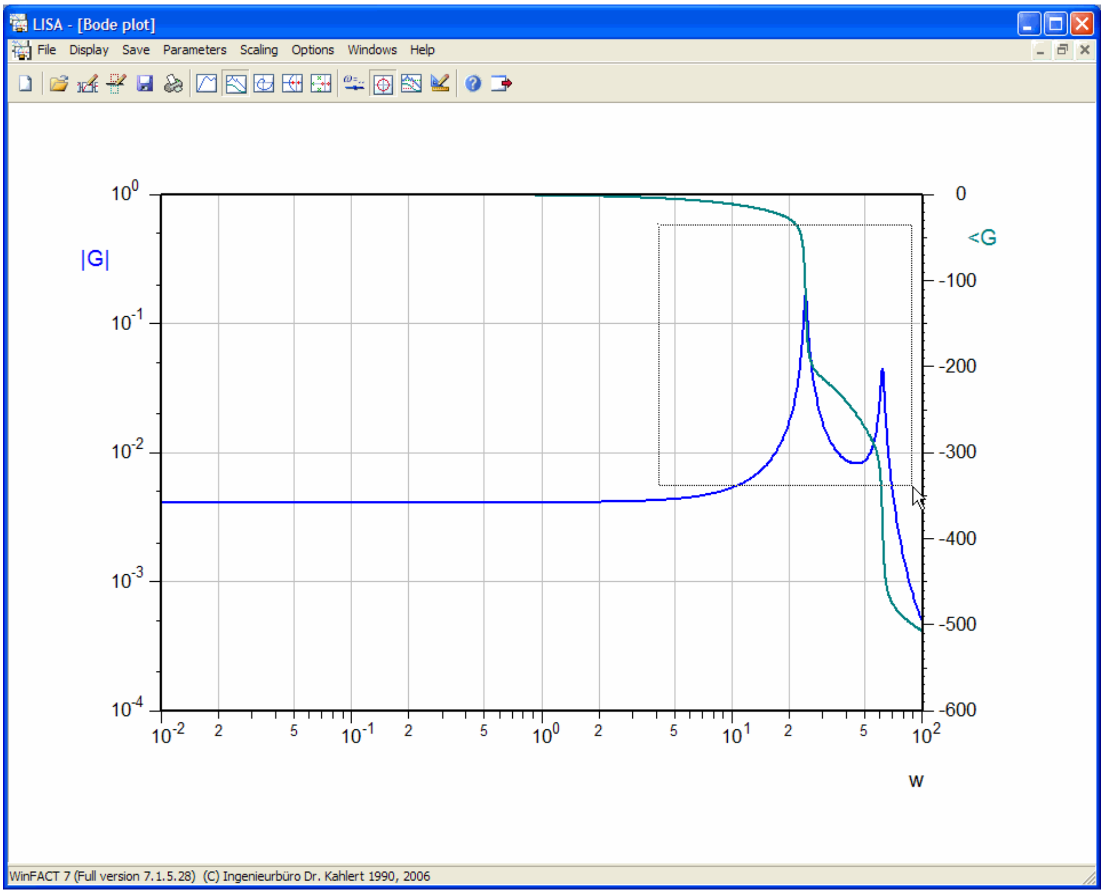
Options dialog



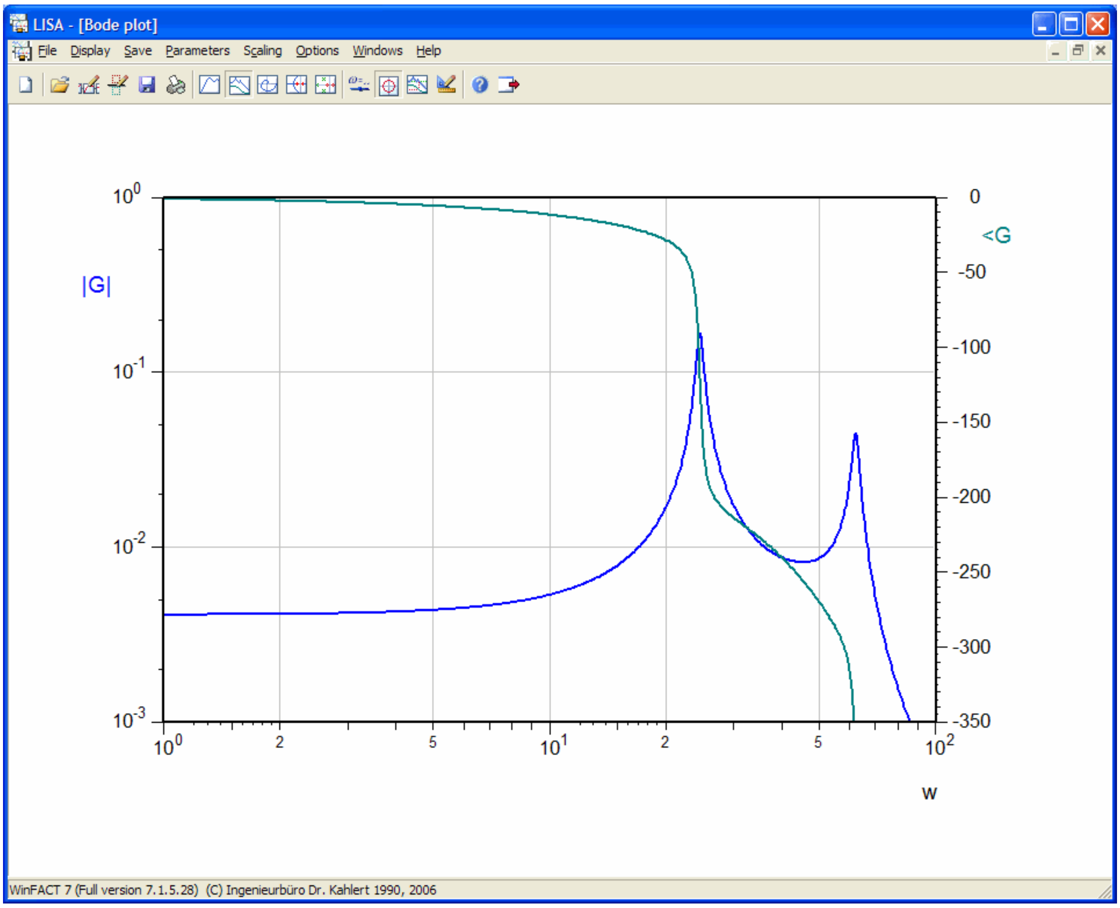
Example: Parameterized Nyquist plot with circular unit circle and help lines for stability analysis

Zoom and measurement mode

For all display modes (except the *poles/zeros* mode) LISA offers a zoom function. This function allows a magnification of a specific part of the graphic by selection with the left mouse key. Simply click at the upper left corner of the rectangular part of the graphic you want to zoom, hold the mouse key pressed and move to the lower right corner; then release the mouse. LISA now automatically switches to the manual scaling mode and displays the selected part (see screenshots below). To get the whole graphic again, change to the automatical scaling mode or simply click the toolbar button representing the current display mode again.



Zoom mode: Selection of the diagram region to be zoomed...

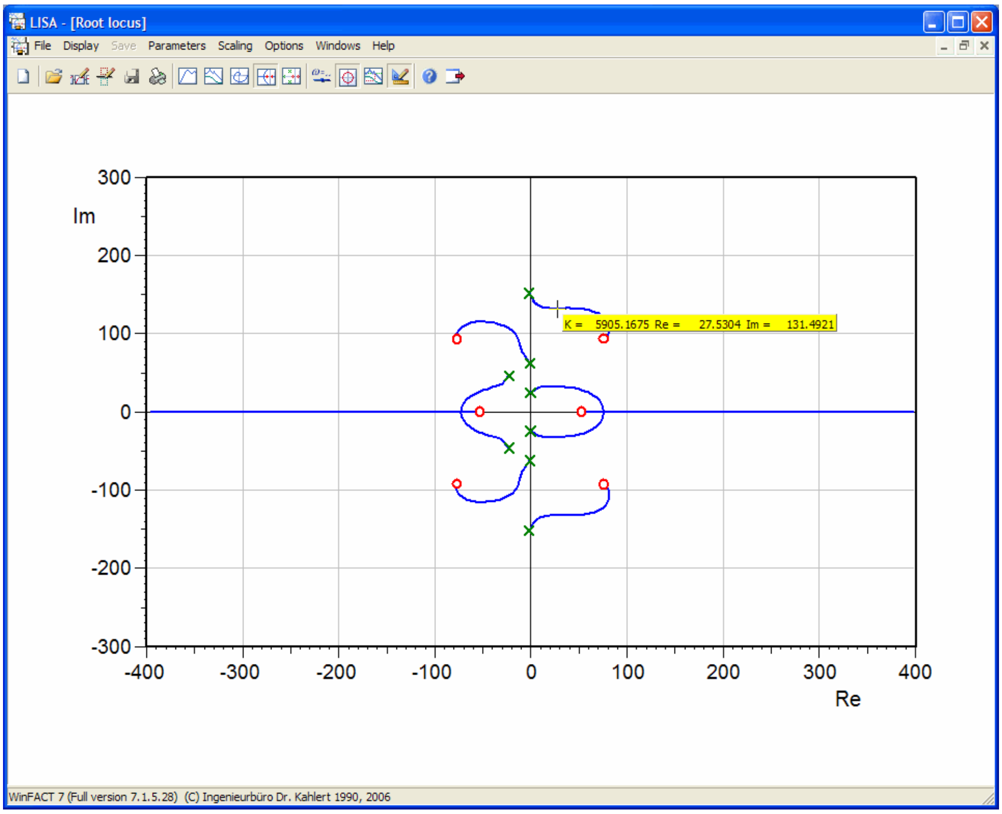


...and window zoomed to selected region

The DISPLAY | ACTIVATE MEASUREMENT MODE menu option resp the  toolbar button activate the measurement mode. If this mode is activated the mouse cursor is followed by a small hint window (tooltip) containing the diagram coordinates of the current cursor position.

If the representation modes *Nyquist plot* or *root locus* are selected this hint window contains further information if the mouse cursor is just located over the curve:

- In the Nyquist plot mode the frequency, the real part and the imaginary part of the curve point at the cursor is displayed
- In the root locus mode the gain, the real part and the imaginary part are displayed



Main window with activated measurement mode (for root locus representation here)

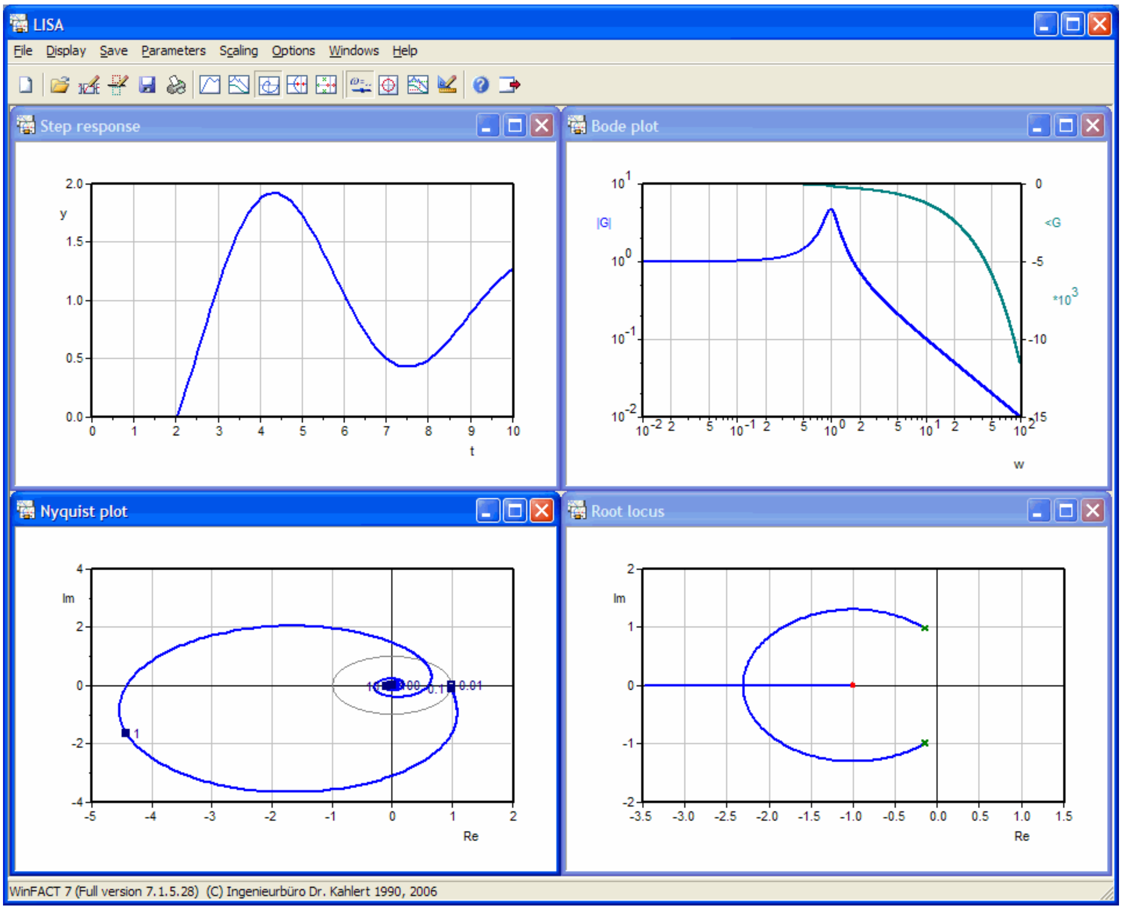
Program constants

Maximum system order: 20

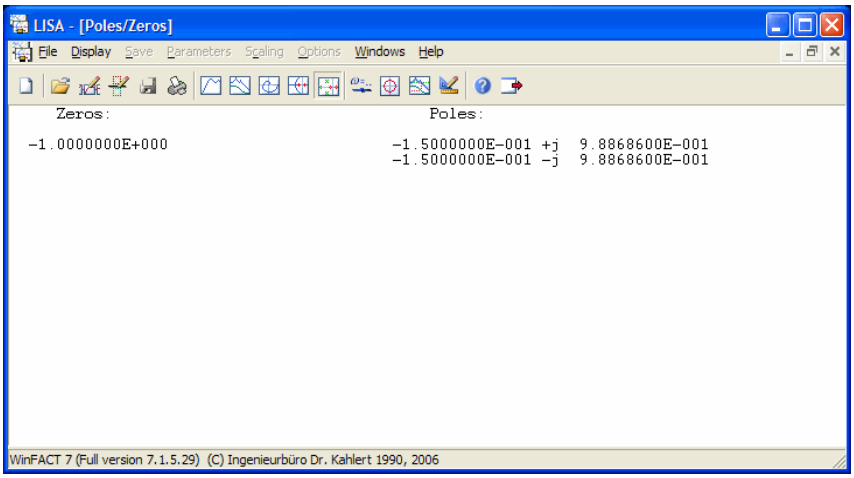
Sample application

The following screenshots show the different display modes for a second order system with the transfer function

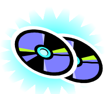
$$G(s) = \frac{s+1}{s^2 + 0.3s + 1} e^{-2s}.$$



Step response, Bode plot, Nyquist plot and root locus diagram for sample transfer function



Poles and zeros for sample transfer function



The Examples-directory of your WinFACT installation contains the following sample files:

LISA1.UFK: System with $m = 1$, $n = 2$ and all-pass characteristic

LISA2.UFK: Equivalent to LISA1.UFK with additional dead time

LISA3.UFK: System with $m = 6$, $n = 8$ and all-pass characteristic