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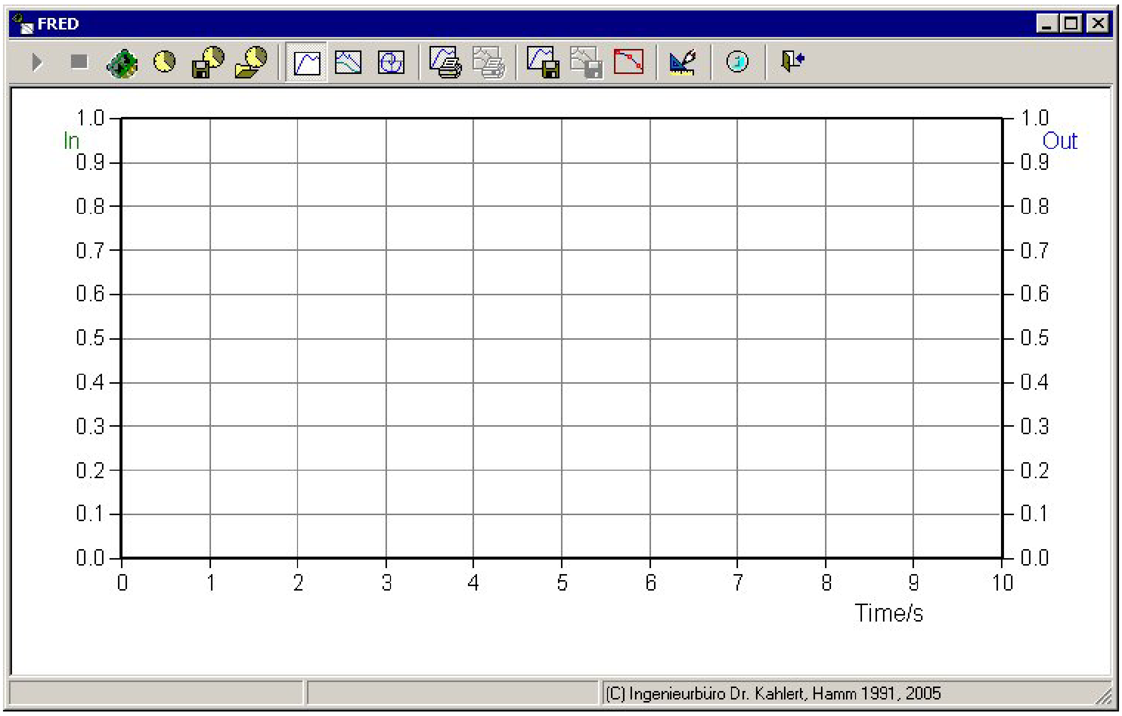
Experimental analysis of frequency response with FRED

Overview

The WinFACT module to measure a frequency response is called FRED. It gives you the possibility to record an experimentally created frequency response. For this a wobble generator, which generates the different frequencies, is composed by a WinFACT driver and its supported hardware. The main features of FRED are:

- Usage of the WinFACT driver.
- Rapid and clear configuration.
- Data handling is done via multi threading, so a good realtime behaviour is achieved.
- Graphical presentation of the measured data and all time responses.
- Saving of the measured data.
- Manipulating of a measured frequency response by adding and deleting further frequencies.



FRED after start up

Measuring frequency response

Background

The frequency response shows, in which way amplitude and phase of different frequencies of harmonic oscillations change, after the according settling time of the dynamic system has elapsed. The frequency response characterizes the dynamic behaviour of the system.

To measure the frequency response a system has to be stimulated with sinusoidal oscillations of different frequencies successively. For each frequency the settling time must be observed, to ensure the system is in a steady state. Only then the amplitude and phase shift will be measured correctly for the currently adjusted frequency. This procedure must be done for the whole range of frequencies and the results are recorded in a diagram.

The amplitude is given in decibel (db) and the phase in degrees of angle (°). The gain is defined as follows:

$$G(\omega)[db] = 20 \cdot \log_{10} \frac{A_A(\omega)}{A_E(\omega)}$$

With:

A_E amplitude of the input signal and

A_A amplitude of the output signal.

The phase is ambiguous because of the periodical sinus signal. It is defined by:

$$\varphi(\omega)[°] = \frac{(t_E(\omega) - t_A(\omega)) \cdot \omega}{2 \cdot \pi} \cdot 360°$$

With:

t_E the point of time the input signal has a maximum and

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t_A the point of time the output signal has a maximum.

Both values must have a causal connection to get the correct phase. This cannot be analysed nor can it be measured.

Therefore FRED assumes the phase shift is changing not more than ±180° from one frequency to the next. This is the case if the difference of the both frequencies (*Δf*) is not too big and the system behaves like a time invariant linear system. When the system has got a dead time, *Δf* is getting too big very fast. This is because the phase shift increases linear with the increasing frequency. In this case you can simply add some measuring points by choosing frequencies in between; - so you will manually reduce *Δf* in this region (s. chapter Add measurement points).

When FRED is getting the phase shift for the first frequency, it assumes that the previous one was zero. Because of this, the maximum of the first angle is ±180°. This means to you as the user of FRED, to start measuring at a frequency which is low enough, to ensure a phase shift that is lower than ±180°.

Configuration

Hardware driver

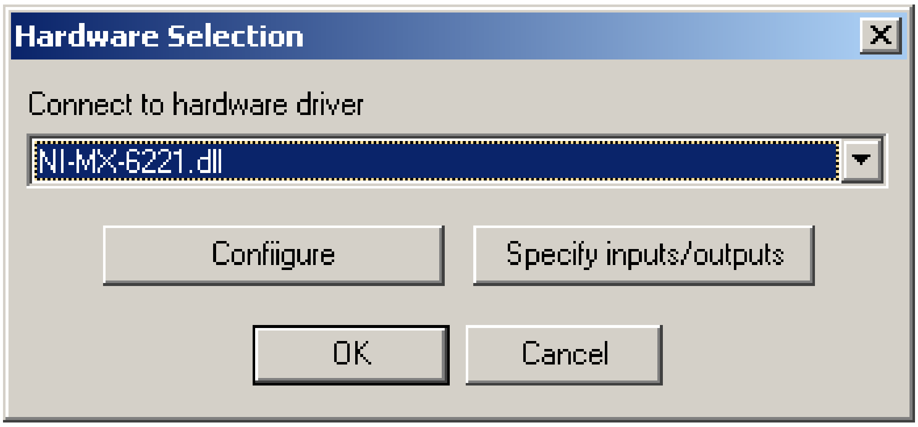
To measure a frequency response for a plant, FRED must be connected to the plant and configured in an appropriate way. The connection of the computer with the plant must be done with some data acquisition hardware that contains the following features:

- at least one analog input,
- one analog output and
- a WinFACT driver for the hardware must exist.

Some model plants provide an opportunity to reset the plant by an external analog or digital input. FRED can use this feature, if your measurement hardware has got an additional analog or digital output channel.

If you have got a hardware and there is no WinFACT driver listed for it (in the internet at www.kahlert.com), feel free to get in contact with us.

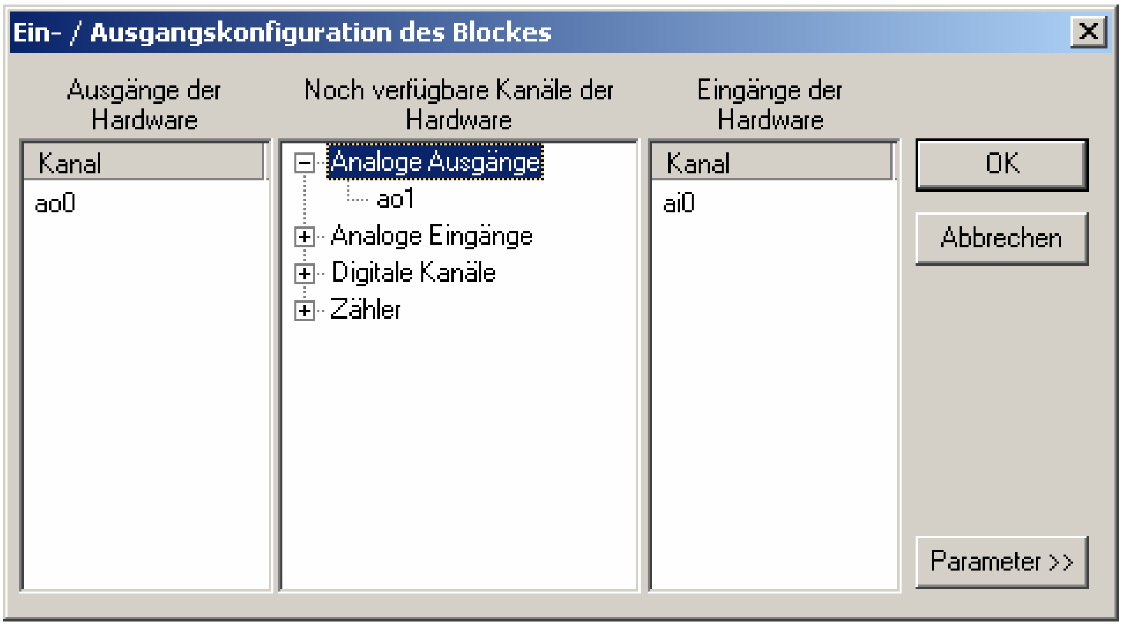
To use the hardware press the button *Driver installation*. A dialog appears with a list of the WinFACT drivers installed on your system.



Dialog to choose a hardware driver

You can configure the driver now. This is hardware dependent, so we cannot give any hints here. You simply have to look in the documentation of the hardware.

Afterwards the inputs and outputs that should be used by FRED must be specified. This can be done in the dialog that will be shown after pressing the button *Specify inputs/outputs*. Drag a channel from the tree in the middle of the window and drop it in the left or right list. In the picture below you can see the dialog with an input and an output.



Configuration of the channels to use as input and output of the hardware

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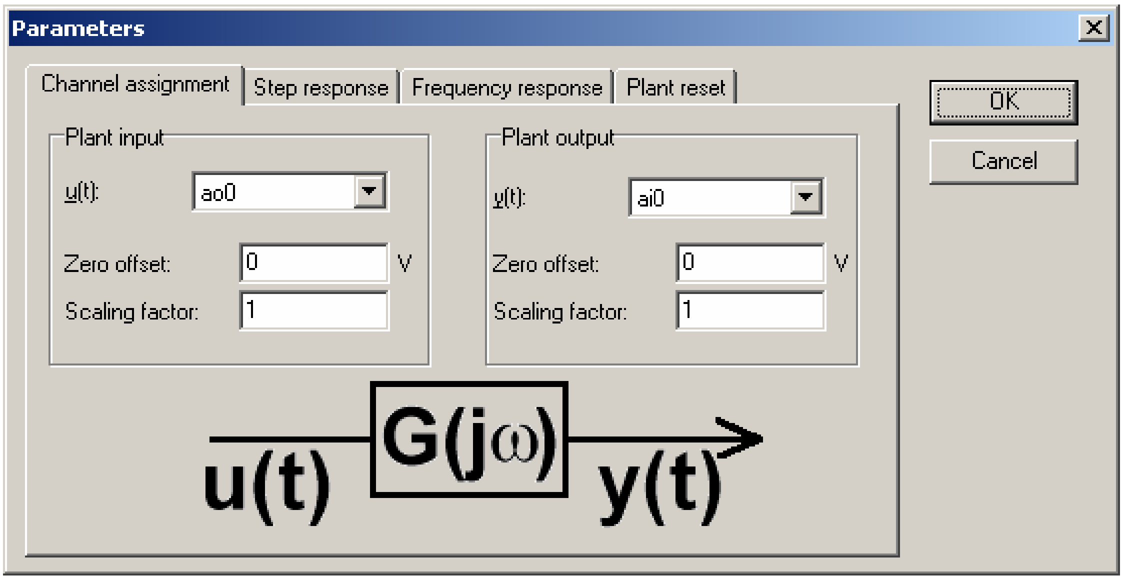
Please keep in mind that channels can have additional parameters and you may wish to adjust these.

Settings for the measurement

If you press the button *Parameter* a dialog will be shown in which all parameters for the measurement can be set. The dialog contains four different pages and will appear with the page according to the mode of the program. Nevertheless all pages are accessible.

Channel assignment

Before you can do some measurements, you have to tell FRED how to use the channels of the hardware. This can be done via the page *channel assignment*.



Page to configure the channels used as plant input and output

Here you can select the channel that is used as the stimuli (plant input) and as the plant output. If your hardware has got a signal converter between itself and the plant, an offset and scaling factor can be taken into account. The point of view of this conversion is different.

For the channel used as plant input the output value is calculated by:

$$u_H = u \cdot f + o$$

The values from the plant output will be converted by:

$$y = \frac{y_H}{f} - o$$

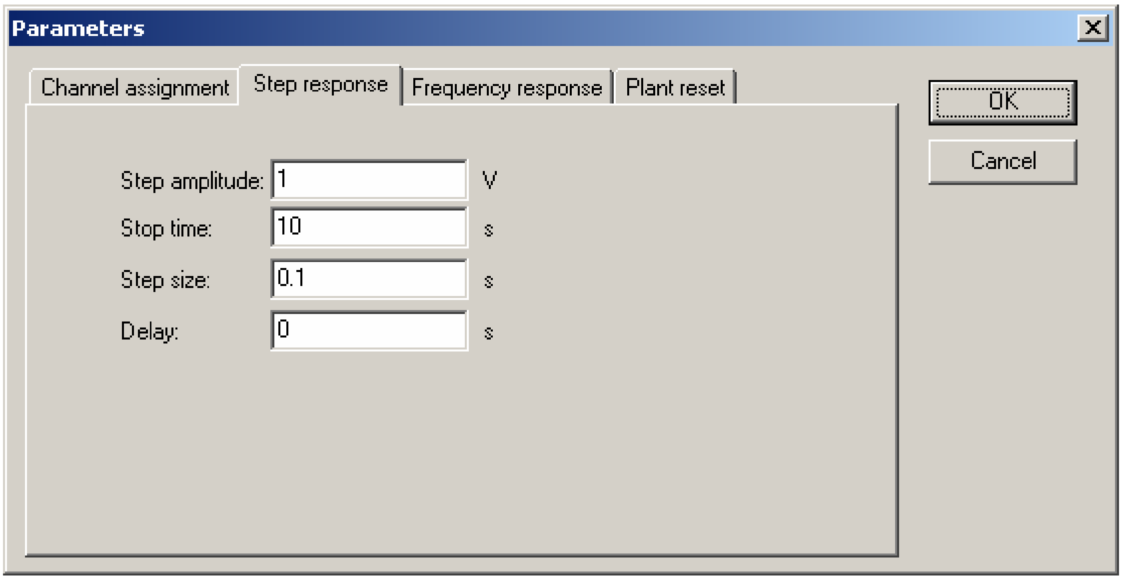
With:

u_H, y_H	the value that is given to resp. coming from the hardware
f	the scaling factor
o	the offset to 0V (zero point offset)

The offset can be determined by setting the output to zero and measuring the output voltage with a digital multimeter. The offset of the input channel can be found out by wiring the channel to ground (GND) and measuring a short (500ms it totally enough) time step response with a step function of 0V (just to ensure that nothing will be destroyed). To get the scaling factors set the output to 1 and measure the output voltage with a digital multimeter resp. connect the input to 1V and record a step response.

Step response

To measure a step response the step amplitude, the stop time until the recording will be done and the step size must be entered. The duration of the measuring process depends only on the stop time, because FRED is doing the measurement using real-time conditions.



Parameter for the measurement of a step response

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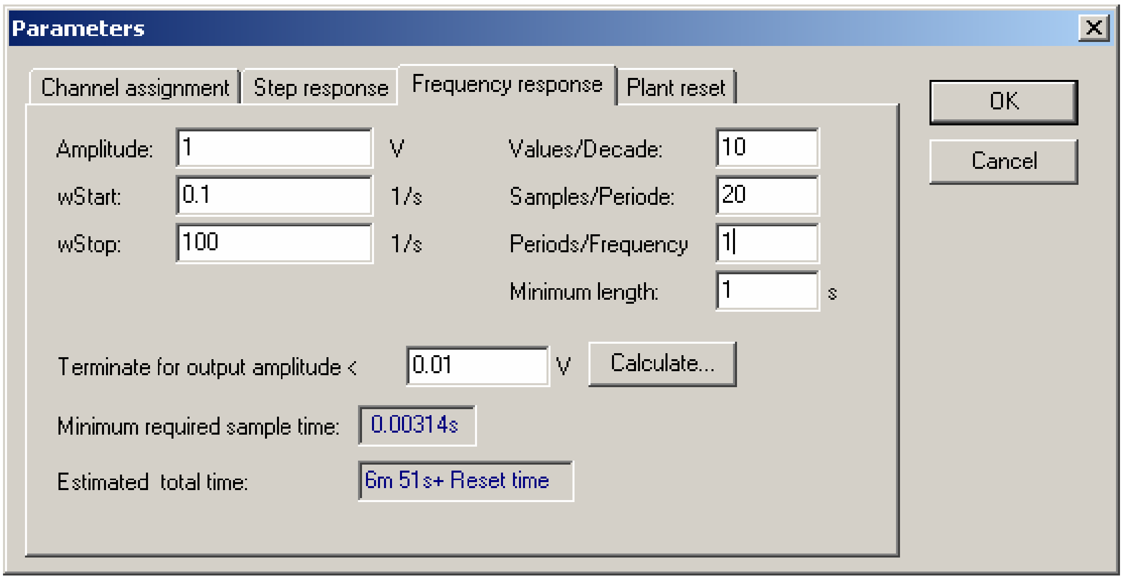
A delay can optionally be used to see the behaviour of the plant before the step function is applied.

Frequency response

There are more parameters to measure a frequency response and these may not be obvious at first view.



Parameter for the measurement of a step response

Because of this circumstance the parameters are explained in detail here.

Amplitude

The amplitude is the maximum value of the generated sinusoid oscillation.

wStart

Denotes the angular frequency, from that the step response starts. This is the first frequency that will go to the plant.

wStop

Denotes the angular frequency, up to that the frequency response is recorded. *wStop* should be about some decades greater than *wStart*. The difference is the number of decades the frequency response should reach.

Values/Decade

The more values per decade are chosen, the more exact the graphic depiction of the frequency response will be. This, however, will increase the time needed for the measurement.

Samples/Period

This parameter is needed to calculate the sampling rate for every sinusoidal oscillation, that has to be generated. The *minimum required sampling time* is given by the value of *wStop* and this one. The minimum reachable sampling time depends on your hardware and can only be found out by just trying. If the actual sampling rate cannot be realized, FRED stops the measurement. You can add points in the frequency diagram manually now (s. chapter *Add measurement* points), to find out what the highest possible frequency will be.

Periods/Frequency

Every frequency will be generated at least for the value of this parameter. To create a big number of periods for lower frequencies will take a long time!

Minimum length

For lower frequencies it often is enough to record only a few periods to get the correct amplitude and phase shift. The plant reaches a steady state during the first period. The time that is needed to get the plant in the steady state is independent of the frequency (assumed the plant is a linear time invariant system). The value of this parameter are the seconds the plant is at least stimulated for every frequency. This is very important for the higher frequencies to ensure the settling process is completed.

Terminate for output amplitude <

If the output amplitude is getting lower than this value, the measurement is stopped. For the most of the dynamic plants the amplitude is decreasing rapidly for higher frequencies, so that it cannot be acquired correctly. It depends on the resolution of your AD converter used in your measurement hardware. With the *Calculate* button next to the entry field, you can compute the parameter from a given voltage range and the bits used by the AD-converter.

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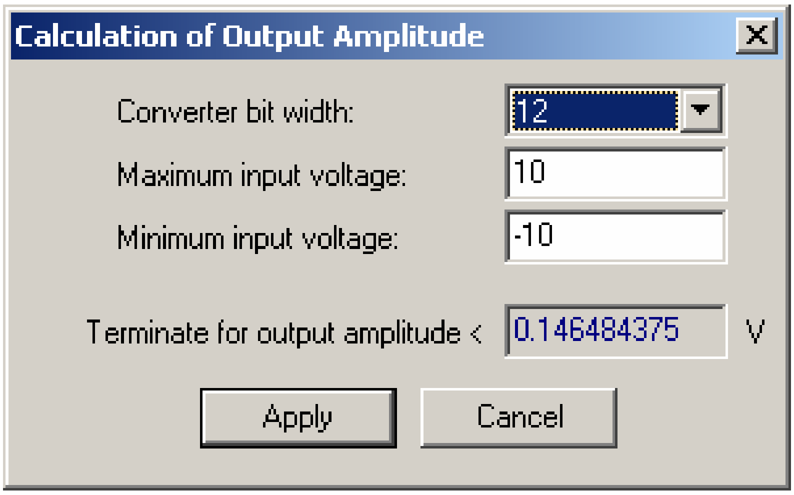

Calculation of the Output Amplitude

Due to this calculation the minimum voltage will need at least 30 conversion steps of your AD converter to be represented.

Because the measurement of the frequency response can possibly take some time, the total time is shown in the dialog. Also the minimum required sampling time is displayed. If the sampling time needed to measure a certain frequency cannot be realized, the measurement will be aborted with a message.

Plant reset

The plant must be reset before a measurement takes place to ensure the same starting conditions. When this is not assured, the settling time can change and the measurement is possibly getting false or only correct by chance because of the assumption of a too short settling time.

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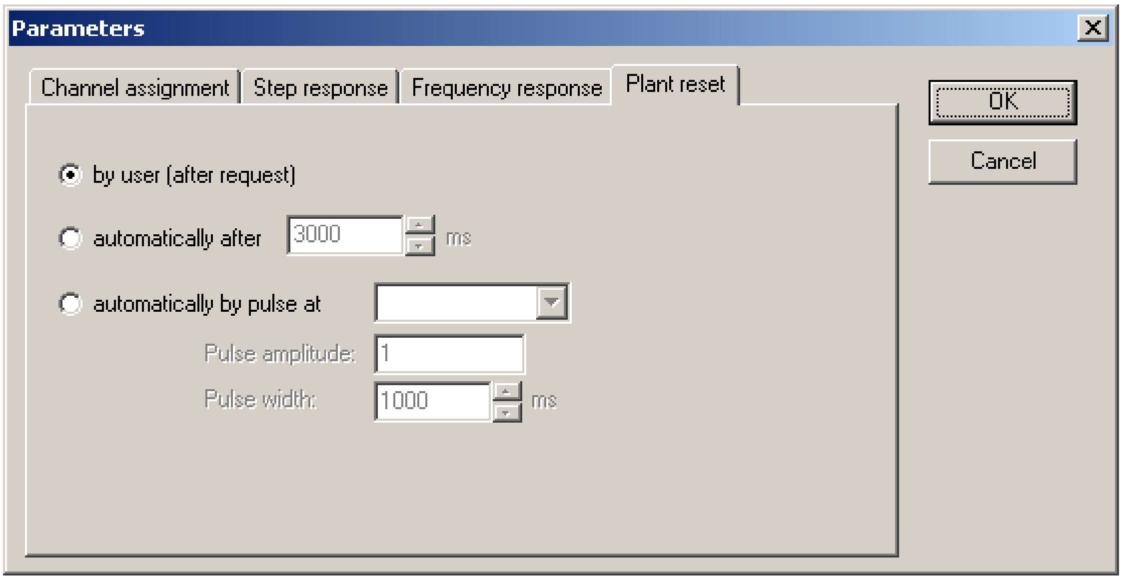

Parameter for resetting the plant

The plant can be reset in different ways. The simplest but most time needing one is to reset the plant manually *by user (after request)*. With this setting you will be noticed to reset the plant when it is required.

For the most plants it is sufficient to set the input of the plant to 0V for the duration of the settling time. In this case you can choose *automatically after n ms,* because FRED sets the output channel, that is getting the sinusoid oscillation, automatically to 0V resp. to the value of the *zero offset* after every measurement.

The reset of the plant is getting comfortable, when there is a possibility to do this in an active way by a pulse signal. Hereby the *pulse amplitude* and the *pulse width* can be parameterised.

Save and Load of the configuration

FRED offers the possibility to save all of the settings you have made. Press the button *Save parameters* for this. You can load the saved configuration again by simply pressing the button *Load parameters*.

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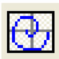
Perform measurements

FRED has got three different buttons to switch the mode of measurement and presentation:

measurement and presentation of a *step response*

measurement and presentation of a *frequency response*



measurement of a frequency response and presentation of this as a *Nyquist frequency response locus*

When the plant is not known, it is expediently to get a look at the step response first. You can get information from this, which can be considered when setting the parameters to measure a frequency response. The interesting ones are:

- the plant behaviour (does the plant oscillate or not, has it an integration part),
- the settling time and
- the maximum output amplitude

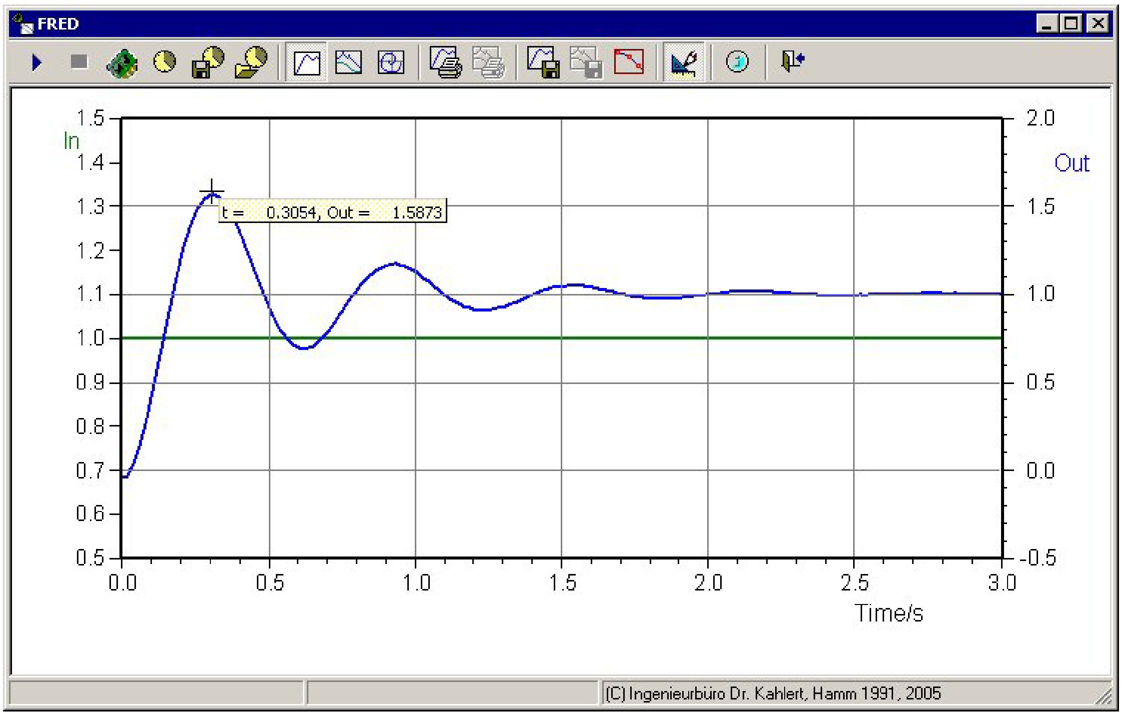
You can start the measurement by pressing the button *start simulation* while you are in the appropriate mode. During measurement some information about the progress of the process is shown in the status bar.

FRED creates a higher privileged thread, which is responsible for the execution of the measurement. It is not unusual, that all other programs and the main thread of FRED are getting only little processing time and therefore appear to be very slow.

The drawing of the curves and the status is done asynchronously! The more time consuming the measurement is (i. e. smaller sampling time), the lesser the update rate for this information will be.

Once the measurement is done, all other processes will react with the normal speed and the measured curves will be completely redrawn by FRED.

After the measurement, the maximum of the amplitude can be obtained from the diagram. You can switch on the mode for measurement which simplifies to read the coordinates out of the diagram.



Step response with measurement mode switched on

In the example above the maximum output amplitude is about 1.5. You cannot read the maximum gain of the plant, but it gives an important hint for you that the plant will have a resonance frequency with a greater amplitude at the output than the input signal. Furthermore you can see that the settling time is about 2.5 seconds and the plant does not have an integration part but is obviously an oscillating plant.

Now some hints for measuring a frequency response are given:

- Choose a suitable range for the analog input channel.
- Choose a suitable voltage range for the sinusoidal oscillation which has to be created.
- Set the minimum length to the time needed to get the system in a steady state.
- Take a value for the number of periods per frequency which is as small as possible but big enough to get a complete period after the settling time.

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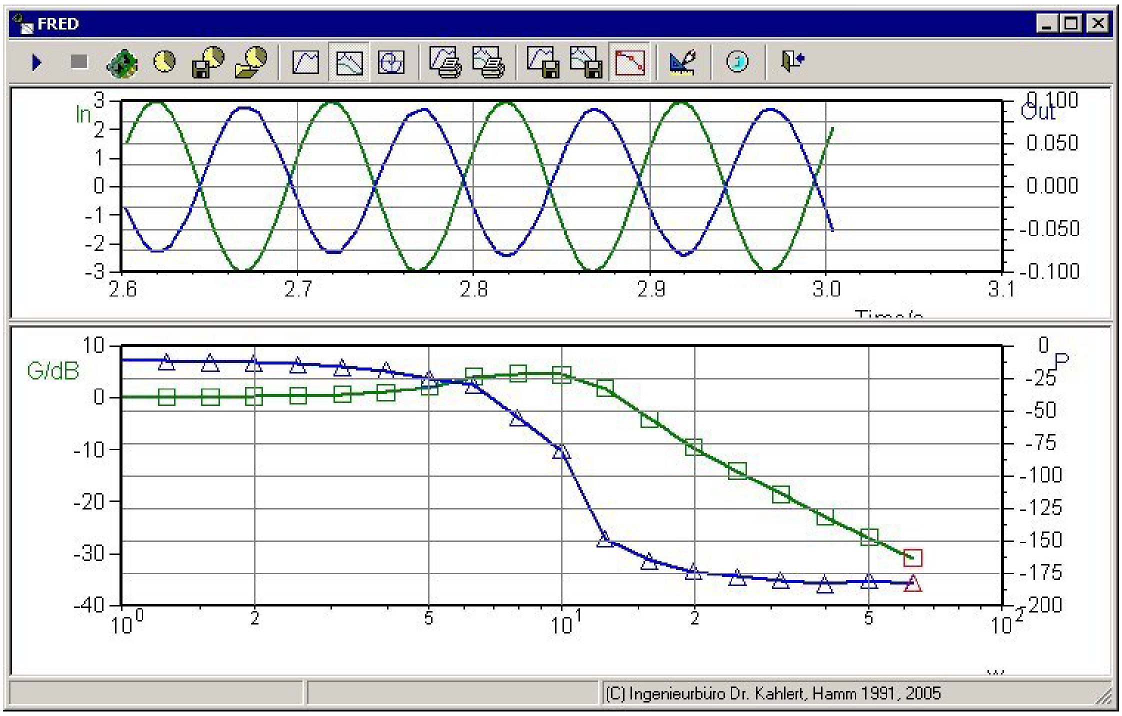
- Start the measurement of a frequency response with a frequency of that you assume that the phase shift will not differ ±180° from 0° (s. chapter Background).
- As stop frequency you can simply choose the maximum frequency you want to record.
- Set the termination voltage according to the voltage range and the bits of the AD converter (s. above).

The following picture shows FRED after the measurement of a frequency response of the plant with the step response you can see in the picture before.



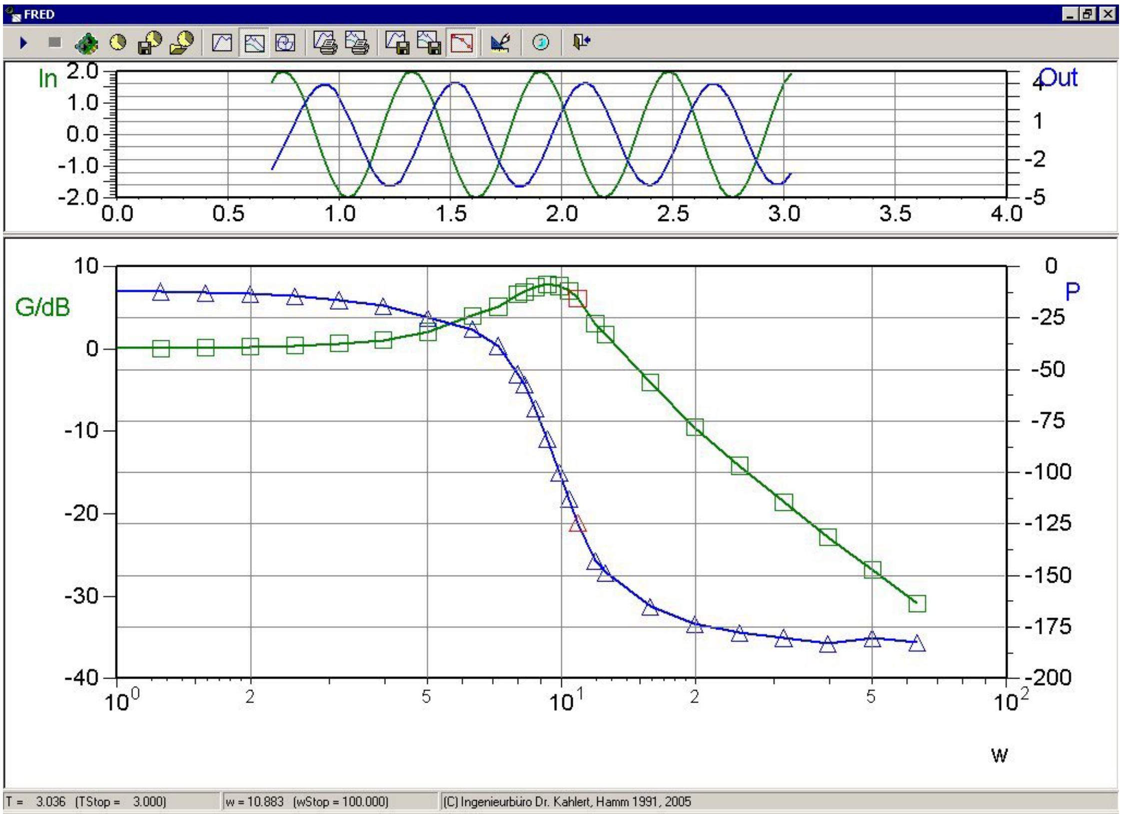
FRED with recorded frequency response

The frequency response is often displayed roughly after the automatic measurement. The visualisation of the measurement points was activated, so the button *Plot measurement points into frequency response* is pushed in. Furthermore you can see only the last 4 periods of the sinusoidal oscillation in the upper part of the window. These are the only ones that are used to determine the amplitude and the phase shift.

When the measurement points are turned on, you can see the time response in the upper part of the window which is responsible for the active (red) measurement point in the frequency response diagram. You can activate another measurement point by clicking the mouse pointer on it.

When all points of this measurement are checked, we discover, that the output signal of the plant was cut at the frequencies ω[1/s] ≈ 8 und ω[1/s] ≈ 10. Because of this, the measurement points were deleted (s. chapter *Delete measurement* points).

After that, some measurment points were added in the interval mentioned above (s chapter *Add measurement* points), whereat a reduced amplitude of the sinusoidal oscillation was used to ensure the output of the plant does not leave the range of the analog input. The picture below shows the result:



Manually improved frequency response

The presentation of the frequency response as a Nyquist diagram is done by switching to the according mode:

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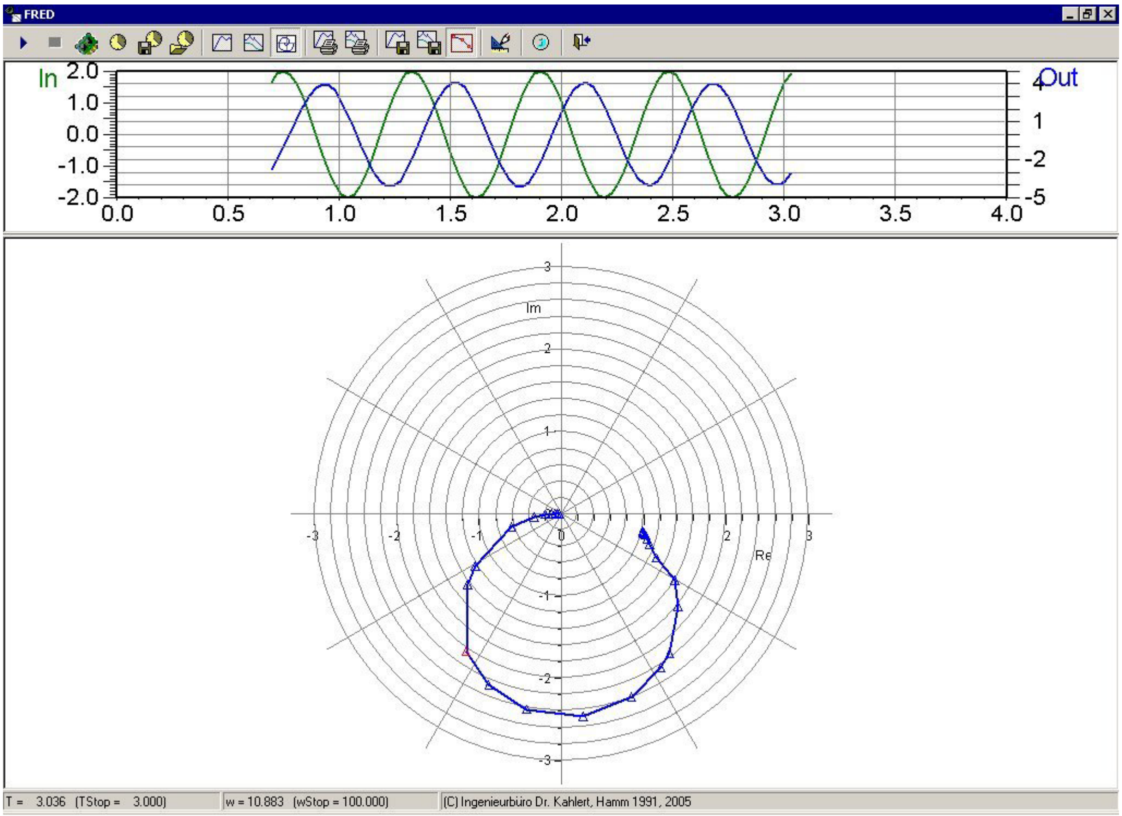


Presentation of the frequency response as Nyquist frequency response

Modifications of a frequency response

Modifications of a frequency response are only allowed in the “normal” frequency response mode. But you can switch between Nyquist and normal presentation to find out where to add resp. delete measurement points to get a smoother diagram. The active measurement point will stay active during the switch.

Delete measurement points

You can delete a measurement point in the following way:

1. Move the mouse pointer to the measurement point you want to delete and press the keys “CTRL” and “SHIFT” (the mouse pointer will get a minus symbol now!).
2. Press the left mouse button now also keeping the keys pressed.

Add measurement points

You can add measurement points in the following way:

1. Move the mouse pointer to that frequency you want to get the amplification and phase shift for. Now press the key "CTRL" (the mouse pointer will get a plus symbol!) and
2. press the left mouse button now.

Please note, that the recording is started immediately and in general takes a long time for a low frequency!

After the measurement has completed all phase shifts for higher frequencies are recalculated to correct the equivocation of the phase shift (the phase shift of one frequency depends on the one before).

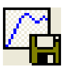
If you want to add frequencies that are out of the diagram, you can change the parameter *wStart* resp. *wStop*, without starting a new frequency response measurement. The diagram will then scale to the appropriate values.

Print and Save measurement data

FRED has the ability to save and print the measurements. This functionality depends on the current presentation mode i. e. when FRED is displaying a step response you cannot print or save a frequency response.

Print the visible step or time response.

Print the visible frequency response resp. the visible Nyquist diagram.



Save the visible step response.

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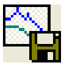

Save the visible frequency response resp. the visible Nyquist diagram.

Printing or saving a time response depends not on the current presentation mode, because all modes have got a time response. So the printed or saved time response will be the one you can see on the screen.

The saving of a time response is done in the SIM-format, the frequency response in BD-format and the Nyquist diagram is saved in OK-format. A detailed description of all file formats can be found in the WinFACT documentation.

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