Operating Instructions

HAEFELY TEST AG

FRA 5310

Frequency Response Analyser

Version 3.2

4843793

Operating Instructions FRA 5310 Frequency Response Analyser

Date	*12-2005*
Authors	*LWA, RSCHO, QCH*
Layout	*LWA*

Revision History

V1.0	*12/2005*	*LWA*	*Initial release of the document*
V1.1	*1/2006*	*LWA*	*Smaller inputs, improvements*
V1.2	*1/2006*	*QCH*	*New screenshot, improvements*
V1.3	*2/2006*	*LWA*	*Uin/Uout, Tech Data, ZeroCal, Interwinding, ProbeCheck*
V1.3.1	*2/2006*	*LWA*	*debugs*
V1.3.2	*2/2006*	*QCH*	*New screenshots*
V1.4	*3/2006*	*QCH*	*Changes based on software version 1.0.2.12, new screenshots, GND tape*
V1.4.1	*10/2006*	*RF*	*Changes in test setup*
V2.0	*11/2006*	*QCH*	*Changes based on software version 2.0.0*
V2.1	*12/2006*	*QCH*	*Changes based on software version 2.1.0, new hardware*
V2.1.1	*2/2007*	*QCH*	*Changes based on software version 2.1.2*
V2.2	*07/2014*	*TH*	*Small modifications on layout*
V3.0	*11/2014*	*SG*	*Update to windows seven, test templates added. Software version 4.0.0*
V3.1	*03/2016*	*SG*	*IEC file format added*
V3.2	*31.08.17*	*SG*	*Accuracy specs updated*

WARNING

Before operating the instrument, be sure to read and understand fully the operating instructions. This instrument produces hazardous voltages. It is the responsibility of the user to ensure that the system is operated in a safe manner.

This equipment contains exposed terminals carrying hazardous voltages. There are no user serviceable components in the unit. All repairs and upgrades that require the unit to be opened must be referred to HAEFELY TEST AG or one of their nominated agents.

Unauthorized opening of the unit may damage the EMI protection of the system and will reduce its resistance to interference and transients. It may also cause the individual unit to be no longer compliant with the relevant EMC emission and susceptibility requirements. If the unit has been opened, the calibration will be rendered invalid.

In all correspondence, please quote the exact type number and serial number of the instrument and the version of software that is currently installed on it. The software version is reported at power-up.

Note

HAEFELY TEST AG has a policy of continuing improvement on all their products. The design of this instrument will be subject to review and modification over its life. There may be small discrepancies between the manual and the operation of the instrument, particularly where software has been upgraded in the field. Although all efforts are made to ensure that there are no errors in the manuals, HAEFELY TEST AG accepts no responsibility for the accuracy of this manual.

HAEFELY TEST AG accepts no responsibility for damage or loss that may result from errors within this manual. We retain the right to modify the functionality, specification or operation of the instrument without prior notice.

2005, HAEFELY TEST AG, Switzerland

Manual Conventions

In the manual, the following conventions are used:

Indicates a matter of note - if it refers to a sequence of operations, failure to follow the instructions could result in errors in measurement.

Indicates hazards. There is a risk of equipment damage or personal injury or death. Carefully read and follow the instructions. Be sure to follow any safety instructions given in addition to those for the site at which tests are being performed.

Contents

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1 Introduction

The Tettex FRA 5310 Sweep Frequency Response Analyser detects transformer winding movements and mechanical failures due to mechanical shock, transportation damages or short circuits.

The corresponding HF circuit of a transformer winding is a complex R-L-C-network. The measured frequency response (transfer function) of this network is unique like a fingerprint.

If a repeated measurement shows deviations that indicates changes in the winding geometry. Even small winding movements or distortions will cause legible changes in the measured transfer function, which is clearly detectable.

Deviations can be caused by short-circuited turns, open windings, mechanical damage to windings or core, loose turns, faulty clamps, etc.

A powerful, easy-to-use operation and analysis Windows software runs on this touch screen controlled measuring instrument. Special active measuring probes minimize the influence of test object connecting and earthing which results in highly reproducible measurements.

1.1 Scope of Supply

The following items are supplied with the standard instrument:

Qty	Description
1	FRA 5310 Sweep Frequency Response Analyser instrument
1	Cable and accessory carrying bag including:
1	Active probe "Source" with 15m cable, two clamps
1	Active probe "Receiver" with 15m cable, two clamps
2	Ground Tapes, 10m
2	Ground Tape Clamp (grip wrench) for grounding connection tape to DUT tank
1	Mains cable
1	Operating Instructions and Test Certificate
1	CD with external PC Analysis Software

On receipt of the unit check that all items have been delivered. Also check that the correct power cord for the location has been supplied.

In the event of missing or damaged parts please contact the user local sales representative stating the serial number and type of the instrument and the sales order number.

2 Technical Data

Measurement and Generator

Type	Active probes
Frequency Range	10 Hz .. 10 MHz, user defined
Sweep Mode	Logarithmic or Linear, user defined
Voltage Output	0.1 V_{pp} .. 12 V_{pp} @ 50 Ω load, user defined
Input Impedance	selectable 50 Ω or 1 MΩ
Output Impedance	50 Ω
Feasible Accuracy 20Hz … 2 MHz	$\pm$ 0.1 dB , from +10db to -40db $\pm$ 1 dB , from –40db to -90db
IF Bandwidth	$\leq$ 10 % of act. Frequency
Dynamic range	> 100 dB
Measuring Points	50 .. 2'000 per stage, user defined
Measuring Time	Varies by measurement configuration and signal level e.g. 1m16s with Logarithmic scale, 56s with Linear scale (20Hz .. 2MHz, 800 points, in most signal level cases)
Protection Output	Short circuit protected
Protection Inputs	Flash protected (Gas arrester 75V ‖ Transzorb diode 15V)
Data Display	
Scaling	Logarithmic or Linear, user defined
Frequency Range	10 Hz .. 10 MHz, user defined
Plot, Frequency vs.	Magnitude, Phase, Impedance, Admittance, Ratio
Controller	
Processor	Intel Atom[1]
RAM	2 GB[1]
Interfaces	USB 2.0
Data Storage	Compact flash
Display	10.4", SVGA, Colour TFT
User Interface	built-in Touch Screen
General	
Operating Temperature	0 .. +50 °C
Storage Temperature	-20 .. +70 °C
Relative Humidity	10 .. 90 % non-condensing
Weight Instrument	8 kg (17 lbs)
Weight Accessories	8 kg (17 lbs)
Dimensions Instrument	41 x 31 x 17 cm (16" x 12.2" x 7")
Remote Start	Remote start button and indicator in probe
Mains	Universal, 90 .. 265 VAC, 50 / 60 Hz, 50 VA
Instrument OS	Windows 7 Embedded[1]
External PC Software	Windows XP / Vista / 7

1 or higher , Exact controller specifications can be found under computer->properties in FRA device

3   Safety

⚠ **Safety is the responsibility of the user. Always operate the equipment in accordance with the instructions, always paying full attention to local safety practices and procedures**

⚠ **This equipment must be operated only by trained and competent personnel who are aware of the dangers and hazards involved in testing transformers. HAEFELY TEST AG accepts no liability for loss, damage, injury or death caused by the incorrect or unsafe operation of this instrument**

⚠ **Do not operate the FRA 5310 from a variable power supply. The FRA 5310 adjusts to the local line voltage at start-up. Changing the line voltage while the unit is in operation may cause damage to the unit and to the test object**

3.1   Grounding

The instrument must always be connected to a grounded power outlet (i.e. a safety earth) It must never be operated in a non-grounded configuration as this may result in electrical shock to the user or damage to the instrument.

The outer casing of the transformer under test shall also be connected to a safety earth to prevent the risk of shock. The measurement ground is taken from the DUT tank which therefore also has to be grounded for measurement purposes.

3.2   Essential Safety Recommendations

⚠ **Before connecting the instrument ensure that the transformer to be tested is completely de-energized and isolated from both line and load. Every terminal should be checked and verified before connection of the instrument. Ground connections may be left in place**

⚠ **Never operate the equipment in an explosive environment or where there are flammable gases or fumes**

3.3   Summary

Note: Many accidents that happen around high voltage equipment involve personnel who are familiar, and perhaps too familiar, with high voltage equipment. Staying alert and ever watchful requires constant training and awareness of the inherent hazards. The greatest hazard is the possibility of getting on a live circuit. To avoid this requires constant vigilance - for oneself and for one's fellow workers.

Remember - Safety, FIRST, LAST, ALWAYS !

Tettex

4   Theory

Frequency Response Analysis, generally known within the industry as FRA, is a powerful diagnostic test technique. FRA consists of measuring the impedance of transformer windings over a wide range of frequencies and comparing the results of these measurements to a reference set. Differences may indicate damage to the transformer, which can be investigated further using other techniques or by an internal examination.

The evaluation of the frequency response (transfer function) can be used on-site to detect defects, in particular displacements in transformer windings. These types of defects can occur during transportation of transformers or during a short circuit near the transformer in the power system. Those defects can also occur after a long service life of transformers in power systems, where several short circuits and over voltages over the life time may happen.

The frequency response method is normally a relative method of diagnosis. Actual measurements have to be compared to reference results (previous measurements).

4.1   General

The frequency response (transfer function) describes the frequency behaviour of a two port. To determine the frequency response of a transformer, the assembly is considered as a linear, complex, time-resistant and passive network.

One input signal U_{IN} and one output signal U_{OUT} or I_{OUT} has to be defined.
The quotient of the two signals represents the frequency response:

Transfer Voltage Function U_{OUT} / U_{IN} (f)   for high (1MΩ) impedance measurement

Transfer Impedance Function U_{IN} / I_{OUT} (f)   if the 50Ω shunt is used for the output measurement

Transfer Admittance Function $I_{OUT} / U_{IN} /$ (f)   if the 50Ω shunt is used for the output measurement

The characteristics of the frequency behaviour of power transformers (poles and zeros) are evident in the absolute value (ratio) and the phase angle of the frequency response. Normally the ratio is used. An examination of both is not necessary.

Results of FRA measurements are conventionally displayed in modulus-argument form. The modulus is usually referred to as the gain or the amplitude and the argument as the phase.

Normally one uses the gain in assessing the results of FRA measurements, rather than the phase. The gain contains almost all of the useful information in the measurements, and it is usually not necessary to consider the phase response as well.

4.2   Comparison Methods

FRA essentially consists of measuring the impedance of the transformer windings over a wide range of frequencies and comparing the results of these measurements with a reference set. The reference measurement will ideally have been made previously on the same winding of the same transformer.

If no measurements from the same winding are available, they can be obtained from another phase, which is known or assumed to be undamaged, or from a sister transformer.

The comparison is usually made by eye. Some research work has already been done on more advanced methods of comparison.

For a comparison by eye, the author plots the results on a log-linear scale. Both sets of measurements are plotted on the same axes. If additional measurements are available, these can be plotted as well. In comparing the sets of measurements, the key indicators of damage are:

Changes to the overall shape of the graph

The creation of new resonant frequencies or the elimination of existing resonant frequencies

Large shifts in existing resonant frequencies.

Types of Comparison
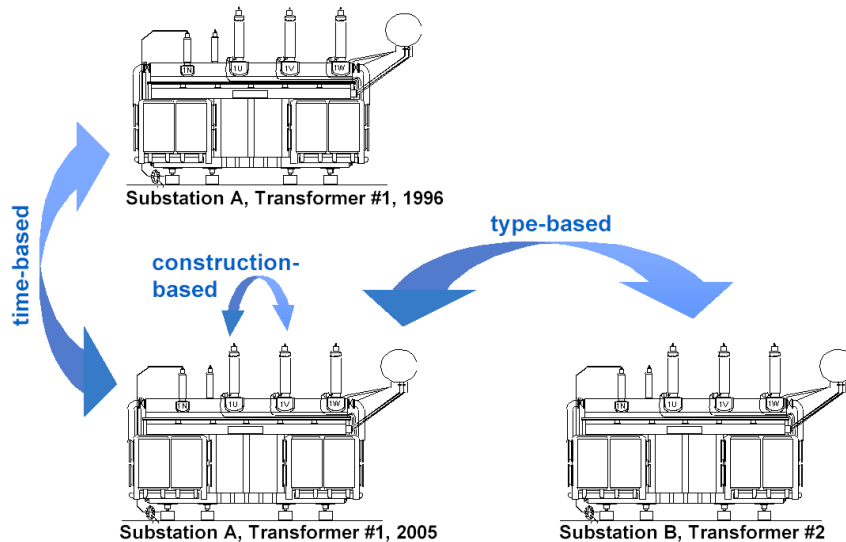
Time-based Comparison. Actual results of measurements are compared to fingerprints of former times. Unfortunately, fingerprint measurements are rarely available. This method is also used for fast detection of transportation damages.

Type-based Comparison *. The results of an identically constructed transformers ("Sister unit") are taken as a comparison reference. Especially, distribution transformers are constructed according to standards. Thus, the results of a set of distribution transformers can be compared

Construction-based Comparison *. Comparing the results of separately tested phases or coils of a transformer. Sometimes, the frequency behaviour of the windings U, V and W of a 3-phase transformer is quite similar. So the results of the separately tested coils can be compared

> ***** with these types of comparisons also design based differences in the compared curves will be seen and sometimes are hard to classify. A previous measurement (fingerprint) of the exact same winding configuration (time-based comparison) is always preferred.

> There is no such thing as a 'typical' measurement, so measurements made on 'similar' transformers cannot be used as a basis for detailed comparison.

# 4.3   Types of Measurements

Open Circuit:
Measurement made from one end of a winding to the other end of the same winding with all other terminals left open (floating).

Short Circuit:
Measurement made from one end of a winding to the other end of the same winding with one or all other terminals shorted together. (Free neutrals should be left floating)
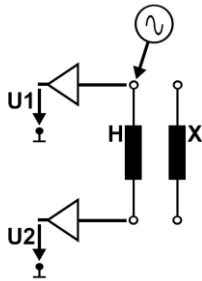
Inter-Winding:
Measurement made from one winding to another winding with all other terminals left open (floating).

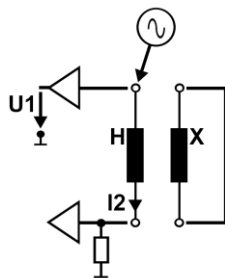Tettex
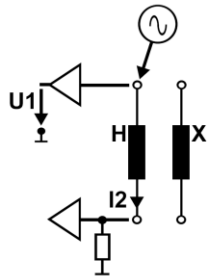
Open Circuit

Impedance measurement.

→ Core influence is dominating in this measurement *
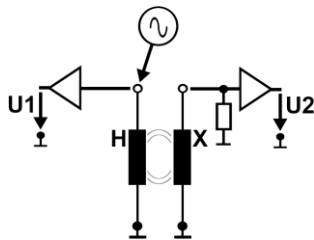
Open Circuit type B

End-to-end voltage measurement.
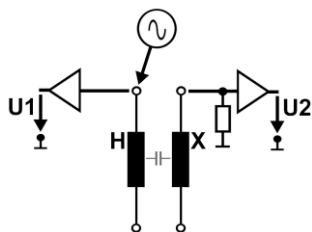
Short Circuit

Impedance measurement.

→ Windings influence is dominating in this measurement *

Inter-Winding

Transfer impedance measurement with inductive coupling

Inter-Winding type B

Transfer voltage measurement with capacitive coupling

* see also Appendix for more details

4.4   Detectable Faults

FRA consists of measuring the impedance of transformer windings over a wide range of frequencies. Faults, which change either the winding capacitances or the winding inductances, are detectable. Fault simulation programs have indicated that the following faults are detectable using FRA:

Additional turns on yoke or limbs, Shorted turns, Open windings, Faulty core grounds, Winding collapse, Broken or loosened clamps, Mechanical damage to windings, Mechanical damage to core, Loose turns and "Normal" ageing.

FRA is probably the only method, which is capable of reliably detecting faults involving damage to the windings (mechanical damage and loose turns). It is a very reliable method for detecting faults involving the short-circuit of existing turns or the creation of new turns (short-circuited turns or additional turns on the limbs or yokes).

For "Measurement Interpretation" see Appendix
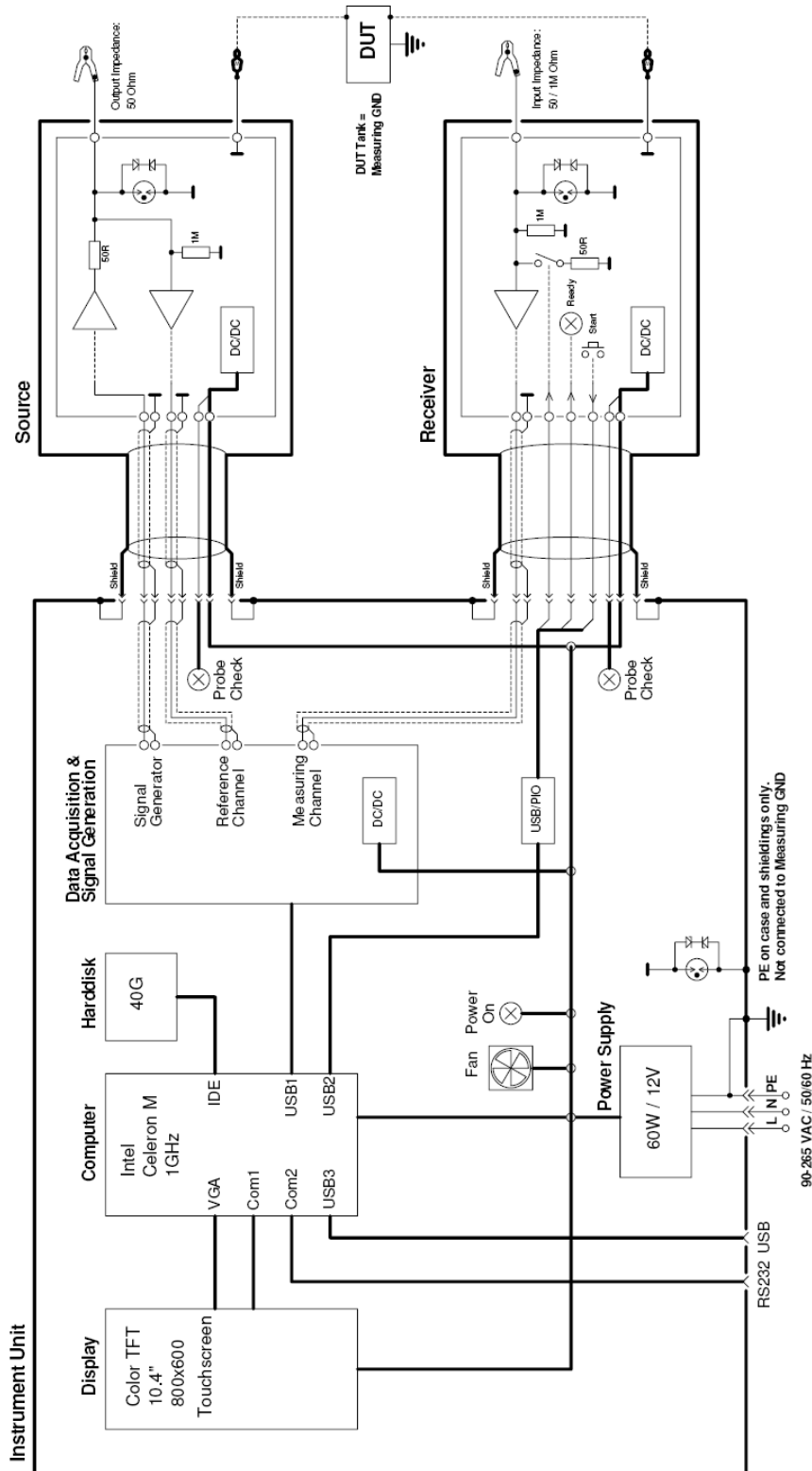
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5   Hardware Description

Figure 1 :   Simplified schematics of the FRA 5310 instrument with its active probes.

Controller

The instrument is computer controlled by its built-in PC board . It has large colour TFT with touch screen interface.

For instrument software and data storage a hard disk is mounted.

For data transfer a USB connector is accessible on the front panel.

Signal Generator

The software controlled sign wave generator on the signal generation board generates an output signal which is buffered on the booster and also in the active "source" probe and therefore generates at the open clamp a signal of up to 24Vpk-pk (12Vpk-pk @ 50Ohm load) in a frequency range of 10Hz..10Mhz.

⚠️ If measurements from conventional network analysers shall be compared with the FRA5310 measurements then the output signal voltage has to be checked.

The active "source" probe delivers the selected output voltage direct on the clamp while a passive connection (depending on the used termination) can have less voltage on the clamp.

(Differences in output voltage can result in pole shifts in the region of several 100Hz).

Measuring Path

The "source" probe delivers the output signal and measures this signal with a high impedance buffer at the output itself. The signal is fed back over the double shielded cable to the data acquisition board where it's digitised and fed into the PC board.

The "receiver" probe measures the output signal of the DUT with either high impedance (→ Ratio U_{OUT}/U_{IN}) or over 50Ohm (→ Ratio I_{OUT}/U_{IN}) which is selectable by software.
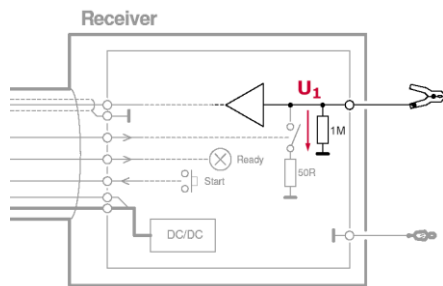

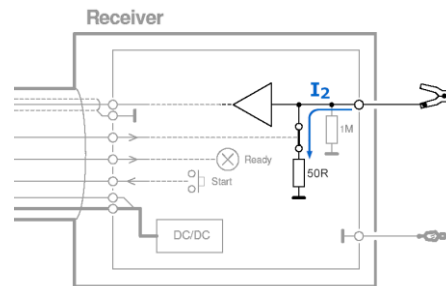*Figure 2 :   High impedance pick up*
(→ Ratio U_{OUT}/U_{IN})

Figure 3 :   50Ohm shunt pick up
(→ Ratio I_{OUT}/U_{IN},
U_{OUT}/U_{IN} if no current flow possible)

The signal is fed back over the double shielded cable to the data acquisition board where it's digitised and fed into the PC board.

The CPU board software filters the actual frequency out of the measured signals and calculates the ratio and the phase information of the two measuring signals. Further it controls the user interface (touch screen, LC display) and the instrument's hardware.

Shielding

For safety reasons the PE from the power cord (which is on all shielding but not connected to the measuring earth to prevent ground circulation currents) is coupled with transzorb diodes to the measuring ground.

Supply

Locally on all measurement related boards there is a DC/DC converter mounted to generate the needed supply voltages. This guarantees minimal influence of environmental noise.

Cables

The special double shielded probe cables contain two 50Ohm coax cables for measuring and generator signals and six additional single cables for control signals and power supply of the active probes.

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6 Operation Elements

Figure 4 :   Instrument front panel

1	Source probe cable connector → when the yellow ☑ lamp is lit the probe is correct connected
2	Receiver probe cable connector → when the blue ☑ lamp is lit the probe is correct connected
3	Power Inlet - Connect only to an earthed power outlet. The unit can be switched on or off using the integrated mains switch. The main fuse holder is also integrated. A green lamp indicates "power ON"
4	RS232 port
5	USB communications port
6	Ventilation slots
7	Touch pen park position
8	Touch screen display.
9	PE plug (connected to case and shields; Used to ground the unit if it's powered e.g. over an isolation transformer)

7 Connection and Setup

⚠️ **Before attempting to connect to the test transformer make sure that it is fully disconnected and de-energized.**

7.1 Probe Colour Indication

For easy recognition of the different cable leads a clear and definite colour indication is used in addition to the description labels:
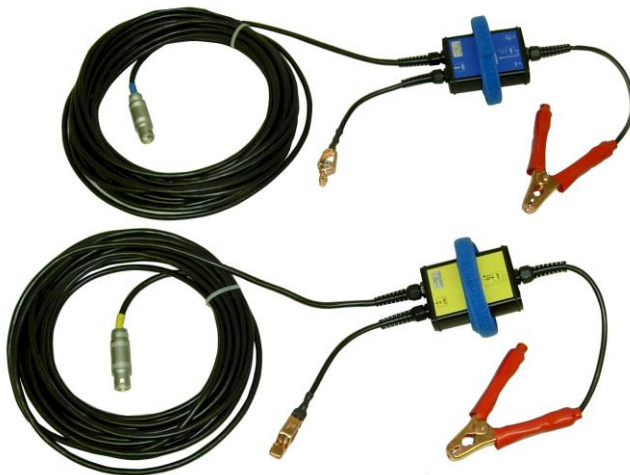
Receiver Probe

The receiver channel of the instrument is labelled *Blue* (Description on the probe box, cable end and connector on the front panel)

Source Probe

The source channel of the instrument is labelled *Yellow* (Description on the probe box, cable end and connector on the front panel)

Figure 5 : The two active probes with cables

For both probes the active lead (source signal and receiver signal) is the red clamp, the black clamp is the measuring ground.

So it's possible to check the correct cable connection to the test object from far even if the description labels are not readable.

7.2 General Notes

The measurement of frequency response requires sensitive voltage measurements to be made. It is necessary to minimize the pick-up and cross-coupling on the cables if the most accurate result possible is to be achieved. The following guidelines should be followed. Good practice in the setting up of the test systems will aid the quality of the measurements made.

Ensure, as far as is feasible, that any sources of interference are eliminated from the test area. Equipment such as welding sets and phase-angle furnace controllers should be switched off if at all possible.

Make sure the cable joints are not touching before starting any measurements

Make sure that the transformer is completely disconnected at every terminal before making the measurements. Even very short lengths of external connections can have at strong effect on the results

Make sure good electrical connections are made at bushing terminals and base, clean, file or brush connections points if necessary.

7.3 Probe Fixing

The probe boxes are equipped with a long Velcro strap to fix them e.g. on a bushing's isolator as a strain-relief. The measuring connection (red clamp) of the fixed probe can now be connected easily to the terminal itself.

The ground tapes are used to make ground extension connections on bushings longer than 50 cm.

One end of the ground tape is mounted to the Velcro strap for fixation.

The ground connection of the probe (black clamp) can then be connected easily to the ground tape on its top end.
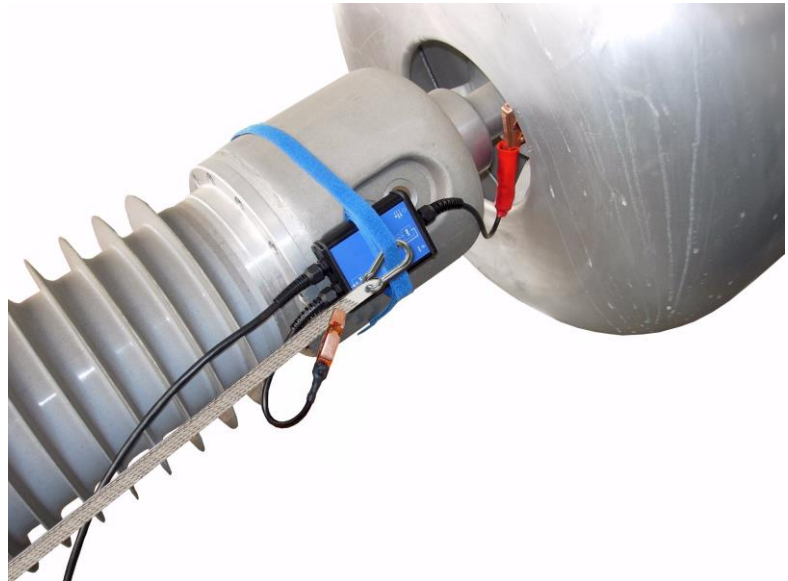
Figure 6 :   Cable fixing on bushing top

Start with the fixing of the probes and the measuring connections first.
Then connect the ground tapes. That makes it easier to keep the ground tapes tight and short.

7.4 Measurement Ground

One end of the tape is fixed to the transformer tank preferred at the bushing foot with the grip wrench.
Grip the wrench to a non-isolated part of the tank, then clamp the tape tight with the wing nut.

Try to find the closest tank connection to the bushing head to keep the ground connection itself as short as possible.

The ground connection can influence the measurement. So the user have to make sure that there is the shortest possible connection between the probe and the next accessible ground-point made. Normally the tape shall be kept close to the bushing isolator and be connected to its base.

Figure 7 :   Ground fixing on bushing bottom with the grip wrench and the Ground Tape.

The measuring ground is taken from the DUT tank as the reference. So the black clamps of the probes **must** be connected to ground for a proper measurement.
The PE from the mains power cord is **not** connected to measuring ground to prevent ground circulating currents. The mains PE is only connected to the complete outer shielding of the instrument, cables and probes.

Grounding Reproducibility

The ground connections are part of the measured "black box". So if the measurements are repeated for comparison the user has to make sure that the same grounding leads and more-or-less the same length is used to get good measurement reproducibility.

7.5   Remote Start Function

If the user has connected the probes to the DUT the measurement or the calibration can be started from the touch screen (start button) or also remotely by pressing the red button (1) on front of the receiver probe.

The indicator lamp (2) on the probe has three different conditions:

Illuminated	System is ready and standby. The red button start function is active.
Fast blinking	System is performing a zero calibration measuring sweep.
Slow blinking	System is performing a normal measuring sweep.

Figure 8 :   Receiver probe

7.6   Probe Check

To check the probes and cables for correct function proceed the following steps:

(1) Shortcut the probes active leads (red clamps)

(2) Shortcut the probes measuring grounds (black / copper clamps)

(3) Make sure that the connectors do not touch each other or any other conductive parts. Do not roll the cables, lay them straight on the floor.

(4) Start a measuring sweep

$\Rightarrow$ The result shall be a flat line
   on 0 dB $\pm$ 0.2 dB

Figure 9 :   Shorted Probes for check

8 Touch Screen

The user interface is done with a touch sensitive screen. The user can touch it either with the fingers, fingernails or the touch pen. Just use your finger as the user would use a mouse pointer.

8.1 Execute Actions

By short pressing an active button the related function or action is started as the user would set the mouse pointer top a button and click the left mouse button.

By pressing and holding (0.5s, changeable by user) an active button the related function or action is started as the user would set the mouse pointer top a button and click the right mouse button.

8.2 Editing Parameters

After touching a input field a virtual keyboard pops up on the screen and the desired value can be entered.
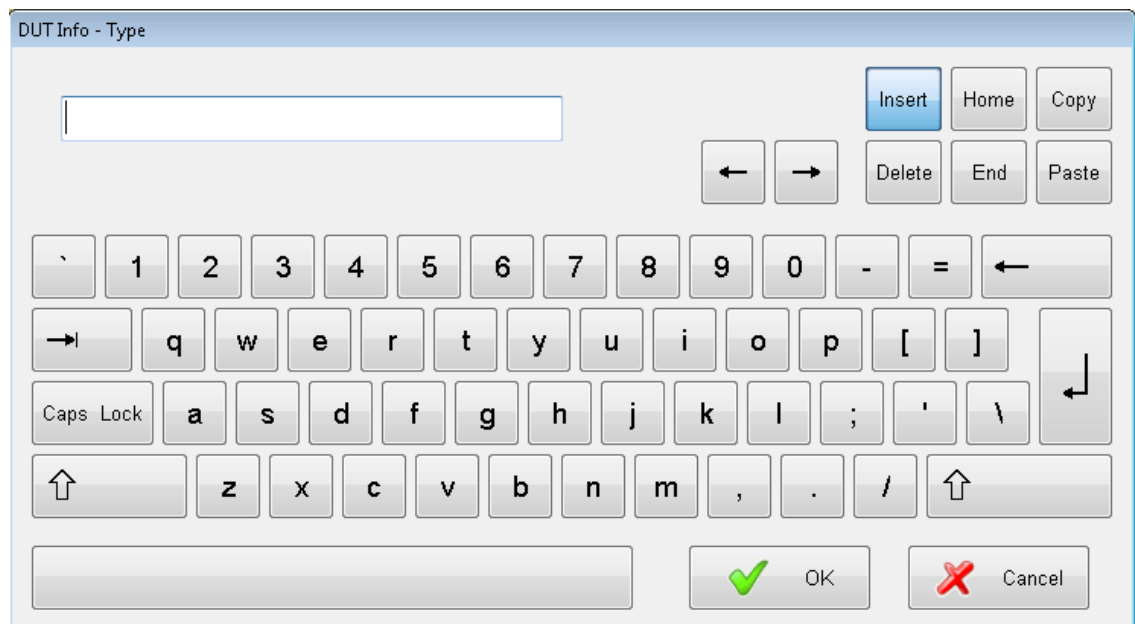
8.3 Calibration

There are two ways to start the "TouchKit" application to calibrate the touch screen cursor position:

From FRA program

Clicking [wrench icon], then in the pop-up menu, clicking [Toutch Kit]

From desktop

Close or minimize the FRA5310 program, then clicking touch kit icon [icon] on the desktop and select "Tools" folder
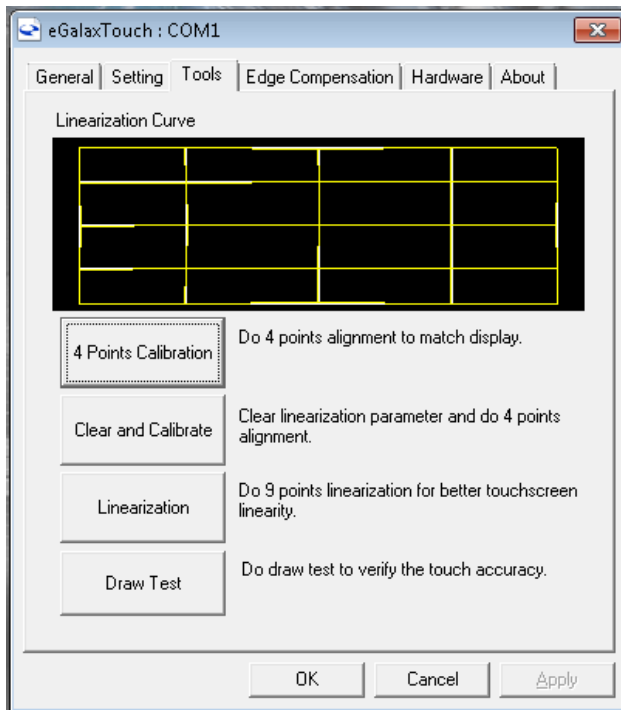
Click "4 pts Cal" button and follow the online instructions.

The red cross has to be clicked until it stops blinking and turns its colour into green.

The focus calibration is done in each corner of the screen.

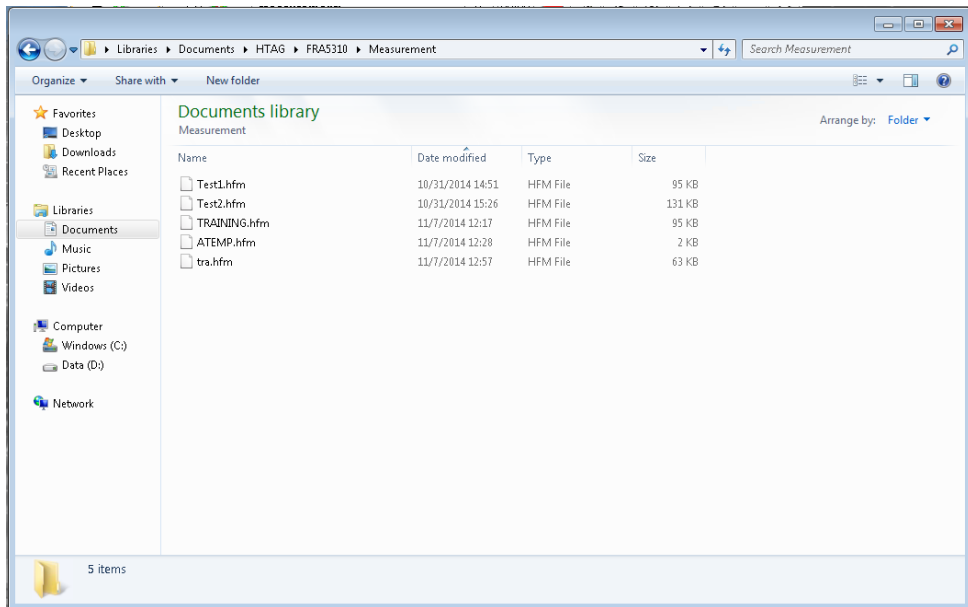# 8.4   File Handling with Windows Explorer

To copy, delete, move, rename files on the FRA5310 unit the Windows Explorer is used. There are two ways to start windows explorer:

From FRA program

Clicking [wrench icon], then in the pop-up menu, clicking [Explorer]

From desktop

Close or minimize the FRA5310 program, then clicking "FRA5310 Data" icon [icon] on the desktop.

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In the Explorer window you have access to the directory tree an the containing files. The user has easy access to the desired file handling functions over the touch screen interface by the windows 7 normal features.

9 Operation Software

The software is running on Microsoft Windows 7 and supports input assistance for operating the software with a touch screen. The software is designed for easy gathering, exchanging and analysing of measuring data.

9.1 Start-up

After switching on the instrument it boots the operating system and then automatically starts up the FRA operation software.

The program can also been started from the instrument desktop by double clicking the FRA 5310 icon.

The program starts up in the same window like the user left the program last time. By default the program starts in the "Measurement / Setup " screen:
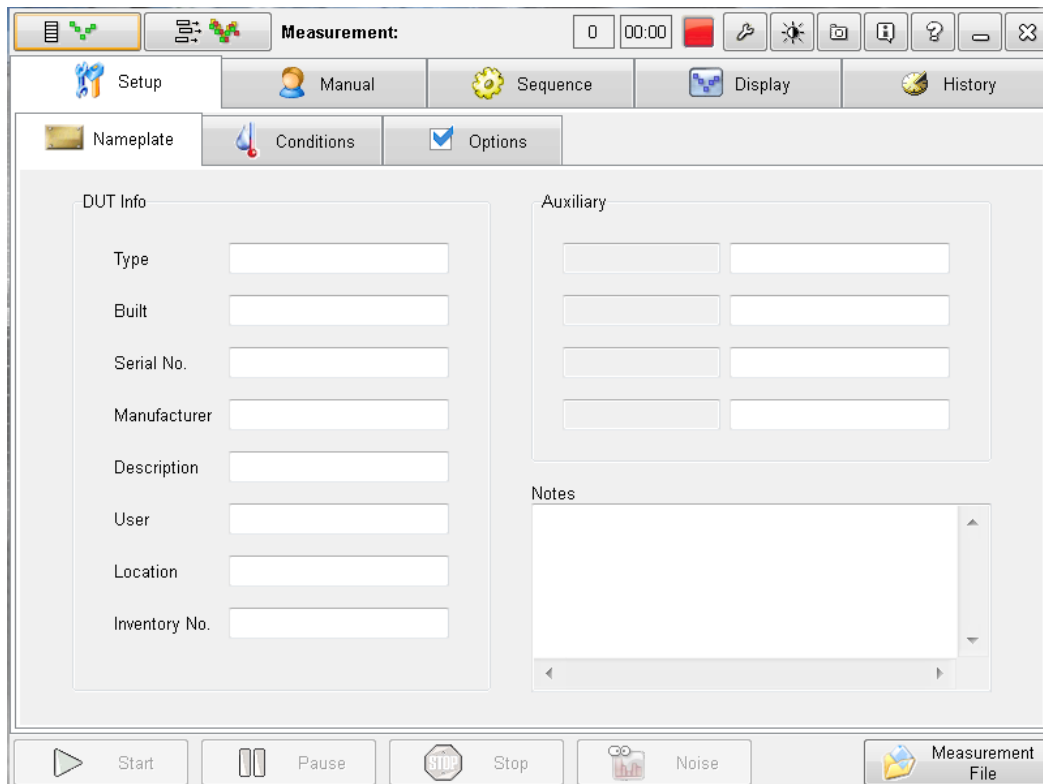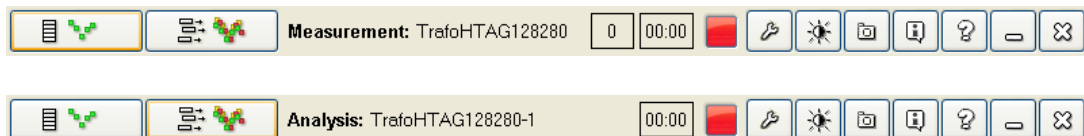

9.2 Operation Modes

The software has two basic modes : The measuring mode and the Analysis mode which are selected by the two buttons top left in the title bar:

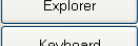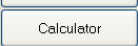|	Measurement Mode
	Select this mode to do the measurement sweeps on the transformer. In this mode the single measurement curves (raw data) are collected.
	A measurement file is created (contains a number of single measurements respectively curves)
	Analysis Mode
	Select this mode to do analysis on the saved measurements. Here the collected single measurements can be compared and analysed (e.g. comparisons of different curves from different files, coherence function, difference calculations, cursor tools etc.)
	A analysis file is created (contains one set of different curves from different measurement files which are compared and saved together)
	The analysis mode can also be used on an office PC or laptop without the FRA instrument hardware.

Remark: The two modes can be active at the same time, e.g. the user can watch the analysis window with older measuring curves while the instrument measures a new curve.

9.3   Title Bar Functions

The functional descriptions of the title bar elements are:

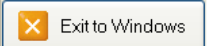|	
	Mode Selector Buttons
	The active displayed mode has a orange frame.
Measurement: / Analysis:	Mode Indicator
	"Measurement" or "Analysis" is displayed. The actual loaded Measurement file name or Analysis file name is displayed
TrafoHTAG128280 / TrafoHTAG128280-1	File Name
	The active measurement file name or analysis file name is displayed. In this File (normally the DUT Name) the measurements respectively the analysis window are stored.
	There are two files active – a Measurement file and a Analysis file.
	Measuring Indicator
	Red is standby, yellow blinking is paused, green fast blinking is a zero calibration sweep and green slow blinking is a normal measurements sweep.
	Counter
	The counter of the actual measurement is shown
00:00	Elapsed Time

	Shows the elapsed measuring time of the actual running measurement respectively the last measurement.
[wrench icon] Touch Kit Explorer Keyboard Calculator	External Tools Button By clicking this button, a menu pops up, there the user can launch the external program which are defined in "ExtTools.cfg" file. "ExtTools.cfg" is a text file and can be modified by any text editor, for example, windows editor. Here is the default command list.
[brightness icon]	Display brightness / contrast adjustment By clicking this button, a dialog pops up, where the brightness and/or contrast of display can be modified. The last settings are loaded automatically when FRA5310 software launched.
[screenshot icon]	Screenshot Creates a "print screen" and then asks for the filename to save the bmp file to.
[about icon]	About Gives information about the unit, software, version number etc.
[help icon]	Online Help function
[minimize icon]	Minimize Button The display of the software will be minimized and the user have access to the Windows OS desktop.
[close icon] [X] Exit to Windows [O] Shut Down	Close Button By pressing this button the user can select between "Exit to Windows" and "Shut Down". Press "Exit to Windows" button to terminate the software and exit to Windows Operating System. Press "Shut Down" button to terminate the software and shut down the system. It's strongly recommend to shut down the system correctly before switching the main power off.

9.4 MEASUREMENT Mode

Select this mode to do the measurement sweeps on the transformer. In this mode the single measurement curves (raw data) are collected. A measurement file is created (contains a number of single measurement curves)

Tab Bar

The tab bar on the top contains five tab sheets. Their function can be summarized as follows:

[Setup icon] Setup	Definitions of the Device Under Test (DUT), measuring conditions, auxiliary information and instrument options.
[Manual icon] Manual	Setup of the measurement parameters for a manual operated measurement
[Sequence icon] Sequence	A tool to predefine the setup of a measuring sequence which can then be executed automatically step-by-step
[Display icon] Display	Shows the actual measured curve while executing a measurement

Tettex

History	This sheet provides access to all stored measurements of the actual loaded "Measuring " file.

See following sections for more details.

9.4.1 Tab Sheet "Setup"
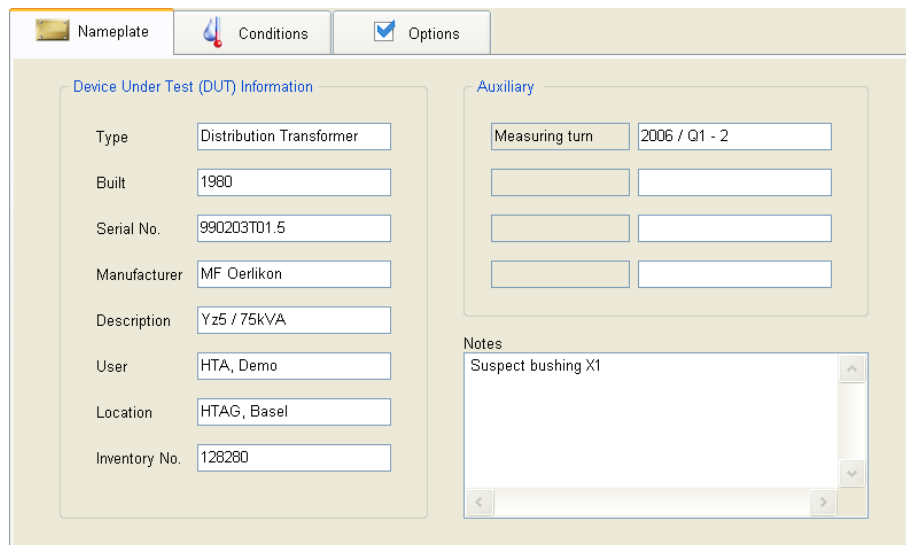
This tab sheet consists of the three sub chapters.

Sub Tab "Nameplate"

Under this menu all general information like transformer type, operator name, location etc. can be specified (the transformer nameplate data).

There are also four free definable "Auxiliary" fields which can be set by the user and an floating text field "Notes" accessible.

Sub Tab "Conditions"

This menu offers the possibilities to enter environmental conditions such as temperature, humidity and the data of the test personnel.
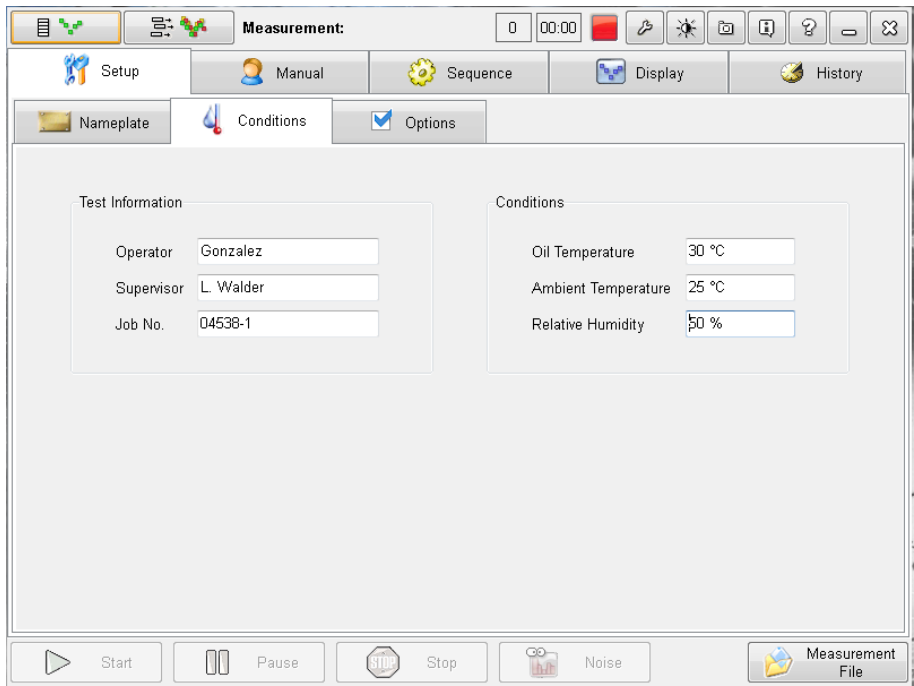
Sub Tab "Options"

In this menu the user can set some general options
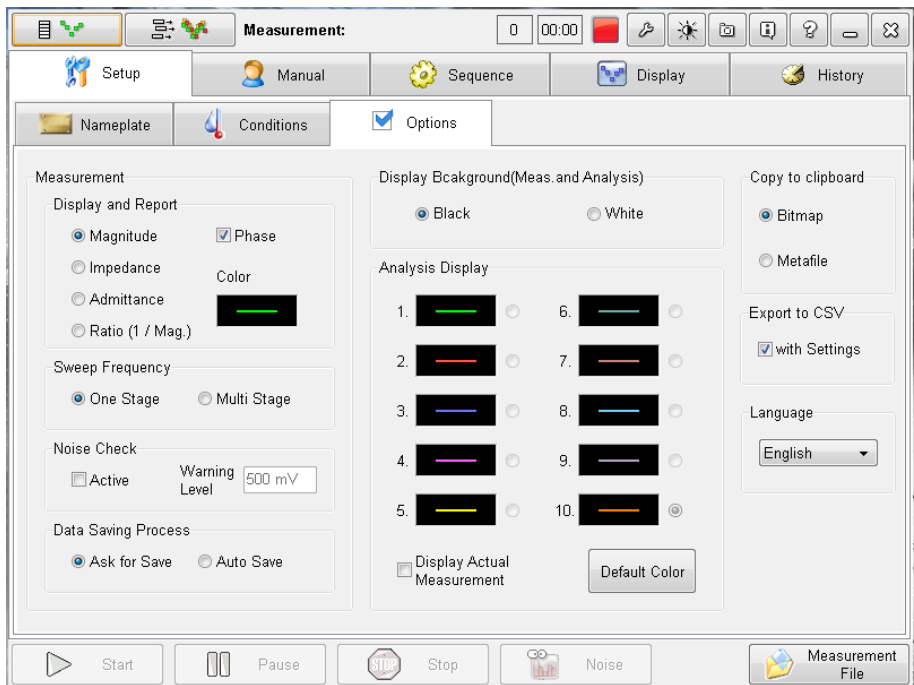
Measurement: Display and Report	The user can select how the single measurement are displayed and reported. Default use is "Magnitude" and "Phase".
	By clicking the "Color" panel, the color can be changed for all measurement chart as well.

Tettex

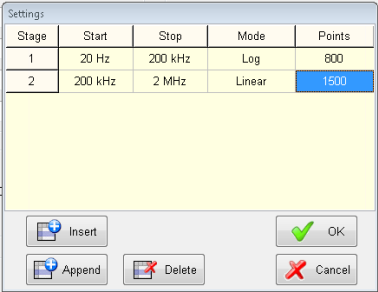|	
Measurement: Settings	One Stage: Only one settings can be set for the measurement Multi Stage: In one measurement, the whole sweep can be split into several stage. The settings (Start/Stop frequency, Sweep Mode and Points) can be set in each stage separately. The selection of the different stages and values is introduced when measuring frequency range textbox is selected. _Settings table:_ | Stage	Start	Stop	Mode	Points | |---|---|---|---|---|
1	20 Hz	200 kHz	Log	800
2	200 kHz	2 MHz	Linear	1500	 Insert / Append / Delete / OK / Cancel .
Measurement: Noise Check	If this option is active, the signal noise will be measured before starting measurement and a warning dialog pops up if the maximum measured value is bigger than the setting value. The noise level dialog also can be opened by clicking the "Noise" button on the bottom of the display.
Measurement: Data Saving Process	The user can select how the system handles measuring data after a measurement sweep is done. Ask before save or Auto Save.
Display Background	The user can select the background of all chart panels between black or white.
Analysis Display	By clicking a "Color" panel, the color of corresponding curve in analysis display can be defined. Clicking "Default Color" button to set the default value for all curves which are suitable for selected background. If "Display Actual Measurement" check box is selected , the actual measured curve is <u>automatically</u> shown in the "Analysis" mode window by desired colour together with the other loaded curves in that window.
Copy to Clipboard	The user can select which format is used when a picture is copied to clipboard. To copy a chart picture to clipboard, press and hold 0.5s on the desired chart (right click in the office version).
Export to CSV	When user export a measurement or analysis file to CSV file, the measurement settings can be included.
Language	Language selection, only Chinese and English available,

9.4.2 Tab Sheet "Manual"

This sheet is used to define the measurement settings and to start a normal measuring sweep.
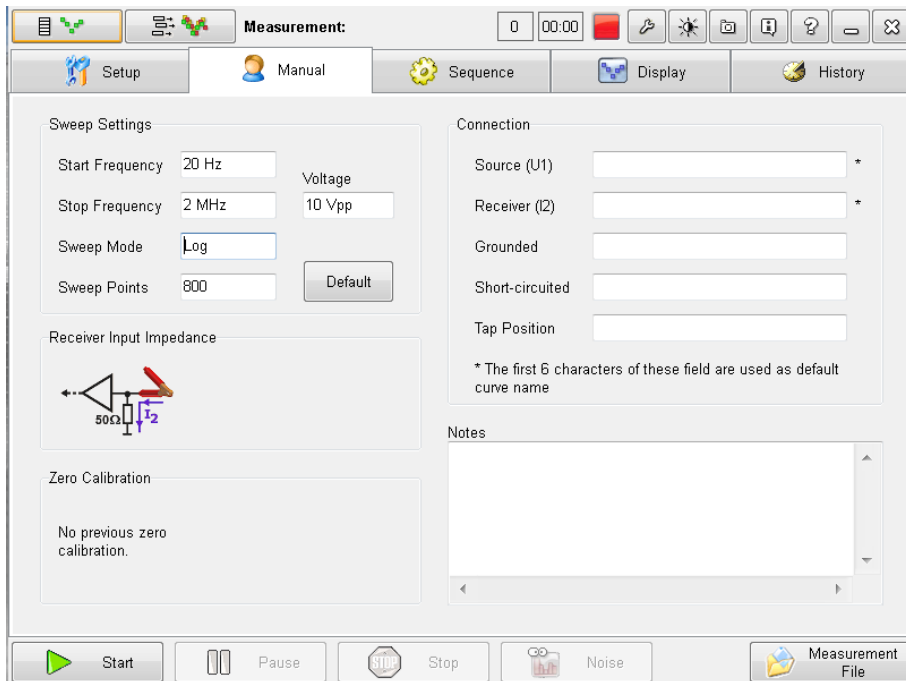
▸ When Start, Stop, Sweep Mode or Points / Sweep is clicked, the action varies depending on the settings in Setup/Options tab: If "One Stage" is active, a input window pops up, in which the selected setting can be modified like other field. Otherwise, the following window pops up to allow the user to define the number of stage and the settings for each one.
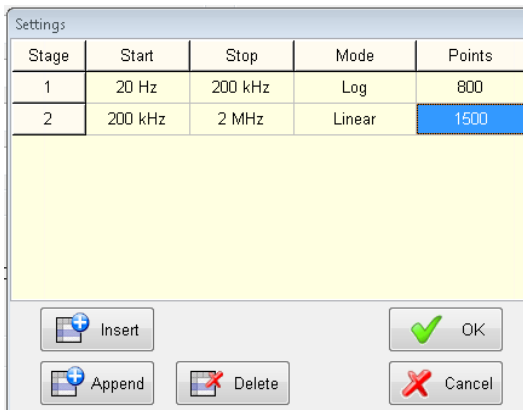
After a starting frequency in a stage changed, the stopping frequency of the last stage will be updated as well.

After a stopping frequency in a stage changed, the starting frequency of the next stage will be updated as well.

If the sweep mode of all stages are not same, "Mixed" will be shown in the Manual tab sheet.

The total sweep points will be the sum of all stage points minus number of stage plus 1.

"OK" button is enabled only when the table is acceptable.

▸ The Sweep Settings (Number of Stage, Start, Stop, Sweep Mode, Points per Sweep, Output voltage on clamp) can be set to a factory default (predefined in the file "Default.cfg") with the "Default" button.

▸ The Receiver Input Impedance (used as a high impedance voltage probe or with a 50Ohm termination).

▸ Select if a previous Zero Calibration measurement shall be done before the actual sweep to further minimize external influences.

▸ Further the Connection of the DUT (Source and Receiver location, bushings grounded, bushings shorted, tap-changer position) has to be exactly defined. This is very important because only with this information the measurement is fully defined and can be used later on to compare to other measurements (with the same test configuration).

Only measurements with same frequency ranges, test voltages, resolution, DUT connections, DUT groundings and DUT shortcuts make an effective curve comparison possible.

The direction from where the measured tap changer position is approached can have an influence on the response curve and therefore should be documented if known.
E.g.   Tap Position: 1 (prev. pos. 2)

The ground connections are part of the measured "black box". So if the measurements are repeated later on the user have to make sure that the same grounding leads and more-or-less the same length is used to get good measurement reproducibility. This can be described here.

Also if unused terminals of the DUT are grounded or short-circuited the user should describe how it was performed.   E.g. Grounded: X1, X2 (with copper wire 1mm2)

Voltage

The output voltage is defined as the peak-to-peak value at the clamp into a 50Ohm load. (e.g. if the probes are shorted and the receiver is set to 50Ohm impedance then the voltage is as entered).

In reality the DUT is connected, the load is higher and therefore also the voltage is higher.

The max. voltage by the signal generator on the open Source probe is $24V_{peak-to-peak}$.

Zero Calibration

The measurement is also influenced by the external ground connections. To measure a transfer function as close as possible to the real transfer function of the DUT only (with minimized grounding connections influences) the instrument setup can be zero calibrated.

That means the transfer function of the shorted instrument (but with connected groundings) is measured and that curve (that ideally would be a zero line) is then subtracted in from the following measurement.
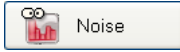
The measuring time with zero calibration is doubled (2 measurements). Due to the fact that the frequency analysis is a comparative measurement and not an absolute result, it has to be ensured that the measurements are just done always in the same manner (with or without zero calibration)

Measuring

After the settings have been entered, click [▷ Start] button to go on with the measurement.

The measurement can be paused by clicking [❚❚ Pause] button or terminated by clicking [STOP Stop] button.

After noise level measured, it can be shown by clicking [Noise] button.

If "Zero Calibration" is selected the user will be asked to shortcut now the probes (red clamps). Disconnect all terminals from the probes and short them together floating.
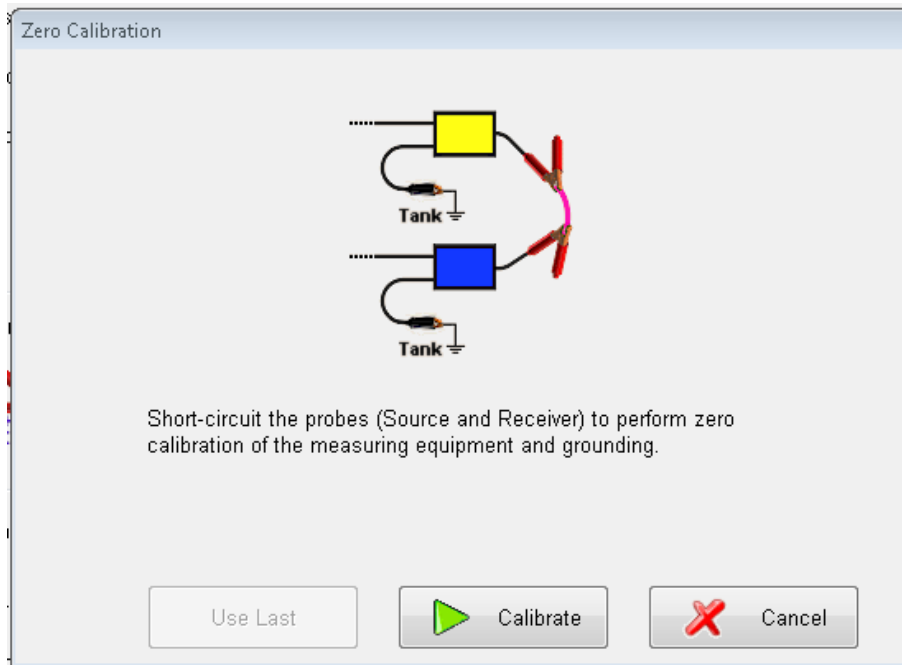
After the confirmation by clicking [Calibrate] button, the system switches over in the "Display" tap and does the zero calibration sweep.

If recently a zero calibration of the probes with the same setup have been done then a "Use Last" button is enabled as well. By pressing that button the last recorded calibration curve is used for the zero correction. But that zero calibration had to be done under the same grounding conditions as the actual measurement now is connected! Else the correction curve would be WRONG. So the "Use Last" button has to be used very carefully.

If a zero calibration is not selected or it has been executed, the user is asked to connect the DUT as defined (the defined setup is now shown on a pop-up window to support the correct connection) and click [Start] button to confirm the cable connections have been done.

If "Noise Check" box in the Setup/Options tab sheet is active, a noise measuring process is started. It may takes few seconds till finished. In case the max. noise value measured is bigger than the predefined warning value, a dialog pops up to show noise level spectrum and ask for confirmation.
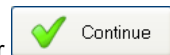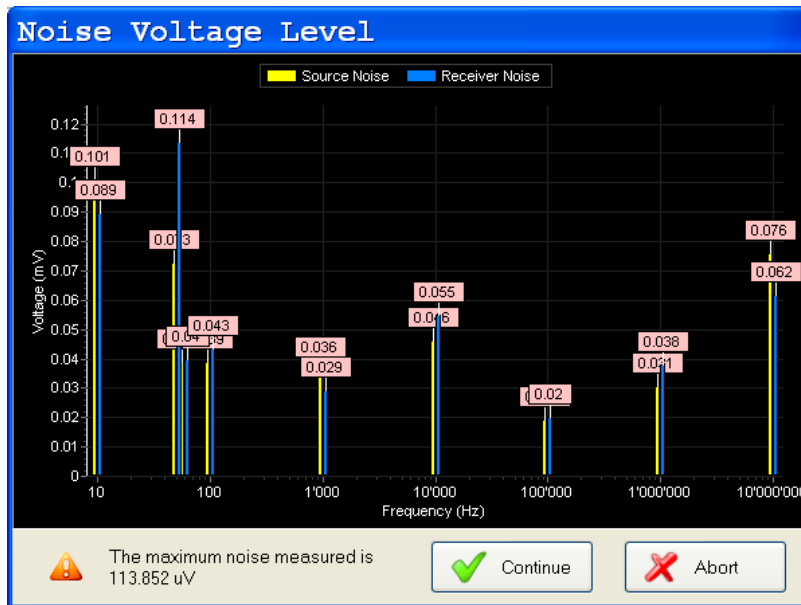
If "Noise Check" is not active, or the measured noise level is less than warning level, or [Continue] button is clicked in the dialog, the measurement process is started immediately.

Signal Overflow
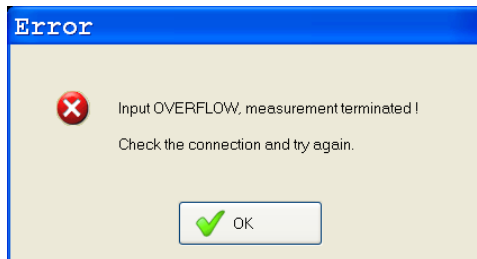
If the voltage signal on the receiver probe overshoots 12.5V_{peak} the voltage will be automatically reduced and increased again to the selected voltage when the overflow is over.

If the overflow stays also with the minimal sweep voltage, the measurement will be terminated to protect the instrument.

An overflow can appear when the probes are connected LV → HV or if there is a specific resonance point within the circuit that can create high overflows.

9.4.3 Tab Sheet "Sequence"

In this Menu the user can predefine a set of several different measurements: Like a list of "Manual" measurement settings, which can be started and then will be executed one after another.

This function helps to repeat predefined measurements e.g. for maintenance measurements since it is saved and accessible when loading the measurement file later on.

| No.	Start	Stop	Mode	Points	Voltage	Source	Receiver	Grounded	Shorted	Tap	Imp.	Z.Cal.	Notes
☒ 1	20 Hz	2 MHz	Log	800	10 Vpp	H1	H3			Highes..	50 Ω	No	
☒ 2	20 Hz	2 MHz	Log	800	10 Vpp	H2	H1			Highes..	50 Ω	No	
☒ 3	20 Hz	2 MHz	Log	800	10 Vpp	H3	H2			Highes..	50 Ω	No	
☒ 4	20 Hz	2 MHz	Log	800	10 Vpp	X1	X0			Highes..	50 Ω	No	
☒ 5	20 Hz	2 MHz	Log	800	10 Vpp	X2	X0			Highes..	50 Ω	No	
☒ 6	20 Hz	2 MHz	Log	800	10 Vpp	X3	X0			Highes..	50 Ω	No	
☒ 7	20 Hz	2 MHz	Log	800	10 Vpp	H1	H3		X1-X2-...	Highes..	50 Ω	No	
☒ 8	20 Hz	2 MHz	Log	800	10 Vpp	H2	H1		X1-X2-...	Highes..	50 Ω	No	
☒ 9	20 Hz	2 MHz	Log	800	10 Vpp	H3	H2		X1-X2-...	Highes..	50 Ω	No	

By clicking **Append Row** or **Insert Row** button, user can either append a new line on the end of the table or insert a new line before the selected line with the default value. Then tip on the single fields to enter the desired settings similar like in the "Manual" settings.

By clicking **Delete Row** button, the selected line will be removed from the table.

By clicking **Template** button, a list of available test configurations (templates) arise, see point Pre-configured test procedures (templates) for clarification.
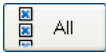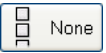
Copy button group:

Copy to Next
Copy to All
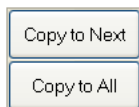
This button group pops up when user click a title of the table except "No.". The first button is used to copy the highlight value to all later rows, while the second one is used to copy the value to all rows of the table. The action also varies depending on the settings in Setup/Options tab: If "Multi Stage" is active and the highlight column is one of Start, Stop, Mode or Points, the settings in all these columns will be copied at same time. Otherwise, only current column will be considered.

The measuring time with zero calibration is doubled (2 measurements). Due to the fact that the frequency analysis is a comparative measurement and not an absolute result, it has to be ensured that the measurements are just done always in the same manner (with or without zero calibration)

By clicking **All** or **None** button, all sequence rows are set to selected or deselected. However, each sequence row can be selected respectively deselected by clicking on the related column "No.".

Clicking **Start** starts with the first selected row of the table and executes all selected rows one by one.

After each row the sequence stops and tells the user how to reconnect the measuring probes to go on with the measurement.

9.4.4 Pre-configured test procedures (Templates)
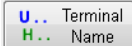
In order to compare tests done at different transformers or with different measuring devices, test procedures (templates) are stored in the device based on the transformer configuration. For detailed information about the sequences please see the Appendix in this manual, chapter "Test setups".
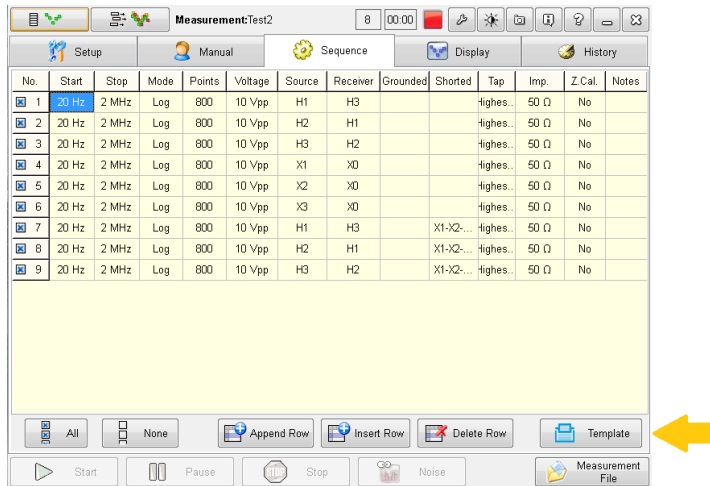
to load an available test procedure (template) select templates in the Sequence window. The template selection window arises
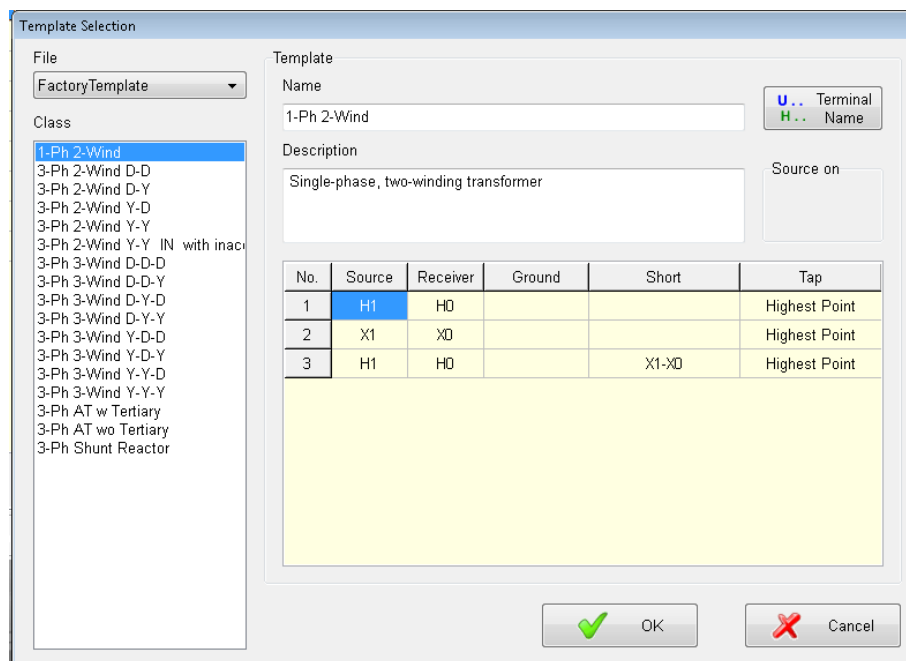
Once the desired transformer configuration is selected, the name, Description and measuring sequence is shown.

Selecting Terminal Name [U.. Terminal / H.. Name], Transformer terminals names can be changed between IEC, IEEE or abc. The complete sequence will be adapted to this terminal naming convention.

To load the sequence select OK, to discard select Cancel. If Ok the sequence will be loaded in the device.

To perform the measurements following the loaded sequence select Start. Measurements can be unselected by unselecting the corresponding row.
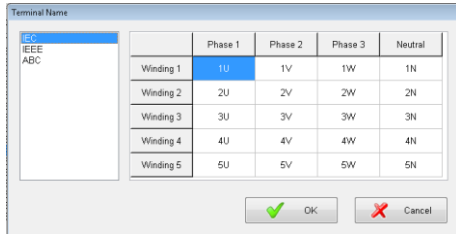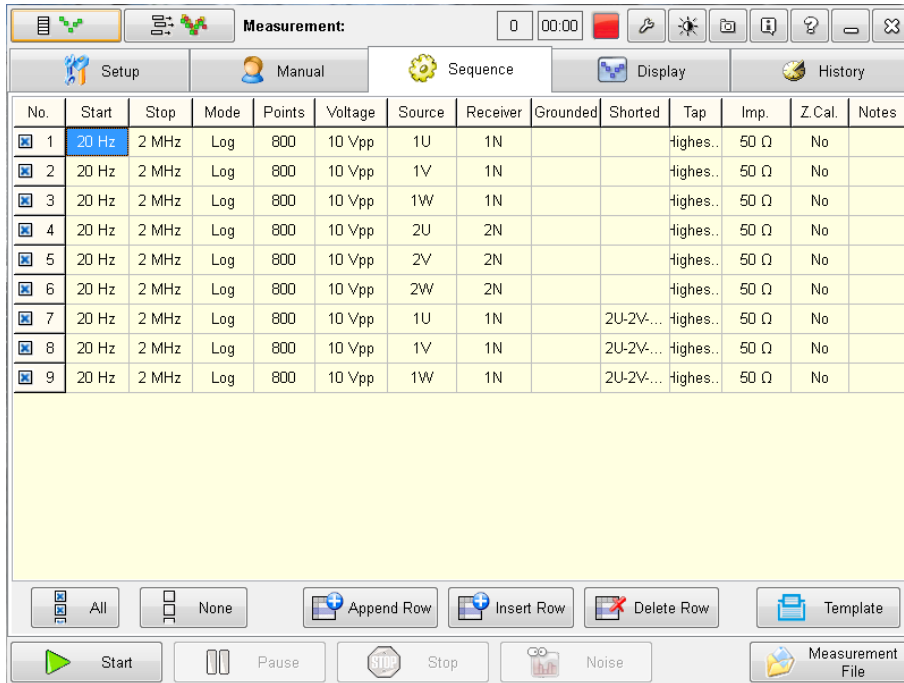

| No.	Start	Stop	Mode	Points	Voltage	Source	Receiver	Grounded	Shorted	Tap	Imp.	Z.Cal.	Notes
☒ 1	20 Hz	2 MHz	Log	800	10 Vpp	1U	1N			Highes..	50 Ω	No	
☒ 2	20 Hz	2 MHz	Log	800	10 Vpp	1V	1N			Highes..	50 Ω	No	
☒ 3	20 Hz	2 MHz	Log	800	10 Vpp	1W	1N			Highes..	50 Ω	No	
☒ 4	20 Hz	2 MHz	Log	800	10 Vpp	2U	2N			Highes..	50 Ω	No	
☒ 5	20 Hz	2 MHz	Log	800	10 Vpp	2V	2N			Highes..	50 Ω	No	
☒ 6	20 Hz	2 MHz	Log	800	10 Vpp	2W	2N			Highes..	50 Ω	No	
☒ 7	20 Hz	2 MHz	Log	800	10 Vpp	1U	1N		2U-2V-...	Highes..	50 Ω	No	
☒ 8	20 Hz	2 MHz	Log	800	10 Vpp	1V	1N		2U-2V-...	Highes..	50 Ω	No	
☒ 9	20 Hz	2 MHz	Log	800	10 Vpp	1W	1N		2U-2V-...	Highes..	50 Ω	No	

9.4.5 Tab Sheet "Display"

This sheet is intended for displaying the actual measured curve. Its layout is defined by "measurement" / "Display and Report" group in Setup/Options tab sheet. By default, the magnitude and the phase are displayed.

This sheet is not intended for analysis of the curve but to get a fast impression of the curve itself. For further analysis and comparisons etc. the user has to switch over in "Analysis mode". See relating chapter.

If "Zero Calibration" was set, the calibration measurement is shown first and the zero curve is plotted while calibrating. This recorded zero curves then will be calculated out of the following measurement sweep.
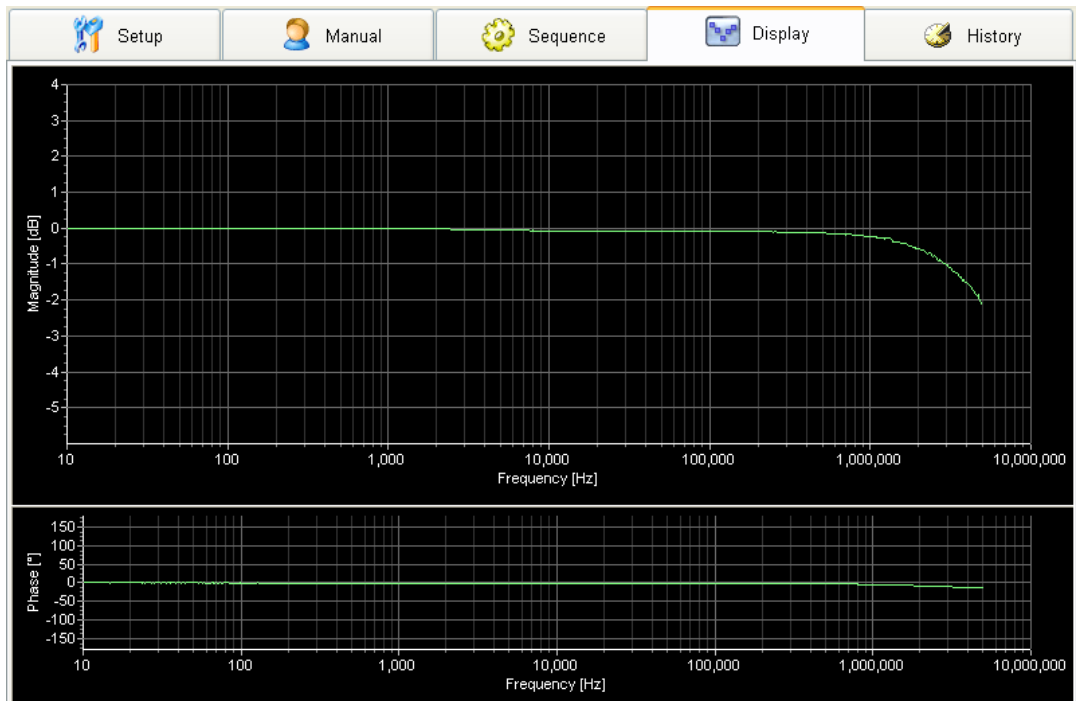
When the measurement is started, the DUT measuring curve is displayed. The zero calibration is calculated out automatically if it was set active.
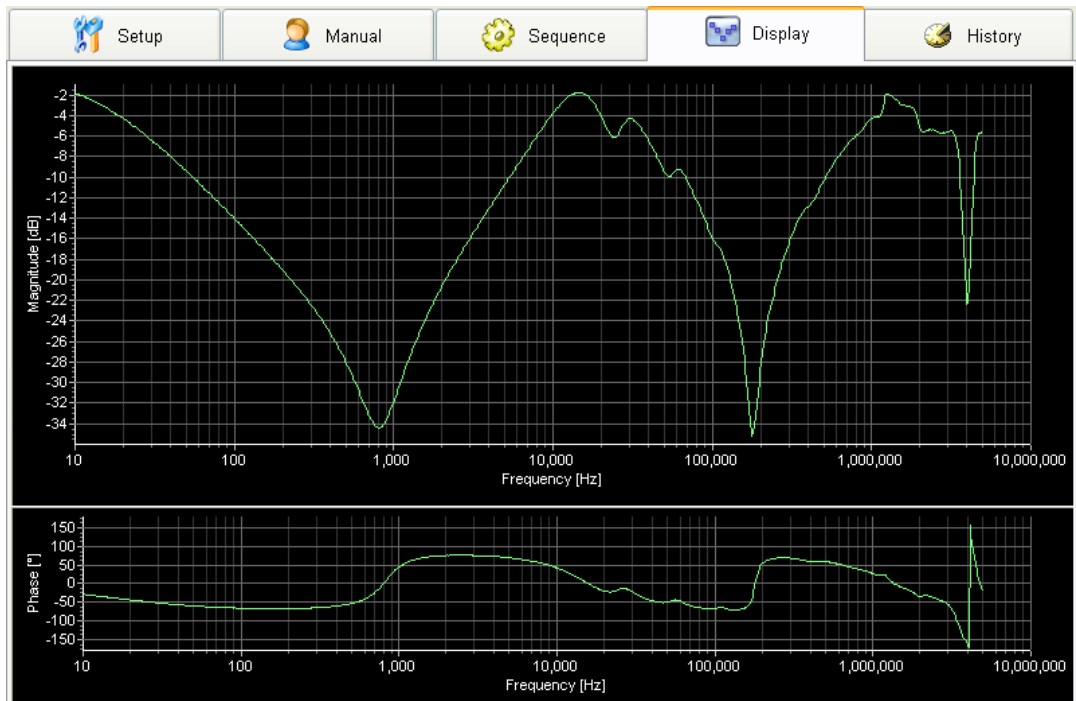
▶ The user can toggle the frequency scaling between linear and logarithmic by clicking on the "Frequency [Hz]" axis label.

▶ The curve can be zoomed by moving the finger over the desired area of the curve. To zoom back (1:1), double-click on the display area.

9.4.6 Tab Sheet "History"

In this tap sheet the user has access to the datasets of the actual loaded measuring file (to which the actual executed measurement curve is added as well)
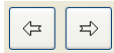
By pressing the navigation buttons the user can click through the already stored measurements in the active file. The curve and its related definition data (as timestamp, DUT, connection etc.) are displayed on the screen.

The following fields are read-only: Counter, Timestamp, Sweep points, Voltage, Impedance, Calibration.
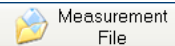
All other fields can be edited here e.g. if the user forgot before the measurement to enter the operator or the actual tap position of the transformer he can add or change the field here.

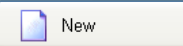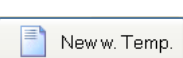By clicking ![Delete] button the user can delete the selected measuring curve out of the actual loaded measurement file.
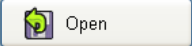
9.4.7 Measurement File Manager
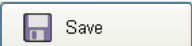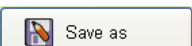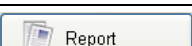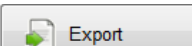
There are two kind of files accessible – a "Measurement" file with extension ".hfm" and a "Analysis" file with extension ".hfa". If the user toggles between the "Analysis" and the "Measuring" mode – also the File Manger will be linked to the corresponding "Measurement" or "Analysis" file. The active filename is always shown in the top bar.

Click ![Measurement File] to launch a pop-up box with several file handling functions. This button is always shown throughout the program.

The functions of the individual elements of the file Manger for a active "Measurement file" are :

New	A new empty file will be created . The name of the file will be asked at the first saving operation : All further measured data will be stored in this file.
New w. Temp.	A new file will be created based on a existing one from where all DUT settings and sequence settings (template) will be taken over. The name of the file will be asked at the first saving operation : All further measured data will be stored in this file.
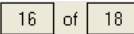
Open	Starts the "Open File" dialog where the user can load an existing file to continue. All further measured data will be stored in this file.
Save	Saves the actual test file. All further measured data will be stored in this file.
Save as	Saves the actual test file under a selectable filename. All further measured data will be stored in this file.
Report	Opens the "Generate Report" dialogue where the measurements can be selected for reporting. See "Reporting" for details.
Export	A copy of the actual loaded file with all its containing measurements is saved , two different export formats are available ◯ CSV ◉ IEC XML • as a CSV file (Comma Separated Values) under "Filename_YYMMDD-hhmmss.csv" in a selectable folder. This format allows easy import of data into other applications like Microsoft Excel. • As XML file according the IEC 60076-18 appendix 3 file format recommendation
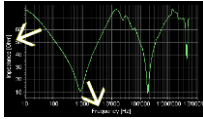
9.4.8 Reporting
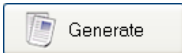
After clicking in the File Manager the following dialogue pops up:
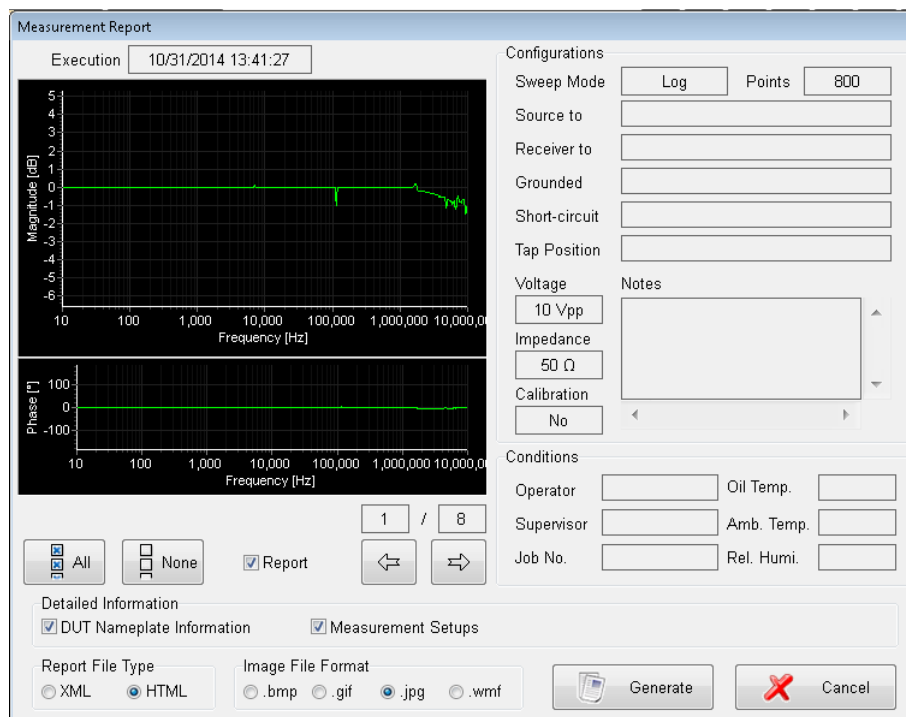
In this dialogue the user has an overview over all stored measurements in the file and he can select the ones to be reported. →

	The counter shows the actual displayed measurement. With the navigation buttons the user can step through the file.
	Select with this checkbox the single measurements to be reported.
	By pressing "All" or "None" all measurements can be selected respectively deselected at once.

	The user can toggle the axis scaling between linear and logarithmic by clicking on the axis label. (Logarithmic scale only possible for Frequency, Impedance, Admittance, Ratio). The selected view will also be used in the report.
☑ Nameplate (DUT) Information	If selected the file header (DUT information) will be printed in the report as well
☑ Measurement Setups	If selected the detailed setups of each selected measurement will be printed separate. (The short form of the setups is always printed with the curve itself)
Report File Type ○ XML ⦿ HTML	Select the report file data format as XML or HTML
Image File Format ○ .bmp ○ .gif ○ .jpg ⦿ .wmf	Select the image file type used in the report file. The user can select the file types `.bmp`, `.gif`, `.jpg` and `.wmf`. Use `.wmf` for best resolution and `.gif` for smallest file size.

By clicking [Generate] button, the report will be created and displayed in "Microsoft Internet Explorer". From there it can be printed onto a PDF file or to a connected (USB) printer.

The report file itself will be saved in its corresponding directory. See chapter "Directory Structure/Data".

For best printout resolution save the report as HTML and open the report then in the Microsoft Word and print it from there. (The Explorer prints also .wmf pictures as bitmaps with low resolution, while the Microsoft Word can handle the higher resolution of the .wmf pictures)

9.5 ANALYSIS Mode
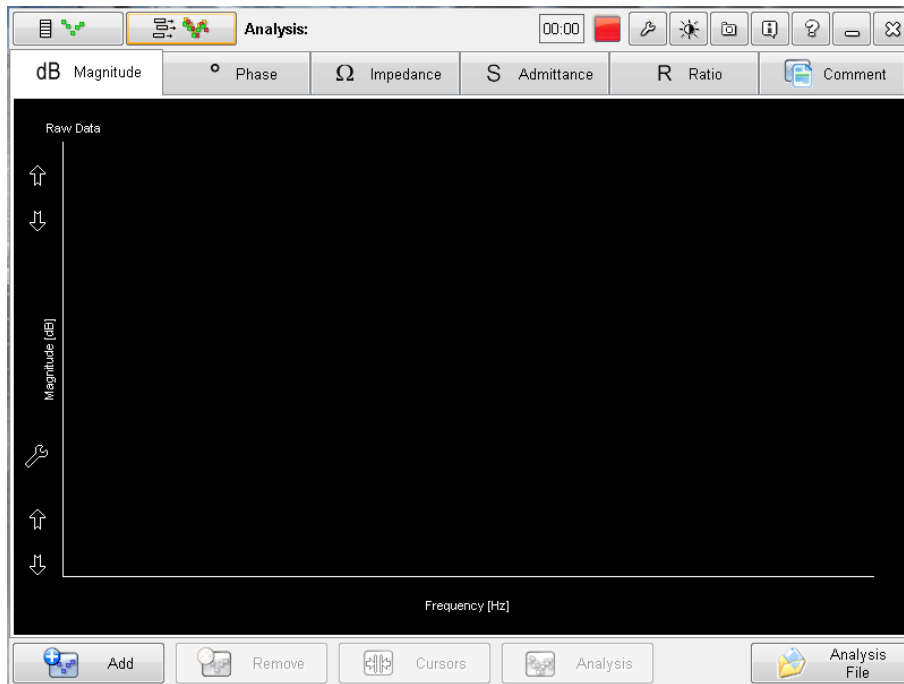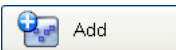
Here the collected single measurements can be loaded together, compared and analysed (e.g. comparisons of different curves from different files, coherence function, difference calculations, cursor tools etc.). A analysis file is created (contains one set of different curves from different measurement files which are compared and saved together).

The tab bar on the top contains four tab sheets. Their function can be summarized as follows:

dB Magnitude	Shows the "Magnitude" display. The magnitude of the transfer voltage function (U_{OUT} / U_{IN} (f) is displayed in dB.
° Phase	Shows the "Phase" display. The phase of the transfer function is displayed in °.
Ω Impedance	Shows the "Impedance" display. The magnitude of the impedance function (U_{IN} / I_{OUT} (f) is displayed in Ohm.
S Admittance	Shows the "Admittance" display. The magnitude of the admittance function (I_{OUT} / U_{IN} (f) is displayed in Siemens (A/V).
R 1 / Magnitude	Shows the "1/Magnitude (Ratio)" display. The magnitude of the transfer voltage function (U_{IN} / U_{OUT} (f) is displayed. This curve corresponds around power frequency with the transformers Voltage Ratio (depending on probe connection).
Comment	Shows a input dialogue to write comments (failure report, conclusions, explanations, descriptions, etc) to the actual analysis file.

9.5.1 Add and Remove Curve

The bottom bar contains amongst others the [Add] and [Remove] buttons.

By clicking [Add] button a pop-up selection opens where the user first selects the colour in which the curve shall be displayed. Up to 10 curves can be displayed.
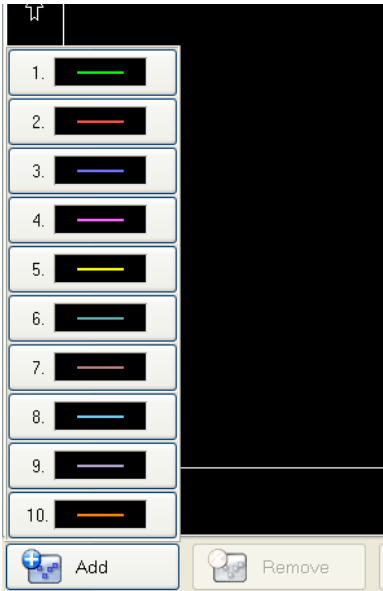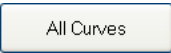
After selecting the colour the Measurement, a selection window opens.
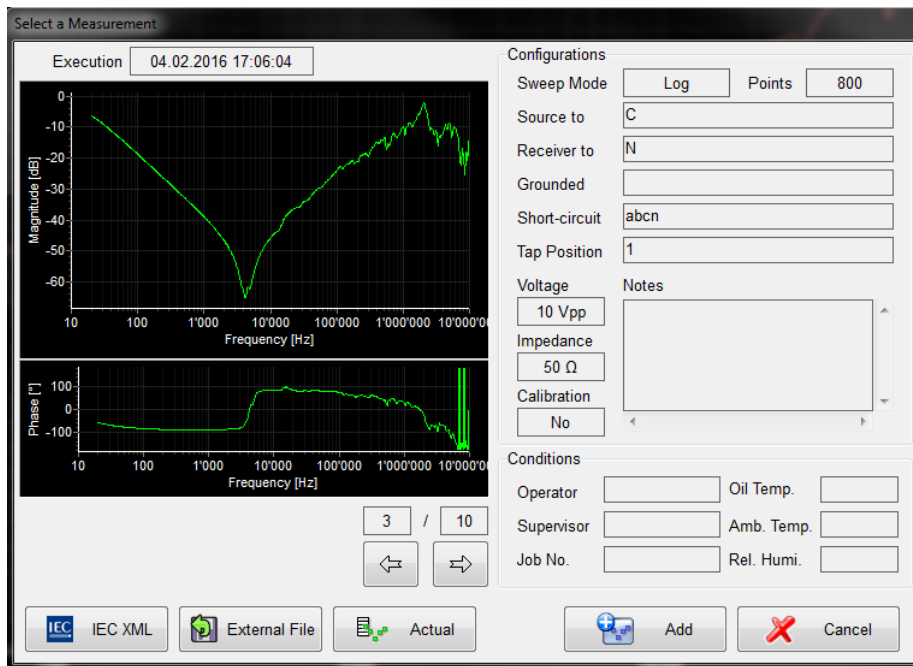
First the user has to choose from where he wants to load a curve.

Actual	From the actual loaded measurement file.
IEC XML	From another stored measurement file in IEC 60076-18 appendix E format, from FRA5310 or any other device fulfilling this format. A "Open file" dialogue will be shown where the desired file can be selected.
External File	From another stored measurement file. A "Open file" dialogue will be shown where the desired file can be selected.
⇦ ⇨	With the navigation buttons the measurements of the loaded file can be stepped through and by pressing "Add" the actual shown measurement is loaded to the analysis display.

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By clicking **Remove** button a pop-up selection opens where the user selects the colour of the curve that will be removed. Also all curves can be removed from the display by clicking **All Curves** button.

To add the next curve follow the same procedure. Up to 10 curves can be maximal displayed.

9.5.2 Curve Display Tools

⇧ ⇩	Increase respectively decrease the end values of the vertical axes.
🔧	Open a toolbox. See "Toolbox" for detail.
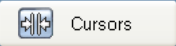
Toolbox

⊙	Auto-scaling the vertical value (Magnitude, Phase, Impedance, Admittance).
f	A dialogue opens where the user can set an exact frequency display range (Start frequency .. Stop frequency). By pressing "Full curve" the full range is displayed again.
Log ↕ Lin	Toggle left axis between "Linear" and "Logarithmic" scaling. Can also be toggled by clicking on the scale label of the left axis. Only enabled in "Impedance" and "Admittance" windows.
Log ↔ Lin	Toggle frequency axis between "Linear" and "Logarithmic" scaling. Can also be toggled by clicking on the scale label of the bottom axis.
dB	Show labels on the single measuring points with the exact vertical axis values. Can be "dB" , "°Degree", "Ohm" , "S" or "R".
f	Show labels on the single measuring points with the exact frequency values.
✗	Switch label function OFF.

	Set zoom one step back.
	Set zoom to full curve (1:1).
	If a curve is zoomed this button enables moving arrow buttons around the display to move the zoomed curve in any direction.
	If curve is zoomed, By clicking this button, the arrow buttons can be turned off (invisible).
	Save a graphic file of the actual shown curve image to a file (a file dialog will appear). The user can select the file types `.wmf`, `.gif`, `.jpg` and `.bmp`. Use `.wmf` for best resolution and `.gif` for smallest file size.
	Print the actual shown curve image to a PDF file or to a connected (USB) printer: A print dialog will appear and the user can select FreePDF or the connected printer.

Remark: If the program runs on an external PC with a mouse connected the actual Diagram display can be copied to clipboard by pressing the right mouse button.

9.5.3 Cursors

By clicking button a pop-up selection panel opens.
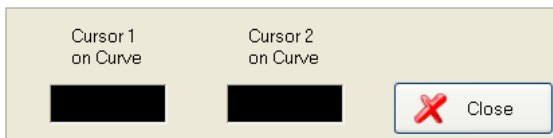
Select the first curve by clicking on the desired curve legend on the top of the display or clicking on the black input field to get a colour list where the user can select the colour of the desired curve. Then the user has to select the second curve to set a cursor on in the top legend respectively out of the colour list.
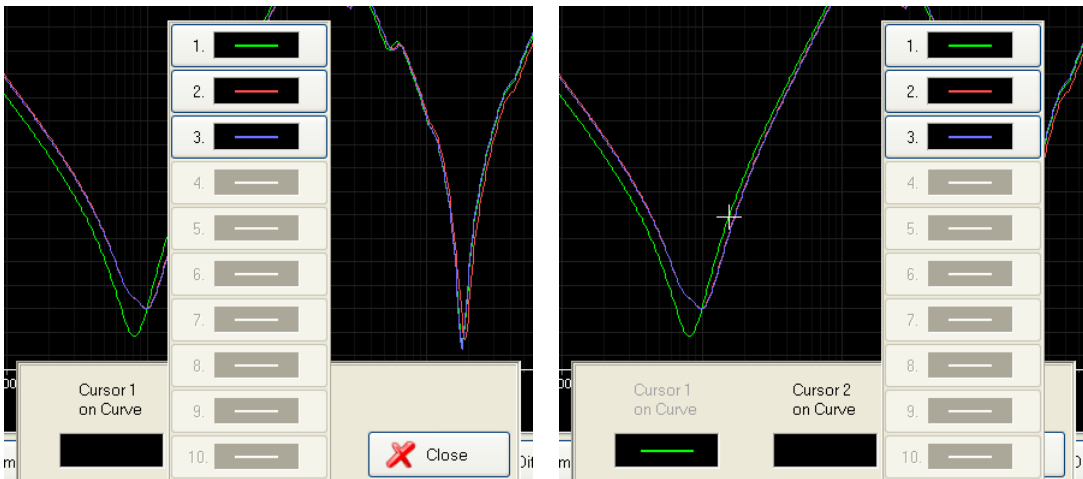
Now the cursors are set on the curves and the info field is shown.

Move the single cursor on the curves with the arrow buttons. By selecting the "x10" check box the cursors jump 10 measuring points instead of one on the curve by one click and therefore moves faster.

In the related displays the position (X Y) of each curser is shown as well as the difference between the two cursors (delta display)

Remove the cursors by pressing the "Close" button.

9.5.4   Analysis functions

Click [Analysis] to launch a pop-up box with several analysis functions.

[Difference]	Create a difference curve based on two measured curves. See "Analysis function: Difference" for details.
[Coherence]	Create a coherence curve based on two or more measured curves. See "Analysis function: Coherence" for details.
[Filtering / Smoothing]	Set filtering and (or) smoothing parameters for all curves shown in display. See "Analysis function: Filtering and Smoothing" for details.
[DL DL / T]	Show the deformation based on Chinese standard DL/T 911-2004. See "Analysis function: DL/T standard" for details.

9.5.5   Analysis function: Difference

By clicking [Difference] button in the "Analysis" box, a pop-up selection panel opens.
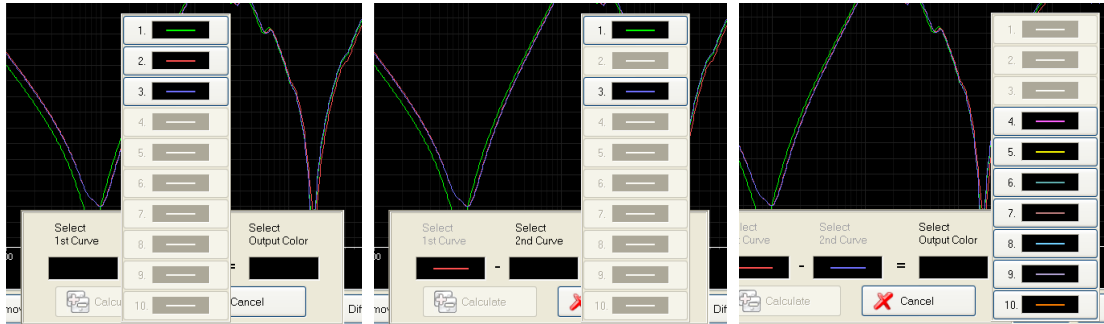
Select the first curve by clicking on the desired curve legend on the top of the display or click on the black input field to get a colour list where the user can select the colour of the desired curve.

The selected curve will be locked and the user has now to select the second curve to subtract in the legend respectively out of the colour list. Finally the colour of the result (difference curve) has to be selected.

Now click [Calculate] button. The difference will be calculated and displayed in the selected colour.

The title in the top legend will be added with [Curve1Name] - [Curve2Name].
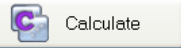
9.5.6   Analysis function: Coherence

The Coherence function is available for "Magnitude", "Impedance" "Admittance" and "Ratio" curves. A coherence can be calculated between two or more curves.

By clicking [Coherence] button in the "Analysis" box, a pop-up selection panel opens with all active loaded measured curve colours enabled.
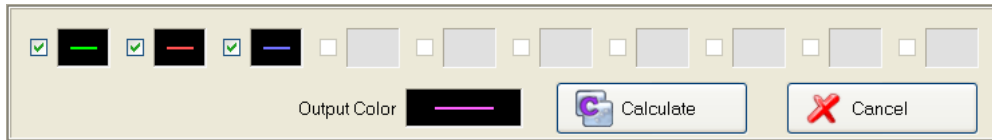
Select the curves where the coherence has to be calculated by clicking on the desired curve colour box. Finally the colour of the resulting coherence curve(output colour) has to be selected.

Now click and the coherence will be calculated and displayed in the selected colour.

The title in the top legend will be added with C[Curve1Name][Curve2Name] etc.

On the right hand side of the diagram the Coherence scale (0..1 unity) is shown.

Theory

The problem of noise imposed on measured quantities has been extensively studied also in other fields, and successful signal processing methods to assess the influence of noise have been first implemented in acoustic measurements.

One of them, referred to as coherence function provides an indication of the areas where the ingress of noise made the signal processing not reliable. The coherence function is derived from all the time domain records used in the transfer function calculation.

Assuming a linear behaviour of the examined winding and an ideal noise-free measuring system, the coherence shall be equal to unity "1" over the entire analysed frequency band.

"Useful" (meaningful) response data produces a coherence in the range of about 0.4 .. 1.

The coherence function $\gamma 2$ is calculated as a quotient of the cross-correlations IGxyI2 and autocorrelation of the applied input voltage Gxx times autocorrelation of the output voltage Gyy.
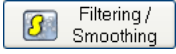
$\gamma 2$ = IGxyI2 / Gxx · Gyy   where:

Gxx = Σ IU_{IN}I2 / n , Gyy = Σ IU_{OUT}I2 / n and Gxy = Σ IU_{IN}✱ · U_{OUT}I / n

In this expression U_{IN} denotes the frequency spectrum of the recorded input voltage, U_{IN}✱ its complex conjugate, U_{OUT} is the output voltage spectrum and n the number of sets.

An example of different records is shown in the above figure. Three transfer functions of a distribution transformer (X1→X0, X2→X0, X3→X0) and their coherence are shown. The graph reveals a gradual reduction of coherence at two resonance points, where the transfer function shows small differences.

9.5.7   Analysis function: Filtering and Smoothing

By clicking [Filtering / Smoothing] button in the "Analysis" box, a pop-up setting panel opens, where the user can set the curves displayed with filtering and (or) smoothing or not. All tab sheets are updated as soon as settings are changed.

Filtering	Smoothing	
☑ Active Magnitude 2 dB ▲▼ Phase 8° ▲▼	☑ Active No. of Points 9 ▾	✗ Close

Filtering and smoothing information will be saved in the analysis file, means the curves show with these settings when a file loaded.

Filtering and smoothing information will be considered in the analysis report, means the curves will be filtered and (or) smoothed in the report in case of "Filtering" and (or) "Smoothing".
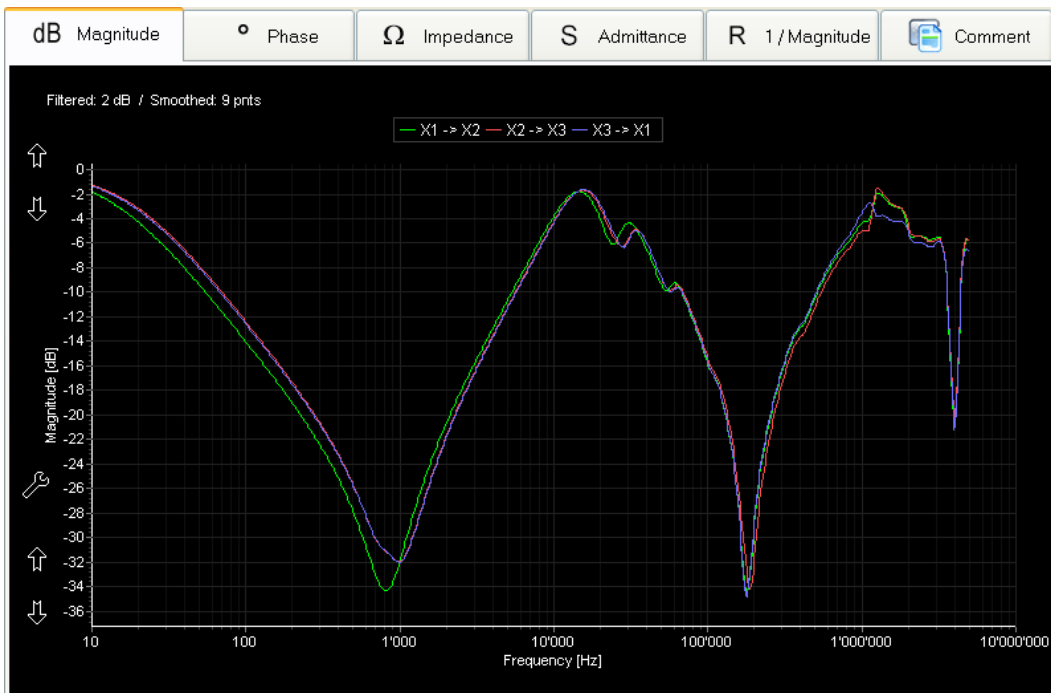
9.5.8   Analysis function: DL / T Chinese Standard

By clicking [DL DL/T] button in the "Analysis" box, a pop-up selection panel opens.
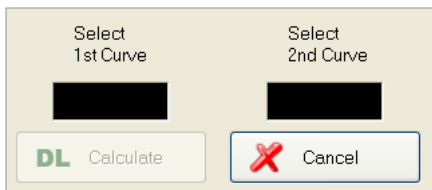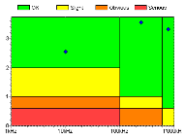
Select the first curve by clicking on the desired curve legend on the top of the display or click on the black input field to get a colour list where the user can select the colour of the desired curve. Now the selected curve is locked and user has to select the second one. After two curves selected, click

DL Calculate button to open the window which shows the deformation calculated by the selected two curves based on Chinese standard DL / T 911 – 2004.
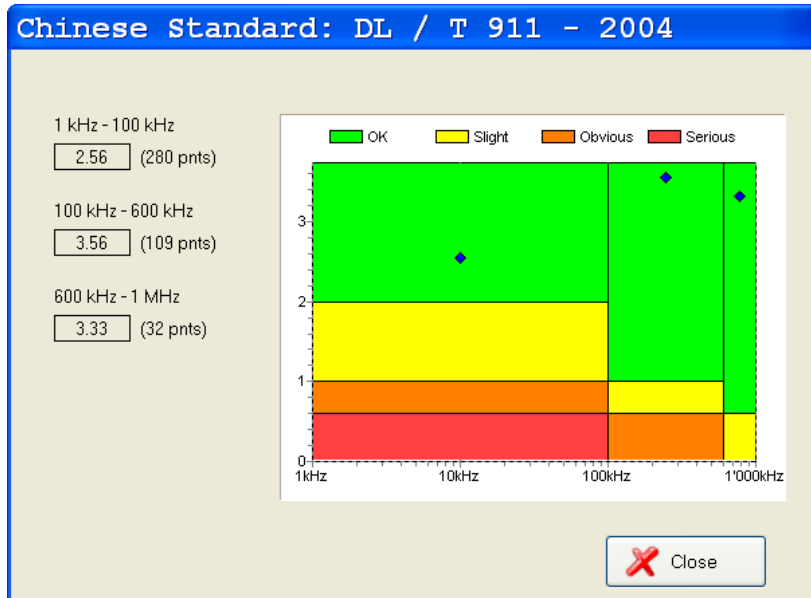
1 kHz - 100 kHz	Frequency range, in which the magnitude series are calculated.
2.56	Relation factor R_{xy}, calculated by the following formula.
(280 pnts)	Measuring points in the frequency range. It varies with the settings of measurement. In general, bigger value makes more believable result.
	This chart shows the deformation level in different frequency range and in which R_{xy} is.

Formula:

$$\overline{X} = \frac{1}{N}\sum_{k=1}^{N} X(k) \qquad\qquad \overline{Y} = \frac{1}{N}\sum_{k=1}^{N} Y(k)$$

$$Dy = \frac{1}{N}\sum_{k=1}^{N}[X(k)-\overline{X}]^2 \qquad\qquad Dy = \frac{1}{N}\sum_{k=1}^{N}[Y(k)-\overline{Y}]^2$$

$$Cxy = \frac{1}{N}\sum_{K=1}^{N}[\,|\,X(k)-\overline{X}\,|\times|\,Y(k)-\overline{Y}\,|\,]$$

$$LRxy = \frac{Cxy}{\sqrt{Dx \times Dy}}$$

$$Rxy = \begin{cases} 10 & 1-LRxy < 10^{-10} \\ -\lg(1-LRxy) & others \end{cases}$$

X(k): magnitude series of 1st selected curve in certain frequency range.

Y(k): magnitude series of 2nd selected curve in certain frequency range.

9.5.9 Curve Name and Information

By clicking the name of a curve on the top legend a dialogue pops up to show the information of the selected curve.

The name of the curve can be **edited** in this dialogue. Also the colour can be changed by clicking the colour box, as same as the function in Setup/Options tab sheet.

Depending on the type of the curve selected, the content in the dialog may be different.

Measurement Curve

The default measurement curve name is the connection information from source and receiver, e.g. X0->H1. If both source and receiver are not defined (blank), the measurement counter is used as the curve name.

The nameplate, condition and configuration information is show as read-only. The filename where this curve is stored in is shown in the blue window top bar.
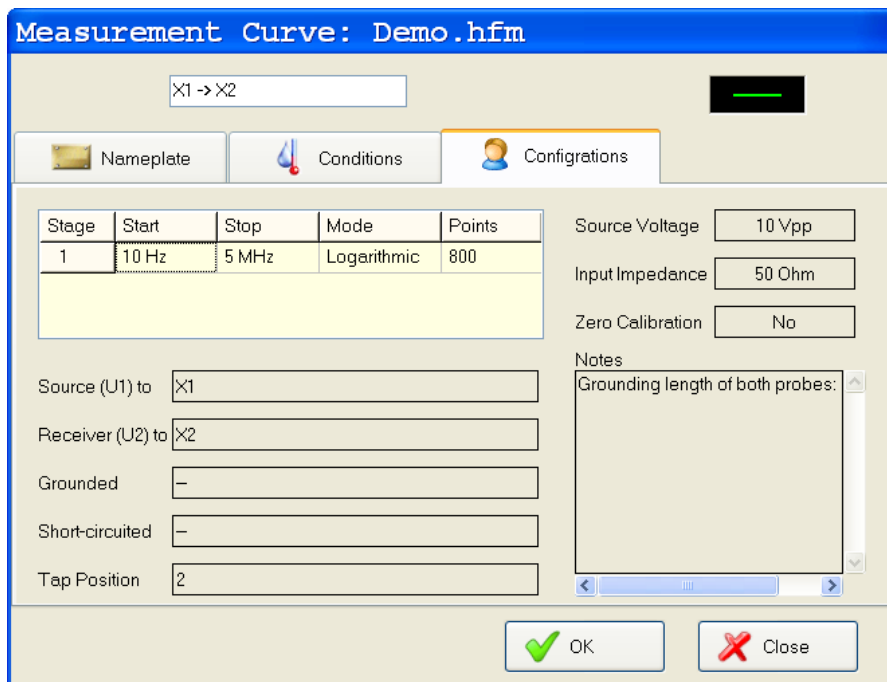
Coherence Curve

The default coherence curve name is C[1st curve name][2nd curve name]…,
e.g. C[X0->H1][X0->H2][X0->H3].

A list of source curves from which the coherence was calculated from is shown in this dialogue.
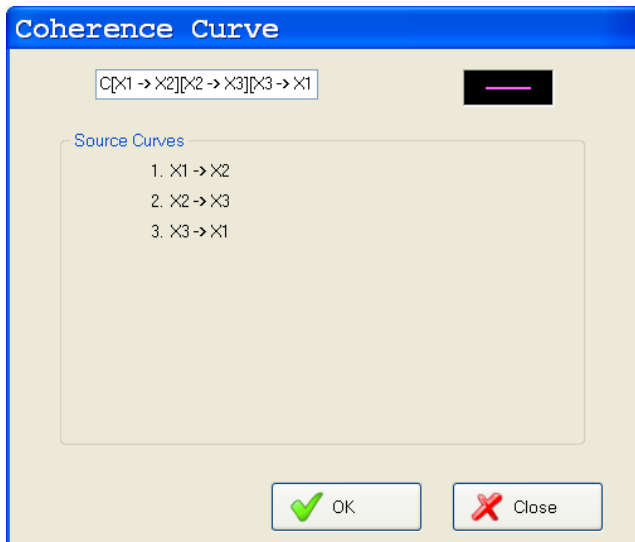
Difference Curve

The default difference curve name is [1st curve name] – [2nd curve name], e.g. [X0->H1] – [X0->H2].

The "Limit Tool" can be set to enable or disable in this dialogue.

When enabled, the user can set a "Pass" band where the difference of two curves is in an acceptable range e.g. +/-10dB. Within this band the difference curve will be displayed with low visibility in grey colour as dotted line.
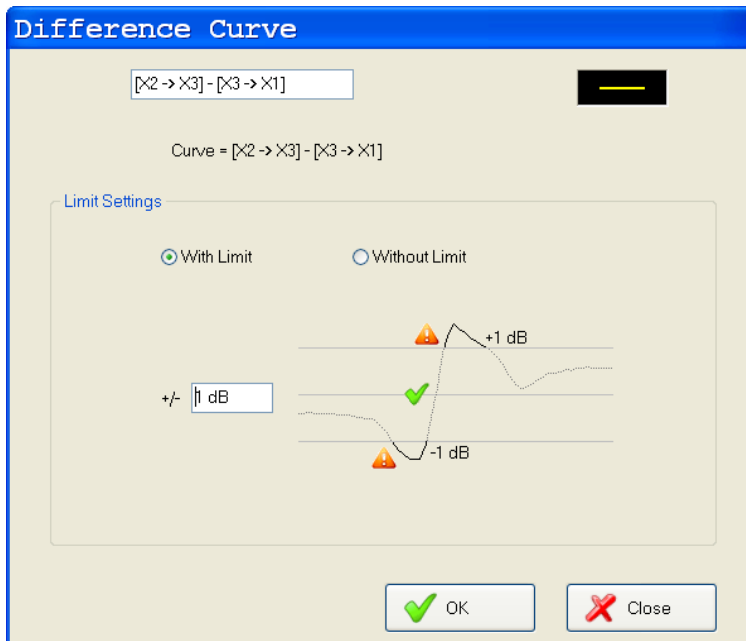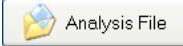
If the difference curve out of the Pass band – the curve will be displayed in the selected colour as solid line. So the really significant discrepancies of the two curves can be highlighted.
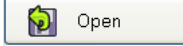
9.5.10 Analysis File Manager

There are two base files accessible – a "Measurement" file and a "Analysis" file. If the user toggles between the "Analysis" and the "Measuring" mode – also the File Manger will be linked to the corresponding "Measurement" or "Analysis" file. The active filename and type is always shown in the top bar.

Click [Analysis File] to launch a pop-up box with several file handling functions. This button is always shown throughout the program.

The functions of the individual elements of the file Manger for an active "Analysis file" are :

New	A new empty file will be created . The name of the file will be asked at the first saving operation. All further analysed data will be stored in this file.
Open	Starts the "Open File" dialog where the user can load an existing file to continue. All further analysed data will be stored in this file.
Save	Saves the actual analysis file. All further analysed data will be stored in this file.
Save as	Saves the actual test file under a selectable filename. All further analysed data will be stored in this file.
Report	Opens the "Generate Report" dialogue where the analysis can be selected for reporting. See "Reporting" for details.
	Filtering and/or smoothing function will be considered in the report. i.e. the curves will be filtered and/or smoothed if filtering and/or smoothing are active.
Export to CSV	A copy of the actual loaded analysis file with all its containing measurement curves is saved as a CSV file (Comma Separated Values) under "Filename_YYMMDD-hhmmss.csv" in a selectable folder. This format allows easy import of data into other applications like Microsoft Excel.
	Filtering and/or smoothing function will be considered in the CSV file. i.e. the data will be filtered and/or smoothed if filtering and/or smoothing are active.

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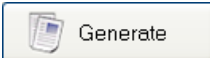
9.5.11 Reporting

After clicking [Report] in the Analysis File Manager, the following dialogue pops up:

The user has to define what shall be reported and how the final report shall look like.

☑ Magnitude	The Analysis view "Magnitude" diagram will be printed in the report
☑ Phase	The Analysis view "Phase" diagram will be printed in the report
☑ Impedance	The Analysis view "Impedance" diagram printed in the report
☑ Admittance	The Analysis view "Admittance" diagram printed in the report
☑ 1 / Magnitude (Ratio)	The Analysis view "1/Magnitude (Ratio)" diagram will printed in the report
☑ Comment	The Analysis view "Comment" text paragraph will be printed in the report as well
☑ Curve Title	A title line for each single curve will be printed in the report as well
☑ Nameplate (DUT) Information	The detailed Nameplate information of each single measurement curve(s) will be printed in the report as well.
☑ Measurement Setups	The setups of each single measurement curve(s) will be printed in the report as well. (A short form of the setups is always printed with the diagram itself.)
☑ Source Curve Infomation (Difference, Coherence)	The source curves' name of a difference or coherence curve will be printed in the report as well.
Report File Type ○XML ⊙HTML	Select the analysis report file data format as XML or HTML
Image File Format ○.bmp ○.gif ○.jpg ⊙.wmf	Select the image file type used in the report file. The user can select the file types `.bmp`, `.gif`, `.jpg` and `.wmf`. Use `.wmf` for best resolution and `.gif` for smallest file size.

By clicking [Generate] button, the report will be created and displayed in "Microsoft Internet Explorer". From there it can be printed onto a PDF file or to a connected (USB) printer.

The report file itself will be saved in its corresponding directory. See chapter "Directory Structure/Data".

9.6 Data Types

Measurement files

The used data format of measurement is binary with extension file name ".hfm" (Haefely Fra Measurement). All raw data are stored in this format.

Analysis files

The used file format of analysis is binary with extension file name ".hfa" (Haefely Fra Analysis). All analysis information are stored in this format.

Report files

The report file data format can be selected in the options as XML(E**x**tended **M**ark up **L**anguage) or HTML (**H**yper**t**ext **M**ark up **L**anguage)

For best printout resolution save the report as HTML and open the report then in the Microsoft Word and print it from there. (The Explorer prints also .wmf pictures as bitmaps with low resolution, while the Microsoft Word can handle the higher resolution of the .wmf pictures).

The layout of the report can be customized.
The top logo can be changed by replacing the file "`Logo.gif`" by the user's own logo.
The appearance of the report can be edited by changing the style-sheet files "`MeasurementRep.xsl`" and "`AnalysisRep.xsl`".

For further information about the XML/XSL language please refer to the appropriate technical literature or the internet www.w3.org.

9.6.1 IEC60076-18 XML file format

Tettex instruments has followed the recommendation of the IEC60076-18 standard and has implemented the recommended file format in the Tettex FRA5310 making it possible to export or import test results.

To save data in an XML file, in measuring window, select "export and then IEC XML file type."

To read data from an XML file, in the analysis window select Add, and then IEC XML file
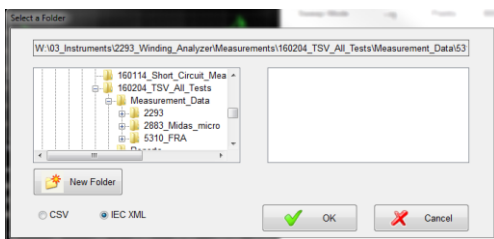
Save data as IEC60076-18 XML file
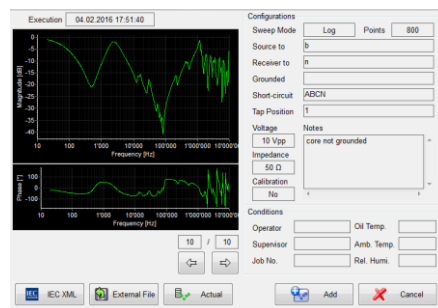
Read data from an XML file

With this feature, loading test results done with other manufacturer's measuring devices is now possible, as long as the manufacturer of that device has fulfilled the requirements of the IEC60076-18 -appendix E file format. In addition, a test done with the Tettex FRA 5310 could also be loaded by any other device capable of reading this file format.

```xml
<?xml version="1.0" encoding="UTF-8"?>
- <IECFraFile Version="1.0">
  - <Transformer identifier="">
      <Manufacturer/>
      <SerialNumber/>
      <Date>2016-02-04</Date>
      <Time>16h54</Time>
    </Transformer>
  - <MeasurementSetup>
      <MeasuringEquipment serial="180002" instrument="FRA5310" manufacturer="HAEFELY"/>
      <PeakVoltage unit="V">10</PeakVoltage>
      <ReferenceTerminal>A</ReferenceTerminal>
      <ResponseTerminal>N</ResponseTerminal>
      <ConnectedTerminals>abcn</ConnectedTerminals>
      <EarthedTerminals/>
      <OLTC from="??">1</OLTC>
      <DETC>1</DETC>
      <TransformerTemperature unit="°C">INF</TransformerTemperature>
      <Fluidfilled>??</Fluidfilled>
      <LengthOfUnshieldedConnection unit="mm">200</LengthOfUnshieldedConnection>
      <Comments/>
    </MeasurementSetup>
  - <MeasurementResult>
      <Point phase="-5.74135E+1" amplitude="-6.13528E+0" frequency="1.99676E+1"/>
      <Point phase="-5.76330E+1" amplitude="-6.21580E+0" frequency="2.02656E+1"/>
      <Point phase="-5.81442E+1" amplitude="-6.28949E+0" frequency="2.05636E+1"/>
      <Point phase="-5.86850E+1" amplitude="-6.37064E+0" frequency="2.08616E+1"/>
      <Point phase="-5.91446E+1" amplitude="-6.51130E+0" frequency="2.13087E+1"/>
      <Point phase="-5.94433E+1" amplitude="-6.65306E+0" frequency="2.16067E+1"/>
      <Point phase="-5.96896E+1" amplitude="-6.72456E+0" frequency="2.20537E+1"/>
      <Point phase="-6.02039E+1" amplitude="-6.79527E+0" frequency="2.23517E+1"/>
      <Point phase="-6.07351E+1" amplitude="-6.94231E+0" frequency="2.27988E+1"/>
      <Point phase="-6.11133E+1" amplitude="-7.07958E+0" frequency="2.30968E+1"/>
      <Point phase="-6.16882E+1" amplitude="-7.14547E+0" frequency="2.35438E+1"/>
      <Point phase="-6.22842E+1" amplitude="-7.25969E+0" frequency="2.38419E+1"/>
```
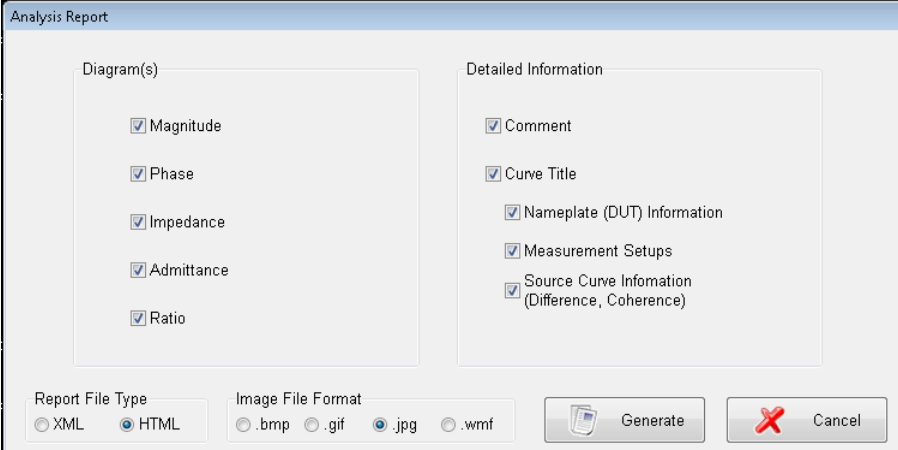
XML file fformat example

9.7 Directory Structure

Executable

The directory `C:\Program Files\HTAG\FRA5310\..` contains the following files:

FRA5310.exe	Instrument operation software
Logo.gif	The used logo on the top of each report page
MeasurementRep.xsl	The style-sheet for a "Measurements" report (raw data)
AnalysisRep.xsl	The style-sheet for a "Analysis" report
Default.cfg	Default measurement settings
ExtTools.cfg	External tools definition
Inpout32.dll	Instrument hardware DLL
hs3.dll	Instrument hardware DLL
hs3f12.hex	Instrument hardware driver
hs3f14.hex	Instrument hardware driver
hs3f16.hex	Instrument hardware driver

The executable program can been started from the instrument desktop by double clicking the FRA 5310 icon.

Data

C:\Documents and Settings\Administrator\My Documents\HTAG\FRA5310\..
is the used data container and contains the following sub-directories:

Measurement	Data directory for the single "Measurement" files.
Analysis	Data directory for the single "Analysis" files.
Image	Directory for the created print-screens or graphical files
Report ↪Name1 ↪Name2	Top-directory for the created "Analysis" and "Measurement" Report files. When generating a report there will be a sub-directory named "ReportedFilename_Rep_YYMMDD-hhmmss" created automatically, which contains the report files (HTML or XML files and associated image files)

These directory paths are used as default for the data storage. These default data directories can be changed by the user when saving data. The last used path will be stored and used as the new default.

The data container is directly accessible from the desktop by double clicking the `FRA5310 Data` shortcut icon.

Make sure to update that shortcut as well when you would change the default directory paths.

10 Office Software

The external Office Software on the provided CD can be installed on a desktop PC or a laptop. Basically it's the same software that's running on the instrument.

When the software detects the office parameter in the execution path (`..\FRA5310.exe /office`) it boots in the office mode.

The measuring unit related functions are disabled but all other functionality is the same.

All files can be loaded, data can be compared, analysed and reports can be generated and printed.

Also the display can be maximised to use the full screen for data analysis and curve interpretation.

Click FRA 5310 icon on the desktop is to start the PC Analysis Software.

11 Miscellaneous

11.1 Care and Maintenance

The FRA 5310 instrument is basically service free, as long as the specified environmental conditions are adhered to. As a result, service and maintenance is restricted to cleaning of the equipment and calibration at intervals stipulated by the application for which the instrument is used.

The insulation of all cables should be periodically checked for damage. If any damage to the insulation is detected then a new measuring cable should be ordered from HAEFELY TEST AG.

Cleaning the Instrument

The instrument should be cleaned with a lint free cloth, slightly moistened using mild household cleanser, alcohol or spirits. Caustic cleansers and solvents (Trio, Chlorothene, etc.) should definitely be avoided.

In particular, the protective glass of the display should be cleaned from time to time with a soft, moist cloth such as used by opticians.

Instrument Calibration

When delivered new from the factory, the instrument is calibrated in accordance with the calibration report provided. A periodical calibration of the instrument every two years is recommended.

As the calibration process is fairly extensive, the instrument can only be calibrated and, if necessary, adjusted at HAEFELY TEST AG's factory. An updated calibration report will then be issued.

Changing Fuses

Before changing the mains fuse, remove the mains power cord. Fuses should only be replaced with the same type and value.

11.2 Instrument Storage

If the instrument is to remain unused for any length of time, it is recommended to unplug the mains lead. In addition, it is advisable to protect this high precision instrument from moisture and accumulation of dust and dirt with a suitable covering.

11.3 Packing and Transport

The packing of the FRA 5310 instrument provides satisfactory protection for normal transport conditions. Nevertheless, care should be taken when transporting the instrument. If return of the instrument is necessary, and the original packing crate is no longer available, then packing of an equivalent standard or better should be used.
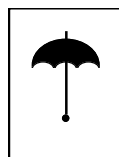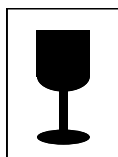
Whenever possible protect the instrument from mechanical damage during transport with padding. Mark the container with the pictogram symbols „Fragile" and „Protect from moisture".

11.4 Recycling

When the instrument reaches the end of its working life it can, if required, be disassembled and recycled. No special instructions are necessary for dismantling.

The instrument is constructed of metal parts (mostly aluminium) and synthetic materials. The various component parts can be separated and recycled, or disposed of in accordance with the associated local rules and regulations.

11.5 Customer Support

All error messages appear on the display of the FRA 5310 measuring instrument. If persistent problems or faulty operation should occur then please contact the Customer Support Department of HAEFELY TEST AG or your local agent.

The Customer Support Department can be reached at the following address:

HAEFELY TEST AG

Customer Service – Tettex
Birsstrasse 300
CH-4052 Basel
Switzerland

Tel:	+41 61 373 4422
Fax:	+41 61 373 4914
e-mail:	tettex-support@haefely.com

We prefer contact via email. Then the case is documented and traceable. Also the time zone problems and occupied telephones do not occur.

Remember: Complete information describing the problem clearly (printouts, software version, DUT type, Instrument serial number, etc.) helps us to help you faster.

11.6 Software Updates

Haefely Test AG runs a Update Homepage where owners of our test instruments can download the newest firmware, software, manuals, related information etc.

http://update.haefely.com/FRA5310

11.7 Conformity

HAEFELY TEST AG

Haefely Test AG
Lehenmattstrasse 353
4028 Basel
Switzerland

declare, under his own responsibility, that the product here mentioned, complies with the requirements of the listed standards or other normative documents.

So, the product complies with the requirements of the EMC directive 89/336/EEC, 92/31/EEC and 93/68/EEC and the low voltage directive 73/23/EEC and 93/68/EEC.

Product: **Frequency Response Analyser FRA 5310**

Description: The Frequency Response Analyser FRA 5310 is used to measure and
                   evaluate frequency responses (transfer functions) to detect defects and
                   displacements in transformer windings.

Standards: EN 50081-1   Jan.   1992
                   EN 50081-2   Aug.   1993
                   EN 50082-1   Jan.   1992
                   EN 50082-2   Mar.   1995

R. Mäder
Quality Department Manager
Haefely Test AG
4028 Basel
Switzerland

Basel, September 26, 2005

....
(Signature)

HAEFELY HIGH VOLTAGE TEST   **Tettex** INSTRUMENTS   **HAEFELY** TECHNOLOGY

Haefely Test AG, Lehenmattstrasse 353, CH-4052 Basel/Switzerland
www.haefely.com

12 Appendix

12.1 Interpretation

This chapter contains information regarding interpretation of the frequency response curves.

12.1.1 General

For interpretation of curve behaviour (changes in amplitude, resonance peaks, overall appearance, etc) we refer also to the CIGRE WG A2.26 paper (Frequency Response Analysis for detecting transformer winding movements). That paper shall become the guidance document for the industry to interpret FRA measurements.

12.1.2 Introduction

The power transformer equivalent circuit is a complex network of distributed resistive, capacitive and inductive elements including :

Capacitance between the neighbouring turns of the same winding, between the turns of different windings and between the turns. and the ground.

Turns self-inductance and turns mutual inductance.

Conductor dc resistance, resistance that accounts for dielectric losses in insulation and resistance that accounts for eddy losses in conducting and magnetic components.

Depending on the test connection, the equivalent circuit involved in the measurement represents an individual phase of the winding, the space between phases in a given winding or the space between the windings. Size of the conductors, diameters of the coils, distance between the coils, distance between the windings, number of turns, type of the core, winding configuration, type and thickness of insulation, geometry and size of supporting material are among the factors that define the elements of the equivalent circuit.
Furthermore, each element is specific to the transformer design and even influenced by the ability of the manufacturer to replicate the transformers of the same design. Therefore, there is a direct relationship between the geometry of core-winding configuration and the network of distributed resistive, capacitive and inductive elements.

The signature that represents the change of the network impedance with frequency uniquely describes the geometry of the core-winding configuration for a given transformer.
The ratio of the output and input signals (network impedance), is often referred to as the transfer function.
The frequency response analysis uses the transfer function behaviour over the specified range of frequencies as the transformer diagnostic signature (fingerprint). The transfer function is described by the magnitude and the phase angle.

Interpretation of frequency ranges are discussed on two basic measuring circuits:
Open Circuit Measurement and Short Circuit Measurement.

Open Circuit Measurement

The open circuit measurement targets the individual phase of a given winding. At low frequencies, the influence of capacitance is negligible and the winding behaves as an inductor. Therefore, the attenuation (described by the magnitude of the transfer function) and the phase shift (described by the phase of the transfer function) of the low-frequency sinusoidal signals, passing through the winding, are determined by inductive and resistive nature of the network.

The magnetic circuit of the core determines the inductive characteristics and the resistive characteristics are dominated by the resistance of the winding and the receiver impedance.
An example of transfer function magnitude and phase for a open circuit (3 phase) measurement is

shown in Magnitude plot and Phase plot.
In Phase plot the phase angle goes down to -60 degrees, indicating the resistive part moving towards the inductive nature of the total impedance (in the region up to 500kHz).

For a three-legged core-type unit, the magnetic flux coupled with the outer phase faces a different reluctance than the flux coupled with the middle phase. Therefore, the corresponding magnitude traces, in the low frequency range, differ as well. The traces for the two outer phases correlate very closely and are shifted from the middle-phase trace.

The presence of the residual magnetism may also have an effect on relationship between the traces. This is the same phenomenon that, during exciting current and loss measurement, creates a pattern of two high similar and one lower reading under normal conditions and a slightly distorted pattern in the presence of residual magnetism.
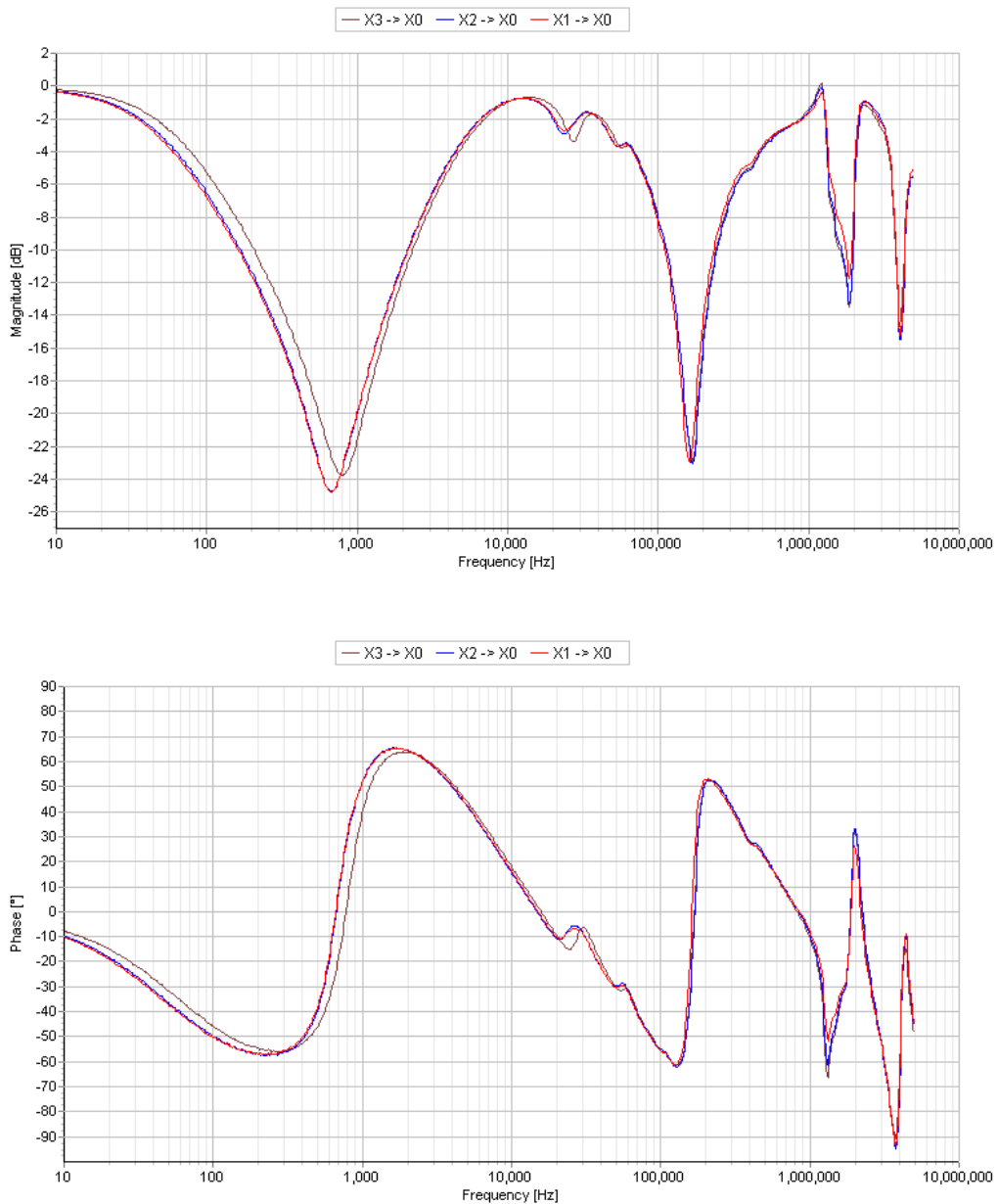
As the frequency of the input signal increases, the capacitive effects begin to dominate and the phase angle quickly goes towards +90 degrees (in the region above 1kHz).

Now, the attenuation and the phase shift of the high-frequency sinusoidal signals, passing through the winding, are determined by inductive and capacitive nature of the network. However, in high-frequency region, the inductive characteristics are determined by the leakage flux coupling and the capacitive characteristics are determined by the various capacitance elements associated with individual turns.

The propagation characteristic of the winding becomes complex as a result of the many resonance frequencies (shown with magnitude poles / phase zero crossings) found in the higher-frequency range. However, since the winding responses become fewer dependants on the magnetic circuit of the core, the traces of the three phases converge and become quite similar.

As the frequency increases even further (over 100kHz in Phase plot), the sinusoidal signals travel mostly outside the winding and reflect the other elements found in the transformer, e.g., leads, support insulation, etc. The magnitude and the phase of the transfer function in that frequency region are influenced by the inductive-capacitive-resistive nature of these elements.

Although most of the low-frequency magnitude responses exhibit a typical shape, there are no typical form responses in the high-frequency region. These vary greatly with design of the unit. Therefore, the frequency ranges noted in description of Magnitude plot and Phase plot, are different for different units.

Short Circuit Measurement

The aim of this measurement is to allow direct comparison between the three phases of a three phase transformer where no prior measurements exist.

The theory behind the short-circuit measurement is straightforward. A two winding transformer may be modelled at low frequencies by a simple T -model, as shown below.
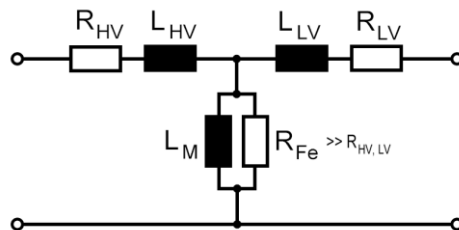
The impedance of the windings ($R_{\#V}$, $L_{\#V}$) is small, while the impedance of the core (R_{Fe}, L_M) to ground is extremely high. This means that for any input signal, the response is dominated by the core.
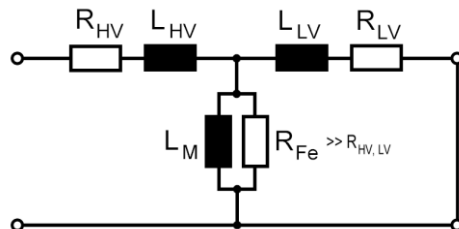
By shorting the LV side, the effect of the core is removed and the response is dominated by the windings, which are predominantly inductors at low frequency. The response of an inductor is to have a low dB response at low frequency with an inductive roll off as frequency rises.

By making a measurement on one winding with another winding short circuited, the effect of the core at low frequencies is removed. The resulting response is that for a large inductor without a core.

All three phases of a transformer have normally similar winding inductances, which means their responses should be very similar at lower frequencies.

12.1.3 Analysis of Measurements

Initial Measurement

Present state of the art is such that analysis of FRA data is based only on a subjective comparison of traces. For the initial measurement, the traces are analysed for changes between responses of the three phases of the same transformer and changes between responses of transformers of the same design. For the single-phase unit, only the later comparison is applicable.

The appearance of new features or major resonance frequency shifts is a cause for concern.

When tapped windings are involved, it is useful to perform measurements on at least two tap positions, to assess whether differences in the trace originate from the tapped or untapped sections of the winding.

When interpreting differences observed between phases, keep in mind that for many windings there may be minor design differences associated with the disposition of internal connections between windings, bushings and tap-changers. These differences could introduce small differences between

phases in the frequency response. Therefore, for the initial measurement, if minor differences between phases are observed, it is not possible to make an unambiguous conclusion about the presence of winding deformation. Fortunately, responses obtained for units of the same design can often serve as a reference data for each other.

Short circuit measurements allow for direct phase-to-phase comparison of a three-phase transformer.

Repeated Measurement

For the repeated measurement, the traces are analysed for changes between the initial and repeated response. Considerations described for the initial measurement apply here as well. Any variation in response between an initial measurement and a repeated measurement must be treated with caution.

Low frequency variations usually relate to core effects, including residual magnetism, which may provide variation between responses. Higher frequencies, above 1MHz, may can be affected by grounding quality; this must be considered as a cause of variation and care must be taken for proper grounding.

Other Diagnostic Measurements

Understanding the significance of each measurement and knowing its conclusion respectively its associated failure modes is essential for a successful diagnostics. No single method can cover the multiplicity of problems occurring in transformers.
Some other diagnostics than can give additional information about the transformer condition are:

Leakage reactance and loss

Exciting Current and Loss

DGA

Capacitance and power factor/ dissipation factor (tan δ)

Winding resistance

Partial discharge

12.1.4 Analysis Zones

Based on the literature the following rough classification of FRA analysis zones (frequency ranges) can be made:

Frequency range	10Hz .. 30kHz	30kHz .. 200kHz	200kHz .. 500kHz	> 500 kHz
Failures	Core deformation, open-circuit windings, shorted turns, residual magnetism	Localized deformation within winding structure	General deformation within winding structure	General loss of clamping pressure, movement of tap winding leads
Origin	Core and magnetic circuit	Winding geometry	Winding geometry	Inter-connections and test system

12.2 Test Setups

The practical realization of transformer test set-ups is free. Common set-ups use either a current, a transferred voltage or both as system responses. Each response signal has its own sensitivity to possible mechanical displacements inside the transformer.
There is not yet a standard recommendation for the test set-ups. The most common and most useful variety for time domain measurements is a combination of transferred voltages and currents.
In general three different configurations can be measured: High voltage winding(s) to its neutral, Low voltage winding(s) to its neutral and Inter winding.

Find here a set of "established" test templates which can be used as a connection proposal. These templates do not indicate tap changer positions.

Basically the nominal tap position shall be measured. Additionally also the extreme position should be measured when time is available or at factory tests (initial fingerprint).

As basic tests the Open- and Short Circuit Measurements shall be done. Additionally also the Inter-Winding measurements should be done when time is available or at factory tests (initial fingerprint).

12.2.1 Single Phase Transformers

Single phase

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	H2	none	none
Open Circuit	X1	X2	none	none
Short Circuit	H1	H2	X1-X2	none
Inter-Winding	H1	X1	none	see page 8

Single phase, Autotransformer

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	X1	none	none
Open Circuit	X1	N	none	none
Short Circuit	H1	H0X0	X1-H0X0	none

Single phase, Autotransformer with tertiary

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	X1	none	none
Open Circuit	X1	N	none	none
Open Circuit	Y1	Y2	none	none
Short Circuit	H1	H0X0	X1- H0X0	none
Short Circuit	H1	H0X0	Y1-Y2	none
Short Circuit	X1	H0X0	Y1-Y2	none
Inter-Winding	H1	Y1	none	see page 8
Inter-Winding	X1	Y1	none	see page 8

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12.2.2 Three Phase Transformers

Three phase, Dy

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	H2	none	none
Open Circuit	H2	H3	none	none
Open Circuit	H3	H1	none	none
Open Circuit	X0	X1	none	none
Open Circuit	X0	X2	none	none
Open Circuit	X0	X3	none	none
Short Circuit	H1	H2	X1-X2-X3	none
Short Circuit	H2	H3	X1-X2-X3	none
Short Circuit	H3	H1	X1-X2-X3	none
Inter-Winding	H1	X1	none	see page 8
Inter-Winding	H2	X2	none	see page 8
Inter-Winding	H3	X3	none	see page 8

Three phase, Dd

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	H2	none	none
Open Circuit	H2	H3	none	none
Open Circuit	H3	H1	none	none
Open Circuit	X1	X2	none	none
Open Circuit	X2	X3	none	none
Open Circuit	X3	X1	none	none
Short Circuit	H1	H2	X1-X2-X3	none
Short Circuit	H2	H3	X1-X2-X3	none
Short Circuit	H3	H1	X1-X2-X3	none
Inter-Winding	H1	X1	none	see page 8
Inter-Winding	H2	X2	none	see page 8
Inter-Winding	H3	X3	none	see page 8

Three phase, Yd

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H0	H1	none	none
Open Circuit	H0	H2	none	none
Open Circuit	H0	H3	none	none
Open Circuit	X1	X2	none	none
Open Circuit	X2	X3	none	none
Open Circuit	X3	X1	none	none
Short Circuit	H0	H1	X1-X2-X3	none
Short Circuit	H0	H2	X1-X2-X3	none
Short Circuit	H0	H3	X1-X2-X3	none
Inter-Winding	H1	X1	none	see page 8
Inter-Winding	H2	X2	none	see page 8
Inter-Winding	H3	X3	none	see page 8

Three phase, Yy

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H0	H1	none	none
Open Circuit	H0	H2	none	none
Open Circuit	H0	H3	none	none
Open Circuit	X0	X1	none	none
Open Circuit	X0	X2	none	none
Open Circuit	X0	X3	none	none
Short Circuit	H0	H1	X1-X2-X3	none
Short Circuit	H0	H2	X1-X2-X3	none
Short Circuit	H0	H3	X1-X2-X3	none
Inter-Winding	H1	X1	none	see page 8
Inter-Winding	H2	X2	none	see page 8
Inter-Winding	H3	X3	none	see page 8

Tettex

Three phase, Autotransformer

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	X1	none	none
Open Circuit	H2	X2	none	none
Open Circuit	H3	X3	none	none
Open Circuit	H0X0	X1	none	none
Open Circuit	H0X0	X2	none	none
Open Circuit	H0X0	X3	none	none
Short Circuit	H0X0	H1	X1-X2-X3	none
Short Circuit	H0X0	H2	X1-X2-X3	none
Short Circuit	H0X0	H3	X1-X2-X3	none

Three phase, Autotransformer with tertiary

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	X1	none	none
Open Circuit	H2	X2	none	none
Open Circuit	H3	X3	none	none
Open Circuit	H0X0	X1	none	none
Open Circuit	H0X0	X2	none	none
Open Circuit	H0X0	X3	none	none
Open Circuit	Y1	Y3	none	none
Open Circuit	Y2	Y1	none	none
Open Circuit	Y3	Y2	none	none
Short Circuit	H0 X0	H1	X1-X2-X3	none
Short Circuit	H0 X0	H2	X1-X2-X3	none
Short Circuit	H0 X0	H3	X1-X2-X3	none
Short Circuit	H0 X0	H1	Y1-Y2-Y3	none
Short Circuit	H0 X0	H2	Y1-Y2-Y3	none
Short Circuit	H0 X0	H3	Y1-Y2-Y3	none
Short Circuit	H0 X0	X1	Y1-Y2-Y3	none
Short Circuit	H0 X0	X2	Y1-Y2-Y3	none
Short Circuit	H0 X0	X3	Y1-Y2-Y3	none
Inter-Winding	H1	Y1	none	see page 8
Inter-Winding	H2	Y2	none	see page 8
Inter-Winding	H3	Y3	none	see page 8
Inter-Winding	X1	Y1	none	see page 8
Inter-Winding	X2	Y2	none	see page 8
Inter-Winding	X3	Y3	none	see page 8

Three phase, Ydd

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	H0	none	none
Open Circuit	H2	H0	none	none
Open Circuit	H3	H0	none	none
Open Circuit	X3	X1	none	none
Open Circuit	X1	X2	none	none
Open Circuit	X2	X3	none	none
Open Circuit	Y1	Y3	none	none
Open Circuit	Y2	Y1	none	none
Open Circuit	Y3	Y2	none	none
Short Circuit	H1	H0	X1-X2-X3	none
Short Circuit	H2	H0	X1-X2-X3	none
Short Circuit	H3	H0	X1-X2-X3	none
Short Circuit	H1	H0	Y1-Y2-Y3	none
Short Circuit	H2	H0	Y1-Y2-Y3	none
Short Circuit	H3	H0	Y1-Y2-Y3	none
Short Circuit	X3	X1	Y1-Y2-Y3	none
Short Circuit	X1	X2	Y1-Y2-Y3	none
Short Circuit	X2	X3	Y1-Y2-Y3	none
Inter-Winding	H1	X1	none	see page 8
Inter-Winding	H2	X2	none	see page 8
Inter-Winding	H3	X3	none	see page 8
Inter-Winding	H1	Y1	none	see page 8
Inter-Winding	H2	Y2	none	see page 8
Inter-Winding	H3	Y3	none	see page 8
Inter-Winding	X1	Y1	none	see page 8
Inter-Winding	X2	Y2	none	see page 8
Inter-Winding	X3	Y3	none	see page 8

Tettex

Three phase, Dyy

Measurement	Source (yellow) to	Receiver (blue) to	Shorted together	Grounded
Open Circuit	H1	H2	none	none
Open Circuit	H2	H3	none	none
Open Circuit	H3	H1	none	none
Open Circuit	X0	X1	none	none
Open Circuit	X0	X2	none	none
Open Circuit	X0	X3	none	none
Open Circuit	Y0	Y1	none	none
Open Circuit	Y0	Y2	none	none
Open Circuit	Y0	Y3	none	none
Short Circuit	H1	H2	X1-X2-X3	none
Short Circuit	H2	H3	X1-X2-X3	none
Short Circuit	H3	H1	X1-X2-X3	none
Short Circuit	H1	H2	Y1-Y2-Y3	none
Short Circuit	H2	H3	Y1-Y2-Y3	none
Short Circuit	H3	H1	Y1-Y2-Y3	none
Short Circuit	X0	X1	Y1-Y2-Y3	none
Short Circuit	X0	X2	Y1-Y2-Y3	none
Short Circuit	X0	X3	Y1-Y2-Y3	none
Inter-Winding	H1	X1	none	see page 8
Inter-Winding	H2	X2	none	see page 8
Inter-Winding	H3	X3	none	see page 8
Inter-Winding	H1	Y1	none	see page 8
Inter-Winding	H2	Y2	none	see page 8
Inter-Winding	H3	Y3	none	see page 8
Inter-Winding	X1	Y1	none	see page 8
Inter-Winding	X2	Y2	none	see page 8
Inter-Winding	X3	Y3	none	see page 8