

Sweep Frequency Response Analyzer (SFRA) User Guide



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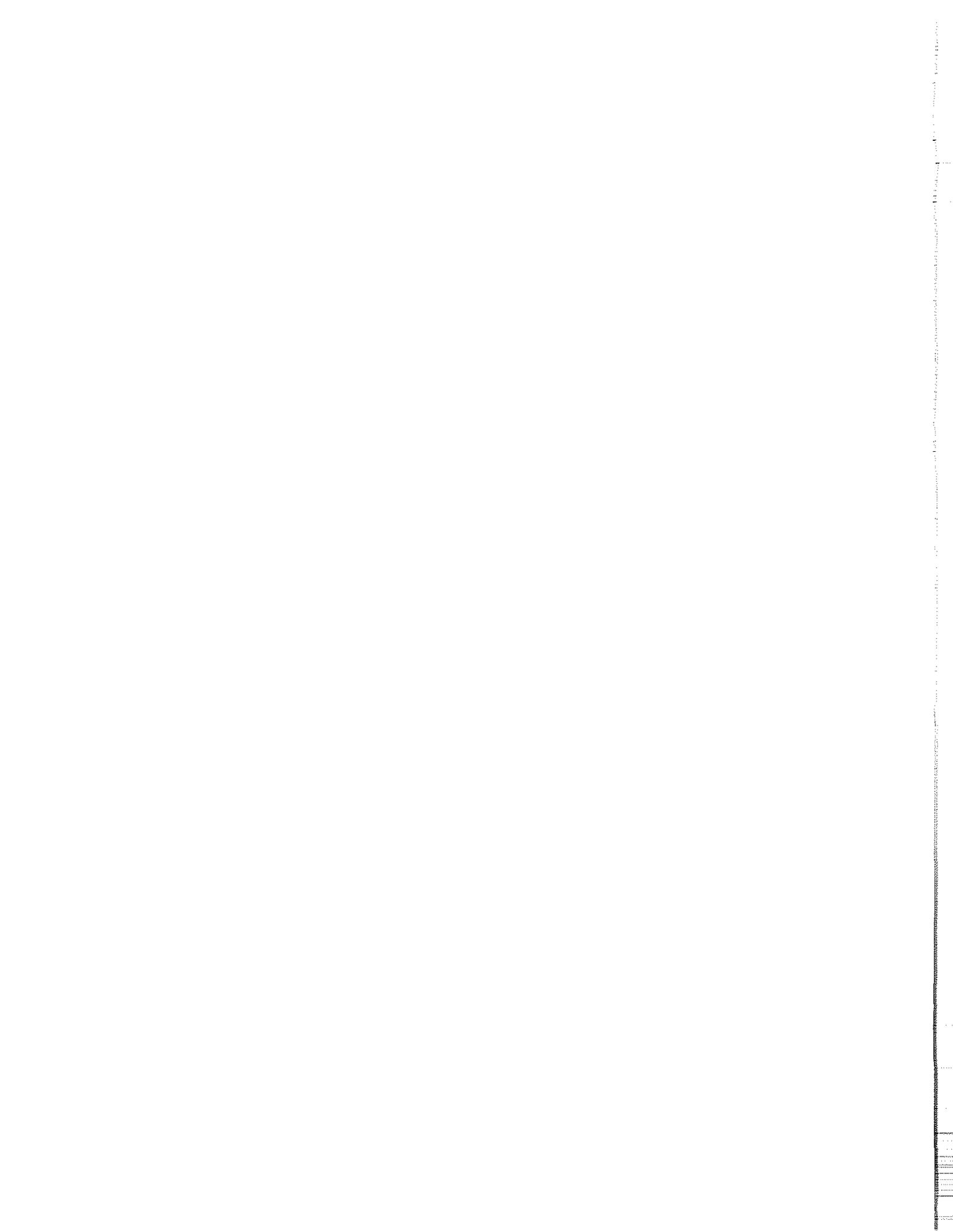
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1. Introduction

The M5200 (Figure 1.1), M5300 (Figure 1.2), and M5400 (Figure 1.3) Sweep Frequency Response Analyzers measure and record the frequency-response characteristics of transformer windings. They accomplish this using a rugged field instrumentation/ controller module, an excitation source, and a measurement module, packaged in a robust molded shell.

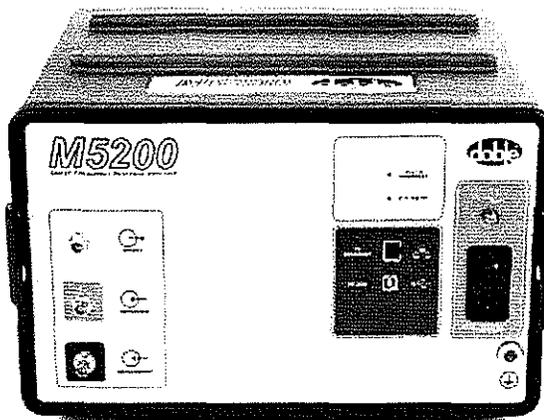


Figure 1.1 M5200 SFRA

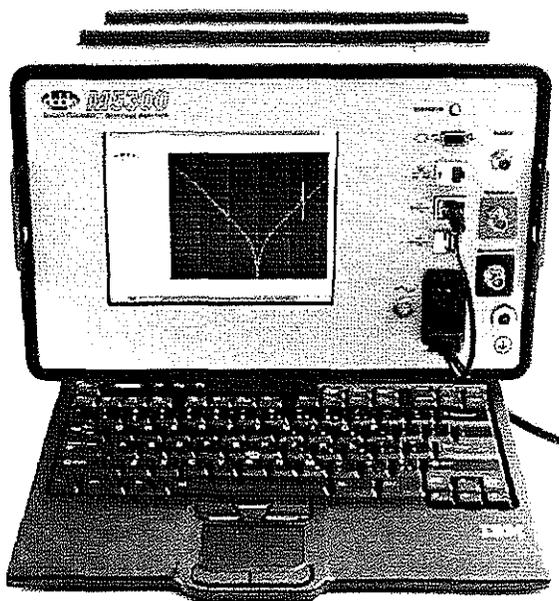


Figure 1.2 M5300 SFRA

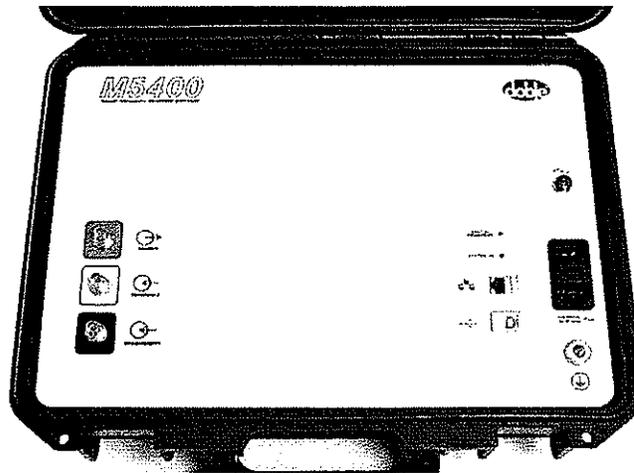


Figure 1.3 M5400 SFRA

Sweep Frequency Response Analysis (SFRA) testing has become a valuable tool for verifying the geometric integrity of electrical apparatus, especially transformers. SFRA provides internal diagnostic information using nonintrusive procedures (Figure 1.4). The SFRA test method has been proven to provide accurate and repeatable measurements, with Doble furnishing the support to extract value from the measurements.

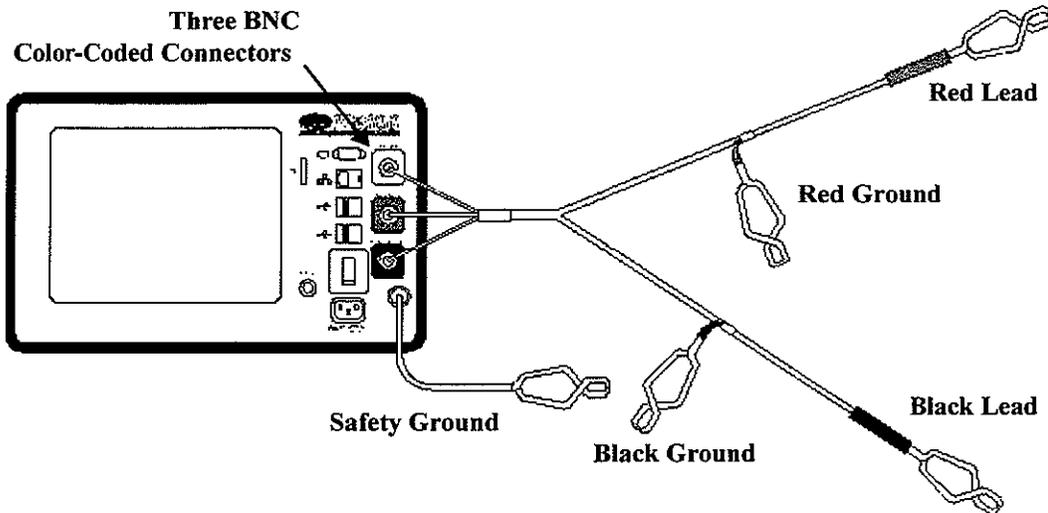


Figure 1.4 M5300 Connections (M5200 and M5400 Similar)

Power transformers are specified to withstand the mechanical forces arising from both shipping and subsequent in-service events, such as faults and lightning. Transportation damage can occur if the clamping and restraints are inadequate; such damage may lead to core and winding movement. The most severe in-service forces arise from system faults and are axial and radial in nature. If the forces are excessive, radial buckling or axial deformation can occur. With a core form design, the principal forces are radially directed, whereas in a

shell-form unit, they are axially directed. This difference is likely to influence the types of damage found.

Once a transformer is damaged, even if only slightly, its ability to withstand further short circuits is reduced. Utility personnel need to effectively identify such damage. A visual inspection is costly and does not always produce the desired results or the correct conclusion. During a field inspection, the oil has to be drained, and confined-entry rules apply. Since so little of the winding is visible, little damage can be seen, other than displaced support blocks. Often, a complete teardown is required to identify the problem. An alternative method is to implement field-diagnostic techniques capable of detecting damage.

There is a direct relationship between the geometric configuration and the distributed electrical elements, otherwise known as RLC networks, of a winding and core assembly. This RLC network can be identified by its frequency-dependent transfer function. Frequency Response Analysis testing can be accomplished by the sweep frequency method. Changes in the geometric configuration alter the impedance network, and in turn alter the transfer function. Changes in the transfer function reveal a wide range of failure modes.

Theory

The primary objective of SFRA is to determine how the impedance of a test specimen behaves over a specified range of frequencies. The impedance is a distributive network of real and reactive electrical components. The components are passive and can be modeled by resistors, inductors, and capacitors. The reactive properties of a given test specimen depend on, and are sensitive to, changes in frequency. The change in impedance versus frequency can be dramatic in many cases. This behavior becomes apparent when we model impedance as a function of frequency. The result is a transfer function representation of the RLC network in the frequency domain.

Frequency response analysis is generally applied to a complex network of passive elements. For practical purposes, we will consider only resistors, inductors, and capacitors as passive circuit elements, and they are assumed to be ideal. These three fundamental elements are the building blocks for various physical devices, such as transformers, motors, generators, and other electrical apparatus.

It is important to understand the difference between the physical device and the mathematical model we intend to use. When large and complex systems are electrically analyzed, we are often faced with a poorly defined distributed network. A distributed network contains an infinite number of infinitely small RLC elements. For example, transmission lines are generally distributed in nature.

It is practical to model such distributed systems by lumping the basic RLC components together, resulting in a lumped network. Lumping elements together for a single frequency is a trivial task, but when system modeling requires spanning a significant frequency interval, producing a suitable lumped model becomes difficult.

When a transformer is subject to SFRA testing, the leads are configured to use four terminals. These four terminals can be divided into two unique pairs—one pair each for the input and output. These terminals can be modeled in a two-terminal pair or a two-port network configuration (Figure 1.5).

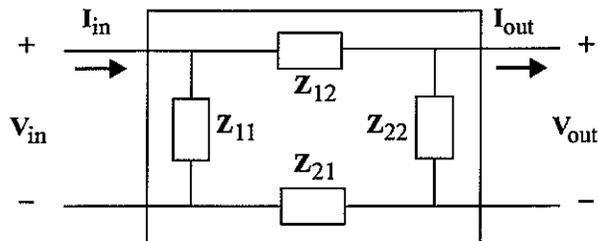


Figure 1.5 Two-Port Network

Solving for the open-circuit impedance for each lumped element forms the impedances Z_{11} , Z_{22} , Z_{12} , and Z_{21} . It should be noted that the negative terminals are short-circuited when transformers are tested. The transformer tank is common for both negative and lower terminals. The transformer tank and lead ground shields must be connected together to achieve a common-mode measurement. This assures that no external impedance is measured. Applying the connection in this manner helps reduce the effects of noise. It is important to obtain a zero impedance between the lower or negative terminals to assure a repeatable measurement.

The transfer function of an RLC network is the ratio of the output and input frequency responses when the initial conditions of the network are zero. Both magnitude and phase relationships can be extracted from the transfer function. The transfer function helps us better understand the input/output relationship of a linear network. The transfer function also represents the fundamental characteristics of a network and is a useful tool in modeling such a system.

The transfer function is represented in the frequency domain and is denoted by the Fourier variable $H(j\omega)$, where $(j\omega)$ denotes the presence of a frequency-dependent function, and $\omega = 2\pi f$. The Fourier relationship for the input/output transfer function is given by:

$$H(j\omega) = \frac{V_{output}(j\omega)}{V_{input}(j\omega)}$$

When a transfer function is reduced to its simplest form, it generates a ratio of two polynomials. The main characteristics, such as half-power and resonance, of a transfer function occur at the roots of the polynomials.

The goal of SFRA is to measure the impedance model of the test specimen. When we measure the transfer function $H(j\omega)$, it does not isolate the true specimen impedance $Z(j\omega)$. The true specimen impedance $Z(j\omega)$ is the RLC network, which is positioned between the instrument leads, and it does not include any impedance supplied by the test instrument.

It must be noted that when using the voltage relationship, $H(j\omega)$ is not always directly related to $Z(j\omega)$. For $Z(j\omega)$ to be directly related to $H(j\omega)$, a current must be substituted for the output voltage and then Ohm's Law can be realized. However, SFRA uses the voltage-ratio relationship to determine $H(j\omega)$. Since SFRA uses a 50-ohm impedance-match measuring system, the 50-ohm impedance must be incorporated into $H(j\omega)$. The next equation shows the relationship of $Z(j\omega)$ to $H(j\omega)$:

$$H(j\omega) = \frac{50}{Z(j\omega) + 50}$$

It is often useful to plot the magnitude and phase relationship of the transfer function in logarithmic format. The units of magnitude and phase are in decibels (dB) and degrees, respectively. Magnitude and phase are represented as follows:

$$A(\text{dB}) = 20 \log_{10}(H(j\omega))$$

$$A(\theta) = \tan^{-1}(H(j\omega))$$

This format takes advantage of the asymptotic symmetry by using a logarithmic scale for frequency. Plotting the phase relationship with the magnitude data helps determine whether the system is resistive, inductive, or capacitive. It is often useful to compare resonance in the magnitude plots with the zero crossings in the phase relationship.

Accessories

Test Cables

The cables and connectors supplied with the M5000 instruments are made from low-loss RG-58 RF coaxial cable, with the shields grounded to the instrument chassis through a standard connector. The instrument requires a matched impedance signal cable and performs a single-end measurement—that is, the signal is measured with respect to the instrument ground. The shield of the signal cable must be connected to the chassis using a 50-ohm impedance-matched RF BCN connector. The test leads should not be modified in any manner.

Practical field experience indicates that the leads be 60 ft / 18 m. This is the shortest length useful to test the largest transformers from a location on the ground, adjacent to the unit. Nevertheless, lead length determines the maximum effective frequency.

The standard cable shield grounds connect the cable shields to the transformer ground at the base of the bushing. These ground connections are 12 ft / 3.6 m back from the terminal connection, on the measurement ends of the cables. If this is not enough to reach from the bushing terminal to the base of the bushing, a 100 foot / 30 m cable is available, with ground connections 18 ft / 5.4 m back from the terminal connection (Table 1.1).

NOTE



The longer cable should be purchased only as an accessory and should not be used in place of the standard cable if the standard cable can be applied. The decision on which cable to use should consider only bushing height, and the cable should be consistent from test to test.

Table 1.1 SFRA Test Cables

	Standard	Optional
Length	60 ft / 18 m	100 ft / 30 m
Trunk	50 / 50 (30 ft / 9 m)	45 / 55 (55 ft / 16.5 m)
Ground	80 / 20 (12 ft / 3.6 m)	82 / 18 (18 ft / 5.4 m)
Application	≤ 362 kV	> 362 kV

Large Cable Clamps

These clamps connect to larger bushing studs or terminals where the normal connectors do not fit. The standard test cables then clip to the large clamps.

Instrument Safety/Chassis Ground

Grounding of signal cable shields, specimen, and instrument chassis is important to achieving a reproducible result. The safety ground (Figure 1.6), also known as the instrument-chassis ground, connects the instrument chassis to the transformer ground.

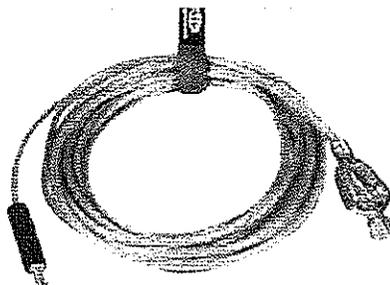


Figure 1.6 Safety Ground

Software

The M5200 and M5400 are controlled by a user-supplied laptop computer running Doble SFRA software (supplied with the instrument). The M5300 comes with a built-in PC, laptop keyboard, and preinstalled Doble SFRA software. Doble SFRA software is discussed in Chapter 2.

Safety and Personnel

Safety cannot be overemphasized when working on or around high-voltage electrical apparatus. Companies that generate, transmit, distribute, or use high-voltage electricity should, and do, have precise rules for safe practices and procedures. These practices are important for personnel whose working responsibilities involve testing and maintaining high-voltage apparatus and its associated lines, cables, conductors, and accessories.

General Rules

1. The transformer under test should be completely de-energized and isolated from the power system before performing any tests using an M5000-series SFRA instrument.
2. The method of testing a high-voltage apparatus (transformer) involves exciting the apparatus with the SFRA instrument. Take care to avoid contact with the apparatus being tested, its associated bushings and conductors, and the SFRA instrument's cables and connectors.
3. The test crew must make a visual check to ensure that the apparatus terminals are isolated from the power system. Because the apparatus under test may fail, take precautions (such as barriers or entrance restrictions to the test area) to avoid harm in case of violent failure.
4. All of your company rules for safe practice in testing must be strictly conformed to, including all practices for tagging and isolating apparatus during testing and maintenance work. State, local, and federal regulations, e.g., OSHA, may also apply.

NOTE



Company rules and government regulations take precedence over Doble recommendations.

NOTE



Personal protective equipment suitable for electrical testing of transformers is recommended.

Grounding

The apparatus under test, its tank or housing, and the SFRA instrument must be solidly and commonly grounded or earthed. This also applies to any mobile equipment being tested.

Figure 1.7 shows a sample safety ground connection.

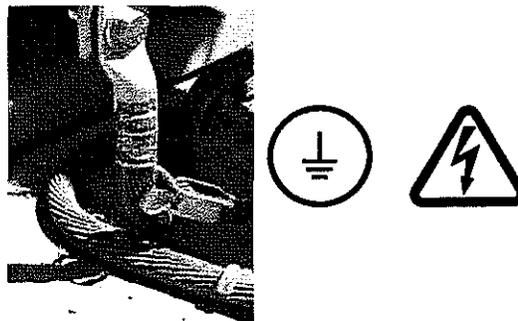


Figure 1.7 Connecting Safety Ground to Transformer

The instrument test-cable shields must also be grounded or earthed to the same common point as the instrument. This is usually achieved by attaching the grounds securely to the bushing flange base.

NOTE



Proper grounding is important for safety and for reliable SFRA test results.

Personnel

1. A pretest meeting is recommended. Frequently, other crews will be working on non-test-related tasks in close proximity to equipment being tested. The pretest meeting should include all personnel who will be working in proximity to the area where testing will be performed. In this meeting, review with crew members the tests to be performed, apparatus, voltage test levels involved, potential hazards, and individual assignments. Test personnel need to remain aware of the work activity taking place around them and alert to the possibility that non-test personnel may enter the test area.
2. Agree on a consistent and uniform set of signals, both visual and verbal. All crew members should follow them during testing.
3. While making the various types of connections involved in the tests, it may be necessary for personnel to climb up on the apparatus, but no one should remain on the apparatus during the test itself.

2. Software

The M5000 instruments come with intuitive, Windows-based SFRA software (Figure 2.1) that runs on a standard PC supplied by the user (for the M5200 or M5400) or on the M5300 itself. The software allows you to make and compare SFRA measurements. The test is easy to perform, but recording all relevant details for future reference is important; otherwise, it becomes difficult to reproduce test results.

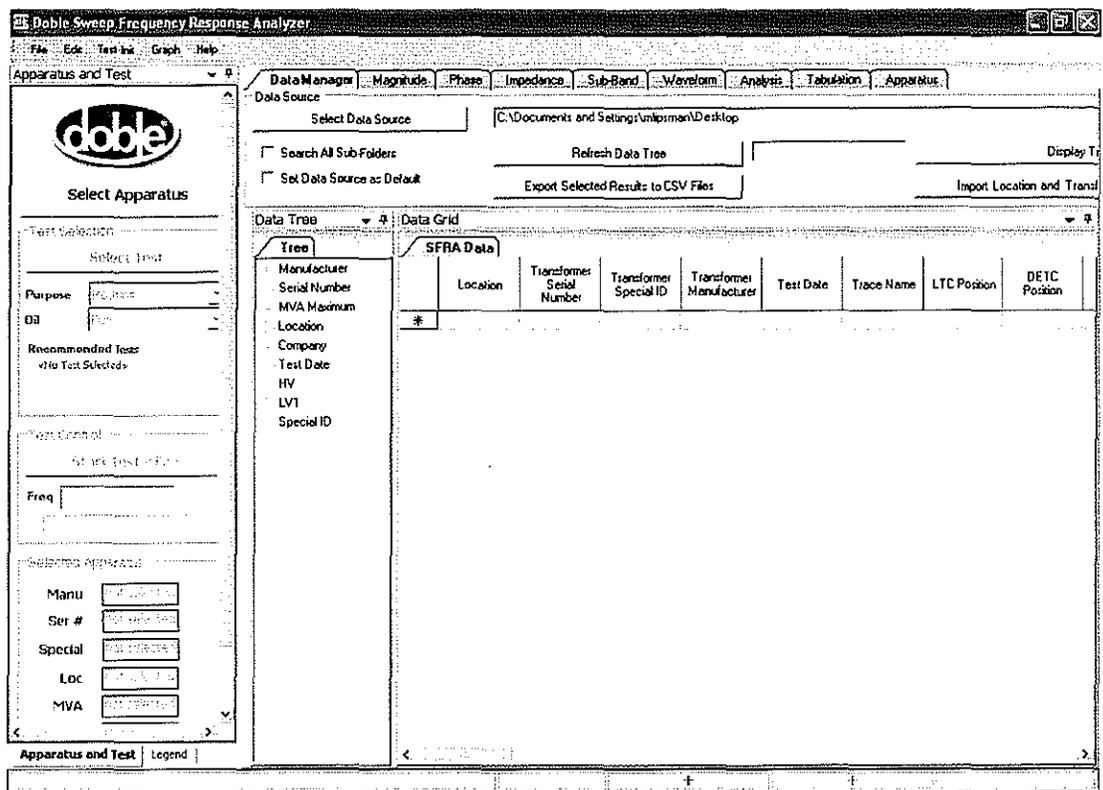


Figure 2.1 SFRA Software Main Screen

The software requires a minimum set of details before taking a measurement:

- Test location
- Testing organization
- M5000 instrument serial number
- Transformer manufacturer
- Transformer serial number
- Red lead location
- Black lead location

You can set up and save basic information before performing tests. Templates of tests are available, with different transformer designs. All traces are automatically saved upon completion.

Installing SFRA on a PC for M5200 or M5400

Doble SFRA software is loaded on your PC using standard software load procedures. As part of the load, the Microsoft .NET framework 2.0 is installed on your machine if it is not already present.

Do not install the software to a network drive or to an image of a network drive—these will not be available in the field, and data will not save.

When testing in the field using an M5200 or M5400, the PC with the software installed should not be connected to any other network and should not have a wireless network enabled (or switched on). Disable firewall and virus software while making measurements. These may be returned to default settings when using the software as a viewer only and not communicating with the M5200 or M5400.

PC Requirements

Minimum requirements for the PC used with the M5200 or M5400 are:

- **Processor:** 500 MHz
- **Operating system:** Windows 2000 or XP
- **RAM:** 256 MB
- **Hard-drive free space:** 20 MB for application
- **Communications:** Ethernet crossover cable and USB cable included with M5200 and M5400

Crossover Cable

Connect the PC running SFRA software to the M5200 or M5400 using the crossover cable included with the instrument. A standard network cable without a crossover adapter will not allow communication.

Title Bar

The title bar (Figure 2.2) displays the Doble logo and the title Doble Sweep Frequency Response Analyzer. Click on the logo to access a dropdown menu that includes:

- Restore
- Move
- Size
- Minimize
- Maximize
- Close

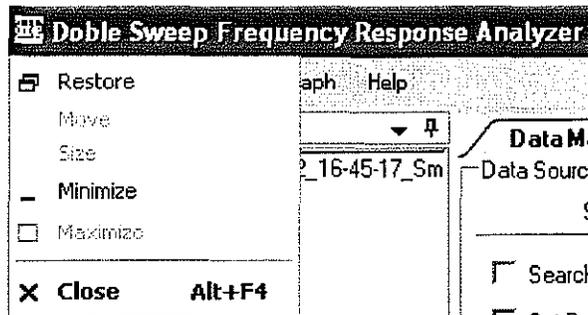


Figure 2.2 Title Bar

Status Bar

Figure 2.3 shows the status bar at the bottom of the main screen. The status bar displays the blue and red cursor coordinates of a graph on the Magnitude, Phase, or Impedance tab. The coordinates reflect the last change you made to the cursor position on any of the three tabs. Click the blue or red “+” sign to show or hide the cursors. The field on the right (active only when both are on) displays the difference between the two.

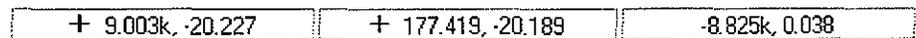


Figure 2.3 Status Bar

Menu Bar

Each item in the menu bar (Figure 2.4) is discussed below. Menu bar options are disabled or grayed out if they are not available in the current tab.



Figure 2.4 Menu Bar

File

File menu (Figure 2.5) items are:

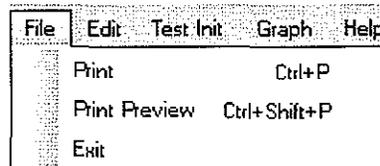


Figure 2.5 File Menu

The File menu has no Save command, because all traces are automatically saved upon completion.

Print. Opens the standard Windows Print dialog box. Shortcut key: Ctrl + P

Print Preview. Previews the print format for the plot shown on the Magnitude tab. Click the up or down arrow at the upper right corner of the Preview window (to the right of the Page field) to view each page. Shortcut key: Ctrl + Shift + P

Exit. Exits the program. Shortcut key: Alt + F4

Edit

Edit menu (Figure 2.6) items are:

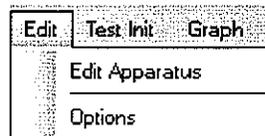


Figure 2.6 Edit Menu

Edit Apparatus. Opens the Test Equipment Editor dialog box (Figure 2.22), allowing you to enter or edit apparatus, location, and company details.

Options. Opens the Sweep Frequency Response Analyzer Settings dialog box (Figure 2.35), allowing you to change the default location of data, lists, and the template file.

Test Init

Test Init menu (Figure 2.7) items are:

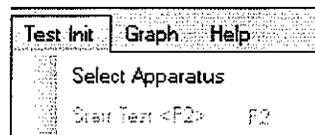


Figure 2.7 Test Init Menu

Select Apparatus. Opens the Apparatus Selection dialog box (Figure 2.29), allowing you to select an apparatus for a test.

Start Test. Starts a test. Active only after you use Select Apparatus to choose an Apparatus/Location combination.

Graph

Graph menu (Figure 2.8) items are shown below.

To pan a graph, press Control and use the left mouse button to drag the trace across the screen.

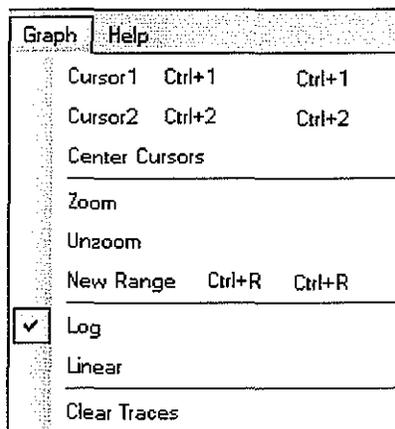


Figure 2.8 Graph Menu

Cursor 1. Displays a blue crosshair cursor on the Magnitude, Phase, or Impedance graph. You can also click the blue “+” field in the status bar to activate the cursor. Coordinates appear in the blue “+” field of the status bar. The cursor attaches to the nearest graph. Click and drag either cursor line to move it.

Cursor 2. Displays a red crosshair cursor on the Magnitude, Phase, or Impedance graph. You can also click the red “+” field in the status bar to activate the cursor. Coordinates appear in the red “+” field of the status bar. The cursor attaches to the nearest graph. Click and drag either cursor line to move it.

Center Cursors. Centers the cursor crosshairs in the graph. This is the center of the scale values, which may be offset on a log scale.

Zoom. Zooms on the graph section between cursor positions. Both cursors must be visible. Shortcut key: Shift + click. You can also shift, click, and drag diagonally to create a rectangle outlining the area you wish to zoom on.

Unzoom. Resets the graph to the default view.

New Range. Opens the Plot Range dialog box (Figure 2.8), allowing you to set the low and high axis limits. This is useful when producing zoomed plots of graph areas for reports.

Log. Displays the graph with a log x -axis scale. This typically emphasizes lower frequencies.

Linear. Displays the graph with a linear x -axis scale. This typically emphasizes higher frequencies.

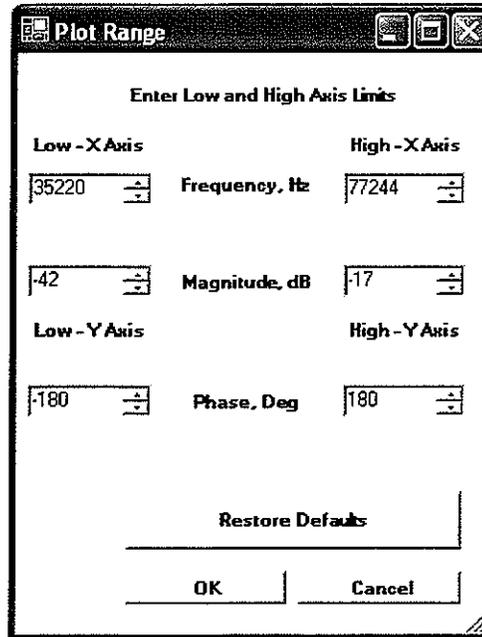


Figure 2.9 Plot Range Dialog Box

Clear Traces. Opens the Clear Traces dialog box (Figure 2.10), allowing you to remove one or more traces from the display. Check the boxes of the traces you wish to remove and click OK.

Clearing traces is different from checking or unchecking boxes in the Legend pane, which leaves the trace there but merely shows or hides it on the tab. Clearing the trace here removes it from the Legend pane.

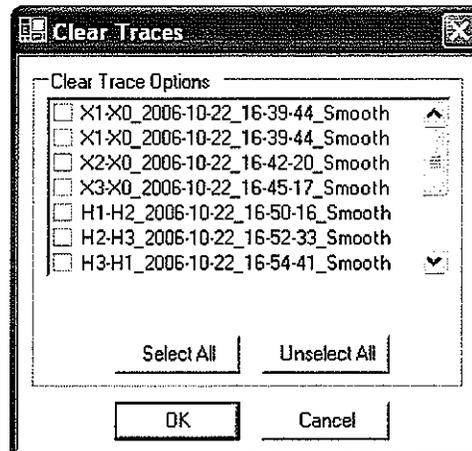


Figure 2.10 Clear Traces Dialog Box

Help

Help menu (Figure 2.11) items are:

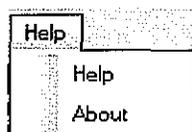


Figure 2.11 Help Menu

Help. Opens the help file.

About. Opens the version information and copyright dialog box. The software version and build number are in the upper right corner. If you are connected to an instrument or are using an M5300, the Instrument Firmware Information field displays the instrument firmware version and related information, which may be useful in diagnostic situations. Scroll down to reach the firmware version.

Apparatus/Test and Legend Panes

Click the appropriate tab at the lower left of the screen to display either of these panes.

Apparatus and Test Pane

Use the Apparatus and Test pane at the left of the main screen to select a transformer for test, set basic test parameters, and start a test. Subsequently, this pane shows which frequency is being measured and the progress of the test. When using an M5200 or M5400, this pane is active only when connected to the instrument.

Legend Pane

The Legend pane allows you to show or hide graphs on the Magnitude, Phase, and Impedance tabs and to set their properties. Check or uncheck the box at the left of the graph name to show or hide the trace. Right-click on a trace name and click Plot Property to display the Plot Property dialog box (Figure 2.12).

Use the dropdown menus to change the color, line style, and width of the plot. Interference Cancellation filters the results if they contain noise. It applies only to plot views and does not alter the saved data. Leave it checked unless you need to identify noise frequencies within the results. This option is not available with results from M5100 version 1.x or 2.x software.

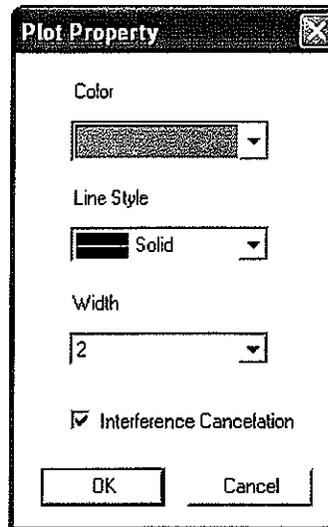


Figure 2.12 Plot Property Dialog Box

Tabs

Data Manager Tab

The Data Manager tab (Figure 2.13) displays test files grouped by folders (default or user-defined), with controls to select, display, and export those files.

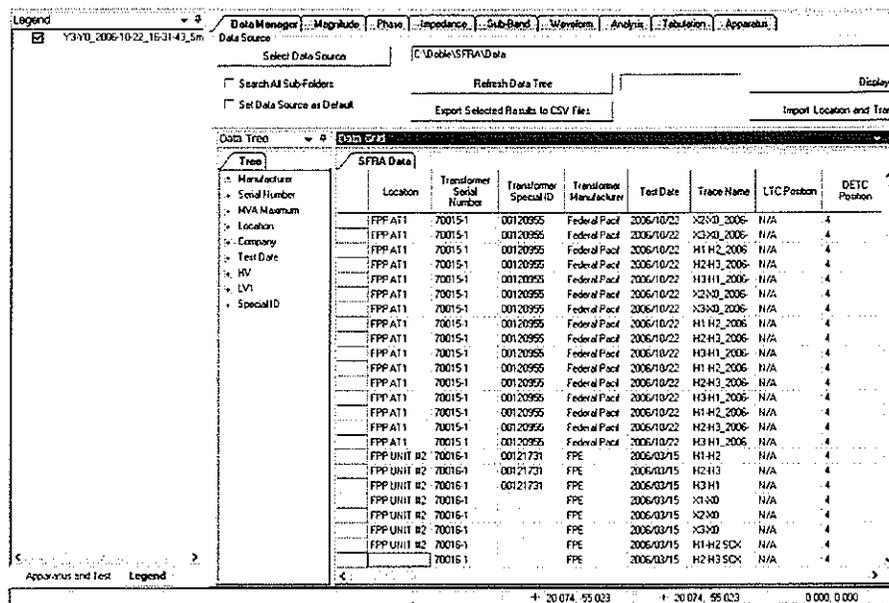


Figure 2.13 Data Manager Tab

Magnitude Tab

The Magnitude tab (Figure 2.14) displays magnitude versus frequency for the selected graph(s).

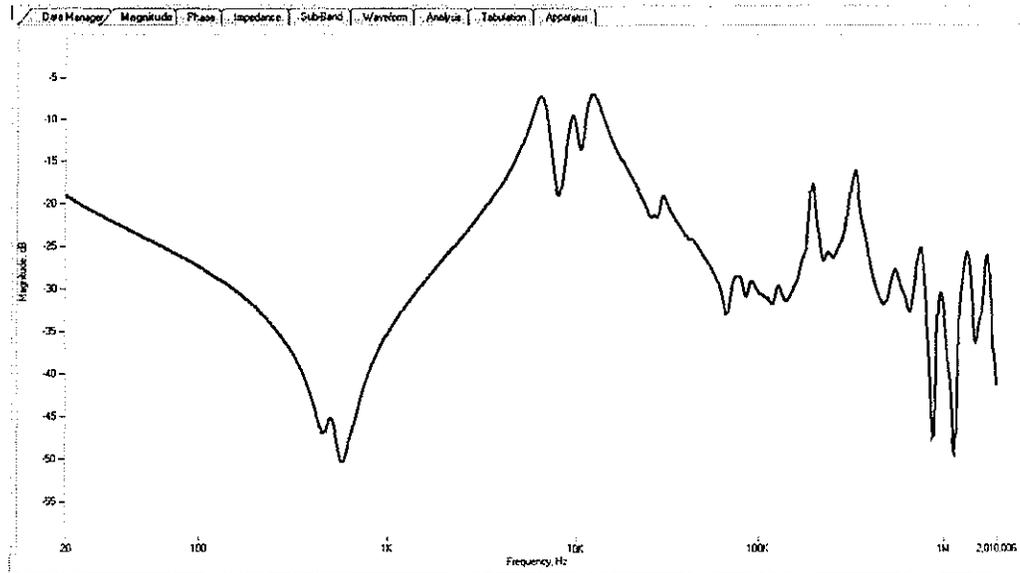


Figure 2.14 Magnitude Tab

Phase Tab

The Phase tab (Figure 2.15) displays phase versus frequency for the selected graph(s). Phase is rarely used but can occasionally be useful when looking at whether a measurement is more inductive or more capacitive.

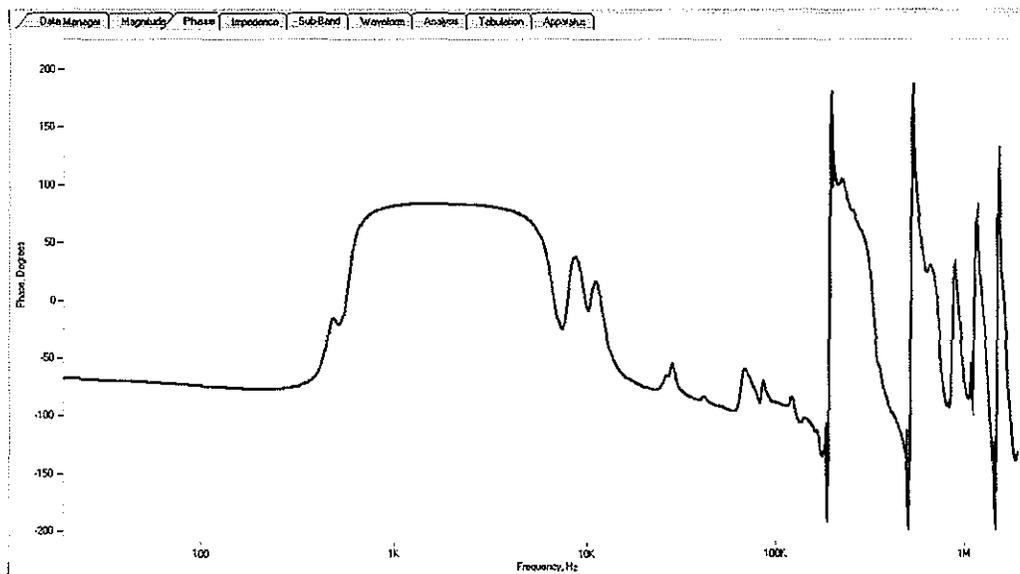


Figure 2.15 Phase Tab

Impedance Tab

The Impedance tab (Figure 2.16) displays Impedance (Z Ohms) and Admittance (Y Mhos) representations, using the magnitude and phase results for calculation. Use the option button at the lower left to select the desired display type.

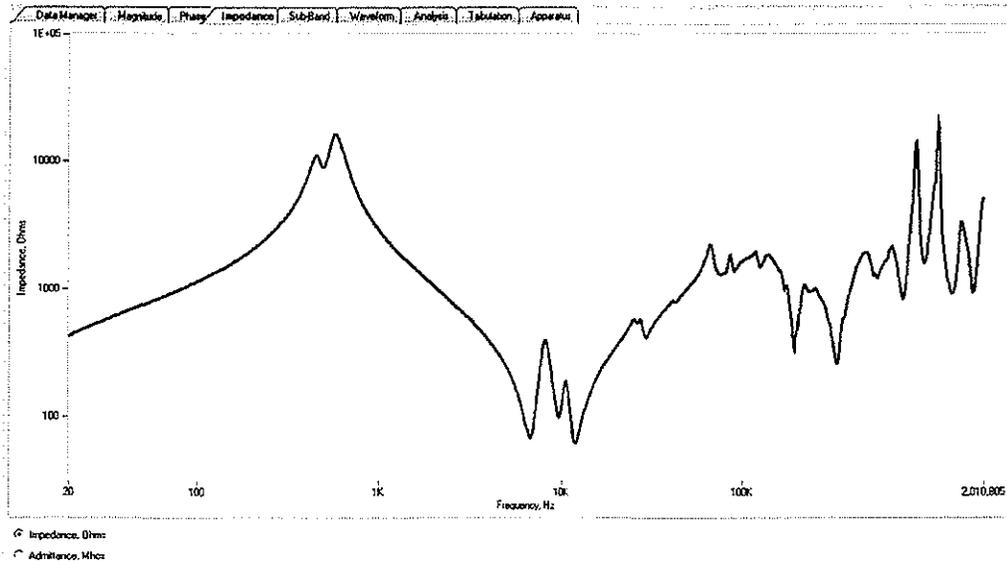


Figure 2.16 Impedance Tab

Sub-Band Tab

The Sub-Band tab (Figure 2.17) is included for historical continuity. Early work on SFRA required results displayed on graphs of 2 kHz, 20 kHz, 200 kHz, and 2 MHz. The last three of these are included here to permit viewing those graphs.

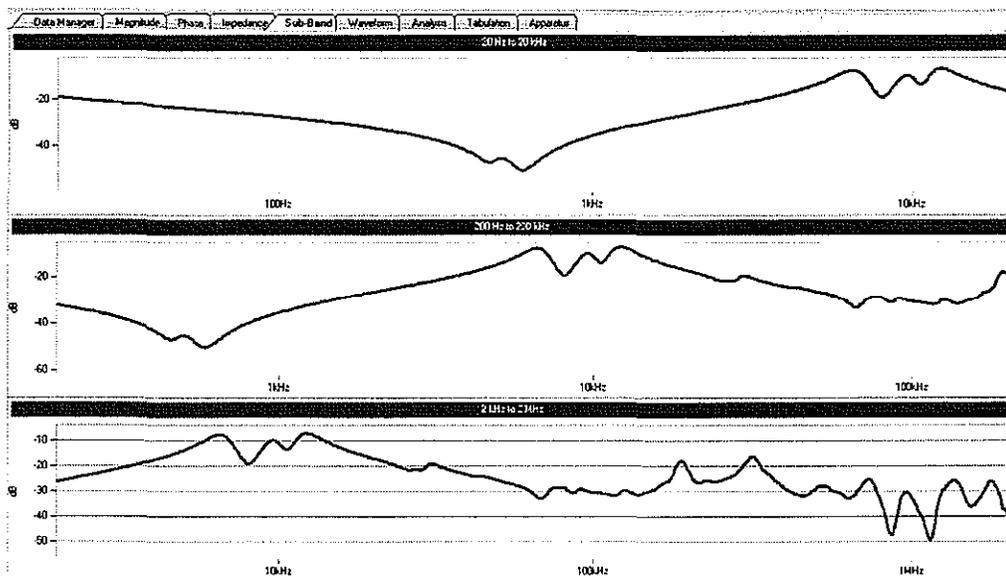


Figure 2.17 Sub-Band Tab

Waveform Tab

The Waveform tab (Figure 2.18) is useful when monitoring the progress of a measurement: it displays both the reference waveform generated by the test set and the measured waveform of the object under test. This tab displays a waveform only when a test is in progress.

It is also possible to use the Waveform tab to help diagnose a bad connection, which will appear as a low, noisy, nonsinusoidal signal.

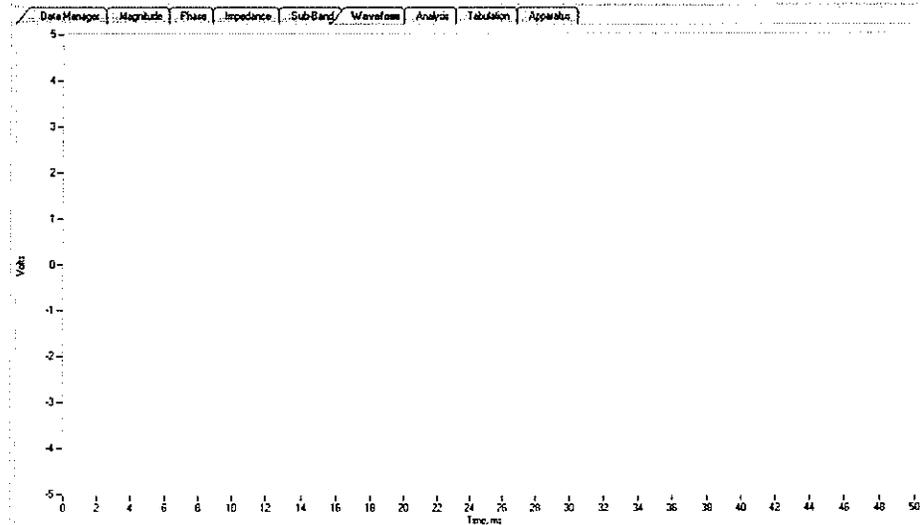


Figure 2.18 Waveform Tab

Analysis Tab

The Analysis tab (Figure 2.19) allows you to compare two traces. The upper pane displays the two traces you select; the lower pane displays the difference between them.

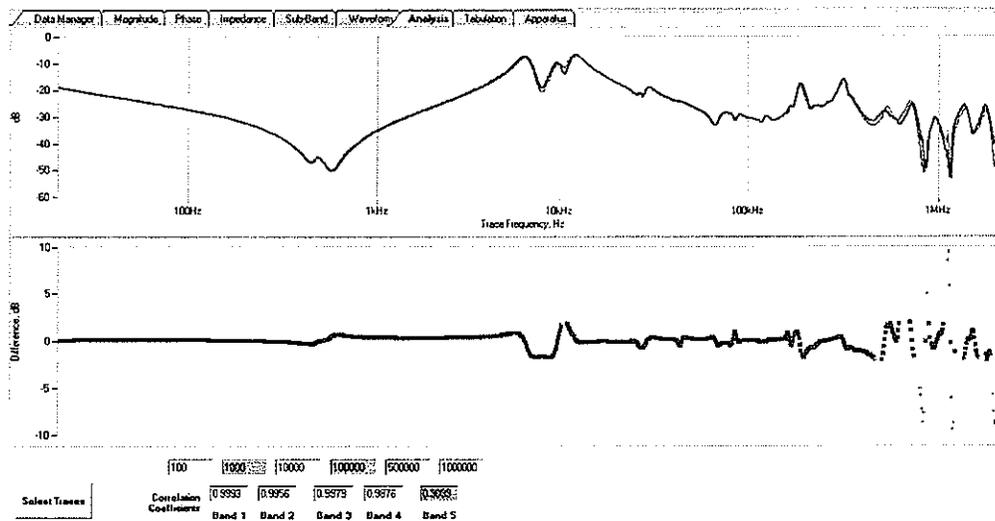


Figure 2.19 Analysis Tab

Tabulation Tab

The Tabulation tab (Figure 2.20) displays graph data in tabular form. Check a box in the Legend pane to display the values for that graph.

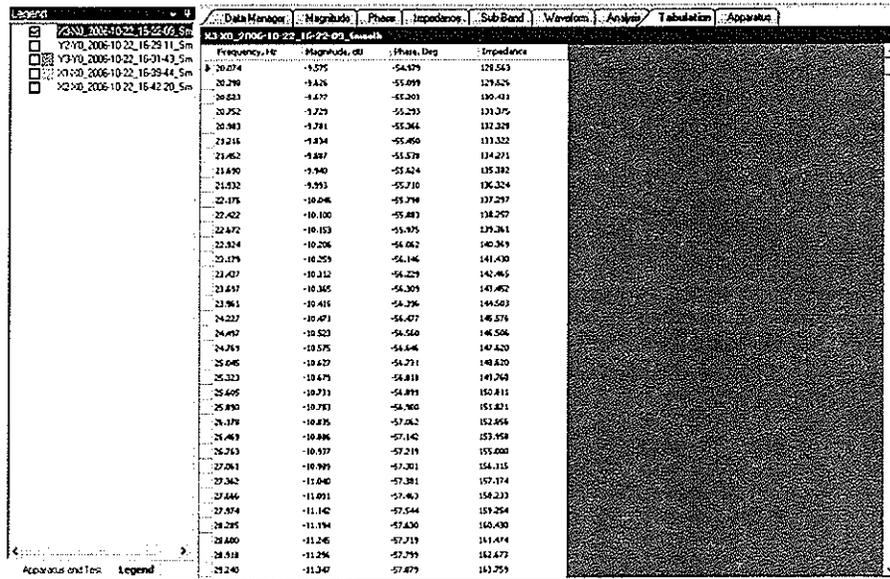


Figure 2.20 Tabulation Tab

Apparatus Tab

The Apparatus tab (Figure 2.21) displays test setup, apparatus location, and transformer nameplate information related to the trace selected in the Legend pane.

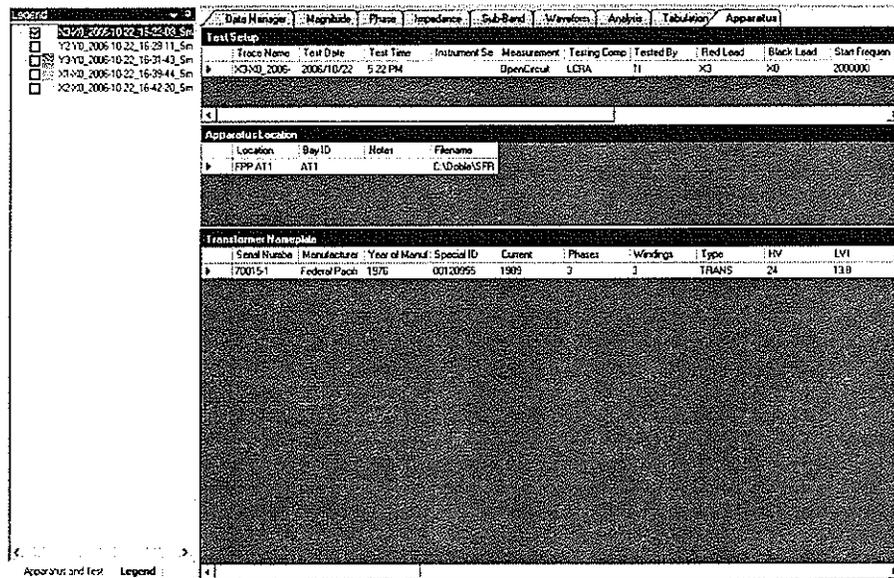


Figure 2.21 Apparatus Tab

Test Equipment Editor for Nameplate Data

The Test Equipment Editor (Figure 2.22) allows you to create, edit, review, and delete nameplate details for tests.

To open the Test Equipment Editor, select Edit > Edit Apparatus. The three editing panes (Location, Test Equipment, and Test Organization) all work the same way: select the desired item in the list on the left; details appear in the fields on the right.

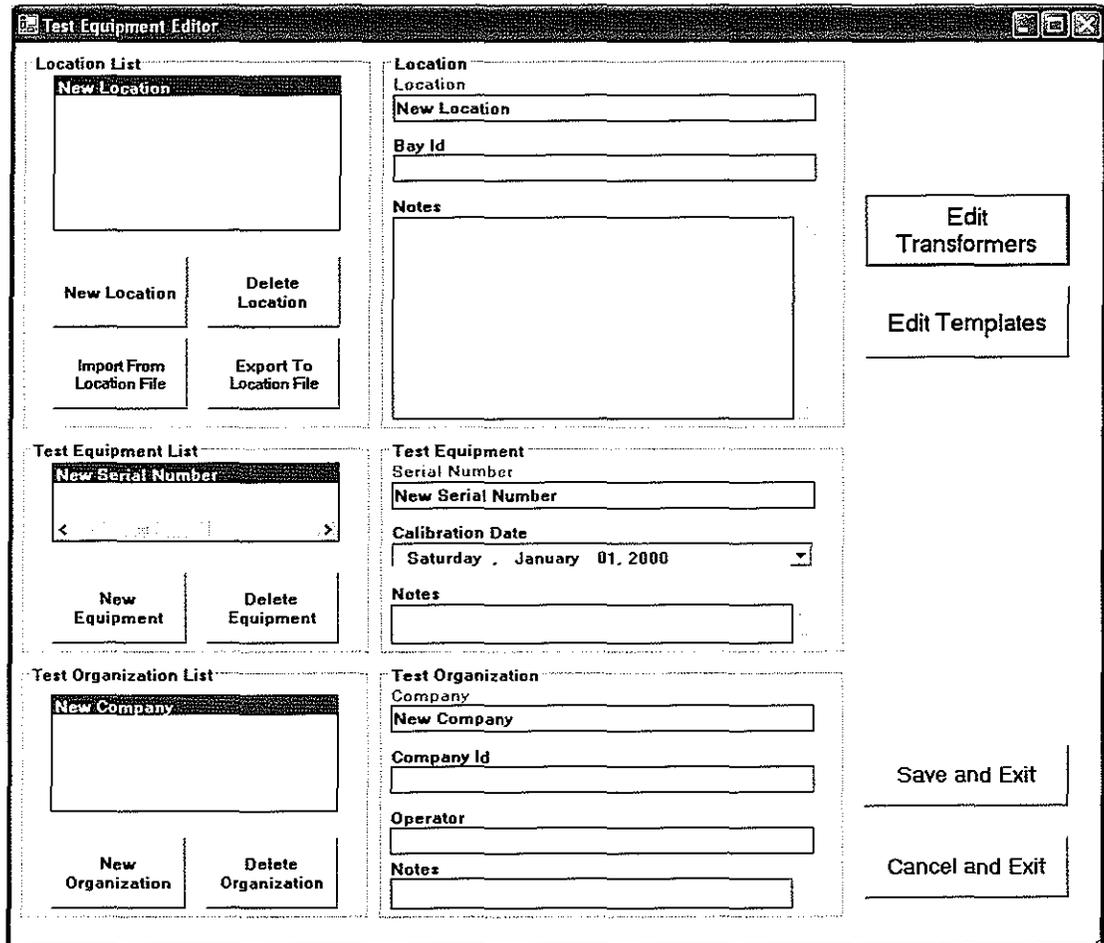


Figure 2.22 Test Equipment Editor

- **Location** is a uniquely identifiable place where the transformer SFRA test takes place. Each entry must have a unique name; this is its key identifier.
- **Test Equipment** is an M5000 test set, uniquely identified by its serial number.
- **Test Organization** is the organization performing SFRA testing.

Creating

To create a new entry:

1. Click the New button for the appropriate category on the left.
A new entry (e.g., New Location) appears in the list.
2. Enter data in the fields on the right, or edit existing data.
3. Click Save And Exit.

Editing

To edit nameplate data:

1. Select the desired item in the appropriate category on the left.
2. Edit the contents of the fields on the right.
3. Click Save And Exit.

Deleting

To delete nameplate data:

1. Select the desired item in the appropriate category on the left.
2. Click the Delete button for that category.
The Confirm Delete dialog box appears.
3. Click Yes.
4. Click Save And Exit.

Deleting an entry does not delete any results associated with that entry.

Importing and Exporting Location Files

SFRA software allows you to import and export Location files. This helps ensure consistency of locations for different users. The files are saved in .xml format.

To export a Location file:

1. Select the location in the Location List.
2. Click Export To Location File.
The Save As dialog box appears.
3. If desired, enter a new filename in the File Name field.
4. Click Save.

To import a Location file:

1. Click Import From Location File.
The Open dialog box appears.
2. If necessary, navigate to the appropriate folder on your computer.
3. Select the file.
4. Click Open.
The Import From Location dialog box appears.
5. Click OK.

Transformer Editor

The Transformer Editor (Figure 2.23) allows you to create, edit, review, and delete Transformers. A transformer is any uniquely identifiable test object. It is, in fact, a complicated object consisting of many parts and subassemblies: coolers, bushings, tap changers. The transformer editor allows you to enter relevant information.

Transformers are not tied to particular locations—Transformers and Locations are combined when you test, so that a test is performed on a transformer at a particular location. The location may change on subsequent tests—after relocating the transformer, for example.

To open the Transformer Editor, first open the Test Equipment Editor, then click Edit Transformers. Available transformers appear in the left pane. The Transformer Editor has three tabs:

- Transformer
- LTC/DETC
- Test Template

Each tab allows access to data related to a particular transformer. Each can be edited independently.

Transformer Tab

The Transformer tab (Figure 2.23) allows you to enter or edit nameplate data for a transformer.

Creating

To create a new transformer:

1. Click New.
A New Serial Number appears in the Transformer List.
2. Select a manufacturer from the dropdown menu on the Transformer tab. This is a required field. If the manufacturer name is not available, select (No MFR Listed).
3. Enter the serial number of the transformer. This is a required field. Each transformer must have a unique serial number; this is its key identifier.
4. Enter any other desired data on the Transformer tab, or edit existing data.
5. Click OK.

Figure 2.23 Transformer Editor – Transformer Tab

Editing

To edit a transformer:

1. Select the transformer in the Transformer List.
2. Edit the contents of the fields on the Transformer tab.
3. Click OK.

Cloning

Cloning duplicates an existing transformer, so you can create a new entry without having to reenter all the data. The only required new field is the serial number.

To clone a transformer:

1. Click Clone.
The Edit Serial Number dialog box appears (Figure 2.24).
2. Enter a new serial number.
3. Click OK.
4. Make any other necessary edits on the Transformer Editor tabs.
5. Click OK.

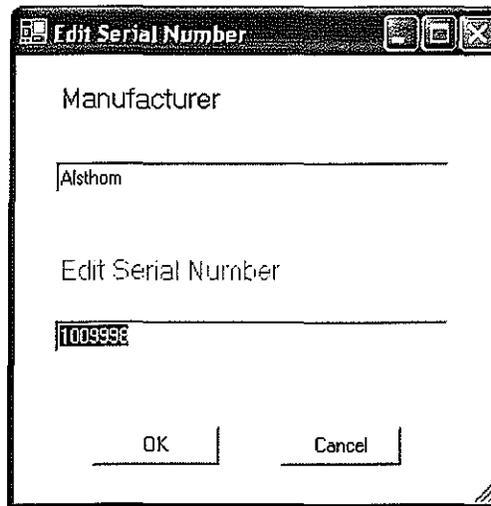


Figure 2.24 Edit Serial Number Dialog Box

Deleting

To delete a transformer:

1. Select the transformer in the Transformer List.
2. Click Delete.
The Confirm Delete dialog box appears.
3. Click Yes.
4. Click OK.

Deleting a transformer does not delete any results associated with that transformer.

Importing and Exporting Transformer Files

SFRA software allows you to import and export Transformer files. This helps ensure consistency for different users. The files are saved in .xml format.

To export a Transformer file:

1. Select the transformer in the Transformer List.
2. Click Export To Transformers File.
The Save As dialog box appears.
3. If desired, enter a new filename in the File Name field.
4. Click Save.

To import a Transformer file:

1. Click Import From Transformers File.
The Open dialog box appears.
2. If necessary, navigate to the appropriate folder on your computer.
3. Select the file.

4. Click Open.
The Import From Transformers File dialog box appears.
5. Click OK.

LTC/DETC Tab

The LTC/DETC tab (Figure 2.25) allows you to enter data associated with any load tap changer (LTC) or de-energized tap changer (DETC) that may be present on the transformer. This is not required but is useful reference data.

The Range fields are used to indicate the full range available for the LTC or DETC.

The position of the tap changer during a test is recorded in a separate table when a test is made.

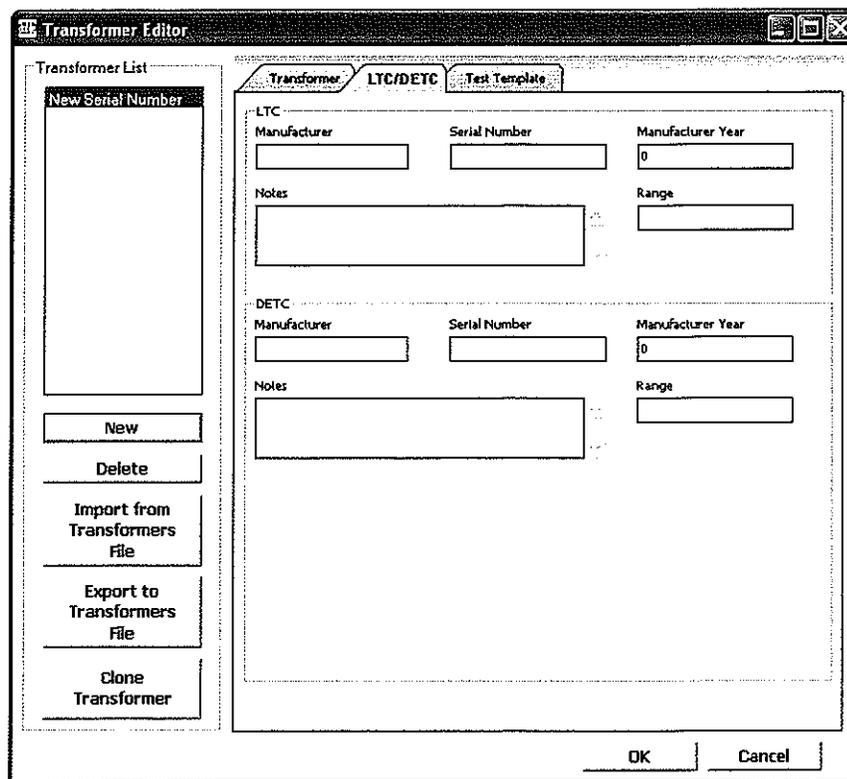


Figure 2.25 Transformer Editor – LTC/DETC Tab

Test Template Tab

A transformer may have a test template associated with it (see "Test Templates" on p. 2-19), which allows you to identify and name a collection of tests—for example, for a three-phase autotransformer. On the Test Template tab (Figure 2.26), you can associate these tests with a transformer.

A test template provides a list of recommended tests for a transformer but does not constrain you to particular tests. It is a guide rather than a constraint.

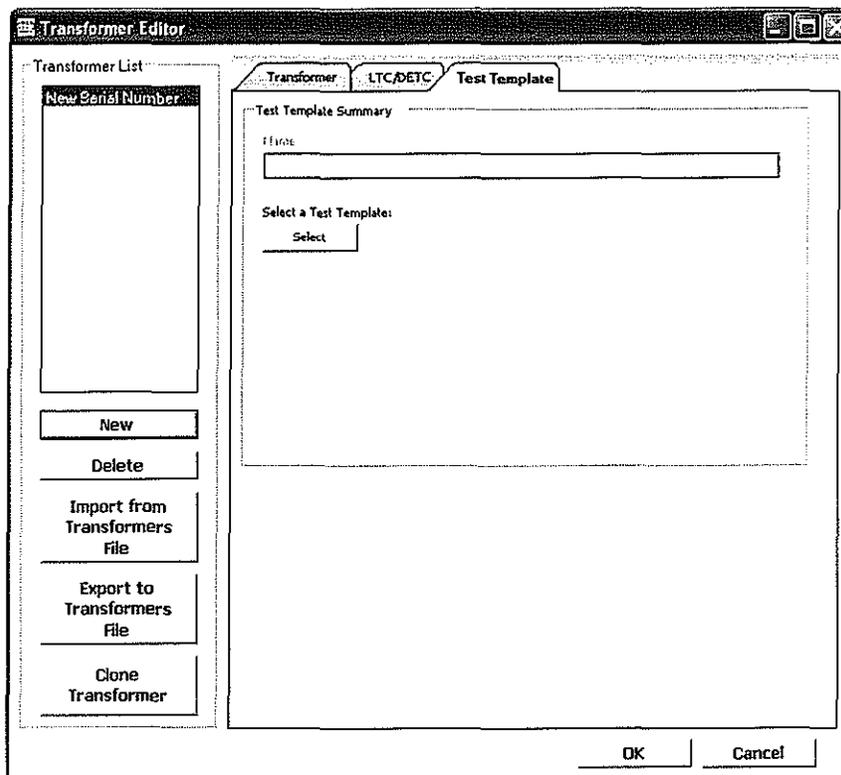


Figure 2.26 Transformer Editor – Test Template Tab

To associate a test template with a transformer:

1. Select the transformer in the Transformer List.
2. Click Select in the right pane.

The Template Editor appears (Figure 2.27).

3. Select an existing template in the Template List or create a new template and select it (see the next section).
4. Click OK twice.

Test Templates

The Template Editor (Figure 2.27) allows you to create, edit, review, and delete test templates. Test templates are a means of grouping tests for a particular transformer design and are a flexible way to specify tests for use in the field. You can associate a template with a number of transformers or create it for future reference and not associate it with any transformer.

SFRA software comes with preconfigured templates, in the Settings folder. You can edit these files or replace them. (Back up data before replacing a file.) You can import other templates using a simple procedure to merge template files (see "Merging Settings Files" on p. 2-33).

A template is a guide and not a constraint. You can select tests from the template, specify tests that are not in the template, or ignore the template recommendations.

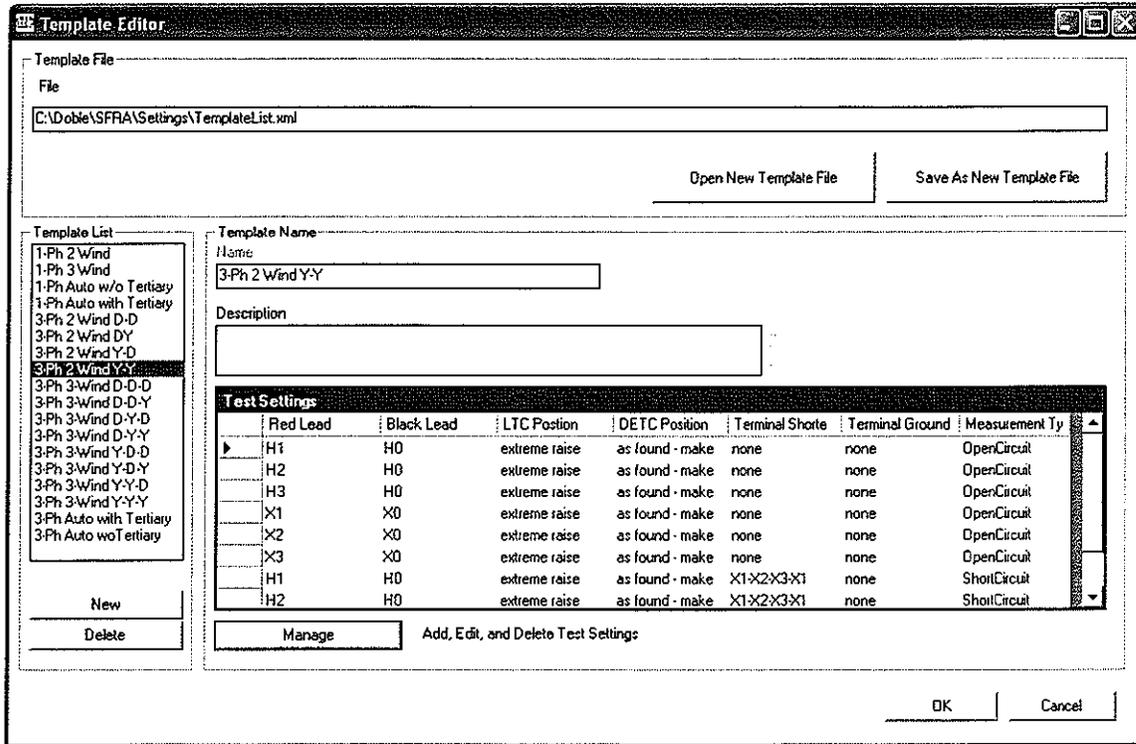


Figure 2.27 Template Editor

To open the Template Editor from the Test Equipment Editor, click Edit Templates. To open the Template Editor from the Template tab of the Transformer Editor, click Select.

Creating

To create a new test template:

1. Click New.
A New Template appears in the Template List.
2. Enter a name in the Name field (required) and a description if desired.
3. Click Manage, or right-click a row or heading of the Test Settings table and click Manage.
The Test Setting Editor appears (Figure 2.28).
4. Enter the appropriate settings. Red Lead and Black Lead are required.
5. Click OK.

Editing

To edit a test template:

1. Select the template in the Template List.

- Click Manage, or right-click a row or heading of the Test Settings table and click Manage.
The Test Setting Editor appears (Figure 2.28).
- Edit the contents of the fields on the right.
- Click OK.

Deleting

To delete a test template:

- Select the template in the Template List.
- Click Delete.
The Confirm Delete dialog box appears.
- Click Yes.
- Click OK.

Managing Tests in a Template

The Test Setting Editor (Figure 2.28) allows you to add, edit, or delete tests in a template.

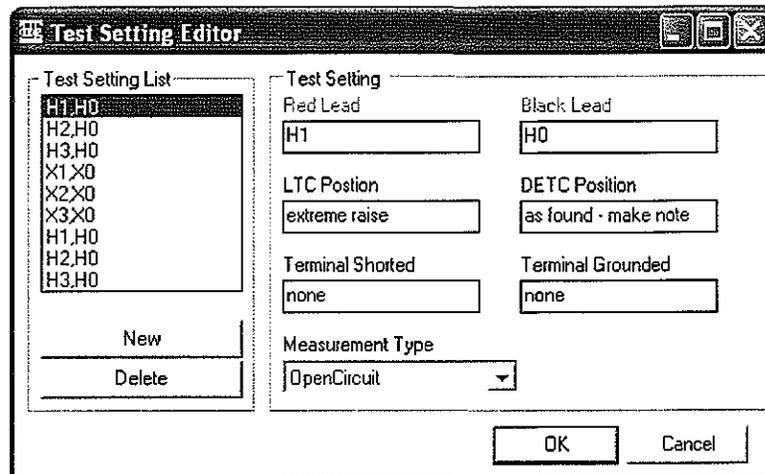


Figure 2.28 Test Setting Editor

To open the Test Setting Editor from the Template Editor, click Manage, or right-click a row or heading of the Test Settings table and click Manage.

The name of each available test appears in the Test Setting List. The minimum required information is the position of the red lead (e.g., H1, A, or N) and the black lead (e.g., X0, n, or v). Together, these values provide the name of the test in the Test Setting List.

Creating

To create a new test setting:

- Click New.

New Red,New Black appears in the Test Setting List.

2. Enter the appropriate settings. Red Lead and Black Lead are required.
3. Click OK.

Editing

To edit a test setting:

1. Select the test in the Test Setting List.
2. Edit the contents of the fields on the right.
3. Click OK.

Deleting

To delete a test setting:

1. Select the test in the Test Setting List.
2. Click Delete.
The Confirm Delete dialog box appears.
3. Click Yes.
4. Click OK.

Running a Test

You can perform a test only with an M5300 or with a PC connected to an M5200 or M5400; it is not possible to perform a test in Viewer mode without an instrument.

To run a test:

Select Apparatus

1. Click Select Apparatus in the Apparatus And Test pane.
The Apparatus Selection dialog box appears (Figure 2.29).

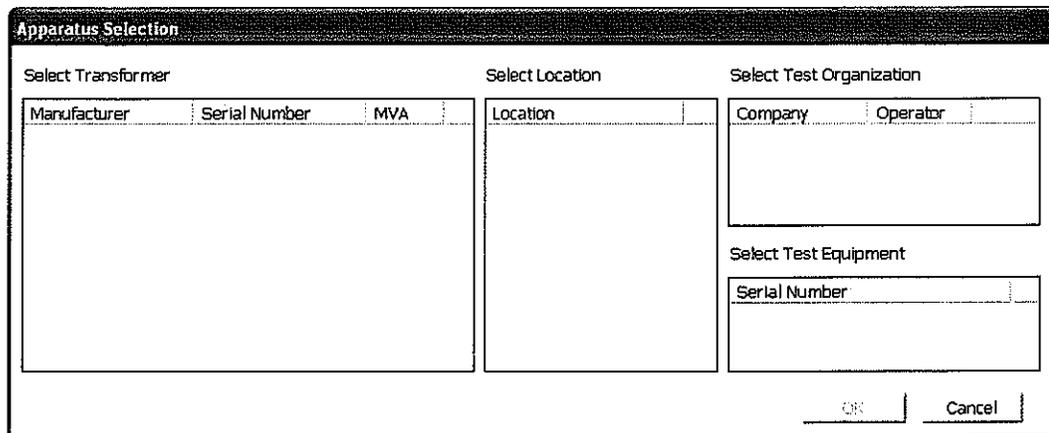


Figure 2.29 Apparatus Selection Dialog Box

2. Select the transformer to be tested, the Location, the Test Organization, and the Test Equipment.
3. Click OK.

Select Test

4. Click Select Test in the Apparatus and Test pane.
The Test Selection dialog box appears (Figure 2.30).

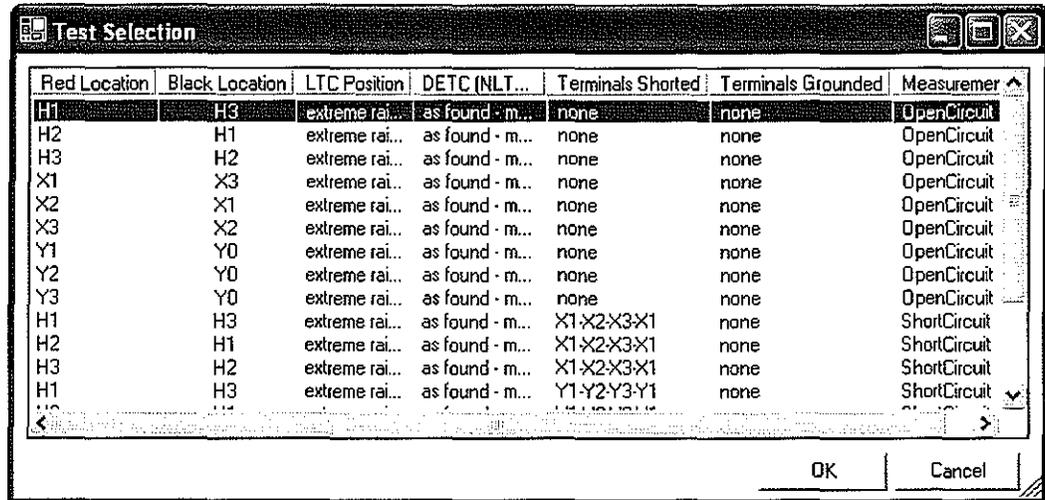


Figure 2.30 Test Selection Dialog Box

5. Select the desired test.
6. Click OK.
7. In the Apparatus and Test pane, select the purpose and oil level conditions from the dropdown menus.

Start Test

8. Click Start Test, press F2, or select Test Init > Start Test.

The Test Details dialog box appears (Figure 2.31).

9. Enter the location of the red and black test leads.

Trace Name is a combination of the red and black lead locations. If no test template has been selected, the fields are blank.

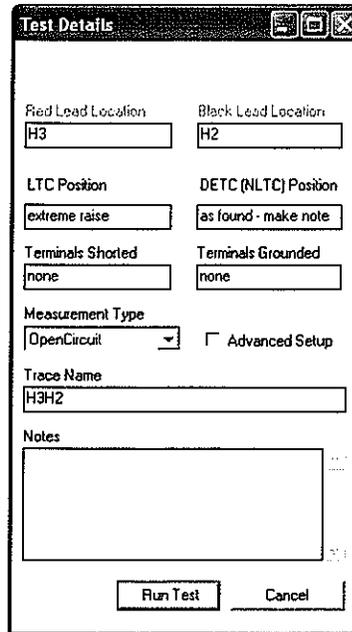


Figure 2.31 Test Details Dialog Box

10. If you wish to run a nonstandard test, check the Advanced Setup box.

A message appears, notifying you that you are about to run a nonstandard test (Figure 2.32) and that you may not be able to compare the results of this test with results from standard tests.

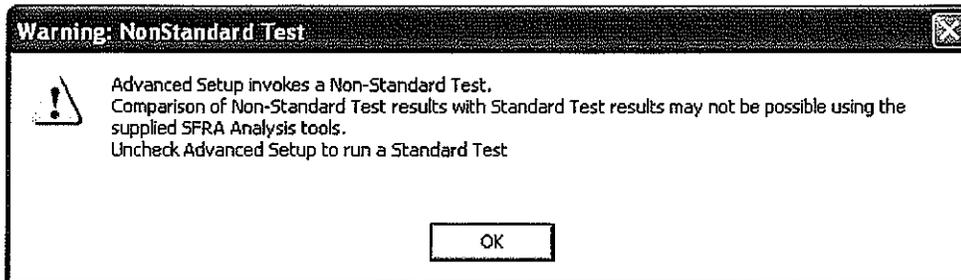


Figure 2.32 Nonstandard Test Warning

11. Click OK.

The Test Details dialog box expands to display an Advanced Test Protocol section on the right (Figure 2.33).

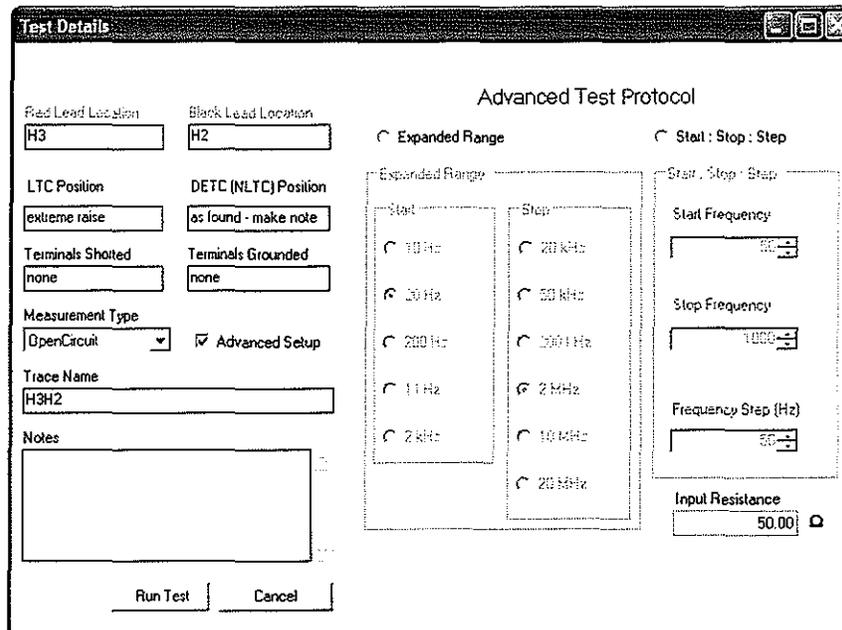


Figure 2.33 Test Details Dialog Box with Advanced Test Protocol

12. At the top of the Advanced Test Protocol section, click the option button for Expanded Range or Start : Stop : Step and make the desired selections.
13. Click Run Test.

Test in Progress

M5000 instruments perform a number of self-tests, to ensure that:

- Internal temperature does not exceed acceptable limits (error 950).
- Noise levels on the test leads do not exceed safe levels for the instrument (error 951).
- Resistance between ground connections is not too high (error 952).
- The internal M5000 performance check was successful (error 953).

If each test is successful, the test begins. If a test fails, an error message appears.

- **Error 950.** M5000 instruments are designed to operate in a 50° C / 122° F environment for extended periods. The instrument checks internal temperature before each test, because an elevated temperature may reduce component life and reduce the instrument's reliability. If the temperature is abnormally high, a warning appears. It is possible to continue with the test, but the instrument should be switched off for a number of minutes to allow it to cool down first.
- **Error 951.** Excessive noise on the input channels may cause excessive noise in the results. If the input noise level rises too high, it may damage the instrument. Consequently, the instrument tests the noise level on the input channels before each test. If the test indicates a high noise level, stop the test, ground the bushing terminals to reduce static, and restart the test. It is possible to continue with the test, but results may be noisy.

- **Error 952.** An SFRA test relies on good test connections at the bushing terminal and at the base of the bushing. The instrument tests the ground-loop resistance before running a test. A value of less than 1 ohm is ideal, but less than 5 ohms is usually acceptable. Causes of high ground-loop resistance include poor connections to bushing studs because of dirt, grease, or paint, or, occasionally, the stud itself not being grounded. Consider any measurement above 250 ohms an open circuit.
- **Error 953.** The instrument generates signals at a number of frequencies and measures them without sending them through the test object. This signal verification test confirms that the device is performing as expected. If the test fails, it is still possible to continue with the measurement, but check the results for acceptability.

Checking and Troubleshooting Results

SFRA is an easy test to perform, but simple problems can occur during a test. These have characteristic signatures, described below.

Monitoring Waveforms

The instrument allows you to monitor the reference and measured waveforms as you run through a test. Click the Waveform tab to display waveforms (Figure 2.18). Both waveforms should appear. At very low dB response, the measured waveform may be small.

Diagnosing Open-Circuit Response

An open-circuit response may be caused by the black test lead dropping off the bushing, a poor connection, or damage within the test lead. The discrete change in the lower frequency range in Figure 2.34 shows typical open-circuit behavior: about -90 to -100 dB. Investigate a test like this to see if the open circuit lies in the test setup or the transformer.

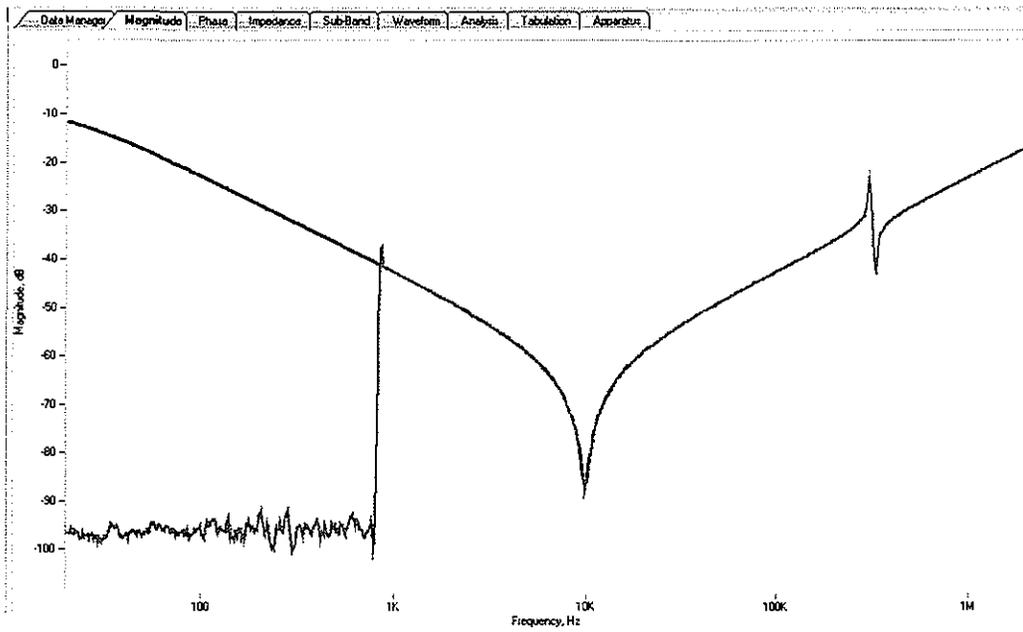


Figure 2.34 Typical Open-Circuit Response

Managing Data

Default Data Locations

The Sweep Frequency Response Analyzer Settings dialog box (Figure 2.35) allows you to change the folder for data from tests (Data Path) and the various Editors (Editors List Path) and the file you wish to use to store template data (Template File).

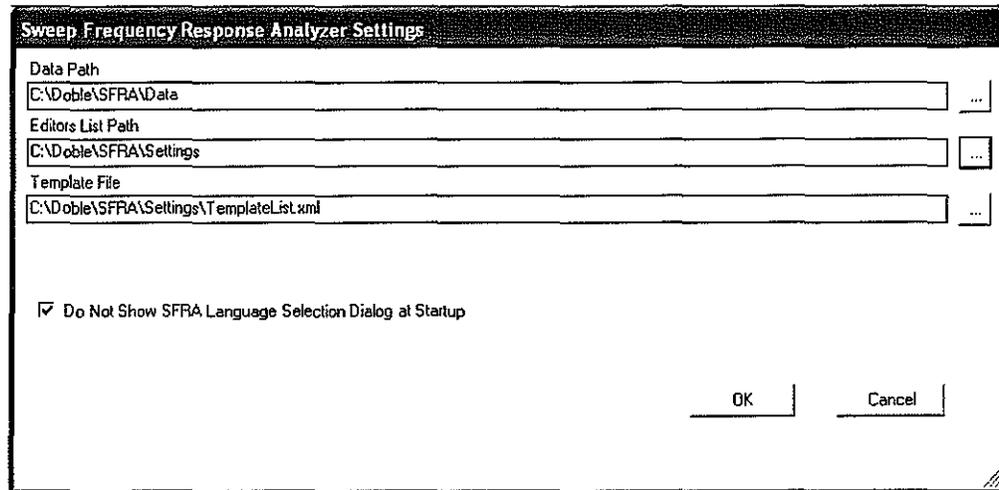


Figure 2.35 Sweep Frequency Response Analyzer Settings Dialog Box

To change the location of a data folder or template file:

1. Select Edit > Options

The Sweep Frequency Response Analyzer Settings dialog box (Figure 2.35) appears.

2. Click the ellipsis button at the right of the path you wish to change.
 - For Data Path or Editors List Path, the Browse For Folder dialog box appears (Figure 2.36).

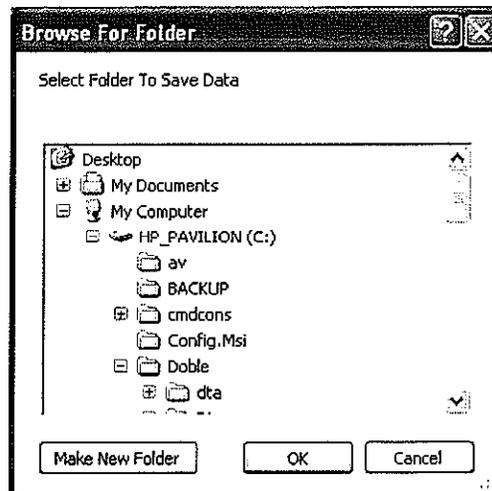


Figure 2.36 Browse for Folder Dialog Box

- a. Navigate to the desired folder.
- b. Click OK.
- For Template File, the Open dialog box appears (Figure 2.37).

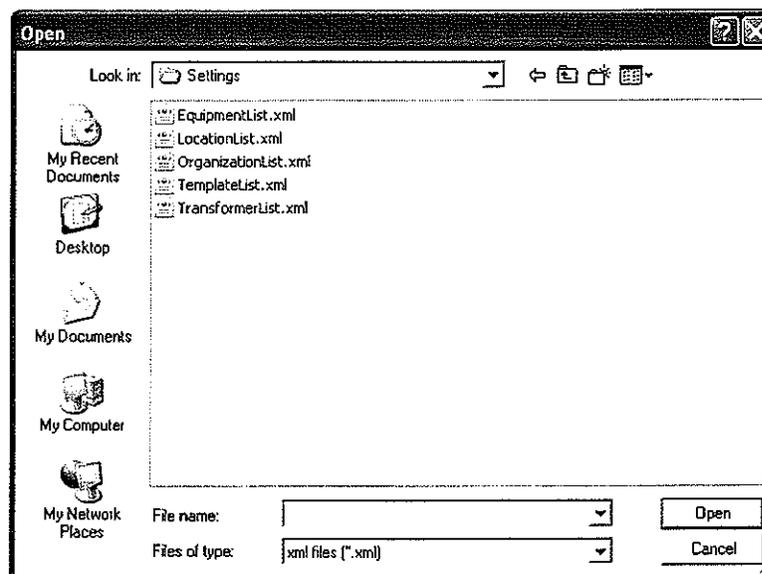


Figure 2.37 Open Dialog Box

- a. Navigate to the desired folder.
 - b. Select the desired file.
 - c. Click Open.
3. Click OK.

Select Data Source

To select a folder for viewing data:

1. To search for files in all subfolders of the data folder, check the Search All Sub-Folders box on the Data Manager tab.
Test results are date- and timestamped and saved to the default folder automatically. You can set up additional data folders based on transformers, substations, manufacturers, or any other category.
2. To make the folder you select the default folder, check the Set Data Source As Default box.
3. Click Select Data Source.
The Browse For Folder dialog box appears (Figure 2.36).
4. Navigate to the desired folder.
5. Click OK.
The files appear in the Data Grid.
6. Click the plus sign to the left of a category in the Data Tree to display the options for viewing a subset of data in that category.
Click Refresh Data Tree if you select a new data source or add SFRA traces to the default folder while the software is open.
To rearrange the order of the columns in the Data Grid, click on a column head and drag it to the desired location.
7. Select one or more traces to view by highlighting the rows in which they appear (see "Highlighting Rows in the Data Manager Tab" on p. 2-30).
8. Click Display Traces.
9. View the traces on the Magnitude, Phase, or Impedance tabs.

Export Selected Results to CSV Files

You can save test files in .csv format, for use in spreadsheets or the M5100 software viewer.

To save test files in .csv format:

1. Select the file(s) in the Data Manager tab (see "Highlighting Rows in the Data Manager Tab" on p. 2-30).
2. Click Export Selected Results To CSV Files.
The Files Converted dialog box appears (Figure 2.38).
3. Click OK.

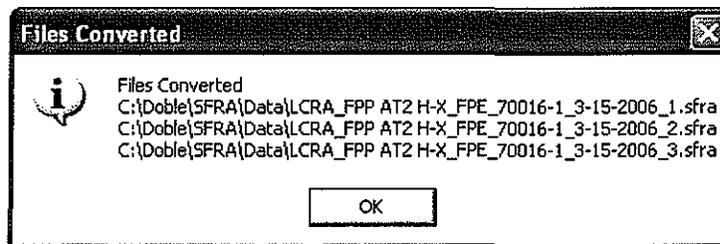


Figure 2.38 Files Converted Dialog Box

Import Location and Transformer from Results Files

You can add the Location and Transformer entries from a file to your own settings files (LocationList.xml and TransformerList.xml in the Settings folder).

To import Locations and Transformers from data files:

1. In the Data Manager tab, select the file(s) from which you wish to import Location(s) and Transformer(s) (see "Highlighting Rows in the Data Manager Tab" on p. 2-30).
2. Click Import Location and Transformer From Results File.

If a Location or Transformer is imported, a Location Data Copied or Transformer Data Copied dialog box appears, with the name(s) of the imported Location or Transformer.

If a Location or Transformer is not imported—typically because it is already in your settings files or is in the wrong format—a No Transformers Imported or No Locations Imported dialog box appears.

3. Click OK for each dialog box.

Highlighting Rows in the Data Manager Tab

When selecting (highlighting) a row or rows in the Data Manager tab, the standard Windows conventions apply:

- To select a single row, click the gray section at the left of the row.
- To select several non-contiguous rows:
 1. Hold down the Control key.
 2. Click the gray section at the left of the desired rows.
- To select a sequence of rows (from top down or bottom up):
 1. Click the gray section at the left of the first desired row.
 2. Hold down the Shift key.
 3. Click the gray section at the left of the last desired row.

You can also select a sequence and then eliminate individual rows from the sequence by pressing Control and clicking the gray section at the left of each row you wish to eliminate.

Saving and Deleting Traces

All completed traces are automatically saved. If the test is canceled, the data is not saved.

The SFRA software has no Delete option. To delete files, locate the file using the timestamp in the folder where it is stored and delete it in Windows Explorer. The filename appears as the last column of each row in the Data Manager tab.

Automatic save and the procedure for deleting files are set up to help protect data from inadvertent replacement or loss.

Importing 1.x and 2.x M5100 SFRA Files

You can import data from M5100 versions 1.x and 2.x software by placing those files in the appropriate data source location. When opened, they will be parsed for content, converted to the new Doble SFRA format, and renamed with a different extension, so as not to be reconverted subsequently. Be sure to back up copies of these files as a precaution against data loss.

Nameplate data in M5100 versions 1.x and 2.x format is not easily converted to M5200/M5300/M5400 format. A number of fields are the same, such as Transformer Serial Number and Location, but the location of test leads may be less obvious. Check imported data for accuracy and details, with no odd characters in any field, such as @, *,? etc.

Transferring Data between Machines or PCs

To transfer data between machines or PCs, copy the desired files to a network or suitable medium and use Windows Explorer to navigate to them in the target machine.

The software will try to identify duplicate files but is not foolproof. Make sure to retain a backup when copying and importing data.

Settings Files

Settings files contain entered data for:

- Transformers
- Locations
- Test Organizations
- Test Equipment
- Test Templates

The files are in .xml format. To locate them on your computer, select Edit > Options. The Sweep Frequency Response Analyzer dialog box (Figure 2.35) displays the file paths.

To open a settings file, use a standard text editor such as Notepad. Do not use Microsoft Word or other word processors, because they will attempt to save files in their native formats, which are typically not compatible with SFRA software. This document assumes the use of Notepad.

Figure 2.39 displays a simplified view of a Transformer settings file that will be used to describe the file in detail.

Line #	XML Code
1	<?xml version="1.0" encoding="utf-8"?>
2	<transformerNameplates>
3	<transformerNameplate version="1">
4	<manufacturer>ABB</manufacturer>
5	<serialNumber>1234</serialNumber>
-	.
-	.
-	.
54	</transformerNameplate>
55	<transformerNameplate version="1">
56	<manufacturer>GE</manufacturer>
57	<serialNumber>xyz</serialNumber>
-	.
-	.
-	.
106	</transformerNameplate>
107	</transformerNameplates>

Figure 2.39 Simplified XML Transformer Settings File

NOTE

Line numbers apply only to this example—they will vary for other settings files. What is important is the xml start and end tags for each section.

- Line 1 is always the xml declaration that describes the xml version and encoding used. This must not be modified.
- Line 2 contains a start tag that is the beginning of the container of all transformers in the file. It must have a matching end tag (line 107).
- Line 3 contains the start tag of the first transformer nameplate and must also have an end tag (line 54).
- Line 55 shows the start of another transformer, which ends on line 106.
- If another transformer were added, it would appear after line 106 and before </transformerNameplates> on line 107.

Merging Settings Files

We will illustrate the merge procedure using an example. The method for merging transformer settings files described here applies to all other settings files.

NOTE



Use caution when merging, because an incorrect merge could corrupt your files and cause unpredictable results. Be especially careful to avoid duplicate entries in any settings file.

The manual merge described here is prone to cut-and-paste errors. Back up all data and settings files before performing a merge operation.

In this example, we look at two SFRA users who wish to share XML files.

Figure 2.40 shows a simplified transformer settings file from User A (as viewed in Notepad):

```
<?xml version="1.0" encoding="utf-8"?>
<transformerNameplates>
  <transformerNameplate version="1">
    <manufacturer>ABB</manufacturer>
    <serialNumber>1234</serialNumber>
  </transformerNameplate>
  <transformerNameplate version="1">
    <manufacturer>GE</manufacturer>
    <serialNumber>678</serialNumber>
  </transformerNameplate>
</transformerNameplates>
```

Figure 2.40 Transformer Settings File – User A

Figure 2.41 shows another simplified transformer settings file, this one from User B:

```
<?xml version="1.0" encoding="utf-8"?>
<transformerNameplates>
  <transformerNameplate version="1">
    <manufacturer>ACME</manufacturer>
    <serialNumber>9999</serialNumber>
  </transformerNameplate>
</transformerNameplates>
```

Figure 2.41 Transformer Settings File – User B

User A's file contains two transformers (underlined in the tables for clarity):

- ABB, with serial number 1234
- GE, with serial number 678

User B's file contains one transformer: ACME, with serial number 9999.

The safest method for merging is to combine the two files into a new file containing elements from both source files. The following procedure merges the contents into a new transformer settings file. It makes use of the fact that several versions of Notepad can be run simultaneously.

To merge settings files:

1. Back up all TransformerList.xml files.
2. Start an instance of Notepad and open User A's TransformerList.xml file.
3. Start another instance of Notepad and open User B's TransformerList.xml file.
4. Start a third instance of Notepad.
5. Select the entire text in User A's file and paste it into the blank Notepad.
6. Close User A's file.
7. Select just the **transformerNameplate** section from User B's file (Figure 2.42).

```
<transformerNameplate version="1">
  <manufacturer>ACME</manufacturer>
  <serialNumber>9999</serialNumber>
</transformerNameplate>
```

Figure 2.42 TransformerNameplate Section of User B's Settings File

8. Close User B's file.
9. In the remaining Notepad, place the cursor at the beginning of line 3 and paste the text.
10. Check that the file has the right format, with carriage returns and indents, to ensure readability of the document.
11. Save the file as TransformerList.xml.
12. Replace the existing TransformerList.xml file, either by saving the new file to in the default location or by dragging and dropping or copying using Windows Explorer.

Reports

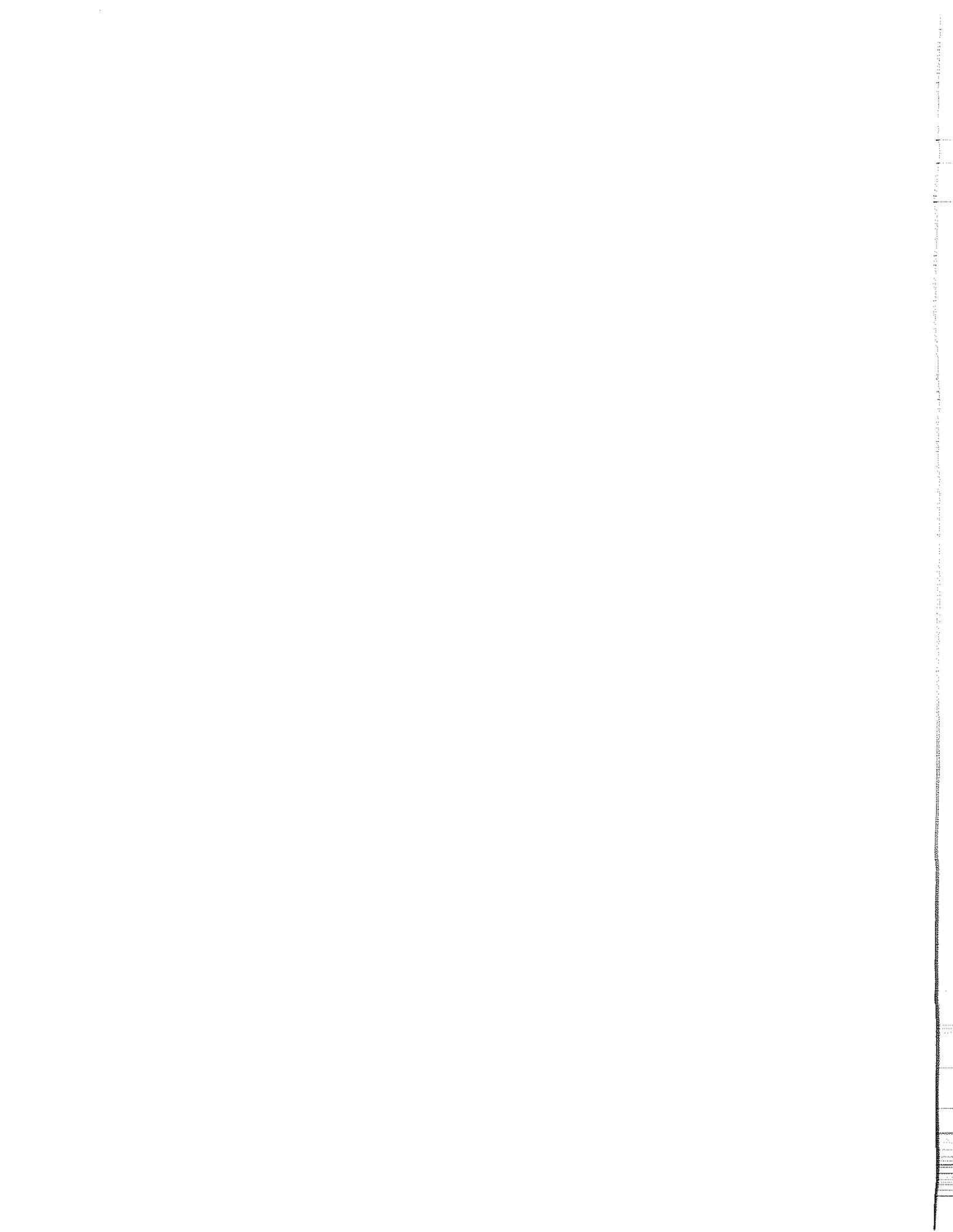
To display the report (print) format for the plot shown on the Magnitude tab, press Ctrl + Shift + P or select File > Print Preview.

Click the up or down arrow at the upper right corner of the Preview window (to the right of the Page field) to view each page.

Reports consists of two parts:

- The graph area, showing the traces on the graph that are checked in the Legend pane.

- The test details for each trace.



3. Testing

Preparation

Transformer

The transformer to be tested must be completely isolated from the power system. This requires that all bushings of all windings be disconnected from any bus and insulators. This ensures that measurements are not adversely affected by interference.

We wish to measure only the RLC network of the transformer. To maintain consistency and repeatability of measurements, all terminals not under test should be isolated and floating. To maintain a balanced and symmetrical approach, where a delta winding is completed and grounded external to the transformer tank, the delta should be complete but floating. Such windings are frequently used for regulation; where such windings are grounded internal to the tank, we are forced to leave that ground in place—but we should expect asymmetry in the results.

We could measure a frequency response with the remaining terminals grounded, but it could not be compared to a response measured with floating terminals, which would display a different RLC response.

SFRA Instrument

M5300

Turn on the power switch located on the front of the M5300.

The M5300 SFRA software should start automatically. If your system has been modified, double-click the SFRA icon or select Start > All Programs > Doble Engineering > SFRA.

The M5300 has a connector for an external video monitor, if desired. The monitors can be configured to run simultaneously or separately in the Windows Control Panel > Display.

M5200 or M5400 and PC

1. Power on the M5200 or M5400 without connecting it to the PC.

The power light should come on. Both LEDs come on, then go out, and finally the System OK LED comes on.

Make sure the SFRA software is installed on your PC's hard drive, not a network drive.

2. Turn off wireless connections and disable firewalls and antivirus software.

These restrictions do not apply if you wish to use the software in Viewer mode only, without communicating with an M5200 or M5400.

3. Double-click the SFRA desktop icon or select Start > Programs > Doble Engineering > SFRA to start the software.

4. When the Connect To Instrument dialog box appears (Figure 3.1), connect the M5200 or M5400 to the PC, using either the USB or Ethernet cable.

Earlier models were supplied with an Ethernet cable and a separate crossover adapter, which must be used for the instrument to function. Later models have the crossover built into the Ethernet cable.

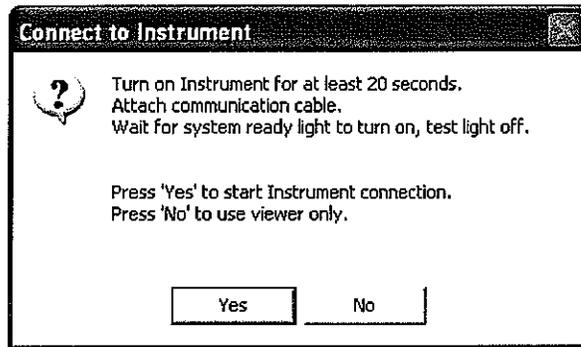


Figure 3.1 Connect to Instrument Dialog Box

5. Click Yes to connect to the M5200 or M5400 only if:
 - The M5200 or M5400 has been powered on.
 - The System OK LED is on and the Test In Progress LED is off.
 - The instrument is connected to the PC with a USB or crossover Ethernet cable.

The Select Instrument dialog box appears. The upper pane displays instruments located on the network or is blank if none were found (Figure 3.2).

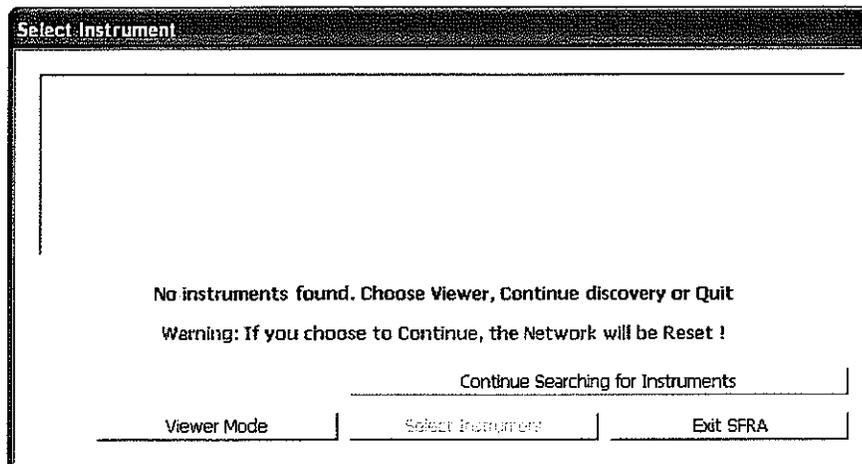


Figure 3.2 Select Instrument Dialog Box

If the PC is unable to locate the instrument:

- a. Check your connection to the instrument and your IP address (if using Ethernet).
- b. Click Continue Searching For Instruments.

You also have the option to use Viewer mode or exit SFRA.

6. When instruments appear, select the desired instrument.
7. Click Select Instrument.

If the PC can communicate with the instrument but cannot transfer data, the Connection Error dialog box appears (Figure 3.3). This can occur with a faulty cable connection or if a firewall or antivirus software is preventing communication.

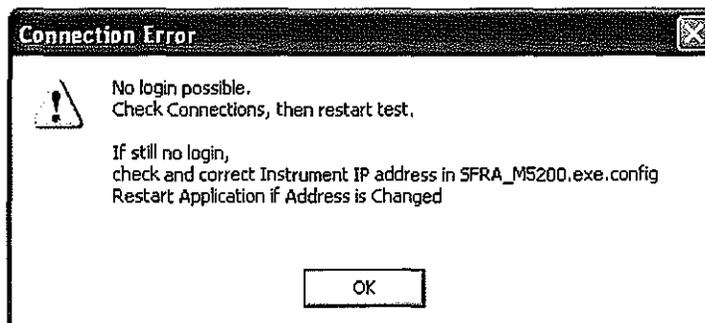


Figure 3.3 Connection Error Dialog Box

If the PC is unable to communicate with the M5200 or M5400, the Connection Not Attempted dialog box appears (Figure 3.4).

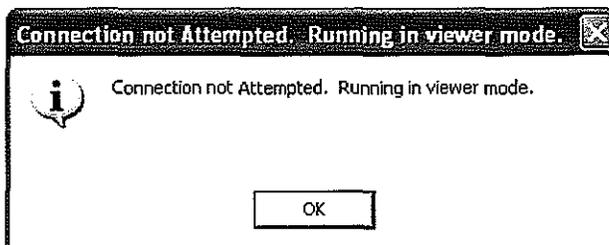


Figure 3.4 Connection Not Attempted Dialog Box

Test Leads

Checking Test Leads

1. Connect the test leads to the instrument; these are color-coded cables with BNC adapters.

NOTE



Test leads may be damaged through incorrect storage, mishandling in application, or accidental damage on site. It is important to check the status of the leads before performing a measurement. This can be done by a short-circuit leads test, as described in the next step.

2. Short the measurement clips (cable end) on the cables together, red to black, and the ground clips (middle of cable) together, red-green to black-green. Do not connect the measurement clips to the ground clips.

WARNING



To minimize the chance of the conductors becoming energized due to static electricity, Doble recommends attaching all leads to the instrument while the other ends of the leads are still on the ground. Attaching the leads to the transformer bushings first increases the risk of operator injury.

3. Perform a short-circuit measurement (see "Short Circuit" on p. 3-6).

The short-circuit lead response test verifies proper condition of the test specimen cable. Since there is no attenuation, signal loss between the Source/Reference and Measure, the resulting data graph plots along the 0 dB horizontal line as frequency increases, until an inductive rolloff occurs (Figure 3.5).

This rolloff is a feature of the cables, because of the 12 ft / 3.7 m ground connections. This rolloff is consistent for all tests and reduces the variability in response arising from variations in ground lead length. It is expected and acceptable.

4. Compare your result to the curve in Figure 3.5.

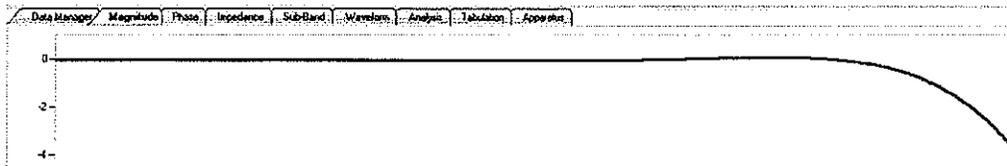


Figure 3.5 Short-Circuit Lead Response

5. If your result resembles Figure 3.6 rather than Figure 3.5, troubleshoot the leads for an open circuit.

Open-circuit behavior is around -90 to -100 dB but is clearly affected by noise and shows a lot of "hashing" compared to the short-circuit lead response. It is relatively easy to identify.

6. Connect the safety ground to the instrument and to the ground on the transformer.

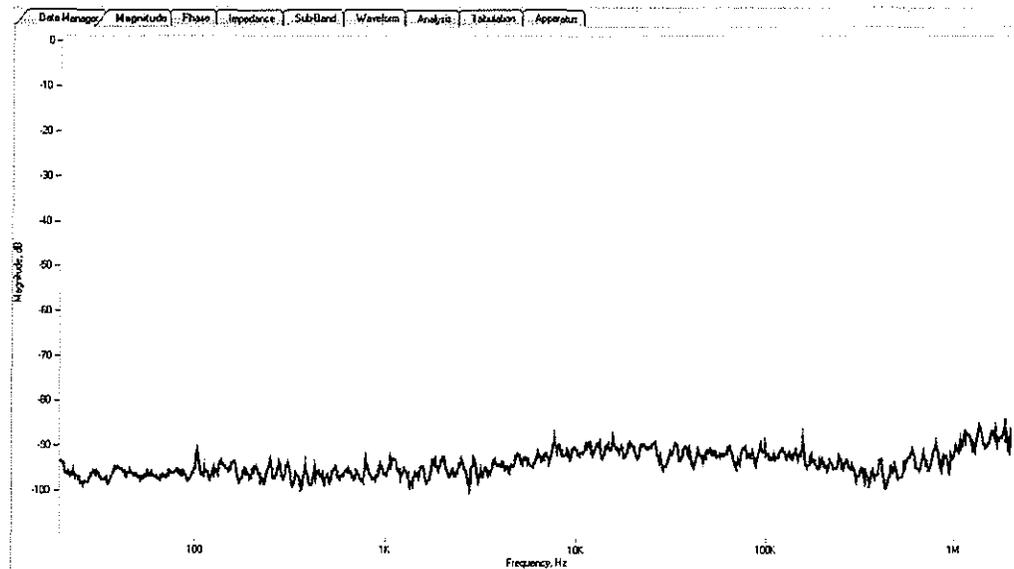


Figure 3.6 Open-Circuit Lead Response

Cable Length

The SFRA instrument uses RG-58 50-ohm impedance-matched test leads. The SFRA measurement requires a matched-impedance signal cable and performs a single-ended measurement—the signal with respect to the instrument ground. Thus, the shield of the signal cable must be connected to the chassis using RF BCN connectors.

Practical field experience dictates that leads be 60 ft / 18 m long. This has been selected as the minimum length required to test the largest transformers from a location on the ground adjacent to the unit. Nevertheless, lead length determines the maximum effective frequency. At 60 ft / 18 m, the cable approximates the wavelengths of the higher measurement frequencies, and probably little is gained from the 2–10 MHz scan. As long as the cable length is less than one-quarter of a wavelength, the short-cable approximation can be used. At lengths greater than one-quarter of a wavelength, phasing effects start to occur. It turns out that at 60 ft / 18 m, the frequency cutoff with respect to wavelength is approximately 2 MHz.

It is important to not only recognize any problems with cables but to be prepared to confirm a problem further—for example, by having an ohmmeter available if the instrument detects an open circuit in a cable. Connections to the apparatus must be contaminant-free metal-to-metal junctions. This assures not only reliable and efficient SFRA data collection but helps reduce the effects of noise and interference inherent in a substation environment. Remember that a bad connection to the apparatus can appear as an open-circuit cable.

Performing a Test

Connect test leads to the transformer according to the recommended tests in "Test Templates" on p. 3-6.

A test consists of three stages:

- Initiate the test (F2).

- Monitor the test progress.
- Test finishes or is aborted (F2).

It is important to monitor the test in progress, to make sure good data is being collected.

Response results appear as soon as the instrument begins to receive data. The software continues to plot results until the test is complete.

Powering Off the SFRA Instrument

- **M5200 and M5400.** Power off using the power switch.
- **M5300.** Shut down the M5300 using standard PC practice: Select Start > Shut Down.

Connections

Generally, an SFRA measurement is made from one terminal on the transformer (e.g., H1 or A) to another terminal (e.g., H2 or N).

It is important to record all relevant information, which includes tap position, oil level, and terminals grounded or shorted.

Where previous test results exist, the best testing procedure is to repeat those tests, taking note of tap position, shorted or grounded bushings, and any details for specific tests.

Doble is a key member of international bodies such as CIGRE and IEEE, which are pursuing FRA test standards. As standards develop, recommended tests may be changed with input from experienced users around the world. Doble will reflect those changes.

Measurement Types

Open Circuit

An open-circuit measurement is made from one end of a winding to another, with all other terminals floating. For a delta winding, connections would be H1 to H3, for example. For a star (wye) winding, measurements are taken from HV terminals to neutral, such as X1 to X0.

Short Circuit

A short-circuit measurement is made with the same SFRA test lead connections as an open-circuit measurement, but with the difference that another winding is short-circuited. To ensure repeatability, Doble recommends that the three voltage terminals on the shorted winding be shorted together. This would mean, for example, shorting X1 to X2, X2 to X3, and X3 to X1. This ensures that all three phases are similarly shorted, to give a consistent impedance. Any neutral connections available for the shorted winding should not be included in the shorting process.

Test Templates

The test templates given here require performing open-circuit and short-circuit tests.

A *standard* set of tests, recorded when a baseline is needed and there is no question of the transformer's health, consists of a set of results taken only at extreme tap position. Doble recommends that the LTC be in the extreme raise position. However, if the transformer is

being tested for post-event reasons, such as fault, this should be done in the as-found LTC position. Note the tap positions on the test report and apply them during the start of each test.

Doble recommends leaving the DETC in the as-found position. The DETC position should not be moved for an SFRA test until all options are exhausted. For new transformers in the factory, use the nominal DETC position, unless otherwise specified by the end-user.

Notes

- **Leads.** Each table gives the recommended tests with position of the red lead and black lead clearly identified. Reversing these test leads may provide small variations in higher-frequency response. Therefore, take care to attaching test leads appropriately.
- **Grounding.** Good grounds are key to good high frequency responses. Make sure grounds are not hampered by loose connections, paint, dirt, or grease.
- **LTC position.** Changing LTC will change SFRA response; LTC position should be recorded. At neutral tap, the previous tap position should also be recorded.
- **DETC position.** Transformers in service occasionally have problems due to DETC movement. Doble does not recommend altering the DETC position for an SFRA test. The exception is in factory tests on a new transformer, where it can be assumed that the DETC is in operating condition and tests can be performed on nominal tap.

Two-Winding Transformers

Table 3.1 Two-Winding Transformers – 9 Tests

Test Type	Test #	3 ϕ Delta- Wye	3 ϕ Wye- Delta	3 ϕ Delta- Delta	3 ϕ Wye- Wye	1 ϕ
HV Open Circuit (OC) All Other Terminals Floating	Test 1	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2(H0)
	Test 2	H2-H1	H2-H0	H2-H1	H2-H0	
	Test 3	H3-H2	H3-H0	H3-H2	H3-H0	
LV Open Circuit (OC) All Other Terminals Floating	Test 4	X1-X0	X1-X2	X1-X3	X1-X0	X1-X2 (X0)
	Test 5	X2-X0	X2-X3	X2-X1	X2-X0	
	Test 6	X3-X0	X3-X1	X3-X2	X3-X0	
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 7	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2(H0) Short X1-X2(X0) *
	Test 8	H2-H1	H2-H0	H2-H1	H2-H0	
	Test 9	H3-H2	H3-H0	H3-H2	H3-H0	

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for 3 ϕ wye connections but may be included for 1 ϕ test connections.

Autotransformers

Table 3.2 Autotransformer without Tertiary or with Buried Tertiary – 9 Tests

Test Type	Test #	3 ϕ	1 ϕ
Series Winding (OC) All Other Terminals Floating	Test 1	H1-X1	H1-X1
	Test 2	H2-X2	
	Test 3	H3-X3	
Common Winding (OC) All Other Terminals Floating	Test 4	X1-H0X0	X1-H0X0
	Test 5	X2-H0X0	
	Test 6	X3-H0X0	
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 7	H1-H0X0	H1-H0X0 Short [X1-H0X0]*
	Test 8	H2-H0X0	
	Test 9	H3-H0X0	

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for 3 ϕ wye connections but may be included for 1 ϕ test connections.

Three-Winding Transformers

Table 3.3 Three-Winding Transformer Table, Part 1 – 18 Tests

Test Type	Test #	3 ϕ Delta- Delta- Delta	3 ϕ Delta- Delta- Wye	3 ϕ Delta- Wye- Delta	3 ϕ Delta- Wye- Wye	1 ϕ
HV Open Circuit (OC) All Other Terminals Floating	Test 1	H1-H3	H1-H3	H1-H3	H1-H3	H1-H2 (H1-H0)
	Test 2	H2-H1	H2-H1	H2-H1	H2-H1	
	Test 3	H3-H2	H3-H2	H3-H2	H3-H2	
LV Open Circuit (OC) All Other Terminals Floating	Test 4	X1-X3	X1-X3	X1-X0	X1-X0	X1-X2 (X1-X0)
	Test 5	X2-X1	X2-X1	X2-X0	X2-X0	
	Test 6	X3-X2	X3-X2	X3-X0	X3-X0	

Table 3.3 Three-Winding Transformer Table, Part 1 – 18 Tests

Tert Open Circuit (OC) All Other Terminals Floating	Test 7	Y1-Y3	Y1-Y0	Y1-Y3	Y1-Y0	Y1-Y2 (Y1-Y0)
	Test 8	Y2-Y1	Y2-Y0	Y2-Y1	Y2-Y0	
	Test 9	Y3-Y2	Y3-Y0	Y3-Y2	Y3-Y0	
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 10	H1-H3	H1-H3	H1-H3	H1-H3	H1-H0 Short [X1-X2]*
	Test 11	H2-H1	H2-H1	H2-H1	H2-H1	
	Test 12	H3-H2	H3-H2	H3-H2	H3-H2	
Short Circuit (SC) High (H) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 13	H1-H3	H1-H3	H1-H3	H1-H3	H1-H0 Short [Y1-Y2]*
	Test 14	H2-H1	H2-H1	H2-H1	H2-H1	
	Test 15	H3-H2	H3-H2	H3-H2	H3-H2	
Short Circuit (SC) Low (L) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 16	X1-X3	X1-X3	X1-X0	X1-X0	X1-X0 Short [Y1-Y2]*
	Test 17	X2-X1	X2-X1	X2-X0	X2-X0	
	Test 18	X3-X2	X3-X2	X3-X0	X3-X0	

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for 3 ϕ wye connections but may be included for 1 ϕ test connections.

Table 3.4 Three-Winding Transformer Table, Part 2 – 18 Tests

Test Type	Test #	3 ϕ Wye- Wye- Wye	3 ϕ Wye- Wye- Delta	3 ϕ Wye- Delta- Wye	3 ϕ Wye- Delta- Delta
HV Open Circuit (OC) All Other Terminals Floating	Test 1	H1-H0	H1-H0	H1-H0	H1-H0
	Test 2	H2-H0	H2-H0	H2-H0	H2-H0
	Test 3	H3-H0	H3-H0	H3-H0	H3-H0
LV Open Circuit (OC) All Other Terminals Floating	Test 4	X1-X0	X1-X0	X1-X2	X1-X2
	Test 5	X2-X0	X2-X0	X2-X3	X2-X3
	Test 6	X3-X0	X3-X0	X3-X1	X3-X1
Tert Open Circuit (OC) All Other Terminals Floating	Test 7	Y1-Y0	Y1-Y2	Y1-Y0	Y1-Y2
	Test 8	Y2-Y0	Y2-Y3	Y2-Y0	Y2-Y3
	Test 9	Y3-Y0	Y3-Y1	Y3-Y0	Y3-Y1
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 10	H1-H0	H1-H0	H1-H0	H1-H0
	Test 11	H2-H0	H2-H0	H2-H0	H2-H0
	Test 12	H3-H0	H3-H0	H3-H0	H3-H0
Short Circuit (SC) High (H) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 13	H1-H0	H1-H0	H1-H0	H1-H0
	Test 14	H2-H0	H2-H0	H2-H0	H2-H0
	Test 15	H3-H0	H3-H0	H3-H0	H3-H0
Short Circuit (SC) Low (L) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 16	X1-X0	X1-X0	X1-X2	X1-X2
	Test 17	X2-X0	X2-X0	X2-X3	X2-X3
	Test 18	X3-X0	X3-X0	X3-X1	X3-X1

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for wye connections.

Examples

In this section we give typical results from a number of transformer windings and designs. These are examples of how results vary between transformers – both designs and phases.

Three Responses for One Transformer

Figure 3.7 shows the two open-circuit responses and the short-circuit response of one phase of an autotransformer. The three traces are clearly quite different at low frequencies.

Typically, the HV response starts at a much lower level than the LV response. The short-circuit response approaches 0 dB at low frequency but comes back in line with the HV response at higher frequencies.

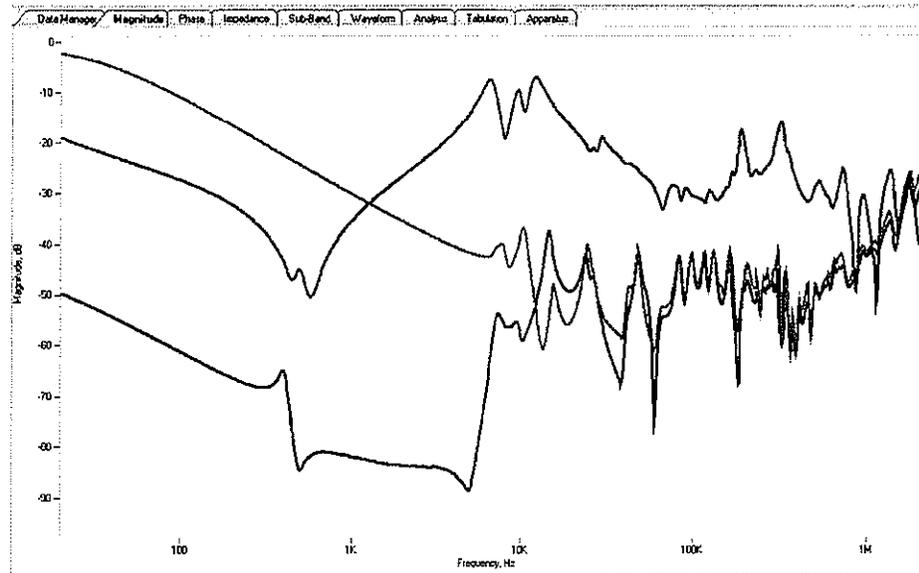


Figure 3.7 Responses for One Phase of a Transformer – Open Circuit HV (Blue), Open Circuit LV (Red), and Short Circuit (Green)

HV Delta Response

Figure 3.8 shows the responses for three phases of a HV delta winding. This is a characteristic response at low frequencies:

- The center phase has a slightly higher impedance (more negative response) at lower frequencies.
- The center phase is different from the outer phases at the first resonance below 10 kHz.
- The center phase is similar to the outer phases as frequency rises.
- All three phases have the same basic shape above about 100 kHz.

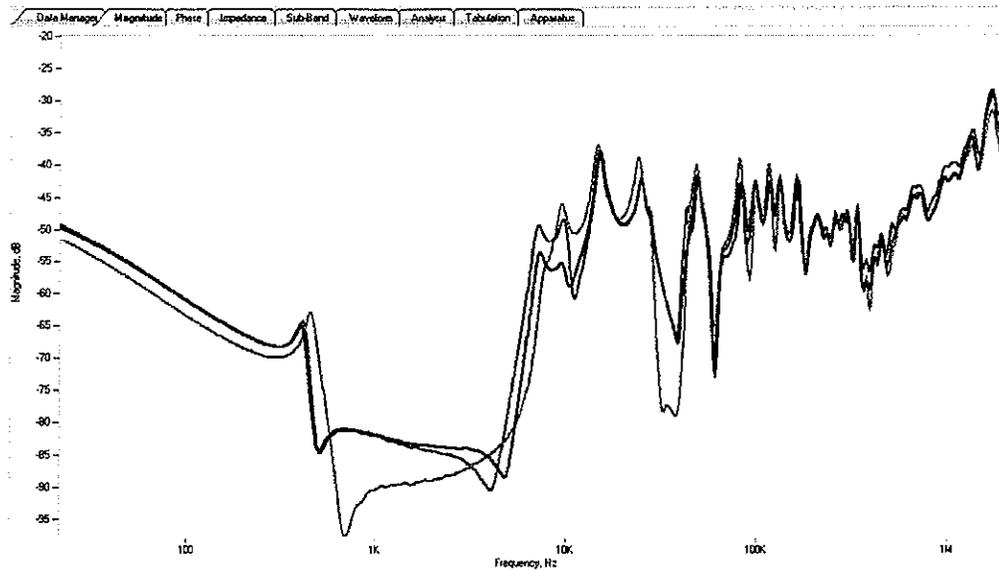


Figure 3.8 HV Delta Winding Responses

HV Wye (Star) Response

Figure 3.9 shows a typical HV wye (star) winding response. All three phases show similar responses at low frequencies, with the following characteristics:

- The center phase has a slightly increased impedance (more negative dB) at low frequencies.
- The center phase has one resonance and the outer phases two resonances below about 1 kHz.
- The outer phases are similar at low frequencies.
- The three phases “come back together” as frequencies rise toward 10 kHz.
- The three phases show regions of similarity and regions of dissimilarity across the frequency range.

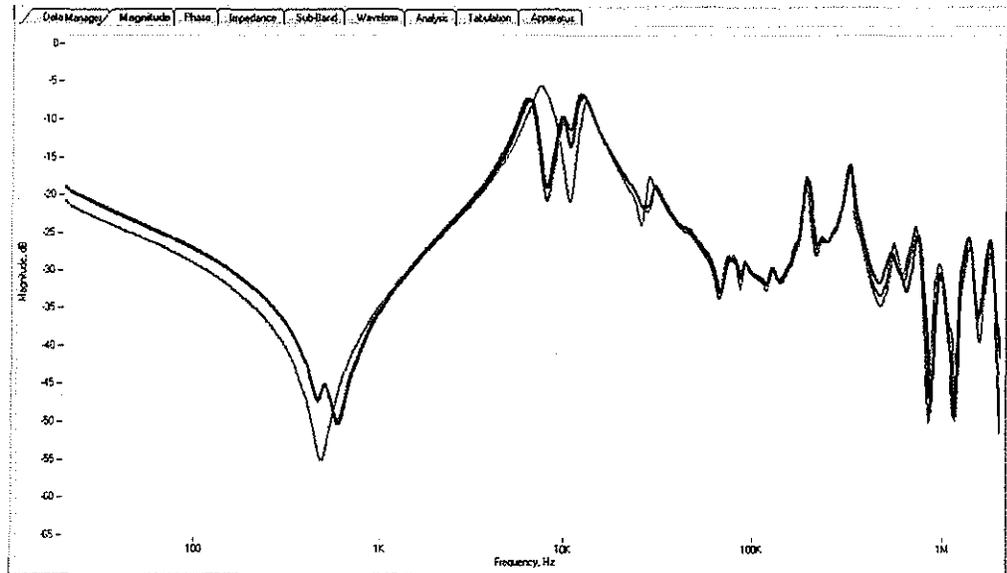


Figure 3.9 HV Wye Winding Response

Short-Circuit Test Response

Figure 3.10 shows the three short-circuit responses from the HV side of a transformer. Clearly, the responses are similar, which is what we would expect from this test.

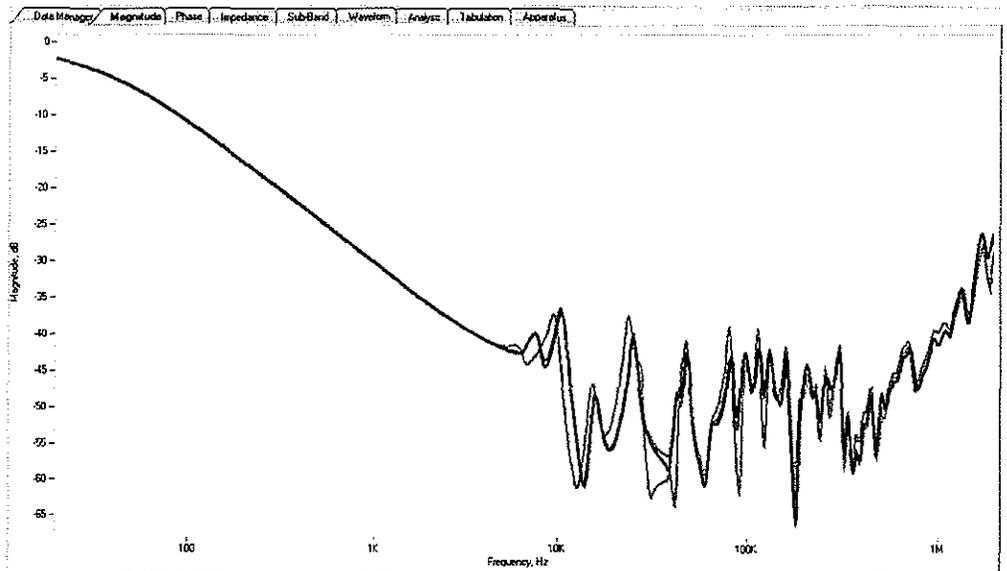


Figure 3.10 Short-Circuit Test Response

Even when we zoom in on the responses (Figure 3.11), they are still quite similar. This is a useful diagnostic where no previous results are available.

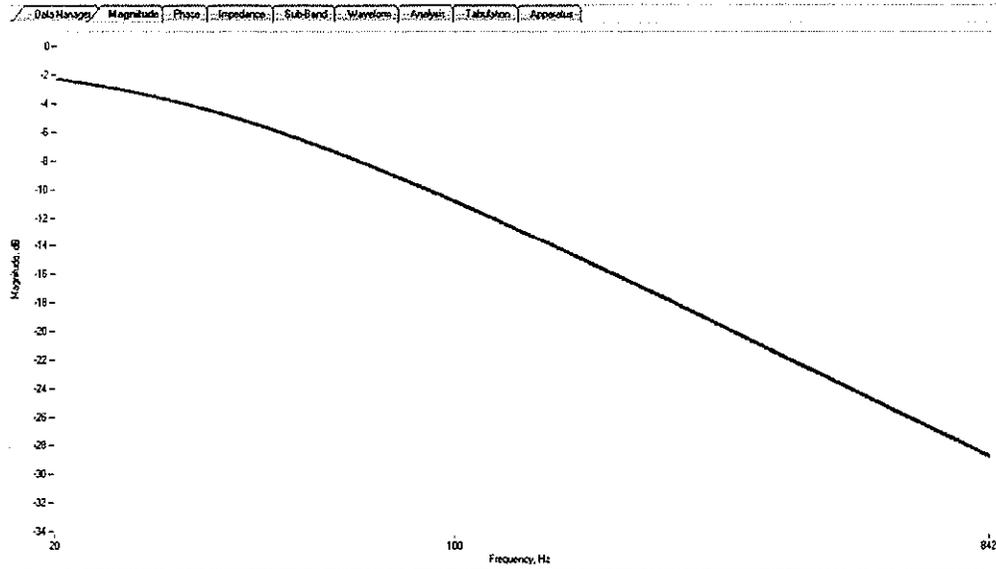


Figure 3.11 Short Circuit Response – Detail

Repeat Results for One Phase at Different Times

The two responses in Figure 3.12 were taken 18 months apart. The original data was taken as a baseline set of results; the subsequent data was taken after an incident involving the transformer. The results are similar.

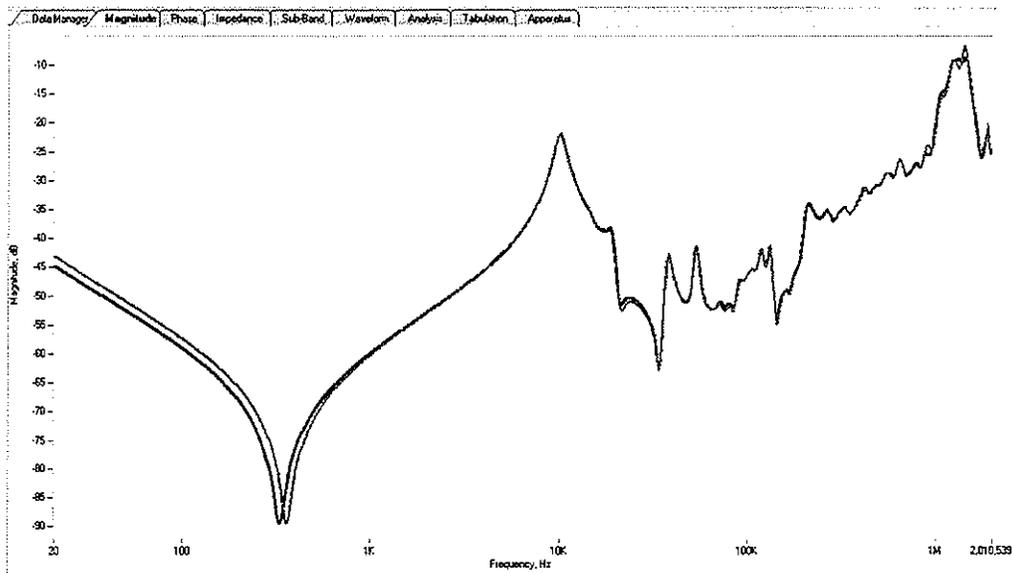


Figure 3.12 Repeat Results for One Phase

Low-frequency variation, below about 5 kHz, is characteristic of core magnetism affecting the results. The traces have the same basic shape, but one is offset compared to the other. They come back into line as we approach 10 kHz.

The higher-frequency results are almost identical. This is strong evidence that there has been no change in this transformer.

Results Showing a Shorted Turn

A shorted turn produces an effect similar to shorting the low-side windings for a short-circuit measurement. The effect is easy to see at low frequencies and does not require reference results.

The original results show the characteristic low-frequency response of a wye (star) winding. The subsequent results, taken a year later after a close-in fault, show the characteristic response of a short somewhere on that phase.

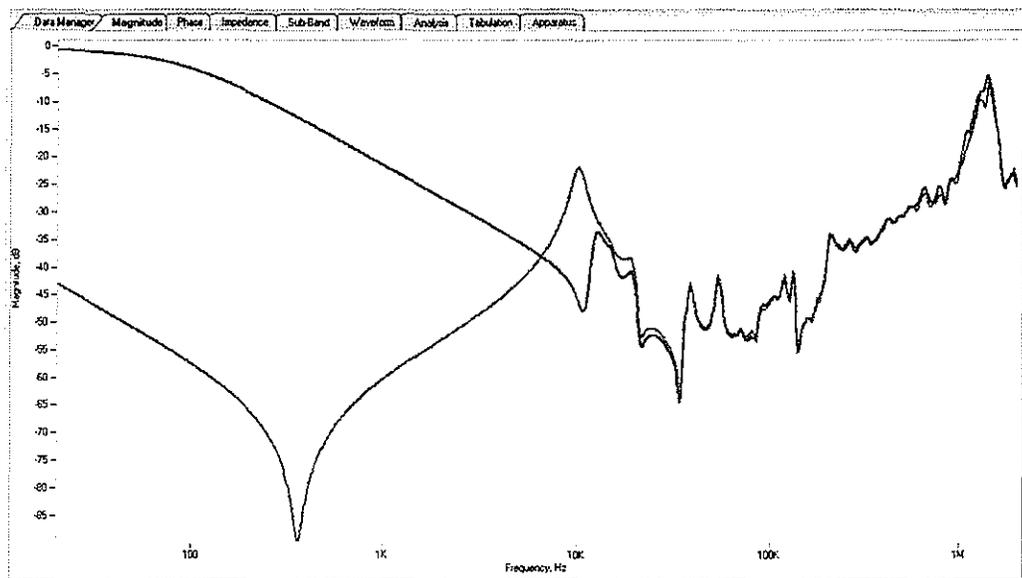
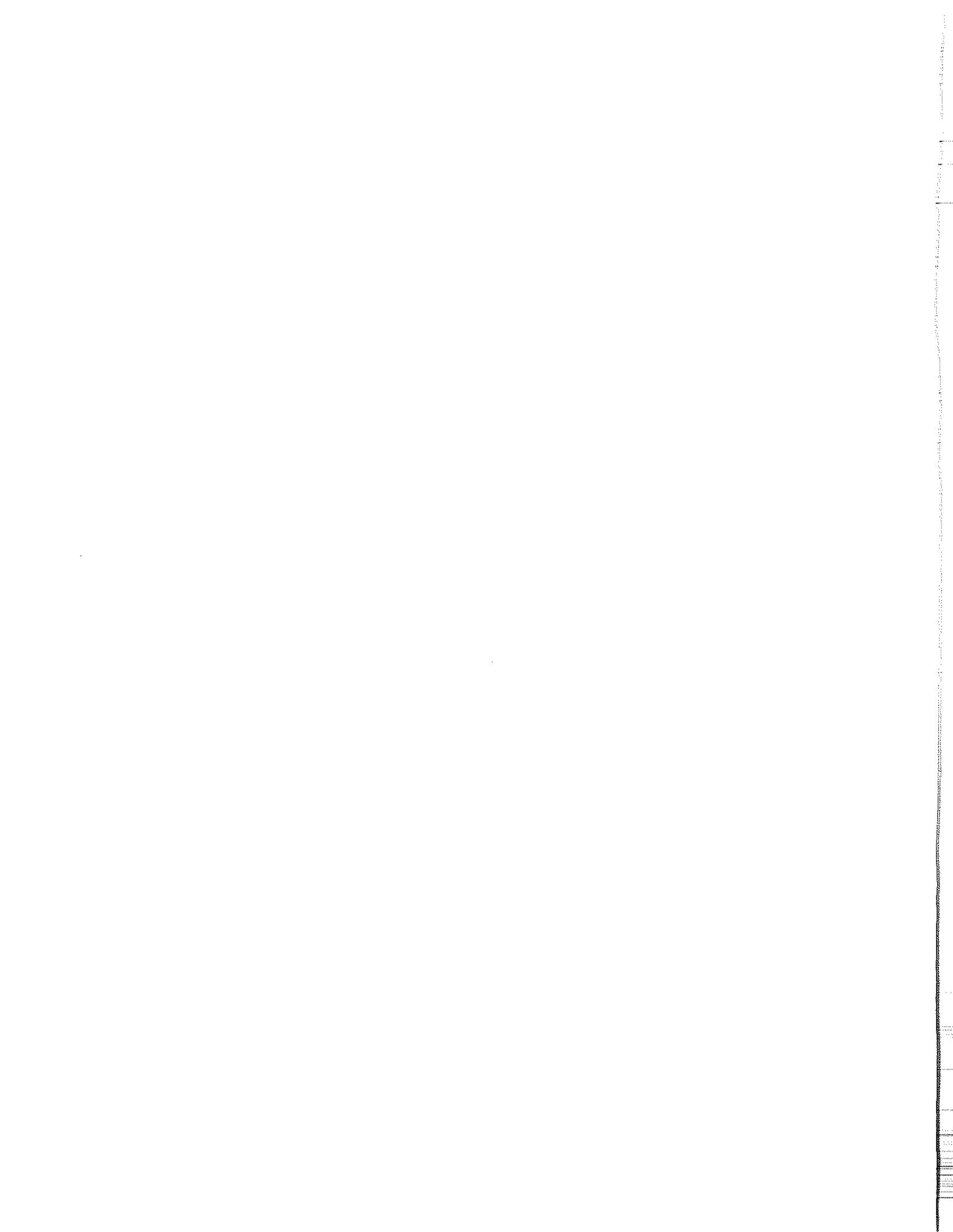


Figure 3.13 Shorted Turn on One Winding



4. Analysis

M5000 Software

The Analysis tab (Figure 4.1) allows you to compare the overlapping ranges of two traces. For example, if one trace is 10 Hz to 2 MHz and the other is 20 Hz to 10 MHz, the analysis covers 20 Hz to 2 MHz—the higher of the lower values to the lower of the higher values. The upper pane displays the two traces you select; the lower pane displays the difference between them. You can perform a difference analysis or a correlation analysis.

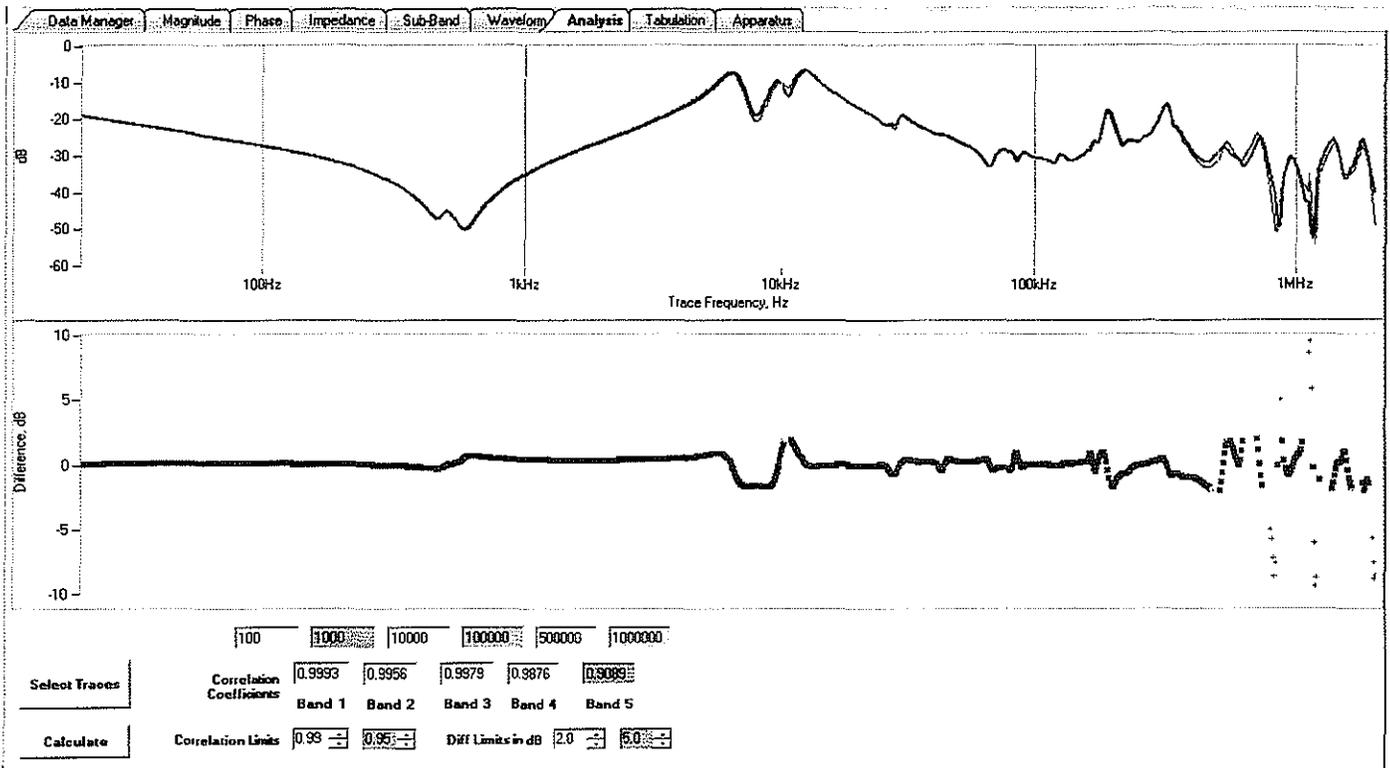


Figure 4.1 Analysis Tab

To select traces for analysis:

1. Click Select Traces.
The Select Traces dialog box appears (Figure 4.2).
2. Check the boxes for the two traces you wish to analyze.
3. Click OK.

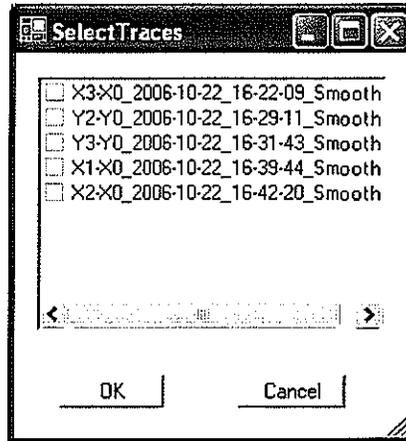


Figure 4.2 Select Traces Dialog Box

Difference Analysis

The difference plot displays the difference between the two traces, using limits you set in the Diff Limits In dB section to color the result. In Figure 4.1, for example, the lower limit (yellow field) is set at 2.0 dB, and the upper limit (red field) is set at 5.0 dB. Therefore, a difference of less than 2.0 dB appears on the difference plot in dark green; a difference between 2.0 dB and 5.0 dB appears in yellow, and a difference of more than 5.0 dB appears in red.

After entering the desired limits in the Diff Limits In dB fields, click Calculate to display the difference plot with the new settings.

Correlation Analysis

You can perform correlation analysis on subsections of the two traces. Cross-correlation coefficients appear in the Analysis tab when two results are compared. The results can range from -1 to 1, where 1 indicates a perfect comparison, -1 indicates inversion, and 0 indicates that the two results are orthogonal.

1. Set the cursor position for a correlation band by clicking and dragging the cursor or by entering the desired value in the corresponding Cursor Position field.
The cursor for each band corresponds to the background color of that field. The values of the correlation coefficients for each range appear in the Correlation Coefficients fields.
2. Set the correlation coefficient limits in the Correlation Limits fields.
3. If you move a cursor or change the correlation limit values, click Calculate to display the new correlation values.

Analysis Discussion

Limits have not yet been set on an acceptable variation for difference between two traces on the same transformer at a given frequency; likewise, limits have not been set on acceptable differences in correlation coefficient in a given frequency range. Both are areas where the international SFRA community is currently undertaking research. Doble is involved in the latest research and submissions to international standards organizations such as IEEE and CIGRE.

Frequency-Dependent Transformer Equivalent Circuit

The power-transformer equivalent circuit is a complicated network of distributed resistive, capacitive, and inductive elements. These include:

- Capacitance between the neighboring turns of the same winding
- Capacitance between the turns of different windings
- Capacitance between the turns and the ground.
- Turns self-inductance
- Turns mutual inductance
- Conductor DC resistance.
- Resistance that accounts for dielectric losses in insulation
- Resistance that accounts for eddy losses in conducting and magnetic components

Depending on the test lead connection, the equivalent circuit involved in the measurement represents an individual phase of the winding, the space between phases in a winding, or the space between 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, and 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 manufacturing shop to replicate units 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.

Since reactance of capacitive and inductive elements is frequency-dependent, each element's contribution to the overall network impedance varies with frequency, making the equivalent circuit unique at each frequency. Therefore, the signature that represents the changing continuum of the network impedance with frequency uniquely describes the geometry of the core-winding configuration for a given unit and carries a wealth of diagnostic information.

The network impedance, which is the ratio of the output and input signals, is often referred to as the *transfer function*. Sweep frequency response analysis (SFRA) uses the transfer function behavior over the specified range of frequencies as the transformer's diagnostic signature. Transfer function, as a complex variable, is described by the magnitude and the phase angle.

Diagnostic Significance of Frequency Ranges

Diagnostics of frequency ranges are discussed on two levels: per-phase open-circuit measurement and short-circuit measurement.

Per-Phase Open-Circuit Measurement

As the name implies, per-phase measurement targets the individual phase of a 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 the inductive and resistive nature of the network.

The inductive characteristics are determined by the magnetic circuit of the core, and the resistive characteristics are dominated by the resistance of the output measuring cable.

Figure 4.3 and Figure 4.4 are examples of transfer-function magnitude and phase for a per-phase measurement.

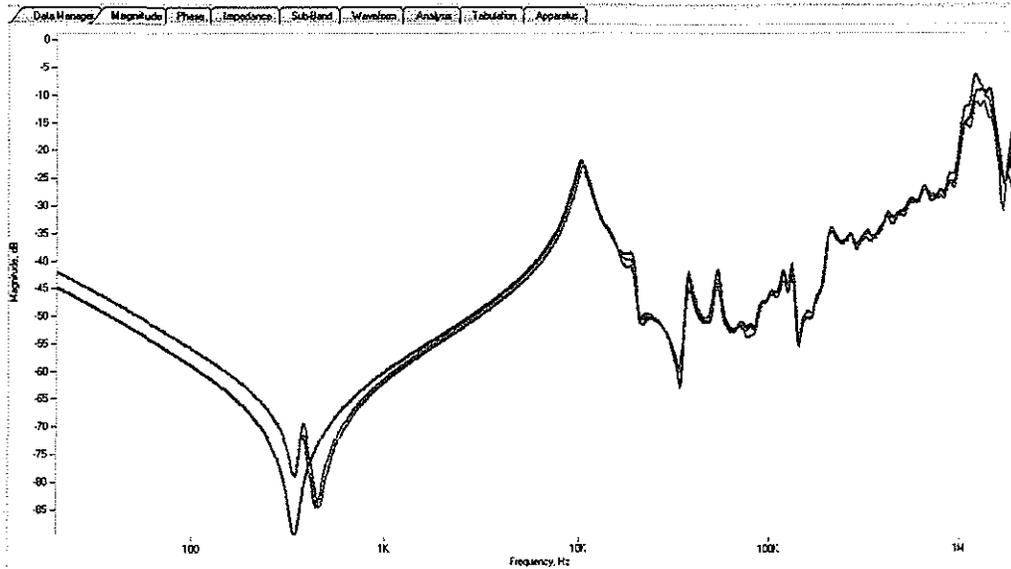


Figure 4.3 Per-Phase Measurement – Magnitude of the Transfer Function

In Figure 4.4, the phase angle is about 80 degrees, indicating the inductive nature of the total impedance (in the region below 1 kHz). For a three-legged core-type unit, the magnetic flux coupled with the outer phase (H1-H3 or H3-H2 in Figure 4.3) faces a different reluctance than the flux coupled with the middle phase (H2-H1 in Figure 4.3).

Therefore, the corresponding magnitude traces, in the low-frequency range, differ as well—i.e., the traces for the two outer phases correlate closely and are shifted from the middle-phase trace. The presence of the residual magnetism may 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.

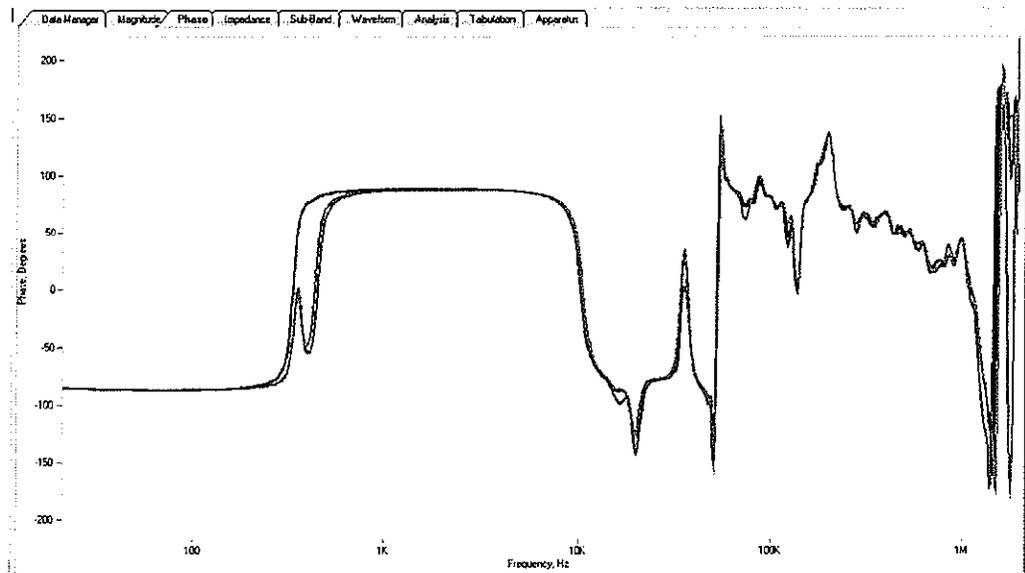


Figure 4.4 Per-Phase Measurement – Phase of the Transfer Function

As the frequency of the input signal increases, the capacitive effects begin to dominate and the phase angle quickly becomes close to +90 degrees (in the region above 1 kHz). 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 the 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 found in the high-frequency range. However, since the winding responses become less dependent 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 100 kHz in Figure 4.4), 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 the design of the unit. Therefore, the frequency ranges noted in the description of Figure 4.3 and Figure 4.4 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.

Taking a measurement on one winding with another winding short-circuited removes the effect of the core at low frequencies. The resulting response is that for a large inductor with no core. The responses for all three phases should be similar at low frequencies.

The theory behind the short-circuit measurement is straightforward:

Any two-winding transformer can be modeled at low frequencies by a simple T model (Figure 4.5).

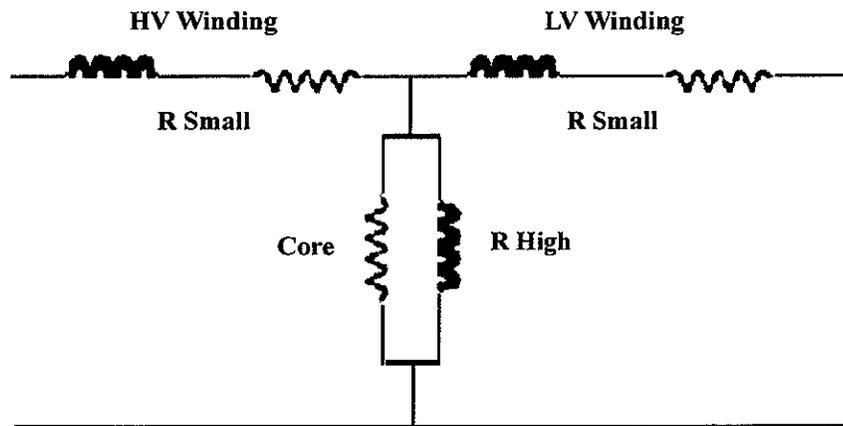


Figure 4.5 T Model of Transformer Winding

The impedance of the windings is small, while the impedance of the core to ground is extremely high. This means that for any input signal, the response is dominated by the core. By adding a short to 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 rolloff as frequency rises (Figure 4.6).

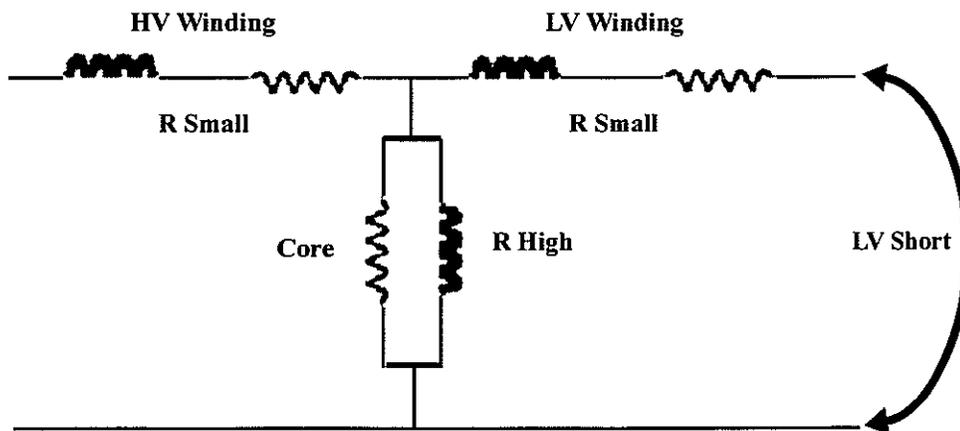


Figure 4.6 T Model with LV Short

All three phases of a transformer have similar winding inductances, which means their responses should be similar. See the next section for examples of the use of the short-circuit response for diagnostic purposes.

Analysis of Test Data

Initial Measurement

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

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, bear in mind that for many windings, the disposition of internal connections between windings, bushings and tap-changers may necessitate minor design differences that could introduce small differences between phases in the frequency response. Therefore, for the initial measurement, if you observe minor differences between phases, 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 reference data for each other.

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

Subsequent Measurement

For subsequent measurements, analyze traces for changes between the initial and subsequent response. Considerations described for the initial measurement apply here also.

Low-frequency variations usually relate to core effects, including residual magnetism, which may provide variation between responses.

Higher frequencies, above 1 MHz, may be affected by grounding quality. This is easy enough to identify but must be considered as a cause of variation.

Other Diagnostic Measurements

Each FRA diagnostic measurement has failure modes to which it is most sensitive as its *purpose in life*. Therefore, understanding the significance of each measurement and knowing its associated failure modes is essential for a successful diagnostic investigation. Table 4.1 relates typical failure modes with various diagnostic measurements. This table also shows that no single method can cover the multitude of problems occurring in transformers.

Table 4.1 Diagnostic Tests

Failure Type	Failure Mechanism	Failure Mode	Diagnostic Measurement

Table 4.1 Diagnostic Tests

Windings	Electromagnetic forces caused by overcurrent conditions change the geometry of the winding, thus changing the measured leakage reactance.	Winding distortion	FRA, leakage reactance
	Insulation failure creates a circuit coupled with the main flux. The resulting circulating current creates a load component in the measured exciting current and loss.	Turn-to-turn winding failure: <ul style="list-style-type: none"> • One or more turns are short-circuited completely. • Two or more parallel strands of different turns are short-circuited. 	FRA, exciting current and loss, DGA
	Insulation failure creates a circuit coupled with the leakage flux. The resulting circulating current contributes a load component to the measured leakage loss.	Strands within the same turn are short-circuited.	Leakage loss, DGA
LTC Contacts	Contact problems affect the current circulating through the preventive autotransformer in bridging positions. The change in the circulating current influences the load components of the exciting current and the loss measured in the bridging positions.	Misalignment, mechanical problems, coking and wear of LTC and DETC contacts	Exciting current and loss, DGA
DETC Contacts	Contact problems change the resistance of the current path.	Misalignment, mechanical problems, coking and wear of LTC and DETC contacts	DC winding resistance, DGA
Conductors	Movement of conductors results in the breaking of strands and the deterioration of terminations changing the resistance of the current path.	Open circuit, broken strands, termination problems	Exciting current and loss, DC winding resistance, DGA
Core	Movement or over excitation of the magnetic system creates a circuit coupled with the main flux. The resulting circulating current contributes a load component to the measured exciting current and loss.	Overheating due to (abnormal) circulating currents in the core, clamping components and through multiple core grounds	FRA, exciting current and loss
Miscellaneous	Moisture, aging, contaminants, poor maintenance, and manufacturing defects leads to insulation deterioration.	Dielectric breakdown of insulation	Power factor and capacitance (including measurements on bushings), oil tests, DGA

5. Troubleshooting

Field Repairs

There are no user-maintainable parts in the M5000 instruments. For support, contact Doble customer service at 617-926-4900 or email customerservice@doble.com.

In case of a severe problem, your Doble technical support team may recommend removing one of the boards in the instrument to return to Doble. This is a simple process, but take appropriate precautions to prevent electrostatic buildup and discharge damage to the boards:

1. Disconnect the instrument from the power supply.
2. Remove power leads and test cables.
3. Remove the main cover.
4. Disconnect the power supply from the input connector on front panel
5. Unscrew the main circuit board assemblies, complete with power supplies.

Before returning any defective modules to Doble, call or email Doble customer service to receive an RMA number. Return the main modules in padded and protective packaging.

The shipping address is:

Customer Service Manager
Doble Engineering Company
85 Walnut Street
Watertown, MA 02472-4037
USA

Replacement Parts

A number in the Qty column of a table indicates the number shipped with each unit. Contact Doble Customer Service to order replacement parts.

M5200 and M5400

Table 5.4 lists cables and adapters used with the M5200 and M5400. If a system failure is traced to a cable, ensure that the cable is properly seated and connected before replacing it.

Table 5.1 M5200 and M5400 Cable and Adapter Shipping/Replacement List

Qty	Description	Part No.
1	Bag, Cable, Large	2FB-3449-01

Table 5.1 M5200 and M5400 Cable and Adapter Shipping/Replacement List

1	Cable, Ground, 30 ft / 9 m, M4K / M2H / MEU	02C-0019-01
1	Cable, RJ45 / Cat 5E, Crossover, 7 ft / 2 m	181-0646
1	Cable, Specimen Test, 60 ft / 18 m	05B-0659-04
	Cable, Specimen Test, 100 ft / 30 m	05B-0659-05
1	Cable, USB, A/B, 6 ft / 1.8 m	181-0585
1	Clip, Battery, Solid Copper, 400A	212-0444
1	Cord, Power	Country-specific

Table 5.5 lists other components shipped with the M5200 and M5400.

Table 5.2 M5200 and M5400 Additional Components

Qty	Description	Part No.
1	CD, SFRA, Product Information	08A-0151-01
1	CD, SFRA Software	08A-0152-01
	Fuse	Littlefuse 312 001P Fast Blo, 3AG Glass Cartridge UI and CSA certified or equivalent M5400: Littlefuse 0.75 Amp, 250 V, Slo-Blo, 3AG, Qty 2
1	SFRA Quick-Start Guide	500-0545
1	SFRA User Guide	500-0590

M5300

Table 5.3 lists part numbers for field-replaceable components.

Table 5.3 M5300 Field-Replaceable Components

Qty	Description	Part No.
1	Assembly, PCB $\pm 15V$ Converter	04S-0852-01
1	CPU Module Assembly	03D-1633-01
1	CPU PC Board	401-0292
1	Fan	380-0055
1	Front Panel Assembly	03D-1632-01
1	High-Density Drive, 20 GB IDE	401-0063
	Fuse	Littlefuse 312 01.5P Fast Blo, 3AG Glass Cartridge UI and CSA certified or equivalent
1	Power Supply +5V, $\pm 12V$ Output	384-0216
1	PPC4/Analog Module Assembly	03D-1631-01
1	USB Keyboard	401-0295

Table 5.4 lists cables and adapters used with the M5300. If a system failure is traced to a cable, ensure that the cable is properly seated and connected before replacing it.

Table 5.4 M5300 Cable and Adapter Shipping/Replacement List

Qty	Description	Part No.
1	Bag, Cable, Large	2FB-3449-01
1	Cable, Ground, 30 ft / 9 m, M4K / M2H / MEU	02C-0019-01
1	Cable, Specimen Test, 60 ft / 18 m	05B-0659-04
	Cable, Specimen Test, 100 ft / 30 m	05B-0659-05
1	Clip, Battery, Solid Copper, 400A	212-0444
1	Cord, Power	Country-specific

Table 5.5 lists other components shipped with the M5300.

Table 5.5 M5300 Additional Components

Qty	Description	Part No.
1	CD, SFRA, Product Information	08A-0151-01
1	CD, SFRA Software	08A-0152-01
	Fuse	Littlefuse 312 01.5P Fast Blo, 3AG Glass Cartridge UI and CSA certified or equivalent
1	SFRA Quick-Start Guide	500-0545
1	SFRA User Guide	500-0590
1	Software, Win XP, OEM Package	401-0196

Appendix A. References

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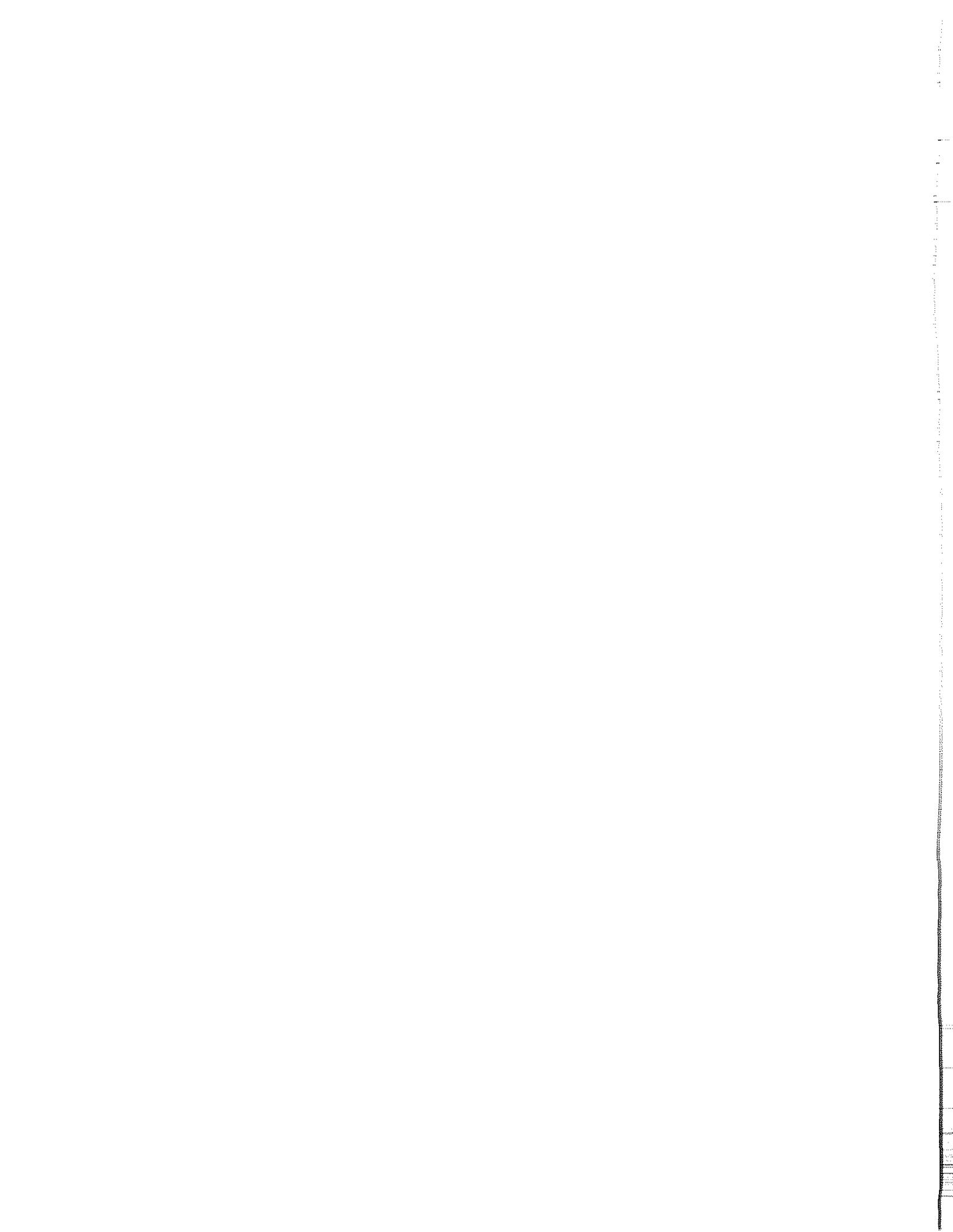
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Appendix B. M5200/M5300/M5400

Technical Specifications

Excitation Source	
Channels	1
Frequency Range	10 Hz to 25 MHz
Output Voltage	20 V peak-to-peak at 50 ohms
Output Protection	Short-circuit protected
Source Impedance	50 ohms
Calibration Interval	2 years
Measurement Channels	
Channels	2
Sampling	Simultaneous
Frequency Range	10 Hz to 25 MHz
Max. Sampling rate	100 MS/s
Input Impedance	50 ohms
Calibration Interval	2 years
Data Collection	
Test Method	Sweep frequency
PC Communication	USB/Ethernet
Frequency Range	10 Hz to 25 MHz
Number of Points	1000 (default); up to 1800 (extended range)
Point Spacing	1.2% logarithmic
Dynamic Range	>90 dB
Repeatability	±1 dB to -80 dB
IF Bandwidth	< 10% of active frequency

Appendix B: M5200/M5300/M5400 Technical Specifications

Data Display	
Scaling	Linear/Log
Frequency Range	10 Hz to 25 MHz, user-defined within frequency range
Plotting	Frequency vs. magnitude / phase
Analysis	Difference, Sub-band cross-correlation
Physical Specifications	
Dimensions	M5200: 10.0 H x 16.0 W x 15.5 D in. / 25 H x 41 W x 40 D cm M5300: 10.0 H x 16.0 W x 15.5 D in. / 25 H x 41 W x 40 D cm M5400: 18.2 H x 13.4 W x 6.7 D in. / 46.2 H x 34.0 W x 17.0 D cm
Weight	M5200: 14.6 lb / 6.6 kg M5300: 22.5 lb / 10.2 kg M5400: 13.1 lb / 6.0 kg
Power	115–230 VAC, 50/60 Hz
Current	M5200: 1 Amp M5300: 1 Amp M5400: 0.5 Amp
Temperature	Operating: 0° to 50° C / 32° to 122° F Storage: -25° to +70° C / -13° to 158° F
Relative Humidity	0–95% non-condensing
Test Lead Construction	
Integrated three-lead system in single cable set	Standard (≤ 362 kV): 60 ft / 18 m Optional (> 362 kV): 100 ft / 30 m
PC Requirements	
M5200 and M5400	Minimum configuration: <ul style="list-style-type: none"> • Ethernet/USB • Windows 2000 or XP • 500 MHz processor • 256 MB RAM • 20 MB hard-drive free space • DVD-RW
M5300	Built-in PC configuration: <ul style="list-style-type: none"> • Windows XP • Intel Celeron 1.3 GHz • Minimum 512 MB RAM • Minimum 40 GB HDD

The M5200 and M5300 come with a carrying strap for easy transportation. The M5400 case has a handle.

Specifications are subject to change without notice.



Appendix B: M5200/M5300/M5400 Technical Specifications



Sweep Frequency Response Analyzer (SFRA) Quick Start Guide



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Sweep Frequency Response Analyzer (SFRA) Quick Start Guide

This Quick Start Guide shows how to take good measurements using a Doble M5200, M5300, or M5400 Sweep Frequency Response Analyzer.

Preparing the Transformer

Disconnect all bushings and windings from any connecting busses and/or insulators. Terminals not under test should be isolated and floating unless otherwise specified.

CAUTION



The transformer under test must be completely de-energized and isolated from the system. Follow your own company rules, policies, and government regulations to ensure safety of personnel and property. The transformer and the M5000 instrument must share a common ground or earthing point.

Connecting the Leads

M5000 Connections

M5000 instruments and leads are configured for use as in Figure 3. Ensure that the cables are connected to the instrument according to the color-coded BNC connections. You can perform a test-lead integrity check if desired (see the *SFRA User Guide*).

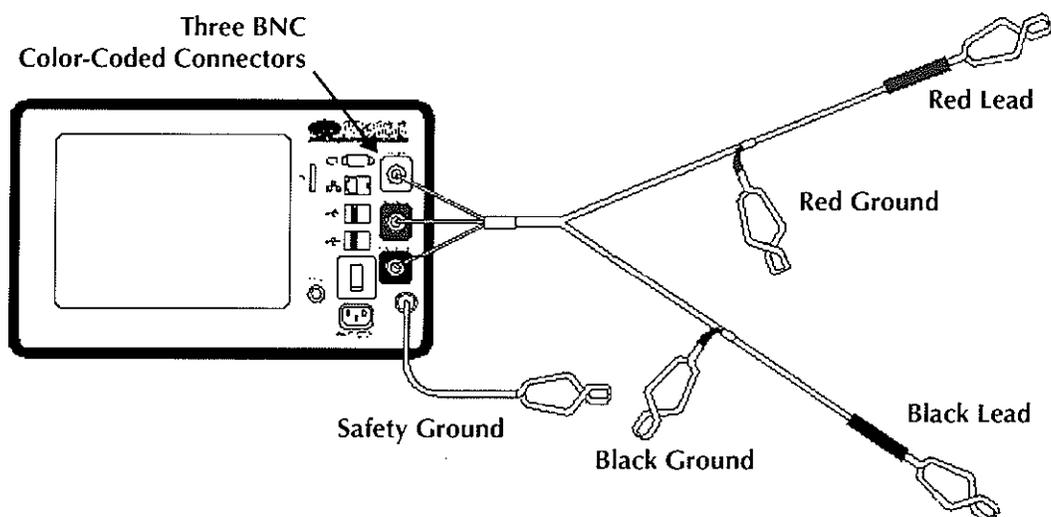


Figure 1. M5300 Connections (M5200 and M5400 Similar)

Transformer Connections

Make good electrical connections at bushing terminals and at the base of bushings; clean, file, or wire-brush connection points if necessary.

When making short-circuit measurements, ensure that all three phases are solidly shorted: 1 to 2, 2 to 3, and 3 back to 1.

When running a test on a transformer winding—for example, H1-H0—attach the red lead to the H1 bushing and the black lead to the H0 bushing (Figure 2).

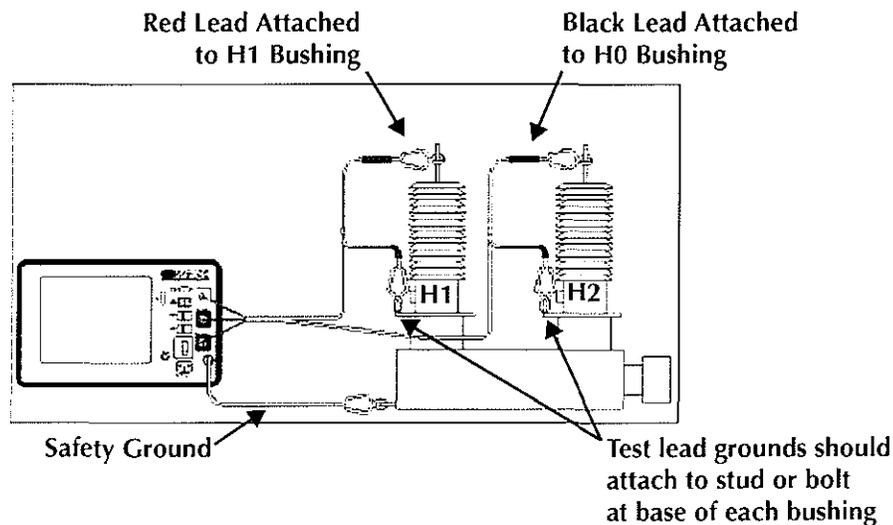


Figure 2. Connecting Leads to the Transformer to Measure H1-H0

CAUTION



When connecting leads to a transformer, ensure that you attach the lead grounds to a stud or bolt at the base of the bushing and that good electrical contact is established and maintained.

Changing tap position or DETC position or removing core ground connections will give different SFRA results. Therefore, where previous results are available, take new measurements in a manner consistent with previous results.

Table 1 through Table 4 show test connections for some common transformer designs; the red lead is the first of the two named terminals. For further designs, see the *Doble Test Connections Guide*.

Two-Winding Transformers

Table 1. Two-Winding Transformers – 9 Tests

Test Type	Test #	3 ϕ Delta- Wye	3 ϕ Wye- Delta	3 ϕ Delta- Delta	3 ϕ Wye- Wye	1 ϕ
HV Open Circuit (OC) All Other Terminals Floating	Test 1	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2(H0)
	Test 2	H2-H1	H2-H0	H2-H1	H2-H0	
	Test 3	H3-H2	H3-H0	H3-H2	H3-H0	
LV Open Circuit (OC) All Other Terminals Floating	Test 4	X1-X0	X1-X2	X1-X3	X1-X0	X1-X2 (X0)
	Test 5	X2-X0	X2-X3	X2-X1	X2-X0	
	Test 6	X3-X0	X3-X1	X3-X2	X3-X0	
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 7	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2(H0) Short X1-X2(X0)*
	Test 8	H2-H1	H2-H0	H2-H1	H2-H0	
	Test 9	H3-H2	H3-H0	H3-H2	H3-H0	

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for 3 ϕ wye connections but may be included for 1 ϕ test connections.

Autotransformers

Table 2. Autotransformer without Tertiary or with Buried Tertiary – 9 Tests

Test Type	Test #	3 ϕ	1 ϕ
Series Winding (OC) All Other Terminals Floating	Test 1	H1-X1	H1-X1
	Test 2	H2-X2	
	Test 3	H3-X3	
Common Winding (OC) All Other Terminals Floating	Test 4	X1-H0X0	X1-H0X0
	Test 5	X2-H0X0	
	Test 6	X3-H0X0	
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 7	H1-H0X0	H1-H0X0 Short [X1-H0X0]*
	Test 8	H2-H0X0	
	Test 9	H3-H0X0	

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for 3 ϕ wye connections but may be included for 1 ϕ test connections.

Three-Winding Transformers

Table 3. Three-Winding Transformer Table, Part 1 – 18 Tests

Test Type	Test #	3 ϕ Delta- Delta- Delta	3 ϕ Delta- Delta- Wye	3 ϕ Delta- Wye- Delta	3 ϕ Delta- Wye- Wye	1 ϕ
HV Open Circuit (OC) All Other Terminals Floating	Test 1	H1-H3	H1-H3	H1-H3	H1-H3	H1-H2 (H1-H0)
	Test 2	H2-H1	H2-H1	H2-H1	H2-H1	
	Test 3	H3-H2	H3-H2	H3-H2	H3-H2	
LV Open Circuit (OC) All Other Terminals Floating	Test 4	X1-X3	X1-X3	X1-X0	X1-X0	X1-X2 (X1-X0)
	Test 5	X2-X1	X2-X1	X2-X0	X2-X0	
	Test 6	X3-X2	X3-X2	X3-X0	X3-X0	
Tert Open Circuit (OC) All Other Terminals Floating	Test 7	Y1-Y3	Y1-Y0	Y1-Y3	Y1-Y0	Y1-Y2 (Y1-Y0)
	Test 8	Y2-Y1	Y2-Y0	Y2-Y1	Y2-Y0	
	Test 9	Y3-Y2	Y3-Y0	Y3-Y2	Y3-Y0	
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 10	H1-H3	H1-H3	H1-H3	H1-H3	H1-H0 Short [X1-X2]*
	Test 11	H2-H1	H2-H1	H2-H1	H2-H1	
	Test 12	H3-H2	H3-H2	H3-H2	H3-H2	
Short Circuit (SC) High (H) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 13	H1-H3	H1-H3	H1-H3	H1-H3	H1-H0 Short [Y1-Y2]*
	Test 14	H2-H1	H2-H1	H2-H1	H2-H1	
	Test 15	H3-H2	H3-H2	H3-H2	H3-H2	
Short Circuit (SC) Low (L) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 16	X1-X3	X1-X3	X1-X0	X1-X0	X1-X0 Short [Y1-Y2]*
	Test 17	X2-X1	X2-X1	X2-X0	X2-X0	
	Test 18	X3-X2	X3-X2	X3-X0	X3-X0	

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for 3 ϕ wye connections but may be included for 1 ϕ test connections.

Table 4. Three-Winding Transformer Table, Part 2 – 18 Tests

Test Type	Test #	3 ϕ Wye- Wye- Wye	3 ϕ Wye- Wye- Delta	3 ϕ Wye- Delta- Wye	3 ϕ Wye- Delta- Delta
HV Open Circuit (OC) All Other Terminals Floating	Test 1	H1-H0	H1-H0	H1-H0	H1-H0
	Test 2	H2-H0	H2-H0	H2-H0	H2-H0
	Test 3	H3-H0	H3-H0	H3-H0	H3-H0
LV Open Circuit (OC) All Other Terminals Floating	Test 4	X1-X0	X1-X0	X1-X2	X1-X2
	Test 5	X2-X0	X2-X0	X2-X3	X2-X3
	Test 6	X3-X0	X3-X0	X3-X1	X3-X1
Tert Open Circuit (OC) All Other Terminals Floating	Test 7	Y1-Y0	Y1-Y2	Y1-Y0	Y1-Y2
	Test 8	Y2-Y0	Y2-Y3	Y2-Y0	Y2-Y3
	Test 9	Y3-Y0	Y3-Y1	Y3-Y0	Y3-Y1
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 10	H1-H0	H1-H0	H1-H0	H1-H0
	Test 11	H2-H0	H2-H0	H2-H0	H2-H0
	Test 12	H3-H0	H3-H0	H3-H0	H3-H0
Short Circuit (SC) High (H) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 13	H1-H0	H1-H0	H1-H0	H1-H0
	Test 14	H2-H0	H2-H0	H2-H0	H2-H0
	Test 15	H3-H0	H3-H0	H3-H0	H3-H0
Short Circuit (SC) Low (L) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 16	X1-X0	X1-X0	X1-X2	X1-X2
	Test 17	X2-X0	X2-X0	X2-X3	X2-X3
	Test 18	X3-X0	X3-X0	X3-X1	X3-X1

* Indicates short-circuit tests where the terminals are shorted together with three sets of jumpers, to provide symmetry (X1-X2, X2-X3, X3-X1) OR (Y1-Y2, Y2-Y3, Y3-Y1). The neutral is not included for wye connections.

Setting Up the SFRA Software

M5300

Turn on the power switch located on the front of the M5300.

The M5300 SFRA software should start automatically. If your system has been modified, double-click the SFRA icon or select Start > All Programs > Doble Engineering > SFRA.

M5200 or M5400 and PC

1. Power on the M5200 or M5400 without connecting it to the PC.
The power light should come on. Both LEDs come on, then go out, and finally the System OK LED comes on.
Make sure the SFRA software is installed on your PC's hard drive, not a network drive.
2. Turn off wireless connections and disable firewalls and antivirus software.
These restrictions do not apply if you wish to use the software in Viewer mode only, without communicating with an M5200 or M5400.
3. Double-click the SFRA desktop icon or select Start > Programs > Doble Engineering > SFRA to start the software.
4. When the Connect To Instrument dialog box appears (Figure 3), connect the M5200 or M5400 to the PC, using either the USB or Ethernet cable.
Earlier models were supplied with an Ethernet cable and a separate crossover adapter, which must be used for the instrument to function. Later models have the crossover built into the Ethernet cable.



Figure 3. Connect to Instrument Dialog Box

5. Click Yes to connect to the M5200 or M5400 only if:
 - The M5200 or M5400 has been powered on.
 - The System OK LED is on and the Test In Progress LED is off.
 - The instrument is connected to the PC with a USB or crossover Ethernet cable.

The Select Instrument dialog box appears. The upper pane displays instruments located on the network or is blank if none were found.

If the PC is unable to locate the instrument:

- a. Check your connection to the instrument and your IP address (if using Ethernet).
- b. Click Continue Searching For Instruments.
You also have the option to use Viewer mode or exit SFRA.

6. When instruments appear, select the desired instrument.
7. Click Select Instrument.

If the PC can communicate with the instrument but cannot transfer data, the Connection Error dialog box appears. This can occur with a faulty cable connection or if a firewall or antivirus software is preventing communication.

If the PC is unable to communicate with the M5200 or M5400, the Connection Not Attempted dialog box appears.

Running a Test

You can perform a test only with an M5300 or with a PC connected to an M5200 or M5400; it is not possible to perform a test in Viewer mode without an instrument.

To run a test:

Select Apparatus

1. Click Select Apparatus in the Apparatus And Test pane on the left.
2. In the Apparatus Selection dialog box, select the transformer to be tested, the Location, the Test Organization, and the Test Equipment.
3. Click OK.

Select Test

4. Click Select Test in the Apparatus and Test pane.
5. In the Test Selection dialog box, select the desired test.
6. Click OK.
7. In the Apparatus and Test pane, select the purpose and oil level conditions from the dropdown menus.

Start Test

8. Click Start Test, press F2, or select Test Init > Start Test.
9. In the Test Details dialog box, enter the location of the red and black test leads.
Trace Name is a combination of the red and black lead locations. If no test template has been selected, the fields are blank.
10. Click Run Test.

The minimum details required for each test are:

- Manufacturer, serial number, location
- HV/LV/TV, MVA, impedance
- LTC and DETC ranges and nominal position
- LTC and DETC positions during test
- Red and black lead locations
- Bushings grounded
- Bushings shorted

Typical Results

Correct use of the instrument and test leads will result in measurements similar to those in Figure 4 and Figure 5. These plots show results for all three phases of a transformer.

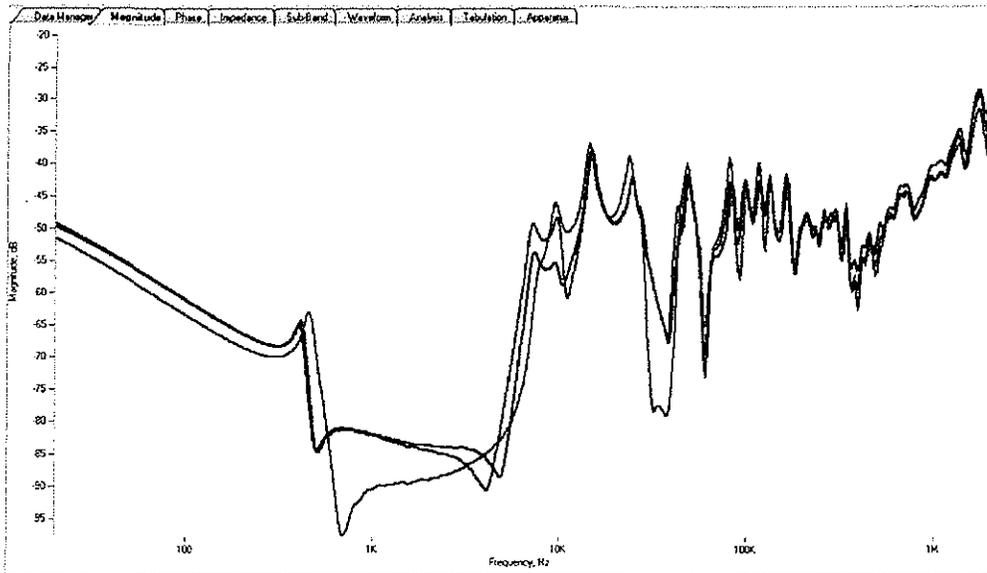


Figure 4. Typical HV Delta Winding Response

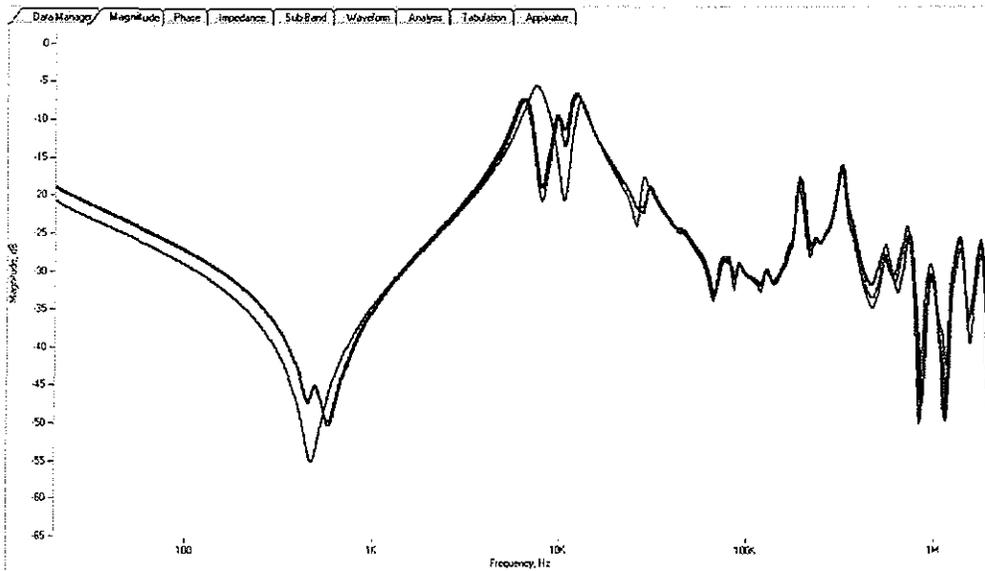


Figure 5. Typical HV Wye Winding Response