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Annexture: SFRA measurment Procedure for Transformer

1.0 Test Setup of SFRA Measurement :

The sweep frequency method for making FRA (SFRA) measurements, the wide range of required frequencies is generated via a sweep of individual sinusoidal signals injected into one terminal. The magnitude of the excitation source remains constant for all frequencies used for the test.
An SFRA measurement is a simple measurement to make. Inject a voltage signal at one end of a winding and measure the voltage response at the other end of the winding. Repeat the measurement at many input frequencies and plot the results in dB (a ratio of output voltage to input voltage).

The frequency response method is the ratio of the transmitted waveform to the applied low voltage waveform, which varies with frequency. The impedance attenuates the input voltage signal. A series of measurements are made to obtain the response at various frequencies.

SFRA plots are the ratio of the transmitted voltage waveform (V_{out}) to the applied voltage waveform (V_{in}) in decibels (dBs). The response in dBs is calculated as $20Log_{10}(V_{out}/V_{in})$. The basic circuit is described in Figure 1. A three lead system is used to measure both the input and output voltages simultaneously as well as apply the input signal. Fifty ohm coaxial test leads are used to apply the input signal and measure V_{in} and V_{out}. These impedances are matched to the measurement hardware to minimize waveform distortions caused by reflections. This ensures good repeatability.

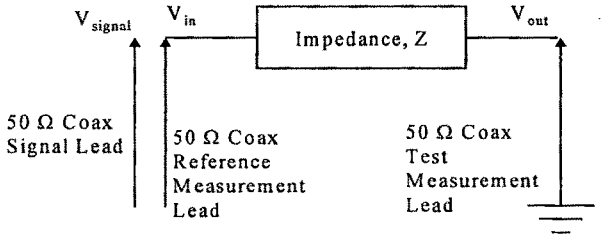


Figure 1. SFRA Voltage Measurements

An SFRA test requires:

- a voltage input to a winding (the Signal)
- the voltage measured at the winding input (Reference)
- the voltage measured at the output from the winding (Test)

Any transformer under test should be completely isolated from any high voltage source or power system source. The transformer tank should be grounded.

Three leads are used:

- Excitation "source" (Yellow color)
- Specimen Input "reference" (Red color)
- Specimen Output "measure" (Black color)

An example of the connections for an H1-H0 terminal measurement are given in Figure 2.

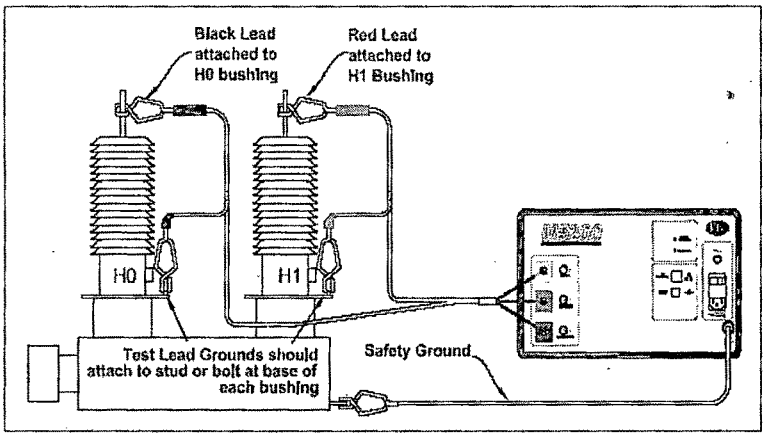


Figure 2. Overview of SFRA Measurement Connections

The input voltage and the voltage measurements are made with respect to ground, usually provided by the flange of the bushings under test, as shown in Figure 2.

2.0 Type of SFRA Measurement :

The SFRA test involves measuring the frequency responses of each individual winding. The frequency response is measured by injecting a sine wave signal with respect to earth at one end of winding to be tested and measuring the signal amplitudes there and at other end of the winding. The attenuation (in dB) of the transmitted signal relative to reference signal at the input terminal is measured over a frequency range from 20 Hz to 2 MHz.

2.1 Measurement of Open circuit SFRA plot of winding:

Open-circuit configurations are used to describe measurements made on a winding with all other windings complete and floating. The Open Circuit test can be applied to both single phase and three phase transformers. Open Circuit tests generally fall into 5 winding categories: High Voltage, Low Voltage, Tertiary, Series, and Common. The Series and Common categories are applied to auto-transformers as shown in Table 1 below.

TABLE 1 – OPEN CIRCUIT SFRA PLOT FOR AUTOTRANSFORMER WITH TERTIARY

Sr. No.	Test winding	FRA connections
1	HV – LV winding (HV-LV) Open circuit SFRA plot **HV terminals- H1,H2,H3,H0** **LV terminals- X1,X2,X3,X0**	Signal injected in "HV " bushing Terminal with respect to earth and measured at "LV" bushing terminal with respect to earth.
2	HV winding (HV-N) Open circuit SFRA plot **HV terminals- H1,H2,H3,H0**	Signal injected in "HV " bushing Terminal with respect to earth and measured at "N" bushing terminal with respect to earth.
3	Common winding (LV-N) Open circuit SFRA plot **LV terminals- X1,X2,X3,X0**	Signal injected in "LV " bushing Terminal with respect to earth and measured at "N" bushing terminal with respect to earth.
4	Tertiary winding (Tertiary1-Tertiary 2) Open circuit SFRA plot **Tertiary terminals- Y1,Y2,Y3**	Signal injected in "Tertiary1 " bushing Terminal with respect to earth and measured at "Tertiary2" bushing terminal with respect to earth.

- All other bushings were floating and not connected to ground during the individual measurement.

2.2 Measurement of Short circuit SFRA plot of winding:

Short-circuit Self Admittance are used to describe measurements made on a winding with one or more windings shorted. The short circuit self admittance measurement is made from one end of a high voltage winding to another while the low voltage winding is shorted. For repeatability purposes, it is recommended that all low voltage windings are shorted on three phase transformers to create a three phase equivalent short circuit model. Any available neutral connections should not be included in the shorting process.The Short Circuit Self Admittance test isolates the winding impedance from the core effects properties at or around the fundamental power frequency. The Short Circuit results should produce similar and comparable diagnostic information as seen in both leakage reactance and DC winding resistance measurements. The auto-transformers Short circuit SFRA measurment are shown in Table 2 below.

TABLE 2 –SHORT CIRCUIT SFRA PLOT AUTOTRANSFORMER WITH TERTIARY

Sr. No.	Test winding	FRA connections
1	HV winding Short circuit SFRA plot	Signal injected in "HV " bushing Terminal with respect to earth and measured at "N" bushing terminal with respect to earth. Terminal X1-X2-X3 shorted for the test.
2	HV winding Short circuit SFRA plot	Signal injected in "HV " bushing Terminal with respect to earth and measured at "N" bushing terminal with respect to earth. Terminal Y1-Y2-Y3 shorted for the test.
3	LV winding (Common winding) Short circuit SFRA plot	Signal injected in "LV " bushing Terminal with respect to earth and measured at "N" bushing terminal with respect to earth. Terminal Y1-Y2-Y3 shorted for the test.

- All other bushings were floating and not connected to ground during the individual measurement.

3.0 SFRA Test Configurations:

All windings of the transformer should be tested as per the test configuration tables shown below for various Type of Transformers. The tables are as follows:

TABLE 3 - TWO WINDING TRANSFORMERS
TABLE 4 - AUTOTRANSFORMER W/O TERTIARY
TABLE 5 - AUTOTRANSFORMER WITH TERTIARY
TABLE 6 - THREE WINDING TRANSFORMER

TABLE 3 - TWO WINDING TRANSFORMERS

Test Type	Test #	3φ Δ-Y Group 2 θ ⇒ 30° LAG	3φ Y-Δ Group 2 θ ⇒ 30° LAG	3φ Δ-Δ Group 1 θ ⇒ 0°	3φ Y-Y Group 1 θ ⇒ 0°	1φ
HV Open Circuit (OC) Self Admittance Terminals Floating	Test 1	H1-H3	H1-H0	H1-H3	H1-H0	H1-H2 (H1-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) Self Admittance Terminals Floating	Test 4	X1-X0	X1-X2	X1-X3	X1-X0	X1-X2 (X1-X0)
	Test 5	X2-X0	X2-X3	X2-X1	X2-X0	
	Test 6	X3-X0	X3-X1	X3-X2	X3-X0	
Short Circuit (SC) Self Admittance	Test 7	H1-H3	H1-H0	H1-H3	H1-H0	H1-H0 Short
	Test 8	H2-H1	H2-H0	H2-H1	H2-H0	

Short [X1-X2-X3]*	Test 9	H3-H2	H3-H0	H3-H2	H3-H0	[X1-X2]*
Inter-Winding (IW)	Test 10	H1-X1	H1-X1	H1-X1	H1-X1	H1-X1
Inter-Winding Admittance	Test 11	H2-X2	H2-X2	H2-X2	H2-X2	
All Terminals Float	Test 12	H3-X3	H3-X3	H3-X3	H3-X3	
Transfer Admittance (TA)	Test 13	H1-X1	H1-X1	H1-X1	H1-X1	H1-X1
High (H) to Low (L)	Test 14	H2-X2	H2-X2	H2-X2	H2-X2	Ground
Ground (H- and X-)	Test 15	H3-X3	H3-X3	H3-X3	H3-X3	[H2, X2]

*Indicates short circuit tests: terminals are shorted together. The neutral is not included for 3ϕ Wye connections, but may be included for 1ϕ test connections.

TABLE 4 - AUTOTRANSFORMER W/O TERTIARY

Test Type	Test #	3ϕ	1ϕ
Series Winding (OC)	Test 1	H1-X1	H1-X1
All Other Terminals Floating	Test 2	H2-X2	
	Test 3	H3-X3	
Common Winding (OC)	Test 4	X1-H0X0	X1-H0X0
All Other Terminals Floating	Test 5	X2-H0X0	
	Test 6	X3-H0X0	
Short Circuit (SC)	Test 7	H1-H0X0	H1-H0X0
High (H) to Low (L)	Test 8	H2-H0X0	Short
Short [X1-X2-X3]*	Test 9	H3-H0X0	[X1-H0X0]*
Transfer Admittance (TA)	Test 10	H1-X1	H1-X1
High (H) to Low (L)	Test 11	H2-X2	Ground
Ground (H0X0)	Test 12	H3-X3	[H0X0]

* Indicates short circuit tests: terminals are shorted together. The neutral is not included for 3ϕ Wye connections, but may be included for 1ϕ test connections.

TABLE 5 - AUTOTRANSFORMER WITH TERTIARY

Test Type	Test #	3ϕ	1ϕ
Series Winding (OC)	Test 1	H1-X1	H1-X1
All Other Terminals Floating	Test 2	H2-X2	
	Test 3	H3-X3	
Common Winding (OC)	Test 4	X1-H0X0	X1-H0X0
All Other Terminals Floating	Test 5	X2-H0X0	
	Test 6	X3-H0X0	
Tertiary Winding (OC)	Test 7	Y1-Y3	Y1-Y2
All Other Terminals Floating	Test 8	Y2-Y1	(Y1-Y0)
	Test 9	Y3-Y2	
Short Circuit (SC)	Test 10	H1-H0X0	H1-H0X0
High (H) to Low (L)	Test 11	H2-H0X0	Short
Short [X1-X2-X3]*	Test 12	H3-H0X0	[X1-H0X0]*
Short Circuit (SC)	Test 13	H1-H0X0	H1-H0X0
High (H) to Tertiary (Y)	Test 14	H2-H0X0	Short
Short [Y1-Y2-Y3]*	Test 15	H3-H0X0	[Y1-Y2]*
Short Circuit (SC)	Test 16	X1-H0X0	X1-H0X0
Low (L) to Tertiary (Y)	Test 17	X2-H0X0	Short
Short [Y1-Y2-Y3]*	Test 18	X3-H0X0	[Y1-Y2]*
Inter-Winding (IW)	Test 19	H1-Y1	H1-Y1

High (H) to Tertiary (Y) All Terminals Float	Test 20 Test 21	H2-Y2 H3-Y3	
Inter-Winding (IW) Low (L) to Tertiary (Y) All Terminals Float	Test 22 Test 23 Test 24	X1-Y1 X2-Y2 X3-Y3	X1-Y1
Transfer Admittance (TA) High (H) to Low (L) Ground (H0X0)	Test 25 Test 26 Test 27	H1-X1 H2-X2 H3-X3	H1-X1 Ground [H0X0]
Transfer Admittance (TA) High (H) to Tertiary (Y) Ground (H0X0 and Y-)	Test 28 Test 29 Test 30	H1-Y1 H2-Y2 H3-Y3	H1-Y1 Ground [H0X0, Y2]
Transfer Admittance (TA) Low (L) to Tertiary (Y) Ground (H0X0 and Y-)	Test 31 Test 32 Test 33	X1-Y1 X2-Y2 X3-Y3	X1-Y1 Ground [H0X0, Y2]

* Indicates short circuit tests: terminals are shorted together. The neutral is not included for 3ϕ Wye connections, but may be included for 1ϕ test connections.

TABLE 6 - THREE WINDING TRANSFORMER

Test Type	Test #	3φ Δ-Δ-Δ Group 1 θ ⇒ 0°	3φ Δ-Δ-Y Group 2 θ ⇒ 30° LAG	3φ Δ-Y-Δ Group 2 θ ⇒ 30° LAG	3φ Δ-Y-Y Group 2 θ ⇒ 30° LAG	1ϕ
HV Open Circuit (OC) All Other Terminals Floating	Test 1 Test 2 Test 3	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H2 (H1-H0)
LV Open Circuit (OC) All Other Terminals Floating	Test 4 Test 5 Test 6	X1-X3 X2-X1 X3-X2	X1-X3 X2-X1 X3-X2	X1-X0 X2-X0 X3-X0	X1-X0 X2-X0 X3-X0	X1-X2 (X1-X0)
Tert Open Circuit (OC) All Other Terminals Floating	Test 7 Test 8 Test 9	Y1-Y3 Y2-Y1 Y3-Y2	Y1-Y0 Y2-Y0 Y3-Y0	Y1-Y3 Y2-Y1 Y3-Y2	Y1-Y0 Y2-Y0 Y3-Y0	Y1-Y2 (Y1-Y0)
Short Circuit (SC) High (H) to Low (L) Short [X1-X2-X3]*	Test 10 Test 11 Test 12	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H0 Short [X1-X2]*
Short Circuit (SC) High (H) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 13 Test 14 Test 15	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H3 H2-H1 H3-H2	H1-H0 Short [Y1-Y2]*
Short Circuit (SC) Low (L) to Tertiary (T) Short [Y1-Y2-Y3]*	Test 16 Test 17 Test 18	X1-X3 X2-X1 X3-X2	X1-X3 X2-X1 X3-X2	X1-X0 X2-X0 X3-X0	X1-X0 X2-X0 X3-X0	X1-X0 Short [Y1-Y2]*
Inter-Winding (IW) High (H) to Low (L) All Terminals Float	Test 19 Test 20 Test 21	H1-X1 H2-X2 H3-X3	H1-X1 H2-X2 H3-X3	H1-X1 H2-X2 H3-X3	H1-X1 H2-X2 H3-X3	H1-X1
Inter-Winding (IW) High (H) to Tertiary (T) All Terminals Float	Test 22 Test 23 Test 24	H1-Y1 H2-Y2 H3-Y3	H1-Y1 H2-Y2 H3-Y3	H1-Y1 H2-Y2 H3-Y3	H1-Y1 H2-Y2 H3-Y3	H1-Y1
Inter-Winding (IW) Low (L) to Tertiary (T)	Test 25 Test 26	X1-Y1 X2-Y2	X1-Y1 X2-Y2	X1-Y1 X2-Y2	X1-Y1 X2-Y2	X1-Y1

All Terminals Float	Test 27	X3-Y3	X3-Y3	X3-Y3	X3-Y3	
Transfer Admittance (TA) High (H) to Low (L) Ground (H- and X-)	Test 28	H1-X1	H1-X1	H1-X1	H1-X1	H1-X1 Ground [H2, X2]
	Test 29	H2-X2	H2-X2	H2-X2	H2-X2	
	Test 30	H3-X3	H3-X3	H3-X3	H3-X3	
Transfer Admittance (TA) High (H) to Tertiary (T) Ground (H- and Y-)	Test 31	H1-Y1	H1-Y1	H1-Y1	H1-Y1	H1-Y1 Ground [H2, Y2]
	Test 32	H2-Y2	H2-Y2	H2-Y2	H2-Y2	
	Test 33	H3-Y3	H3-Y3	H3-Y3	H3-Y3	
Transfer Admittance (TA) Low (L) to Tertiary (T) Ground (X- and Y-)	Test 34	X1-Y1	X1-Y1	X1-Y1	X1-Y1	X1-Y1 Ground [X2, Y2]
	Test 35	X2-Y2	X2-Y2	X2-Y2	X2-Y2	
	Test 36	X3-Y3	X3-Y3	X3-Y3	X3-Y3	

* Indicates short circuit tests: terminals are shorted together. The neutral is not included for 3ϕ Wye connections, but may be included for 1ϕ test connections.

4.0 Test data records

A number of different elements of a particular test need to be recorded – these ensure that the same test set up is possible on subsequent tests, and with respect to tests on other transformers. The Test data recorded for a sample SFRA plot in Figure 3 is shown in Figure 4

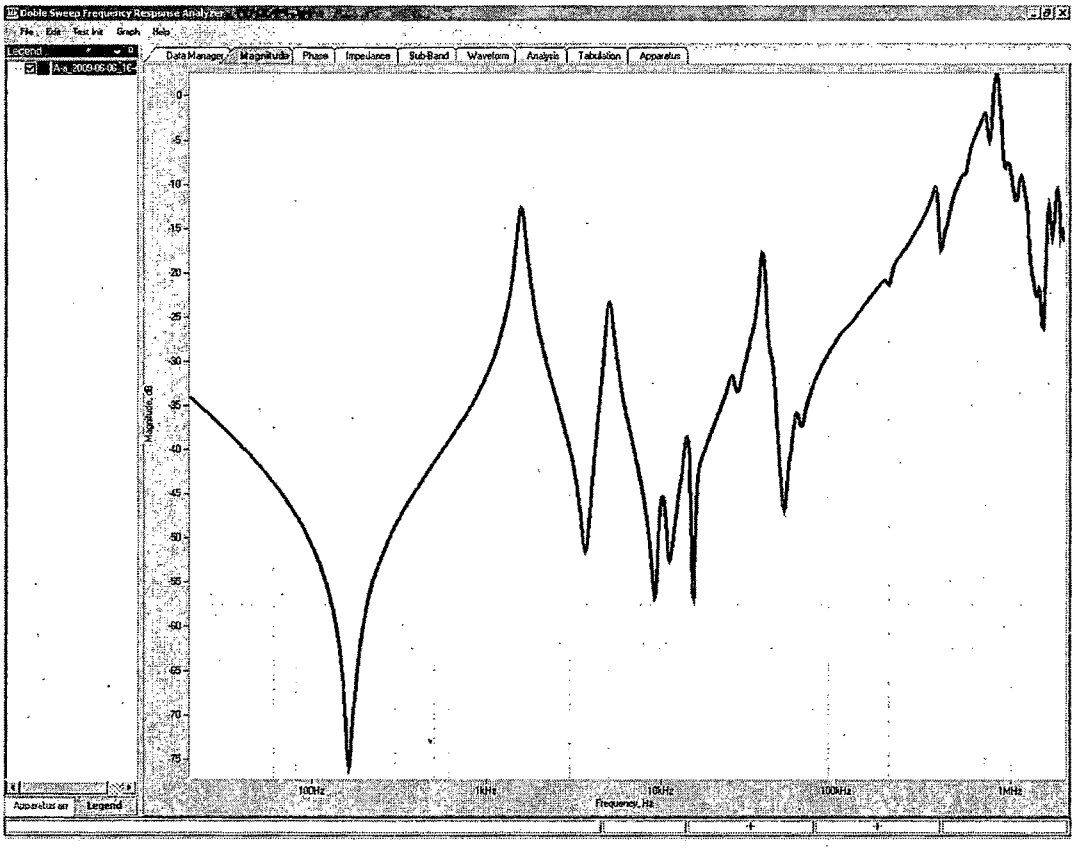
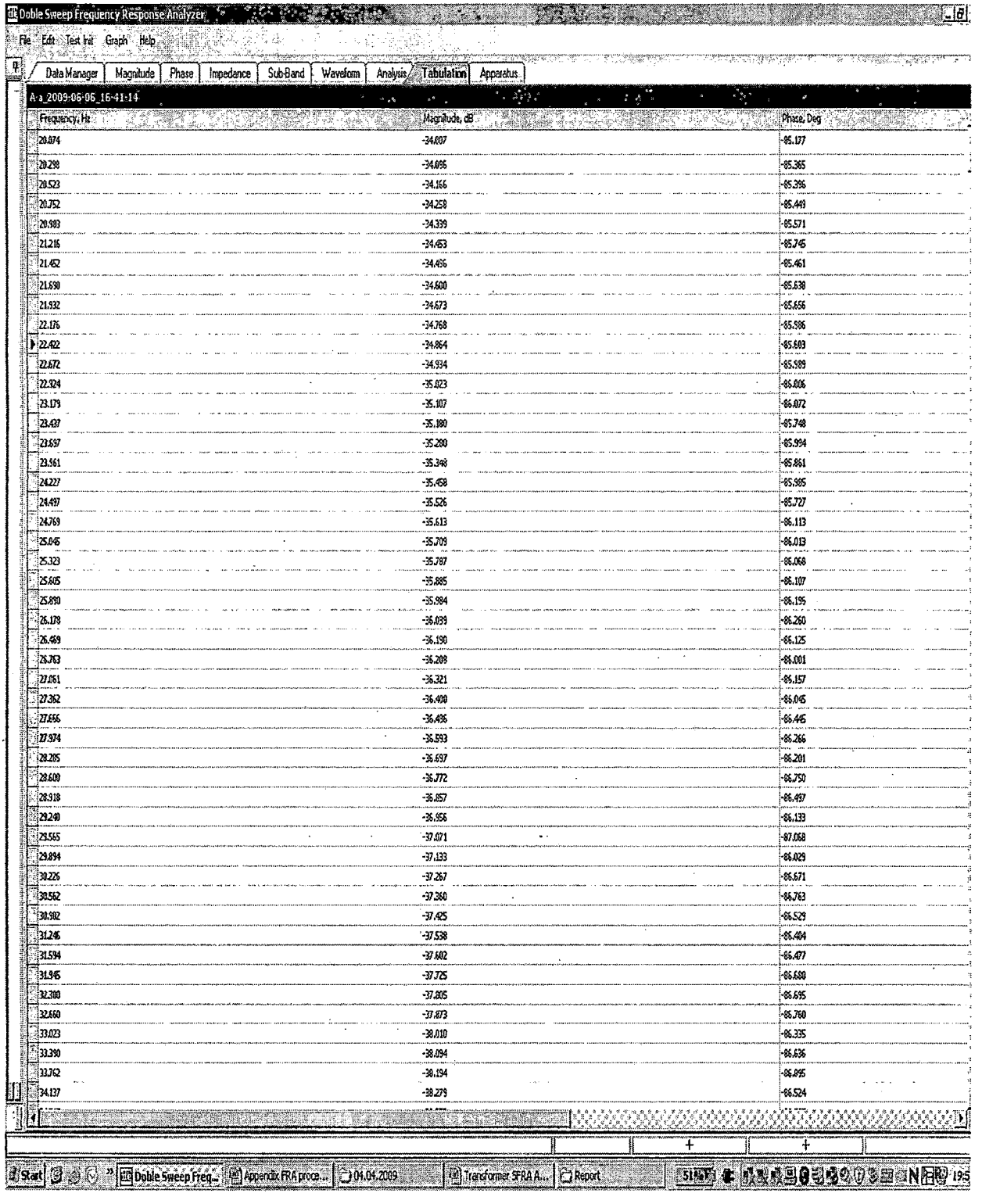


Figure 3.: Open Circuit SFRA Plot


Doble Sweep Frequency Response Analyzer

File Edit Test Init Graph Help

Data Manager | Magnitude | Phase | Impedance | Sub-Band | Waveform | Analysis | Tabulation | Apparatus

A-a_2009-06-06_16-41-14

Frequency, Hz	Magnitude, dB	Phase, Deg
20.074	-34.807	-85.177
20.298	-34.895	-85.365
20.523	-34.166	-85.396
20.752	-34.258	-85.449
20.983	-34.339	-85.571
21.216	-34.453	-85.745
21.452	-34.496	-85.461
21.690	-34.600	-85.638
21.932	-34.673	-85.656
22.176	-34.768	-85.586
22.422	-34.864	-85.603
22.672	-34.934	-85.589
22.924	-35.023	-85.806
23.179	-35.107	-86.072
23.437	-35.180	-85.748
23.697	-35.280	-85.994
23.961	-35.348	-85.861
24.227	-35.458	-85.985
24.497	-35.526	-85.727
24.769	-35.613	-86.113
25.046	-35.709	-86.013
25.323	-35.787	-86.068
25.605	-35.885	-86.107
25.890	-35.984	-86.195
26.178	-36.039	-86.260
26.469	-36.190	-86.125
26.763	-36.209	-86.001
27.061	-36.321	-86.157
27.362	-36.400	-86.045
27.666	-36.406	-86.445
27.974	-36.593	-86.266
28.285	-36.697	-86.201
28.600	-36.772	-86.750
28.918	-36.857	-86.497
29.240	-36.956	-86.133
29.565	-37.071	-87.068
29.894	-37.133	-86.029
30.226	-37.267	-86.671
30.562	-37.360	-86.763
30.902	-37.425	-86.529
31.246	-37.538	-86.404
31.594	-37.602	-86.497
31.945	-37.725	-86.689
32.300	-37.805	-86.695
32.660	-37.873	-86.760
33.023	-38.010	-86.335
33.390	-38.094	-86.636
33.762	-38.194	-86.895
34.137	-38.279	-86.524

Start | Doble Sweep Freq... | Appendix FRA proce... | 04.04.2009 | Transformer SFRA A... | Report | SIMATIC | 19:5

Figure 4.: Measured parameter of Open Circuit SFRA Plot