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On-Site Test Report

Product:	**Tri-Layer Magnetically Shielded Room for a MEG system**
Customer:	**Senate Properties P.O.B. 237 (Lintulahdenkatu 5 A) FI-00531 Helsinki Finland**
Place of installation:	**Helsinki University of Technology Low Temperature Laboratory Nanotalo Puumiehkuja 2 FI-02015 Espoo**
IMEDCO Project No.:	**3255.68**
Date of test:	**November 21st, 2007**

0. Table of content

1. MSR Project Test Report Summary

IMEDCO has completed the detailed on-site test report for the three layer magnetically shielded room (MSR) that is installed in Espoo, Finland.

This MSR was tested in Espoo, Finland on November 21st, 2007. All tests were performed in accordance with the test procedure previously defined. Specific details, and the list of equipment utilized and all data are included in this report.

- Summary of Results:

The attenuation values for this MSR were found to be equal to, or in excess of, the values specified in the IMEDCO quotation no. 6504 dated June 7, 2006, which was part of the contract signed in Helsinki on November 8, 2006.

The values measured were as follows:

DC Residual Field		
	Measured	**Specified**
Residual Field	9.85	< 20 nT

Frequency	**Attenuation Value**			
	Measured		**Specified**	
[Hz]	**[-]**	**[dB]**	**[-]**	**[dB]**
0.01	1999 – 2028	66.7 – 67.6	1000	60
0.1	4105 – 6429	71.6 – 75.2	1000	60
1	158236 – 295316	104.0 – 109.4	10000	80
10	987494 – 2004507	119.9 – 126.0	50000	95
100	614596 – 1179198	115.8 – 117.8	100000	100
1000	592914 – 710752	115.5 – 117.0	100000	100
10 MHz	-	114 – 116	100000	100
100 MHz	-	110 – 112	100000	100

The information and data in this report is certified to be accurate and complete. If you should have any questions or comments regarding this report, please submit them in writing to IMEDCO AG, Attention: Urs Schläpfer and they shall be quickly addressed and answered.

Hägendorf, Switzerland
March 26, 2008

Imedco AG

U.Schläpfer

2. Test procedure

2.1 General

High attenuation factors are obtained in the DC and AC fields with magnetically shielded enclosures. These rooms are built with several conductive layers from high permeability alloys and highly conductive aluminum.

The measurement of the total attenuation must be made over a wide frequency range.

The following test program describes the different performance tests for a magnetically shielded room. No standards are available for testing large magnetic shields. IMEDCO had therefore to develop its own test program. Some tests are similar to international standards but using different parameter such as frequency, amplitude etc.

In the following pages we use the term: magnetic field strength. The unit for the magnetic field strength is Ampere per meter [A/m] (old: Oersteds). Our test equipment measures the magnetic flux density or induction in Tesla.

2.2 DC-Field measurement

This test is made in the earth field i.e. the magnetic field of the earth serves as reference. The attenuation factor will be measured in the center of the magnetically shielded room.

A second measurement on different locations in the room will give information about the homogeneity of the residual magnetic field. The different test points and their corresponding value allow a plot of the residual magnetic field distribution (homogeneity) which in turn leads to the discovery of the possible existence of weak points.

2.2.1 Test equipment

- Three axis magnetic field probe, resolution < 1 nT, offset max. ± 20 nT
- mV-meter, sensitivity 0.1 mV

2.2.2 Method of measurement

The earth magnetic field (approx. 30 µT to 50 µT) serves as reference. The reference measurements must be taken on different locations and at a sufficient distance from the magnetically shielded room. A distance of approx. 5 m to 10 m is considered sufficient.

The measurement of the residual magnetic field is first made in the middle of the room. To compensate the offset of the test equipment, the probe has to be turned by 180° in all directions. The residual field can be calculated as follows:

$$Bi = \frac{Bi_+ - Bi_-}{2}$$

where:

i :	Direction x,y,z
B :	Flux density in nT
Bi_+ :	Flux density in one direction in nT
Bi_- :	Flux density in opposite direction in nT

The vector of the residual field can be calculated as follows:

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

where:
B : Flux density [nT] (Residual vector)
B_x : Flux density [nT] in x-direction
B_y : Flux density [nT] in y-direction
B_z : Flux density [nT] in z-direction

The definition of the directions is given by the orientation of the magnetic field probe. Therefore the direction may be different from the conventionally used direction. For the whole test of the magnetically shielded room the directions are specified as follows:

x-direction: horizontal, transversal
y-direction: vertical
z-direction: horizontal, longitudinal

The attenuation factor is the ratio of the reference value and the residual magnetic field inside the magnetically shielded room. The attenuation factor can be calculated as follows:

$$SE = \frac{B_{Ref}}{B_{Inside}}$$

where:
SE : Attenuation factor [-]
B_{ref} : Reference flux density outside [nT]
B_{Inside} : Residual flux density inside [nT]

Prior to this test the enclosure has to be demagnetized for equalization of the different layers. For the degaussing procedure refer “Degaussing of a magnetic shielded room“ from IMEDCO.

2.3 Low frequency attenuation measurement

The low frequency range covers the frequency form 0.01 Hz to 1000 Hz. The measurement shall be performed in all three directions, if space around the magnetically shielded room is available.

A pair of rectangular coils generates an alternating magnetic field. The coils are placed symmetrically to the room.

The low frequency attenuation test is similar to the “Standard Test Method for Magnetic Shield Efficiency in attenuating alternating Magnetic Fields“, ASTM A698/A 698M – 92 [1]. Different parameters such as shape of the coils, field strength etc. vary from the original standard.

2.3.1 Test equipment

- Function generator with a continuous sine wave output.
  Frequency range: 0.1 mHz to 10 kHz (min.)
  Output voltage: 0 V to 40 V

- Power amplifier
  Output voltage: +/- 50 Volts
  Output current: +/- 8 Amps
  max. Power 400 Watts

- Magnetic field probe (fluxgate)

Frequency range:	DC to 1 kHz
Linearity:	< 0.0015%
Accuracy:	± 0.5%
Orthogonality:	± 0.5°
Internal Noise:	< 10 pTrms/√Hz at 1 Hz

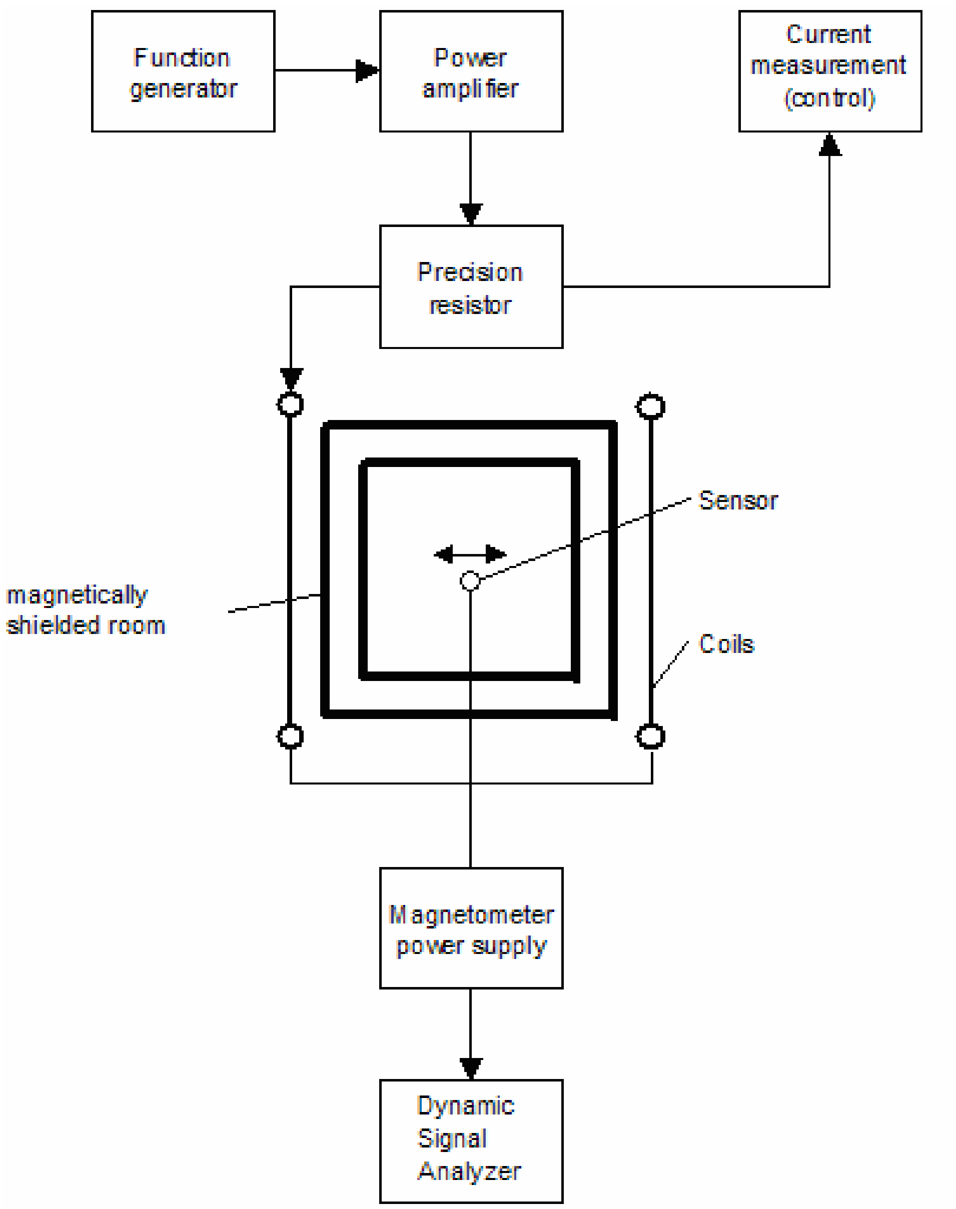
- Precision resistor

Value:	1 Ω
Accuracy:	1 %

- FFT analyzer PC driven with a laser printer

- Various multi meters

- Block diagram of the test setup with the FFT-analyzer (0.01 Hz to 1000 Hz)



2.3.2 Generation of the magnetic field

A pair of rectangular coils is put up to generate the test field. In the center of the room the residual field is measured. To measure in all three directions, three pairs of coils are necessary. The dimensions will have to be determined during the test. However the coils shall be made as large as possible. The coils shall be installed symmetrically to the center (all three directions) of the room.

The magnetic flux density of the generated field can be calculated as follows:

$$B_{Ref} = \mu_o * H_{Ref} = \left(\frac{1600}{(D^2 + L^2)} + \frac{1600}{(D^2 + W^2)}\right) * \frac{L * W * N * I}{(L^2 + W^2 + D^2)^{0.5}}$$

where:
- B_{Ref}: Magnetic flux density in free space [μT]
- H_{Ref}: Magnetic field strength in free space [A/m]
- μ_o : Magnetic field constant $4*\pi*10^{-7}$ [Vs/Am]
- L, W: Dimension of the coil [mm]
- D: Distance between the coils [mm]
- N: Number of turns of one coil [-]
- I: Current [A]

The generated field has a magnetic flux density $B_{Ref} = \mu_o * H_{ref} = 2\ \mu T_{pp}$ (peak- to-peak).

The difference between the calculated value and the measured value has to be within 5%. Large ferro-magnetic objects close by the test setup may have a negative influence on the magnetic field distribution between the coils.

The values can be verified in the free space with the same coil configuration.

2.3.3 Method of measurement

The pair of rectangular coils is placed at symmetrical distances from the enclosure. The magnetic field probe is positioned in the center of the enclosure.

The value $B_{Inside} = \mu_o * H_{Inside}$ is measured. The attenuation calculated as follows:

$$SE = \frac{B_{Ref}}{B_{Inside}} = \frac{\mu_o * H_{Ref}}{\mu_o * H_{Inside}}$$

where:
- SE: Attenuation factor [-]
- B_{Ref}: Flux density [nT] in free space
- B_{Inside}: Residual flux density [nT] in the center
- H_{Ref}: Magnetic field strength [A/m] in free space
- H_{Inside}: Residual magnetic field strength [A/m] in the center
- μ_o: Magnetic field constant $4*\pi*10^{-7}$ [Vs/Am]

During the entire test the door shall be closed. The degaussing coils shall be disconnected from the power supply (no closed loop).

The voltage on the output of the magnetic field probe (fluxgate magnetometer) is linear to the magnetic flux density. With the voltage the flux density can be calculated as follows:

10 Volts = 70 µT (Ratio of the magnetic field probe)

$$B = \frac{U_{Meas}\,[V] \cdot 70 \cdot 10^{-6}\,[T]}{10\,[V]}$$

where: U: Voltage of the magnetic field probe [V]
B: Magnetic flux density [T]

2.4 High frequency attenuation measurements

The high frequency range applies to frequencies of 10 MHz where the magnetic field and up to 100 MHz where the plane wave is measured.

The high frequency attenuation test of the magnetically shielded room shall check the highly conductive aluminum shell, the joints of the door and the different penetrations. For this test some sections of the IEEE Std 299-1997 [3] will be used.

The MSR was tested at the following frequencies:

Magnetic field (H)	10 MHz
Plane wave	100 MHz

2.4.1 Test equipment

- Signal generator
  - Frequency range: 10 kHz Hz to 1 GHz
  - Output power: 0 dBm
- Power amplifier
  - Frequency range: 10 kHz Hz to 1 GHz
  - max. Power 10 Watts
- Spectrum analyzer
  - Frequency range: 10 kHz Hz to 2 GHz
  - Dynamic range: min. 120 dB
- 1 Set of dipole antennas for plane wave
  - Frequency range: 30 MHz Hz to 140 MHz
- 1 Set of loop antennas for H-field
  - Frequency range: 10 MHz

2.4.2 Method of measurement

Between the transmitting and the receiving antenna shall be a distance of 600 mm for the magnetic field and 1000 mm resp. 5000 mm for plane wave. After a free space calibration the MSR shall be tested at different test points.

3. Test results

3.1 DC-Field measurements

	X Transversal	Y Vertical	Z Longitudinal	Unit
Specified direction	25.9	-13.3	-25.9	[nT]
Opposite direction	22.4	-22.4	-28.7	[nT]
B_{Inside}	3.5	9.1	1.4	[nT]
$B_{Outside}$	3200	-39900	10300	[nT]

B_{Res} Outside = 41332 [nT]

B_{Res} Inside = 9.85 [nT]

SE = 4196 [-] → 72.5 dB

3.2 Low frequency attenuation measurements

3.2.1 Dimension of the coils

	Length [mm]	Height [mm]	Distance [mm]	Turns [-]	Current [A_{PP}]
Transversal	6750	2550	5650	5	3.42

	Length [mm]	Width [mm]	Distance [mm]	Turns [-]	Current [A_{PP}]
Vertical	6750	5650	2550	5	1.33

	Width [mm]	Height [mm]	Distance [mm]	Turns [-]	Current [A_{PP}]
Longitudinal	5650	2550	6750	5	4.96

3.2.2 Attenuation 0.01 Hz to 1000 Hz

- X-Direction (transversal)

Coil length 6750 mm	Coil height 2550 mm	Coil distance 5650 mm
Current calculated 3.42 A_{PP}		

Frequency [Hz]	Reference [nT]	B_{Inside} [nT]	Shielding factor [-]	Attenuation [dB]
0.01	1999	0.8320	2403	**67.6**
0.05	1995	0.5252	3799	**71.6**
0.1	728	0.1133	6429	**76.2**
0.2	726	0.0579	12540	**82.0**
0.5	726	0.0147	49520	**93.9**
0.7	725	0.0075	97339	**99.8**
1.0	726	0.0025	295316	**109.4**
2	724	0.0005	1592921	**124.0**
5	724	0.0005	1370611	**122.7**
7	724	0.0006	1263464	**122.0**
10	724	0.0004	2004507	**126.0**
20	722	0.0003	2246814	**127.0**
40	781	0.0008	940979	**119.5**
60	772	0.0008	965075	**119.7**
100	749	0.0010	773907	**117.8**
200	812	0.0009	872984	**118.8**
500	792	0.0009	839214	**118.5**
1000	796	0.0011	710752	**117.0**

- Y-Direction (vertical)

Coil length 6750 mm	Coil width 5650 mm	Coil distance 2550 mm
Current calculated 1.33 A_{PP}		

Frequency [Hz]	Reference [nT]	B_{Inside} [nT]	Shielding factor [-]	Attenuation [dB]
0.01	2028	0.9323	2175	**66.7**
0.05	2024	0.7730	2618	**68.4**
0.1	715	0.1742	4105	**72.3**
0.2	715	0.0845	8461	**78.5**
0.5	715	0.0230	31136	**89.9**
0.7	715	0.0112	63734	**96.1**
1.0	715	0.0045	158236	**104.0**
2	713	0.0008	850164	**118.6**
5	712	0.0007	1032905	**120.3**
7	712	0.0009	797932	**118.0**
10	712	0.0007	1010613	**120.1**
20	759	0.0005	1517404	**123.6**
40	749	0.0003	2272233	**127.1**
60	736	0.0006	1142461	**121.2**
100	749	0.0006	1179198	**121.4**
200	786	0.0006	1255979	**122.0**
500	738	0.0007	996457	**120.0**
1000	830	0.0012	666385	**116.5**

- Z-Direction (longitudinal)

Coil length	Coil height	Coil distance
5650 mm	2550 mm	6750 mm
Current calculated 4.96 A_{PP}		

Frequency [Hz]	Reference [nT]	B_{Inside} [nT]	Shielding factor [-]	Attenuation [dB]
0.01	2014	0.9323	2161	**66.7**
0.05	2005	0.6550	3062	**69.7**
0.1	710	0.1240	5728	**75.2**
0.2	709	0.0600	11828	**81.5**
0.5	710	0.0122	58114	**95.3**
0.7	709	0.0053	133179	**102.5**
1.0	709	0.0029	241902	**107.7**
2	708	0.0005	1336888	**122.5**
5	740	0.0011	649181	**116.2**
7	740	0.0011	683524	**116.7**
10	740	0.0007	987494	**119.9**
20	737	0.0004	2074145	**126.3**
40	756	0.0005	1390526	**122.9**
60	736	0.0003	2646830	**128.5**
100	736	0.0012	614596	**115.8**
200	769	0.0006	1252559	**122.0**
500	785	0.0007	1084676	**120.7**
1000	762	0.0013	592914	**115.5**

3.3 High frequency attenuation measurements

3.3.1 H-field measurement

Frequency [MHz]	Test Position	Ambient Level [dBm]	Reference Level [dBm]	Reading Inside [dBm]	Final Attenuation [dB]	Short Calibration [dB]
10	Door	-130	4	-112	**116**	4
	IMEDCO feedthrough panel	-130	4	-110	**114**	4

3.3.2 Plane wave measurement

Frequency [MHz]	Test Position	Ambient Level [dBm]	Reference Level [dBm]	Reading Inside [dBm]	Final Attenuation [dB]	Short Calibration [dB]
100	Door	-131	20	-90	**110**	19
	Center (far field condition)	-131	20	-92	**112**	19

4. List of instruments

Quantity	Item	Serial Number
1	Fourier Analyzer SigLab 20-42	11289
1	Signal Generator, Fluke Philips, Model PM 5138A/105	LO 670565
1	Power Amplifier, KEPCO, Model BOP 50-8M max. output voltage: ± 50 Volts max. output current: ± 8 Amps	E144510R17
1	3-axis magnet field probe, Bartington, Model MAG-03MCL-70 Range: ± 70 µT	957
1	Power supply for magnet field probe, Bartington, Model MAG-03PSU	1041
1	Multimeter, ABB, Model M2007	M32726617
1	Multimeter, ABB, Model M2008	M32666228
1	Precision resistor 1 Ω for current control, FW30-175	07-50901

Quantity	Item	Serial Number
1	Spectrum Analyzer ANRITSU, Type MS2711D	706174
1	Signal Generator MARCONI, Type 2023	112224096
1	RF Power Amplifier AMPLIFIER RESEARCH, Type 10W1000B	20846
2	P-Field Antenna set ELECTRO METRICS, Type EM6924	271 272
2	Loop Antenna IMEDCO, 10 MHz	01-99021 01-99022
1	RF Leakage Sniffer ELECTRO METRICS, Type EM6882	137

5. References

[1] ASTM A 698/A 698M - 92, Standard Test Method for Magnetic Shield Efficiency in Attenuating Alternating Magnetic Fields. Current edition approved Jan. 15, 1992. Published June 1992. Originally published as A 698 - 74.

[2] IEEE STD 299-1997: IEEE Standard for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.

6. Enclosures

Enclosure 1: Performance 0.01 Hz – 1000 Hz

On-Site test report - Enclosure 1: MSR for HUT, Performance 0.01 Hz - 1000 Hz