NTP Study Exposure System

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Outline

- Introduction
- Communication standards and signals
- Reverberation chambers
- NTP study chambers and characteristics
- Animal watering system
- Environmental monitoring and data logging
- Chamber construction and installation
- Summary

Exposure Groups

NTP Requirements for this study

- three exposure groups plus sham
- 100 animals per group

up to 24 hours exposure per day

- perform A determined that 2 hours was not enough
- animals need to be unconstrained

- NIST proposed reverberation chambers and made the first feasibility studies

Exposure System Requirements for Non-Thermal/Minimally Thermal Effects

- ability to:
  - expose large numbers of rodents
  - expose to a high dose – high specific absorption rate (SAR) and up to 20 hours per day
- animals to be unconstrained and housed in standard laboratory cages
  - minimum cage sizes defined in animal husbandry standards
- food and water to be available on demand
- excellent field and SAR homogeneity
- detailed dosimetry (numerical and experimental)
- ability to discern a possible dose response
- third party verification of the correct operation of the system

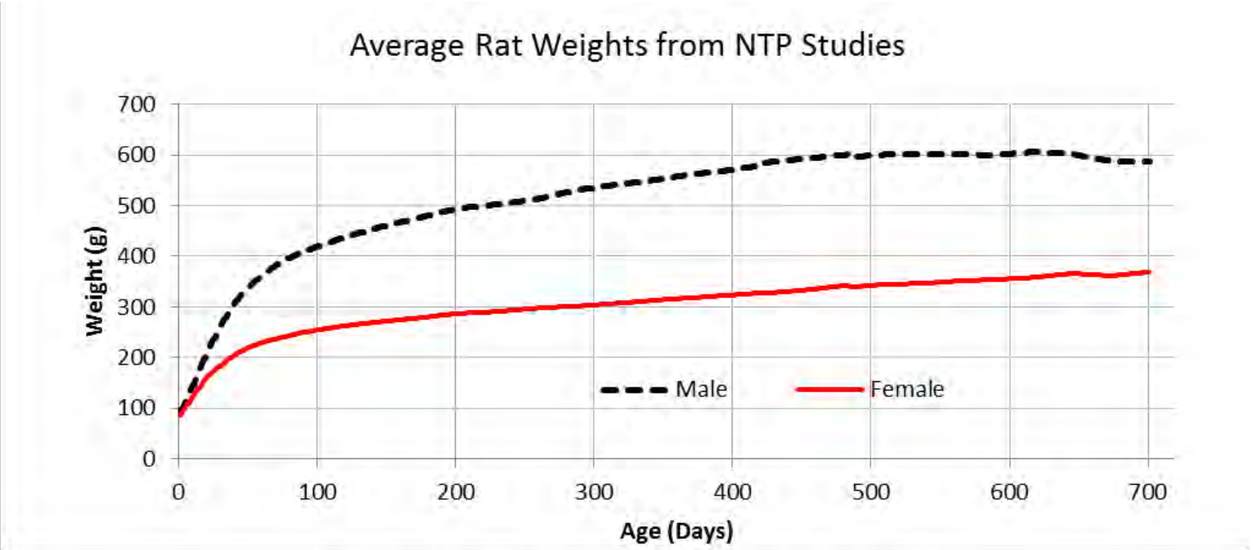
Exposure Groups

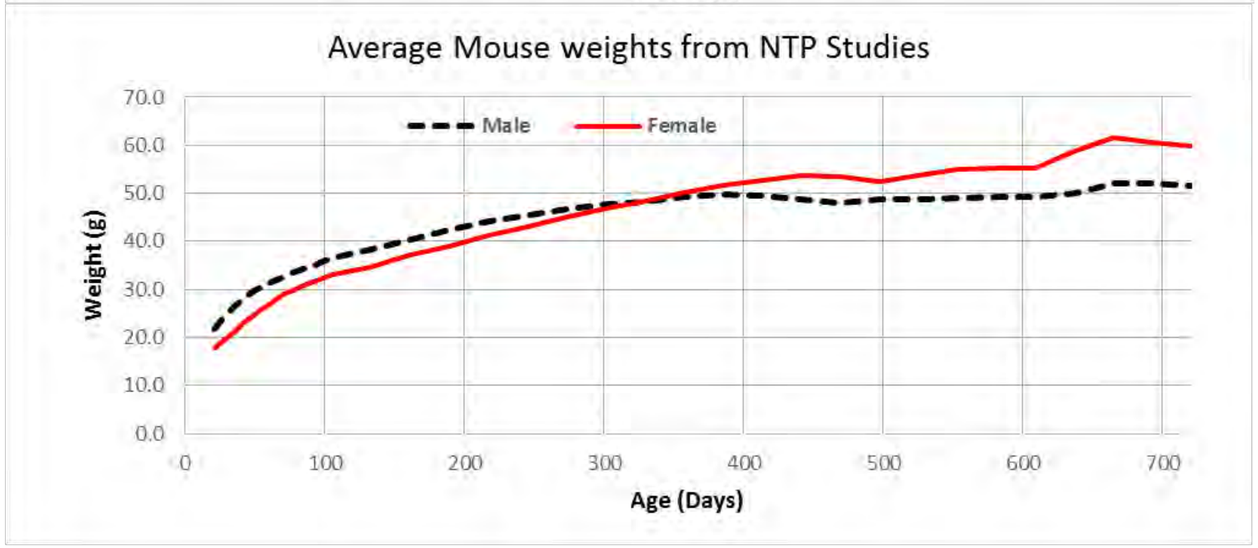
Exposure quantification

- incident field
- induced fields (SAR)

SAR is a function of:

- incident field
- body mass





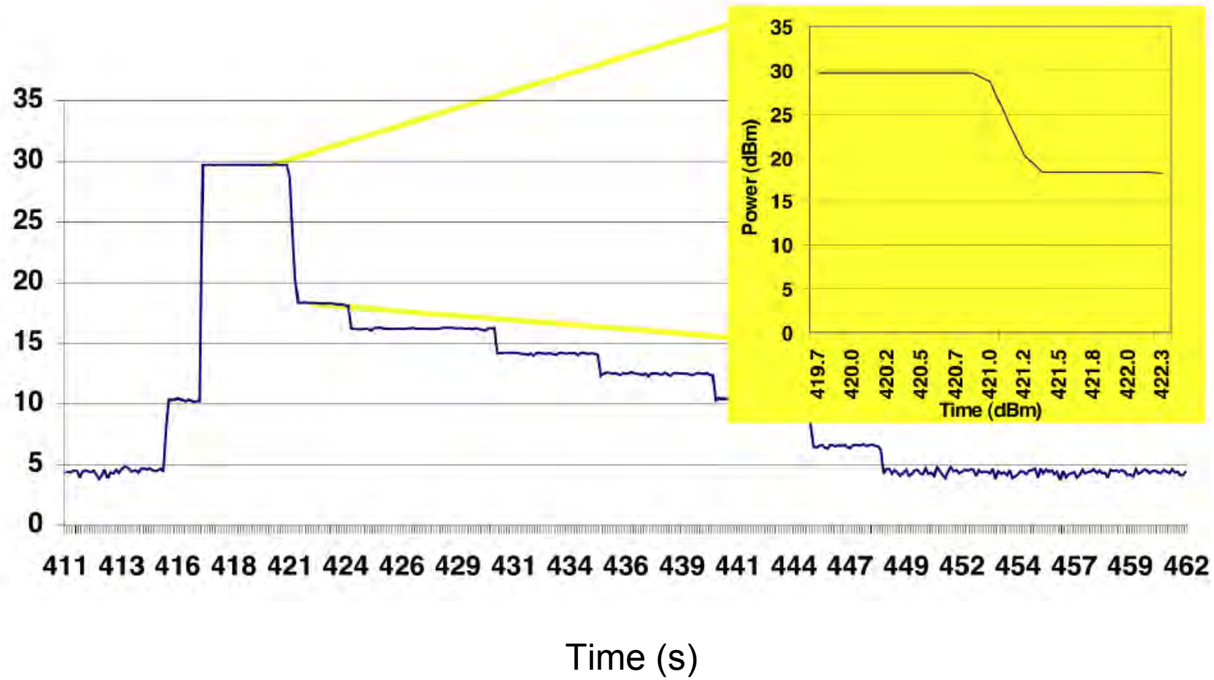
Rationale for Selection of Exposure (Frequency & Modulation & ELF Envelope)

- [1]selection of carrier frequency is mainly relevant for coupling but is considered of less biological importance
- [1]signals should contain the maximum spectral power of all modulation components generated by the handsets as well as by the base stations
- [1]although the human exposure largely depends on several parameters (device, tissue, etc.) for the handset, the maximum local exposure averaged over a small volume, e.g., a few thousand cells, can be considerably larger than the values for the spatial peak SAR (>6 W/kg) for most wireless cellular systems in use today.
- [2]several authors have emphasized the importance of the On-/Off cycles (e.g., Adey et. al., Perform A, Reflex, etc.)
- consequences for the exposure selection
  - selection of frequencies that provide maximum uniformity of exposure
  - combine modulation and power control to maximize the ELF spectral envelope

1: Kuster et. al, “Recommended Minimal Requirements …, BEM 21:508-515 (2000)
2: Ebert et. al, “Criteria for Selecting Specific EMF Exposure …, https://www.emf.ethz.ch/fileadmin/redaktion/public/downloads/3.../EMC01Kuster.pdf (2000)

Synthesis and Choice of Signals

- a cell phone user is exposed to radiofrequency (RF) signals that are a combination of the signal modulation, multiple access characteristics and the environmental influences
- the applied signal should be a synthesis of all these factors
- consider GSM
  - modulation envelope is constant
  - carrier on 1/8th of the time due to time division multiple access
  - output power varies in sympathy with environment and handover between cell towers



Time (s)

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Current Cell Phone Bands in the USA

Legend:	in use	partially in use	not in use

Carrier	2G Frequency in MHz Band name			3G Frequency in MHz Band name			4G LTE Frequency in MHz Band number											
	800	850	1900	850	1700 2100	1900	600	L700	L700	U700	800	850	1700 2100	1900	2300	2500	3500	5200	5700
	SMR	CLR	PCS	CLR	AWS	PCS	71	12,17	29[1]	13	26	5	4,66	2,25	30	41	48	252	255
AT&T	No	No	No	UMTS	No	UMTS	No	Yes	Yes	No	No	Partial	Yes	Partial	Yes	No			
T-Mobile	No	No	GSM	No	UMTS	UMTS	Yes	Yes	No	No	No	(Yes)[2]	Yes	Partial	No	No		Yes[3]	Yes
Sprint	CdmaOne[4]	No	CdmaOne	No	No	CDMA2000	No	No	No	No	Yes	No	No	Partial	No	Yes			
Verizon	No	CdmaOne	CdmaOne	CDMA2000	No	CDMA2000	No	No	No	Yes	No	Partial	Yes	Partial	No	No			
U.S. Cellular	No	CdmaOne	CdmaOne	CDMA2000	No	CDMA2000	No	Yes	No	No	No	Partial	Yes	Partial	No	No			

Communications Standards and Signals

- 2nd Generation mobile phone signals
- GSM uplink
- CDMA – IS95 uplink

zurich med tech

Quantity	CDMA (IS95)	GSM
Modulation:	QPSK	GMSK
Chip rate:	1.22880 Mcps	n/a
Rev link filter	IS95	Gaussian
Roll-off factor	0.2	0.5
Uplink channel type	traffic	traffic
Channel rate	9600 bps	270,833 symbols/s
Frame quality indicator	on	n/a
Convolutional encoder	on	n/a
Block interleaver	on	n/a
Peak-to-average ratio	5.39 dB	9.1 dB

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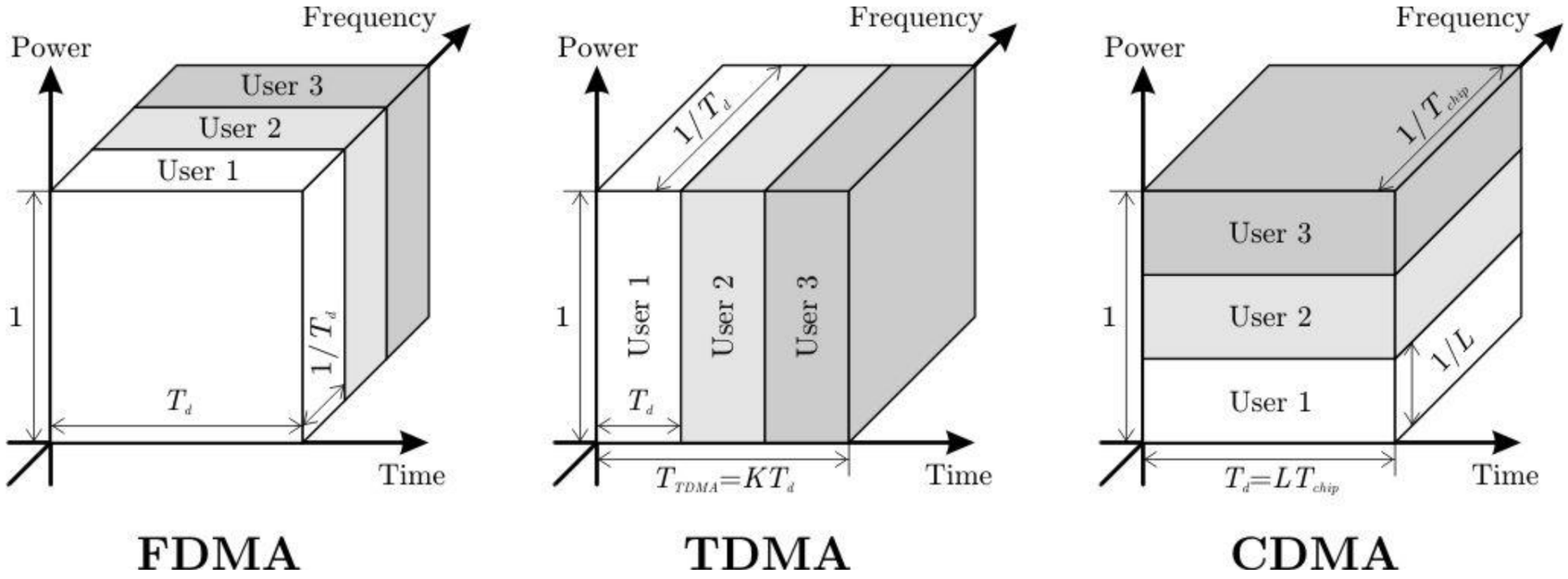
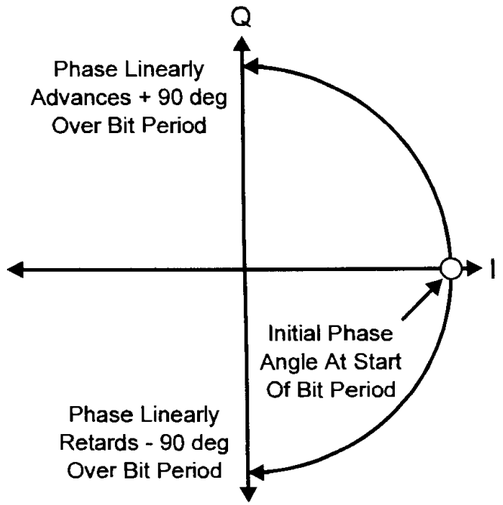
Multiple Access Methods (1G, 2G, 3G)

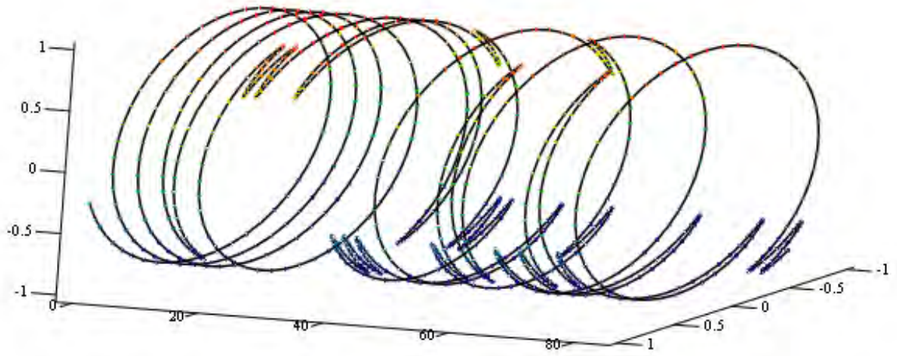


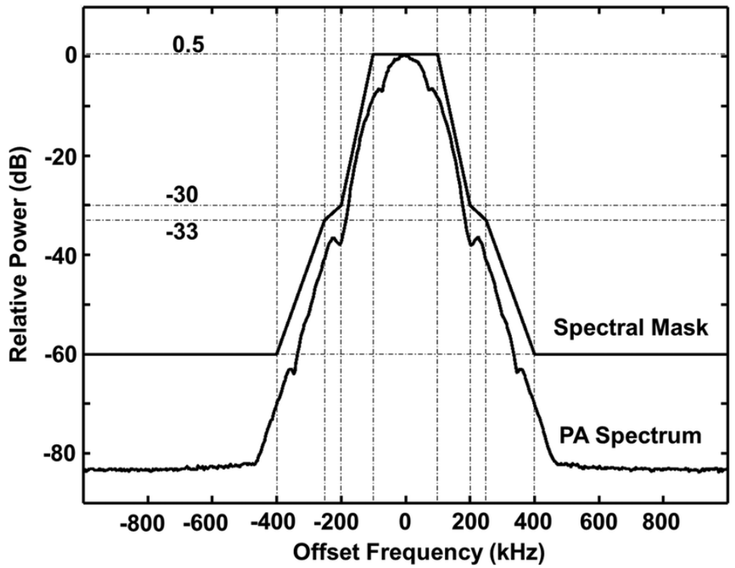
Picture: Karoling, Wikimedia.org

GSM

- 200 kHz channel spacing
- constant envelope – only the phase changes
- Gaussian minimum shift keying

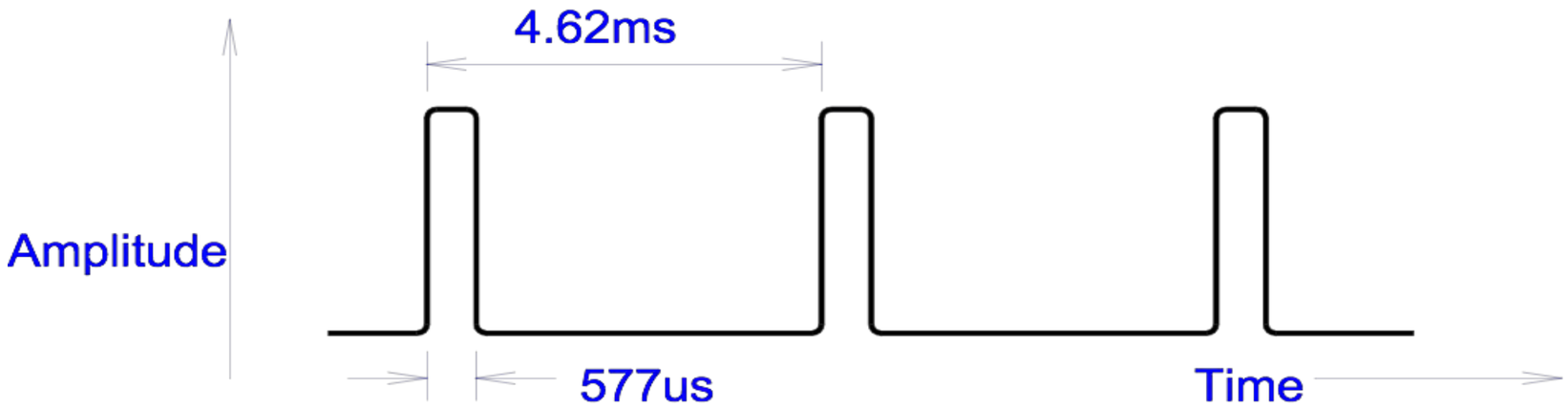






GSM Time Division Multiple Access

- each base station can support up to 8 users
- the resource is shared by allowing each user to transmit for 1/8th of the time
- users are allocated time slots
- transmitted power for a single user



CDMA – IS95 / CDMA One

- 1.25MHz channel
- 2nd generation standard – voice channels
- precursor for CDMA 2000 (3G)

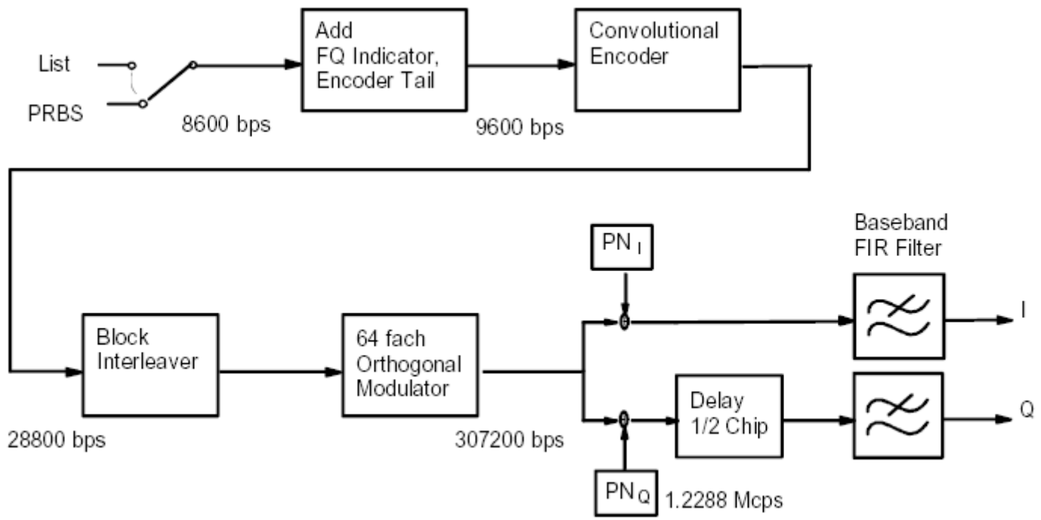
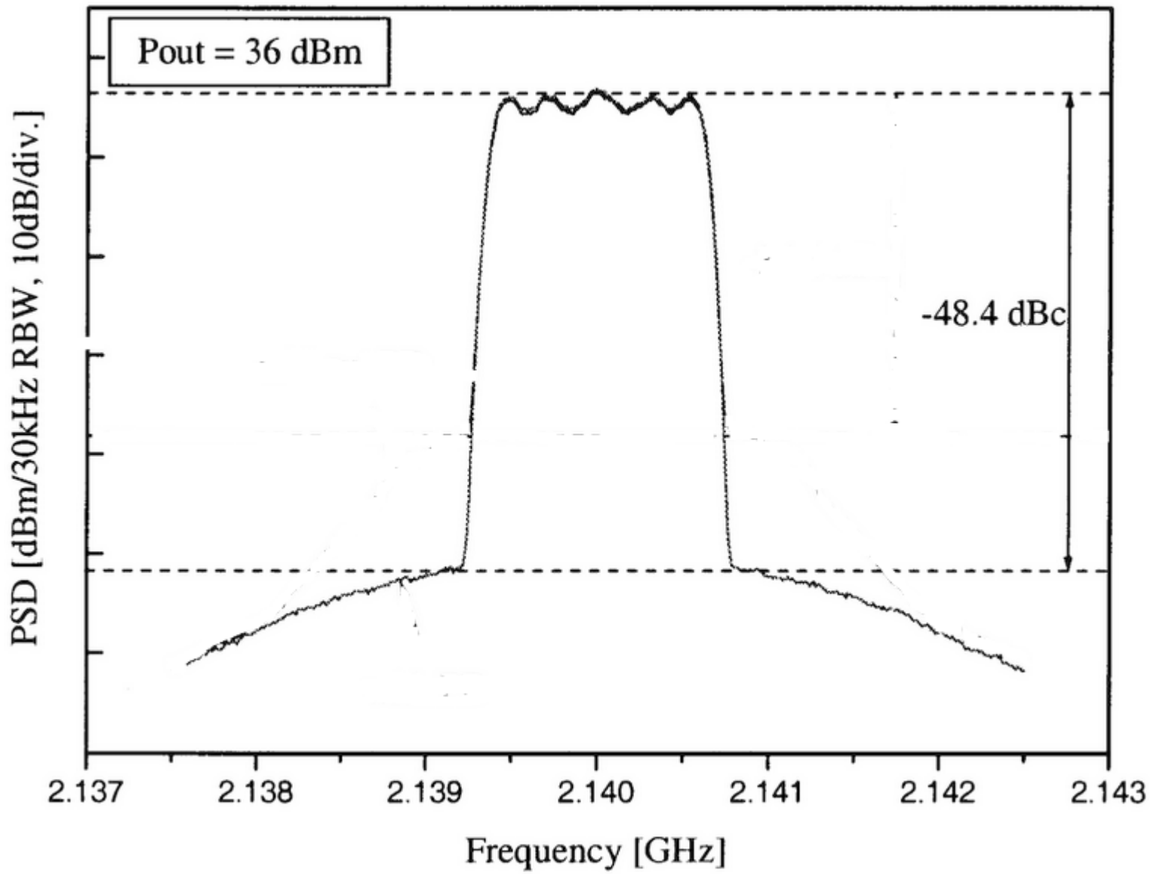
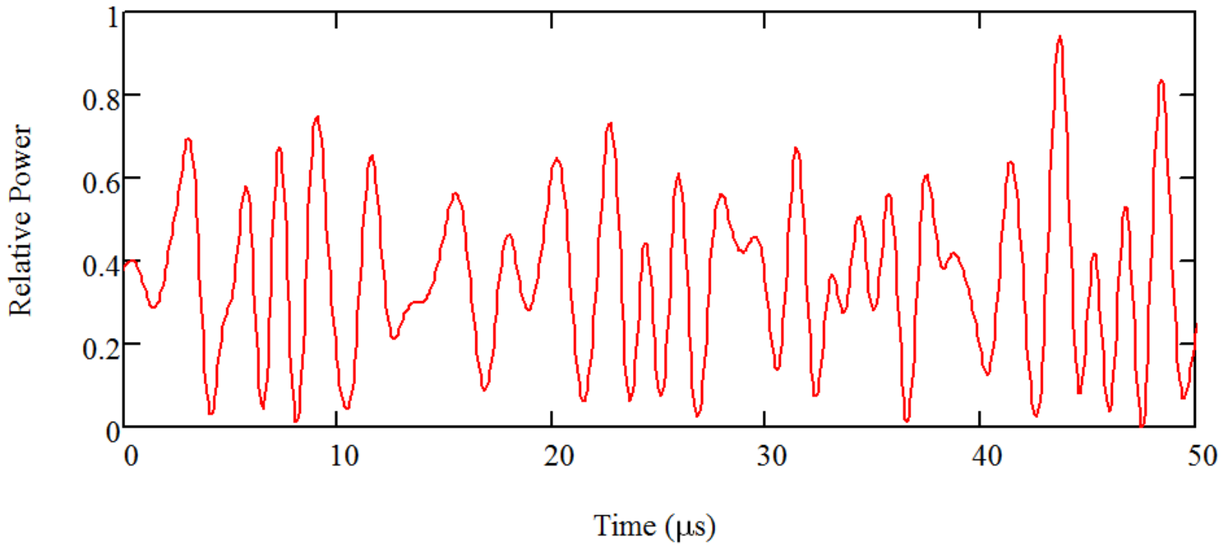


Fig. 2-78 Traffic channel 9600 in "Reverse Link Coded" mode



CDMA



time domain variation in power

- the variation is at the chip rate (1.23 MHz) very much more rapid than TDMA
- no on – off modulation

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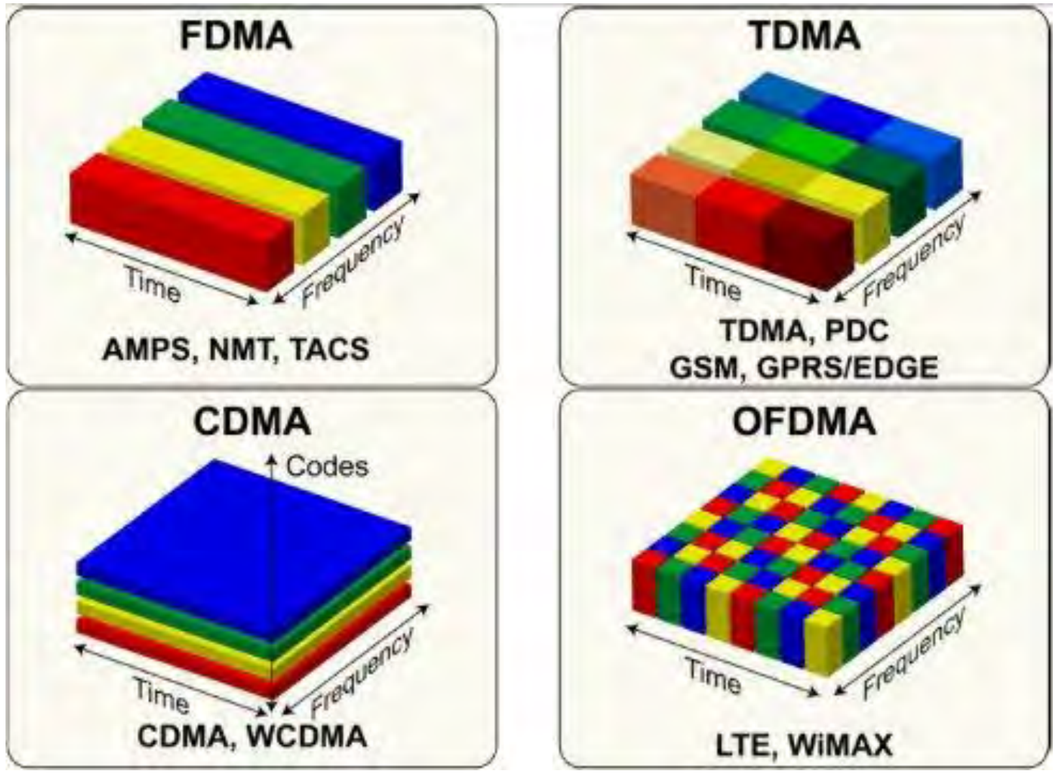
Relation of the Exposure Signals to the Present Day and Beyond

4G and beyond use or propose OFDMA

- the characteristics of the signals are not fixed
- the bandwidth utilized is variable
- the amount of time used is variable (multiple of 10ms)
- the total RF power is variable

- all depends on: number of users, capacity, the amount of data to be transferred, proximity to the base station, etc.



Picture: http://www.maixj.net

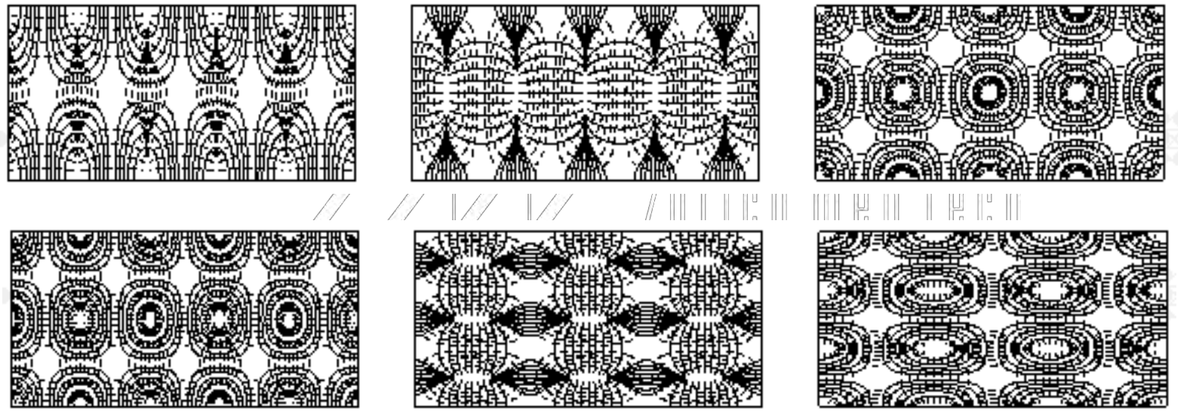
Reverberation Chamber

two elements

- chamber
- mode stirrers

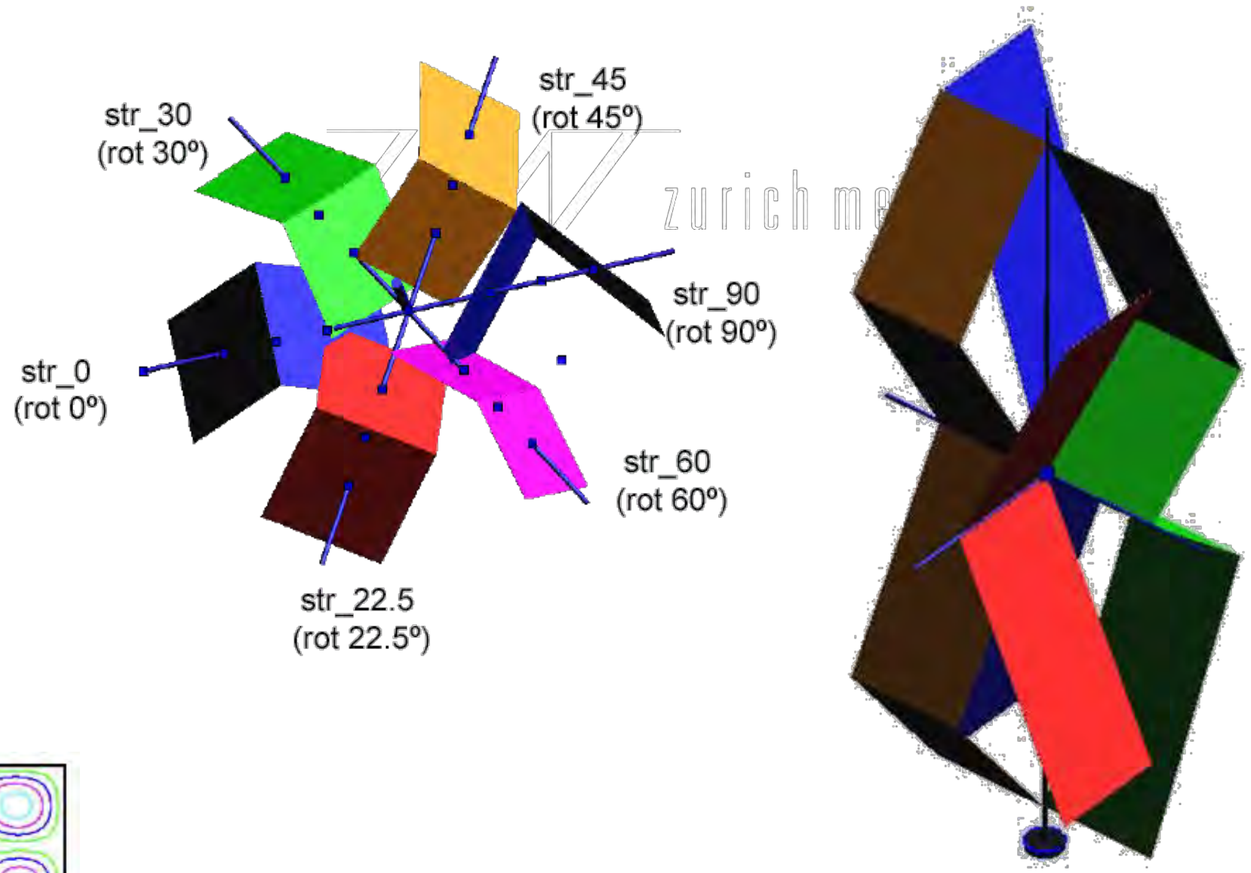
chamber

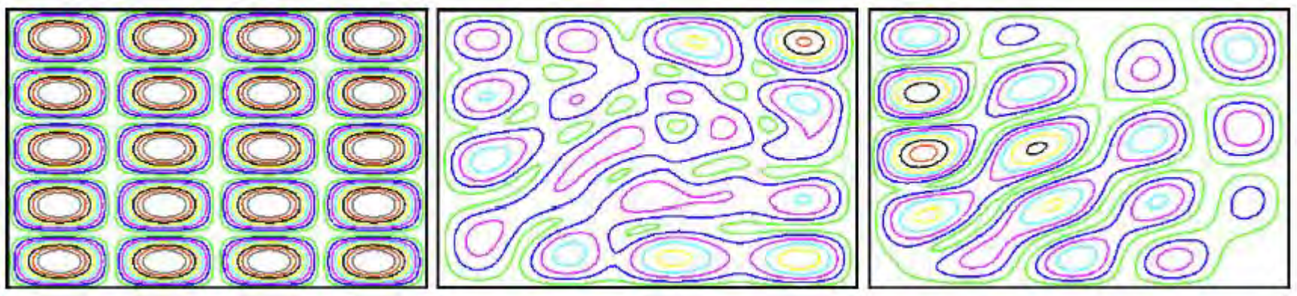
- a fully shielded enclosure or room
- forms a resonant cavity
- supports many resonant modes dependent on the size or volume
- the modes are excited by introducing a source of EM fields into the chamber (antenna)
- for the same excitation antenna, location and frequency, the field structure will be the same
  - peaks
  - troughs



Mode stirrers

- paddles or fans that rotate, scattering the incident field
- asymmetric design chosen to provide complex scattering patterns
- maximize the number of modes excited within the chamber





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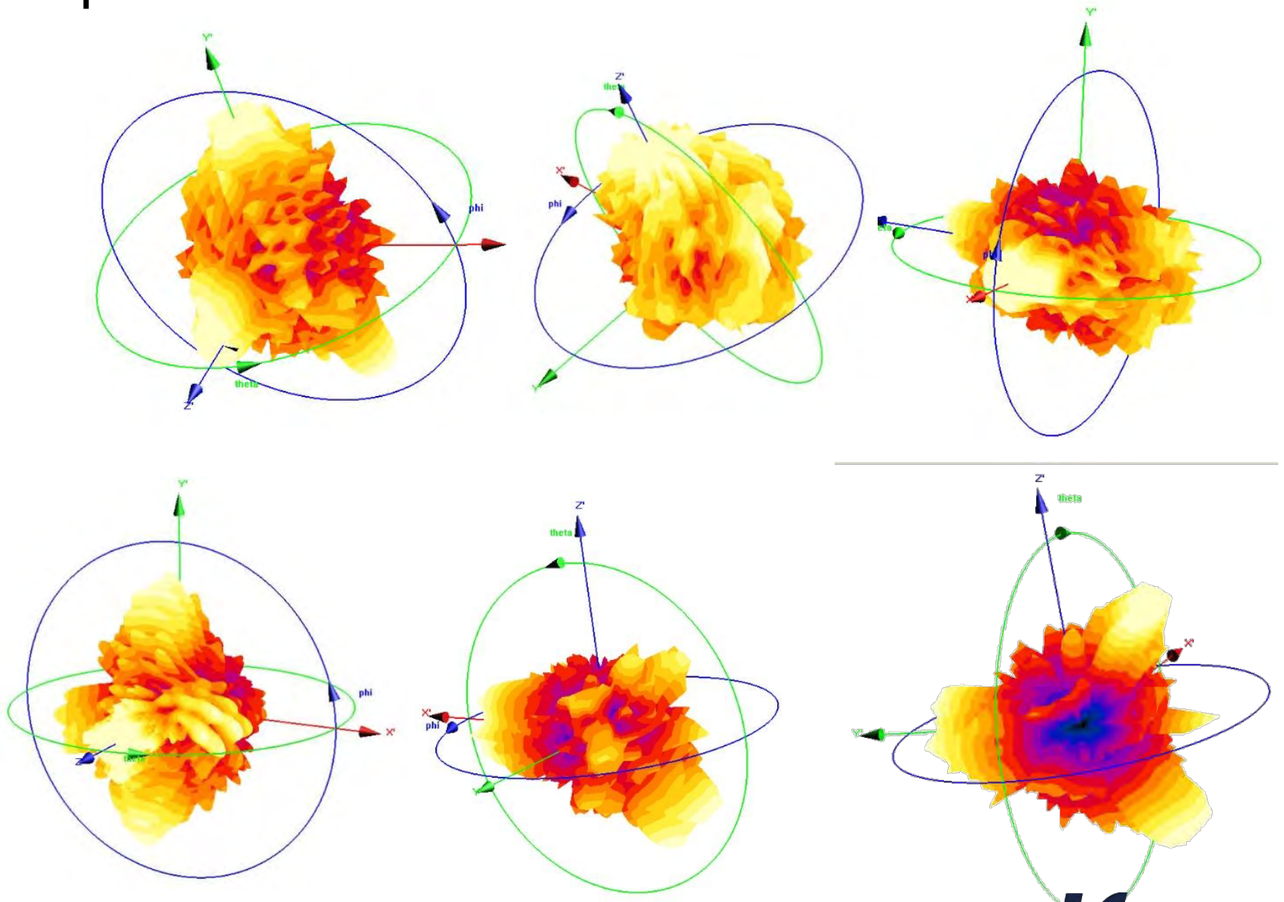
Reverberation Chamber: Two stirrers

- two mode stirrers to achieve high field homogeneity and isotropy
- stirred to unstirred volume is of importance



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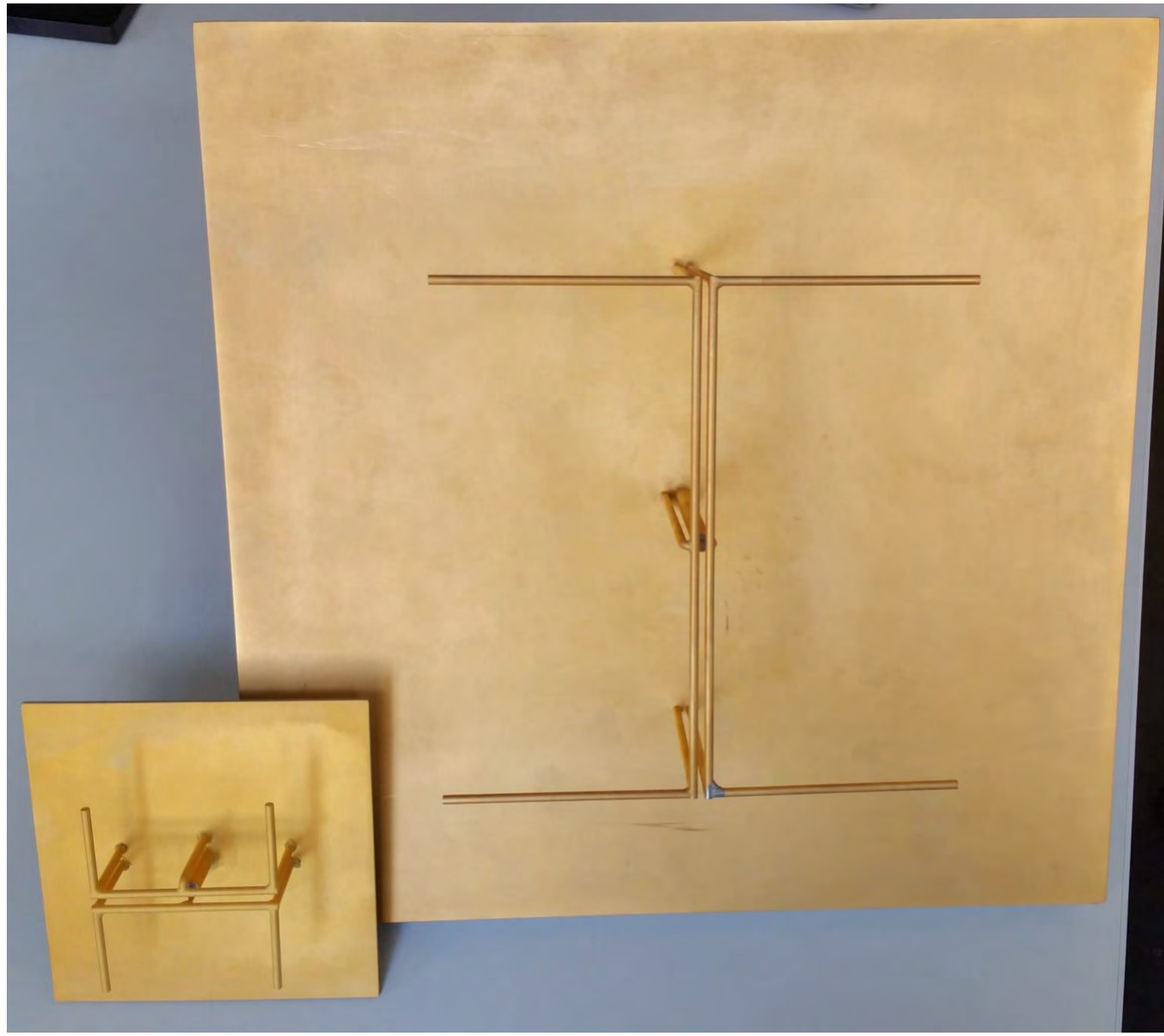
Antennas

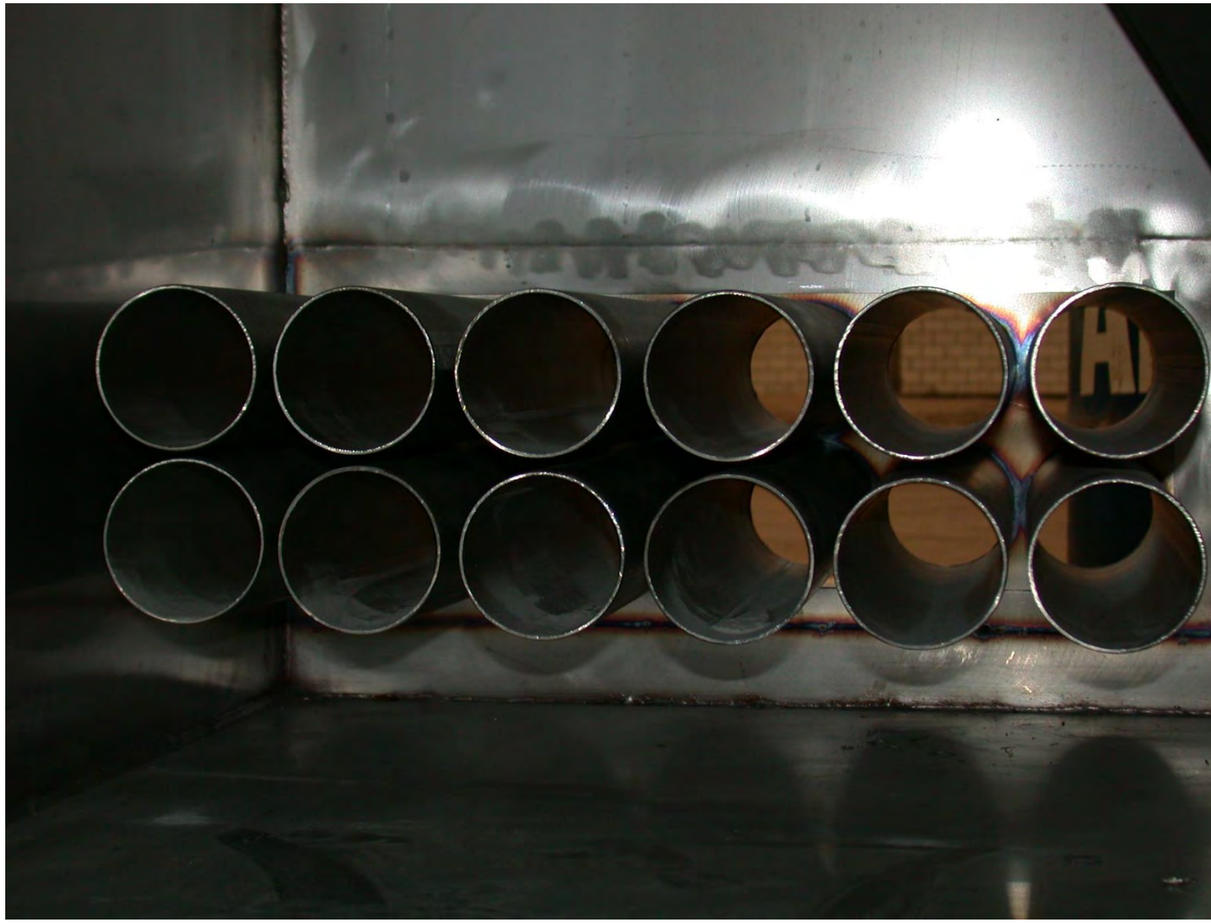
- standard gain antennas
  - a pair of dipoles spaced half a wavelength apart
  - fed in phase
  - spaced quarter of a wavelength above a square ground plane
  - ground plane with a side length of one wavelength
  - passivated using gold plating

- well controlled and symmetrical main beam pattern

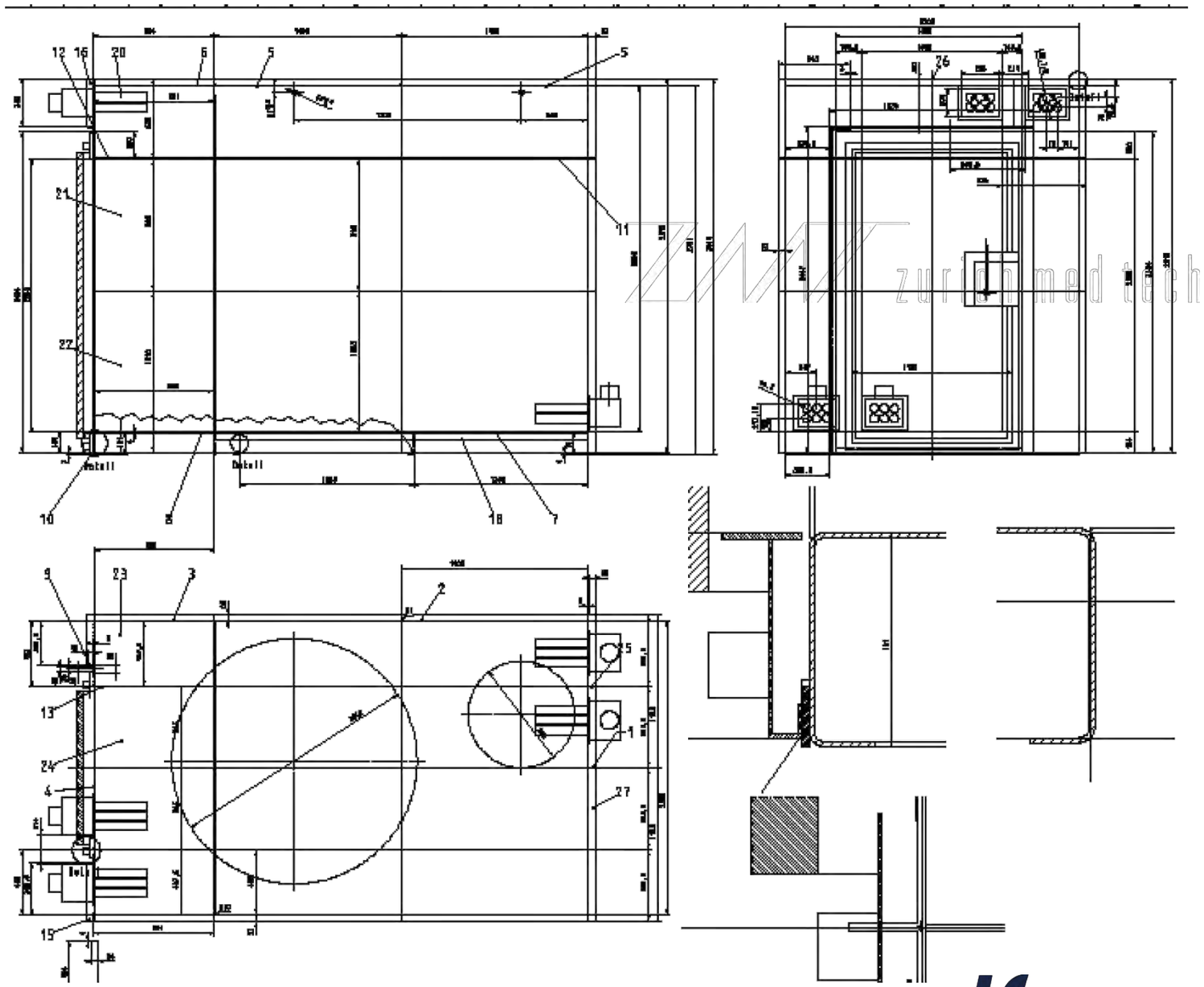


Air Flow

- NTP requirements
  - the number of air changes per hour >12
  - maximum noise levels
- noise due to turbulence of high air velocity
  - vents are dimensioned to keep the air velocity low
- vents must provide high RF isolation
  - vents have a maximum diameter to ensure that RF cannot propagate
  - maximum diameter < half a wavelength
  - length chosen to have > 100 dB isolation



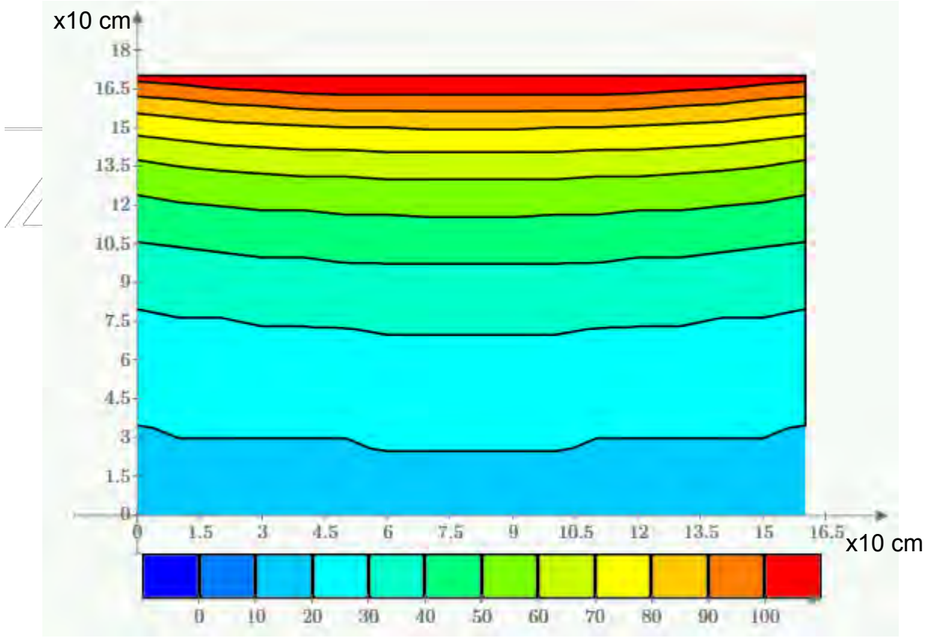
Chamber Design



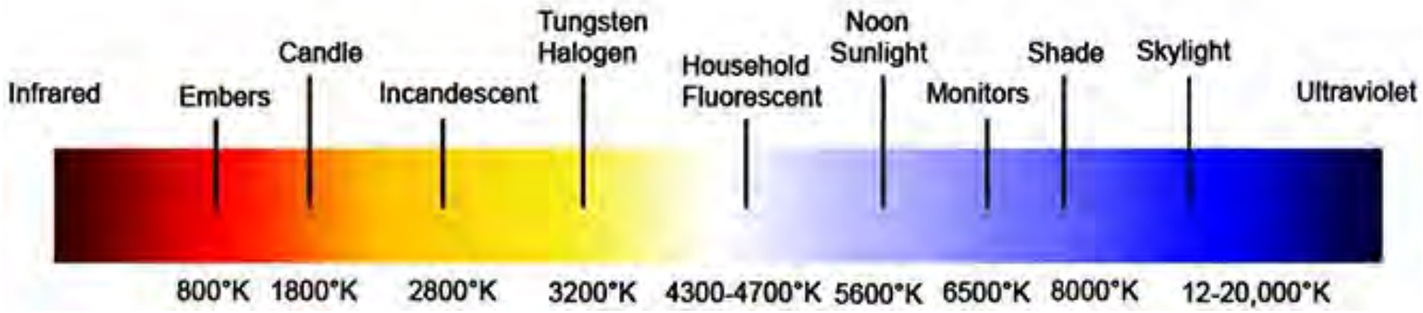
Prototype Chamber in Zurich

Lighting (Specific NTP Requirements)

- 40 – 50 foot-candles 5 feet above the floor
- ceiling mounted luminaries not possible because of the roof mounted stirrer
- the aim was to meet the spirit of the requirement if not the letter of the requirement
- this was achieved by looking at a vertical plane down the center of the chamber rather than a horizontal plane 5 feet above the floor.



Foot-Candles



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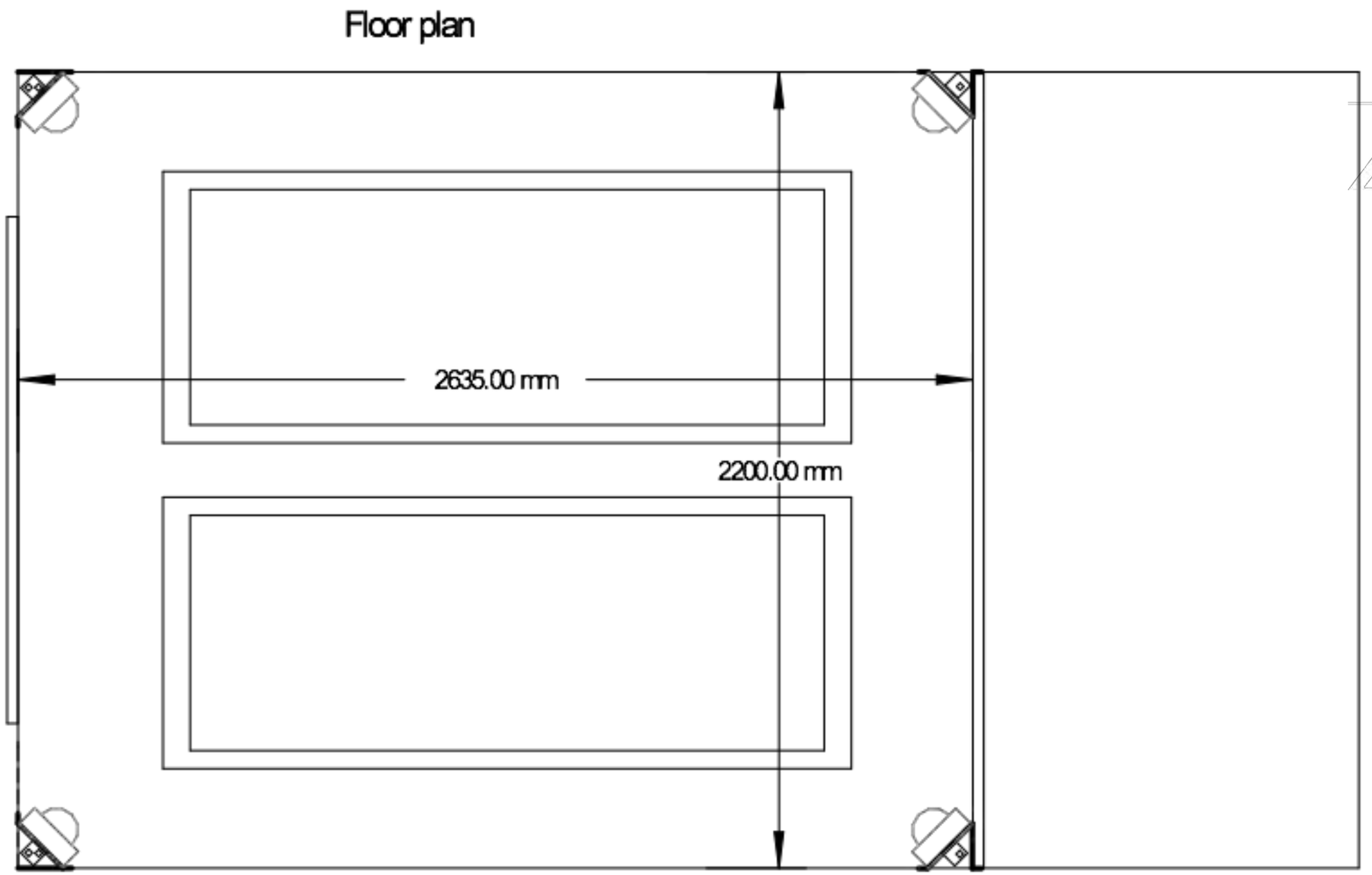
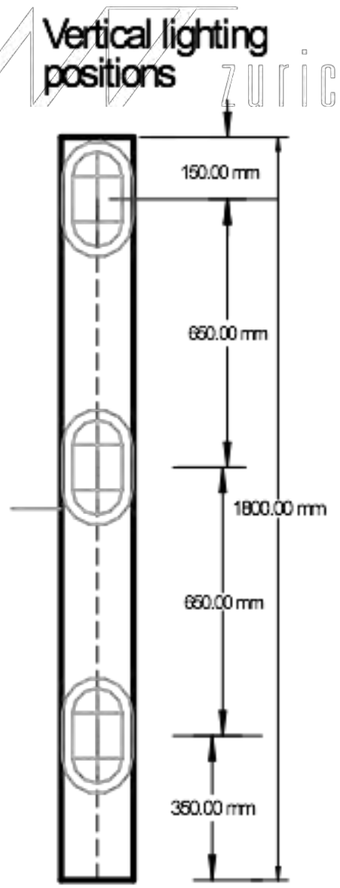
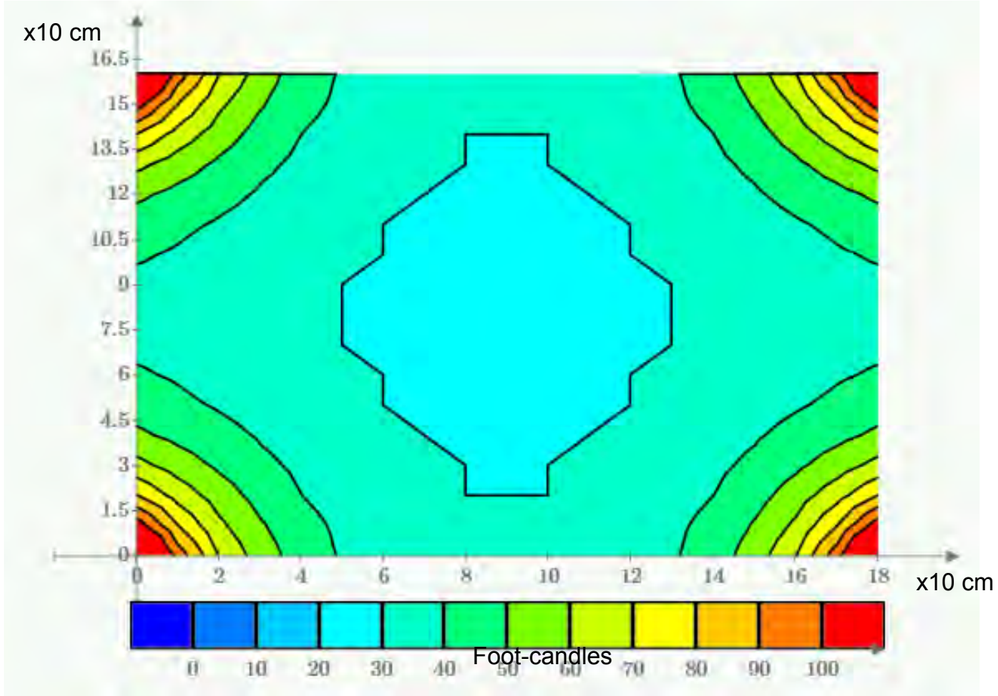
Lighting Locations

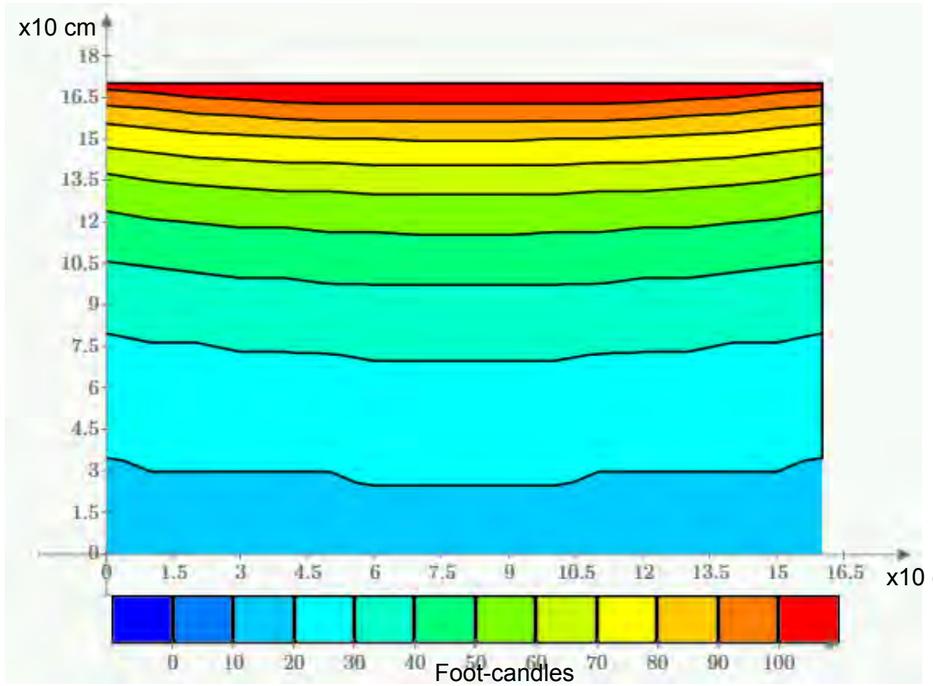




Light Levels and Distribution

- lighting had to be evaluated to determine the compliance with NTP requirements
- incandescent lighting – 12 x 40W bulbs





Performance Characterisation

stirred to unstirred energy

- all samples randomly distributed about the center
- ideally the average is zero

Homogeneity

Isotropy

At 900 MHz

- 20.4 dB

At 1900 MHz

- 16.7 dB

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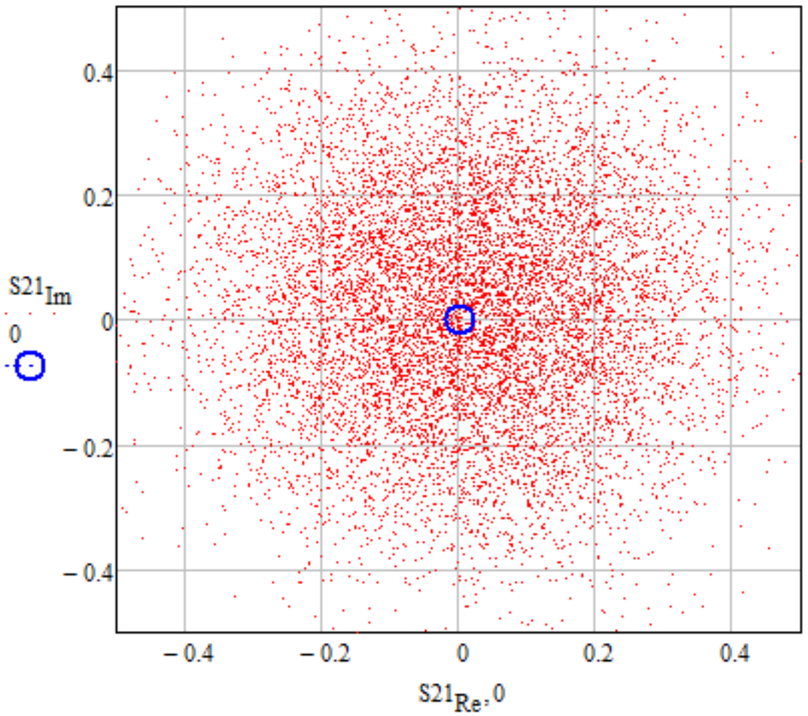

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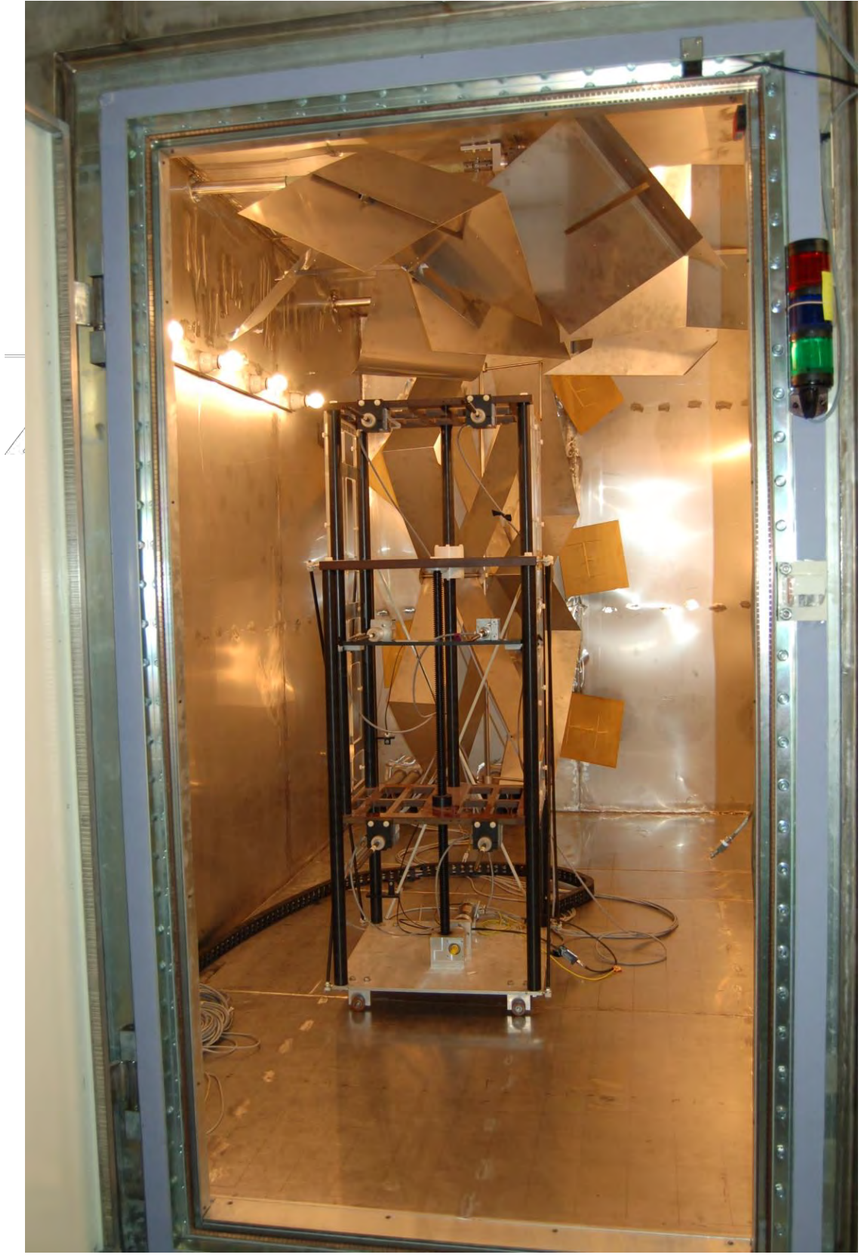
NIEHS Chamber Field Uniformity

- measured at 216 individual points in the exposure volume
- using field probes with effective volume of 5 mm x 5 mm x 5 mm
- 4 x E-field probes
- 2 x H-field probes



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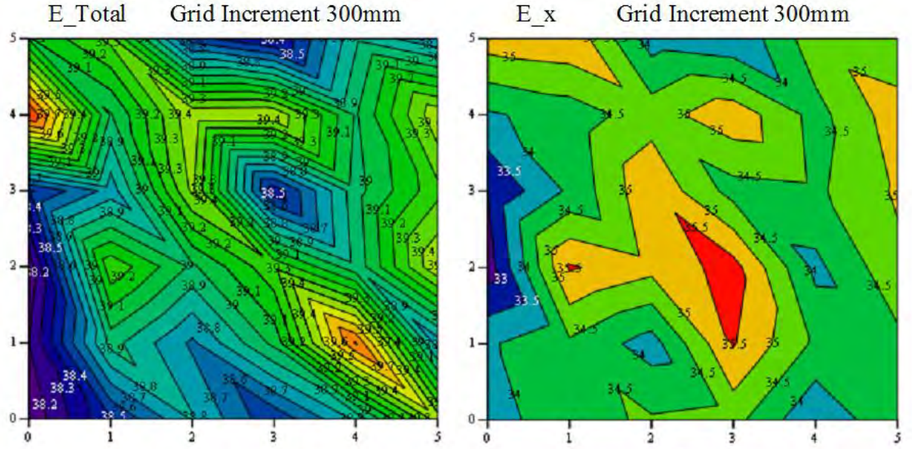
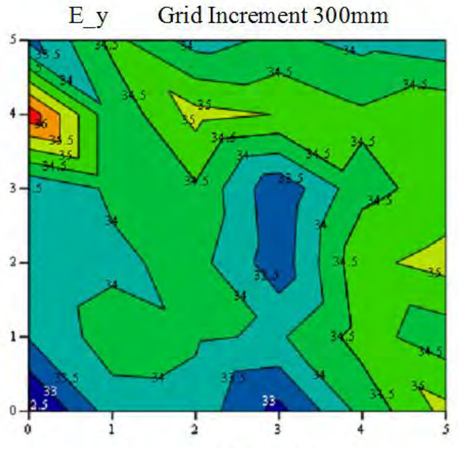


$E_T(h)$

$$E_T(h) = \begin{pmatrix} 38.12 & 38.2 & 38.13 & 38.48 & 39.91 & 39.09 \\ 38.49 & 38.94 & 39.28 & 38.74 & 38.99 & 39.33 \\ 38.81 & 38.68 & 38.98 & 39.42 & 39.48 & 38.54 \\ 38.52 & 39.03 & 39.28 & 38.43 & 39.49 & 38.37 \\ 38.82 & 39.81 & 38.93 & 38.96 & 38.99 & 38.88 \\ 39.46 & 38.74 & 39.5 & 39.27 & 39.48 & 38.71 \end{pmatrix}$$

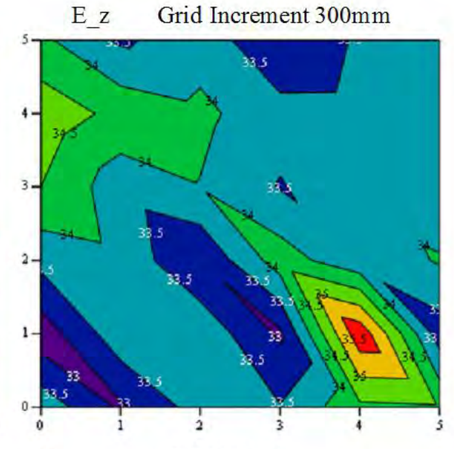
$E_x(h)$

$$E_x(h) = \begin{pmatrix} 33.75 & 33.93 & 32.74 & 33.01 & 33.93 & 35.27 \\ 34.35 & 34.41 & 35.56 & 34.09 & 34.22 & 35.39 \\ 34.56 & 33.77 & 35.16 & 35.42 & 34.78 & 33.76 \\ 34.67 & 35.54 & 35.7 & 34.3 & 35.34 & 33.55 \\ 33.56 & 34.4 & 33.87 & 34.4 & 34.32 & 34.81 \\ 34.43 & 34.36 & 34.87 & 35.07 & 35.28 & 34.52 \end{pmatrix}$$



$E_y(h)$

$$E_y(h) = \begin{pmatrix} 32.32 & 33.54 & 33.63 & 33.5 & 36.33 & 33.35 \\ 33.75 & 34.26 & 33.88 & 34.1 & 34.1 & 34.65 \\ 33.79 & 34.07 & 34.19 & 34.43 & 35.17 & 33.78 \\ 32.84 & 33.93 & 33.2 & 33.11 & 34.98 & 34.12 \\ 34.15 & 34.7 & 34.88 & 34.35 & 34.59 & 33.84 \\ 35.15 & 34.21 & 35.18 & 34.7 & 34.92 & 33.63 \end{pmatrix}$$



$E_z(h)$

$$E_z(h) = \begin{pmatrix} 33.82 & 32.71 & 33.64 & 34.5 & 34.82 & 34.11 \\ 32.93 & 33.82 & 33.84 & 33.71 & 34.35 & 33.42 \\ 33.72 & 33.87 & 33.04 & 33.98 & 34.12 & 33.78 \\ 33.53 & 32.91 & 34.26 & 33.47 & 33.67 & 33.07 \\ 34.39 & 35.87 & 33.61 & 33.8 & 33.68 & 33.57 \\ 34.45 & 33.25 & 34.05 & 33.58 & 33.79 & 33.62 \end{pmatrix}$$

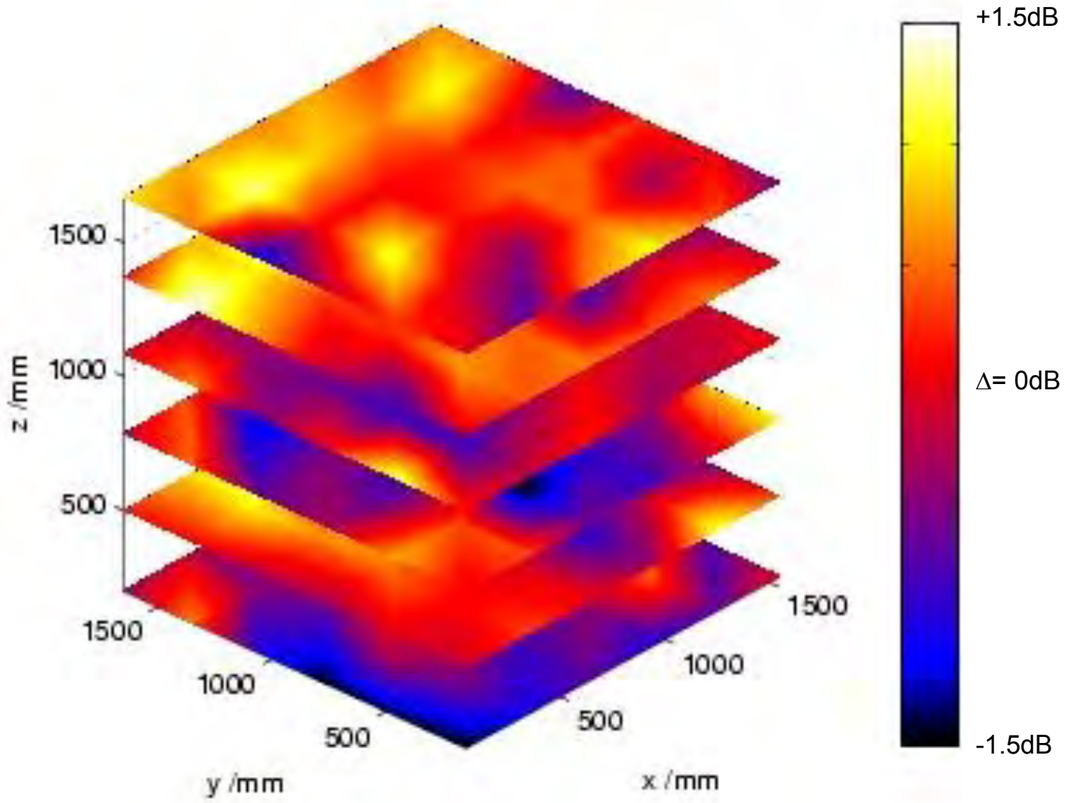
NIEHS Chamber Field Uniformity (Measured at 216 Individual Points)

900MHz

- total field standard deviation (Homogeneity) 0.6dB
- component fields SD (Isotropy) 0.9dB
- total population range (components) ±2.4dB

1900 MHz

- total field standard deviation (Homogeneity) 0.5dB
- component fields SD (Isotropy) 0.7dB
- total population range (components) ±1.8 dB



Homogeneity with Chamber Loaded with Phantoms

- the chamber was fully loaded with rat or mouse phantoms
- measured at 32 positions using 4 x H-field probes
- components and total field

900 MHz

- homogeneity 0.74 dB
- isotropy 1.1 dB
- total fields ±1.6 dB

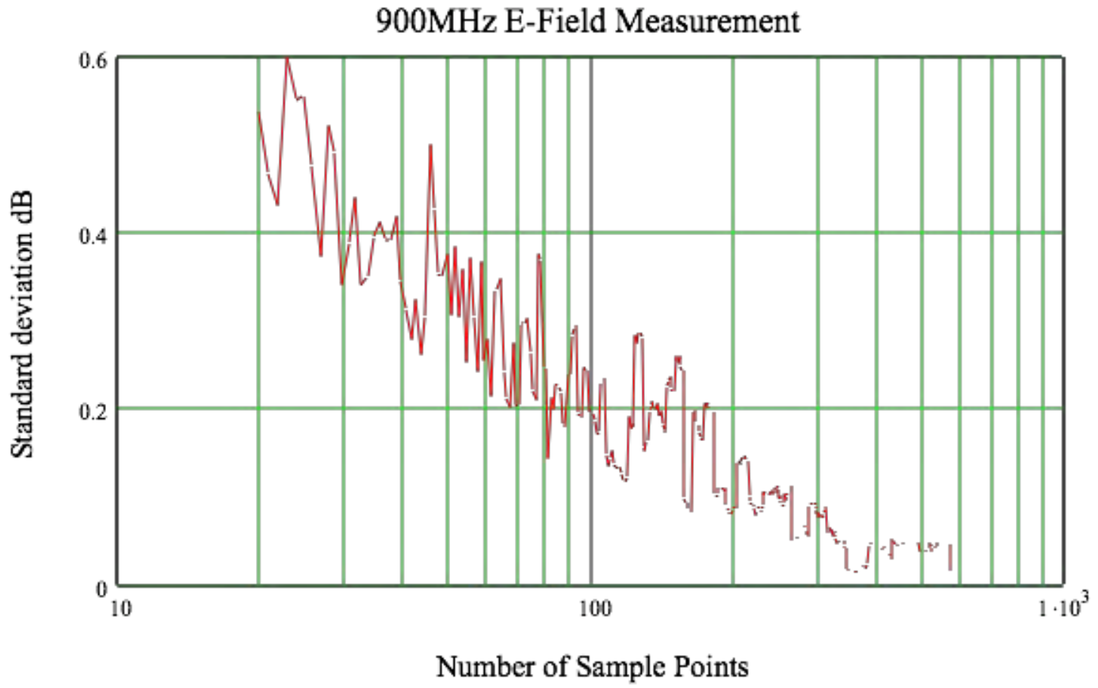
1900 MHz

- homogeneity 0.7 dB
- isotropy 1.3 dB
- total fields ±2.0 dB

Uncertainty for Field Homogeneity Measurements

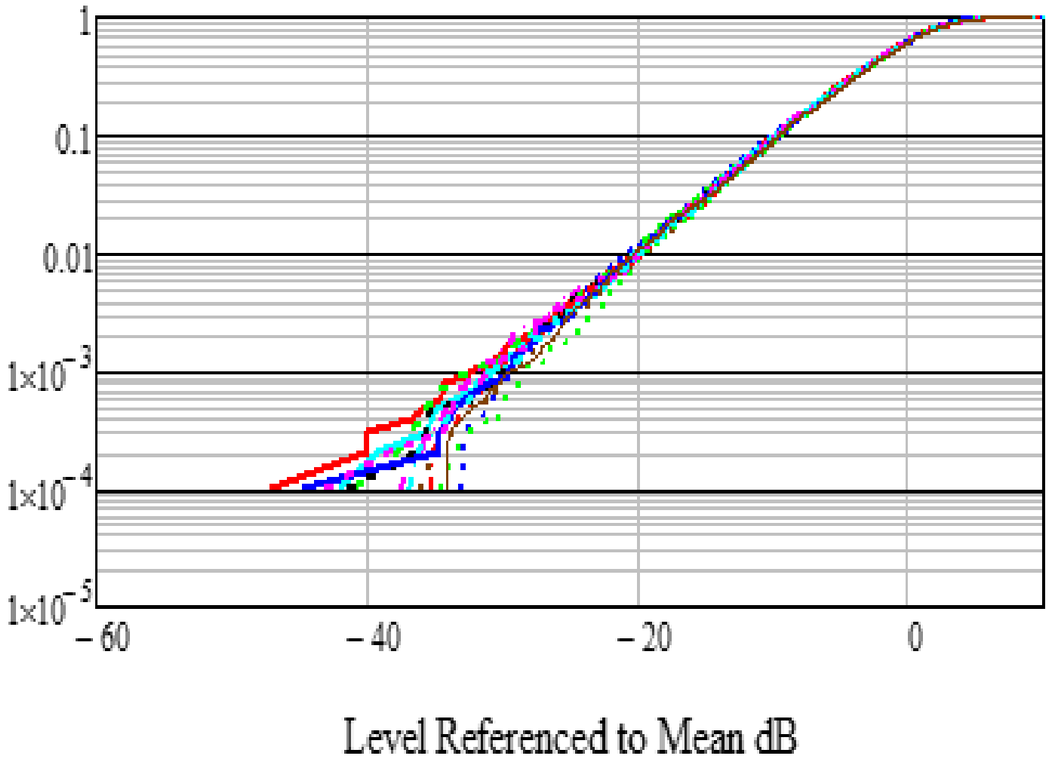
- good estimates of the average field strength at a given position requires a lot of time
- largest contribution to uncertainty comes from the finite number of stirrer positions sampled

Equipment	Uncertainty	Distribution	Divisor x coverage	Standard Uncertainty ±dB
E & H – field probe absolute accuracy	±0.26dB	normal	1	0.26
Frequency linearity	±0.2dB	rectangular	√3	0.12
Dynamic range linearity	±0.2dB	rectangular	√3	0.12
Isotropy	±0.4dB	rectangular	√3	0.12
Stirrer modulation	±0.6dB	normal	1	0.45
Combined Standard Uncertainty				0.58



Field Variation Statistics and Relative Losses

- CDF for Qs from 257 to 3071 at 900MHz



	Q	
Element	900MHz	1900MHz
Empty Chamber	7463	24457
Lights and antennas required for 6W/kg	3430	28901
Two Racks	4296	4725
Maximum Number of animal Phantoms	370	2021
Dry Sawdust	5278	8420
Food Pellets	9218	6791
Stirrer Guard	54398	27708
Total Q	272	922

	Power	Dissipated
Element	900MHz	1900MHz
Empty Chamber	15	4
Lights and antennas required for 6W/kg	33	4
Two Racks	27	19
Maximum Number of animal Phantoms	310	45
Dry Sawdust	22	11
Food Pellets	12	14
Stirrer Guard	2	3
Total Power	422	99
Efficiency %	74.0	46.0

Consequence of Inhomogeneity

- the estimate of the field strength in the chamber becomes less certain
- using multiple field probes decreases the uncertainty by the factor $\sqrt{n}$ where n is the number of probes
- therefore best to use more than one probe

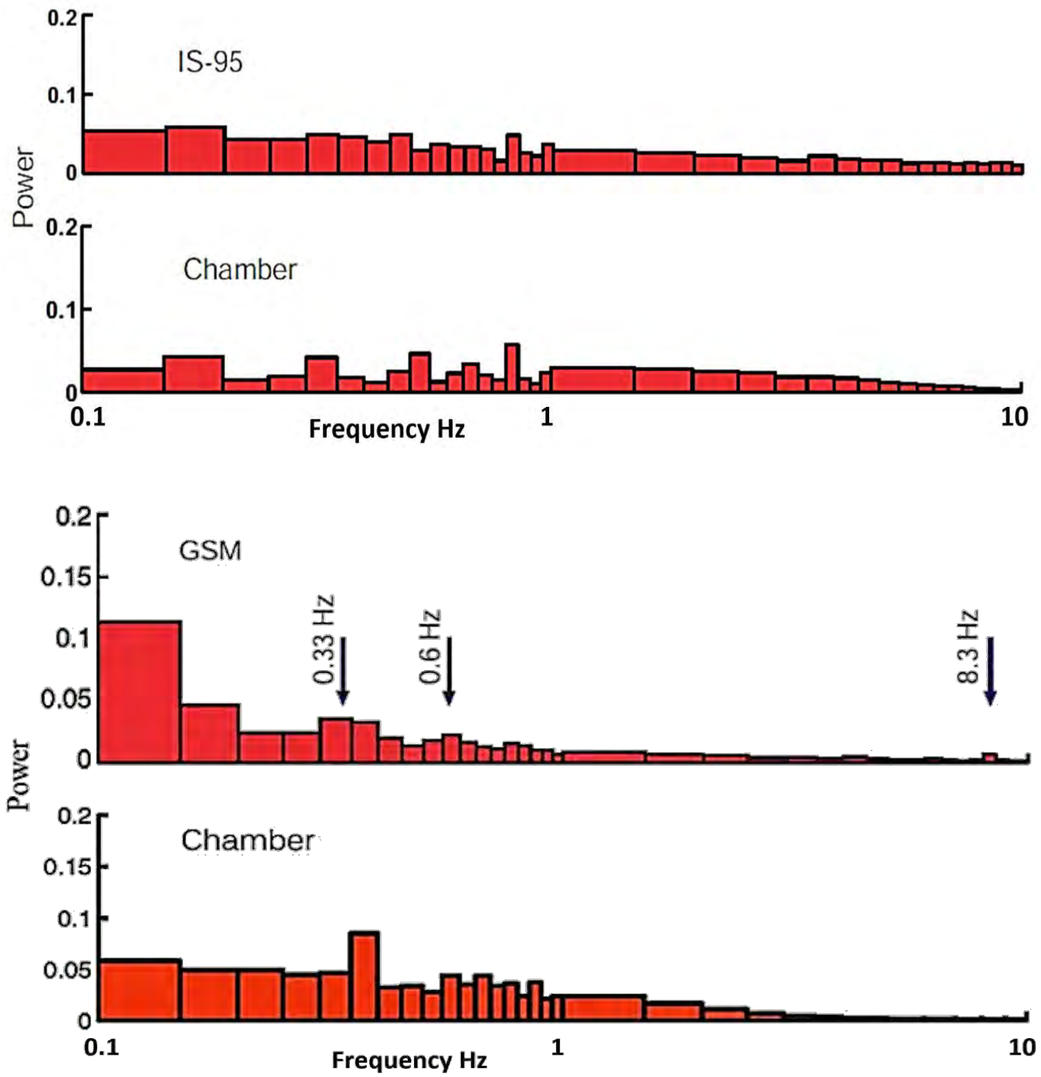
Exposure Field Uncertainty

Equipment	Uncertainty	Distribution	Divisor x coverage	Standard Uncertainty
E & H – field probe absolute accuracy	±0.26dB	Normal	1	±0.26dB
Frequency linearity	±0.2dB	Rectangular	√3	±0.12dB
Dynamic range linearity	±0.2dB	Rectangular	√3	±0.12dB
Isotropy	±0.4dB	Rectangular	√3	±0.12dB
Homogeneity / 2 probes	±0.43dB	Normal	1	±0.43dB
Field control	±0.2dB	Normal	1	±0.2dB
Combined Standard Uncertainty				±0.59dB

Reverberation Chamber: Stirrer Speed

- the speed of the stirrers can be set to mimic use of power control to counteract the effect of multipath fading.
  - in IS-95 power control feedback is provided ~800 times/second, but only alters the power by ±1dB each time
  - in GSM the power control is handled by the Slow Associated Control Channel SACCH at a rate of 2.08 times/sec, increased to 50 times/sec in the 1999 GSM/Edge release with Fast Associated Control Channel FACCH. In GSM phones the power is stepped in 2dB increments.
- stirrer speeds in the mouse and rat exposure setups will be different due to the different number of modes present at the different frequencies and the different rate of mode change with stirrer angle.

Stirrer Speeds and Modulation Characteristics



- the relative stirrer speeds were for:
  - CDMA (IS95), 4 : 5
  - GSM, 1 : 2
- the absolute speed depended on the mode density

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Stirrer Speeds

the stirrer speeds depend on the frequency and power control characteristics

	Rats 900MHz	Mice 1900MHz
CDMA	8 rpm 10 rpm	4 rpm 5 rpm
GSM	2 rpm 4 rpm	1 rpm 2 rpm

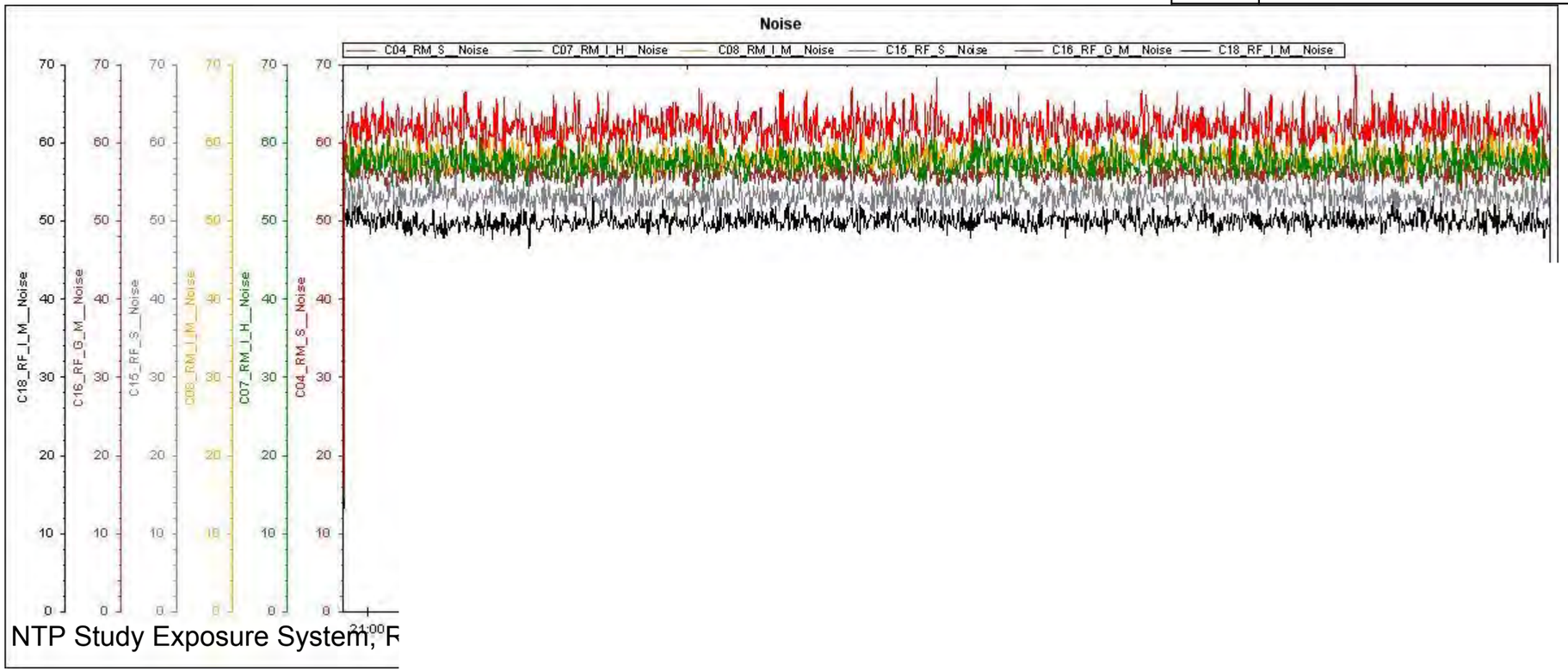
so that the common control animals experience the same stirrer speeds as the exposed animals, the speed changes every 10 minutes in all chambers

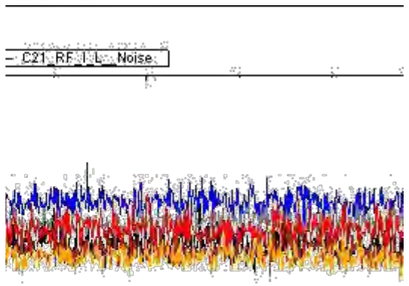
Time	Exposure	Rat Chambers	Mouse Chambers
0 – 10 min	GSM	2, 4 rpm	1, 2 rpm
10 - 20 min	CDMA	8, 10 rpm	4, 5 rpm
20 - 30 min	GSM	2, 4 rpm	1, 2 rpm
30 - 40 min	CDMA	8, 10 rpm	4, 5 rpm
40 - 50 min	GSM	2, 4 rpm	1, 2 rpm
50 - 60 min	CDMA	8, 10 rpm	4, 5 rpm

Noise (Measured in dBA)

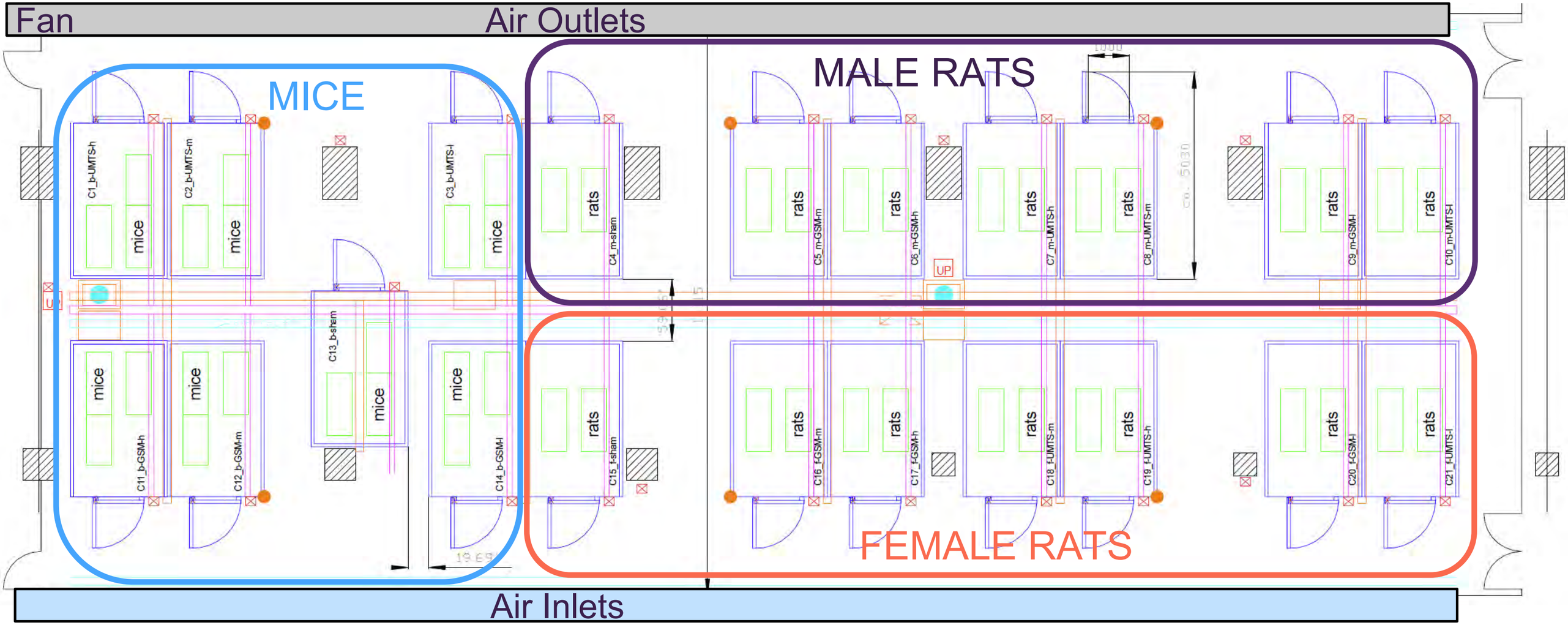
- highest levels of noise measured in the chambers closest to the outlet fan
- white noise was added to equalize the noise in all the chambers

dBA	Example	Home Appliances
0	healthy hearing threshold	
10	a pin dropping	
20	rustling leaves	
30	whisper	
40	babbling brook	computer
50	light traffic	refrigerator
60	conversational speech	air conditioner
70	shower	dishwasher
75	toilet flushing	vacuum cleaner





Air Handling



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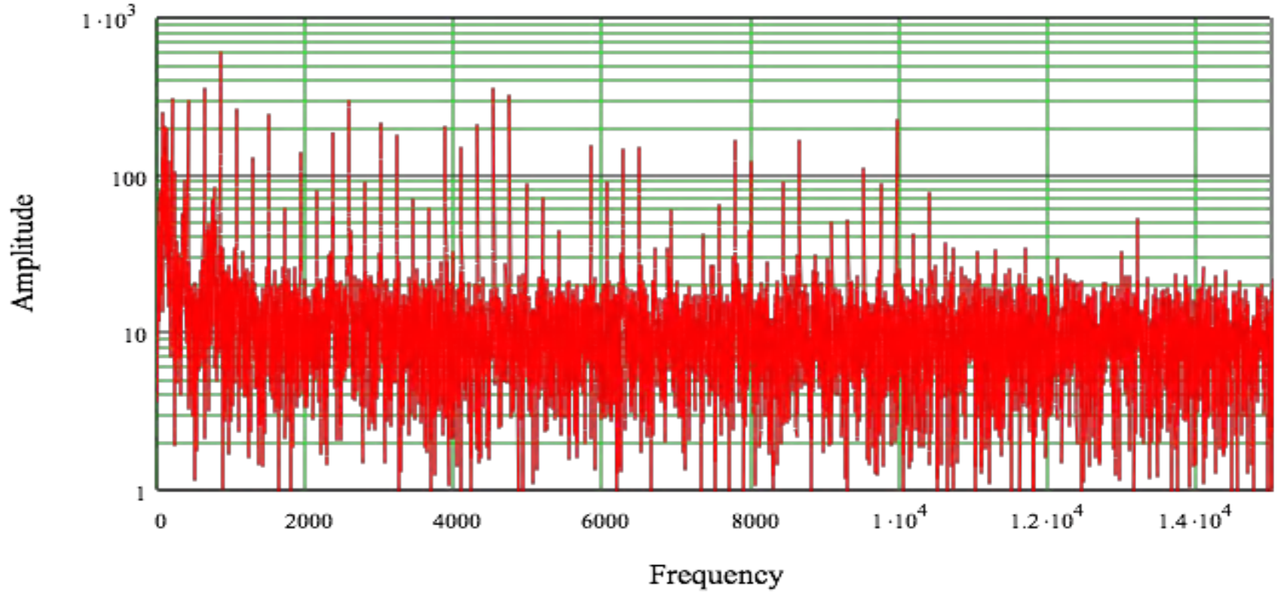
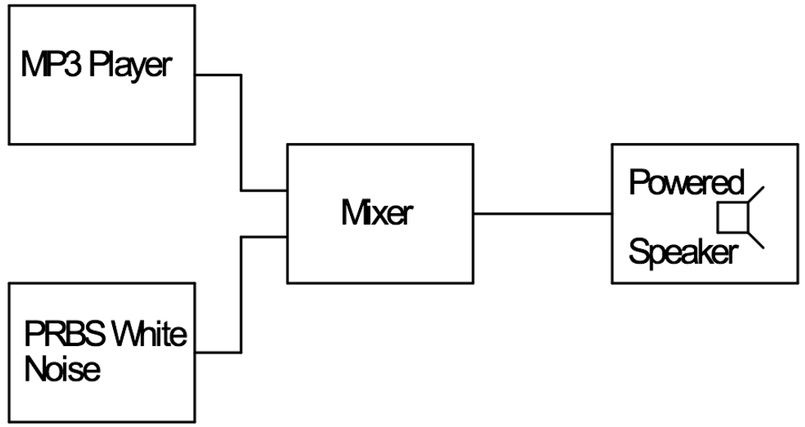
GSM Noise

in the GSM chambers there was a field dependent noise at the frame rate (213 Hz)

- bright sound with many harmonics



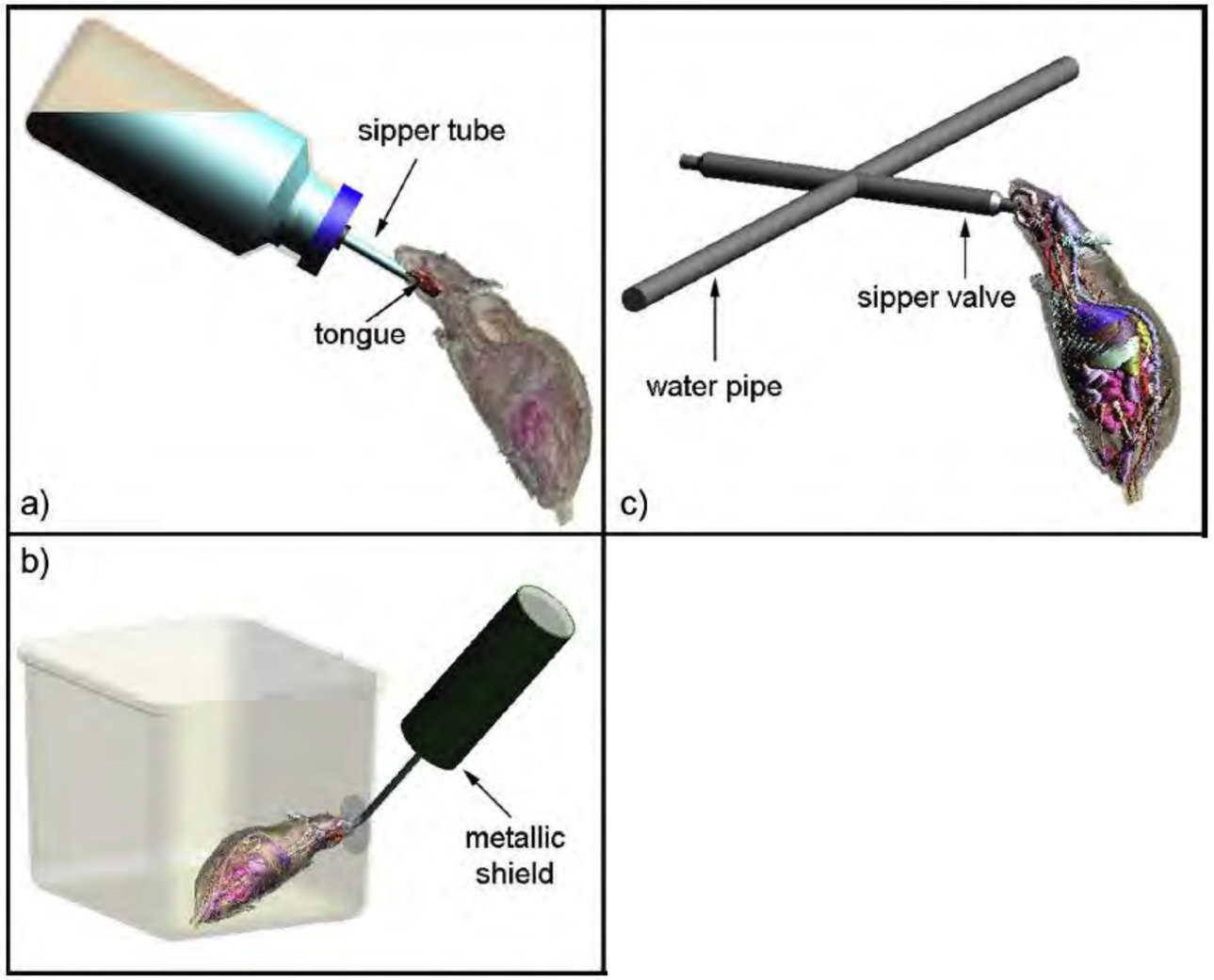


- the sound was recorded and added to all chambers at the highest level observed in all the chambers using MP3 players

Drinking Water Provision

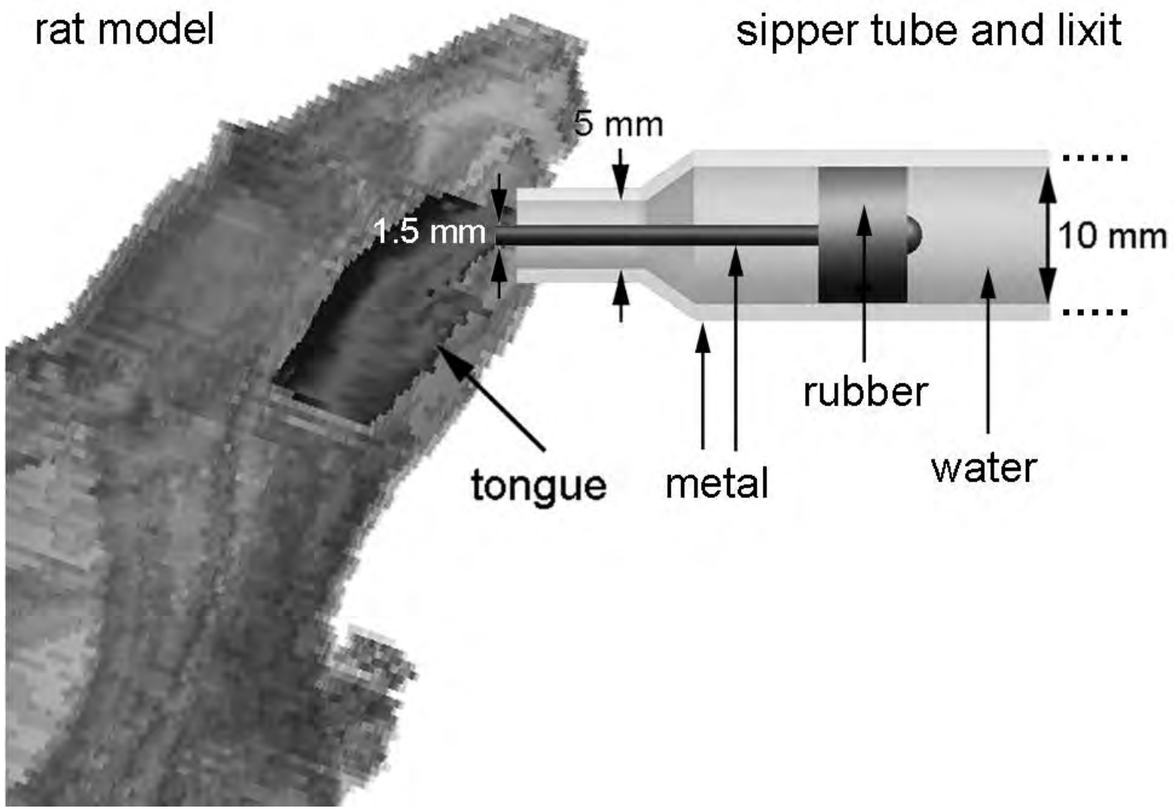
typical solutions

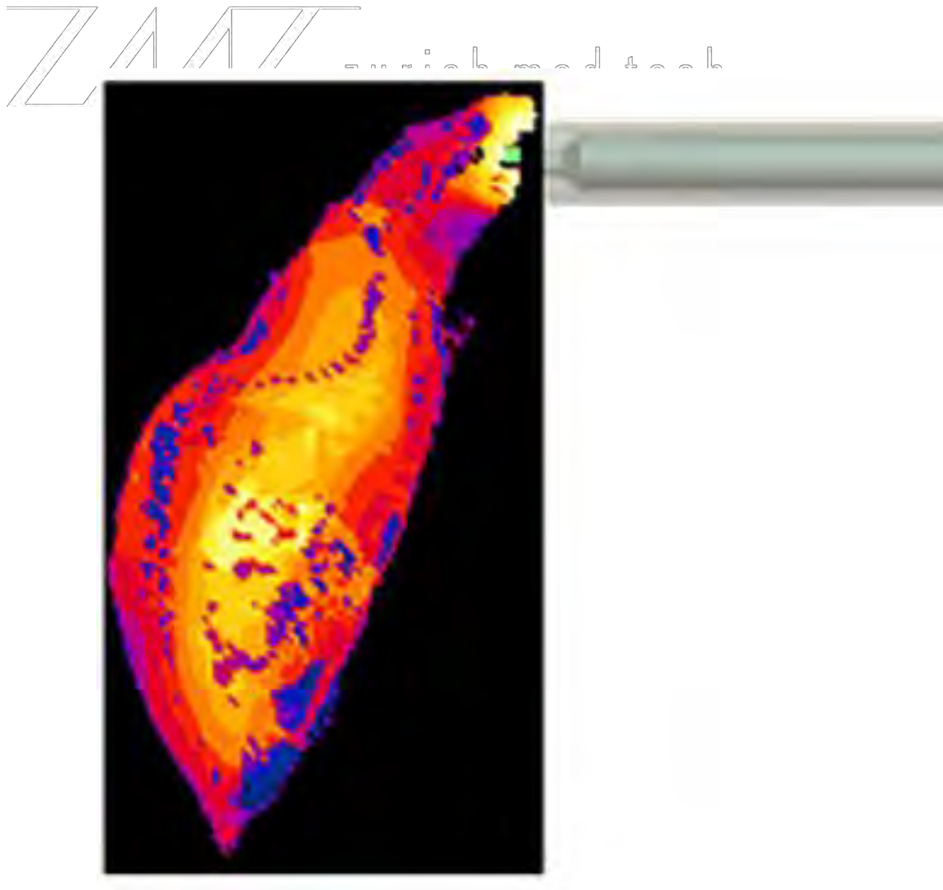
- (a) with a standard bottles of water,
- (b) in a cage with a shielded water bottles,
- (c) with a part of the automatic water system including sipper and pipes



Automatic Watering System

- the evolution of a safe high field strength environment water supply system





Automatic Watering System

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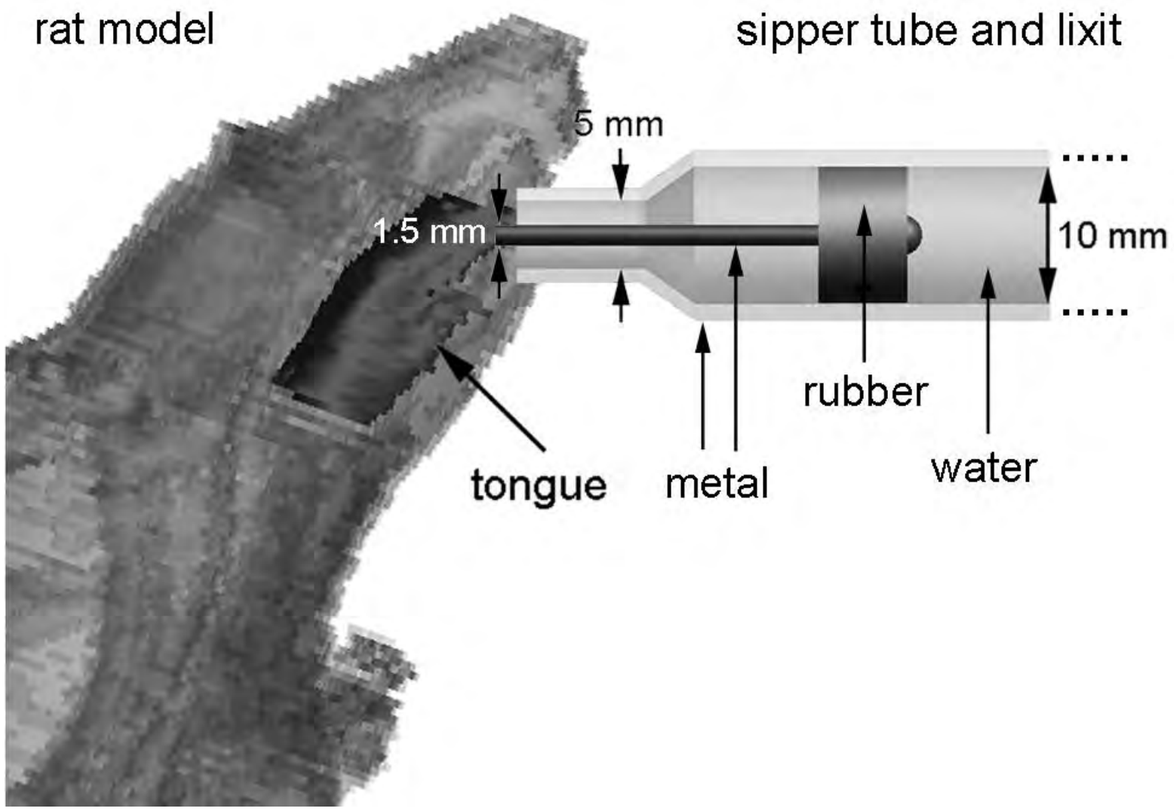
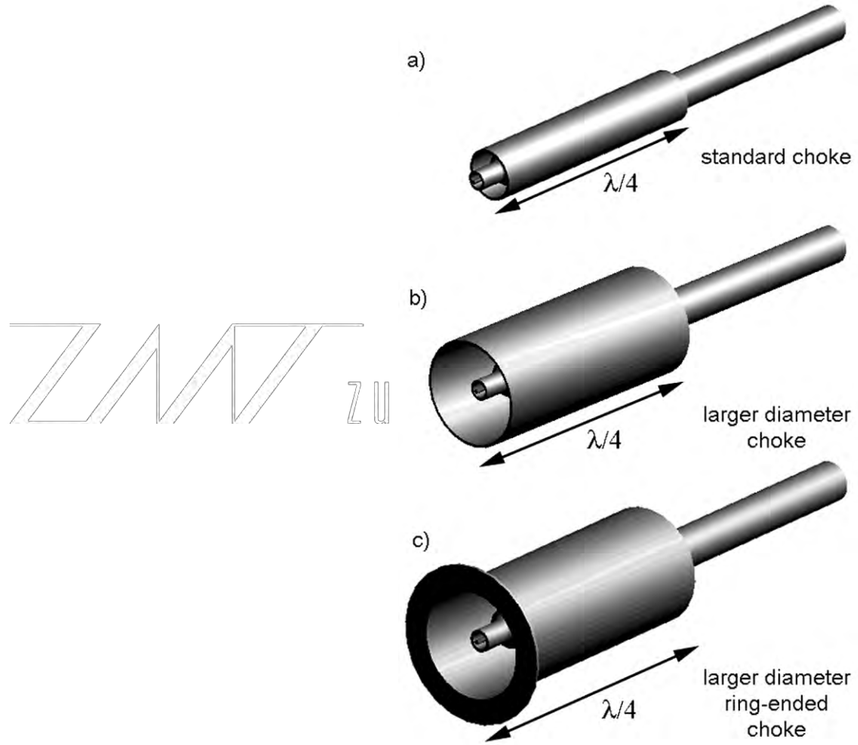
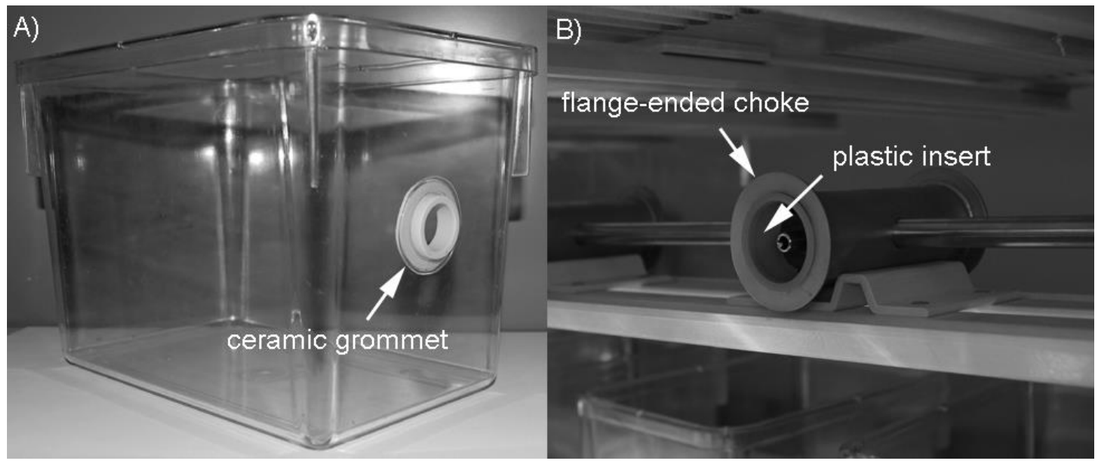
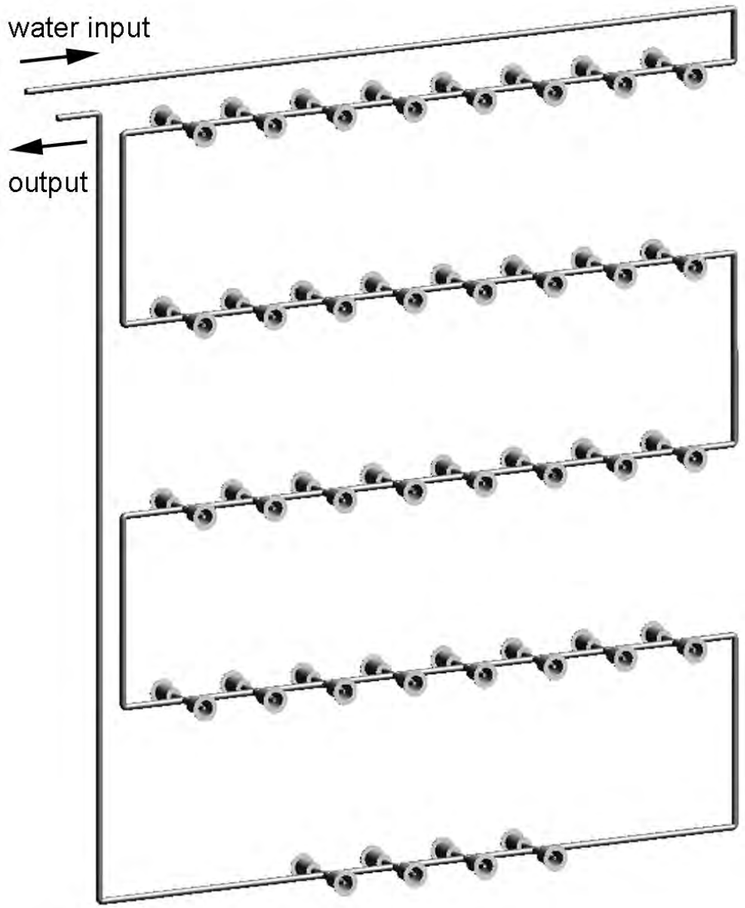




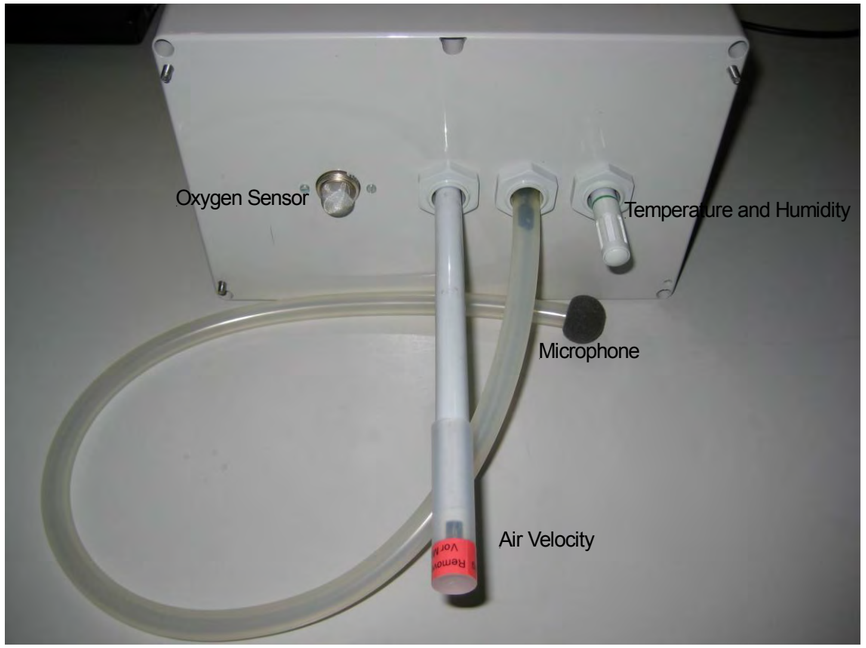


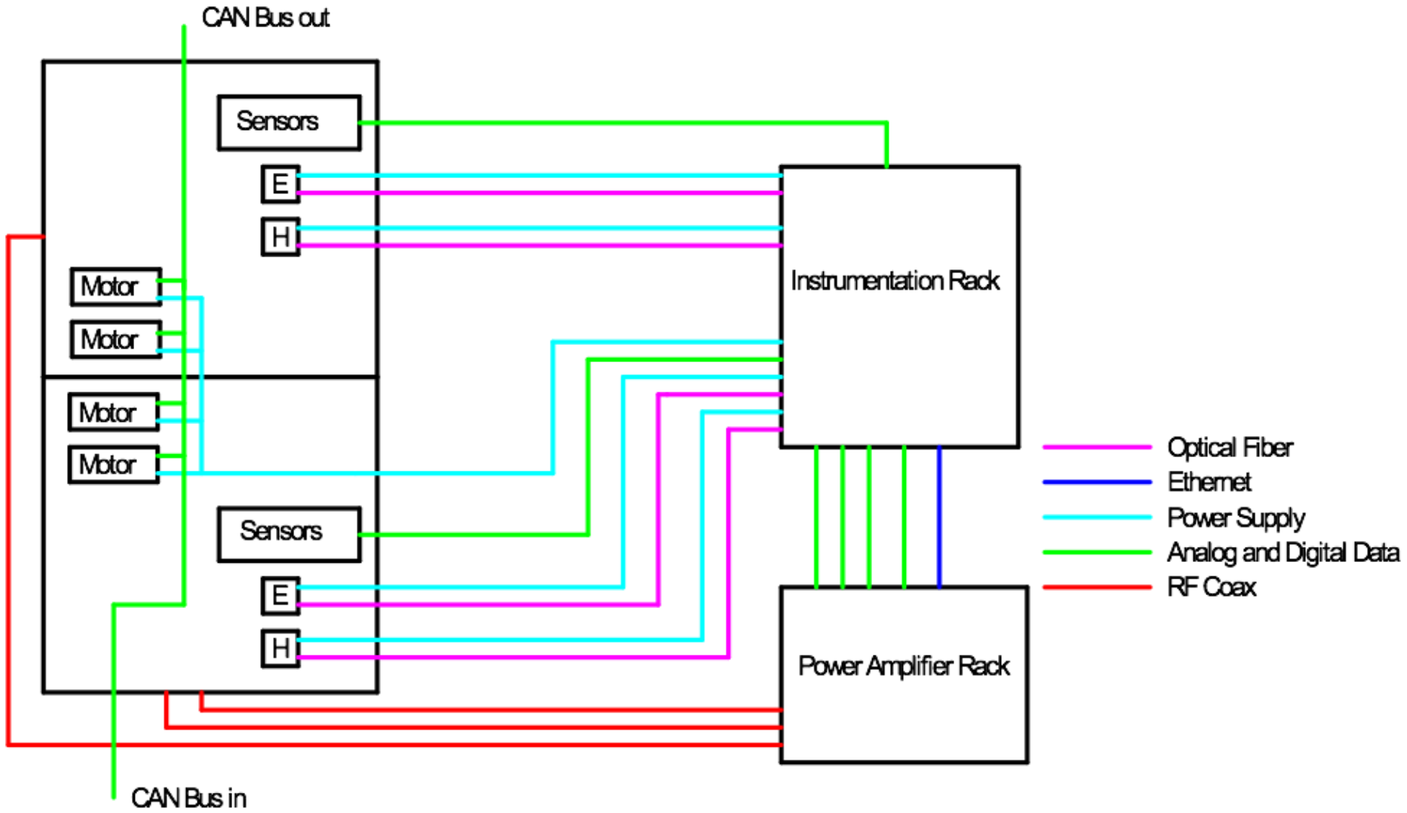
Automatic Water System and Cage Racks

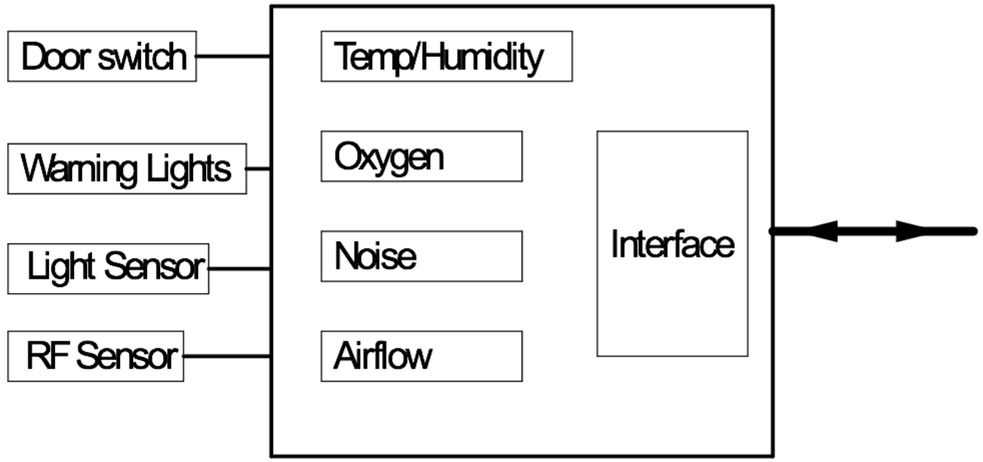
- the water system was installed in the center of the rack with access from both sides for the animal cages
- racks fabricated from low loss fiber glass materials
- plastic cages and lids, ceramic grommets



Stirrers and Sensors







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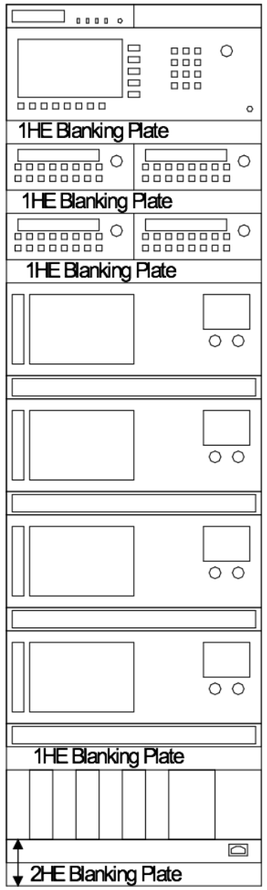
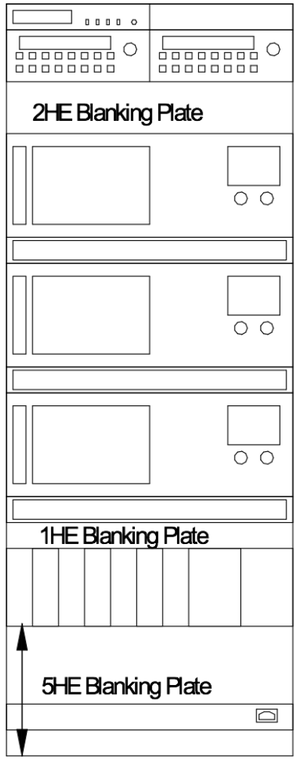
Control Equipment and Amplifiers





Data Acquisition

field strength

- sampled 1250 times per second, 20 sets of 1s averaged data sent to control system for each probe every 20s
- 1s data stored into the log file, averaged values reported every 20s
- SAR calculated only during exposure 10 min periods

environmental parameters

- temperature, humidity, oxygen, noise, air flow, light
- measured every 20 seconds
- data stored in the log file

log files

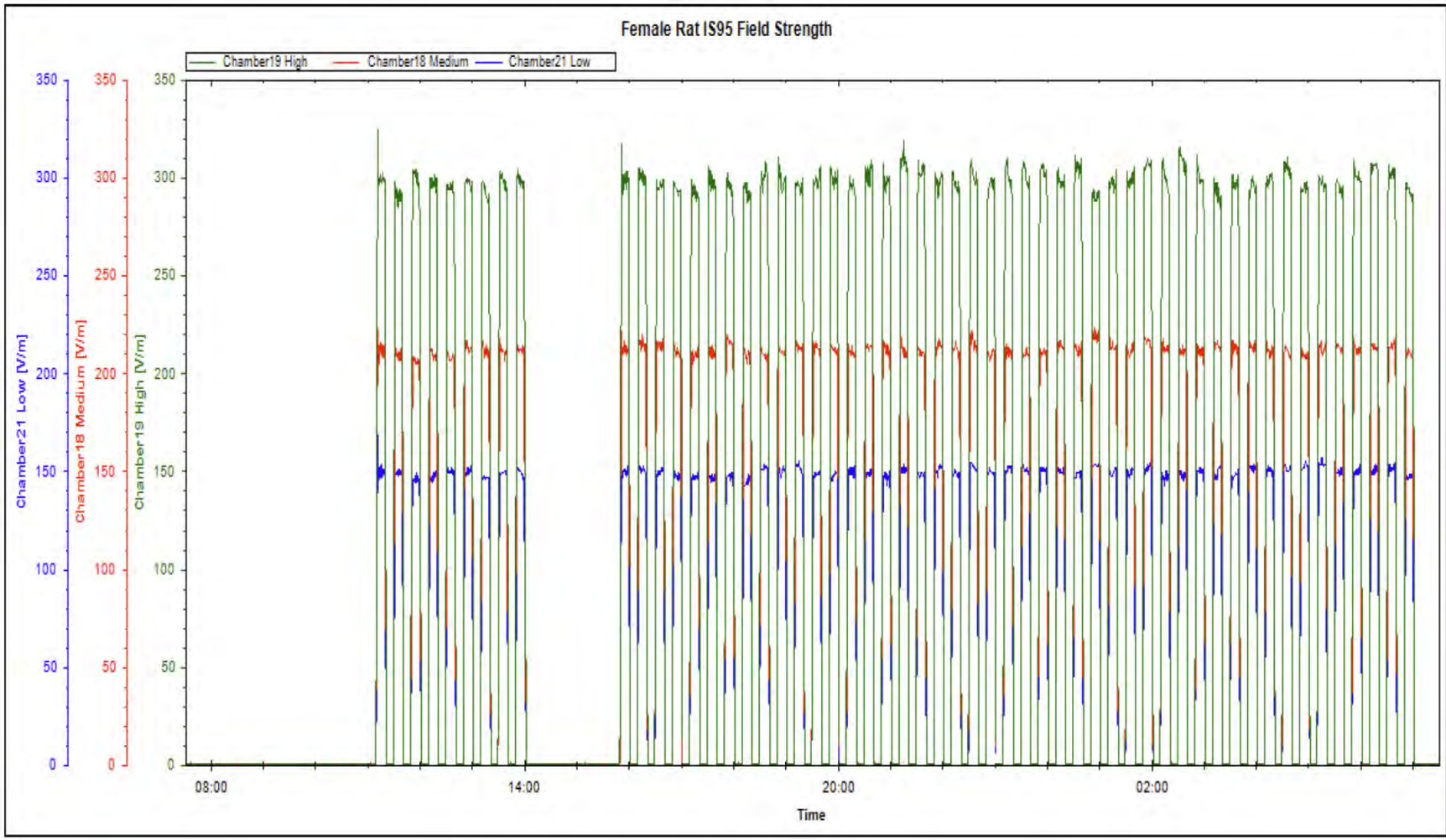
- 4319 values per day for each measured parameter
- 1798 values during exposure per day

Log Files (Daily Analysis)

Female Rat SAR								
Chamber	Animal Weight [g]	Target [W/kg]	Mean [W/kg]	Stdev [dB]	Min [dB]	Max [dB]	InRange/ Total	Ratio
Ch17 Female Rat GSM High	422.90	6.000	6.030	0.27	-0.72	1.02	1798/1798	1.000
Ch16 Female Rat GSM Med	418.10	3.000	3.038	0.24	-0.71	0.89	1798/1798	1.000
Ch20 Female Rat GSM Low	431.10	1.500	1.471	0.18	-0.65	0.46	1798/1798	1.000
Ch19 Female Rat IS95 High	430.60	6.000	5.899	0.16	-0.50	0.64	1798/1798	1.000
Ch18 Female Rat IS95 Med	440.10	3.000	2.977	0.13	-0.36	0.42	1798/1798	1.000
Ch21 Female Rat IS95 Low	439.90	1.500	1.483	0.14	-0.46	0.97	1798/1798	1.000
Ch15 Female Rat Sham	426.90	0.000	0.000	--	--	--	1798/1798	1.000

Graphical Interpretation

- the 10 minute on – off periods are clearly shown
- the morning and afternoon pauses in exposure



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Chronic Study Exposure Levels

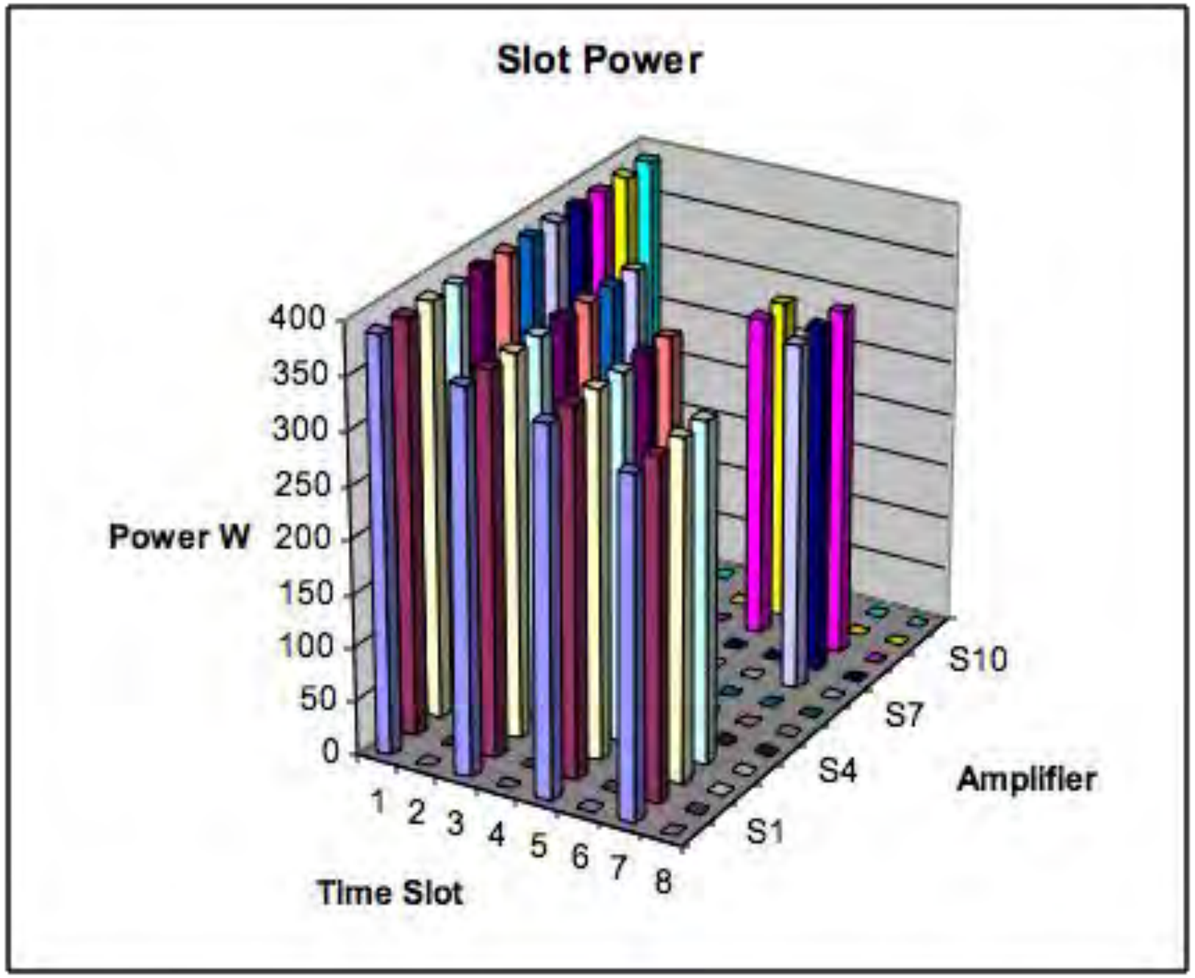
rats

- dose groups
  - 6.0 W/kg
  - 3.0 W/kg
  - 1.5 W/kg
  - 0 W/kg
- 7 chambers for male rats with up to 112 animals
- 7 chambers for female rats with up to 112 animals

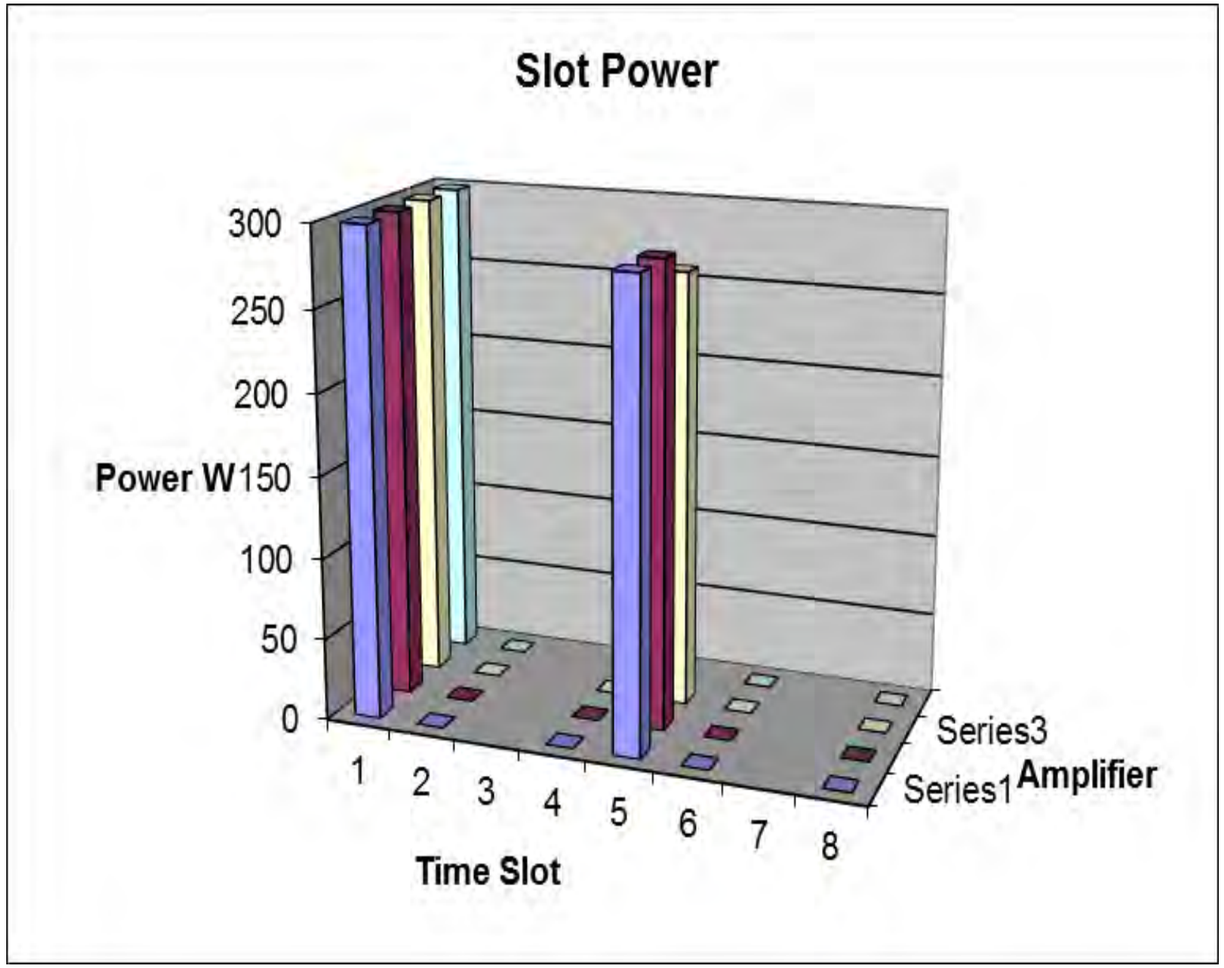
mice

- dose groups
  - 10 W/kg
  - 5.0 W/kg
  - 2.5 W/kg
  - 0 W/kg
- 7 chambers with 216 mice, half male, half female

Amplifiers and Output Power for Planned SAR - GSM



Rat system 12 x 400W amplifiers



Mouse system 4 x 400W amplifiers

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Amplifiers and Output Power for Planned SAR - CDMA

Rats

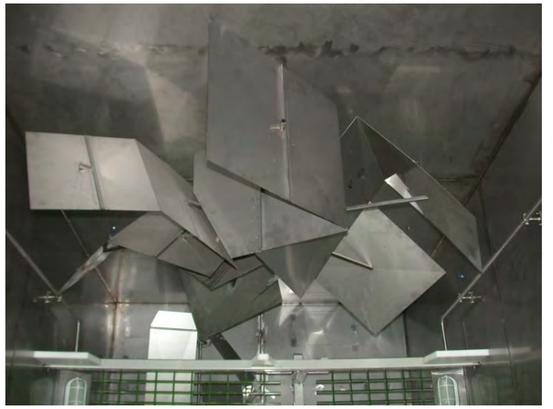
Mode	Amplifiers	Chamber
CDMA	1-4	Male-H
CDMA	5-7	Female-H
CDMA	8-9	Male-M
CDMA	10	Female-M
CDMA	11	Male-L
CDMA	12	Female-L

Mice

Mode	Amplifiers	Chamber
CDMA	1-2	H
CDMA	3	M
CDMA	4	L

Internal Fitting and Storage Prior to Shipping (Ferrowohlen)

Internal Fit-Out



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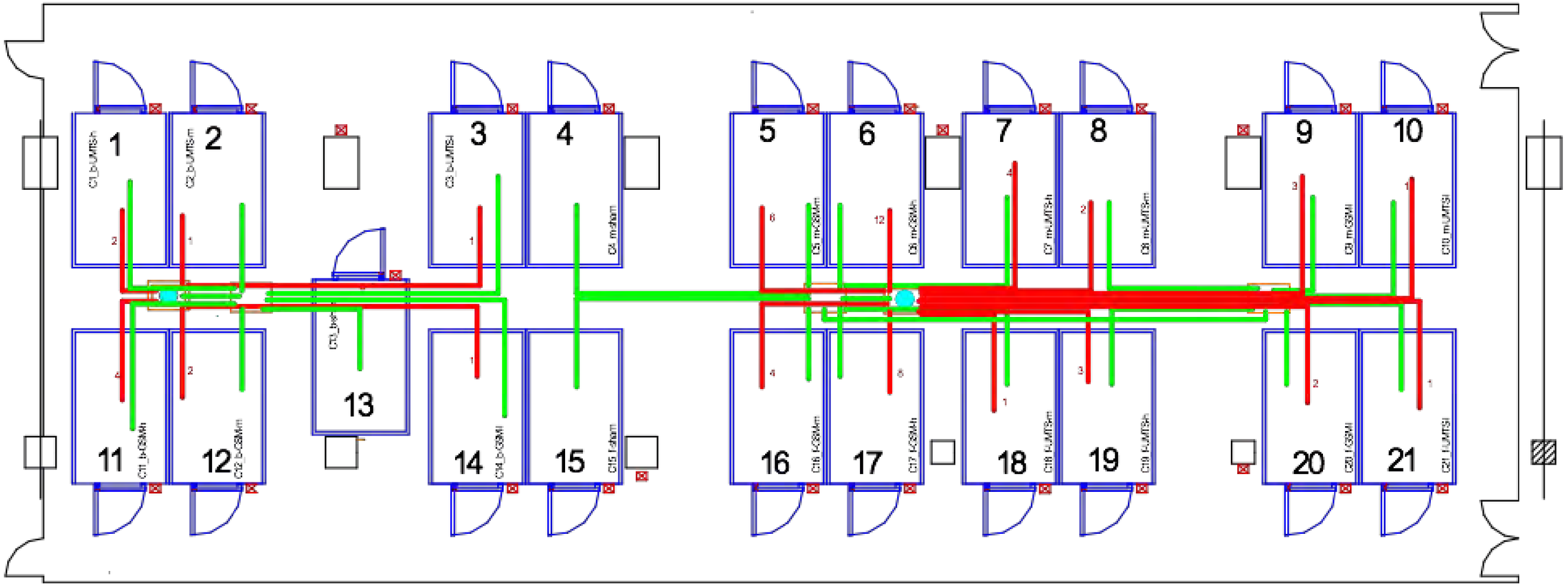
Room Layout



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EXIT

Finished System

Summary

- reviewed the communication standards and signals and how they relate to current standards
- introduced reverberation chambers and the electromagnetic environment
- presented the NTP study chamber characteristics
- the development of the animal watering system
- detailed the environmental monitoring and data logs providing the record of the experiment
- showed the chamber construction and installation