

Exposure Variability as a Function of Technology

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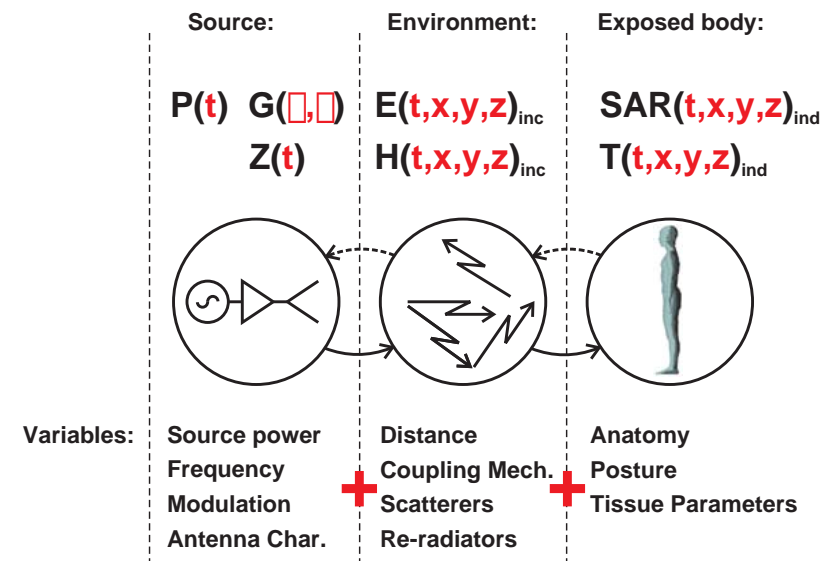
NFP-Project:

- Cumulative Exposure in Time and Frequency Domains of the CNS
 - Evaluation of SAR dose (induced fields):
 - from mobile handsets in real life.
 - from short range cordless phones.
 - from quasi-far-field and far-field sources.
 - from head mounted devices other than mobile phones.
 - Extrapolation from mobile phone compliance test data to central nervous system region specific dose.
 - Combination matrix of doses from various sources of exposure.

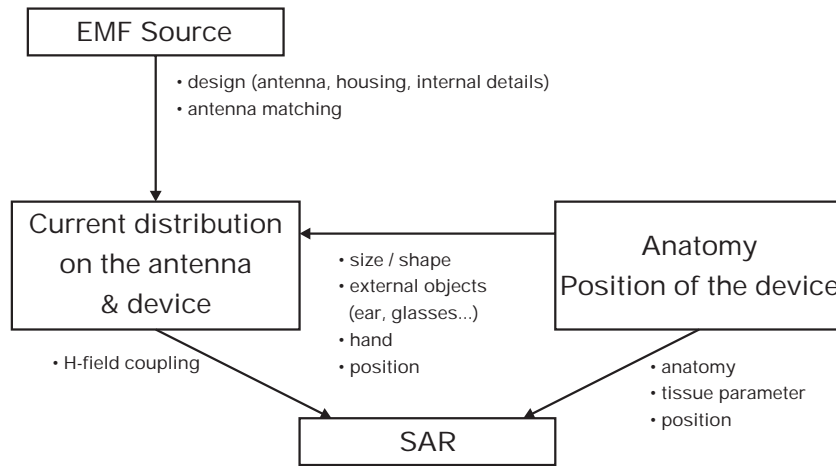
Introduction

- Exposure:
 - The condition of being subject to a source of risk.
- Health risks that may be imposed by exposure to EMF may be of a **thermal** or **non-thermal** nature.
- Epidemiology: is generally dealing with EMF exposure of a non-thermal nature:
 - The hypothesis is that non-thermal effects are a function of the applied modulation.
- ➔ **Strong technology dependence.**
- **Required:** Exposure assessment for the characterization of the EMF induced in the exposed tissue of interest including low frequency time variations (SAR(t)).

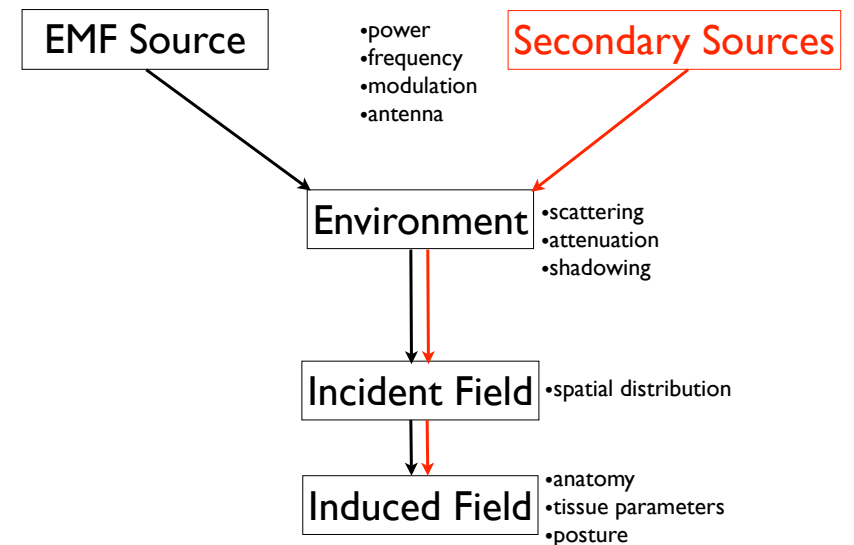
Exposure Variables



Near-Field Source -> Site of Exposure



(Quasi) Far-Field Source -> Site of Exposure

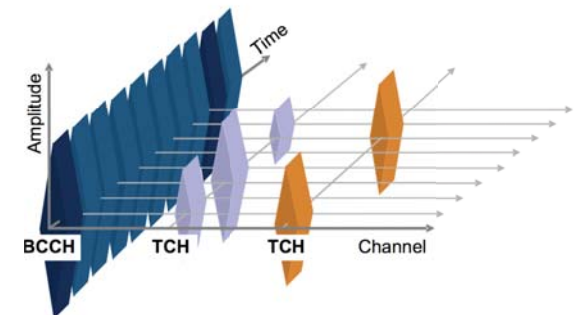


Typical Sources

	sources	frequency	P
Far-Field	cell tower (GSM, UMTS, TETRA ...)	450; 900; 1800; 2140 MHz	W ... kW
	radio / TV broadcast	88-108 MHz ,180 - 860 MHz	kWs
	WIMAX	3500 MHz	W ... X00 W
	RFID	865 MHz	<2W
Near-Field	DECT	1890 MHz	<250mW
	WLAN (IEEE802.11x)	2450; 5200; 5700 MHz	<100mW
	UMTS	2140 MHz	<1W
	RFID	865; 2450 MHz	<2W
	Bluetooth	2450 MHz	<100mW
Close Near-Field	DECT	1890 MHz	10mW
	GSM	900; 1800 MHz	250; 125 mW
	UMTS	1950 MHz	<250mW
	Tetra	400 MHz	125mW
	WLAN (IEEE802.11x)	2450; 5200; 5700 MHz	<100mW
	Bluetooth	2450 MHz	<100mW
	2way radio	27; 435; 868 MHz	<100mW
	wireless peripherals	13; 27; 40; 435; 2450 MHz	<10mW
	RFID	500kHz; 13; 865; 2450 MHz	<10mW

GSM BS - Signal Characteristics

- GSMK / EDGE: 8PSK (200 kHz BW)
- FDMA (935-960MHz; 1805-1880 MHz)
- TDMA (8 slots / 4.6 ms)
- BCCH
 - constant power in 8 slots
- TCH (multiple)
 - variable slot power
 - slow frequency hopping
 - DTX



GSM Terminal - Signal Characteristics

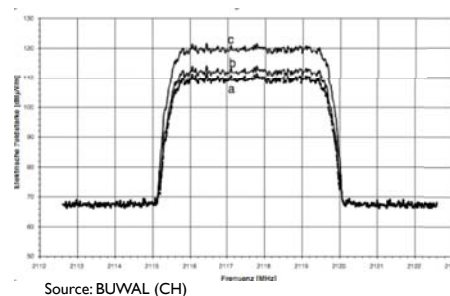
- GSMK / EDGE: 8PSK (200 kHz BW)
- FDMA (880-915 / 1710-1785 MHz)
- TDMA
 - typically 1 slot
 - power control (30 dB dynamic, 2 dB steps)
 - slow frequency hopping (optional)
 - DTX
- Hard-Handoff
 - maximum power excursion
 - slow power control (>480 ms)

GSM - ELF Characteristics

- TDMA: 217 Hz
- Multi-frame: 8 Hz
- DTX: 2 Hz
- PWC: < 1 Hz (slow min. 480 ms)
- Hopping: 217 Hz
- Hard-handoff (maximum power excursion)
- Typically, ELF components from power control and DTX from BS exposure will be less prominent than for handset exposure due to continuous BCCH and parallel TCH channels.
- Large scale (day) temporal power variations of the downlink field strength can be as large as 30 dB.

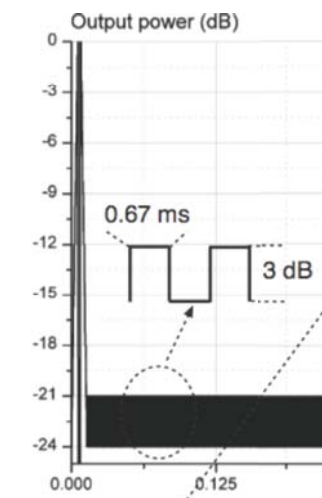
UMTS (FDD) BS - Signal Characteristics

- WCDMA, 4-PSK modulation (5 MHz bandwidth)
- FDD (1920-1980/2110-2170 MHz)
- Common Channels:
 - P-CPICH
 - constant and known power
 - typical 10% of maximum site power
- Dedicated Channels:
 - DPDCH/DPCCH
 - dynamically assigned
 - inner loop power control
 - same for control and data
 - 1500Hz
 - 1 dB step mandatory, 0.5/1.5/2 dB steps optional
 - >25dB dynamic per channel



UMTS (FDD) Terminal - Signal Characteristics

- WCDMA, 4-PSK modulation (5 MHz bandwidth)
- FDD (1920-1980 MHz)
- Inner loop power control
 - 1500Hz
 - 1,2,3 dB power steps
 - <-50 dBm ... 21,24 dBm
- Main reproducible ELF component in UMTS is at 1500 Hz from power control.

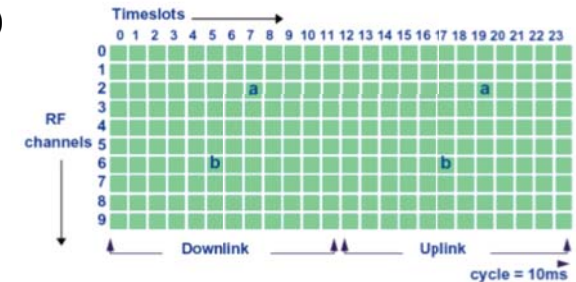


WLAN - Signal Characteristics

- IEEE 802.11b/g/a/h/(n)
- several channel access and modulation schemes implemented, e.g.:
 - digital phase and QAM modulations with dynamic coding rates
- Asynchronous packet (burst) oriented on the physical layer.
 - ELF components from burst packet transmission; range: 0 Hz ... 10Hz (typical beacon) ... kHz
- Power control only mandatory for 802.11h standard
 - average output power depends on channel occupation (packets)

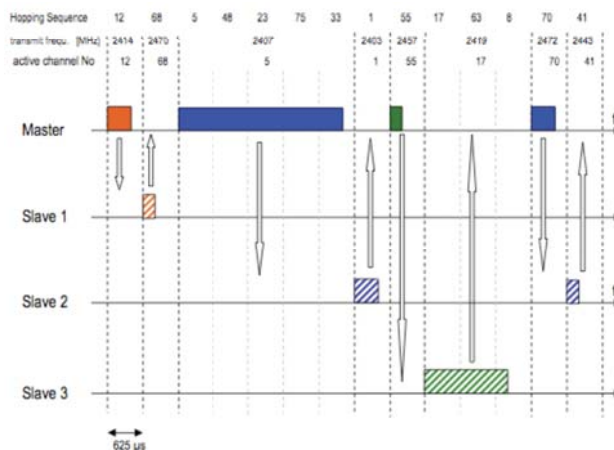
DECT - Signal Characteristics

- FDMA (1880-1900 MHz)
- GFSK (1.728 MHz BW)
- TDMA, TDD
 - 2x12 slots (10ms frame)
- Power:
 - FP: typically 10 mW / idle: 2 mW
 - PP: typically 10 mW
- Power Control:
 - not mandatory
 - typically no
- ELF: 100 Hz from frame-structure.



Bluetooth - Signal Characteristics

- FHSS (2402-2480 MHz), GFSK (1 MHz BW)
- TDD (0.625 ms slots)
- Power
 - 1...100mW
- Power Control
 - yes (100mW)
 - opt. (≤ 2.5 mW)



Summary - Signal Characteristics

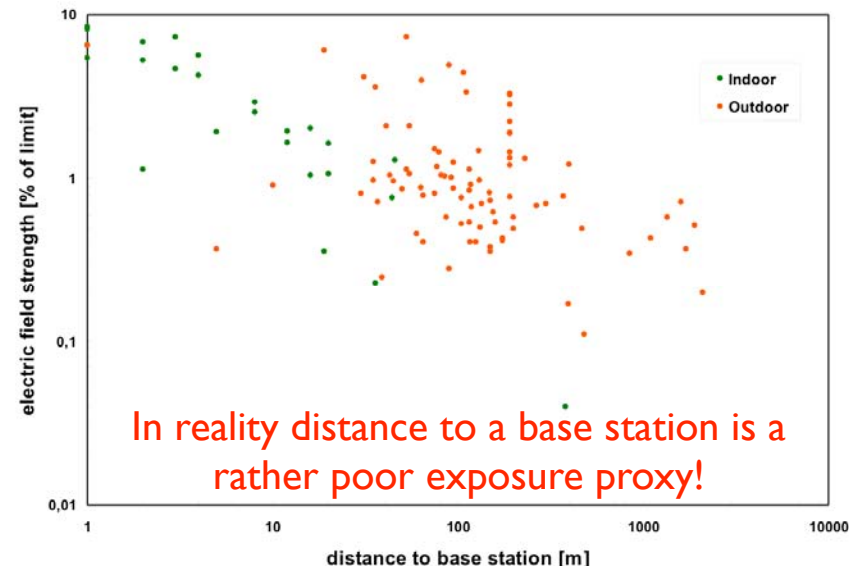
ELF	Hz:	2	8	10	100	217	1500
GSM Handset	cf	$\approx rDTX \cdot 1.625$	1.04	0	0	8	0
DECT Handset	cf	0	0	0	24	0	0
UMTS Handset	cf	0	0	0	0	0	1.25...2
GSM Base Station	cf	$\ll rDTX \cdot 1.625$	$\ll 1.04$	0	0	$\ll 8$	0
DECT Base Station	cf	0	0	0	24	0	0
UMTS Base Station	cf	0	0	0	0	0	$\ll 1.25...2$
WLAN Base Station	cf	0	0	200	0	0	0

- Dosimetry requires appropriate weighting of ELF components by consideration of the induced field strength.

Worst-Case vs. Realistic Exposures

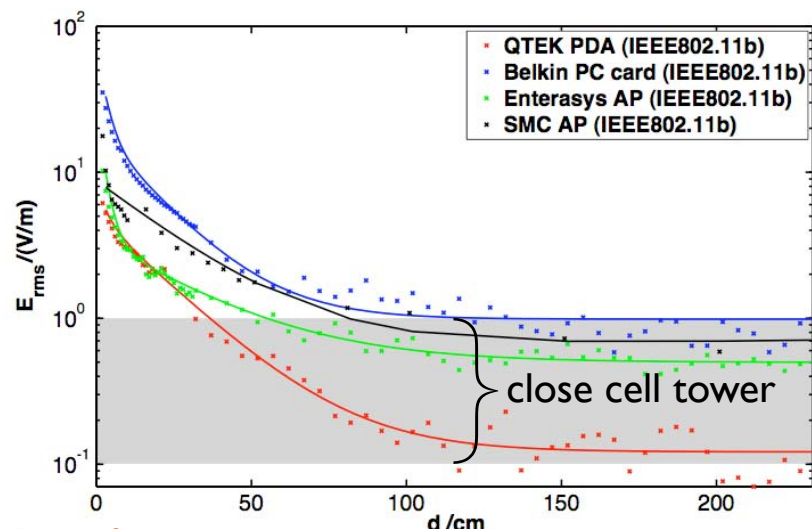
- Known exposure levels are mostly based on information from compliance evaluations, i.e., worst-case estimates.
- Realistic exposure levels are subject to:
 - environmental;
 - spatial;
 - temporal;
 - user;
 - and system variations;
 - and "secondary" sources.
- Dosimetric metrics?!

Cellular Base Station - Incident Fields



Source: C. Bornkessel, M. Wuscheck: "Exposure of the general public due to GSM and UMTS base station transmitters"

WLAN Base Station - Incident Fields



Fields from indoor sources might dominate incident fields even from close cell towers.

Other Sources - Incident Fields

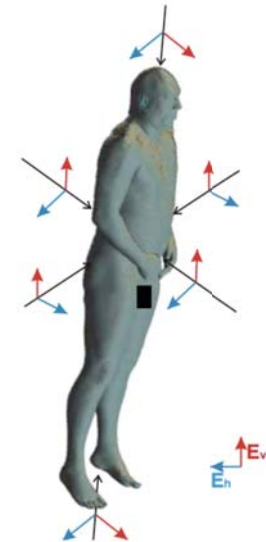
	Band Center Frequency (MHz)	E _{rms} (V/m)							
		5cm		10 cm		50 cm		200 cm	
Communication System		min	max	min	max	min	max	min	max
PC peripherals	27 / 40	5.7	8.3	1	1.5		0.1		0.01
Baby Surveillance	40 / 446 / 863	8.6	13.5	5.5	9.5	0.8	4.4	0.2	2.3
IEEE802.15.1	2440	5.1	9.7	2.0	5.5	0.2	0.6	0.1	0.2
IEEE802.11b	2440	3.6	16.4	2.9	10.2	0.5	2.1	0.1	0.9
IEEE802.11g	2440	1.9	5.0	1.3	3.1	0.4	0.6	0.2	0.3
IEEE802.11a	5250 / 5600	3.3	6.0	2.9	7.2	0.5	1.9	0.1	0.4
EGPRS900 (MS)	900	14.0	21.7	9.1	11.7	2.5	4.0	1.0	1.1
EGPRS1800 (MS)	1750	10.0	16.4	7.8	11.6	1.3	2.5	0.5	1.1
HSUPA (MS)	1950	16.0	16.0	10.1	10.4	1.7	2.3	0.4	0.6

Summary - Spatial Incident Field Variations

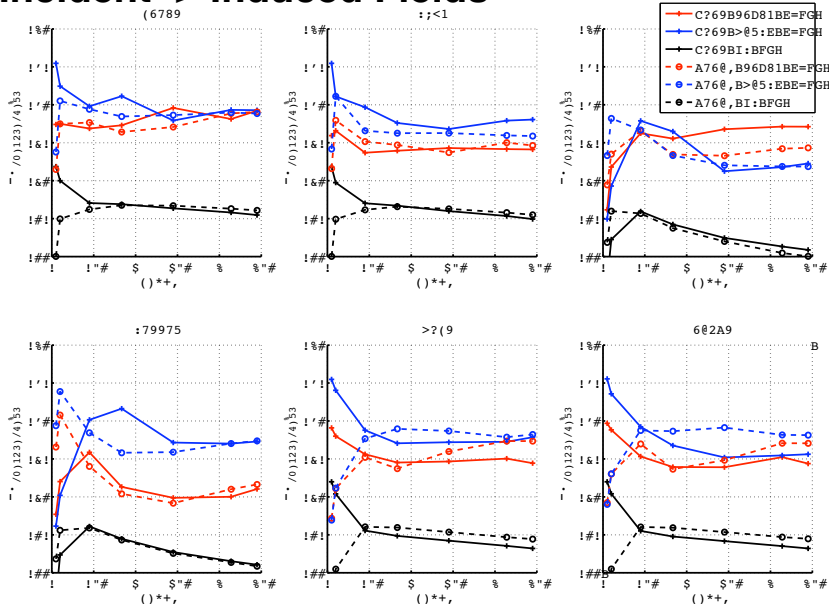
- Far-field sources cannot necessarily be characterized by a simple distance metric.
- Multi-path propagation (interference) and shadowing has to be taken into account.
 - Uncertainties of measurements as well as real-life exposure due to fading effects may be large.
 - In reality fading laws can often not be linked to specific environments.
- General mobile indoor transmitters are likely to mask exposure from fixed outdoor transmitters even at close distances.

Incident -> Induced Fields

- Incident field are not a meaningful to characterize exposure!
- ➔ Numerical investigations.
- Example: Far-field like exposure of anatomical human models.
- Investigation of different incidence directions and polarizations.
- Allows: Determination of induced SAR and weighting for different exposure scenarios.



Incident -> Induced Fields



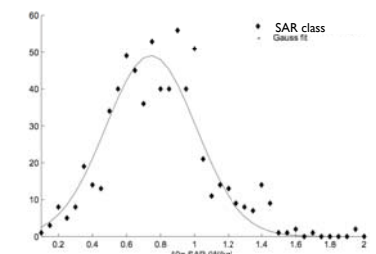
Close Near-Field Transmitters - Induced Fields

- Worst-case induced fields determined by dosimetric compliance testing.

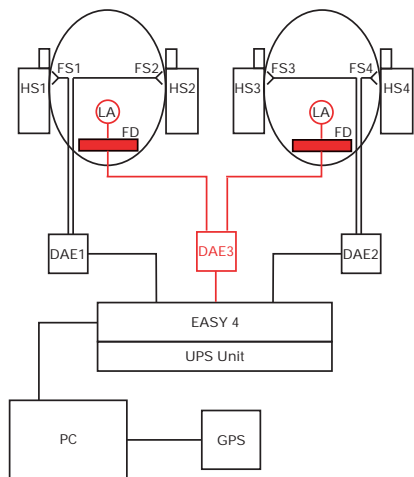


Device Class	typical 10g ps SAR / (W/kg)
Cellular Handset	0.8
DECT Handset	0.03
WLAN Handset	0.15*
WLAN body mounted	0.3
Bluetooth body mounted	0.01
Wireless Peripheral	<0.005
Babyphone	0.05

* only one sample

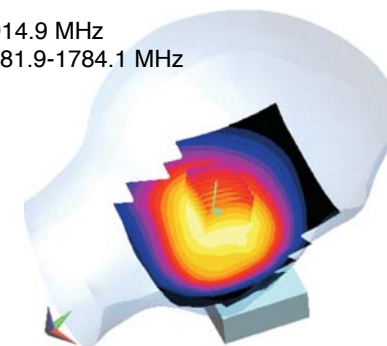


Mobile Transmitter - Variability Assessment

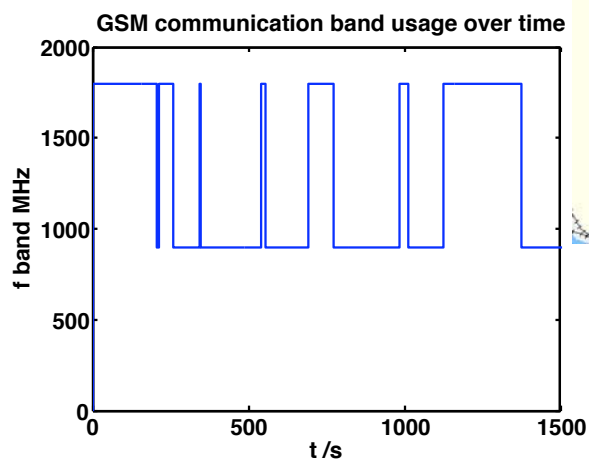


Evaluation Plan

- Dosimetric evaluation of a multi-band, multi-system mobile phone with DASY5
 - evaluation of touch and tilt positions for low, mid, and high band frequencies of GSM900,1800 and UMTS
- Swiss TDC Sunrise network:
 - GSM uplink frequencies:
 - 883.5-889.9 MHz, 902.5-907.3 MHz, 909.1-914.9 MHz
 - 1751.9-1760.3 MHz, 1763.9-1766.9 MHz, 1781.9-1784.1 MHz
 - UMTS uplink frequencies:
 - 1935.3-1950.1 MHz
 - Network coverage:
 - GSM: 99%
 - UMTS: 62%
- Test Routes:
 - 2 rural
 - 3 urban



Results - Channel Usage



Results - Channel Usage (Urban)

	band	N	t avg /s	t min /s	t max /s	t total /s	t fraction of total
route 1	900	3	65	19	132	196	20.6%
	1800	4	189	9	441	755	79.4%
	1950	0					0.0%
	total	7	135	9	441	951	
route 2	900	4	38	9	77	152	20.3%
	1800	3	80	61	105	240	32.0%
	1950	1	358	358	358	358	47.7%
	total	8	94	9	358	751	
route 3	900	1	88	88	88	88	13.6%
	1800	1	561	561	561	561	86.4%
	1950	0					0.0%
	total	2	325	88	561	650	
all routes	900	8	55	9	132	436	18.5%
	1800	8	195	9	561	1557	66.2%
	1950	1	358	358	358	358	15.2%
	total	17	118	9	561	2351	

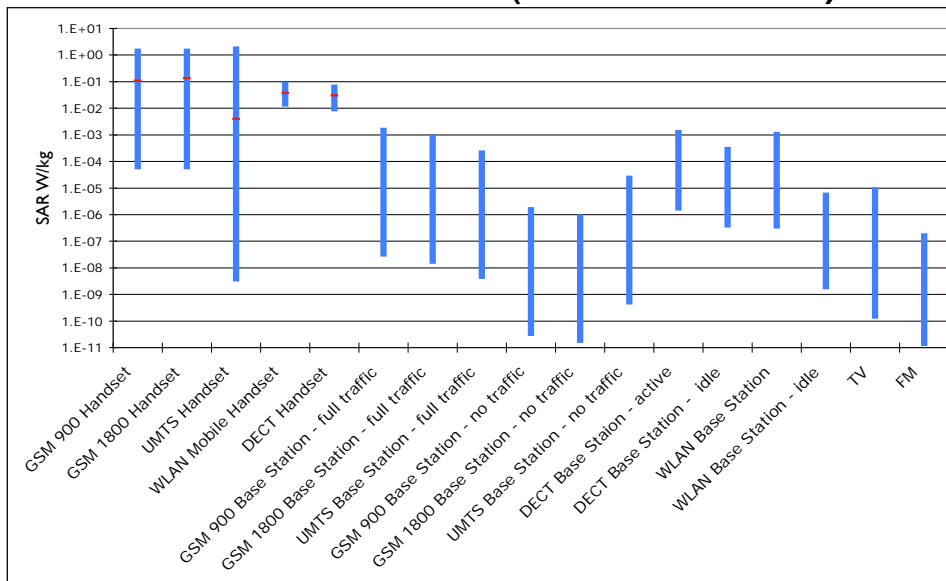
Results - Dose (Urban)

	band	N	t fraction of total	ps SAR test /(W/kg)	peak SAR drive /(W/kg)	avg. SAR drive /(W/kg)	SAR drive PAR (dB)	cumul. SAR %
route 1	900	3	20.6%	0.5	0.5	0.11	-6.6	22.9%
	1800	4	79.4%	0.23	0.23	0.098	-3.7	77.1%
	1950	0	0.0%	0.13				
	total	7				0.1		
route 2	900	4	20.3%	0.5	0.5	0.12	-6.1	48.2%
	1800	3	32.0%	0.23	0.23	0.083	-4.4	51.7%
	1950	1	47.7%	0.13	0.008	1.30E-04	-17.8	0.12%
	total	8				0.05		
route 3	900	1	13.6%	0.5	0.5	0.02	-13.5	3.5%
	1800	1	86.4%	0.23	0.23	0.096	-3.8	96.5%
	1950	0	0.0%	0.13				
	total	2				0.09		
all routes	900	8	18.5%	0.5	0.5	0.096	-7.1	22.2%
	1800	8	66.2%	0.23	0.23	0.095	-3.8	77.8%
	1950	1	15.2%	0.13	0.008	1.30E-04	-17.8	0.025%
	total	17				0.08		

Summary - Hand-held Transmitters

- Close near-field transmitters locally induce much higher fields than far-field transmitters.
- Real-life exposure variability between different technologies for the same applications can be large despite similar exposure levels during compliance testing.
- Dosimetry requires appropriate weighting of the compliance test data with environmental, system and user-behavior.
- Correlation with induced SAR in anatomically correct human model requires further numerical investigations.

Induced SAR Estimation (Indoor Scenario)



Conclusions

- Simple exposure metrics are not appropriate - they are missing correlation to real-life exposure.
- Variability due to many factors must be taken into account.
- Possible dominance of quasi far-field over far-field sources (e.g., indoor).
- Dominance of close-near field transmitters for locally induced fields over quasi far- and far-field sources.
- Only induced field strengths in terms of SAR and the corresponding low frequency signal waveforms will be sufficient to characterize non-thermal effects in epidemiological studies.
- Sound characterization of exposure requires experimental and numerical investigations!