The results of the localized SAR for Iridium Satellite Phone

For FCC T/A Kyocera Corp. Jul 15, 98

No.	R/L	out／in	use condition	angle (degree)	SAR value (1g ave.)
1	R	out	intended	(80,65)	0.121
2	R	in	intended	(80,65)	0.429
3	R	out	100°	(100,65)	0.332
4	R	in	100°	(100,65)	0.719
5	R	out	tilted	(90,35)	0.220
6	R	in	tilted	(90,35)	0.474
7	R	out	touch	(70,65)	0.100
8	R	in	touch	(70,65)	0.332
9	L	out	intended	(80,65)	0.102
10	L	in	intended	(80,65)	0.396

A unit of SAR: mW/g
Measurement condition: measurement condition No.1 to 16 complies with FCC
Measurement equipment : DASY3
R: the condition fitting the speaker part of the hand set to right ear by right hand.
L: the condition fitting the speaker part of the hand set to left ear by left hand.
Out: the condition of the long antenna
In: the condition of the short antenna
Use condition and angle: It refers to page 11-12 in the enclosed document "Safety Considerations for Human Exposure to EMFs from Mobile Telecommunication Equipment(MTE) in the Frequency Range 30MHz-6GHz, THIRD DRAFT, Zurich, 30 April1996".
Transmitting ch: sub-band=30, frequency-ch= 8 (1625.979167 MHz)

The specified value: 1.6mW/g

Note: We provide with data in all R conditions, because R conditions have worse SAR values than L conditions do. In addition, we provide with data in all intended use conditions where some user will usually operate the handset.

07/15/98

P29

No. 1

Generic Twin Phantom; Right Hand Section; Position: (80°, 65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]
Cube 5x5x7: SAR (1g): 0.121 [mW/g], SAR (10g): 0.0886 [mW/g], (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0

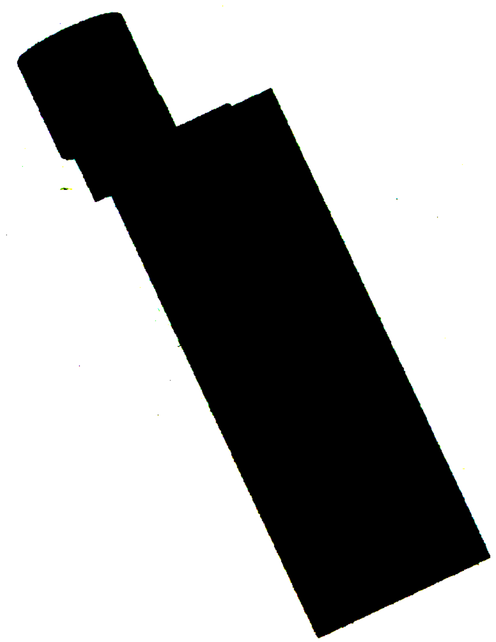
Kyocera

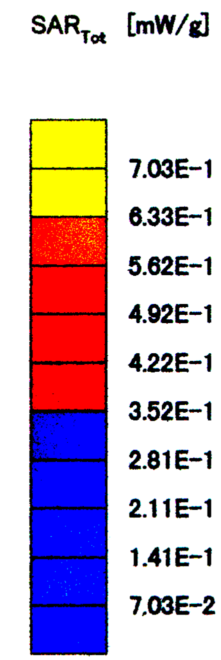
07/15/98

No. 2

P29

Generic Twin Phantom; Right Hand Section; Position: (80° ,65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]
Cube 5x5x7: SAR (1g): 0.429 [mW/g], SAR (10g): 0.274 [mW/g], (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0



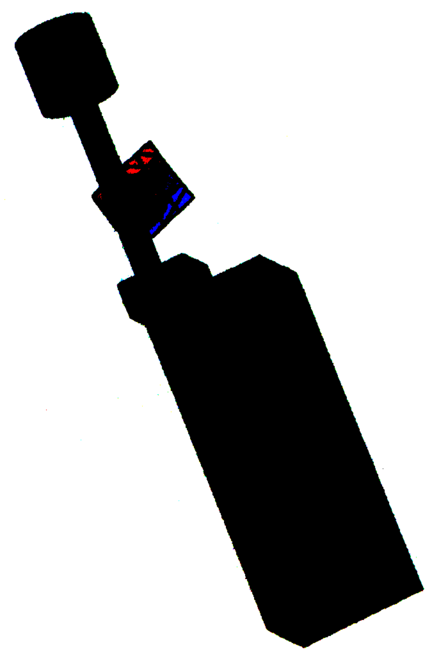


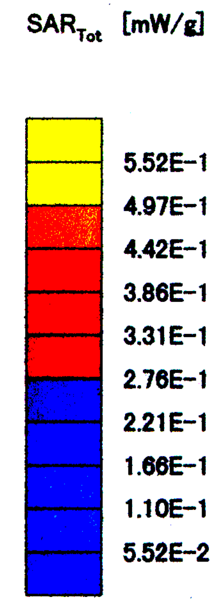
Kyocera

P29

No. 3

Generic Twin Phantom; Right Hand Section; Position: (100° ,65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm^3]
Cube 5x5x7: SAR (1g): 0.332 [mW/g], SAR (10g): 0.212 [mW/g] * Max outside, (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0

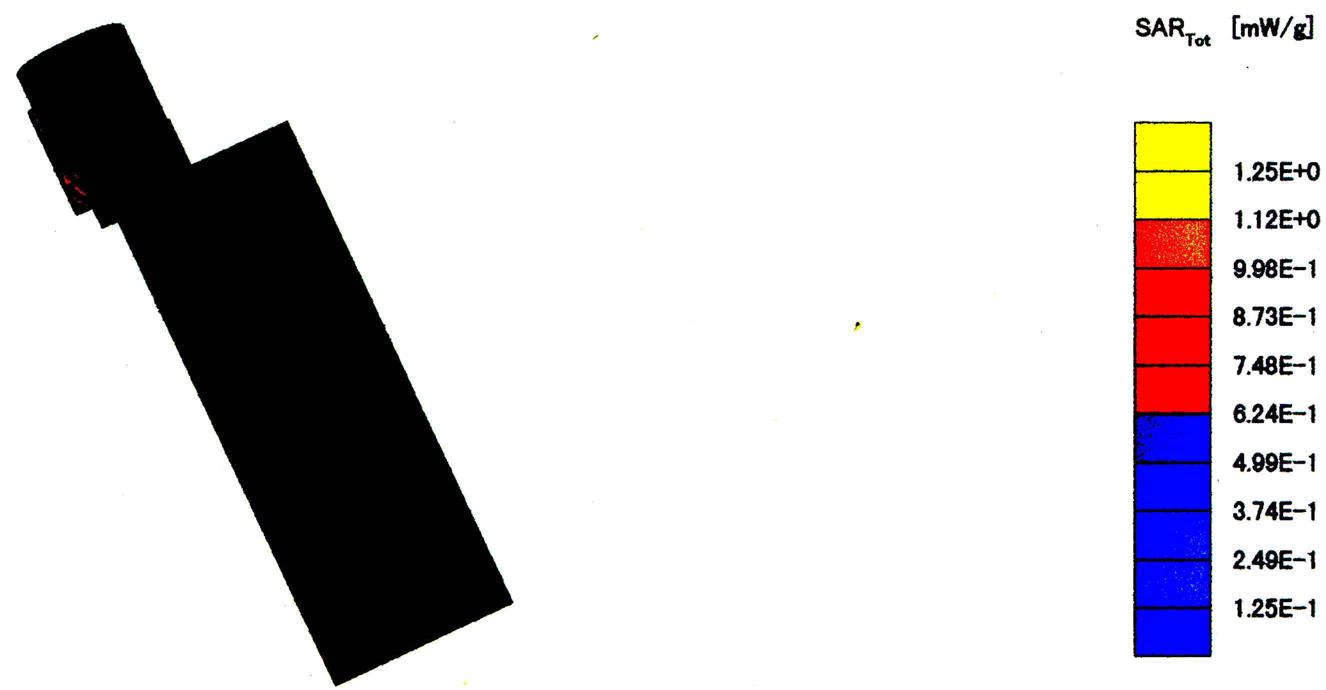




No. 4

P29

Generic Twin Phantom; Right Hand Section; Position: (100° ,65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57)]; Crest factor: 9.0; Brain 1500 MHz]: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm^3]
Cube 5x5x7: SAR (1g): 0.719 [mW/g], SAR (10g): 0.435 [mW/g], (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0

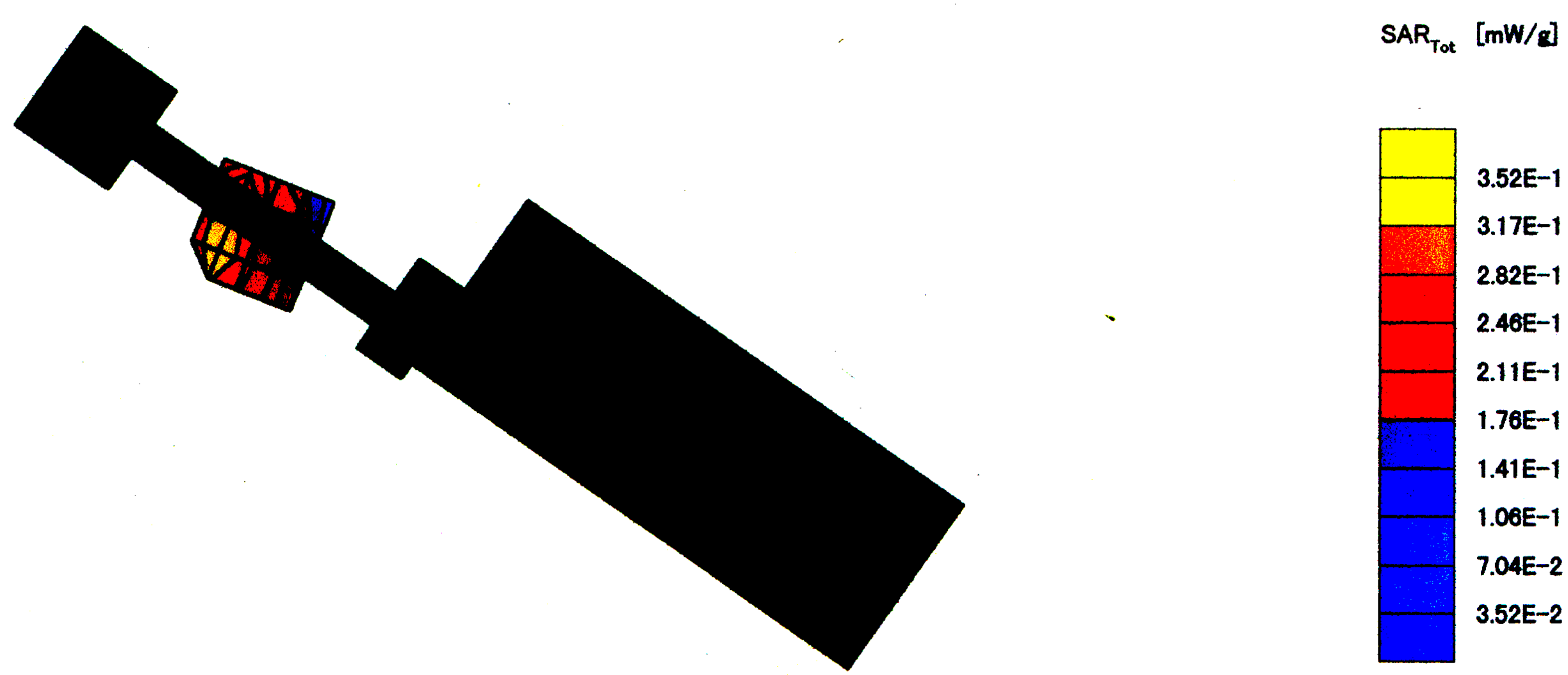


07/15/98

No. 5

P29

Generic Twin Phantom; Right Hand Section; Position: (90°, 35°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz]: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm^3]
Cube 5x5x7: SAR (1g): 0.220 [mW/g], SAR (10g): 0.141 [mW/g] * Max outside, (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0

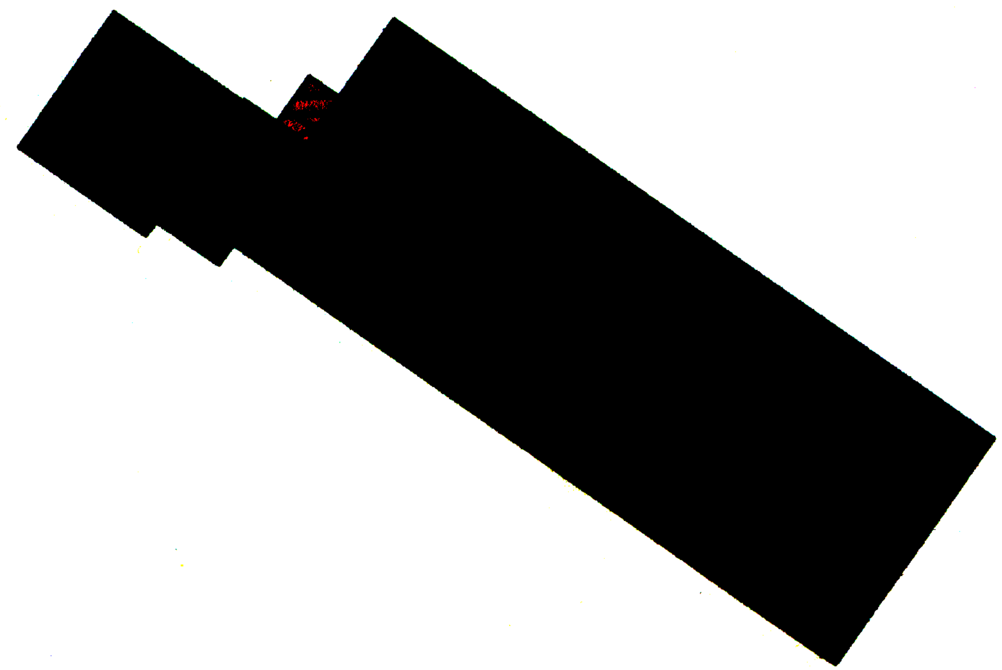


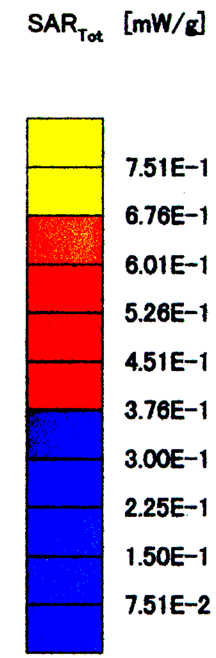
Kyocera

No. 6

P29

Generic Twin Phantom; Right Hand Section; Position: (90° ,35°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]
Cube 5x5x7: SAR (1g): 0.474 [mW/g], SAR (10g): 0.304 [mW/g], (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0



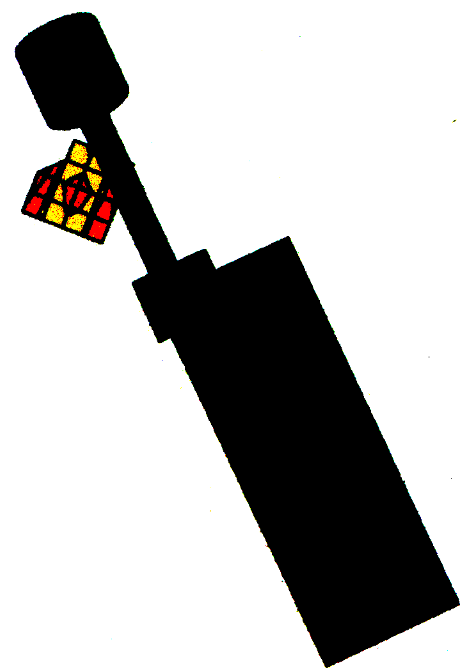


07/15/98

No. 7

P29

Generic Twin Phantom; Right Hand Section; Position: (70° ,65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]
Cube 5x5x7: SAR (1g): 0.0995 [mW/g] * , SAR (10g): 0.0746 [mW/g] * Max outside, (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0



SAR_{Tot} [mW/g]
1.43E-1
1.29E-1
1.14E-1
1.00E-1
8.58E-2
7.15E-2
5.72E-2
4.29E-2
2.86E-2
1.43E-2

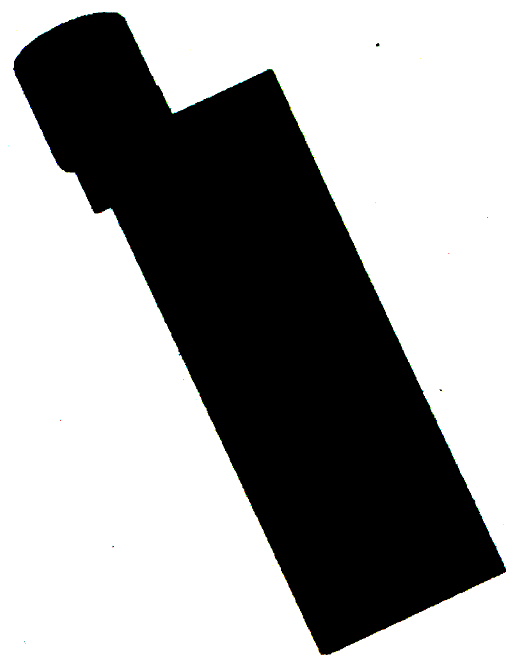
Kyocera

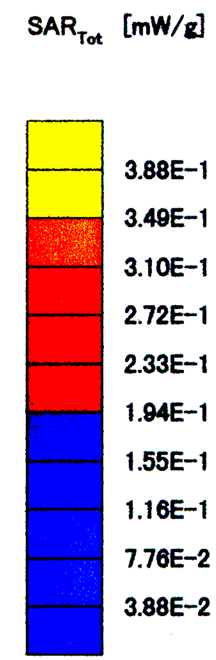
07/15/98

No. 8

P29

Generic Twin Phantom; Right Hand Section; Position: (70° ,65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57); Crest factor: 9.0; Brain 1500 MHz: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]
Cube 5x5x7: SAR (1g): 0.332 [mW/g], SAR (10g): 0.218 [mW/g], (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0





Kyocera

07/15/98

No. 9

P29

Generic Twin Phantom; Left Hand Section; Position: (80° ,65°); Frequency: 1500 [MHz]

Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57)]; Crest factor: 9.0; Brain 1500 MHz]: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]

Cube 5x5x7: SAR (1g): 0.102 [mW/g] * , SAR (10g): 0.0747 [mW/g] * Max outside, (Worst-case extrapolation)

Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0

Kyocera

No. 10

P29

Generic Twin Phantom; Left Hand Section; Position: (80° ,65°); Frequency: 1500 [MHz]
Probe: ET3DV5 - SN1311; ConvF(5.57,5.57,5.57)]; Crest factor: 9.0; Brain 1500 MHz]: σ = 1.38 [mho/m] ε_r = 42.6 ρ = 1.00 [g/cm³]
Cube 5x5x7: SAR (1g): 0.396 [mW/g], SAR (10g): 0.258 [mW/g], (Worst-case extrapolation)
Cube 5x5x7: Dx = 8.0, Dy = 8.0, Dz = 5.0

Kyocera

4. Information for Test Device Setup and System Uncertainties

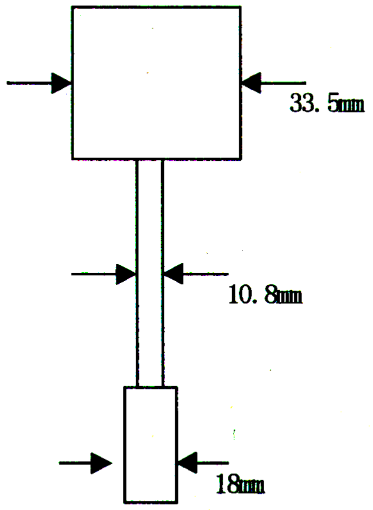
General Information:

- FCC ID : JOYKC-SSSD-66K
- (Device category mobile or portable)
- RF exposure environmental controlled or uncontrolled
- Test method: measurement or computation
- Statement indicating compliance with FCC adopted limits

SAR values of Our Iridium Satellite Phone measured by DASY3 complies with the FCC adopted limits of SAR value (1.6W/kg).

Antenna Description

- antenna type: patch
- antenna location on device: left, top, back
- antenna dimension length:extended---239.7mm, retracted---159mm



- antenna gain: 0dBi

Test Signal and Output Power

- test signal source: test mode
- signal modulation: TDMA/FDMA
- output power measurement condition: SAR test configuration
- output power measured with: spectrum analyzer
- output power measured at 1625.979167MHz, 9.2% duty factor
- max. power measured before SAR with fully charged battery: 595 mW (EIRP, ERP or net output)
- max. power measured after SAR: 580 mW

(max. power after SAR is only applicable to RF exposure evaluation with SAR measurement)

Test Position and Condition:

handset position: setup description, picture, illustration etc.-----appendix 1

center of ear piece aligned with ear canal of phantom

ear piece against phantom -----appendix 1

in alignment with 3-point (ears & mouth) plane of reference---

1. intended angle(80, 65)
2. 100° angle(100, 65)
3. tilted angle(90, 35)
4. touch angle(70, 65)

normal usage position---intended condition, antenna orientation---

and distance from phantom

		extended	retracted
intended	angle(80, 65)	7.5cm	4.5cm
100°	angle(100, 65)	4.0cm	3.0cm
tilted	angle(90, 35)	5.0cm	3.5cm
touch	angle(70, 65)	8.5cm	5.0cm

antenna extended and retracted

left or right side of head, ma?? , RF coupling condition

tested with or without hand

(CENELEC positions: 80° or other positions)

(Other positions: setup description, picture, illustration, etc.)

Measurement or Computation Uncertainty:

description of measurement or computational uncertainties

Uncertainties have the errors of the phone position setting(0%), measuring person(<20%), measurement equipment(±20%) and measured place(<±5%).

individual sub-system uncertainties probe: ±10% ,

repeated accuracy of Robot: ±0.02mm

estimated total system uncertainties (%) ±20%

5. Information for SAR Measurement

System and Phantom Descriptions:

. description of measurement system & performance appendix 2

. description of positioning system & performance appendix 2

. overall system performance verification procedures appendix 3

. RF susceptibility verification appendix 4

. system verification results

averaged over $1cm^3$ (1g) of tissue: 3.85mW/g

averaged over $10cm^3$ (10g) of tissue: 2.73mW/g

. description of phantom: shape, size and complexity appendix 5

. phantom with ear, without ear or using spacer

. phantom shell thickness at ear(4mm), cheek or other locations(2mm)

Tissue Properties:

. types of tissues used B1800

. composition of ingredients water 45.0%, Sugar 53.9%, HEC(hydroxyethycellulosis) 1.0%

. description of methods used to characterize tissue materials and ambient conditions---

appendix 6

. dielectric constants 41.0

. conductivities (S/m) 1.67

. tissue densities (kg/m^3) 1.0

Electric Field Probe Descriptions and Calibration:

. (E-field probe description & performance, probe type and serial no. ET3DV5-SN1311)

. (E-field probe calibration procedures)

. (media and frequency for E-field probe calibration)

. probe offset (8mm), isotropic response appendix 7

. (E-field probe calibration factor)

. (calibration or expiration date)

SAR Measurement Parameters, Procedures and Results:

. (SAR test frequencies)

. description of coarse scan region, size 10 x 10 x 0 cm^3, scanning resolution 20 mm

. description of fine scan region, size 3.2 x 3.2 x 3.0 cm^3, scanning resolution 8 mm

. (source-based time averaging applied to SAR (if tested with CW))

. (SAR distribution of worst case test results (frequency, antenna position - fixed, extended or retracted))

. identification of peak SAR location (98, 64, 4.4) mm

. highest peak SAR (W/kg) and its test configuration 0.719(W/kg) right hand 100°

. (I-gram averaged peak SAR (W/kg))

. (other SAR test positions)

. (I-gram SAR for other positions)

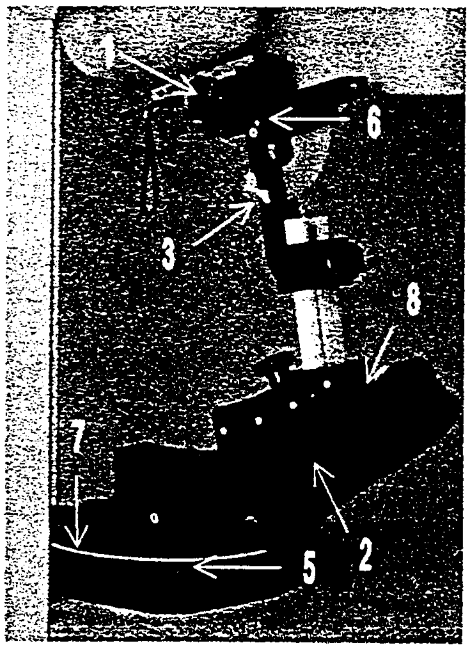
. description of I-gram average procedures, highest SAR gradient at peak location (W/kg/mm) 0.0125

. description of procedures used to extrapolate SAR to phantom surface

This will be able to be extrapolated by the evaluation of z-direction SAR characteristics.

Appendix 1

2.6 Device Holder for Generic Twin Phantom



1. Put the phone in the clamp mechanism (1) and hold it straight while tightening. (Curved phones or phones with asymmetrical ear pieces should be positioned so that the ear piece is in the symmetry plane of the clamp).

2. Adjust the sliding carriage (2) to 90°. Then adjust the phone holder angle (3) until the reference line of the phone is horizontal (parallel to the flat phantom bottom). The phone reference line is defined as the front tangential line between the ear piece and the center of the device bottom (or the center of the flip hinge).

3. Place the device holder at the desired phantom section and move it securely against the positioning pins (4) (see picture on previous page). The screw in front of the turning plate can be applied for correct positioning (5). (Do not tighten it too strongly).

4. Shift the phone clamp (6) so that the ear piece is exactly below the ear marking of the phantom. The phone is now correctly positioned in the holder for all standard phantom measurements, even after changing the phantom or phantom section.

5. Adjust the device position angles to the desired measurement position. The rotation scale (7) gives the tilt angle from the body axis. C1 denotes the intended use position (plane through ear openings and mouth); C2 is the 30°-tilt position according to CENELEC. The angle of the sliding carriage (8) gives the inclination angle of the phone (80° = intended use position).

6. After fixing the device angles, move the phone fixture up until the phone touches the ear marking. (The point of contact depends on the design of the device and the positioning angle).

   Note:
   Always lower the phone fixture prior to changing the device angles.

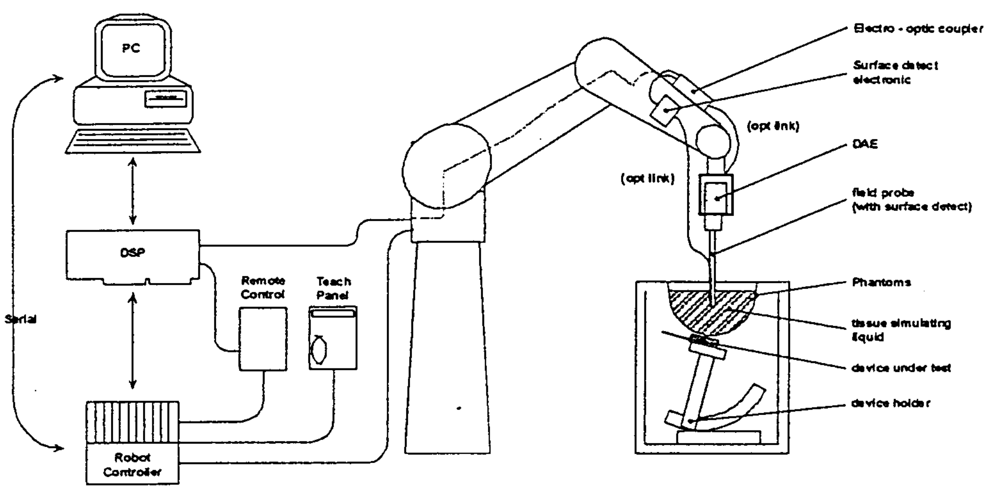
   If the ear piece of the phone is shifted horizontally after changing the device angles, the phone or the device holder is not correctly positioned.

Appendix 2

1. SYSTEM DESCRIPTION

1.1 System setup

The DASY3 system consists of at least:



- Miniaturized field probes
- Highly sensitive probe output measuring system split into data acquisition unit (DAE) (see figure 2) and a PC plug-in card with Signal processor for time-critical evaluations (see figure 3)
- A probe positioning system (six-axis robot) for automatic field scans with its own robot controller
- Remote control with teach pendant and warning lamp for safe operation of the robot.
- A surface detect system that permits automatic positioning of the probe within a known distance to a phantom, surface, or device
- A shell phantom for body related SAR-measurements
- A system validation kit which allows to validate the whole system

To perform a SAR-measurement the customer must supply the following components (see figure 1):

- Device to be measured. It must be in a known and stable state during measurements (output power level, frequency, and modulation).
- Medium (tissue simulating liquid) with known dielectric parameters. Since the parameters might change with time (due to water evaporation) the customer must be able to assess the actual parameters and to mix or change the liquid composition to adjust the parameters.

For system validation a source with specified frequency and accurately known forward power at the validation kits SMA connector must be availabl

(signal source (>=10 dBm output power),
cables).

1.2 Software

The DASY3 so
is written i
Windo
libr

(signal source (>=10 dBm output power), power meter (<5% accuracy), cables).

1.2 Software

The DASY3 software is destined to work with DASY2 or DASY3 hardware. It is written in Visual C++ (full 32-bit version) and is runs under Windows 95 or Windows NT. The software is built in a modular way with dynamic link libraries. This allows new components easily to be appended and to be changed according existing components to special customer needs without the necessity of rewrite the whole software.

The DASY3-Software makes use of all system components to allow field measurements on these hierarchical complexity levels.

1.2.1 Field measurements

These are standard field measurements at the location of the probe tip. The software reads the output of each probe sensor and uses the calibration parameters of all involved components to calculate the correct field strength (The probe positioning system can be used manually to position the probe but no information from the robot is used in the evaluation). The output can be in many different units, by component or as a total, as a single value with statistics or as a function of time (scope).

Different measurement profiles (time, auto-zero cycles, accuracy, filter) can be used. The data can be exported to text files. For more information Field Measurements with Multimeter Option, page 42.

1.2.2 Field Scans

Using the positioning system, automatic field scans over lines, planes or volumes can be performed. The field is measured at discrete points, and the raw data from the probe is stored together with the position information from the robot and all involved calibration parameters. This allows utilization of the stored data for all possible selections or evaluations at the moment of visualizing or exporting the data. To visualize the data graphic-tools for 1D, 2D and 3D are included in the software.

A field scan can be defined as a free space scan or can be related to a phantom using automatic grid adaptation to the phantom boundary, automatic detection of the phantom surface, etc. If the device outline and position is specified in the scan, a simple picture of the device can be included in the graphic.

1.2.3 Documents

Several scans can be combined in one measurement document. The scans can be measured individually or automatically (e.g. reference point measurement, surface scan for maximum, fine cube measurement, power drift measurement). Sophisticated evaluation and documentation is possible by using data simultaneously from several scans in the document.

In order to work properly, the system requires a good deal of information from the user:

- Probe calibration parameters
- Data acquisition electronics parameters
- PC-Card parameters
- Device or source parameters (frequency, modulation)
- Scan parameters (grid size and orientation, phantom position, type)
- Measurement profile (filtering, time)
- Graphic format and evaluation

Many parameters are absolutely necessary to operate the system, others are optional and only necessary for special features (e.g. the device dimensions are necessary if the device shall be shown in the graphic; otherwise they can be omitted). Some parameters are coupled to components and do not change (e.g. probe calibration parameters), others might differ between measurements (e.g. liquid parameters, scans and evaluation). To make work easy, the parameters are arranged in data sets, and each data set is stored in the system under a specific name (e.g. each field probe has a set of calibration parameters stored under a unique name. Instead of entering the parameters the user has to select the corresponding parameter set each time a component (e.g. probe) is changed in the system. The necessary selections are:

- PC-Card
- DAE (only if several data acquisition electronics are available)
- Probe
- Liquid
- Device
- Phantom (including defined scans)
- Graphic formats

Selecting new parameter sets is only necessary when components are changed when different grids or graphic formats are desired. The last selected set is always the default for new measurements. However, sometimes it is necessary to add or change existing data sets. The parameters in the system can be manipulated in different ways:

- Import data file with factory-settings (electronic, probe, phantom)
- Change parameters in setup options dialog

- Enter completely new data set in the options menu

Changed or entered data sets can be stored in the system or exported to configuration-files (e.g. for use in other systems). Each system component from SPEAG comes with a configuration file including all necessary system data. To prevent accidental changes in the crucial parameters, all configuration files with manufacturer's settings have the read-only attribute.

If several people will use the system, it is recommended to have one system operator who defines all measurement procedures and phantom settings. This prevents incorrect measurement data due to improper parameter settings from users who are not very familiar with the system.

Several procedures are supported from SPEAG based on our experience with the system, but more might be added.

Predefined procedures:

- FCC measurement procedures (for one position and one frequency), including the following scans: reference measurement, maximum search, fine cube measurement and drift measurement.
- FCC graphic format
- Validation measurement procedure with: power reference measurement, maximum search, fine cube measurement, rotated fine cube measurement, z-axis measurement, drift measurement.
- Validation graphics format

Appendix 3

4.1 SAR – Measurement

1. Stir liquid until it shows no effects of inhomogeneity.
2. Measure dielectric parameters. If the parameters are outside of tolerances adjust or change the liquid.
3. Mount probe on electronics box. Make sure that the connector catches properly and the probe is mounted straight.
4. Mount electronics box on robot arm. Turn electronics box on (allow 15 min. warm up for sensitive measurements).
5. Select mounted probe from menu 'Setup Probe' .
6. Open robot-window in DASY3, select 'Generic Twin' from the 'Setup Phantom' menu and move to the Point ('Move Start').
7. Check for interference while the arm power is on: Open multimeter window. Select profile 'm4s az4s' in the 'Option' page of the multimeter. If the measured voltage is out of the acceptable range (± 2.5 μV) check grounding system (see Grounding Problems, page 79).
8. Check phantom position via reference points. If the phantom has been moved or if the difference in the x-,y- or z – direction is grater than 2 mm, reinstall the Phantom (Installing the Generic Twin Phantom, page 52).
9. Stir liquid if necessary. The liquid should be homogeneous. If the liquid shows effects of inhomogeneity, remeasure the liquid and or replace the liquid.
10. Check surface detector using the 'Move surface'. The probe should stop ca 1 mm above the surface. (If not, move probe up and clean the probe tip, repeat surface detect).
11. Move probe into selected phantom section.
12. Check for interference in liquid (analogue point 5).
13. Set up device.
14. The following files exist as predefined templates in the directory:

FCC left.da3	Intended use position, left hand
FCC right.da3	Intended use position, right hand
CEN intended left.da3	Intended use position, left hand
CEN intended right.da3	Intended use position, right hand
CEN touch left.da3	Touching position, left hand
CEN touch right.da3	Touching position, right hand
CEN 100° left.da3	100° position, left hand
CEN 100° right.da3	100° position, right hand
CEN 30° tilted left.da3	30°-tilted position, left hand
CEN 30° tilted right.da3	30°-tilted position, right hand

Open the file, save it under a different file name and start the measurement.

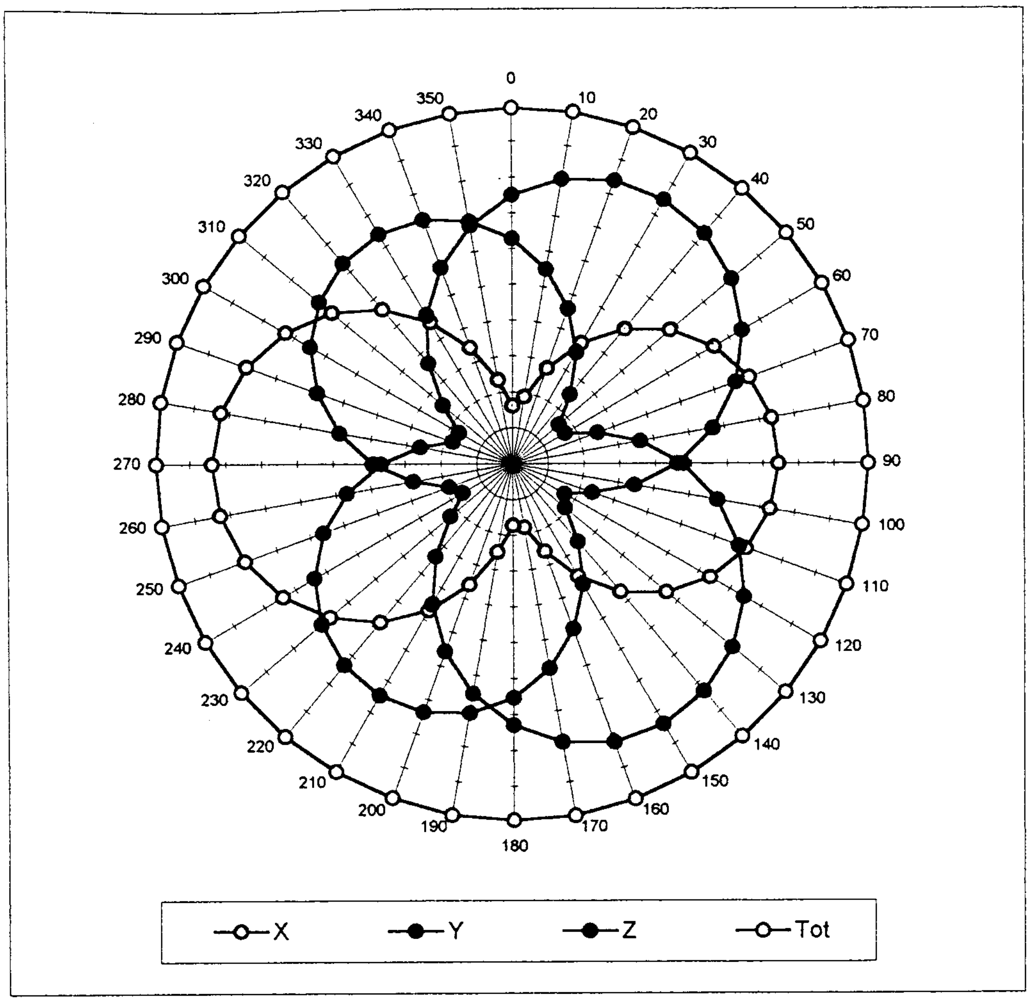
Appendix 4

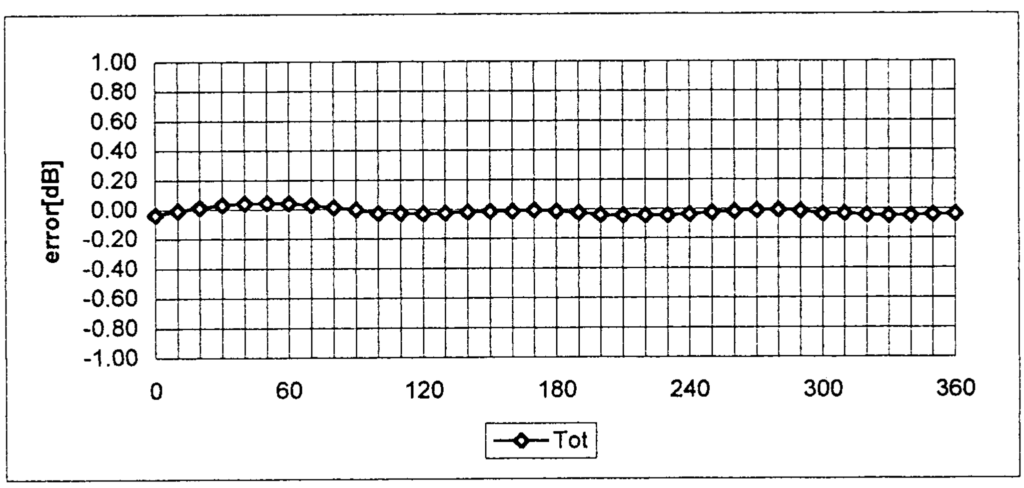
Parameters of Probe ET3DV4 SN:1311

NormX	2.07	$\mu V/(V/m)^2$
NormY	2.02	$\mu V/(V/m)^2$
NormZ	1.92	$\mu V/(V/m)^2$
DCP	50000	μV
ConvF(450MHz)	6.9 ± 10%	ε_r=47.2 ± 5%; σ=0.45 ± 10% mho/m[1]
ConvF(900MHz)	6.1 ± 10%	ε_r=42.1 ± 5%; σ=0.85 ± 10% mho/m[1]
ConvF(1800MHz)	5.3 ± 10%	ε_r=40.0 ± 5%; σ=1.7 ± 10% mho/m[1]
$d_{probe\_tip - center\_dipoles}$	2.7	mm
$d_{surface - probe\_tip}$	1.7 ± 0.2	mm

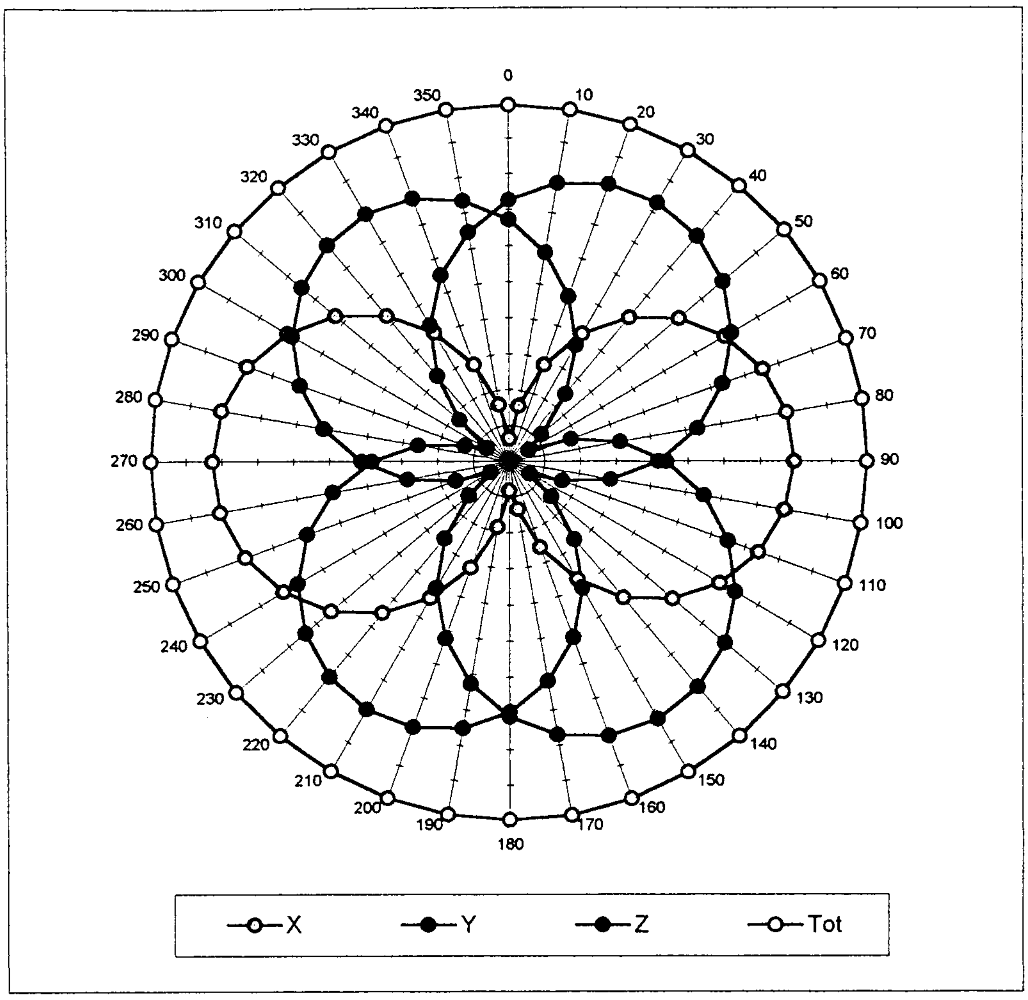
[1] Brain tissue simulating liquids

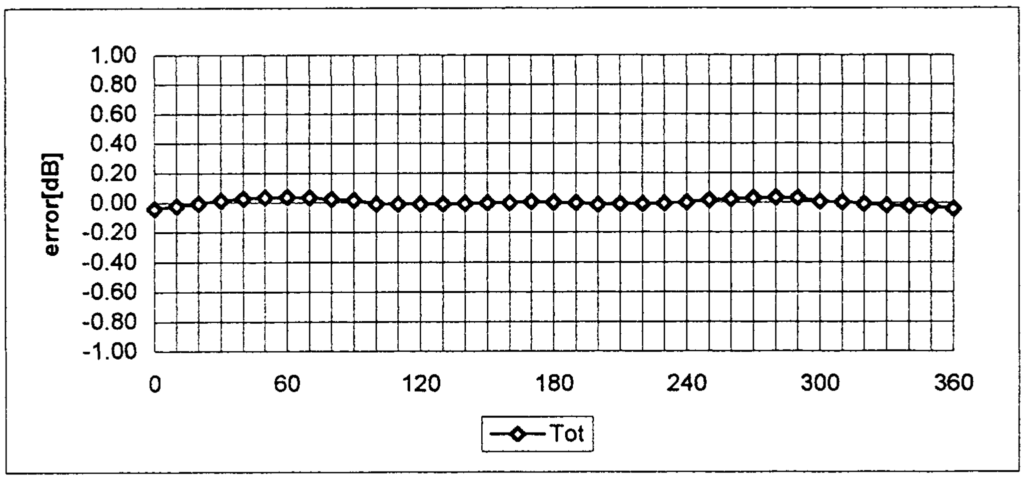
Receiving Pattern (ϕ), θ = 0°, f = 30 MHz
(TEM-Cell:ifi110)



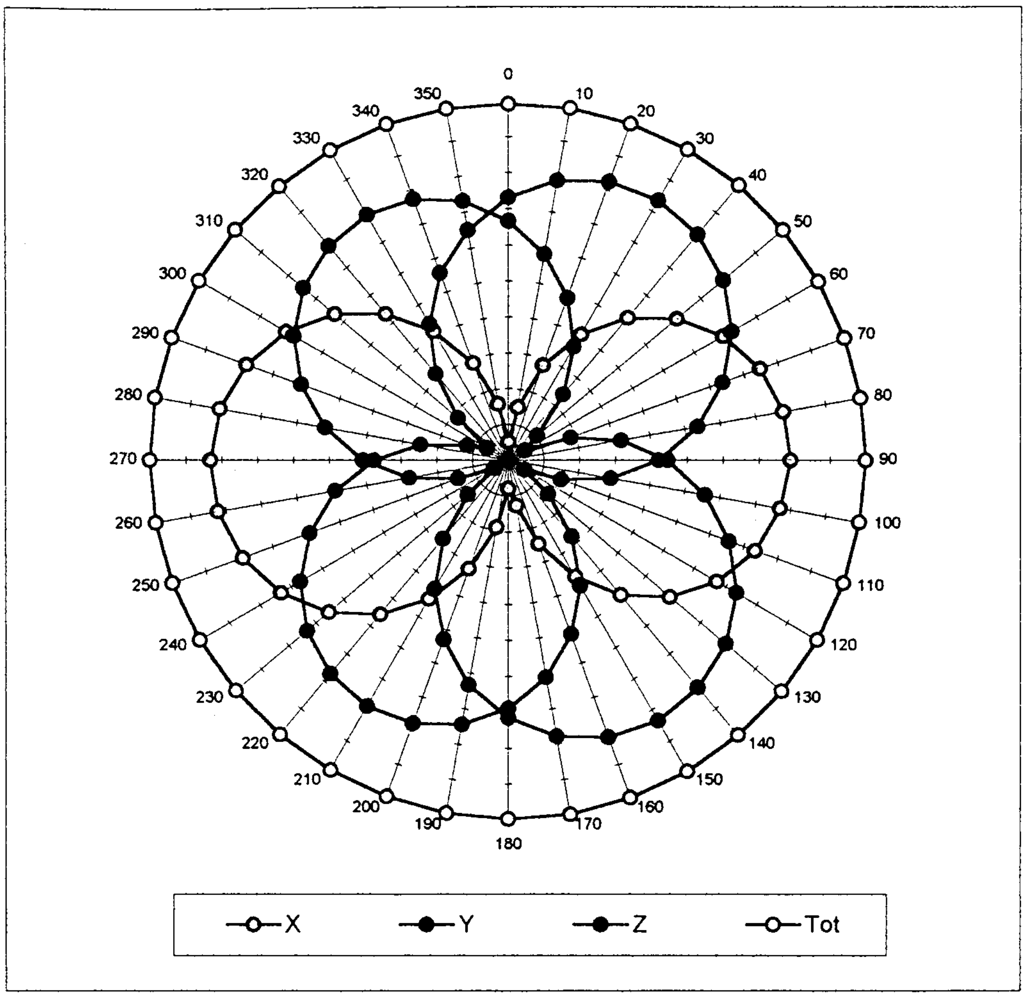


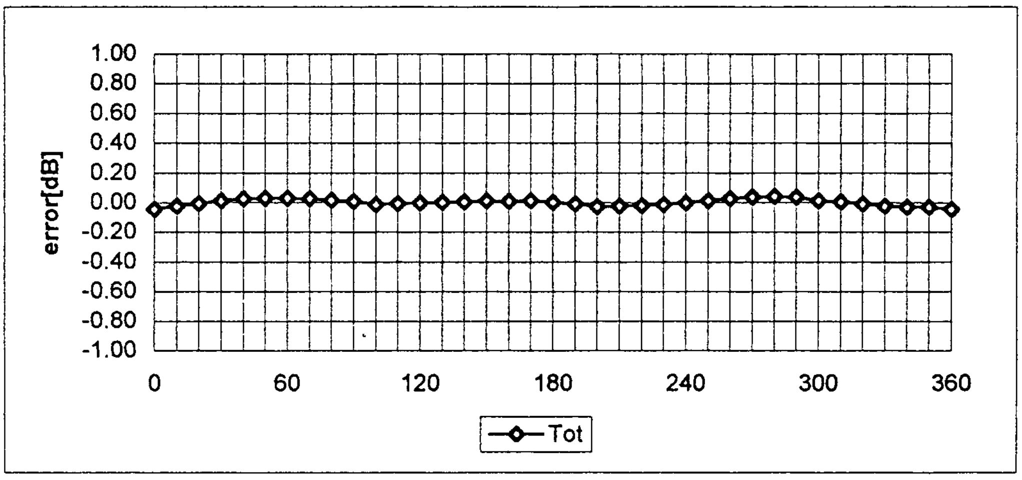
Receiving Pattern (ϕ), θ = 0°, f = 100 MHz
(TEM-Cell:ifi110)



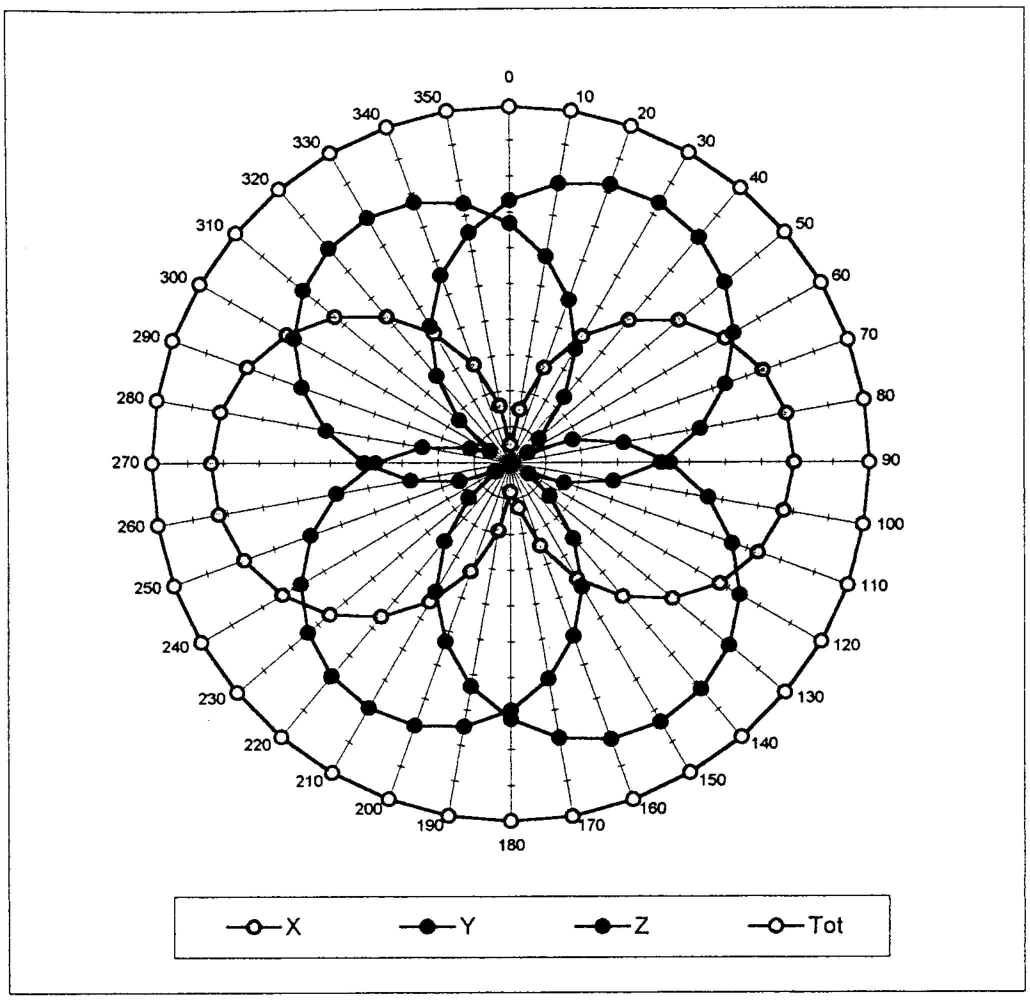


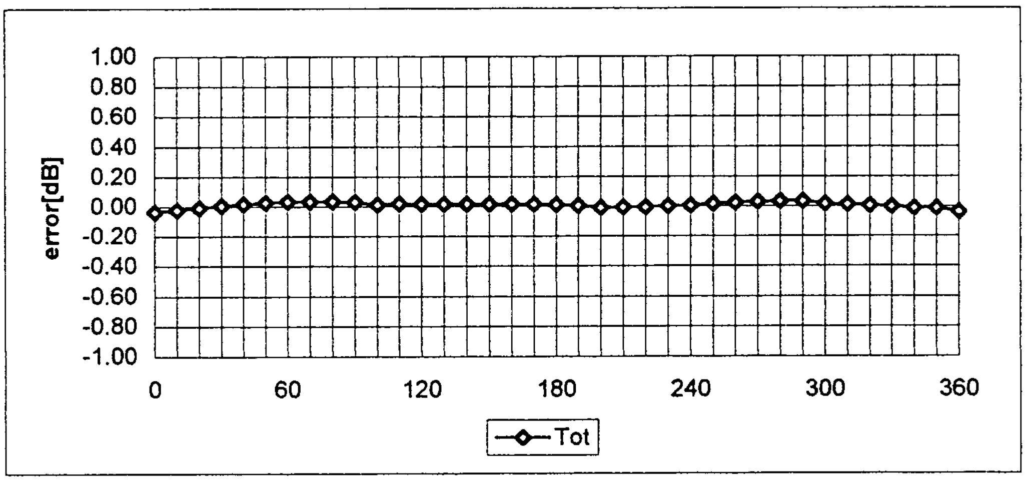
Receiving Pattern (ϕ), θ = 0°, f = 300 MHz
(TEM-Cell:ifi110)



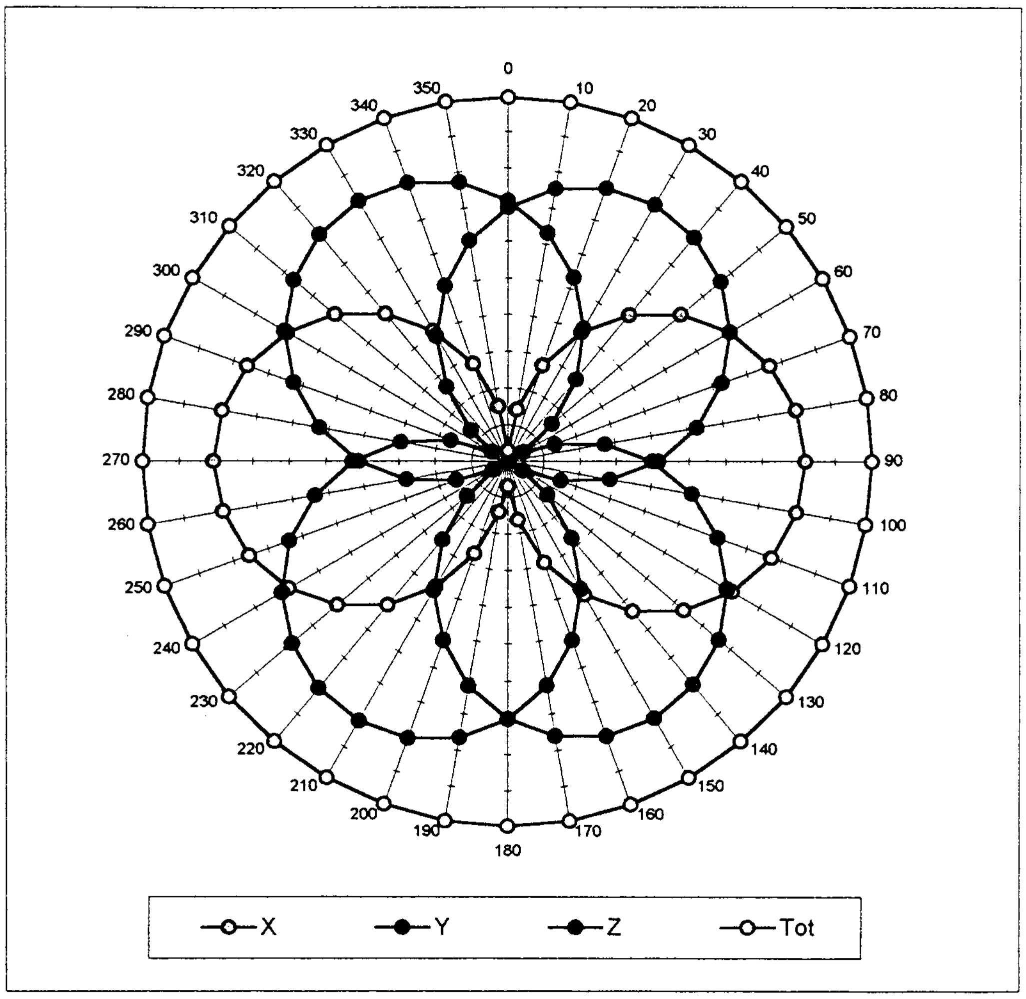


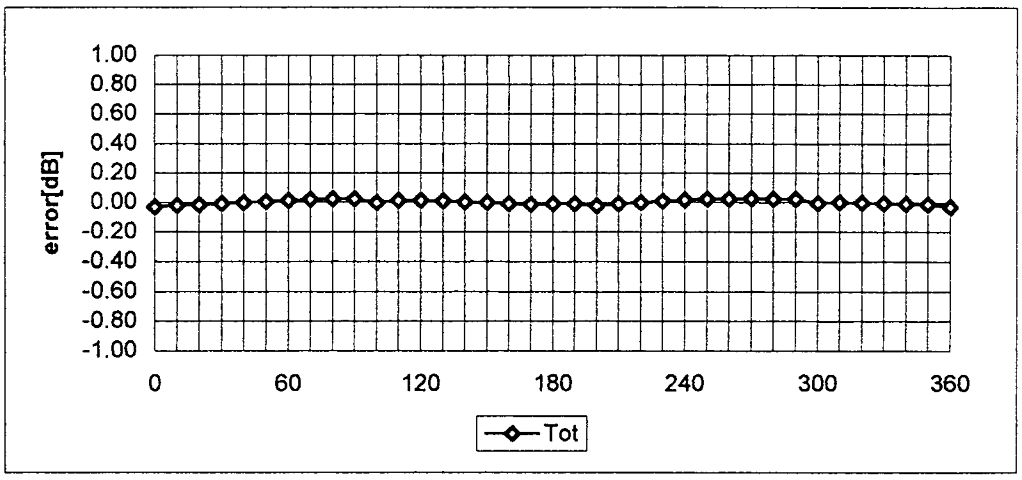
Receiving Pattern (ϕ), θ = 0°, f = 900 MHz
(TEM-Cell:ifi110)



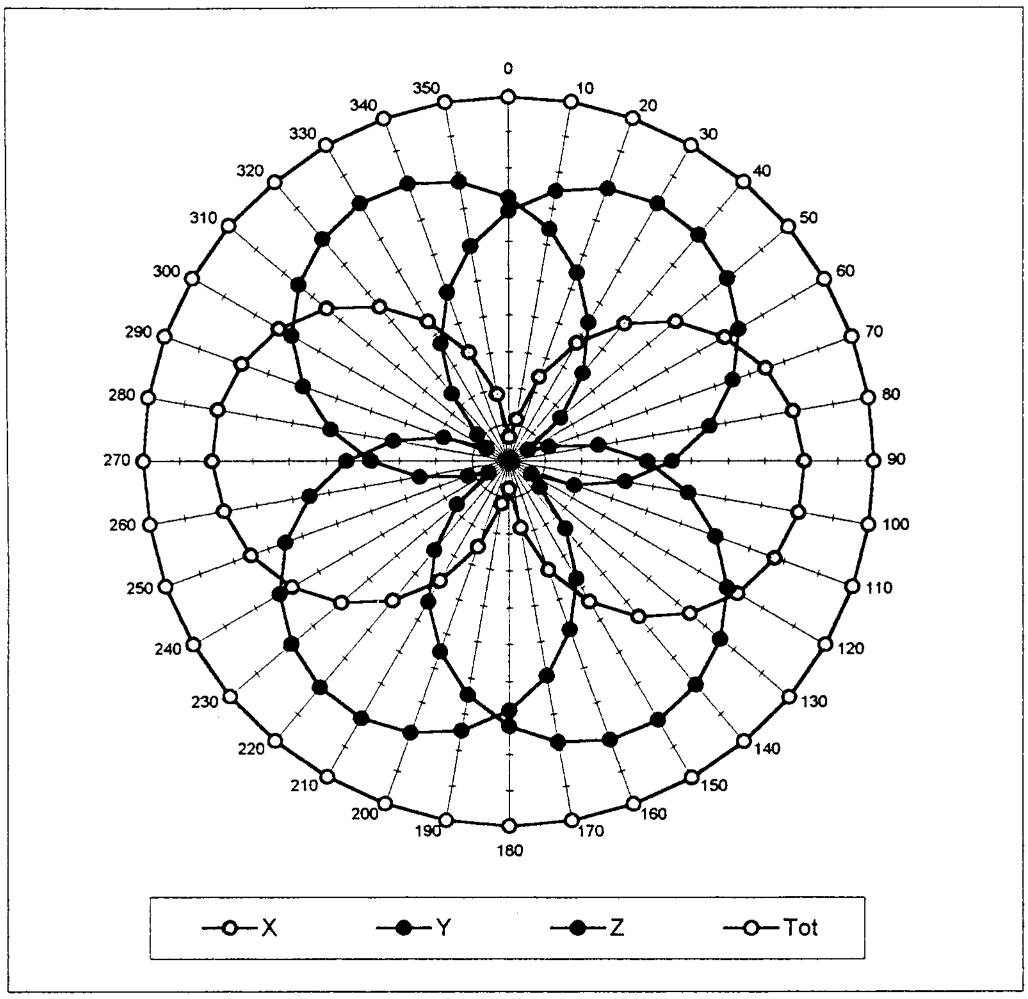


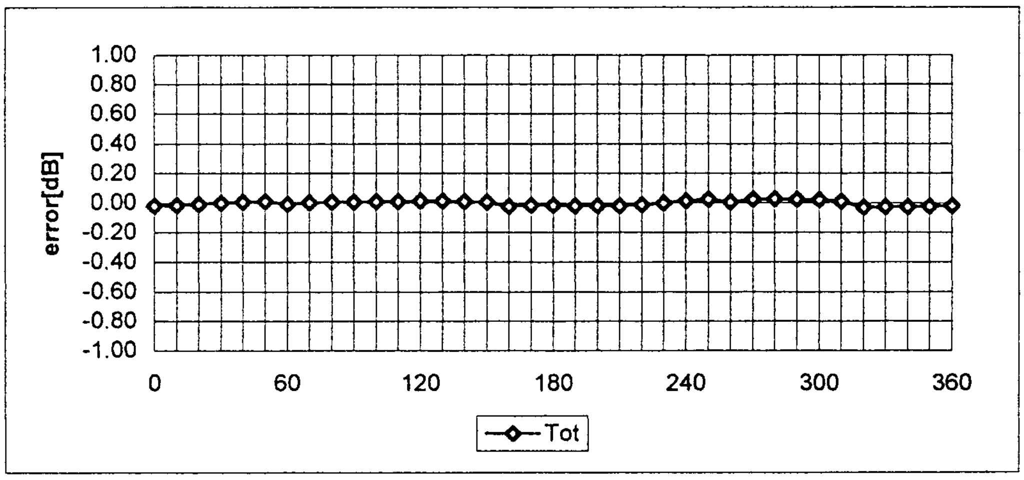
Receiving Pattern (ϕ), θ = 0°, f = 1800 MHz
(Waveguide R22)





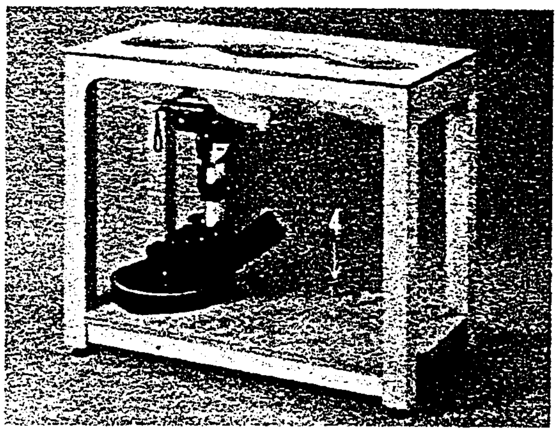
Receiving Pattern (ϕ), θ = 0°, f = 2500 MHz
(Waveguide R26)





Appendix 5

2.5 Phantom



The generic twin phantom is a fiberglass shell phantom with 2 mm shell thickness. It has three measurement areas:

- Left hand
- Right hand
- Flat phantom

The device holder can be fixed in any of these: a 100x50x85 cm (BxTxH) support for free standing robots and a 100x75x85 cm (BxTxH) version for table mounted robots.

A white cover is provided to tap the phantom during off-periods to prevent water evaporation and change in liquid parameters. Free space scans of devices on the cover are possible; however the optical surface detector is not working properly at the cover surface. Place a white paper on the cover when using optical surface detection.

Three reference markers are provided to identify the phantom position with respect to the robot (see Installing the Generic Twin Phantom, page 52):

Phantom use with tissue simulating liquids:

- Water-sugar-solutions can be left permanently in the phantom. Always cover the liquid if the system is not used, otherwise the parameters will change due to water evaporation (see Tissue Simulating Liquid, page 82).
- Buthyldiglycol-solutions should be used with care. As glycol is a softener for most plastics, the solution should be taken out of the phantom and the phantom should be dried when the system is not used (also overnight!). A test has shown a slight coloring of the inner surface after 3 months on continuously being filled with 1.8 GHz Buthylfiglycol solution.
- Do not use other organic solvents without testing the phantom resistively previously.

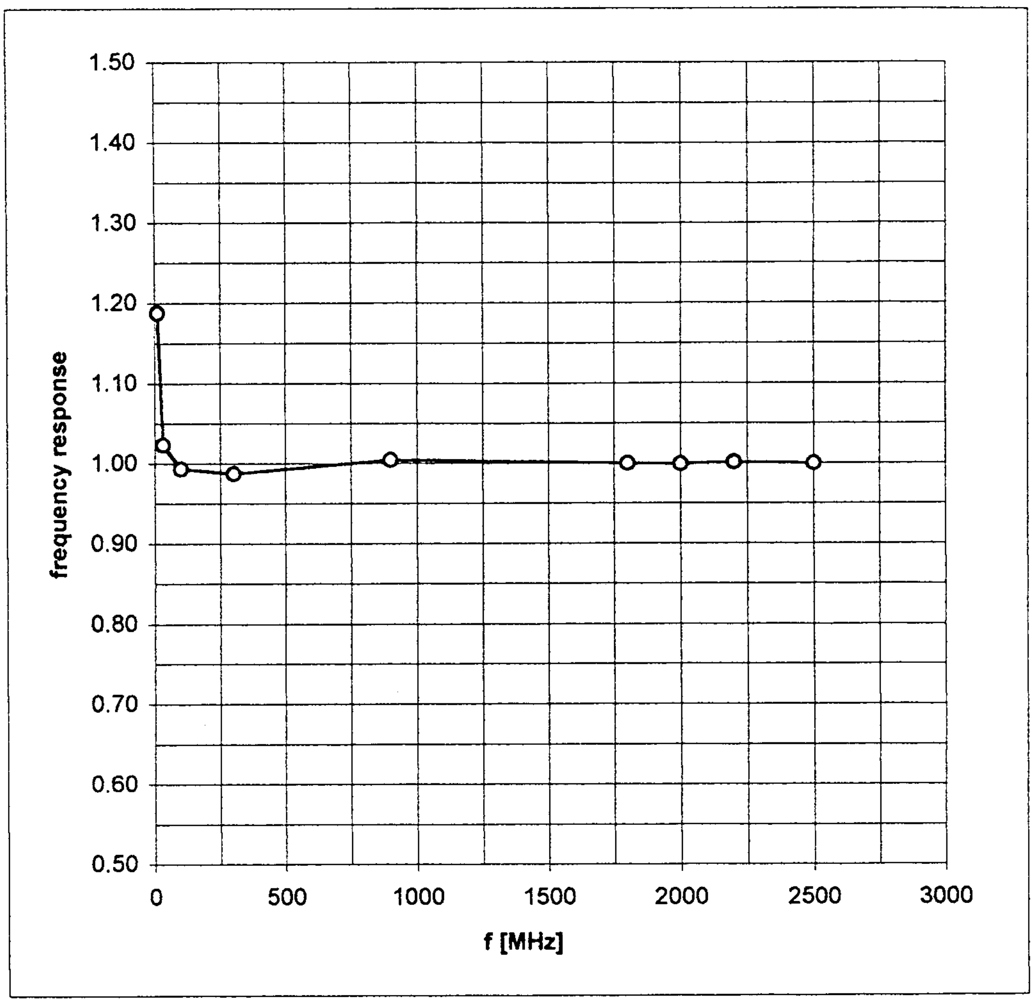
Appendix 6

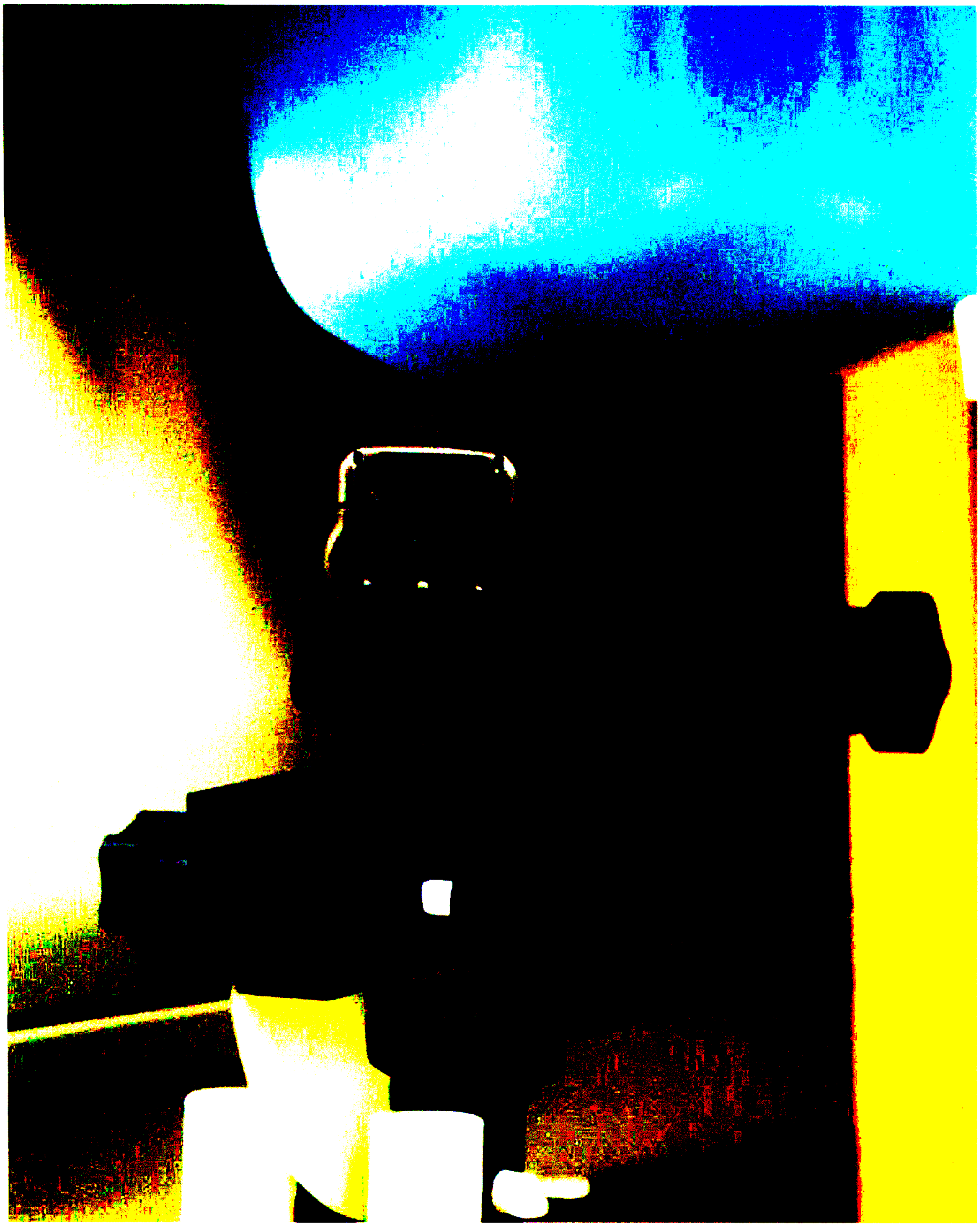
5.5.2 Testing Brain Simulating Liquid

1. Turn NWA on and allow at least 30 min. warm up.
2. Mount dielectric probe kit so that interconnecting cable to NWA will not be moved during measurements or calibration.
3. Pour de-ionized water and measure water temperature (±1°).
4. Set water temperature in HP-Software (Calibration Setup).
5. Perform calibration.
6. Validate calibration with dielectric material of known properties (e.g. polished ceramic slab with >8mm thickness ε'=10.0, ε"=0.0). If measured parameters do not fit within tolerance, repeat calibration (±0.2 for ε': ±0.1 for ε").
   Conductivity can be calculated from ε" by $\sigma = \omega\, \varepsilon_0\, \varepsilon'' = \varepsilon''\, f\, [GHz] / 18$.
7. Measure liquid shortly after calibration. Repeat calibration every hour.
8. Stir the liquid to be measured. Take a sample (~50ml) with a syringe from the center of the liquid container.
9. Pour the liquid into a small glas flask. Hold the syringe at the bottom of the flask to avoid air bubbles.
10. Put the dielectric probe in the glas flask. Check that there are no air bubbles in front of the opening in the dielectric probe kit.
11. Perform measurements.
12. Adjust medium parameters in DASY3 for the frequencies necessary for the measurements ('Setup Config', select medium (e.g. Brain 900 MHz') and press 'Option'-button.
13. Select the current medium for the frequency of the validation (e.g. Setup Medium Brain 900 MHz).

Appendix 7

Frequency Response of E-Field
(TEM-Cell:ifi110, Waveguide R22, R26)





Schmid & Partner
Engineering AG

Staffelstrasse 8, 8045 Zurich, Switzerland, Telefon +41 1 280 08 60, Fax +41 1 280 08 64

Preliminary Manual

DASY3 V1.0

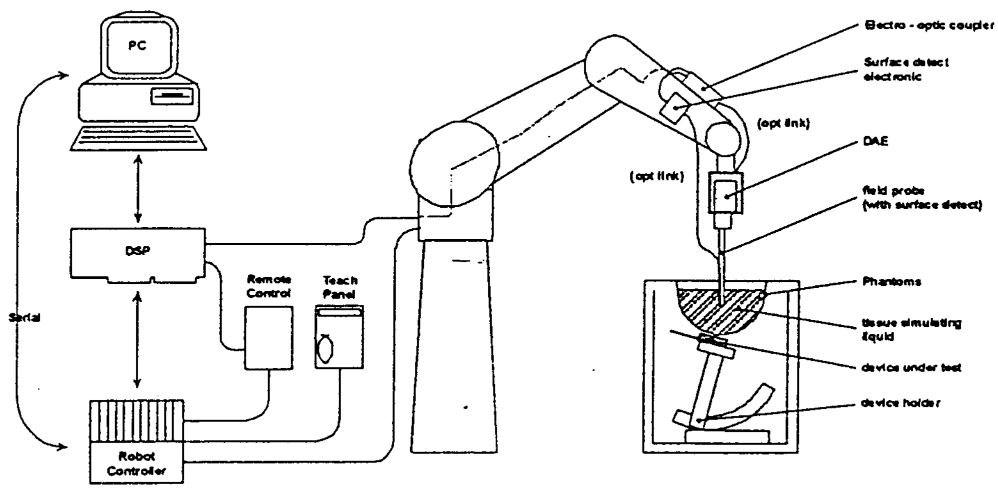
for Windows 95

August 1997 Edition
Schmid & Partner Engineering AG
Staffelstrasse 8
8045 Zurich
Switzerland
Tel +41 1 280 08 60
Fax +41 1 280 08 64
Email: speag@access.ch
WWW: www.access.ch/speag

1. SYSTEM DESCRIPTION

1.1 System setup

The DASY3 system consists of at least:



- Miniaturized field probes
- Highly sensitive probe output measuring system split into data acquisition unit (DAE) (see figure 2) and a PC plug-in card with Signal processor for time-critical evaluations (see figure 3)
- A probe positioning system (six-axis robot) for automatic field scans with its own robot controller
- Remote control with teach pendant and warning lamp for safe operation of the robot.
- A surface detect system that permits automatic positioning of the probe within a known distance to a phantom, surface, or device
- A shell phantom for body related SAR-measurements
- A system validation kit which allows to validate the whole system

To perform a SAR-measurement the customer must supply the following components (see figure 1):

- Device to be measured. It must be in a known and stable state during measurements (output power level, frequency, and modulation).
- Medium (tissue simulating liquid) with known dielectric parameters. Since the parameters might change with time (due to water evaporation) the customer must be able to assess the actual parameters and to mix or change the liquid composition to adjust the parameters.

For system validation a source with specified frequency and accurately known forward power at the validation kits SMA connector must be availabl (signal source (>=10 dBm output power), power meter (<5% accuracy), cables).

1.2 Software

The DASY3 software is destined to work with DASY2 or DASY3 hardware. It is written in Visual C++ (full 32-bit version) and is runs under Windows 95 or Windows NT. The software is built in a modular way with dynamic link libraries. This allows new components easily to be appended and to be changed according existing components to special customer needs without the necessity of rewrite the whole software.

The DASY3-Software makes use of all system components to allow field measurements on these hierarchical complexity levels.

1.2.1 Field measurements

These are standard field measurements at the location of the probe tip. The software reads the output of each probe sensor and uses the calibration parameters of all involved components to calculate the correct field strength (The probe positioning system can be used manually to position the probe but no information from the robot is used in the evaluation). The output can be in many different units, by component or as a total, as a single value with statistics or as a function of time (scope).

Different measurement profiles (time, auto-zero cycles, accuracy, filter) can be used. The data can be exported to text files. For more information Field Measurements with Multimeter Option, page 42.

1.2.2 Field Scans

Using the positioning system, automatic field scans over lines, planes or volumes can be performed. The field is measured at discrete points, and the raw data from the probe is stored together with the position information from the robot and all involved calibration parameters. This allows utilization of the stored data for all possible selections or evaluations at the moment of visualizing or exporting the data. To visualize the data graphic-tools for 1D, 2D and 3D are included in the software.

A field scan can be defined as a free space scan or can be related to a phantom using automatic grid adaptation to the phantom boundary, automatic detection of the phantom surface, etc. If the device outline and position is specified in the scan, a simple picture of the device can be included in the graphic.

1.2.3 Documents

Several scans can be combined in one measurement document. The scans can be measured individually or automatically (e.g. reference point measurement, surface scan for maximum, fine cube measurement, power drift measurement). Sophisticated evaluation and documentation is possible by using data simultaneously from several scans in the document.

In order to work properly, the system requires a good deal of information from the user:

- Probe calibration parameters
- Data acquisition electronics parameters
- PC-Card parameters
- Device or source parameters (frequency, modulation)
- Scan parameters (grid size and orientation, phantom position, type)
- Measurement profile (filtering, time)
- Graphic format and evaluation

Many parameters are absolutely necessary to operate the system, others are optional and only necessary for special features (e.g. the device dimensions are necessary if the device shall be shown in the graphic; otherwise they can be omitted). Some parameters are coupled to components and do not change (e.g. probe calibration parameters), others might differ between measurements (e.g. liquid parameters, scans and evaluation). To make work easy, the parameters are arranged in data sets, and each data set is stored in the system under a specific name (e.g. each field probe has a set of calibration parameters stored under a unique name. Instead of entering the parameters the user has to select the corresponding parameter set each time a component (e.g. probe) is changed in the system. The necessary selections are:

- PC-Card
- DAE (only if several data acquisition electronics are available)
- Probe
- Liquid
- Device
- Phantom (including defined scans)
- Graphic formats

Selecting new parameter sets is only necessary when components are changed when different grids or graphic formats are desired. The last selected set is always the default for new measurements. However, sometimes it is necessary to add or change existing data sets. The parameters in the system can be manipulated in different ways:

- Import data file with factory-settings (electronic, probe, phantom)
- Change parameters in setup options dialog

- Enter completely new data set in the options menu

Changed or entered data sets can be stored in the system or exported to configuration-files (e.g. for use in other systems). Each system component from SPEAG comes with a configuration file including all necessary system data. To prevent accidental changes in the crucial parameters, all configuration files with manufacturer's settings have the read-only attribute.

If several people will use the system, it is recommended to have one system operator who defines all measurement procedures and phantom settings. This prevents incorrect measurement data due to improper parameter settings from users who are not very familiar with the system.

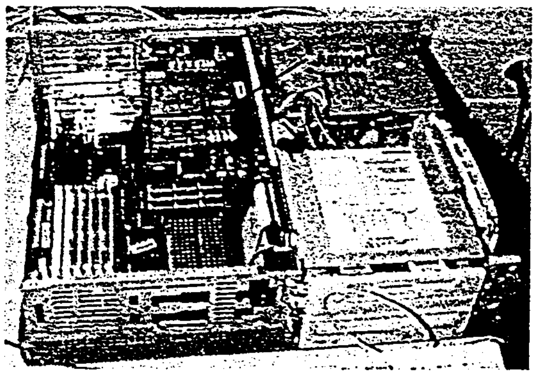
Several procedures are supported from SPEAG based on our experience with the system, but more might be added.

Predefined procedures:

- FCC measurement procedures (for one position and one frequency), including the following scans: reference measurement, maximum search, fine cube measurement and drift measurement.
- FCC graphic format
- Validation measurement procedure with: power reference measurement, maximum search, fine cube measurement, rotated fine cube measurement, z-axis measurement, drift measurement.
- Validation graphics format

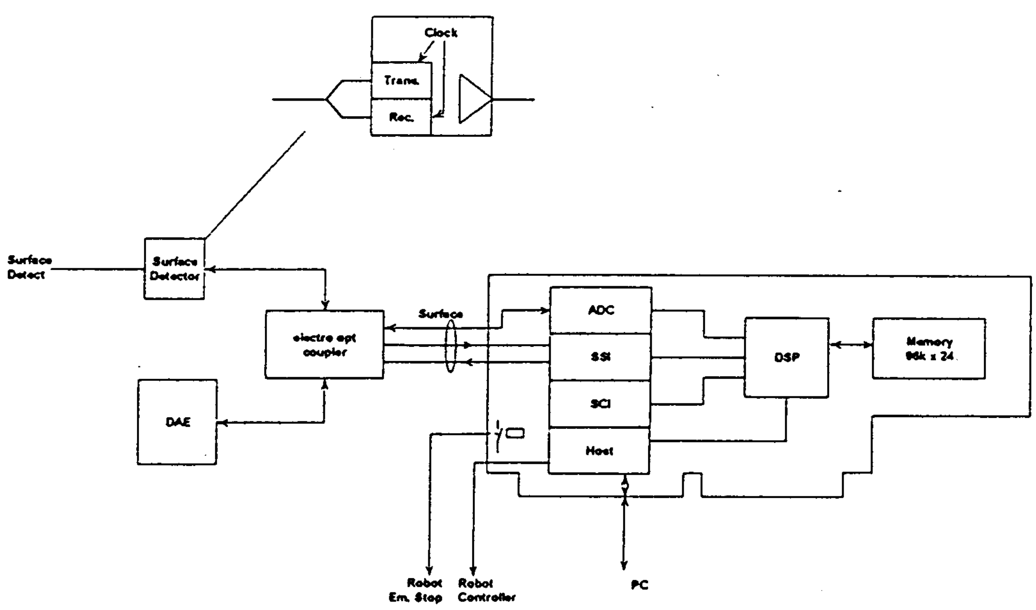
2. HARDWARE

2.1 DASY3 plug-in card



The PC-Plug-in card uses one standard medium-sized ISA-slot. It contains all necessary circuitry for the operation of the DASY3 software with either DAE2 or DAE3 electronic box. Room for peripheral extensions (parallel I/O, ...) is provided on the board.

The card contains a 24 bit 66 MHz data signal processor (DSP) and 96k x 24bit 12ns memory-bank. The DSP does real-time data evaluation for field measurements and surface detection, controls the robot movements and handles safe operation. The PC-operating system cannot interfere with these time critical processes. All connections are supervised. The disconnection of any of these cables to the board will automatically disable all program controlled robot movements.



Calibration: No calibration is required.

Jumpers for the base address have to bet set in the software accordingly (see Data Acquisition, page 30). The new values are ready after a complete shutdown of the computer.

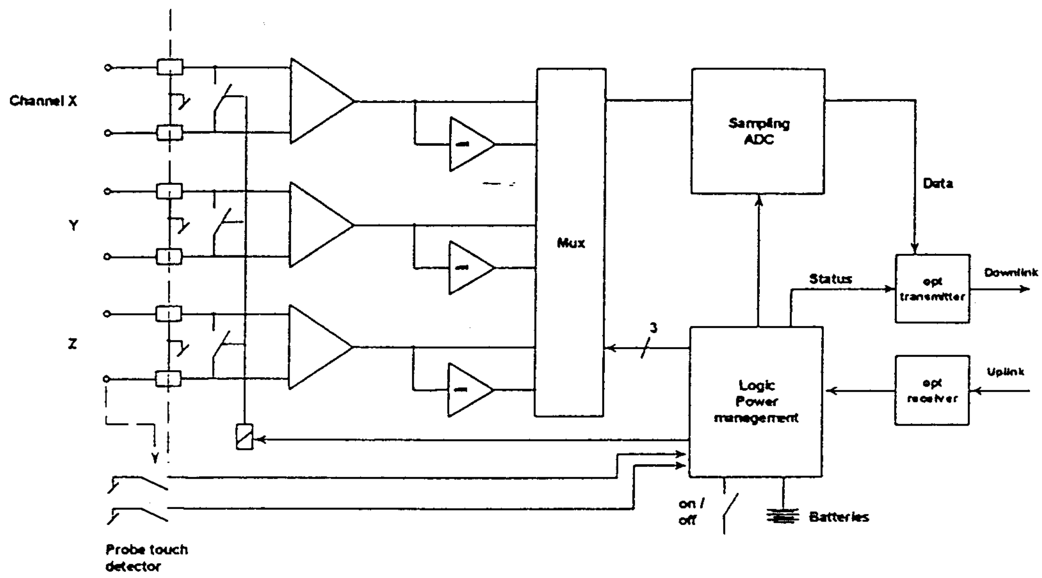
Connections:

1. DB9 female
   Connection to robot (or electro-optical adapter in DASY mini version)
2. Subminiatur connector 3p male (Binder 712, Amphenol)
3. DB9 female
   RS232 connection to robot controller (SIO Board)

2.2 Data Acquisition Electronics

2.2.1 Description

The data acquisition electronics consists of a highly sensitive electrometer-grade preamplifier with auto-zeroing, a channel and gain-switching multiplexer, a fast 16 bit AD-converter and a command decoder and control logic unit. Transmission to the PC-card is accomplished through an optical downlink for data and status information and an optical uplink for commands and clock.



The mechanical probe mounting device includes two different sensor systems for frontal and sidewise probe contacts. They are used for mechanical surface detection and the emergency system.

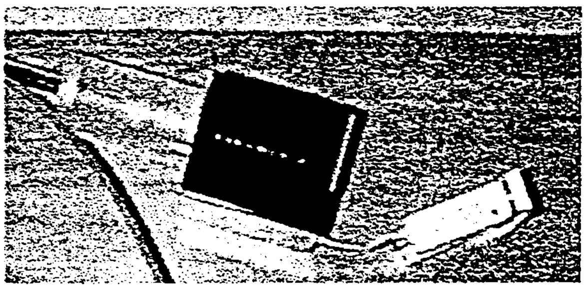
The input impedance of the DAE3 box is 200 MΩ; the inputs are symmetrical and floating. Common mode rejection is above 80 dB.

Note:
Due to the high impedance the offset voltage might drift to several tenths of microvolts if the inputs are left open. To take advantage of the high sensitivity of the input electronic, a properly designed grounding and power distribution system in the laboratory is necessary. See Grounding Problems, page 79 for further information.

Important:
Keep the DAE dry; absolutely avoid condensing humidity in the DAE-box.

Calibration: Required once a year.

2.2.2 Batteries

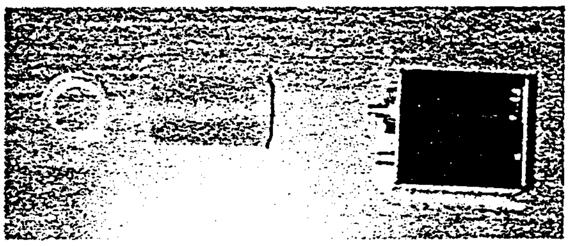


The DAE works with either two standard 9V batteries or two 9V (actually 8.4V) accus. As the electronics automatically powers down unused components during breaks or between measurements, the battery lifetime depends on system usage. Typical lifetime are >15 hours for batteries and >8 hours for accus. Remove the batteries if you do not use the DAE over a longer time.

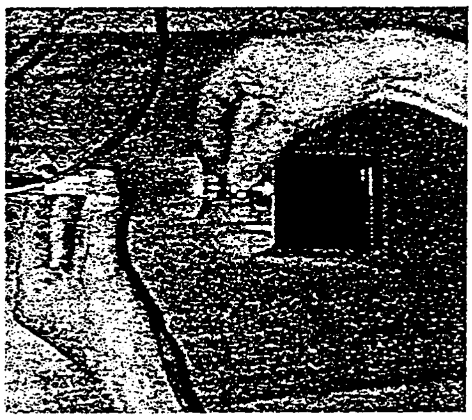
Note: The use of accus is highly recommended.

2.2.3 Probe mounting

The following steps illustrate how a probe should be connected to the data acquisition electronics. Be careful when handling the probe!

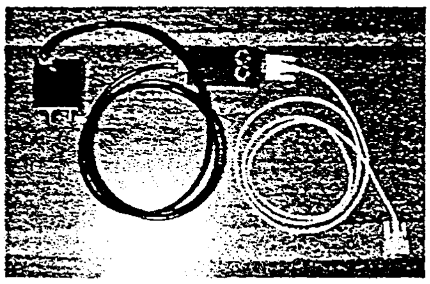


Picture 1 Assemble the probe shielding



Picture 2 Connect probe to box

2.2.4 DAE connection

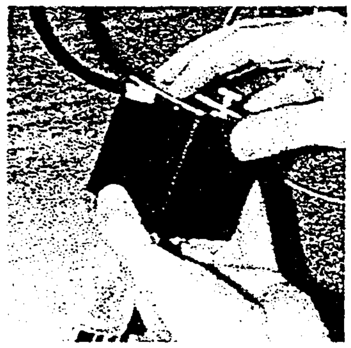


Connect the optical cable (black) from the DAE (blue box) to the optical adapter (gray box), and the serial cable from the optical adapter to the PC-Board.

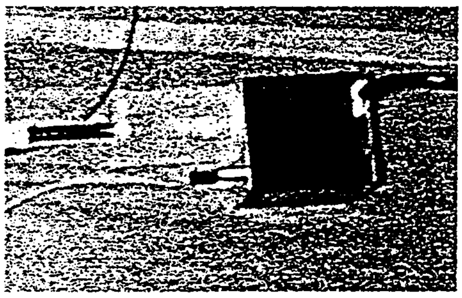
Picture 3 Cable connections

To switch on press the push button on top of the electronic box shortly (less than a second). Pressing it for more than two seconds turns the electronic box off.

The box will turn off automatically 15 minutes after switching off the computer.

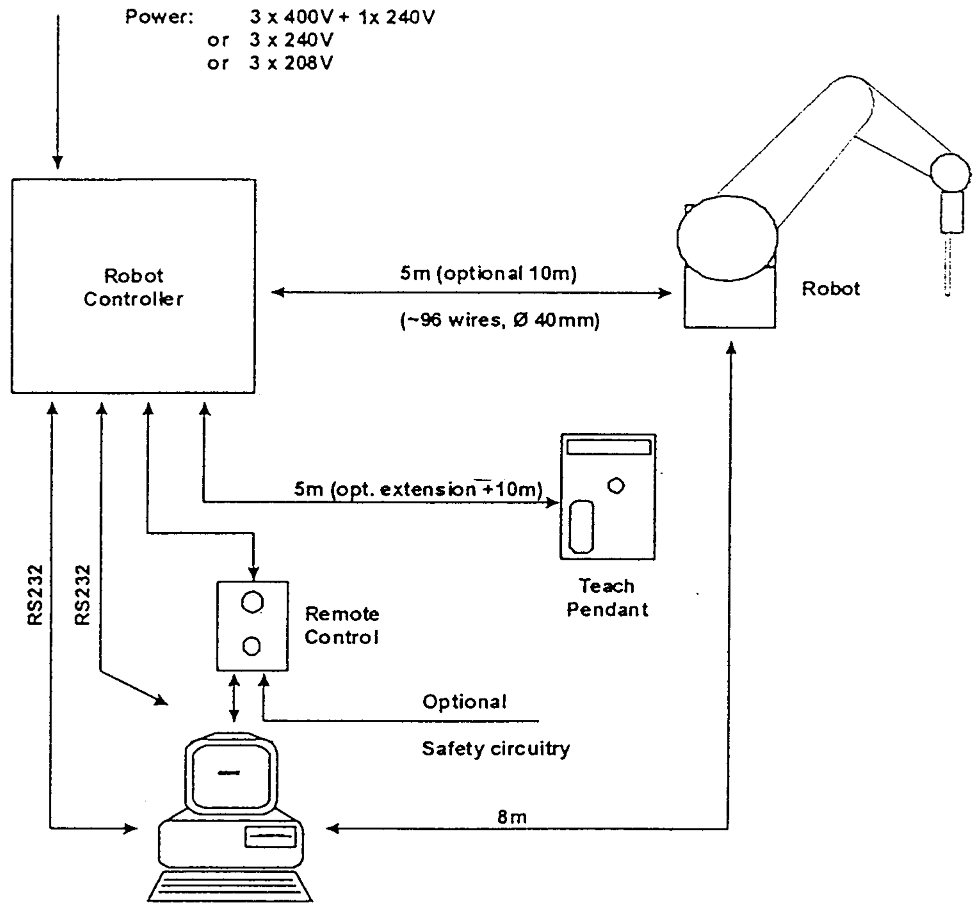


Picture 4 Switch on (red light starts blinking)

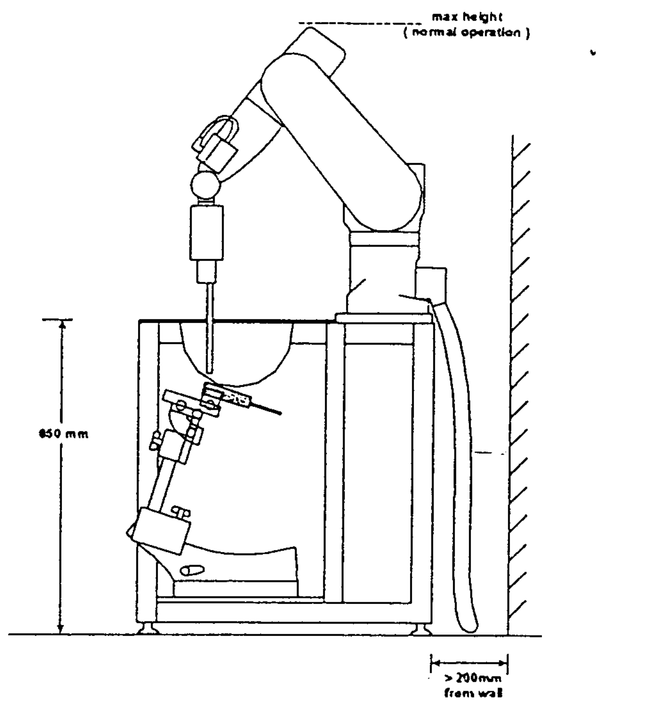


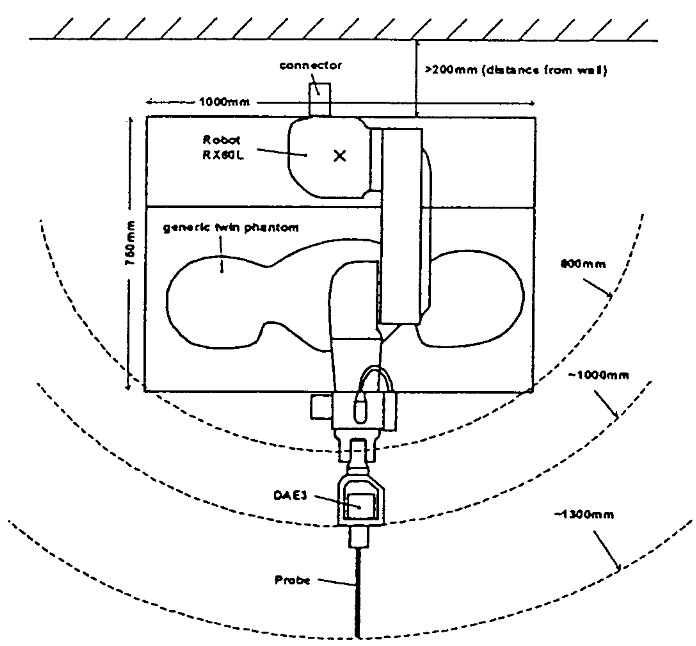
Picture 5 Grounding connection

2.3 Cabling

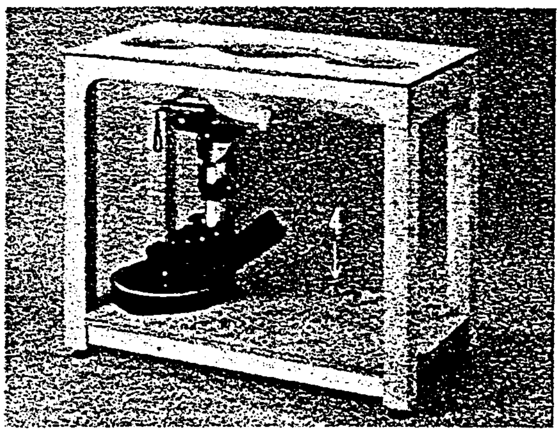

Power: 3 x 400V + 1x 240V
or 3 x 240V
or 3 x 208V
Robot Controller
5m (optional 10m)
(~96 wires, Ø 40mm)
Robot
5m (opt. extension +10m)
Teach Pendant
RS232
RS232
Remote Control
Optional
Safety circuitry
8m

2.4 Dimension compact version





2.5 Phantom



The generic twin phantom is a fiberglass shell phantom with 2 mm shell thickness. It has three measurement areas:

- Left hand
- Right hand
- Flat phantom

The device holder can be fixed in any of these: a 100x50x85 cm (BxTxH) support for free standing robots and a 100x75x85 cm (BxTxH) version for table mounted robots.

A white cover is provided to tap the phantom during off-periods to prevent water evaporation and change in liquid parameters. Free space scans of devices on the cover are possible; however the optical surface detector is not working properly at the cover surface. Place a white paper on the cover when using optical surface detection.

Three reference markers are provided to identify the phantom position with respect to the robot (see Installing the Generic Twin Phantom, page 52):

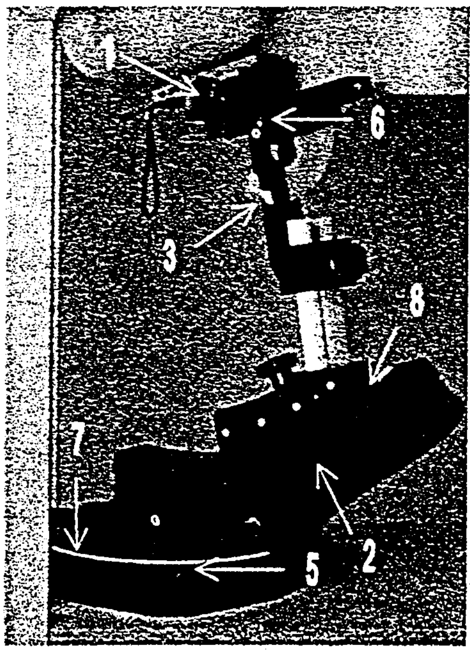
Phantom use with tissue simulating liquids:

- Water-sugar-solutions can be left permanently in the phantom. Always cover the liquid if the system is not used, otherwise the parameters will change due to water evaporation (see Tissue Simulating Liquid, page 82).

- Buthyldiglycol-solutions should be used with care. As glycol is a softener for most plastics, the solution should be taken out of the phantom and the phantom should be dried when the system is not used (also overnight!). A test has shown a slight coloring of the inner surface after 3 months on continuously being filled with 1.8 GHz Buthylfiglycol solution.

- Do not use other organic solvents without testing the phantom resistively previously.

2.6 Device Holder for Generic Twin Phantom



1. Put the phone in the clamp mechanism (1) and hold it straight while tightening. (Curved phones or phones with asymmetrical ear pieces should be positioned so that the ear piece is in the symmetry plane of the clamp).

2. Adjust the sliding carriage (2) to 90°. Then adjust the phone holder angle (3) until the reference line of the phone is horizontal (parallel to the flat phantom bottom). The phone reference line is defined as the front tangential line between the ear piece and the center of the device bottom (or the center of the flip hinge).

3. Place the device holder at the desired phantom section and move it securely against the positioning pins (4) (see picture on previous page). The screw in front of the turning plate can be applied for correct positioning (5). (Do not tighten it too strongly).

4. Shift the phone clamp (6) so that the ear piece is exactly below the ear marking of the phantom. The phone is now correctly positioned in the holder for all standard phantom measurements, even after changing the phantom or phantom section.

5. Adjust the device position angles to the desired measurement position. The rotation scale (7) gives the tilt angle from the body axis. C1 denotes the intended use position (plane through ear openings and mouth); C2 is the 30°-tilt position according to CENELEC. The angle of the sliding carriage (8) gives the inclination angle of the phone (80° = intended use position).

6. After fixing the device angles, move the phone fixture up until the phone touches the ear marking. (The point of contact depends on the design of the device and the positioning angle).

   Note:
   Always lower the phone fixture prior to changing the device angles.

   If the ear piece of the phone is shifted horizontally after changing the device angles, the phone or the device holder is not correctly positioned.

2.7 Validation kit

The validation dipole is a highly symmetric dipole. It comes with a special support and a snap-on distance holder.
Using the dipole at the specified frequency with support and distance holder at the flat section of the generic twin phantom filled with tissue simulating liquid produces a repeatable and specified situation in which the dipole is matched and characterized with respect to SAR.

See the dipole documents and the section system validation for more information.

2.8 Robot

2.8.1 Description

The Stäubli RX60L, RX90, RX90L robots are high precision industrial robots. The important characteristics in the DASY system are:

- High precision
- High reliability
- Low maintenance costs
- Low ELF-fields due to closed metallic construction

Calibration

The probe positioning in the DASY SAR measurement system is not depending on absolute robot accuracy. In vertical axis an optical or mechanical surface detection system positions the probe accurately with specified distances from the phantom shell. In the horizontal planes the measurement location for integrated peak SAR-measurements is based on a coarse grid search routine.

In the measurement document the position of each measured surface point is stored as actual robot position read from the robot controller. Software positioning errors can be traced in the document file.

The only necessary calibration of the robot which influences SAR-accuracy is the accuracy of relative movements in the measurement volume, but the robot will stop if the desired accuracy cannot be reached.

2.8.2 Robot safety

Follow the safety regulations from robot manual provided by Stäubli (Chapter 1 Safety):

- Check that no one is within the robot work envelope when switching arm power on or moving the robot. Always take tool offset into account.
- Each time that the robot is moved using the teach pendant, select a low speed.
- Before any maintenance on the arm, make sure arm power is off.
- Before any maintenance in the controller cabinet, switch off the mains supply via the mains isolator.

Note:
The customer must meet specific robot safety regulations of the corresponding country.

The Stäubli robot offers many possibilities for safe operation in industrial and labor environments.

The minimum requirements should be:
- Instructed persons should only operate the system.
- The safe area around the robot must be clearly marked (warning signs, floor markings, barriers, shielded room).
- For installation, teaching etc. the robot area may be entered only when the robot is in manual mode and the operator has the teach pendant in hand with the “dead man switch” functional.

Additionally the following options should be considered:

- An external warning lamp can be connected to the robot indicating when the robot arm is powered and when the robot is in program controlled mode.
- Additional safety products like switching floor mats, door switches, etc. can be connected to the robot. They can be disabled by bringing the robot in manual mode with the key switch on the front panel.
- The robot controller can be rewired to reduce the voltage to the motor amplifiers. (This mode is called “turtle mode” and Stäubli offers the controller with switchable motor voltages). The DASY system works well with reduced voltage. See the installation documents if the voltage has been reduced.

3. SOFTWARE

3.1 Installation

To install DASY3 for Windows 95 insert the CD-ROM and run the program setup.exe in the directory 'DASY3\DISK1\'. Perform the steps of the installation program.

Afterwards restart your computer and start the DASY3 program. Select 'Setup Config...' from the menu and change to the 'Configuration' Page in the dialog (see Configuration, page 22). Press the 'Import' button in the dialog. A File Dialog will appear. Change to the directory 'Configuration data' on the CD-ROM and select all files (press SHIFT - Key and select the first and the last entry).

Afterwards try to check the installation by performing the steps described on the next page.

If you are not sure that you have all options installed, check if the following files are in the program directory:

dasy3.exe	Main program
da3core.dll	Base functionality for data acquisition
da3boardv3.dll	DASY3 PC-Board support
da3e3d.dll	E-field probe 3-dimensional
da3h3d.dll	H-field probe 3-dimensional
da3temp.dll	Temperature probe
da3tempscan.dll	Temperature scan
da3full.dll	Robot and Phantom support

3.1.1 *Test Installation*

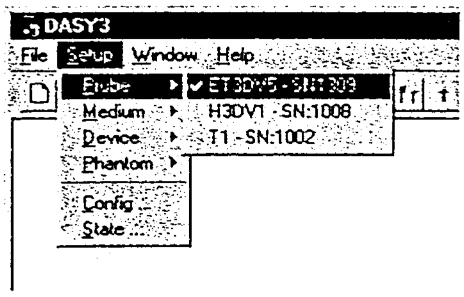
After having successfully executed the proceeding actions, the following steps should be performed:

- Start up the application DASY3.
- Press the multimeter button on the toolbar. ( ) If any error messages appear in the window, perform the steps described in State Information of Data Acquisition (page 45).
- Choose your current settings (page 22).
- Check for noise on the probe as described in Grounding Problems (page 79).
- Press the robot button on the toolbar. ( ) If any error messages appear in the window, perform the steps described in Starting up the Robot (page 46).
- Choose your current settings (page 22).
- Setup the generic twin phantom (page 52).
- Perform a validation (page 72).

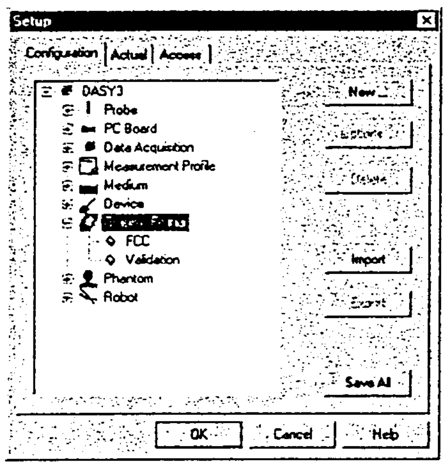
Note:

- Be sure that the optical detector is connected for dosimetric probes.
- The DAE is switched on.
- DAE box is connected.
- All cables between robot, robot controller and PC-card are connected.
- DAE unit corresponds to the probe calibration data.

3.2 Configuration



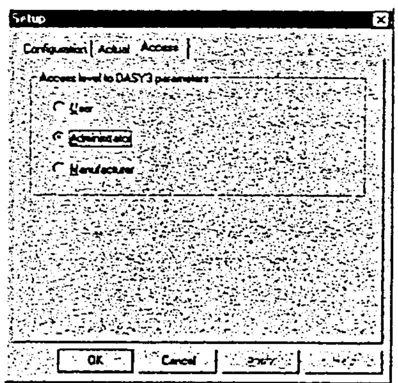
You can choose your current setting by selecting 'Setup' from the menu and selecting the entry you want to use (e.g. ET3DV5-SN1309 is the selected probe in figure) or you can open a configuration dialog with 'Setup Config...' where you can also set the current configuration under 'Actual' page.



To see the parameters of the different settings, you have to select the 'Configuration'-page. Double click on the type. You can remove items ('Delete' – button) add new entries ('New'-button), Import or Export entries to a different file and rearrange the order of the items with drag and drop. To see the properties of the entries press the 'Options ...' button. 'Save All' writes the configuration data to disk.

3.2.1 Access Rights

If several people will use the system, we recommend having one system operator ('Administrator') who defines all measurement procedures and phantom settings. This prevents incorrect measurement data due to improper parameter settings from users who are not very familiar with the system.



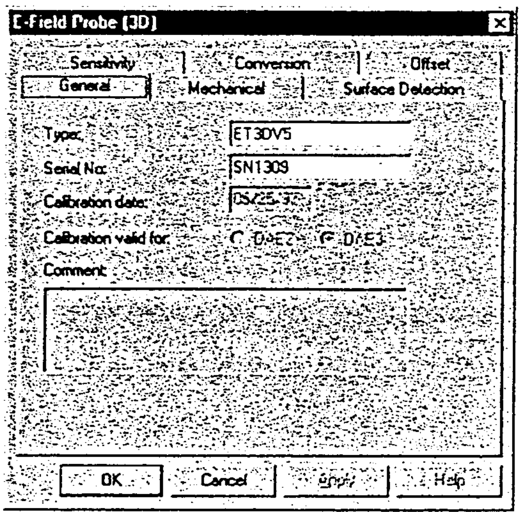
If the access right is 'User', the parameters of the complete acquisition system cannot be changed, except for setting the parameters for the device and the medium to be measured and selecting with which probe, medium, device and phantom the user wants to measure.

As an 'Administrator', you can setup the system for the user, e.g. set new conversion factors for the probe, create new phantoms, and import, export, or delete entries. To change from user to administrator mode you need a password (see label on configuration disk).

Manufacturer mode is reserved for Schmid & Partner Engineering AG.

3.2.2 Probe

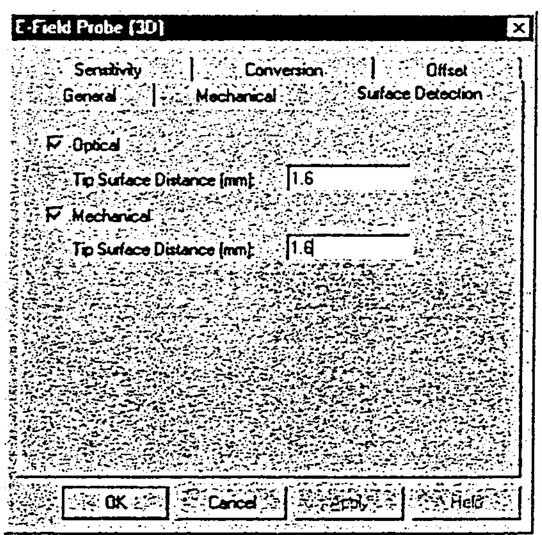
If you want to see the parameters of a probe press the button 'Options' in the 'Setup Config...' dialog.



Every probe has a 'General' page consisting of the type name, serial number, and calibration date, as well as whether the calibration data is valid for data acquisition electronics version 2 or version 3.

In the 'Mechanical' page the mechanical information of the probe is stored. The length is used to move the coordinate system from the robot to the probe tip.

If the probe has the capability to detect the surface, a 'Surface Detection' page is added.



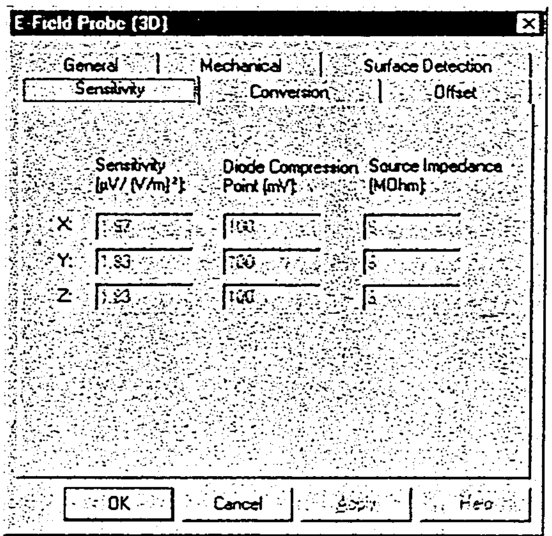
For optical detection, the distance between the surface and where the probe stops upon surface detection must be entered (see probe calibration sheet) for further evaluation of the parameters see Cube Evaluation, page 76.

With DAE3 a mechanical surface detection capability was added. If the value in the 'Tip Surface Distance' box is greater than zero, the probe will be retracted by this amount after detecting the surface mechanically.

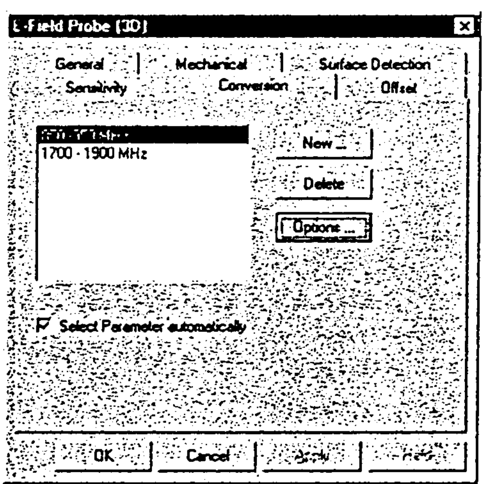
The 'Offset'-page shows the current offset setting for the probe. See Field Measurements, page 42.

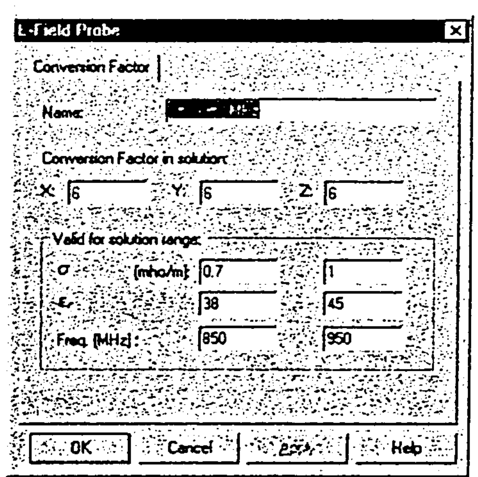
3.2.2.1 E-field Sensitivity Factors

For detailed evaluations of the sensitivity factors, see Data Evaluation on page 74. This data corresponds to the sensitivity factors on your calibration sheet.



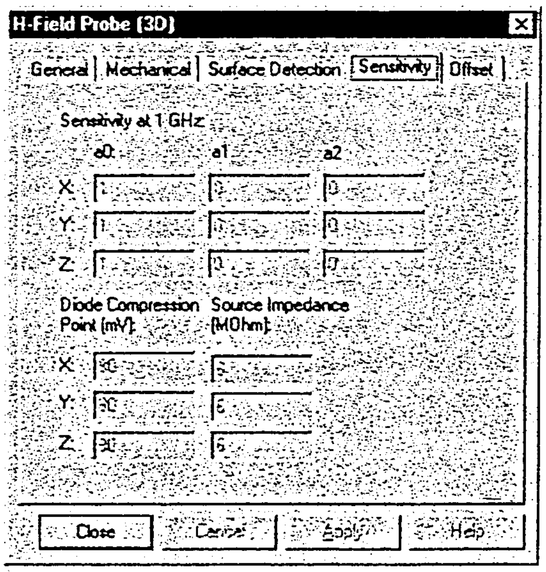
To account for different types of mediums for SAR – measurements, you have to define a conversion factor between the E-field in air and medium. Select the 'Conversion'-page:





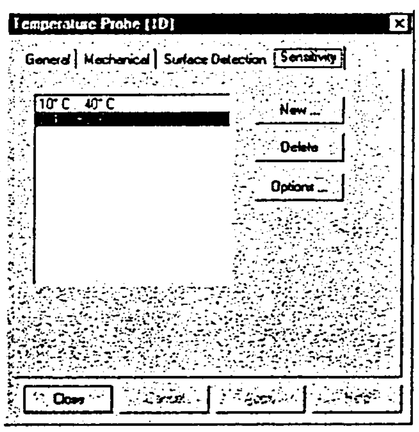
For each medium and frequency range (for example brain simulating liquid around 900 MHz) a conversion factor for the probe can be defined (see figure on the right side). If you have checked the box 'Select parameter automatically' and you want to perform measurements with the probe, then depending on the frequency and the medium the first conversion factor which fits the solution range is used for subsequent measurements. If no conversion factor for this solution range can be found, a warning will appear. If you have not checked the box 'Select Parameter automatically' the highlighted set of conversion factors will be used if the frequency of the device and the medium is within the solution range. You can add your own new conversion factors for different frequencies or solution parameters by pressing the 'New'-button or delete a conversion factor set by pressing the 'Delete'-button.

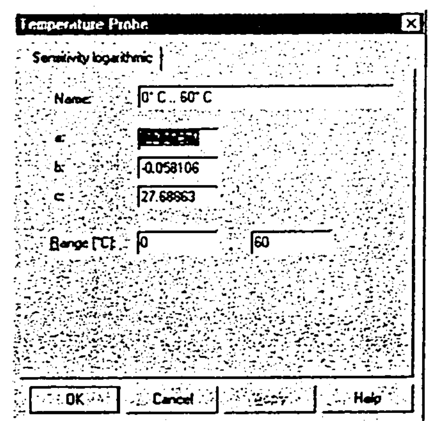
3.2.2.2 H-field Sensitivity Factors



The sensitivity factors for the H-field probes are similar to those of the E-field probe. However, because of the frequency dependence of the H-field probe, more parameters are need. For the process of Data Evaluation, see page 74.

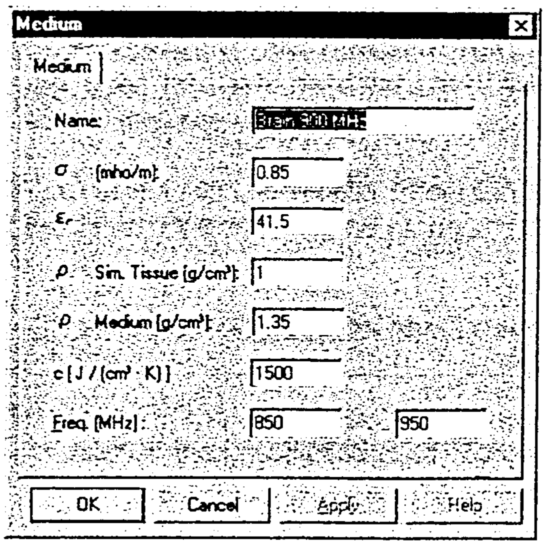
3.2.2.3 Temperature Sensitivity Factors





For different temperature ranges a set of sensitivity factors for the probe can be defined (see figure on the right side). The selected temperature range will be used for calculations and in scans (e.g. 0°-60° in left picture). For the process of Data Evaluation, see page 74.

3.2.3 Medium



A medium type (e.g. see example in left figure) is defined by the solution conductivity (σ), the relative permitivity of the solution (ε_r), the density of the simulating tissue in g/cm^3 and the frequency range in which these parameters are valid. If you perform SAR-measurements with temperature probes, you also have to specify the density of the medium and the heat coefficient factor.

To add a new entry press the 'New' button in the 'Setup Configuration' Dialog.

For information how to measure the tissue simulating liquid and what tolerances are acceptable, see Tissue Simulating Liquid, page 82.

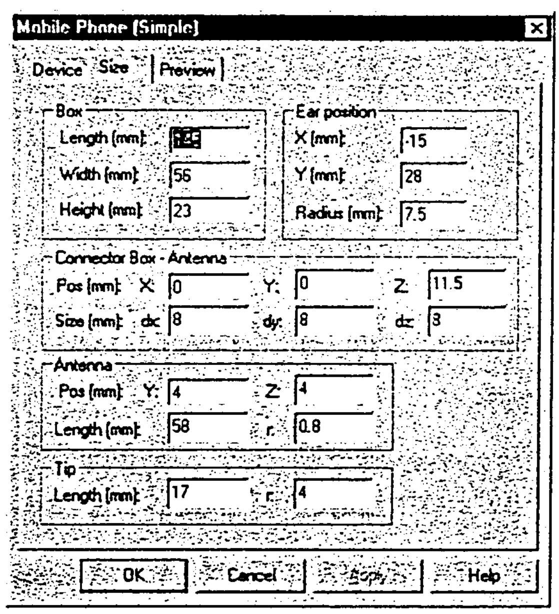
3.2.4 Device

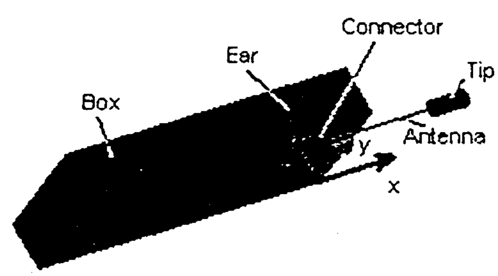
The device defines the excitation field. You must specify the carrier frequency (only used for the evaluation of H-field probes) and crest factor. The crest factor is the ratio between peak and average power (e.g. analog 1, GSM 8).

If you select 'Simple Mobile Phone' instead of just 'Device' when creating a new device, a simple outline of the device can be entered.

3.2.4.1 Showing the Outline of the Device

To improve the visualization of the measurement, the device can be visualized in the graphics. Select 'Options Device' and press the 'New' button.

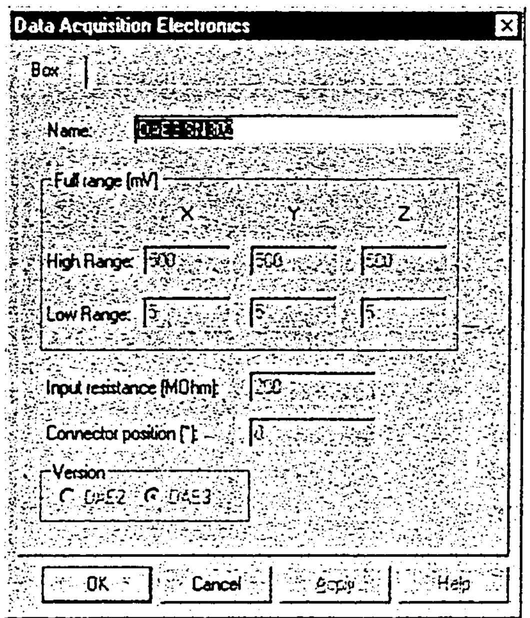




To generate an approximation of the device tested, enter the data for the box, the ear position, the connector size, the antenna and the tip length. You can change to the preview window to see whether your data matches with the phone. In the graphics the ear center point will be put to the device reference point defined in the section (see Section, page 34).

3.2.5 *Data Acquisition*

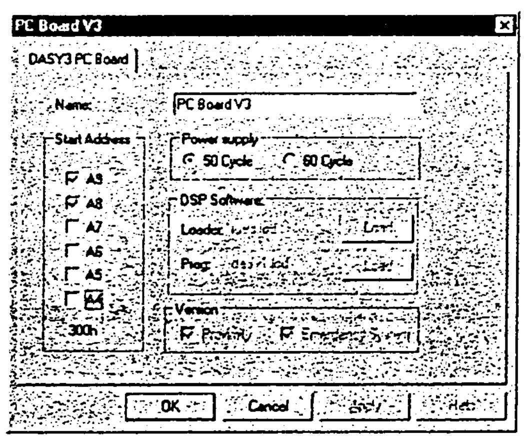
The Data Acquisition is based on the Data Acquisition Electronics (short DAE, black or blue box) and the PC-Board. The parameters of the PC-Board can be changed with the jumpers on the board. Enter the same settings in the dialog as are on your card (default from manufacturer). Afterwards, restart the computer.



DASY3 can work in the configurations DAE2 or DAE3. However, the probes must be calibrated for the correct Data Acquisition Electronics, since the input resistance is different for the different DAE versions.

The range parameters correspond to the DAE calibration sheet and cannot be changed.

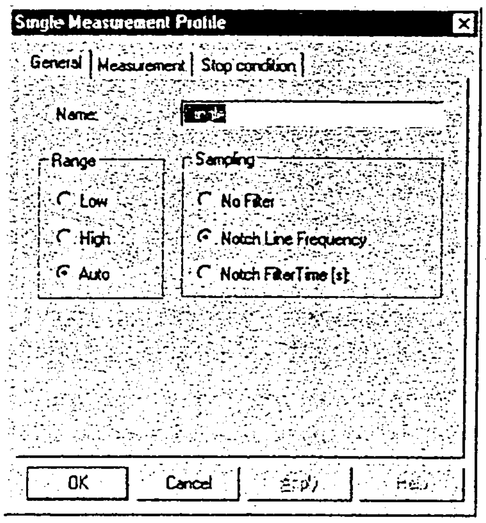
Attention! *If you are working with two different versions of DAEs, be sure to change the DAE. The software cannot automatically recognize the DAE version.*



Manufacturer setting for the PC-Board is 300 (hex). If you have conflicts with other boards in your PC you can change the jumper settings on the card and in the software, but the computer has to be restarted first before measurements can be done. If the power supply is not 50 cycles, it can be changed to 60 cycles.

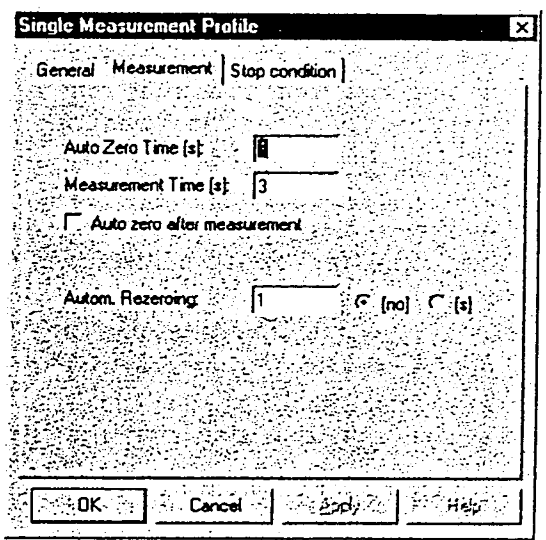
3.2.6 Measurement Profiles

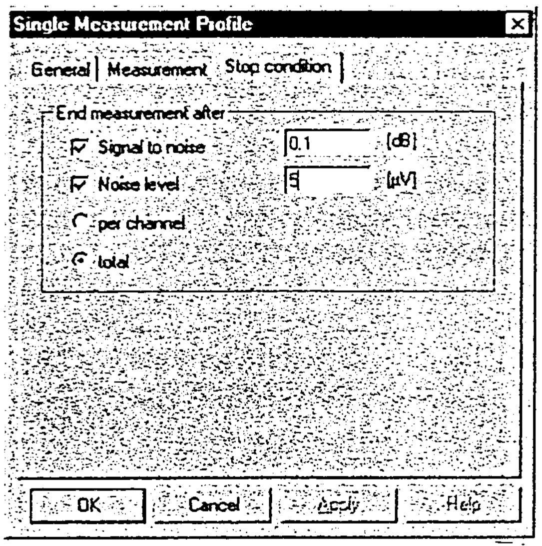
You can define different measurement profiles and store them similar as other resources in DASY. You can define a measurement profile for a precise single measurement or a measurement profile that is very fast. You also have the possibility to visualize each individual measurement point in the complete measurement.



The Data Acquisition Electronics supports two different ranges, a low range (up to 5 mV) and a high range (up to 500 mV). If 'Auto' is selected, the first 20 ms are used to determine the appropriate range used for the next measurements. By selecting 'No Filter' every measurement sample (128μs x 3) is used, but the measuring time is limited due to fifo overflow depending on the speed of your PC-system. To remove the noise from the line frequency the 'Notch line frequency' is best used. However, a free notch filter time can also be chosen.

A measurement consists of two parts, an auto zeroing and a measurement cycle. Enter the time for each cycle. The auto zeroing cycle zeroes the offset voltage of the input amplifiers. Specify the number of measurements after which the zeroing cycle should be repeated (or after how much time if you click on [s]) and whether you want to perform the zeroing cycle after the measurement cycle. For sensitive measurements and during the warm-up of the electronics box, the auto zeroing cycle should be reactivated regularly.





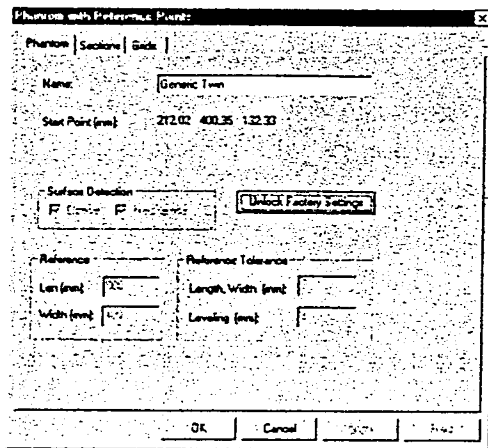
If the 'Signal to noise ratio' or 'Noise level' is activated, the measurement will be evaluated after 32 samples (e.g. if you have selected the notch line filter this will be around 0.6s). If the measured error is within the signal to noise error or below the noise level in a 99.9% interval, the measurement will be stopped. Otherwise, the accuracy evaluation will be further perfomed until the accuracy has been achieved or the measurement time has passed.

If 'per channel' is selected, every channel must be within the accuracy definition, instead of only the total value.

For proximity profiles see Proximity Sensor Values, page 51; for temperature probes see Temperature Scan, page 63.

3.2.7 Phantom

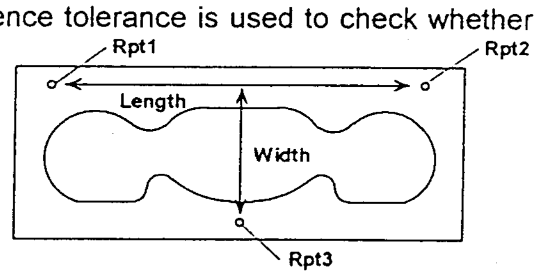
DASY3 allows setting up two different kinds of phantoms; phantoms with three reference points (e.g. Generic Twin Phantom) or phantoms without reference points. The advantage of phantoms with reference points is that all data stored for the phantom (boundary, origin, grids etc.) is relative to these points, and if the phantom is moved the phantom can be reinstalled. In the following sections the parameters for the 'Generic Twin Phantom' is explained.

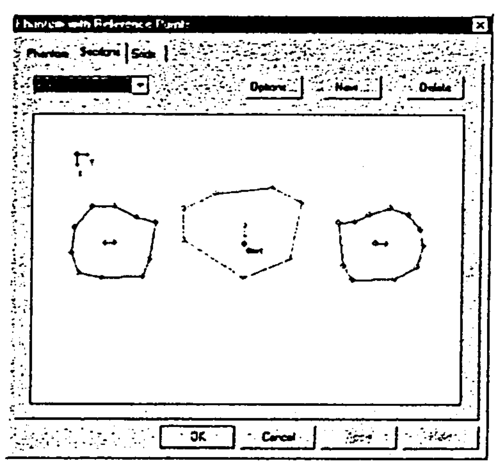


Each phantom is identified by a name and must have a start point (select 'Phantom Teach Start' in the robot window). The start point should be at a place where the probe can easily be cleaned and removed from the probe holder.

If 'Unlock Factory Settings' is pressed, you can specify which type of surface detection is applicable to this phantom.

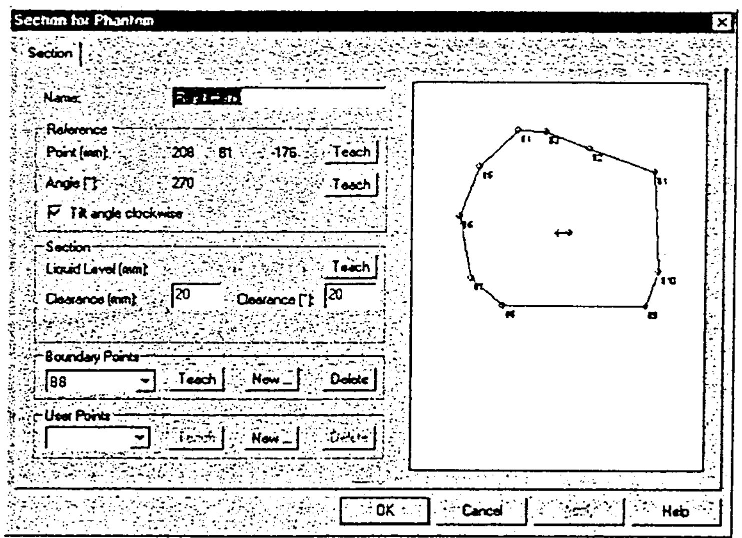
If a reference system is used, the length and width of the reference system can be entered. If the phantom is installed (the three reference points have to be teached with the robot) the reference tolerance is used to check whether the measured length and width is within the specified tolerance. Another check is if the leveling error of the phantom (absolute z-difference between reference Pt1, Pt2 and Pt3) is within the tolerance.





When the 'Sections'-page is selected a view from the top to the phantom is selected. The coordinate system has its zero point on reference Pt1. One or more sections define the phantom. The section that is active is displayed green, the inactive sections in blue. Another section can be selected by the drop-down listbox. You can delete sections ('Delete'-button), or create new sections ('New'-button).

3.2.7.1 Section



If you press 'Option' on the 'Sections' page, all parameters for the section can be set. A section is defined by the following parameters:

Reference point

Each section has a reference point. This point must be above the surface where the probe stops with the surface detection. This point is used to define different grids, display the device at this location and to do reference and drift measurements. If the phantom is active in the robot window, press 'Teach' and a dialog will appear to teach the current robot position as the teach point.

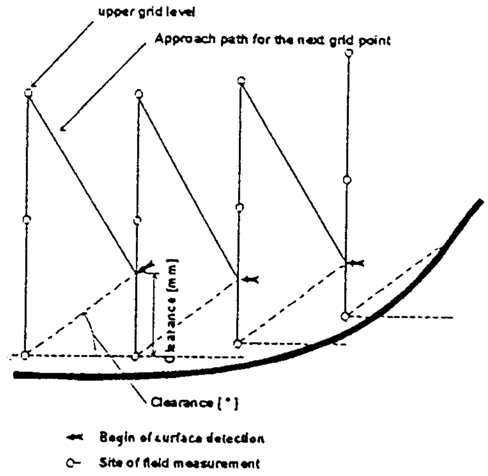
Reference angle

With the reference angle the zero (tilt) angle of the probe holder can be set. Move the probe with the robot into the direction of the zero angle and press the 'Teach'-button. Afterwards the zero reference angle will be displayed as an arrow in the window. If the probe holder has the tilted angle scale in the clockwise direction, check the 'Tilt angle clockwise'-box (e.g. Generic Twin Phantom, Right hand Section).

Liquid level

If the liquid level is defined, all movement in this section from point to point will be 1 cm below the liquid level (press 'Teach'-button to set liquid level).

Clearance



The 'Clearance' option defines the minimum amount by which the probe should be lifted before being moved horizontally to the next measuring site. This ensures that the probe does not touch any part of the phantom while moving between the two points. As a short cut, the probe is actually moved at an angle away from the surface while moving towards the next point. This also ensures that it has a given clearance when reaching the next point.

	Clearance [mm]	Clearance [°]
Air	0	0
Flat phantom	15	0
Head phantom	20	15

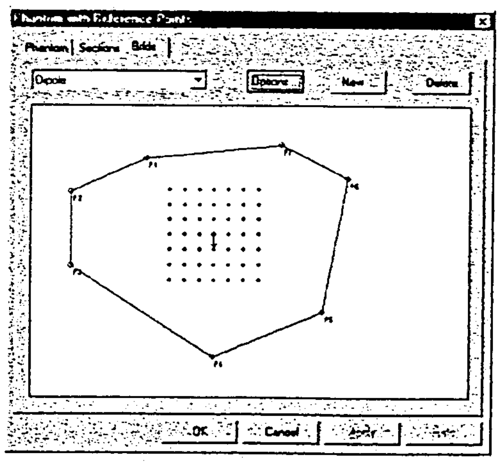
Boundary

If you define more than one section for a phantom or you have an area that is not freely accessible, it is absolutely necessary that a boundary is defined (blue lines). A boundary consists of at least three points: it is not allowed to have two points on the same location, and the boundary should be a polygon with no intersecting lines in-between. You can add new points with 'New' button, removing the selected point with the 'Delete'-button or reteach the selected boundary point with the 'Option'-button.

User points

If you want to define points for the phantom yourself, define user points the same way you have defined boundary points.

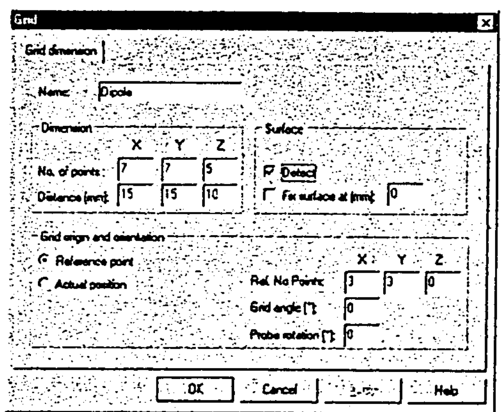
3.2.7.2 Grids



Every section can have predefined grids, which users can easily select for their measurements. Change to the 'Grids'-page in the phantom dialog and you can select different grids, add new grids or delete existing ones.

Black circles displayed in the graph are the points to measure viewed from the top.

If you press 'Options' the grid dialog will appear:

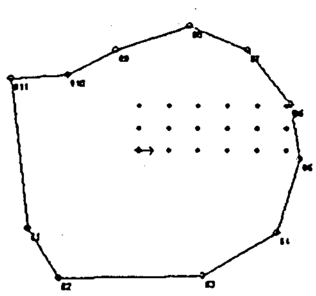


The grid dimension is defined by the number of points in each direction and the distance between the points.

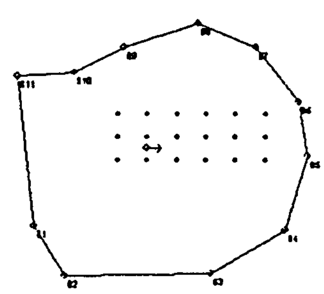
The origin of the grid can be either the reference point or the actual position where the grid is started.

With 'Detect' the probe will be moved towards the surface, with 'Fix surface' checked the probe will not move lower than the coordinate.

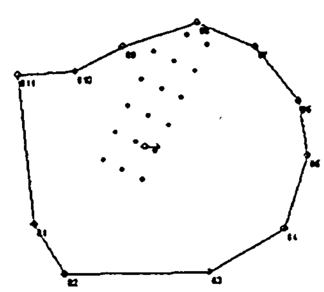
To align the grid to the current orientation of the phone, the grid can be shifted and rotated. Enter the number of points in the x- and y-direction to shift the start point away from the grid point. The value in 'Grid angle' rotates the grid.



nx: 6, ny: 3



relx: 1, rely: 0.5



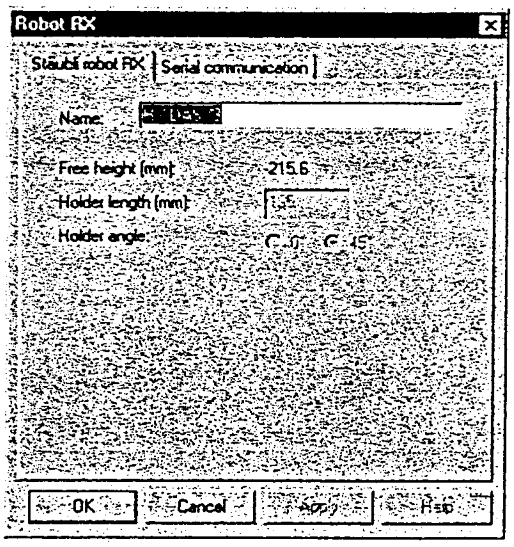
grid angle: 65°

Points that are outside of the boundary will not be displayed nor measured (see third grid above).

If you specify a relative amount for z, the probe will first detect the surface and then move the relative point number times the distance of one z-axis point up before measuring.

The orientation of the probe towards the grid is such that the x-sensor is aligned toward the x-axis of the grid, if the rotation angle of the DAE-box and the probe is specified. If another orientation is desired the probe orientation angle can be specified to rotate the probe itself for the grid measurement.

3.2.8 Robot



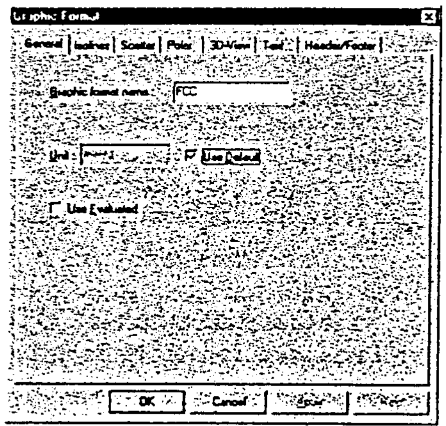
The parameters of the robot are the free height, holder length and holder angle.

The free height defines a height where the robot can move the probe around without touching any part of the phantoms. If movements from the software between sections or phantoms are to be done, the robot will first move the probe up to the free height and move to the next location at the free height before going down to the next point.

The holder length is fixed set, the angle differs from the RX60L (45°) to the RX90(L) (0°).

3.2.9 Graphic Formats

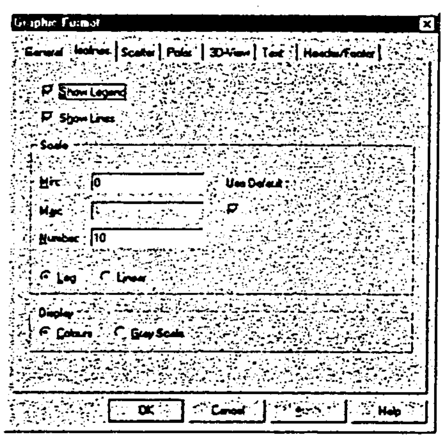
Various graphic formats can be defined for specific measurement types (e.g. validation format, compliance format). See also Graphics, page 66.



The 'graphic format name' will be displayed in the graph menu.

If 'Use Default' is selected a unit can be specified which will be set as the default unit for opening a graph.

If 'Use Evaluated' is selected extrapolated values from the cube scans will also be displayed.



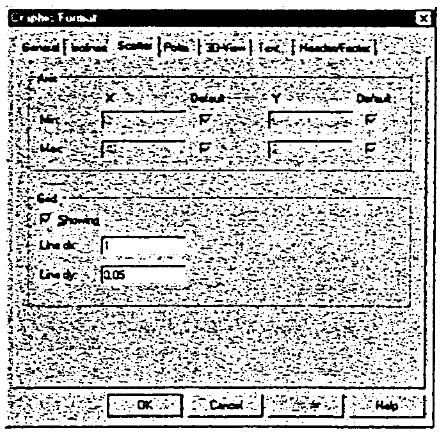
A 3D scan is displayed with 2D contour plots and a legend.

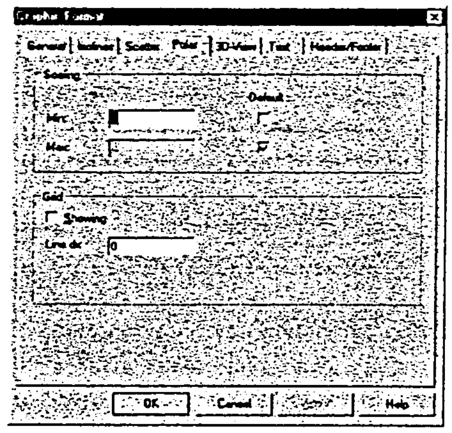
The legend will be displayed only if 'Show Legend' is selected.

'Show Lines' draws a black line on isolines and between grid points.

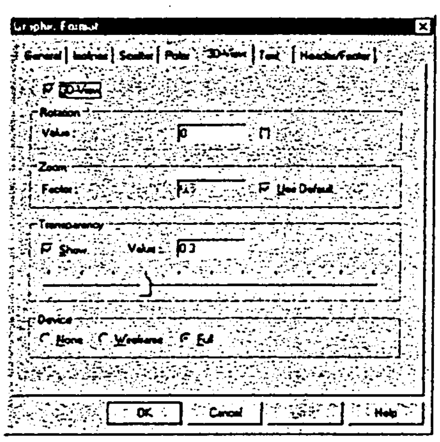
For scaling the isoline, the minimum and maximum values (automatic if 'Use Default' is selected) as well as the number of isolines can be specified.

Scaling is either linear or pseudo log-scale (three lines per decade 0.1 0.2 0.5 1 ...). The graphics can be displayed in colors or in black-white.





For scatter graphics (f(x) or f(x,z)) and polar graphics (f(angle)) minimum and maximum values can also be set. Additionaly a grid can be displayed behind the graphics ('Showing' checked, distance in 'Line dx' and 'Line dy').

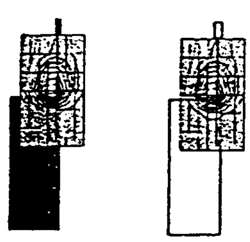


The device can be visualized in the graphic. Select 'Full' or 'Wireframe' to display, 'None' not to display the device.

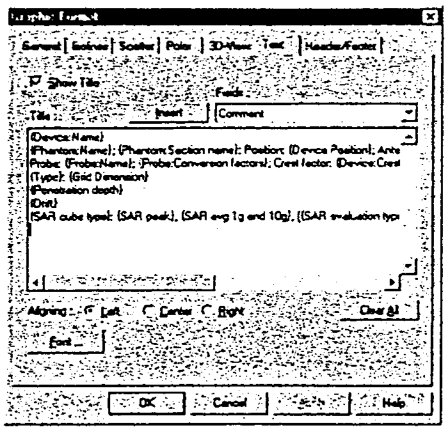
The plane can be made transparent, so that the device outline can be shown (see picture below). Set the transparency value and select 'Show'.

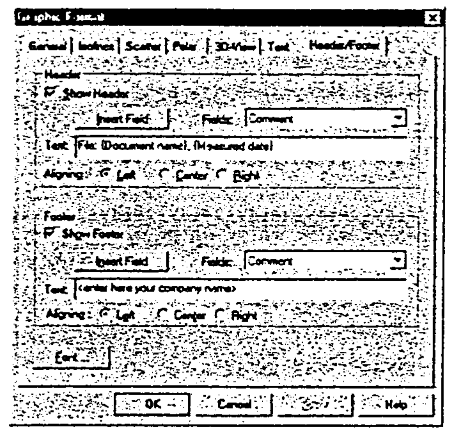
Note: *A plane will only be drawn transparently if there is only one plane in the graphics.*

If a rotation value is entered, the graph will be rotated counter clockwise from the default setting angle when the graphic window is opened. An additional zoom factor can be specified as well.



The option '3D-View' displays a curved grid which corresponds to the measured data in a curved phantom. When the option has not been selected, the measured coordinates are substituted by computed coordinates which form a regular grid (without surface information, therefore the device will not be included in the graphics).





For the graphics a title, header and footer can be specified. If 'Show Title', 'Show Header' or 'Show Footer' is selected, the text will be shown; otherwise the text is hidden. The alignment can be left, center or right, and the font can be selected (Button 'Font ...').

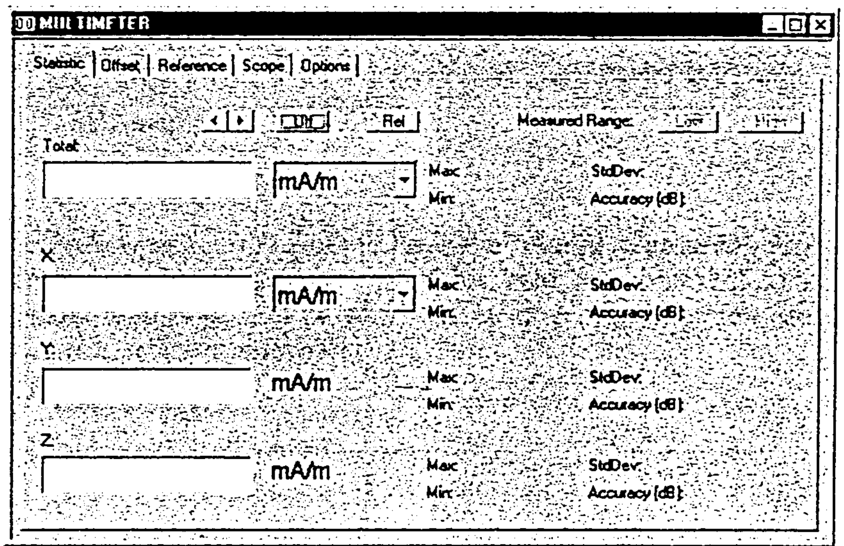
The first line in the title will be 50% larger fonts than the other lines. Text entered in brackets (e.g. {Device:Name}) will be replaced by the current settings in the scan (e.g. Dipole 1800 MHz).

To insert a new variable choose the drop down box (only functional when using 'Graph Options' in the graphics menu):

Variable	Description	Example
{Comment}	Comment in measurement document 'Settings'-page	
{Device:Crest factor}	Device parameter	1.0
{Device:Frequency [MHz]}	Device parameter	1800 [MHz]
{Device:Name}	Device parameter	Dipole 1800
{Device Antenna}	Antenna position in scan	Out
{Device Position}	Device Position (horiz and tilted angle)	(80°, 65°)
{Document name}	Filename	Validation 1800.da3
{Drift}	Evaluation from Drift - Scan	Powerdrift: 0.3 dB
{Graph pos}	Position in graphics	Plane(1)
{Grid Dimension}	Grid dimension of scan	Dx = 10.0, Dy = 10.0, Dz = 10.0
{Maximum}	Maximum value of grid points	1.66
{Medium:Parameters}	Medium parameter	σ=1.7[mho/m] ε_r= 1.2 ρ=1.00 [g/cm^3]
{Medium:Name}	Medium parameter	Brain 1800 MHz
{Name}	Name of scan	Coarse
{Penetration depth}	Average, Min and Max Penetration depth calculated from Cube 5x5x7 or z-axis scan	Penetration depth: 8.3 (7.8,9.2) mm
{Phantom:Name}	Phantom parameter	Generic Twin
{Phantom:Section Name}	Phantom parameter	Flat
{Probe:Name}	Probe parameter	ET3DV5 SN:2008
{Probe:Converson factors}	Probe parameter	ConvF(4.50, 4.50, 4.50)
{SAR avg 1g and 10g}	Cube evaluation	SAR (1g):1.50 [mW/g] SAR(10g) ...
{SAR cube type}	Cube evaluation	Cube 5x5x7
{SAR evaluation type}	Cube evaluation	Worst-case extrapolation
{SAR peak}	Cube evaluation (extrapolated peak)	Peak [2.75 mW/g]
{Scan evaluation}	Scan evaluation	Max at 33.0,4.5,3.9

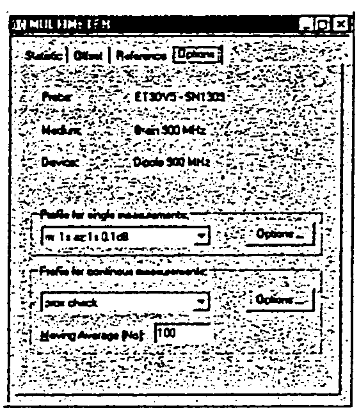
3.3 Field Measurements with Multimeter Option

If you have pressed the multimeter button and the data acquisition displays no error, the multimeter window will appear. You can display the multimeter in a small ('View Small'), an extended ('View Extended') or a large ('View Large') window.



If you have started a measurement ('Measure Single'), the values and the statistics will be displayed afterwards on this window. The values are displayed in the specified unit, which can be changed in the gray listbox. The number of the significant digits can be increased or decreased by pressing the two arrow buttons. If you choose the 'Off'-switch, offset compensation will be activated; if you choose 'Rel', the reference value will be taken into account.

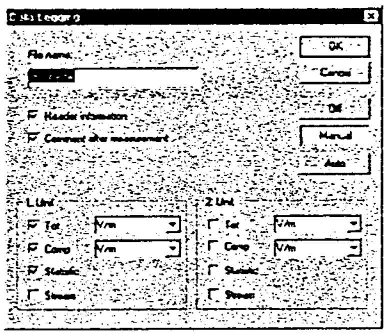
The multimeter can also be used for continuous measurements ('Measure Continuous').



Select the 'Options' page and choose a measurement profile for continuous measurements.

Select in Continuous Measurement Profile' the new profile. If the value in 'Moving Average' is greater than 1, the statistics will be based on the specified number of measurements. The profile can be directly changed by pressing the 'Options' button.

3.3.1 Data Logging

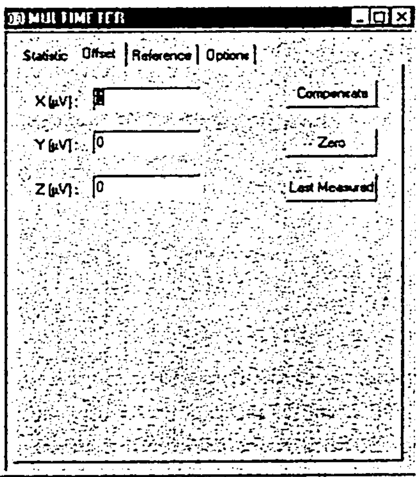


All measured data can be exported to a text file. The file will be created in the directory where DASY3 was started.

If 'Manual' mode is selected, you must press the 'Data Logging' button every time; if 'Auto' is enabled, all measurement data will be added.

You can specify whether you want to have the header information (units and components) and whether you want to add a comment after each measurement. Two units can be exported for one measurement, depending on the selection, which is active.

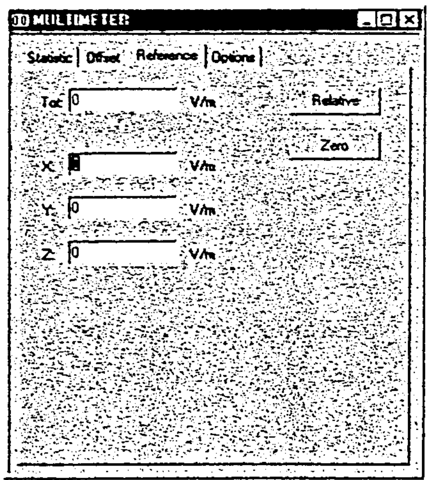
3.3.2 Offset Compensation



When measuring extremely weak fields, the offset inherent in the probe can cause relatively large measurement errors. In order to avoid this effect, the offset can be measured and automatically accounted for in the following measurements.

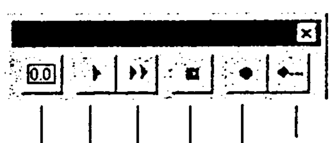
It is important to have no electromagnetic fields when measuring the offset for any probe. Increase the measurement time in the profile to about 5 seconds, perform the measurement and press the button 'Last measured' afterwards. If you want to compensate the measurement for further measurements, press the 'Compensate' button. The offset compensation will be assigned to the probe until you overwrite it again or quit the DASY3 software.

3.3.3 Measurements with a Reference



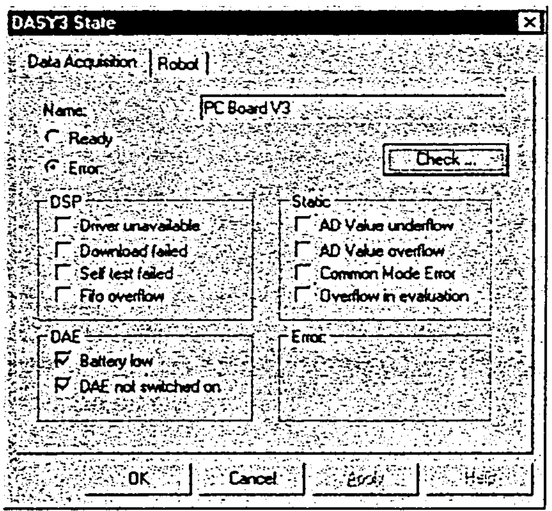
If a relative value in the 'Reference' page is entered and the 'Relative' switch is set, the measurement data will be relative to this value.

3.3.4 Toolbar



Data logging options
Add data to a file
Stop a measurement
Measure continuously with continuous profile
Start a measurement with single profile
Open multimeter, Initialize Data Acquisition

3.3.5 *State Information of Data Acquisition*



If an error occurs during measurements, the Data Acquisition Page will be shown. If the state is not correct the Error radio button is checked. 'Check' – button triggers a measurement in high range and returns the new state.

If measurements cannot be started in the multimeter because the buttons and menus are grayed press one more time the 'multimeter button' to reinitialize the Data Acquisition.

Battery low
Battery or accu pack is empty. Change batteries or accus.

DAE not switched on
Switch DAE on (upper part of the electronics box) or check the connection from the PC to the DAE.

AD value underflow
The DAE received zero values. This appears in most cases when there is high noise (e.g. from a power line) in the surrounding area.

AD value overflow
The measurement signal is too high for the DAE.

Common mode errors
Common mode signal is too high. DAE is not working in the linear range Follow Grounding Problems on page 79.

Overflow in evaluation
The notch filter time is too long.

Driver unavailable or Download failed
The DAE-Driver cannot be started. Try to restart the computer, check that there are no conflicts with base addresses. If the problem does not disappear, contact Schmid & Partner Engineering AG.

Self test failed
There are problems with the PC-BoardV3. Please contact Schmid & Partner Engineering AG.

Fifo overflow
Shorten the measurement time if you are not using a filter during measurements.

3.4 Robot and Phantom handling

3.4.1 Starting up the Robot

ROBOT

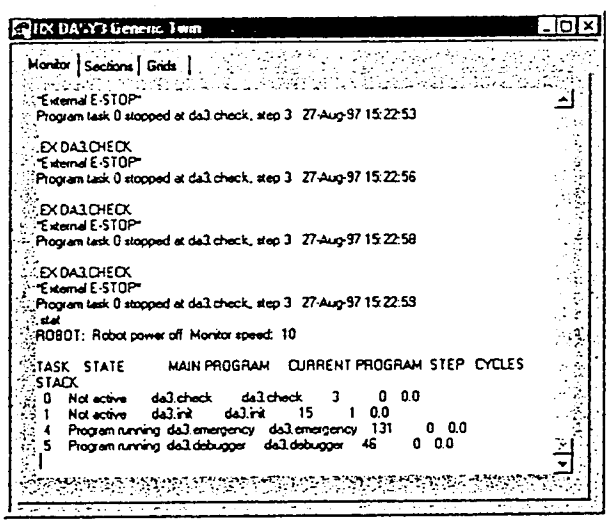
Turn on the main power switch of the control cabinet. The robot is ready when all the lights on the manual control pendant have ceased to blink (approximately 3 minutes). The arm power can then be switched on with the COMP PWR button on the manual control pendant and pressing afterward the arm power ON from the control cabinet (if .remote control is used the power can be switched on/off trough the remote control instead of control cabinet). The arm Power ON button on the control cabinet or on the remote control will now light up. Only when this control lamp is activated can the robot arms be powered.

IMPORTANT:

When you switch the robot off, always turn the ARM POWER off before turning the controller switch off (position 0). If you switch the controller off before the arm power is turned off, the robot arm collapses considerably before the brakes can stop it.

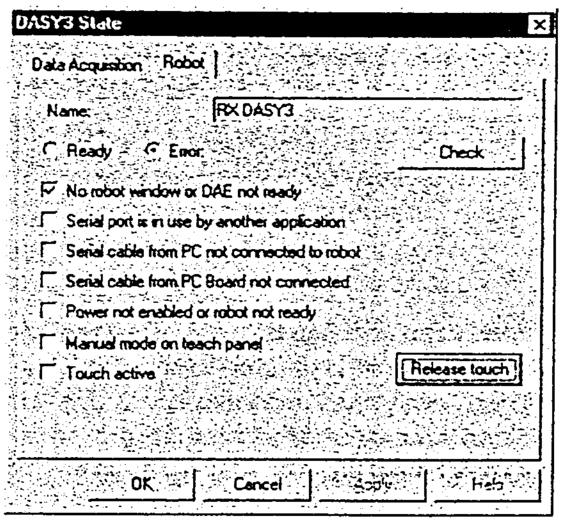
PROGRAM

To use the robot and phantom support press the Robot–button in the Robot Toolbar.



The robot is controlled by the PC via the serial port (RS-232). The 'Monitor' Page provides you with direct access to the serial interface. From this monitor level you are able to send robot commands (in its own language) directly to the robot controller.

The first time the system is used software from the PC will be downloaded to the PC. If the initialization of the robot was not successful an error dialog will appear.



No robot window or DAE not ready

The Data Acquisition is not working properly or is not correctly set up. First perform the initialization in 'Data Acquisition'-Page.

Serial port is in use by another application

Another application is using serial port number one. Quit this application.

Serial cable from PC not connected to robot

The serial cable from PC to robot is not connected. Check the connection.

Serial cable from PC Board not connected

The serial cable from PC Board to PC is not connected. Check the connection.

Power not enabled or Robot not ready

Robot arm power is not on, see Starting up the Robot, page 46, first paragraph. If the problems remain, check whether the calibration was successful (see Known Startup Problems, page 48).

Manual mode on teach panel

Switch on the teach panel back from 'Manual' to 'Comp' mode.

Touch active

First check, that all emergency buttons from the robot are released and that the probe is not touching anything (otherwise the probe must be removed). Afterwards press 'Touch Release', see also Touch System, page 50).

If the initialization of the robot succeeds, a new window will appear called MONITOR which displays communication information between the robot and the PC.

If you choose the Monitor option you are actually on the robot control level. At this level several movement and coordinate-handling instructions are provided by the Menu. If you no longer need the monitor or direct access, just double click on the system box of the Monitor window.

With <ENTER> you call the robot, which answers back with the ready signal <.>. Instructions to the robot can be directly typed in and can be transferred to the robot controller by typing <ENTER> again or can be selected from a pull-down menu. Any new instruction can only be transmitted to the robot after the ready signal <.> reappears. Which means that the previous instruction has been successfully executed and the robot is ready to receive new instructions.

3.4.2 Known Startup Problems

Problem:

Sometimes, after the robot has been initialized, it is not possible to turn on the arm power. First verify that the emergency stop has not been activated.

Solution:

Switch off the robot and turn off and on the robot control cabinet. In the 'Monitor'-page the message "Calibration failed" will appear and the joint angle of the robot which could not be calibrated will be displayed. Take the teach pendant, change to the joint mode and try to adjust the incorrect joint angle. If this does not work, you must move the joint angle of the robot manually (first release the brake on the back side of the robot).

If you are using the RX60L robot and the calibration is lost you have to recalibrate the robot, restart the controller (key switch to manual) and perform the instructions in the monitor window.

ATTENTION! Before making manipulations manually within the workspace of the robot, be sure to turn off the arm power for safety reasons.

3.4.3 *Elementary Robot Commands*

Upper case letters are the robot controller instructions. Lower case letters are variable parameters.

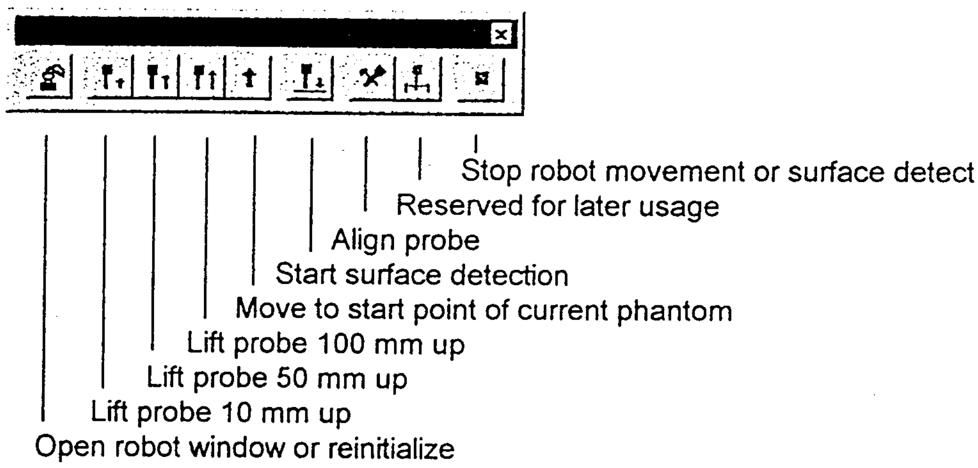
SPEED v
The speed (v) of the robot can be set as a percentage of the maximum speed (100) with an integer value between zero and 100. For safety reasons the speed is restricted to 20.

EX DA3.WHERE
Shows the current location of the tool (global Cartesian coordinates plus tool orientation angles). The command WHERE can be used, but the coordinates will not be relative to the phantom.

STAT
Returns the current robot status (speed information, current robot mode, program tasks, etc...).

DO DEPARTS
Moves the probe the distance (in mm) up.

Robot commands can also be directly performed from the menu, and or toolbar:



Align probe aligns the probe to the nearest world axis (x,y or z) and should be done before the phantom is installed.

Surface detection can be performed, if the probe, phantom and Data Acquisition Electronics support have the capabilities to detect the surface.

If all buttons are grayed the initialization was not successful. Press the robot button one more time.

3.4.4 Touch System

In case the probe touches the surface of the shell phantom, a so called "touch" is activated, which should avoid damage to the probe. The probes are very sensitive to mechanical stress and shocks. In a touch situation the robot will immediately stop any further movements and turn off power to the arm. If the probe slightly touches a surface robot power will go off. If the probe touches hard the FAULT light turns on (located on the front side of the robot control panel).

If the FAULT light appears on the robot, the emergency stop feature must first be reset. The "Release Touch" command in 'Setup State', 'Robot'-page releases the "touch state" and deactivates the emergency stop.

Attention!
If the emergency stop is activated while the robot is moving, do not just repower the arm after resetting the emergency stop. When the power is turned on in this special case the robot arm usually makes an unpredictable movement that could badly damage the probe. Therefore, ***REMOVE THE PROBE*** *from the robot arm, if possible.*

3.4.5 *Proximity Sensor Values*

The proximity sensor provides information on how close the field probe has approached the surface of the body. The information is provided using a cylindrical bundle of optical fibers integrated into the field probe. One half (semi-circle) of the fibers in the cross-section of this bundle transmits light, which when reflected on a surface can be collected by the fibers in the other half. Due to the parallax effect caused by the geometrical separation of the transmitting and receiving fibers; the intensity of the reflected light always reaches a maximum when the tip of the fibers is at a given distance from the reflecting surface, largely independent of the angle of approach and the nature of the reflecting surface.

The intensity of the reflected light is displayed as AD-values (16 bit). The proximity sensor begins sensing an approaching surface at a distance of about 10mm. As the sensor comes closer to the surface the reflected light reaches a maximum at a distance of 2mm from the surface. However, the distance at which the maximum can be detected depends on the angle of approach.

There are two checks to be sure that the proximity sensor is working properly.

1. Detect the surface on a white paper. Select the proximity profile in the multimeter, if the AD-values are around 40000, the proximity sensor is correctly setup.

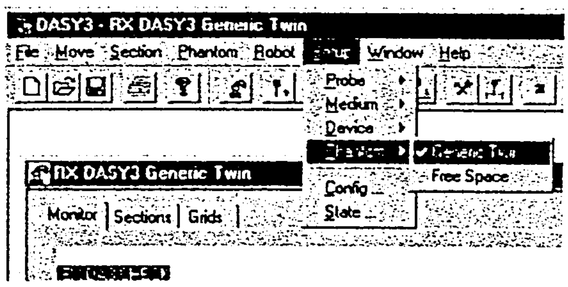
2. Detect the surface of the liquid. If the probes stops just above the liquid surface, the proximity sensor is properly cleaned.

Note:
Always clean the sensor (at the tip of the field probe) after removing it from the tissue simulating solution.

3.4.6 Installing the Generic Twin Phantom

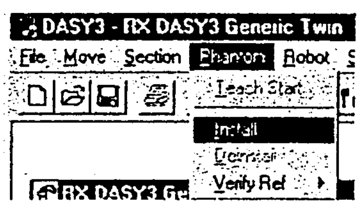
To set up the 'Generic Twin' Phantom perform the following steps:

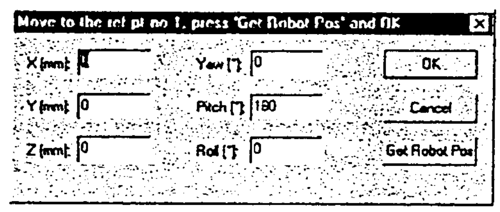
1. Select the 'Generic Twin' Phantom from the menu.



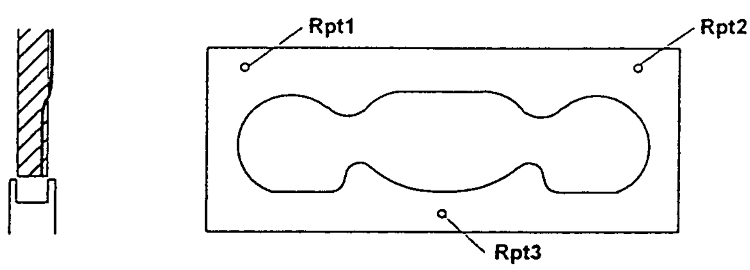
2. Press the Align button on the toolbar to align the probe on the z-axis.

3. Select 'Phantom Install' from the menu, and the following dialog will appear:

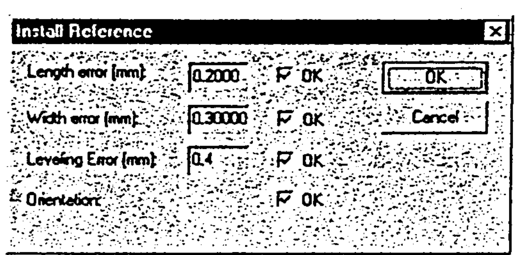




4. The probe has to be moved using the teach pendant to the first reference point. Position the probe just above the marker (see picture below left). Press the button 'Get Robot Pos' in the dialog to read in the current robot position. Then press OK. The orientation (roll) of the probe does not matter for installing the phantom.

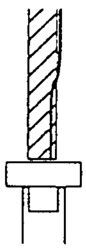


5. The same procedure must be repeated for reference points 2 and 3. When this has been done a dialog will appear which indicates if the installation is now within the tolerances set out in the 'Factory Settings' for the phantom.



3.4.7 Verifying a Phantom with a Reference System

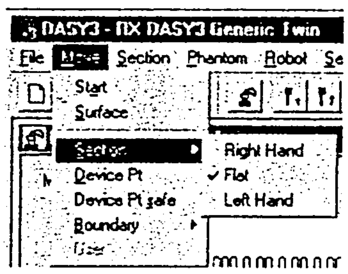
A check of the positioning of the phantom must be performed after you have changed the probe or the phantom has been shifted slightly. If the phantom is not active, select it from the 'Setup Phantom' menu.



If you select 'Phantom Verify Ref Pt1' the probe will move to a position 1 cm above the marker. If the horizontal position is correct place the space between the probe and the marker to see if the vertical position is also correct. Repeat this procedure with Reference Pt2 and Reference Pt3. If the probe is not placed properly with respect to the marker uninstall the phantom ('Phantom Uninstall') and reinstall it (see Installing the Generic Twin Phantom, 52).

3.4.8 Additional Phantom Commands

Only a single phantom can be active at a time, during which the sections and grids of the phantom can be seen beside the 'Monitor'-page in the robot/phantom – window. If you need to change to another phantom, change to the other phantom under 'Setup Phantom' and move to the starting point of the new phantom.



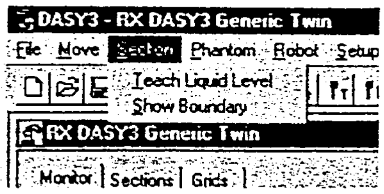
'Move Start'
Moves the probe to the free height (see Robot, page 38) and then to the starting point. Use this starting point to disable the power of the robot and to clean the probe whenever changing to another probe.

'Move Section ...'
Moves the probe over the free height to the section. If a boundary has been defined or if the liquid level has been teached, the probe moves to the device point at the height of the boundary or 1 cm below the liquid level.

'Move Device Pt'
Moves the probe to the device point. Should you have changed probes, first check with a 'Move Device Pt safe', followed by a 'Move Surface' if the stored device point is on the same height.

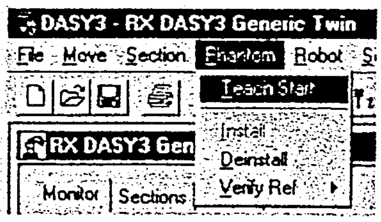
'Moves Device Pt safe'
Same as Move Section, but then the movement does not go over the free height.

'Move Boundary ...,' 'Move User ...'
Moves the probe to the boundary or user point.



'Section Teach Liquid Level'
Teaches the liquid level of a section.

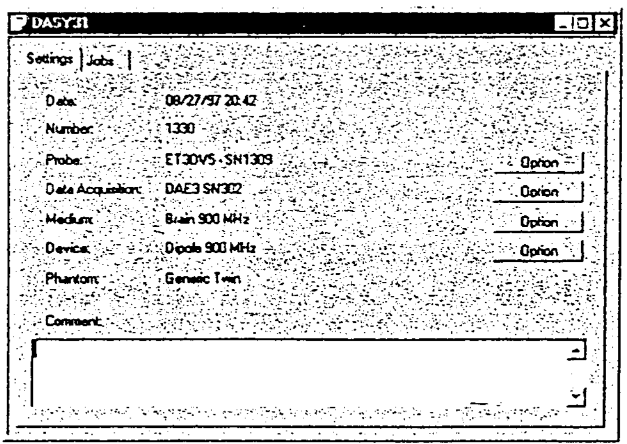
'Show Boundary'
Moves the probe along the boundary.



'Phantom Teach Start'
Teaches the start point of the phantom.

3.5 Field Scans, Documents

Select 'File New' to create a new measurement document. The document has two pages, a 'Settings' – page and a 'Jobs'-page.



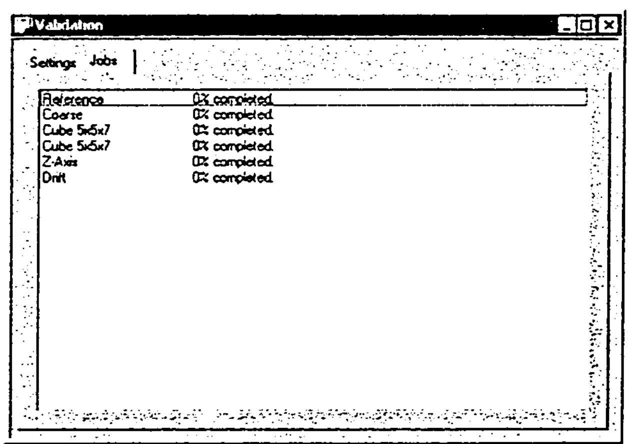
The 'Settings'-page displays the measurement date, measurement number and measurement environment.

Each measurement document is limited to a set of one of each of the following: probe, data acquisition, medium, and phantom. (e.g. for two different frequencies two measurement documents are required).

When a measurement document is opened the configuration of the setup are copied into the document and continually updated until the actual measurement has been performed.

Pressing 'Option' displays the parameters of each resource.

Any written comment can be entered into the 'Comment' field.



The 'Jobs'-page contains a list of the various tasks that have to be performed for a given measurement. The example shows the first task to be a reference measurement above the device point (Reference), search for a maximum (Coarse), and then two cube scans to determine average SAR-values; and finally a z-Axis measurement followed uup by a drift measurement to check the power drift of the device. An explantion of the jobs is given in the next chapter.

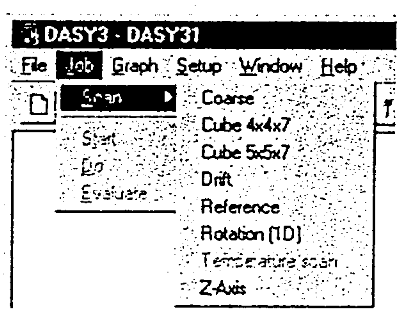
Jobs can be removed with the 'Delete'-Key.

3.5.1 Scans

The position enables automated field scans to be made along lines, across planes or within volumes. The field is measured at discrete points, and the raw data from the probe is stored together with the position information from the robot and all involved calibration parameters.

A field scan can be defined as a free space scan or can be related to a phantom using automatic grid adaptation to the phantom boundary, automatic detection of the phantom surface, etc.

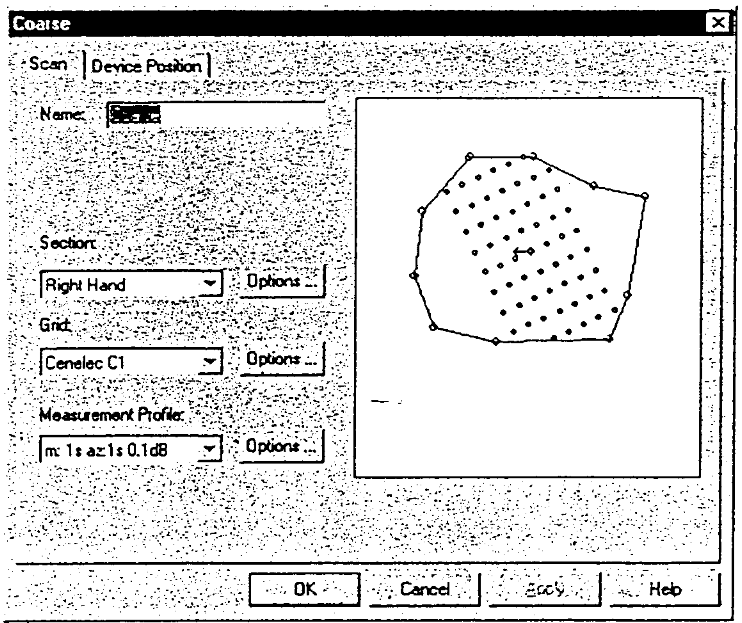
To start scans or jobs select the scans to measure and select 'Job Start'. A dialog will display a statistics of the scan (estimated time, values of last measured point). Pressing the 'stop' – button will stop the current scan, and the percentage of the points measured will be shown. A scan can be resumed if 'Job Start' is pressed again.



New Scans (and Jobs) can be inserted with the 'Job Scan ...' menu. Scans can be inserted depending on the measuring setup (e.g. Temperature scan is not possible with an E-field probe).

3.5.1.1 Coarse Scan

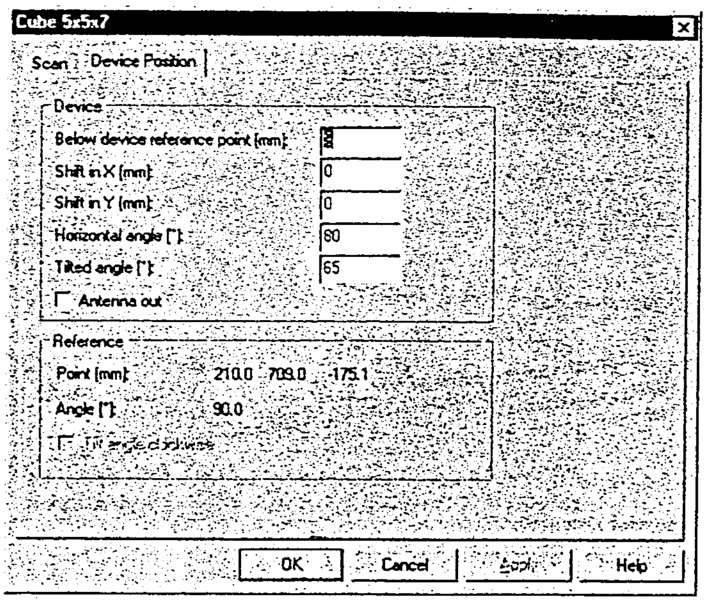
Coarse scans are used for the quick measurement of the field distribution in a wider area and the determination for the interpolated maximum.



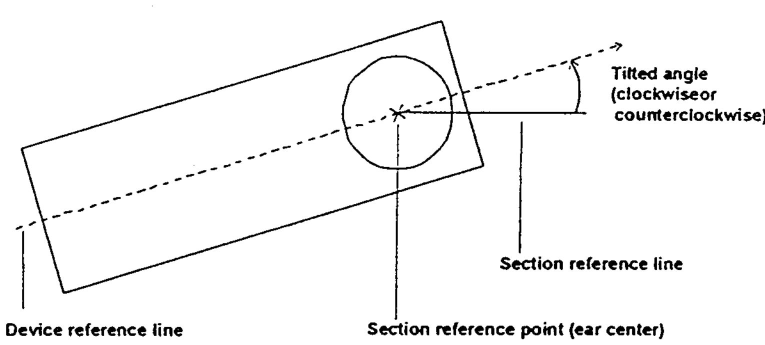
In the 'Scan'-page of the section, the grid to measure and the measurement profile (time and accuracy settings) have to be selected (current section and grid are displayed on the right).

If you press option the parameters of the section, grid and measurement profile can be examined at and changed (see Phantom, page 33 and Measurement Profiles, page 31). To define new grids for coarse scan measurements change to the phantom setup.

If a device with graphics has been defined the parameters for the device position can be defined:



Grid coordinate angle and offset with respect to the reference point and direction are defined in the grid menu (e.g. if you want to have the grid the same alignment as the device, the tilted angle of the device position should correspond to the grid rotation).

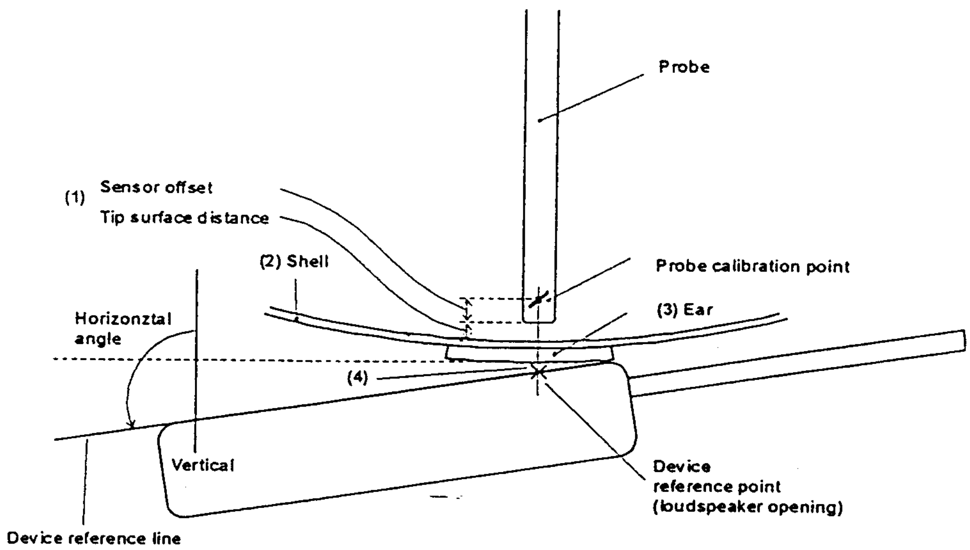


The reference point of the section determines the location of the device in the graphics. Device angles can be changed for each scan.

Example positions:

Position	horizontal angle	tilted angle
intended use	80°	65° (C1)
touching position	until touching head (<80°)	65° (C1)
100° position	100°	65° (C1)
30° tilted position	90°	35° (C2)

The device will be shown below the reference point of the section. The distance can be calculated approximately as follows:



Probe dipole point to surface of phantom (1):	ca 4 mm
(Depends on how the device point was teached)	
Thickness of phantom shell (2):	2 mm
Thickness of ear (3):	2 mm
Distance of device ear point to phantom (4):	0 mm
(Depending on position of device)	
Total	8 mm

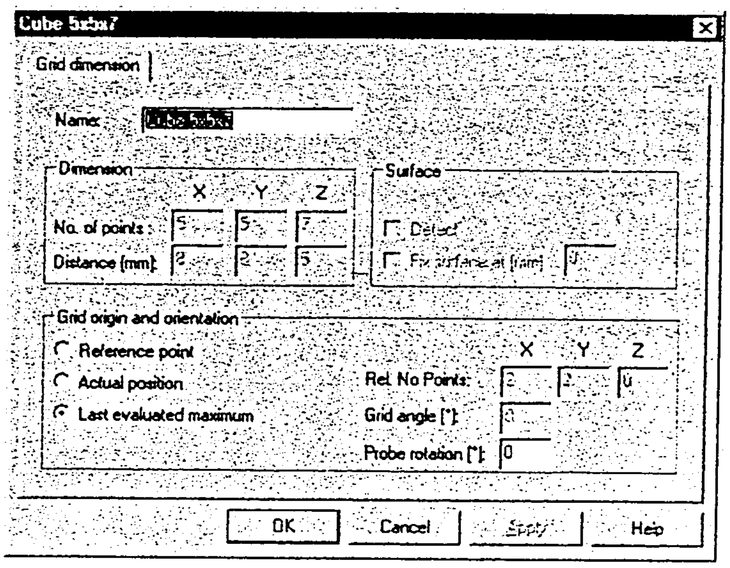
If the device should be shifted, change the device reference point (e.g. if a free space grid should be centered at the antenna feed point, use the antenna feed point as device reference point and shift the ear center position to the antenna feed point).

If only small shifts are needed you can add a shift in x-direction and y-direction (***Note:*** *coordinate system is that of the phantom for these distances*).

3.5.1.2 Cube Scan (4x4x7, 5x5x7)

Cube Scans are used to determine the averaged SAR-distribution for 1g and 10g. These two scans (Cube 5x5x7 whole frequency range, Cube 4x4x7 frequency smaller than one 1 GHz) can only be used when an E-field probe is selected and the medium is a tissue simulating liquid.

If you press 'Options' on the grid page, the following dialog is displayed:

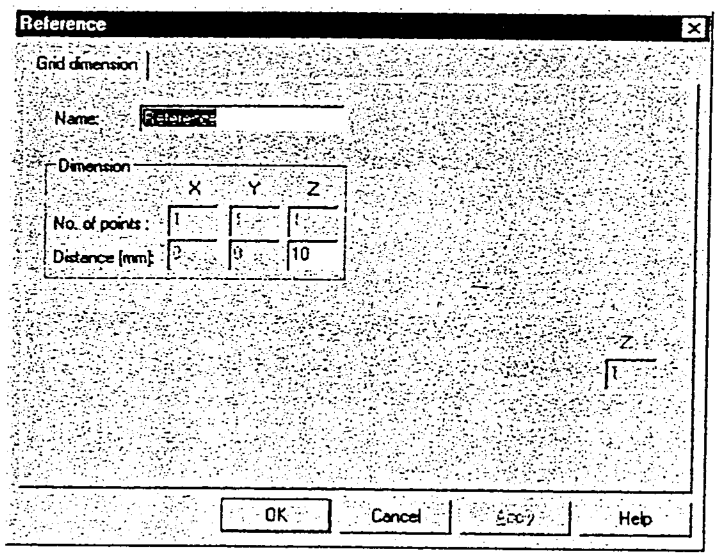


If 'Last evaluated maximum' is checked, the cube will be centered at the last evaluated maximum in a previous scan and the surface detection parameters will be adjusted accordingly. An additional probe rotation can be added (e.g. see System Validation, page 72).

If a cube has to be measured at the current position or reference point the grid angle and surface detection have to be adjusted.

3.5.1.3 Reference and Drift scan

DASY3 supports the measurement of the power drift of the device over different scans. To measure the power drift, the reference scan has to be first selected. If you press options on the grid page, the following dialog is displayed:

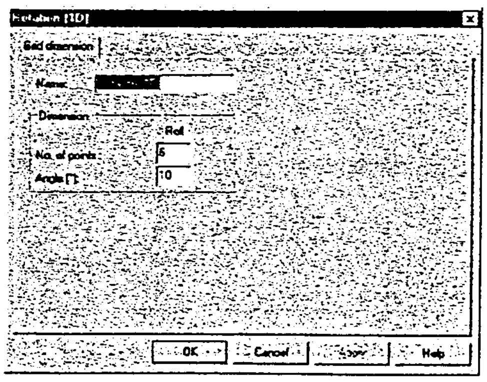


The power reference measurement will move the probe the z-distance (e.g. 10 mm) above the reference point of the section. Therefore it is important that the reference point has been chosen at the proper height.

To measure the power drift add the drift scan after the end of the measurement scan. A reference scan has to be inserted previously. The probe will move to the same location of the reference scan and then the difference in dB of the previous and the current values will be calculated.

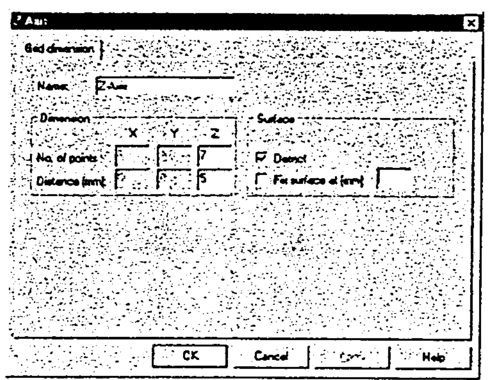
Reference	8.24 V/m
Coarse	Max at 46.0, 52.0, 3.9
Cube 4x4x7	SAR (1g): 0.380 [mW/g], SAR (10g): 0.225 [mW/g]
Drift	0.29 dB
Cube 5x5x7	SAR (1g): 0.389 [mW/g], SAR (10g): 0.226 [mW/g]
Drift	0.27 dB
Reference	8.50 V/m
Drift	-0.01 dB

3.5.1.4 Rotation (1D)



To check the isotropy of the probe move the probe 1 cm above the section reference point and perform a rotation scan. Specify the number of points and the angle between the points (e.g. No. of points 36, Angle 10°). The probe will be rotated about the z-axis and then the deviation will be calculated.

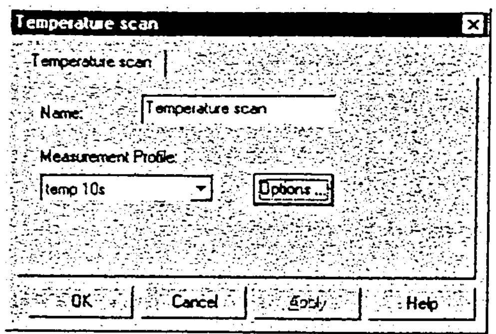
3.5.1.5 Z-Axis



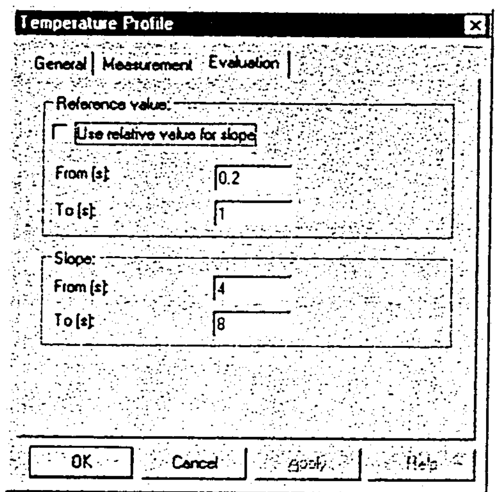
To measure the field distribution along the z-axis at the current location insert a z-axis scan. Specify the number of points and the distance between the points. If no surface detect has been selected the scan will start at the current location.

Note:
If 'fix surface' is selected and a phantom with reference points is used, use the command 'EX DA3.WHERE' in the robot monitor window to read the z-height.

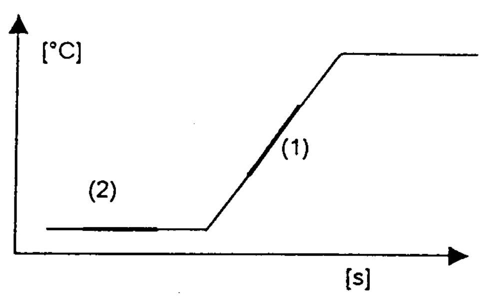
3.5.1.6 Temperature Scan



To measure temperature rise at the current location insert a temperature scan. It is important that a temperature profile is selected for the measurement profile.



A temperature profile is defined in an additional page. Specify the time interval where the calculation of the temperature rise (1) should be performed, and if a relative time interval (2) should be deducted from this amount.



3.5.1.7 Evaluation

After each scan has been performed, the evaluation begins, and the result of the evaluation is displayed at the right sight of the list box.

Reference	8.24 V/m
Coarse	Max at 46.0, 52.0, 3.9
Cube 4x4x7	SAR (1g): 0.380 (mW/g), SAR (10g): 0.225 (mW/g)
Drift	0.29 dB
Cube 5x5x7	SAR (1g): 0.389 (mW/g), SAR (10g): 0.226 (mW/g)
Drift	0.27 dB
Reference	8.50 V/m
Drift	-0.01 dB

Coarse Scan

Displays the interpolated maximum (in grid coordinates). With 'Job Do Move Interpolated Max' the robot moves the probe to the interpolated peak of the measurement (only in x,y direction, z is on liquid or boundary height for safety reasons). With 'Job Do Move Max' the probe is moved to the peak value measured.

Cube

Displays the averaged volumes for 1g and 10g, a warning will appear if the interpolated volume is touches the scan area. See Cube Evaluation, page 76 for a detailed explanation of the algorithm.

Reference, Drift

Displays the drift from the last reference value in dB.

Temperature scan

Displays temperature rise in mK/s.

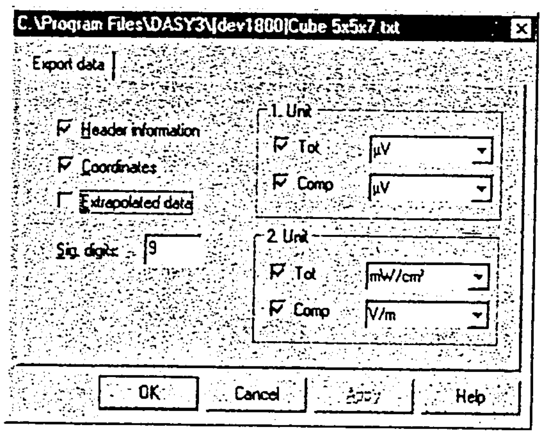
3.5.1.8 Modifying Measurement Parameters

If the measurement is performed with wrong measurement parameters (e.g. different medium parameters) the parameters can be changed. Select 'File Modify' and change the parameters in the 'Settings'-page (these changes are only done in the document, if these changes are needed for the next measurement change the parameters in the 'Setup'-dialog too.).

Note:
The evaluation will not automatically be repeated. If some parameters have been changed, select all measured scans in the 'Job'-page and repeat the evaluation with 'Job Evaluate'.

3.5.1.9 Export of scan data

From a measured scan it is possible to export the data to a text file. Select the scan to be exported and select 'File Save Scan As' from the menu. A dialog will appear where a filename must be specified. A dialog appears up, asking which data you want to have exported:

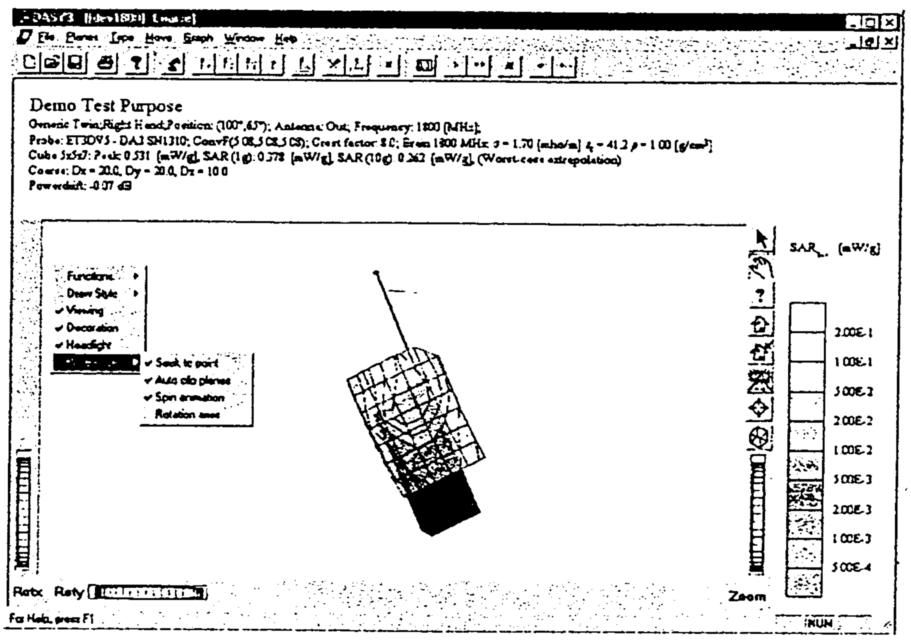


The text file consists of a measured point on every line. The fields are spearted by tabs. If 'Coordinates' is selected the coordinates of the grid points are included, and afterwards the first and the second unit will be added with the selected components.

If 'Extrapolated data' is selected the unit windows disappear because only mW/g can be exported.

3.6 Graphics

The measured and evaluated scans can be visualized graphically by selecting a graphics format from the menu 'Graph'. All predefined graphic formats (see Graphic Formats, page 39) are listed in the 'Graph' menu. The first selected scan is visualized and the other selected scans are used for title information (e.g. SAR evaluation results).



3.6.1 Viewer Buttons

If the viewer window is too small, not all of these buttons will be visible.

 Select/Pick Button
Selects object manipulation or pick mode (and deselects camera or viewer mode). The cursor shape will change to an arrow.
Note: *Not reserved for DASY3.*

 View Button
Selects camera or viewer mode (and deselects object manipulation or pick mode). The cursor shape will change to a hand icon. In this mode, the user is moving the camera in 3D space.

 Help
This menu provides help about the application
Note: *reserved for future versions.*

Home Button
Returns the camera to its home position (initial position if not reset).

Set Home Button
Resets the home position to the current camera position.

View All Button
Brings the entire scene graph into view.

Seek Button
Allows the user to select a new center of rotation for the camera. When clicked on (and in viewer mode) the cursor changes to a crosshair. The next left mouse button press causes whatever is underneath the cursor to be selected as the new center of rotation. Once the button is released, the camera either jumps or animates to its new position.

Projection Button
Selects the type of camera used by the viewer. It toggles between the two available camera types perspective and orthographic. Only displayed for Examiner and Plane viewers.

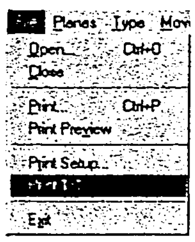
3.6.2 Mouse Usage and Predefined Keys

Left Mouse:	Rotate the virtual trackball.
Ctrl + Left Mouse:	Used for roll action (rotates around the viewer forward direction).
Shift + Left Mouse:	Translate up, down, left and right.
Ctrl + Shift + Left Mouse:	Dolly in and out (gets closer to and further away from the object).
Right Mouse:	Open the popup menu.
Home:	Sets camera to Home position
's':	Activate Seek mode. Press (but do not hold down) the 's' key, then click on a target object.

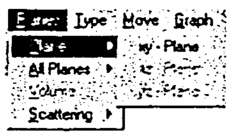
3.6.3 Popup Menu

The viewer can be removed by pressing the right mouse button and removing the 'Decoration' check. The axes of the coordinate system can be shown with 'Preferences Rotation axes'.

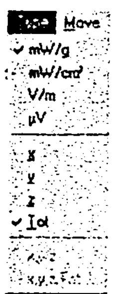
3.6.4 Menu



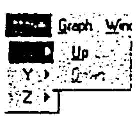
If 'Print 1/1' is checked, the contour plot will be printed with the same dimension as the measurement scan was. This can be useful for printouts of a flat measurement area (e.g. free space measurement of a mobile phone).



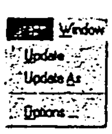
Different types of visualization can be chosen: one contour plane in xy-, xz-, or yz-directions; all planes; a volume; or scattering diagrams (f(z), f(x,z)).



The measured data can be displayed either by components or as the resulting value. Select the unit in which the values should be displayed.



If different planes are possible and only one plane is selected, you can move this plane around the different levels. The same applies to scatter graphics. To insert the number or position into the plane, enter the variable {Graph pos} into the title.



The parameters of the current graphics format can be modified by selecting 'Graph Options'. The modifications will be valid only for this graph, except when 'Graph Update' is selected to update the format permanently. When 'Graph Update As' is selected, a new graphic format with this modifications can be created.

4. EXAMPLE PROCEDURES

In the following chapters three example procedures are explained:

- SAR – Measurement
- H-Field Scan
- System Validation

4.1 SAR – Measurement

1. Stir liquid until it shows no effects of inhomogeneity.
2. Measure dielectric parameters. If the parameters are outside of tolerances adjust or change the liquid.
3. Mount probe on electronics box. Make sure that the connector catches properly and the probe is mounted straight.
4. Mount electronics box on robot arm. Turn electronics box on (allow 15 min. warm up for sensitive measurements).
5. Select mounted probe from menu 'Setup Probe' .
6. Open robot-window in DASY3, select 'Generic Twin' from the 'Setup Phantom' menu and move to the Point ('Move Start').
7. Check for interference while the arm power is on: Open multimeter window. Select profile 'm4s az4s' in the 'Option' page of the multimeter. If the measured voltage is out of the acceptable range (± 2.5 μV) check grounding system (see Grounding Problems, page 79).
8. Check phantom position via reference points. If the phantom has been moved or if the difference in the x-,y- or z – direction is grater than 2 mm, reinstall the Phantom (Installing the Generic Twin Phantom, page 52).
9. Stir liquid if necessary. The liquid should be homogeneous. If the liquid shows effects of inhomogeneity, remeasure the liquid and or replace the liquid.
10. Check surface detector using the 'Move surface'. The probe should stop ca 1 mm above the surface. (If not, move probe up and clean the probe tip, repeat surface detect).
11. Move probe into selected phantom section.
12. Check for interference in liquid (analogue point 5).
13. Set up device.
14. The following files exist as predefined templates in the directory:

FCC left.da3	Intended use position, left hand
FCC right.da3	Intended use position, right hand
CEN intended left.da3	Intended use position, left hand
CEN intended right.da3	Intended use position, right hand
CEN touch left.da3	Touching position, left hand
CEN touch right.da3	Touching position, right hand
CEN 100° left.da3	100° position, left hand
CEN 100° right.da3	100° position, right hand
CEN 30° tilted left.da3	30°-tilted position, left hand
CEN 30° tilted right.da3	30°-tilted position, right hand

Open the file, save it under a different file name and start the measurement.

4.2 H-Field Scan

1. Mount probe on electronics box. Make sure that the connector catches properly and the probe is mounted straight.
2. Mount electronics box on robot arm. Turn electronics box on (allow 15 min. warm up for sensitive measurements).
3. Select mounted probe from 'Setup Probe' - menu.
4. Open the robot-window in DASY3, select 'Free Space' from the 'Setup Phantom' menu and move to the Point ('Move Start').
5. Check for interference while arm power is on: Open multimeter window. Select profile 'm4s az4s' in the 'Option' page of the multimeter. If the measured voltage is out of the acceptable range (± 2.5 μV) check grounding system (see Grounding Problems, page 79).
6. Reteach the section reference point and angle to the antenna feedpoint of the device.
7. Create the device with ear angle radius set to zero and the position of the ear set to the antenna feedpoint.
8. Open a new file and measure a coarse scan with no surface detection.

4.3 System Validation

1. Perform steps 1-12 described in SAR – Measurement, page 70.
2. Set up validation dipole at flat section of generic twin phantom using the distance holder.
3. Apply input power to dipole (10mW - 10W). The input power to the dipole should be measured at the dipole input with a 50Ω measuring device to an accuracy of 0.1 dB or better.
4. Select dipole from 'Setup Device' (e.g. 'Setup Device Dipole 900 MHz').
5. In the directory predefined the following files exists as templates:

Validation 900MHz.DA3	Validation with Dipole 900 MHz
Validation 1800MHz.DA3	Validation with Dipole 1800 MHz

   Open the file, save it under a different file name and start the measurement.

6. Use the 'Validation' – graphics format for the graphics. Since there are two cubes (probe is 90° rotated to the other), the average and the deviation of the evaluated values are displayed.

4.3.1 Additional System and Probe Checks

7. Move probe to interpolated maximum and perform z-axis measurement (using surface detection, ca 30 points @ 2mm spacing). Compare the measured decay in the liquid with the expected decay (see AN about SAR-sensitivities); check for standing waves and layering within the liquid. However, the extrapolated data will not be comparable with the extrapolated data for the cube measurement).
8. Move probe to interpolated maximum, move to surface and retire the probe ca 5mm ("do departs 5"). Perform a probe rotation scan. (Check first that the cables to the electronics box allow for rotational movement. Watch probe movements and abort operation if cables are stressed). Check the result for isotropy within specifications.
9. Perform SAR-measurements, Z-scan or probe rotation with different input power levels (<100mW and >10W). Normalize both results to 1W and compare (linearity). Check for correct compression point setting if results differ.

5. TECHNICAL INFO

The following chapters are appended to the User manual to add a deeper understanding of how DASY3 works, and what steps are necessary to guarantee exact measurements.

- Data Evaluation
- Cube Evaluation
- Software Verification
- Grounding Problems
- Tissue Simulating Liquid

5.1 Data Evaluation

The first step of the evaluation is a linearization of the filtered input signal to account for the compression characteristics of the detector diode. This compensation depends on the input signal, the diode type and the DC-transmission factor from the diode to the evaluation electronics. If the exciting field is pulsed, the crest factor of the signal must be known to correctly compensate for the peak power. The formula for each channel can be given as:

$$V_i = U_i + U_i^2 \cdot \frac{cf}{dcp_i}$$

with V_i = compensated signal of channel i (i = x,y,z)
$U_i[\mu V]$ = input signal of channel i (i = x,y,z)
cf = crest factor of exciting field (DASY parameter)
dcp_i = diode compression point in mV (DASY parameter)

From the compensated input signals the primary field data for each channel can be evaluated as follows, depending on the probe type:

$$E_i = \sqrt{\frac{V_i}{Norm_i \cdot ConvF}} \qquad H_i = \sqrt{Vi} \cdot \frac{a_{i0} + a_{i1} f + a_{i2} f^2}{f}$$

with V_i = compensated signal of channel i (i = x,y,z)
$Norm_i$ = sensor sensitivity of channel i (i = x,y,z) $\mu V/(V/m)^2$ for E-field Probes
a_{ij} = sensor sensitivity at 1 GHz for H-field probes
ConvF = sensitivity enhancement in solution
f = carrier frequency [GHz]
E_i = electric field strength of channel i in V/m
H_i = magnetic field strength of channel i in A/m

The total field strength (Hermitic magnitude) can be calculated by taking the RSS value of the field components.

$$E_{tot} = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

The primary field data are used to calculate the derived field units.

$$SAR = E_{tot}^2 \cdot \frac{\sigma}{\rho \cdot 1000}$$

with SAR = local specific absorption rate in mW/g

E_{tot}	= total field strength in V/m
σ	= solution conductivity in Siemens (mho)
ρ	= solution density in g/cm^3

Note that the density is normally set to 1 (or 1.06), to account for the actual brain density. (Parameter simulating tissue density).

The power flow density is calculated assuming the exciting field to be a free space field.

$$P_{pwe} = \frac{E_{tot}^{2}}{3770}$$

with P_{pwe} = equivalent power density of a plane wave in mW/cm^2
E_{tot} = total field strength in V/m

5.2 Cube Evaluation

The spatial peak SAR - value for 1 and 10 g is evaluated after the Cube - measurements have been done. If you change any parameter afterwards with 'File Modify' (for example crest factor or medium factors) you will have to reevaluate the measurements. This evaluation can be repeated, if your press Job Evaluation on the selected scans. The algorithm that finds the maximal averaged volume is divided into three different stages.

(1) The data between the dipole center of the probe and the surface of the phantom is extrapolated. This data cannot be measured, since the center of the dipoles is 2.7 mm away form the tip of the probe and the distance between the surface and the lowest measuring point is ca 1 mm (see probe calibration sheet). You can visualize the extrapolated data from a cube measurement if you select Graph Evaluated.

(2) The maximal interpolated value is searched with a straight-forward algorithm. Around this maximum the SAR - values averaged over the spatial volumes (1g or 10 g) are computed using the 3d-spline interpolation algorithm. If the volume cannot be evaluated (i.e., if a part of the grid was cut off by the boundary of the measurement area) the evaluation will be started on the corners of the bottom plane of the cube.

(3) All neighboring volumes are evaluated until no neighboring volume with a higher average value is found.

Extrapolation
The extrapolation is based on a least square algorithm [W. Gander, Computermathematik, p.168-180]. Through the points in all z-axis polynomials of order four are calculated. This polynomial is then used to evaluate the points between the surface and the probe tip. The points, calculated from the surface, have a distance of 1 mm from one another.

Interpolation
The interpolation of the points is done with a 3d-Spline. The 3d-Spline is composed of three one-dimensional splines with the "Not a knot"-condition [W. Gander, Computermathematik, p.141-150] (x, y and z -direction) [Numerical Recipes in C, Second Edition, p.123ff].

Volume Averaging
Firstly the size of the cube is calculated. The volume is integrated with the trapezoidal - algorithm. 1000 points (10x10x10) are interpolated to calculate the average.

Advanced Extrapolation
The BIOEMC group of the ETH Zurich is currently investigating the boundary effects on E-field probes. As soon as the research is finished DASY3 will allow to compensate for these boundary effects. But until then we do not encourage to use the 'Advanced Extrapolation' – option.

5.3 Software Verification

The Software DASY3 V3 has been written specifically for the measurement of SAR in liquid filled shell phantoms and has been thoroughly tested. During SAR measurements, the software performs the following tasks:

- Generates a measurement grid and sends the grid positions to the robot controller. The robot will perform a slow downward movement at each grid position.
- Filters and evaluates the signal from the surface detector to stop the surface approach within a defined distance from the surface.
- Reads the data from the data acquisition electronics (DAE2 or DAE3) and evaluates the field strength using the software parameters from the probe, liquid and device.
- During a fine cube measurement (for integrated SAR-values), moves the probe backward from the surface in several steps and measures the field values are.
- Extrapolates the measured fine cube values to the surface. A numerical process then searches within the measured and extrapolated cube for the 1g and 10g volume which yields the highest averaged SAR values. Integrated SAR values are calculated in mW/g using the parameter for tissue density.

All of these procedures influence the final integrated SAR value and are specifically adapted and tested for the specified task. To make the whole measurement process transparent and accessible for validation, the data are stored in the measurement file (.DA3 extension) in the following format:

- The assessed data from the data acquisition electronics are stored as raw data (as microvolt readings from the probe sensors), together with all the necessary software parameters for the data evaluation (probe calibration data, liquid parameters and device frequency and modulation data). The evaluation is done at the moment of data visualization or export of the evaluated data to other file formats. The measurement file can be used to check (or change in case of erroneous values) the correct parameter settings and repeat the evaluation. Raw data can also be exported to perform the evaluation with other software packages.
- The surface positions stored in the measurement file are the actual robot positions read from the robot controller as well as the measurement grid positions sent to the robot. Visualization is based on actual robot positions. Any failure in the software to calculate or transmit the correct positions would be visible in the graphics and traceable in the exported data.

The standard system validation procedure uses a calibrated dipole at a specified distance (with spacer) and position from the phantom. The dipole must be fed with a known input (forward) power, and normal SAR measurements must be performed. The results (integrated SAR values, SAR distribution, decay within liquid) are compared with calibration data delivered with the dipole or with any older measurements under equal conditions. This validation checks the complete system, including software. Any malfunction in the robot positioning system, the surface detection system, the probes or the data acquisition would be detected, as well as incorrect liquid parameters or incorrect parameter settings in the software.

5.4 Grounding Problems

5.4.1 Introduction

The DASY3 measurement system includes field probes with high source impedance and a very sensitive data acquisition unit. Since the interaction of the probe with the measured field should be as small as possible, conventional shielding of the probe is not practical. Small signals from the detector diodes in the probe are transmitted through highly resistive lines inside the probe body to the data acquisition electronics (DAE). These lines are completely exposed to any electric and magnetic fields produced in the laboratory. Several measures in the system try to reduce the effects of any signals picked up by these lines:

- High line resistiveness
- Highly symmetric construction of the probe
- Highly resistive antistatic shielding in the probe to prevent the effects of static charges produced by moving the probe
- Differential input amplifiers in the DAE, with high common mode ranges and very high common mode rejection ratios
- Resistive filters between the line and the detector diodes
- RF filters at the input of the DAE
- Floating ground of the DAE (battery operation and optical links to the data evaluation unit)
- Numerical data filtering in the data evaluation unit

Despite all these measures, a bad measurement setup can produce undesired output and decrease the sensitivity of the system. The smallest signals detectable by the DAE are around 1μV, with source impedance of around 10MΩ. To profit from this high sensitivity, a careful measurement setup is crucial.

5.4.2 Measurement of the System Noise and Offset

The multimeter in the DASY3 software lets you access the DAE. You can directly measure the input signals of the three channels in microvolts.

The statistics beside the channel signal values provide maximum values, minimum values and standard deviations. The standard deviation is taken from the filtered signals; with no filtering, the standard deviation is a direct measure of the input noise.

The filter is a notch filter on the power line frequency and all its harmonics. (The power line frequency can be set in the options of the PC-Board).

To check the setup, measure the offset voltage of the input channels in microvolts when everything is in place but the signal source is switched off. In ideal situations the offset in each channel should be within ± 1 μV; under realistic measuring conditions offset values within ± 3 μV should be reached. If this value is exceeded, it is most likely due to interference from high field strengths in the probe area. These fields can often be considerably reduced by proper grounding of the systems components. The disturbing fields can have many sources, which can be different in each laboratory.

- Static charges in the setup
- ELF-fields from power lines
- other RF-fields

It is therefore not possible to indicate a general method for grounding. The best strategy must be determined at each site. In the following sections we indicate some measures which might prove helpful in the above mentioned situations. A grounding point is provided in the system (2mm connector in the front of the data acquisition electronic box).

If you encounter a constant offset independent of the probe position, you can compensate for it via the software in the multimeter-offset page.

5.4.3 Strategies to Reduce System Noise (Offset)

Laboratory
If the offset is too high (> ± 3 μV) and the probe is freestanding, check the laboratory for disturbing field sources (ELF or RF).

Static charges
People are excellent vehicles for static charges. Do not move around within about 50cm of the measurement site when you want to do very sensitive measurements. Never touch the phantom during a measurement, even from the outside - the charge you carry around will likely produce an AD-overflow and abort the measurement. If you have to touch the phantom during a measurement, you must ground the phantom and yourself beforehand. (Use resistive cable or antistatic arm wrists to ground yourself.)

Measurements without phantom

When the measured device is floating (no ground connection, e.g., mobile phones), there is generally no further problem. If you use grounded radiating systems, the different grounding systems normally used for robot and exposure systems can produce high signals between the probe and measured device due to ground loops.

If the measured field is confined within an exposure system (e.g., measurements in small TEM-cells or in Waveguides), the DAE can be directly connected to the outside metallic structures of the exposure system.

In open field situations such a direct connection might influence the field to be measured. If the offset is still too high, connect the exposure equipment to a power line outlet (electrically) near the power connection.

Measurements in phantoms

Regarding ground loop problems, everything said in the last section applies here as well. Additionally, there might be some problems with static charges when moving the probe around in liquid. In that case you should connect the liquid to a grounding point. If this is not sufficient, the DAE can be connected with a resistive line to a grounding point as well.

5.5 Tissue Simulating Liquid

5.5.1 Recipes

Recipe I:

Water	40.1%
Sugar	58.0%
Salt (NaCl)	0.8%
HEC (Hydroxyethylcellulosis)	1.0%
Preservative Substance	

900 MHz: $\varepsilon_r = 42.5 \pm 5\%$ and $\sigma = 0.85 \pm 10\%$ mho/m[1]
450 MHz: $\varepsilon_r = 47.2 \pm 5\%$ and $\sigma = 0.45 \pm 10\%$ mho/m
[1]*simulates tissue according to the data provided by C. Gabriel at 900 MHz.*

Recipe II:

Water	40.4%
Sugar	56.0%
Salt (NaCl)	2.5%
HEC (Hydroxyethylcellulosis)	1.0%
Preservative Substance	

900 MHz: $\varepsilon_r = 41.2 \pm 5\%$ and $\sigma = 1.2 \pm 10\%$ mho/m[2]
[2]*simulates tissue according to the data provided by Pethig at 900 MHz (Hartsgrove et al. BEMS 8:29-36, 1987).*

Recipe III:

Water	45.0%
Sugar	53.9%
HEC (Hydroxyethylcellulosis)	1.0%
Preservative Substance	

1800 MHz: $\varepsilon_r = 41.0 \pm 5\%$ and $\sigma = 1.65 \pm 10\%$ mho/m[3]
[3]*simulates gray brain tissue according to the data provided byC.Gabriel at 1800 MHz.*

Recipe IV:

Water	53.8%
Buthyldiglycol[5]	46.1%
Salt (NaCl)	0.1%
Preservative Substance not necessary	

1800 MHz: $\varepsilon_r = 40.3 \pm 5\%$ and $\sigma = 1.23 \pm 10\%$ mho/m[4]
[4]*simulates the mean value of gray and with brain tissue according to the data provided by C. Gabriel at 1800 MHz.*
[5]*Dietylenglycol-mono-buthyl-ether (Buthyldiglycol) is an organic solution and only very sligthly toxic. Caution: it dissolves aliphatic and aromatic Epoxy resins.*

5.5.2 *Testing Brain Simulating Liquid*

1. Turn NWA on and allow at least 30 min. warm up.
2. Mount dielectric probe kit so that interconnecting cable to NWA will not be moved during measurements or calibration.
3. Pour de-ionized water and measure water temperature (±1°).
4. Set water temperature in HP-Software (Calibration Setup).
5. Perform calibration.
6. Validate calibration with dielectric material of known properties (e.g. polished ceramic slab with >8mm thickness ε'=10.0, ε''=0.0). If measured parameters do not fit within tolerance, repeat calibration (±0.2 for ε': ±0.1 for ε'').
   Conductivity can be calculated from ε'' by $\sigma = \omega\, \varepsilon_0\, \varepsilon'' = \varepsilon''\, f\,[GHz] / 18$.
7. Measure liquid shortly after calibration. Repeat calibration every hour.
8. Stir the liquid to be measured. Take a sample (~50ml) with a syringe from the center of the liquid container.
9. Pour the liquid into a small glas flask. Hold the syringe at the bottom of the flask to avoid air bubbles.
10. Put the dielectric probe in the glas flask. Check that there are no air bubbles in front of the opening in the dielectric probe kit.
11. Perform measurements.
12. Adjust medium parameters in DASY3 for the frequencies necessary for the measurements ('Setup Config', select medium (e.g. Brain 900 MHz') and press 'Option'-button.
13. Select the current medium for the frequency of the validation (e.g. Setup Medium Brain 900 MHz).

CENELEC

European Committee for Electrotechnical Standardisation
SECRETARIAT SC 211/B
WGMTE96/4

Safety Considerations for Human Exposure to EMFs from Mobile Telecommunication Equipment (MTE) in the Frequency Range 30 MHz÷6GHz.

THIRD DRAFT

Zurich, 30 April 1996

INDEX

INTRODUCTION

:ar and far field exposure of the human body to electromagnetic fields in the frequency ıge of mobile communications (30 MHz - 6 GHz) results in induced electromagnetic fields the human tissue. The macroscopic interaction with the field increases the random olecular motion in the tissue, i.e., part or the entire induced electromagnetic energy is nverted to heat energy. The depth of penetration is frequency dependent and ranges from veral centimetres to a few millimetres. The biological effects which result from such nperature increases are rather well understood and are commonly referred as thermal ects. They are the basis for the *basic restrictions* in the current standards for the protection the occupational and general population to electromagnetic exposure above 1 MHz. In the lowing the requirements for testing mobile communication equipment (MTE) are defined, :h that compliance with the basic restrictions are achieved. The basic restrictions and erence levels given in this report are consistent with those of the European Prestandard [50166-2 [ENV,1995] approved by CENELEC on 30.11.94.

ıer standards discussed by the working group are the ICNIRP [IRP,1988] recommendation l the ANSI/IEEE standard [ANS/1,1992]. It was concluded by the majority of the working ›up member that compliance with the European Prestandard EN50166-2 provides nprehensive protection from thermal adverse health effects due to exposure from MTE. wever, the requirements defined for testing procedures may also be extended to testing npliance with different basic restrictions, e.g., as those defined in the ANSI/IEEE standard NS/1,1992]. The considerations and conclusions of this report are also consistent with the ently published statement of ICNIRP about the health issues related to the use of handheld iotelephones and base transmitters [ICN,1996].

2. SCOPE

This report deals with the safety considerations of thermal effects for human exposure to electromagnetic fields from MTE in the frequency range of 30 MHz to 6 GHz. It does not consider the effects on implants, such as cardiac pacemakers, nor does it consider the exposure of persons to electric and magnetic fields during medical research, diagnosis or treatment. Additional considerations are also necessary for persons with metalic implants in the area of the brain or ear (i.e., metal plates or clamps).

Although this report assumes a fairly wide interpretation of the word "mobile" (see Appendix A), the material herein concentrates solely on handheld and other portable MTE and the basic requirements for testing the compliance of such devices with the basic safety limits which have been developed.

PHYSICAL QUANTITIES, UNITS AND CONSTANTS

1 Quantities

ıe internationally accepted SI-units are used throughout the standard.

ıantity	Symbol	Unit	Dimensions
ırrent density	J	Ampere per square metre	A/m^2
ːctric field strength	E	Volt per metre	V/m
ːctric flux density	D	Coulomb per square metre	C/m^2
ːctric Conductivity	σ	Siemens per metre	S/m
ːquency	f	Hertz	Hz
ıgnetic field strength	H	Ampere per metre	A/m
ıgnetic flux density	B	Tesla (Vs /m^2)	T
ıss Density	ρ	Kilo per cubic metre	kg/m^3
meability	μ	Henry per metre	H/m
mittivity	ε	Farad per metre	F/m
ver density	S	Watt per square metre	W/m^2
cific absorption rate	SAR	Watt per kilogram	W/kg
velength	λ	Metre	m
ıperature	T	Kelvin	K

Constants

sical constant		Magnitude
ɔcity of light	c	2,997 x 10^8 m/s
ıittivity of free space	ε_0	8,854 x 10^{-12} F/m
ıeability of free space	μ_0	4 π x 10^{-7} H/m
ːdance of free space	Z_0	120 π or 377 Ω

4. TERMS AND DEFINITIONS

4.1 Average (temporal) absorbed power (Pavg). The time-averaged rate of energy transfer defined by:

$$\bar{P}_{avg} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} P(t)dt \qquad (4.1)$$

where t_1 and t_2 are the start and stop time of the exposure. The period $t_2 - t_1$ is the exposure duration time.

4.2 Averaging time (t_{avg}). The appropriate time over which exposure is averaged for purposes of determining compliance with the limits.

4.3 Basic restriction. The basic restriction is the ceiling level that should not be exceeded under any conditions. The basic restriction includes the necessary safety margins.

4.4 Conductivity (σ). The ratio of the conduction-current density in a medium to the electric field strength. Conductivity is expressed in units of Siemens per metre (S/m).

4.5 Continuous exposure. Exposure for a duration exceeding the corresponding averaging time. Exposure for less than the averaging time is called short-term exposure.

4.6 Dielectric constant (ε), see Permittivity.

4.7 Duty factor (duty cycle). The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of unity corresponds to continuous-wave operation.

4.8 Electric field strength (E). The magnitude of a field vector at a point that represents the force (F) on a positive small charge (q) divided by the charge.

$$E = \frac{F}{q} \qquad (4.2)$$

Electric field strength is expressed in units of volts per metre (V/m).

4.9 Electric flux density (D). The magnitude of a field vector that is equal to the electric field strength (E) multiplied by the permittivity (ε)

$$D = \varepsilon E \qquad (4.3)$$

Electric flux density is expressed in units of coulomb per square metre (C/m^2).

4.10 Exposure. Exposure occurs whenever a person is subjected to electric, magnetic or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

4.11. Exposure level. The value of the quantity used when a person is exposed to electromagnetic fields or contact currents.

4.12 Exposure, direct effect of. The result of a direct interaction of the exposed human body with electromagnetic fields.

4.13 Exposure, partial-body. Partial-body exposure results from concentrated deposition of the energy.

.14 **Exposure, non uniform.** Non uniform exposure levels result when fields are non niform over volumes comparable to the whole human body. This may occur due to standing- /aves, scattered radiation or in the near field of active or passive radiators. *See* RF "hot pot" and "exposure, partial body".

.15 **Far field region.** In this region, the field has a predominantly plane-wave character, i.e., ·cally uniform distributions of electric and magnetic field strengths in planes transverse to e direction of propagation.

16 **General Public.** All persons except the group of workers.

17 **Intrinsic impedance (of free space).** The ratio of the electric field strength to the agnetic field strength of a propagating electromagnetic wave. The intrinsic impedance of a ane wave in free space is approximately 377 ohms.

18 **Magnetic flux density (B).** The magnitude of a field vector that is equal to the magnetic ·ld H multiplied by the permeability (μ) of the medium.

$$B = \mu H \tag{4.4}$$

agnetic flux density is expressed in units of Tesla (T).

19 **Magnetic field strength (H).** The magnitude of a field vector in a point that results in a ·ce (F) on a charge q moving with the velocity v.

$$F = q(v \times \mu H) \tag{4.5}$$

e magnetic field strength is expressed in units of ampere per metre (A/m)

.0 **Near-field region.** A region generally in the proximity of an antenna or other radiating ɹcture, in which the electric and magnetic fields do not have a substantially plane-wave ɹracter, but vary considerably from point to point. The near-field region is further ›divided into the reactive near-field region, which is closest to the radiating structure and t contains most or nearly all the stored energy, and the radiating near-field region, where radiation field predominates over the reactive field but lacks substantial plane-wave ɹracter and is complicated in structure.

te: For many antennas, the outer boundary of the reactive near field region is commonly ɜn to exist at a distance of one-half wavelength from the antenna surface (See 3.2.19.).

l **Permeability, (μ).** The magnetic permeability of a material is defined by the magnetic density B divided by the magnetic field:

$$\mu = \frac{B}{H}, \tag{4.6}$$

re μ is the permeability of the medium expressed in Henry per metre (H/m)

· **Permittivity, (ε).** The property of a dielectric material (e.g., biological tissue) defined ɪe electrical flux density D divided by the electrical field E.

$$\varepsilon = \frac{D}{E} \tag{4.7}$$

permittivity is expressed in units of farads per metre (F/m).

4.23 **Power flux density (S).** Power per unit area normal to the direction of electromagnetic wave propagation, usually expressed in units of watts per square metre (W/m^2).

Note: For plane-waves electric field strength (E) and magnetic field strength (H) are related by the intrinsic impedance of of the medium. For free space

$$S = \frac{E^2}{377} = 377\,H^2 = E\,H \tag{4.8}$$

where E and H are expressed in units of V/m and A/m, respectively, and S in units of W/m^2. Although many survey instruments indicate power density units, the actual quantities measured are E or H.

4.24 **Power flux density, plane-wave equivalent.** A commonly used term associated with any electromagnetic wave, equal in magnitude to the power flux density of a plane wave having the same electric (E) or magnetic (H) field strength.

4.25 **Reference level.** The rms and peak electric and magnetic field strengths or the plane-wave equivalent power densities associated with these fields and the induced and contact currents, all derived from the basic restrictions, to which a person may be exposed without adverse effect and with an acceptable safety factor. The reference values may be exceeded, provided that the basic restrictions are met.

4.26 **Radio frequency (RF).** For purposes of these safety considerations, the frequency range of interest is 30 MHz to 6 GHz.

4.27 **RF "hot spot".** A highly localised area or volume of irradiation or absorption due to scattered radiation, focusing effects of other nonhomogenities.

4.28 **Root-mean-square (rms).** The effective value or rms value is obtained by taking the square root of the average of the square of the value of the periodic function taken throughout one period.

4.29 **Root-sum-square (rss).** The rss value or the Hermitian magnitude of a vector **v** is obtained by the square root of the sum of the squared rms values of all three orthogonal components of vector **v**. The rss value is proportional to the joule heating and can be quite different from the rms amplitude of vector **v**.

4.30 **Short-term exposure.** An exposure duration of less than the corresponding averaging time.

4.31 **Specific absorption rate (SAR).** The time derivative of the incremental energy *(dW)* absorbed by (dissipated in) an incremental mass *(dm)* contained in a volume element *(dV)* of given mass density (ρ)

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right) \tag{4.9}$$

SAR is expressed in units of watts per kilogram (W/kg).

ote: SAR can be calculated by:

$$SAR = \frac{\sigma E_i^2}{\rho} \quad (4.10)$$

$$SAR = c_i \frac{dT}{dt} \quad (4.11)$$

$$SAR = \frac{J^2}{\rho \sigma} \quad (4.12)$$

$\frac{\sigma}{2\rho}|E|^2$

ıere

rss value of the electric field strength in the tissue in V/m

conductivity of body tissue in S/m

density of body tissue in kg/m^3

heat capacity of body tissue in J/kg K

time derivative of temperature in body tissue in K/s

magnitude of the induced current density in the body tissue in A/m^2

Wavelength (λ). The wavelength (λ) of an electromagnetic wave is related to the uency (f) and velocity (c) by the expression $c = f \cdot \lambda$. In free space the velocity of an tromagnetic wave is equal to the speed of light.

Workers. Employed and self-employed persons are termed workers, whilst following employment.

average detector

5. NORMATIVE REFERENCES

The normative references or basic restrictions given in Table 1 are defined in terms of the specific absorption rate (SAR). They are consistent with the European standard (ENV 50166-2) [ENV], defined to protect the general public and workers from the adverse health effects of exposure to electromagnetic fields.

The basic restrictions for workers shall only apply when the MTE is used at work. If the MTE is neither technically nor administratively restricted to professional use only, the MTE shall comply with the basic restrictions for the general public.

Table 1: Basic Restrictions

	SAR averaged over any 6-min. time interval and over the whole body	SAR averaged over any 6-min. time interval and any 10g[a] tissue other than hands, wrists, feet, ankles	SAR averaged over any 6-min. time interval and any 10g[a] tissue in the hands, wrists, feet, ankles
General Population	0.08 W/kg	2 W/kg	4 W/kg
Workers	0.4 W/kg	10 W/kg	20 W/kg

[a]The shape of the averaging mass shall be chosen as a cube of 10g weight.

REFERENCE LEVELS

: reference levels or derived levels for the electric and magnetic field strengths as well as the power density are given in Tables 2 and 3. They correspond to those of the European standard ENV 50166-2 [ENV,1995].

: reference levels are defined for the incident field at the location of the body but without presence of the human body. If they are satisfied, the basic restrictions are met as well.

he near field it is not sufficient for only one of these field measures to be satisfied. At least reference levels of the electric and magnetic field strengths must be met. Although the rence levels are normally exceeded in the closest vicinity of MTE, the basic restrictions not necessarily exceeded.

reference levels for workers shall only apply when the MTE is used at work. If the MTE either technically nor administratively restricted to professional use only, the MTE shall ply with the reference levels given for the general public.

le 2: General public. Derived Reference Levels for Field Strength and Power density for tinuous and Quasi-continuous Exposure (f in Mhz)

Frequency	RMS - value of electric field strength (V/m)	RMS - value of magnetic field strength (A/m)	Mean power density (W/m^2)
30 - 400	27.5	0.07	2
400 - 2000	$1.37 \cdot f^{0.3}$	$3.64 \cdot 10^{-3} \cdot f^{0.5}$	f/200
2000 - 6000	61.4	0.163	10

le 3: Workers. Derived Reference Levels for Field Strength and Power density, for tinuous and Quasi-continuous Exposure (f in Mhz)

Frequency [MHz]	RMS - value of electric field strength [V/m]	RMS - value of magnetic field strength [A/m]	Mean power density [W/m^2]
30 - 400	61.4	0.16	10
400 - 2 000	$3.07 \cdot f^{1/2}$	$8.14 \cdot 10^{-3} \cdot f^{1/2}$	f/40
2000 - 6 000	137	0.364	50

7. MEASUREMENTS/SIMULATIONS AND MODELING

7.1 Preliminary Considerations

This section describes the measurement/simulation and modeling requirements for the procedures involved in testing compliance of MTE with safety limits. Measurement and numerical simulation procedures shall be considered as equivalent approaches under the conditions of Section 7.4. The testing of compliance with the basic restrictions or reference levels requires special considerations, particularly in extremely close near fields. In the Appendix several measurement and simulation techniques are described with respect to their suitability for testing compliance.

If the exposure due to the MTE exceeds the reference levels, compliance with the basic restrictions shall be demonstrated. This can be done by directly determining the spatial distribution of the specific absorption rate (SAR) induced in experimental or theoretical phantoms representing the human body, from which the maximum SAR averaged over any 6 minute interval and any 10 g of tissue shall be determined. However, it is recommended that the measurement or simulation techniques allow for averaging over a mass of 1 g tissue as well, since this smaller mass has been favoured by a minority of the working group members. The averaging mass of 1 g is required by the ANSI/IEEE standard [ANS/1,1992].

Mobile terminal equipment not complying with the reference levels and not falling under the exclusion clause as defined in Section 8 shall be tested. Procedures described in this section shall be used to demonstrate compliance with the basic restrictions.

7.2 Basic Requirements

The method must ensure that the assessed volume-averaged peak SAR value does not underestimate the actual exposure of any MTE user[1] under the tested operational conditions. It must also enable the testing of the effects of manufacturing tolerances and imperfections on the volume-averaged peak SAR values.

The MTE shall be tested at the highest time averaged antenna input power which might occur under operational conditions. Tests shall be performed for each configuration (e.g., with all antennas provided) and for each system the MTE can operate with (multi-system devices).

The results must be reproducible for all devices and various operating conditions.

7.3 Operational Conditions for Certain Classes of Devices

The technical realisation and handling differ significantly for individual MTEs. Hence, the operational conditions for each class of MTE must be well defined for testing.

[1] This requirement can be satisfied based on worst-case considerations without knowing the actual values (see Appendix 3).

3.1 Handheld Mobile Phones
this context handheld mobile phones are those cellular telephones consisting of one unit ith integrated microphone, ear piece, transceiver and antenna. When testing the compliance these devices with basic SAR values, measurements must be taken under the exposure nditions specified below.

3.1.1 Intended Use
ıe intended or normal operating condition of the MTE is generally established by fully tending the antenna of the radio, i.e., when the case plus the antenna are extended to the ıximum possible overall length. If this condition is not intended for operational conditions, : manufacturer shall specify the intended position in detail.

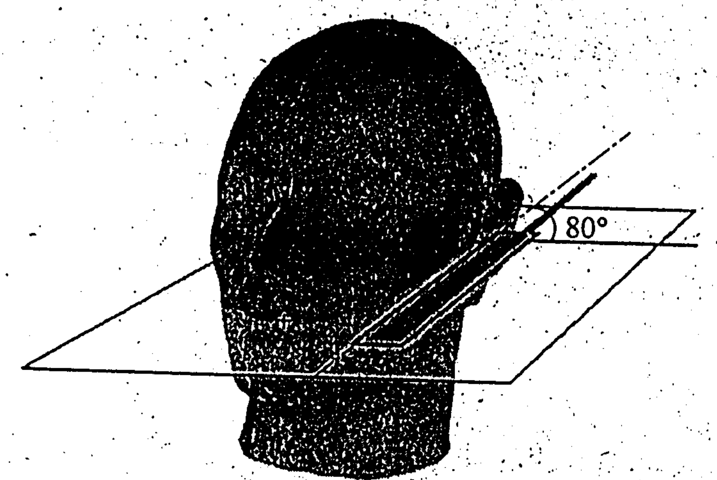
e intended use or normal position is a position which is convenient and provides good ɔustic coupling. It is defined as follows and illustrated in Figure 1:

a) The centre of the ear piece shall be placed directly at the entrance of the auditory canal.

b) The reference line of the phone is defined to be the line (on the surface of the phone's case facing the phantom) which connects the centre of the ear piece with the centre of the bottom of the case (typically near the microphone).

c) The reference line defined above shall lie in the reference plane defined by the following three points: auditory canal openings of both ears and the centre of the closed mouth.

d) The intended use position is defined by an angle between the reference line of the phone and the line connecting both auditory canal openings of 80°. If this position is not applicable, the manufacturer shall specify in detail the intended position of use.



ɿure 1: Intended use position.

7.3.1.2 Additional Operational Conditions and Positions
Since it is often difficult for the user of a handheld mobile phone to precisely control the position of the device with respect to the head, considerable variations of this intended use cannot be avoided. Parallel shifts as well as different orientations must be expected. Since the range of parallel shifts can be covered by the requirements for the modeling of the head (see Section 7.4.1.), the following additional operational conditions shall cover the variation range of the intended use orientation:

(1) The angle between the reference line of the phone and the line connecting both auditory canal openings shall be reduced until the device touches the face of the phantom.

(2) The angle between the reference line of the phone and the line connecting both auditory canal openings shall be increased to 100°, provided that the antenna does not touch the head. If the antenna does touch the head before an angle of 100° has been reached, this smaller angle shall be applied.

(3) The reference plane shall be tilted by 30° in the direction of the body's axis, whereby the angle between the reference line of the phone and the line connecting both auditory canal openings shall be 90°.

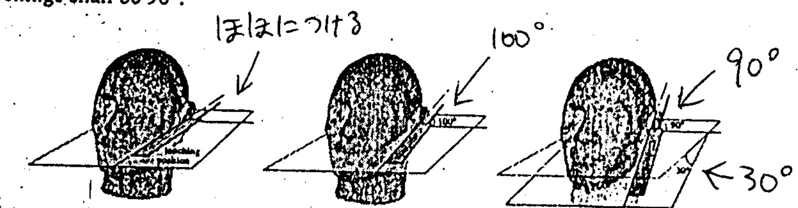


Figure 2: Additional operational positions (left: touch; middle: 100°; right: tilted).

7.3.1.3 Conditions to be Tested
Tests shall be done in the intended use and additional positions. If the antenna can be extended, tests shall be performed for the antenna fully extended and fully retracted, in all four positions defined in 7.3.1.1 and 7.3.1.2[2].
If the antenna is mounted to the right of the reference line seen from the surface of the phone case facing the phantom, a left-hand phantom shall be used; otherwise a right-hand phantom shall be used.

7.3.1.4 Compliance Criteria
Compliance is established when the maximum value found among the "intended use" positions defined in 7.3.1.1 and the additional operational conditions and positions defined in 7.3.1.2 is within the basic restrictions.

[2] Although operation with the antenna retracted does not correspond to the intended use condition, tests with the antenna retracted shall also be performerd in the intended use position.

.2 Dispatch MTE
is Section applies for dispatch radios held in front of the face. For dispatch radios held like idheld mobile phones, the test conditions of 7.3.1 shall apply. The appropriate minimum rational distance between the centre of the mouth and the microphone should be clearly icated in the user manual, or preferably on the device. If the minimum operational distance arger than 5 cm, the tests shall be conducted at a distance of 5 cm between the centre of the uth and the microphone.

vertical axis of the radio shall be parallel to the axis of the phantom, whereby the line pendicular to the axis through the centre of the closed mouth shall meet the centre of the rophone which faces the phantom.

3 Portable MTE
table MTEs are often used in close vicinity to the body. Most user manuals contain ructions on a minimum distance to be kept between the antenna and the human body. The isurement shall be made at this distance. If no distance is specified, the distance shall be 5

4 Other MTE
delines for installation and test conditions of fixed MTE are currently under consideration.

Basic Technical Requirements

1 Modeling of the Human Body
basic requirements for the modeling of the human body are as follows:
- The SAR values assessed must never be less than the actual maximum SAR values that can be induced among all users under the operational conditions defined in Section 7.3[3].
- Parallel shifts in any direction of the MTE with respect to the surface of the body shall not esult in any significant increase of the SAR values assessed for a range of 1 cm around he operational conditions defined in Section 7.3[4].
- Left-hand and right-hand use of the MTE shall be appropriately simulated (Section .3.1.4).
- Tests shall be conducted without simulating the hand[5].

Basic Requirements for the Dosimetric Simulation Software

[3] e the orientation of the MTE is defined by global angles, the body must have a shape which well ents the minimum distances between the device and skin occuring among all users.

[4] equirements are necessary, since the operational conditions are restricted to one location only. Small l shifts in the range of 1 cm radius must be tolerated as variations of the intended use position.

[5] iuman hand is an anatomically and geometrically complex structure which can cover an MTE in almost an number of configurations. Certain ways of holding the device with the hand significantly lower the d SAR values and others not at all. Significant increases have never been observed. Thus, nonmodeling of id represents a worst case method of holding the device.

The basic requirements for the dosimetric simulation software are as follows:
- Ability to model a phantom satisfying the requirements of Section 7.4.1.
- Accurate electrodynamics modeling of the MTE in all the operational positions and conditions described in Section 7.3[6].
- Accurate simulation of the near-field coupling between head and device.
- Capability of assessing the solution and modeling uncertainties as defined in Section 7.5[7].

7.4.3 Basic Requirements for the Dosimetric Measurement System
The general requirements for the dosimetric measurement system are as follows:
- The three-dimensional SAR distribution must be determined in the exposed body part[8]. Smaller volumes can be used if it can be demonstrated that the spatial peak SAR occurs within that volume.
- If the local SAR at and close to the surfaces between different materials cannot be directly determined, then a procedure must be established by which an accurate extrapolation to the surface can be guaranteed.
- Appropriate measures must be taken to avoid significant errors due to reflections from objects or nearby walls. Special consideration with respect to the test environment is required for frequencies within the range of the body's resonance.
- The system must ensure accurate time-averaged SAR values for pulsed and amplitude modulated systems.
- All ambient sources which may induce SAR values of greater than 10 mW/kg shall be eliminated.

7.5 Assessment of Uncertainties
The uncertainties of the assessed SAR values must be carefully determined. The following uncertainties must be considered according to [ISO, 1995].

7.5.1 Assessment of Measurement Errors
- Uncertainty of the electrical parameters of the phantom.
- Error due to deviation from isotropy.
- Error due to deviation from linearity.
- Error induced by unwanted interactions of the measurement equipment with the ambient low and high frequency fields.
- Uncertainty of the probe calibration (required for each frequency and tissue simulating material for which the system is used).
- Error at or close to a material discontinuity.
- Uncertainty due to the limited spatial resolution.
- Uncertainty due to the implemented averaging procedure (volume, time).
- Uncertainty of the phantom with respect to the phantom requirements (Section 7.4.1)[9].

[6] In most cases, the modeling of the device as a metallic box is not appropriate, since contructional details, even internal details, may significantly alter the absorption.

[7] Code validation is not sufficient, since significant errors may be introduced by modeling uncertainties and nonphysical solutions.

[8] It is generally difficult to predict *a priori* exactly where the spatial peak SAR will occur in the segment of the body that is close to the radio. In complex phantoms the peak SAR may occur in any tissue, i.e., assessments of the induced SAR in all tissue types must be possible.

[9] To be assessed by numerical simulation tools or measurements using nonhomogeneous phantoms.

.2 Assessment of Errors in Numerical Simulations

Uncertainties of each solution by appropriate numerical or experimental validation tools[10].
Uncertainties due to neglect of any details of the device that cannot be simulated due to limitations of the software package used or because some constructional details were not available (e.g., internal structures, the material parameters of the structures, etc.). A procedure to assess these uncertainties must be given and documented in the report.
Uncertainty of the chosen head phantom with respect to the phantom requirements (Section 7.4.1)[11].
Uncertainty due to the unknown effect on the output circuit from the proximity of the scatterer to the MTE.

Testing Procedure

:s must be performed according the following procedure:
The tests must be performed with a measurement system or simulation software satisfying the requirements specified in 7.4.2 or 7.4.3, using a phantom satisfying the requirements specified in Section 7.4.1.
All tests must be performed with the highest power available under operational conditions (e.g., fully charged batteries, highest power level defined by the system).
The maximum SAR value averaged over a volume of 10 g shall be assessed in all positions as specified for the particular MTE in 7.3.
The values with which the safety limits shall be compared shall be achieved by adding the uncertainty assessed according to 7.5 to the measured or numerically obtained values.
The documentation shall provide the SAR values averaged over a volume of 10 g for all conditions and positions (Section 7.3) to be tested. In addition, the method used for determining the uncertainty shall be documented. It is further recommended that the SAR values averaged over 1g be reported as well.

:h tools must have been proven to be highly reliable, as every simulation may have its own potential :s of error (e.g., due to the wide variety of different antenna structures operating in the closest vicinity of :sy scatterer).

ɔe assessed by numerical simulation tools or measurements using nonhomogeneous phantoms.

8. EXCLUSIONS

8.1 General

This clause allows exclusion of mobile telecommunication equipment from expensive SAR measurements and/or modeling as defined in Section 7, when it can be ensured by other measures that the basic restrictions are satisfied. Two more simple and alternative measures are described in the following.

8.2 Definitions

This exclusion applies to equipment used in the intended way for telecommunications only.

Such devices which emit low RF power and are used close to the body can be regarded as sources producing SAR values sufficiently below the basic restrictions when the RF radiating source and hardware fulfil certain conditions.

These conditions have been investigated by SAR measurements and/or modelling. For uncertainties, such as power and electromagnetic field variations due to near field loading of the radiating structure or current distribution changes on the case, additional safety factors are included in the exclusion conditions.

8.3 Exclusion conditions

Two criteria are available:
1) MTE generating an RF output power below 20 mW, measured at 50 Ohms or as EIRP.
2) MTE generating magnetic field strengths below the limits set in Table 5, as measured at a distance of less than 10 mm from the outer surface.

8.3.1 Basis for exclusion conditions

8.3.1.1 Exclusion condition 1)

Under worst case conditions, the whole RF power of 20 mW is deposited in the tissue, resulting in a SAR maximum of 2 W/kg integrated over 10 g. Therefore, mobile telecommunication equipment generating RF output power below 20 mW can be regarded as producing SAR values below the basic limits for all intended operating conditions.

8.3.1.2 Exclusion condition 2)

According to Ref. [KUS], an approximation for the relation between the incident magnetic field strength H_{inc} and SAR can be made as follows :

$$SAR = \frac{\sigma}{\rho}\frac{\mu\omega}{\sqrt{\rho^2+\varepsilon^2\omega^2}}\left(1+c_{corr}\gamma_{pw}\right)^2\left(H_{i_{inc}}\right)^2 \qquad (8.1)$$

$$= \frac{2\left|\sqrt{\varepsilon^{*}}\right|}{\left|\sqrt{\varepsilon^{*}}+\sqrt{\varepsilon_0}\right|}-1 \qquad (8.2) \qquad c_{corr} = \begin{cases} 1 & : d \geq 0.08\, \lambda / \gamma_{pw} \\ \sin\left(\frac{\pi}{2}\frac{\gamma_{pw}}{0.08}\frac{d}{\lambda}\right) & : d < 0.08\, \lambda / \gamma_{pw} \end{cases} \qquad (8.3)$$

= conductivity of the tissue
= mass density of the tissue
= approximation for the changed reflection properties for small distances of the antenna from the scatterer
= plane-wave reflection coefficient
= incident magnetic field at the surface of the body
= $\varepsilon + i\omega/\sigma$
= permittivity of the tissue

; approximation has been tested in the frequency range of 400 MHz to 2000 MHz and ıd to be accurate within ± 3 dB for the SAR value induced at the surface of a ıogeneous body. An additional safety factor of 3 dB has been included to the SAR nated according to equation (8.1) (i.e., a total of 6 dB) in order to account for further ertainties. The dielectric parameters chosen where those of muscle tissue. For the time g, the proposed method is applicable above 400 MHz only. Methods for devices ating at lower frequencies are under verifications.

Test methods and Compliance Requirements

Exclusion Condition 1)

.1 Test methods
e mobile telecommunication device has an accessible RF output connector, the output er may be measured using a calibrated power metre. For mobile telecommunication ment without accessible RF output connections (e.g., fixed mounted or built-in antenna) EIRP values must be measured using the test procedures given in the relevant ETSI ment ERT 0.27.XXXX.

.2 Requirements
output power should be below 20 mW at 50 Ohms or below 20 mW EIRP. For safety ns, the uncertainties of the test equipment must be taken into account.

Exclusion Condition 2)

.1 Test methods
ı anechoic chamber the device should be placed on a nonconductive sample holder ing free access to the magnetic field probe. The tip of the magnetic field probe should a diameter of less than 5 mm. The connecting lead between the magnetic field probe and ıdicating device should be constructed as not to disturb the electromagnetic field.

levice should be scanned at a distance of less than 10 mm from the outer surface (case ıdiating structure).

8.4.2.2 Requirements
If the magnetic field strength measured at a distance of 10 mm from the surface of the device is below the values given in Table 5, the device can be considered to produce SAR-values in the body below the basic limits. For safety reasons, the uncertainty of the test equipment must be added to the measured magnetic field strength levels.

Table 5: Maximum allowable magnetic field strength measured at a distance of 10 mm[12]

Frequency Range [MHz]	Magnetic Field [A/m]
400 - 1000	0.5 - 0.26 * f / [GHz]
1000 - 2500	0.3 - 0.06 * f / [GHz]

[12] At frequencies > 1 GHz, the decreasing skin depth will allow for a relaxation of the proposed limit values. However, further study on this subject is necessary.

nformation and Marking (NOT YET REVISED)

nformation

rmation according with 1.1 and 1.2 shall be provided at least in the official language(s) of European state of destination.

User information

following information for the user shall be supplied with the mobile radio communication pment:

a) the number of this standard
b) trade mark, or other means of identification, of the manufacturer, importer or distributor
c) model designation
d) radiated power (P): peak value or average value
e) frequency range
f) radio transmit antennas configuration and direction(s) for max. radiation under normal use
g) following instructions for use:
  " - keep the transmit antenna in a distance from the body
  - use the external antenna only while driving
  - minimise use of hand-held mobile radio communication equipment with integral antenna in cars and other closed, metallic structures
  - observe local warning signs concerning use of mobile radio communication equipment"
h) the address from which additional information can be obtained

dditional information

ollowing information shall be available from the manufacturer on request:

a) information as specified in 1.1
b) results of tests performed in accordance with this standard
c) the name and country of the test laboratory which performed the tests specified in 1.2 b) and the date of the tests.

rking

nobile radio communication equipment shall be durably marked with the following nation:

a) the number of this standard
b) trade mark, or other means of identification, of the manufacturer, importer or distributor
c) model designation
d) antenna input power of the transmitter (P): peak value or average value
e) frequency range
f) the statement: "Follow the user information".

10. REFERENCES

[ENV,1995] CENELEC, ENV 50166-2, European Prestandard prENV 50166-2, Human Exposure to Electromagnetic Fields High-Frequency : 10 kHz - 300 GHz, January 1995.

[IRP,1988] International Non-Ionizing Radiation Committee of the International Radiation Protection Association: Guidelines on limits of exposure to radio frequency electromagnetic fields in the frequency range from 100 kHz to 300 GHz, Health Physics, Vol. 70, No. 1, January 1988

[ICN,1996] International Commission on Non-Ionizing Radiation Protection, Health issues related to the use of hand-held radiotelephones and base transmitters, Health Physics, Vol. 54, No. 4, April 1996

[ANS/1,1992] ANSI/IEEE C95.1-1992: IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 10017, 1992.

[ANS/2,1992] ANSI/IEEE C95 3-1992, IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave, The Institute of Electrical and Electronics Engineers, Inc., New York, N.Y. 10017, 1992.

[KUS, 1992] N. Kuster and Q. Balzano, "Energy absorption mechanism by biological bodies in the near field of dipole antennas above 300 MHz," *IEEE Transaction on Vehicular Technology*, Feb. 1992

[ISO, 1995] International Organization for Standardization, "Guide to the Expression of Uncertainty in Measurement," ISO, CH-1211 Geneva; 1st printed 1993; corrected second printing 1995.

ANNEXES

ANNEX A : Characteristics of Mobile Telecommunication Equipment

A.1. Introduction

The aim of this annex is to provide some technical information on the various types of mobile telecommunication equipment in use in Europe and throughout the world.

Section A.4 of this annex provides detailed data on a great number of existing systems, presented by means of tables listing their characteristics.

Section A.2 briefly describes the characteristics of the main families of systems that are detailed in A.4.

Section A.3 explains the meaning and the importance with regard to exposure of the user of some of the different parameters gathered for each system in A.4.

Finally, section A.5 gives the meaning of the abbreviations used throughout this annex.

Although an attempt has been made to include as many systems as possible, this annex is not supposed to be exhaustive: existing systems (especially old generation systems that were defined on a country by country basis) as well as planned or systems currently developed (for which the detailed characteristics are not presently known) are not mentioned here.

A.2. General characteristics of the different families of MTE

Mobile Telecommunication Equipment can be gathered into main categories, depending on the type of telecommunication network they use. Each family is briefly described below; a detailed list of systems belonging to each family is provided in section A.4.

a) Private/Professional Mobile Radio (PMR)
Formerly called "private" mobile radio, PMR systems are widely used to provide an internal communication network within a fleet of vehicles or individuals using hand-held units (walkie-talkies...). In some networks, the mobile units communicate via one or several base stations. In some other networks there is no base station and mobiles communicate directly with one another. Communications are only possible within the members of the network: no interconnection with the public telephone network (generally called PSTN: Public Switched Telecommunication Network) is provided. Examples of applications are communication networks of taxi or ambulance companies, security teams, firemen...

b) Cordless systems
A cordless telephone (CT) is a terminal connected to an exchange line or to an extension line. It is generally made of two parts, the fixed and the mobile unit, connected via a radio link. Cordless phones are suitable for short range applications and show reduced performances compared with the more sophisticated cellular networks.

The first generations (CT0, CT1) consist of simple cordless telephones that can only be used within a home (one base and one or several mobiles) and are part of the public telephone network (PSTN). The new generation (CT2, DECT) belongs to separate networks (with an interconnection within the PSTN) and can be used in addition to the classical home application, within a limited service area. The principle of this new application is similar to a cellular mobile network (see below) but with reduced performance and also a lower cost. Depending on the systems, voice and/or data transmission are available with cordless systems. Very low power devices are used for cordless applications.

Cellular mobile radio systems

ellular radio systems involve communication from hand-held radiotelephones or vehicle ounted transceivers to fixed base stations which each provide coverage over a given area. he communications are full duplex (transmit/receive capability), with a separate RF channel ovided for the signal travelling via the uplink to the base station and the downlink back to e mobile. The coverage of a base station is known as a cell and is ideally hexagonal in iape, so that a honeycomb mesh of cells can give total coverage. The base station may be at e centre of a cell or at the junction of three cells, depending on the volume of call traffic ithin the cells. Typical cells range from 1 to 15 km, with a limit of about 35 km for the gital communications system. Interconnection with the PSTN is provided both ways and nversation between mobiles is also possible.

the early 1980s various analogue cellular systems were introduced in Europe with quency bands around 150, 200, 450 and 900 MHz. These are currently used by millions of stomers all over Europe and they are expected to remain in existence until early next ntury, when it is envisioned that digital communications will supplant them. Digital stems based on the harmonised European standard GSM have been introduced since 1992, y offer enhanced performance and better spectrum efficiency than analogue systems, and ir number of users is rapidly increasing. A new system called DCS 1800 has been very ently introduced in some countries.

e output power of hand-held devices is progressively being reduced with the development new systems, as they work on smaller cells.

Local area networks

cal Area Networks (LANs) allow data communication between computers located in a tricted area. Today, most of these networks use wire connections, but some new wireless lications of Radio LANs have been introduced and will be more and more widely used. h node of the network is then equipped with a small radio emitter and receiver and rconnecting cables are no longer necessary, simplifying the use of the network and wing mobility of its components (portable computers...).

light telephone

aim of such systems is to provide communication (voice/data) for the passengers of mercial flights. One system called TFTS (Terrestrial Flight Telephone System) has been ntly introduced.

bile stations on board planes communicate with a mesh of ground stations that provide rconnection with the PSTN.

atellite systems

llite systems were initially launched to enable communications from locations not hable with land networks. The first systems were those of the International Maritime llite Organisation (Inmarsat) and initially involved mobile satellite dishes on board ships h communicate through a network of 4 satellites covering the world (except the Poles). erent standards Inmarsat A, B, C and M were developed with specific characteristics. The recent involve small portable units (the size of a suitcase) which can be used throughout world and are generally used in remote areas not covered by cellular networks (deserts, ntains...).

systems under development (Inmarsat P, Iridium, Globalstar) are aimed at allowing use nd-held units (similar to the existing hand-held cellular telephones).

A.3. Explanations concerning some of the parameters gathered for each system

The first column of the tables given in section A.4 lists a certain number of parameters for which the relevant information has been looked at for each system. Some explanations of a number of these techhical parameters are given below:

- **system:** generic name under which one type of system with given characteristics is known. For the most recent equipment, this name is also given fort the international standard detailing the specifications of the system (e.g. GSM). Generally, each network operator is defined in addition to the specific brand name under which the system is commercialised.

- **existing applications:** we have seen in the main body of the standard that exposure situations can belongs in general terms to one of the following three categories: hand-held, portable and permanently installed. The categories encompassed for each system are given here.

- **frequency range (MHz):** the overall part of the frequency spectrum occupied by the system. When relevant, a distinction is made between the uplink frequency (for land services : from the mobile to the base; for satellite and sky services: from the earth to the satellite or the mobile in the sky (aircraft)) and the downlink frequency (reverse transmission). When considering exposure to MTE, the uplink is relevant for land and satellite services and the downlink only for flight telephones.

- **RF carrier spacing:** the frequency range allocated to one system is divided into frequency channels which can all be used individually for communications. The Radio Frequency (RF) carrier spacing represents the frequency separation between these channels (the total number of channels is approximately obtained by dividing the frequency range by the RF carrier spacing).

- **multiple access:** to allow several users to share one channel simultaneously, several techniques of multiple access are used. The main ones are: FDMA (frequency division multiple access), each RF channel is divided into sub-channels; TDMA (time division...), one user communicates during a small portion of the time, a second one during the next portion... up to, for example, 8 users in the case of GSM (voice is encrypted and compacted so that for the listener the conversation is continuous); CDMA (code division...), data or voice from several users is encrypted ("mixed") all together and transmitted on one channel and decrypted by each one after.

- **duplexing method:** for simple applications like paging, there is a one way or "simplex" communication only (base towards mobile). For most other services, communication is both ways or duplex, one being called the uplink and the other one the downlink. In this case, two main duplexing methods are used: FDD (frequency division duplex), uplink and downlink are done in different frequency bands; TDD (time...), uplink and downlink are done on the same frequency channel at different moments in time (the simplest example is a walkie-talkie: when one person speaks the other cannot and vice-versa).

- **unidirectional traffic channel per RF carrier:** the number of one way (up or down) links that can be established simultaneously on one frequency channel is determined by the multiple access mode and the duplexing method used.

- **frame duration (ms):** for digital systems, the unmodulated signal containing the transmitted information is periodic and consists of a series of "frames"; its periodicity is called the frame duration.

time slot duration (ms): the time during which information is transmitted during one frame (this parameter is only relevant for TDMA systems).

modulation technique: the way the wanted low frequency signal is mixed to the high frequency carrier before being transmitted.

modulation data rate: the total amount of data information per time unit capable of being transmitted on a frequency channel.

filter: characteristics of the input filter of the receiving part of the system.

speech coding: for digital systems, speech coding is used to encrypt and compact the voice information transmitted.

voice/data: the amount of data per time unit capable of being transmitted corresponding to well defined protocols: for some systems, one or more data channels and one or more voice channels are transmitted and form together the overall modulation data rate.

peak output power: the peak value of the power emitted by the system observed in the time domain. When the system is equipped with power control (see below), only the maximum possible emitted level is indicated.

ratio peak/mean power: depending on the kind of multiple access technique used, the ratio between the peak and the mean (rms) emitted power is sometimes defined by a round number: 1 for FDMA, an integer greater than one for TDMA (e.g., 8 for GSM for example).

mean (rms) output power: the mean (root mean square) value of the power emitted by the system observed in the time domain. When the system is equipped with power control (see below), only the maximum possible emitted level is indicated.

mobile power control: when the emitter and the receiver (e.g., mobile and base) are close to one another, it is not necessary to emit at the maximum possible power. Indeed, it is more efficient in terms of the reduction of interference and energy savings to emit at the minimum power which enables the link to operate. For this reason, a lot of systems are equipped with a power control system, which automatically regulates the power. The first operational regulations were static (control set once at the beginning of the communication), but most new ones are dynamic (permanent adjustment) to take into account the movements of the mobiles.

A.4. Tables with the characteristics of MTE

PRIVATE/PROFESSIONAL MOBILE RADIO (PMR)

System	ARDIS	COGNITOR	DATA TAC
Type of service	Analogue data dedicated trunked mobile radio network	Analogue data dedicated trunked mobile radio network	Analogue data dedicated trunked mobile radio network
Existing applications	portable	portable	portable
Countries using the system	UK, USA, Canada, Hong Kong	UK	Germany
Introduction	1989	1991	1992
Frequency range (MHz)	800 MHz band (up-downlink freq. separation = 45 MHz)	171 - 191 MHz (up-downlink freq. separation = 8 MHz)	400 MHz band 900 MHz band
RF Carrier Spacing	25 kHz		12.5 kHz
Multiple Access	DS/CDMA	TDMA	Slotted DS/CDMA
Duplexing Method	FDD	FDD	
Unidirectional / traffic channel per RF carrier			
Frame Duration (ms)			
Timeslot Duration (ms)			
Modulation Technique	4 FSK	3 FSK BCH coded	4 FSK
Modulation Data Rate	4.8 Kbit/s 19.2 Kbit/s		
Filter			
Speech Coding			
Data	2.048 Kbit/s 8 Kbit/s	6.144 Kbit/s	9.6 Kbit/s
Peak Output Power		5 W	4 - 20 W
Ratio peak/mean power			
Mean (rms) Output Power			
Mobile Power Control			
Reference Standard	MOTOROLA (Proprietary)	COGNITO (Proprietary)	MOTOROLA (Proprietary)
Note:			

PRIVATE/PROFESSIONAL MOBILE RADIO (PMR)

stem	MOBITEX	EDACS	MPT 1327
pe of service	Analogue data dedicated trunked mobile radio network	Analogue trunked mobile radio private network voice & data	Analogue trunked mobile radio private network voice & data
isting applications	portable	portable, hand-held	portable, hand-held
untries using the system	Finland, Norway, UK, Sweden, France, Netherlands, USA, Canada, Australia	Worldwide: Europe, USA, Far East...	Europe, ...
roduction	1986		
quency range (MHz)	80 MHz band 160 MHz band 450 MHz band 900 MHz band	*80 - 900 MHz* Europe: 80 - 170 MHz 380 - 510 MHz USA, Far East: 800 MHz	31 - 41 MHz 66 - 520 MHz 66 - 88 MHz 300 - 350 MHz 400 - 520 MHz
Carrier Spacing		12.5 kHz (Narrow EDACS) 25 kHz	12.5 kHz 25 kHz
ltiple Access	Slotted CSMA	FDMA	FDMA
plexing Method		FDD	FDD
idirectional traffic nnel per RF carrier		1	1
me Duration (ms)			
eslot Duration (ms)			
dulation Technique	GMSK	FSK	FM G3E voice FFSK data
dulation Data Rate			
er			
ech Coding		AME ADPCM	
e & Data	1.2 - 8 Kbit/s	9.6 Kbit/s 4.8 Kbit/s (Narrow Edacs)	1200 bit/s
Output Power	15 - 20 W	BS: 25 W MS: 10 W (portable) 5 W (hand-held) according to ETS 300 086	BS: 25 W MS: 10 W (portable) 5 W (hand-held) according to ETS 300 086
o peak/mean power		1	1
n (rms) Output Power		BS: 25 W MS: 10 W (portable) 5 W (hand-held)	BS: 25 W MS: 10 W (portable) 5 W (hand-held)
ile Power Control		Yes, dynamic	Yes, static
ence Standard	ERICSSON TELEVERKET (Proprietary)	ERICSSON (Proprietary)	ETS 300 086 (1991)
:			

PRIVATE/PROFESSIONAL MOBILE RADIO (PMR)

System	ETSI PMR	TETRA
Type of service	Analogue Professional Mobile Radio for Data Transmission	Digital trunked mobile radio private network (voice & data) or public access mobile radio network (data)
Existing applications	portable	portable, hand-held
Countries using the system	Europe	Europe
Introduction		to be defined
Frequency range (MHz)	Specific to each country	380 - 385 MHz uplink 395 - 400 MHz downlink
RF Carrier Spacing	12.5, 20 and 25 kHz	25 kHz
Multiple Access	Not defined	TDMA
Duplexing Method		FDD
Unidirectional traffic channel per RF carrier		4
Frame Duration (msec.)		56.67 msec
Timeslot Duration (msec.)		14.167 msec (510 bits)
Modulation Technique	Constant envelope modulation	π/4 DQPSK
Modulation Data Rate		36 Kbit/s
Filter		square root raised cosin - =0.4
Speech Coding		ACELP 7.2 Kbit/s
Voice & Data		data 19.2 Kbit/s 28.8 Kbit/s
Peak Output Power	Not defined	BS: from 28 dBm to 44 dBm (by step of 2 dBm) MS: 40 dBm (10 W) 35 dBm (3 W) 30 dBm (1 W) average power measured through the filter during one transmitted burst
Ratio peak/mean power		4
Mean (rms) Output Power	Not defined	MS: 2.5 W 0.75 W 0.25 W
Mobile Power Control		Yes, dynamic MS: from 15 dBm to 40 dBm (step 5 dBm)
Reference Standard	I-ETS 300 113 (January 1992)	RES 6: I-ETS 300 392 I-ETS 300 393
Note:		

CORDLESS SYSTEMS

tem	CT0	CT1	CT2/CAI	DECT	JCT (PHP)
›e of service	Analogue wireless PBX	Analogue wireless PBX	Digital wireless PBX, personal communications	Digital wireless PBX, personal communications	Digital personal communi-cations
sting applications	hand-held	hand-held	hand-held	hand-held	hand-held
untries using the em	France		Worldwide	Europe	Japan
oduction			1989	to be defined	1994 (private systems)
quency range (MHz)	41.3125 - 41.4875 MHz	914 - 915 MHz uplink 959 - 960 MHz downlink	864.1 - 868.1 MHz uplink and downlink	1880 - 1900 MHz uplink and downlink	1895 - 1907 MHz uplink and downlink
Carrier Spacing	12.5 kHz	25 kHz	100 kHz	1728 kHz	300 kHz
ltiple Access	FDMA	FDMA	FDMA	FDMA/TDMA	FDMA/ TDMA
lexing Method	FDD	FDD	TDD (ping pong)	TDD	TDD
directional traffic nel per RF carrier	1	1	1	12	4 8
ne Duration (ms)			2 msec	10 msec	
eslot Duration (ms)					
ulation Technique	Phase modulation	Phase modulation	2 level GFSK	GFSK	π/4 DQPSK
ulation Data Rate			72 Kbit/s	1152 Kbit/s	384 Kbit/s
r			BT=0.5 Gaussian	BT=0.5 Gaussian	square root raised cosine =0.4
ch Coding			ADPCM 32 Kbit/s	ADPCM 32Kbit/s	ADPCM 32Kbit/s
e & Data				data up to 256 Kbit/s	
Output Power	10 mW ERP	10 mW ERP	from 1 mW to 10 mW	250 mW	10 mW
peak/mean power			2	25	
n (rms) Output r	10 mW ERP	10 mW ERP	5 mW max	10 mW	
le Power Control	No	No	No	No	
ence Standard	NF C 98-220 (November 1984)		MPT 1375 : (CAI) common air interface	ETS 300 175 (1992)	RCR Spec. Std 2B (TBA)
				No frequency hopping	

CELLULAR MOBILE RADIO SYSTEMS

System	TACS	NMT 450	Radiocom 2000
Type of service	Analogue public cellular mobile radio network	Analogue public cellular mobile radio network	Analogue public cellular mobile radio network
Existing applications	portable, hand-held	portable, hand-held	portable
Countries using the system	UK, Italy, Austria, Spain, Malta, Ireland	Scandinavia, Switzerland, France	France
Introduction			
Frequency range (MHz)	890 - 915 MHz	in France : 441.5 - 443.55 MHz	165.2 - 168.3875 MHz* 176.5 - 427.9875 MHz** 884 - 889.9875 MHz***
RF Carrier Spacing		25 kHz (12.5 KHz)	12.5 kHz
Multiple Access	SCPC/FDMA	SCPC/FDMA	FDMA
Duplexing Method	FDD	FDD	
Unidirectional traffic channel per RF carrier	1	1	1
Frame Duration (ms)			
Timeslot Duration (ms)			
Modulation Technique	Phase modulation	PM speech FSK control signals	π/4 DQPSK
Modulation Data Rate			48.6 Kbit/s
Filter			square root raised cosine =0.35
Speech Coding			VSELP 8 Kbit/s
Voice & Data			
Peak Output Power	Portable: 1.6 W Hand-held: 0.6 W	Portable: 15 W Hand-held: 1 W	8 W * 11 W ** 6 W ***
Ratio peak/mean power	1	1	1
Mean (rms) Output Power	Portable: 1.6 W Hand-held: 0.6 W	Portable: 15 W Hand-held: 1 W	8 W * 11 W ** 6 W ***
Mobile Power Control	No	No	No
Reference Standard	MPT 1324 (1987) TACS Spec. (1991)		Spec. Radiocom 2000 mobile station DRM/CNET Ver. 3 Ed. 7 (December 1991)
Note:			

CELLULAR MOBILE RADIO SYSTEMS

tem	ETACS	NMT 900	NADC	JDC (PDC)
ne of service	Analogue public cellular mobile radio network	Analogue public cellular mobile radio network	Analogue public cellular mobile radio network	Digital public cellular mobile radio network
sting applications	portable, hand-held	portable, hand-held	portable, hand-held	portable, hand-held
intries using the system	UK, Italy, Austria, Spain, Malta, Ireland	Scandinavia, Switzerland	North America, Asia, Pacific	Japan
oduction	1985	1986	1992	1994
quency range (MHz) nk nlink	872 - 905 917 - 950	890 - 915 935 - 960	824 - 849 869 - 894	810 - 826 uplink 940 - 956 downlink 1429 - 1453 uplink 1477 - 1501 downlink
Carrier Spacing	25 kHz	25 kHz (12.5 kHz)	30 kHz	50 kHz (25 kHz interleaved)
tiple Access	SCPC/FDMA	SCPC/FDMA	FDMA/TDMA	FDMA/TDMA
lexing Method	FDD	FDD	FDD	FDD
directional traffic nnel per RF carrier	1	1	3 6	3 6
ne Duration (ms)				
eslot Duration (ms)				
ulation Technique	PM speech FSK control signals	PM speech FSK control signals	π/4 DQPSK	π/4 DQPSK
ulation Data Rate			48.6 Kbit/s	42 Kbit/s
r			square root raised cosine a=0.35	square root raised cosine a=0.5
ch Coding			VSELP 8 Kbit/s	VSELP 8 Kbit/s
e & Data				
Output Power	MS: 10 W 7 W 4.0 W 2.8 W 1.6 W 1.1 W 0.6 W 0.45 W ERP* Chassis Power	1 W	MS: from 2.2 mW up to 6 W	MS: from 300 mW up to 3 W
peak/mean power				
(rms) Output Power				
le Power Control	Yes	Yes	Yes	Yes
ence Standard	MPT 1324 (1987) TACS Spec. (1991)		IS 54, IS 55, IS 56	RCR Spec. Std 27B (Dec. 1992)
	*tolerance: +2dB -4dB			

CELLULAR MOBILE RADIO SYSTEMS

System	GSM	GSM UIC	DCS1800	CDMA
Type of service	Digital public cellular mobile radio network	Digital railway cellular mobile radio network	Digital personal communications	Digital public cellular mobile radio network
Existing applications	portable, hand-held	portable, hand-held	hand-held	portable, hand-held
Countries using the system	Europe, Asia, Pacific	Europe, Asia, Pacific	Europe	North America
Introduction	1992	1992	1993	1995
Frequency range (MHz) uplink downlink	880 - 915 925 - 960		1710 - 1785 1805 - 1880	824 - 849 869 - 894
RF Carrier Spacing	200 KHz	200 KHz	200 KHz	1230 kHz
Multiple Access	TDMA	TDMA	TDMA	DS/CDMA
Duplexing Method	FDD/TDD	FDD/TDD	FDD/TDD	FDD
Unidirectional traffic channel per RF carrier	8 16 (half rate)	8 16 (half rate)	8 16 (half rate)	118
Frame Duration (ms)	4.615 msec	4.615 msec	4.615 msec	
Timeslot Duration (ms)	0.577 µsec	0.577 µsec	0.577 µsec	
Modulation Technique	GMSK	GMSK	GMSK	MS: QPSK BS: OQPSK
Modulation Data Rate	270.883 Kbit/s	270.883 Kbit/s	270.883 Kbit/s	1228.8 Kbit/s
Filter	BT=0.3 Gaussian	BT=0.3 Gaussian	BT=0.3 Gaussian	613 KHz Chebychev low pass
Speech Coding	RPE-LPT 13 Kbit/s (half rate to be defined)	RPE-LPT 13 Kbit/s (half rate to be defined)	RPE-LPT 13 Kbit/s (half rate to be defined)	8.55 Kbit/s CELP
Voice & Data	data: up to 9.6 Kbit/s	data: up to 9.6 Kbit/s	data: up to 9.6 Kbit/s	data: 1.2 - 9.6 Kbit/s
Peak Output Power	MS: 8 W 5 W 2 W 0.8 W (power at the antenna connector)	MS: 8 W 5 W 2 W 0.8 W (power at the antenna connector)	MS: 1W 0.25 W (power at the antenna connector)	MS: 1 Π 8 dBW -3 Π 4 dBW -7 Π 0 dBW ERP*
Ratio peak/mean power	8	8	8	
Mean (rms) Output Power	1W 0.625 W 0.25 W 0.1 W	1W 0.625 W 0.25 W 0.1 W	0.125 W 0.031 W	
Mobile Power Control	Yes	Yes	Yes	Yes
Reference Standard	ETSI GSM 05.05	ETSI GSM 05.05	ETSI GSM 05.05	Qualcom IS 95
Note:	* tolerance Ī 2 dB **DTX reduces the mean output power	* tolerance Ī 2 dB **DTX reduces the mean output power	* tolerance Ī 2 dB **DTX reduces the mean output power	*-2.14 dB at the antenna connector

LOCAL AREA NETWORKS & FLIGHT TELEPHONE

tem	RLAN	HIPERLAN	TFTS
pe of service	Digital Radio Local Area Network	Digital Radio Local Area Network	Digital airplane phone
sting applications	permanently installed, portable	permanently installed, portable	permanently installed, portable
verage	Worldwide (USA, Europe, Japan...)	Worldwide	Worldwide
roduction	1994	1996 (?)	1995
quency range (MHz)	Europe: 2400 - 2483,5 USA: 2400 - 2483 Japan: 2471 - 2497	5150 - 5250 5250 - 5300 (in 1996)	uplink: 1670 - 1675 downlink: 1800 - 1805
Carrier Spacing	1 MHz (USA)		30.3 kHz
ltiple Access	CDMA	CDMA	TDMA
lexing Method			
idirectional traffic nnel per RF carrier			4 (voice transmission)
me Duration (ms)			
eslot Duration (ms)			
lulation Technique	Spread spectrum	Spread spectrum	QPSK
lulation Data Rate	Europe: 250 Kbits/s minimum Japan: 256 to 2000 Kbits/s	20 to 1000 Mbits/s	per RF channel : 44.2 Kbits/s fax: 4.8 Kbits/s data: 1.2 to 4.8 Kbits/s
er			
ech Coding			codex 9.6 Kbits/s
a			
k Output Power	Europe, Japan: ERP max: 100 mW USA: output power max 1 W (with a 6 dB antenna gain) = 4 W EIRP	EIRP max : 1 W	
o peak/mean power	1	1	4
n (rms) Output Power	Europe, Japan: EIRP max : 100 mW USA : output power max 1 W (with a 6 dB antenna gain) = 4 W EIRP	EIRP max: 1 W	
ile Power Control			
rence Standard	prETS 300 328 (November 1993)		ETS 300
:			

SATELLITE SYSTEMS

System	INMARSAT C	INMARSAT M	IRIDIUM (draft specifications)	GLOBALSTAR (draft specifs)
Type of service	maritime-land mobile services data	maritime-land mobile services voice & data	digital personal communications voice & data	digital personal communications voice & data
Existing applications	permanently installed, portable	permanently installed, portable	portable, hand-held	portable, hand-held
Coverage	Worldwide	Worldwide	Worldwide	Worldwide
Introduction		1992	to be defined	to be defined
Frequency range (MHz) Uplink Downlink	1626.5 - 1645.5 1530.0 - 1545.0	1631.5 - 1660.5 1530.0 - 1559.0	1610 - 1626.5 2483.5 - 2500	1610 - 1626.5 2483.5 - 2500
RF Carrier Spacing		10 kHz	160 kHz Uplink 350 kHz Downlink	1230 MHz
Multiple Access	FDMA/TDMA		FDMA/TDMA	CDMA
Duplexing Method	FDD		FDD	
Unidirectional traffic channel per RF carrier			25 RF ch. = 55 Traffic Channels	
Frame Duration (ms)			60 msec (14 ts)	
Timeslot Duration (ms)			1.3 msec Uplink 2.9 msec Downlink	
Modulation Technique	BPSK	OKPSK	QPSK	
Modulation Data Rate	1200 symbols/s	8 Kbit/s		
Filter				
Speech Coding		----- 2.4 Kbit/s	DSI VSELP 4800 b/s	
Data	600 bit/s 1200 bit/s store & forward	2.4 Kbit/s 4.8 Kbit/s		
Peak Output Power	MS: 12 - 14 dBW EIRP	MS: 25 dBW EIRP	MS: 8.45 dBW (7 W)	MS: 1 W Handheld 15 W Installed
Ratio peak/mean power				
Mean (rms) Output Power			-4.7 dBW (338 mW)	0.8 mW/cm^2 max power flux
Mobile Power Control			Yes	Yes
Reference Standard	INMARSAT	INMARSAT	MOTOROLA (Proprietary)	ALCATEL (Proprietary)
Note: Antenna G/T (dB/K°) C/No	Helix 100x25 mm -23 dB/K° 37 dB	Panel 400x500 mm -12 dB/K° -10 dB/K° land mobile 42 dB	Quadrifliar Helix -23.8/-21.8 dBi Eb/N°= 3.1 dB (BER=10^{-2})	Antenna gain 2.5 dB

.5 Abreviations used in Annex A

PSK	Binary Phase Shift Keying
S	Base Station
DMA	Code Division Multiple Access
SMA	Carrier Shift Multiple Access
T	Cordless Telephone
CS 1800	Digital Communication System at 1800 MHz
ECT	Digital European Cordless Telecommunication
QPSK	Differential Quadrature Phase Shift Keying
S/CDMA	Direct Sequence CDMA
TX	Discontinuous Transmission (used by GSM & DCS 1800)
RP	Equivalent Isotropic Radiated Power EIRP = output power x antenna gain
RP	Equivalent Radiated Power (referred to a half-wave dipole) EIRP = ERP x 1.64
ACS	Extended Total Access Communication Systems
S	European Telecommunication Standard (developed by ETSI)
SI	European Telecommunication Standardisation Institute
D	Frequency Division Duplex
MA	Frequency Division Multiple Access
SK	Fast Frequency Shift Keying
1	Frequency Modulation
K	Frequency Shift Keying
SK	Gaussian Frequency Shift Keying
ISK	Gaussian Minimum Shift Keying
M	Global System for Mobile Communications
PERLAN	High Performance European Radio Local Area Network
MARSAT	International Maritime Satellite organisation
J	International Telecommunication Union
;	Mobile Station
IT	Nordic Mobile Telephone
PSK	Offset Keyed Phase Shift Keying
PSK	Offset QPSK
X	Private Branch Exchange
	Pulse Modulation
R	Professional Mobile Radio
TN	Public Switched Telecommunication Network
SK	Quadrature Phase Shift Keying
AN	Radio Local Area Network
	Radio Frequency
PC	Single Channel Per Carrier
CS	Total Access Communication System
D	Time Division Duplex
MA	Time Division Multiple Access
RA	Trans European Trunked Radio
S	Terrestrial Flight Telecommunication System
	International Railway Union

ANNEX B: BIOMEDICAL CONSIDERATIONS

not yet revised

INEX C: Experimental and Numerical Modeling of the Human Head

Introduction

: basic requirements of the human modeling are defined in Section 7.4.1. In the following advantages and disadvantages of different phantoms are discussed with respect to these uirements.

Dependence of the Modeling on the spatial peak SAR values

;eneral numerical techniques allow highly detailed modeling of the external and internal tomy of the human body, whereas only relative course modeling is possible in the erimental approach. The degree of detailed modeling required to satisfy the basic uirements has been recently researched, by investigating the dependence of :tromagnetic energy absorption upon human head modeling for the frequency range at 900 z [HOM, 1996] and for 1.8 GHz [MEI, 1997]. The studies were conducted using several ierical and experimental phantoms. Among the numerical phantoms were three :pendently discretized head phantoms based on MRI scans of three different adults. The ial resolution of discretization was up to 1 mm³ and up to 13 different tissue types were nguished. The numerical results were compared with those of different homogeneous ıtoms and a complex experimental phantom (consisting of skin, bone, muscle, eye and n tissue). The findings of these studies can be summarized as follows:

Γhe global SAR distribution is similar for homogeneous and nonhomeneous modeling, .e., the energy absorption mechanism is not changed. In other words, the absorption listribution is strongly related to the expected incident magnetic field, i.e., to the RF :urrent distribution versus the distance. Most of the power is absorbed close to the adiating structure and focusing effects are negligible.

\s expected, the local SAR distribution depends significantly on the local distribution of he electrical tissue properties. In humans the local tissue distribution for various ndividuals varies largely and can even change with time. For example, the outer shape epends on the individual profile and on any movement of the mouth or the eyes. The lectric parameters of a human body vary with levels of physical and metabolic activity, ealth, and age.

)bviously, spatial peak SAR values also depend on the local anatomy. On the other hand, ıe homogeneous modeling led to results which overestimated the values of the onhomogeneous head with the highest absorption. However, the overestimation is urprisingly small for the site above the ear, i.e., <10% at 900 MHz and <20% at 1.8 GHz.

mall shifts (<10 mm) of the source parallel to the surface of body can result in variations f the spatial peak SAR of >3 dB with nonhomogeneous modeling, if the maximum SAR :curs in the strongly nonhomogeneous area of the ear. For homogeneous bodies such ıifts do not lead to any changes in the spatial peak SAR values, which always /erestimate the values of the nonhomogeneous case.

ıe effects due to the shape of the head are negligible for a given small distance (>3 cm) the source from the body.

The two parameters which determine the SAR distribution most are clearly the actual current distribution on the device and the distance of these currents from the tissue.

In a follow-up study [MEI, 1996] possible enhancement effects of external metallic accessories, such as optical glasses or jewelry, are investigated. Enhancement of several dBs are possible for nonhomogeneous modeling when the maximum occurs in the strongly nonhomogeneous area of the ear. The effects become negligible with homogeneous phantoms.

The effects of the human hand have also been studied. It is an anatomically and geometrically complex structure, which can cover an MTE in almost an infinite number of configurations. The results testing numerous different devices have shown that the largest spatial peak SAR values measured for different ways of holding the devices is well represented by not considering the hand [MEI, 1996].

C.3 Influence of the Scattered Field on the Source

Conductive scatterers in the close vicinity of the antenna generally affect the source. This has been studied for a dipole source at different distances from a head-shaped body [KUS, 1996]. Whether a change in the feedpoint impedance results in a significant increase or decrease of the feedpoint current (i.e., of the absorbed power) depends on the actual design of the RF-frontend circuits. Although the radiating structures of most devices have rather low Q-values, the actual current distribution on the device could be significantly modified by the vicinity of the body, which may in turn have a large effect on the spatial peak SAR value.

C.4 Dependence on the Shape with Respect to Testing Conditions

In Section 7.3 the orientation between the MTE structure is defined by a plane and different angles. This has the consequence that the distances (d) of each point on the MTE structure to the closest point on the head are determined by the shape of the phantom. This is a critical parameter, since the SAR is approximately proportional to $1/d^2$ [KUS, 1992].

C.5 Conclusions

The requirement of Section 7.4.1 can be satisfied with homogeneous phantoms. The most suited dielectric parameters leading to the lowest overestimation of the actual maximum SAR values are those of average brain tissue (i.e., mean parameter of grey and white matter) below 1.5 GHz and those of wet skin tissue for frequencies above. For devices exposing the trunk tissues, the simulation of muscle tissue is recommended. The SAR overestimation of about 20% might be further reduced by phantoms of increased complexity. The shape must be derived on the basis of the *worst case* distance between the MTE structure and the head. It is further necessary that a right-hand and a left-hand phantom is available. The same approach must be taken for face phantoms used for testing dispatch MTE.

ANNEX D: Measurement Techniques

D.1 Introduction

The direct approach for demonstrating compliance with safety standards is to experimentally determine the SAR distribution in phantoms simulating animals or human bodies. One possibility to determine the SAR is by temperature measurements. The SAR is proportional to the temperature increase only when the effects of heat diffusion can be neglected. Because of thermodynamic processes, this is only the case at the moment the exposure begins ($t \rightarrow +0$) and when the thermal equilibrium was prevalent on the site of measurement prior to the exposure

$$SAR = c\frac{\partial T}{\partial t}\bigg|_{t\rightarrow +0} \qquad \text{(D.1)}$$

here c is the specific heat of the tissue at the site of measurement. Since the heat transfer echanisms that lead to thermal equilibrium are relatively slow, SAR can be determined by valuating $c\ \Delta T/\Delta t$ if the effects of thermal conduction, convection and radiation are egligible in the time interval Δt. In fluids with relatively low viscosity, convection is the ominant heat transfer mechanism. Since convection is a non-linear process, assessment of e SAR by taking measurements over a longer period of time (> 30 - 60 s) and accounting r heat exchange processes is very intricate and should be avoided. The advantages and awbacks of this approach will be discussed in Section D.3.

other way of determining the SAR distribution inside tissue simulating materials is by asuring the electric field (E) inside the exposed tissue. The advantages and drawbacks of s method will be discussed in Section D.4.

th approaches have some common requirements. Any field disturbance caused by the be must be avoided. A further requirement, which is often but not necessarily concomitant h the previous, is that any signal picked up by any parts of the probe other than the sensor lf should be sufficiently suppressed. For tests of compliance with safety limits a sensitivity t least a magnitude better than the safety limits is required, since unmodified equipment is erably to be tested. A sensitivity of at least 0.1 W/kg would certainly satisfy these irements, which approximately corresponds to 0.03 mK/s or 10 V/m for current liquids or simulating tissues rich in water.

spatial resolution should be better than the smallest spatial dimension of any local field ima or minima, in order to enable accurate assessment of the SAR distribution. pliance tests and most dosimetric assessments require the determination of the SAR ibution in the tissue volume of interest. In larger volumes with greatly non-uniform ibutions, measurements in several hundred points might be necessary. Since the location e sensor must be precisely known, stereotactic or robot positioning is a costly but often ssary solution.

'issue Simulating Materials

lielectric properties of tissue simulating materials at the specific frequency and at room erature should accurately correspond with that of the dielectric properties of living s at body temperature. Since the SAR is defined as the time rate of energy absorption it weight, only the macroscopic simulation of the tissue's permittivity ε, permeability μ and conductivity σ are required. For SAR determination by temperature measurements, material with low specific heat and high viscosity would be advantageous.
Tissue simulating material is preferably liquid, since holes in solid material would significantly alter the field distribution in the phantom and would also severely limit the number of spatial points of measurements. For practical reasons, the material should be inexpensive, stable, nonpoisonous and easy to handle.

Animal tissues are generally used as the biological material for assessing the dielectric properties of the various tissues. The values for living tissue parameters presently found in literature show large variations. This is due to the difficulties encountered when handling living or freshly excised tissues during data collection and due to the natural variations of tissues. The most recent dielectric data from living tissue are provided by MCL Consultants [GAB] additional data can be found in [PET, 1984] and[HART, 1987].

In the frequency range below 1 GHz most biological tissues having high water contents (e.g., skin, muscle, various brain tissues, blood, cerebrospinal fluid) can be easily simulated by a water-sugar-salt solution. Above 1 GHz a solution based on Butyldiglycol has recently been suggested. Solid materials for all kinds of tissues and frequencies have also been developed. Summaries and recipes are given in [HART, 1987], [MEI, 1996a], [NOJ, 1991], [CHO, 1984], [ROB, 1991].

The dielectric parameters of liquids can either be measured by the slotted line method or by the open coaxial method. The latter method is simple to implement and gives the value of complex dielectric parameters over a broad frequency range. A commercial measurement kit is available from Hewlett Packard (HP 85070A Dielectric Probe Kit). The achievable accuracy is ±5% for the permittivity and ±10% for the conductivity. A better accuracy for the conductivity of about ±6% can be achieved by the slotted line method.

D.3 Temperature Measurement Methods

D.3.1 Introduction

An important advantage of the temperature measurement method is that temperature is a scalar, which makes it easier to produce probes of very small size and short time constants. One major difficulty is to achieve high SAR sensitivity, i.e., <<1 W/kg. Another important drawback is that the time derivative can only be determined by temperature measurements at two discrete times, whereby the thermodynamic state prior to exposure must be known and preferably be in equilibrium. Since the exposure alters thermal equilibrium, means and time must be provided to reestablish equilibrium after each measurement cycle.

D.3.2 Implantable Electrical Temperature Probes

A temperature probe based on a high-resistance thermistor connected to high-resistance leads was first described by Bowman [BOW, 1976]. By using the four lead configuration, a high impedance current source and voltage amplifier, the temperature can be measured accurately, despite the instability and temperature dependence of the leads. Such probes are commercially available and have been successfully used in dosimetry in the last two decades. Excellent sensitivity (Table 1) has recently been achieved by using specialized electrometer grade amplifiers and sophisticated software for filtering and data evaluation [BUR, 1996]. One disadvantage is that the leads of these probes are not totally unaffected by electromagnetic fields.

3.3 Implantable Optical Temperature Probes

the eighties temperature sensors utilizing optical temperature effects were developed and mmercialized for applications such as temperature control in high voltage transformers, lustrial microwave heating, hyperthermia, dosimetry, etc.

ıe of the effects employed for temperature measurements is the rate of fluorescent decay ım a phosphorescent layer on the tip of an optical fiber. An exponentially decaying material th a long half life is preferably used (e.g., magnesium fluorogermanate activated with ravalent manganese excitable by Xenon flash light) [WIC, 1987]. Currently commercially ailable devices typically do not have a noise level of better than ±0.1°C (averaging time 1s). ıltichannel devices with a wide operational range from -200°C to 450°C are now available.

other effect that has been utilized for optical probes is the interferometric microshift of a ity resonator, which is filled with a material of very high refractive temperature dependent ex. The short term drifts and noise is about 10 mK/s for practical applications. This can be uced by improved data processing. In small animal cadaver a sensitivity of about 2-3 mK/s s achieved, due to the larger thermal constant in the tissue compared to liquids [BUR,)6].

ble 1: Comparison of commercially available temperature measurement systems. Measured by exposing the first 6 cm of the line from the tip to an incident field of 950 n.)

hysical Principle	Fluorescent decay	Cavity resonator	Thermistor
oise level/short term drifts ampling time)	±0.1°C (1s)	±0.1°C (1s)	±0.005°C (0.1s)
nsitivity 0s of exposure)	±15mK/s	±10mK/s	±0.15mK/s
nsitivity to RF exposure 35 MHz)			
esistive lines parallel to E-field	< noise	< noise	< 0.5mK/s*
esistive lines normal to E-field	< noise	< noise	< 0.1mK/s*

.4 Radiation Thermometry

iation thermometry was one of the first methods utilized for SAR measurements [GUY, 1]. The technology for infrared imaging has been continuously improved since then, and iisticated devices for various applications (e.g., medical diagnosis, infrared sensing, etc,) today available. However, the sensitivity of >10 W/kg achievable in practice is not icient for compliance tests of MTE. In addition, this technique is limited to certain cross ions.

5 Calorimeters

riety of calorimeters have been used to measure the total energy delivered to a whole-ıal cadaver. Although this method is accurate in the determination of whole-body aged SAR, it cannot provide information about the SAR distribution within the body.

D.3.6 Conclusions

The required sensitivity for compliance tests of approximately 0.1 W/kg can only be achieved by thermistor probes, since the measurements must be performed within 20 s to avoid convection problems. Also, the achievable spatial resolution of the probe is excellent. Nevertheless, because of the strong limitations on the minimum measurement time per spatial point, this technique is not suitable for the implementation of a certification procedure for MTE.

D.4 Electrical Field Measurement Methods

D.4.1 Introduction

E-field probes have been utilized since the early 70's for experimental measurement of RF fields inside tissue simullating liquids [JOH, 1972]. The first prototype of a miniature isotropic diode loaded E-field probe for dosimetric assessments was presented by Bassen [BAS, 1975]. The utilization of fiberoptical E-field sensors for dosimetric assessments was suggested as far back as 1978 [BAS, 1978], although it has taken present day technology for commercial application.

Since the field polarization is unknown in the close near fields of radiators, only probes with an isotropic response in the tissue simulating material should be used. This is accomplished by measuring the field components with three orthogonal sensors. Because of the short wave length in the tissue and since the induced field may have relatively large spatial gradients, the probe size should be as small as possible. Furthermore, the interaction of the probe with the field should be negligible.

These requirements are difficult to satisfy, because the usually fragile sensors must be mounted on a supporting core and covered with an outer shell to strengthen the probe tip and to protect the single probes from contact with the tissue simulating material. However, any dielectric material around electric probes has an effect on the local signal strength, depending on the surrounding material. A good orthogonal response in a particular material might be greatly impaired in another media. Ways of realizing isotropic probes within tissue simulating materials have been discussed in [SCH, 1996]. In addition, the sensitivity of these probes in lossy media depends on the frequency and to a lesser extent also on the relative permittivity of the media [MEI, 1996a].

D.4.2 Diode Loaded Dipole Sensors

Isotropic diode loaded dipole sensors consist of three small orthogonally arranged dipoles which are directly loaded with Schottky diodes. Direct conversion of the high frequency voltage across the gap into a DC voltage and highly resistive lines (RF transparent) are used to transmit the DC signal to the data acquisition unit. The resistive lines have been realized either by carbon impregnated Teflon strips, thin-film or thick-film technology on a ceramic or quartz substrate. Reviews about the theory of this type of probe are discussed in [BAS, 1983] and [SCH, 1996a]. Different probes are currently commericaly available, e.g., [NARDA] and [ET3DV4].

D.4.3 Fiberoptical E-Field Sensors

Several groups worldwide are currently developing fiberoptical E-field sensors for various applications (e.g., EMC, measurements on ICs, etc.) utilizing the Pockels effect. The Pockels effect describes the change in the optical dielectric permittivity of noncentrosymmetric crystals, which is linear with the electric field. This effect is used in many integrated optics devices to alter the real or imaginary index of refraction (i.e., tuning of a filter, optical switches, modulators, etc.) but can also be used to realize E-field sensors. The promising advantages of this approach are that these sensors are non-metallic, extremely broad band

actically from DC - to several GHz) and enable measurements in the time domain, i.e., vide frequency and phase information.
:h sensors are already commonly used in high voltage applications. In [KUW, 1992] a all wideband sensor realized on a $LiNbO_3$ substrate is presented, whereby the E-field uced in the crystal is enhanced by attached metallic dipole arms. Another approach has n recently presented, which is based on a CdTe (Cadmium Telluride) crystal and has tively low permittivity [CEC, 1994]. The one-dimensional probe has no attached metallic ole arms but a sensing crystal of about 10 mm length. None of these probes are currently mercially available.

.4 Calibration of E-field Probes

iable and accurate standardized procedures must be available to calibrate E-field probes in different tissue simulating liquids and to assess the uncertainties in assessing the spatial k SAR values. Keeping uncertainties small is crucial for compliance tests; since all ertainties must be added to the measured values (Section 7.5).

ı recent study [MEI, 1996a] the calibration issue has been analyzed in detail and an erimental procedure has been developed which allows an absolute calibration of the es for dosimetric assessments with an uncertainty of less than ±10%.

.5 Discussion

required sensitivity for compliance tests of 10 V/m can easily be met by electrical field surement methods. The loss of phase and frequency information is no disadvantage for dosimetric analysis of near field exposure, since the signal characteristic is known "a ri". Although the smallest achievable dimensions are still considerably larger than those mperature probes, they are sufficiently small for measurements inside human phantoms for the frequencies used by mobile communications. A disadvantage is that special oration data are required for each material. However, this is not a problem for routine surements such as device certifications, which are always conducted with a limited ber of different tissues and narrow frequeny bands.

ropic sensors arecurrently not a real alternative to the diode loaded sensors, because of lack of sensitivity and particularly because of the significantly larger dimensions of the ors and more expensive technology.

H-Field Probes

usionary Clause 2 definded in Section 8 requires the measurement of the magnetic field distance of 10 mm from the surface of the MTE. The principle of small loops directly tively loaded with diodes has been discussed in [NIOSH, 1975].

CH, 1996] a two-dimensional H-field probe for the range between 100 MHz and 1 GHz een presented. It consists of two concentric orthogonal loops with diameters of 5.4 and nm. The same filtering technique is used to decouple the lines from the loop. The loops ot loaded; i.e., the detected signal is proportional to the square of the frequency (in the re law region of the detector diode). This makes the probe unusable for measuring d-band fields, but gives it a higher sensitivity and better accuracy for the narrow-band with known frequencies. The sensitivity is about 12 pT at 1 GHz, decreasing to 1.2 nT 0 MHz. A similar probe has recently been made commerciallly available [H2DV3]. If robe were always be held orthogonal to the surface of the MTE, a two-dimensional probe d be sufficient. A one dimensional probe with loops of 3 mm having an extended ency range (100 - 2000 MHz) is also commercially available [H1DV4]. A three-nsional probe, however, would be preferable. Fiberoptical H-Field sensors are currently studied as well (e.g., [CEC, 1994]) but no probes based on this approach have yet been nercialized.

D.6 Automated Dosimetric Scanners

The experimental assessment of the 3-dimensional SAR distribution within a phantom easily involves measurements in several hundred points. Especially at higher frequencies, the locations of these points with respect to the phantom must be determined with the greatest precision, in order to obtain repeatable measurements in the presence of rapid spatial attenuation and field variations. High precision is also required to accurately evaluate the spatial peak SAR values. It is obvious that the measurement process must be highly automated if such measurements must be performed routinely.

This implies that those measurements are basically restricted to shell phantoms filled with a liquid which simulates human tissue.

Although automated scanners based on temperature probes are possible, the maximum measurement speed would be unacceptably slow. Because of this and of the low sensitivity of temperature probes, only scanning systems based on E-field probes have been implemented so far. The systems developed in the 80's range from one-dimensional positioners [CLE, 1989] to 3-axis scanners [STU, 1983] and most recently to 6-axis robots [BAL, 1995]. The first version of the latter goes back to the early 80's and has been continually improved and extended since then.

The first system designed for testing compliance of MTE with safety limits is described in [SCH, 1996a]. It incorporates a high precision robot (working range greater than 0.9 m and a position repeatability of better than ±0.02 mm), isotropic E-field probes with diode loaded dipole sensors, an optical proximity sensor for automated positioning of the probe with respect to the phantom surface (precision better than ±0.2 mm) and sophisticated software for data processing and measurement control. The bandwidth ranges from 10 MHz to at least 3 GHz; the sensitivity is better than 1 μW/g. The dynamic range covers values up to 100 mW/g. Complex measurements, such as assessment of the spatial peak SAR value when starting with an unknown field distribution in the body, can be completed within 15 minutes. Three dimensional magnetic field probes and temperature probes are also available for this system, which has been made commercially available under the name DASY2 [DASY2]. Another system based on the same concept has recently been announced [IDX].

꞉NEX E: Numerical Techniques

l Introduction

eoretical approaches and numerical methods have always provided important information dosimetry in the frequency range of mobile communications. In the following a short ərview of the various numerical tools is given.

alytical methods are restricted to very simple configurations and are not applicable for ting devices. They nevertheless can provide valuable insights into the physical mechanisms l yield typical parameters.

ıdies on complex-shaped nonhomogeneous bodies have been conducted using general pose codes for solving electromagnetic scattering problems. These codes are most sonably classified into boundary and volume techniques. In boundary methods, space is ided into linear, homogeneous and isotropic domains, the boundaries of which are cretized.

volume techniques, on the other hand, the space is discretized directly. Depending on the thod, this can entail problems with infinite domains. Boundary methods are obviously re efficient for geometrically simple configurations with a low surface/volume ratio, ereas volume methods have their strength for complex geometries and inhomogeneous terials.

hould be kept in mind that a severe difficulty of many codes with respect to compliance ing is that error estimates for the uncertainty of the solution are difficult to obtain, since solution is "exact" only within the approximation space.

Method of Moments (MoM)

method of moments (MoM) was introduced in electrodynamics by Richmond [RIC, 1965] Harrington [HAR, 1967] in the mid 60s. They originally presented MoM in a very eral formulation. The same approach is also known in other branches of numerical lysis under the names of the method of weighted residuals, method of projection, Galerkin hod etc. Nowadays, MoM denotes methods that solve the electromagnetic problems retized into unknown charges and current distributions by integral equations.

M is especially popular for problems with perfectly conducting objects, such as antennas cattering from other metal structures. Modeling of a finitely conducting ground, layered lia, etc. can be introduced via Green's functions.

idely used MoM code is the Numerical Electromagnetic Code NEC of which different ions and several commercial front-ends have been developed. NEC2 [NEC2] is currently licly available, whereas the most recent version NEC4 is under strategic export limitations not easily available outside the United States. A simpler but similar code is MiniNEC NINEC]. These codes, however, are not applicable for simulations of MTE close to ıan bodies, because lossy dielectric materials cannot be included.

ariant of MoM based on the tensor integral equation with volumetric discretization was ied in the mid seventies to study the absorption in human-like phantoms [LIV, 1974]. body was subdivided into N blocks, in which a constant volume current is expanded with unknown for each spatial dimension. The electric field integral equation (EFIE) is

evaluated in the centers of the cells. This leads to a system of equations with $3N$ unknowns and a dense matrix [LIV, 1974].
As the cost of the solution is roughly proportional to N^3, the problem size grows so fast that the method does not allow a reasonably fine discretization of the human body.

The boundary element method (BEM) can be considered either as a MoM or a finite element (FE) technique if the surfaces of the scatterers are modeled with a finite element like surface mesh and finite-element compatible basis functions. It is normally used in conjunction with a space-discretizing finite element method (see Section E.5), but can also be used as a stand-alone technique.

An implementation of a surface-discretization MoM that allows the modeling of arbitrary dielectrical and lossy domains uses -- according to the equivalence principle -- electric and magnetic surface currents for each domain [BRU, 1993]. It has lately been successfully applied in the study of antenna performance when operating in the vicinity of homogeneous lossy bodies. The code CONCEPT is commercially available and made be applicable for testing MTE.

Moment method matrix equations were originally solved by direct methods. Later iterative methods such as the conjugate gradient method were also used. Recently there have been some breakthroughs in iterative methods coupled with good preconditioners and the faster approximation of the matrix-vector products used during the solution process. This speedup might again improve the competitiveness of the MoM approach.

There have been many publications on MoM. The classical reference is [HAR, 1967], [WANG, 1991] is a new and highly detailed book, whereas an overview with reprints of classical papers is given in [MIL, 1991].

E.3 Generalized Multipole Technique (GMT)

During the eighties, several groups developed methods that were later unified under the name *generalized multipole technique* (GMT) [LUD, 1989]. GMT refers to methods which approximate the unknown field in each domain by several sets of functions which, in contrast to MoM, do not have singularities within their respective domains or their boundaries.

The expansions are matched in discrete points on the boundary of the domains, resulting in an overdetermined system of equations with a dense matrix. The overdetermination factor is typically between 2 and 10. This system is solved in the least squares sense, usually with QR-factorization methods [GOL, 1989].

As the global expansion functions of the GMT are very smooth on the boundaries, the accuracy close to the boundaries is very high, which is important for dosimetric applications. The greatest advantage of the GMT, however, lies in the fact that the residual errors resulting from the least squares technique can be employed to validate the quality of the result [KUS, 1993]. Since the largest errors usually occur on the boundaries, the accuracy of the entire solution can be accurately evaluated [REG, 1993]. The GMT therefore leads to very reliable dosimetric assessments. Since this method is closely related to analytical methods, accurate simulation of scattering problems ranging many orders of magnitudes of field strength are possible.

The severe limitation of GMT is the difficulty involved in simulating real world applications. In contrast to MoM, in which subsectional basis functions are equivalent to a compact current, a GMT expansion is equivalent to a current distribution over the whole boundary of domain. For geometrically complex bodies, the selection and location of origine of the ›ansion functions is not quite obvious and requires considerable expertise.

e method is described in detail in [HAF, 1990]. The software package 3D MMP based on GMT is commercially available [HAF, 1993], including a graphic interface for the PC. e code has been successfully applied for dosimetric studies [KUS, 1992] and [KUS, ›2a], as well as for antenna design [TAY, 1994].

Finite-Difference Time-Domain (FDTD)

hough the finite difference approach can also be applied in the frequency domain stabilities likely occur at higher frequencies), the *Finite-Difference Time-Domain* ›TD)method is much more popular. Maxwell equations are directly discretized in space as ll as time on a staggered Yee-grid [YEE, 1966]. The solution is directly computed in the e domain in explicit time steps, whereby the field strengths in the computational space are to zero at the beginning, i.e., the method does not involve the solution of a matrix ation. Since the entire volume must be divided into cells, the number of unknowns is very ;e. However, the computational effort grows only linearly with the number of unknowns the number of cells. Thus, the method scales much better to large problems than other niques. The technique was first proposed by Yee [YEE, 1966] and since then has been ensively studied and improved. The time-domain Transmission-Line Matrix method (TD-M) [HOE, 1989] and the Finite Integration Technique (FIT) [WEI, 1990] are conceptually htly different methods which, however, lead to the same numerical scheme.

a long time, the applications of the method were limited by the relatively large uirements for computational power in both memory size and processor performance. On other hand, the algorithm is very easy to vectorize or parallelize.

ny other early limitations of the method have been eliminated. Several approaches for urate absorbing boundary conditions at the boundary of the computational domain have n proposed [BERN, 1995], [MUR, 1981], [BERE, 1994] offering excellent approximation open space with a minimum of "white space". An approximation for the frequency endent media *water* in the time domain has been reported in [TAF, 1988] that allows ılts to be obtained for a wide range of frequencies from a single time domain solution.

;reat advantage, but also a limiting factor, is the extremely simple though rigid and exible discretization of problems in the Yee-grid. Data conversion from CAD files to -grids can be accomplished by simple routines, and even very complicated structures like ogical bodies are relatively easily to discretize from magnetic resonant images. However, in cubical grid, local refinement, such as in finite element meshs, is not possible, and all aces have to be aligned with the grid orientation or are modeled in a staircase roximation. Although several ways of circumventing these weaknesses have been studied, are not generally applicable. They also complicate the modeling and can reduce the ierical efficiency, accuracy and stability of the method.

rawback of the method is that there is no internal check for assessing the quality of the tion, i.e., the quantitative uncertainty of the resulting field distribution. Coarse retization or too small distances between scatterer and absorbing boundaries can cause rs which are difficult to detect.

ove was the first to use FDTD for dosimetric problems [TAF, 1975]. Since the mid 80's, dhi and his group [GAN, 1990] have extensively applied this technique to a wide range of metric problems. Most recently, several groups have been using this technique

specifically to study the dosimetric problems of mobile communications, e.g., [PED, 1994], [DIM, 1994], [JEN, 1995]; [MAR, 1995], [SCI, 996].

The method is also used for antenna design and has produced excellent results, at least for geometrically simple structures that fit well into the Yee-grid. However, major difficulties are encountered if fine wires must be simulated which do not align to the grid, such as helical antennas.

Recently, books on FDTD that give a complete overview and have extensive further references have been published [TAF, 1995], [KUNZ, 1993]. Several codes have been made commercially available. Among those which have been applied to dosimetric problems are MAFIA [CST], XFDTD [XFDTD], EMA3D [IEMA].

E.5 Finite Element Method (FE)

The method of finite elements was introduced to electromagnetics by Silvester and Ferrari [SIL, 1996]. Space is discretized in a finite element mesh with linear or polynomial expansion functions within each element. The unknowns are associated with the field values in the nodes. A variational method or a method of weighted residuals is used to obtain a system of equations with a sparse matrix.

In wave propagation problems, the finite element technique is often used in the frequency domain. For a long time, its applicability for solving the Helmholtz equation was quite limited because of problems with spurious modes [SUN, 1995], [LYN, 1985]. Another limitation were open domains, as no efficient radiation boundary conditions were available. Therefore, the finite element method was often paired with a boundary element method in a hybrid scheme (see next Section).

Although penalty methods can be used to avoid the corruption of results with spurious solutions [LYN, 1985], the advent of edge-element techniques that prevent the possibility of spurious modes altogether [BOS, 1988], [JIN, 1993] seems more promising. In the edge-element technique the unknowns are associated with the field tangential to the edges of the basic element. Within each element vector expansion functions are used that are tangential to all element surfaces of which the edge is part and normal to all other surfaces. The edge-element technique is also much better suited to nonhomogeneous problems, since no internal boundary conditions between elements with different electromagnetic properties need to be enforced. Furthermore, in contrast to the conventional, node-based finite element technique, the edge element technique possesses a direct way of controlling discretization errors in the solution by looking at the behavior of the normal components of the field between elements.

Recently, more efficient methods for radiation boundary conditions have been developed, and currently *Berenger*-style boundary conditions for the finite element technique are under development. This makes earlier hybrid combinations with the boundary element method for many applications obsolete, as discussed in the next Section.

The finite element mesh gives in principle a very high flexibility for discretizing almost arbitrary geometries. However, the generation of meshs in 3D is still a formidable task. While there are reasonably good techniques for the discretization of technical structures, the difficulty of generating finite element models for the typically very inhomogeneous problems in dosimetry currently prevents wider use. Nevertheless, the finite element method has been used for 2D and 3D problems in hyperthermia treatment [LYN, 1985] and MRI dosimetry [SIM, 1995].

good text-book with many further references is [SIL, 1996]. Commercial codes are rketed by Hewlett-Packard, Ansoft and the McNeal-Schwendler Corporation.

Hybrid Techniques

discussed, each of the various numerical method has its particular strengths. Whereas one nique is particularly efficient and well-suited for one kind of problem, it has difficulties others. Many attempts have been made to combine different methods into a hybrid roach that has all the advantages without the disadvantages of the component methods.

most simple simulation scheme which could be considered as a hybrid variant is the directional or explicit coupling of different methods. An example would be if the current ribution on a MTE simulated with a MoM code could be used as the excitation in imetry simulations performed with FDTD.

ny of the implicit hybrid techniques (i.e., where the methods are algorithmically coupled nified) are combinations of the finite element method with the boundary element method simulating open space [EMS, 1988]. Applications beyond the simple simulation of open ce can hardly be found. Many of these hybrid combinations were also 2D applications. In the relative sizes of the FE and the BEM problem shift toward FE, which makes the ical hybrid algorithm inefficient or impractical. Improvements in FE absorbing boundary ditions have made such hybrid codes obsolete.

combination of FE with GMT has been presented in [BOM, 1994]. This approach was sequently generalized into a combination of MoM, GMT and FE within a iterative hybrid eme. The advantage of this approach is that the solution of an explicitly combined matrix ation is avoided which usually is the bottleneck of implementation and efficiency of rid techniques.

ther disadvantages of hybrid methods are that knowledge of several numerical methods is ded and that the coupling might lead to unexpected problems.

Discussion

TD is currently the most appropriate choice if highly inhomogeneous structures are olved for which boundary techniques have fundamental limitations. FE lacks from the c problem that techniques for efficient 3D discretization of the complex structures are not wn.

the design of antennas with complex geometries, such as helix antennas, patch antennas, MoM based codes are still the most popular ones, although FDTD and FE are gaining ind.

rently none of the commercial codes satisfy all the requirements of Section 7.4. Further kthroughs, however, can be expected in the next few years. The largest deficiency is seen he capability to perform reliable uncertainty assessments. Procedures combined with isurements might be applicable for testing MTE.

References to the Annexes C,D,E

[HOM, 1996] Volker Hombach, Klaus Meier, Michael Burkhardt, Eberhard Kühn, and Niels Kuster, "The dependence of EM energy absorption upon human head modeling at 900 Mhz", *IEEE Transactions on Microwave Theory and Techniques*, vol.44, Oct. 1996, in press.

[MEI, 1997] Klaus Meier, Ralf Kästle, Volker Hombach, Roger Tay, and Niels Kuster, "The dependence of EM energy absorption upon human head modeling at 1800 Mhz", *IEEE Transactions on Microwave Theory and Techniques*, 1997, submitted.

[MEI, 1996] Klaus Meier, RF-Nearfield Exposure of the Human Head: *Scientific Bases for Dosimetric Assessments in Compliance Tests*, PhD thesis, Diss. ETH Nr.xxxxx, Zurich, 1996.

[KUS, 1996] Niels Kuster, Quirino Balzano, and James I. Lin, Eds., *Progress in Safety Assessments of Mobile Communications*, Chapman & Hall, London, 1996, in review.

[KUS, 1992] Niels Kuster and Quirino Balzano, "Energy absorption mechanism by biological bodies in the near field of dipole antennas above 300 Mhz", *IEEE Transactions on Vehicular Technology*, vol. 41, no. 1, pp.17-23, Feb. 1992.

[GAB] C.Gabriel, Personal Communication.

[PET, 1984] P.Pethig, "Dielectric properties of biological materials: Biophysical and medical applications", *IEEE Transactions on Electrical Insulation*, vol. 19, no. 5, pp. 453-474, 1984.

[HART, 1987] G.Hartsgrove, A.Kraszewski, and A.Surowiec, "Simulated biological materials for electromagnetic radiation absorption studies", *Bioelectromagnetics*, vol. 8, no. 1, pp. 29 36, Jan. 1987.

[MEI, 1996a] Klaus Meier, Michael Burkhardt, Thomas Schmid, and Niels Kuster, "Broadband calibration of E-field probes in lossy media", *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, Oct. 1996, in press.

[NOJ, 1991] T. Nojima, T. Kobayashi, K. Yamada, and S. Uebayashi, "Ceramic dry-phantom and its application to SAR estimation", *IEEE MTT-S Digest*, pp. OF-I-11, 1991.

[CHO, 1984] C.K. Chou, G.W. Chen, A.W. Guy, and K.H. Luk, "Formulas for preparing phantom muscle tissue at various frequencies", *Journal of the Bioelectromagnetics Society*, vol. 5, no. x, pp.435-441, 1984.

[ROB, 1991] M.P. Robinson, M.J. Richardson, J.L. Green, and A.W. Preece, "New materials for dielectric simulation of tissues", *Phys. Med. Biol.*, vol. 36, no. 12, pp. 1565-1571, 1991.

[BOW, 1976] Ronald R. Bowman, "A probe for measuring temperature in radio-frequency-heated material", *IEEE Transactions on Microwave Theory and Techniques*, vol. 24, no. 1, pp. 43-45, 1976.

:UR, 1996] Michael Burkhardt, Katja Pokovic, Marcel Gnos, Thomas Schmid, and Niels Kuster, "Numerical and experimental dosimetry of petri dish exposure setups", *Journal of the Bioelectromagnetic Society*, 1996, submitted.

/IC, 1987] Kenneth A. Wickersheim and Mei H. Sun, "Fiberoptic thermometry and its application", *Journal of Microwave Power*, pp. 85-93, 1987.

UY, 1971] Arthur W. Guy, "Analyses of electromagnetic fields induced in biological tissue by thermographic studies on equivalent phantom models", *IEEE Transactions on Microwave Theory and Techniques*, vol. 19, no. 2, pp. 205-213, Feb. 1971.

)H, 1972] C.C. Johnson and Arthur W. Guy, "Nonionizing electromagnetic wave effects in biological meterials and systems", *Proc. IEEE*, vol. 60, pp. 692-718, June 1972.

AS, 1975] Howard I. Bassen, Mays Swicord, and J. Abita, "A miniature broad-band electric field probe", *Annals New York Academy of Science*, vol. 20, no. 5, pp. 481-493, Sept. 1975.

AS, 1978] Howard I. Bassen and R. Ross, "An optically-linked telemetry system for use with electromagnetic field hazard probes", *IEEE Transactions on Electromagnetic Compatibility*, vol. 20, no. 5, pp. 483-488, Sept. 1978.

:H, 1996] Thomas Schmid and Niels Kuster, "Novel E-field probes for close near field scanning", *IEEE Transactions on Vehicular Technology*, 1996, submitted.

AS, 1983] Howard I. Bassen and Glen S. Smith, "Electric field probes - a review", *IEEE Transactions on Antennas and Propagation*, vol. 31, no. 5, pp. 710-718, Sept. 1983.

:H, 1996a] Thomas Schmid, Oliver Egger, and Niels Kuster, "Automated E-field scanning system for dosimetric assessments", *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, pp. 105-113, Jan. 1996.

.RDA] E-Field Probe NARDA, No. 8021B, The NARDA Microwave Corporation, 435 Moreland Road, Hauppauge, New Yourk, NY 11788-3994.

3DV4] Isotropic E-Field Probe for Dosimetric Assessments ET3DV4, Schmid & Partner Engineering AG, Oberer Deutweg 59, 8400 Winterthur, Switzerland.

W, 1992] Nobuo Kuwabara, Kimihiro Tajima, and Fujio Amemiya, "Development and analysis of electric field sensor using $LiNbO_3$ optical modulator", *IEEE Transactions on Electromagnetic Compatibility*, vol. 34, no. 4, pp. 391-396, Nov. 1992.

C, 1994] F. Cecelja, W. Balachandran, M. Berwick, and S. Cvetkovic, "High precision, high frequency electromagnetic field optical sensors", *Proceeding of the COST244 Meeting*, XIII/J31/94-FR, pp. 190-208, 1994.

)SH, 1975] Frank M. Greene, "Development of magnetic near-field probes", Tech. Rep., National Institute for Occupational Safety and Health, 1975.

[H2DV3] Two-Dimensional H-Field Probe H2DV3 (100 - 1000 MHz), Schmid & Partner Engineering AG, Oberer Deutweg 59, 8400 Winterthur, Switzerland.

[H1DV4] One-Dimensional H-Field Probe H1DV4 (100 - 2000 MHz), Schmid & Partner Engineering AG, Oberer Deutweg 59, 8400 Winterthur, Switzerland.

[CLE, 1989] Robert F. Cleveland and Whit T. Athey, "Specific absorption rate (SAR) in models of the human head exposed to hand-held UHF portable radios", *Bioelectromagnetics*, vol. 10, no. 1, pp. 173-186, Jan. 1989.

[STU, 1983] Stanisllaw S. Stuchly, Mariusz Barski, Benjamin Tam, Georhe Hartsgrove, and Steven Symons, "Computer-based scanning system for electromagnetic scanning", *Rev. Sci. Instrum.*, vol. 54, no. 11, pp. 1547-1550, Nov. 1983.

[BAL, 1995] Quirino Balzano, Oscar Garay, and Thomas J. Manning, "Electromagnetic energy exposure of simulated users of portable cellular telephones", *IEEE Transactions on Vehicular Technology*, vol. 44, no. 3, pp. 390-403, Aug. 1995.

[DASY2] Dosimetric Assessment System 2 (DASY2), Schmid & Partner Engineering AG, Oberer Deutweg 59, 8400 Winterthur, Switzerland.

[IDX] IDX Systems Inc., "Near field measurement systems", Tech. Rep., 20 NE Granger Ave Bldg. B, Coryallis OR 97330, USA, 1996.

[RIC, 1965] J.H. Richmond, "Digital computer solutions of the rigorous equations for scattering problems", *Proc. IEEE*, vol. 53, pp. 796-804, Aug. 1965.

[HAR, 1967] R.F. Harrington, "Matrix methods for field problems", *Proc. IEEE*, Feb. 1967, vol. 55, pp. 136-149.

[NEC2] NEC2 - Developed at Lawrence Livermore National Laboratory, available by anonymous ftp from ftp.netcom.com.

[MININEC] MiniNEC Professional - EM Scientific Inc., 2533 N. Carson Street, Suite 2107, Carson City, NV 89706.

[LIV, 1974] D.E. Livesay and K.M. Chen, "Electromagnetic fields induced inside arbitrary shaped biological bodies", *IEEE Transactions on Microwave Theory and Techniques*, vol. 32, no. 12, pp. 1273-1280, Dec. 1974.

[BRU, 1993] H.D. Brüns, H. Singer, and T. Mader, "Field distributions of a hand-held transmitter due to the influence of the human body", *Proc. of the 9th Symposium on Electromagnetic Compatibility*, Zürich, pp. 0-14, Mar. 1993.

[WANG, 1991] J.J.H. Wang, *Generalized Moment Methods in Electromagnetics*, Wiley, 1991.

[MIL, 1991] Edmund K. Miller, Louis Medgyesi-Mitschan, and Edward H. Newmann, Computational Electromagnetics - Frequency Domain Method of Moments, IEEE Press, 1991.

[LUD, 1989] Art Ludwig, "A new technique for numerical electromagnetics", *IEEE AP-S Newsletter*, vol. 31, pp. 40-41, Feb. 1989.

3OL, 1989] Gene H. Golub and Charles F. Van Loan, *Matrix Computations*, Johns Hopkins University Press, 2nd edition, 1989.

<US, 1993] Niels Kuster, "Multiple multipole method for simulating EM problems involving biological bodies", *IEEE Transactions on Biomedical Engineering*, vol. 40, no. 7, pp. 611-620, July 1993.

EG, 1993] Peter Regli, "Estimating the far field accuracy of MMP results", *2nd Int. Conference and Workshop on Approximations and Numerical Methods for the Solution of the Maxwell Equations*, The George Washington University, Workshop Proceedings, Oct. 1993.

IAF, 1990] Ch. Hafner, *The Generalized Multipole Technique for Computational Electromagnetics*, Artech House Books, 1990.

IAF, 1993] Ch. Hafner and Lars H. Bomholt, *The 3D Electrodynamic Wave Simulator*, New York: John Wiley & Sons Inc., 1993.

US, 1992a] Niels Kuster, "Multiple multipole method applied to an exposure safety study", *ACES Special Issue on Bioelectromagnetic Computations*, A.H.J. Fleming and K.H.Joyner, Eds., vol. 7, pp. 43-60. Applied Computational Electromagnetics Society, No. 2, 1992.

'AY, 1994] Roger Yew Tay and Niels Kuster, "Performance of the generalized multipole technique (GMT/MMP) for antenna design and optimization", *Applied Computational Electromagnetics (ACES) journal*, vol. 9, no. 3, pp. 79-89, Dec. 1994.

'EE, 1966] K. S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media", *IEEE Transactions on Antennas and Propagation*, vol. 14, pp. 585-589, 1966.

OE, 1989] W.J.R. Hoefer, *The Transmission Line Matrix (TLM) Method*, T. Itoh, John Wiley & Sons, 1989.

'EI, 1990] T.Weiland, "Maxwell's grid equations", *Frequenz*, vol. 44, no. 1, pp. 9-16, 1990.

ERN, 1995] S. Berntsen and S.N. Hornsleth, "Retarded time absorbing boundary condition", *IEEE Transactions on Antennas and Propagation*, 1995.

UR, 1981] G. Mur, "Absorbing boundary conditions for the finite-difference approximation of the time-domain electromagnetic field equations", *IEEE Transactions on Electromagnetic Compatibility*, vol. 23, pp. 377-382, 1981.

ERE, 1994] J.P. Berenger, "A perfectly matched layer for the absorption of electromagnetic waves", *Journal of Computational Physics*, vol. 4, pp. 185-200, 1994.

AF, 1988] Allen Taflove, "Finite-difference time-domain (FD-TD) modeling of electromagnetic wave scattering and interaction problems", *IEEE AP-S Newsletter*, pp. 5-20, Apr. 1988.

[TAF, 1975] K. Umashankar and Allen Taflove, "A novel method to analyze electromagnetic scattering of complex objects", *IEEE Transactions on Electromagnetic Compat.*, vol. 25, no. 2, pp. 623-660, Feb. 1975.

[GAN, 1990] Om P. Gandhi, "Numerical methods for specific absorption rate calculations", Biological Effects and Medical Applications of Electromagnetic Energy, Om P. Gandhi, Ed., pp. 113-140. Prentice Hall Advanced Reference Series, 1990.

[PED, 1994] Gert Frolund Pedersen and Jorgen Bach Andersen, "Integrated antennas for handheld telephones with low absorption", *IEEE Vehicular Technology Conference 44rd*, Stockholm, Sweden, June 1994, pp. 1537-1541.

[DIM, 1994] Peter J. Dimbylow and S.M. Mann, "SAR calculations in an anatomically realistic model of the head for mobile communication transceivers at 900 MHz 1.8 Ghz", *Phys. Med. Biol.*, vol. 39, no. 12, pp. 1537-1553, 1994.

[JEN, 1995] Michael A. Jensen and Yahya Rahmat-Samii, "EM interaction of handset antennas and a human in personal communications", *Proceeding of the IEEE*, vol. 83, no. 1, pp. 7-17, Jan. 1995.

[MAR, 1995] Luc Martens, J. De Moerloose, and D. De Zutter, "Calculation of the electromagnetic fields induced in the head of an operator of a cordless telephone", *Radio Science*, vol. 30, no. 1, pp. 283-290, Jan. 1995.

[SCI, 1996] A. Schiavoni and G. Richiard, "FDTD analysis of the EM fields in a human head like phantom and comparison with measurements", *13th International Wroclaw Symposium and Exhibition on EMC*, June 25 - 28, 1996.

[TAF, 1995] A. Taflove, *Computional Electrodynamics: The Finite-Difference Time-Domain Method*, Artech House, 1995.

[KUNZ, 1993] Karl S. Kunz and Raymond J. Luebbers, *The finite difference time domain method for electromagnetics*, CRC Press, 1993.

[CST] *The MAFIA collaboration*, User's Guide Mafia Version 3.x, CST GmbH, Lautenschlaegerstr. 38, D 64289 Darmstadt, 1994.

[XFDTD] *XFDTD*, Remcom Inc., Calder Square, P.O. Box 10023, State College, PA 16805-0023, USA.

[IEMA] ElectroMagnetic Applications, IEMA Inc., *FDTD code*.

[SIL, 1996] Peter P. Silvester and Ronald F. Ferrari, *Finite Elements for Electrical Engineers*, Cambridge University Press, Cambridge UK, Apr. 1996.

[SUN, 1995] Din Sun, John Manges, Xingchao Yuan, and Zoltan Cendes, "Spurious modes in finite-element methods", *IEEE Antennas and Propagation Magazine*, vol. 37, no. 5, pp. 12, 1995.

[LYN, 1985] Daniel R. Lynch, Keith D. Paulsen, and John W. Strohbehn, "Finite element solution of maxwell's equations for hyperthermia treatment planning", *Journal of Computational Physics*, vol. 58, pp. 246-269, 1985.

)S, 1988] A. Bossavit, "A rationale for "edge elements" in 3-d fields computations", *IEEE Transactions on Magnetics*, vol. 24, pp. 74-79, 1988.

\, 1993] J. Jin, *The Finite Element Method in Electromagnetics*, Wiley, 1993.

\M, 1995] D. Simunic, P. Wach, W. Renhart, and R. Stollberger, "RF energy deposition in the human head during magnetic resonance imaging", *Electromagnetic Compatibility, 11th International Zurich Symposium*, pp. 275-278, 1995.

1S, 1988] C.R.I. Emson, "Methods for the solution of open-boundary electromagnetic-field problems", *IEE Proceedings*, number 3, Mar. 1988.

)M, 1994] Lars H. Bomholt, "Coupling of the generalized multipole technique and the finite element method", *Applied Computational Electromagnetics Society Journal*, vol. 9, no. 3, pp. 63-68, 1994.