SAR – A Basic Restriction for Electromagnetic Field Safety

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Electromagnetic Fields

- A form of energy
- Non-ionizing
- Can be propagated through space
- Can interact with biological tissue (absorption)

Biological Effects

- Biological Effects
  - Below approximately 100 kHz effects focus on induced current density and electro-stimulation of cells.
  - From 100 kHz to 3 GHz bulk tissue absorption is the primary mechanism.
  - Above about 3 GHz, heating of superficial tissues (body surfaces) become more important that body absorption..

Biological Effects

- Biological Effects
  - Below approximately 100 kHz effects focus on induced current density and electro-stimulation of cells.
  - **From 100 kHz to 3 GHz bulk tissue absorption is the primary mechanism.**
  - Above about 3 GHz, heating of superficial tissues (body surfaces) become more important that body absorption.

Basic Restrictions - Definitions

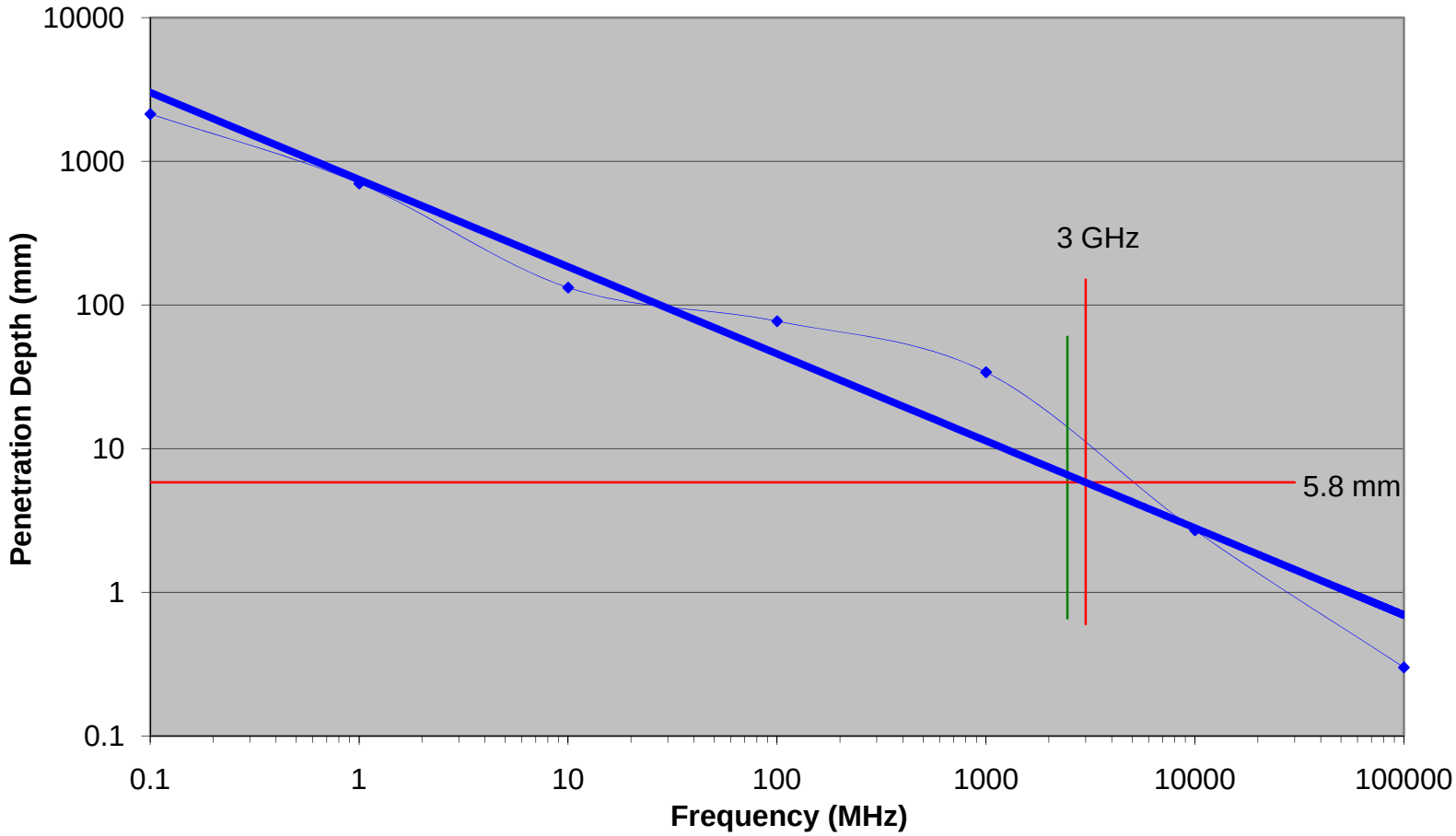
- IEEE C95.1: Exposure restrictions that are based on established adverse health effects that incorporate appropriate safety factors and are expressed in terms of:
  - *In Situ* electric field (3 kHz to 5 MHz)
  - Specific absorption rate (100 kHz to 3 GHz)
  - Incident power density (3 GHz to 300 GHz)

- ICNIRP: Restrictions ... that are based directly on established health effects

Specific Absorption Rate (SAR)

- Units of Watts/kg
- Maximum allowable SAR empirically determined to be 4 W/kg
- Safety factor (10X) added – 0.4 W/kg
- Basis for determination of MPE (maximum permissible exposure) fields
- Variation with penetration depth
- Variation with frequency (body resonance)

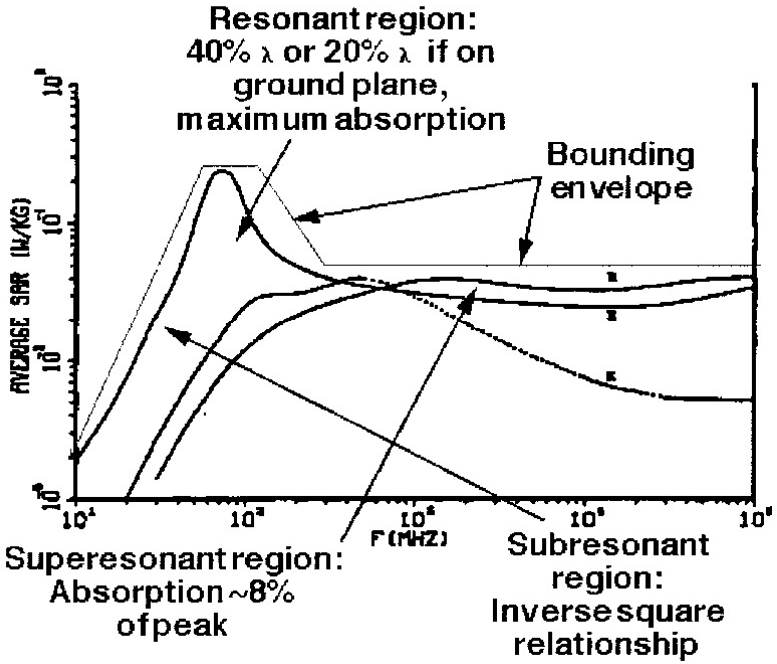
Field Penetration Depth in muscle tissue

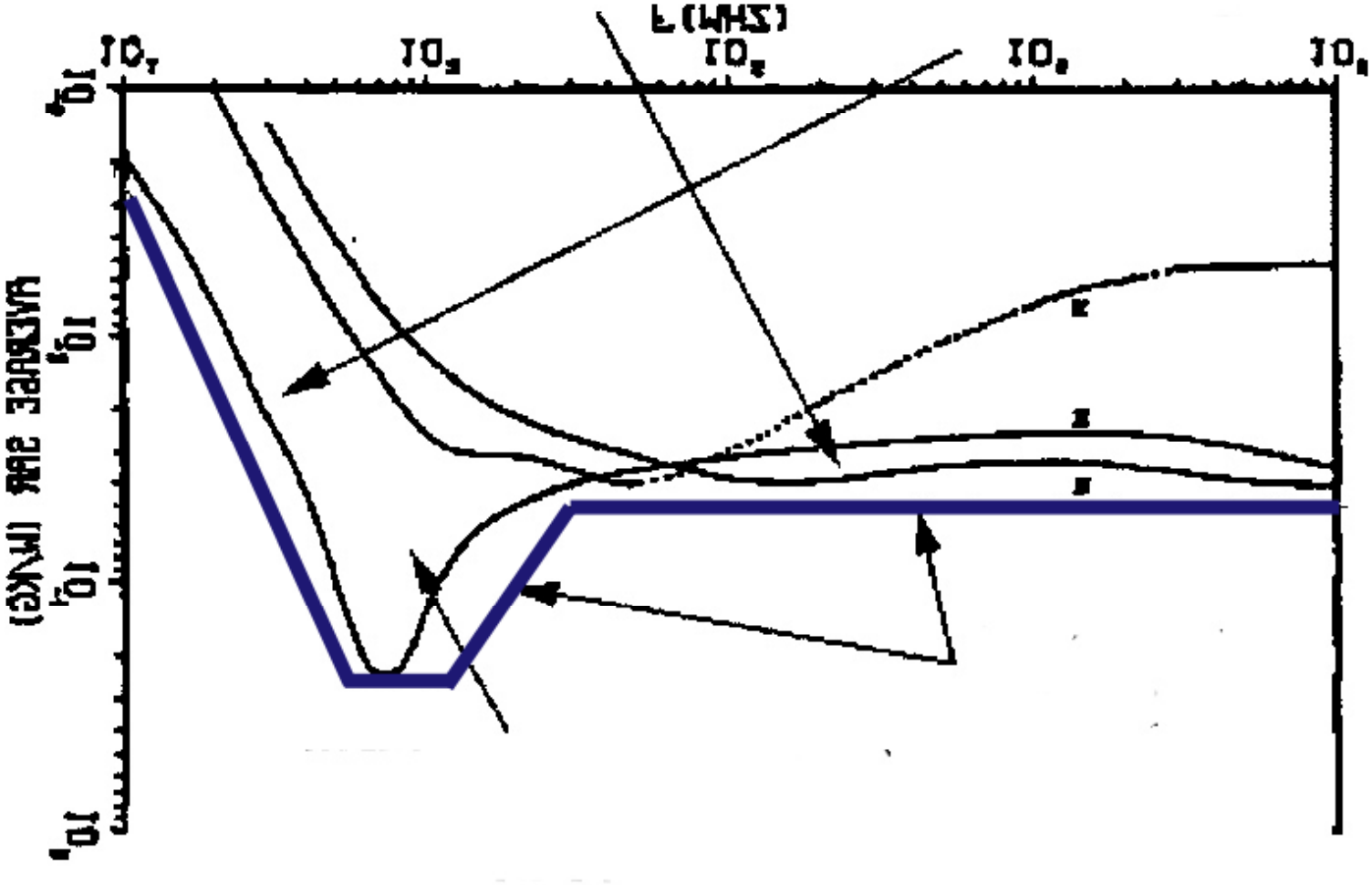


SAR vs. Frequency

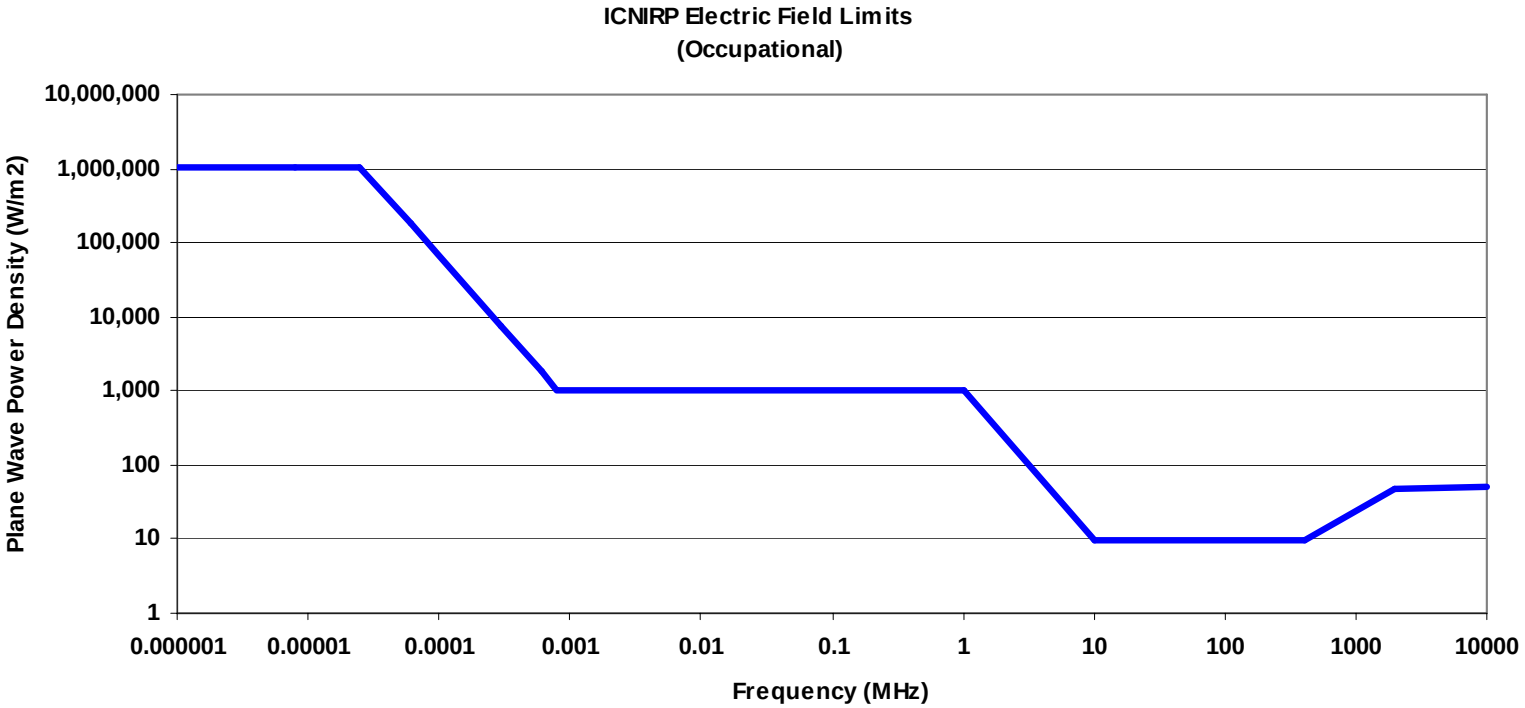
The size of an organism affects absorption

- A rule of thumb is an object absorbs most when 40% of wavelength if insulated or 20% of wavelength if well grounded.
- So a lab rat will best absorb a shorter wavelength than a human!





Typical Safety Guideline



Standards Driven

- IEEE C95.1- 2005
- ICNIRP
- National Standards:
  - ACGIH
  - FCC
  - US Food and Drug Administration (FDA)
  - Mexico, Canada, UK

Reference Levels - Occupational

Table 6 Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20 000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20 000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

Reference Levels – General Public

Table 7 Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values)

Frequency range	E-field strength ($V\ m^{-1}$)	H-field strength ($A\ m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W\ m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

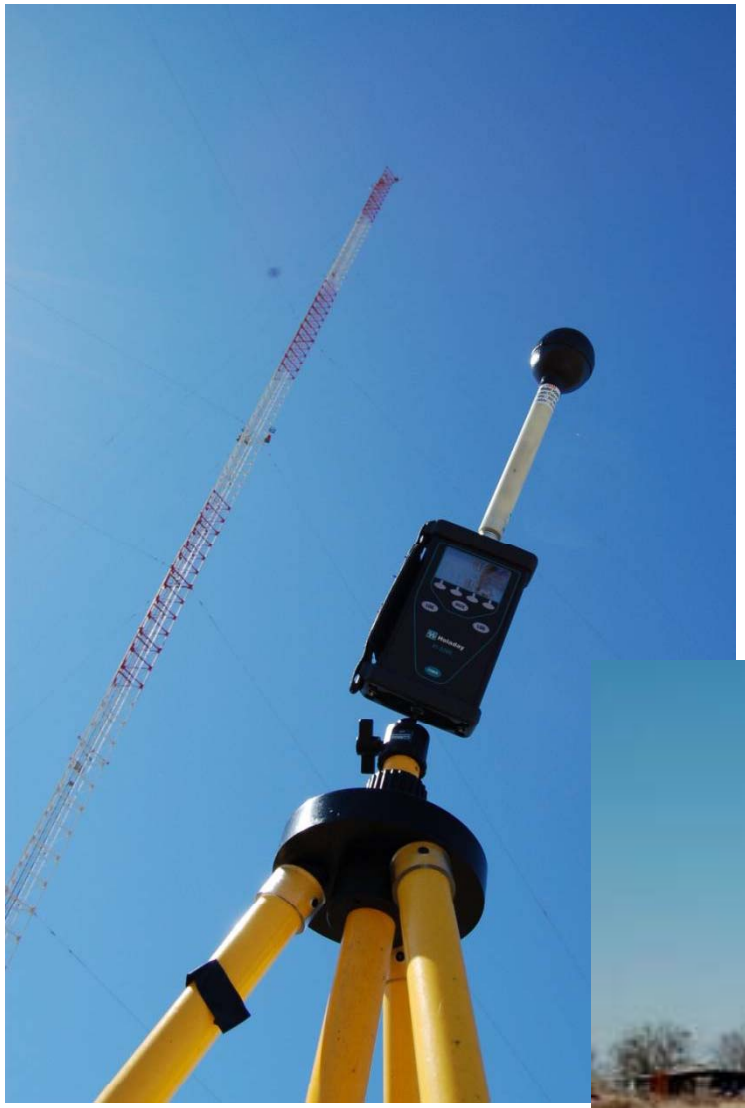
Field Strength ⟶ SAR

- Field Strength Limits
  - Maximum Permissible Exposures (MPEs)
  - Reference Levels
- Empirical testing to determine MPE
- Exposure variables
- Conservative MPE values
- Exceeding MPE values does not assure that SAR limits are exceeded

Exposure Monitoring Methods

- Estimating SAR with Indirect Measurements
  - Electric Fields
  - Magnetic Fields
  - Induced Currents
- Direct SAR Measurement Methods
  - Simulated Exposure Environment

Field Measurements



1 MHz
50,000 watts

Whole-Body Averaging

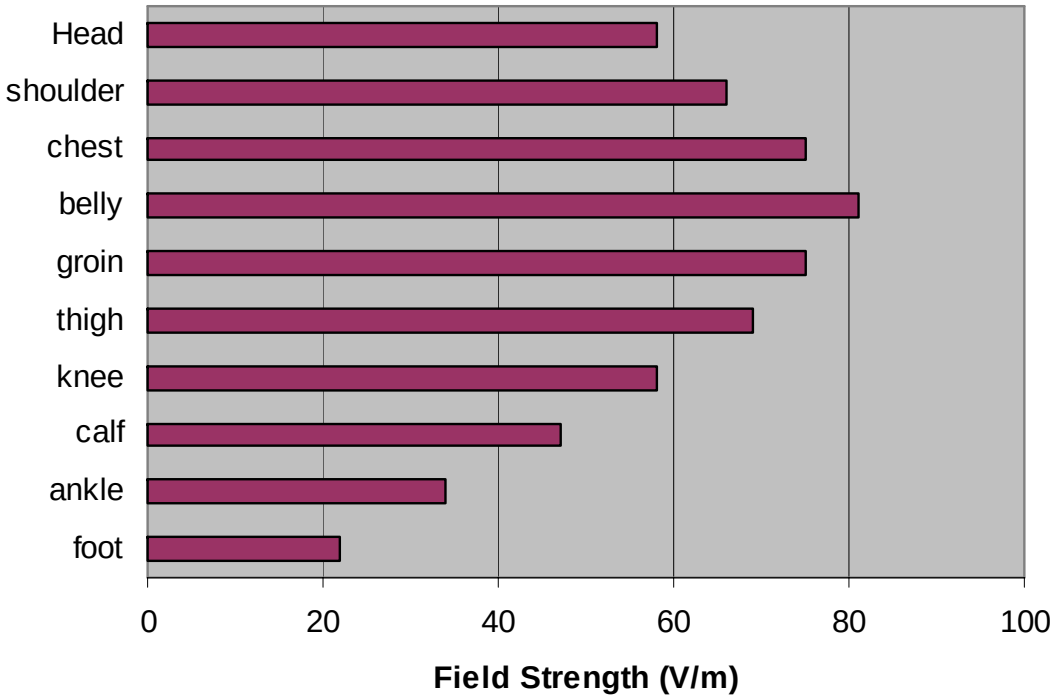
- Exposure limits are based on “unperturbed” fields
- Replacing the subject with a surrogate yields more accuracy
- Dielectric Stickman used to simulate subject
- Use as guide for “whole-body” average reading

Whole-Body Averaging

- Replacing the subject with a surrogate yields more accuracy
- Dielectric Stickman used to simulate subject
- Multiple data points are recorded over the body area.
- Use as guide for “whole-body” average reading

Spatial Averaging Example

- Series of 10 measurements
- Spaced over subject's body
- Average power density (square of field values)
- Compare to limits in standard

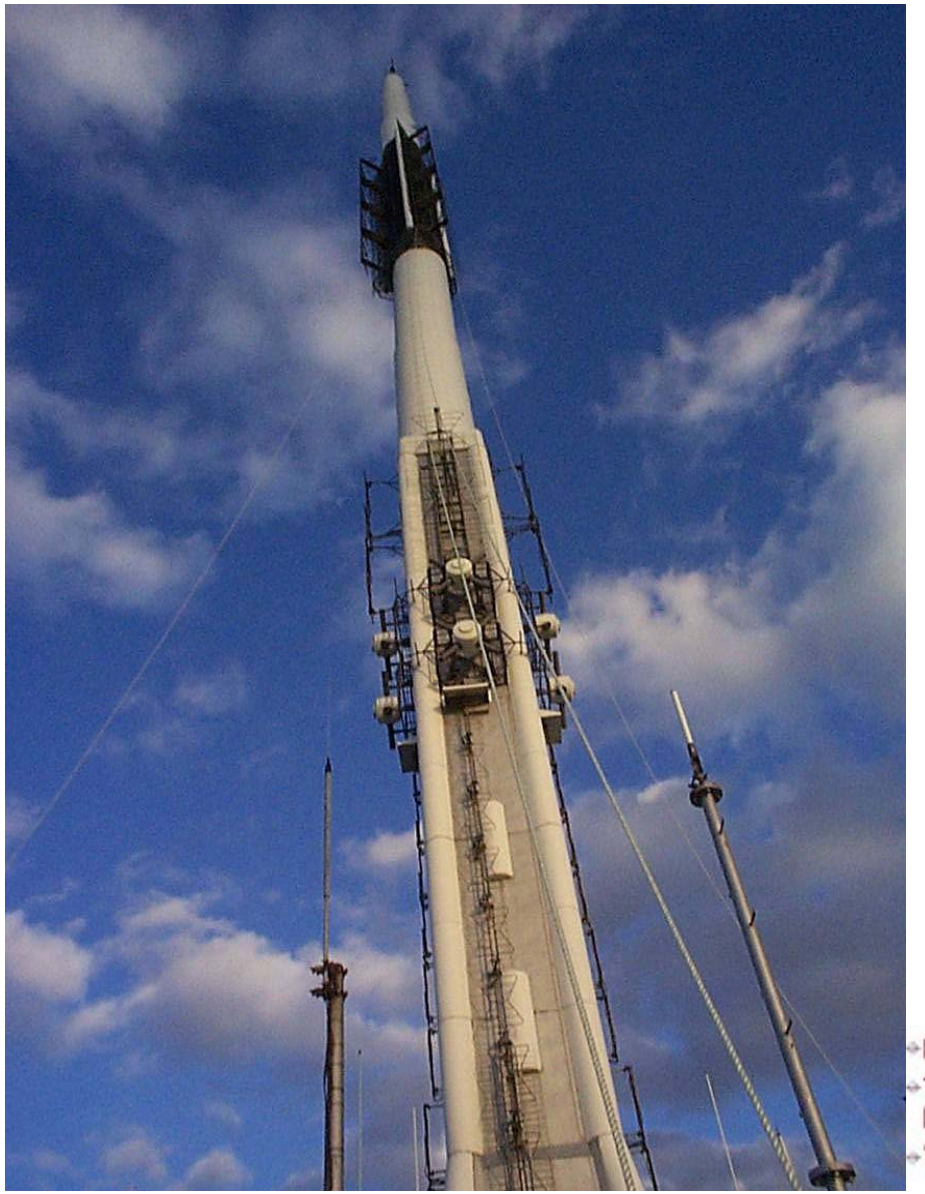


Calculating Spatial Average Exposure

- Measure field data points
- Square field values and average
- Compare average value to limits in standard

	Location	Field Strength (V/m)	|FSU|2
1	foot	22	484
2	ankle	34	1156
3	calf	47	2209
4	knee	58	3364
5	thigh	69	4761
6	groin	75	5625
7	belly	81	6561
8	chest	75	5625
9	shoulder	66	4356
10	Head	58	3364
	Average	61.2	3751

High Power 100 MHz Application

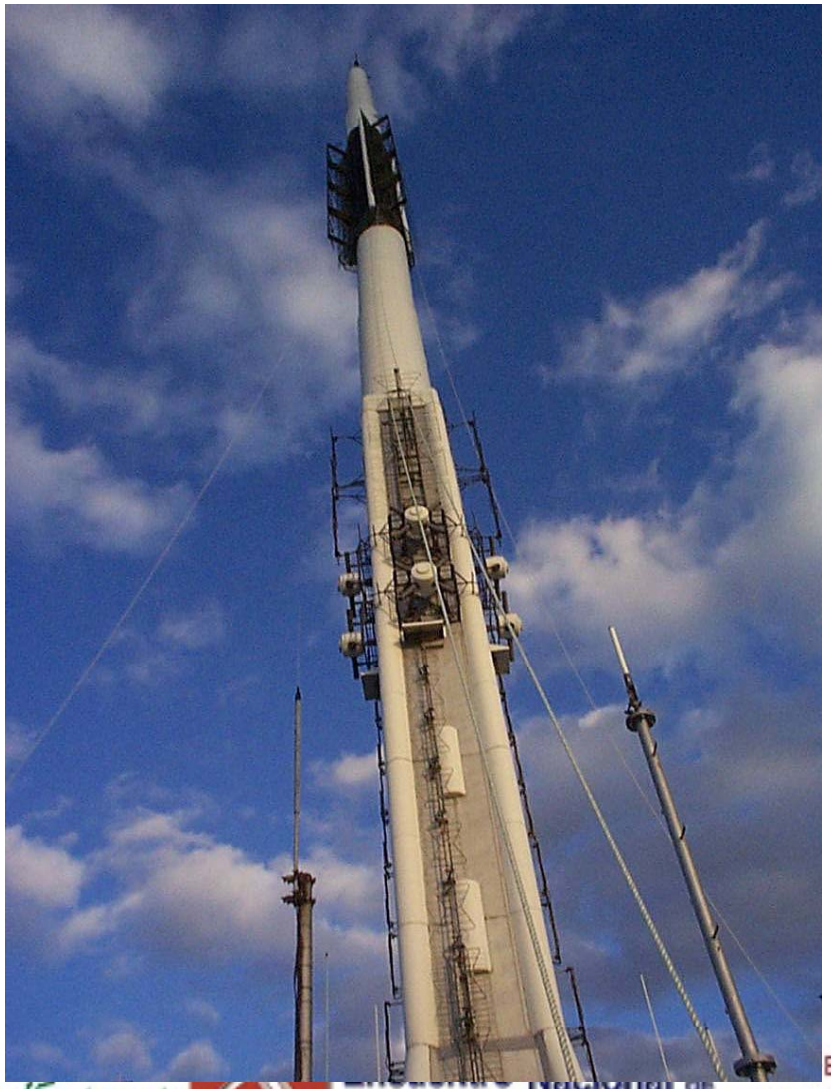


100 MHz
50,000 watts
x 8 antennas

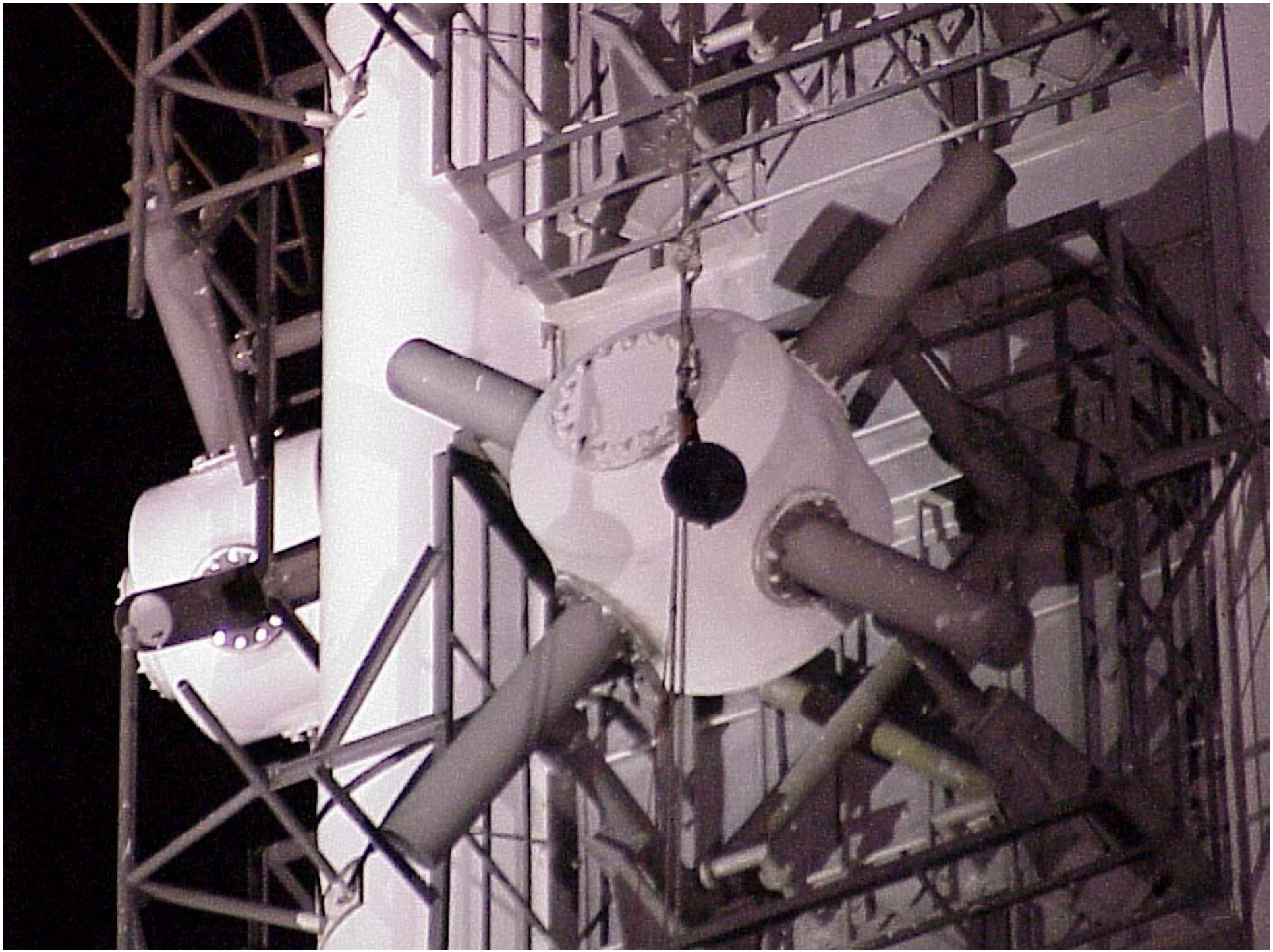
Electromagnetismo
Temperatura y Propiedades Termofísicas
Tiempo y Frecuencia

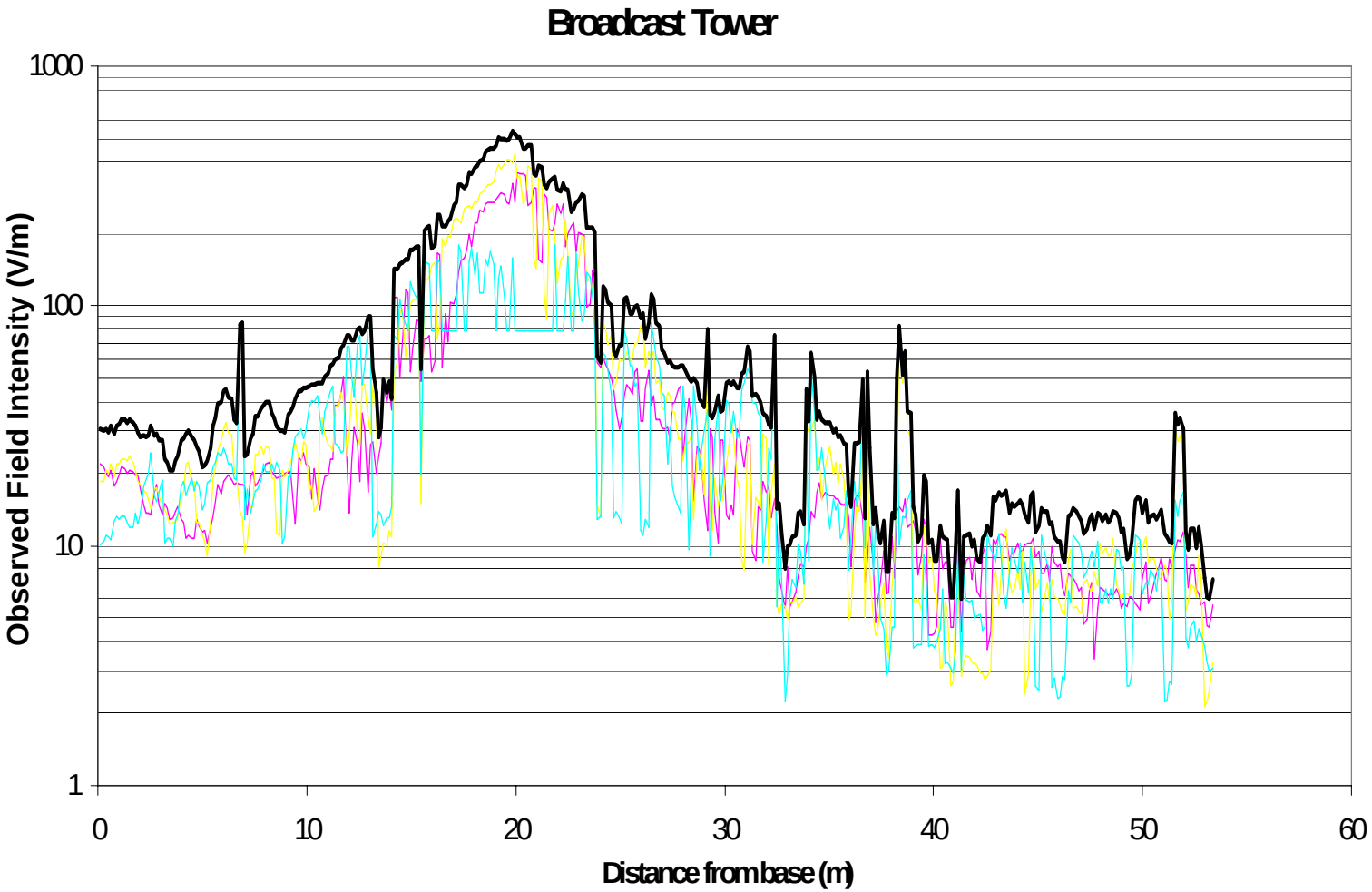
- Multiple RF Sources

Broad Range of Field Intensities

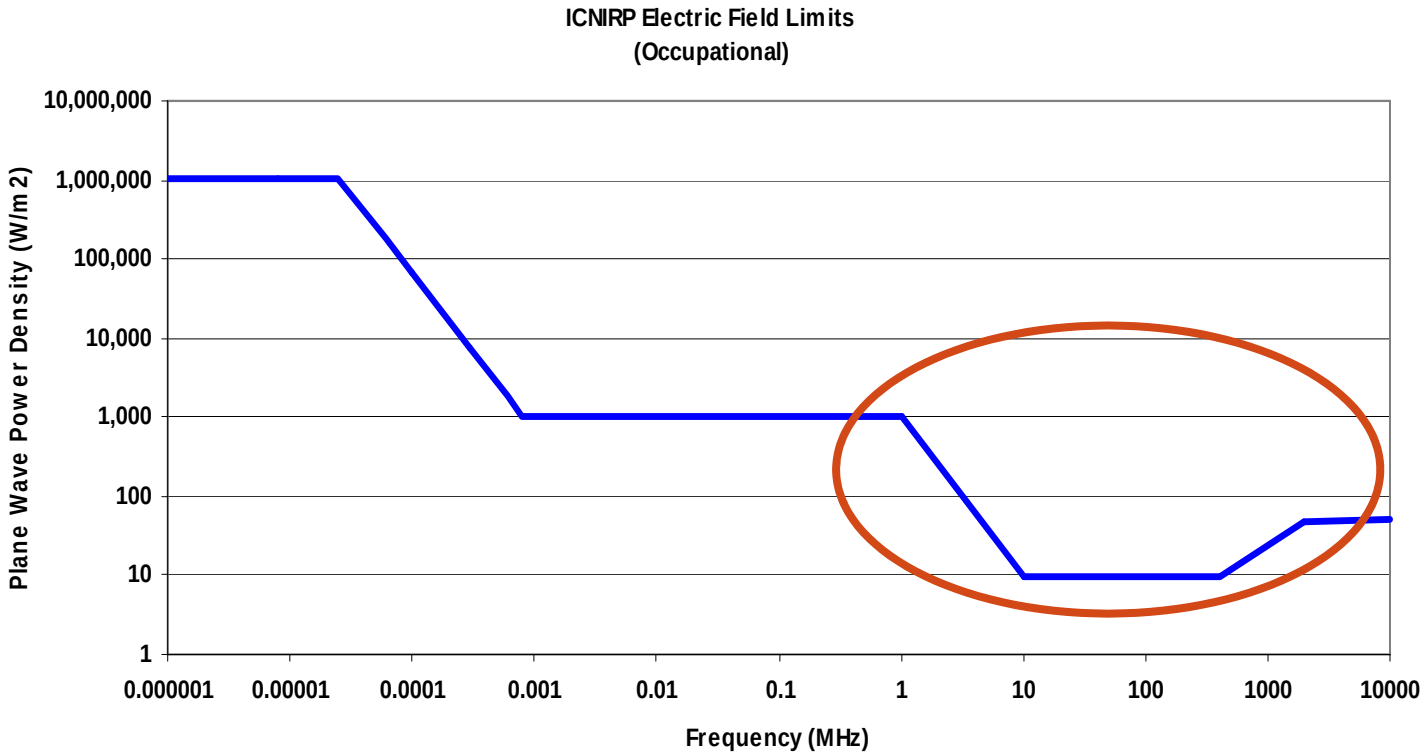


Wide dynamic range required



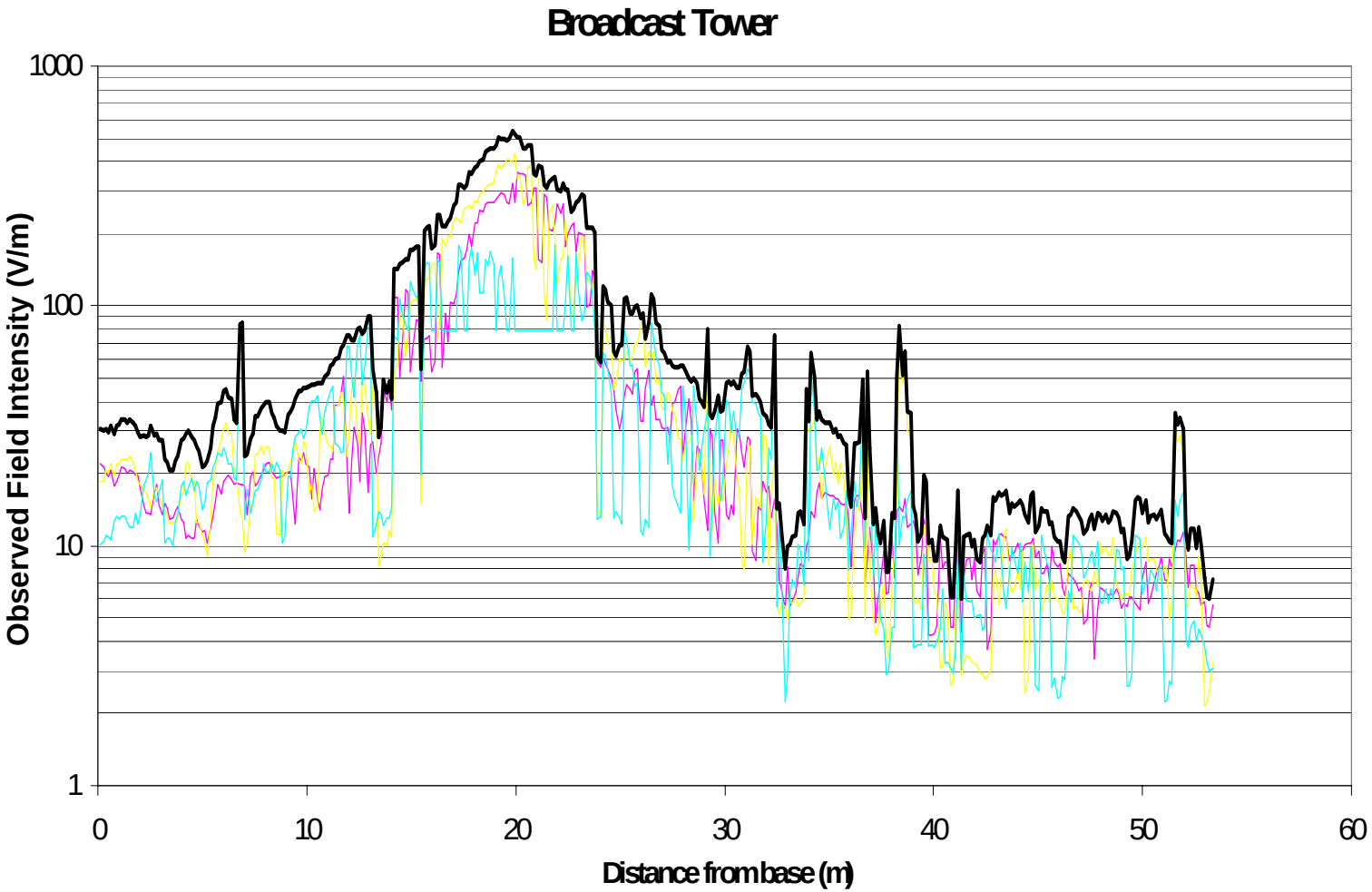


Frequency Dependence

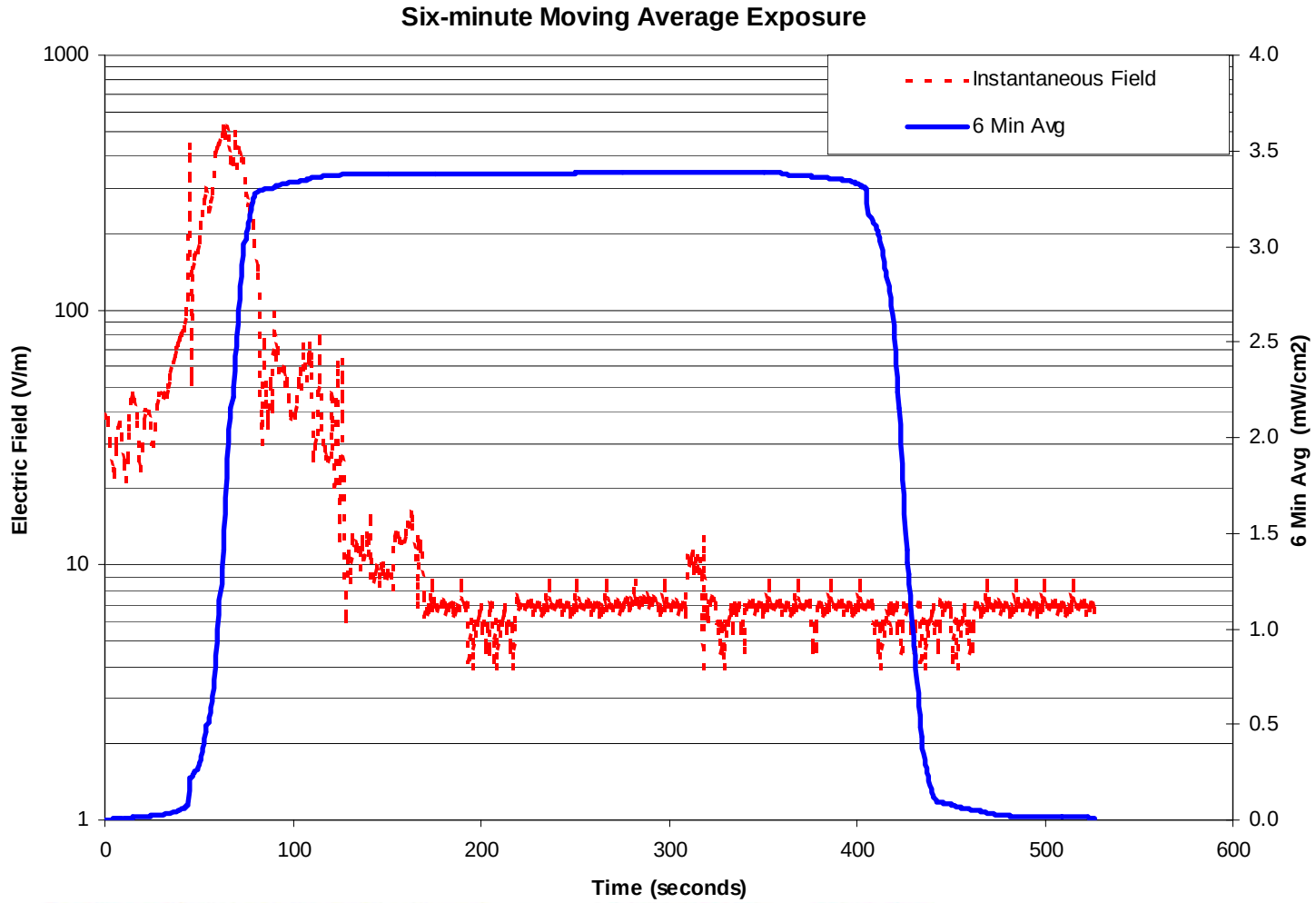


Occupational Exposure Guidelines

- 61.4 V/m [10 Watts/m^2] at 100 MHz
- Time averaged exposure (6 Minutes)



Time-Averaged Personnel Exposure

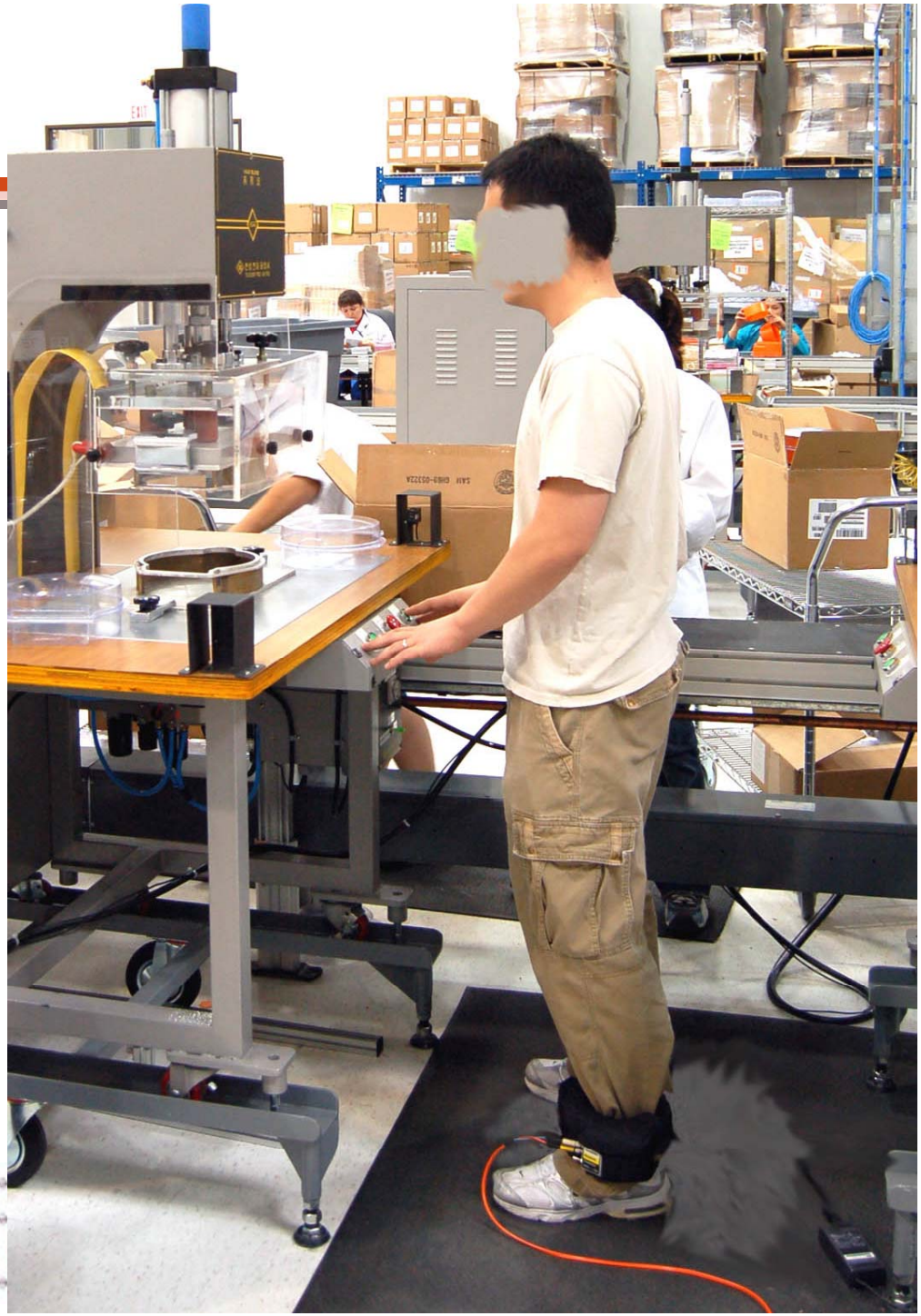


Exposure Monitoring Methods

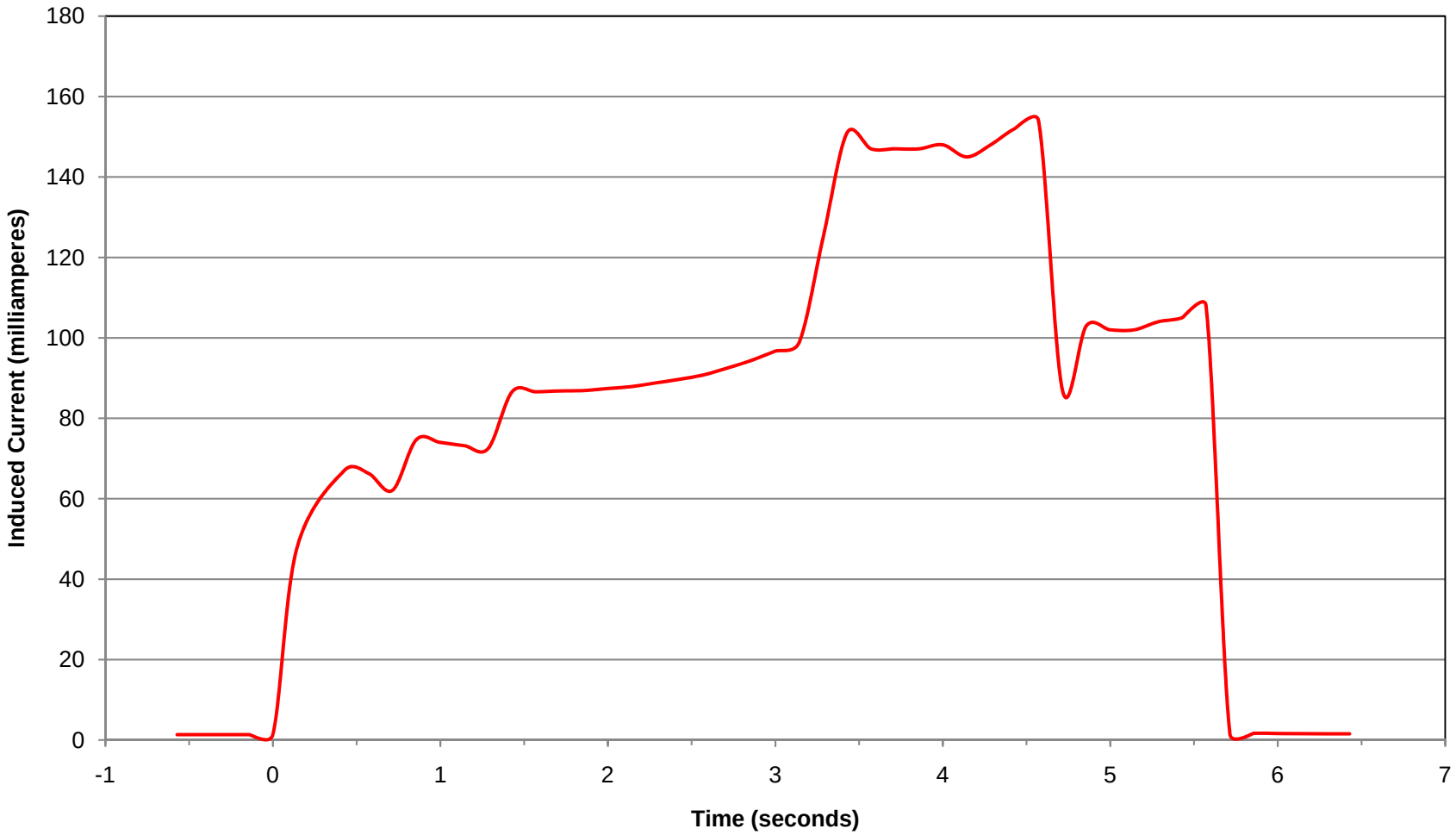
- Estimating SAR with Indirect Measurements
  - Electric Fields
  - Magnetic Fields
  - Induced Currents
- Direct SAR Measurement Methods
  - Simulated Exposure Environment

Induced Currents

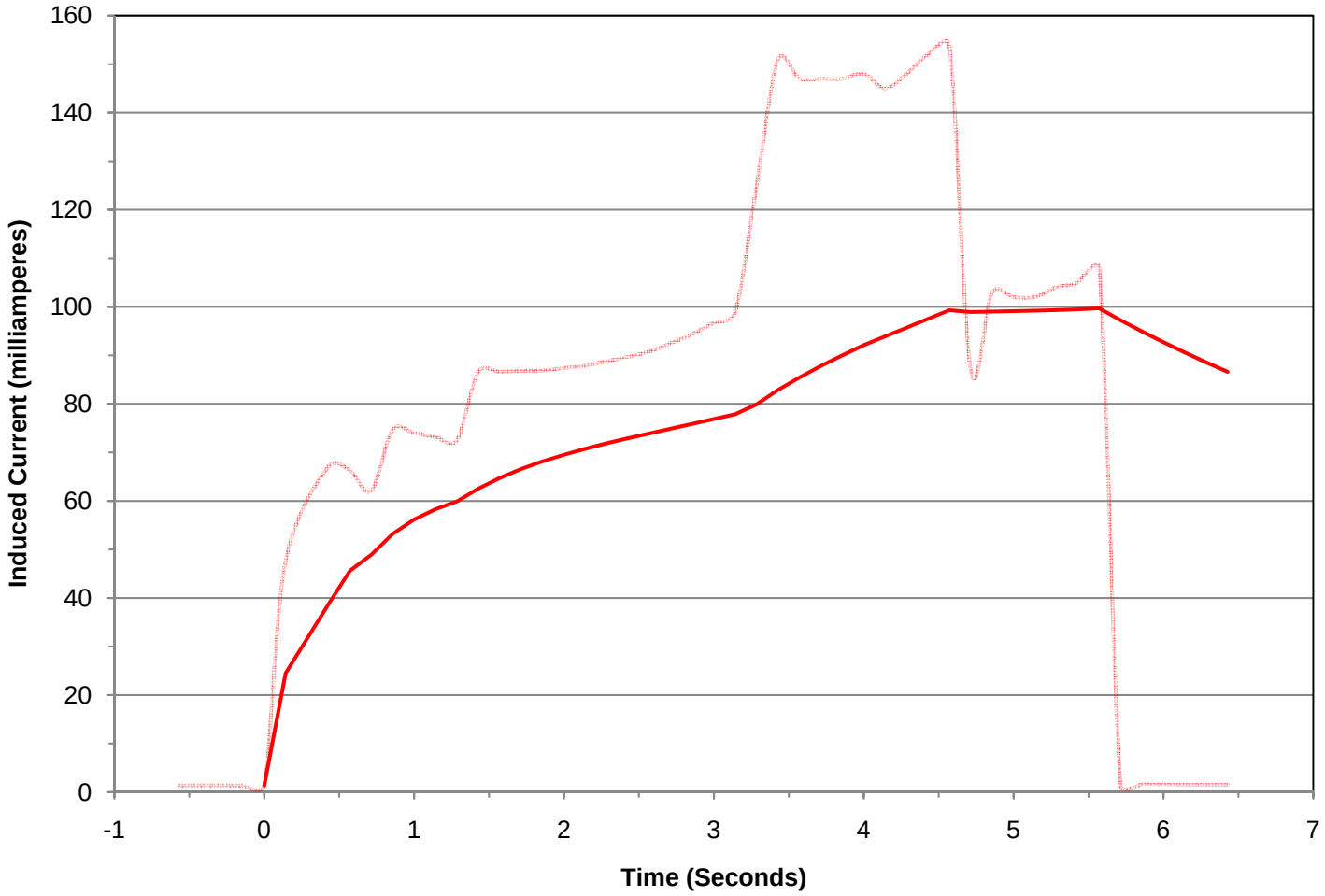
- Currents induced in subject's body by RF electric fields
- Absorbed energy can be greater than that predicted by field measurements



Induced Current During Heating Cycle



Average Induced Current



Calculating SAR from Induced Current

$$J = \frac{I}{A}$$

amperes per square meter

$$SAR = \frac{J^2}{\sigma \rho}$$

watts per kilogram

RMS induced and contact current limits for continuous sinusoidal waveforms, f = 100 kHz to 110 MHz

Condition	Action Level [a] (mA)	Persons in Controlled Environments (mA)
Both feet	90	200
Each foot	45	100
Contact, grasp [b]	-	100
Contact, touch	16.7	50

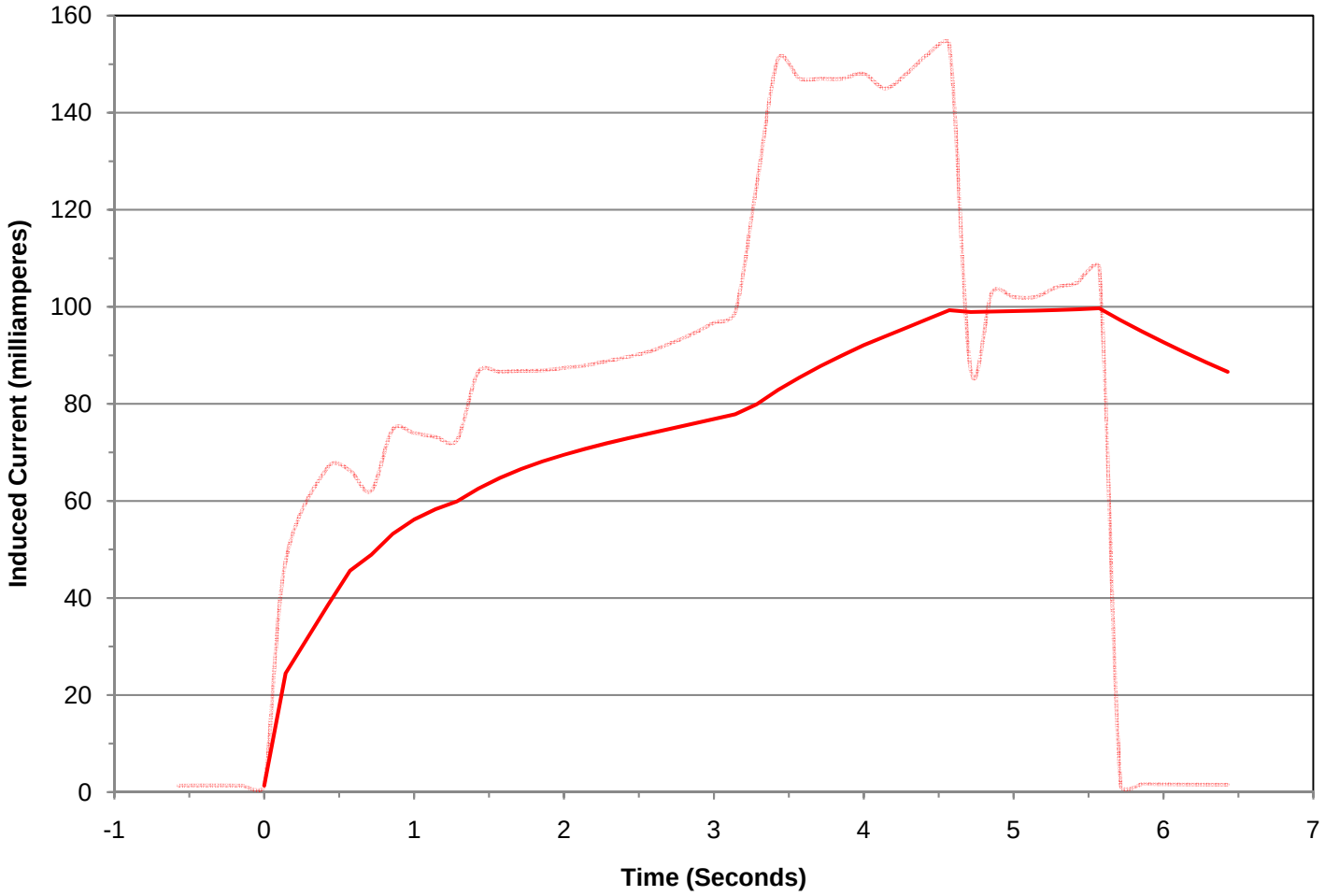
NOTE 1—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.

NOTE 2—The averaging time for determination of compliance is 6 minutes.

[a] MPE for the general public in absence of an RF safety program.

[B] Grasping contact limit pertains to controlled environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact

Average Induced Current



Induced Current with Insulating Mat

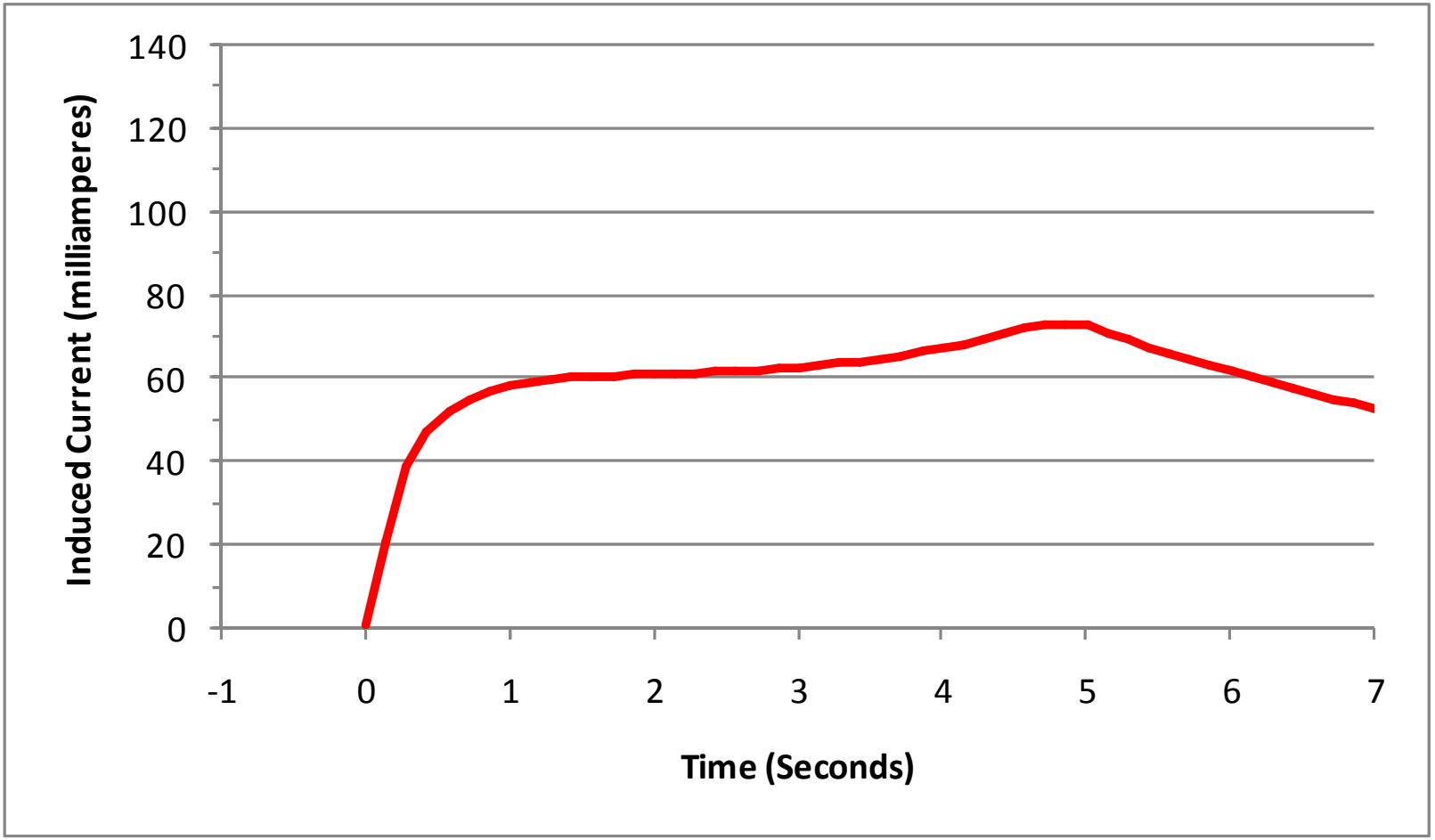
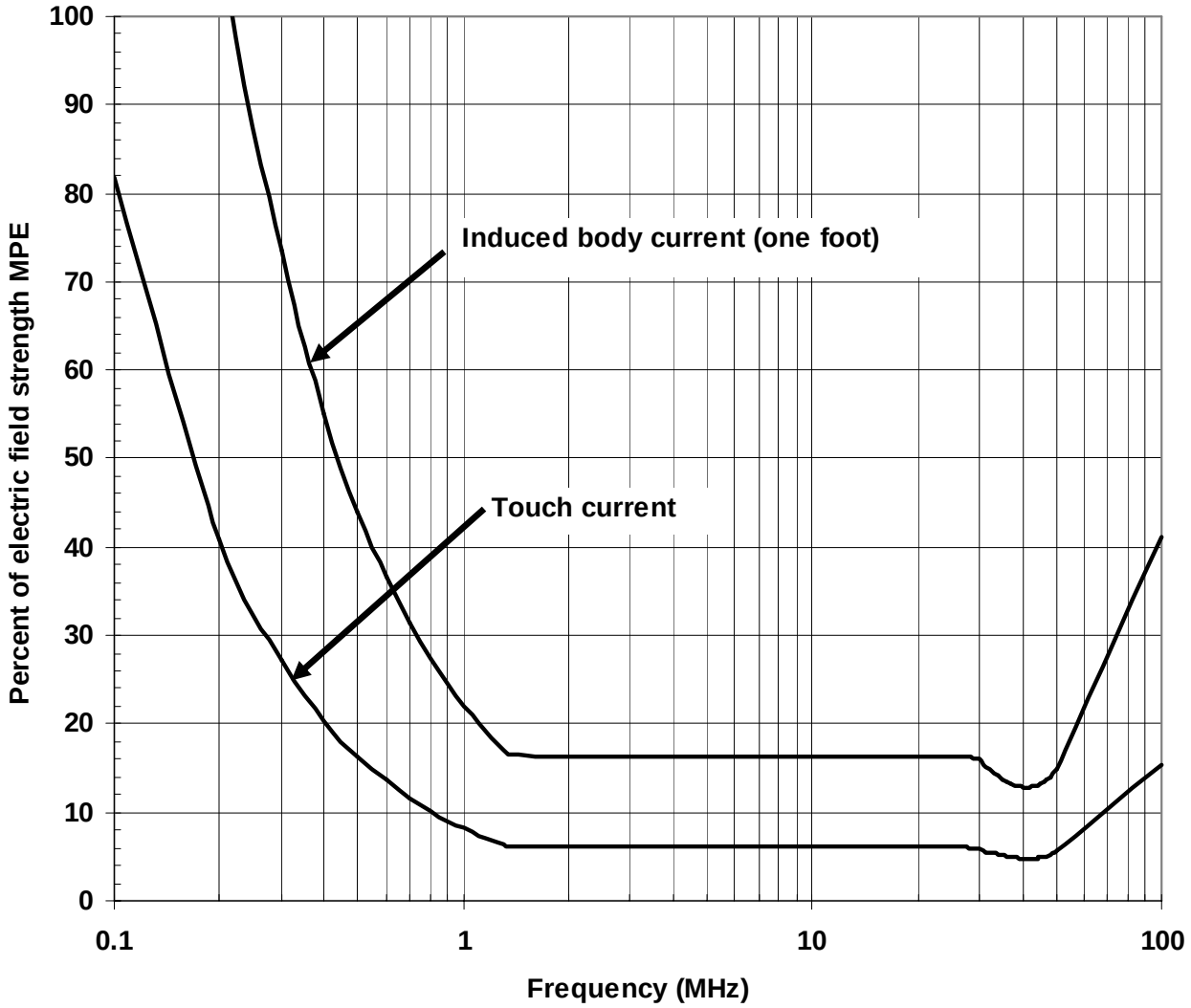


Figure 2—Percent of electric field strength MPE below which the induced current through one foot, or the touch current, will meet the MPEs of Table 7 for the lower tier. Based on a body height of 1.75 m.



Exposure Monitoring Methods

- Safety requires compliance with basic restrictions
  - Free-field measurements are one means of evaluating compliance
- Exposures in excess of standards (MPE values) do not necessarily mean that basic restrictions are exceeded
- It is possible to directly evaluate SAR, however, this evaluation is :
  - Complex
  - Expensive
  - Time-consuming

Exposure Monitoring Methods

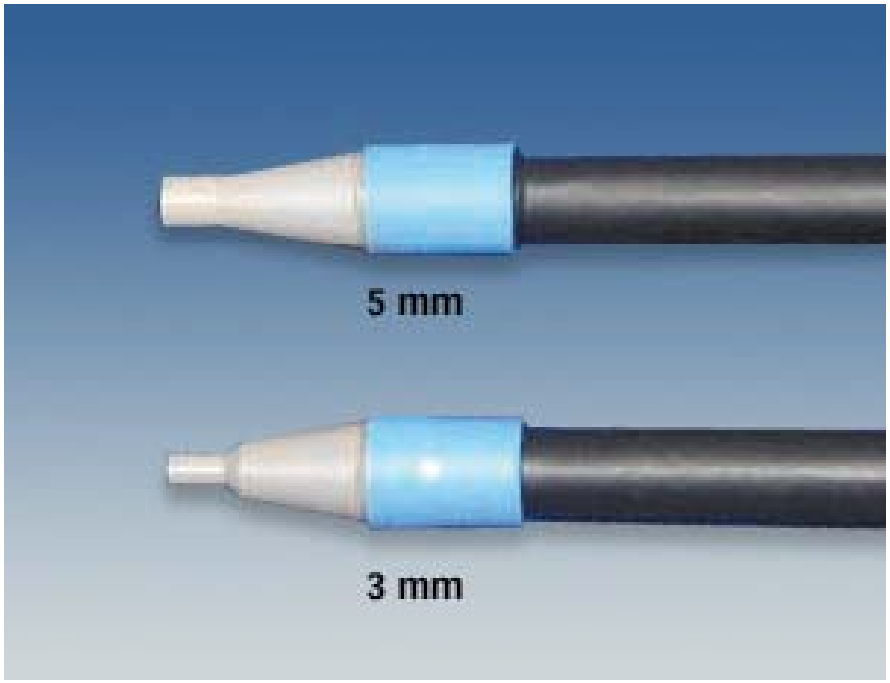
- Estimating SAR with Indirect Measurements
  - Electric Fields
  - Magnetic Fields
  - Induced Currents

- Direct SAR Measurement Methods
  - Simulated Exposure Environment

SAR Measurement

- Complex coupling between RF source and subject
- Use phantom subject to directly measure internal RF electric field strengths

SAR Electric Field Probes



- Small isotropic field probes to resolve the RF field distribution within the phantom head

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

- Phantom head with standard shape (SAM)
- Filled with ‘tissue equivalent fluid’ having know dielectric characteristics
- Measure electric field distribution within the phantom head
- Calculated SAR in accordance with the applicable standards (IEEE 1528, IEC 622209)
- 2 watts/kg averaged over an 10 grams of tissue

SAR Test Data Results

- SAR test results for mobile phones available on-line
  - Government regulatory agencies
  - Phone manufacturers

- US Federal Communications Commission
  - FCC SAR limit: 1.6 watts per kilogram
  - http://www.fcc.gov/oet/ea/fccid/

- http://docs.blackberry.com/en/smartphone_users/deliverables/5473/SIB_8100_293846_11.pdf

Specific absorption rate data

THIS WIRELESS DEVICE MODEL MEETS GOVERNMENT REQUIREMENTS FOR EXPOSURE TO RADIO WAVES.

The BlackBerry® device is a radio transmitter and receiver. It is designed and manufactured not to exceed the emission limits for exposure to radio frequency (RF) energy set by the Federal Communications Commission (FCC) of the U.S. Government, Industry Canada of the Canadian Government (IC), and recommended by The Council of the European Union. These limits are part of comprehensive guidelines and establish permitted levels of RF energy for the general population.

The highest SAR value for each device model when tested for use at the ear is outlined below:

Device	1 g / 10 g SAR (W/kg)
BlackBerry® Pearl™ 8100 smartphone	1.22/0.76

The highest reported SAR value for this BlackBerry device when clipped on a belt, in a Research In Motion (RIM) approved holster equipped with an integrated belt clip, is outlined below.

Device	1 g / 10 g SAR (W/kg)
BlackBerry 8100 smartphone	1.52/0.98

In Summary…

- Each means of determining compliance with EMF safety standards uses an estimator of the basic restriction
- Lack of compliance with an MPE (maximum permissible exposure) requirement does not necessarily mean non-compliance with the basic restriction
- It is important to choose the most practical field parameter to monitor when performing EMF safety evaluations.
- Select the proper instrumentation for your measurements

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18-20 de noviembre

- Electromagnetismo
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Gracias