RF Safety Solutions LLC

RF Safety Analysis versus EMC

IEEE

Prepared for

Long Island Chapter

IEEE EMC Society

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RF Safety versus EMC

Related disciplines with major differences.

Topics

- EMC versus RF Safety—an Overview
- RF Safety Biology
- RF Safety Standards
- RF Safety Measurements
- Summary

EMC versus RF Safety—Overview

Types of measurements, objectives, levels, frequencies, units of measure, and test environments.

EMC Measurements

- Radiated susceptibility
- Conducted susceptibility
- Radiated emissions
- Conducted emissions
- Resistance to ESD

RF Safety Measurements

- Field intensity
- Induced and contact currents (not common)

Objectives

- **EMC:** Determine whether a UUT functions correctly when subjected to RF fields.
- **RF Safety:** Insure that people are not exposed to potentially hazardous RF fields.

Typical Electric Field Levels

- **EMC:**

  3 to 200 V/m (2.5 μW/cm² to 11 mW/cm²)

- **RF Safety:**

  6 to 1,380 V/m (10 μW/cm² to 500 mW/cm²)

Units of Measure

- **EMC:**

  V/m and A/m

- **RF Safety:**

  mW/cm² and Percent of Standard

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Frequency Range

- **EMC:**

  10 kHz to 40 GHz

- **RF Safety:**

  Standards: 3 kHz to 300 GHz

  Measurements: 300 kHz to 100 GHz

EMC Measurement Environments

- Anechoic chamber
- TEM cell
- G-TEM cell
- Antenna range (indoor or outdoor)

RF Safety Environments

- Outdoors
- Around industrial processing equipment
- Waveguide leaks

Biology

Non-ionizing versus ionizing radiation and RF bio effects

Ionizing versus Non-ionizing

- The electromagnetic spectrum generates two types of radiation:
  – Ionizing radiation
  – Non-ionizing radiation

Ionizing versus Non-ionizing Radiation

Sources and Effects
are totally different

Defining an Electromagnetic Wave

- ***Frequency***—most common definition for people working in electronics.
- ***Wavelength***—most common way of defining light "frequencies", also used in electronics. $\{\lambda_{\text{(meters)}} = 300/f_{\text{(MHz)}}\}$
- ***Energy***—most common way of defining the higher "frequency" sources of energy such as x-rays and gamma rays. $\{E_{\text{(energy)}} = h \times f\}$

Ionizing Versus Non-ionizing Radiation

- ENERGY = h x f
  - Where f = frequency

    h = Planck's constant

    $(6.63 \times 10^{-34}$ joule seconds)
  - The higher the frequency, the higher the energy

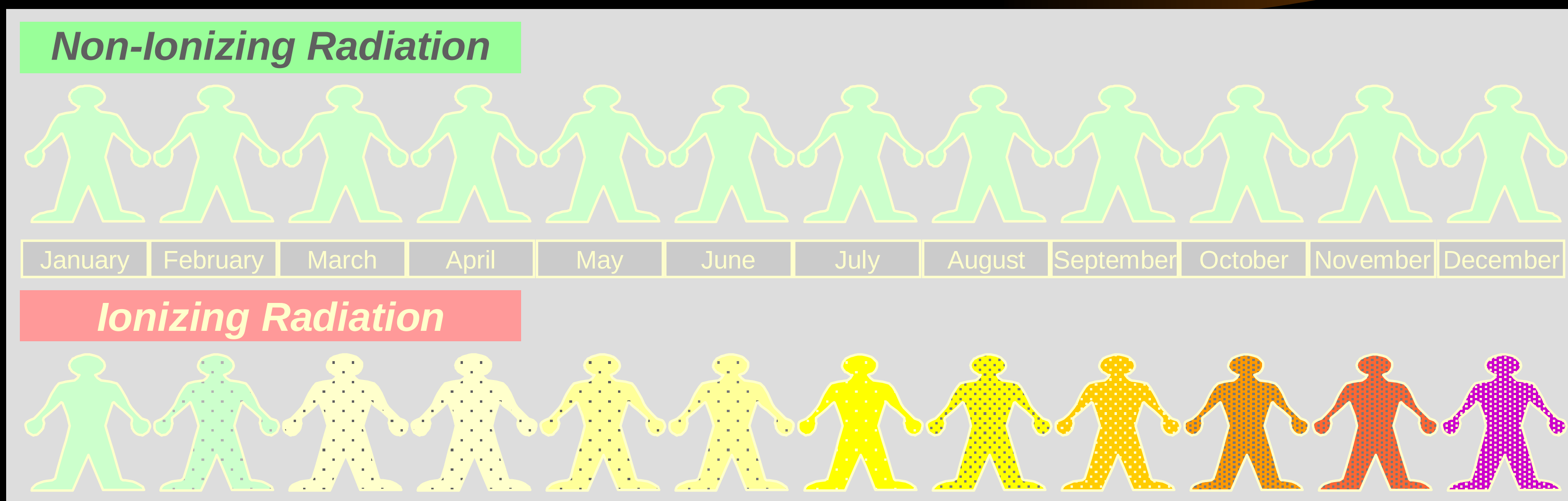
Ionizing Versus Non-ionizing Radiation

- At a frequency of approximately 2420 thousand GHz (the upper end of the UV range) the energy level is sufficient to "ionize" water molecules. This equates to 12.4 eV.
- Frequencies and energies at or above this level are classified as ionizing.

Ionizing Versus Non-ionizing Radiation

- Ionizing radiation can cause permanent, biological changes to molecular structure.
- The ability to ionize is totally frequency dependent, i.e.
  - The world's largest radio transmitter can not cause ionization.
  - An extremely small amount of "radioactive" material, such as uranium, can cause ionization.
- The biological effects are totally different.

Ionizing Versus Non-ionizing



- Effects of non-ionizing radiation ***are not*** cumulative.
- Effects of ionizing radiation ***are*** cumulative.

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Ionizing Versus Non-ionizing

- **Electromagnetic energy at frequencies above UV light is *"ionizing", i.e.*** photons have enough energy to tear electrons from their atoms, creating ions. This can cause permanent biological changes to molecular structure of cells.
- The primary concern with RF (***non***-ionizing) radiation is tissue heating.
- Shocks and burns (electro-stimulation) are a concern at the lower RF frequencies.

Biological Effects

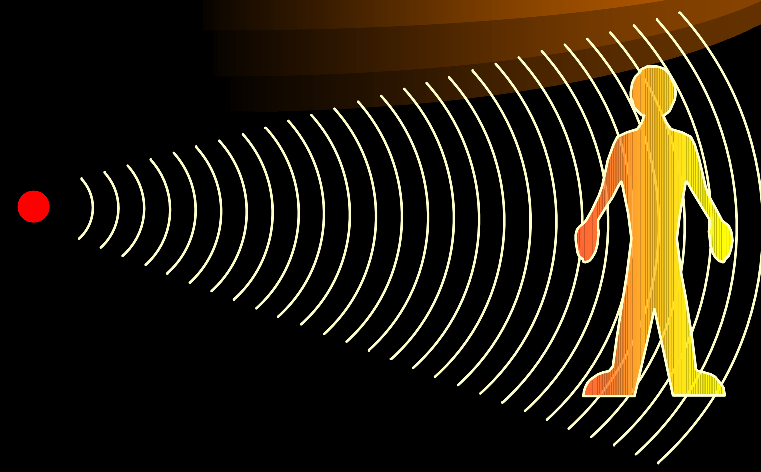
Non-ionizing Radiation and the Human Body

Key Points to Understand

- Which factors determine how effectively a body (or parts of a body) are heated?
- How much heat can a body absorb before adverse affects are felt?
- At what levels can permanent biological damage occur?

Specific Absorption Rate (SAR)

- The rate of absorption of energy into the body.
- The method used to quantify the effects of electromagnetic fields on the body.
- The basis for all modern standards.



SAR measured in W/kg

RF Energy and the Human Body

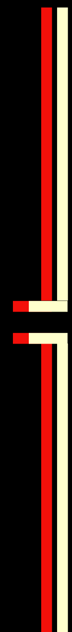
There are many factors that affect absorption into the human body:

- Dielectric composition.
- Size of the body.
- Shape, orientation and polarization.
- Complexity of the RF field.

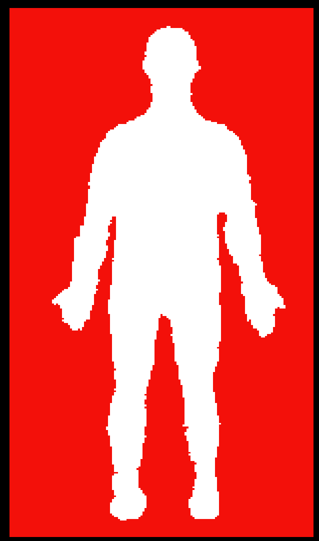
RF Absorption Versus Frequency

Whole Body Heating

The body acts like an absorptive antenna.



Thin, lossless dipole antenna



Fat, lossey body

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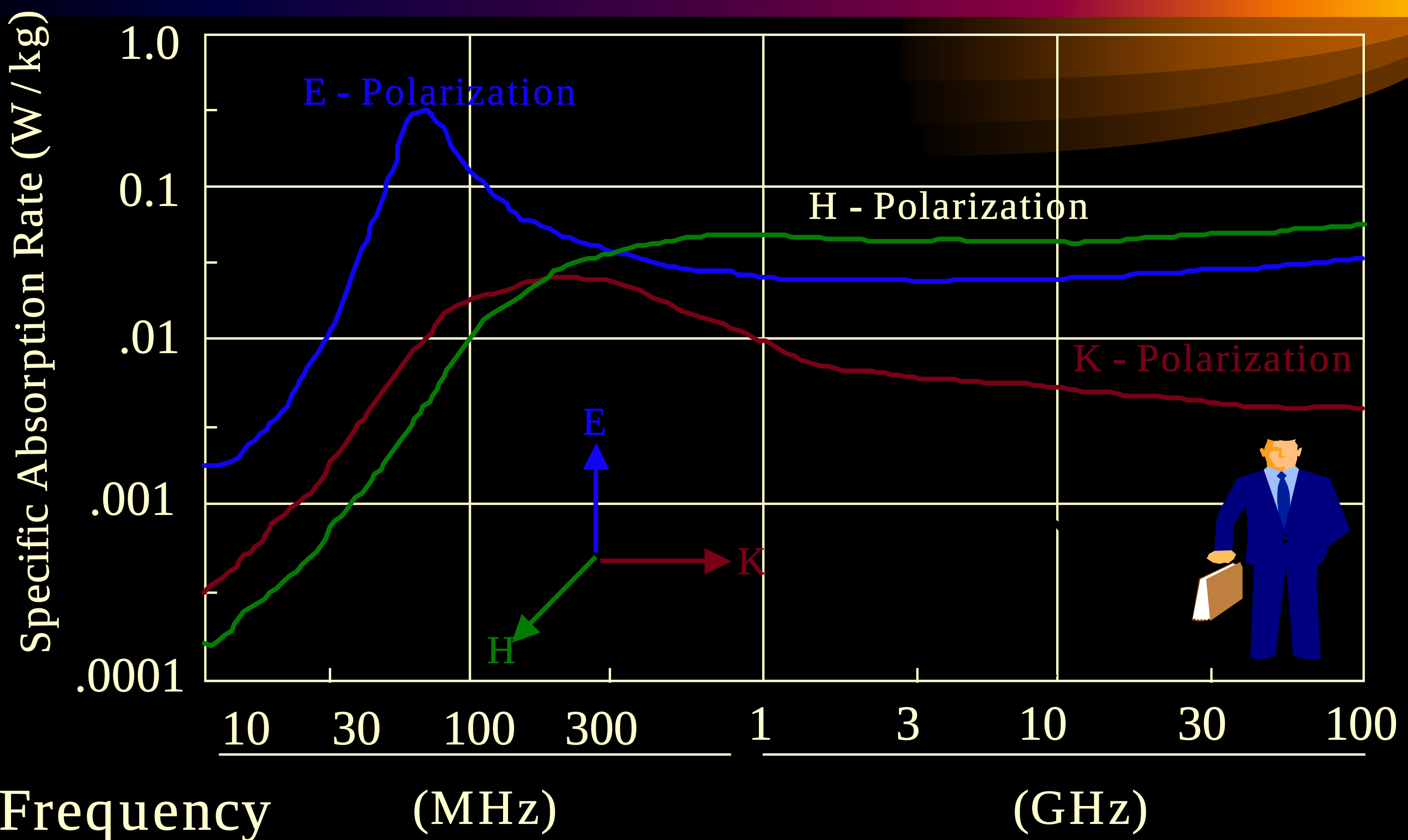
Shape, Orientation & Polarization

- The human body in a vertical position absorbs 10 times more energy in a vertically polarized field than in a horizontally polarized field.
- Similarly, a prone body in a horizontally polarized field also absorbs the most energy.

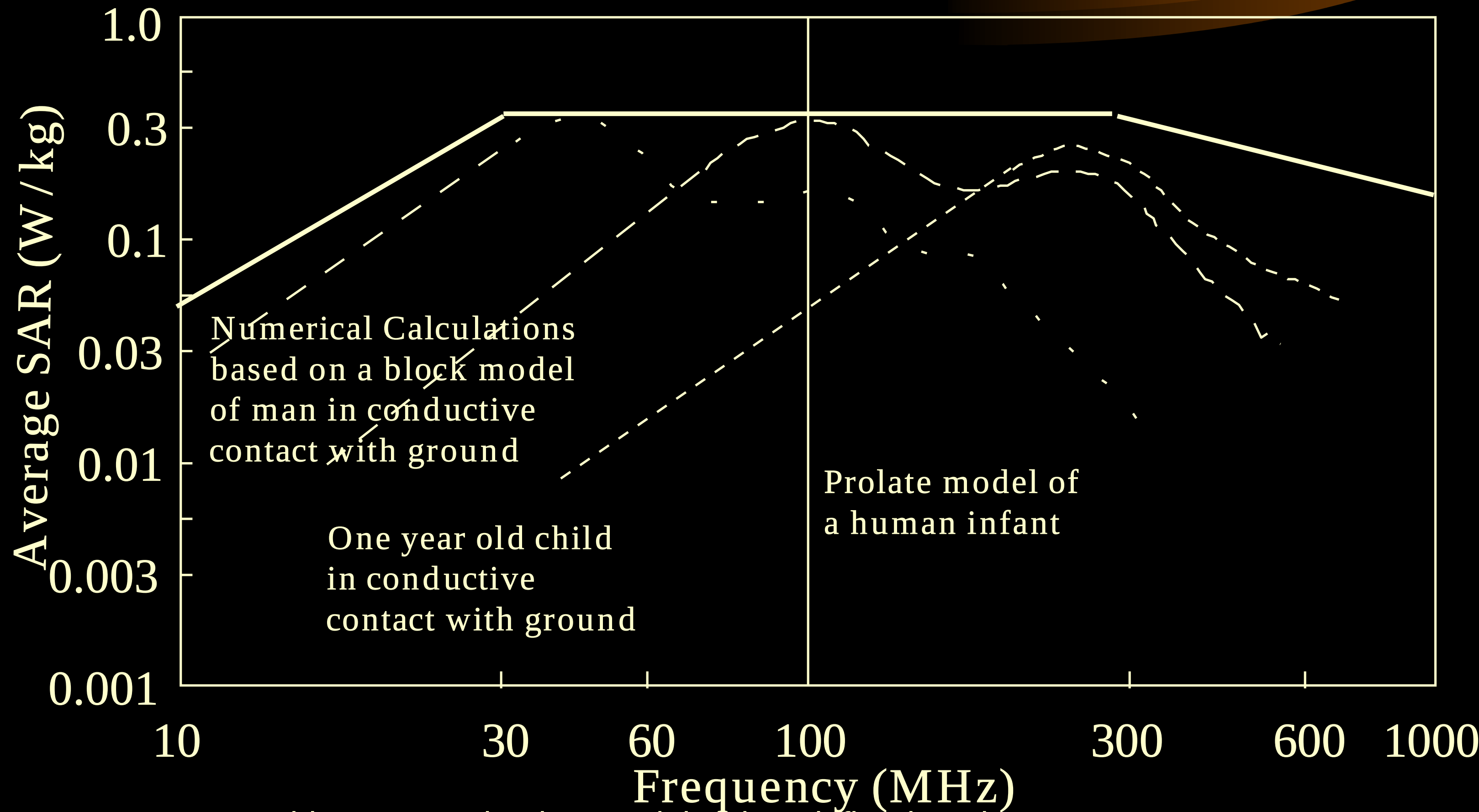
SAR Versus Frequency



SAR Induced in a 1.75m high Human Exposed to a 1 mW/cm^2 RF Field

SAR Versus Frequency

Upper limit for the range of human beings from infant to adult



Whole Body Resonance

Subject	Ht(m)	Ht(in)	$f_{R(Isolated)}$	$f_{R(Grounded)}$
Adult male	1.75	69	86 MHz	43 MHz
NBA player	2.29	90	66 MHz	33 MHz
Infant	0.5	20	300 MHz	150 MHz

Where λ (m) = 300/F (MHz); assumes a dipole = $\lambda/2$

Time Averaging

- Because the primary effect is thermal, exposure is averaged over time.
- In most standards the averaging time is six minutes, which is close to the thermal regulatory response time of the human body.
- There are limits on peak exposure levels, but they only apply in highly unusual circumstances such as EMP testing.

Spatial Averaging

- Measurements are averaged over an area equivalent to the vertical cross section of the human body.
- The limbs can tolerate higher levels since the body's circulatory system acts as a coolant with the remainder of the body functioning as a radiator. (Typically 20:1 higher).
- The basic limits apply for the eyes and testes due to the poor blood flow of these organs.

SAR Versus Metabolic Rate

- How much heat can a body absorb before adverse affects are felt?
- At what levels can permanent biological damage occur?

Specific Absorption Rate

- Normal metabolic rate for humans:
  - 1 w/kg when sleeping.
  - 2.4 w/kg during normal exercise.
- Maximum rate for healthy young adults over a period of 5 to 6 hours:
  - 4 to 5 w/kg.
- Most western standards are based on levels of 0.4 w/kg – a 10:1 safety factor.

Safety Factors

- If healthy young adults can tolerate 4 W/kg, then why are most standards based on only 0.4 W/kg?

Why a 10:1 "Safety Factor"

- Rate assumes room temperature—if RFR exposure occurs at high temperature, the body already has a thermal load.
- Hot spots can occur within the body, especially in the human resonance range.
- Not everyone is young or healthy.
- The individual may be engaged in a physically stressful task, such as climbing a tower, that generates heat by itself.

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Specific Absorption Rates (SAR)

SAR Level*	Situation/Limit
5.0	Permanent damage can occur with whole body heating.
0.4	FCC Maximum Permissible Exposure (MPE) limit for Occupational/Controlled exposure.
0.08	FCC Maximum Permissible Exposure (MPE) limit for General Population/Uncontrolled exposure.
1.6	Cell phone limit for the head.

*Watts per kilogram of body mass.

Overexposure Symptoms

As time and/or energy level (intensity) increases, an individual is likely to experience:

- First, an overall feeling of warmth.
- Then, symptoms similar to overexertion (perspiration, elevated body temperature, labored breathing).
- Symptoms (nausea, headache) are often mistaken for the flu.
- Severe cases have the same effect as heat stroke.

Medical Implants

- If you have a medical implant with electronic circuitry, it may be prone to malfunction in moderate level RF fields.
- Devices such as cardiac pacemakers, medical monitoring equipment, and pumps *may* malfunction at field levels ***far*** below the FCC regulations.

Standards & Regulations

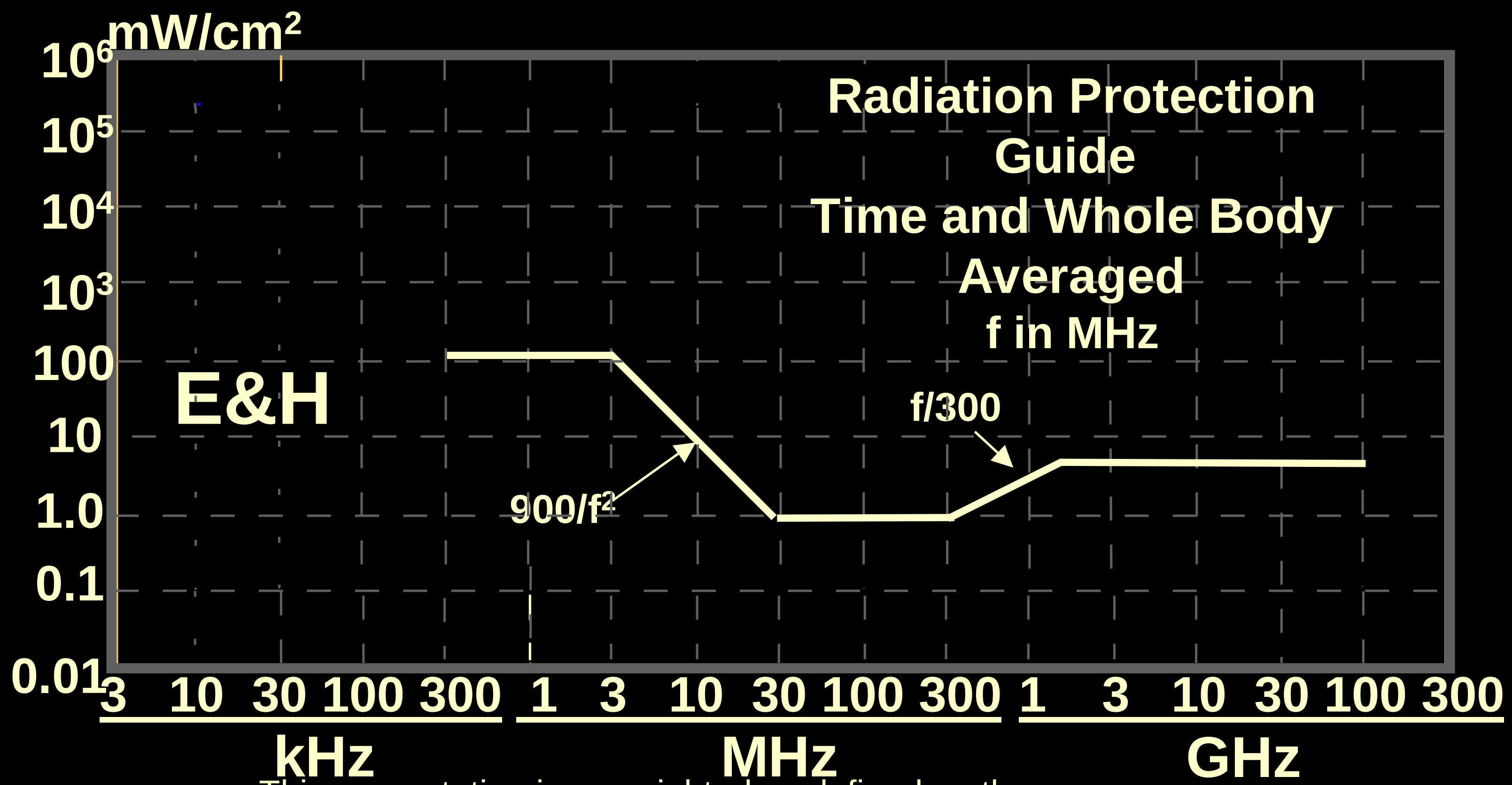
Standards in the U.S.

Two major standards are used in the U.S.:

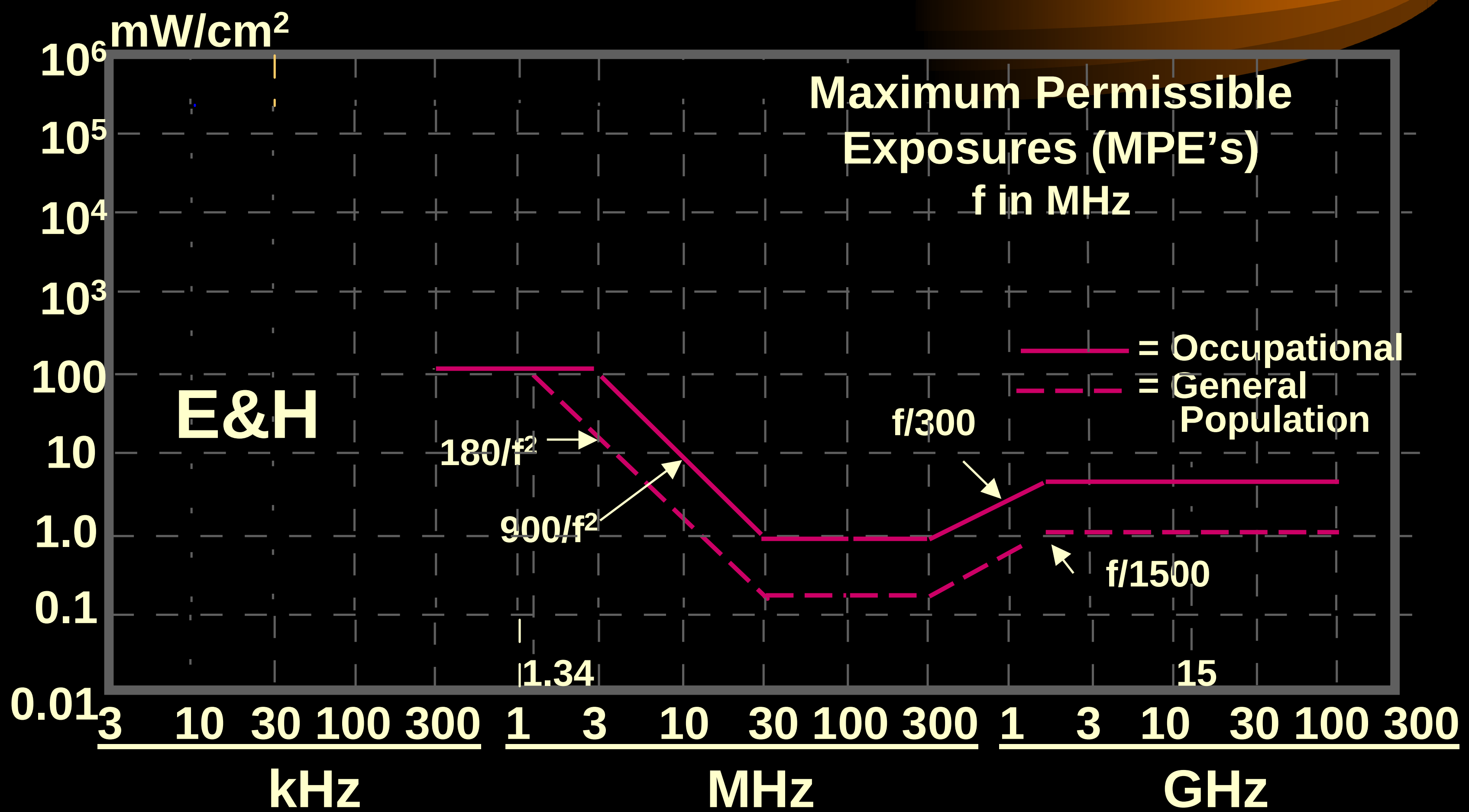
- FCC 1997 Regulations
  – Levels based on NCRP Report 86 (1986)
- IEEE C95.1-1999 (ANSI C95.1-1999)
  – DOD Instruction based on IEEE
  – DOE (proposed) based on IEEE
  – ACGIH based on IEEE

First Standard Based on SAR

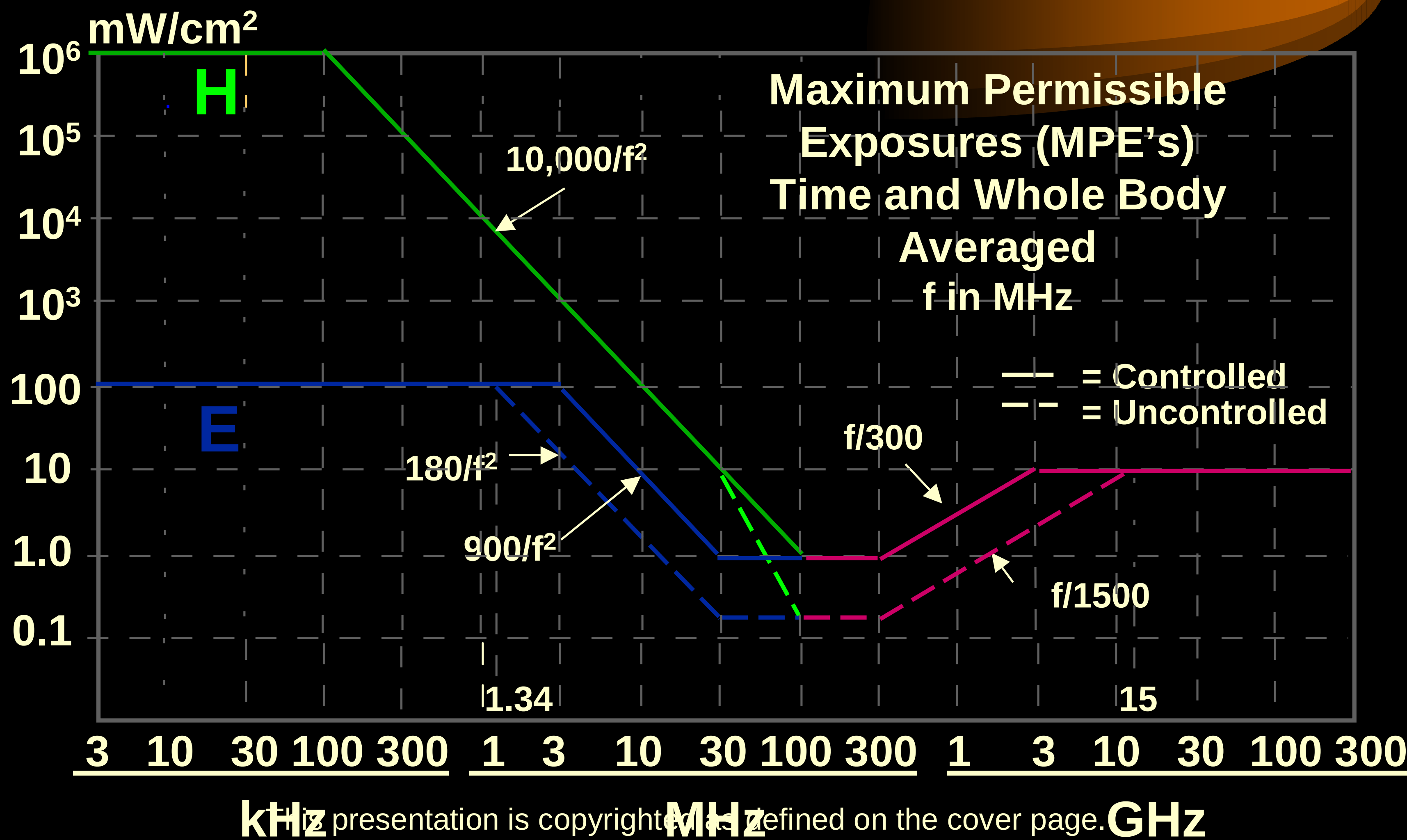
ANSI C95.1-1982. Adopted by the FCC in 1986



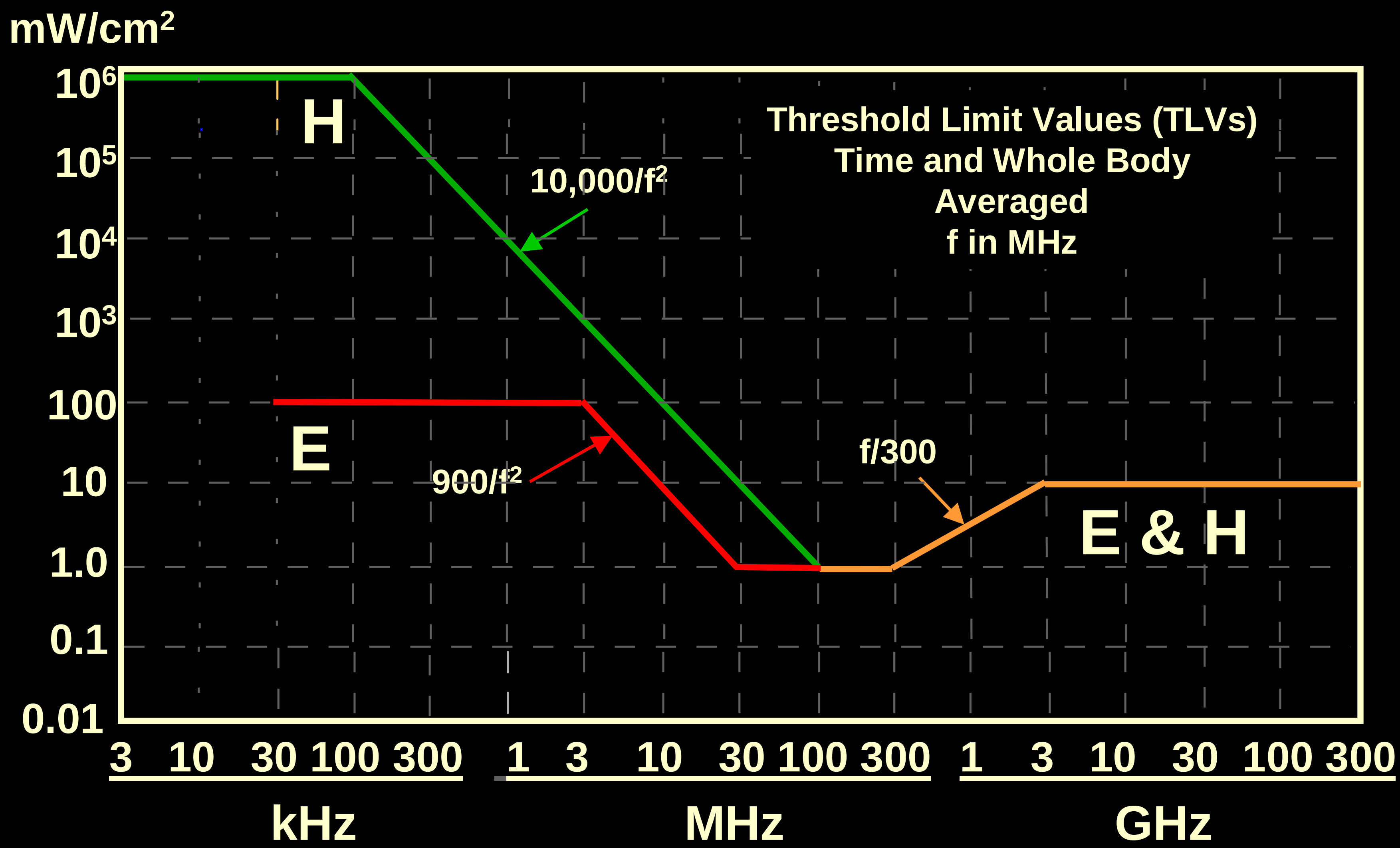
FCC 1997 Regulations



IEEE C95.1-1999



American Conference of Governmental Industrial Hygienists (ACGIH)

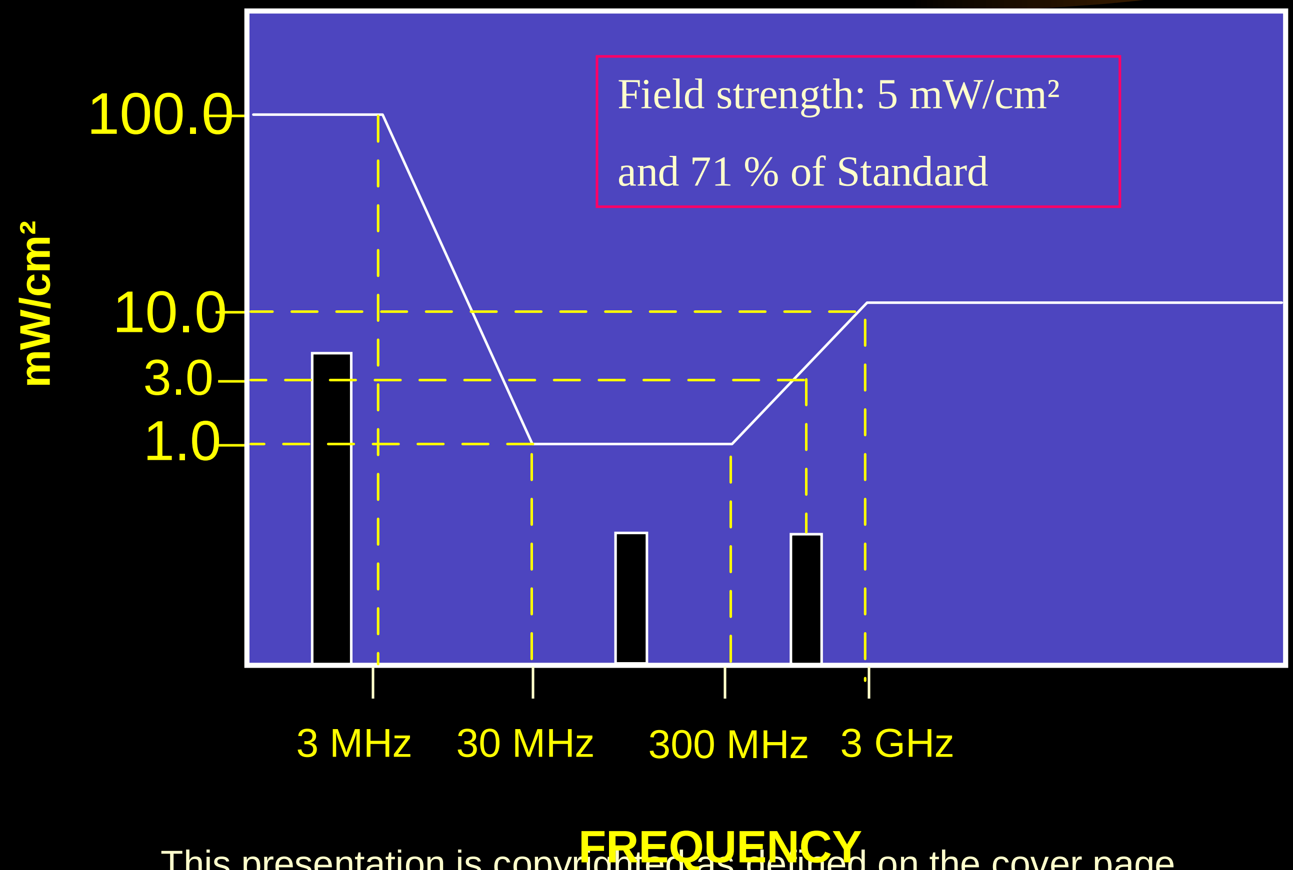


RF Safety Measurements

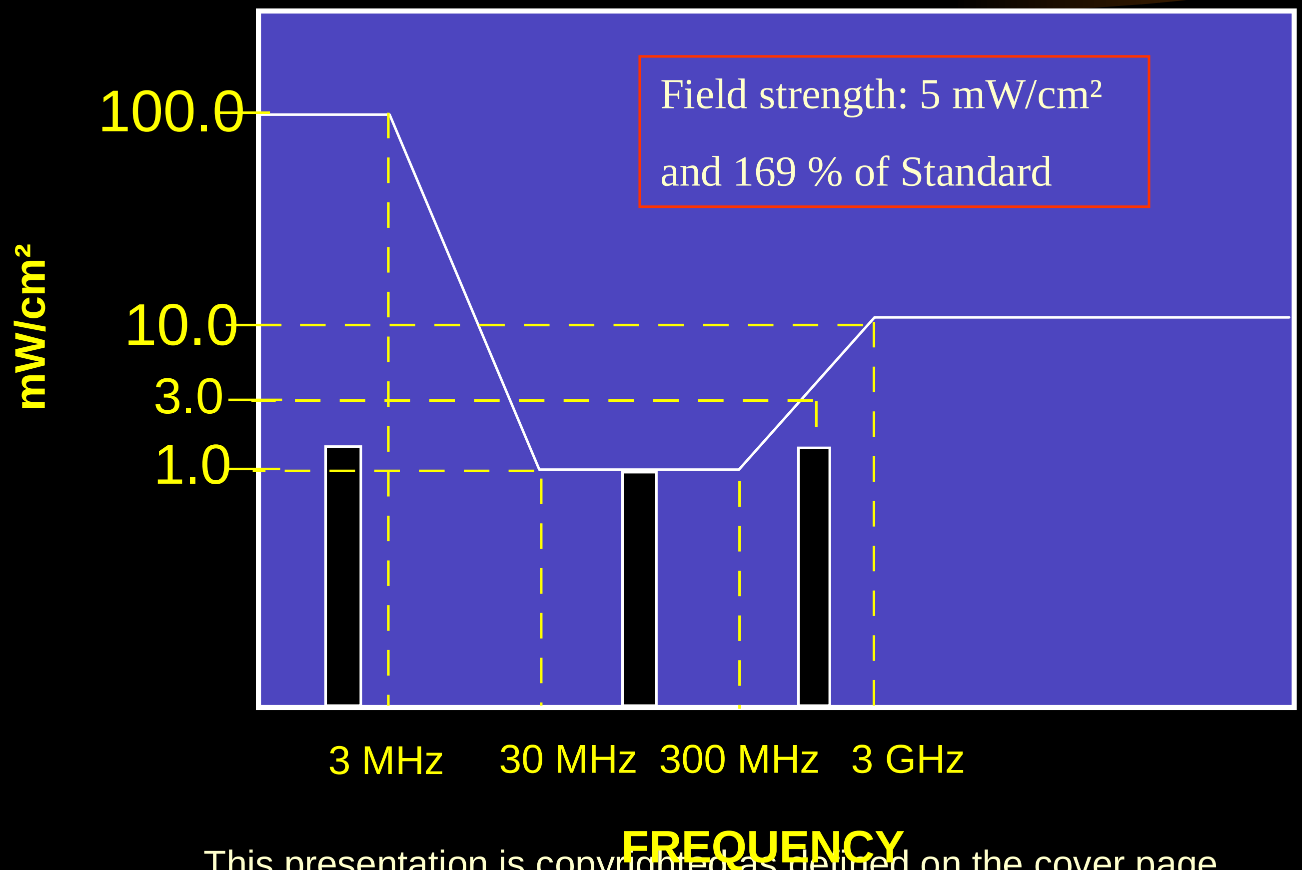
EMC versus RF Safety Measurements

- EMC engineers work to establish a precise RF field level under controlled conditions. Normally only one frequency is used at a time.
- RF safety measurements focus on trying to determine RF field levels under conditions that are anything but controlled.
  - Output levels vary over time.
  - Multiple emitters and modulation schemes.
  - Reflections from towers, buildings, and the ground.
  - Field interaction.
  - Influence of the surveyor and the instruments.

Determining Compliance in a Multi-Signal Environment



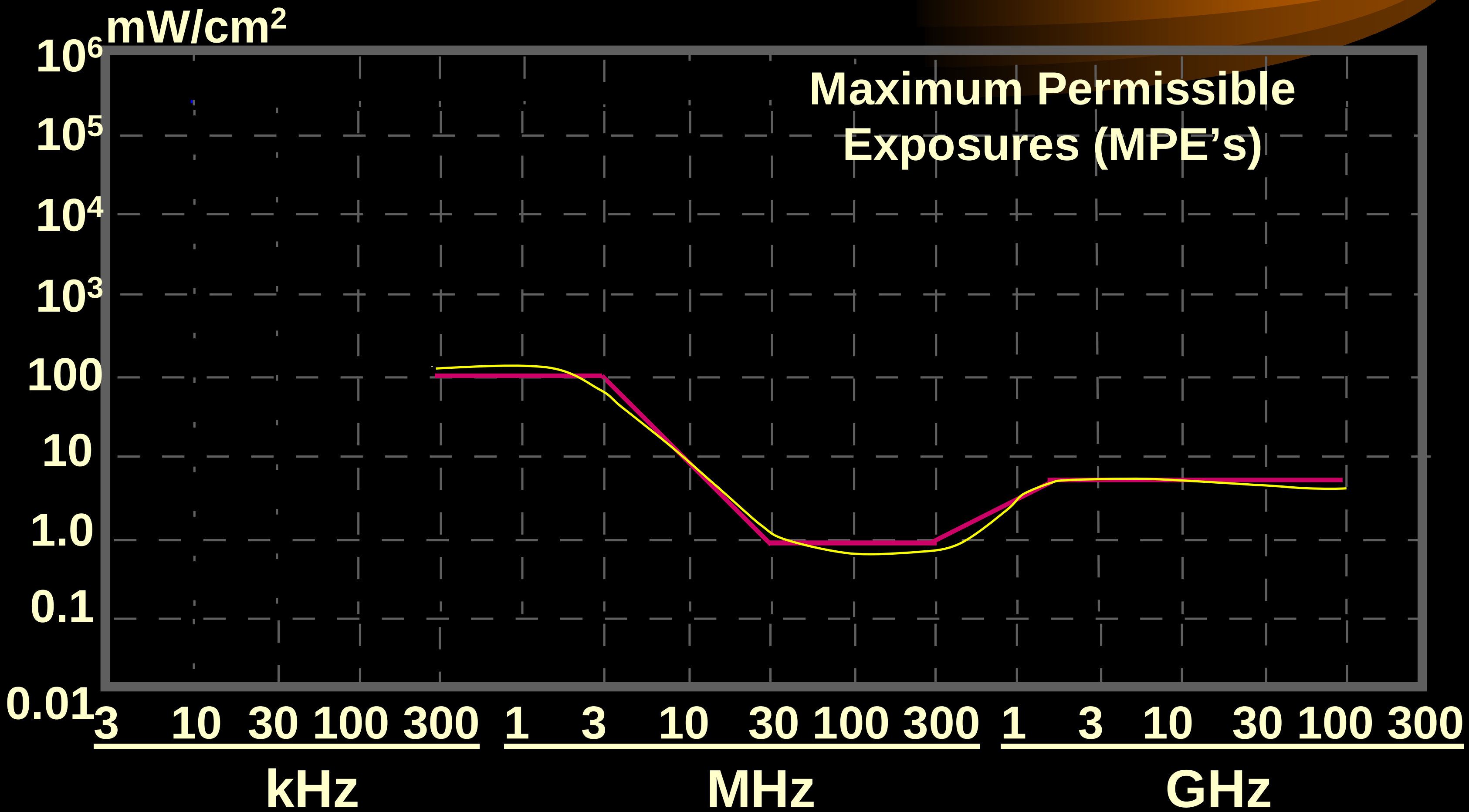
Determining Compliance in a Multi-Signal Environment



Shaped Frequency Response Probes

- Shaped probes have frequency-dependent sensitivity that attempts to mimic the exposure limits of a specific standard.
- Design of sensors is similar to a filter.
- Deviation from standard is normally greatest in the transition regions. Best probes conform within ±2 dB.
- Output is in Percent of Standard.

Shaped Frequency Response Probes



Mt. Wilson Antenna Farm

- The antenna farm on Mt. Wilson contains all of the TV and most of the FM stations that serve the Los Angeles area.
- There are > 30 towers and >50 broadcast antennas.
- One area recently cited by the FCC has 21 emitters contributing significant field strength.

South Mountain

- South Mountain contains all the television stations that serve the Phoenix area. It also contains numerous FM stations and wireless services.
- There are >30 towers on South Mountain and countless antennas.

Tucson Mountain

- Tucson Mountain is one of three modest sized antenna farms that serves the Tucson area.
- It contains five 100 kW FM stations, several TV stations, and numerous wireless antenna systems

Rooftop Sites

- In addition to the multitude of wireless systems, this rooftop in Houston also has an FM antenna.
- Field levels vary constantly as the number of channels in use change and pagers go on and off.

Rooftop Sites

- This rooftop in Phoenix has an FM antenna aimed towards the door.
- The RF fields near the entrance door are about 300% of ***Occupationa***l limits.
- Personnel will now wear an RF personal monitor when visiting this site.

A Small Antenna Farm

- This small antenna farm on a mountain in Santa Barbara has more than 50 wireless, FM, and television transmit antennas.
- The FM antennas that are mounted close to the ground generate significant RF fields.

Summary

RF Safety

- Determining RF safety compliance is not just about making measurements.
- Limiting human exposure, not emissions, is the goal. This involves risk assessment and the use of controls.
  - Engineering controls, such as interlocks and automatic shutoffs.
  - Administrative controls, such as policies and procedures.

Relationship of EMC to RF Safety

- Both disciplines involve the measurement of RF fields.
- Similar equipment is often used.
- There are different objectives and very different measurement conditions.

EMC Measurements

- Standards are precise.
- Test procedures are well defined.
- Test conditions are controlled.
- Personnel are well trained.

RF Safety Measurements

- Standards have specific exposure limits but the criteria for which tier to use and how to apply are confusing.
- Test procedures are not defined.
- Test conditions are not controlled.
- Personnel are often poorly trained. The recent growth in the industry has seen an influx of personnel that fit the description of "Last week I couldn't spell surveyor, this week I am one."

Summary

Questions?

Additional Information

Web site contains a great deal of information with links to other sources.

www.RFSafetySolutions.com

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