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
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. \( \lambda \text{ (meters)} = \frac{300}{f} \text{ (MHz)} \)
- **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 = $h \times f$
  - Where $f$ = frequency
    - $h$ = Planck’s constant
      - $(6.63 \times 10^{-34}$ joule seconds)
  - The higher the frequency, the higher the energy
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.

This presentation is copyrighted as defined on the cover page.
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

SAR Induced with a 1 mW/cm² RF Field

Specific Absorption Rate (W/kg)

Frequency (MHz) (GHz)
Whole Body Heating

The body acts like an absorptive antenna.

Thin, lossless dipole antenna

Fat, lossey body

This presentation is copyrighted as defined on the cover page.
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 Induced in a 1.75m high Human Exposed to a 1 mW/cm² RF Field
SAR Versus Frequency

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

Average SAR (W/kg)

0.001 0.01 0.1 0.3 1.0

Frequency (MHz)

10 30 60 100 300 600 1000

Numerical Calculations based on a block model of man in conductive contact with ground

One year old child in conductive contact with ground

Prolate model of a human infant

This presentation is copyrighted as defined on the cover page.
Whole Body Resonance

Where \( \lambda \) (m) = \(\frac{300}{F} \) (MHz); assumes a dipole = \( \lambda/2 \)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Ht(m)</th>
<th>Ht(in)</th>
<th>( f_R ) (Isolated)</th>
<th>( f_R ) (Grounded)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult male</td>
<td>1.75</td>
<td>69</td>
<td>86 MHz</td>
<td>43 MHz</td>
</tr>
<tr>
<td>NBA player</td>
<td>2.29</td>
<td>90</td>
<td>66 MHz</td>
<td>33 MHz</td>
</tr>
<tr>
<td>Infant</td>
<td>0.5</td>
<td>20</td>
<td>300 MHz</td>
<td>150 MHz</td>
</tr>
</tbody>
</table>

This presentation is copyrighted as defined on the cover page.
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.
### Specific Absorption Rates (SAR)

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

*Watts per kilogram of body mass.

This presentation is copyrighted as defined on the cover page.
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
Two major standards are used in the U.S.:

- **FCC 1997 Regulations**
  - Levels based on NCRP Report 86 (1986)
  - 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

Radiation Protection Guide
Time and Whole Body Averaged
f in MHz

E&H

mW/cm²

MHz

GHz

kHz

This presentation is copyrighted as defined on the cover page.
FCC 1997 Regulations

Maximum Permissible Exposures (MPE’s)

f in MHz

E&H

1.34

180/f²

900/f²

f/300

f/1500

0.01

10

100

1000

10⁴

10⁵

10⁶

mW/cm²

3 10 30 100 300

1 3 10 30 100 300 1 3 10 30 100 300

kHz MHz GHz

This presentation is copyrighted as defined on the cover page.
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

Field strength: 5 mW/cm² and 71% of Standard
Determining Compliance in a Multi-Signal Environment

Field strength: 5 mW/cm² and 169% of Standard
**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

Maximum Permissible Exposures (MPE’s)

This presentation is copyrighted as defined on the cover page.
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 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.
• 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 Occupational 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.

This presentation is copyrighted as defined on the cover page.
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.”
Questions?
Additional Information

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

www.RFSafetySolutions.com