Radiation Protection Principles: Interpreting Measurements & Evaluation of Occupational Exposure Risk

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Measurement, Quantification and other Factors
Measurements and Comparison to Standards/Guidelines

• Measurements and Calculations
• Types of Instruments used for measuring NIR/RF fields
• A walk through of how to make measurements and what the results look like
Measurement, Quantification and other Factors

- Most all standards are based on the far field relationships and their interaction with the body.
- Near field exposures are difficult to measure and almost impossible to calculate (simply), because of mutual coupling effects. Software can now do this for RF antennas. SAR is impossible to practically measure. Instead the Electric Field Strength (E) in V/m, the Magnetic Field Strength (H) in A/m, and Power Density (S) in mW/cm² are measured with limits that would result in a SAR of no more than 0.4 W/kg for controlled environments.
Sources of RF

Courtesy of Fred McWilliams, MIT
Industrial, Scientific and Medical (ISM) Bands (For Unlicensed Operations)

<table>
<thead>
<tr>
<th>Center Frequency</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>13.56 MHz</td>
<td></td>
</tr>
<tr>
<td>27.12 MHz</td>
<td></td>
</tr>
<tr>
<td>40.68 MHz</td>
<td></td>
</tr>
<tr>
<td>915 MHz</td>
<td></td>
</tr>
<tr>
<td>2.45 GHz</td>
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<tr>
<td>5.8 GHz</td>
<td></td>
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<tr>
<td>24.125 GHz</td>
<td></td>
</tr>
</tbody>
</table>
Utility Van with SmartMeter
(very low exposure but workers are concerned)
RF Heat Sealers

- Power levels ranging from a few thousand to greater than 50,000 watts
- Shields not making electrical contact with work surface
- Those exposures can result in induced currents in the operator – most concentrated in the ankles (27 MHz)
- Bar type sealers (no shield)
- Maintenance
- Removal of shields
RF Induction Heaters

Induction heaters, welders...
- Typically operate at frequencies in the MF band at powers of 10s to 100s of kW
- Range in size from small portable units to large stationary units
- Used for welding, soldering, brazing, heat treating, crystal-growing, and other applications where high induced currents are required
- Potential exposures depend on power, material being heated, size... assessed by measurement.
RF Industrial Heating Equipment

Dielectric heaters, plastic welders, heat sealers…

- Typically operate at frequencies in the 6, 27 and 40 MHz ISM bands, kW power
- Workers may be unaware of exposure
- NIOSH reports cases where operator exposure significantly exceeded the exposure limits
- Potential exposure assessment by measurement
RF and Microwave Ovens

500 kW oven with conveyor for continuous heating and drying applications

Microwave ovens, microwave dryers...
- Typically operate in the 0.915, 2.450 or 5.8 GHz ISM bands at 100s of kW
- Many are automated with minimal operator involvement/exposure
- Used in lumber, food, pharmaceutical and other industries where heating/drying of materials is required
- Potential exposure assessed by measurement
Radar

Range in size from small hand-held units, e.g., “police radar” to large over-the-horizon radars used for missile defense, pulsed and CW, physically rotating and stationary antennas...
## Radar: Applications

<table>
<thead>
<tr>
<th>Band Name</th>
<th>Frequency Range</th>
<th>Wavelength Range</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HF</strong></td>
<td>3–30 MHz</td>
<td>10–100 m</td>
<td>Coastal radar systems, over-the-horizon radars</td>
</tr>
<tr>
<td><strong>VHF</strong></td>
<td>30–300 MHz</td>
<td>1–10 m</td>
<td>Very long range, ground penetrating</td>
</tr>
<tr>
<td><strong>UHF</strong></td>
<td>300 MHz–1 GHz</td>
<td>0.3–1 m</td>
<td>Very long range (e.g., ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency'</td>
</tr>
<tr>
<td><strong>L</strong></td>
<td>1–2 GHz</td>
<td>15–30 cm</td>
<td>Long range air traffic control and surveillance</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>2–4 GHz</td>
<td>7.5–15 cm</td>
<td>Moderate range surveillance, terminal air traffic control, long-range weather, marine radar</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>4–8 GHz</td>
<td>3.75–7.5 cm</td>
<td>Satellite transponders, weather; long range tracking</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>8–12 GHz</td>
<td>2.5–3.75 cm</td>
<td>Missile guidance, marine radar, weather, medium-resolution mapping and ground surveillance; airport radar, short range tracking</td>
</tr>
<tr>
<td><strong>Ku</strong></td>
<td>12–18 GHz</td>
<td>1.67–2.5 cm</td>
<td>High-resolution, also used for satellite transponders</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>18–24 GHz</td>
<td>1.11–1.67 cm</td>
<td>Meteorology, police radar</td>
</tr>
<tr>
<td><strong>Ka</strong></td>
<td>24–40 GHz</td>
<td>0.75–1.11 cm</td>
<td>Mapping, short range, airport surveillance, photo radar (used to trigger cameras which take pictures of license plates of cars running red lights) – operates at 34.300</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>75–110 GHz</td>
<td>2.7–4.0 mm</td>
<td>High-resolution meteorological observation, and imaging</td>
</tr>
<tr>
<td><strong>UWB</strong></td>
<td>1.6–10.5 GHz</td>
<td>18.75 cm–2.8 cm</td>
<td>Through-the-wall radar and imaging systems</td>
</tr>
</tbody>
</table>
Radars Estimating Exposure

Exposures to most radars are best characterized by measurement but in some cases, e.g., a simple system with a rotating antenna, computational techniques can be used. For example, consider a radar with a mechanically rotating antenna and the following characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Pulse width ($T_w$)</td>
<td>10 μs</td>
</tr>
<tr>
<td>Pulse repetition frequency (PRF)</td>
<td>1200 pulses/s (Hz)</td>
</tr>
<tr>
<td>Beam width ($\theta$)</td>
<td>2 degrees</td>
</tr>
<tr>
<td>Antenna rotation (360°)</td>
<td>6 revolutions per minute (r/min)</td>
</tr>
<tr>
<td>Peak power density</td>
<td>300,000 W/m²</td>
</tr>
<tr>
<td>Frequency</td>
<td>9.4 GHz</td>
</tr>
</tbody>
</table>

The pulse width ($T_{br}$) of a single burst of RF pulses (associated with rotation of the beam) is

$$T_{br} = \frac{60 \text{ s}}{6 \text{ r/min}} \times \frac{2^\circ}{360^\circ} = 55.6 \text{ ms}$$

The 55.6 ms exposure (while the beam sweeps by) will consist of approximately $(0.0556 \text{ s})(1200 \text{ pulses/s}) = 66.7$ pulses of RF energy, each pulse lasting 10 μs.

However, since there will be more than five 55.6 ms bursts during any 6 min interval, normal averaging-time rules (e.g., 6 minutes for upper tier ELs) apply, i.e.,

$$S_{avg} = (300,000 \text{ W/m}^2)(1200 \text{ Hz})(10 \mu\text{s})(2^\circ/360^\circ) = 20 \text{ W/m}^2$$

From IEEE Std C95.1-2005
Smart Meters

- Electric utility meters with communications capabilities allowing remote frequent meter reading by the utilities.

- While data may be collected from a typical Smart Meter only a few times a day, the meter itself may transmit RF pulses at much more frequent intervals.

- The transmissions are brief, representing a total transmission time of only a few minutes per day.

- Most Smart Meter systems transmit at frequencies in the 915 or 2450 MHz ISM bands (the same frequency ranges employed by Wi-Fi, many cordless telephones, remote controlled light switches, some baby monitors, and other wireless-enabled appliances).

- The peak pulse power is limited to approximately 1 watt (0.4 watt)

- Exposures in normally accessible locations is far less than 1% of general public exposure limit
Typical RF Exposures in the Home Associated with Wireless RF/Consumer Products

Exposure to individual devices (average of 20 homes)

From Croft et al., “EME In Homes Survey: Final Report,” Australian Centre for Radiofrequency Bioeffects Research, July 2009
The SAR from handsets and other sources is normally determined by the manufacturer and a matter of public record (does not need to be determined by the health physicist at a site).
Mobile (Cellular) Telephone Base Stations

Omnidirectional (whip) antenna

Directional (panel) antenna

Front plane
Spatial Averaging

The exposure values (the values that are compared with the appropriate MPEs) in terms of electric and magnetic field strengths are the mean values obtained by spatially averaging the squares of the fields over an area equivalent to the vertical cross-section of the human body (projected area).

The spatial average can be obtained by scanning (with a suitable measurement probe) a planar area equivalent to the area occupied by a standing adult human. An approximate method for spatial averaging is to make measurements at equal intervals (at least ten) along the axis of the projected area of the exposed subject. The spatial average is equal to the sum of the squares of the measured fields divided by the number of measurements.
Spatial Averaging

- Measurements are averaged over an area equivalent to the vertical cross section of the human body.
- There are many methods to accomplish this task.
- In its most basic form, record measurements at 20 cm height intervals from 0 to 200 cm (IEEE).
- The SRM 3006 has software that enables the recording of the spatial average via a number of methods.
- The big picture, as the following slide shows, is to measure the area of the body.
- Recognize that due to ground reflection or reflection off lossy surfaces, peak exposure rates may not be where you expect them.
Spatial Averaging

The values shown below are the results of measurements made along the vertical axis of a standing individual. Determine the appropriate exposure value to compare with the E-field MPE.

<table>
<thead>
<tr>
<th>Distance Above Grade (cm)</th>
<th>$E^2$ (V$^2$/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>1200</td>
</tr>
<tr>
<td>36</td>
<td>1600</td>
</tr>
<tr>
<td>54</td>
<td>2200</td>
</tr>
<tr>
<td>72</td>
<td>3000</td>
</tr>
<tr>
<td>90</td>
<td>3500</td>
</tr>
<tr>
<td>108</td>
<td>3700</td>
</tr>
<tr>
<td>126</td>
<td>4600</td>
</tr>
<tr>
<td>144</td>
<td>5400</td>
</tr>
<tr>
<td>162</td>
<td>3600</td>
</tr>
<tr>
<td>180</td>
<td>3400</td>
</tr>
<tr>
<td>Total</td>
<td>32,200</td>
</tr>
<tr>
<td>Spatial Average</td>
<td>3220</td>
</tr>
</tbody>
</table>

If, for example, the frequency is 150 MHz the exposure would be less than the controlled environment EL for the electric field strength (3770 V$^2$/m$^2$) even though the MPE is exceeded over a portion of the body.
Spatial Averaging

Measure over the area of a Human Body

Vertical position, $z$

Power density

Courtesy of Fred McWilliams, MIT
Calculations in Lieu of Measurements

• In many instances, measurements in the field may not be required if you know all of the information regarding the emitters.

• Estimates are relatively easy to calculate for near and far field conditions.

• In complex environments with multiple emitters, in field measurements may be the most expedient method of determining compliance.
Near Field and Far Field Exposures

Near Field

Near field exposures:
measure E, H or calculate SAR

Far Field

Far field exposures: measure incident power density
Conservatism Using Far Field Calculations

Example – 900 MHz Antenna, 2 m, 100W

- Far Field
- Reactive Near Field
- Radiating Near Field

\( \lambda / 2\pi \)

\( 2D^2 / \lambda \)
Far Field Power Density

The simple far field Power Density (PD) formula is from OET Bulletin 65²:

$$S = \frac{EIRP}{\pi \times R^2}$$

WHERE:
S = Power density (mW/cm²)
EIRP = Effective isotropic radiated power (mW).
R = Hypotenuse distance (cm)
The EIRP varies with direction with respect to the main beam due to the antenna beam pattern (manufacturer supplied)
Mobile (Cellular) Telephone
Estimating Exposure

For mobile telephone installations, the power density at any point in space can be calculated using:

\[
S = 4 \left( \frac{1.64 \cdot n \cdot P_n \cdot G(\theta)}{4\pi r^2} \right)
\]

Where:

\( n \) = number of radio channels per sector

\( P_n \) = antenna input power per radio channel (W)

\( G_d(\theta) \) = Directional gain of the antenna compared with a resonant half-wave dipole. The directional gain is obtained from the antenna manufacturer.

1.64 = correction factor to convert \( G_d(\theta) \) to \( G_o(\theta) \)

The factor of 4 is included to account for the possibility of constructive interference of reflections.
Far Field Power Density

Equation 1

\[
S = \frac{2.56 \times 1.64 \times P \times G}{4 \times \pi \times R^2}
\]

Where:

\( P \) = Total input power (# of transmitters * power into each transmitter)

\( G \) = gain of a half-wave dipole antenna (dBi)

Gain (dBd) = Gain (dBi) – 2.15
Near Field Exposure Calculations

- The estimates of power density using a far field equation will over-estimate the actual power density in a near field condition.
- However, the RV program has some limitations in the near field environment that should be considered.
Near Field On Axis Exposures (Cylindrical Model)

\[ S = \frac{360 \times P}{\theta_{bw} \times 2 \times \pi \times D \times H} \]

Where:
- $360 = 360$ degrees of a circle
- $\theta_{bw}$ = horizontal 3 dB beamwidth for a given antenna
- $D$ = horizontal distance from antenna to measurement point
- $H$ = height of antenna
Partial beam exposures are simply adjusted by the percentage of the body exposed to the beam of the antenna with the stipulation that the maximum partial body exposure when an individual head height is just at the bottom of the antenna is 10% of the main beam exposure.

\[ S = \frac{360 \times P}{\theta_{bw} \times 2 \times \pi \times D \times H} \times \frac{T}{H_p} \]

Where:
- \( T \) = intercepted portion of the body to the main beam
- \( H_p \) = Height of the person standing parallel in front of the antenna
Near Field Exposures below Height of Antenna

Practical experience shows that the approximate extent of the near field is about 1.5 times the height of the antenna aperture height.

\[
S = \frac{360 \times P}{\theta_b \times 2 \times \pi \times D \times H} \times 0.1 \times \left(\frac{6}{Z}\right)^2
\]

Where:
- \(Z\) = Height from ground level to bottom of antenna (ft)
The exposure associated with stationary antennas, such as those used for a mobile telephone, can be calculated if the antenna input power and gain are known. (Spreadsheets of the antenna gain, \( G(\theta) \), at 1° increments in both the vertical and horizontal planes are available from most manufacturers.)
What Does A Cell Phone Antenna Pattern Look Like?
Directional Antenna Pattern

Propagation of "main beam" from antenna mounted on a tower or rooftop

Courtesy of Fred McWilliams, MIT
Spreadsheet Calculations..

Antenna used in analysis is TMBX-6515-R2M from Andrew antennas. Effective tower height assumes a person 6 ft. tall.

<table>
<thead>
<tr>
<th>height (ft)</th>
<th>2.26E-03</th>
</tr>
</thead>
<tbody>
<tr>
<td>max power density in mW/cm² (4TRX)</td>
<td>0.002264</td>
</tr>
<tr>
<td>percentage of standard</td>
<td>0.228%</td>
</tr>
</tbody>
</table>

Note: 1 mW/cm² is 100% of allowable standard

<table>
<thead>
<tr>
<th>radiation</th>
<th>effective tower height, y</th>
<th>horiz. Dist., x</th>
<th>hypotenuse</th>
<th>main beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>62</td>
<td>2.26E-03</td>
<td></td>
<td></td>
<td></td>
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<td>2.26E-03</td>
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<td></td>
</tr>
</tbody>
</table>

Peak spatial average result

CONTINUING EDUCATION PROGRAMS
NORTHWEST CENTER FOR OCCUPATIONAL HEALTH AND SAFETY
DEPARTMENT OF ENVIRONMENTAL AND OCCUPATIONAL HEALTH SCIENCES
University of Washington School of Public Health
Typical workup for a rooftop site

<table>
<thead>
<tr>
<th>Ant Num</th>
<th>ID</th>
<th>Name</th>
<th>(MHz)</th>
<th>Input Power</th>
<th>Calc Power</th>
<th>Mfg</th>
<th>Model</th>
<th>(ft) X</th>
<th>(ft) Y</th>
<th>(ft) Z</th>
<th>Type</th>
<th>ApHt</th>
<th>Gain</th>
<th>BWdth</th>
<th>PtDir</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1</td>
<td>850 CDM</td>
<td>860.000000</td>
<td>17.8</td>
<td>17.8</td>
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<td>LNX-8514DS</td>
<td>11.0</td>
<td>30.0</td>
<td>4.1</td>
<td>vc</td>
<td>8.0</td>
<td>14</td>
<td>84:010</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A2</td>
<td>AWS</td>
<td>2120.000000</td>
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<td>142.6</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
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<td>17.8</td>
<td>Amphenol</td>
<td>QUAD334W000X</td>
<td>17.0</td>
<td>5.7</td>
<td>4.1</td>
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</tr>
<tr>
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<td>Amphenol</td>
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<td>107.0</td>
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<tr>
<td>17</td>
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<td>13.0</td>
<td>4.1</td>
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<td>8.0</td>
<td>15.9</td>
<td>36:260</td>
<td></td>
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<tr>
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<td>27.0</td>
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<td>107.0</td>
<td>Commscope</td>
<td>JAHH-33C-R3B</td>
<td>12.3</td>
<td>16.0</td>
<td>4.1</td>
<td>vc</td>
<td>8.0</td>
<td>15.9</td>
<td>36:260</td>
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<tr>
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<td>850 LTE</td>
<td>850.000000</td>
<td>27.0</td>
<td>27.0</td>
<td>Commscope</td>
<td>JAHH-33C-R3B</td>
<td>12.3</td>
<td>16.0</td>
<td>4.1</td>
<td>vc</td>
<td>8.0</td>
<td>15.9</td>
<td>36:260</td>
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<td>26</td>
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<td>1960.000000</td>
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<td>vc</td>
<td>4.2</td>
<td>16.4</td>
<td>44:260</td>
<td></td>
</tr>
</tbody>
</table>
Mobile (Cellular) Telephone
Rooftop Exposure

Probe placed approximately 20 cm from edge of front face of panel antenna, 6 ft above rooftop.

Min values
Avg values
Max values

Power Density ($\mu$W/cm$^2$) vs Time (HH:MM)

- 5000 $\mu$W/cm$^2$ - FCC Occupational MPE at 1930 MHz
RoofView® software visual output negates the need for separate E and H field measurements in near field environments.

Colors in blue are greater than the FCC occupational exposure limit. Stay times are on the order of 1 minute.
Typical Rooftop Site
# Ground level power density

<table>
<thead>
<tr>
<th>Carrier Type</th>
<th>Worst Case ERP (watts)</th>
<th>Worst Case ERP (dBm)</th>
<th>Antenna Height (ft)</th>
<th>Maximum outdoor exposure (with ground reflection) (mW/cm²)</th>
<th>% of Standard</th>
<th>General Population Exposure Limit (mW/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>700 Upper LTE</td>
<td>600</td>
<td>57.78</td>
<td>35.9</td>
<td>0.1245</td>
<td>25.05%</td>
<td>0.497</td>
</tr>
<tr>
<td>850</td>
<td>377.6</td>
<td>55.77</td>
<td>35.9</td>
<td>0.0731</td>
<td>12.90%</td>
<td>0.567</td>
</tr>
<tr>
<td>PCS</td>
<td>791</td>
<td>58.98</td>
<td>38.1</td>
<td>0.1327</td>
<td>13.27%</td>
<td>1.000</td>
</tr>
<tr>
<td>AWS</td>
<td>929.1</td>
<td>59.68</td>
<td>38.1</td>
<td>0.1523</td>
<td>15.23%</td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>66.46%</strong></td>
<td>0.4827</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Table 2: Calculated Ground Level Power Density**
Point-to-Point Microwave Radio

Features:
- line-of-sight transmission
- narrow beam transmission (~1 depending on the ratio of wavelength to aperture size)
- low transmitter power (a few watts for terrestrial systems; hundreds of watts for satellite uplinks)

Uses:
- point-to-point telecommunications (analog and digital)
- satellite communications
Microwave Radio

- Directional antennas are mounted such that the line of sight to the receiving antenna is unobstructed.
- Very little power scattered outside of the main beam.
- Exposures at normally accessible locations are typically below 0.01% of the occupational exposure limits.
- The power density in the main beam of an antenna can be found from:

\[
S_{\text{max}} \approx \frac{4P}{A_e} \, \text{W/cm}^2
\]

radiating near field

\[
S = \frac{A_e P}{\lambda^2 d^2}
\]

far field

\[A_e = \text{aperture area}, \quad d = \text{distance from antenna}, \quad \lambda = \text{wavelength}\]
Monitoring Personal Exposure

• Many monitors available.
  • Make sure they cover the frequency band of interest and have a suitable dynamic range
• recommended instruments: RadMan XT and Nardalert S3 (3 MHz to 40 GHz)
• Field Sense 2.0 (50 MHz to 6 GHz)
Instruments for the real world

Huge advantage of having a dual electric and magnetic field probe

NIM-511 and NIM-513 Industrial Field Meters

- Complete Measurement System with Dual Electric and Magnetic Field Probe for Frequencies up to 100 MHz
- Covers Most Industrial Equipment
- Fast and Reliable Measurements
- Extremely Easy to Use
- Low Cost, Compact and Lightweight
- RMS Detection

Applications
- RF Heat Sealers and Vinyl Welders
- Semiconductor Process Equipment and Glass Deposition
- RF Induction Heating
- Dielectric Dryers and Heaters
- Plasma Generation Systems
What About Induced and Contact Current?

RF induces voltage in ungrounded conductors. Person acts as current path to ground when touching charged conductor.

RF induces voltage in person resulting in a current that flows to ground.

From F McWilliams-MIT
Scenario for accident involving RF currents induced in the body by contact with “hot” surface.

RF burn from contact current.

(B. Hocking)
1 mA to 1 A output range

9 kHz to 70 MHz linear response
Spectrum analyzer in use: SRM 3006. Other equivalent analyzers are available on the market.
RF Measurements

• 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 interactions
  • Influence of the surveyor and the instruments
  • ELF fields
Evaluation Challenges

<table>
<thead>
<tr>
<th>Source Field Region</th>
<th>Environment Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive near-field</td>
<td>No Scatter</td>
</tr>
<tr>
<td>Radiating near field</td>
<td>One Reflector</td>
</tr>
<tr>
<td>Far field</td>
<td>Multiple scatters/absorbers (Unknown)</td>
</tr>
<tr>
<td></td>
<td>Few scatters/absorbers (known)</td>
</tr>
</tbody>
</table>
Near Field, Transition, and Far Field

- Reactive Near Field
  - Energy is stored in vicinity of antenna
  - Near-field antenna quantities
    - Input impedance
    - Mutual coupling
- Radiating Near Field (Fresnel) Region
- Transition Field
- Far Field (Fraunhofer)
  - All power is radiated out
  - Radiated wave is a plane wave
  - Far-field antenna quantities
    - Pattern
    - Gain and directivity
    - Polarization

Courtesy of Fred McWilliams, MIT
Factors

- Dielectric composition
- Size of the body
- Shape orientation and polarization
- Complexity of the RF field
- Scattering Environments – ground, type of ground cover, buildings, you.
- Weather conditions
Measurements..

• For ground level and rooftop level measurements. Measurements are for spatially averaged exposures over the height of a person.
  • Personal experience is that spatially averaged values are about 50% to 60% of the peak value found.

• Have a good idea of the frequencies and power densities one should expect prior to entering the field. The instrument used should be capable of measuring 10X the maximum expected signal.

• In mixed field environments it is useful to have an instrument capable of performing spectral analysis and therefore can compensate for the different MPE limits.

• Have your personal monitor with you. In some instances the results from the personal monitor may be all one needs.
Measurements..A walk through

• Use of a three axis antenna for isotropic response. I typically use either an E-field 27 MHz – 3 GHz or 420 MHz to 6 GHz instrument for most RF measurements that I perform.

• Take spatially averaged measurements (more on that later..)

• Set the Resolution Bandwidth (RBW). Allows the ability to discern frequencies close together. Make the RBW too small and the sweep time climbs dramatically. 500 kHz is usually a safe median ground.

• Set the Measurement Range (MR) OR, in an unknown environment let the instrument select the appropriate MR so that the appropriate sensitivity may be selected.

• If this is an initial scan of an area use the full frequency range of the probe. Scans will take on the order of 1 second for a full sweep with the RBW used above.

• Select the frequency range for the instrument. A range of output considerations is necessary. What units are desired? V/m, W/m², % of FCC limit?
Measurements..

• What result type is of interest? Maximum, maximum average, average?

• Again, if this is the first set of measurements for an area I would use the maximum, knowing that fine tuning of results can occur with more details measurements later.

• For the SRM 3006, one can select the time period for which measurements are obtained. For a restricted access roof, I use a 6 minute time period.

• The SRM also has the capability to display both the maximum and average values at the same time (color coded)

• Once general area measurements have been made, go back to the identified hot spots and make detailed measurements. Spectral files can be saved electronically although I keep a log book of the location, file name, time, and type of measurement.

• Be aware, if the emitters are mounted at eye level on a roof, then it is likely that the head (eyes) will experience the greater exposure rate.
Rooftop Environments

- Rooftop exposure environments are the most common RF occupational environment (that I see)
- Largest hazard from antennas mounted within head height. Antennas with the bottom of the antenna > 10’ less of a hazard.
You’ve Collected the Data, Now What?

• Data stored in the SRM 3006 is exported to a *.csv file where the background noise is stripped, depending upon the signal to noise ratio, and the integrated power density is determined for each frequency band of interest.

\[
S_{\text{integrated}} = \sum_i \frac{S_i}{1.055 RBW} \Delta f = 0.47 \sum_i S_i
\]

• Where \( S_i \) is the power density of the \( i^{th} \) spectral component in the frequency band of interest and \( \Delta f = \frac{1}{2} \) of the Resolution Bandwidth (RBW).

Foster, K.R. Radiofrequency Exposure from Wireless LANS Utilizing Wi-Fi Technology. Health Physics 92(3); 280-289; 2007.
Pre and post ground level survey results

<table>
<thead>
<tr>
<th>Source</th>
<th>Power Density (μW/cm²)</th>
<th>% of FCC public limit</th>
<th>FCC Public Limit (μW/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table 15: Summary of Pre RF Analysis, 9804 NE 19th St</strong></td>
<td></td>
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</tr>
<tr>
<td>FM and TV Contribution</td>
<td>0.006</td>
<td>0.003%</td>
<td>200</td>
</tr>
<tr>
<td>UHF TV contribution</td>
<td>0.012</td>
<td>0.003%</td>
<td>400</td>
</tr>
<tr>
<td>Cellular Contribution</td>
<td>0.011</td>
<td>0.002%</td>
<td>530</td>
</tr>
<tr>
<td>PCS and AWS contribution</td>
<td>0.010</td>
<td>0.001%</td>
<td>1000</td>
</tr>
<tr>
<td>WiFi contribution</td>
<td>0.000</td>
<td>0.000%</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.039</td>
<td>0.009%</td>
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</tr>
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</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Power Density (μW/cm²)</th>
<th>% of FCC public limit</th>
<th>FCC Public Limit (μW/cm²)</th>
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<tr>
<td><strong>Table 16: Summary of Post RF Analysis, 2120 98th Ave</strong></td>
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<td>FM and TV Contribution</td>
<td>0.014</td>
<td>0.007%</td>
<td>200</td>
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<tr>
<td>UHF TV contribution</td>
<td>0.002</td>
<td>0.001%</td>
<td>400</td>
</tr>
<tr>
<td>Cellular Contribution</td>
<td>0.133</td>
<td>0.025%</td>
<td>530</td>
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<tr>
<td>PCS and AWS contribution</td>
<td>0.013</td>
<td>0.001%</td>
<td>1000</td>
</tr>
<tr>
<td>WiFi contribution</td>
<td>0.000</td>
<td>0.000%</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>0.162</td>
<td>0.034%</td>
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</tr>
</tbody>
</table>
A Few Exposure Thoughts

• Shape Orientation and Polarization
  • 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
Questions?