Biological Effects of Radiofrequency Fields: Does Modulation Matter?

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COMMENTARY

Biological Effects of Radiofrequency Fields: Does Modulation Matter?

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Effect of modulation on the waveform of a signal. (NRPB)

- Signal to be modulated
- Carrier
- Amplitude modulated waveform
  
  (a) Amplitude modulation (AM)
  
  - Signal to be modulated, e.g., speech or music
  - Carrier radio signal with higher frequency
  - Amplitude modulated carrier with speech or music information

- Frequency modulated waveform
  
  (b) Frequency modulation (FM)
  
  - Signal to be modulated, e.g., speech or music
  - Carrier radio signal with higher frequency
  - Frequency modulated carrier with speech or music information

- Pulse modulated waveform
  
  (c) Pulse modulation - a form of AM, where the signal to be modulated is a square wave
Changes of potential biological significance

- Changes in peak relative to average signal level
- Changes in frequency content of a signal
<table>
<thead>
<tr>
<th>Technology</th>
<th>Typical form of modulation</th>
<th>Ratio of bandwidth to carrier frequency</th>
<th>Ratio of peak to RMS field strength (order of magnitude)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>Pulse</td>
<td>Very small $\ll 1$</td>
<td>Very large $\gg 1$ (typically $&gt;100$)</td>
<td>Airport control radar</td>
</tr>
<tr>
<td>AM broadcasting</td>
<td>Amplitude</td>
<td>Very small $\ll 1$</td>
<td>Small (order of magnitude one)</td>
<td>AM radio station at 1 MHz</td>
</tr>
<tr>
<td>FM radio and television</td>
<td>Frequency</td>
<td>Very small $\ll 1$</td>
<td>Small (order of magnitude one)</td>
<td>FM radio station at 100 MHz</td>
</tr>
<tr>
<td>Mobile communications</td>
<td>Combination of pulse and frequency</td>
<td>Very small $\ll 1$</td>
<td>Moderate (order of magnitude ten)</td>
<td>TETRA, GSM, TDMA, CDMA, UMTS at 400, 850–900 or 1800–1900 MHz (varies in different countries)</td>
</tr>
<tr>
<td>Ultrawideband communications</td>
<td>Short pulse</td>
<td>Large, possibly exceeding 1</td>
<td>Very large $\gg 1$</td>
<td>UWB communication system; certain military applications</td>
</tr>
</tbody>
</table>
GSM handset - single frame

0.577 ms

4.6 ms (rep. Rate 217 Hz)
Figure 3. Spectrum of a signal from a GSM handset operating on one channel centered at 900 MHz. The spectrum was calculated by Fourier transformation of a signal produced by the simulation program ADS (Agilent, Palo Alto CA). In actual use the handset would change channels frequently due to frequency hopping. Courtesy Mr. Carlo DiNallo, Motorola, Inc.
Spectrum of power in GSM signal from handset
Spectrum of Signal vs. Spectrum of Power

- Frequency content of GSM signal: $900 \pm 0.1$ MHz
- Frequency content of power in GSM signal: $< 10$ kHz with components at frame repetition rate and other frequencies

**Problem**: biological systems have slow response times (milliseconds or longer)

Low-frequency components in the stimulus might appear if a mechanism demodulated the RF field.
Biological system might show modulation-dependent effect if:

- It responded directly to the field (requires fast response)
  - *example*: electroporation

- It had a nonlinear response
  - *example*: dielectrophoretic forces
  - *example*: rectification of membrane potential

- Some other mechanism demodulated the RF field causing the appearance of a low-frequency stimulus.
  - *example*: changes in EEG triggered by nonlinear electrode impedance in the presence of a RF field

- It responded to the absorbed power (thermal effect)
  - *example*: microwave auditory effect
Established mechanisms for RF-tissue interaction

- **Nonthermal**
  - field dipole
  - field induced dipole
  - field quadrupole
  - nonlinear (e.g., Membrane breakdown)

- **Thermal mechanisms**
  - temperature effects
  - rate of temperature effects
### Direct Field (Nonthermal) Mechanism: Dielectric Saturation

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Dipole Moment (µ)</th>
<th>Relaxation Frequency</th>
<th>$E_s$ V/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.8</td>
<td>20 GHz</td>
<td>$9 \cdot 10^9$</td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>170</td>
<td>5 MHz</td>
<td>$10^7$</td>
</tr>
<tr>
<td>DNA</td>
<td>$\approx 100,000$</td>
<td>$&lt; 1$ kHz</td>
<td>60,000</td>
</tr>
</tbody>
</table>

Saturation: $\mu E_s = 5kT$

based on Takashima (1989)
Direct Field (Nonthermal) Mechanism: Dipolorophoresis

\[ F = \frac{\alpha}{2} \frac{\partial (E^2)}{\partial x} \]

“Pearl Chain” effect (aggregation of cells in E field) due to induced dipole moments requires
- high field strengths (> 1000 V/m)
- forces become small > 1 MHz
Less well established/speculative mechanisms for RF -tissue interactions

- “Point heating” (1930’s)
- Preferential heating of
  - bound water
  - biomagnetite
- Chaotic/nonlinear response/solitons
- Disturbance of counterion layer
- Phase transitions
  - of bound water
  - of membranes
- Quantum effects/coherence/Bose-Einstein condensation
The term ‘mechanism’ is usefully defined for present purposes in terms of the following characteristics (quoted from Reference 8):

- it can be used to predict a biological effect in humans;
- an explicit model can be made using equations or parametric relationships;
- it has been verified in humans, or animal data can be confidently extrapolated to humans;
- it is supported by strong evidence; and
- it is widely accepted among experts in the scientific community.
The Paradox

No established direct-field mechanisms (linear or not) that are capable of producing biologically significant responses (modulation dependent or not) from RF fields of reasonable strength

Numerous biological effects have been reported from RF fields, some apparently related to modulation.
Recommendations

- **Basic science** Follow up selected research findings (not necessarily related to health) to identify and understand biophysical mechanisms

- **Risk-related studies**
  - SAR remains the major dosimetric quantity; modulation should not be added to a study unless adequate statistical power can be maintained.
  - Some research, not necessarily a full set of studies, is warranted for new technologies that employ new modulation schemes if the potential for public exposure is high