Biological Effects of Radiofrequency Fields: Does Modulation Matter?

Kenneth R. Foster*

Department of Bioengineering

University of Pennsylvania

Philadelphia PA 19104 USA

kfoster@seas.upenn.edu

RADIATION RESEARCH **162**, 219–225 (2004)
0033-7587/04 $15.00

COMMENTARY

Biological Effects of Radiofrequency Fields: Does Modulation Matter?

Kenneth R. Foster[a,1] and Michael H. Repacholi[b]

[a] *Department of Bioengineering, University of Pennsylvania, Philadelphia, PA 19104; and* [b] *World Health Organization, Geneva, Switzerland*

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

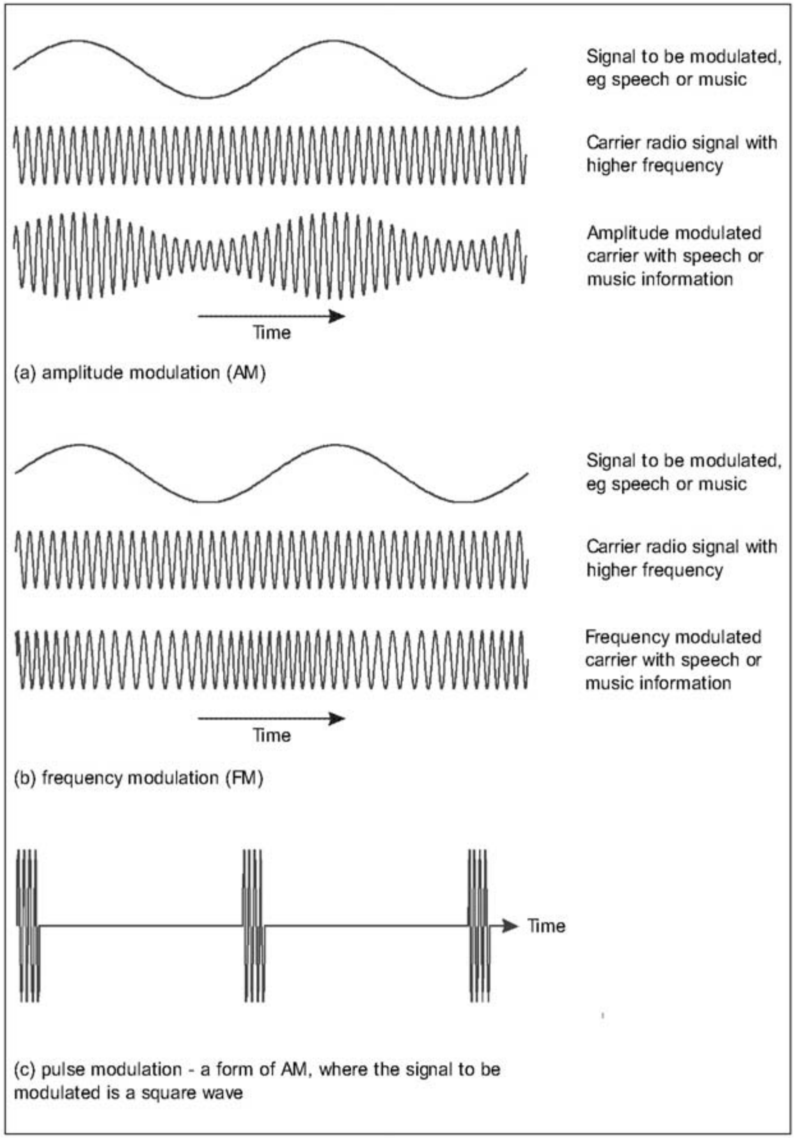
signal to be modulated

carrier

amplitude modulated waveform

frequency modulated waveform

pulse modulated waveform

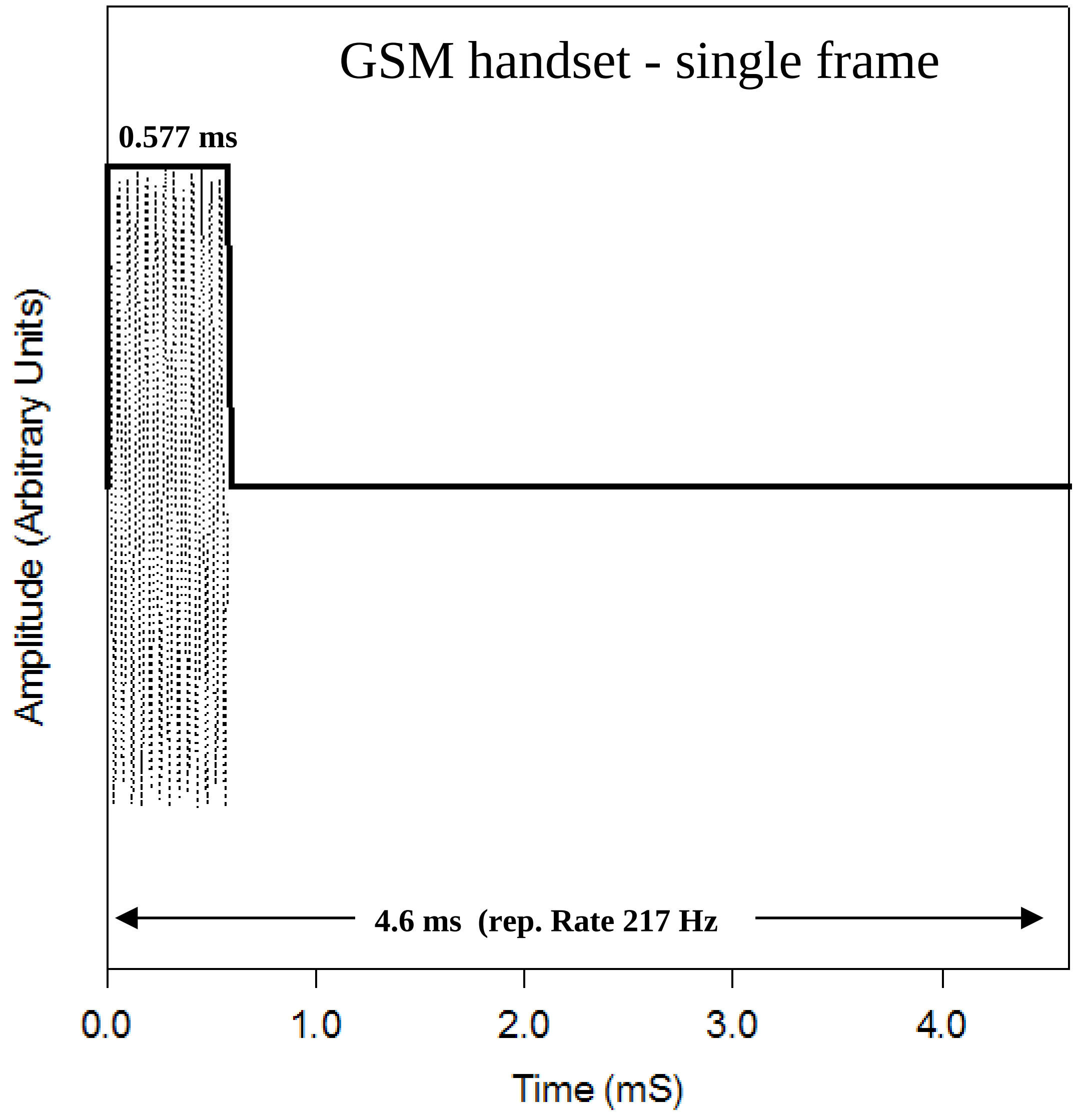


Changes of potential biological significance

- *Changes in peak relative to average signal level*
- *Changes in frequency content of a signal*

Modulation Characteristics of RF Fields Used in Important Technologies

Technology	Typical form of modulation	Ratio of bandwidth to carrier frequency	Ratio of peak to RMS field strength (order of magnitude)	Example
Radar	Pulse	Very small $\ll 1$	Very large $\gg 1$ (typically >100)	Airport control radar
AM broadcasting	Amplitude	Very small $\ll 1$	Small (order of magnitude one)	AM radio station at 1 MHz
FM radio and television	Frequency	Very small $\ll 1$	Small (order of magnitude one)	FM radio station at 100 MHz
Mobile communications	Combination of pulse and frequency	Very small $\ll 1$	Moderate (order of magnitude ten)	TETRA, GSM, TDMA, CDMA, UMTS at 400, 850–900 or 1800-1900 MHz (varies in different countries)
Ultrawideband communications	Short pulse	Large, possibly exceeding 1	Very large ($\gg 1$)	UWB communication system; certa military applications


GSM handset - single frame
0.577 ms
Amplitude (Arbitrary Units)
4.6 ms (rep. Rate 217 Hz
0.0
1.0
2.0
3.0
4.0
Time (mS)

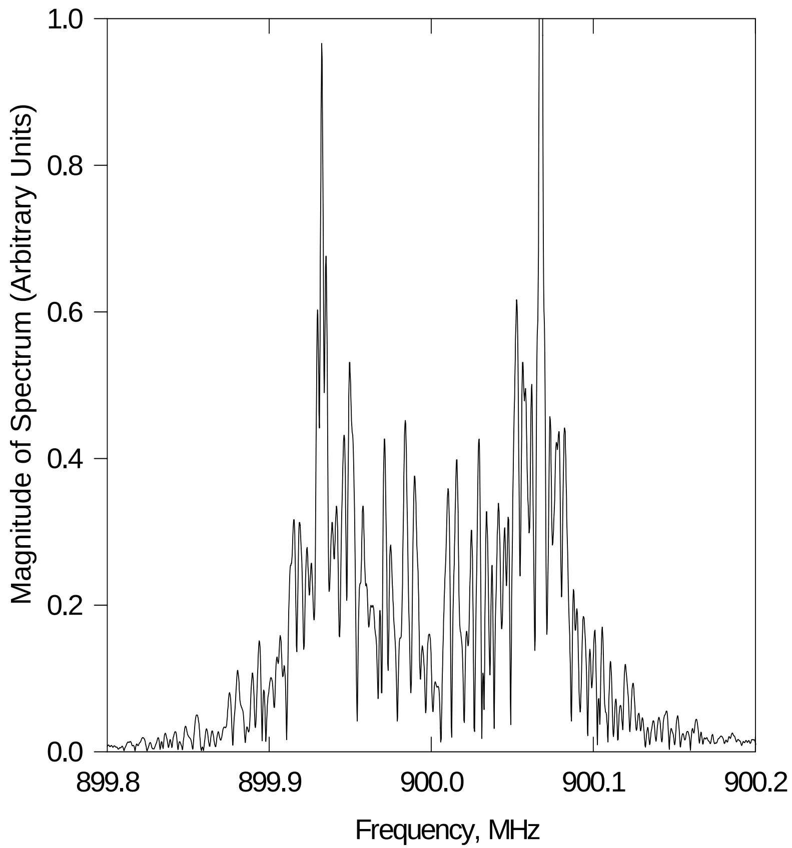
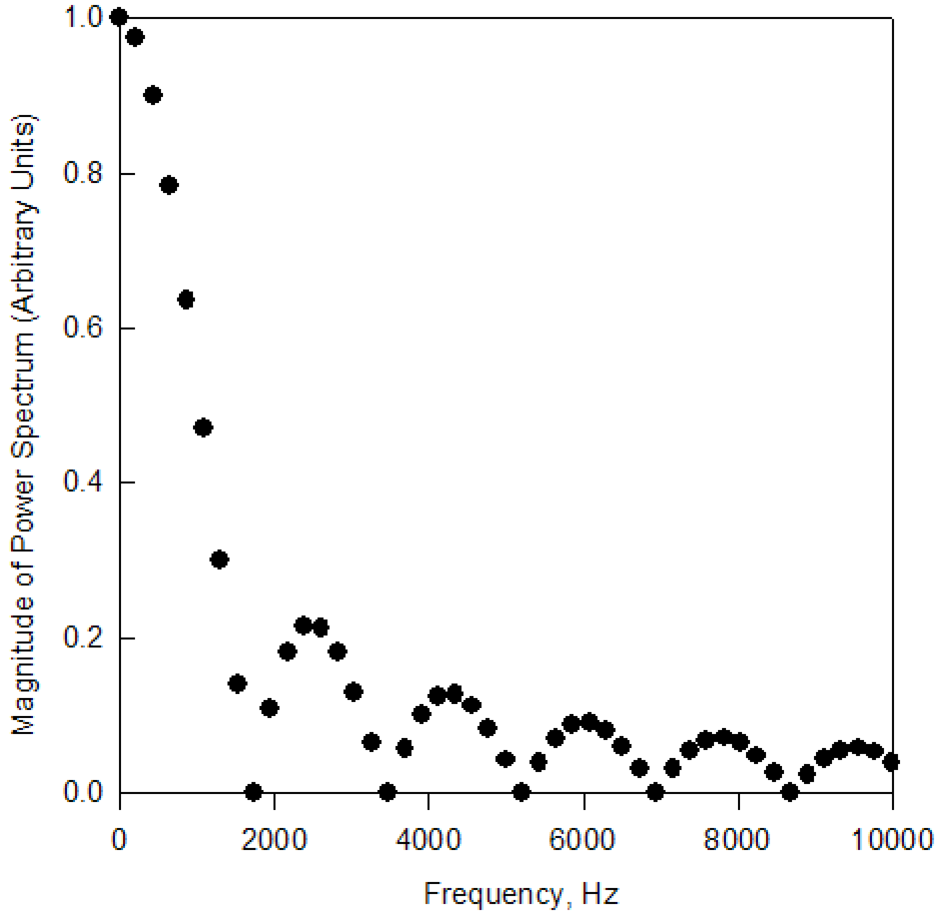


Figure 3. Spectrum of a signal from a GSM handset operating on one channel centered at 900 MHz. The spectrum was calculated by Fourier transformation of a signal produced by the simulation program ADS (Agilent, Palo Alto CA). In actual use the handset would change channels frequently due to frequency 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 ± 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 (eg. Membrane breakdown)
- Thermal mechanisms
  - temperature effects
  - rate of temperature effects

Direct Field (Nonthermal) Mechanism: Dielectric Saturation

Molecule	Dipole Moment (μ)	Relaxation Frequency	E_s V/m
Water	1.8	20 GHz	$9 \bullet 10^9$
Hemoglobin	170	5 MHz	10^7
DNA	$\approx$ 100,000	< 1 kHz	60,000

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

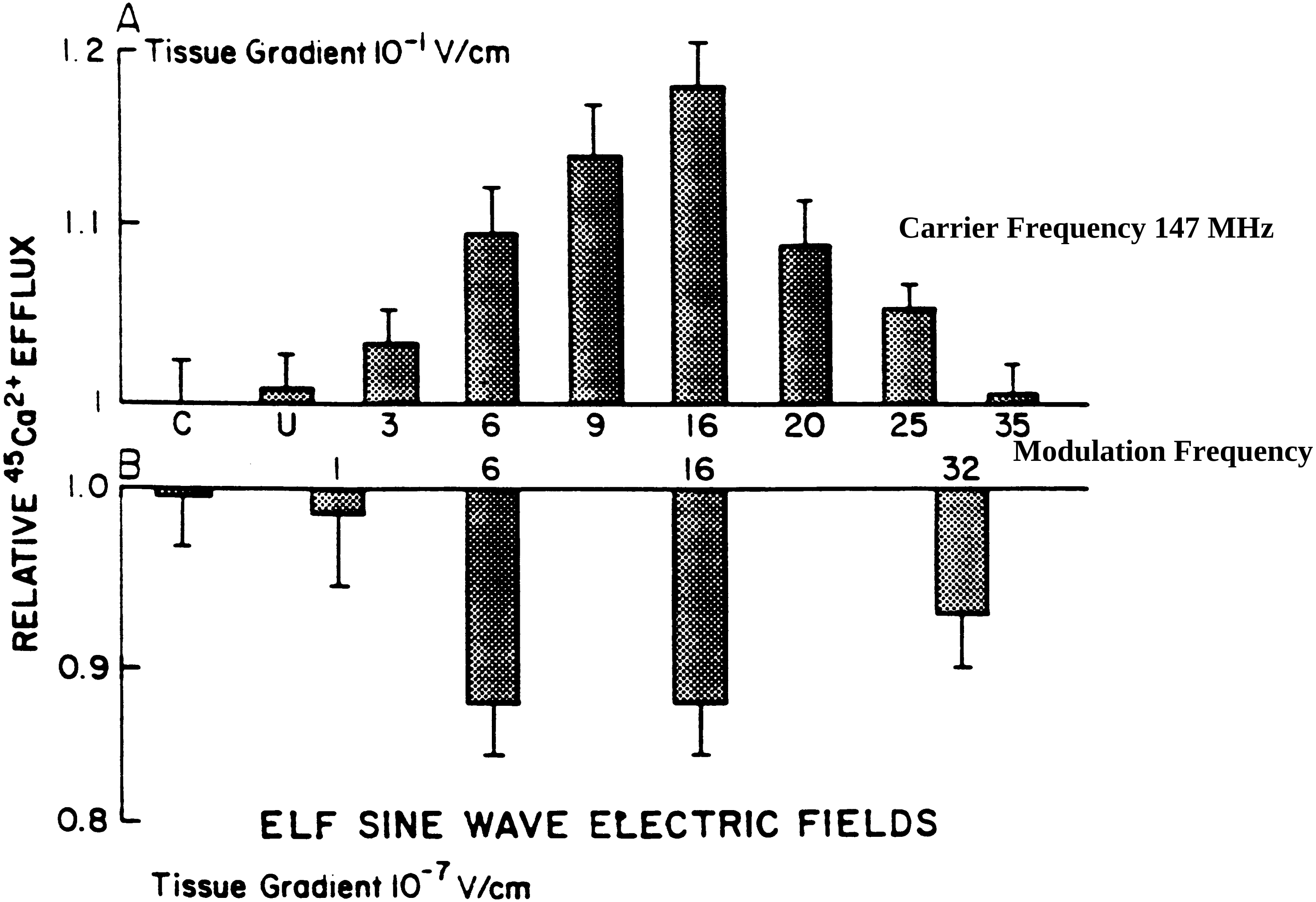
- **high field strengths (> 1000 V/m)**
- **forces become small > 1 MHz**

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.



S. M. Bawin, L. K. Kaczmarek and W. R. Adey, Effects of modulated VHF fields on the central nervous system. *Ann. N. Y. Acad. Sci.* 247, 74-81 (1975).

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