A Primer on Antenna/Human Body Interaction

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How do antennas behave in the presence of the multi-layer dielectric that is the human body? If we expect the many wireless communications devices to operate safely and with predictable performance, we need to understand the interactions of the radiation from their antennas with the human body that dominates the nearby environment.

This understanding is required for two purposes. First is a concern for safety. Although the heated discussion of the recent past has subsided, there is no less need to study the effects of radio-frequency energy on the human body. The second reason is to accommodate the performance variations in antenna pattern and radiation efficiency caused by the proximity of radio transmitters and receivers to a large (in wavelength) semiconductive object that a body represents.

A dielectric model of the body

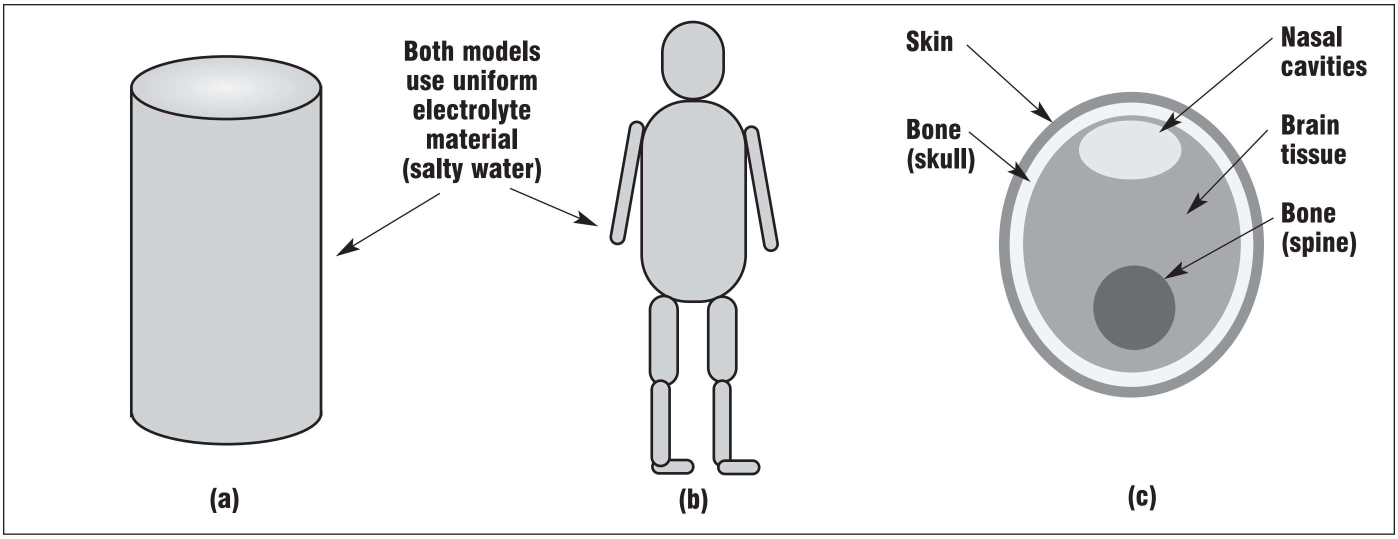
Basically, the human body is made up of layers of materials: tissue, bone and fluids. The simplest model is a cylinder of salty water approximately the right height and diameter to be equivalent to the average person. This model is primarily used for analysis of radio performance issues, such as antenna performance of a body-worn paging receiver, rather than safety concerns.

A more complex human body model uses a single material, but divided into torso and extremities. This model is useful for analyzing both radio performance and safety. For example, resonances that may enhance the absorption of energy at particular frequencies can be identified by method-of-moments analysis of this model.

Finally, detailed models are in development for localized portions of the body, in particular, the head. The widespread use of cellular and PCS handsets, positioned next to the head while in operation, makes it necessary to understand both the radiation performance and the exposure of the person to the RF energy. These three models are illustrated in Figure 1.

Safety issues

The topic of human exposure to electromagnetic fields has been both carefully studied and hotly debated. A general consensus among the engineering community covers two areas. First, exposure to high-level fields that can cause dielectric heating is unquestionably hazardous. Studies in this particular area have resulted in IEEE Standard C95.1 (1991), which has exposure limits shown in Figure 2. These limits, in general, represent a 10 dB margin below levels which can be shown to cause dielectric heating in the body. As the agency governing all radio communications, the FCC has implemented regulations concerning exposure to RF fields from all



■ **Figure 1. Progressively more detailed models of the human body for analysis of radio and safety factors: (a) A cylinder of uniform material (salty water); (b) multiple cylinders representing torso and extremities; and (c) a more detailed layer model of the human head.**

RF total field exposure:

Frequency (MHz)	Controlled Environment (W/m^2)	Uncontrolled Environment (W/m^2)
100-300	10	2
300-3,000	f/30	f/150
3,000-15,000	100	f/150
15,000-300,000	100	100

Electric (V/m) and Magnetic (A/m) field exposure:

Frequency (MHz)	Controlled Environment		Uncontrolled Environment	
	(V/m)	(A/m)	(V/m)	(A/m)
0.003-0.1	614	163	614	163
0.1-1.34	614	16.3/f	614	16.3/f
1.34-3	614	16.3/f	823.8/f	16.3/f
3-30	1842/f	16.3/f	823.8/f	16.3/f
30-100	61.4	16.3/f	27.5	$158.3/f^{1.668}$
100-300	61.4	0.163	27.5	0.0729

■ **IEEE C95.1 (1991) recommended limits for exposure to RF radiation. A "controlled environment" is an occupational area where RF energy is known to be present, while an "uncontrolled environment" applies to public or other occasional exposure to fields.**

communications facilities that have the potential to exceed chosen limits (a modified form of C95.1). These facilities include radar installations, broadcast stations, mobile and cellular base stations, amateur radio stations and other radio services. For more information, readers should consult the pertinent FCC Rules and Regulations [1].

The second area of safety concern is long-term exposure to lower levels of RF radiation. This is the most debated area, with a majority view accepting research that shows a response to low level RF at the human cell level but is not yet conclusive as to the result of those effects, especially over time. Without question, all health and engineering professionals recommend the principle of "prudent avoidance," which might be translated to something like, "If you're afraid that a cell phone will cause you harm, don't use it."

Long-term studies using proper control groups and study groups are underway, with results that will be determined when the proper length of time has elapsed.

Antenna performance issues

An antenna operating in proximity to a person will have its radiation characteristics altered, as it would for a location near any partially-conducting dielectric. Using the cylindrical model of a human body, a pager receiver with an internal antenna may have its radiation significantly altered. Siwiak [2] reports an average of 9 dB difference from maximum to minimum at 153 MHz in the VHF pager band, and 20 dB difference at 466 MHz in the UHF pager band. These measurements were made with the pager worn at the belt line, with maximum signal response in the direction unobstructed by the user's body.

Similar performance has been modeled for cellular handsets [4]. The model used is a more detailed version of that shown in Figure 1(c), which has been verified as a good representation of the human head. At 835 MHz, variations of up to nearly 9 dB from an ideal omnidirectional pattern have been seen, with variations of about 2 dB greater at 1875 MHz.

Related work modeling the human head has been directed toward safety, to determine the expected power density experienced by the user. Should research indicate that lower exposure levels are desirable, antennas can be developed that radiate away from the body, reducing exposure, but also further distorting the radiation pattern from omnidirectional.

Summary

Radiation from antennas is affected by the human body's proximity. The effects include absorption of energy, which is a safety matter, and distortion of the antenna's radiation pattern, which may require modification of communication system performance parameters to allow for variations in signal level. Ongoing study in both safety and performance areas continues to shed light on the nature of these interactions. ■

References

1. FCC Rules and Regulations are contained in 47 CFR of the Federal Regulations, and can be found in larger public libraries, university libraries or law libraries. Information can also be obtained from the FCC's excellent Web site (http://www.fcc.gov/).

2. Kazimierz Siwiak, *Radiowave Propagation and Antennas for Personal Communications*, 2nd ed., Artech House 1998.

3. M. A. Stuchly, M. Okoniewski, M. Rahman, K Caputa, "Modeling of Human Interaction with Antennas Using the Finite Difference Time Domain Technique," *1998 IEEE AP-S Conference on Antennas and Propagation for Wireless Communications*, Waltham, MA, Nov. 1998.

4. Recommended reading: Ronald Kitchen, *RF Radiation Safety Handbook*, Butterworth-Heinemann 1993.