Antenna Design for Improved Efficiency and Reduced SAR

Frank M. Caimi, Ph.D.
Kerry L. Greer

April 2001

Introduction

The wireless revolution has spawned a flood of new products that dramatically increase the availability of voice and data nearly anywhere in the world. While this revolution has significantly expanded the opportunity for new and better wireless communication terminals, it has made design considerations for antennas more involved than ever before.

Before the evolution of mobile handsets and portable wireless terminals, antenna engineers were able to develop designs based on individual radio specifications and requirements. Elements of the design included a variety of factors, such as gain, bandwidth, and polarization. However, with the recent emphasis on reducing size, providing increased power efficiency, and meeting FCC requirements for mobile handset emissions, two additional elements of the antenna design have risen in importance. Antenna efficiency and control of Specific Absorption Rate (SAR) are new factors that must be equally considered along side traditional design parameters.

SAR Design Issues

In the United States and in other countries, cellular and other wireless handsets must meet regulatory requirements for maximum SAR levels. The motivation for developing these regulations has been to ensure appropriate limits for users of wireless handsets from the standpoint of energy absorption into body tissues. Although the radio frequency emissions of wireless handsets are classified as non-ionizing, they are able to transfer energy in the form of heat to any absorptive material. The antenna location, near field emission characteristics, radio frequency power, and frequency establish the basis for conformance to SAR limits.

In the interest of ensuring public and user safety, the FCC and other regulatory bodies have developed safety standards for mobile phone radio frequency emissions. All cellular and PCS phones manufactured after August 1, 1996 must be tested for compliance against these FCC guidelines for safe exposure. Also, all PCS handsets subject to equipment authorization since 1994 are required to meet FCC safety guidelines. SAR is defined mathematically as the time derivative of the incremental energy (dU) deposited in an incremental mass (dm) contained in a volume element (dV) of density (rho):

$$SAR = d/dt\{dU/dm\} = d/dt\{dU/\ \ dV\} = \ \ E^2/$$

As indicated, SAR can be also be computed from the total electric field strength (E), the conductivity of the medium (sigma), and the density of the mass (rho). Thus, SAR is a measure that estimates the amount of radio frequency power absorbed in a unit mass of body tissue. SAR is measured in units of watts per kilogram, or equivalently in milliwatts per gram, averaged over a specified volume of measurement. The limit for SAR in Australia, United States, and Canada is 1.6 milliwatts per gram. In Korea and Japan it is 2 milliwatts per gram. In Europe, the testing is voluntary.

SAR limits are different for different regions of the body, as well as the volume over which the average is made. Since cellular antennas can produce highly localized near field intensities, small test volumes—perhaps as small as 1 cubic centimeter — are used where the near field concentration of energy may be the highest. At present, this volume is nearing the lower limit over which measurements can be accurately made, and represents the required volume for measurements applicable to the head.

SAR test procedures and data are available for most new phones at the FCC website www.fcc.gov/oet/fccid. It is necessary to find the manufacturer ID code and model ID in order to access this information. Compliance with the recommended maximum SAR limits is usually obtained under specific conditions. Tests are done with the antenna extended and with it stowed. In some cases, the antenna must be held at a minimum distance from the body in order to meet the 1.6 mW-per-gram SAR limit.

There are five primary factors that control actual versus measured SAR values. These are the frequency (energy) of the incident radiation in relation to the composition of the test mass; the radiation intensity (near field pattern) of the energy source and the proximity of the source to the test mass; the presence of reflecting surfaces and their orientation; the power provided by the RF output stage to maintain communication; and the polarity (orientation) of the field vectors in relation to the test mass. Little control is afforded for the first factor, since operating frequency is fixed for most wireless services. This leaves various combinations of the remaining factors as possible design solutions.

Depending on the particular wireless standard, active control of the RF power output is used by most wireless handsets to conserve battery life, so actual SAR is lower than the maximum possible. But manufacturers must meet the imposed requirements under the condition of full power output, since prolonged operation in fringe reception areas is possible. Since the output power may be up to ~1/2 watt from cellular phones, careful design is required to meet the 1.6 milliwatts/gram limit. The available options are techniques that increase the distance from the phone’s antenna to the user, and that control the near field RF emission from the phone. Specifically these are: transmitting at lower than optimal (for communication) power levels to comply with regulations; moving the transmitting antenna far enough away from the user to achieve compliance; transmitting in a non-uniform (non-circular) pattern to reduce RF power density toward the user; and distributing the near field power emitted by the antenna to reduce the power density available.

In essence, the design strategy has become a complex procedure of locating the antenna for good performance, while minimizing measured SAR. Measurements are generally conducted using a phantom head or body composed of a gel-like material that has similar dielectric properties as those of the human body. Since SAR is affected by the aforementioned factors, it is necessary to test using realistic products, i.e., with a near-final production design of the phone with a properly located antenna. Manufacturers often use existing ground planes to shield the user from the antenna. They also have the option of using parasitic antenna elements external to the case as reflectors to control the near-field antenna pattern. The latter solution can be cumbersome when used with a monopole antenna since an additional rod element must be located between the user and the antenna. Patch antennas and variants on the loop antenna can permit design flexibility without resorting to cumbersome reflector elements.

Another approach is to purposely design an antenna to minimize near field emissions in a particular direction. The design approach for achieving this is to limit the power density toward the user to meet the SAR requirement, while re-directing most of the signal away from the user. This has the complementary benefit of putting the previously absorbed energy to new use, boosting reception in other directions.

An example of an antenna exhibiting the desired radiation characteristics without the use of parasitic reflectors is the meander line antenna originally developed for military use and now being commercialized by SkyCross, Inc. This antenna has the ability to operate at two or more frequency bands simultaneously without dynamic tuning, is highly efficient, and approaches the Chu-Harrington limit in terms of small volumetric size for a given bandwidth of operation. The radiation pattern in one of its operating modes mimics the far field pattern of a monopole or dipole. A significant reduction of the near field is achieved due to its novel design. The antenna produces a reduced near field intensity advantage from 3 to 10 dB depending on position at 1” distance when compared to a quarter-wave monopole at the same distance. A difficulty with the standard monopole is the dependence on the ground plane as a conjugate radiating element, as well as its small cross-section. The former characteristic has the effect of placing the user in capacitive contact with radiating portions of the antenna system while the latter provides for high field strengths in close proximity to the antenna, which can produce radiation densities that may exceed government safety limits if adequate spacing or shielding cannot be obtained. The near field reduction in the meander line antenna is due to its spatially distributed radiating sections which sum to form the far field radiation pattern. At some distance from the antenna, the far field intensities of both antennas are identical, assuming equal losses.

Improved Efficiency

Combining spatial distribution methodology of the meander line, or other spatially distributed antennas, with the use of fractional wavelength reflectors, such as circuit-board ground planes or shields, can result in additional reduction of near field intensity in the direction of the user. The same is possible with loop and patch antennas, but efficiency and bandwidth must be considered to obtain the desired level of performance. Directing radiation away from the user can actually be preferable when handset performance is considered, as measurements suggest that 40% of the RF power from a mobile phone in either the 800-MHz or 1900-MHz band is absorbed by the user’s head when an omni-directional antenna is used. Directing this energy away from the user allows most of the emitted RF energy to be recovered, which can in some conditions improve overall average performance. This is particularly true in propagation environments where the signal is subject to multiple reflections, as in dense urban settings. In the worst case, the energy is directed away from the cellular tower but at a higher effective radiated power than would be possible with an omni-directional antenna that would be subject to absorption from the user’s body. In the case where the maximum radiation direction is toward the tower, active power control can reduce the RF power output from the transmitter to a lower level than that achieved with an omni-directional antenna, producing the same received signal level.

The aforementioned use of spatially distributed antenna elements might not only provide advantages in meeting SAR limits, but might also provide additional overall performance improvements from the standpoint of antenna diversity. However, advantages with respect to SAR are only possible if the average power from each antenna element is sufficiently shared.

In order for improved efficiencies to be realized, it is also necessary to prevent the antenna detuning that can occur from proximity to objects via electromagnetic (capacitive or inductive) coupling. An obvious way to avoid such problems is to limit proximal coupling by intentional use of shielding, or through active control of the antenna itself. The latter method can be highly effective, but adds complexity to the design. The former requires special considerations in antenna design through modeling and test.

While smaller and more efficient communications terminals are being developed through circuit refinements, battery design improvements, and circuit integration, antenna design remains an important process for achieving conformance to standards and optimal performance with minimal interaction from the environment. Methods exist for minimization of near field intensities and SAR through the use of distributed antenna elements combined with design processes that place the antenna optimally with respect to case shields and the user. The meander line family of antennas exhibit reduced near field intensities, and can be configured to produce directional radiation characteristics. Such methods avoid the use of absorbing materials to protect the user, and can result in simultaneous improved performance and safety.