ELECTRIC POWER
RESEARCH INSTITUTE

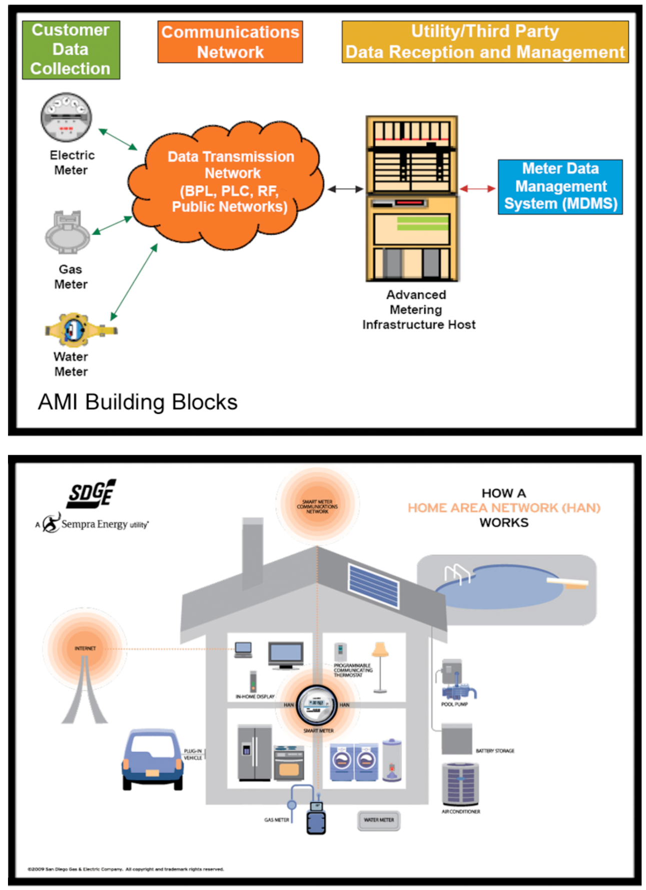
A Perspective on Radio-Frequency Exposure Associated With Residential Automatic Meter Reading Technology

EMF Health Assessment and RF Safety

Introduction

Advanced Metering Infrastructure (AMI) is "comprised of state-of-the-art electronic/digital hardware and software, which combine interval data measurement with continuously available remote communications. These systems enable measurement of detailed, time-based information and frequent collection and transmittal of such information to various parties. AMI…typically refers to the full measurement and collection system that includes meters at the customer site, communication networks between the customer and a service provider, such as an electric, gas, or water utility, and data reception and management systems that make the information available to the service provider." [EPRI Fact Sheet (1014793, 2007)] The National Energy Technology Laboratory's February 2007 report, "Integrated Communications," expresses the indispensable nature of AMI: "Due to its dependency on data acquisition, protection, and control, the modern grid cannot exist without an effective integrated communications infrastructure. Establishing these communications must be of highest priority since it is the first step in building the modern grid." The collection of such information from end users would occur through Neighborhood Area Networks (NANs) for transmission to service providers over Wide Area Networks (WANs). NANs consist of low-power transmitters and local receivers or data collectors (e.g., mounted on poletops), which relay the information via WANs to a remote repository where the data can be managed and analyzed. WANs commonly use the same kind of technology as the so-called Aircards® that individuals use for wireless Internet connectivity from their laptop computers. AMI is also envisioned as including a Home Area Network (HAN), whereby various devices throughout a household – these may include lighting, thermostats, and other electrical appliances, etc. – would be in wireless contact with a central coordination and data collection node within the residence. The HAN would enable such a household to receive data describing its electrical usage behavior, and enable optimal energy usage efficiency. General schematics of AMI with the HAN component are shown in Figure 1.

Figure 1. Schematics of Automatic Metering Infrastructure (Top[1]) and a House Area Network (Bottom[2])



[1] Assessment of Demand Response and Advanced Metering – Staff Report, FERC Docket AD06-2-000; August 2006

[2] Used with the permission of San Diego Gas & Electric

As these technologies have developed over the past few years, one component of AMI, the Automatic Meter Reader (AMR) has especially attracted questions from electric utility residential customers. AMR displaces and expands the role of the meter reader, who entered a home or building premises to manually record electrical power usage, mainly for billing purposes. AMRs transfer data wirelessly with a radio-frequency (RF) transmission to a nearby NAN, as described above, in some cases to a utility service vehicle with data collection equipment situated outside of the residence, or less commonly, over a physical wire system, such as telephone or powerline carrier current. The technology not only provides a highly efficient method for obtaining usage data from customers, but it also can provide up-to-the-minute information on consumption patterns since the meter reading devices can be programmed to provide data as often as needed. AMR can also be used for Time-of-Use pricing applications and pinpointing outages. Specifically, customer questions have arisen concerning the level of personal RF exposures from AMRs within and around a residence and any health implications of such exposure. The remainder of this commentary deals with this issue.

Figure 2. Meter Technologies Old and New

A Modern Solid State Smart Meter (left) and an older Electromechanical Watt hour Meter

NETL, Feb 2008 ("NETL Modern Grid Strategy Powering our 21st-Century Economy")

Applicable RF Exposure Standards

Several guidelines or standards exist that recommend safe limits for human exposure to RF fields. These include exposure limits developed by the Institute of Electrical and Electronics Engineers (IEEE, 2005), guidelines published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998) and rules on maximum permissible exposures promulgated by the Federal Communications Commission (FCC, 1997). These exposure limits are all based on the fact that RF exposures, at sufficiently high levels, may increase the temperature of the body (or portions thereof), to a level that may be considered hazardous. Despite the vast amount of research conducted in recent years to address potential health effects associated with the use of cell phones, no other specific biological effects, save for heating, have been confirmed or generally accepted. All exposure guidelines and standards specify limits for the general public as well as for groups including workers, specifically trained to be aware of their environments. The exposure limits for working environments include safety factors indexed to the adverse effect threshold, which is currently based on the level at which behavioral disruption occurs in laboratory animals trained to perform learned tasks (Behavioral disruption, or work stoppage in the context of experimental psychology studies, is related to an increase in deep core body temperature of about 1ºC.)

Maximum permissible exposures (MPE) to radiofrequency electromagnetic fields are usually expressed in terms of the plane wave equivalent power density expressed in units of milliwatts per square centimeter (mW/cm^2) or alternatively, microwatts per square centimeter ($\mu W/cm^2$). Because absorption of RF energy is a function of frequency (as well as body size and other factors), the limits vary with frequency. The quantity called SAR or Specific Absorption Rate refers to the time rate of energy deposited per mass of tissue, usually stated in terms of watts per kilogram of tissue (W/kg). The benchmark for behavioral disruption has been determined to be approximately 4 Watts per kilogram (W/kg) across several different species tested across a range of frequencies. The occupational exposure limit, which includes a safety factor of ten compared to the threshold for behavioral effects in laboratory animals, ensures energy deposition rates will not exceed 0.4 W/kg, and an extra safety factor of five is included for the general public such that RF absorption will remain below 0.08 W/kg (or 50 times less than the threshold for behavioral disruption) as averaged over the whole body. The FCC permits a localized energy absorption rate of 1.6 W/kg in any 1 gram of tissue; for extremities, this limit is relaxed to 8 W/kg. The MPEs in various standards, regulations or guidelines are expressed in terms of root mean square (rms) values, which represent an average deposition of energy over a designated period; for the public the averaging period is 30 minutes.

Many, but not all of the various AMR systems, operate in the FCC's "license free" band of 902-928 MHz (some systems may also operate within a different licensed band, e.g., the 450-470 MHz range). Part 15 of the FCC rules specifies that systems operating in the license-free band must not cause interference with other licensed services. Consequently, AMR transmitter power and associated RF emissions are restricted to very low levels. In contrast, the FCC imposes strict exposure limits to its licensees such as operators of radio and television broadcast stations, two-way radio communications systems, cellular telephone base stations, etc. While license-free bands are not specifically addressed by the FCC's regulations on human exposure, using FCC limits as an exposure benchmark represents a conservative approach, because the FCC limits are more stringent than the other published guidelines and represent the most conservative values that any U.S. government agency applies.

Characterizing AMR Units

Several types of AMR units on the market have been evaluated but a comprehensive characterization was beyond the scope of this commentary. The exposure levels from the AMR units were characterized with the technical specifications provided by the manufacturers incorporated into the following equation:

$$S(W/m^2) = \frac{P_t \times G_{\max} \times \delta \times 2.56}{4\pi R^2}$$

Where,

S is plane wave equivalent power density (W/m^2)

P_t is maximum transmitter output power (W)

G_{max} is the maximum possible antenna power gain (a dimensionless factor); this means that the transmission has directionality with maximum power transmitted in one particular direction.[1]

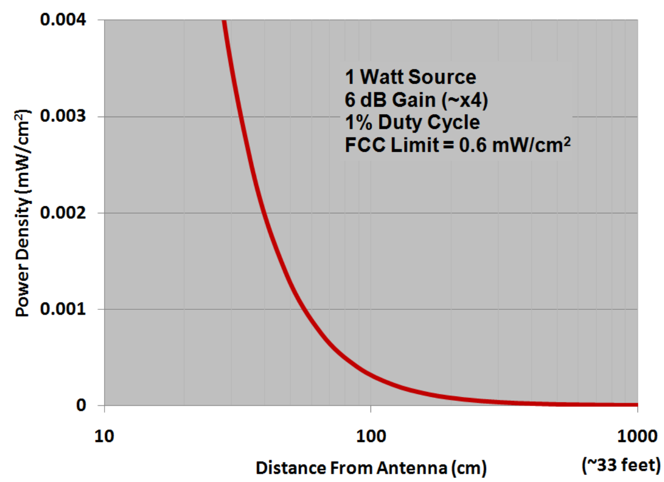
δ is the duty cycle of the transmitter

R is the radial distance between the transmitter and the point of interest (meters)

2.56 This factor accounts for possible ground reflections that could enhance the resultant field. Ground reflection could cause a maximum 1.6-fold increase of the field strength leading to an increase of $(1.6)^2$ or 2.56 in the power density since it is proportional to the square of field strength. [2]

Note that the formula includes the duty cycle, δ, which is the fraction of time a unit transmits, or stated in perhaps more practical terms for current purposes, the fraction of time that a person in proximity to an AMR unit would be exposed to its emission. For example, a cell phone in general has a 100% duty cycle during a call, but an AMR equipped power meter may only transmit for the equivalent of a few seconds per hour. A typical lateral profile of average power density transmitted versus distance from a unit is shown in Figure 3, which illustrates the inverse square character of the power with distance. The gain factor, G_{max}, relates to the fact that RF transmissions are not omnidirectional (i.e., the same power radiated in every direction). Rather the signal from the meter is transmitted in a narrower beam directed toward the receiver, thus conserving total power, but concentrating the AMR's signal in that direction by a multiple (or gain) of that which would be produced by an omnidirectional transmission (in the example of Figure 3, the gain of the antenna was assumed to be 6 dBi or a power gain of about 4). Figure 3 provides estimates of the RF field that would be associated with a one watt transmitter operating with a duty cycle equivalent to 36 seconds of transmission in each hour (a duty cycle of 1%). It must be pointed out that, while very low duty cycles on the order of seconds per hour are typical in the vast majority of situations, the future will see the development of large-scale mesh networks. With this development, AMI/AMR units in some residences could become collection nodes, channeling data to the wireless local area network (WLAN) from many residences, perhaps as many as 1,000. Such cases, however, would be exceptions, with duty cycles remaining very low throughout the residences in any particular service territory.

Figure 3. Power density versus distance for a typical AMR equipped electric power meter.



Note: To maintain simplicity and consistency with figure 4, this graph does not account for possible ground reflections. However, ground reflections would not change the basic shape of the curve.

Besides the electric meter transmitting data to area data collectors (the LAN), it was mentioned that the meter may also contain a separate low power transmitter designed for HAN communications with electrical appliances within a home or business. Typically, this HAN transmitter operates with lower power than the LAN transmitter, commonly at a level of approximately ¼ watt. The activity of this transmitter will be dependent on the configuration of the customer's HAN; for example, how many devices may be interfaced with the system. Hence, it is difficult to estimate the duty cycle that might be associated with the HAN

---

[1] The power density transmitted in this direction at a given distance is greater – by a factor, G_{max} - than the power density at the same distance were it transmitted symmetrically in all directions (or omnidirectionally) in a spherical pattern as from an isotropic source. This also means that there are areas near the antenna with transmitted power lower than the power density from an omnidirectional source.

[2] The inclusion of the ground reflection factor of 2.56 makes this formula extremely conservative since it assumes that the AMR signal emitted by a power meter is also reflected from the ground causing an enhancement of the resultant RF field due to what is called phase addition of the direct and reflected signals. If this occurs, it will only happen at very specific points above the ground while at other points, the signals will add destructively, reducing the signal intensity. Hence, when considering the body as a whole, the ground reflection will generally not affect the body's average exposure. Nonetheless, it is common when performing FCC compliance analyses to include the possibility of ground reflections.

transmitter. Nonetheless, if the HAN transmitter were to operate, for example, four times as much as the LAN transmitter, the estimated time-averaged RF fields would be essentially the same as the values shown in Figure 3. This would mean that the total, cumulative power density from operation of the AMI/AMR equipped meter might be twice the values shown, i.e., less than 10 microwatt per square centimeter at a distance of one foot from the meter.

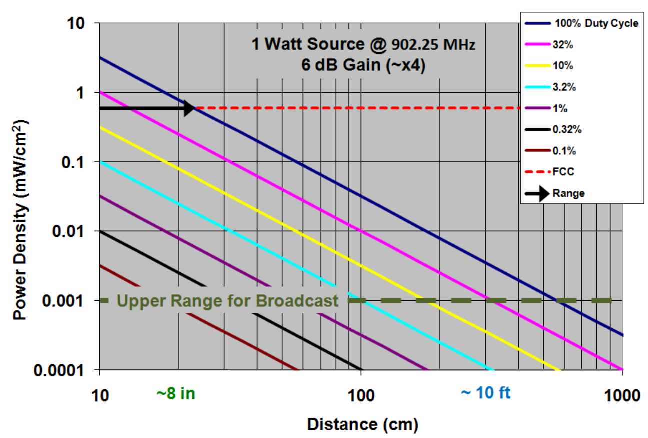
AMR Exposures Referenced to the FCC Guideline and Other Common RF Exposures

The largest RF fields in urban environments are typically those from the domestic broadcasting services, including AM and FM radio and VHF and UHF television (more below). The U.S. Environmental Protection Agency (EPA) took measurements across the United States between 50 to 900 Megahertz (MHz), whose upper range corresponds to AMI/AMR systems. The EPA data showed that most people, most of the time, are exposed to very weak RF fields from such sources. In that study, the median RF field exposure of the public was determined to be approximately 0.005 $\mu W/cm^2$ ($5x10^{-6}$ mW/cm^2), and the study estimated that 1% of the public in metropolitan areas was exposed to RF fields exceeding 1 $\mu W/cm^2$ (0.001 mW/cm^2).

Figure 4 shows the exposure levels for a 1 watt transmitter with a gain of 6 dB (about 4) over a range of duty cycles from 0.1% to 100% benchmarked against the FCC guideline level for the public at a typical AMI frequency. In the interest of illustrating a worst case scenario, a duty cycle of 100% is included (rightmost blue line). In reality, AMI/AMR units, on average, need to “listen” for incoming signals for about the same period of time as they transmit (i.e., produce RF exposure). Thus, at the outside, with a residence fully-loaded as a node serving a local mesh network, 50% would be the maximum possible duty cycle. However, as mentioned, the norm for the vast majority of residences would in all likelihood involve transmit duty cycles of less than a few percent (and maybe lower). The chart indicates how as duty cycle increases, the minimum distance from the antenna remaining in compliance correspondingly increases. For all operating conditions represented in the chart, compliance is achieved within a foot of an antenna, and in most realistic situations, and in most realistic scenarios, by a factor of 100 or more.

Also shown on the figure is the upper range for the public’s exposure to RF exposures from radio/TV broadcasts. Beyond 10 feet of the antenna used in the example, AMI/AMR exposures would not exceed exposures from broadcast sources. A typical exposure one meter from a Wi-Fi transmitter as might be located in a coffee shop is about one-third of the upper boundary for broadcast (~0.0003 mW/cm^2 or 0.3 $\mu W/cm^2$). Other familiar RF exposures at frequencies comparable to the typical AMR systems include walkie-talkies operating in the family radio service (FRS) band (462.5625-467.7125 MHz) with up to 500 mW of radiated power; general mobile radio service (GMRS) band (462-467 MHz) with up to 1,000-5,000 mW of radiated power, and cellular phones with up to about 600 mW of radiated power, and microwave ovens (which operate at about 750-1000 W, but whose leakage emission is limited by the Food and Drug Administration to no greater than 5 mW/cm^2 5 cm and further from a unit).

Figure 4. Exposure Levels by Duty Cycle Benchmarked Against the FCC Guideline



AMI/AMR exposure levels are shown as a function of distance for a 1 watt AMI antenna operating with a 6 dB gain over a range of duty cycles. The FCC Maximum Permissible Exposure for the frequency used in this example (902.25 MHz) is indicated with a horizontal broken line. For this example, the black arrow indicates the worst case exposure distance (unit constantly transmitting) in terms of FCC exceedance. Also shown is the upper range of exposures from broadcast sources.

Technical Note: The FCC does not apply external RF field power densities for assessing compliance with exposure rules when closer than 20 cm (~8 inches) to a device. In that case, they would normally recommend a direct assessment of SAR (see text for definition). Nonetheless, for typical duty cycles (~1%) an exposure exceedance level would not occur until one was within a few inches of a unit.

Interference

The FCC requires that unlicensed low-power RF devices must not create interference and users of such equipment must resolve any interference problems or cease operation. According to the FCC (47CFR Part 15): “The operator of a radio frequency device shall be required to cease operating the device upon notification by a Commission representative that the device is causing harmful interference. Operation shall not resume until the condition causing the harmful interference has been corrected.” The low power levels at which the AMI/AMR components in a residence operate (described above) assure that the probability of interference is negligible if not totally absent.

Conclusion

Advanced Metering Infrastructure is rapidly expanding to improve the service quality and efficiency of our electrical power systems. This short paper focused specifically on questions that have arisen with regard to residential radio-frequency exposure from Automatic Meter Reading technology, a component of AMI, which over time is replacing conventional electrical meters. As a society we are exposed constantly to varying levels of radio-frequency emissions, most often and constantly from radio/TV stations. In recent years, RF exposure from cell phones has expanded exponentially, and has attracted attention worldwide as to potential health effects associated with their use. Such questions will take time to resolve. Despite these issues, guidelines promulgated by the FCC and other organizations are recognized as protective of known adverse biological effects. We conclude that AMR equipped electric power meters installed in residences produce RF exposures that are far lower than the FCC guideline stipulates, even at very close range.

Summary

- Automatic Metering Infrastructure (AMI) enables measurement of detailed time-based information across the grid, as well as within neighborhoods and residences. Automatic Meter Reader systems that replace manual meter reading are included in AMI.

- The normal operation of an AMI system includes radio frequency transmissions from the power meter attached to a residence or business to local data collectors over WLANs, as well as within a residence from its Home Area Network.

- The exposures from AMI systems, including AMRs, generally occur with very low duty cycles at average levels far below safety standards specified by the Federal Communication Commission (FCC). Even if an AMI unit were to continuously operate it would still have exposures in a home far below FCC limits for the public. The FCC exposure limit is more stringent than others in common usage.

Acknowledgement: The EMF Health Assessment & RF Safety program wishes to thank Brian Seal of EPRI’s Knoxville facility for his helpful comments.

Contact Information

For further technical information, contact Rob Kavet at 650.855.1061 (rkavet@epri.com) or Gabor Mezei at 650.855.8908 (gmezei@epri.com).

1020798 February 2010

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com