ELECTRIC POWER
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Radio-Frequency Exposure Levels from Smart Meters: A Case Study of One Model

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Introduction

This paper presents results from measurements of radio-frequency (RF) emissions from one specific type of smart meter. These tests were conducted as an initial step in responding to questions from the public concerning RF exposure levels from wireless smart meters. Smart grid technology promises to deliver enhanced reliability and economy of electrical power use. Consumers will be empowered with knowledge about—and with greater control over—their patterns of electricity use. Coincident with such benefits must also be an assurance that these new systems are operating in a manner compatible with human health and safety.

In the real world, smart meters transmit on an unpredictable schedule for very brief periods throughout the day, consisting of individual transmissions milliseconds long in duration, amounting to an average of up to about a minute and a half of transmitting per hour. For a valid RF field characterization with the meters continuously transmitting, it was necessary to conduct the measurements under defined conditions. With the manufacturer volunteering its test facility, measurements were able to proceed producing the data presented in this White Paper, representing the first well-documented study of its type. As there is a great diversity in the kinds of smart metering systems currently in use nationally and internationally, with many brands, architectures, frequencies, power levels, and communication activity levels represented, this study, naturally, may not fully describe all possible exposure values for all systems. Nevertheless, data from this study may be used to gain valuable insight into exposure scenarios for one widely used type of smart meter.

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This white paper was prepared by Rob Kavet and Gabor Mezei of the Electric Power Research Institute (EPRI).

Smart Meters' Role in a Modern Electricity Grid

Advanced Metering Infrastructure (AMI) is instrumental in changing the way electricity is used in industrial, commercial, and residential settings. EPRI's 2008 report, Wide Area Communications for Advanced Metering and Demand Response (1016959), states "…a modern grid requires a communications system with the capacity to support traditional utility functions—and the flexibility to adapt to advanced metering, demand response, distributed generation, and the many other new challenges." As an important component of the smart grid, AMI systems often use wireless communications to provide metering data that can be used to assess how, when, and where electricity is used. Anticipated benefits include enhanced reliability across the grid and pricing options for end users to economize on their electricity consumption.

As an integral component of AMI systems, smart meters are being installed in homes and businesses across the United States and abroad. EPRI's 2010 report, Accuracy of Digital Electricity Meters (1020908), indicates that "residential meters are expected to provide a range of measurements, with some including demand, TOU [time-of-use], or even continuous interval data. Some may also be required to keep a record of additional quantities like system voltage—helping utilities maintain quality of service in a world that includes fast-charging electric vehicles and solar generation."

AMI systems are generally two-way communicating systems and are envisioned to perform a wide-range of applications in addition to simply reading the meter. For example, some utilities envision using the meter as a "gateway" to the home, transmitting energy price signals and load management events to the consumer. Others may be used as distribution system voltage monitors, sending local voltage readings back to a distribution control system in near real-time. Yet others may be used to bring customer consumption data back to a central repository or transmit it into the home in real-time. In the context of wireless AMI systems, the two-way nature of these systems is normally implemented through the medium of so-called mesh networks, in which the meter on one home acts as a router for data coming from one or many other homes.

The Federal Communications Commission established limits for exposure to radio-frequency electromagnetic fields, which are published in FCC OET Bulletin 65 (August 1997), and codified in the Code of Federal Regulations (47 CFR § 1.1310). The FCC rule was adopted from two previous guidelines, one published by the National Council on Radiation Protection and Measurements (NCRP Report No. 86) in 1986, and the other by the Institute for Electrical and Electronic Engineers (IEEE C95.1 1991) in 1991. Both had extensively reviewed the biological and health literature, concluding that the only established effects were associated with tissue heating and no confirmed effects below heating thresholds were identified. The effects associated with heating, so-called "thermal effects", concerned diminished response rates in food-motivated behavioral experiments in laboratory animal subjects (rhesus monkeys and rats) and were accompanied by a rise in body core temperature of about 1° C. The exposure limits specified by the FCC afford the public a margin of safety 50-fold lower than the adverse effect threshold identified in the behavioral studies. Since the FCC rule was promulgated, other organizations concerned with RF health and safety have developed exposure guidelines very similar to the FCC's. These include the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guideline (Health Physics 74:494, 1998) and IEEE Std C95.1™ published in 2005. These have again been based on thorough reviews of the literature, concluding that in the absence of heating, there have been no consistently demonstrated "non-thermal" mechanisms that could lead to adverse biological or health effects. A 2009 review of the radio-frequency health literature conducted by ICNIRP concluded:

> *The mechanisms by which RF exposure heats biological tissue are well understood and the most marked and consistent effect of RF exposure is that of heating, resulting in a number of heat-related physiological and pathological responses in human subjects and laboratory animals…Whilst it is in principle impossible to disprove the possible existence of non-thermal interactions, the plausibility of various non-thermal mechanisms that have been proposed is very low…the recent in vitro and animal genotoxicity and carcinogenicity studies are rather consistent overall and indicate that such effects are unlikely at specific absorption rate levels up to 4 W kg^{-1} [the level associated with behavioral disruption in animal experiments].*

EPRI Perspective

The use of RF-based smart meter technology for the residential sector has raised questions from the public as to potential health and safety risks that may be related to the meters' RF emissions. The Electric Power Research Institute's (EPRI's) EMF Health Assessment and RF Safety program initiated its research in response to these concerns with a preliminary commentary, A Perspective on Radio-Frequency Exposure Associated With Residential Automatic Meter Reading Technology (1020798), which described how wireless smart meters communicate, and provided insights into what kind of exposure levels may result. The EPRI research program has followed up with two ongoing research activities. One is an analysis of the amount of RF energy deposited in persons exposed to smart meter emissions. This study uses computer simulations of anatomically correct models of children and adults exposed under a range of conditions in very close proximity to a smart meter.

A second activity, the main subject of this paper, concerns a measurement study of RF emissions from one type of smart meter, taken under controlled conditions at the manufacturer's facility (as described in the Introduction). The purpose of the study was to take a first step in collecting empirical smart meter emission data. (*An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter*. EPRI Technical Report 1021126, December 2010, www.epri.com). These data could potentially provide insight into the range of exposure levels produced by other wireless smart meter systems. Key results of the study described below were that (1) exposure levels from an individual meter fall off rapidly with distance as one moves away; (2) based on empirical data from two electric utility service territories in California, the meters transmit only a small fraction of the time, and (3) exposure levels—even when one is close to a meter that is continuously transmitting—remain below the FCC exposure limits.

Smart Meter Measurement Study

When deployed across neighborhoods, meters of the type studied operate as part of a "mesh" network. The meters distributed across the mesh network are referred to as "end-point" meters and are the most common. Data from the end-point meters at individual residences are routed to "cell relays" (referred to by some as "collectors") with typically one of the latter installed for every 500 to 750 customers. From the cell relay the data are sent to a central repository over a wireless link that operates in the same manner as a cell phone transmission. The study conducted at the manufacturer's site involved RF emissions from only one type of end-point meter configured to transmit at its rated power level of nominally a quarter watt (W) or 250 milliwatts (mW) in the unlicensed frequency band of 902 to 928 MHz. The cell relay meters for the system tested operate similarly to end-point meters, but at a power level of 1 W. In addition, some utilities are deploying meters with a second radio inside for connection to a wireless Home Area Network (HAN). HANs, which can be either wired or wireless, can be used to provide communication connections between the utility and end-use devices for the purpose of demand response. HAN meters were also characterized in the EPRI study, but as they operate at a lower power level (roughly 60 to 100 mW) compared to the end-point units (and thus with lower exposure levels), the results of the HAN measurements are not covered in this paper; cell relays were studied as well, but only under laboratory conditions, and are not covered here either.

When in actual use in a field application, transmissions from the type of smart meter tested may occur in a somewhat unpredictable manner, for only small amounts of time interspersed throughout the day. Because of this, the manufacturer's cooperation was necessary to program the meters at their test site to allow for measurements taken under well-defined conditions, and thus be readily interpretable. The manufacturer's test site, also known as a "meter farm," contained about 7000 meters across a 20-acre area, and each structure consisted of a rack of 10 meters (see Figure 1). The measurements were conducted over a four-day period.

Figure 1 – Meter farm at the manufacturer's facility with a rack of 10 smart meters in the inset.

In order to facilitate the test measurements, the choice was made to take measurements using a single rack of continuously operating meters. The reader should note that, while the meters were specially programmed to operate continuously for the measurement study, when actually deployed they transmit intermittently for very brief periods (see later). To help differentiate the test rack from the background signals emitted across the site, the measurement team split the 10 meters within the test rack into three groups, each with a unique frequency within the unit's operational band of 902 to 928 Megahertz (MHz). In this manner, the rack of 10 meters had a unique fingerprint of emissions at 902, 915, and 928 MHz. As shown in Figure 2, measurements were taken both in front of and behind the meter racks. The exposure values reported were expressed

Figure 2 – Reading in front of (left) and behind (right) the rack.

in terms of the percentage of the FCC exposure limit for the general public. At the operational frequencies of the meters, the FCC exposure limits for the general public are equal to the transmitting frequency in MHz divided by 1500, expressed in units of milliwatts per square centimeter (mW/cm^2); the FCC exposure limits thus ranged between power densities of 0.60 to 0.62 mW/cm^2 as applied to the meters within the rack.

It should also be pointed out that while the testing was conducted with end-point meters rated nominally at ¼-watt (~250 mW), the manufacturer's data illustrated in the EPRI Report allow one to estimate, based on a sample of 200,000 meters, that 99.9% operate at powers between 150 and 475 mW, with a possible maximum of 500 mW for no more than 0.05% of units. For the HAN "Zigbee" emitter, one may estimate, again on the basis of a 200,000-unit sample, that 99.9% operate at powers between 35 and 142 mW, with a possible maximum of 160 mW for no more than 0.05% of units. Finally, though comparable statistics are not available for cell relays, as they are provided to the manufacturer by an outside vender, the specifications provided by the vender indicate a maximum power of 1.5 W for cell relays rated nominally at 1 W.

Compliance with FCC Rule: Spatial and Temporal Averaging

Prior to a summary of the results it is important to review the FCC's approach to compliance assessment, which involves averaging exposure across both space and time under the appropriate exposure conditions. FCC's exposure limits, published in "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields" (OET Bulletin 65, Edition 97-01, August 1997) states for spatial averaging (Figure 3) that:

> A fundamental aspect of the exposure guidelines is that they apply to power densities or the squares of the electric and magnetic field strengths that are spatially averaged over the body dimensions. Spatially averaged RF field levels most accurately relate to estimating the whole body averaged SAR [Specific Absorption Rate, the measure of dose to the body, described below] that will result from the exposure and the MPEs [Maximum Permissible Exposure, FCC's term for exposure limit]… (page 10)

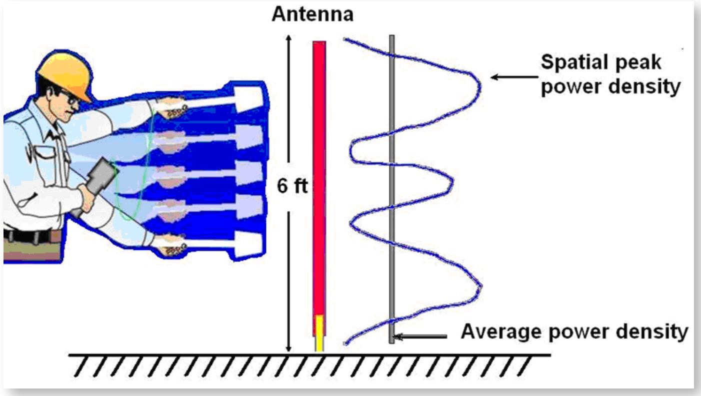


Figure 3 – Depiction of Assessing RF Exposure Across the Body (Source: EPRI Resource Paper 1014950)

With respect to time-averaging, OET Bulletin 65 states:

> …exposures, in terms of power density…may be averaged over certain periods of time with the average not to exceed the limit for continuous exposure…the averaging time for occupational/controlled exposures is 6 minutes, while the averaging time for general population/uncontrolled exposures is 30 minutes. (page 10)

The OET further states:

> Time-averaging provisions may not be used in determining typical exposure levels for devices intended for use by consumers in general population/uncontrolled environments. However, "source-based" time-averaging based on an inherent property or duty-cycle of a device is allowed. (page 74)

Thus, as RF electromagnetic fields associated with smart meters are *source-based*, meaning they can be associated clearly with a specific emitter or set of emitters, time averaging is permitted for such sources. For example, a reading in the study of 0.1 mW/cm^2 from meters operating between 902 and 928 MHz continuously would be about 16.7% of the FCC limit for the general public in that frequency range. When deployed at residences during actual conditions, these units typically operate with a maximum duty cycle of about 5% (*duty cycle* refers to the fraction of time a meter is transmitting). Thus, with this maximum duty cycle, one would then derive that the exposure was 20-fold less or 0.84% of the FCC limit. For a 1% duty cycle, a more typical value, the exposure would be 0.17% of the FCC limit.

Reflections

An additional consideration concerns the fact that certain surfaces can reflect an RF electromagnetic field, which can result in an exposure greater than would be experienced in free space with no reflection (Figure 4). The extent of an added exposure due to reflection depends on the reflectivity of the surface (e.g., metallic surfaces are highly reflective; carpeted and wood floors are more absorptive and less reflective), the antenna's beam characteristics (e.g., its angular width and direction) the angle of reflection, and the distance traveled by the wave to an exposed person. The FCC OET 65 Bulletin states:

> For a truly worst-case prediction of power density at or near a surface, such as at ground level or on a rooftop, 100% reflection of incoming radiation can be assumed, resulting in a potential doubling of predicted field strength and a four-fold increase in (far-field equivalent) power density. (Page 20)

A recent study modeled SAR resulting from a rooftop exposure to a base station antenna, with a highly reflective ground plane and/or highly reflective wall present. At 900 MHz—roughly the frequency of the RF LAN in the wireless smart meter investigated—the study reported that the SAR could increase by as much as a factor of about 3.6 (5.5 dB) on a localized basis in 10 grams of tissue, and by a factor of about 2.8 (4.5dB) on a whole body basis, both of these values being consistent with the FCC OET 65 cited above. At the same time, reflections modeled at 900 MHz may also result in a reduction of SAR compared to the free-space scenario. At lower frequencies (300 and 450 MHz) reflections were slightly greater, and at higher frequencies, including 2,100 MHz (roughly the HAN's operating frequency), the reflections were lower (Vermeeren et al., Phys Med Biol 55:5541, 2010).

Results

Examples of the data readouts over distance from the rack of 10 meters are shown in Figure 5. The top panel taken 1 foot in front of the rack displays the discernible peaks associated with the three pre-programmed operating frequencies as well as the background activity between the peaks from the other meters in the meter farm. By 20 feet from the meter rack, the peaks are sinking into the background, from which they are indistinguishable by 50 feet.

A summary of these measurements in Figure 6 indicates that for continuous operation at 1 foot from the rack, the exposure is about 8% of the FCC limit, with the fitted curve (in blue) indicating that the exposure diminishes roughly as the inverse of the distance from the rack. The dashed green line indicates the percentage of the FCC limit for a meter transmitting for 1% of the time (or with a 1% duty cycle). With a single meter, one would expect exposure to diminish with the inverse square of the distance, meaning that for every doubling of distance the exposure level is quartered. The reason that the power density diminishes more slowly with distance from the rack than it does from any individual meter is because the measurements at the rack were taken on a path leading away from its center, meaning that the contributions from the meters at

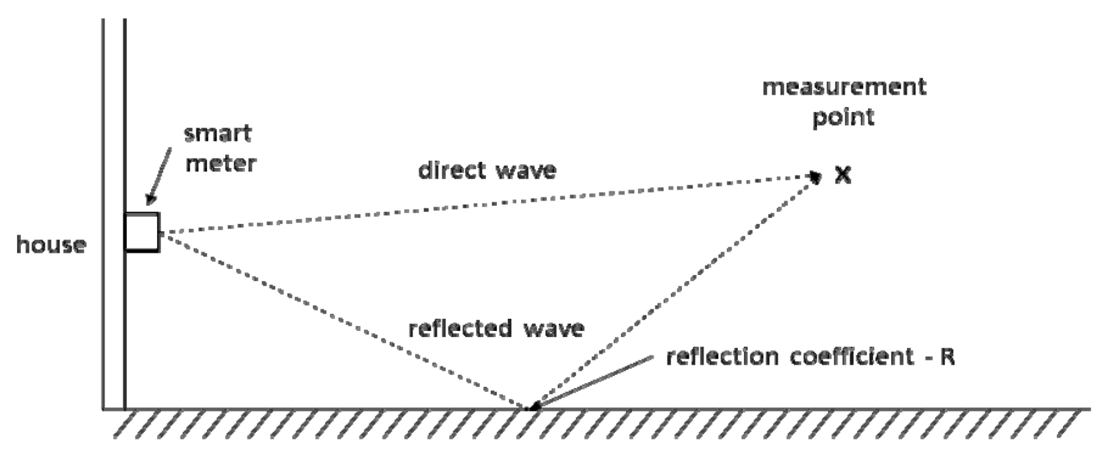
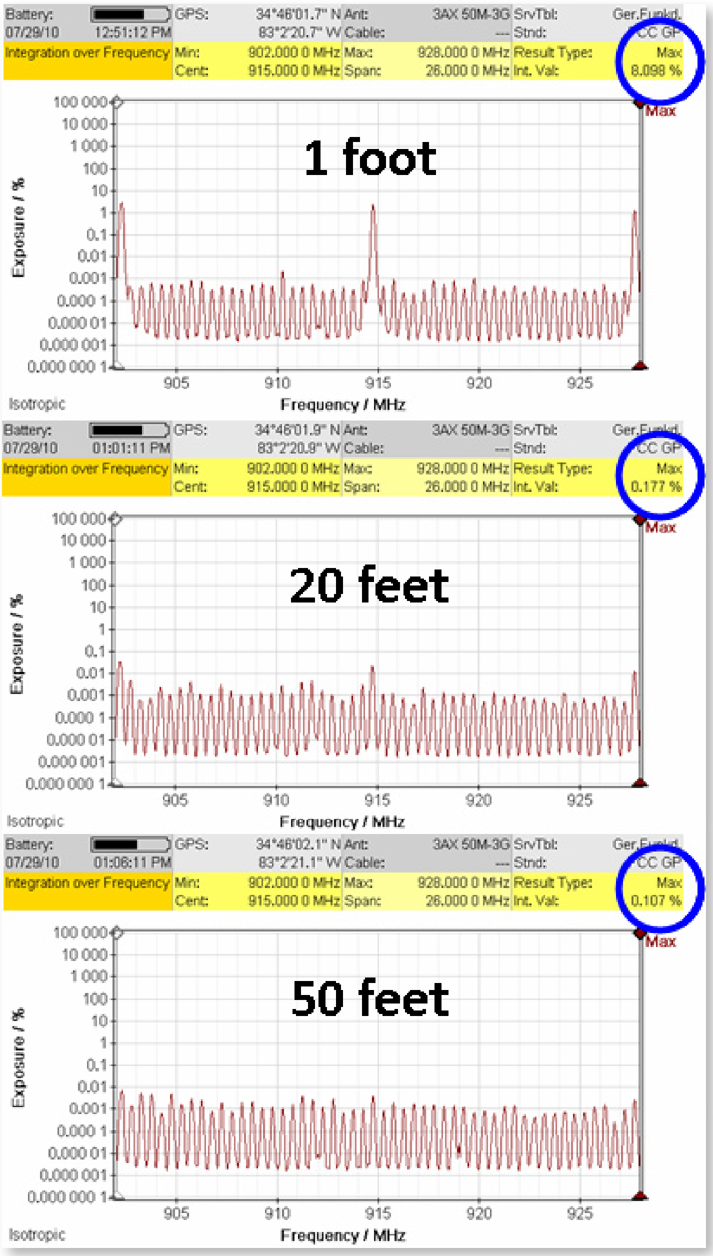


Figure 4 – Schematic view of the combination of a direct wave with a reflected wave.



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07/29/10	12:51:12 PM		83°2'20.7" W	Cable:	---	Stnd:	CC GP
Integration over Frequency		Min:	902.000 0 MHz	Max:	928.000 0 MHz	Result Type:	Max
		Cent:	915.000 0 MHz	Span:	26.000 0 MHz	Int. Val:	8.098 %

Battery:		GPS:	34°46'01.9" N	Ant:	3AX 50M-3G	SrvTbl:	Ger.Funkd.
07/29/10	01:01:11 PM		83°2'20.9" W	Cable:	---	Stnd:	CC GP
Integration over Frequency		Min:	902.000 0 MHz	Max:	928.000 0 MHz	Result Type:	Max
		Cent:	915.000 0 MHz	Span:	26.000 0 MHz	Int. Val:	0.177 %

Battery:		GPS:	34°46'02.1" N	Ant:	3AX 50M-3G	SrvTbl:	Ger.Funkd.
07/29/10	01:06:11 PM		83°2'21.1" W	Cable:	---	Stnd:	CC GP
Integration over Frequency		Min:	902.000 0 MHz	Max:	928.000 0 MHz	Result Type:	Max
		Cent:	915.000 0 MHz	Span:	26.000 0 MHz	Int. Val:	0.107 %

Figure 5 – Readouts of exposure levels at 1, 20 and 50 feet from the front of the rack. Note that the exposure levels are expressed as a percentage of the FCC limit (circled in blue).

the two lateral positions, operating at slightly different frequencies than each other, as well as from the rack's centrally located meters, had mutual phase relationships plus possible ground reflections, all which led the measured field to fall off more slowly with distance compared to the spatial gradient expected from a single meter.

Furthermore, as the distance from the rack increases, the relative contribution from the meter farm background increases. Since the measurements included background emissions in addition to the rack's emissions, the falloff of measured power density with distance is less than if the background sources were silenced.

A question that has also been voiced concerns the possibility of a person located adjacent to the wall immediately behind the meter. Therefore, measurements were also taken behind the meter rack. The readout, shown in Figure 7, indicates that even at 8 inches behind the rack, exposure for continuous operation was about 0.6%

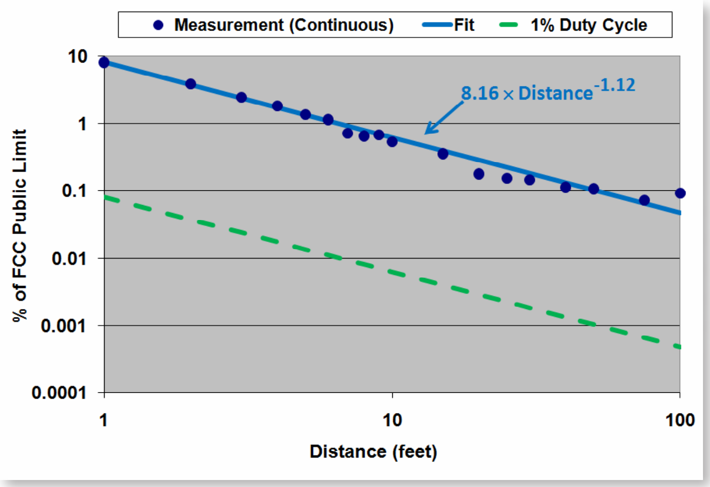
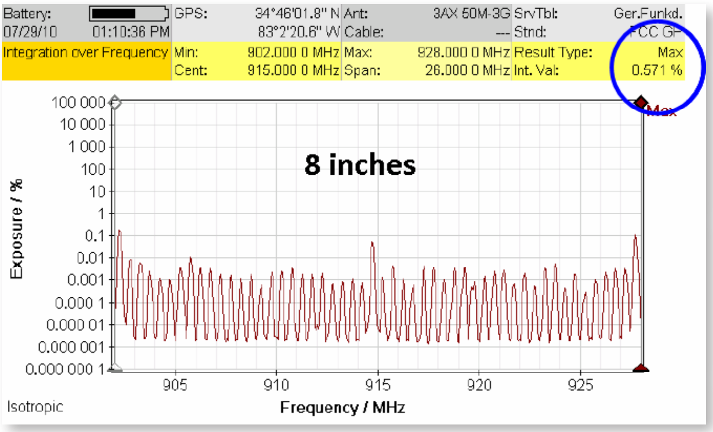


Figure 6 – Profile of emissions from the rack of ten Smart Meters as a function of distance, expressed as a percentage of the FCC exposure limits. The blue line is a mathematical fit to the measured data. The green dashed line indicates exposure relative to FCC limits when units transmit 1% of the time.



Battery:		GPS:	34°46'01.8" N	Ant:	3AX 50M-3G	SrvTbl:	Ger.Funkd.
07/29/10	01:10:36 PM		83°2'20.6" W	Cable:	---	Stnd:	FCC GP
Integration over Frequency		Min:	902.000 0 MHz	Max:	928.000 0 MHz	Result Type:	Max
		Cent:	915.000 0 MHz	Span:	26.000 0 MHz	Int. Val:	0.571 %

Figure 7 – Readouts of exposure levels at 8 inches behind the rack. Note that the exposure levels are expressed as a percentage of the FCC limit (circled in blue).

of the FCC limit or 0.03% for a 5% duty cycle. Exposure was measured at less than half this value at 10 feet behind the rack.

Smart Meters in Context of Other Typical Radio-Frequency Exposures

Most environments have numerous sources of RF emissions to which most people are exposed to some extent. The total exposure depends on such factors as one's proximity to the source and the intensity of the emission, the time over which exposure lasts, and the emission's distribution in space and its time course. With regard to spatial characteristics, the exposure levels for virtually all sources found near homes, including smart meters, diminish very rapidly with distance. Furthermore, for many sources, the exposure is localized with respect to the part of the body exposed. For example, a cell phone's emission, when it is in use, is confined to the ear and nearby bone, and the adjacent part of the brain. For a smart meter, the exposure varies significantly over a vertical pathway from the floor through the length of a person's body. A sample measurement of a meter conducted in the EPRI study indicated that exposure would occur primarily from 3 to 6 feet above the floor, with the average across the body less than a quarter of the peak measurement. (This was just a single sample, and though the general principle of variability with height applies, this observation should not be generalized.)

For other sources usually at a distance from the home, including radio and TV broadcast antennas and cellular telephone base stations, the exposures are relatively more uniform across the body. This arises because the body's dimensions are negligible compared to the distances from such sources.

As one considers RF levels from various sources, it is important to keep in mind that the FCC exposure limits for the general public aim to limit exposure such that first, the absorption of RF energy averaged across the whole body is limited to 0.08 watts per kilogram (W/kg); this metric is referred to as the *specific absorption rate* or *SAR*, which serves as the basis for specifying the exposure limit (the SAR not to be exceeded is referred to as the *basic restriction*). Second, the FCC stipulates that "[f]or most consumer-type devices, such as hand-held cellular telephones, the appropriate SAR limit is 1.6 watt/kg as averaged over any one gram of tissue." As indicated in the discussion earlier on spatial and temporal averaging, 30-minute averaging of SAR applies to the general public's exposure to fields from "source-based" devices, which include smart meters. However, for consumer devices, classified as "portable" (such as cellular telephones), the FCC states (OET Bulletin 65, page 10) "…it is often not possible to control exposures to the extent that averaging times can be applied. In those situations, it is often necessary to assume continuous exposure." A further distinction is that, while the RF field levels associated with various common sources can be viewed as snapshots of potential exposure levels, they do not necessarily translate to an exceedance insofar as concerns the FCC rule. For example, although a cell phone's RF emission within inches of the headset may exceed the FCC level that applies to whole body exposure, the local SAR for phones marketed today is to not exceed the 1.6 W/kg stipulated by the FCC.

With this perspective in mind, comparative levels of RF emissions are shown in Table 1. In the bottom row, the table shows estimates for exposure levels from a single meter for the direction in which the field is maximum (assuming an antenna gain of about 4, meaning the field at the maximum point is four times the field for the same antenna power radiated evenly in all directions, or isotropically). The table indicates levels for distances of 3 and 10 feet, with meters operating at 1 watt (W) and at a quarter watt (or 250 milliwatts, mW) with duty cycles of 1%, 5% for each power level (footnote 6 describes how to calculate instantaneous power density levels, which are the same as for 100% duty cycle or continuous operation). The entries in the table indicate that these estimated smart meter emissions, even at the maximum point, are at the same order of magnitude as emissions from such sources as radio/TV transmission and WiFi routers and far lower than the localized exposure fields from cell phones or microwave ovens. At 3 feet, the level in the table for the condition with the greatest exposure (1 W, 5% duty cycle) is about 0.3% of the FCC limit, and for the lowest, but not atypical condition (250 mW, 1% duty cycle), the level is 0.016% of the FCC limit; at 10 feet these values are 0.03% and 0.0014%, respectively. Using values published by Dimbylow and Bolch (Phys. Med. Biol. 52:6639-6649, 2007), one would estimate that for the 1 W, 5% duty cycle case, a uniform exposure of 0.002 mW/cm^2 as shown in the table, would produce a SAR of between 0.00012 W/kg for an adult-sized person to 0.00023 W/kg for a small child, which respectively are 0.15% and 0.28% of the whole body SAR limit of 0.08 W/kg. Further consider that, because of the non-uniformity of the field along the vertical, the exposure averaged across the body (and thus the SAR) is lower than the peak value (perhaps by a factor of 3 or 4). Further technical information and references for the table are provided in its footnotes.

Table 1 – Radio-Frequency Levels from Various Sources

Source	Frequency	Exposure Level (mW/cm^2)	Distance	Time	Spatial Characteristic
Cell phone(1)	900 MHz, 1800 MHz	1–5	At ear	During call	Highly localized
Cell phone base station(2)	900 MHz, 1800 MHz	0.000005–0.002	10s to a few thousand feet	Constant	Relatively uniform
Microwave oven(3)	2450 MHz	~5 0.05-0.2	2 inches 2 feet	During use	Localized, non-uniform
Local area networks(4)	2.4–5 GHz	0.0002–0.001[a] 0.000005–0.0002 [b]	3 feet	Constant when nearby	Localized, non-uniform
Radio/TV broadcast(5)	Wide spectrum	0.001 (highest 1% of population) 0.000005 (50% of population)	Far from source (in most cases)	Constant	Relatively uniform
Smart meter(6)	900 MHz, 2400 MHz	0.0001 (250 mW, 1% duty cycle) 0.002 (1 W, 5% duty cycle)	3 feet	When in proximity during transmission	Localized, non-uniform
		0.000009 (250 mW, 1% duty cycle) 0.0002 (1 W, 5% duty cycle)	10 feet		

[a] wireless router

[b] client card

FCC rule: From 300 MHz to 1,500 MHz, $MPE = 0.2 \times f/300$ mW/cm^2 (f is frequency in MHz); for 1,500 MHz and greater, $MPE = 1$ mW/cm^2. For example, at 900 MHz $MPE = 0.2 \times (900/300)$ mW/cm^2 = 0.6 mW/cm^2. Note: Compliance for cell phones is provided by manufacturers, and expressed in terms of SAR, which cannot exceed 1.6 W/kg for any single gram of tissue.

(1) Based on a 3-inch, 250 mW antenna emitting in a cylindrical wavefront.

(2) Elliott P, Toledano MB, Bennett J, Beale L, de Hoogh K, Best N, Briggs DJ. 2010. Mobile phone base stations and early childhood cancers: case-control study. BMJ 340:c3077.

ICNIRP. 2009. "Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz)." International Commission on Non-Ionizing Radiation Protection, Oberschleißheim, Germany, page 14.

Ramsdale PA, Wiener A. 1999. Cellular Phone Base Stations: Technology and Exposures. Radiat Prot Dos 83:125-130.

(3) ICNIRP. 2009. "Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz)." International Commission on Non-Ionizing Radiation Protection, Oberschleißheim, Germany, page 21.

Tell RA. 1978. Field-strength measurements of microwave-oven leakage at 915 MHz. IEEE Trans Electromagnetic Compatibility 20:341-346.

R.A. Tell, personal communication.

(4) Wireless router based on 30-100 mW isotropic emitter.

Client card based on: Foster KR. 2007. Radiofrequency exposure from wireless LANs utilizing Wi-Fi technology. Health Phys 92:280-9.

(5) Tell RA, Mantiply ED. 1980. Population Exposure to VHF and UHF Broadcast Radiation in the United States. Proc IEEE 68:6-12.

(6) Based on spatial peak power density with 6 dB (x4) antenna gain. For instantaneous power density during transmission, multiply the value for 1% duty cycle by 100, and the value for 5% duty cycle by 20.

Conclusion

The measurement study described in this paper is a valuable first step in characterizing the RF environment associated with wireless smart meter technology. For the type of smart meter and relatively small sample of meters characterized, the results indicate that in front of the meters, even with 10 meters nominally rated at ¼ watt operating continuously (100% duty cycle) on the same rack, the exposure level a foot from the center of the rack was a small fraction of the FCC exposure limit for the general public and, as expected, diminished with increasing distance from the rack. The power density levels were comparably lower behind the meters. An extensive analysis of smart meter transmissions for almost 47,000 meters in southern California was included in the EPRI study. The report estimated that 99.5% of the sample was operating at a duty cycle of about 0.22% or less, a value that translates to 3 minutes and 10 seconds of transmitting over a day; the maximum duty cycle associated with any meter did not exceed 5%. The duty cycle for cell relays

within the same sample did not exceed 1%. In a smaller study of over 6,800 meters, also in the EPRI study, end-point and cell relay meters were monitored for the number of bytes of data transmitted over an observation period of one day. This method provided a direct (exact) measure of time, and reported duty cycles even lower than those in the larger sample, with no one-day average duty cycle exceeding 1%.

The average exposure levels from smart meters, as measured in the current study, are at levels similar to those that are present from other common RF sources, both indoor and outdoor. As there may be differences in power levels, duty cycles, and other configurations between smart meters and AMI systems, EPRI plans to evaluate other types of smart meters and systems, as well, and also reevaluate exposure patterns as the currently existing systems evolve. The current study was conducted as part of a wider objective at EPRI to address questions about exposures from emerging smart grid technologies and to better understand issues about potential health effects in association with such exposures. EPRI wishes to thank the peer reviewers of this paper for their insightful comments.

The full EPRI technical report detailing the study titled, *An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter* (1021126) is available to the public at the EPRI website, www.epri.com. EPRI wishes to thank the peer reviewers of this paper for their insightful comments.

EPRI Resources

Robert Kavet, *Senior Technical Executive, EPRI*
650.855.1061, rkavet@epri.com

Gabor Mezei, *Program Manager, EPRI*
650.855.8908, gmezei@epri.com

EMF Health Assessment and Radio-Frequency Safety (Program 60)

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
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