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An Evaluation of Radio Frequency Fields Produced by Smart Meters Deployed in Vermont

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By

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Summary

During November and December, 2012, a comprehensive series of measurements was performed for the Vermont Department of Public Service to evaluate radiofrequency (RF) emissions produced by electric smart meters deployed within the state. A primary impetus for the study is the current public concern about smart meter generated RF fields (the signals produced by the meters) and the potential for such fields to cause adverse biological effects. This study was aimed at assessing compliance of smart meter signal intensities with regulations established by the Federal Communications Commission (FCC) that prescribe limits for safe exposure of humans.

As commonly implemented in many parts of the country, the smart meter systems investigated in Vermont are configured as mesh networks wherein each end point meter installed on a home can wirelessly communicate with other neighboring meters as well as data collection points referred to as Gatekeepers by Green Mountain Power (GMP) and Cell Routers by Burlington Electric Department (BED). Each data collection point can serve some hundreds of end point meters and send the electric energy consumption data received from the meters back to the electric utility company via a wireless wide area network (WWAN) or over a fiber optic network.

The study included extensive measurements of smart meter RF fields in one of the GMP service territories in the Rutland, VT area and in the BED service territory within Burlington, VT. In total, measurements were conducted at 37 different locations in the state which included 18 residential sites, six banks of smart meters (four of which were on residences), two data collection points (one each in the GMP and BED areas), one isolated meter and 14 general environmental measurement sites. Field measurements were accomplished with a spectrum analyzer based selective radiation meter (Narda model SRM-3006) permitting direct measurement of the intensity of RF fields expressed as a percentage of the FCC maximum permissible exposure (MPE) values. The instrumentation also allowed for time analysis of the detected RF fields from which the duty cycle of the RF emissions could be determined.

The meters deployed by both GMP (manufactured by Elster) and BED (manufactured by Itron) operate as RF local area networks (RF LANs) in the configuration of a mesh network and communicate within the FCC designated license free band of 902-928 MHz. The internal radio transceivers operate at low powers of 182 milliwatts (mW) and 304 mW by GMP and BED respectively.

Summary

Besides the RF LAN that operates in the 900 MHz region, an additional radio is contained in both the GMP and BED meters that, in the future, can be used to facilitate home area networks (HANs) at customer homes. A HAN, utilizing radios that operate in the 2.4 GHz band, will allow, for example, the customer to observe in real time their residential consumption of electric energy. This feature had not been implemented within the BED service territory at the time of the field measurements but GMP has a pilot project of evaluating customer reactions to a HAN in a sample of residences in the Rutland area. During this study, it was observed that all GMP meters emitted short, infrequent RF pulses from the HAN radios though some 500 meters were commissioned to communicate with in home display (IHD) devices. Hence, field measurements included determining the same characteristics for the HAN radio emissions in Rutland as was performed for the RF LAN emissions.

RF fields were measured as a function of distance in front of smart meters and throughout most of the homes to which the meters were attached. The measurement approach involved detecting the instantaneous peak value of the pulsed RF fields emitted by smart meters to examine how the RF field decreases with distance from the meter. Separately, strategic measurements were made to assess the duty cycle of meter emissions at many locations with a focus on determining the greatest duty cycle that could be achieved. The duty cycle of a smart meter is a measure of how the average value of RF field is related to the peak value of RF field. By knowing the duty cycle, the peak values could be adjusted to arrive at their corresponding time-averaged values. Field work in Vermont was supplemented with measurements on two test meters provided by GMP and BED in Colville, WA. Many measurements were performed over half-hour periods, both in Vermont and in Colville; 30 minutes is the averaging time specified in the FCC RF exposure regulations.

As a means for forming a perspective on potential smart meter RF exposures, additional measurements of ambient levels of FM radio and television (TV) broadcast signals as well as mobile phone base station signals were made in Rutland, Burlington, Montpelier and Saint Albans, VT. Additionally, as the opportunity presented itself, limited measurements were also made of RF emissions of microwave ovens, wireless routers used for distribution of Internet connectivity and a mobile phone. Azimuth and elevation plane patterns of RF emissions of the smart meters were determined and measurements were made of low frequency electric and magnetic fields from 0 to 100 kHz with the test meters in Colville.

Measurement data collected during the project support the following conclusions in regard to potential exposure associated with the smart meters investigated in Vermont:

- The instantaneous peak value of RF field, during the pulses, may be as high as 3.9% of the MPE at the closest distance measured of one foot.

Summary

- Consistent with certification reports filed with the FCC on behalf of smart meter manufacturers by independent test labs, the instantaneous peak values of RF fields found in this study, without any consideration of time or spatial averaging, comply with the MPE.

- Smart meters produce intermittent bursts of pulsed RF fields that are small when compared to the FCC MPE for public exposure[1]. When the field is adjusted for duty cycle and spatial averaging, in accord with FCC rules, the resulting maximum value of potential exposure at one foot directly in front of the meter represents about 0.068% of the time-averaged/spatial-averaged exposure limit for GMP meters and 0.032% in the case of BED meters.

- The smart meter emissions decrease sharply with increasing distance from the meter being equivalent to about 0.0013% of the exposure limit (time averaged and spatial averaged) at 10 feet from the meter (equivalent to 3,800,000 times less than the actual hazard threshold).

- Maximum duty cycles were in the 3–4% range and were comparable to duty cycles found in earlier studies [1, 2].

- Exposure, in terms of instantaneous peak as well as time-averaged RF fields, caused by deployed smart meters in Vermont is small in comparison to that related to many other sources of RF fields in the environment. For instance, local values of long term, time-averaged RF fields (as a fraction of the MPE) from FM radio broadcasting can, in some areas as found in this study, be as much as ten to hundreds of times greater than those values found immediately near smart meters. The common use of normal appliances within a home or office, such as microwave ovens and wireless routers, can lead to RF fields that are comparable to or substantially greater than those produced by smart meters. This applies to the use of mobile phones as well; both mobile phones and smart meters operate with roughly the same transmitter peak powers. In this context, however, mobile phones are normally held against the head during use while smart meters are not.

- Low frequency electric and magnetic fields produced by the smart meters and their internal switch mode power supplies, at one foot from the meters, were substantially smaller in value than recommended limits [13].

[1] For convenience in this report, the term pulse is used interchangeably with the term burst.

Summary

- Smart meters make use of pulsed RF signals, a characteristic common to other devices found in the everyday environment such as wireless routers, radar systems used for air traffic control and most mobile phones.

- Peak RF fields associated with large banks of smart meters are not materially different from those of a single meter. Average RF field levels can be greater due to the number of meters. However, there is no general correlation between overall higher average RF fields associated with large banks of meters since the greatest duty cycle of any given smart meter appears to be more related to a specific meter's position within the wireless network's hierarchy, i.e., how close it is, from a communications perspective, to its data collection point. Hence, a single meter that serves to relay energy consumption data from many other meters to the data collection point can exhibit a greater time-averaged RF field than a large group of meters that are not close, network wise, to a data collection point.

- Of 141 interior RF field measurements inside residences, the greatest measured value was equivalent to 0.0014% of the MPE in term of time-averaged and spatially-averaged exposure. This maximum value was associated with a location directly behind the installed smart meter but inside the home. The average interior residential RF field, time and spatially averaged, was equivalent to 0.000058% of the MPE.

The FCC MPE values were derived with the inclusion of a safety factor of 50 below the actual threshold of hazard from prolonged exposure. When the above estimated RF field exposures for GMP and BED meters at the closest distance of one foot are considered in this light, this means that the most conservative estimates of potential exposure range between approximately 75,000 and 156,000 times less than the hazard threshold respectively.

Using the highest indicated results from the measurements performed in this study, potential exposure of individuals to the RF fields associated with the currently deployed smart meters in the GMP and BED service territories is small when compared to the limits set by the FCC. It is concluded that any potential exposure to the investigated smart meters will comply with the FCC exposure rules by a wide margin.

Introduction

The work documented in this report is related to an evaluation of the radiofrequency (RF) emissions associated with the operation of electric smart meters in Vermont. A proliferation of smart meters across the nation, as a component of the so-called smart grid initiative in the United States, has raised the question among some in the public of how the RF emissions of these new technology meters compare with limits that have been set for safe human exposures. Recent studies have determined that the low power of the radio transceivers inside the meters results in only low level RF fields that comply with Federal standards, generally by wide margins [1, 2, 3]. Nonetheless, this relatively new technology that includes the production of brief but numerous pulses of RF energy and the sheer number of emitters (one on each home and business) continues to elicit questions regarding smart meter emissions and has influenced a more in-depth examination of smart meters in Vermont. This study, commissioned by the Vermont Department of Public Service, explored the RF emission characteristics associated with smart meters being deployed by two electric utilities in Vermont, Green Mountain Power (GMP) and the Burlington Electric Department (BED). These two utilities employ smart meters that were presumed to be representative of most smart meters within the state (GMP makes use of meters manufactured by Elster and BED uses meters by Itron). At the time of the study, GMP had deployed approximately 95,000 smart meters of a future total estimated number of 180,000 meters in its service territory. BED had deployed approximately 14,000 meters within its relatively small service territory within the city of Burlington extending some six miles north and south and three miles east and west. The field work in Vermont occurred during November and December, 2012.

Electric power meters are designed to measure the amount of electric energy used by a customer and are calibrated to read in terms of the unit kilowatt-hour (kWh).[2] Older style electro-mechanical power meters, with rotating disks, were first widely introduced by Westinghouse and have been used for over 100 years [3]. Such meters are referred to as analog meters and have proved to be extremely reliable. Usually, monthly, a utility meter reader visits the site of the meter to manually record how much energy has been consumed during the previous month. However, with the introduction of digital electronics in electric power meters, and RF technology more recently (approximately 2006), the smart meter communicates energy consumption data wirelessly to the electric utility company. Wireless smart meters are generally referred to as a part of advanced metering infrastructure (AMI).

This study examined the strengths of the RF fields emitted by smart meters with attention to both the instantaneous peak values of field power density and average values. The work also included measurements of the duration of the brief emissions and

[2] A kilowatt-hour (kWh) represents an amount of energy used by an electric load of one kilowatt of electric power over a period of one hour.

the number of emissions that could be observed to occur over sampling intervals so that the amount of time that the meters actually transmit could be determined[3]. Effort was made to identify the maximum amount of transmitter activity that might occur during smart meter operation.

A primary focus of the measurements was, ultimately, to develop data to allow for an accurate and precise comparison of smart meter emissions in Vermont with the regulatory exposure limits promulgated by the Federal Communications Commission (FCC) [4], as well as to other common RF emission sources.

[3] This is related to a term called duty cycle, described later in this report.

Smart Meter Mesh Networks

To better understand the challenge of characterizing RF fields of smart meters, it is helpful to envision how the meters work and how they are configured in a geographic area to report energy consumption data. Both of the meter types used by GMP and BED are deployed as so-called mesh networks. The term "mesh" refers to the geographic distribution of smart meters throughout a neighborhood area wherein each meter has the ability to communicate with other neighboring meters and each meter can be called a node in the network. When the many nodes of the network are viewed on a diagram, it resembles the rough geometrical shape of a mesh.

Associated with operation of the mesh network is the requirement that the data that each meter generates, somehow, gets back to the electric utility company. This can be accomplished via alternative means including land line telephone, fiber optic network coverage or a wireless link, typically through use of a wireless data plan with a cellular carrier that serves the area with a Wireless Wide Area Network (WWAN). So, each end point meter (the meter attached to a home) would ideally be able to communicate directly to the data collection point from where the data would then be uplinked via a wireless Internet connection (as used by GMP) back to the utility or placed on an area fiber optic network (as used by BED). However, this ideal link between each end point meter and the data collection point is rarely achieved in a single "hop" except for meters that happen to be located close to the collection point and, rather, the data from each meter is relayed to the data collection point via the data signals hopping between various smart meters such that the data eventually arrives at the collection point. Each end point meter identifies a suitable communications route by briefly communicating with other meters from time to time, storing this path information in its memory and, then, when sending its data, using the routing information it has retained to communicate to the data collection point via some number of "hops"[4]. Mesh networks are complex in that if, for some reason, a communication path is blocked, the network can identify an alternative routing, ultimately, to get the data to the collection point. This aspect of mesh networks is sometimes referred to as the network being "self healing"; i.e., it has the ability to dynamically adjust to conditions for reliable communication by invoking the use of different end point meters in the region for communications assistance. Larger geographic areas are typically broken into different networks where each network may consist of about 400 to 500 end point meters each. Figure 1 illustrates a simple smart meter mesh network topology (physical configuration).

The electric utility company receives "load profile" data for each end point meter from the data collection points several times each day. In the case of GMP, data is

[4] In this context, a hop refers to a transmission between two end point meters.

received every six hours or four times per day. For BED, load profile data is obtained every eight hours or three times per day. The load profile data consists of 15-minute

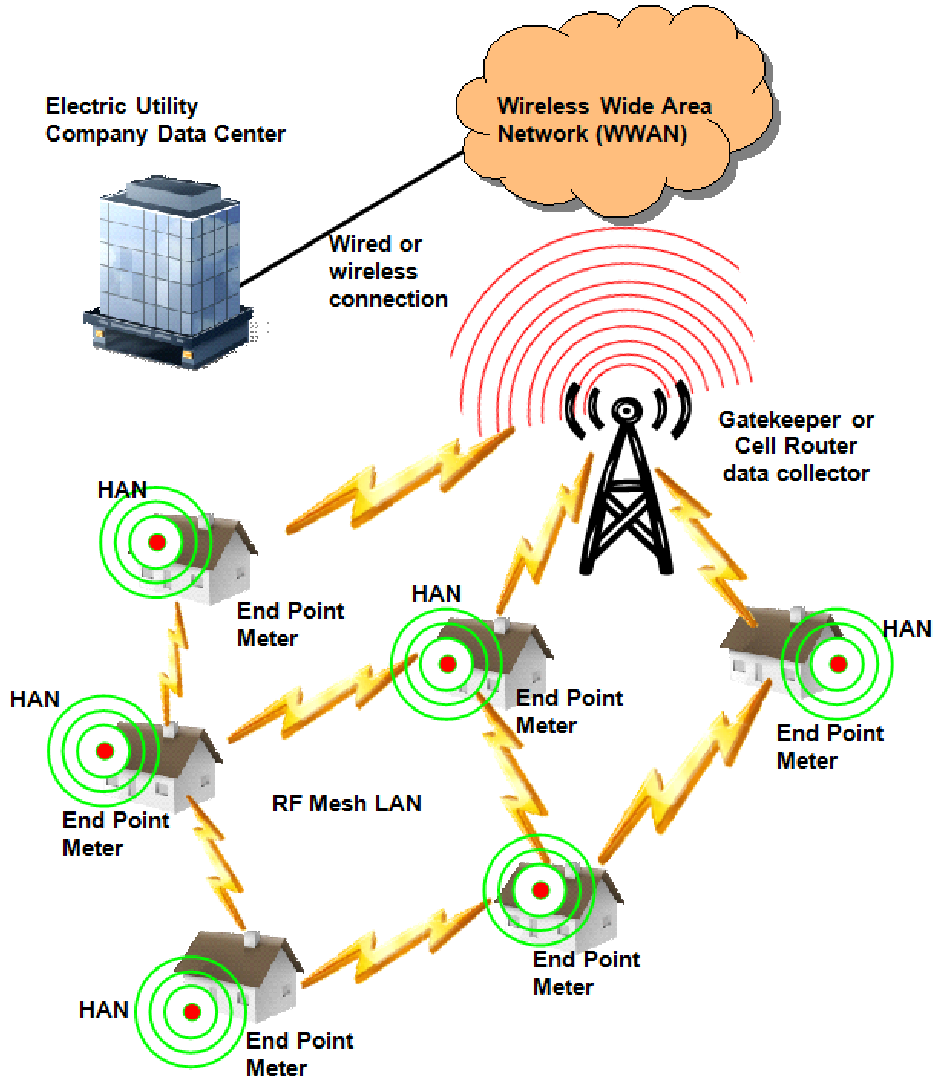

Figure 1. Simplified diagram of a smart meter mesh network configuration. Some meters communicate directly with the data collector while the signal from some meters must hop from meter to meter to reach the tower-mounted data collector. Data is sent to the electric utility company, in this example, from the data collector via a WWAN connection to the Internet. The RF LAN for the two smart meter systems studied operates in the 902-928 MHz license free band. HANs are illustrated if such capability is implemented in the future.

interval reads from the meter. The interval reads may consist of energy consumption, voltage levels and other electrical parameters. The total amount of time that smart meters actually emit RF fields over the period of a day, however, is extremely small with transmission of signals increasing when each meter receives a request to report past interval data. However, smart meters are not totally "silent" during other times; meter

RF activity typically occurs throughout the day with periodic signals used to maintain its organization within the network and to assist other meters in relaying data upstream toward the data collection point. Hence, although the meter transmissions consist of only very brief signals, lasting typically only fractions of a second in duration, it is common to observe these intermittent emissions all during the day with the amount of activity varying according to what the meter is doing at the time. At locations where a bank of meters exists, it is normal to observe more transmitter activity due to the cumulative number of meters.

Different smart meter manufacturers call the data collection points by different names but they serve the same basic purpose. In the case of Elster meters, the term "Gatekeeper" is used while for the Itron meters, the term "Cell Router" is used[5]. A difference between the GMP networks and the BED networks is that GMP makes use of a digital cellular link (WWAN) for transmitting data from all of the meters served by the Gatekeeper back to the company. In the case of BED, the company takes the data collected by its Cell Routers and places it on a fiber optic network that exists throughout the city of Burlington for transmission back to the company (in this case, there are no RF emissions associated with this delivery of data from the Cell Router to the company). In each case, either the Gatekeeper or Cell Router queries each end point meter via the RF LAN 900 MHz radio, receives the data from the end point meters associated with the particular Gatekeeper or Cell Router, stores these data and then communicates the aggregate data back to the utility either four or three times throughout the day. At the time of the study, GMP employed some 267 Gatekeepers (out of a future potential number of some 500) while BED made use of 27 Cell Routers as data collection points. Both GMP and BED used elevated locations for the Gatekeeper or Cell Router, typically on telephone or power poles within the region served by the device.

Both the Elster and Itron meters use low power radio transceivers inside the meters for the meter-to-meter communications within the mesh networks, referred to as an RF LAN (RF local area network), that operate in a license free band designated by the FCC in the 902 MHz to 928 MHz frequency range (the terminology of the 900 MHz band and 900 MHz radios will be used commonly throughout this report in the interest of brevity). Each Gatekeeper or Cell Router also contains a similar 900 MHz radio transceiver for the communication between it and various end point meters. In the case of the Gatekeeper, a WWAN transceiver (very similar to an AirCard that might be used with a laptop computer for connection to a high speed digital network)[6] is the device responsible for connection to the WWAN. This WWAN transceiver module (also commonly called a modem) is similar to a cell phone and operates with approximately

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[5] Itron uses the name Cell Router since the device has the ability to transmit via a WWAN but in the case of the Cell Routers used by BED, the transmission is via a fiber optic link installed by the city.

[6] Note that a WWAN is different from common WiFi which allows wireless connectivity between computers and so-called hot spots and wireless routers typically used within homes for distribution of the Internet.

the same power as a cell phone. Depending on the particular wireless carrier that provides the WWAN service to the utility company, the operating frequency of the WWAN transceiver may be in several different bands but typically either the 800-900 MHz or 1.9 GHz bands.

A common and additional feature of smart meters is the provision of the means for implementing a Home Area Network (HAN). A HAN provides for a separate wireless connection between the meter and devices inside the home such as an "in home display" (IHD) for displaying electric energy consumption from moment to moment. This communication feature is accomplished with a lower power radio transceiver that normally operates in the license free band of 2.4 to 2. 5 GHz (referred to as the 2.4 GHz band in this report). The HAN radio, as it is referred to, makes use of a low data rate digital communications protocol with the name ZigBee and often, this radio is simply called a ZigBee radio. Not all smart meters are equipped with a HAN radio but it is a rather common practice to do so. Both the Elster and Itron meters deployed by GMP and BED, respectively, contain HAN radios. However, at the time of this study, neither GMP nor BED had implemented the HAN radios for day-to-day use by customers. Only in the case of some homes in the Rutland area, in the GMP service territory, have the HAN radios been "commissioned" to communicate with an IHD on an experimental basis to test the ability of the HAN to operate properly. Richard Tell Associates discovered during the course of the study that, contrary to what GMP had originally told the Department of Public Service, all the HAN radios within the GMP smart meters were observed to emit short, infrequent RF pulses[7]. The BED had not activated the use of the HAN radio at any end point meter.

[7] After learning that HAN or Zigbee radios in GMP and Stowe Electric Department smart meters are actively emitting RF pulses, the DPS sent a letter to the utilities on December 11, 2012, and GMP and Stowe responded on January 2, 2013 to say that meter manufacturer Elster is working on a firmware update to be released by the end of June 2013 that would shut off the HAN radio emissions until such time that the devices are ready to be commissioned to pair with IHDs.

Basic Meter Specifications

Basic Meter Specifications

This study examined RF fields associated with two different meter types manufactured by Elster and Itron (Figure 2). Both meters are of the 200 ampere class rated for residential service and contain both 900 MHz and 2.4 GHz radios.

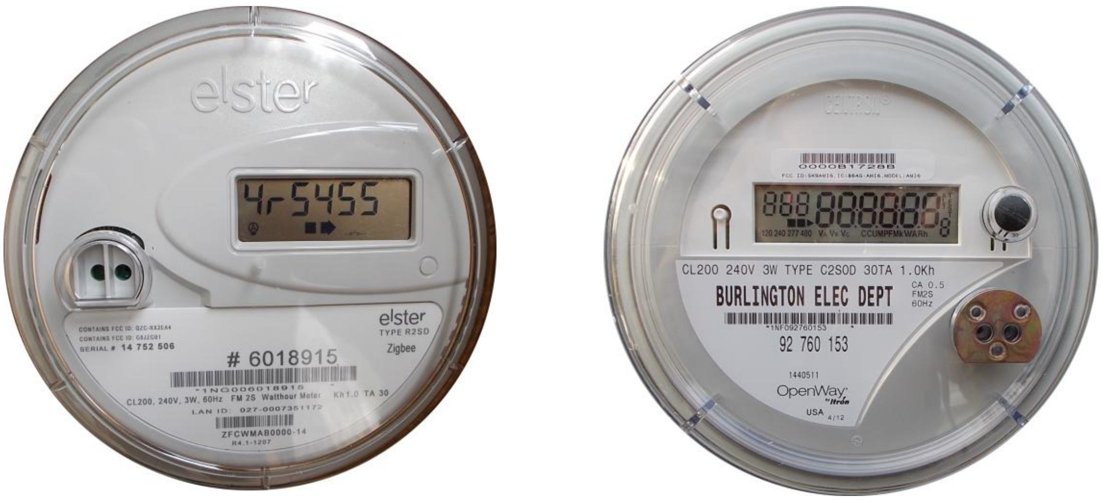

Figure 2. The Elster (left) and Itron smart meters deployed within the state of Vermont by Green Mountain Power (GMP) and the Burlington Electric Department (BED).

Prior to sale of these meters, the manufacturers must submit the meters to a series of laboratory tests to insure that they meet technical requirements of the FCC[8] such as compliance with transmitter output power, harmonic production, etc. such that they may be used within the FCC's license free bands. Once entered into the FCC's database of equipment authorizations, an FCC identification number is assigned to each device for which testing has been accomplished.[9] The relevant reports provided to the FCC for the Elster and Itron meters to support the finding of compliance with FCC rules on human RF exposure are reproduced in Appendices A and B respectively. Table 1 summarizes the relevant technical specifications of each meter in terms relevant to assessing RF fields.

[8] This process is designated as a part of the FCC's equipment authorization process.

[9] The FCC equipment database is found at: http://transition.fcc.gov/oet/ea/fccid/

Basic Meter Specifications

Table 1. RF specifications of the Elster and Itron smart meters being used in Vermont that are relevant to consideration of RF fields that may be produced by them.

	Elster		Itron	
	FCC ID Numbers			
Specification	QZC-RX2EA4/G8JZGB1		SK9AMI6	
Band of operation	RF LAN (900 MHz)	HAN (2.4 GHz)	RF LAN (900 MHz)	HAN (2.4 GHz)
Transmitter power output- dBm (mW)	22.6 dBm (182)	18.7 dBm (74.8)	24.8 dBm (304)	18.9 dBm (78.3)
Antenna gain (dBi)	5.64	0	2.2	3.8
Maximum EIRP- dBm (mW)	28.2 (667)	18.7 (74.8)	27.0 (505)	22.7 (188)
Frequency range (MHz)	902-928	2400-2500	902-928	2400-2500

The 900 MHz RF LAN transceivers in the smart meters use a frequency hopping spread spectrum digital modulation scheme wherein the emitted RF signal hops randomly over a series of frequencies across the band. In the Elster meter, the transceiver hops over 25 different, specific frequency channels within the 902-915 MHz part of the band while the Itron meter uses 52 hopping frequency channels distributed across the entire 902-928 MHz band.

The HAN radios employ direct sequence spread spectrum modulation on 16 possible channels across the 2.4 to 2.5 GHz (2,400 MHz to 2,500 MHz) band. It is relevant to note that the 2.4 GHz band is also widely used for other applications including, most notably, operation of microwave ovens, cordless telephones and wireless routers used for distribution of Internet content.

The data collection points, represented by Gatekeepers (GMP) and Cell Routers (BED), are composed of 900 MHz radios that are essentially the same as those found in end point meters for connectivity with the RF LAN and with the end point meters that they serve. For the WWAN connection, for sending data back via the Internet to the electric utility, a cellular modem designed to operate on one of the WWAN frequencies is employed that has nominally the same power characteristics of a mobile (cell) phone. Also, since the Gatekeepers and Cell Routers used by GMP and BED are mounted high above ground, common public access to the immediate region of the units is eliminated.

The in home display (IHD) used during measurements for evaluating the HAN radio characteristics was the Tendril model IHD-5 that carries the FCC ID of TFB-APEXLT. This unit has a manufacturer’s specified output power of 20 dBm (100 mW) but during laboratory testing for its certification was found to produce only 18.56 dBm (72 mW). The IHD contains an internal “inverted F” type of antenna on the unit’s printed circuit card.

Assessing Potential Exposure to Smart Meter RF Fields

Smart meters present a considerable challenge to the assessment of potential exposure that can occur in their vicinity. Issues include the fact that the transceivers in the meters are low power, less than one watt, the RF fields are not uniform around the meter due to directional properties of the internal antenna and the effects of the meter box in which the meter is installed and the typical emissions of smart meters consist of very brief bursts of pulses of RF energy lasting normally less than one-tenth of a second or far less. Additionally, the amount of transmitting activity of a smart meter typically varies throughout the day and depends not only on its normal transmission of data at prescribed times during the day but, also, on whether it is assisting other meters in relaying data to other meters. Further, current human exposure limits are specified in terms of time-averaged levels of RF fields and in terms of spatial averages over the body dimensions [5]. Finally, for frequency hopping systems, such as those employed by the meters deployed by both GMP and BED, the frequency of the emission can rapidly change. Characterizing the RF emissions is, therefore, not always straightforward.

Several factors determine the magnitude of RF fields that can be produced by any source at a given point. These include the effective isotropic radiated power (EIRP) in the relevant direction, the mounting location of the source relative to where an individual may be and the duty cycle of the source (i.e., a measure related to the amount of time that the transmitter actually transmits a signal). For evaluating compliance with RF exposure standards, the time-averaged value of plane wave equivalent power density is usually the most fundamental aspect of specifying exposure. Existing RF exposure standards specify averaging times of either six minutes, normally applied to assessing occupational exposures, or 30 minutes, usually applied to exposure assessment for members of the general public.

The antennas contained within smart meters are not omnidirectional, although the pattern of emitted field is commonly very broad and can approximate the pattern of an omnidirectional source; there is, however, usually a preferred direction in which the strongest RF field is transmitted, normally away from the front of the meter with directions of reduced RF fields usually to the sides and almost always toward the rear of the meter. When a wireless smart meter is installed in a meter socket (typically in the electric service panel on a home), the metal electrical box that contains the meter socket interacts with the RF fields to distort what the antenna pattern would be in the absence of the meter box. The meter box can also provide significant shielding in directions to the rear of the meter, generally in directions toward the home on which the meter is installed, such that interior RF field strengths (or power densities) inside the home will be significantly less than at equivalent distances but in front of the meter.

The signal pattern of the smart meter antenna determines the intensity of the transmitted RF field in both the azimuth (horizontal) plane and elevation (vertical) plane. The significance of this is that the RF fields found near smart meters can be relatively non-uniform due to the metal components of the meter itself and the metal box within which it is mounted. This results in exposure of the body that can be highly non-uniform. Since exposure limits are based on spatial averages over the body as well as time averages over time, compliance assessments normally include a measure of the spatial variation of field along the vertical axis of a person standing near the meter. This means that the body-averaged value of exposure will be less than the spatial peak value that might occur directly in front of the meter where the field is most intense. Nonetheless, for purposes of this study, measurements of RF fields at the height of the meter were obtained for exterior locations near the meter. Limited data were also obtained to document the variation in field over a distance from ground level to six feet (1.83 m) above ground so that spatial average values of field could be estimated from the measured spatial peak values of fields.

Because the transmitted fields from smart meters can exhibit a dependency on direction away from the meter, mounting locations will strongly influence the exposure values for a person near the meter. If the meter is mounted relatively high above ground, most of the body may be exposed to only very weak RF fields. If the meter is mounted lower, more of the body may be subjected to stronger emissions since the body may intercept most of the transmitted fields within the elevation plane. The issue of how much more localized exposure of the body is when compared with the average over the entire body dimension depends strongly on the distance between the meter and a person; the greater the distance from the meter, the more uniform the field across the body will be but, at the same time, the weaker the field will also be, simply because of the typical rapid decrease in RF field with distance.

The RF exposure limits adopted by the FCC are based on averages over time [5]. For the smart meters used by GMP and BED, this is determined by the duty cycle of emissions and, as discussed above, exposure will depend on occupancy of areas near the meter. Closer distances can result in greater exposure while farther distances result in lower exposure. The issue of averaging of RF field power density, based on the duty cycle of emissions, with specific reference to smart meter emissions has been addressed by the FCC [6]. The FCC states that the “source based” time-averaged value of power density is the relevant factor with respect to compliance with their exposure rules. In summary, estimates of potential exposure to the GMP and BED smart meters were accomplished by determining both the instantaneous peak and average values of RF field power density near the smart meters directly in front of the meters as well as inside homes equipped with smart meters.

In total, smart meter measurements were performed at 23 sites in the GMP Rutland (13 sites) and BED (10 sites) service territories. These sites included measurements at 18 residences (12 detached homes and six apartments) as well as six meter banks (four meter banks were on apartment buildings included as residences), two data collection points (one GMP Gatekeeper and one BED Cell Router) and a single, isolated smart meter mounted on a pole in Rutland. Measurement locations for the Rutland and Burlington areas are illustrated on maps shown in Figures 3 and 4 respectively.

Because present day RF exposure limits are based on time-averaged values of RF power densities, considerable effort was applied to collecting data on smart meter duty cycles at many of the measurement locations (see section below on technical approach used in this project).

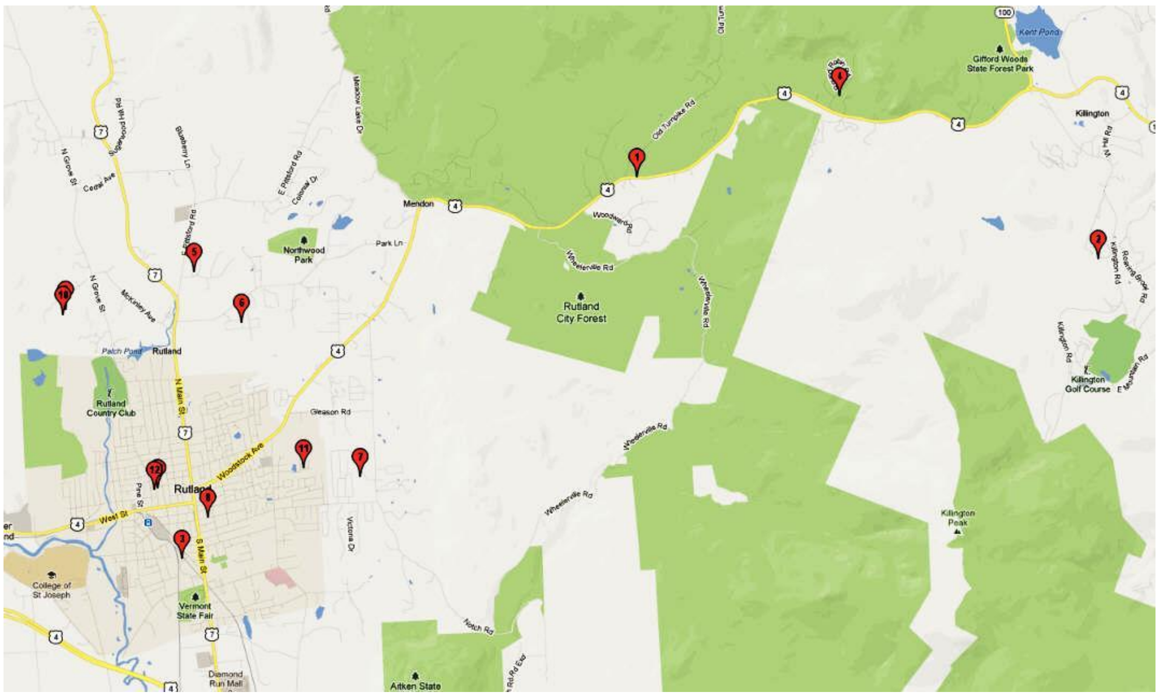

Figure 3. Smart meter measurement locations (13 total) in the Rutland, VT GMP service territory. Sites 9 and 10 and 12 and 13 are close together.

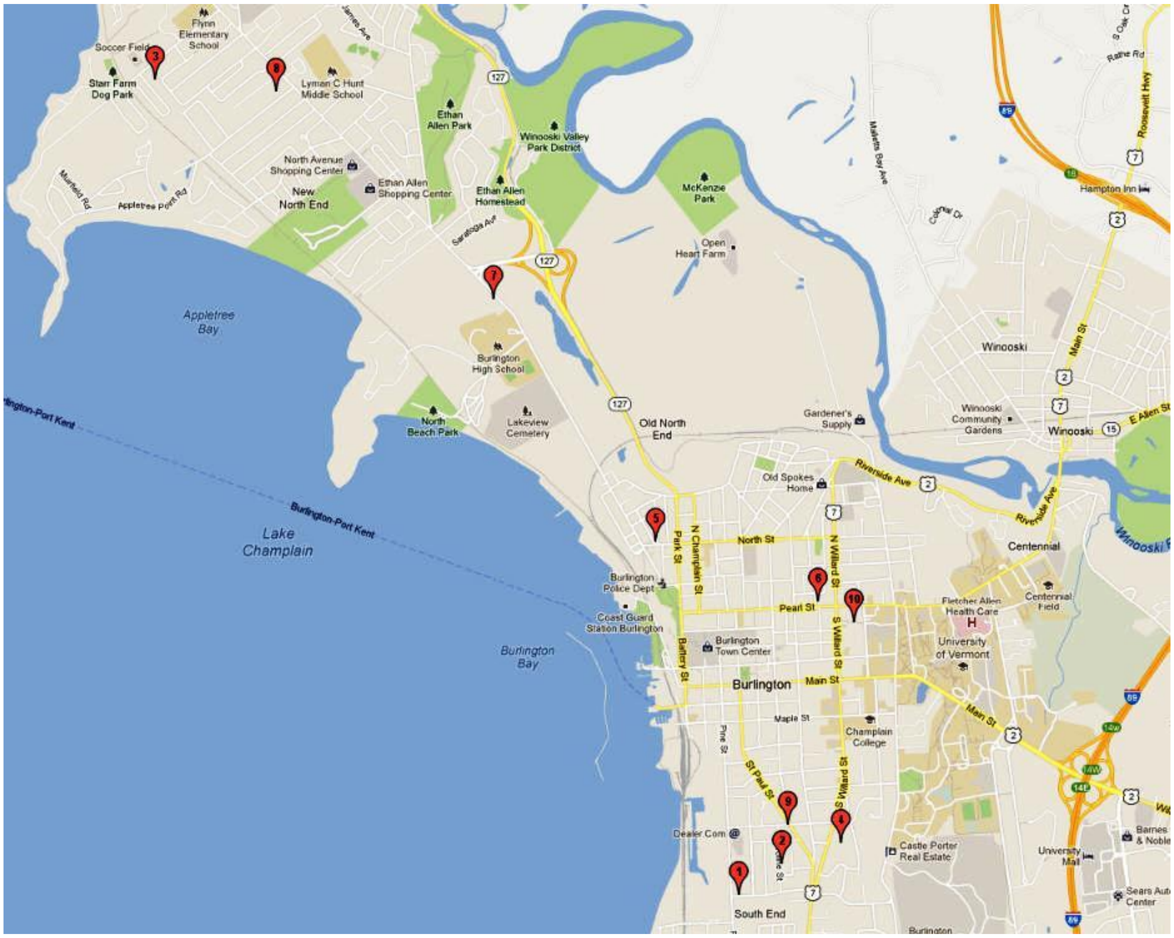

Figure 4. Smart meter measurement locations (10 total) in Burlington, VT in the BED service territory.

RF Exposure Limits

Recommended safe exposure limits in the United States have existed since the 1960's. Over the years, these limits have evolved to account for more recent research findings relative to biological effects of RF fields. Internationally, the three most prominent exposure limits include those of the FCC [4] and the Institute of Electrical and Electronic Engineers (IEEE) [7] in the U.S. and the guidelines of the International Commission on Non-ionizing Radiation Protection (ICNIRP) in Europe [8].

In the United States, the controlling limits for human exposure are those adopted by the FCC[10]. FCC maximum permissible exposures (MPEs) apply to FCC licensees but also apply to the use of RF emitting equipment used in the license-free bands. Because of this, smart meters are evaluated prior to sale to utility companies for compliance with the FCC's RF exposure limits and such evaluations are documented in equipment certification reports provided by the manufacturer to the FCC (see above discussion of where these reports can be found). Table 2 summarizes the MPEs from the FCC that are applicable to the emission frequencies associated with the smart meters evaluated as part of this project[11].

Table 2. FCC MPEs applicable to the RF fields produced by smart meters operated by GMP and BED in the state of Vermont. MPE values are in terms of power densities averaged over 6 minutes for occupational exposure and 30 minutes for exposure of the general public. The limits given are in terms of spatially-averaged values of power density averaged over the dimensions of the body and averages over 6 minutes or 30 minutes as the case may be.

Frequency	902-928 MHz		2.4-2.5 GHz	
	General public	Occupational	General public	Occupational
MPE (mW/cm^2)	0.601-0.619	3.00-3.10	1.0	5.0

It is relevant to note that compliance with the FCC MPEs for general public exposures allows for time averaging so long as the modulation of the field is source based, i.e., inherently a consequence of the way the source operates. Examples include the pulsed RF fields produced by radars, the typically intermittent operation of two-way mobile and portable radios and, in this case, the normal intermittency of smart meter emissions [6]. For situations in which the continuous RF field exceeds the MPE, however, the FCC has taken the position that time averaging is not permissible for showing compliance with the exposure rules in the case of public exposure. This is based on the

[10] The FCC MPEs are somewhat greater in value than the ICNIRP guidelines in the 900 MHz band. For example, at 915 MHz, the ICNIRP reference level is 0.457 mW/cm^2 vs. 0.610 mW/cm^2 used by the FCC.

[11] The MPE is a value of exposure in terms of a time-averaged value that is 50 times less than the threshold for potentially adverse biological effects (i.e., the MPE contains a safety factor of 50) for general public exposure and 10 times less for occupational exposure (i.e., the MPE contains a safety factor of 10).

conservative assumption that compliance would only be achievable if an individual physically moved about to result in a variable exposure level that could, upon averaging, be reduced below the MPE. Thus for smart meter emissions, a comprehensive determination of compliance with the FCC exposure rules includes assessing the average RF field across the dimensions of the body (spatial average) and the average over time (time average). In practice, and as found in virtually all of the certification reports filed with the FCC for smart meter emissions by manufacturers, a simplifying assumption is made that if the maximum, instantaneous field[12], without inclusion of time or spatial averaging, is compliant with the MPE, then no further evaluation is necessary. In this investigation, however, the issues of how duty cycle and spatial averaging can affect exposure assessment were addressed so that a more accurate assessment of compliance with the exposure rules could be performed; for both the time averaging and spatial averaging factors, potential exposures will be found that are less than maximum, instantaneous field values. The MPEs are based on the assumption of uniform exposure over the whole body; the non-uniform fields, common to real-world exposure, are normally spatially averaged to obtain the best estimate of an equivalent, uniform exposure. For convenience in interpreting the reported values of measured RF fields, measured RF fields are expressed in terms of a percentage of the public MPE; i.e., a value of 100% represents the exposure limit. The rationale for this approach is that the MPE varies with frequency and reporting of RF fields simply in terms of power density requires adjustment of the power density values to determine how the value compares to the actual limit for evaluating compliance. Note that the MPE varies across the 900 MHz license free band (by approximately 3%) and is also different for the 2.4 GHz license free band (approximately 66% different from the MPE for the 900 MHz band).

The MPEs listed in Table 2 are based on limiting the underlying basic restriction on RF energy absorption within the body, as averaged over the whole body, and on local tissue absorption. The energy absorption rate is referred to as the specific absorption rate (SAR) which is expressed in the unit watts per kilogram (W/kg) of tissue. The FCC MPEs, for general public exposures, are based on a whole-body averaged SAR limit of 0.08 W/kg with a local, peak SAR of 1.6 W/kg averaged over any one gram of tissue (defined as a tissue volume in the shape of a cube) except for the extremities (hands, wrists, feet and ankles) in which a local SAR of 4 W/kg averaged over any 10 grams of tissue is permitted. For occupational exposures, the FCC MPEs correspond to a whole body averaged (WBA) SAR of 0.4 W/kg with a local, peak SAR of 8 W/kg averaged over any one gram of tissue except for the extremities in which the SAR limit is 20 W/kg averaged over any 10 grams of tissue.

RF exposure limits are derived from a presumption that the resultant RF field, taking all possible polarization components of the field into account, complies with the

[12] The term instantaneous refers to the absolute peak magnitude of the RF field in the time domain, similar to the peak power of a radar pulse.

limit. The MPE values vary with frequency because of the frequency dependent variation of RF energy absorption of the body. The limits presume the possibility of the resultant magnitude of the RF field being oriented in such a way as to result in the greatest energy absorption possible within the body. Thus, the limits are, generally, conservative since such alignment of the polarization of the incident RF field with the body orientation during real world exposure is often not the case. Hence, for compliance assessments, relative to exposure limits, RF fields are to be measured such that the overall resultant magnitude of the field is obtained, regardless of the different polarization components that may exist. The RF field measurements accomplished in this project included the measurement of three mutually orthogonal polarization components and the formation of the resultant magnitude of the incident RF field.

Technical Approach Used in this Project

Technical Approach Used in this Project

RF Instrumentation Used in the Measurements

The principal measurement effort in this study was directed toward determining two things about the RF fields emitted by the GMP and BED smart meters: (a) the instantaneous peak magnitude of RF fields emitted by the meters and the (b) duty cycle of the various emissions. The very intermittent nature of the smart meter emissions as well as the fact that the emissions can occur over a range of frequencies requires an instrument that has both frequency resolution and brief signal capture ability. Broadband probes, commonly used for RF field exposure assessment, for smart meter measurements, suffer from two perspectives. They do not discriminate the frequency of the field that is causing a response of the instrument and they typically have response times that are entirely too long to be able to accurately measure the RF field during the very brief pulses of RF energy produced by smart meters. For example, a common response time of most broadband RF field probes is approximately one second. This means that the instrument requires that the signal (RF field) that is being measured must exist for at least one second before the meter response can reach the peak or full value of the field. For the typical emissions of smart meters of the type explored in this study, that are often less than 1/10 of a second in duration, this places a significant disadvantage on the broadband type of measurement instrument. Further, if the broadband probe has a flat frequency response (the output of the probe does not change with frequency for a constant RF field level), it cannot properly weight the detected RF field in accordance with the frequency dependence of the MPE. The MPE for RF emissions in the 900 MHz band are about 60% of the MPE values applicable to the 2.4 GHz band. Hence, the flat responding probe, while it may indicate the presence of pulses of RF field, will not accurately add up the RF fields across all frequencies to obtain a proper measure of the aggregate RF field relative to permissible exposure levels.

Because of the above instrumentation issues, a spectrum analyzer based detector was used for these measurements (Narda Selective Radiation Meter model SRM-3006, SN D-0069). Figure 5 shows the instrument which consists of a wideband probe/antenna (SN K-0242) that is connected to a spectrum analyzer base unit that is controlled with firmware that allows for measurement and display of detected RF fields.

This instrument permits display of the detected RF signals from the probe/antenna in the frequency domain so that the strength of any individual signal can be determined. Further, the probe/antenna contains a solid state switch that provides for a very fast sequential sampling of the measured RF field over the three axes of the probe/antenna elements. This allows for display of the resultant field magnitude as a function of frequency. Illustrative spectral displays of the RF LAN (900 MHz band) fields observed in front of the Elster and Itron smart meters are shown in Figures 6 and 7 respectively. These figures represent the capture of absolute peak values of momentary RF fields on any frequency emitted during the measurement period. The spectra shown in these figures develop over time since an RF emission on any specific frequency may only exist for an extremely brief period. The spectrum in Figure 7 shows the result of a less active meter over the measurement period. In practice, the RF field measurement data acquired during the many measurements of the project were stored in the digital memory of the SRM instrument and downloaded to a computer for subsequent further analysis and display.

A powerful feature of the SRM-3006 is that measurements can be displayed in alternative units of measure and, for these measurements, directly as a percentage of the FCC MPE for general public exposure, automatically adjusting the measured field for the frequency dependency of the FCC MPEs. Notice that the spectrum displays of RF fields (Figure 6 and 7) are presented against a logarithmically calibrated vertical scale of percent of the FCC's public MPE. With the instrument settings used in most measurements, the noise floor of the instrument, in terms of peak values, was less than 10^{-5} percent of the FCC public MPE (i.e., less than 0.00001% of the MPE).

Figure 5. The Narda SRM-3006 Selective Radiation Meter is based on fast Fourier transform (FFT) spectrum analyzer technology and uses a probe/antenna to measure the absolute magnitude of incident RF fields across the frequency range of 26 MHz to 3,000 MHz and digitally converts the detected field to the equivalent percentage of the FCC MPE.

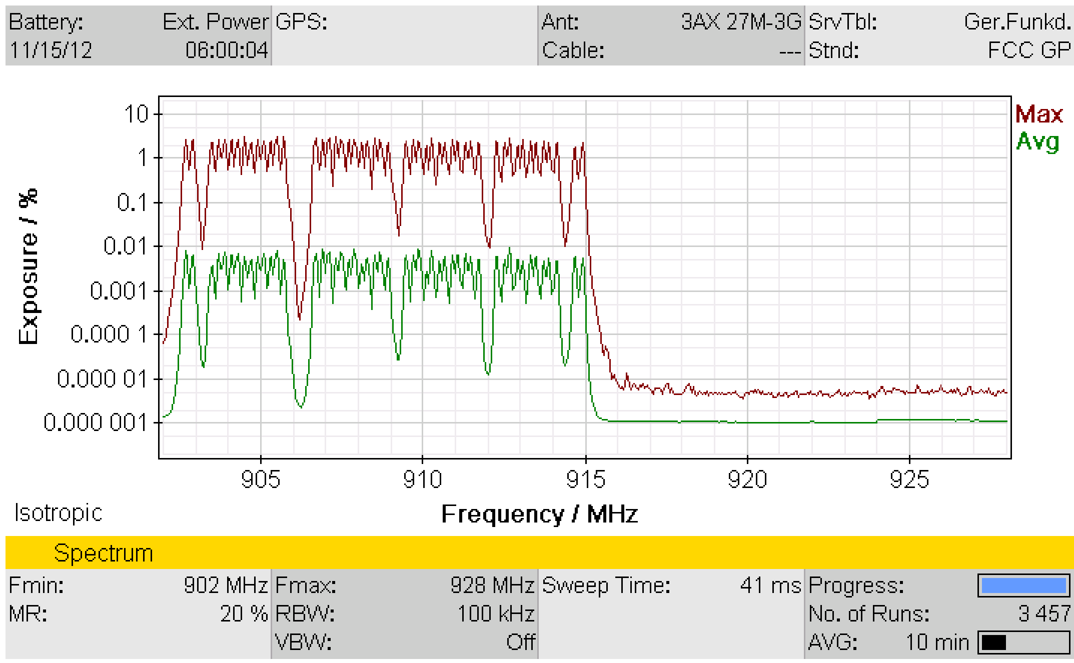

Figure 6. Illustrative maximum-hold RF spectrum display at one foot in front of a GMP smart meter showing the peak signal strengths of intermittent signals occurring randomly on 25 channels across the 902-915 MHz band during transmission of historical load profile data.

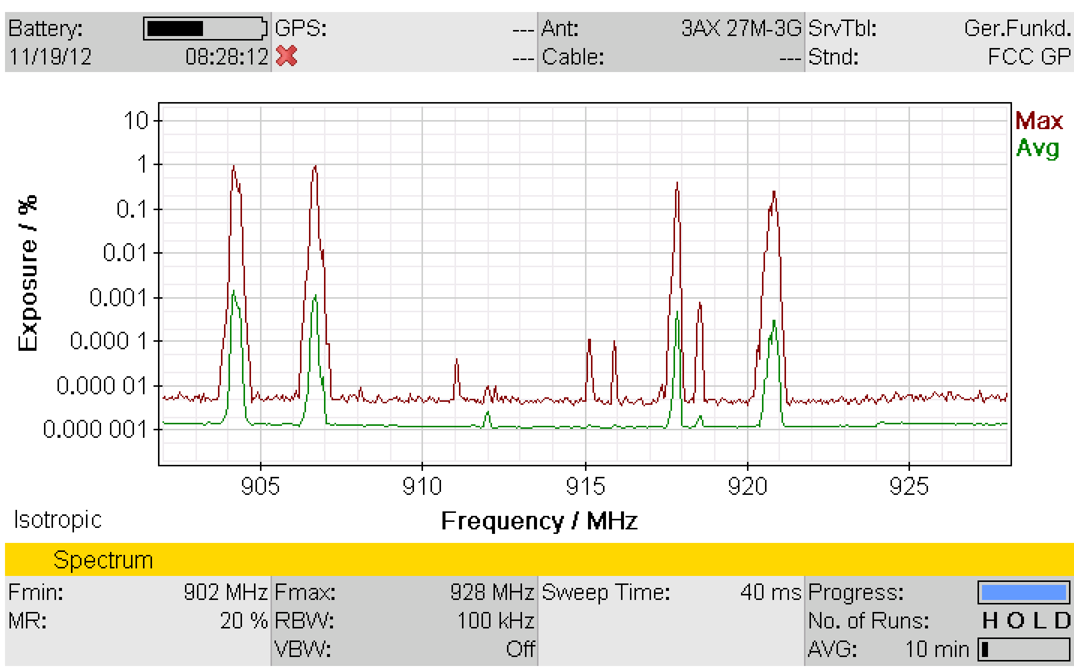

Figure 7. Illustrative RF spectrum display at one foot in front of a BED smart meter showing the peak signal strengths of intermittent signals occurring randomly across the 902-928 MHz band during transmission from a less active meter.

An additional feature of the SRM-3006 that made it particularly useful in this investigation was a scope or time-analysis mode in which the instrument can be tuned to a specific frequency with an adjustable resolution bandwidth (RBW) so that detected signals can be measured in the time domain. For pulsed RF fields that may have a fast rise time, a sufficiently wide RBW is necessary to properly detect the pulse. This facilitated capture of bursts of RF signals emitted by the smart meters. For the measurements performed in time-analysis mode, a RBW of 32 MHz (the widest possible on the SRM-3006) was used when centered on the specific signal frequency of interest. In this mode, the instrument becomes a "tuned oscilloscope" allowing observation and capture of the time domain waveform of RF signals within its RBW. The RBW may be thought of as a measure of the instrument's ability to discriminate two frequencies; the narrower the RBW, the better the instrument can show the presence of two frequencies that are close together. When used in time-analysis mode, however, wider RBWs permit detection of fast rise time pulses.

The SRM-3006, with accompanying probe/antenna, is capable of performing narrowband measurements of signals from 26 MHz to 3,000 MHz (3 GHz). For spectral measurements of the smart meter emissions, a RBW of 100 kHz was used for both the 900 MHz RF LAN signals as well as the 2.4 GHz HAN signals. The significantly wider RBW (32 MHz) was used for the time domain measurements to accommodate the fast rise time of the pulses. This value was deemed sufficient to allow accurate detection of the peak value of pulsed fields from the smart meter but was arrived at through evaluation of the indicated peak value of smart meter pulses with different RBWs.

For measurement of the 900 MHz band RF fields associated with the RF LAN emissions of smart meters, the instrument exhibited a sweep time of approximately 40 milliseconds (ms) for most of the measurements. During this period, measurements are made of the three polarization components of the RF field; the three values obtained at each frequency are assembled as the resultant value and the resulting spectrum is displayed on the instrument's screen. While this is a very fast process to accomplish this task, the capture of signals emanating from the meters which are only fleetingly present requires that the measurement process extend for a period sufficiently long to acquire a spectral display wherein the peak signal values are stable. As the pulsed fields on any given frequency across the band are only present for very brief periods, the challenge presented to the instrument is to sample each frequency where a signal exists for enough times that the displayed resultant field no longer changes over additional sweeps of the analyzer. When the spectral peaks no longer continue to increase in magnitude, the indicated resultant represents the true value of the peak RF field. Sampling for shorter durations can lead to an underestimate of the actual magnitude of the field since the analyzer may have not captured sufficient samples of the field strength on a specific frequency to insure that the peak value has been obtained. This means that most measurements, especially when they were not as frequent as at other times, required that the measurement might take as much as a minute or more to obtain a stable peak height of the signals. For the 900 MHz RF LAN fields, the typical emission (pulse) duration is in the range of 30 to 100 ms; this length of pulse is easily captured in terms of its peak value. For much shorter pulses, a different method is needed.

The approach used for evaluation of RF fields was, after acquisition of a spectrum of signal peaks (each peak representing the signal on a given frequency), to have the instrument identify the maximum peak value in terms of a percentage of the MPE. For all of the measurements reported here, only the greatest measured RF field from the spectrum of signals measured was used for assessing potential exposure. As the spectra shown in Figures 6 and 7 illustrate, there is typically some variation in the peak heights of the measured RF fields, i.e., not all peaks are exactly of the same magnitude. This variation can be related to the power output characteristics of the transceiver within the meters [9], the difference in MPE value at different frequencies, the possibility that not all spectral peaks were sufficiently sampled to arrive at a completely stable value for each peak and instrument measurement repeatability. Nonetheless, the maximum peak value from each measured spectrum was always used in the subsequent evaluation of fields.

For measurements of the HAN radio emissions, in the case of the GMP smart meters, an alternative method was determined to be necessary to capture meaningful measures of the resultant RF field magnitudes. Because of the very narrow pulses produced by the HAN radio, typically less than 2 ms, and the long period between each emission, the spectrum analyzer method of scanning across the entire frequency band was insufficient to allow collection of the resultant field magnitude due to the scan time being too long, even at 40 ms per scan. In this case, the SRM-3006 was configured in time-analysis mode with the center frequency of the analyzer placed on the fixed frequency produced by the HAN radio (although the HAN radio can operate over the entire band, it remains fixed during communication with an IHD or is simply attempting to connect with an IHD). In practice, at each site where HAN radio measurements were performed, the 2.4 GHz band was scanned to observe for the frequency at which the radio was transmitting. Once this frequency was identified, the instrument was then set to time-analysis mode, centered on the operating frequency of the HAN radio as observed from the spectrum measurement, and then adjusted to permit capture of the peak value of the emission by use of a 32 MHz RBW and fast sweep time. Even with this approach, each polarization component was measured separately to insure capture of the peak RF field. Data for the X, Y and Z probe axis readings were recorded for subsequent computation of the resultant magnitude of field.

Duty cycles were determined by the ability of the SRM-3006 to automatically indicate the duty cycle produced by time domain measurements over any period of time. A unique aspect of the instrument is its ability to collect RF field values across the time domain of a full 30 minutes but still respond to the momentary, very brief pulses presented by the smart meters. The duty cycle was calculated internally in the instrument as the ratio of the overall average power of the measured RF fields to the highest peak value of RF fields. For RF fields that are always exactly of the same amplitude, when they are present, this is equivalent to the ratio of the total signal on-time to the overall observation time.

Low Frequency Instrumentation Used in the Measurements

Although the prime effort in this study was that of characterizing the RF fields emitted by the GMP and BED smart meters, supplementary measurements were also performed of low frequency fields that might be associated with the operation of the meters. Such emissions, for example, could result from the use of switch mode power supplies within the smart meters to power the radios. Measurements of low frequency electric and magnetic fields were conducted in Colville with test meters provided by both GMP and BED using a Narda model EHP-50D electric and magnetic field analyzer (SN 000WX10510). This device, shown in Figure 8, provides for isotropic measurements with a dynamic range of 140 dB for electric and magnetic fields (depending on the specific configuration of the device). Internal to the sensor cube are three mutually orthogonal coil sensors for magnetic fields and three orthogonal sets of capacitor plates used as electric field sensors. Minimum detectable electric field strength is nominally 1 V/m and minimum magnetic field flux density is nominally 1 nanotesla (nT). The instrument is battery powered and is connected to a personal computer (PC) via an optical fiber cable for spectral analysis. Built-in fast Fourier transform (FFT) spectrum analysis allows evaluation of the frequency content of the electric and magnetic fields over the frequency range of 5 Hz to 100 kHz. Measured values of electric and magnetic field are displayed on the PC and saved to disc memory for subsequent analysis. Measurements with the EHP-50D were performed at a distance of 1 foot directly in front of each of the test meters. Electric and magnetic field spectra were measured across the 0 to 1 kHz, 0 to 10 kHz and 0 to 100 kHz frequency ranges.

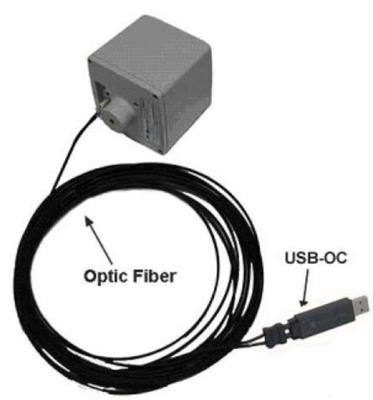

Figure 8. The Narda model EHP-50D Electric and Magnetic Isotropic Field Analyzer. The analysis of output from the sensor is performed via FFT in a connected laptop computer running special software.

Technical Approach Used in this Project

Background measurements of both electric and magnetic fields were made with each test meter unpowered for comparison to the measurements with the meters being powered up. All measurements were performed for a period of 2 minutes each to obtain the RMS value of fields detected by the probe. During these measurements, the smart meters were powered up but not connected to either an RF LAN or HAN IHD (in the case of the Elster meter).

Instrument Calibrations

Both the SRM-3006 and associated probe/antenna as well as the EHP-50D were used within 24 months of the respective instruments having been placed in service. Factory generated calibration certificates are provided in Appendix C for the SRM-3006 and Appendix D for the EHP-50D. The SRM system used in this project was calibrated by Narda on October 7 (probe) and October 13, 2010 (spectrum analyzer unit), but was not placed into service until February 22, 2011 (next factory calibration due February 22, 2013).

Prior to the measurements in Vermont, the SRM-3006 and associated probe/antenna were evaluated for their response to RF fields at 915 MHz, the center of the 902-928 MHz band in which the smart meter RF LANs operate, by comparing the indicated value of RF field to a similar probe/antenna (SN H-0368) that had been calibrated by Narda on October 27, 2011. The calibration certificate for the comparison probe is shown in Appendix E.

The probe/antenna comparison was performed in Colville, WA by positioning each probe at one foot directly in front of a test smart meter operating in the 900 MHz band, acquiring a spectrum of the observed smart meter emissions for approximately two minutes and, then, comparing the indicated value of the maximum peak RF field from the two units. This procedure yielded readings that differed by 6.5% in terms of percentage of the public MPE. This is equivalent to 0.27 dB, this value being well within the uncertainty of the manufacturer's calibration method of 1 dB. Through this quality assurance process, it was deemed that the SRM system as used for measurements in Vermont was in compliance with the manufacturer's stated specifications

How the Measurements Were Made

The measurements performed for this project were accomplished in the state of Vermont at installed smart meter sites, primarily residential locations, and in Colville, WA where measurements on test meters provided by both GMP and BED were conducted. The Colville measurements allowed for examining the time domain waveforms of the signals under alternative scenarios. For example, in the case of the GMP Elster meter, the HAN radio was used to connect with an IHD so that differences in RF performance could be observed.

RF fields were measured as a function of distance from the front face of the meters in both Vermont and Washington from 1 foot to 10 feet from the meters as illustrated in Figure 9. Measurements were performed by holding the instrument probe/antenna at the height of the meter face, standing to the side as illustrated in Figure 9, with the probe/antenna perpendicular to the front surface of the meter face. A tape measure was used to locate the measurement distance relative to the front surface of the meter as well as adjusting the probe/antenna to the correct height.

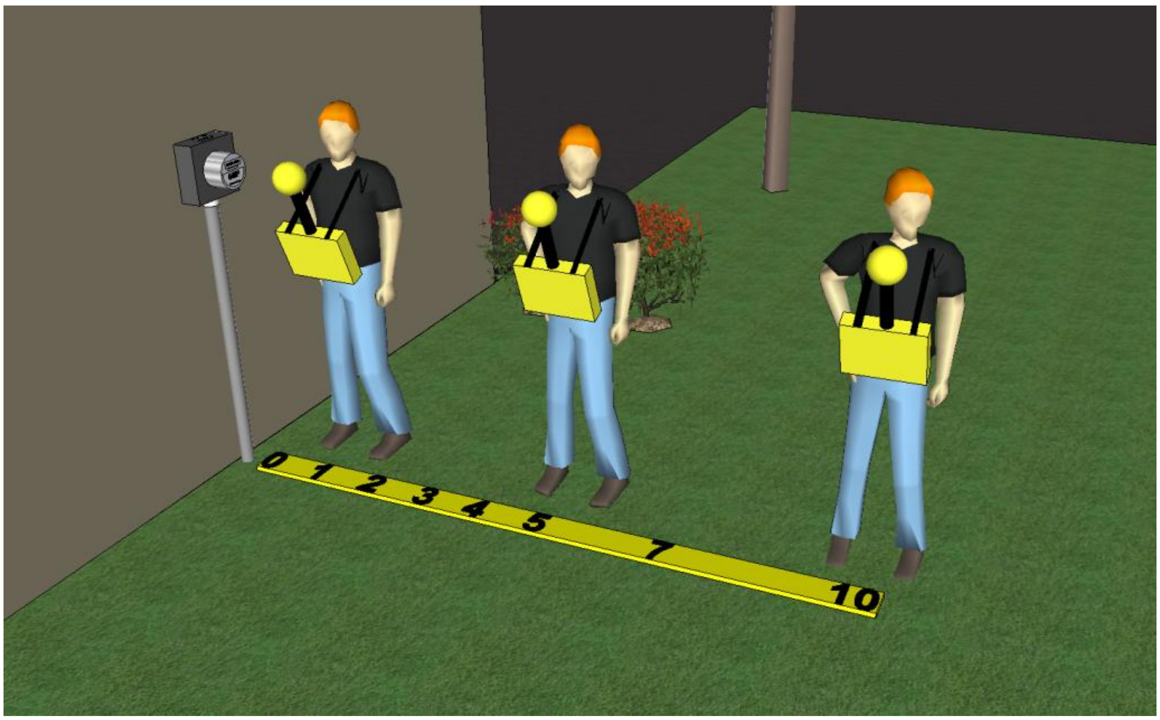

Figure 9. Illustration of the measurement of RF fields at different distances, ranging from one foot to 10 feet from the front surface of a smart meter.

At the Vermont sites, measurements were performed inside most of the buildings on which the meters were attached. RF fields as a function of height above ground were also measured in both Vermont and Washington. Measurements related to the directional properties of the meters were made in Washington. In Colville, there are no smart meter networks and, hence, the meters could not connect with a mesh network as they did in Vermont. Figure 10 shows measurements being made at a site in Burlington using the SRM-3006.

Figure 10. Measurement of RF fields in front of a residential smart meter installation. Measurements were made at distances from 1 foot to 10 feet in front of the meters.

For determining meter emission duty cycles, the SRM-3006 was supported on a tripod as shown in Figure 11 so that the probe could be held fixed in position for the 30-minute measurement periods typically used.

Measurement of Other Wireless Devices

During the indoor measurements of smart meter RF fields, on a few occasions, the opportunity to measure fields produced by other common devices occurred. Hence, measurement data were also collected near two microwave ovens and six wireless routers used for distribution of Internet connectivity.

Environmental RF Field Measurements

To help provide some perspective on the relative amplitude of smart meter RF fields, additional environmental measurements were made of signals produced by VHF FM radio and TV broadcast, UHF TV broadcast, and mobile phone base stations and a long range FAA air traffic control radar at 14 different sites within the state. Figure 12 illustrates these measurement locations within the state. Areas where measurements were performed included Rutland, Burlington, Montpelier and Saint Albans, Vermont. To facilitate rapid measurement of RF fields in many locations, a portable, spectrum analyzer based instrumentation system that could be used with a vehicle was determined as the most practical approach for acquiring data. These measurements were made from a vehicle with the SRM-3006 probe/antenna connected to the analyzer via a 1.5 meter long cable and held with a 24 inch PVC pipe to support the probe/antenna above the roof level of the vehicle. All measurements were performed with the vehicle stopped and turned off.

Figure 11. Use of the SRM-3006 to measure the duty cycle of smart meter emissions over a 30-minute period at a meter bank in Rutland.

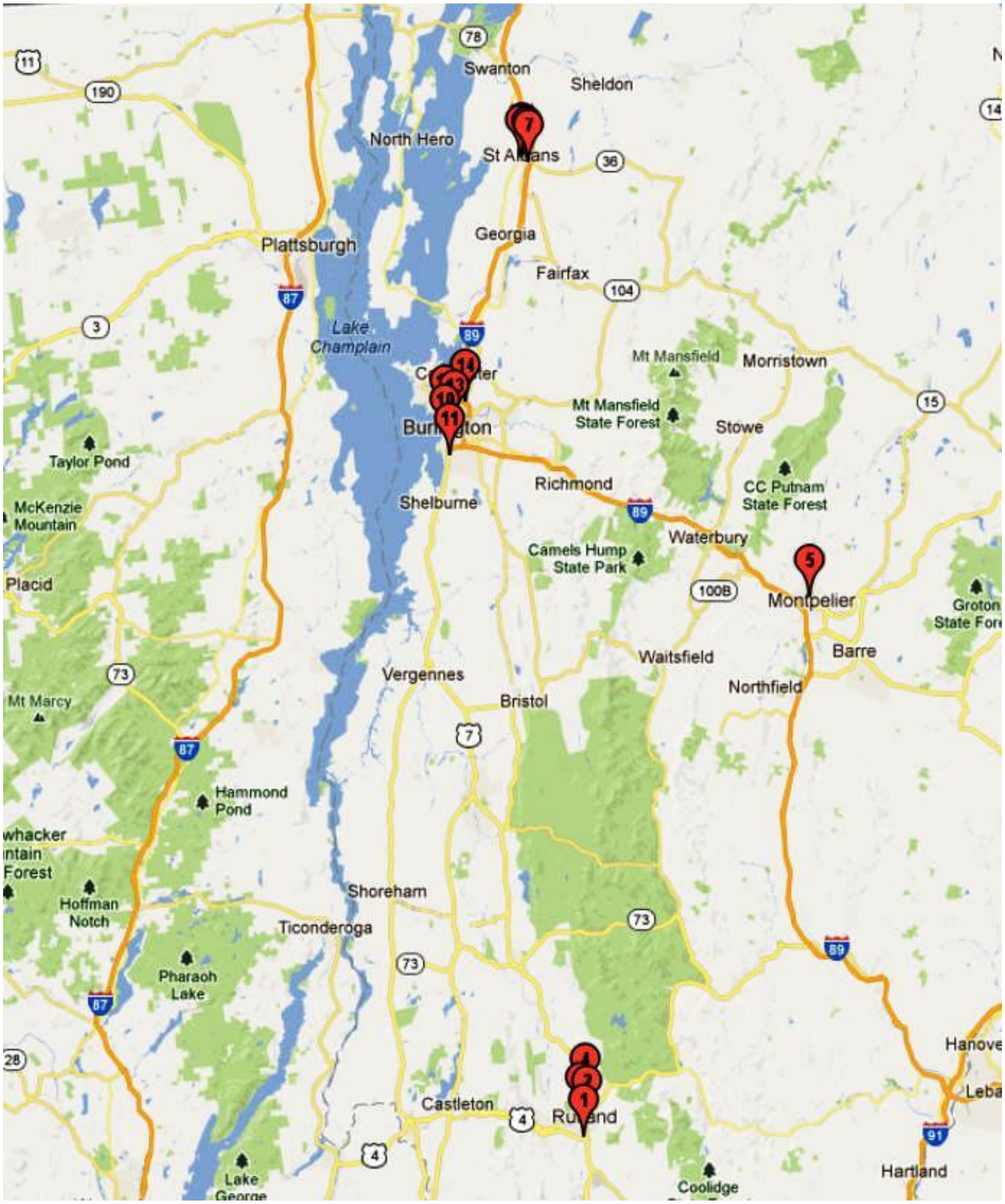

Figure 12. Environmental RF measurement locations within Vermont included in the study.

Results

Results

RF Fields of Smart Meters vs. Distance

Field measurements were made no closer to a smart meter than 1 ft (0. 3m). IEEE Standard C95.3-2002 [10] recommends a minimum measurement distance of 0.2 m to minimize nearfield coupling and field gradient effects when using common broadband field probes. Measurement data can be distorted when using an isotropic probe to measure steep spatial gradients close to a radiating element of a smart meter. These gradients can lead to considerable variation of the indicated amplitude of the field being measured over the volume of space occupied by the measurement probe elements. Nearfield coupling, and associated erroneously high field readings, can be particularly troublesome when employing field probes in the reactive near field that are comparable to the size of the source antenna. The elements inside the SRM-3006 probe/antenna are approximately 10 cm long. Based on the potential for significant probe nearfield coupling with the smart meter internal transmitting antenna, measured values with surface contact between the probe/antenna and a smart meter should be avoided and considered likely substantial over-estimates of the true field. It was deemed appropriate that the minimum distance at which fields would be measured with the SRM-3006 should be one foot. A distance of one foot (~0.3 m) is equivalent to approximately one wavelength at 915 MHz.

The process of measuring smart meter RF emissions was facilitated by instructing each meter to transmit in the 900 MHz band during the measurement period. Since most of the time there is only intermittent activity from smart meters, performing reliable field strength measurements can be problematic since the emissions, when they do occur, are so brief. In the measurements in the GMP service territory, GMP assisted with the process by providing access to a device which could be used to "ping" the specific meter being measured. The device, variously called a field service unit, can issue wireless signals directed to the meter and cause the meter to respond by sending an acknowledgment and data. This method insured that when the RF field measurements were made, there was sufficient signal activity to allow for an accurate capture of the instantaneous peak field magnitudes. The device, a Radix model FW-950, is a handheld portable computer equipped with a 900 MHz band radio and associated software that provides communication with the smart meter. By invoking a "continuous ping" feature on the FW-950, smart meter transmitter activity could be started and this procedure was used during the measurements of the GMP meters. To insure that the measurement process was not "contaminated" by any signal sent from the FW-950 to the smart meters, the device was kept typically about 50 feet from the smart meters being measured.

While the on-site use of the field service unit was used with the GMP meters in the Rutland area, an alternative approach to insuring smart meter transmission was pursued with the BED meters in Burlington. The BED issued commands from their network head-end at the utility headquarters over the network to invoke a response from the meter targeted for measurements. This required relaying the meter network number to personnel at the utility via a mobile phone. BED technical staff accompanying the measurement team attended to this task prior to each set of measurements. Once the request for transmission was issued from the network head-end, it would typically take a few seconds for the request to be received by the smart meter before it began its transmission response. A field service unit was provided by GMP to facilitate measurements on the GMP test meter sent to Colville. In the case of the BED test meter, once powered up, the meter begins to issue 900 MHz band signals as a means of "discovering" a smart meter network to which it can connect. These signals, while not present as often as those elicited for the GMP meter, served for the measurements of the Itron meter in Colville.

Peak RF fields, obtained at the various smart meter locations, expressed as a percent of the FCC MPE for general public exposure, are tabulated for the different distances at which measurements were made in Table 3 for the GMP and BED meters. The designation 'T' refers to the test meters provided by both GMP and BED for testing in Colville, WA. Measurements at a distance of 10 feet were not possible at GMP site 11 and BED site 3 due to nearby obstructions.

Table 3. Peak 900 MHz RF field magnitudes obtained at different individual smart meter sites in the GMP (Rutland) and BED (Burlington) service territories. These values represent the greatest instantaneous RF field observed at any frequency within the 902-928 MHz band and are expressed as a percentage of the FCC MPE for public exposure. The 'T' designates test meters measured in Colville. Data for sites at meter banks, GateKeepers and Cell Routers are shown elsewhere.

	Distance (ft) from meter face						
Site	1	2	3	4	5	7	10
GMP-1	3.540	1.146	0.492	0.304	0.179	0.093	0.020
GMP-2	3.533	0.945	0.145	0.283	0.136	0.079	0.012
GMP-4	1.325	0.536	0.305	0.109	0.034	0.076	0.046
GMP-5	3.924	1.312	0.586	0.342	0.204	0.224	0.078
GMP-6	3.097	0.756	0.508	0.461	0.284	0.146	0.087
GMP-7	2.462	0.976	0.588	0.250	0.277	0.081	0.046
GMP-9	1.190	0.408	0.161	0.087	0.118	0.063	0.033
GMP-10	2.566	1.134	0.183	0.214	0.083	0.076	0.049
GMP-11	1.532	0.423	0.231	0.130	0.089	0.053	
GMP-T	1.300	0.276	0.183	0.065	0.055	0.016	0.010
BED-2	0.863	0.097	0.059	0.101	0.038	0.029	0.00716
BED-3	0.982	0.434	0.259	0.316	0.173	0.056	
BED-4	0.564	0.162	0.051	0.040	0.092	0.042	0.017

Results

Table 3 continued.							
BED-5	0.355	0.184	0.076	0.041	0.028	0.043	0.0096
BED-7	0.263	0.149	0.036	0.060	0.026	0.027	0.104
BED-8	2.498	0.351	0.386	0.127	0.103	0.100	0.029
BED-T	1.356	0.373	0.255	0.193	0.119	0.046	0.030

The data in Table 3 are graphically displayed in Figures 13-14 for the Rutland area meters (linear and logarithmic plots). Variations in the measured value of fields are expected to be caused by measurement uncertainty and the real-world presence of uneven ground over which the measurements were performed and nearby objects that undoubtedly introduced ground reflections and scattering of RF fields that resulted in the observed variations in field values. Figure 15 plots the mean values of individual smart meter fields with plus and minus one standard deviation of measured values at each distance for the nine sites Vermont sites.

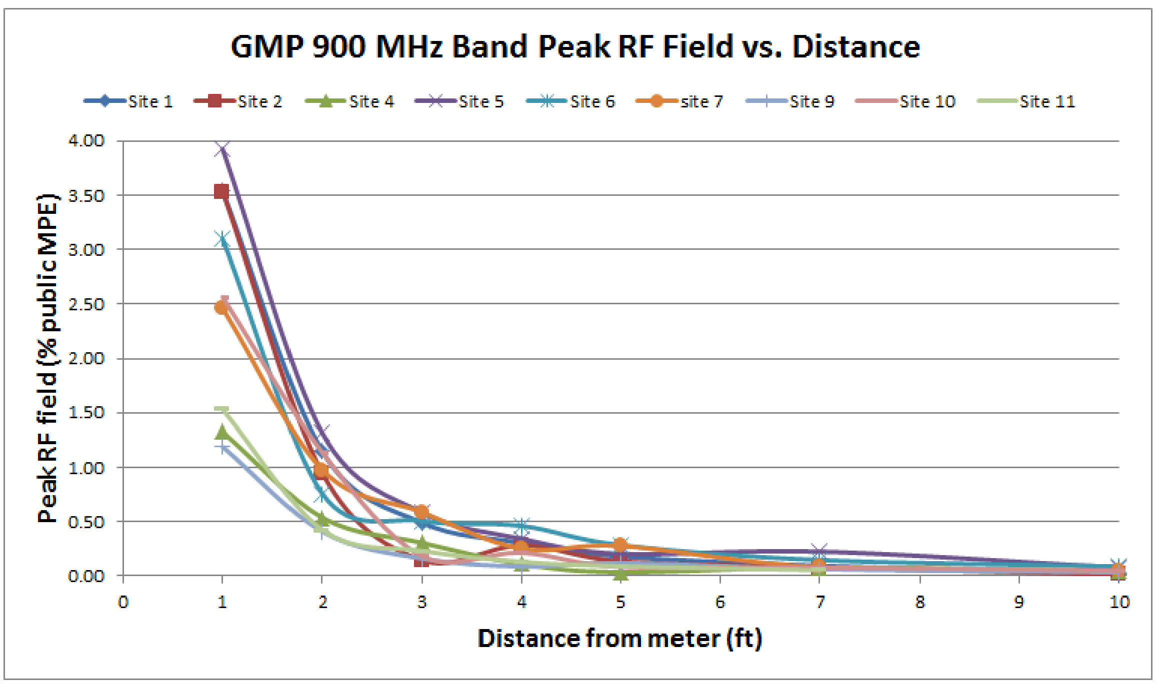

Figure 13. Linear display of measured peak values of RF fields at distances up to 10 feet in front of individual smart meters operated by GMP.

Results

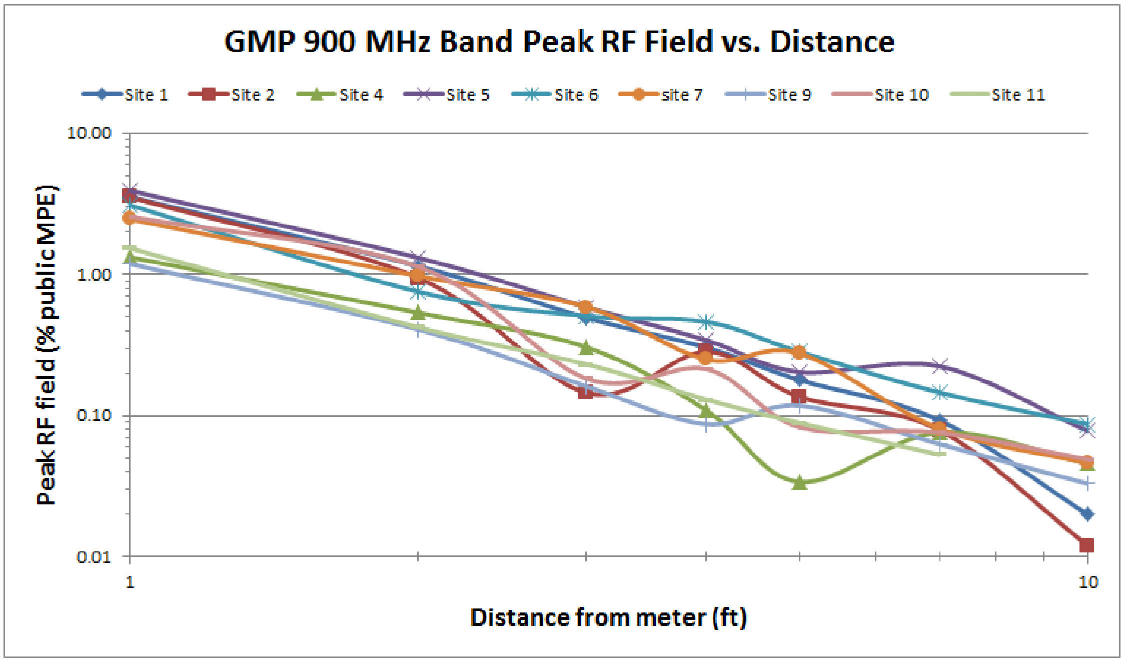

Figure 14. Logarithmic display of measured peak values of RF fields at distances up to 10 feet in front of individual smart meters operated by GMP.

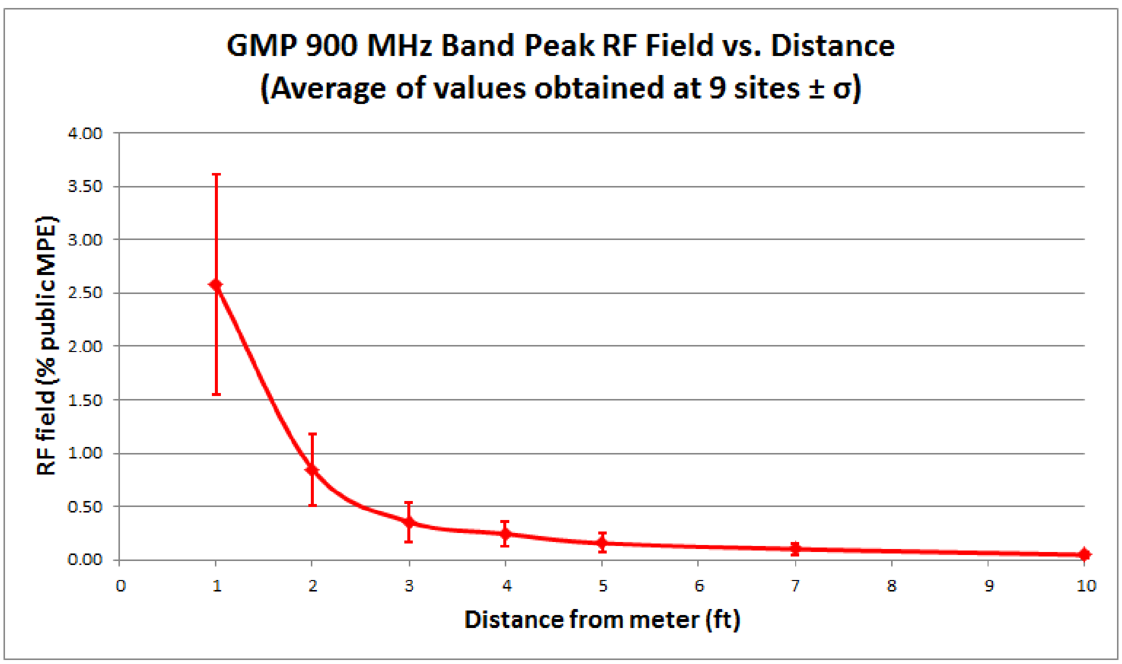

Figure 15. Average of 900 MHz band peak RF fields vs. distance ± 1 standard deviation of values obtained at nine individual smart meter sites in the GMP Rutland area.

Results

Similar graphical plots of RF fields obtained near individual BED smart meters in Burlington are provided in Figures 16 and 17 (linear and logarithmic plots). Figure 18 shows a plot of the mean values with the standard deviations at the six sites.

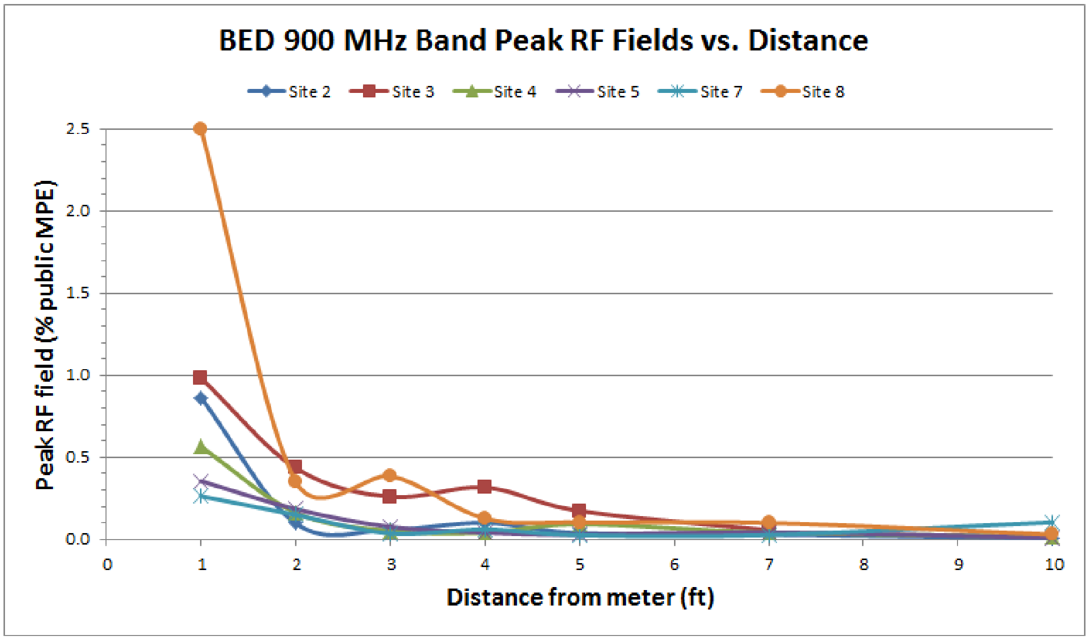

Figure 16. Linear display of measured peak values of RF fields at distances up to 10 feet in front of individual smart meters operated by BED.

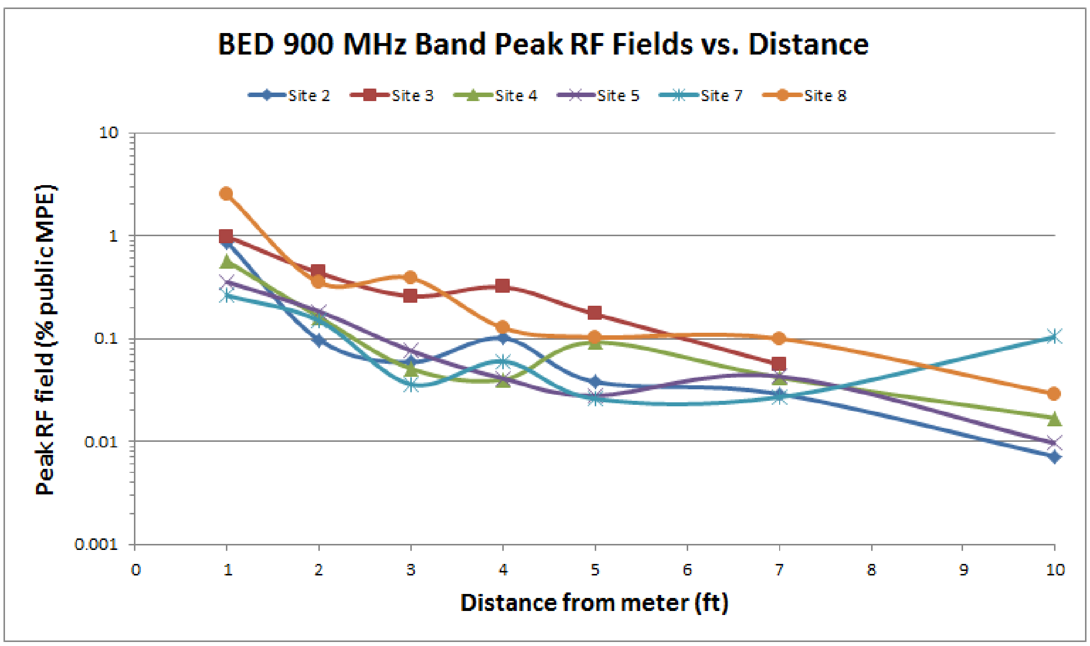

Figure 17. Logarithmic display of measured peak values of RF fields at distances up to 10 feet in front of individual smart meters operated by BED.

Results

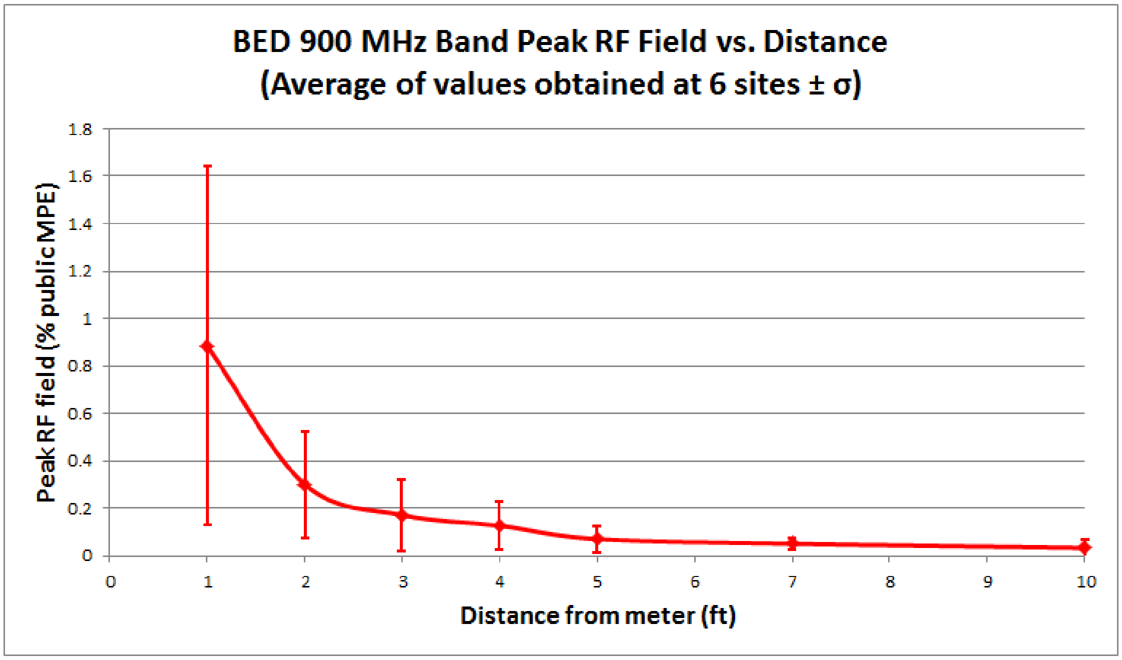

Figure 18. Average of 900 MHz band peak RF fields vs. distance ± 1 standard deviation of values obtained at nine individual smart meter sites in the BED service territory.

Separate measurements of RF fields were performed on two test meters shipped to Colville by GMP and BED. Figure 19 shows the variation of measured peak RF fields vs. distance for these two meters.

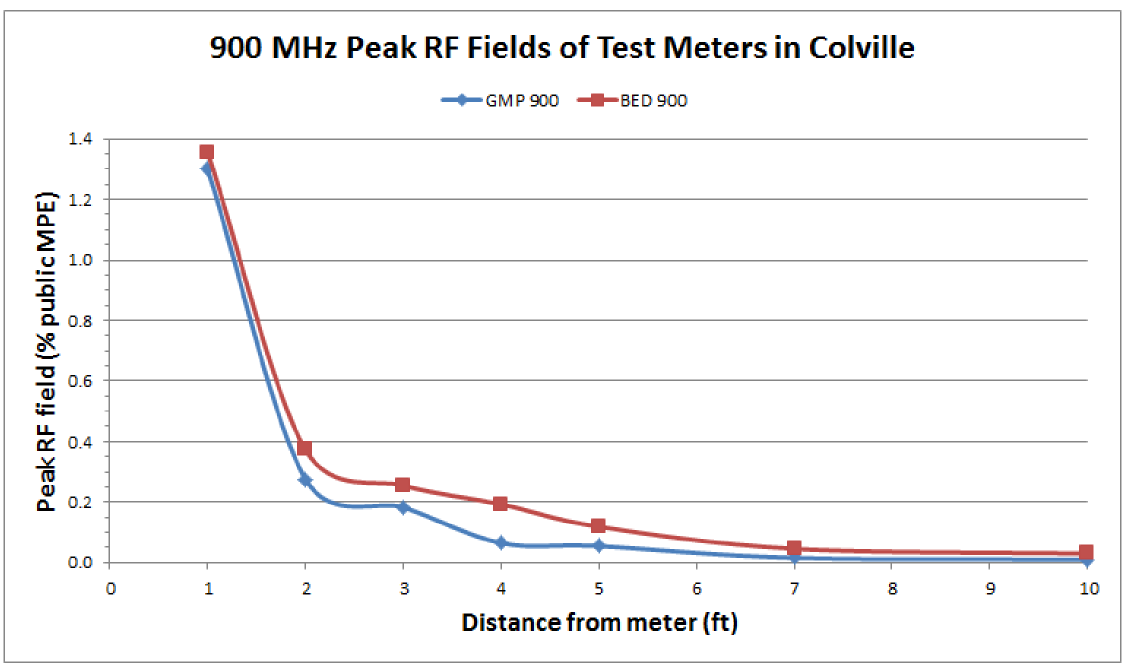

Figure 19. Measured peak RF fields produced by the Elster and Itron test meters in Colville, WA.

Results

RF fields associated with 900 MHz band emissions from a total of five different meter banks (collections of more than one meter) were also measured. Field variation with distance was measured at two of the locations while duty cycles were measured at four of the five sites. The variation of field with distance was determined by centering the meter on one of the meters in the bank and increasing the distance from that meter. The results for the two meter banks at which this was accomplished in the BED service territory are shown in Figure 20. It is noted that BED site 10 was inside a large closed, below ground electrical room (Figure 21) with irregular interior walls.

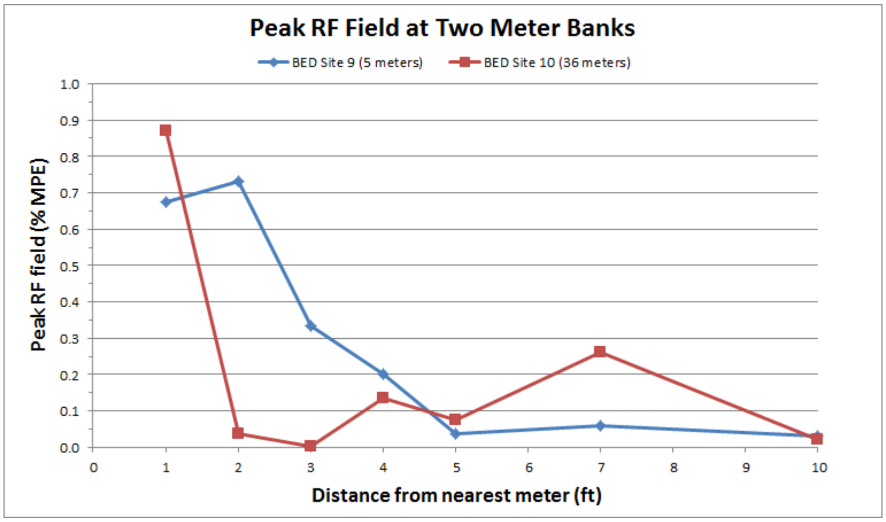

Figure 20. Measured peak RF fields of 900 MHz emissions observed at two meter banks (one with 5 meters and the other with 36 meters) in the BED service territory.

Figure 21. BED site 10 with 36 smart meters inside an electrical room.

Results

Implementation of the HAN radio feature by either GMP or BED for routine customer use had not occurred as of the time that this study was performed. GMP had established approximately 500 residential locations within their Rutland regional service territory as experimental sites to test the capability of the HAN system and explore customer reaction to the in home display (IHD). Whether all of those customers had "paired" the IHD with their smart meter to be able to see their electrical energy consumption was not known at that time. BED had not made any use of the HAN system as of the time of the project field work in Vermont. Despite the fact that the Elster meters used by GMP were not generally "activated" to interact with IHDs, the HAN radios in the smart meters periodically issue a very brief signal lasting approximately 1.75 ms once every 15 seconds plus a group of four closely spaced signals once per minute for a total of eight pulse emissions per minute. These signals are presumably related to the HAN radio searching for IHDs in the vicinity that have been commissioned to wirelessly connect to the meter. This characteristic of the HAN radios in the Elster meters means that one expects to observe periodic pulsed signals from the radio even if there is no IHD in range; in the case of multiple meters located together, as in a meter bank, more pulsed signals should be observed over time simply due to the greater number of meters, each sending out a periodic signal.

The time domain characteristics of the HAN (ZigBee) radio signal are the subject of a later section in this report. Measurements at BED smart meter sites during the project as well as work with the BED test meter in Colville did not reveal any HAN radio transmission activity.

Measured peak values of the RF field of the HAN radio in the vicinity of nine GMP smart meter sites, each composed as the resultant of the three orthogonal polarization components of the detected fields, are tabulated in Table 4. The resultant peak values are displayed graphically in linear and logarithmic format in Figures 22 and 23. Figure 24 illustrates the mean value of the measured peak HAN RF fields at each distance with the associated standard deviation of values obtained at nine GMP sites.

Table 4. Peak 2.4 GHz RF field magnitudes, associated with the HAN (ZigBee) radio, obtained at nine residential smart meter sites in the GMP (Rutland) service territory. These values represent the instantaneous RF field observed at any frequency within the 2.4 to 2.5 GHz band and are expressed as a percentage of the FCC MPE for public exposure. A 'T' designates measurements of the GMP test meter in Colville. Sites not listed here included nonresidential locations or locations where interior measurements were not conducted.

	Distance (ft) from meter face						
Site	1	2	3	4	5	7	10
GMP-2	0.276	0.21	0.05495	0.03912	0.03639	0.01948	0.00524
GMP-4	0.075	0.03836	0.07782	0.05009	0.04596	0.02047	0.01647
GMP-5	0.311	0.078	0.0273	0.0369	0.02981	0.00459	0.0037

Results

Table 4 continued.							
GMP-6	0.311	0.06291	0.074	0.03879	0.02024	0.00848	0.00847
GMP-7	0.545	0.212	0.0867	0.04518	0.01215	0.02555	0.00765
GMP-9	0.254	0.139	0.11	0.04917	0.03597	0.0317	0.01264
GMP-10	0.51685	0.071	0.03448	0.01325	0.01436	0.01418	0.00689
GMP-11	0.317	0.16076	0.04742	0.01115	0.01052	0.00928	
GMP-13	0.18	0.00359	0.011	0.00047	0.00124	0.00192	0.00419
GMP-T	0.255	0.085	0.081	0.043	0.01322	0.01346	0.00936

RF Field Variation vs. Height above Ground

A comprehensive assessment of compliance with the FCC RF exposure rules includes an evaluation of the spatial average value of RF field over the dimensions of the body. The IEEE [7] provides guidance on this process.[13] In accord with this guidance, fields were measured over six-foot vertical lines at a lateral distance of one foot from the front surface of the 900 MHz band GMP and BED smart meters as well as the 2.4 GHz GMP meter with an active HAN radio. Spatially averaged fields, while less than the spatial maximum, more accurately correspond with the limiting energy absorption rates (SARs) of the body upon which the exposure limits are specified by the FCC.

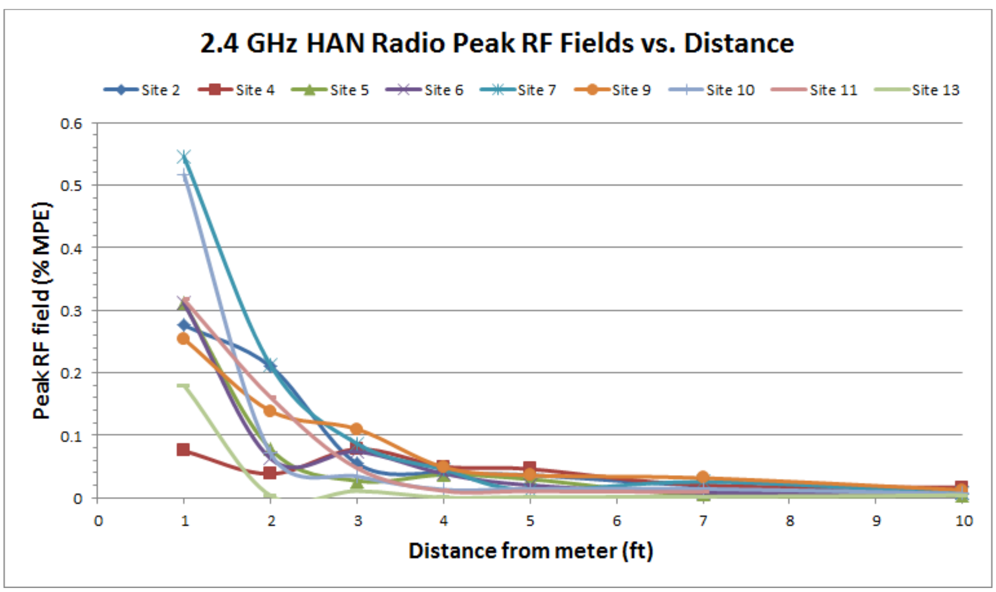

Figure 22. Linear display of measured peak 2.4 GHz RF fields of the HAN radio at GMP smart meters observed at nine individual meter sites.

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[13] From IEEE [7]: The spatial average is measured by scanning (with a suitable measurement probe) a planar area equivalent to the area occupied by a standing adult human (projected area). In most instances, a simple vertical, linear scan of the fields over a 2 meter height (approximately 6 feet), through the center of the projected area, will be sufficient for determining compliance with the MPEs.

Results

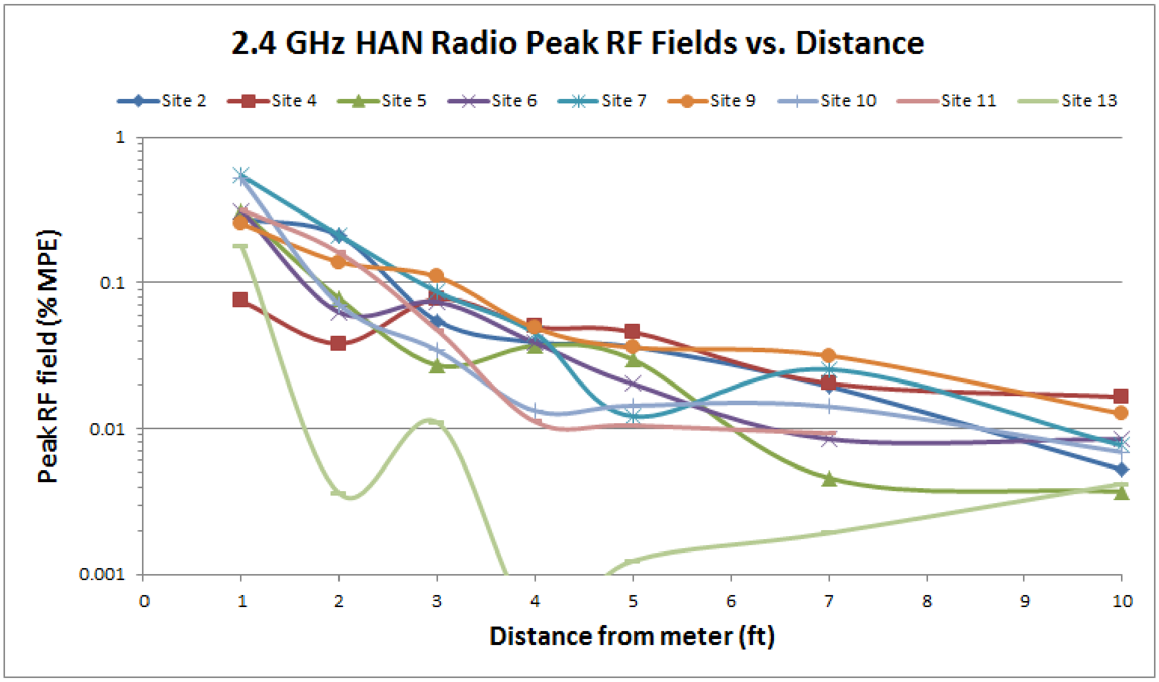

Figure 23. Logarithmic display of measured peak 2.4 GHz RF fields of the HAN radio at GMP smart meters observed at nine individual meter sites.

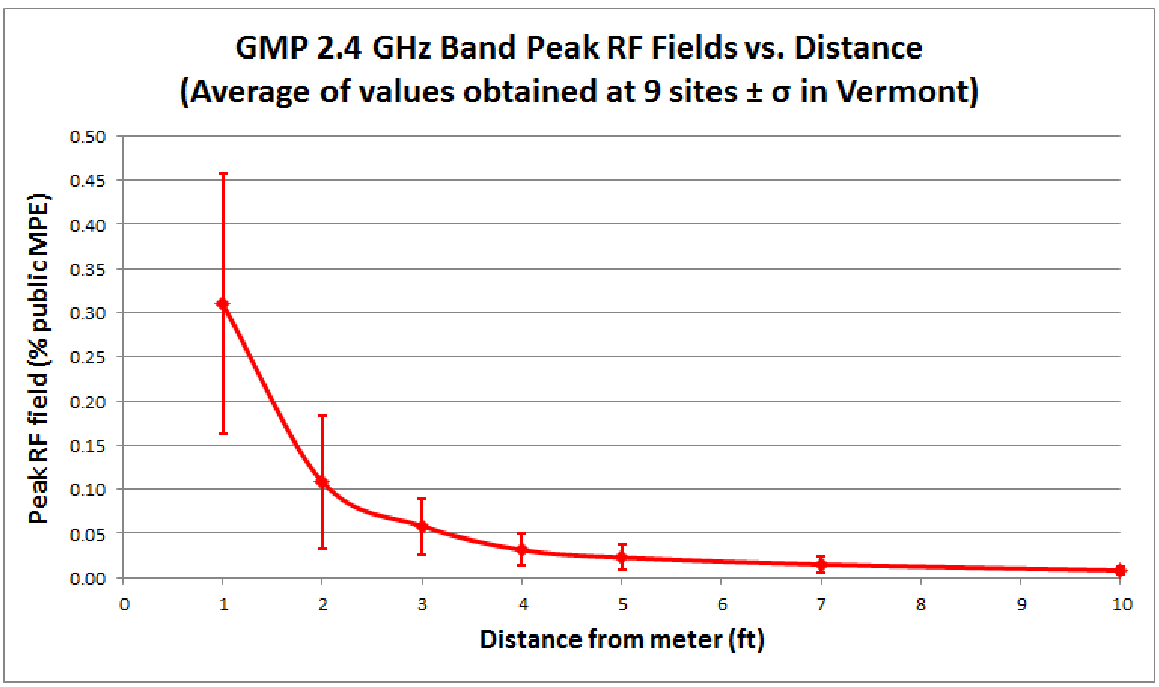

Figure 24. Average of 2.4 GHz band peak RF fields vs. distance ± 1 standard deviation of values obtained at nine individual smart meter sites in the GMP service territory.

Results

Figure 25 displays the 900 MHz band measurement results obtained near a GMP Elster meter for determining the vertical spatial average value of RF fields where the values have been normalized to a value of unity representing the greatest value at any height above ground. Figure 26 shows that the overall spatial average of peak RF field, expressed as a fraction of the FCC MPE, is 30.4% of the spatial maximum.

A similar set of measurement data shown in Figure 26, but for a different meter mounting height for the two test meters in Colville, show a consistent observation of the maximum field being associated with the mounting height of the meter. Spatially averaged RF fields of 36.3% and 48.9% of the spatial maximum values were measured. With both meters mounted at the same height, the results suggest a somewhat different distribution of RF fields in the elevation plane.

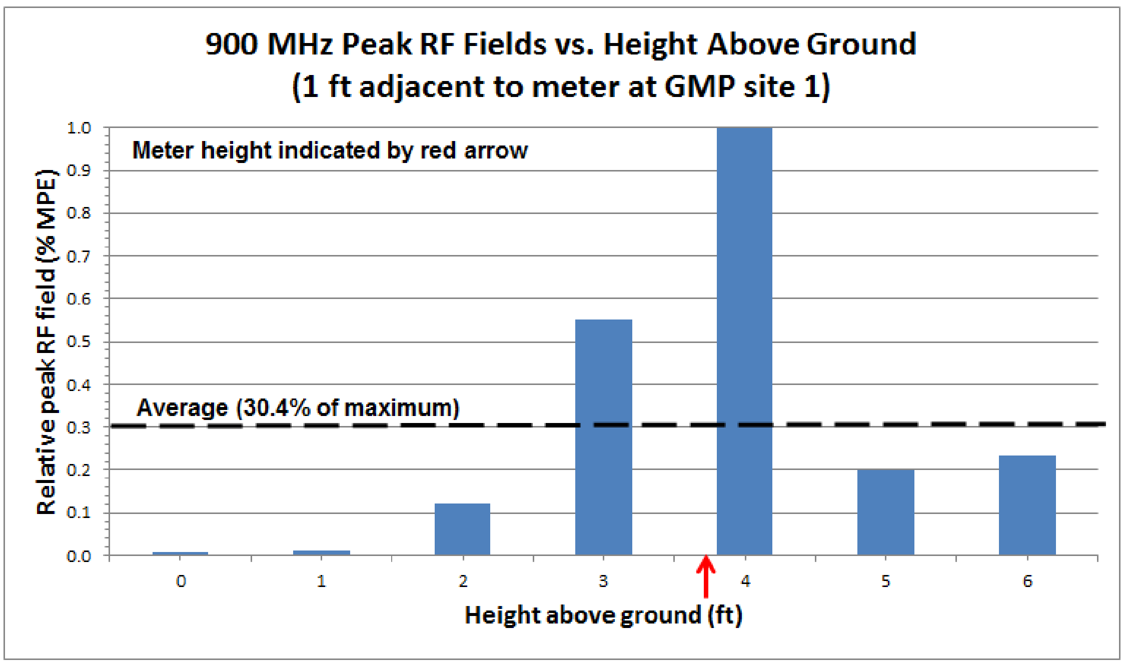

Figure 25. Relative peak RF field (as a percent of the MPE) vs. height above ground at one foot in front of a 900 MHz Elster meter operated by GMP in Vermont. Measured fields were normalized to the greatest value determined from all measurements. Overall, the spatial average was found to be 30.4% of the spatial maximum value. The variation in relative values is due to the fact that the smart meter emissions are mainly directed horizontal to the meter.

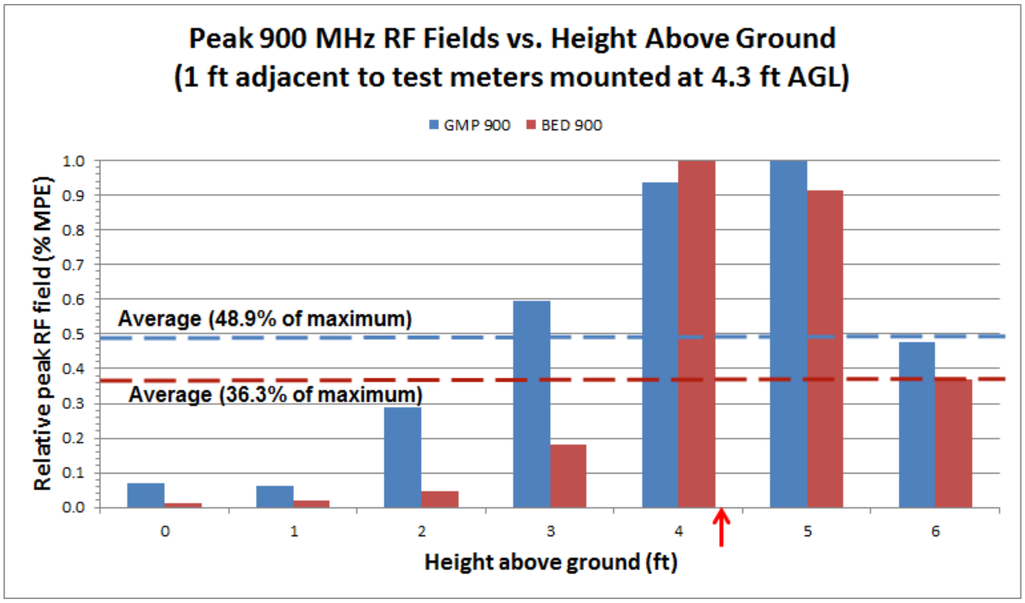

Figure 26. Relative peak 900 MHz band RF field (as a percent of the MPE) vs. height above ground at one foot in front of the Elster and Itron test meters in Colville, WA. Measured fields were normalized to the greatest value determined from all measurements.

The vertical spatial variation of 2.4 GHz peak RF fields of the HAN radio in front of the Elster meter is shown in Figure 27 where the spatially averaged RF field was 34.9% of the spatial maximum observed near the mounting height of the meter.

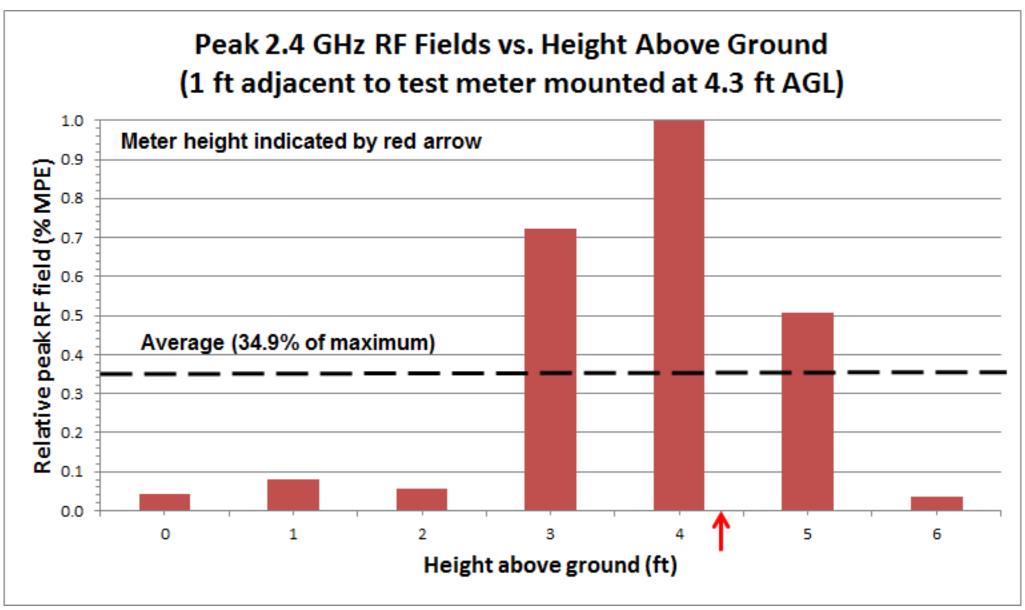

Figure 27. Relative peak 2.4 GHz band RF field (as a percent of the MPE) vs. height above ground at one foot in front of the Elster test meters. Measured field was normalized to the greatest value determined from all measurements.

Results

Azimuthal Directivity

Beyond variation of RF fields in the elevation plane, measurements were also performed to examine the directional properties of the smart meter emissions in the azimuth (horizontal) plane near the smart meters. The meters were installed in a standard electrical meter socket, powered up and, with the SRM-3006 and probe/antenna supported on a tripod, the peak RF fields were measured. The smart meter positioned in four directions: 0° (face of the meter facing the probe/antenna), 90° (smart meter facing to the left), 180° (smart meter facing to the rear and away from the probe/antenna) and 270° (smart meter facing right). These relative pattern data are shown in Figure 28. For both meters, including the 900 MHz and 2.4 GHz bands, the weakest RF fields were found to the rear of the meter, ranging from approximately 6% to 8% of the maximum value. This is the side of the meter that would typically face the exterior wall of a residence. For the 900 MHz emissions, the strongest RF fields were always from the front of the meter with lesser values to the sides and to the rear. RF fields of the 2.4 GHz HAN radio, however, were observed to be as much as 27% stronger off to one side of the meter as directly from the front.

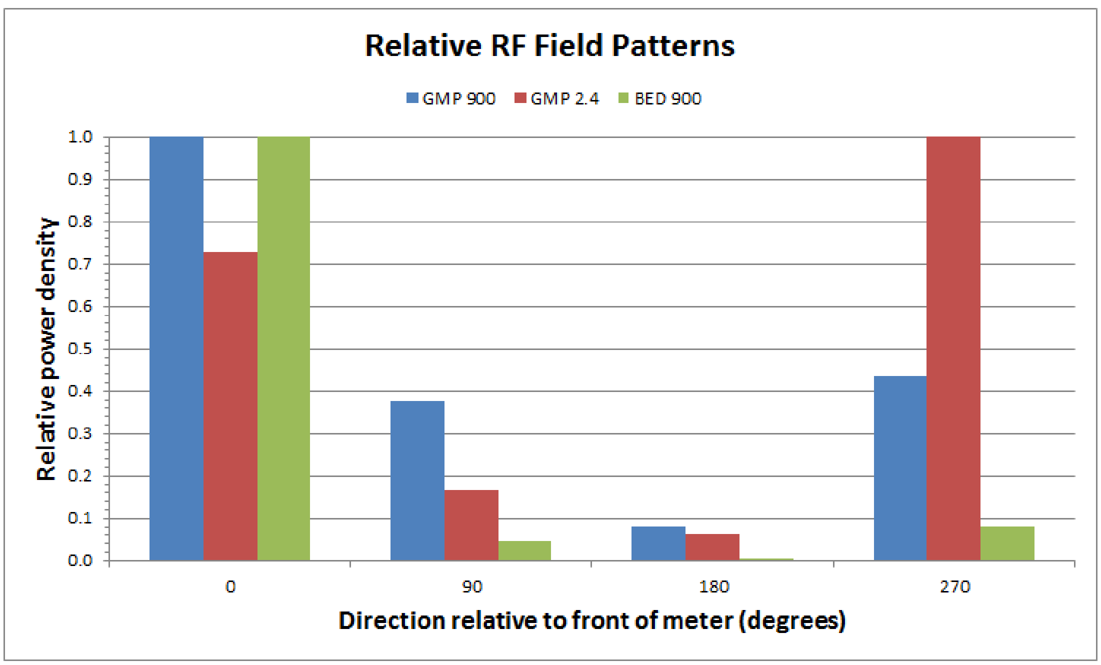

Figure 28. Relative RF field patterns in the azimuth plane for the GMP and BED 900 MHz radios and the GMP 2.4 GHz HAN radio. Generally, RF fields to the rear of the meters are weakest, being between approximately 6% and 8% of the maximum values.

Results

Interior RF Measurement Results

An important aspect of this project was determining the magnitude of smart meter RF fields found inside of residences equipped with smart meters operated by both GMP and BED. This process involved a similar approach as used for the exterior field vs. distance measurements. The respective meters were "pinged", either via the field service unit in the GMP territory or via the network in the BED area, and different rooms within each residence were scanned with the SRM-3006 to acquire a spectrum of the RF emissions. The maximum values were extracted from the saved spectral data as the value representative of potential exposure within the room. For interior measurements of the GMP HAN radio emissions, time domain measurements of the separate X, Y and Z polarization component fields were acquired by standing within the room, toward the center of the room where accessible, and capturing the narrow pulses that were relatively infrequently emitted. In this instance, the room was not spatially scanned since the acquisition of a meaningful measure of the RF field magnitude required the three polarization measurement values to be obtained at the same point in space.

A total of 141 interior RF field measurements (RF LAN and HAN emissions from GMP meters) were made between those in the Rutland area and in Burlington. The 900 MHz band measurement results are tabulated for the GMP and BED service territory homes in Tables 5 and 6 respectively. Interior RF fields associated with the operation of the 2.4 GHz HAN radios of the GMP meters are tabulated in Table 7. Collectively, the interior residential measurements yielded a maximum peak value of RF field of 0.08% of the MPE for public exposure, an average peak value of 0.0033% of the MPE and a minimum value of 0.00001% of the MPE.

Figure 29 shows the results of a cumulative percentile analysis of the interior peak RF field measurements. The median value of peak field was 0.00019% of the MPE. The horizontal axis of this figure represents the percent of all measurements having values equal to or less than the values on the vertical axis. For example, 40 percent of the measurements had values of peak RF field equal to or less than 0.0001% of the FCC MPE.

Results

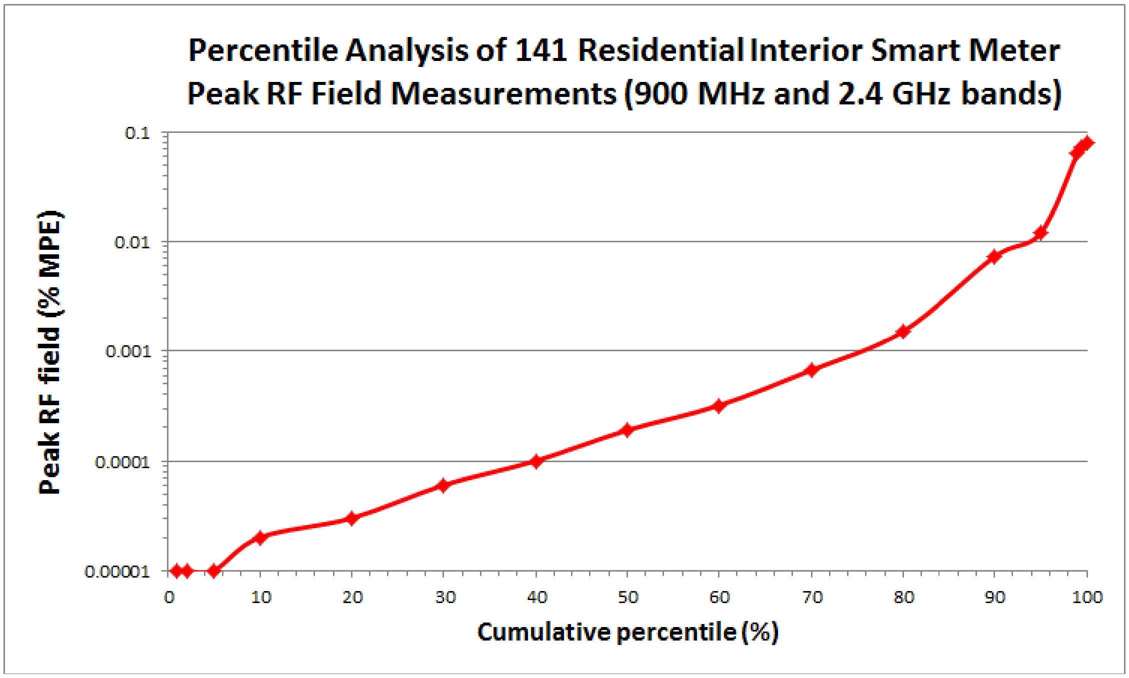

Figure 29. Percentile analysis of 141 residential interior field measurements of the instantaneous peak RF field as a percentage of the FCC MPE for public exposure performed in Rutland and Burlington, VT residences.

Results

Table 5. Summary of interior 900 MHz RF field measurements in residences in the GMP Rutland service territory (values in terms of instantaneous peak RF field as a percent of the FCC MPE for public exposure). Shaded cells represent rooms that were either not present at the site or were unavailable for measurement at the time of the visit.

Location	Site 2	Site 4	Site 5	Site 6	Site 7	Site 9	Site 10	Site 11
Inside Garage	0.00752	0.080	0.00038	0.024	0.00003			
Inside Living Room	0.07	0.00341	0.00935	0.00005	0.00071	0.00005		0.00055
Inside Dining Room			0.00029		0.016		0.00009	
Inside Family Room			0.00156	0.00009	0.00022			0.00003
Inside Kitchen	0.0033	0.00083	0.0001	0.00015	0.00015	0.00553	0.00067	0.00127
Inside Basement						0.00002		
Inside Master BR	0.00735	0.00439	0.00375	0.00315		0.00003	0.00306	0.00007
Inside BR1	0.00009	0.00056	0.00013	0.00025		0.00004		0.00002
Inside BR2	0.00039	0.012	0.00009	0.00025				0.00003
Inside BR3				0.011				
Inside BR4				0.00093				
Inside Office	0.00032	0.055		0.00029			0.00005	
Inside enclosed porch						0.038		
Utility Room							0.011	0.00505

Results

Table 6. Summary of interior 900 MHz RF field measurements in residences in the BED service territory (values in terms of instantaneous peak RF field as a percent of the FCC MPE for public exposure). Shaded cells represent rooms that were either not present at the site or were unavailable for measurement at the time of the visit.

Location	Site 2	Site 3	Site 4	Site 5	Site 7	Site 8	Site 9
Inside Garage		0.00133				0.00067	
Inside Living Room	0.00754				0.00091	0.00006	0.00069
Inside Dining Room	0.00038	0.022		0.00001	0.00004	0.00004	0.00003
Inside Family Room		0.0001					
Inside Kitchen	0.00019	0.0005	0.00034	0.00001	0.00011	0.00028	0.00001
Inside Basement							
Inside Master BR	0.00003	0.00002	0.0007	0.00001	0.00002	0.00002	0.00001
Inside BR1	0.00041	0.00006			0.00012	0.00007	0.00021
Inside BR2	0.00007	0.00042			0.00012	0.00006	
Inside BR3		0.00017					
Inside BR4							
Inside Office	0.00003			0.00003			
Inside enclosed porch							0.00011
Utility Room							

Results

Table 7. Summary of interior 2.4 GHz HAN radio RF field measurements in residences in the GMP Rutland service territory (values in terms of instantaneous peak RF field as a percent of the FCC MPE for public exposure). A * indicates that the home had an active HAN radio that was communicating with an IHD. Shaded cells represent rooms that were either not present at the site or were unavailable for measurement at the time of the visit.

Location	Site 2	Site 4*	Site 5	Site 6	Site 7	Site 9	Site 10	Site 11*
Inside Garage	0.00033	0.00149	0.00001	0.00008	0			
Inside Living Room	0.00078	0.0071	0.00417	0.00002	0.00007	0.00016		0.00152
Inside Dining Room							0.00002	
Inside Family Room			0.0001		0.00002			0.00037
Inside Kitchen		0.00294	0.00007	0.00001	0.00025	0.00008	0.00005	
Inside Basement		0.00142		0.00001		0.00003		
Inside Master BR	0.00023	0.0003	0.00013	0.00003		0.00002	0.00005	0.00031
Inside BR1	0.00007	0.00055	0.00002	0.00387		0.00001		0.00032
Inside BR2	0.00023	0.00034	0.00002	0.00128				0.00929
Inside BR3				0.00009				
Inside BR4								
Inside Office	0.00017			0.00004			0.00002	
Inside enclosed porch								
Utility Room								

An alternative way of viewing the residential interior field measurement values is provided in Figure 30 where each of the 141 measurements is plotted in order of decreasing value ranging from the overall maximum of 0.08% of the MPE to smaller values. The greatest measured values pertain to approximately 20% of the total number of measurements. After correction for time and spatial averaging, the maximum and average values are equivalent to 0.0014% and 0.000057% of the MPE respectively.

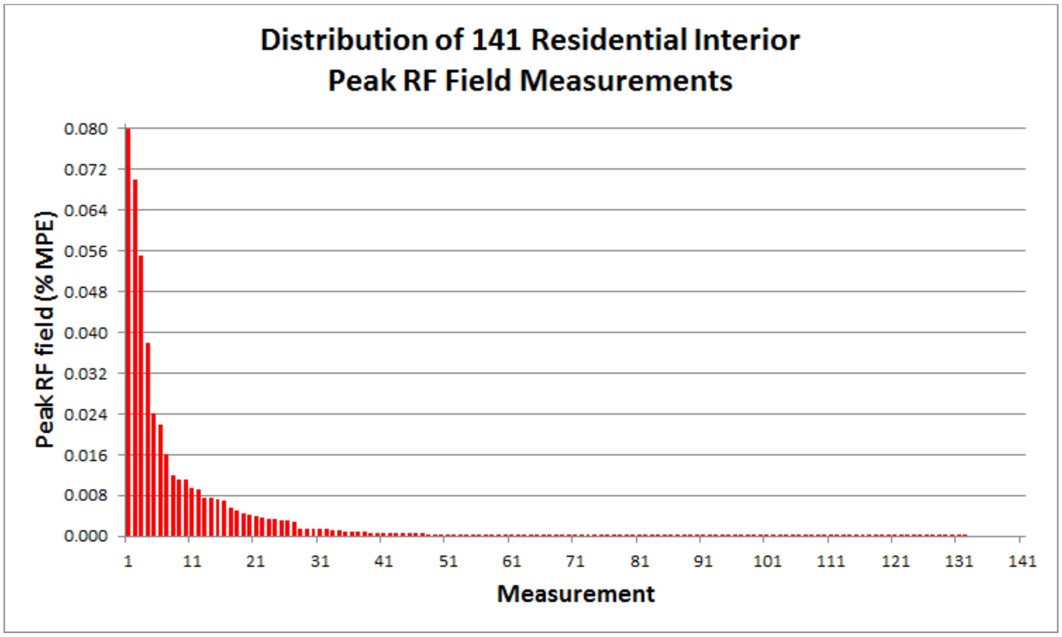

Figure 30. Distribution of 141 residential interior peak RF field measurements in decreasing order.

Assessing Duty Cycles of Smart Meters

The most demanding aspect of characterizing potential exposure of individuals to smart meter RF emissions is determining the duty cycle of operation of the smart meters. This determination is relevant to adjusting measures of instantaneous peak values of RF fields to obtain the actual time-averaged value of field. Time-averaged RF fields, averaged over any 30-minute period, are specified by the FCC for compliance with their exposure regulations. The measured values of RF fields in this report are in terms of instantaneous peak values, relative to a percentage of the MPE. The duty cycle of a smart meter emission is a measure of the ratio of the average power transmitted by the meter to its peak power transmitted over an observation time. For intermittent RF fields that are exactly of the same amplitude, the duty cycle can be defined as the ratio of the "on time" of the field to the total time of observation. As an example, if an intermittent field is on for 1 second once every 10 seconds, then the duty cycle is simply 1/10 or 10%.

Results

In a more general sense, for RF fields that may vary in magnitude during their on-time, duty cycle is defined as the ratio of the overall average of the power, or overall average of percentage of MPE that the signal represents, to the peak value of field, as a percentage of the MPE, during the observation or measurement period. For fields that exhibit the same amplitude each time they exist, these two definitions are the same.

Frequency hopping, spread spectrum smart meters produce only intermittent RF fields (pulses) that last for very short times. The upper range of smart meter signal on-time is in the range of 100 milliseconds (ms) (one tenth of a second) or less with the length of the pulse being related to the information content carried by the transmissions from the smart meter. Previous studies of similar smart meters have indicated typical duty cycles of only a few percent or less [1, 2, 10]. Such small duty cycles result because of the digital nature of the wireless RF LAN, the relatively high speed of data transmission and the small amount of data on electric energy consumption that needs to be transmitted. While each end point meter also serves as a repeater for neighboring meters that need assistance in getting their data to a data collection point, all of this activity only adds up to a relatively small amount which does not require much transmitting time on the part of the smart meter. Taking all of the requirements for the smart meter to actually transmit, including beacon pulses and other network organizational overhead, maximum duty cycles are remarkably small.

How one determines what the duty cycle of a meter is presents considerable challenge. From a measurement perspective, the normal variability in transmission by a smart meter means that measurements performed at any individual meter can take a lot of time and may be fraught with considerable uncertainty. For instance, typical meter activity may vary from moment-to-moment, hour-to-hour and day-to-day. To obtain a good overall picture of transmitting activity of a large number of smart meters could require many days of effort and result in considerable uncertainty from a statistics perspective in the resulting estimate of average activity.

Generally, for exposure assessment purposes, the conservative approach is to determine the maximum duty cycle that may be exhibited by any meter within the network and using this value for adjusting all measured peak values to obtain average levels of potential exposure. It becomes clear that attempting to do this by a direct physical measurement of fields by statistically sampling a large number of smart meters over time can be extremely arduous. Because of this difficulty, past studies have made use of a statistical approach to examining smart meter transmitting activity that has relied on collecting and analyzing data from the utility's smart meter data management software system [1, 2, 10]. If data can be collected from a large portion, or all, of the deployed smart meters in an area on the amount of data transferred wirelessly by the meters, then estimates of the total transmit time can be developed for the associated sampling period. Typical sampling periods have ranged from nominally an hour to as much as a 24 hour period. Thus, average duty cycles can be generated that are applicable to whatever the sampling period was. The strength of this approach is that the statistical estimates can be based on very large numbers of meters and produce results on duty cycles that have high confidence.

An alternative approach was taken for this project in which direct measurements were performed under conditions that would correspond to the greatest meter transmission activity. For both the GMP and BED measurements, each utility arranged for measurements to be made at specific times during which maximum amounts of data would be transmitted. Rather than performing measurements at a large number of meters, focused measurements could be performed on a selected meter or the RF LAN component of a data collection point to obtain estimates of the maximum likely duty cycle of any of the meters in the system. Hence, through a contrived scenario in which the greatest amount of data that would normally ever be transmitted, duty cycles could be directly measured for the Vermont smart meters in this study.

In this project, a feature of the SRM-3006 that is based on its time-analysis mode of operation was used to directly measure duty cycles. In essence, RF field amplitudes, as a percent of the MPE, were monitored over various time periods but with an emphasis on 30 minutes. The SRM-3006 makes many measurements of the peak and average RF field magnitude that occur within small time increments across the long term monitoring period and directly indicates the measured duty cycle. During these measurements, examples of smart meter pulse characteristics were also collected to examine the duration of the pulses.

Measurements of 900 MHz band RF pulse characteristics during the Vermont field work allowed evaluation of smart meter duty cycles. Measurements were conducted on single end point meters as well as at banks of meters. In the GMP territory, measurements were strategically made at a single end point meter during the scheduled time of day when maximum meter activity would occur. A 30-minute measurement in the time domain was made at GMP site 1 beginning at 9:15 A.M. (one of the four periods during the day that meters report energy consumption data) as shown in Figure 31. During this measurement period, the meter is scheduled to transmit load profile data back to its data collection point (Gatekeeper in GMP terminology)[14]. This particular meter was selected specifically for the measurements because of its location within the mesh network to which it was assigned; because of its hierarchy within the network, this meter would be expected to exhibit transmit activity related to the 554 meters that communicate through it (GMP was able to provide network maps that allowed the identification of this meter). Based on examination of the Rutland service territory, this meter represented the best opportunity for finding maximum transmit activity and, hence, would provide a conservative measure of maximum meter activity across the

[14] Load profile data consists of the historical record of all 15-minute interval data since the last reporting period, normally six hours.

network. During the measurement period of 30 minutes, a duty cycle of 0.0355 (3.55%) was determined. In Figure 31, the recorded instantaneous peak value of RF field was retained for use in preparing this graph of signal activity. The sweep time of the instrument is divided into as many as 4000 time-resolution increments depending on the overall sweep time. The instrument measures the overall peak and average value of all pulses occurring within each time increment and represents this result as a vertical bar. Each bar can, visually, only represent signal values associated with each time resolution increment. Hence although the peak and average signal amplitudes are accurately measured for all pulses, the number of pulses that occurred or precisely when they occur can be obscured by the particular time, and graphical, resolution.

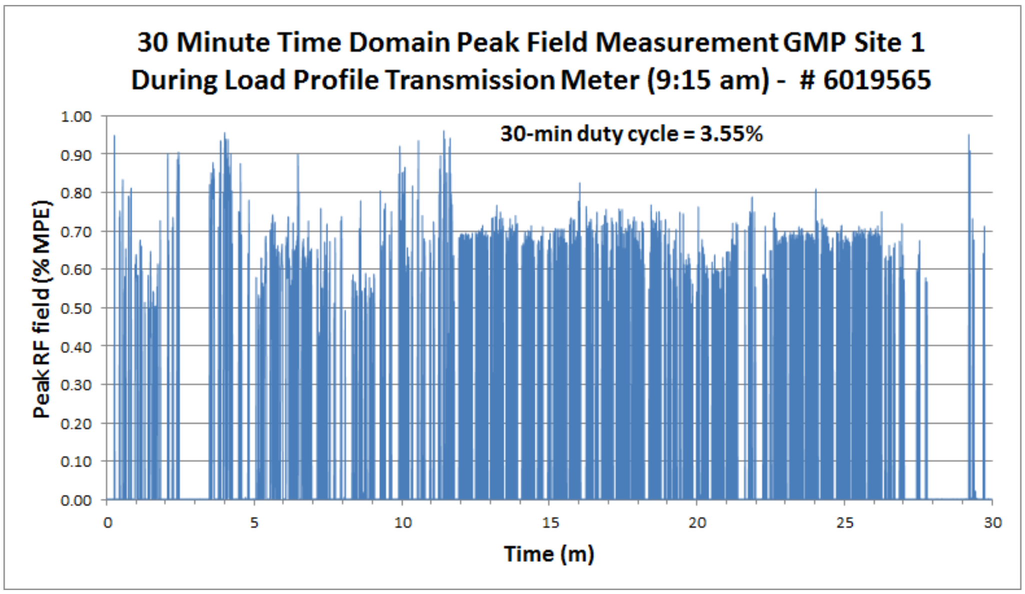

Figure 31. Result of 30-minute time domain measurement of peak RF fields at GMP site 1 during period of maximum expected transmit activity.

The duty cycle result obtained from the measurement shown in Figure 31 represents the greatest 30-minute duty cycle value that was found during any of the project measurements in Vermont.

At the same GMP site (site 1), an additional 30-minute measurement of duty cycle was conducted beginning at 10:15 A.M. This signal sample was captured near the end of the transmission of load profile data but included part of the register reads from meters across the network. Figure 32 illustrates the results of this measurement. The 30-minute duty cycle was measured to be 1.21%.

These values of duty cycle may be interpreted in terms of the how the time-average value of RF field is related to the overall instantaneous peak value of RF field during the 30-minute period in which the measurement was made. From a practical, but conservative perspective, the greatest duty cycle may be used to adjust all reported peak values of RF fields to equivalent 30-minute time-averaged values.

The waveform of a typical pulsed signal response from the GMP meters, after being pinged by the field service unit, is shown in Figure 33. This time domain display shows that the pulse width is very close to 100 ms.

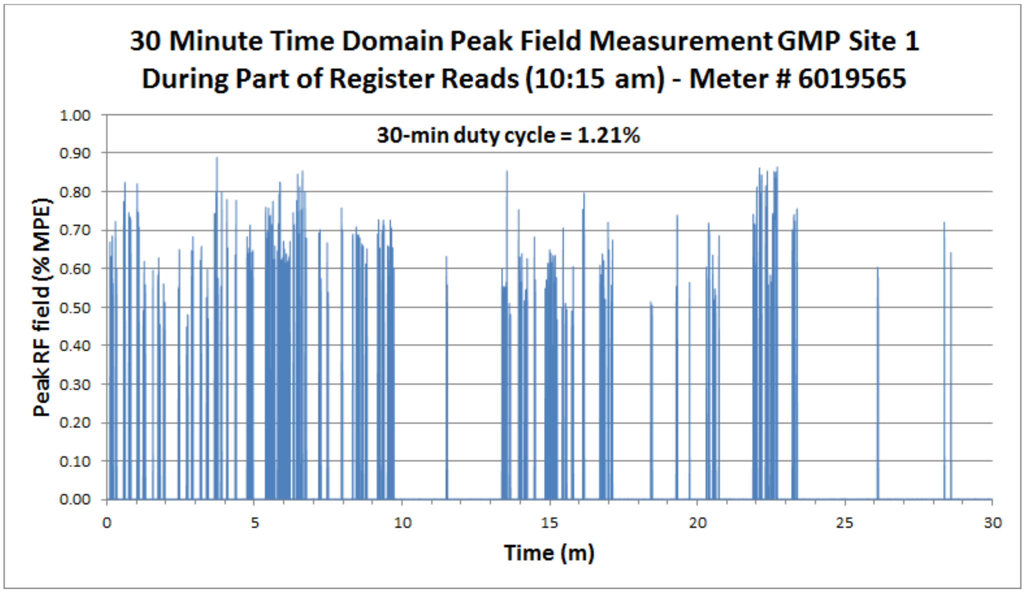

Figure 32. Result of 30-minute time domain measurement of peak RF fields at GMP site 1 during a second period of high expected transmit activity including transmission of register reads from meters.

Results

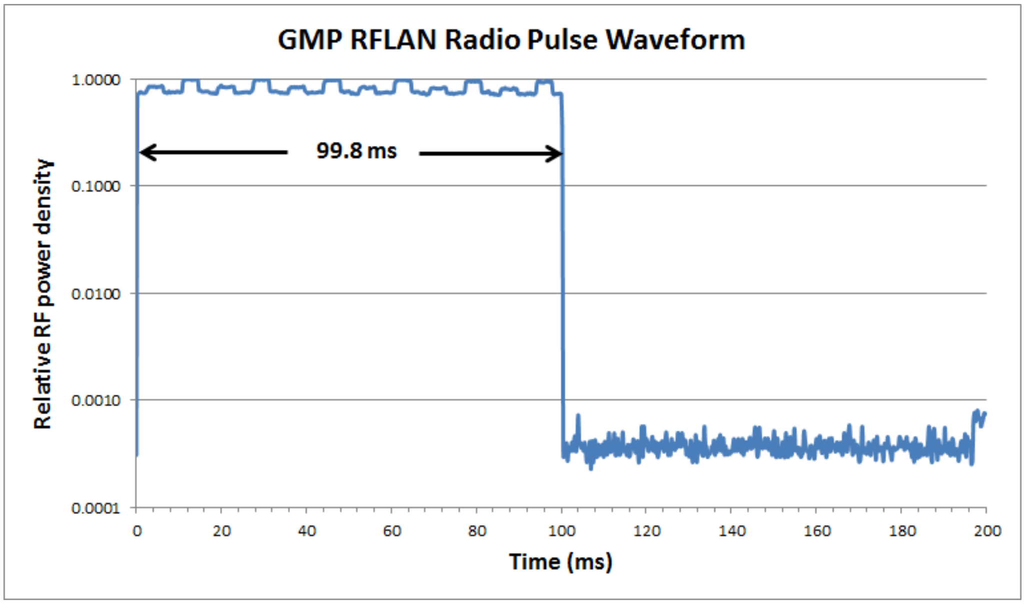

Figure 33. Waveform of GMP end point meter emission when pinged by field service unit.

Additional time-domain measurements were conducted at an end point meter located near the bottom of the network hierarchy (no other end point meters would normally make use of this meter for relaying of data). Three different data transmission scenarios were arranged for these measurements by sending commands from the GMP head end via the wireless network that requested the meter to transmit back the retained 15-minute interval data collected and stored during the past one day, during the past two days and during the entire period (~70 days) since the meter had been initially installed. Figure 34 illustrates these measurement data where the instrumentation was kept active for capturing signal levels as the meter was sequentially instructed to transmit according to the three scenarios. The data collection period existed for approximately 15 minutes. The increased transmit activity is evident, depending on the amount of data being requested from the network head end. In this contrived scenario, the 15 minute duty cycle was found to be 0.141%. The normal duty cycle of this meter would be far less than this value since it would only be transmitting data applicable to the past six hours. Importantly, although the maximum amount of data that could be pulled from this meter was included in the measurement, the process resulted in a very small overall duty cycle when compared to the data acquired at GMP site 1 where historical data from more than 500 meters was involved in the transmission.

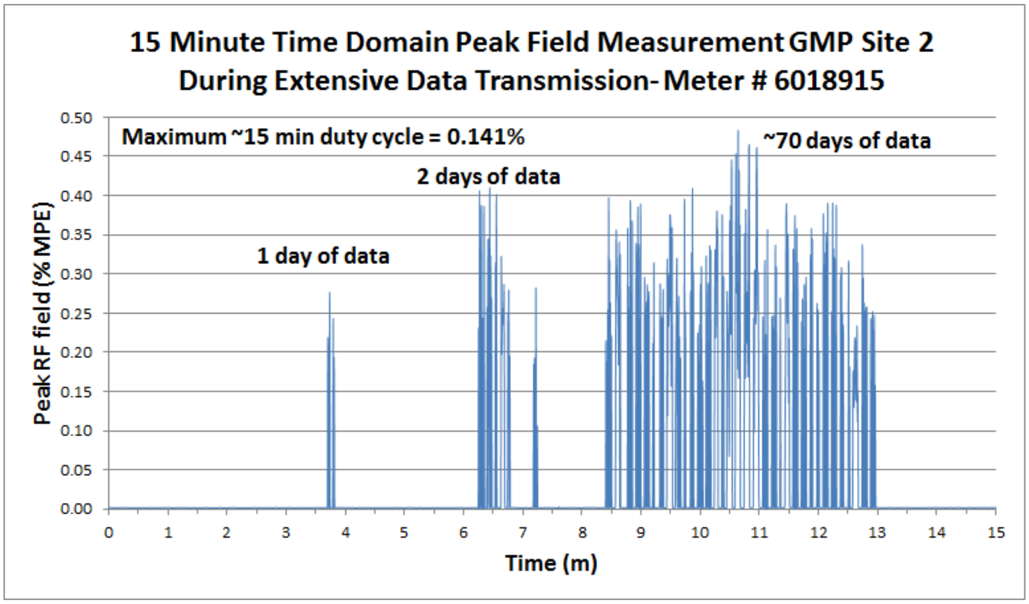

Figure 34. Result of 30-minute time domain measurement of peak RF fields at GMP site 2 during a contrived scenario of three different data transmission requests of the meter (one day's worth of data, two days of data and all of the data stored since the meter had been installed).

Arrangements were made to perform additional measurements of the meter emissions at GMP site 2 during a typical data transmission for comparison with the contrived scenario of maximum data transmission. Figure 35 presents the time domain results for a 30-minute observation. The observed 30-minute duty cycle was found to be 0.022% verifying that the meter transmitting activity is very low under normal operating conditions.

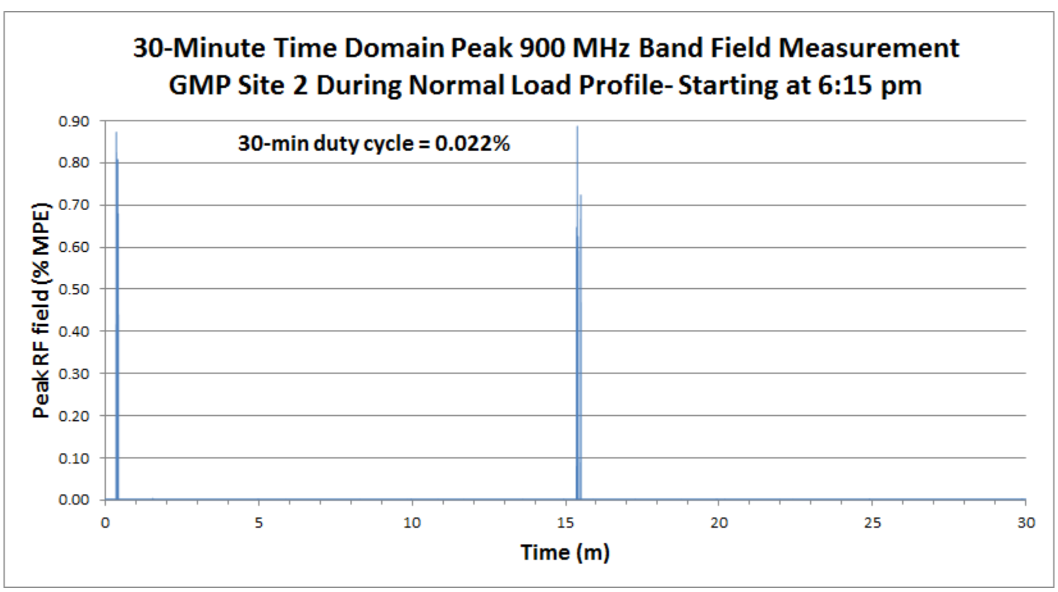

Figure 35. Result of 30-minute time domain measurement of peak 900 MHz band RF fields at GMP site 2 during a normal data transmission request that occurs four times per day.

Results

The 30-minute RF field duty cycle observed at a meter bank of 14 meters (GMP site 3) was measured during the scheduled period for meter transmissions. The SRM-3006 probe/antenna was positioned on a tripod near the center of the bank of meters and signal activity was monitored for 30 minutes. The observed result is shown in Figure 36 for which a 30-minute duty cycle of 0.041% was measured. Although there were 14 meters within this bank, only minimal transmit activity was observed. It is relevant to note that when the request for meters to report interval data is transmitted out to all of the end point meters from the network head end, this does not necessarily mean that the meters within this specific bank of meters will report sequentially in time. While one meter in the bank may report, other meters located physically elsewhere may sequentially report before another one of the meters within the bank becomes active. This likely leads to the relatively sparse amount of signal activity over this period near the bank. Differences among signal peak values are likely related to the different distances between the probe/antenna and various meters within the bank and the transmitting pattern of each meter.

Measurements of meter transmit activity were also performed at a GMP Gatekeeper (site 8). This was accomplished by, first, identifying the cellular WWAN frequency used by the Gatekeeper, using the SRM-3006, in spectrum analysis mode, to observe for the presence of a predominant signal when the probe/antenna was held near the WWAN antenna on the Gatekeeper (a step ladder was used to gain access to

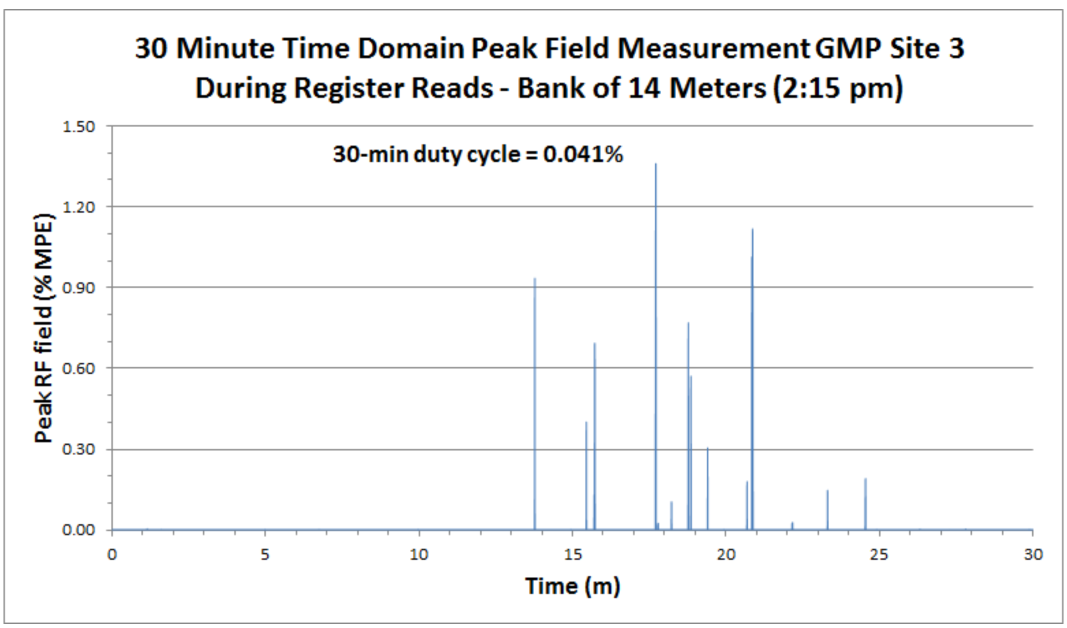

Figure 36. Result of 30-minute time domain measurement of peak RF fields at a bank of 14 meters (GMP site 3) during a normal data transmission period that occurs four times per day.

the elevated Gatekeeper antennas). Once this frequency was identified, approximately 825 MHz, the SRM-3006 was set to time-analysis mode with a center frequency of 825 MHz and a RBW of 5 MHz to capture the time domain waveform of the emitted WWAN signals. This process was accomplished in rapid manner beginning with the expected start of transmission by the Gatekeeper via the WWAN at 10:15 A.M. The subject Gatekeeper at site 8 has 1245 end point meters that report back to it; it is these data that are, then, put on the WWAN back to the GMP data management system. The measurement of duty cycle was performed with the SRM-3006 on a tripod at three feet above ground level. Figure 37 shows the Gatekeeper box mounted on a power pole at GMP site 8 with the measurement instrumentation situated on a tripod.

Figure 38 shows the result of this measurement exercise. Over the 30-minute observation period, a duty cycle of 0.141% was determined. The relatively small duty cycle observed, despite the large amount of data accumulated from all 1245 end point meters, is likely a result of the high data transmission rate associated with the WWAN such that only a very small amount of time is required to convey the large amount of data to the Internet.

Figure 37. GMP Gatekeeper mounted on a power pole at GMP site 8 with the WWAN antenna on the top and the 900 MHz RF LAN antenna on the bottom.

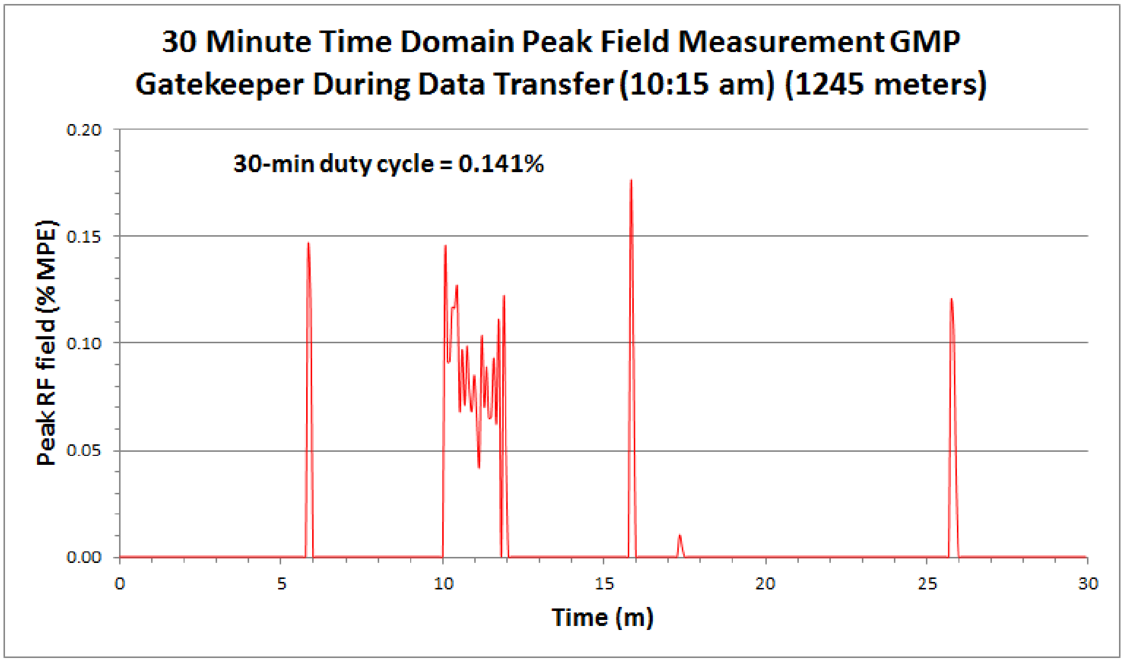

Figure 38. A 30-minute time domain measurement of peak RF fields near the base of a GMP Gatekeeper (site 8) during a scheduled transmission of data accumulated from 1245 end point meters.

In the BED service territory, a different approach was taken to estimate the maximum duty cycle of end point meters. At the time of the project, it was difficult for BED to cause, on command, a prolonged transmission of data from end point meters during which measurements could be made. As an alternative, it was deemed that a suitable substitute could be represented by the transmission activity of the 900 MHz radio within one of the BED Cell Routers during the time that it sends instructions to a mass of end point meters requesting each meter to transmit its data back to the Cell Router. This was assumed to be representative of a high transmission activity from a given end point meter sending stored load profile data. Accordingly, measurements were performed near the base of one of the BED Cell Routers at BED site 1 beginning shortly before a scheduled transmission of instructions via the Cell Router at 8:00 A.M. The measurement began at 7:55 A.M. and continued for a total of 35 minutes, observing the Cell Router 900 MHz emissions. Figure 39 shows the resulting time domain data. The 35 minute duty cycle was measured as 0.041%.

The characteristics of a typical RF pulse observed at one of the BED end point meters is shown in Figure 40. The duration of the pulse is 69.5 ms.

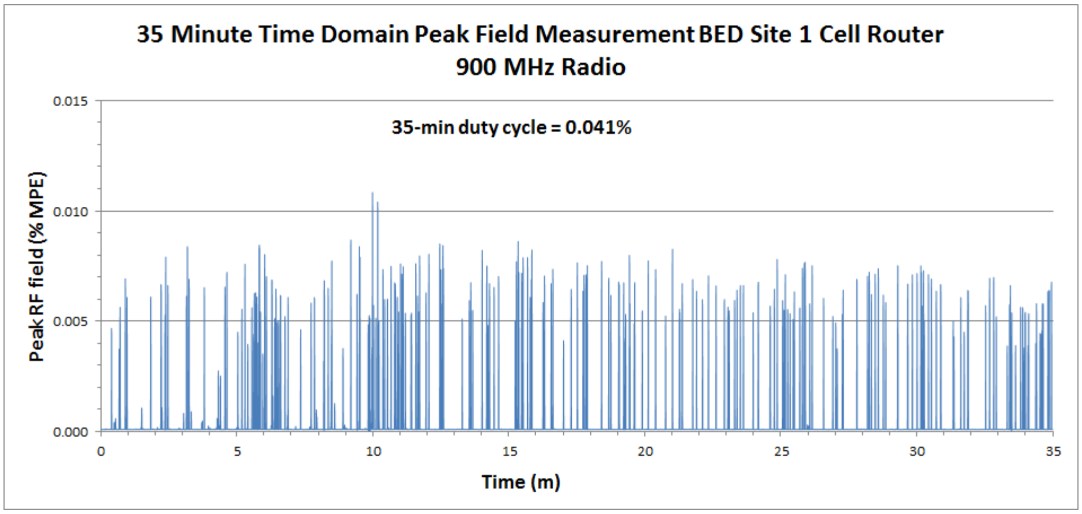

Figure 39. A 35-minute time domain measurement of peak RF fields near the base of a BED Cell Router (BED site 1) during a scheduled transmission of commands to end point meters to respond with data. These data pertain to the 900 MHz band emissions associated with the Cell Router.

Other measurements performed at BED end point meters, while the meter was pinged via the network head end, were used to estimate potential duty cycles during different scenarios consisting of varying amounts of data being transmitted back to a Cell Router. This method was limited in that the software at the head end of the network was difficult to control for specific amounts of data to be transmitted and how often the commands could be repeated. Nonetheless, the greatest observed duty cycle from a single end point meter was measured to be 0.157% over a two minute period.

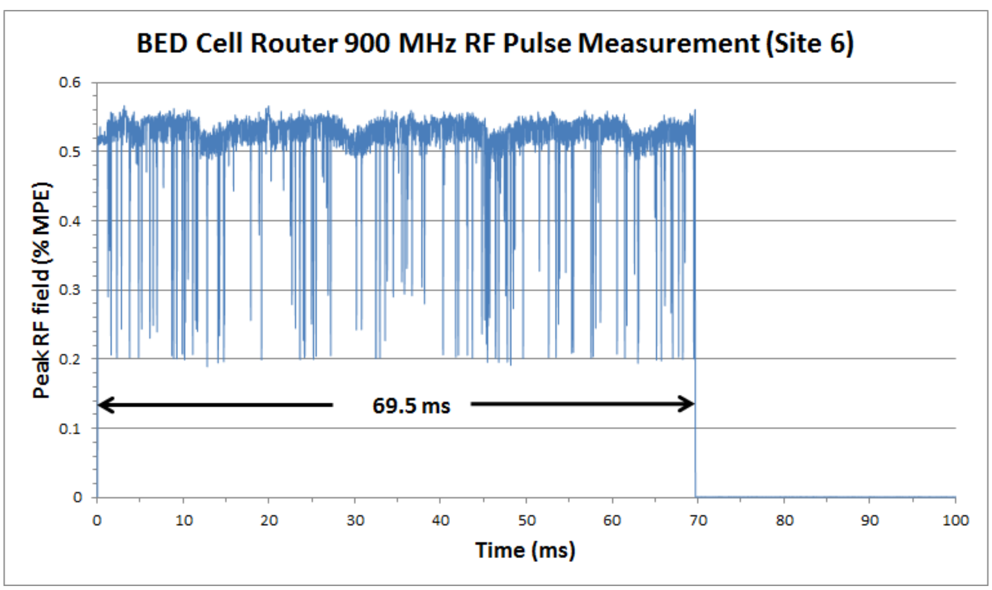

Figure 40. The time domain waveform of a 900 MHz RF pulse emitted by a BED Cell router RF LAN radio (BED site 6). The duration of the pulse was measured to be 69.5 ms.

As a conservative estimate of maximum duty cycle, if one pulse lasting for 69.5 ms were to be emitted once per second (not supported by any of the measurements performed during the project), the corresponding duty cycle, based on a 1 second time analysis of the signal from an end point meter at BED site 8, would be 3.49%. It is not reasonable to assume a continuous stream of such pulses over a 30-minute period but were such to occur, this could represent the maximum possible duty cycle.

HAN radio emissions associated with the GMP end point meters presented considerable challenge because of the rather narrow pulses of RF produced by the HAN transceiver. A time domain waveform of the pulse emitted by the HAN radio is shown in Figure 41. The pulse exists for only 1.79 ms with an even shorter pulse when connected to an IHD.

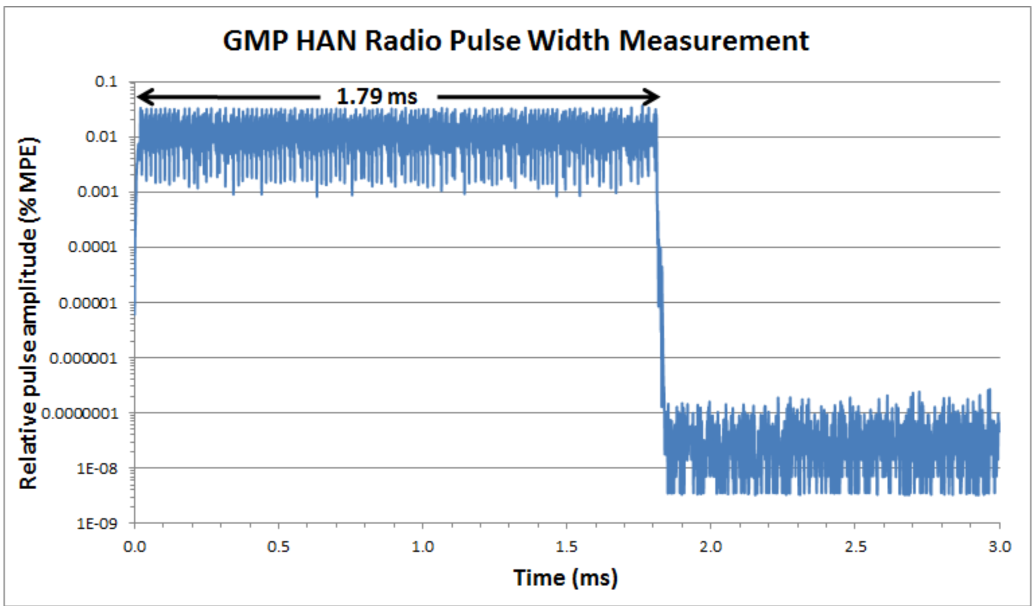

Figure 41. The time domain waveform of an RF pulse emitted by a GMP end point meter HAN radio when there is no IHD to connect with the meter. The duration of the pulse was measured to be 1.79 ms.

Because of the narrow HAN pulse width, the alternative approach of separately measuring the three orthogonal polarization components of the composite RF field was necessary since the settling time of the internal filters within the instrument could not provide a response to the instantaneous peak value of the pulsed field when using the isotropic mode of operation of the instrument. Using the time-analysis mode of the SRM-3006, however, measurements of each field component, corresponding to the X, Y and Z polarizations from the probe/antenna were recorded for each measurement location. Following the measurements, these three component values were summed to obtain the resultant RF field magnitude expressed as a percentage of the MPE.

Initial investigation of the HAN radio emission characteristics revealed that, when the radio is not paired with an IHD, the time profile of emissions consists of nominally four pulses spaced approximately 15 seconds apart plus a burst of four pulses once approximately each minute for a total of some eight pulses, each 1.79 ms wide, every minute. This is illustrated with the time domain measurement shown in Figure 42. This pattern of radio emission activity describes the normal operation of the majority of HAN radios in the GMP deployed meters as observed in this project.

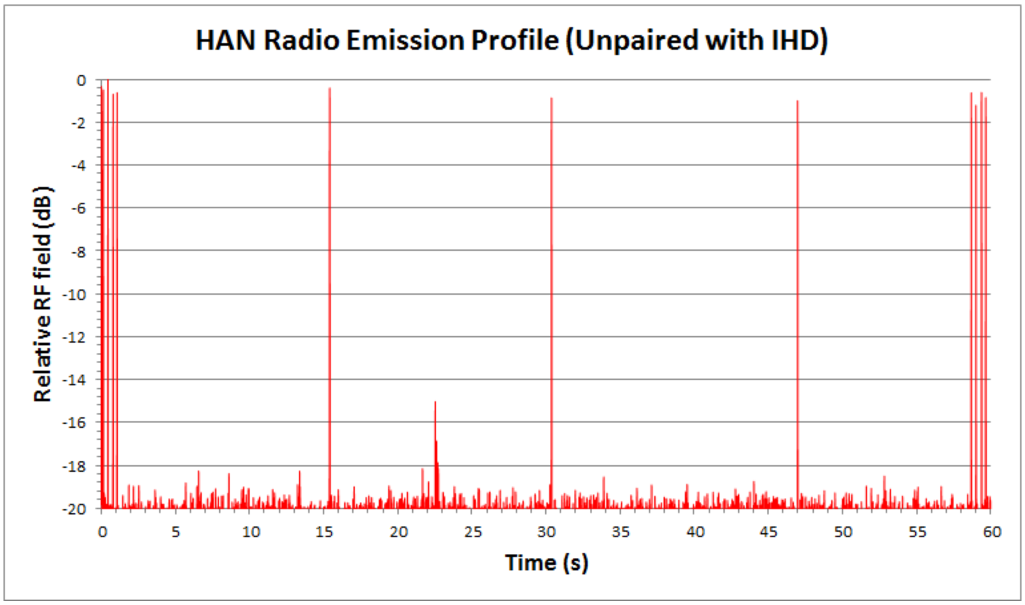

Figure 42. The time domain pattern of RF emissions from a GMP end point meter HAN radio showing a repeating pattern corresponding to nominally eight pulses every minute. The much smaller peak at approximately 23 seconds is unrelated to the operation of the HAN radio.

A different transmit activity exists, however, when a HAN radio becomes linked with an IHD. Interestingly, the pulse emission characteristics of the HAN radio change when it becomes wirelessly connected to an IHD. When connected to an IHD, two things happen; the number of pulses occurring increase and the width of the pulse decreases substantially. This observation is best illustrated in Figures 43 and 44. When the HAN radio is paired with the IHD, the pulse width of the emitted signal is reduced from 1.79 ms to 0.35 ms. However, the IHD signal is approximately the same width as the HAN radio signal when it is not paired with the IHD.

In Figure 44, the amplitude of the IHD signal is substantially greater simply because the IHD was relocated to the top of the smart meter, placing it at the same distance from the instrument probe/antenna as the smart meter and its internal HAN radio.

A 30-minute measurement of the time domain profile of the emissions from the HAN radio obtained at GMP site 2, where the smart meter HAN radio is not paired with an IHD, is shown in Figure 45. The 30-minute duty cycle in this case was measured to be 0.00030%, reflective of the narrow pulses of RF field and relatively long periods between pulses.

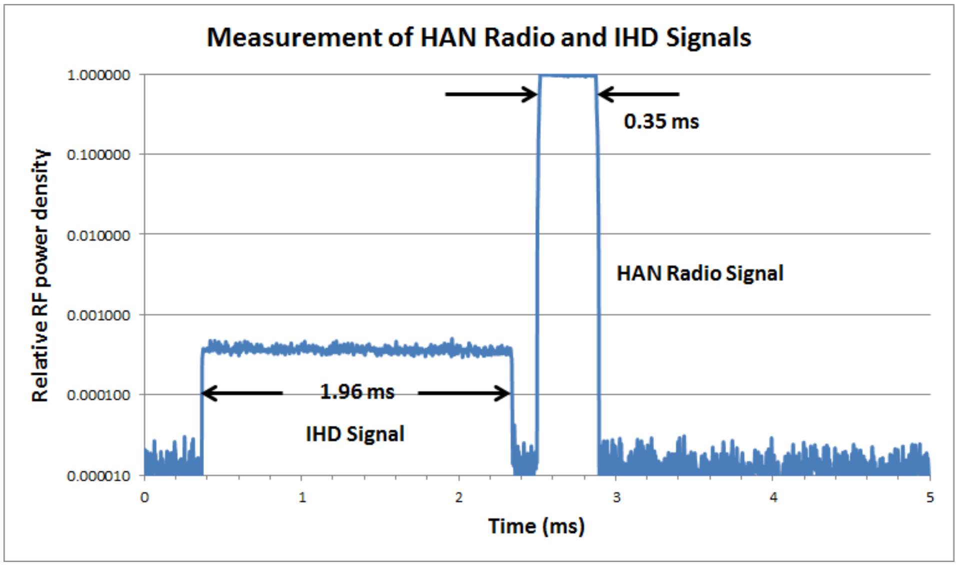

Figure 43. Time domain pattern of RF emissions from the HAN radio and an IHD located approximately 30 feet from the smart meter when the radio is paired with the IHD. Note the narrower pulse width of the HAN radio and the broad signal from the IHD that has the same approximate pulse width of the HAN radio when the HAN radio is not connected to the IHD.

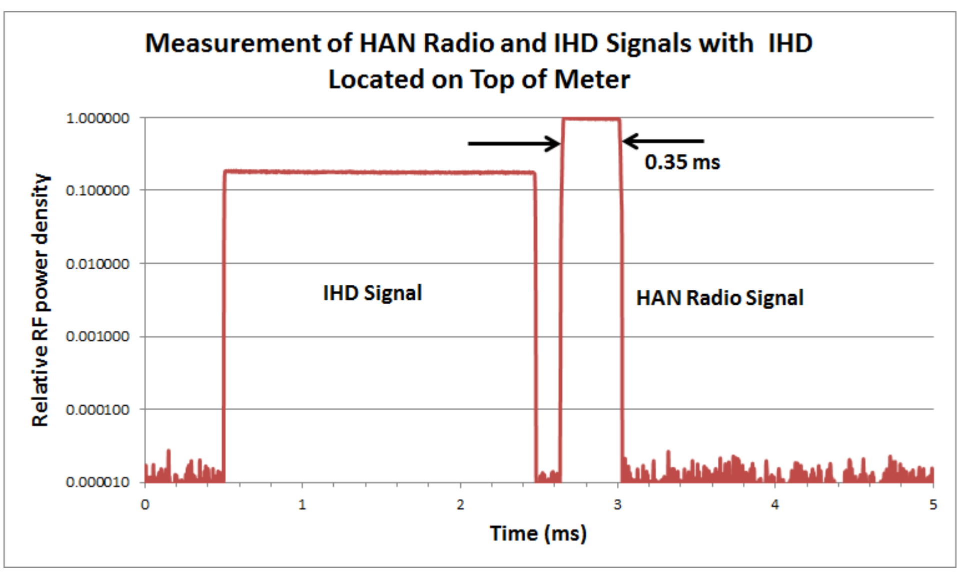

Figure 44. Time domain pattern of RF emissions from the HAN radio and an IHD located on top of the smart meter with the radio paired with the IHD. The amplitude of the IHD signal has increased significantly since it is at the same distance to the measurement probe/antenna.

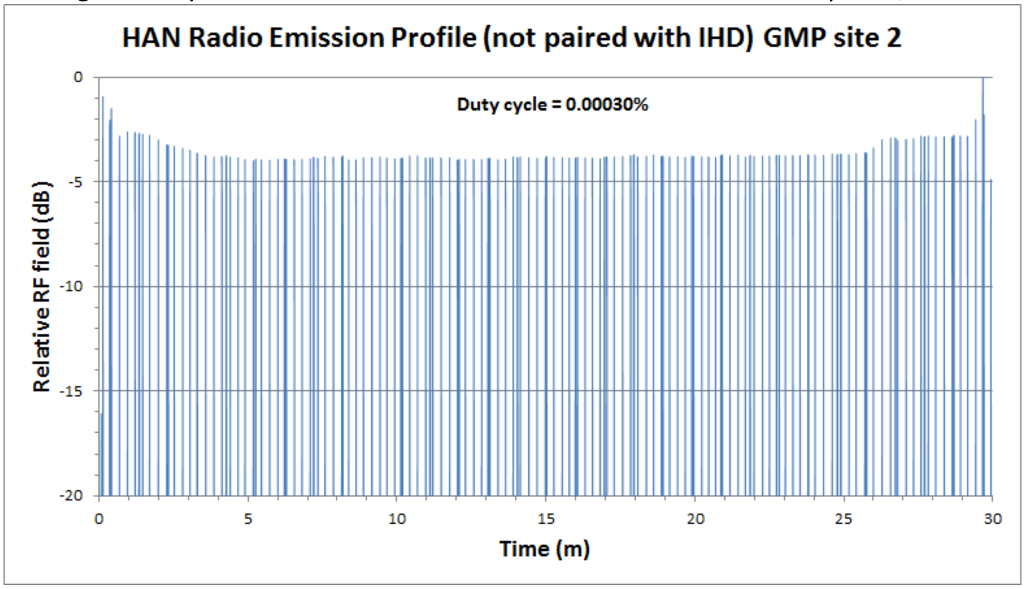

Figure 45. 30-minute time domain pattern of RF emissions from a smart meter HAN radio at GMP site 2 that is not connected with an IHD.

For comparison, another 30-minute measurement performed with the HAN radio that is paired with an accompanying IHD is shown in Figure 46. The result of this measurement was a 30-minute duty cycle of 0.00087%, approximately three times greater than for the unpaired HAN radio.

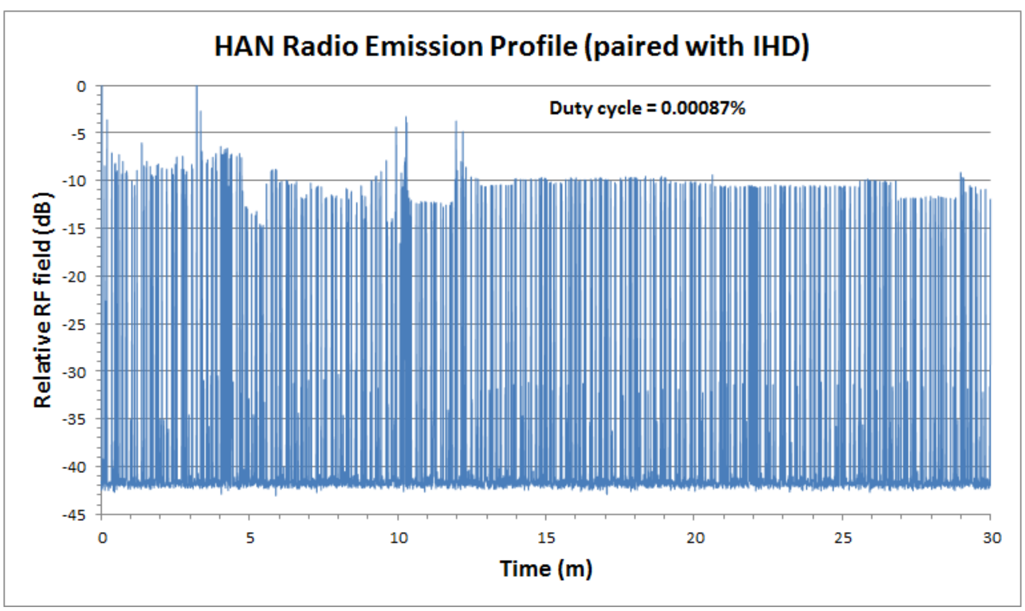

Figure 46. 30-minute time domain pattern of RF emissions from a smart meter HAN radio paired with an IHD.

Further insight to the HAN radio emission characterization is provided in Figure 48 which represents a time domain measurement at a bank of six smart meters (GMP site 13), none of which were paired with an IHD. A long term duty cycle of 0.00034 resulted. In Figure 47, a visual image of varying line density of the vertical bars representing the measured signals is presumably caused by the presence of other HAN radio signals incident on the measurement probe/antenna. At least four different levels of apparent signal strengths are seen. The top level of signal, closest to the 0 dB line, is due to the signal from the smart meter that the probe/antenna was closest to with the other lower level signals being related to emissions of the other smart meters within the bank. Only the closest smart meter will lead to the strongest measured signal; the other meters, due to greater distance between the probe/antenna and meter as well as variations in the emission pattern of the smart meter HAN radios, results in lower measured signal levels.

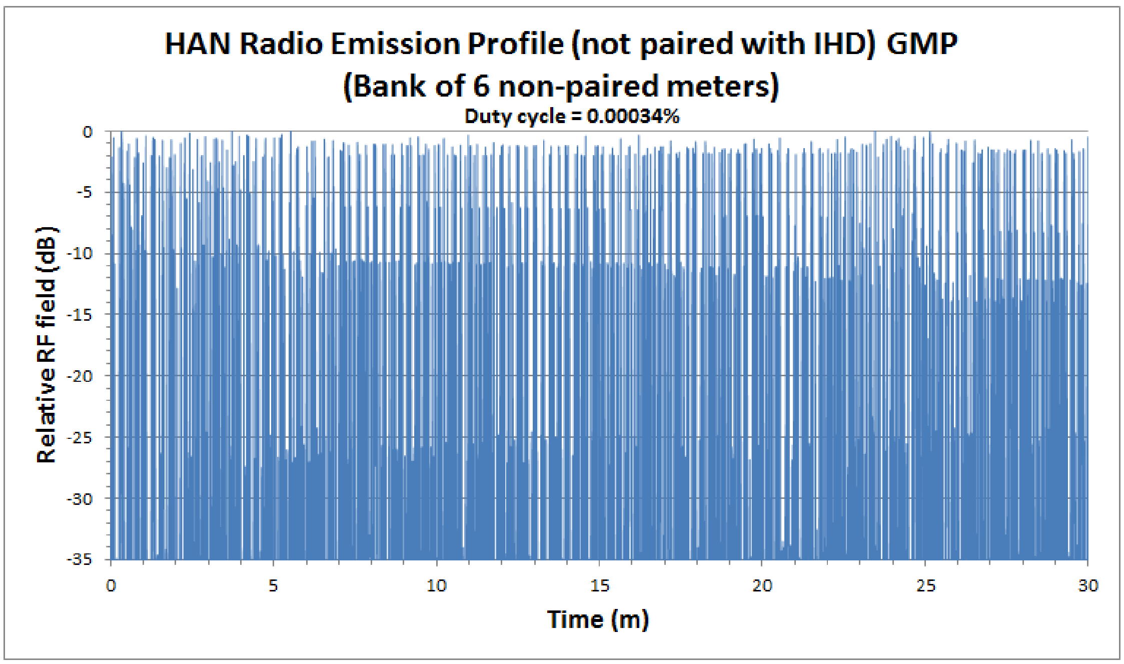

Figure 47. 30-minute time domain pattern of HAN radio emissions from a bank of six meters (GMP site 13) that are not paired with IHDs.

Another 30-minute HAN radio emission profile with the radio paired with an IHD is shown in Figure 48 where the overall duty cycle was found to be 0.00073%.

Results

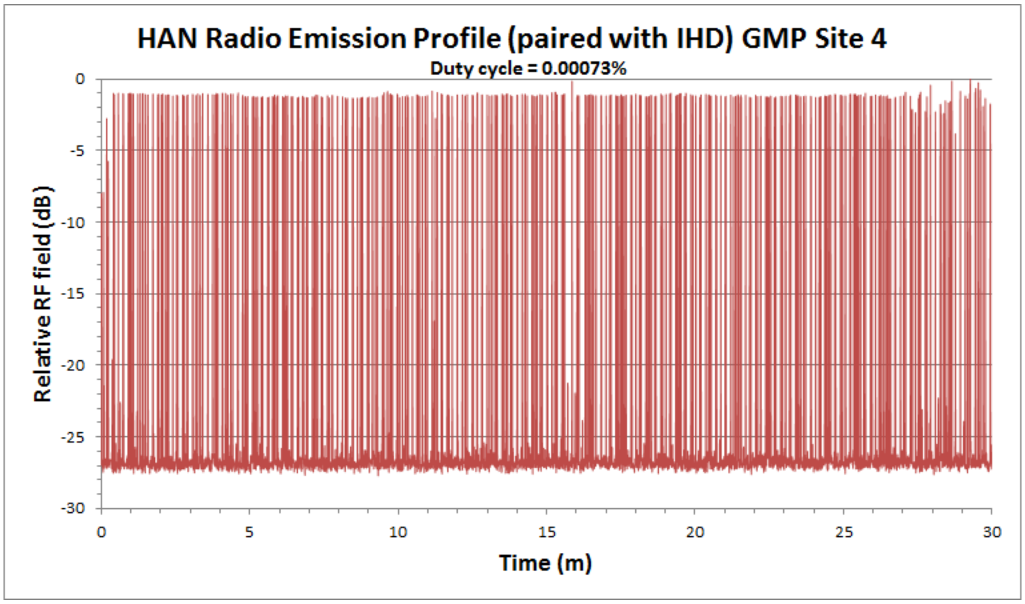

Figure 48. 30-minute HAN radio emission profile at GMP site 4 with radio paired to an IHD.

Table 8 summarizes the duty cycle assessments of the HAN radios obtained under a number of different conditions and at several different sites during this project. These measurements include work done in Vermont at different GMP sites and in Colville. For the measurements in Vermont, the designation Active Meter means that the meter had been activated for use with a specific IHD; an Inactive Meter was not activated for use with an IHD. An additional, third, smart meter was made available for use during the tests in Vermont. During the Colville measurements, two separate GMP smart meters were available designated as SM1 and SM2. SM1 had the HAN radio activated for use with an IHD; SM2 did not.

Table 8. Summary of duty cycle measurements of HAN radios, IHDs and a 2.4 GHz cordless telephone under different conditions and for different measurement durations.

Measurement	Condition	Duration (min)	Duty cycle (%)
1	SM1 on paired with IHD	30	0.087
2	SM1 on with IHD off	30	0.016
3	SM1 and SM2 on, IHD off, observing SM1	30	0.030
4	SM1 and SM2 on, IHD off, observing SM2	30	0.061
5	SM1 and SM2 on, IHD on nearby,	30	0.073

	observing SM2		
6	SM2 on with IHD on, SM1 off	30	0.082
Table 8 continued.			
7	SM1 and SM2 off, IHD on	30	0.106
8	SM2 on and SM1 off, IHD on and close to instrument	30	0.171
9	SM1 on, IHD off	2	0.016
10	Active meter paired with IHD, 2nd active meter paired with separate IHD, 3rd inactive meter on	2	0.062
11	Active meter paired with IHD, second IHD on but not paired with meter, 2nd inactive meter on	2	0.019
12	Active meter paired with IHD, 2nd active meter with IHD off, 3rd inactive meter on	2	0.067
13	2 active meters + 1 inactive meter, all IHDs off	2	0.045
14	2 active meters with paired IHDs both on, 3rd inactive meter on + 2.4 GHz cordless phone on in house	2	0.258
15	2.4 GHz cordless phone	2	1.552
16	Active meter on, non-paired IHD on, 2nd inactive meter on	2	0.024
17	Bank of 6 inactive meters, no IHD	2	0.032
18	Bank of 6 inactive meters, no IHD	30	0.034
19	Inactive meter, no IHD	2	0.003
20	Inactive meter, no IHD	30	0.034
21	Bank of 14 meters, all non-paired, no IHDs	2	0.022
22	Active paired meter with IHD on, measurement near IHD in home	2	0.071
23	Active paired meter with IHD in home, measurement near meter	2	0.087
24	Active paired meter with IHD in home, measurement near meter	30	0.029

Low Frequency Field Measurements

Results

As part of this project, low frequency electric and magnetic fields were measured at one foot in front of the test meters provided by both GMP and BED. The Narda EHP-50D instrument, capable of isotropic measurements (that provide measures of the resultant field magnitude by forming the result of three orthogonal polarization values), was used to acquire background spectra of electric (E) and magnetic (B) fields prior to powering on the smart meters and, subsequently, acquisition of the E and B field spectra upon powering up the meters. Measurements were performed over the frequency spans of nominally 0 to 1 kHz, 0 to 10 kHz and 0 to 100 kHz to provide a broad perspective on any fields within these frequency ranges. Associated with the spectral measurements of field vs. frequency, a value of the wideband RMS value of the field is also provided.[15] Table 9 lists the wideband values of electric field strength and magnetic flux density for each of the three frequency ranges mentioned and for both the GMP Elster meter and the BED Itron meter. No electrical loads were placed on either meter during the measurements that would introduce potentially strong 60 Hz magnetic field components simply due to the current flow through the meter.

Table 9. Summary of low frequency measurement values of wideband (RMS) electric field strength (V/m) and magnetic field flux density (µT) at 1 foot in front of meter.

		Electric field (V/m)		Magnetic flux density (µT)	
	Frequency	Background	Smart Meter	Background	Smart Meter
GMP	0-1 kHz	0.4682	35.126	0.0235	0.0909
GMP	0-10 kHz	0.1775	12.105	0.0107	0.045
GMP	0-100 kHz	0.1866	0.2091	0.019	0.0196
BED	0-1 kHz	0.4682	35.808	0.0235	0.5708
BED	0-10 kHz	0.1775	12.375	0.0107	0.2987
BED	0-100 kHz	0.1866	0.2227	0.019	0.0296

Spectrum analysis results showing the distribution of frequency components across the 0 to 1 kHz, 0 to 10 kHz and 0 to 100 kHz spans are shown in Figures 49, 50 and 51 for electric fields and in Figures 52, 53 and 54 for magnetic fields.

[15] Wideband values of electric and magnetic fields do not include the first 1.2% of any components in the frequency spectrum. This is to eliminate the local oscillator zero feed through associated with any spectrum analyzer at zero frequency.

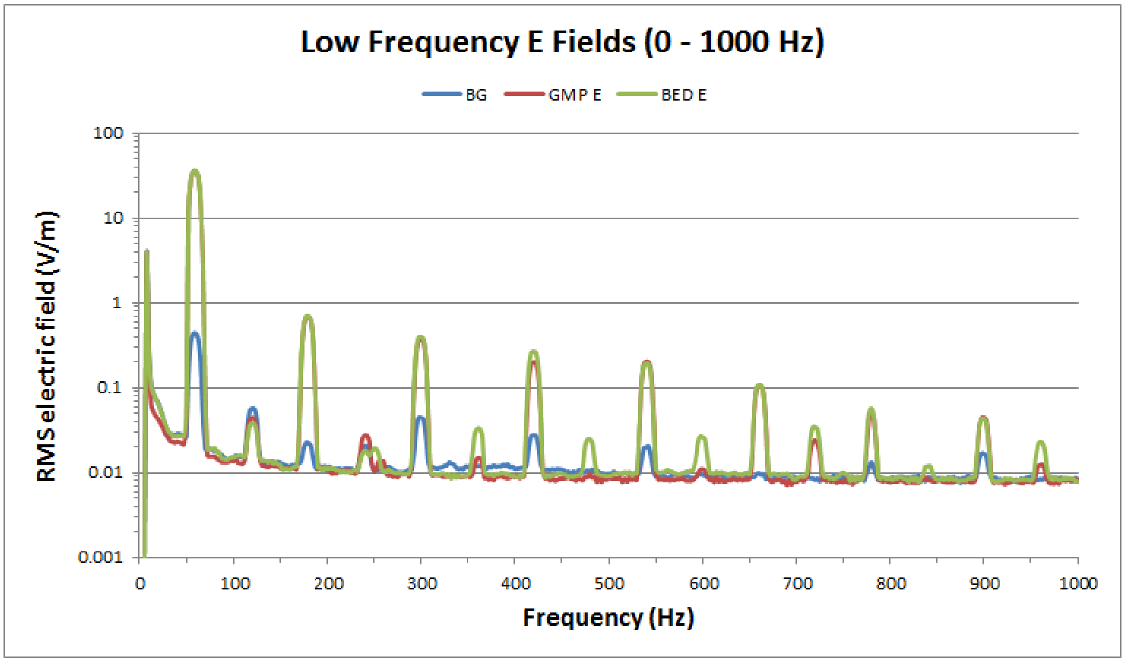

Figure 49. Low frequency electric (E) fields measured in the range of 0 to 1,000 Hz (1 kHz) for the GMP Elster meter, the BED Itron meter and background.

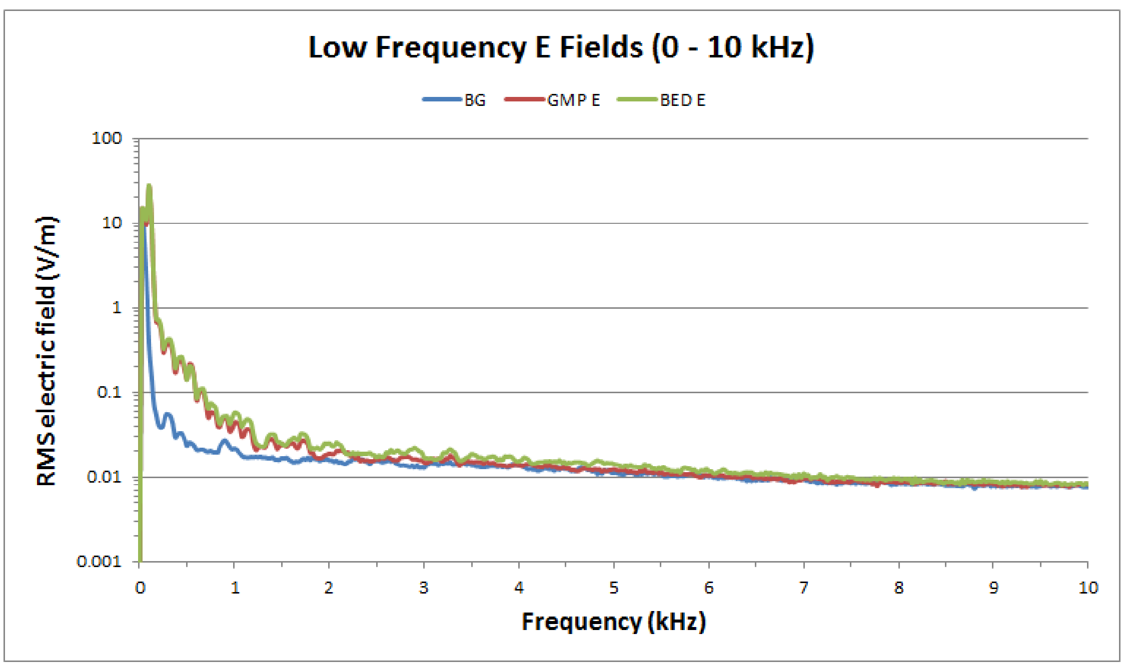

Figure 50. Low frequency electric (E) fields measured in the range of 0 to 10 kHz for the GMP Elster meter, the BED Itron meter and background.

Results

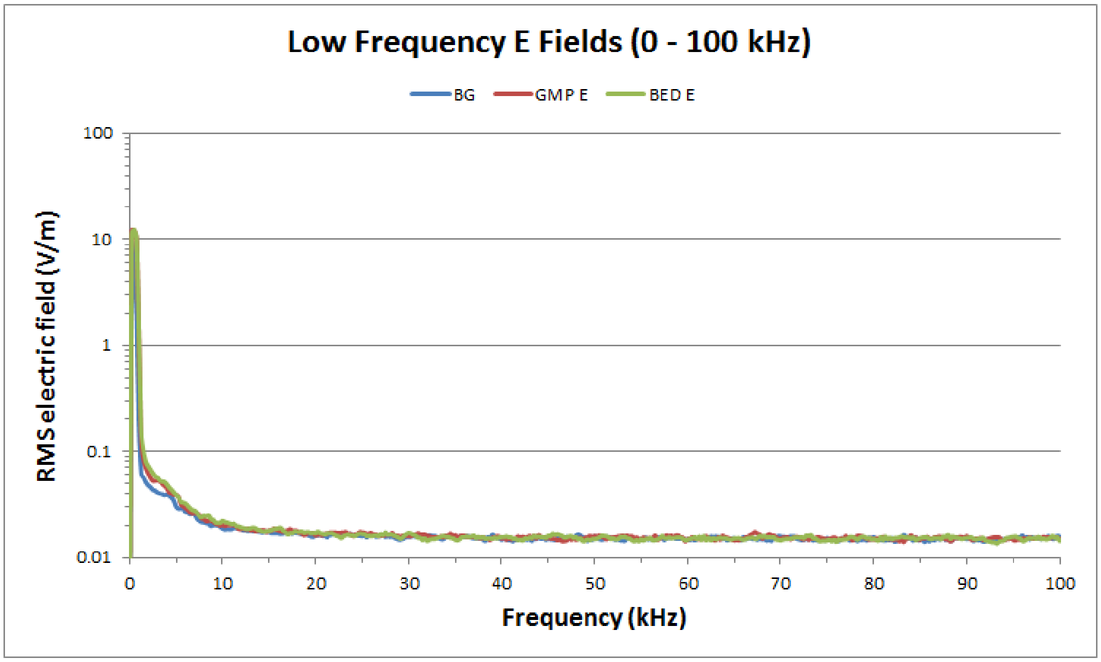

Figure 51. Low frequency electric (E) fields measured in the range of 0 to 100 kHz for the GMP Elster meter, the BED Itron meter and background.

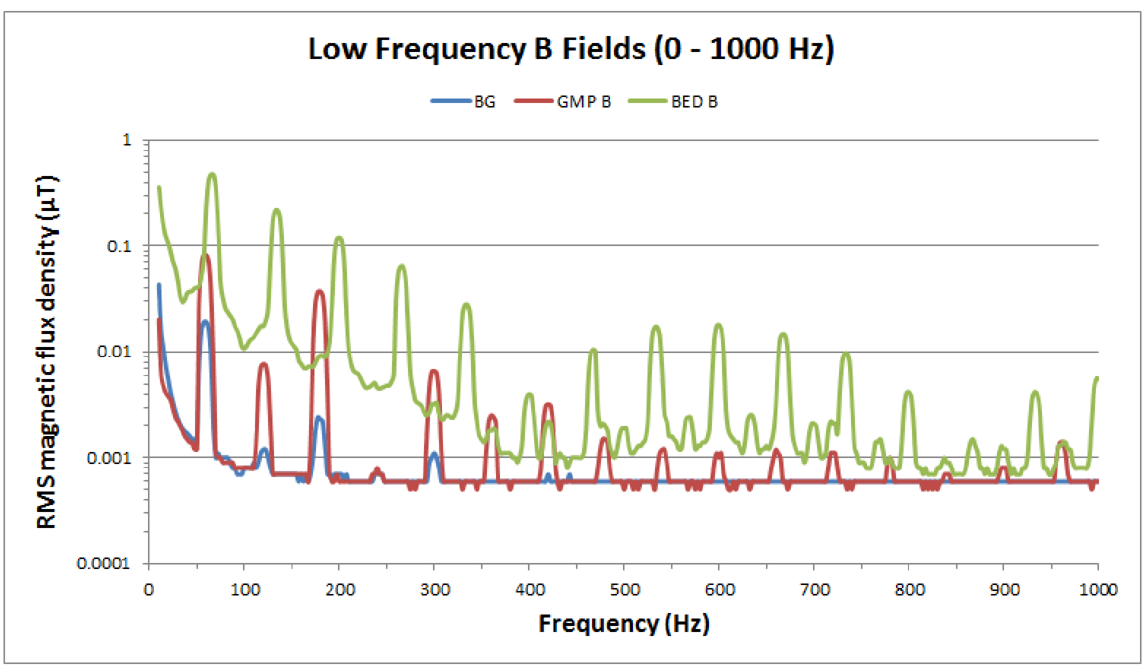

Figure 52. Low frequency magnetic flux density (B) measured in the range of 0 to 1,000 Hz (1 kHz) for the GMP Elster meter, the BED Itron meter and background.

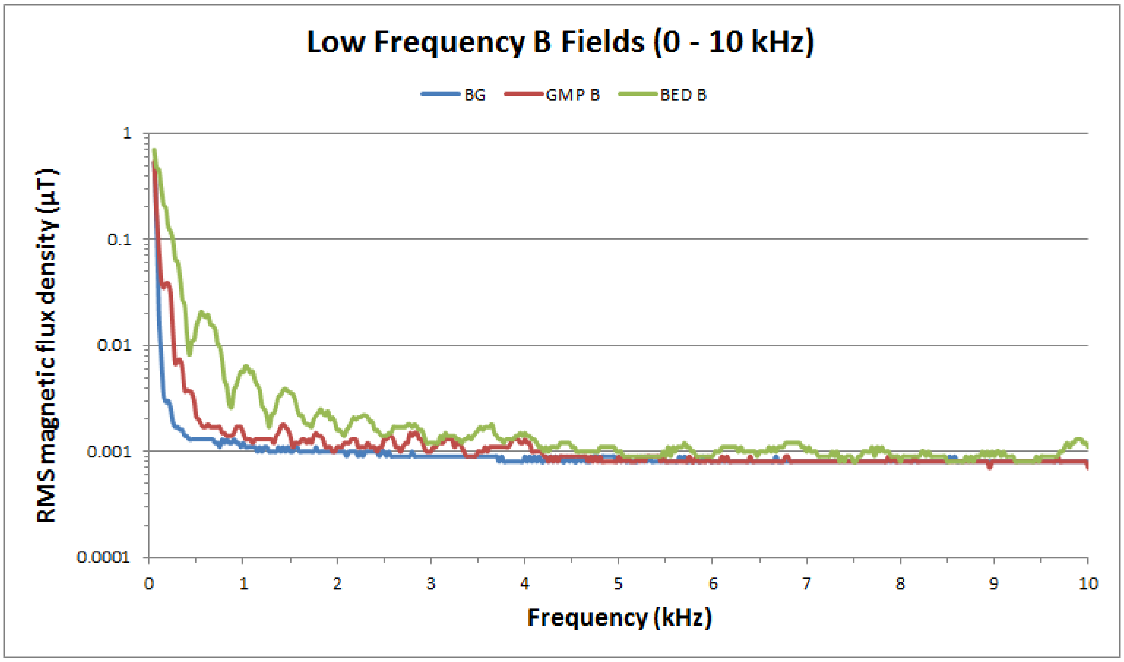

Figure 53. Low frequency magnetic flux density (B) measured in the range of 0 to 10 kHz for the GMP Elster meter, the BED Itron meter and background.

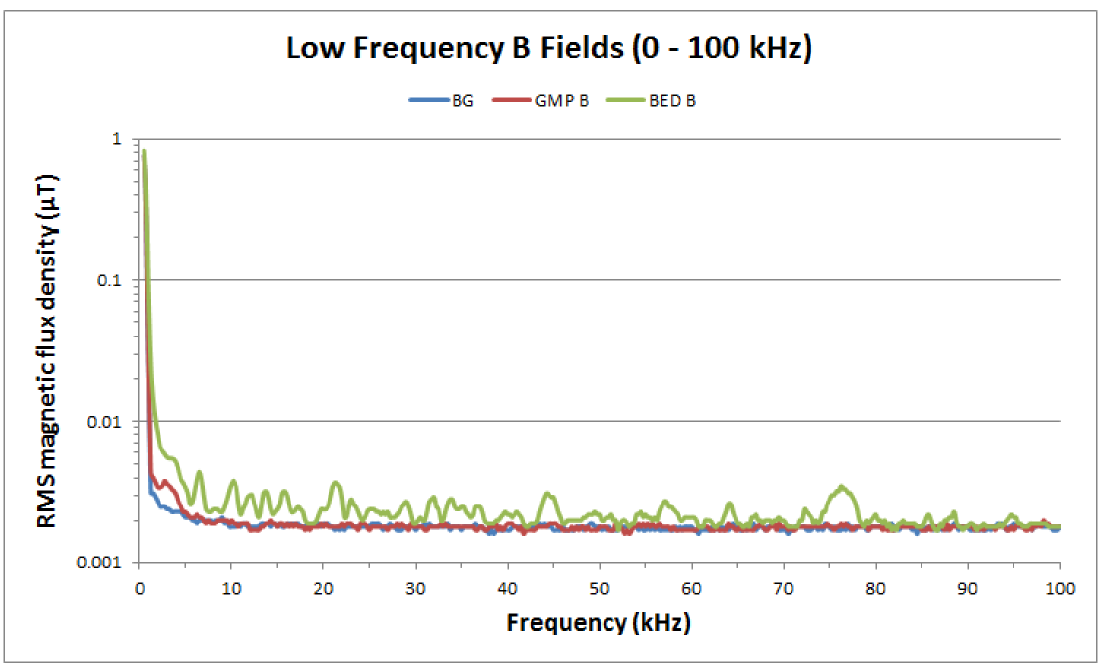

Figure 54. Low frequency magnetic flux density (B) measured in the range of 0 to 100 kHz for the GMP Elster meter, the BED Itron meter and background.

Measurements of Other Sources

While smart meter RF emissions were the principal focus of this study, during the field work in Vermont, measurements of RF fields associated with a number of other types of RF sources were also conducted. Mostly, these measurements were opportunistic in nature when the opportunity presented itself. In some cases, these measurements took place during the measurement of interior smart meter RF fields in homes included in the study. In others, referred to as "environmental" measurements, the measurements were performed outdoors in different parts of the state ranging from Rutland in the South, Montpelier in the East, Saint Albans in the North and Burlington to the West. A total of 14 environmental sites were included at which measurements of radio and television (TV) broadcast signals and wireless base station signals were performed as well as a few instances of investigation of unique signal characteristics. These data help provide a foundation for interpreting the relative magnitude of potential public exposure to RF fields produced by smart meter emissions.

Multiple HAN Radio Emissions

When measuring in the 2.4 GHz license free band, signal activity from a number of different kinds of devices can often be observed. This is illustrated by Figure 55 which shows a measured spectrum at GMP site 3. The measurement was performed inside the building on which the meter bank was mounted, inside a closet located directly behind the meter bank. In this case, the emissions of four HAN radios are clearly seen as well as a wireless router (see labels in figure). Given more time, other HAN radio emissions would be expected to be seen but it is important to note that the display of RF fields is the result of a "maximum hold" mode of the measuring instrument in which the greatest measured RF field at any given instant in time and on any given frequency is retained and displayed. This means that while there may be numerous peaks shown in a spectrum, each associated with a particular HAN radio transmission, they may have not occurred simultaneously nor operate continuously.

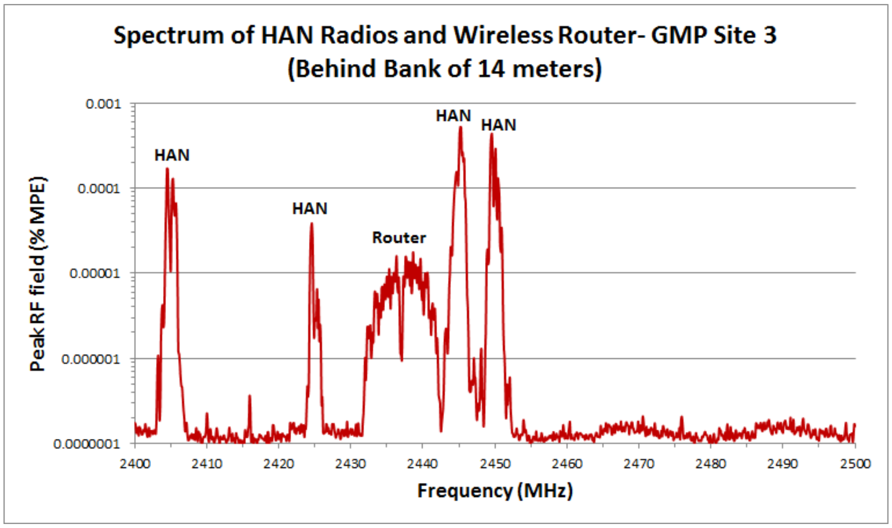

Figure 55. A measured spectrum of RF fields at GMP site 3, behind a bank of 14 smart meters, showing the presence of four HAN radio emissions and a wireless router.

<u>2.4 GHz Cordless Phone</u>

At one of the measurement locations, measurements were made of the RF spectrum produced by a 2.4 GHz cordless telephone (not a cell phone). The phone handset was removed from its base station cradle and turned on as if to make a call while the measurement probe/antenna was placed at one foot from the handset. A broadband display of RF fields resulted from 2400 MHz to approximately 2483 MHz that appeared to be relatively continuous in nature. Figure 56 illustrates this measurement.

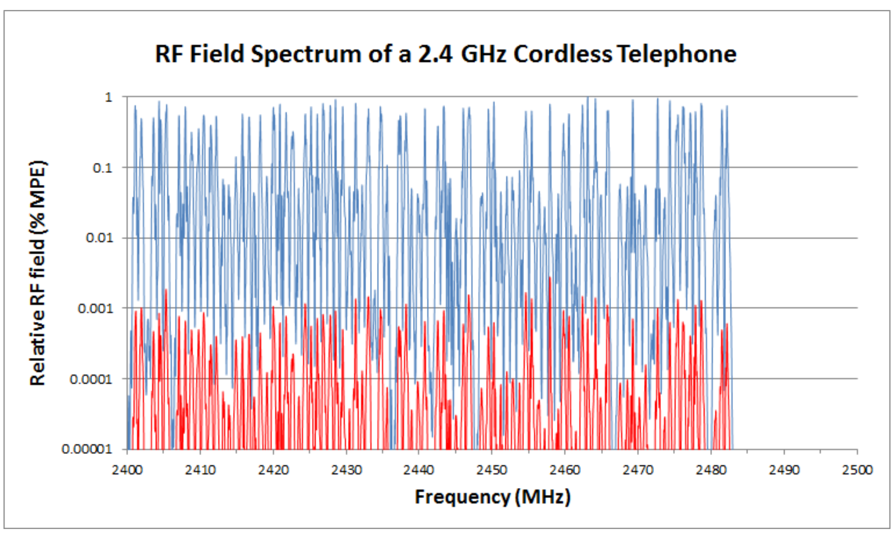

Figure 56. The relative RF field spectrum (blue is peak, red is average) of a 2.4 GHz cordless telephone at one foot from the hand set after it was turned on. RF emissions occur across a large portion of the 2.4 GHz license free band.

Following the spectrum measurement shown in Figure 56, a time domain measurement was made of the cordless phone signal over a two minute period. This measurement resulted in a two-minute duty cycle of 1.6% as shown in Figure 57.

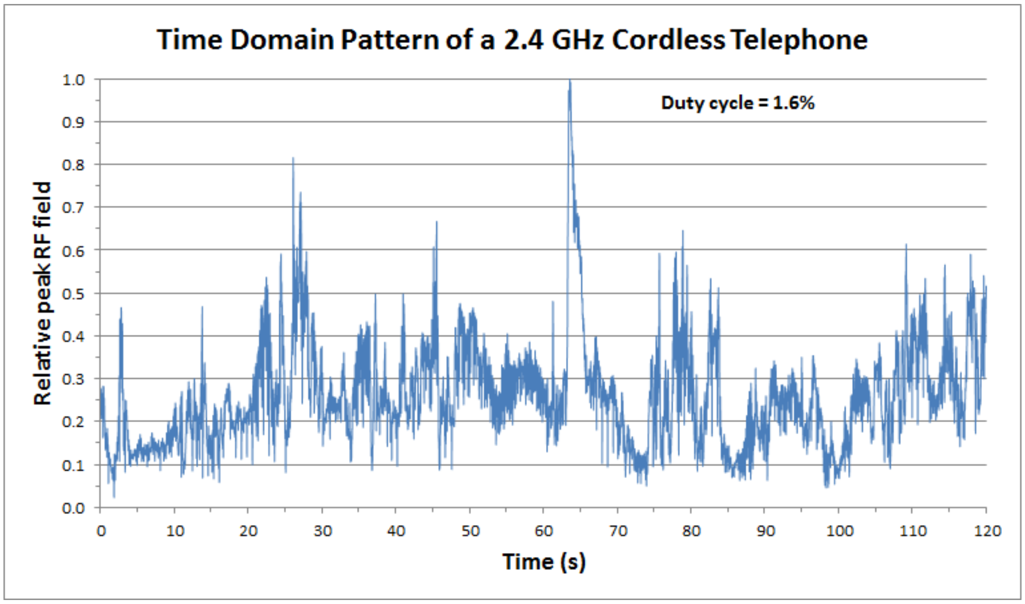

Figure 57. A measured time domain profile of the 2.4 GHz cordless telephone over a two minute (120 second) period. The duty cycle of this two minute capture of signal was 1.6%.

<u>FAA Long Range Air Traffic Control Radar</u>

While in the Saint Albans vicinity, the RF fields associated with an FAA long range air traffic control radar were monitored. While the instantaneous peak RF fields were relatively weak, the measurement illustrates another source in the environment that can result in long term exposure to pulsed fields. The radar site near Saint Albans was taken over full time by the FAA from the Air Force in approximately 1979. Since that time, it has been modified and includes what is now referred to by the FAA as a Common Air Route Surveillance Radar (CARSR). Such radars commonly use an antenna rotation rate, for scanning the skies, of five revolutions per minute (RPM), peak transmitter powers of over a megawatt (1,000,000 watts) and pulse repetition rates of, typically several hundred pulses per second.

Figure 58 shows the results of a one minute time domain profile of the detected signal (at 1,269.5 MHz) from the radar which was located approximately 1.5 miles southeast of the measurement site (environmental site 7). The illumination of the measurement probe/antenna of the SRM-3006 on each revolution of the radar antenna is evident with the maximum peak signals (fields) spaced in time by exactly 12 seconds (equivalent to five RPM). The arrival of main beam emissions of the radar antenna are indicated by the small blue arrows above the peaks. Each time the radar antenna rotates the signal level significantly increases and repeats its pattern. Other peaks in Figure 58 represent side lobes of the radar antenna. Their relative amplitude, compared with that of the main beam, are also influenced by the terrain between the radar and the measurement location which introduces reflections of the radar signal and alters what would be expected purely on the basis of the antenna transmitting pattern in free space.

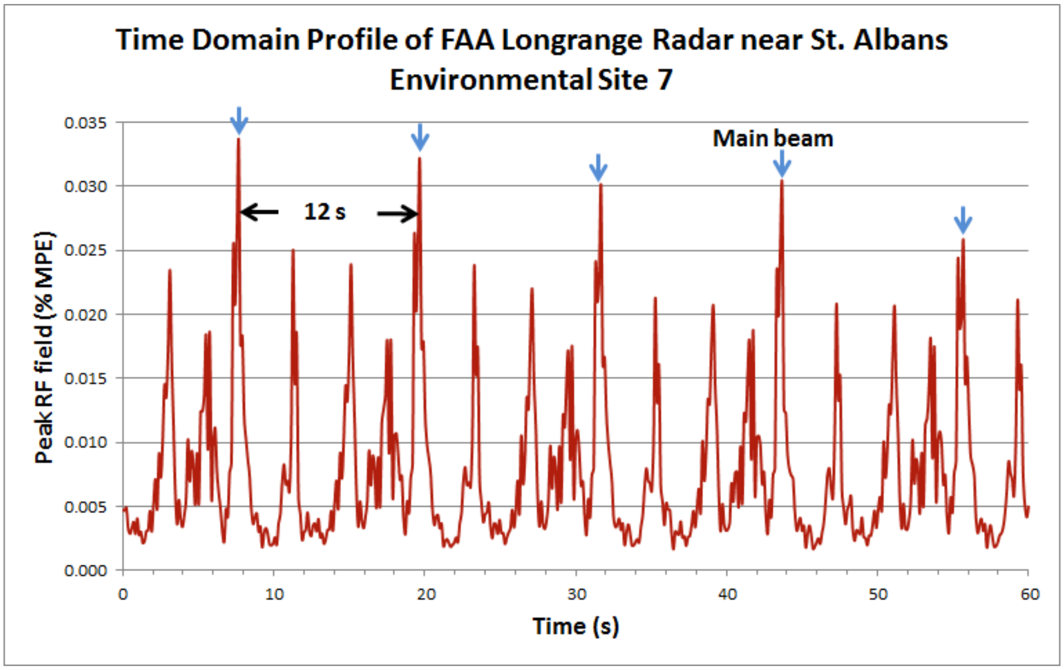

Figure 58. Time domain profile of an FAA long range radar located on a hill east of Saint Albans, VT at environmental site 7. The 5 RPM rotation rate of the antenna is apparent with the major peaks spaced exactly 12 seconds apart. The smaller peaks are side lobes of the antenna and the result of reflections within the environment of the measurement.

Microwave Ovens

Generally, the strongest source of RF fields within a home is a microwave oven. Most microwave ovens operate with powers ranging from about 750 watts to 1200 watts at 2.45 GHz. Despite careful design which reduces any leakage from microwave ovens to very low levels, some microwave energy is always present near ovens while they operate. RF field measurements were performed at distances from one foot to five feet in front of two microwave ovens during the course of this project, one at GMP site 4 and the other at BED site 2. The results of these measurements are plotted in Figure 59 in terms of the average RF field. A cup of water was place in each oven during while it operated and the field measurements were taken. The differences in measured values of RF fields for the two ovens can be related to the possible different operating power levels of the ovens, their physical condition at the time of measurements (which can affect leakage) and the nature of the local measurement environment near the ovens. The data show that average RF fields corresponding to 1% of the exposure limit for the public were observed at distances of as much as three feet from the oven.

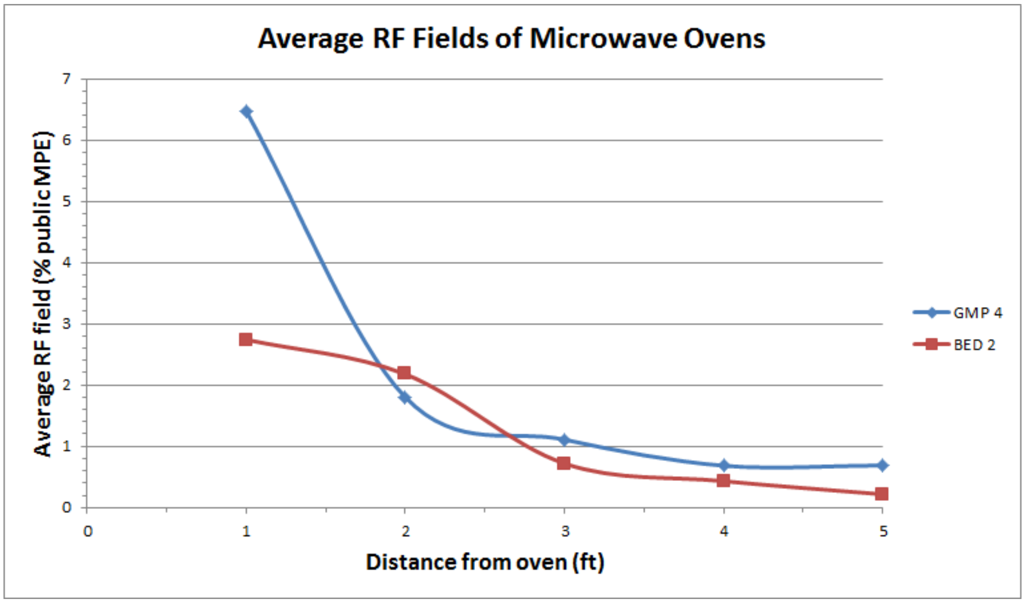

Figure 59. Measured average RF fields produced by two microwave ovens between one and five feet from the oven as it operates.

Wireless Routers

The widespread use of the Internet in many homes has led to the presence of wireless routers for distribution of Internet connectivity with portable/mobile devices. The spectral characteristic common to wireless routers is shown in Figure 60 for a router at GMP site 5 at a distance of one foot from the router. At the time of the measurement, the data transfer rate through the router was unknown. The unique spectrum signature presented by wireless routers permitted easy identification of their presence during measurements of the smart meter HAN radios that operate in the same band. In some cases, as many as four, and possibly more, routers were seen in the background of the measured spectra of the HAN radios, this more commonly associated with homes that had been converted to multiple apartments.

Results

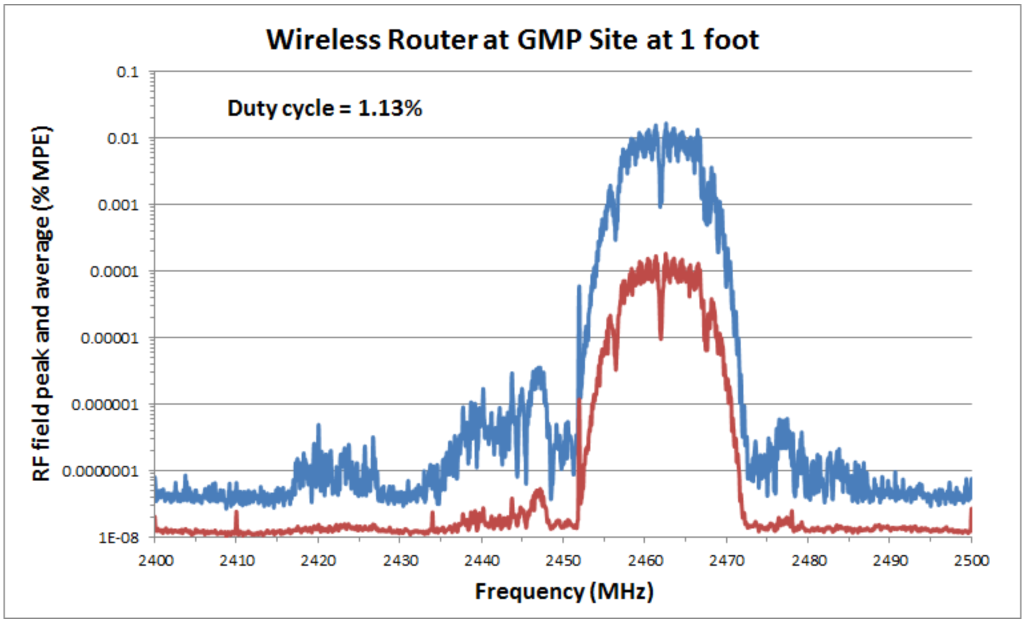

Figure 60. Unique spectral characteristic of 2.4 GHz wireless router at GMP site 5. Based on an integration of the peak (blue) and average (red) RF fields, the apparent duty cycle of the router was determined to be 1.13%.

The continuous peak RF field as a function of distance from six different routers measured during the study is shown in Figure 61. The RF fields are seen to vary widely and this is undoubtedly due to the highly variable nature of the local environments of the routers. In some cases, the routers were in the clear while in other cases they were buried behind monitors, books or other items. Also, the measurements were made with the router in its normal orientation at the site; this may have not been optimum in terms of the antenna for producing the maximum field at the location of the measurement probe/antenna for any particular router. In most cases, accessing the near vicinity of the router was difficult. Since the router is a source of intermittent RF emissions while it is powered on, the intermittent peak RF fields reported are constantly present.

Additional measurements of router duty cycles were performed in Colville. A LinkSys model WRT-54G router was configured for operation on WiFi channel 1, centered at 2412 MHz, and used to wirelessly transfer large amounts of data in different formats to a distant laptop computer. With the router in idle mode, the observed duty cycle was approximately 0.53%, this being roughly comparable with the router simply transmitting its narrow and periodic beacon signals (for network management) at a 10 Hz rate. When transferring binary data, the duty cycle rose to 2.4%. The greatest duty cycles were observed when transferring video files in either .avi or .mov formats when a maximum value of 6.5% could be measured. The issue of duty cycles of routers used with Wi-Fi technology as it is related to the transmission of data has been addressed previously [11].

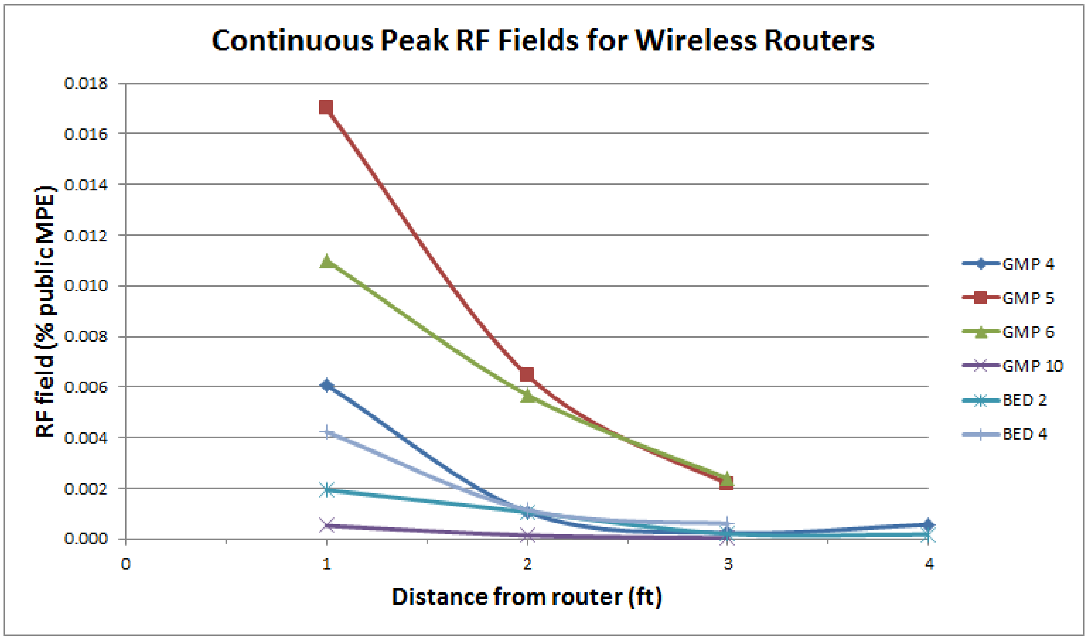

Figure 61. Spatial variation of peak RF fields continuously emitted by six wireless routers measured during this project.

<u>Cell Phones</u>

During the work in Colville, measurements were made of RF fields produced by a mobile phone (Samsung model Blackjack II). Although mobile phones are evaluated for RF exposure on the basis of specific absorption rate (SAR), these measurements were performed to provide perspective on potential exposure to cell phones and smart meters. The measurements consisted of supporting the mobile phone on a dielectric stand at a height of five feet above a concrete floor. The phone was placed into a continuous call during the measurements and the SRM-3006 was used to measure the field starting at floor level and in one foot intervals up to six feet above the floor. At each measurement point, the phone was rotated in three axes while the instrument was in maximum hold mode. This allowed the instrument to record the greatest RF field that might be associated with any particular orientation of the phone and its internal antenna. The phone operated at approximately 840 MHz during the measurements though it was a dual band phone and could operate in the 1.9 GHz band as well.

Figure 62 illustrates the measured peak values of RF field produced by the cell phone at the seven different heights. The greatest field is correlated with the fixed height of the phone. Similar to a smart meter, the spatially averaged value of RF field is substantially less than the spatial peak value near the mounting height of the phone.

The ratio of the spatially averaged field to the spatial peak field is 0.308; i.e., the spatially averaged field is 30.8% of the spatial peak value, similar to the finding for a smart meter. Relative to the MPE, the spatially averaged RF field, derived from instantaneous peak values of field, corresponded to 3.28% of the MPE.

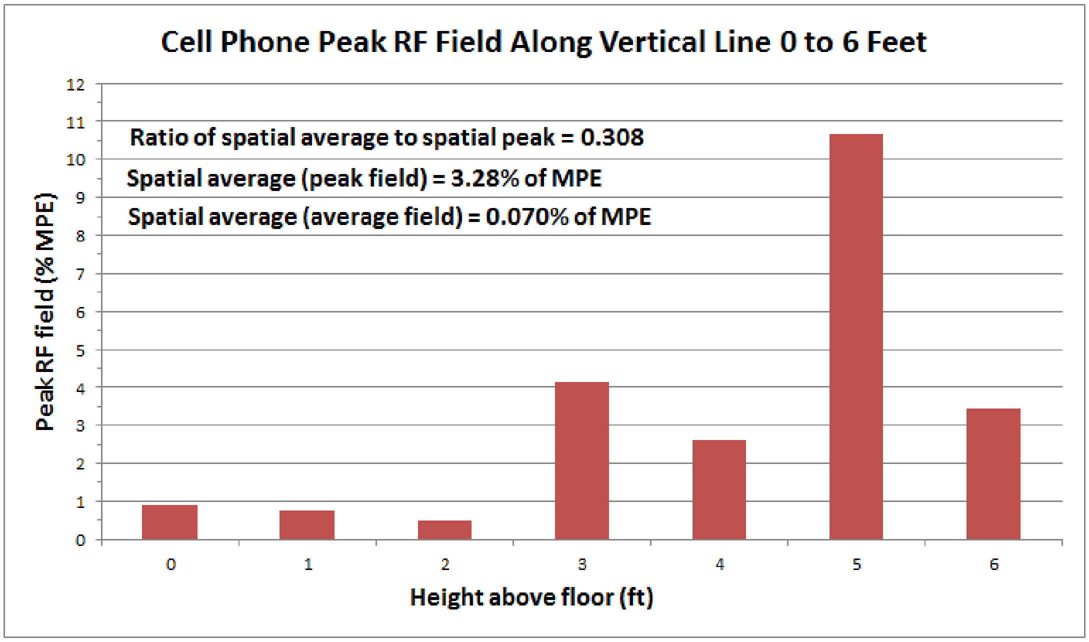

Figure 62. Peak RF fields along a six foot vertical line spaced laterally one foot from an active 840 MHz cell phone fixed at five feet above a concrete floor. The spatially averaged field in terms of time-averaged RF fields (0.070% of MPE) is obtained by multiplying the peak value by the duty cycle (see text below).

To calibrate this peak value of field to an average value, a measurement was made of the duty cycle of a one minute transmission (phone call during which the phone was modulated by a moderate level of speech) by observing the time domain profile of the phone's emission and simultaneously recording the peak and average values of field.[16] Figure 63 illustrates this measured time domain pattern of fields from the phone. It is noted that there are abrupt changes in the signal level (RF field) at different times during the test call suggesting that the phone is dynamically changing its power in response to the mobile phone base station to which it is connected at the time. The observed duty cycle of the phone during this transmission was 2.13% meaning that the average RF field, as a percent of MPE, is nominally 2% of the instantaneous peak field. Using this value of duty cycle, the spatial average of fields shown in Figure 62 (above), when converted to a time-averaged value of field (relative to the MPE) is 0.070% of the MPE.

[16] Note that with a continuously present RF field, this is straightforward with the SRM-3006. However, for intermittent emissions, such as smart meters, this is more difficult to do via a single measurement.

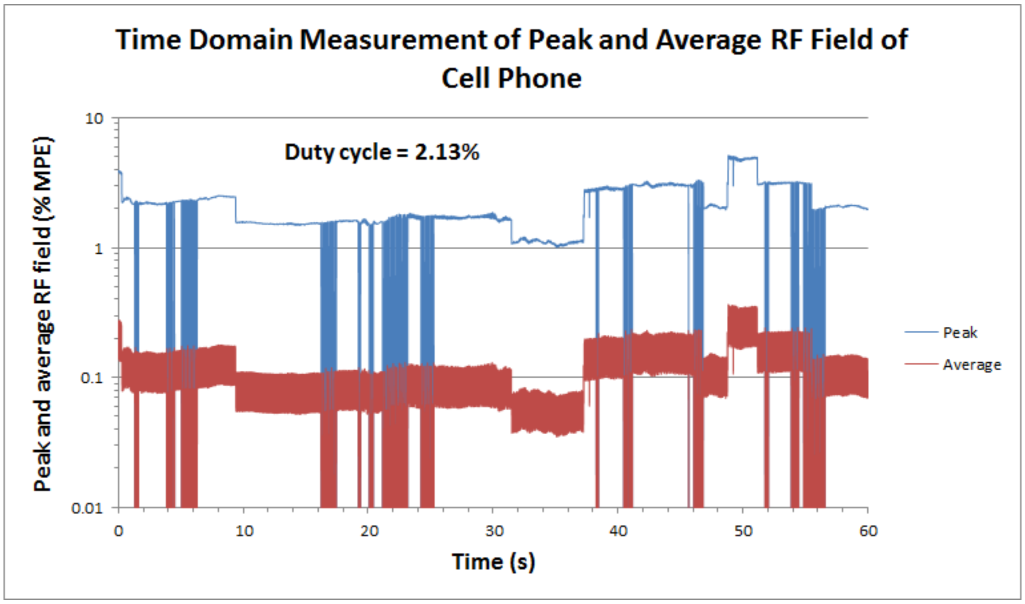

Figure 63. A measurement of the duty cycle of a cell phone across a 60 second phone call during which the phone was modulated with a moderate level of speech. The measured duty cycle was 2.13%.

Broadcast Signals

Broadcast stations provide essentially continuous RF fields of low magnitude that are widespread throughout the environment. The SRM-3006 instrumentation allowed for relatively convenient measurement of both broadcast signals, consisting of signals in the low and high very high frequency (VHF) television (TV) bands, the FM radio broadcast band, and the ultrahigh frequency (UHF) TV band, and the signals produced by wireless communications base stations used for mobile phones. Measurements of these frequency bands were made at 11 of the 14 general environmental sites for this study. Table 10 lists each band measured, the frequency range of the band and the resolution bandwidth (RBW) of the SRM-3006 used for the measurement[17].

[17] Resolution bandwidth is a measure of the ability of the instrument to distinguish signals that are close in frequency. It is similar to the selectivity of a radio receiver.

Results

Table 10. List of frequency bands measured at environmental sites in Vermont, their frequency ranges and the resolution bandwidth (RBW) of the SRM-3006 instrument used during the band measurement.		
Band	Frequency range (MHz)	RBW of SRM-3006 (kHz)
Low VHF TV	54 to 88	100
FM radio	88 to 108	30
High VHF TV	176 to 216	100
UHF TV	470 to 700	500
Cell	700 to 2500	1000

The measurement process consisted of supporting the SRM-3006 probe/antenna above the roof of a vehicle with the use of a 24 inch piece of PVC pipe and a cable allowing connection to the SRM basic unit. Representative spectra of detected average RF fields for the different bands from several different locations within the state are shown in Figures 64, 65, 66, 67, and 68 for the low VHF TV, high VHF TV, FM radio, UHF TV and what will be designated in this report as the cell band (for cellular telephone base stations) respectively.

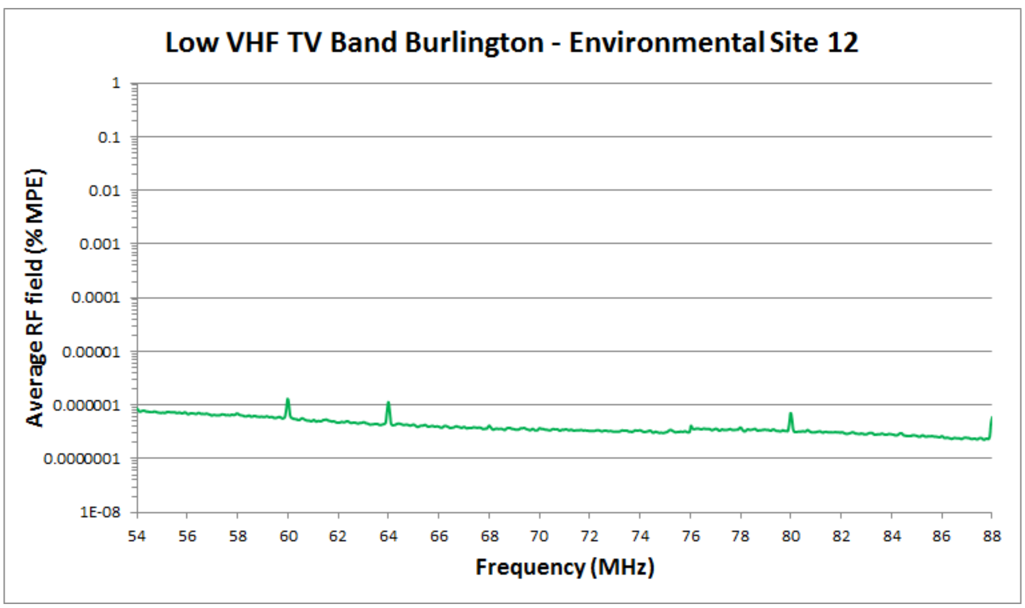

Figure 64. Spectrum measurement of average RF field (% MPE) across the low VHF TV broadcast band at environmental site 12 in Burlington.

Results

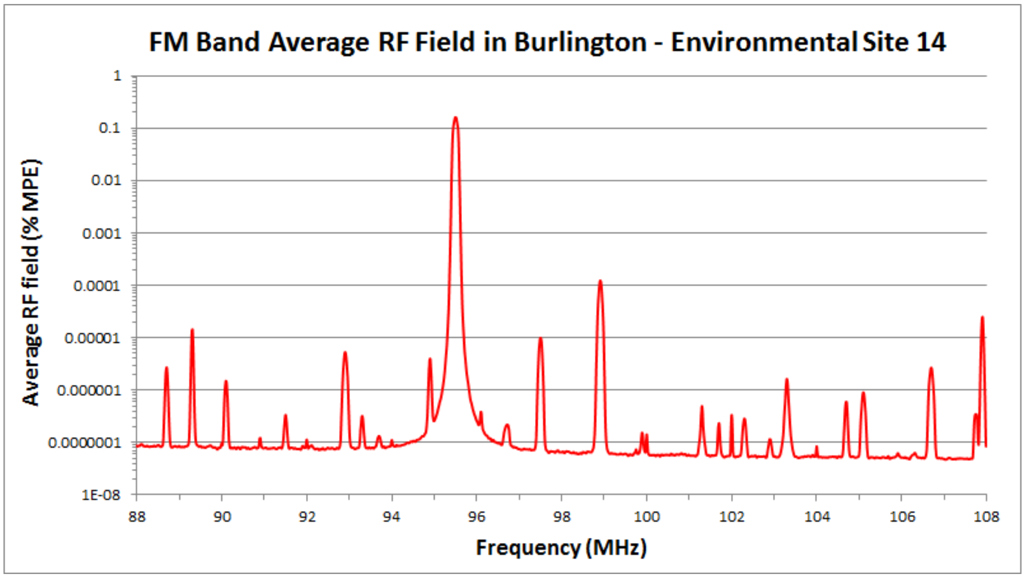

Figure 65. Spectrum measurement of average RF field (% MPE) across the FM radio broadcast band at environmental site 14 in Burlington.

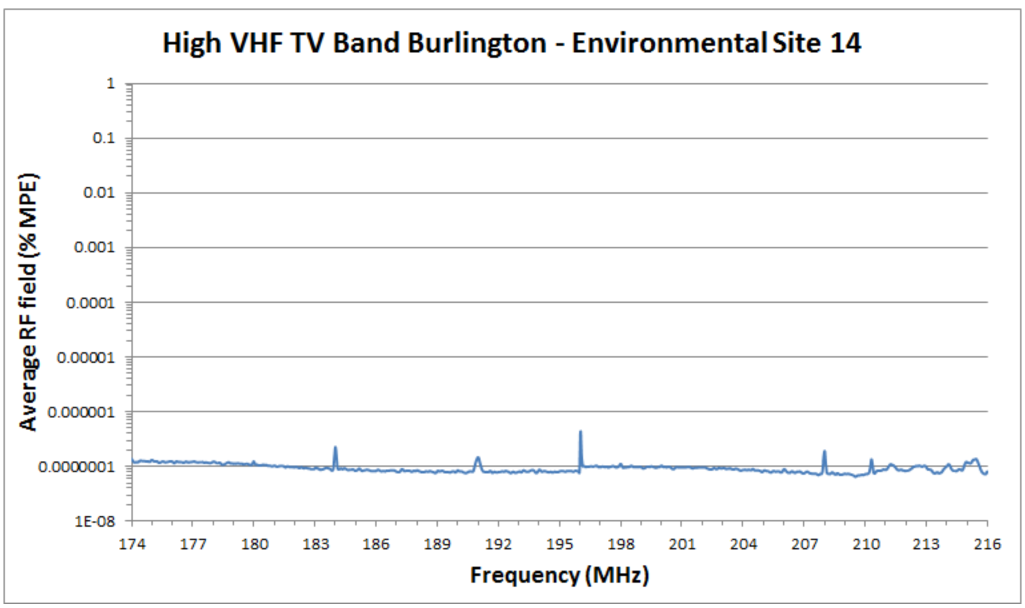

Figure 66. Spectrum measurement of average RF field (% MPE) across the high VHF TV broadcast band at environmental site 14 in Burlington.

The general lack of broadcast signals in the low and high VHF TV broadcast bands is the current result of the transitioning from analog to digital (high definition) TV wherein virtually all VHF TV stations were provided UHF TV spectrum for establishing a digital presence. This has resulted in these two bands becoming relatively vacated.

Results

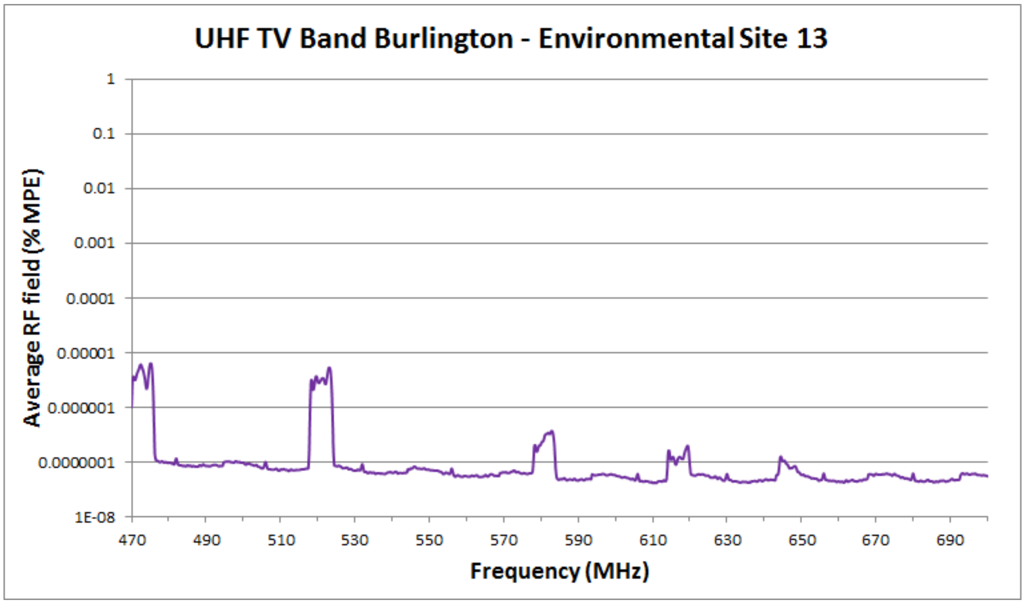

Figure 67. Spectrum measurement of average RF field (% MPE) across the UHF TV broadcast band at environmental site 13 in Burlington.

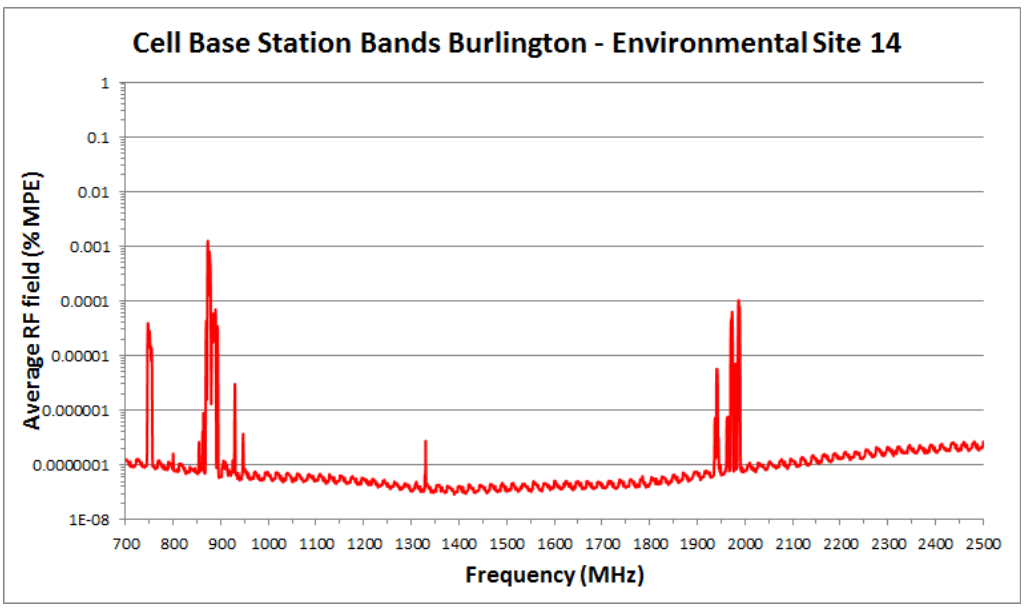

Figure 68. Spectrum measurement of average RF field (% MPE) across the wireless communication (cellular telephone) base station bands at environmental site 14 in Burlington.

For each spectrum measured, the data were retained and subsequently post processed to obtain the aggregate value of RF field from all signals detected within each band. This process consists of integrating the amplitude data obtained from the analyzer using a method specified by Narda. By independently integrating the spectra, using a computer based software tool developed for this purpose, a threshold could be specified for each band measurement such that only the amplitudes of legitimate signals were included in the integration. In this fashion, there was no impact caused by integration of the noise level of the instrument which can drive integrated results to erroneously high values. The specifics of the integration process are provided in Appendix F.

After integration of each measured spectrum of signals, the overall effective value of RF fields in that band were assessed as a percentage of the FCC MPE and tabulated in Table 11. These results are graphically illustrated in Figure 69. Generally, signals measured in the FM radio broadcast band were strongest and resulted in the greatest integrated values of RF field. In some instances, the fields in the cell (wireless) band were greater. This is consistent with a dated but only nationwide study of broadcast RF fields in metropolitan areas of the US [12].

Table 11. Summary of environmental RF field measurements (non-smart meter) in Vermont. Average RF fields are expressed in terms of a percentage of the MPE for public exposure and were obtained through an integration process described in the text to obtain a composite RF field value that also accounted for the noise floor of the instrument.

	Lo VHF	FM	Hi VHF	UHF	Cell
1	4.99E-06	0.003315	1.71E-05	0.000119	0.000237
2	1.36E-05	9.09E-05	3.69E-05	4.49E-06	0.009462
3	2.53E-05	0.000252	1.5E-05	8.14E-06	0.000171
4	3.22E-05	8.21E-05	5.33E-06	8.4E-06	0.000122
5	7.98E-06	1.58E-05	2.95E-07	2.76E-06	0.001135
6	1.92E-05	7.99E-05	2.57E-07	9.84E-06	4.89E-05
10	3.23E-05	0.006532	3.41E-07	9.43E-06	0.00393
11	3.14E-05	0.00925	6.09E-07	3.14E-05	2.55E-05
12	3.81E-05	0.000657	3.36E-07	5.52E-05	4.97E-05
13	3.66E-05	0.003438	3.24E-07	9.56E-05	0.001101
14	2.93E-05	0.616876	3.27E-07	8.71E-05	0.004996

These data support the conclusion that the total composite field of all of these bands range from 0.00016% to 0.62% of the MPE, depending on the site.

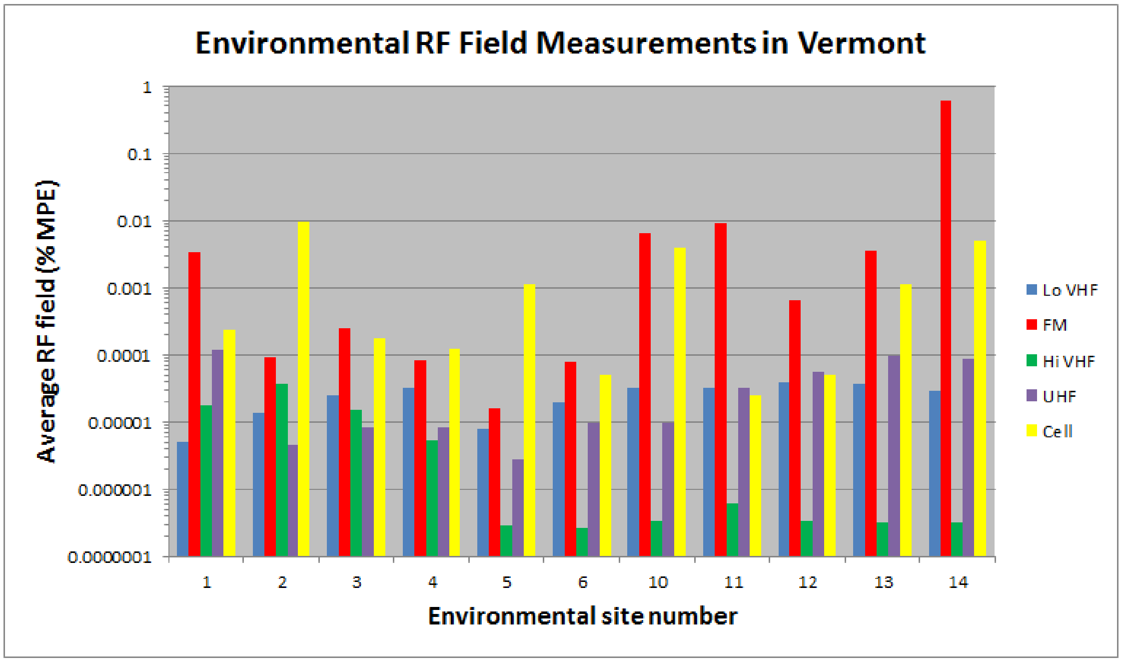

Figure 69. Graphical display of the integrated RF fields across five different frequency bands allocated to broadcast TV and FM radio as well as mobile phone base stations (wireless or cell band).

Water Meter Signals

In the GMP service territory measurements, at some sites, RF signals were observed that were not associated with the smart meters. This was evident since the Elster smart meters only operated in the lower half of the license free 900 MHz band. When extraneous signals appeared, it was very evident. Upon investigation, these signals that occur above 915 MHz but within the 900 MHz band were identified as being emitted by a small box, sometimes located on the home in the same area as the smart meters. This box was found to be related to a wireless remote water meter reading system present on some homes[18]. Figure 70 shows a measurement result in Rutland where the RF signals above 915 MHz are seen. Because the output power of the water meter transmitter is lower than that of the Elster RF LAN radio, it is unlikely that the strength of the water meter generated signals that could exist, from time to time, below 915 MHz would exceed that of the smart meters measured.

[18] Neptune Technology Group, frequency hopping spread spectrum transmitter used for remote water meter reading that operates on 50 hopping frequencies between 910 MHz and 920 MHz with 22 dBm (158 mW) of power and transmits once approximately every 14 seconds.

Results

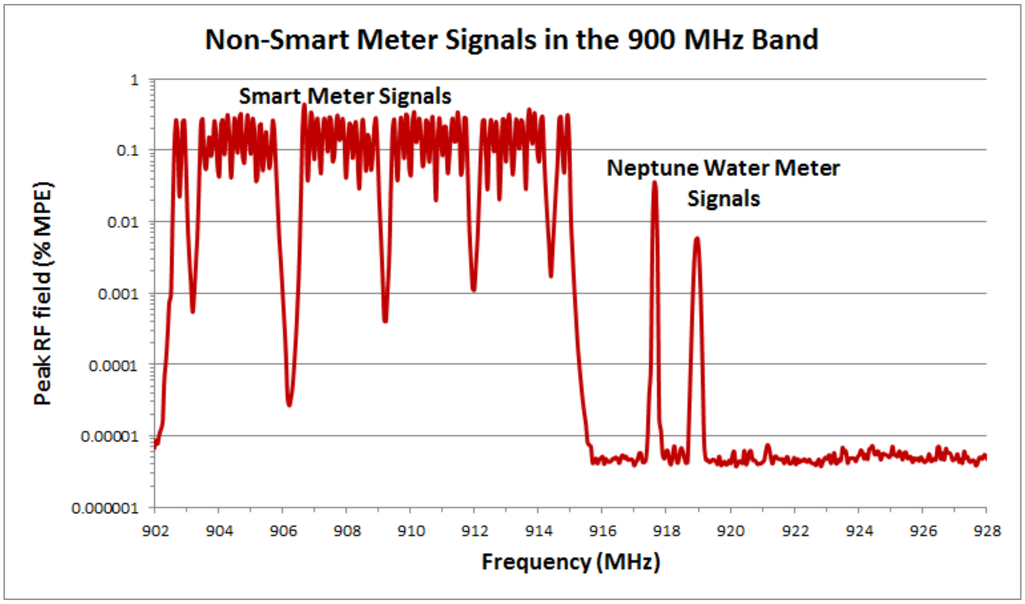

Figure 70. Spectrum measurement result at GMP site 4 where RF fields above the frequency range in which the Elster meter operates are apparent. The signals are intermittent and appear approximately once every 14 seconds.

Discussion

Discussion

This study is, generally, about low power radio transmitters and how they relate to potential exposure of individuals. An extensive set of measurements of two different types of smart meters being deployed within Vermont determined that the RF emissions produced by them are, in fact, low in value when compared to the applicable limits on human exposure promulgated by the FCC. The field characterization process consisted of measurement of the instantaneous peak value of RF fields during the emitted brief pulses from the meters and a direct determination of the meter duty cycles. Hence, both the peak values of RF fields as well as their time-averaged values, needed for direct comparison to the FCC MPE values, were determined. The frequency hopping, spread spectrum radios in the GMP and BED smart meters operate with very small duty cycles which means that time averaged values of RF fields to which someone may be exposed will be even lower than the measured peak values by typically two orders of magnitude.

The duty cycle may be thought of as a factor that is used to adjust the peak measured value of field to a time averaged value; it is a measure of the ratio of average to peak RF fields, or exposures. An averaging time specified in the FCC RF exposure rules of 30 minutes is required for proper exposure assessment and considerable effort was used to acquire direct measurements of 30-minute duty cycles in the project.

The matter of assessing compliance with the FCC rules can be simplified by the process illustrated in Figure71.

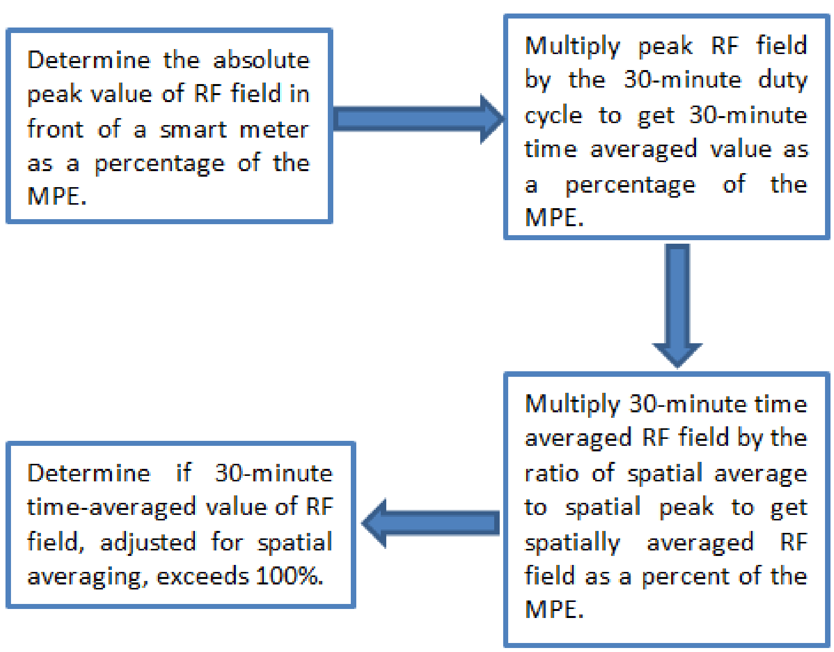

Figure 71. Illustration of steps for assessing compliance with the FCC rules on human exposure used for this study.

Discussion

A simple but conservative observation from all of the presented RF LAN (900 MHz band) data is that the greatest measured peak RF field obtained at a distance of one foot from any smart meter in the GMP service territory corresponded to 3.9% of the MPE and 2.5% of the MPE in the BED service territory. Other measurements resulted in lower values, sometimes considerably lower. In the GMP meter measurements, the maximum duty cycle found under a condition representing the greatest possible amount of data transmission during the measurement, was 3.55% (Figure 31). For the BED area measurements, a maximum duty cycle of 3.49% was deduced on the basis of pulse width measurements and a presumption of such pulses repeating at a rate of once per second. Using these duty cycle values, the 30-minute time averaged RF fields would be 0.14% of the MPE for GMP meters and 0.087% of the MPE for BED meters, both at a distance of one foot directly in front of the meters.

As a strict interpretation of the FCC exposure rules, these time-averaged values are to be adjusted to correspond to spatial averages over the body. Using the values of the ratio of spatial average to spatial peak RF fields over a six foot tall person obtained from direct measurements (0.489 for GMP meters and 0.363 for BED 900 MHz band meters), the overall estimated RF exposure to the RF LAN smart meter emissions at one foot would be 0.068% of the MPE for the GMP meters and 0.032% of the MPE for BED meters.

Associated with the operation of the GMP meters are emissions of the HAN radio that operates in the 2.4 GHz band. A similar exercise with the maximum measured RF field at one foot from the meter, the maximum estimated duty cycle and the spatial variation of field in front of the meter yields a local peak value of field of 0.55% of the MPE, a 30-minute time averaged field equivalent to 0.0014% of the MPE (using a duty cycle of 0.258%) and a resulting, six-foot spatially averaged field equal to 0.00049% of the MPE (spatial ratio of 0.349). The exceptionally low duty cycle for the HAN radios is related to the very narrow pulses that they emit and the relatively large amount of time between pulses.

Hence, using the most conservative results from the measurements performed in this study, a potential maximum exposure of individuals to the RF fields associated with the currently deployed smart meters in the GMP and BED service territories is small when compared to the limits set by the FCC. To provide an alternative perspective on how the anticipated exposure near the smart meters compares to the hazard upon which the present exposure limits are based, it is relevant to know that the FCC limits include a safety factor of 50 fold below the presumed threshold of hazard. In other words, the exposure limit is not set at the boundary of potentially hazardous effects. When the above estimated RF field exposures are considered in this light, this means that the most conservative estimates of potential exposure range between approximately 74,000 and 156,000 times less than the hazard threshold.

Discussion

Using manufacturer's specified values for the peak output powers of the RF LAN transceivers and antenna gains (tabulated in Table 1), the peak RF field power density at one foot from the respective smart meters can be calculated with the following expression.

$$S = \frac{EIRP}{4\pi R^2} \qquad \text{Eq. 1}$$

Where
S is the power density (milliwatts per square centimeter, mW/cm^2)
EIRP is the effective isotropic radiated power (milliwatts)
R is the radial distance from the smart meter (cm)

For the GMP Elster meter, at one foot, the peak power density is calculated to be 0.059 mW/cm^2 and for the BED Itron meter, a value of 0.045 mW/cm^2 is obtained. These values can then be expressed as a percentage of the MPE by dividing by the MPE (nominally 0.61 mW/cm^2 at 915 MHz) and multiplying by 100. This leads to calculated peak RF fields at one foot for the GMP and BED meters of 9.6% and 7.4% of the MPE respectively. These values are greater than the maximum peak values measured in this study, an often typical result of modeling calculations for RF fields when compared to actual measurements. In fact, in the FCC certification report provided by Elster to the FCC in which measured RF fields at a distance of 3 meters are provided, the measured values proved to be approximately 4.5 times less than what the theoretical calculation would suggest.

RF fields found behind the smart meters are considerably lower than those values at the same distance but directly in front of the meters. In this work, rearward directed RF fields were found to range between 6 and 8% of the forward value. This generally has a significant influence on the strength of the RF fields that are found inside homes that have smart meters. Indeed, the interior measurements of RF fields for both the RF LAN and HAN radios of the GMP meters and the RF LAN radios of the BED meters prove this. The greatest value of RF field anywhere within a residence was 0.08% of the MPE with an average value of 0.0033% of the MPE, these values before adjustment for duty cycle or spatial averaging. Arguments that reflections will significantly increase ambient values of smart meter fields are not borne out during measurements. Certainly, reflections can, and will, influence the actual value of field measured at any given point in space. This is partly why the plots of RF field vs. distance in front of the meters do not follow a strict inverse square law. But, based on the extensive measurement data taken inside homes, including areas immediately behind the meters, extraordinary fields were not found.

Discussion

If the maximum and mean interior RF fields, found in homes, are adjusted for duty cycle using the largest duty cycle found in this study, they become equivalent to 0.0028% and 0.00012% of the MPE respectively. When further spatially averaged, these values become 0.0014% and 0.000058% of the MPE respectively.

The task of making smart meter RF field measurements is made more complex because of the non-uniform pattern of emissions from the meters. This is illustrated in Figure 72 where a detailed set of measurements were performed in Colville on both of the test meters provided by GMP and BED. This figure shows the spatial dependence of the measured RF field in relation to the center of the face of the GMP Elster and BED Itron meters. It clearly shows how slight differences in the exact location of the measurement probe/antenna can influence the result and this certainly is a factor in some of the spread of data in measurements taken during this study. The difference between the two meters is related to the location within the meter housing where the radios are installed. All distances are from the surface of the meter face to the center of the SRM probe/antenna.

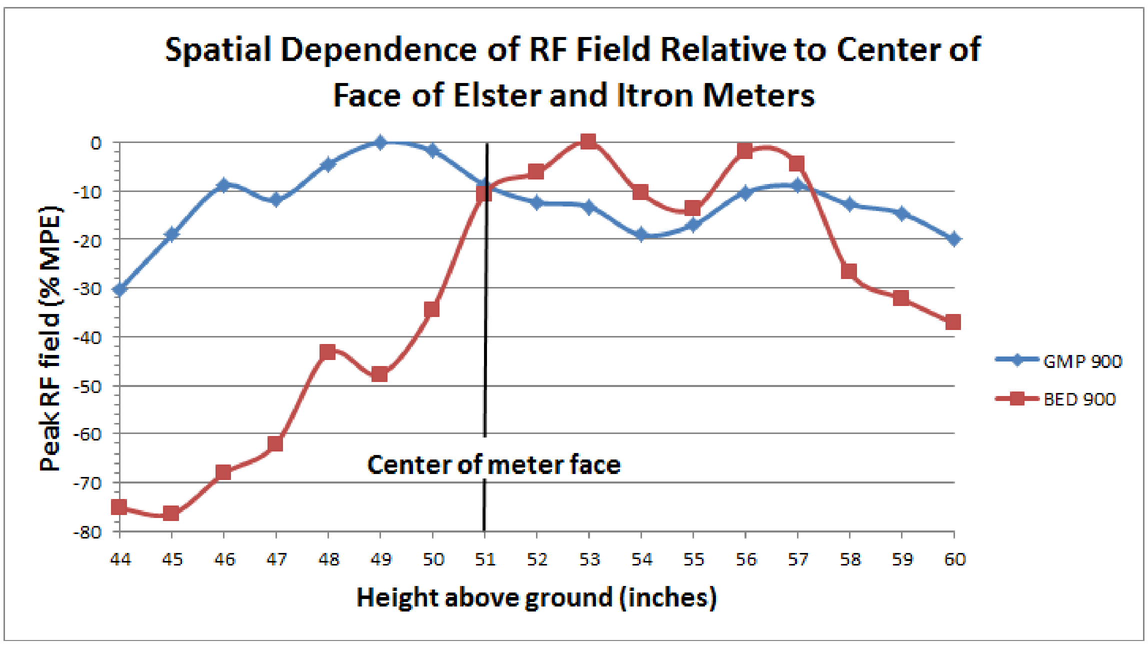

Figure 72. The measured spatial dependence of 900 MHz band RF fields produced at one foot from the GMP Elster and BED Itron smart meters along a vertical line extending from 44 inches to 60 inches above the floor.

Smart meter RF emissions can be put in perspective by comparing their emission levels to RF fields associated with other kinds of sources. A few highlights of such a comparison include:

Discussion

- The likely strongest source of RF exposure in the home is the microwave oven that can result in average RF fields exceeding 6% of the FCC MPE at one foot from the oven and greater than 1% of the MPE at three feet.

- Wireless routers can result in average field levels of as much as 0.0011% of the MPE in the 2.4 GHz band at a distance of one foot (based on a measured peak field of 0.017% of the MPE and a duty cycle of 6.5%).

- The prevalence of FM radio broadcast stations leads to RF field levels that are roughly uniform over the body dimensions, operate with 100% duty cycle and can be in the range of about 1% of the MPE (greatest average value of 0.6% of the MPE was found at environmental site 14 in the Burlington area). This value of field is almost 9 times greater than the time-averaged field at one foot in front of the maximum field smart meter and 400 times the smart meter field at 10 feet from a smart meter.

- The most likely source of personal exposure to RF today is the mobile (cell) phone. Cell phones make use of transceivers that, in terms of power and frequencies used, are not very different from the transceivers in smart meters. Thus, one would not expect that there would be very much difference in exposure between the two devices except for the fact that cell phones are intended to be used against the body while smart meters are not. In a measurement of the spatially averaged RF field over a six-foot vertical dimension, with the phone positioned at five feet above the floor, the field was found to be equivalent to 0.070% of the MPE (Figure 62). Interestingly, this is in quite close agreement with the value obtained for the maximum field smart meter in terms of time-averaged field, including spatial averaging of 0.068% of the MPE. The local energy absorption rate associated with use of the cell phone, however, because of the proximity of the phone to the body during typical use, will result in a far greater local SAR than the smart meter positioned at one foot in front of a person.

Interestingly, when a large group of smart meters are installed together in a bank, such as on an apartment building, the instantaneous peak RF field produced is no different from that of a single meter. However, the time-averaged value of RF field can be greater simply due to the number of meters present. The measurement data collected as part of this study did not, however, reveal any duty cycles of the aggregate RF fields of a meter bank greater than that associated with a single end point meter during its reporting of historical data to the Gatekeeper or Cell Router. The aggregation of smart meters in a bank does not necessarily imply that the long-term time-averaged RF field will be any greater than a high activity end point meter because the smart meters are not interrogated in a physically sequential manner. While one meter in the bank may respond with data, the next meter queried may be located substantially far from the bank of meters and, consequently, its fields are negligible in comparison to those immediately at the bank.

RF fields found near data collection points in both the GMP and BED service territories were unremarkable other than for the amount of data traffic observed. Because of the elevated height of these Gatekeepers and Cell Routers, RF field emissions are greatly reduced from those found immediately in front of smart meters. As such, the data collection points do not represent any significant increase in potential RF exposure. This is related to the fact that, in the GMP territory, the WWAN connection operates at high speed, thereby allowing for overall low duty cycles when it is transmitting large amounts of data back to the utility company. In the BED region, all data collected by the Cell Router is routed back to the company via a fiber optic network and no additional RF is involved.

Smart meters emit short duration pulses of RF energy in their communication with other meters and data collection points. These emissions generally happen all through the day. Besides the normal three (in the case of BED) or four (in the case of GMP) times a day that electric energy consumption data are reported back to a data collection point for subsequent transmission to the company, smart meters must maintain their organization within the RF LAN to which they belong and this necessitates the transmission of beacon signals from time to time. Additionally, each meter can, when required by the mesh network, assist neighboring smart meters by transmitting the neighbor's data on to another meter or data collection point. Further, the HAN radio can produce pulsed fields in its search for and communication with IHDs. All of this means that most smart meters remain relatively active in terms of brief signals being transmitted. However, the total amount of time that a smart meter transmits during a day is small but non-zero. For instance, the greatest 30-minute duty cycle found for the GMP meters in the` 900 MHz band of 3.55% means that, if this meter were to continue to operate at this rate, the meter would be active for 3.55% of each 30 minute window of time. This corresponds to 63.8 seconds during each half-hour period that it may be active at this level. If this high duty cycle were to be maintained for, say, two hours, four times per day, this would amount to some 17 minutes of transmit time during the day. It is likely that there would be some additional network overhead activity that would increase the total transmit time but, suffice it to say, actual emission of RF fields occurs only for a small fraction of the day. For most meters within the mesh network, the activity will be far less than for those meters that happen to lie within one hop to the data collector since it is these meters that do the most work in transferring RF LAN data.

An evaluation of low frequency electric and magnetic fields of the smart meters that could be a product of switch mode power supplies within the meters showed that the two test meters exhibited different magnitudes of fields but in both cases, all such fields were substantially less than applicable science based guidelines and standards for exposure. Recommended exposure limits at low frequencies have been recommended by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [13] and the IEEE [14]. Of the two, the more stringent values are those of ICNIRP which are summarized in Table 12 for sinusoidal electric and magnetic fields for general public exposure.

Table 12. Recommended public exposure limits (reference levels) from ICNIRP [13] for sinusoidal low frequency electric and magnetic fields for whole-body exposure.

Frequency range	Electric fields (V/m) RMS	Magnetic fields (μT) RMS
1 Hz – 8 Hz	5000	40,000
8 Hz – 25 Hz	5000	625
25 Hz – 50 Hz	5000	200
50 Hz – 400 Hz	5000	200
400 Hz – 3 kHz	625	200
3 kHz – 10 MHz	83	27

The low frequency measurement data for the two smart meters in the various ICNIRP defined frequency ranges are very substantially less than the recommended values contained in Table 12.

Smart meters emit pulses of RF energy similar to many other everyday sources in the environment. For instance, wireless routers continuously transmit beacon pulses at a rate of 10 pulses per second (10 Hz). Signals from airport and long range air traffic control radars and Doppler weather radar systems produce a constant stream of pulsed RF fields to which individuals may be exposed. For systems such as radars, high pulse repetition frequencies (PRFs) are often used that can range from several hundred Hz to greater than one kilohertz.

Conclusions

A number of field measurement studies conducted by one of the authors address RF emissions from wireless smart meters [1, 2, 3, 9, 15]. All of these studies have demonstrated that the potential exposures that could result from proximity to the subject smart meter emissions comply with the limits set by the FCC. This study is no different.

The RF emissions produced by the smart meters deployed by GMP and BED were found to comply with the public exposure regulations of the FCC by a wide margin, typically by a factor of approximately 1500 times, even at one foot from the meters. The measurement data show that the RF field emissions decrease sharply with increasing distance from the smart meters. At distances more likely associated with common day-to-day exposures to smart meter emissions, the RF fields become even dramatically less. For example, at a distance of 10 feet in front of a meter, the RF field drops to approximately 76,000 times less than the FCC limit. Relative to the actual biological hazard thresholds, not the MPE which contains a safety factor of 50 for the general public, the RF fields at one foot and ten feet from a smart meter are some 75,000 times and 3,800,000 times less respectively.

Detailed measurements of RF fields found inside of smart meter equipped homes showed that the highest fields (typically directly behind the meter but inside the home) were comparable to that found at 10 feet in front of the meter. However, the average of residential indoors smart meter RF fields measured in this study was more than 1.7 million times less than the FCC public exposure limit.

Potential exposure to RF emissions of banks of smart meters was not found to be significantly greater than that of a single meter in terms of the peak value of field but the time-averaged level of RF field can increase simply because of the larger number of meters. However, there is no general correlation between overall higher average RF fields associated with large banks of meters since the greatest duty cycle of any given smart meter appears to be more related to a specific meter's position within the wireless network's hierarchy, i.e., how close it is, from a communications perspective, to its designated data collection point. Hence, a single meter that serves to relay energy consumption data from many other meters to the data collection point can exhibit a greater time-averaged RF field than a large group of meters that are not close, network wise, to a data collection point.

The greatest measured smart meter duty cycles found through this investigation were in the 3-4% range and are comparable to those values determined from statistical analysis of meter transmission activity derived from electric utility data management software systems in earlier studies [1, 2]. Average duty cycles of most meters are substantially less than 1%.

Conclusions

Exposure, in terms of instantaneous peak as well as time-averaged RF fields, caused by deployed smart meters in Vermont is small in comparison to that related to many other sources of RF fields in the environment. For instance, local values of long term, time-averaged RF fields (as a fraction of the MPE) from FM radio broadcasting can, in some areas, be as much as ten to hundreds of times greater than those values found immediately near smart meters. The common use of normal appliances within a home or office, such as microwave ovens and wireless routers, can lead to RF fields that are comparable to or substantially greater than those produced by smart meters. This applies to the use of mobile phones as well; both mobile phones and smart meters operate with roughly the same transmitter peak powers. In this context, however, mobile phones are normally held against the head during use while smart meters are not.

Low frequency electric and magnetic fields produced by the smart meters and their internal switch mode power supplies, at one foot from the meters, were substantially smaller in value than the recommended limits of the ICNIRP guidelines [13].

The communications technology used by smart meters makes use of low power, pulsed RF transmissions that result in weak RF fields by comparison to currently scientifically based human exposure limits. The pulsed nature of smart meter emissions is not very dissimilar to other sources such as wireless routers, mobile phones or air traffic control and weather radars, for example. Pulse repetition rates from 10 Hz for routers sitting idle, 217 Hz for GSM type mobile phones and up to more than a kilohertz for radars characterize many of the signals found in the everyday environment.

The operation of the HAN radios in smart meters produces additional RF emissions for communication with IHDs but the extremely low duty cycle and lower transceiver power levels result in very weak additions to the overall fields that individuals may experience near them.

Applying the highest indicated results from the measurements performed in this study, the RF fields associated with the currently deployed smart meters in the GMP and BED service territories are small when compared to the limits set by the FCC. It is concluded that any potential exposure to the investigated smart meters will comply with the FCC exposure rules by a wide margin.

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http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001021829

Appendix A

RF Exposure Report Prepared for the FCC on Behalf of Elster Solutions, LLC
By
TUV Rheinland North America

Appendix A

RF Exposure Report

EUT Name: Rex2 Power Meters
EUT Model: RX2EA4, RX2EA4-I
FCC ID: QZC-RX2EA4 , QZC-RX2EA4I

FCC Title 47, Part 15.247(i), 1.1307(b), and 1.1310

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Report/Issue Date: 9 February 2010
Report Number: Supplement to 30953899.001 - MPE

1 RF Exposure Measurement (Mobile Device) 15.247(i)

1.1 Test Methodology

In this document, we try to prove the safety of radiation harmfulness to the human body for our product. The limit for Maximum Permissible Exposure (MPE) specified in FCC 1.1310 is followed. The Gain of the antenna used in this product is measured in a Semi-Anechoic Chamber, and also the maximum total power input to the antenna is measured. Through the Friis transmission formula (see section 4.9.6) and the maximum gain of the antenna, we can calculate the distance, away from the product, where the limit of MPE is reached.

Although the Friis transmission formula is a far field assumption, the calculated result of that is an over-prediction for near field power density. We will take that as the worst case to specify the safety range.

1.2 RF Exposure Limit

According to FCC 1.1310 table 1: The criteria listed in the following table shall be used to evaluate the environmental impact of human exposure to radio-frequency (RF) radiation as specified in 1.1307(b)

LIMITS FOR MAXIMUM PERMISSIBLE EXPOSURE (MPE)

Frequency Range (MHz)	Electric Field Strength (V/m)	Magnetic Field Strength (A/m)	Power Density (mW/cm^2)	Average Time (minutes)
(A)Limits For Occupational / Control Exposures				
300-1500	...	...	F/300	6
1500-100,000	...	...	5	6
(B)Limits For General Population / Uncontrolled Exposure				
300-1500	...	...	f /1500	6
1500-100,000	...	...	1.0	30

f = Frequency in MHz

1.3 EUT Operating condition

The software provided by Manufacturer enabled the EUT to transmit data at lowest, middle and highest channel individually.

1.4 Classification

The antenna of the product, under normal use condition, is at least 20cm away from the body of the user. Warning statement to the user for keeping at least 20cm or more separation distance with the antenna should be included in users manual. Therefore, this device is classified as a **Mobile Device**.

1.5 Test Results

1.5.1 Antenna Gain

The maximum Gain measured in Semi-Anechoic Chamber is 5.64 dBi or 3.66 (numeric).

1.5.2 Output Power into Antenna & RF Exposure value at distance 20cm:

Calculations for this report are based on highest power measurement and the highest gain of the antenna. Limit for MPE (from FCC part 1.1310 table 1) is f (MHz) / 1500 = 927.6 / 1500 = 0.62 mW/cm^2

Highest Pout is 250mW, highest antenna gain (in linear scale) is 3.27, R is 20cm, and f = 927.6 MHz

Pd = (250*3.66) / (1600π) = **0.182 mW/cm^2**, which is 0.438 mW/cm^2 below to the limit.

As originally tested, the EUT was found to be compliant to the requirements of the test standard(s).

1.6 Sample Calculation

The Friis transmission formula: Pd = (Pout*G) / (4*π*R^2)

Where;

Pd = power density in mW/cm2
Pout = output power to antenna in mW
G = gain of antenna in linear scale
$\pi \approx 3.1416$
R = distance between observation point and center of the radiator in cm

Ref. : David K. Cheng, *Field and Wave Electromagnetics*, Second Edition, Page 640, Eq. (11-133).

Appendix B

RF Exposure Report Prepared for the FCC on Behalf of Iton
By
Advanced Compliance Solutions (ACS)

Excellence in Compliance Testing

Certification Exhibit

FCC ID: SK9AMI6
IC: 864G-AMI6

FCC Rule Part: 15.247
IC Radio Standards Specification: RSS-210

ACS Report Number: 10-0158.W06

Manufacturer: Itron Electricity Metering, Inc.
Model: AMI6

RF Exposure

Appendix B

General Information:

Applicant: Itron Electricity Metering, Inc.
ACS Project: 10-0158
Device Category: Mobile
Environment: General Population/Uncontrolled Exposure
Simultaneous Transmission: Yes

Technical Information 900 MHz LAN Radio

Antenna Type: Quarter Wave Embedded Slot Antenna
Antenna Gain: 2.2dBi
Transmitter Conducted Power: 24.83dBm
Maximum System EIRP: 27.03dBm (505mW)

Technical Information 802.15.4 Zigbee Radio

Antenna Type: Quarter Wave Embedded Slot Antenna
Antenna Gain: 3.8dBi
Transmitter Conducted Power: 18.94dBm
Maximum System EIRP: 22.74dBm (188mW)

MPE Calculation

The Power Density (mW/cm^2) is calculated as follows:

$$S = \frac{PG}{4\pi R^2}$$

Where:
S = power density (in appropriate units, e.g. mW/cm2)
P = power input to the antenna (in appropriate units, e.g., mW)
G = power gain of the antenna in the direction of interest relative to an isotropic radiator
R = distance to the center of radiation of the antenna (appropriate units, e.g., cm)

MPE Calculator for Mobile Equipment Limits for General Population/Uncontrolled Exposure*							
Transmit Frequency (MHz)	Radio Power (dBm)	Power Density Limit (mW/Cm2)	Radio Power (mW)	Antenna Gain (dBi)	Antenna Gain (mW eq.)	Distance (cm)	Power Density (mW/cm^2)
902.25	24.83	0.60	304.09	2.2	1.660	20	0.100
2475	18.94	1.00	78.34	3.8	2.399	20	0.037

Summation of Power Densities – Simultaneous Transmissions

This device contains multiple transmitters which can operate simultaneously and therefore the maximum RF exposure is determined by the summation of power densities. The 900 MHz LAN and 2.4GHz Zigbee radio can operate simultaneously there it is appropriate to include both of those power density values in the summation of power densities.

The maximum power density is calculated by a summation of power densities for each simultaneous transmission combination as follows:

900MHz LAN: 0.100 (mW/cm^2)
2.4GHz Zigbee: 0.037 (mW/cm^2)
TOTAL: **0.137 (mW/cm^2)**

Installation Guidelines
The installation manual should contain text similar to the following advising how to install the equipment to maintain compliance with the FCC RF exposure requirements:

RF Exposure
In accordance with FCC requirements of human exposure to radio frequency fields, the radiating element shall be installed such that a minimum separation distance of 20 centimeters will be maintained.

Conclusion
This device complies with the MPE requirements by providing adequate separation between the device, any radiating structure and the general population.

Appendix C
Calibration Certification of the Narda SRM-3006 Selective Radiation Meter

Narda Safety Test Solutions GmbH
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narda Safety Test Solutions®
an L3 Communications Company

Calibration Certificate

Narda Safety Test Solutions hereby certifies that the object referred to in this certificate has been calibrated by qualified personnel using Narda's approved procedures. The calibration was carried out in accordance with a certified quality management system which conforms to ISO 9001

OBJECT	Selective Radiation Meter, Basic Unit, SRM-3006
MANUFACTURER	Narda Safety Test Solutions GmbH
PART NUMBER (P/N)	3006/01
SERIAL NUMBER (S/N)	D-0069
CUSTOMER	
CALIBRATION DATE	2010-10-13
RESULT ASSESSMENT	within specifications
AMBIENT CONDITIONS	Temperature: (23 ± 3)°C Relative humidity: (25 to 75) %
CALIBRATION PROCEDURE	3006-8701-00A

ISSUE DATE: 2010-10-18

MANAGEMENT SYSTEM

CALIBRATED BY:
Paul Geyer

AUTHORIZED SIGNATORY:

Certified by DQS against ISO 9001:2008 (Reg.-No. 099379 QM08)

This calibration certificate may not be reproduced other than in full except with the permission of the issuing laboratory. Calibration certificates without signature are not valid.

CERTIFICATE 300601-D0069-20101013-73

PAGE 1 OF 6

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OBJECT

The spectrum analyzer is based on digital signal processing. Small frequency spans were measured at fixed local oscillator (1st LO) settings using discrete Fourier transformation (DFT). The LO was also swept for larger frequency spans.
A memory chip contains correction values for various frequencies and object settings. The stored values were taken into account automatically during the measurement.

METHOD OF MEASUREMENT

Calibration using the reference standard. The output power level of the synthesized CW generator was adjusted and calibrated using power sensors as reference standards.
The frequency of the generator was calibrated using a frequency counter.

The reflection of the object was measured directly using a vector network analyzer (VNA) calibrated by means of a calibration kit. The measuring equipment and the associated uncertainty were verified using a reference standard (verification kit).

CALIBRATION PROCEDURE

The object was connected to the signal source instead of the power sensors in order to calibrate it.

Measurement of the RF frequency response was made with different settings of the measurement range. As a result, the measured values also include the effects due to the “input attenuator” and the “reference level accuracy”.
The calibration factor was calculated for various frequencies and settings from a comparison between the “actual level” and the “indicated level”.

All the selection filters are digital filters. No calibration of the filters is necessary.

TRACEABILITY

The calibration results are traceable to the International System of Units (SI) in accordance with ISO/IEC 17025. The measuring equipment used for calibration is traceable through the reference standards listed below.

STANDARD	MANUFAC-TURER	MODEL	SERIAL NUMBER	ID	CERTIFICATE	NEXT CAL. DATE	TRACE
HF-MILLIVOLTMETER	R&S	URV 55	100143	913	0116 DKD-K-16101 2010-05	2012-05	DKD
DIODE POWER SENSOR	R&S	NRV Z4	100199	956	0104 DKD-K-16101 2010-05	2012-05	DKD
THERMAL POWER SENSOR	R&S	NRV Z51	101777	1635	0264 DKD-K-16101 2008-11	2010-11	DKD
MISMATCH VSWR 1,2 (f)	Rosenberger	--	01237	552-3	12996 DKD-K-00201 2008-05	#	DKD
FREQUENCY COUNTER	Advantest	R5362B	120700137	923	15137 DKD-K-00201 2009-09	#	DKD

\# Reference standard; not used for routine calibration

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UNCERTAINTY

The reported expanded uncertainty U is based on a standard uncertainty multiplied by a coverage factor *k* = 1.96, providing a level of confidence of approximately 95 %. The uncertainty evaluation has been carried out in accordance with the "Guide to the Expression of Uncertainty in Measurement" (GUM).
The reported measurement uncertainty is derived from the uncertainty of the calibration procedure and the object during calibration, and makes no allowance for drift or operation under other environmental conditions.

MEASURING CONDITIONS

The following results were obtained after adjustment of the object under calibration.
These values are within the setting ranges defined by the manufacturer.

RESULTS

1	FREQUENCY RESPONSE (IF):	passed
2	FREQUENCY RESPONSE (RF):	passed
3	OUT-OF-BAND RESPONSE:	passed
4	FREQUENCY ACCURACY	passed
5	NOISE SIDEBAND (SSB):	passed
6	SPURIOUS (input related)	passed
7	SPURIOUS (residual)	passed
8	NOISE FLOOR:	passed
9	INTERMODULATION REJECTION (2nd and 3rd order):	passed
10	INPUT RETURN LOSS:	passed

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APPENDIX

FREQUENCY RESPONSE (RF)

The generator was set to the *Fgen*. The object settings were *Fspan*, *RBW*, and *Fcent*.
The measurements were made at different settings of the measurement range *MR*. The nominal level of the generator was -32 dBm (for *MR* < -5 dBm) and -7 dBm (for *MR* ≥ -5 dBm), respectively. The frequency response *G* was calculated as the difference of the actual generator level L_{actual} and the indicated level $L_{indicated}$ according to the following equation: $G/\text{dB} = \left(L_{indicated} - L_{actual}\right)/\text{dBm}$

Frequency in MHz	Fspan in MHz	RBW in kHz	Fcent in MHz	MR												U
				-30	-28	-25	-20	-15	-10	-5	0	5	10	15	20	
0.00901	0.002	0.01	0.01	0	0	0	-0.01	-0.01	0	0	0	0	0	-0.01	-0.01	0.2
0.012	0.006	0.5	0.012	0.01	0.01	0.01	0	0	0.01	0.01	0.01	0	0.01	0	0	0.2
0.02	0.02	2	0.02	0.01	0	0	0	-0.01	0.01	0.01	0	0	0	0	-0.01	0.2
0.04	0.02	2	0.04	0	0	0	-0.01	-0.01	0	0	0	0	0	0	-0.01	0.2
0.1	0.02	2	0.1	0	0	0	-0.01	-0.01	0	0	0	-0.01	-0.01	-0.01	-0.01	0.2
0.5	0.02	2	0.5	0	0	0	-0.01	-0.01	0	0	0	-0.01	-0.01	-0.01	-0.01	0.2
2	0.02	2	2	0	0	0	-0.01	-0.01	0	0.01	0	0	0	0	0	0.2
10	0.02	2	10	0.01	0.01	0	0	0	0.01	0.01	0.01	0	0	0	0	0.2
20	0.02	2	20	0.01	0.01	0.01	0.01	0	0.01	0.01	0.01	0.01	0	0	0	0.2
30	0.02	2	30	0.01	0.01	0	0	0	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.2
31.233	26.75	30	44.578	-0.11	-0.19	-0.15	-0.18	-0.29	-0.12	-0.14	-0.15	-0.29	0	-0.14	-0.21	0.2
36.1	26.75	30	44.578	-0.03	-0.11	-0.07	-0.13	-0.17	-0.06	-0.08	-0.1	-0.17	-0.02	-0.1	-0.14	0.2
40	0.02	2	40	0.01	0.01	0	0	0	0	0.01	0.01	0	0	-0.01	-0.01	0.2
44.1	26.75	30	44.578	0.04	-0.01	-0.01	-0.03	-0.03	0.01	0	-0.01	-0.02	-0.04	-0.03	-0.06	0.2
50	0.02	2	50	0.01	0	0	0	0	0.02	0.01	0.01	0	0.01	0.01	0.02	0.2
52.1	26.75	30	44.578	0.03	0	-0.01	-0.05	-0.01	0	-0.01	-0.03	0	-0.11	-0.07	-0.07	0.2
57.9948	0.02	2	57.9868	0.01	0	0	-0.01	-0.01	-0.01	0	0	-0.01	-0.01	-0.03	-0.05	0.2
58.344	26.75	30	44.999	-0.02	-0.04	-0.07	-0.12	-0.05	-0.05	-0.06	-0.09	-0.05	-0.18	-0.13	-0.11	0.2
60.1	26.75	30	60.1	0.02	0.01	0.01	0	-0.01	0	0.01	0.01	0.01	0	-0.01	-0.03	0.2
100.1	26.75	30	100.1	0.02	0.01	0.01	0.01	0	0	0.02	0.01	0	0	-0.02	-0.02	0.2
200.1	26.75	30	200.1	0	0	0	-0.01	-0.02	-0.02	0	-0.01	-0.02	-0.02	-0.03	-0.04	0.2
300.1	26.75	30	300.1	0	0	0	0	-0.01	0	0.01	0	0	0	-0.02	-0.02	0.2
400.1	26.75	30	400.1	0	0	-0.01	-0.01	-0.02	-0.02	0	-0.01	-0.01	-0.02	-0.02	-0.05	0.2

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Frequency in MHz	Fspan in MHz	RBW in kHz	Fcent in MHz	MR												U
				-30	-28	-25	-20	-15	-10	-5	0	5	10	15	20	
500.1	26.75	30	500.1	-0.01	-0.01	-0.01	-0.01	-0.02	-0.03	0	-0.01	-0.01	-0.02	-0.03	-0.04	0.2
600.1	26.75	30	600.1	0	0	0	-0.01	-0.01	-0.02	0	-0.01	-0.01	-0.01	-0.02	-0.04	0.2
700.1	26.75	30	700.1	0	0	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01	-0.02	-0.02	-0.04	-0.04	0.2
800.1	26.75	30	800.1	0	0	-0.01	-0.01	-0.02	-0.03	-0.01	0	-0.01	-0.02	-0.04	-0.05	0.2
900.1	26.75	30	900.1	-0.01	-0.01	-0.02	-0.01	-0.02	-0.03	-0.01	-0.01	-0.01	-0.03	-0.03	-0.05	0.2
1000.1	26.75	30	1000.1	-0.02	-0.03	-0.02	-0.03	-0.04	-0.05	-0.02	-0.03	-0.03	-0.04	-0.05	-0.08	0.2
1100.1	26.75	30	1100.1	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.01	-0.02	-0.02	-0.03	-0.04	-0.06	0.2
1200.1	26.75	30	1200.1	-0.01	-0.01	-0.02	-0.02	-0.03	-0.03	-0.02	-0.02	-0.03	-0.04	-0.04	-0.06	0.2
1300.1	26.75	30	1300.1	-0.01	-0.01	-0.01	-0.02	-0.03	-0.02	-0.02	-0.02	-0.02	-0.03	-0.04	-0.05	0.2
1400.1	26.75	30	1400.1	0.01	0.02	0.02	0.01	0.01	0	0.01	0.01	0	0	-0.01	-0.03	0.2
1500.1	26.75	30	1500.1	0.03	0.03	0.03	0.02	0.02	0.01	0.03	0.03	0.02	0.01	0	0	0.2
1600.1	26.75	30	1600.1	0.02	0.02	0.01	0.01	0.01	0	0.03	0.02	0.01	0	0	-0.01	0.2
1700.1	26.75	30	1700.1	0.06	0.06	0.06	0.05	0.05	0.04	0.07	0.06	0.04	0.04	0.03	0.02	0.2
1800.1	26.75	30	1800.1	0.02	0.02	0.02	0.01	0	0.01	0.01	0.01	0	0	-0.01	-0.04	0.2
1900.1	26.75	30	1900.1	0.01	0	0	-0.01	-0.02	-0.02	0	0	-0.01	-0.01	-0.02	-0.04	0.2
2000.1	26.75	30	2000.1	0.01	0	0.01	0.01	-0.01	-0.01	0.01	0.01	0	0	-0.02	-0.03	0.2
2100.1	26.75	30	2100.1	0.02	0.01	0.01	0	-0.01	0	0.01	0.01	0.01	0	-0.01	-0.03	0.2
2200.1	26.75	30	2200.1	0.01	0.02	0.01	0.01	-0.01	0	0.02	0.01	0	0	-0.01	-0.03	0.2
2300.1	26.75	30	2300.1	0.02	0.02	0.01	0.01	0	0	0.02	0.02	0.01	0.01	-0.01	-0.01	0.2
2400.1	26.75	30	2400.1	0.03	0.04	0.03	0.02	0.02	0.02	0.04	0.03	0.03	0.01	0	-0.03	0.2
2500.1	26.75	30	2500.1	-0.01	-0.01	0	-0.02	-0.02	-0.02	0	0	-0.01	-0.02	-0.03	-0.04	0.2
2600.1	26.75	30	2600.1	0.01	0	0.01	0	-0.01	0	0.02	0.01	0	0	-0.01	-0.03	0.2
2700.1	26.75	30	2700.1	0.04	0.04	0.03	0.02	0.02	0.03	0.04	0.03	0.03	0.02	0.02	-0.01	0.2
2800.1	26.75	30	2800.1	0.05	0.05	0.04	0.03	0.03	0.04	0.05	0.05	0.04	0.03	0.02	0.01	0.2
2900.1	26.75	30	2900.1	0.02	0.02	0.02	0.01	0	0.01	0.04	0.04	0.03	0.03	0.01	0	0.2
2999.9	26.75	30	2999.9	0.01	0.02	0.03	0	0.01	0.02	0.03	0.03	0.01	0.02	0	-0.01	0.2
3002.1	26.75	30	3002.1	-0.04	-0.02	-0.02	-0.01	-0.03	0	0.01	0.01	-0.01	0	-0.02	-0.03	0.2
3100.1	26.75	30	3100.1	-0.02	-0.02	-0.02	-0.02	-0.02	0	0	0.01	-0.01	0	-0.01	-0.03	0.2
3200.1	26.75	30	3200.1	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.03	0.02	0.02	0.02	0.01	-0.01	0.2
3300.1	26.75	30	3300.1	0	0.01	0.01	0	0	0.02	0.03	0.01	0.03	0.02	0.02	0	0.2
3400.1	26.75	30	3400.1	0	0	-0.01	-0.02	-0.02	0.02	0.03	0.01	0.01	0.01	0	-0.02	0.2
3500.1	26.75	30	3500.1	0.01	0.01	0	0	-0.01	0.02	0.04	0.02	0.03	0.02	0.01	-0.01	0.2

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Frequency in MHz	Fspan in MHz	RBW in kHz	Fcent in MHz	MR												U
				-30	-28	-25	-20	-15	-10	-5	0	5	10	15	20	
3600.1	26.75	30	3600.1	0	0	-0.01	0	-0.02	0.01	0.02	0.02	0.03	0.02	0	-0.02	0.2
3700.1	26.75	30	3700.1	-0.02	-0.02	-0.02	-0.02	-0.03	0	0.03	0.01	0.01	0.01	0	-0.02	0.2
3800.1	26.75	30	3800.1	-0.02	-0.01	-0.02	-0.02	-0.04	0.01	0.02	0.01	0.01	0	-0.01	-0.03	0.2
3900.1	26.75	30	3900.1	-0.01	-0.01	-0.02	-0.02	-0.02	0	0.02	0.02	0.01	0.01	-0.01	-0.02	0.2
4000.1	26.75	30	4000.1	-0.02	-0.01	-0.01	-0.02	-0.03	0.01	0.01	0.01	0	0	-0.02	-0.04	0.2
4100.1	26.75	30	4100.1	0.02	0.01	0.01	0	0	0.04	0.05	0.05	0.04	0.03	0.01	0.02	0.2
4200.1	26.75	30	4200.1	0.03	0.03	0.03	0.03	0.01	0.06	0.07	0.05	0.07	0.04	0.05	0.02	0.2
4300.1	26.75	30	4300.1	0.03	0.04	0.03	0.03	0.01	0.04	0.06	0.06	0.06	0.04	0.03	0.01	0.2
4400.1	26.75	30	4400.1	0	-0.01	-0.01	-0.01	-0.01	0.01	0.03	0.03	0.02	0.01	-0.01	-0.05	0.2
4500.1	26.75	30	4500.1	-0.02	-0.03	-0.04	-0.04	-0.05	-0.02	0.01	0.01	0	-0.02	-0.04	-0.05	0.2
4600.1	26.75	30	4600.1	0	0	0	0	-0.01	0	0.04	0.03	0.01	0	0.01	-0.03	0.2
4700.1	26.75	30	4700.1	0.02	0.01	0.01	0	-0.01	0.01	0.04	0.03	0.03	0.01	0.01	-0.02	0.2
4800.1	26.75	30	4800.1	-0.01	0	-0.02	-0.01	-0.03	-0.02	0.01	0	-0.01	-0.02	-0.06	-0.08	0.2
4900.1	26.75	30	4900.1	-0.04	-0.03	-0.04	-0.06	-0.07	-0.05	-0.02	-0.03	-0.04	-0.06	-0.06	-0.09	0.2
5000.1	26.75	30	5000.1	-0.03	-0.03	-0.04	-0.04	-0.05	-0.04	-0.01	-0.02	-0.04	-0.04	-0.05	-0.07	0.2
5100.1	26.75	30	5100.1	-0.02	-0.02	-0.01	-0.01	-0.04	-0.02	-0.01	-0.01	-0.01	-0.03	-0.04	-0.09	0.2
5200.1	26.75	30	5200.1	0	0	0.01	0	-0.03	0	0	0.01	-0.01	-0.01	-0.03	-0.05	0.2
5300.1	26.75	30	5300.1	0.03	0.02	0.03	0.01	0	0.01	0.02	0.02	0.01	0.01	-0.02	-0.06	0.2
5400.1	26.75	30	5400.1	0.01	0.02	0.01	0.01	-0.01	0	0.02	0	0	0	-0.03	-0.07	0.2
5500.1	26.75	30	5500.1	0.01	0.01	0.02	0.01	0	-0.02	0.02	0.01	0	-0.01	-0.03	-0.05	0.2
5600.1	26.75	30	5600.1	0.03	0.04	0.02	0.03	0.01	-0.02	0.02	0.02	0.02	0.01	-0.02	-0.04	0.2
5700.1	26.75	30	5700.1	0.03	0.03	0.04	0.03	0.03	-0.01	0.03	0.01	0	0.02	0	-0.04	0.2
5800.1	26.75	30	5800.1	0.03	0.04	0.04	0.03	0.02	0	0.02	0.01	0.01	0	-0.02	-0.04	0.2
5900.1	26.75	30	5900.1	0.04	0.04	0.04	0.02	0.01	-0.02	0.01	-0.01	0	-0.02	-0.03	-0.06	0.2
5986.1	26.75	30	5986.625	0.05	0.05	0.05	0.04	0.04	0	0.02	0.02	0.01	0	-0.01	-0.06	0.2

Frequency Response *G* and Uncertainty *U* in dB

Appendix C

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Calibration Certificate

Narda Safety Test Solutions hereby certifies that the referenced equipment has been calibrated by qualified personnel to Narda's approved procedures. The calibration was carried out within a certified quality management system conforming to ISO 9001.

Object	**Antenna, Three-Axis, E-Field, 27 MHz to 3 GHz**
Part Number (P/N)	**3501/03**
Serial Number (S/N)	**K-0242**
Manufacturer	Narda Safety Test Solutions GmbH
Customer	
Date of Calibration	07-Okt-2010
Results of Calibration	Test results within specifications
Confirmation interval recommended	24 Months
Ambient conditions	Temperature: (23 ± 3) °C Relative humidity: (20 to 60) %
Calibration procedure	3000-8702-00A

Pfullingen, 07-Okt-2010

MANAGEMENT SYSTEM

Person in charge
Geyer

i.A.
Head of Laboratory
J. v. Freeden

Certified by DQS according to ISO 9001:2008 (Reg.-No. 099379 QM08)

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Measurements

The calibration of RF field strength probes involves the generation of a calculable linearly polarized electromagnetic field, approximating to a plane wave, into which the device is placed.
The RSS value of three axis is used.

At each test frequency, the probe is orientated in the analytic angle (54.74 degrees between probe axis and electric field vector) and rotated 360 degrees. The noted indicated output voltage is calculated from the geometric mean of the minimum and maximum readings during rotation. The antenna factor is calculated from the ratio of the applied field strength to the output voltage (nominal impedance 50 Ohm). The minimum and maximum readings during rotation are further used to calculate the ellipse ratio.
A power meter head is connected by means of an ferrite beaded 50 Ohm coaxial cable.

A Crawford TEM cell is used to generate the known field at frequencies up to 100 MHz. The field strength is derived from the TEM cell's properties and from the output power of the cell.
Over the frequency range from 200 MHz to 1.6 GHz, the probe is positioned in front of a double balanced ridge horn antenna. The field strength is set to a known value by means of a calibrated E-field reference probe.
Above 1.7GHz the probe is positioned with the boresight of a linearly polarized horn antenna. The field strength is derived from the mechanical dimensions and the input power of the antenna.

The antenna factor is permanently stored in the antenna connector memory. When combined with the SRM basic unit (BN 3001 series) the frequency response of the antenna is automatically compensated.

Uncertainties

The measurement uncertainty stated in this document is the expanded uncertainty with a coverage factor of 2 (corresponding, in the case of normal distribution, to a confidence probability of 95%).

The uncertainty analysis for this calibration was done in accordance with the ISO-Guide (**G**uide to the expression of **U**ncertainty in **M**easurement). The measurement uncertainties are derived from contributions from the measurement of power, impedance, attenuation, mismatch, length, frequency, stability of instrumentation, repeatability of handling and field uniformity in the field generators (TEM cell and anechoic chamber).

This statement of uncertainty applies to the measured values only and does not make any implementation or include any estimation as to the long-term stability of the calibrated device.

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Traceability of Measuring Equipment

The calibration results are traceable to National Standards, which are consistent with the recommendations of the General Conference on Weights and Measure (CGPM), or to standards derived from natural constants. Physical units, which are not included in the list of accredited measured quantities such as field strength or power density, are traced to the basic units via approved measurement and computational methods.

The equipment used for this calibration is traceable to the reference listed above and the traceability is guaranteed by ISO 9001 Narda internal procedure.

Reference- / Working- Standard	Manu facturer	Model	Serial Number	Certificate Number	Cal Due Date	Trace
Power Sensor	R&S	NRV-Z4	100122	0171 DKD-K-16101 2008-11	2010-11	DKD
RF-Millivoltmeter	R&S	URV55	100213	0224 DKD-K-16101 2010-08	2012-08	DKD
Set-Up "A" (1800 MHz to 3 GHz)						
Calliper	Preisser	0-800mm	310121016	649724 DKD-K-12001 06-05	#	DKD
Power Sensor	agilent	8481A	US37299951	1-2217165994-1	2011-08	UKAS147
Power Sensor	agilent	8481A	US37299952	1-2217214152-1	2011-09	UKAS147
Power Meter	agilent	E4419A	MY40330449	1-2217141092-1A	2011-09	UKAS147
Set-Up "B" (200 MHz to 1600 MHz)						
E-Field Reference Probe	Narda	Type 9.2	V-0017	51200637E	#	SIT08
Power Sensor	agilent	8481A	US37299870	1-2217214643-1	2011-09	UKAS147
Power Sensor	agilent	8481A	2702A57611	1-2217165866-1	2011-09	UKAS147
Power Meter	agilent	E4419B	GB43311917	1-2295928041-1A	2011-11	UKAS147
Set-Up "D" (100 kHz to 100 MHz)						
Calliper	Preisser	0-800mm	310121016	649724 DKD-K-12001 06-05	#	DKD
Power Sensor	agilent	8482A	2652A13544	08D177 DKD-K-02201 2008-06	2010-12	DKD
Power Meter	agilent	438A	2741U00723	1-1321958613-1A	2010-12	UKAS147
Attenuator	Weinschel	49-30-33	KC115	3248 DKD-K-00501 2008-06	2011-06	DKD

\# Reference standard; not used for routine calibration

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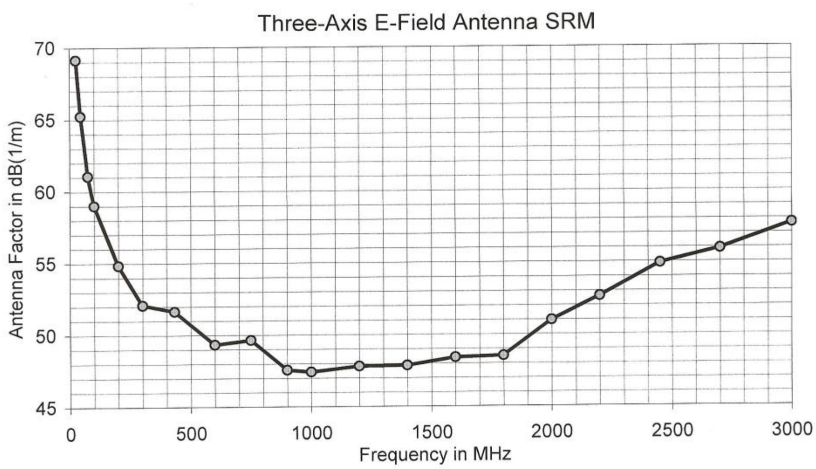
Results

Frequency Response passed

Frequency in MHz	E_applied in V/m	Output voltage in dB(µV)	Meas. Uncertainty in dB	Antenna Factor in dB(1/m)
26	10,0	70,85	1,0	69,15
45	10,0	74,76	1,0	65,24
75	10,0	78,95	1,0	61,05
100	10,0	81,00	1,0	59,00
200	10,0	85,17	1,0	54,83
300	10,0	87,92	1,0	52,08
433	10,0	88,36	1,5	51,64
600	10,0	90,66	1,5	49,34
750	10,0	90,35	1,5	49,65
900	10,0	92,45	1,5	47,55
1000	10,0	92,59	1,5	47,41
1200	10,0	92,20	1,5	47,80
1400	10,0	92,15	1,5	47,85
1600	10,0	91,60	1,5	48,40
1800	10,0	91,49	1,0	48,51
2000	10,0	89,04	1,0	50,96
2200	10,0	87,37	1,0	52,63
2450	10,0	85,11	1,0	54,89
2700	10,0	84,11	1,0	55,89
3000	10,0	82,34	1,0	57,66

Frequency Flatness (100 - 3000 MHz): 11,6 dB

The Antenna Factor data is permanently stored in the antenna connector memory.
The SRM basic unit uses this correction data to correct the display.



Certificate No. 350103-K0242-101007 Date of issue: 07-Okt-2010 Page 4 of 5

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Rotational Ellipticity **passed**

Frequency in MHz	Ellipse Ratio in dB
26	+/-0,13
45	+/-0,17
75	+/-0,12
100	+/-0,10
200	+/-0,10
300	+/-0,11
433	+/-0,11
600	+/-0,10
750	+/-0,15
900	+/-0,17
1000	+/-0,24
1200	+/-0,37
1400	+/-0,41
1600	+/-0,63
1800	+/-0,80
2000	+/-1,13
2200	+/-1,55
2450	+/-1,53
2700	+/-1,37
3000	+/-1,69

Output Return Loss **passed**

Appendix D

Calibration Certificate for the Narda EHP-50D Electric and Magnetic Field Analyzer

Appendix D

narda Safety Test Solutions
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Narda Safety Test Solutions S.r.l.
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20090 Segrate (MI)
Tel.: +39 02 2699871 Fax: +39 02 26998700
Manufacturing Plant: Via Benessea, 29/B
17035 Cisano sul Neva (SV)
Tel.: +39 0182 58641 Fax: +39 02 586400

CERTIFICATE OF CALIBRATION
Certificato di taratura

Number 10510
Numero

Item *Oggetto*	Electric and Magnetic field Probe - Analyzer
Manufacturer *Costruttore*	Narda S.T.S. / PMM
Model *Modello*	EHP50D
Serial number *Matricola*	000WX10510
Calibration procedure *Procedura di taratura*	Internal procedure PTP 09-31
Date(s) of measurements *Data(e) delle misure*	23.06.2011
Result of calibration *Risultato della taratura*	Measurements results within specifications

This calibration certificate documents the traceability to national/international standards, which realise the physical units of measurements according to the International System of Units (SI). Verification of traceability is guaranteed by mentioning used equipment included in the measurement chain. This equipment includes reference standard directly traceable to (inter)national standard (accuracy rating A) and working standard calibrated by the calibration laboratory of Narda Safety Test Solutions (accuracy rating B) by means of reference standard A or by other calibration laboratory.
The measurement uncertainties stated in this document are estimated at the level of twice the standard deviation (corresponding, in the case of normal distribution, to a confidence level of about 95%). The uncertainties are calculated in conformity to the ISO Guide (Guide to the expression of uncertainty in measurement).The metrological confirmation system for the measuring equipment used is in compliance with ISO 10012-1. The applied quality system is certified to UNI EN ISO 9001.
Questo certificato di taratura documenta la tracciabilità a campioni primari nazionali o internazionali i quali realizzano la riferibilità alle unità fisiche del Sistema Internazionale delle Unità (SI). La verifica della tracciabilità è garantita elencando gli strumenti presenti nella catena di misura.La catena di riferibilità metrologica fa riferimento a campioni di prima linea direttamente riferiti a standard (inter)nazionali (classe A), di seconda linea, tarati nel laboratorio metrologico della Narda Safety Test Solutions con riferibilità ai campioni di prima linea oppure tarati da Enti esterni accreditati (classe B).
Le incertezze di misura dichiarate in questo documento sono espresse come due volte lo scarto tipo (corrispondente, nel caso di distribuzione normale, a un livello di confidenza di circa 95%). Le incertezze di misura sono calcolate in riferimento alla guida ISO. La conferma metrologica della strumentazione usata è conforme alla ISO 10012-1. Il sistema di qualità è certificato ISO 9001.

COMPANY WITH QUALITY MANAGEMENT SYSTEM CERTIFIED BY DNV
= ISO 9001:2000 =

Date of issue *Data di emissione*	**Measure operator** *Operatore misure*	**Person responsible** *Responsabile*
28.06.2011	F. Ferrari (OPERATORE n. 03)	G. Basso

The calibration was carried out at an ambient temperature of (23 ± 3)°C and at a relative humidity of (50 +10/-20)%.

Calibration method

The magnetic calibration was set up with the probe in a region of uniform magnetic field at the centre of a calibrated Helmholtz coil system. The magnetic flux density is calculated from the current flowing in the coil. The current waveform was sinusoidal. The current in the Helmholtz coil system was adjusted to produce a series of indicated magnetic flux densities on the instrument at various frequencies. The calibration procedure agrees with the indication of IEC 61786 "Measurement of low frequency magnetic and electric fields with regard to exposure of human beings- Special requirements for instruments"
The instrument readings were recorded and the actual values of magnetic flux density were calculated from the measured currents.
The magnetic correction factor (CF) is defined as rapport between actual and indicated magnetic flux density.

$$CF = \frac{Bo}{Bmis}$$

where Bo is the applied magnetic flux density and Bmis is the indicated magnetic flux density

For the electric calibration the probe is positioned inside a big TEM cell (section 1.8x1.8 mete
For each measurement, the input voltage was adjusted so that the field strength was set to a specified reading on the monitor.
The actual field strength, at the plane of reference of the probe was then determined and the correction factor calculated using the following definition.

$$CF = \frac{Eo}{Emis}$$

where Eo is the applied field strength and Emis is the indicated field strength

The correction factor data are permanently stored in the internal EEPROM.

Calibration equipment and traceability

ID Number	Description	Manufacturer	Model	Trace
PMM 391	Digital multimeter	Agilent	34401A	/SIT
CMR 169	Electric and Magnetic ref. Probe	Narda	EHP50C-REF	/INRIM
CMR 090	Standard resistor	Narda	PMM BSD250	/NPL
CMR 095	Current Trasformer	Frer	AP10-1TAC010	/INRIM
CMR 001	TEM Cell	Narda	1818	/Narda
CMR 020	Helmholtz coil	Narda	HCSS001	/Narda

Uncertainty of measurements

The statement of uncertainty (see first page) does not make any implication or include any estimation as to the long term stablity of the calibrated monitor. The relative expanded uncertainty result are given below

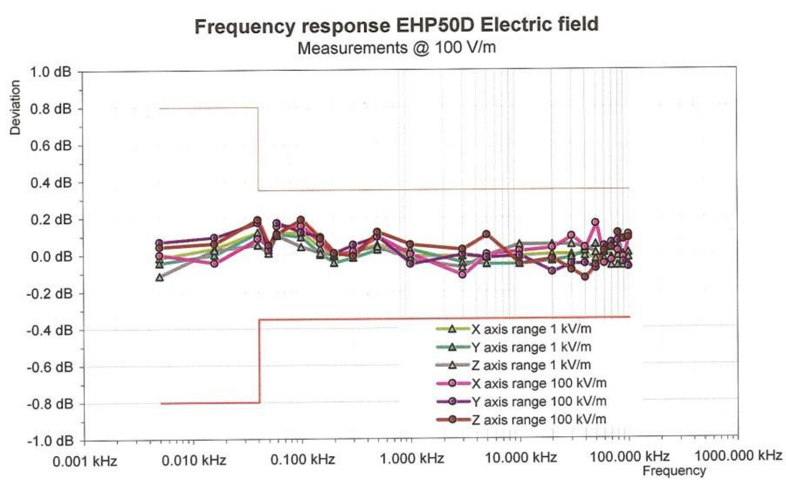
E field	3% at 50 Hz
	7.5% other frequencies
H field	2% at 50 Hz with 100µT range
	3.5% at 50 Hz with 10mT range
	3% other frequencies

Results

The results of measurements in the following pages were obtained after calibration data storing and indicates the residual of the reciprocal CF.
The results given on the tables were obtained with the axis aligned at the electric vector for electric measurements and with axis concatenated at the magnetic flux density for magnetic mesurements
The shown limits of the EHP50D specification in the diagrams are in orange.

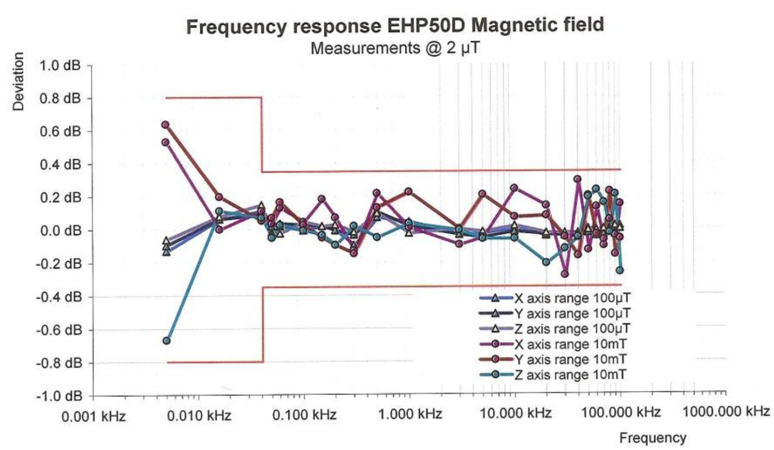
Electric field Frequency response for each axis at nominal field of 100 V/m.
The instrument was set as electric field measure with 100 Hz span up to the frequency of 100 Hz, 200 Hz span up to the frequency of 200 Hz, 500 Hz span up to the frequency of 500 Hz, 1 kHz up to 1000 Hz, 10 kHz up to 10 kHz and 100 kHz span for frequency over 10 kHz

Freq. (kHz)	Deviation with 1kV/m range			Deviation with 100 kV/m range		
	X axis	Y axis	Z axis	X axis	Y axis	Z axis
	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
0.005	-0.02	-0.04	-0.11	0.00	0.07	0.04
0.016	0.03	0.00	0.03	-0.04	0.10	0.06
0.04	0.12	0.12	0.05	0.09	0.17	0.19
0.05	0.03	0.03	0.01	0.04	0.03	0.05
0.06	0.11	0.11	0.10	0.15	0.17	0.11
0.10	0.12	0.10	0.04	0.15	0.12	0.19
0.15	0.03	0.00	0.01	0.06	0.10	0.09
0.20	-0.01	-0.04	0.00	0.00	0.01	0.01
0.30	0.02	-0.02	0.02	0.02	0.05	-0.01
0.50	0.05	0.03	0.04	0.10	0.10	0.12
1.00	-0.01	0.03	-0.03	0.00	-0.05	0.05
3.00	-0.01	-0.04	-0.07	-0.11	0.00	0.03
5.00	-0.02	-0.05	-0.01	0.00	-0.02	0.10
10.00	-0.01	-0.05	0.05	0.02	-0.01	-0.05
20.0	0.00	-0.03	0.05	0.03	-0.10	-0.03
30.0	0.00	-0.02	0.05	0.10	-0.05	-0.09
40.0	-0.01	0.02	0.03	0.03	-0.05	-0.13
50.0	-0.03	0.05	0.01	0.16	-0.08	-0.06
60.0	0.01	0.02	-0.03	-0.05	0.04	0.02
70.0	0.03	-0.02	-0.06	-0.03	0.06	0.03
80.0	-0.01	-0.06	0.03	0.02	0.07	0.11
90.0	-0.06	0.00	-0.03	-0.02	-0.04	0.08
100.0	-0.05	0.01	-0.02	0.10	-0.07	0.09



Magnetic Field Frequency response for each axis at nominal magnetic flux density of 2μT.
The instrument was set as magnetic field measure with 100 Hz span up to the frequency of 100 Hz, 200 Hz span up to the frequency of 200 Hz, 500 Hz span up to the frequency of 500 Hz, 1 kHz up to 1000 Hz, 10 kHz up to 10 kHz and 100 kHz span for frequency over 10 kHz

Freq. (kHz)	Deviation with 100μT range			Deviation with 10mT range		
	X axis (dB)	Y axis (dB)	Z axis (dB)	X axis (dB)	Y axis (dB)	Z axis (dB)
0.005	-0.13	-0.10	-0.06	0.53	0.64	-0.67
0.016	0.06	0.06	0.08	0.00	0.20	0.11
0.04	0.11	0.09	0.15	0.11	0.05	0.07
0.05	-0.02	0.02	-0.03	0.03	0.07	-0.05
0.06	0.02	0.03	-0.03	0.13	0.16	0.03
0.10	-0.01	0.03	0.04	0.04	0.03	-0.01
0.15	0.02	0.02	0.02	0.18	-0.05	-0.03
0.20	-0.01	-0.01	0.03	0.07	-0.10	-0.10
0.30	-0.10	-0.03	-0.02	-0.13	-0.15	0.02
0.50	0.07	0.10	0.10	0.21	0.13	-0.05
1.00	0.04	0.02	-0.03	0.01	0.22	0.03
3.00	-0.03	-0.03	0.00	-0.10	0.00	-0.01
5.00	-0.03	-0.05	-0.02	-0.05	0.21	-0.06
10.00	0.00	-0.02	0.02	0.24	0.07	-0.06
20.0	-0.04	-0.03	-0.03	0.14	0.08	-0.21
30.0	-0.03	-0.04	-0.03	-0.28	-0.05	-0.12
40.0	-0.03	-0.05	-0.03	0.29	-0.17	-0.05
50.0	0.00	-0.03	-0.01	-0.13	0.20	0.19
60.0	-0.01	-0.04	-0.01	0.13	-0.03	0.23
70.0	-0.02	-0.03	0.00	-0.10	-0.07	0.15
80.0	-0.02	0.00	-0.02	0.05	0.22	-0.03
90.0	-0.03	-0.03	0.02	-0.04	-0.16	0.21
100.0	0.02	0.00	0.00	0.15	-0.06	-0.26



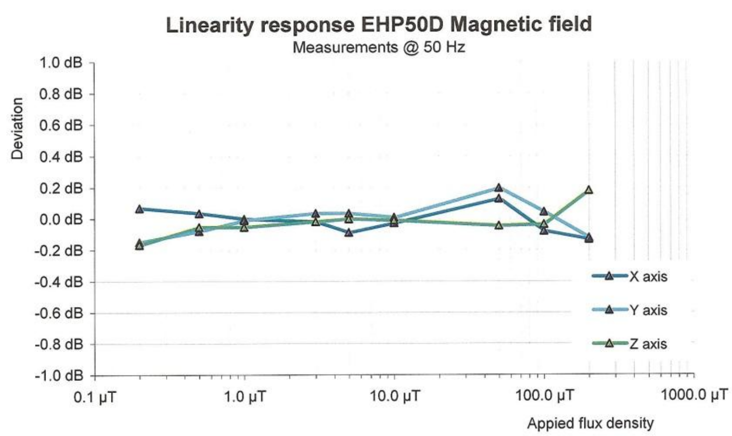
EHP50D_Narda-Certificate of Calibration_r01_000WX10510.xls

Appendix D

Magnetic Field Linearity response for each axis at applied frequency of 50 Hz and magnetic flux density below
The instrument was set with 100 Hz span.

Applied flux density (μT)	Deviation		
	X axis (dB)	Y axis (dB)	Z axis (dB)
0.2	0.07	-0.15	-0.17
0.5	0.03	-0.08	-0.05
1.0	0.00	-0.01	-0.05
3.0	-0.02	0.03	-0.02
5.0	-0.09	0.03	0.00
10	-0.03	0.01	-0.01
50	0.13	0.20	-0.04
100	-0.08	0.04	-0.03
200	-0.13	-0.12	0.18

X axis linearity 0.13 dB
Y axis linearity 0.17 dB
Z axis linearity 0.17 dB



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Appendix D

narda
Safety Test Solutions
an L3 Communications Company

Determining the Recalibration Due Date

Determinazione della data di ricalibrazione

The Certificate of Calibration accompanying this product states the date that this unit was calibrated according to Narda Safety Test Solutions procedures. We have determined that the calibration of this product is not affected by storage prior to its initial receipt by the customer.
The recalibration of this unit should be based on the date when the product is put into service, plus the recommended calibration interval.

The Narda Safety Test Solutions recommended calibration interval is 24 months. To determine the date for recalibration, the customer should use the appropriate start date, and apply either the Narda Safety Test Solutions calibration interval, or an interval that satisfies their own organization's internal quality system requirements.

Il certificato di taratura che accompagna questo strumento attesta la data di taratura, quest'ultima eseguita in accordo alle procedure interne. La Narda Safety Test Solutions assicura che la taratura dello strumento non viene alterata da eventuali tempi di attesa prima del ricevimento da parte del cliente.
La ri-taratura di questo strumento dovrebbe essere effettuata adottando appropriati intervalli di taratura, a partire dalla data di messa in servizio.

La Narda Safety Test Solutions raccomanda un massimo intervallo di taratura di 24 mesi. Per determinare la data di ri-taratura, l'utente dovrebbe considerare l'intervallo raccomandato dalla Narda Safety Test Solutions o un intervallo che soddisfa i requisiti interni di qualità della propria organizzazione.

Model *Modello*	EHP 50 D
Serial Number *Matricola*	000WX10510
Put into service date *Data di messa in servizio*	05/15/2012

For additional information please contact
Per informazioni aggiuntive

Narda S.T.S. Calibration Laboratory
Via Benessea, 29/B
17035 Cisano sul Neva (SV) - Italy
Tel.: +39 0182 58641 Fax: +39 0182 586400

Appendix E

Calibration Certificate for the Comparison SRM-3006 Probe/Antenna

Narda Safety Test Solutions GmbH
Sandwiesenstrasse 7 - 72793 Pfullingen - Germany
Phone: +49 7121 9732 0 - Fax: +49 7121 9732 790

narda Safety Test Solutions®

Calibration Certificate

Narda Safety Test Solutions hereby certifies that the object referred to in this certificate has been calibrated by qualified personnel using Narda's approved procedures. The calibration was carried out in accordance with a certified quality management system which conforms to ISO 9001

OBJECT	Three-Axis-Antenna, E-Field, 50 MHz to 3 GHz
MANUFACTURER	Narda Safety Test Solutions GmbH
PART NUMBER (P/N)	P/N 3501/02
SERIAL NUMBER (S/N)	H-0368
CUSTOMER	
CALIBRATION DATE	27-Okt-2011
RESULT ASSESSMENT	within specifications
AMBIENT CONDITIONS	Temperature: (23 ± 3) °C Relative humidity: (20 to 60) %
CALIBRATION PROCEDURE	3000-8702-00A

ISSUE DATE: 2011-10-27

MANAGEMENT SYSTEM

CALIBRATED BY
Kretschmann

AUTHORIZED SIGNATORY

Certified by DQS against ISO 9001:2008 (Reg.-No. 099379 QM08)

Appendix F

Integration of RF Spectra Acquired on the SRM-3006

Appendix F

SRM-3006 Spectrum Signal Integration

The SRM-3006 Selective Radiation Meter is a fast Fourier transform (FFT) type of analyzer. Rather than using traditional analog frequency sweeping technology in which the instrument tunes from a lower frequency to a higher frequency, the SRM samples the RF signal provided to it from the associated probe/antenna subsystem for a short period of time using an ultra-fast analog to digital converter. Upon Fourier transform of the time series data, this process produces a data set of signal amplitudes at frequencies distributed uniformly through the desired analysis band. The number of such frequencies (bins) depends on the overall frequency span and the resolution bandwidth (RBW) of the analyzer. The power associated with a given signal detected by the instrument can be determined through an integration process in which the powers found within all of the frequency bins over the selected frequency range are, effectively, summed.

This integration process, which can be implemented via firmware within the SRM, can also be accomplished manually by processing each stored amplitude value corresponding to a frequency bin. This approach was taken for integrating the composite (equivalent) RF field represented by multiple signals detected in the various frequency bands during the project for environmental measurements in Vermont.

Based on information provided by Narda, the integrated spectral RF field, $F_{integrated}$, derived from the measured spectral amplitude components, F_i, is obtained through the expression:

$$F_{\text{integrated}} = M_B \sum_i F_i$$

where M_B are multiplicative factors that depend on the specific frequency span and RBW setting for a given band. For the various settings used with the SRM for different frequency bands, the multiplicative factor values are listed in Table F-1.

A spreadsheet macro was developed that applied this process to the measured spectral data obtained from the SRM; the stored digital data file within the SRM was downloaded to a computer and then inserted into the spreadsheet tool for integration. An important part of the process, however, was the implementation of a threshold to be used with each band's data below which integration did not take place. This feature eliminated the potential of adding in noise floor values to the integration process, thereby increasing the overall integrated value erroneously. The noise thresholds listed in Table F-1 were experimentally determined by observing the displayed spectrum of detected RF fields across each band and selecting a value that would just slightly exceed the noise level for peak and average signal values.

Table F-1. Parameters used for band integration of the measured RF field spectral signals from the SRM including the multiplicative factors, M_B, and thresholds used for integration of spectra containing the peak values of RF fields (max threshold) and average values of fields (average threshold).

BAND	Multiplicative Factor	Max threshold	Average threshold
Low VHF	0.493680853	0.000003000	0.000000600
FM	0.493680885	0.000000500	0.000000100
High VHF	0.493680853	0.000000700	0.000000200
UHF	0.473933649	0.000000350	0.000000080
Cell	0.473933649	0.000001000	0.000000200

Glossary

Glossary of Terms Used in this Report

AMI- Advanced metering infrastructure.

antenna- A device designed to efficiently convert conducted electrical energy into radiating electromagnetic waves in free space (or vice versa).

antenna pattern- Typically a graphical plot illustrating the directional nature of radiated fields produced by an antenna. The pattern also shows the directional nature of the antenna when used for receiving signals.

attenuation- The phenomenon by which the amplitude of an RF signal is reduced as it moves from one point in a system to another. It is often given in decibels.

averaging Time (T_{avg})- The appropriate time period over which exposure is averaged for purposes of determining compliance with the maximum permissible exposure (MPE). For exposure durations less than the averaging time, the maximum permissible exposure, MPE', in any time interval, is found from:

$$\mathrm{MPE'} = \mathrm{MPE}\left(\frac{T_{avg}}{T_{exp}}\right)$$

where T_{exp} is the exposure duration in that interval expressed in the same units as T_{avg}. T_{exp} is limited by restriction on peak power density.

azimuth pattern- Commonly a term referring to an antenna pattern showing the distribution of radiated field from the antenna in the azimuth plane (horizontal plane).

bandwidth- A measure of the frequency range occupied by an electromagnetic signal. It is equal to the difference between the upper frequency and the lower frequency, usually expressed in Hertz.

burst- A wave or waveform composed of a pulse train (group of pulses) or repetitive waveform that starts at a prescribed time and/or amplitude, continues for a relatively short duration and/or number of cycles, and upon completion returns to the starting amplitude.

calibration correction factor- A numerical factor obtained through a calibration process that is used to multiply RF field meter readings by to obtain corrected readings to achieve the maximum accuracy possible.

continuous exposure- Exposure for durations exceeding the corresponding averaging time (usually 6 minutes for occupational exposure and 30 minutes for the general public). Exposure for less than the averaging time is called short-term exposure.

dBi- Decibel referenced to an isotropic antenna- a theoretical antenna which transmits (or receives) electromagnetic energy uniformly in all directions (i.e. there is no preferential direction).

dBm- A logarithmic expression for radiofrequency power where 0 dBm is defined as equal to 1 milliwatt (mW). Hence, +10 dBm is 10 mW, +20 dBm is 100 mW, etc., and -10 dBm is 0.1 mW.

decibel (dB)- A dimensionless quantity used to logarithmically compare some value to a reference level. For power levels (watts or watts/m^2), it would be ten times the logarithm (to the base ten) of the given power level divided by a reference power level. For quantities like volts or volts per meter, a decibel is twenty times the logarithm (to the base ten) of the ratio of a level to a reference level.

direct sequence- As used in direct sequence spread spectrum radio transmission, a modulation technique wherein the resulting transmitted bandwidth of a signal is spread over a much wider band and resembles white noise.

duty cycle- A measurement of the percentage or fraction of time that an RF field exists over some observation period.

effective isotropic radiated power (EIRP)- The apparent transmitted power from an isotropic antenna (i.e. a theoretical antenna that transmits uniformly in all possible directions as an expanding sphere). The EIRP can be greater than the actual power radiated because of the ability of the antenna to concentrate the transmitted power in certain directions. See gain.

electric field strength- A field vector (E) describing the force that electrical charges have on other electrical charges, often related to voltage differences, measured in volts per meter (V/m).

electromagnetic field- A composition of both an electric field and a magnetic field that are related in a fixed way that can convey electromagnetic energy. Antennas produce electromagnetic fields when they are used to transmit signals.

electromagnetic spectrum- The range of frequencies associated with electromagnetic fields. The spectrum ranges from extremely low frequencies beginning at zero hertz to the highest frequencies corresponding to cosmic radiation from space.

elevation pattern- Commonly a term referring to an antenna pattern showing the distribution of radiated field from the antenna in the elevation plane (vertical plane).

end point meter- A term used to designate a smart meter that is installed on a home or business to record and transmit electric energy.

exposure- Exposure occurs whenever a person is subjected to electric, magnetic or electromagnetic fields or to contact currents other than those originating from physiological processes in the body and other natural phenomena.

far field- The far field is a term used to denote the region far from an antenna compared to the wavelength corresponding to the frequency of operation. It is a distance from an antenna beyond which the transmitted power densities decrease inversely with the square of the distance.

Federal Communications Commission (FCC)- The Federal Communications Commission (FCC) is an independent agency of the US Federal Government and is directly responsible to Congress. The FCC was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite, and cable. The FCC also allocates bands of frequencies for non-government communications services (the NTIA allocates government frequencies). The guidelines for human exposure to radio frequency electromagnetic fields as set by the FCC are contained in the Office of Engineering and Technology (OET) Bulletin 65, Edition 97-01 (August 1997). Additional information is contained in OET Bulletin 65 Supplement A (radio and television broadcast stations), Supplement B (amateur radio stations), and Supplement C (mobile and portable devices).

FFT- Fast Fourier Transform, a mathematical method for transforming data acquired in the time domain into the frequency domain. Some modern spectrum analyzers use high speed analog to digital converters (ADCs) to sample an input signal in the time domain and electronically implement the FFT to calculate and display the frequency spectrum of the sampled signal(s).

free space- A term used to denote an environment free of objects that can reflect, scatter or absorb RF energy. Anechoic chambers can provide free space environments that eliminate most reflections when testing antennas.

frequency hopping- A term describing the transmission frequency of a spread spectrum transmitter or transceiver that jumps (hops) instantaneously to different frequencies within a certain band of frequencies.

gain, antenna- A measure of the ability of an antenna to concentrate the power delivered to it from a transmitter into a directional beam of energy. A search light exhibits a large gain since it can concentrate light energy into a very narrow beam while not radiating very much light in other directions. It is common for cellular antennas to exhibit gains of 10 dB or more in the elevation plane, i.e., concentrate the power delivered to the antenna from the transmitter by a factor of 10 times in the direction of the main beam giving rise to an effective radiated power greater than the actual transmitter output power. In other directions, for example, behind the antenna, the antenna will greatly decrease the emitted signals. Gain is often referenced to an isotropic antenna (given as dBi) where the isotropic antenna has unity gain (unity gain is equivalent to 0 dBi). At regions out of the main beam of an antenna, such as behind the antenna in a smart meter, the gain of the antenna may be so small that it is less than that of an isotropic antenna and has a gain specified as a negative dBi.

gigahertz (GHz)- One billion hertz.

ground reflection factor- A factor commonly used in calculations of RF field power densities that expresses the power reflection coefficient of the ground over which the RF field is being computed. The purpose of the factor is to account for the fact that ground reflected RF fields can add constructively in an enhanced (stronger) resultant RF field. The ground reflection factor becomes significantly less important for near-field exposures very close to an RF source, such as a smart meter.

HAN- See home area network

hertz- The unit for expressing frequency, one hertz (Hz) equals one cycle per second.

Home Area Network- A term that refers to residential local area network for communication between digital devices typically deployed in the home, commonly implemented by way of a ZigBee radio.

IEEE- Institute of Electrical and Electronics Engineers.

inverted F antenna- The name given to an antenna design typically implemented on printed circuit cards in which the conductive part of the antenna resembles an inverted letter F. The antenna is typically approximately a quarter wavelength long and is fed from the attached transmitter near the end of the antenna that has a short conductive lead that extends from the longer part of the 'F' to the ground plane of the circuit. The antenna is vertically polarized when the long aspect of the 'F' is horizontal.

isotropic antenna- A theoretical antenna which transmits (or receives) electromagnetic energy uniformly in all directions (i.e. there is no preferential direction). The radiated wavefront is assumed to be an expanding sphere.

isotropic probe- Similar to isotropic antenna but normally related to RF measurement instruments designed to evaluate the magnitude of RF fields from a safety perspective. The isotopic character of the probe results in a measurement of the resultant RF field produced by all polarization components.

"license free"- A phrase meaning that an RF transmitter is operated at such low power and within an authorized frequency band that no formal license to operate is required by the FCC. There are restrictions placed on these devices, however, such as they shall not produce interference and/or may not create RF fields exceeding particular field strengths.

lobe, antenna- The name given to regions of an antenna transmitting pattern in which local maxima of the radiated field exist. See main lobe.

local oscillator zero feed through- A characteristic of mixer circuits, typically used in spectrum analyzers, wherein the local oscillator signal is coupled into the intermediate frequency (IF) path due to its limited isolation. As an example, if very low frequency input signals are converted by the mixer, the first IF can be very nearly zero Hz and with relatively large resolution bandwidth, the local oscillator signal is sent to the detector and displayed at zero Hz. This is an extraneous signal that is not related to the actual amplitude of the very low frequency input signal.

Main beam- see main lobe.

main lobe- A region of the transmitting pattern of an antenna in which the greatest intensity exists, also called the main beam of the antenna.

max hold spectrum- A feature often present on instruments such as spectrum analyzers in which the instantaneous peak values of measured signals are captured and continuously displayed so that, over time, the absolute maximum signal values can be determined even if they were only present for a short period.

maximum permissible exposure (MPE)- The rms and peak electric and magnetic field strength, their squares, or the plane wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effect and with an acceptable safety factor.

megahertz (MHz)- One million hertz.

mesh network- A term describing a network, typically wireless, in which multiple nodes communicate among themselves and data can be relayed via various nodes to some access point. Mesh networks are self healing in that should a particular pathway become nonfunctional for some reason, alternative paths are automatically configured to carry the data. Mesh networks can expand beyond the normal range of any single node (smart meter) by relaying of data among the different meters.

microwatts- One-millionth of a watt, a microwatt (µW) or 10^{-6} watts.

modulation- Refers to the variation of either the frequency or amplitude of an electromagnetic field for purposes of conveying information such as voice, data or video programming.

near field- A region very near antennas in which the relationship between the electric and magnetic fields is complex and not fixed as in the far field, and in which the power density does not necessarily decrease inversely with the square of the distance. This region is sometimes defined as closer than about one-sixth of the wavelength. In the near field region the electric and magnetic fields can be determined, independently of each other, from the free-charge distribution and the free-current distribution respectively. The spatial variability of the near field can be large. The near field predominately contains reactive energy that enters space but returns to the antenna (this is different from energy that is radiated away from the antenna and propagates through space).

nearfield coupling- A phenomenon that can occur when an RF measurement probe is placed within the reactive near field of an RF source such that the probe interacts strongly with the source in a way that typically draws power from the source than would not occur at greater distances. When nearfield coupling occurs, field probe readings are typically erroneously greater than the actual RF field magnitude. For this reason, an IEEE measurement standard (C95.3) recommends a minimum spacing between source and sensor of 20 cm.

planar scan- In the context of this study, a spatial scan over a plane in front of a smart meter or a group of smart meters at a fixed distance from the smart meters.

plane wave- Wave with parallel planar (flat) surfaces of constant phase (See also Spherical wave). Note: The cover of this report shows an idealized spherical wave that expands outward- in an appropriate region that this spherical wave can be considered as a plane (flat) wave.

polarization- The orientation of the electric field component of an electromagnetic field relative to the earth's surface. Vertical polarization refers to the condition in which the electric field component is vertical, or perpendicular, with respect to the ground, horizontal polarization refers to the condition in which the electric field component is parallel to the ground.

power density- Power density (S, sometimes called the Poynting vector) is the power per unit area normal to the direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, milliwatts per square centimeter (mw/cm^2) or microwatts per square centimeter ($\mu w/cm^2$). For plane waves, power density, electric field strength, E, and magnetic field strength, H. are related by the impedance of free space, i.e. 120π (377) ohms. In particular, $S = E^2/120\pi = 120\pi H^2$ (Where E and H are expressed in units of V/m and A/m, respectively, S is in units of $W/m^{2)}$. Although many RF survey instruments indicate power density units, the actual quantities measured are E or E^2 or H or H^2.

pulse- A brief presence of an RF signal (field).

radiation pattern- A description of the spatial distribution of RF energy emitted from an antenna sometimes referred to as transmitting pattern. Two radiation patterns are required to completely describe the transmitting performance of an antenna, one for the azimuth plane and another for the elevation plane.

radio- A term used loosely to describe a radio transmitter or transceiver.

radio frequency (RF)- Although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3000 GHz, the frequency range of interest is 3 kHz to 300 GHz.

radio spectrum- The portion of the electromagnetic spectrum with wavelengths above the infrared region in which coherent waves can be generated and modulated to convey information- generally about 3 kHz to 300 GHz.

RBW- see resolution bandwidth.

reflection- An electromagnetic wave (the “reflected” wave) caused by a change in the electrical properties of the environment in which an “incident” wave is propagating. This wave usually travels in a different direction than the incident wave. Generally, the larger and more abrupt the change in the electrical properties of the environment, the larger the reflected wave

resolution bandwidth- A specification for spectrum analyzers that denotes the ability of the analyzer to identify two signals on different frequencies, a measure of the frequency selectivity of the analyzer.

resultant field- The combined result of all polarization components of an electromagnetic field found by determining the sum of three orthogonal components of power density or the root sum squared of three orthogonal components of electric or magnetic field strength.

Glossary

RF - Radiofrequency.

RF LAN- A term representing a local area network formed by wireless nodes. In the case of smart meters, the 900 MHz band radios communicate with one another forming an RF LAN.

root-mean-square (RMS)- The effective value of, or the value associated with joule heating, of a periodic electromagnetic wave, current or voltage. The RMS value of a wave is obtained by taking the square root of the mean of the squared value of the wave amplitude.

shielding effectiveness- A measure of the ability of a material or structure to attenuate RF fields, typically specified in decibels.

spatial average- For RF exposure limits, a determination of the average value of power density over the projected cross section area of the body. In practice, an average along a vertical line representing the height of a person.

specific absorption rate (SAR)- The time derivative of the incremental energy absorbed by (dissipated in) an incremental mass contained in a volume) of a given density. SAR is expressed in units of watts per kilogram (W/kg) or milliwatts per gram (mW/g). Guidelines for human exposure to radio frequency fields are based on SAR thresholds where adverse biological effects may occur. When the human body is exposed to a radio frequency field, the SAR experienced is proportional to the squared value of the electric field strength induced in the body. Compliance with RF exposure limits for devices that are intended to be placed, in normal use, closer than 20 cm of the body surface, are evaluated by a direct measurement of the local SAR within the body at the point of maximum exposure. In the case of cell phones, this is usually at the side of the head and is accomplished through the use of a phantom model that simulates the size and shape of the human body and contains a liquid that has electrical properties comparable to human body tissues.

spectrum analyzer- An electronic instrument, similar to a receiver, that sweeps across a part of the RF spectrum and displays detected signals as peaks on a visual display screen. Spectrum analyzers normally continuously sweep repetitively over a given frequency band at a relatively high rate thereby allowing for the observation of intermittent signals.

spread spectrum- Refers to a method by which an RF signal that is generated in a particular bandwidth is deliberately spread in the frequency domain resulting in a signal with a wider bandwidth. Such a technique is used to enhance secure communications, to reduce interference and to prevent detection.

sweep time- In an oscilloscope or spectrum analyzer, the time spent to sweep across either the time or frequency axis in the measurement of signals. Typically, the amount of time it takes to perform a defined measurement before starting the next measurement. Commonly, the instrument is set to continuously and repetitively update the measurement according to its sweep time.

switch mode power supply (SMPS)- A power supply design that incorporates solid state switching elements that significantly increase power conversion efficiency when converting AC to DC. In an SMPS, the input line voltage is typically rectified and applied to the switching element in the supply that chops or switches the DC current at a high frequency. This process, which effectively increases the frequency of input voltage of the supply, results in much smaller component sizes needed for a transformer and associated capacitors for filtering of the output DC voltage. Typically, a feedback signal from the SMPS output is also used to generate a pulse width modulated signal for regulating the supply output voltage.

time-averaged exposure- In the context of RF exposure limits, an average of the exposure value over a specified time period. Commonly, for occupational exposures, the averaging time is six-minutes and for members of the general public 30-minutes. All scientifically based RF exposure limits are in terms of time-averaged values.

time resolution- In a display of signal amplitude vs. time, the incremental time interval (window) within which an instrument samples the instantaneous peak and average values of signals prior to display. The smaller the time resolution, the better the instrument can indicate the time at which signals occurred. Larger time resolutions do not mean that the instrument necessarily does not detect narrow signal pulses, only that it may not indicate the exact time of occurrence during the time resolution window.

transceiver- A radio device that has both transmitting and receiving capability. Strictly, the radio devices in Smart Meters are transceivers since they can both transmit data and receive data. Commonly, in the context of evaluating RF fields, the term transmitter or radio is used to refer to the transmitting feature of the transceiver.

ZigBee radio- A radio transceiver inside some smart meters that allows communications with an in-home-device (IHD) for displaying electric energy consumption data. The radio operates in the 2.4-2.5 GHz license free band often used by wireless routers, some cordless telephones and other devices and can be used in a home area network (HAN). The term ZigBee refers to a set of high level digital communication protocols based on an IEEE 802 standard for personal area networks.