An Evaluation of Radio Frequency Fields Produced by Smart Meters Used by the Benton PUD

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Table of Contents

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Summary

The deployment of electric “smart meters” across the United States, including the Benton Public Utility District (Benton PUD) service territory, has stimulated questions by the public about the safety of exposure to the radiofrequency (RF) fields produced by the low power (1 watt) transceivers contained within the meters. Smart meters make use of wireless digital communication technology to transmit customer electric energy consumption data to the Benton PUD. This report describes a study to determine the potential exposure of the public to the RF fields produced by smart meters used by the Benton PUD.

The Benton PUD smart meters make use of frequencies in the nominal 901-940 MHz range and employ several different frequency shift keying (FSK) methods for digitally modulating the transmitted signal with electric energy usage data. In contrast to other implementations of smart meter technology that use “mesh networks”, the Benton PUD meters typically transmit short messages at six specific times of day directly to tower gateway base stations (TGBs); the message consists of the customer’s energy consumption data sent to the Benton PUD. The TGBs also transmit messages outbound to the meters.

On-site measurements at several residential locations in the Benton PUD service territory were conducted to determine the strength of the RF emissions very close to the meter as well as within homes equipped with smart metes. The study also examined the composite RF field environment where smart meters were aggregated in banks of meters at two apartment complexes. Measurements of the short-term duty cycle for banks of smart meters were accomplished as well as ground level field measurements at a single TGB.

Most of the measurements revolved around application of a spectrum analyzer based instrument (Narda model SRM-3006) that makes use of an attached probe/antenna and can indicate measured RF field magnitudes directly as a percentage of the maximum permissible exposure (MPE) values of the Federal Communications Commission (FCC). The detection equipment contains three mutually orthogonal probe elements that results in an isotropic spatial response to all polarization components of the RF field. The instrument also contained a “scope” option that permitted measurement of smart meter signal waveforms (duration of the emitted signals). The sensitivity of the instrument and ability to measure the intensity of the RF field on specific frequencies were essential to the success of the measurement program.

Directly in front of the smart meters included in these measurements, the greatest peak RF field at one foot from the meter was found to be 12.2% of the FCC MPE. The measured RF field decreased quickly with increasing distance from the meter. For example, at a distance of five feet, the field was measured to be less than 1% of the MPE. When adjusted for the amount of actual transmit time for the meter, the RF field values for 99% of the meter population at one foot from the meter are typically 8,000 times less than the measured peak value. It was found that spatial averaging of the smart meter RF field across the body dimension, consistent with FCC rules on human exposure, results in exposure that is approximately 29.5% of the spatial maximum value.

Analysis of the digital messages transmitted from most of the Benton PUD service territory meters (46,040 meters), collected via the Benton PUD data management system, revealed the statistical distribution of meter duty cycles, thereby permitting adjusting of measured peak RF field intensities to values of time-averaged potential exposure. This analysis identified one meter in the service territory that exhibited the greatest average daily duty cycle of 0.047%. Half of the meters exhibited duty cycles of 0.00128% or less, 99% had duty cycles not exceeding 0.0124%, and 99.999% of meters had duty cycles of 0.0465% or less. These data confirm the view that the smart meters, while they transmit intermittently throughout the day, create RF fields for only tiny fractions of the day. For example, half of all endpoint meters would be expected to actually transmit no more than about one second each day with 99% of meters transmitting less than 11 seconds per day. A single meter out of the 46,040 meters studied exhibited a maximum transmit time during one day out of seven contiguous days of observation equivalent to 68.4 seconds in the day.

Banks of smart meters, such as found on some apartment buildings, do not result in greater peak values of RF fields than those produced by an individual meter but can exhibit higher average field magnitudes due to the multiple meter operation. However, because the duty cycles of endpoint meters are so small, the time-averaged RF fields from large banks of meters are not capable of resulting in exposure that would exceed the FCC limits. Hence, in terms of both instantaneous peak (signal burst maximum) and average values, the RF fields comply by a wide margin with the FCC MPEs.

Exposure of individuals in their smart meter equipped homes is commonly orders of magnitude less than that which would occur for an individual standing immediately adjacent to and in front of the meter. Within any of the Kennewick, WA, homes included in this study, the greatest smart meter related peak RF field was equivalent to 0.155% of the FCC MPE for public exposure. When adjusted for the actual transmit time of the smart meter, the time-averaged value is substantially less.

Although the Benton PUD TGBs are remotely located, measurements at the Joe Butte TGB site found peak RF fields equivalent to 0.0079% of the FCC MPE for the public.

Potential exposure to Benton PUD smart meters is constrained by the low power of the transmitter and low antenna gain. A one-watt transmitter produces limited RF field power density. A simple and conservative method for estimating smart meter fields is a straightforward calculation based on the effective isotropic radiated power (EIRP) of the meter. For locations at which the greatest exposure can occur, directly in front of the meter, no special consideration of reflections is warranted in such calculations.

This study demonstrates that the Benton PUD smart meters result in potential exposure of the public that is very small in comparison to the applicable FCC limits for exposure. This finding of compliance with the MPEs holds true whether or not the peak measured fields are corrected for meter duty cycles, whether spatial averaging or any other factor that reduces RF fields such as the construction materials of homes is considered or whether the meters exist in a large group or whether individuals are outside near the smart meter or inside their residence. The strongest fields were, as expected, at the closest distance at which measurements were performed, i.e., 1 foot or 0.3 meters with a maximum <u>peak field</u> of about 12.2% of the MPE. Time-averaged values, at this point of maximum peak field, were concluded to be, at most, about 0.01% of the FCC MPE after adjusting for the maximum single meter transceiver duty cycle determined in this study or about 0.4% of the MPE based on a theoretical hardware limited duty cycle (3.4%)[1,2]. When viewed from the perspective that the FCC MPE includes a safety factor of 50, the potential exposure of persons near the Benton PUD smart meters not only complies by a wide margin with the MPE limit but will be as a minimum ten thousand times less than that value associated with adverse health effects as defined by the FCC exposure limits.

Introduction

This report documents a study of radiofrequency (RF) emissions associated with operation of electric smart meters deployed by the Benton County Public Utility District (Benton PUD). Benton PUD has approximately 47,000 smart meters in its service territory within Benton County, Washington, as replacements for older, electromechanical electric power meters. The new smart meters are manufactured by Sensus and contain low power (nominally one watt) transceivers that provide wireless digital communications for transmitting electric energy consumption and other meter status data between end point meters on residences and businesses and four tower gateway base stations (TGBs) located in the region. Sensus refers to their wireless communications technology as FlexNet™. The wireless technology is part of so-called Advanced Metering Infrastructure (AMI) being implemented across the country.

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[1]The greatest possible duty cycle is limited by the smart meter transmitter electronics circuitry and charge capacity delivered by a capacitor and its ability to be continually recharged. [See section on duty cycle.]

[2] While not the focus of this study, non-smart meter sources such as radio and television broadcasting can result in significantly greater RF fields that would be associated with long-term exposure.

Although the low power radio transceivers result on only low level RF fields emitted by the meters, public concerns over potential exposure to the meter RF fields have influenced a more in-depth examination of these RF emissions. This report examines the RF fields that can be produced by the smart meters being used by Benton PUD and provides information that may be useful for a more informed assessment of potential public exposure. Current recommendations on exposure limits are summarized for comparison with the RF fields associated with operation of the wireless smart meters deployed by Benton PUD.

The Benton PUD meters contain transceivers that operate on frequencies licensed by the Federal Communications Commission (FCC) in the nominal 901-941 MHz range. This approach stands in contrast with some other AMI implementations with wireless smart meters that operate in license-free bands designated by the FCC and are configured as mesh networks. The transmitters in the Sensus meters, used by Benton PUD, transmit brief signals, at designated times of the day (currently six times per day) that are normally received directly by TGBs distributed throughout the Benton PUD service territory. A total of four TGBs provide the data reception function for approximately 47,000 smart meters. Endpoint meters, those installed on homes and businesses, contain timers that control when the meter transmits its data. The transmissions are very brief, typically about one-tenth second in duration. Due to the short duration of transmissions and the length of time between transmissions, the overall duty cycle[3] of each meter is very small, typically being expressed in terms of only fractions of a percent (typically actual transmissions exist for only some seconds during a whole day). This is relevant to the issue of assessing compliance with the exposure limits set by the FCC. Contrary to wireless smart meters that operate in mesh networks, in the Benton PUD system there is no need for individual meters to periodically identify themselves for purposes of staying connected with neighboring meters. This further reduces the duty cycle of the meters.

Although most meters will transmit a fairly consistent digital message length (corresponding to the amount of time the meter actually transmits a signal), there can be variations among the installed meters, leading to a range of duty cycles that the entire population of meters may exhibit. This potential variability in meter operation from hour-to-hour and from day-to-day suggests that some form of statistical assessment of operation over a large number of meters can provide useful insight to the range of meter transmissions and, thus, provide the most accurate way of determining time-averaged values of meter emissions.

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[3] Duty cycle, for signals of the same strength, is defined as the ratio of the amount of time that RF emissions occur to some baseline amount of time. The baseline time may be a few minutes, hours or a day, depending on the circumstance or what is relevant at the time, such as assessing compliance with human exposure limits.

Basic Meter Specifications

This report describes measurements of RF fields produced by the smart meters presently used by Benton PUD in their smart meter deployment. The Sensus iCon meter is shown in Figure 1. These meters contain low power radio transceivers that have the capacity of operating on four different frequencies in the range of 901 and 941 MHz. Based on certification reports filed with the FCC[4,5], Table 1 provides the FCC ID numbers, maximum transmitter output powers, antenna gains and maximum effective isotropic radiated power (EIRP[6]) for the Sensus iCon meters (two different FCC ID numbers were found during the investigation of Benton PUD meters). The Sensus meters use a proprietary frequency shift keying (FSK) modulation method for transmitting data as opposed to a frequency-hopping, spread spectrum technology used by some other smart meters.

Figure 1. Photograph of the Icon Sensus smart meter deployed by Benton PUD.

[4] Transmitter Certification. FCC ID: SDBIDTB001. Report No. 06-0011-LD. Advanced Compliance Solutions, 5015 B.U. Bowman Drive, Buford, GA 30518.
[5] Transmitter Certification. FCC ID: SDBIDTB002. Report No. 09-0322-LD. Advanced Compliance Solutions, 5015 B.U. Bowman Drive, Buford, GA 30518.
[6] EIRP is the product of the power delivered to the antenna and the gain of the antenna in a specific direction. For example, if the antenna gain is 3 dB in a particular direction, it results in the EIRP being twice the value in that direction compared to an isotropic radiator.

Table 1. Benton PUD smart meters, FCC ID numbers, possible operating frequency ranges and transmitter output powers indicated in associated certification reports to the FCC.

	iCon 1	iCon 2
FCC ID	SDBIDTB001	SDBIDTB001
Transmitter power output	+30.78 dBm	+30.6 dBm
Antenna gain	0 dBi	0 dBi
Maximum EIRP	+30.78 dBm (1,197 mW)	+30.6 dBm (1,148 mW)
Frequency range	901-941 MHz	901-941 MHz

The indicated antenna gains are the maximum values; antenna gains in directions other than the main beam would be less, resulting in less transmitted power density.

During the measurements of RF fields at the Benton PUD, it was found that the principal emission frequency was 940.1125 MHz which corresponds to what Sensus terms the mPass mode of communication. All measurements of RF fields in this report were with detected transmissions on 940.1125 MHz.

Assessing Potential Exposure to Smart Meters

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), the directional pattern of the antenna in the source, 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 approximates the pattern of an omnidirectional source; there is a preferred direction in which the strongest RF field is transmitted, usually away from the meter with directions of reduced RF fields usually to the sides and almost always to 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 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) 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 are highly 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 is also 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 is always something 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 the evaluation reported here, 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 peak values of fields.

Because the transmitted fields from smart meters can exhibit such a strong dependency on the 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 predominant 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 rapid decrease in RF field with distance.

The RF exposure limits adopted by the FCC are also based on averages over time. For the smart meters used by the Benton PUD, this is determined by the duty cycle of emissions, as discussed above, and on occupancy of areas near the meter. Closer distances can result in greater exposure while farther distances result in lower. In summary, potential exposure to the Benton PUD smart meters was accomplished by measurement of the instantaneous peak RF fields near the smart meters and, then, adjustment of the peak value by the duty cycle of the meters to obtain the relevant time-averaged value of field.

RF Exposure Limits

In the United States, the controlling limits for human exposure are those adopted by the FCC. FCC maximum permissible exposures (MPEs) apply to FCC licensees and because the smart meters operated by Benton PUD are covered by an FCC license, these MPE values directly apply to the operation of the meters and certifications before the FCC by the meter manufacturer. Table 2 summarizes the MPEs from the FCC applicable to the emission frequencies associated with the Benton PUD smart meters[7].

Table 2. FCC MPEs pertinent to the Benton PUD smart meter RF fields over the range of nominal relevant frequencies. MPE values are in terms of power densities averaged over 6 minutes for occupational exposure and 30 minutes for exposure of the general public. Values given are in terms of spatially averages over the body and averages over 6 minutes or 30 minutes as the case may be.

Frequency	901 MHz		940 MHz	
	General public	Occupational	General public	Occupational
MPE (mW/cm^2)	0.601	3.00	0.627	3.13

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.[8] 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. This is based on the 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 would require assessing the average RF field across the dimensions of the body and the average over time. 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[9], without inclusion of time- or spatial-averaging, is compliant with the MPE, then no further evaluation is necessary. In this investigation, the issues of how duty cycle and spatial averaging can affect exposure assessment will be addressed; for both of these factors, exposures will be found that are less than maximum, instantaneous field values. The RF

[7] The MPE is a value of exposure that is 50 times less than the threshold for adverse biological effects (i.e., the MPE contains a safety factor of 50).

[8] See, for example, letter from Julius P. Knapp, Chief, Office of Engineering and Technology, Federal Communications Commission to Cindy Sage, Sage Associates Environmental Consultants, August 6, 2010.

[9] 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.

field measurement values documented in this report are expressed in terms of a percentage of the public MPE; i.e., a value of 100% represents the exposure limit.

The MPEs listed in Table 2 are based on limiting the underlying basic restriction on RF energy absorption within the body, as a whole, 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.

Technical Approach Used in this Project

When characterizing the emissions of smart meters, it is convenient if the normally intermittent operation of the transceiver within the meter can be programmed to operate in continuous transmit mode since this allows for ready identification of a particular meter’s emissions against the background of intermittent emissions from other meters. Unfortunately, Sensus Flexnet™ meters do not have this continuous transmitting functionality.

RF field measurements were performed by capturing the instantaneous peak field power density of the smart meter emission by observing the signal over multiple transmissions to insure detection of the greatest value of RF field. To facilitate the measurement process, Benton PUD personnel made use of the FlexNet™ software utility and hardware to transmit a signal to the smart meter under investigation, causing it to respond with its signal. To cause a relatively rapid repetition of smart meter signals for measurement, the FlexNet™ equipment was used to “ping” the smart meters at a rate of about once each three seconds. By keeping the equipment used to ping the meters at a reasonable distance from the smart meter, it was possible to isolate and detect just the response of the smart meter without any interference from the signal pinging the meter.

Measurements of peak RF fields as well as time-domain measurements of signal presence vs. time were conducted at three smart-meter equipped single-family residences both directly in front of the meter and within the home and at two different apartment complexes where access to banks of meters (25 in one case and 45 in a second case) could be accomplished. Measurements were also conducted at the location of one of the Benton PUD TGBs on Joe Butte. All measurements were performed within the city of Kennewick, WA during June 20-21, 2012. Figure 2 illustrates the approach of performing measurements over a range of distances from 1 foot to a maximum of 25 feet.

At one location, RF fields in front of a smart meter were measured as a function of height above ground to assess how the spatially averaged value of RF field compares to the spatial maximum field.

In addition to the measurement of RF fields, data collected by the Benton PUD software management system were analyzed to assess the duty cycle of installed smart meters. The results of this analysis were used to adjust measurements of instantaneous peak power densities to appropriately time-averaged values for comparison with the FCC MPEs.

Figure 2. Illustration of the measurement of RF fields at different distances, ranging from one foot to 25 feet from the front surface of the smart meter.

Instrumentation Used in Measurements

The primary concern in this study was the magnitude of RF fields emitted by the Benton PUD smart meters. Due to the highly intermittent nature of the smart meter transmitters, a spectrum analyzer based detector was used for the measurements (Narda Selective Radiation Meter model SRM-3006, SN D-0069). Figure 3 shows the instrument which consists of a wideband probe/antenna (SN K-0242) that is connected to a spectrum analyzer that is controlled with firmware that allows for measurement and display of detected RF fields. A powerful feature of the SRM-3006 is that all measurements can be displayed 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. Calibration certificates for the SRM and probe/antenna are provided in Appendix A.

Figure 3. 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.

A feature of the SRM-3006 that made it particularly useful in this investigation was a “scope mode” in which the instrument can be tuned to a specific frequency with an adjustable and wide resolution bandwidth (RBW) so that detected signals can be measured in the time domain. This facilitated capture of bursts of RF signals emitted by the smart meters. For the measurements performed in scope mode, a RBW of 8 MHz was used when centered on the specific signal frequency of interest.

Figure 4 illustrates an example measurement of the smart meter signals displayed by the SRM-3006 during the study where the horizontal axis represents frequency and the vertical axis represents the measured magnitude of RF field expressed as a percent of the FCC MPE for public exposure.

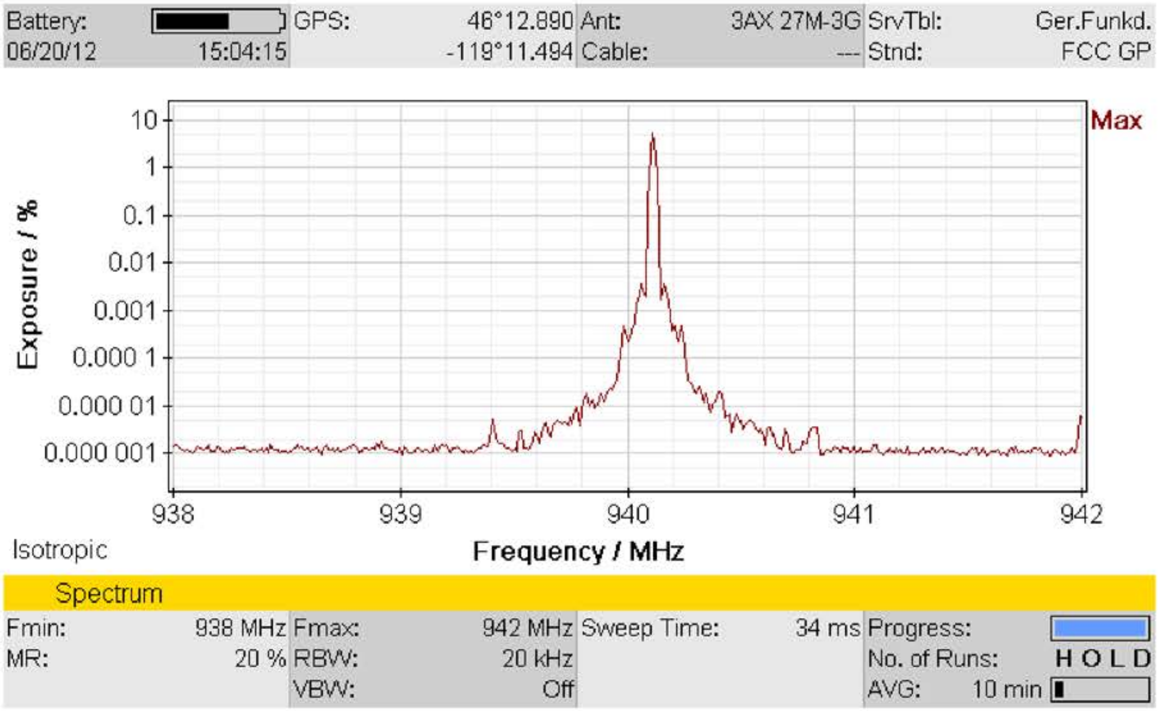

Figure 4. Example SRM-3006 spectrum measurement of the FSK signal produced by the Sensus iCon smart meter at 1 ft from the meter. The use of markers allows for determining the peak value of field (in this case, 5.4% of the general public MPE).

The SRM-3006, with accompanying probe/antenna, is capable of performing narrowband measurements of signals from 26 MHz to 3,000 MHz. For spectral measurements of the smart meter emissions, a RBW of 20 kHz was used (Note: the significantly wider RBW was used for the time-domain measurements in scope mode 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.

Results

RF Field vs. Distance

Peak RF fields, obtained at the three residential locations, expressed as a percent of the FCC MPE for general public exposure, are tabulated for a range of distances in Table 3. The greatest indicated value of field was obtained by using a marker feature on the SRM-3006 following capture of the bursting signal such that the maximum peak value was obtained. Each measurement was made with the SRM-3006 probe/antenna positioned in front of the meter at the specified distance with the instrument at the same height as the smart meter.

Field measurements were made no closer to the smart meter than 1 ft (0. 3m). IEEE Standard C95.3-2002 (IEEE, 2002) 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 0.1 m 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 is equivalent to approximately one wavelength at 940 MHz.

The data in Table 3 are graphically displayed in Figure 5. 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 that undoubtedly introduced ground reflections that resulted in the observed variations in field value. Obstacles inhibited measurements at all distances at all three locations.

Table 3. Summary of peak RF field values from the Sensus iCon smart meter measured at three residential locations in Kennewick, WA (field expressed as percentage of FCC MPE for general public).

	RF field (% MPE)		
Distance (ft)	Home 1	Home 2	Home 3
1	6.726	12.21	4.803
2	1.828	3.564	1.381
3	1.023	1.903	0.630
4	0.448	1.074	0.483
5	0.261	0.977	0.261
7	0.185	0.376	0.135
10	0.083	0.188	0.053
15	0.030		0.078
20	0.027		
25	0.016		

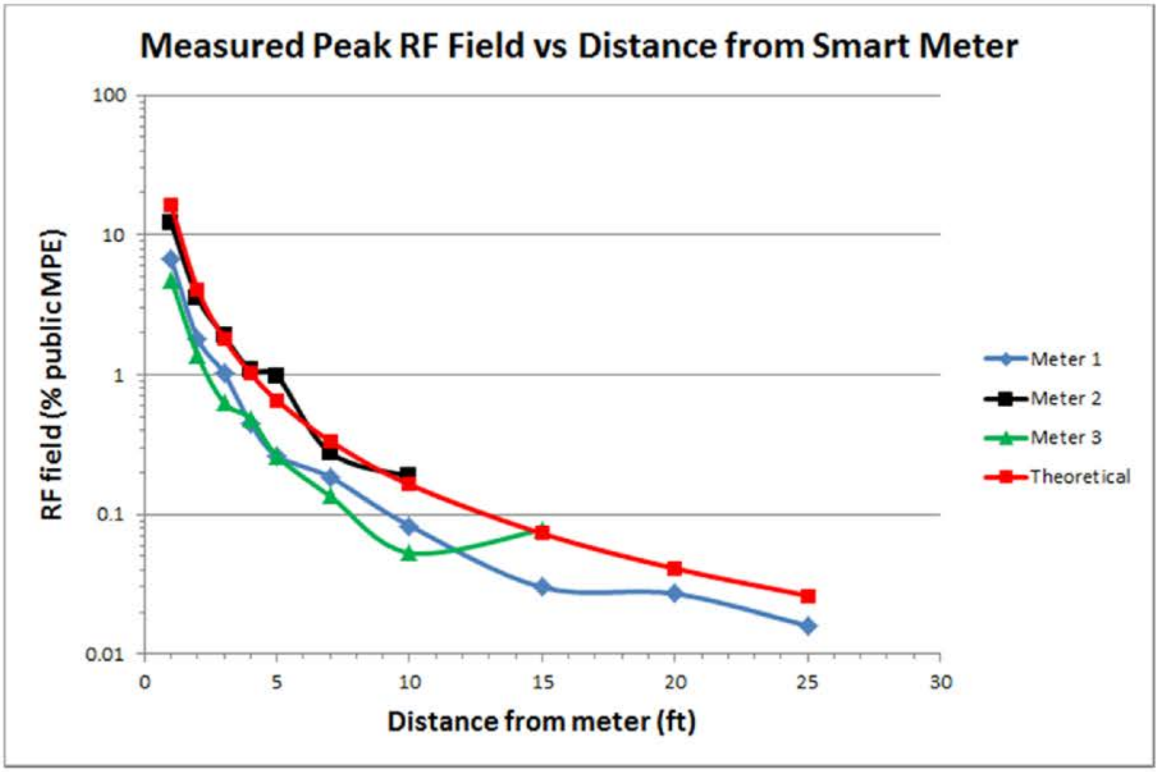

Figure 5. Measured peak RF field from the Sensus iCon smart meter determined at three residential locations in Kennewick, WA. RF field is expressed as a percentage of the FCC MPE for general public exposure and represents the instantaneous peak value of field during the brief transmissions from the meters. Time-averaged values of field are obtained by applying the duty cycle for the meter (see section on duty cycles). The red curve is a theoretical prediction of the RF field based on known transceiver output power.

To provide additional perspective on the magnitude of RF fields to be expected from the Benton PUD smart meters, Figure 5 also shows a curve (red) based on a theoretical calculation of the RF field based on the known transceiver power level. The power density was calculated from the free space formula:

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

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

Calculated power densities were then expressed as a percentage of the MPE by dividing by the MPE and multiplying by 100.

RF Fields Produced by Banks of Smart Meters

Additional field measurements were conducted at two apartment complexes. At the first apartment complex (under construction at the time of the measurements), meter banks consisting of 21 and 25 meters, respectively, were measured in two different buildings. By physically scanning a plane at 1 foot from the front surface of the meters, see Figure 6, while pinging the meters sequentially, a peak RF field equivalent to 7.22% of the FCC MPE was detected. The bank of meters was facing one of the apartments directly across a breezeway (61 inches wide). Measurements were performed in the apartment and directly in line with the meter bank inside a closet that represented the closest point to the meter bank. In this location, a peak value of RF field of 0.043% of the FCC MPE was measured. Measurements were also made inside the apartment directly behind the meter bank and within 12 inches of the rear surface of the bank of meters. In this location, a peak field of 0.087% of the MPE was measured. Figure 6 shows the 21 meter bank.

Figure 6. Performing RF field measurements in front of a 21 meter bank of smart meters at an apartment complex under construction. Measurements were also performed inside the apartment facing the meter bank and inside the apartment directly behind the bank.

A second set of measurements was conducted in another building at the same apartment complex in which 25 meters were mounted in a square configuration of 5 rows and 5 columns of meters. This installation included Sensus iCon meters bearing both of the FCC ID numbers described above. These two different FCC IDs may be referred to as the old and new meters, referring to the ID ending in 001 and 002 respectively. Measurements at 1 foot in front of the meters were obtained when, first, a new meter and, then, an old meter were pinged to produce emissions that could be measured. The resulting data are summarized in Table 4. The physical orientation of the various meters used in the measurement is illustrated in Figure 7.

Table 4. Measured RF fields at 1 foot in front of old and new versions of the Sensus iCon smart meters in a bank of 25 meters. RF field is expressed as a percentage of the MPE.

	Old (FCC ID: SDBIDTB001)		New (FCC ID: SDBIDTB002)	
Reference	Meter no.	(% MPE)	Meter no.	(% MPE)
1	108802	3.228	141533	9.949
2	116932	3.656	128359	4.034
3	108545	3.871	142234	7.805
4	113898	5.693	130493	3.413
5	115461	7.853	122482	6.020
Average		4.860		6.244

Additional measurements of RF fields were performed at a retirement apartment complex where a bank of 45 smart meters is installed. Figure 8 and the cover of this report show the meter array consisting of three rows of 15 meters each. The meters are installed with the bottom row at 50 inches above ground level and the row at 68 inches above ground. The bank of meters varies between 4 and 6 feet in front of a wall of the apartment complex due to the structure of the wall. Measurements were performed by walking back and forth in front of the bank of meters, moving the SRM-3006 probe/antenna in an oscillatory manner up and down to scan the entire frontal plane of the meter bank. As the meters were pinged, the maximum RF field was captured on the instrument. These data, for two successive scans of the meter bank, resulted in maximums of 4.915% and 5.372% of the FCC MPE for the peak field. A measurement along the surface of the apartment wall yielded a maximum field of 1.365% of the MPE.

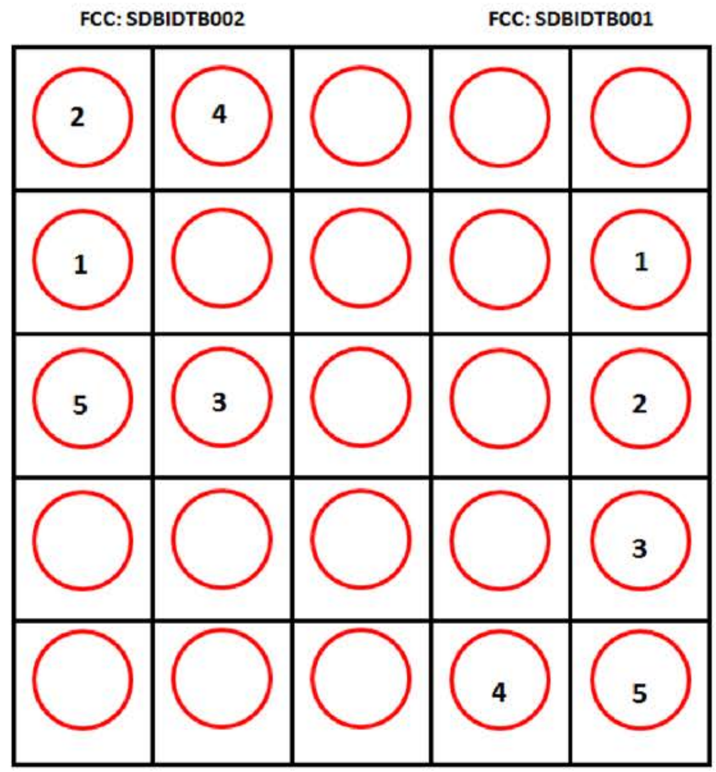

Figure 7. Locations of smart meters within a bank of 25 meters at an apartment complex where measurements were performed at 1 foot in front of each of the indicated 10 meters. Meters on the right side of the bank possessed the older FCC ID number while meters on the left side carried the newer FCC ID number. Each meter number shown on the diagram represents a pair of meters, one bearing the older FCC ID and the other, the more recent FCC ID.

Figure 8. Large smart meter bank consisting of 45 meters at a retirement apartment complex. The meters face an adjacent apartment.

RF Fields Observed at the Joe Butte TGB Site

Figure 9 shows the Joe Butte TGB site where a TGB is installed on a tower at a height of 90 feet above ground (2180 feet above sea level). The RF signals observed from the TGB were substantially weaker (transmitting at 30 watts) than those found directly in front of the lower powered end point smart meters. The significant elevation of the antenna accounts for the much weaker signals at ground level. The measurement approach taken at the TGB site was to capture the strongest RF field as a function of distance from the TGB tower. This was accomplished by slowly walking along a straight line in a generally Easterly direction that was free of obstacles and allowing the SRM-3006 to retain the maximum value of RF field as the TGB emitted signals. By observing both the actual (real time) and maximum value of retained signal level, measurements were performed along this line only as signals were observed to be transmitted. During moments when there was no observed signal transmission from the TGB, the walk was stopped momentarily until subsequent signals were observed. In this fashion, the maximum RF field that could be found along a 275 foot long path was recorded. This process resulted in a value corresponding to 0.0079% of the FCC MPE and was found at approximately 100-150 feet from the fence surrounding the TGB tower.

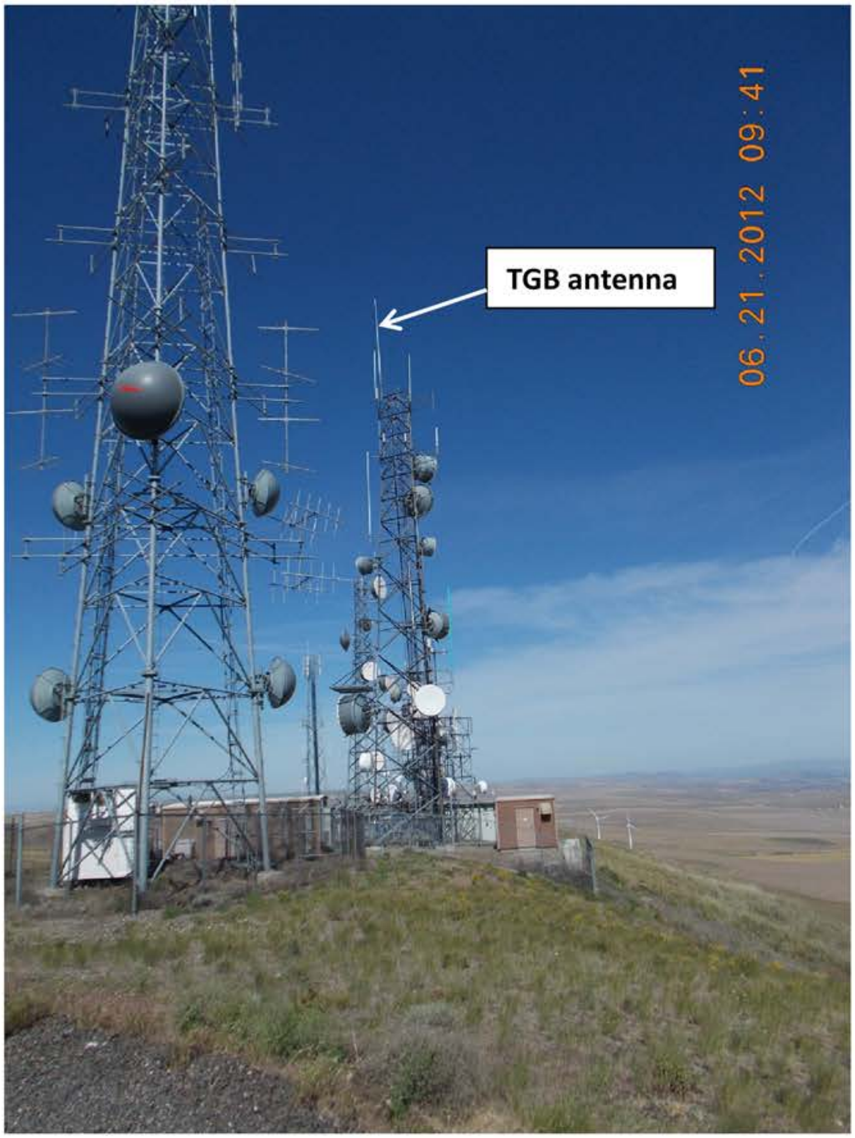

Figure 9. The Benton PUD Joe Butte Tower Gateway Base station (TGB) site. A single omnidirectional antenna is mounted at the highest point on the tower at approximately 90 feet above ground level. The TGB transmits with 30 watts of power.

Time Domain Measurements of the Smart Meter Signal

When the Sensus smart meter transmits data, the data is transmitted in a so-called message that lasts for a very brief period. For the transmission mode of the meters during the measurements, Sensus provided a specified duration of 0.1576 seconds per message or 157.6 milliseconds (ms)[10]. Other modes of communication by

[10] Information provided by Patty Sunford at the Benton PUD.

the meter use message lengths ranging from 38.8 ms to a maximum of 214.8 ms. The 157.6 ms value corresponds to the most common communication mode from the meters to the TGB and, hence, represents the most likely mode of operation on a day-to-day basis. Using the scope mode of operation of the SRM-3006, measurements were made of the duration of the smart meter transmission bursts (message length) on several occasions. All of these message length measurements were similar to the specified value. These measurements validate the specified message length from Sensus.

Figure 10 is a representative display of the measured time domain of two bursts of signal from the smart meter as it was pinged to respond. Using the marker feature of the SRM-3006, the duration of the bursts shown in Figure 10 was measured to be 156.3 ms.

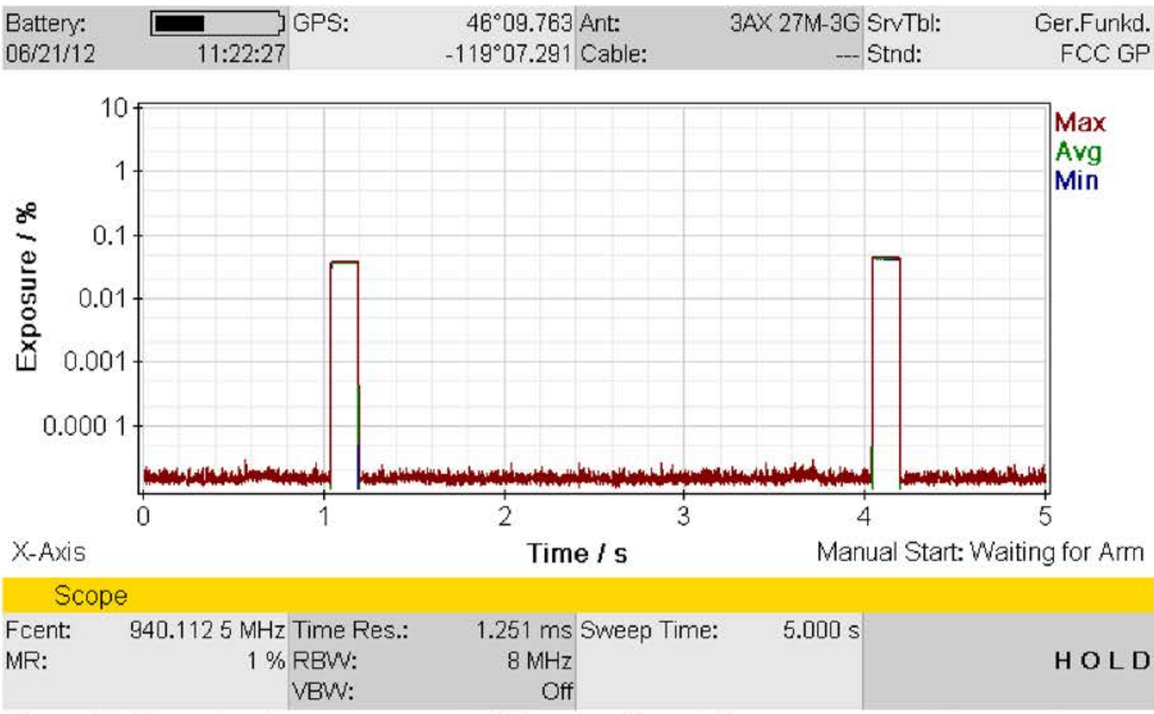

Figure 10. Time domain measurement of the signal bursts from a representative smart meter. This image represents two successive bursts while the meter was pinged. The burst width was 156.3 ms.

Table 5 lists seven values of message lengths measured from different smart meters during the project.

Table 5. Measured message lengths for seven smart meters operating in the mPass mode.	
Arbitrary meter reference number	Burst duration (ms)
1	156.3
2	160.1
3	160.1
4	155.0
5	156.3
6	155.1
7	153.8
Average	156.7

From measurement-to-measurement, on different smart meters, the exact message duration was observed to vary slightly. However, the average value, as seen in Table 5, was 156.7 ms, very close to the value specified by Sensus. This value will be used later in calculating the duty cycle of smart meter operation (see section on duty cycle).

When multiple meters are grouped together, the instantaneous peak value of RF field was found to not be different from that observed in front of individual meters in isolation. However, over time, there can be greater communication activity simply because of the multiple meters reporting their data from time-to-time. It was of interest to devise a way to observe the greatest amount of transmitter activity possible from a group of smart meters; this was accomplished at two apartment locations where all of the meters were pinged to cause a maximum amount of transmitter activity. In these two instances, time domain signal measurements were obtained by allowing the SRM-3006 to scan over a prolonged period, observing the various bursts from the different meters. Figure 11 shows a one minute signal capture in front of a bank of 21 meters. These data correspond to a duty cycle of 1.9% during the one minute observation period. This means that during the one minute measurement, smart meter signals occurred for approximately 1.9% of the time or about 1.1 seconds.

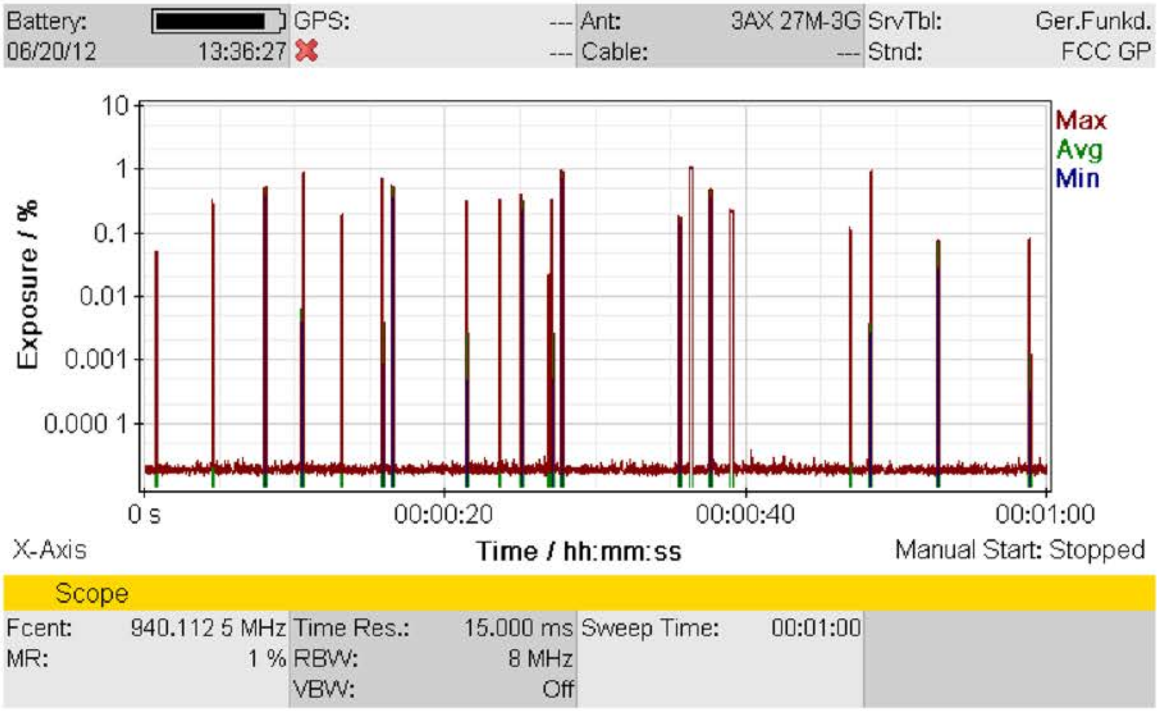

Figure 11. Time domain measurement of the signals from a bank of 21 smart meters. This image represents signals from various meters while the meters were pinged to respond with a digital message. The observed duty cycle over the one minute period is 1.9%.

A similar measurement in front of a bank of 45 meters is shown in Figure 12. Despite the greater number of meters in this particular bank, the overall one minute duty cycle was observed to be less at 0.70%. This lower value could be due to the particular way the meters were pinged with fewer meters being pinged during the observation window.

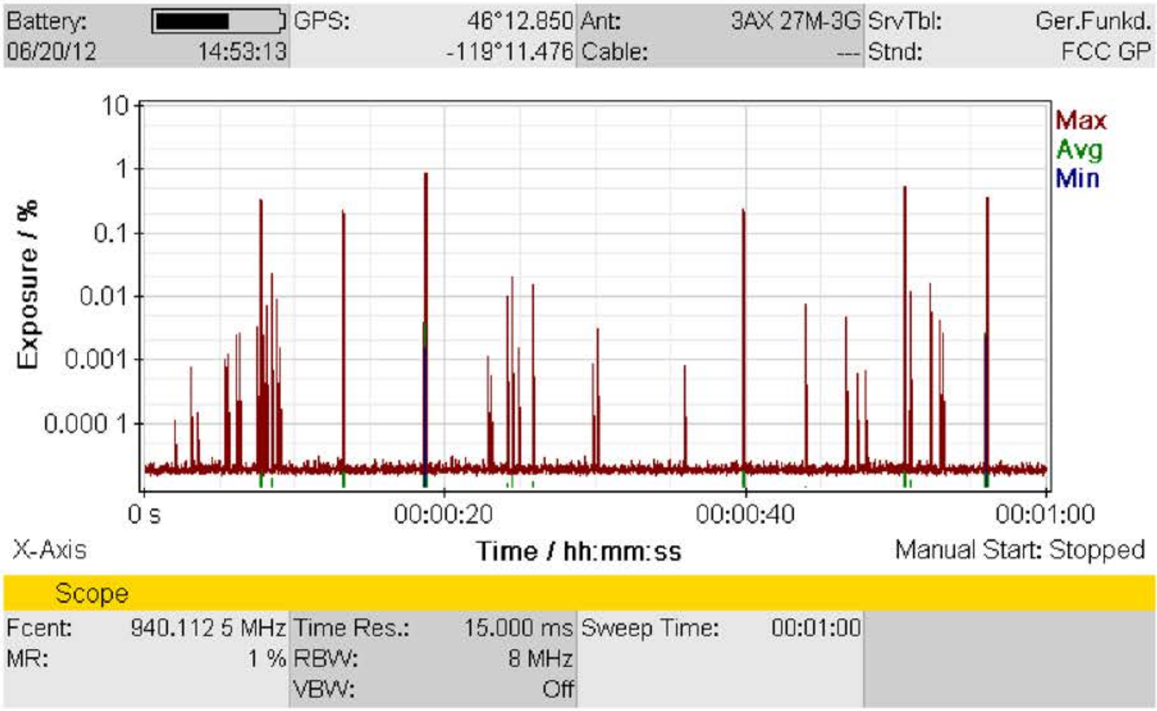

Figure 12. Time domain measurement of the signals from a bank of 45 smart meters. This image represents signals from various meters while the meters were pinged to respond with a digital message. The observed duty cycle over the one minute period was 0.70%.

At the TGB site, emissions from the TGB were observed over a five-minute period as the TGB transmitted in response to the various end point meters sending their data to the TGB. The data were captured by holding the SRM-3006 at a fixed location on the ground for the duration of the observation period. Because of the elevation of the TGB antenna at 90 feet above ground (elevation of 2180 feet above sea level), the detected signals were much weaker than near end point smart meters. Figure 13 shows the result of the five-minute time-domain scan at the TGB. During the five-minute period, the overall duty cycle was measured to be 1.1%.

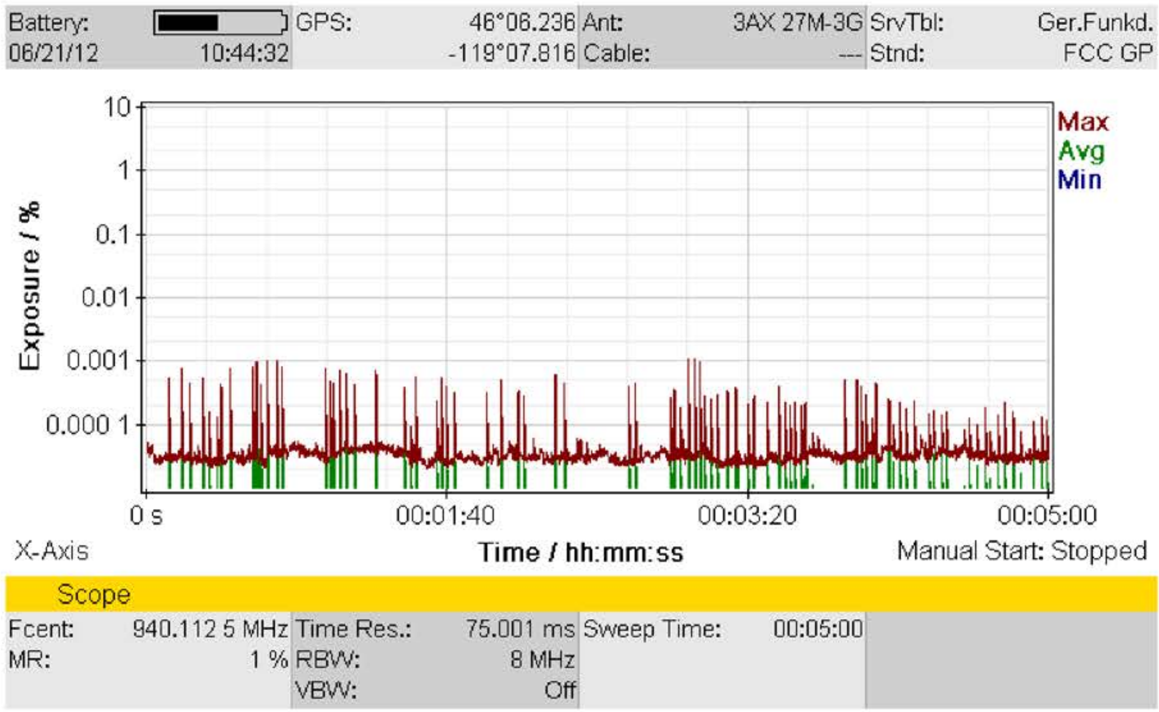

Figure 13. Five-minute time-domain measurement of the signals from the Joe Butte TGB. This image represents signals from the TGB to various end point meters in the service territory. The observed duty cycle over the five minute period was 1.1%.

Spatial Average Measurements

The RF exposure limits set by all of the present standards, guidelines or regulations (including those of the FCC) are expressed in terms of RF fields that are spatially averaged over the body dimensions. To explore how the RF fields from the Benton PUD smart meters are distributed along a vertical axis, near one of the meters, measurements were performed by using the SRM-3006 to capture the emissions of the smart meter. Acquisition of the spatial variation of fields was accomplished by positioning the SRM-3006 to the side of the smart meter (mounted at 67 inches above ground to the center of the display screen on the meter) with the probe/antenna approximately 12 inches in front of the meter at seven different heights above ground. The data are presented in terms of the relative measured RF field (relative to the percentage of the MPE detected) in Figure 14. At this particular meter, chosen because of its lower mounting height, the spatially averaged RF field corresponded to 2.98% of the MPE or 29.5% of the measured spatial maximum. For this meter mounting height, spatially averaged RF fields are roughly one-third of the maximum field at the same distance from the meter.

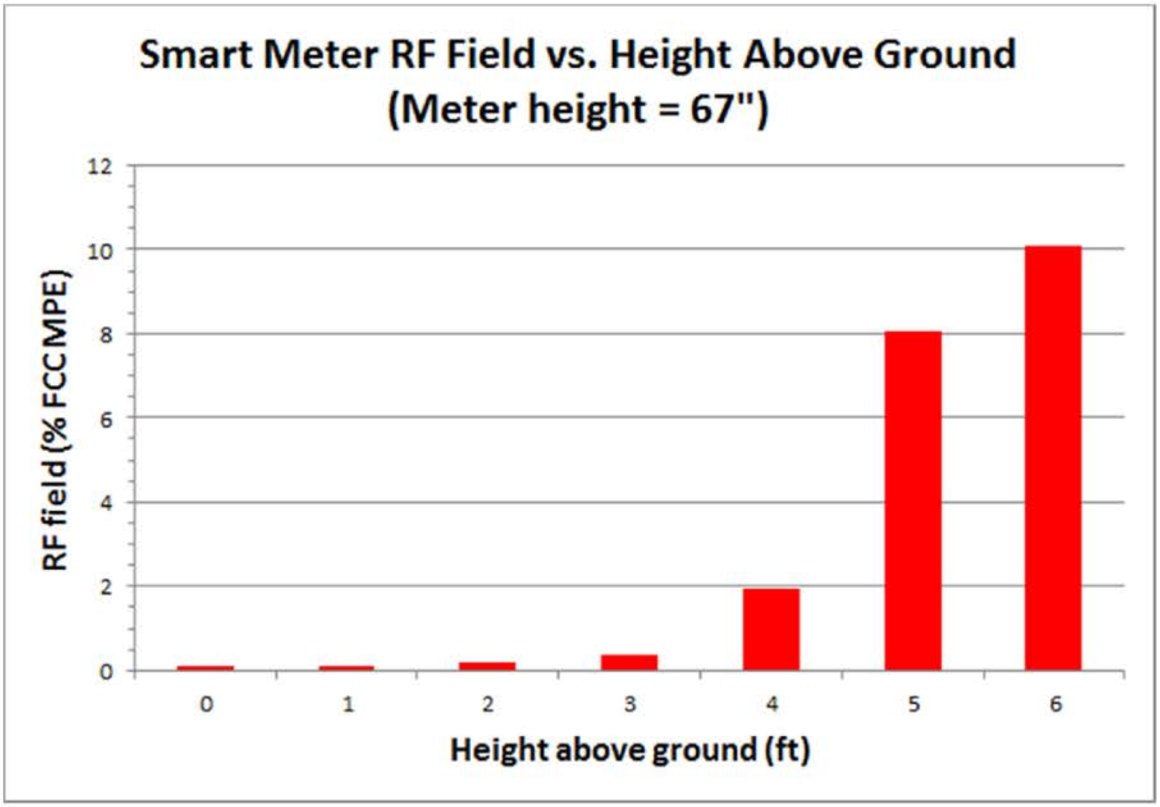

Figure 14. Measured RF fields along a vertical line from ground surface to a height of 6 feet (72 inches) (1.83 m) at approximately 1 ft in front of the Sensus iCon smart meter. The maximum field is observed near the mounting height of the meter (67 inches). The overall spatial average is 29.5% of the spatial maximum value of field. A total of seven measurements, taken at different heights, limits the precision of the spatially averaged value of field.

Residential Interior Measurements

Measurements of smart meter RF emissions were performed in three different single-family residences. The measurement approach used in each case was, first, to establish connection with the smart meter, repeatedly pinging the meter. A maximum ping rate of about one time in every three seconds was used to maximize the presence of the smart meter emission and facilitate capture of the signal. Each room of the house, typically including the garage, was then swept with the SRM-3006 to capture the peak value of RF field that could be found within the room or area. All readings are in percent of the FCC MPE for general public exposure. Tables 6, 7 and 8 list the residential house measurement values. In all of the residential measurements, the device used to ping the smart meter was kept in a truck located on the street.

Data obtained inside the three residences show that the strongest interior RF fields were always found on the opposite side of the wall on which the smart meter was installed, this typically being the garage. However, at these maximum field points, the RF field was at least a factor of 10 less than the field found in front of the meter with the maximum observed value being 0.155% of the FCC MPE.

Table 6. Interior RF field measurements in residence A, Kennewick, WA. Sensus iCon meter number 270069.

Area in Residence	% MPE
Garage ‡	0.155
Kitchen	0.0005
Bedroom 1	0.00006
Bedroom 2	0.00002
Living room/dining room	0.00017
Family room	0.00004

‡ Measurement taken at wall directly on back side of meter

Table 7. Interior RF field measurements in residence B, Kennewick, WA. Sensus iCon meter number 100111.

Area in Residence	% MPE
Garage ‡	0.036
Kitchen	0.00014
Bedroom 1	0.022
Master Bedroom	0.00161
Living room/dining room	0.00027
Dining area	0.00007
Office	0.00141
Bath	0.00072

‡ Measurement taken at wall directly on back side of meter

Table 7. Interior RF field measurements in residence C, Kennewick, WA. Sensus iCon meter number 100146.

Area in Residence	% MPE
Garage ‡	0.019
Kitchen/Dining area	0.0002
Bedroom 1	0.00001
Master Bedroom	0.00012
Living room	0.00002
Family room	0.00002
Bedroom 2	0.00017
Laundry room	0.00007

‡ Measurement taken at wall directly on back side of meter

Appendix B provides photographs showing the exterior of each of the homes included in the measurements.

Benton PUD Smart Meter Duty Cycle Analysis

RF exposure associated with the operation of the Benton PUD wireless smart meters consists of highly intermittent RF fields. While the peak value of the power density near these meters is much smaller than the MPE for public exposure adopted by the FCC, the time-averaged value of field is even less. From the perspective of a comprehensive assessment of compliance with the FCC rules on human exposure, the RF field is to be expressed in terms of an average value, averaged over <u>any</u> 30-minute window of time and spatially averaged over the dimensions of the body. With knowledge of the smart meter duty cycle, the peak values of RF fields can be adjusted to yield time-averaged values for comparison with the FCC MPEs.

In practice, a direct measurement of the 30-minute time-averaged value of smart meter emissions represents several significant challenges. First, simply acquiring the necessary field amplitude data over a 30-minute period places time constraints on the process, making it extremely time consuming to characterize exposures over a wide range of environments and varying proximity to the smart meters. Secondly, because the network activity of any given endpoint meter can vary from moment-to-moment and day-to-day, depending on network conditions and reporting times for the meters to transmit energy consumption data, any direct RF field measurement that might successfully yield the duty cycle will be subject to the normal but potentially erratic activity of meter transmissions over time. This imposes an uncertainty on how well a measurement of average exposure represents actual exposure at other times. Such challenges suggest that attempts to directly measure overall time-averaged smart meter RF fields near smart meters will be prohibitively time consuming and not likely to yield quantifiable estimates of confidence in the results.

Sensus has established a maximum duty cycle for the endpoint meters based on limitations of the meter transmitter power supply. According to Sensus documentation[11], transmitter power relies on the charge on a capacitor in the circuitry that can only provide electrical power sufficient for sending two or three consecutive messages before needing time to recharge. The recharge time is stated as six seconds. Using an assumed message length of 107 ms and assuming that the meter would transmit two messages, go through the recharge interval, and then repeat the process over and over, Sensus arrived at a calculated maximum duty cycle of 3.4%.[12] Sensus

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[11] MPE Calculations for FlexNet Endpoint-Equipped Electric and Gas Meters. Robert J. Davis, Principal RF Engineer, Sensus USA, Inc. Document AFXWP-40000.

[12] Duty cycle was calculated based on the duration of two messages of 107 ms each and a total cycle time of 6 seconds plus the duration of the two messages [0.214 sec/6.214 sec].

described this estimated, worst case duty cycle as unlikely and that it could only occur if the meter were to continually transmit in the "message pass" or "buddy mode" when it relays a message it receives from another meter. Hence, the Benton PUD smart meters are inherently limited in terms of their maximum possible duty cycle. Realistically, the meters are anticipated to transmit at significantly lower duty cycles.

An alternative approach to answering the question of what the Benton PUD smart meter duty cycles are in actual practice and what the range of duty cycle values can be is to directly determine the amount of data transmitted by the meter via a software approach using the electric utility smart meter data management system. In discussions with Benton PUD, it was determined that one approach to such an assessment could be logging the number of messages that various meters within the Benton PUD service territory transmit over a defined period of time. Since counting the messages was already a relatively straightforward task, and built into the data management software, Benton PUD launched an effort to query their entire population of smart meters. While not a precise measure of the data transfer from each meter, but rather messages, this method was deemed the most practical way of assessing the statistical distribution of meter activity. By knowing the number of messages transmitted by a meter during a day, for example, and knowing the typical message length (measured in terms of time), the duty cycle can be estimated. As described earlier, the specified message length for the mPass mode of operation of 156.7 ms was validated via measurements and is used in the subsequent calculations of duty cycles.

Message counts were obtained for a contiguous seven-day period for approximately 47,000 meters during June 1-7, 2012, within the Benton PUD service territory. This represents, essentially, the entire population of deployed smart meters. These data, consisting of the number of messages associated with each meter, were provided to the author for subsequent analysis. Valid data were ultimately identified for 46,040 meters for each of the seven days, allowing an analysis of the variability in the message counts on a day-to-day basis. Figure 15 illustrates the result of a cumulative percentile analysis of estimated average daily duty cycles. Average daily duty cycles were calculated by finding the ratio of the transmission time, correlated to the number of messages for each meter, to the length of a day and expressing the result as a percentage. For example, for a meter exhibiting an average daily message count of 10 messages, the total amount of transmit time would be 10 × 0.1576 seconds or 1.576 seconds over the one day period. This corresponds to (1.576/86400) × 100 = 0.0018%.

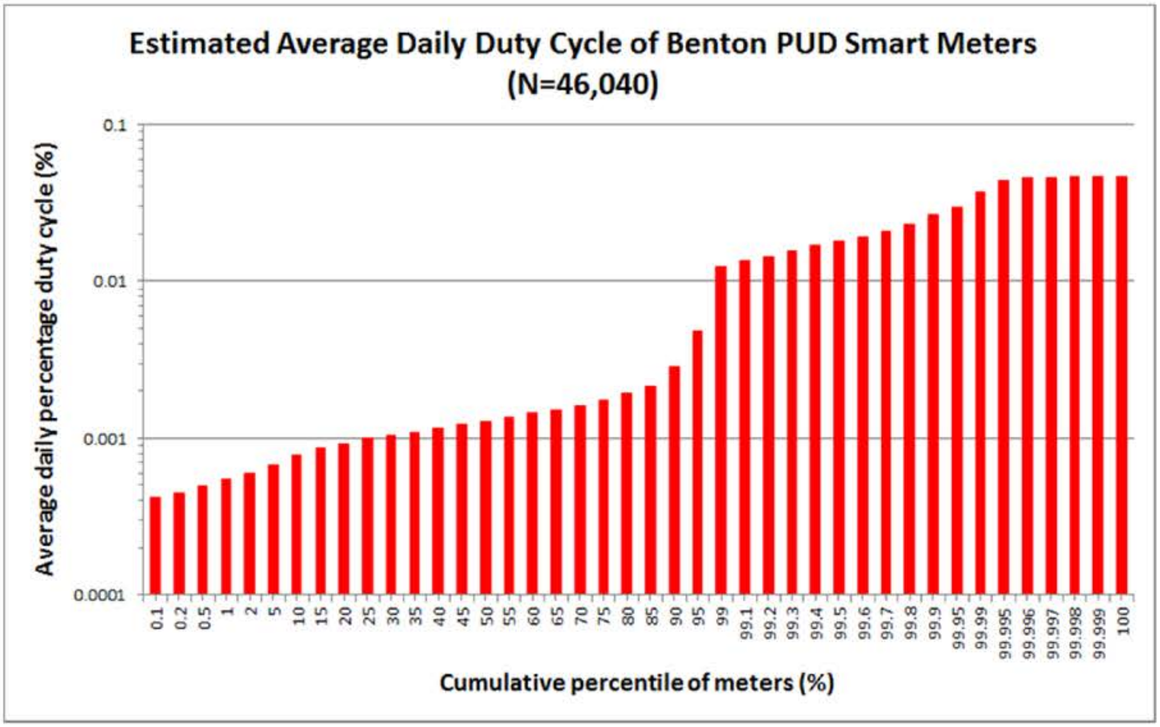

Figure 15. Cumulative percentile analysis of estimated average daily duty cycle for 46,040 smart meters in the Benton PUD service territory. Half of all meters in the study exhibited duty cycles of 0.0013%. The maximum average duty cycle found was 0.047% for a single meter.

Figure 15 shows that all of the meters exhibited very small duty cycles with more than 99% of meters exhibiting duty cycles in the range of 0.012% or less. A tiny fraction of the meters exhibited duty cycles ranging up to 0.047%, this highest value being associated with a single meter in the entire service territory.

Added insight to the transmitter activity of the meters is provided in Figure 16. This figure shows the number of meters transmitting different numbers of messages during the one day study. A message count of six messages during the day was associated with the greatest number of meters, almost 6,986 meters[13]. Smaller message counts were found for lesser numbers of meters while some meters exhibited greater message counts. One meter was observed to produce a daily average message count of 257 messages. These data support the conclusion that only a tiny fraction of all meters exhibit daily transmit durations that are significantly greater than the majority of meters. The most likely number of daily messages results in an estimated 24-hour duty cycle of only 0.0011%, this value being applicable to almost 7,000 meters.

[13] The Benton PUD smart meters are programmed to transmit six times per day, nominally once every four hours. Other data transmissions from the meters will result in a greater number of messages from a smaller fraction of the meter population.

These duty cycle data are directly applicable to the practice of using source based modulation, specified by the FCC, to assess potential exposure to the Benton PUD smart meter fields and the finding is that most meters, most of the time, transmit very little. This means that any exposure resulting when individuals are located close to a meter will be, typically, orders of magnitude below the present FCC limits. For instance, if the highest value of peak RF field found during this study of 12.2% of the FCC MPE, for a location directly in front of the smart meter at residence B, is adjusted for the highest daily average duty cycle from the above study, the resulting 24-hour time-averaged RF field is equivalent to just 0.0057% of the exposure limit.

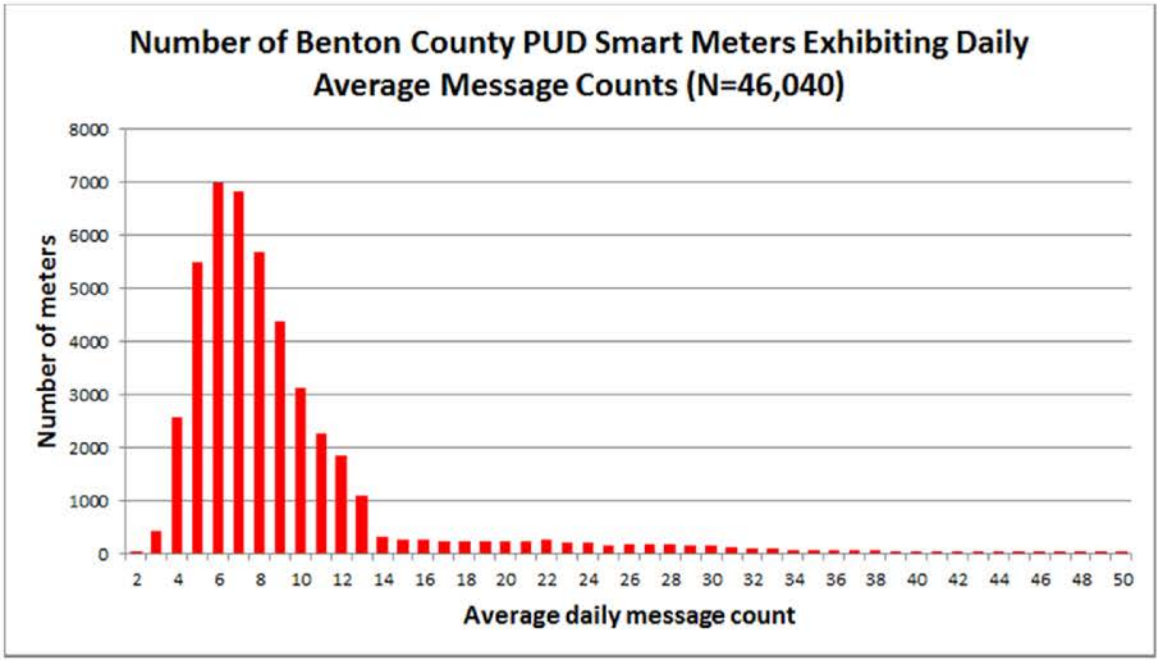

Figure 16. Frequency analysis of 46,040 smart meters in the Benton PUD service territory showing number of meters with different average daily message counts (up to 257 messages) during a seven day study. Most meters were found to have sent six messages during each 24-hour observation time. One meter in the total population reported 257 messages during the day. Most meters were found to transmit six messages during the day.

Using the message count data over the seven day period, the mean and standard deviation of the daily meter duty cycle was computed. The variation in individual meter duty cycle over the seven day period (the standard deviation) was expressed as a percentage of the mean and is displayed in Figure 17 for all 46,040 smart meters. A maximum percentage standard deviation of meter duty cycle was found to be 191.4% (corresponding to a meter duty cycle of 0.005%) and a minimum value of 0%. The overall mean of the percentage standard deviations was 31.1%.

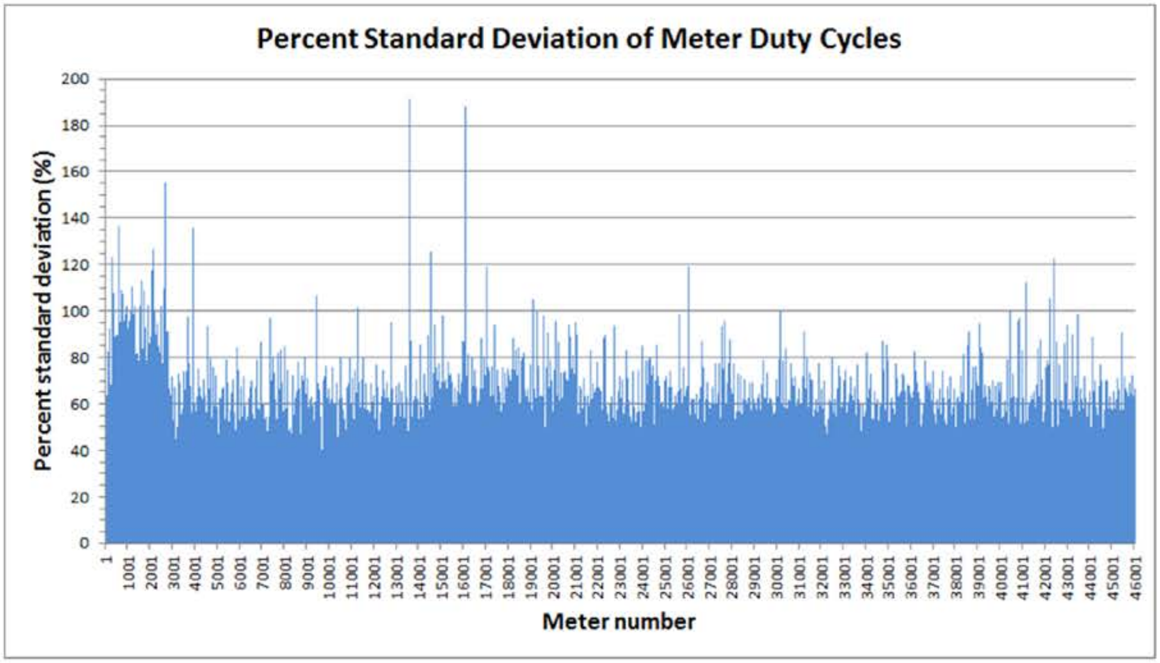

Figure 17. Percentage standard deviation of daily meter duty cycles based on values for seven contiguous days for the study population of 46,040 smart meters. The overall maximum percentage standard deviation was 191.4% and the minimum was 0%. The mean of all percentage standard deviations was 31.1%/

Appendix C lists the results of a percentile analysis of calculated daily average numbers of messages and daily average duty cycles (expressed as a percentage).

Discussion

This study provides insight to characterizing potential exposure of individuals to the RF fields that can be produced by the wireless smart meters deployed by the Benton PUD. When taken collectively, the RF field data presented in this report show that common exposures to the Benton PUD smart meters investigated comply by a wide margin with the applicable human exposure rules of the FCC. This conclusion holds whether RF fields are quantified in terms of their instantaneous peak magnitude, their time-averaged value and/or their spatially averaged value. For example, at a distance of 1 ft directly in front of a smart meter, the greatest peak RF field measured in this study was 12.2% of the FCC public MPE found at a single meter. If this peak field value is adjusted by applying the 99.9th percentile daily average duty cycle observed among the actual installed smart meter population (0.0268%) and for spatial averaging (29.5% of spatial peak), the resulting exposure value for comparison with the FCC limit would be 0.00096% of the public MPE. This would be deemed a conservative estimate of the average exposure that an individual might experience if standing very close to and in front of one of the Benton PUD smart meters for a whole day.

The FCC MPEs for public exposure are based on 30-minute time averages, however, not 24- hour averages. Daily variability in the transmitter activity of most smart meters could result in 30-minute duty cycles being greater than those found over a full 24 hours as messages can become more frequent during a particular time of day and over a shorter period of time. Based on the 24-hour count of meter messages, used for determining the average daily duty cycles, higher short-term duty cycle values can be envisioned by assuming that the total of daily messages could occur over a shorter time than a full day. As a worst case analysis, if the absolute greatest number of messages counted during a single day from any single meter, 434, is used to compute a maximum observed duty cycle for the meter that exhibited the single greatest measured RF field (12.2% of MPE) and it is assumed that all of this meter activity occurred during a 30-minute period, the maximum, 30-minute time averaged RF field at 1 ft in front of the meter would correspond to 0.46% of the MPE before correction for spatial averaging. If adjusted for spatial averaging, the resulting exposure could be 0.14% of the MPE. It should be noted, however, that the presumed 30-minute duty cycle in this case (3.8%) actually exceeds the hardware limited value of 3.4% provided by the manufacturer and, thus, would not be possible.

RF field data reported here were measured at a minimum distance of 1 ft (0.3 m) from the face of various smart meters. This distance was used to eliminate possible nearfield coupling between the measurement probe/antenna and the smart meter that can lead to erroneously high indicated values. Nonetheless, RF field magnitudes at the minimum measurement distance can be projected to even shorter distances. The absolute maximum measured peak RF field, as a percentage of the FCC MPE, found in this study of 12.2%, could be expected to be as great as 28.3% of the MPE at 0.2 m (assuming free space propagation and not considering possible nearfield gain reduction of the antenna or taking spatial averaging into account). The FCC prescribes a 0.2 m (20 cm) distance as the distance at which all devices not intended for use at the surface of the body should comply with the MPEs. Hence, even at the 0.2 m distance, the data acquired in this project would imply that exposures would comply by a wide margin with the FCC MPE. A maximum value of time-averaged RF field equivalent to about 1.1% of the public MPE would be projected at 0.2 m using the maximum duty cycle (with assumption of 30-min worst case averaging) found for smart meters in the Benton PUD service territory.

It is noted that for those devices that are intended for operation at the surface of the body, more meaningful measures of exposure are in terms of specific absorption rate (SAR). For example, cellular telephones of the same maximum power as the 900 MHz radios within the smart meters evaluated here are subject to an FCC SAR limit of 1.6 W/kg in any one gram of tissue. Clearly, however, smart meters are not intended for use at the surface of the body.

The data also show that the Benton PUD smart meter deployment results in only very weak RF fields inside residences. When the directional properties of the smart meter are considered with the RF field attenuating effect of common construction materials, peak RF fields corresponding to potential indoor smart meter exposures of substantially less than 1% of the MPE would be expected. For example, the greatest peak value of field found inside any residence, including an apartment next to a bank of smart meters, was 0.155% of the MPE.

Although this study did not specifically determine the transmitting pattern of the smart meters, it was found that the rearward directed RF energy was substantially less than the values found directly in front of the meter. For example, at one residence where the peak RF field at 1 ft in front of the meter was 12.2% of the MPE, the greatest value behind the meter, inside a garage, was 0.155%. This is approximately 1/100th of the frontal value.

The matter of multiple smart meters that are grouped together in banks, such as commonly found on apartment buildings, and how such groups of meters may affect potential exposure, was investigated at the apartment locations. The measurement results indicate that the peak levels of RF fields are not reliably different from that found at a single smart meter. This observation is consistent with the manner in which the smart meters in the Benton PUD system operate and how the meters were pinged to produce a response; meters operate with a timer circuit that determines when the meter is to transmit its data on electrical energy consumption. Hence, while there may be, from time-to-time, simultaneous transmissions, the smart meters as a whole transmit their intermittent and brief signals in different time slots. This means that there is a smaller likelihood that the instantaneous RF field will be represented by the superposition of signals arriving from a multiplicity of meters. Also, for the measurements conducted in this study, while there could be the possibility that more than one meter in the group might coincidentally be pinged at the exact same time to facilitate measurements, this was probably unlikely. This insight was supported by acquiring time domain measurements of the broadband waveform of smart meter emissions at the three banks of 21, 25 and 45 meters. Hence, it would seem that the peak RF field associated with multiple meters in a group is not likely to exceed the greatest peak value produced by any one of the meters. The time-averaged value of field in the near vicinity of a group of meters, however, would be expected to increase due to the greater, overall transmitter activity. This potential increase in average field, however, must be weighed against the very low duty cycle of most meters. For instance, if all meters were assumed to operate with the observed 99.99th percentile duty cycle (0.0366% over a day or 1.76% over any 30-min period), the 30-min time-averaged RF field for the meter with the highest observed peak field in this study of 12.2% would be just 0.21% of the public MPE. Hence, it would, presumably, require simultaneous operation of some 466 meters to reach the FCC MPE value, an unlikely scenario within the Benton PUD system. Further, this worst case analysis presumes that the maximum field measured for one meter would apply to all 466 meters and this is, basically, not physically possible since all meters would have to be arranged such that the distance between each meter and the exposure location was the same.

Ambient environmental peak RF fields produced by Benton PUD operated TGBs were found to be less than 0.008% of the FCC MPE for public exposure. Although the duty cycles of TGBs are expected to be substantially greater than that of endpoint meters, the already very low values of peak RF fields at ground level result in time-averaged potential exposure levels that are very small in comparison with the FCC limits. When adjusted for the observed duty cycle of the TGB over a 5-minute monitoring period (1.09%), the maximum time-averaged value of RF field was 0.000086% of the MPE.

Measurements documented in this report suggest that simplistic calculations of peak RF fields based on the maximum EIRP of a smart meter can provide conservative estimates of potential exposure at close range. As an example, a calculation of the smart meter power density (S) with the following expression results in values that are greater than the fields measured in this study.

$$S(mW/cm^2) = \frac{EIRP(mW)}{4\pi R^2}$$

When the EIRP[14] is given in dBm, R is distance in cm and the frequency is 940 MHz (the frequency wherein the MPE is the most stringent for the principal operation of the Benton PUD smart meters), the percent of the FCC public MPE, S(%), is given by:

$$S(\%) = 12.69 \times \frac{10^{(dBm/10)}}{R^2}$$

This formula adjusts the calculated power density for the FCC public MPE at 940 MHz. Using the specified EIRP for the Sensus iCon smart meter transmitter, given in Table 2 (20.78 dBm), at 1 ft (30.48 cm), a peak RF field magnitude of 0.103 mW/cm^2 results which is equivalent to 16.3% of the FCC MPE at 940 MHz. Two issues are noteworthy; (1) <u>the computed RF field is greater than that measured</u> for the Benton PUD smart meters in this study (see Table 3) and (2) the above formula includes no corrections that would correct for possible reflections indicating that when close to the meter, any reflections from the ground are inconsequential. Hence, the formulas provide conservative estimates of the actual power density.

Conclusions

A series of field measurements and theoretical calculations were used to characterize possible RF fields produced by smart electric meters being deployed by the

[14] EIRP is the effective radiated power and is equal to the product of the power delivered to the antenna and the gain of the antenna relative to an isotropic source.

Benton PUD. The study shows that the smart meter fields are substantially less than applicable FCC limits for exposure. Importantly, this finding of compliance with the FCC MPEs holds true whether or not the peak measured fields are adjusted for meter duty cycles, whether spatial averaging or other factors that reduce RF fields such as the construction materials of homes are considered or whether the meters exist in a large group or whether individuals are outside near the smart meter or inside their residence. The strongest measured fields were, as expected, at the closest distance at which measurements were performed, i.e., 1 foot or 0.3 meters with typical peak fields of about 12% of the MPE. 30-min time-averaged values were concluded to be, at most, less than 0.46% of the FCC MPE.

The RF field directly behind smart meters was found to be substantially reduced from the value found directly in front of the meter. This finding is related to the directional properties of the smart meter antenna and the shielding properties of the metal meter box and any building materials between the smart meter and the area behind the meter. Measured RF fields within areas immediately behind the meters were nominally about 1/100th of the value in front of the meter.

Large groups of smart meters, such as found on some apartment buildings, do not result in greater peak values of RF fields than those produced by an individual meter but can exhibit higher average field magnitudes due to the operation of multiple meter transceivers. Such higher average composite duty cycles do not, however, change the conclusion that such exposures are compliant with the established FCC limits since the duty cycles of individual meters are so small.

Measurements at one TGB indicate that ground level RF fields associated with their operation do not approach the FCC exposure limits. The significant mounting height of the TGB results in substantial reduction of field magnitude with the greatest peak field on the ground near the TGB investigated being 0.0079% of the MPE.

Exposure of individuals in their smart meter equipped homes is commonly orders of magnitude less than that which would occur for an individual standing immediately adjacent to and in front of the meter. In measurements performed inside three Kennewick, WA, residences, the greatest peak RF field found that was associated with smart meter operation was 0.155% of the MPE. The greatest interior RF fields were always associated with proximity to the smart meter.

The RF field produced by Benton PUD smart meters is constrained by the low power of the transmitter and low antenna gain (low EIRP). A one-watt transmitter limits the maximum emitted RF field. A simple and conservative method for estimating smart meter fields is a straightforward calculation based on the EIRP of the meter. For locations at which the greatest exposures can occur, no special consideration of reflections is warranted.

When the results of this assessment are viewed from the perspective that the FCC MPE includes a safety factor of 50 against adverse health effects, the potential exposure of persons near the Benton PUD smart meters not only complies by a wide margin with the limit but will be as a minimum ten thousand times less than that value associated with adverse health effects.

References

IEEE (2002). IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz-300 GHz. IEEE Standard C95.3-2002. IEEE, Inc., 3 Park Avenue, New York, NY 10016-5997.

IEEE (2005). IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEEE Std. C95.1-2005. IEEE, Inc., 3 Park Avenue, New York, NY 10016-5997, 19 April 2006.

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

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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.

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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 $MR \geq -5$ 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: $G/\text{dB} = (L_{indicated} - L_{actual})/\text{dBm}$

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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				-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

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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

DQS

Person in charge
Geyer

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

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

This certificate may only be published in full, unless permission for the publication of an approved extract has been obtained in writing from the Managing Director.

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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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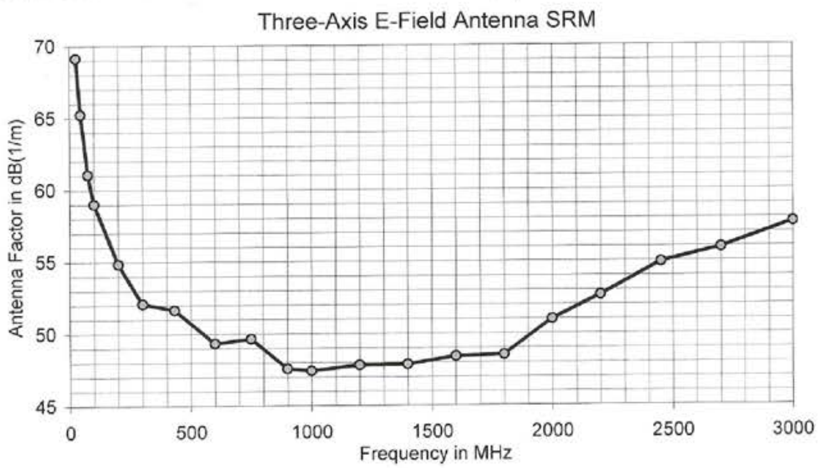
Results

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.



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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 B
Residential Measurement Site Photographs

Figure B-1. Residence A, Kennewick, WA.

Figure B-2. Residence B, Kennewick, WA.

Figure B-3. Residence C, Kennewick, WA.

Appendix C
Percentile Analysis of Daily Average Message Counts and Daily Average Duty Cycles (expressed as a percentage)

Percentile	Daily average messages	Daily average duty cycle (%)
0.1	2.285714	0.000417
0.2	2.428571	0.000443
0.5	2.714286	0.000495
1	3	0.000547
2	3.285714	0.000599
5	3.714286	0.000678
10	4.285714	0.000782
15	4.714286	0.00086
20	5	0.000912
25	5.428571	0.00099
30	5.714286	0.001042
35	6	0.001094
40	6.285714	0.001147
45	6.714286	0.001225
50	7	0.001277
55	7.428571	0.001355
60	7.857143	0.001433
65	8.285714	0.001511
70	8.857143	0.001616
75	9.571429	0.001746
80	10.57143	0.001928
85	11.71429	0.002137
90	15.71429	0.002866
95	26.28571	0.004795
99	67.85714	0.012378
99.1	73.14286	0.013333
99.2	79.42857	0.014472
99.3	85.85714	0.015661
99.4	92.57143	0.016886
99.5	99.54286	0.018137
99.6	105.6914	0.019257
99.7	114.1257	0.020785
99.8	125.2743	0.022815
99.9	147.2629	0.026754
99.95	163.42	0.029731
99.99	209.7789	0.036659
99.995	251.7949	0.0438
99.996	253.2729	0.045676
99.997	255.3118	0.045892
99.998	257	0.046135
99.999	257	0.046507
100	257	0.046879

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:

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

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.

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 device is in operation. A duty cycle of 1.0, or 100%, corresponds to continuous operation. Also called duty factor. A duty cycle of 0.01 or 1% corresponds to a transmitter operating on average only 1% of the time.

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).

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).

endpoint meter- A term used to designate a smart meter that is installed on a home or business to record and transmit electric energy consumption but that does not provide access point features.

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).

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.

FSK- Frequency shift keying is a modulation method in which a carrier frequency is shifted between a number of frequencies to represent digital information. In the simplest implementation, two frequencies are used transmit binary “1”s and “0”s. More complex schemes such as 7-level FSK as used by the Sensus FlexNet™ system are used for greater reliability.

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.

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

IEEE- Institute of Electrical and Electronics Engineers.

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.

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.

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.

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.

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.

RF - Radiofrequency.

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

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.

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.

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.

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.