ELECTRIC POWER RESEARCH INSTITUTE

Characterization of Radiofrequency Emissions From Two Models of Wireless Smart Meters

2011 TECHNICAL REPORT

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NOTE

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This publication is a corporate document that should be cited in the literature in the following manner:

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Product Description

Concomitant with the widespread deployment of Advanced Metering Infrastructure (AMI) is the need to characterize radio-frequency (RF) emissions from wireless smart meters. A previous EPRI Technical Report (1021126) provided a detailed characterization of RF emissions from one type of wireless smart meter deployed across several service territories in the U.S. This report describes emissions from wireless smart meters produced by two manufacturers that are currently in operation within a large service territory in the U.S.

Results and Findings

The RF field levels from the smart meters studied are below the exposure limits stipulated by the Federal Communications Commission (FCC). Furthermore, data from the meter provider permits one to estimate that, as the system currently operates, nearly 99.9% of the meters transmit 1% or less of the time, and 99% of the meters transmit less than four-tenths of one percent of the time. These duty cycles are taken into account when estimating potential exposures of people in relation to FCC exposure limits for the general public, which are based on a 30-minute average of power density across the body.

Challenges and Objectives

Characterizing RF emissions from wireless smart meters requires an intimate knowledge of the principles upon which a particular system operates. For example, the smart meters studied cannot be configured to operate continuously under any practical conditions in the field. Thus, a method was introduced under controlled conditions to "ping" the meters so as to obtain a reliable data stream of emissions. This technique was used for measurements within residences, but in the case of apartment structures, the normal, ambient emissions were measured without deliberately "pinging" of the meters.

Application, Values and Use

The data in this report add to an accumulating body of knowledge concerning the operation of wireless smart meters and the RF emissions associated with their use. This information has value insofar as responding to questions from agencies, such as Public Utility/Service Commissions, as well as to the interested public and scientific community.

EPRI Perspective

Measuring electric energy consumption with smart meters in residential and commercial environments is becoming more commonplace as part of the development of Advanced Metering Infrastructure (AMI) in the electric utility industry. With the deployment of wireless smart meters, public concern has been raised about potential health effects associated with their RF emissions. EPRI is responding to these concerns with research efforts to provide objective information on RF emissions related to smart meters.

Approach

The investigator conducted measurements of the RF emissions of the various models of wireless smart meters distributed throughout the service territory's customer base. To accomplish this objective cooperation was obtained from both the vendor and the utility. Measurements were conducted under controlled conditions with individual units isolated from any sources of spurious fields. Measurements were also conducted to characterize field levels both within and outside of residences. Additionally, estimates were made of the operational duty cycle range of the system based on data the vendor provided to the investigator.

Keywords

Advanced Metering Infrastructure
Electromagnetic fields
Exposure assessment
Smart meters
Source characterization

Summary

Pacific Gas & Electric (PG&E) is in the process of deploying wireless smart meters throughout its service territory. These meters contain low power (1 watt and 0.1 watt) transmitters for communication in what is termed a radiofrequency (RF) local area network (RF LAN) and a potential, future Home Area Network (HAN). Over a period of approximately six months during 2011, the RF emitting characteristics of two different smart meters, a General Electric-I210 and a Landis-Gyr Focus AXR-SD, each equipped with one of two different wireless communication packages developed by Silver Spring Networks (SSN) were investigated. The focus of the work was to better understand the operating characteristics of the meters in terms of the magnitude and temporal patterns of their RF emissions.

These smart meters make use of 900 MHz band (902-928 MHz) spread spectrum, frequency hopping signals for the RF LAN communication within a so-called mesh network. Within a wireless mesh network, each endpoint meter transmits and receives data from a central access point (AP), which is wirelessly connected back to the electric utility. The nature of the mesh network is that each endpoint meter can communicate with neighboring meters that can act as routing points, if necessary, to ultimately communicate with the AP. The HAN transmitter would be used in the future for wireless communication with HAN devices within the home, such as small transceiver type devices attached to various electrical appliances and electrically operated systems that can be programmed to control when the appliances or systems operate, thereby taking advantage of optimum energy rates.

Preliminary measurements on the meters were conducted in Colville, Washington, to determine the magnitude of the RF fields generated by the 1 watt (W) RF LAN transmitter and to examine the directional characteristics of the meters, observe for any unusual low frequency emissions in the 5 Hz to 100 kHz band that might be produced by the electronic circuits within the meters and to measure the attenuation that could be afforded by a simulated stucco wall, common to many California homes. Following the preliminary phase of the project, on-site measurements at six residential locations in the PG&E service territory were conducted. The focus of the residential measurements was to determine typical indoor values of the RF fields produced by the smart meter installed on the home. In addition, measurements were performed to examine the composite RF field environment where collections of smart meters are aggregated in a small space at three different apartment

complexes including one where 112 smart meters are collocated. Measurements of short-term duty cycles for several meters were accomplished as well as field measurements at a single access point which acts as a collector of data from on the order of thousands of endpoint meters on residences.

Most of the measurements employed a spectrum analyzer based instrument (Narda model SRM-3006) that makes use of an attached probe/antenna and can present measured RF field magnitude directly as a percentage of the Federal Communications Commission (FCC) limits on exposure (maximum permissible exposures – MPEs). The SRM-3006 probe/antenna contains three mutually orthogonal elements that results in an isotropic spatial response to all polarization components of incident RF fields. The instrument also contains a "scope" option that allowed the time-domain measurement of smart meter signal waveforms. The sensitivity of the instrument and ability to measure the RF field magnitude on specific frequencies was key to the success of the measurement program.

Analysis of data transmissions from 88,296 smart meters, collected via the PG&E data management system, revealed the statistical distribution of meter duty cycles, thereby permitting highly confident correction of peak RF field magnitudes to values of time-averaged potential exposure. This analysis identified one meter in 88,296 that exhibited a maximum duty cycle of 13.9%. Half of the meters exhibited duty cycles not exceeding 0.0465%, 99% of meters had duty cycles not exceeding 0.355%, 99.9% had duty cycles not exceeding 1.12% and 99.99% of meters had maximum duty cycles not exceeding 4.53%. These data confirm the position that the smart meters, while they transmit intermittently throughout the day, create RF fields for only very small fractions of the day. For example, half of all endpoint meters would be expected to actually transmit no more than 40 seconds per 24 hour day.

Directional emission patterns for the meters were investigated and found to favor the forward direction with a conservative reduction factor of approximately 10 dB (a factor of ten) in rearward directed fields with some specific angles exhibiting reduction factors of approximately 20 dB (factor of 100).

In three locations tested aggregations of smart meters on apartment buildings did not result in greater peak values of RF fields than those produced by an individual meter but did exhibit higher average field magnitudes due to the operation of multiple meter transmitters.

Although not presently implemented, the HAN radio inside the smart meter, when activated, results in substantially weaker RF fields due to its lower effective isotropic radiated power (EIRP) and, also, complies with the FCC exposure limits.

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 the measurements performed in the six California residences, 99% of the measured peak values were less than 0.8% of the MPE for the general public with 90% of the measured values being less than 0.1% of the MPE.

RF emissions from wireless smart meters are constrained by the low power of the transmitter's power and the antenna's gain. 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 exposure can occur, no special consideration of reflections is warranted.

The study shows that the subject smart meter emissions are 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 typical peak fields of about 10-15% of the MPE. Time-averaged and spatially averaged values, at this point of maximum peak field, were estimated to be, at most, about 0.14% of the FCC MPE, depending on the activity of the meter.

Glossary of Terms

AMI – Advanced metering infrastructure.

AMR – Automatic meter reading.

anechoic – A term meaning without echos or reflections. Anechoic chambers are often used for antenna pattern measurements to minimize any disturbance of the measurement data due to reflections from the local environment.

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.

beacon signal – A very short duration signal emitted by smart meters to indicate their availability to connect to other meters within a mesh network. Beacon signals occur periodically at different time intervals depending on the state of connectivity with the mesh network and any requirements to transmit data.

This interval can vary from approximately once every few seconds to once an hour but can be absent during times when the smart meter must transmit energy consumption data to the network.

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 – 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).

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).

gigahertz (GHz) – One billion hertz.

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

HAN – Home Area Network. In the context of smart meters, a local area network for communication between a personal computer and various electrical appliances, equipment or systems to accomplish optimized electric energy consumption at the home. Small sensors with low power radio transmitters are attached to the various electrical appliances for communication in the HAN.

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.

magnetic field strength – A field vector (H) that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

magnetic flux density – Related to the magnetic field H by the permeability of the medium where the field is observed. Magnetic flux density has units of magnetic charge per unit area (Webers per square meter, also known as a Tesla). Often, a convenient unit is a millionth of a Tesla or microtesla (μT).

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

mode – A statistical term referring to the most frequently observed value among many. It is distinguished from the mean or median of a distribution.

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.

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.

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).

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. 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.

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.

router, wireless – A device commonly used in homes and offices for wireless distribution of Internet connectivity, most commonly operating in the 2.4 GHz license free band.

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 (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.

WWAN – Wireless wide area network. WWANs are provided by several cellular telephone companies for wireless connectivity directly to the Internet for data transmission. WWANs are different from so-called wireless “hot spots” such as found in cyber cafes and operate in either the 850 MHz cellular or 1900 MHz PCS bands.

Table of Contents

List of Figures

List of Tables

Section 1: Introduction

Electric utility companies nationwide have begun the deployment of smart meters as one element in the development of a smart grid throughout the country. Pacific Gas and Electric (PG&E) is but one of many such companies currently engaging in the replacement of older electromechanical electric power meters with new digital wireless smart meters as a part of the company's embracing of Advanced Metering Infrastructure (AMI). While the smart meters being installed by PG&E employ low power radio transmitters with maximum powers of about one watt, with correspondingly low level radiofrequency (RF) fields emitted by the meters, public concerns over potential exposure to the meter RF fields has 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 PG&E 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 wireless smart meters deployed by PG&E.

Common to many smart meter implementations, the meters deployed by PG&E contain two low power (one watt or less) transmitters that are designed to operate in designated Federal Communications Commission (FCC) license-free bands. The transmitter that maintains communication with both other meters and the electric utility operates in the 902-928 MHz license-free band. A second transmitter can operate in the 2,400-2,500 MHz (2.4-2.5 GHz) band and is available for use in a so-called Home Area Network (HAN). Although this transmitter is presently disabled from normal operation throughout the PG&E service territory, PG&E may, in the future, make use of this second transmitter so that customers, who wish to do so, can allow for communication between various electrical appliances and electrically operated systems within their homes and the smart meter to exploit optimum energy pricing.

The particular wireless smart meter technology being adopted by PG&E exploits the capability of wireless mesh networks for communicating with the smart meters as installed on homes and businesses and in collecting electrical usage data. In a mesh network, multiple endpoint meters, installed on homes, may communicate with other endpoint meters within the network in such a way that the data can be, ultimately, relayed to an access point that receives data from many meters distributed throughout a particular geographic area. This area may be a neighborhood or a collection of neighborhoods. In the case of the PG&E implementation, an individual access point may serve to collect electrical usage data from as many as 5,000 endpoint meters. Meters within the mesh network automatically establish network routes that permit communication with an appropriate access point. Each meter can store several route tables within its digital memory, allowing it to optimally connect with an appropriate neighboring meter for relaying of data in the event that an alternative network connection does not work. For instance, if a particular propagation path between an endpoint meter and the access point becomes broken, alternative paths are automatically adopted to successfully communicate with its access point. In this sense, mesh networks are sometimes described as "self-healing" meaning that communication between any given meter in the network and its associated access point can be achieved through the meter's interaction with other meters within the network. This concept actually allows meters that cannot directly reach an access point (the access point is not directly within transmission range) to work through other meters in the network to get its message through. This feature of mesh networks forms a very powerful capability in terms of network communications and provides for considerable reliability in terms of the network's ultimate purpose.

In spite of this sophisticated communication methodology, the transmitters within smart meters generally only operate for small fractions of time and this is accomplished via very brief transmissions, often lasting for a few thousandths of a second at a time. The meters periodically emit signals throughout the day to remain appropriately connected within the wireless network, to relay data from neighboring meters, when needed, and to transmit residential electrical usage data. The cumulative time that signals are actually transmitted from an endpoint meter is normally on the order of a few minutes or less each day. In the case of the smart meter use within PG&E, as currently operated, meters report electrical usage data to the company six times per day. Hence, the duty cycle (see Glossary) associated with most smart meters is a few percent, and in most cases, less. The duty cycle can vary between time windows throughout a given day from time-to-time, depending on network performance and a meter's position in a network relative to the other meters within that network. This complex variability in meter operation from hour-to-hour and from day-to-day suggests that a quantitative analysis of operation over a large sample of meters can provide useful insight into the range of endpoint meter duty cycles. Such analysis will permit estimates of time-averaged emissions, which form the basis for FCC exposure limits.

Within the PG&E service territory, some 5,275,000 electric smart meters will be deployed throughout a geographical region ranging from Eureka in the North to Bakersfield in the South, and from the Pacific Ocean in the west to the Sierra Nevada in the East. Distributed among these many endpoint meters will be approximately 1360 access points for the utility to communicate with the meters.

Section 2: Meter Characteristics

Basic Meter Specifications

This report describes measurements of RF fields produced by two different meters that represent those presently in use by PG&E. These include the GE I-210 meter and the Landis-Gyr (L+G) Focus AXR-SD as shown in Figure 2-1. Each of these meters contain either of two different radio (transmitter) configurations developed by Silver Spring Networks (SSN) that carry FCC ID numbers of OWS-NIC507 and OWN-NIC514. Hence, a total of four combinations of meters and radios were included in the evaluations in this report. Both of the radios consist of a nominal 1 watt (+30 dBm) frequency-hopping, spread-spectrum transmitter that operates in the 902-928 MHz license-free band and a nominal 0.1 watt (+20 dBm) radio that uses the Zigbee protocol for use in the 2,400-2,500 MHz license-free band. The specific meters used in preliminary tests are identified in Table 2-1.

Table 2-1
Smart meters and serial numbers used in preliminary testing in Colville

Radio FCC ID	GE I-210	L+G Focus AXR-SD
OWS-NIC507	1003786409	1005290337
OWS-NIC514	1009216599	1008114960

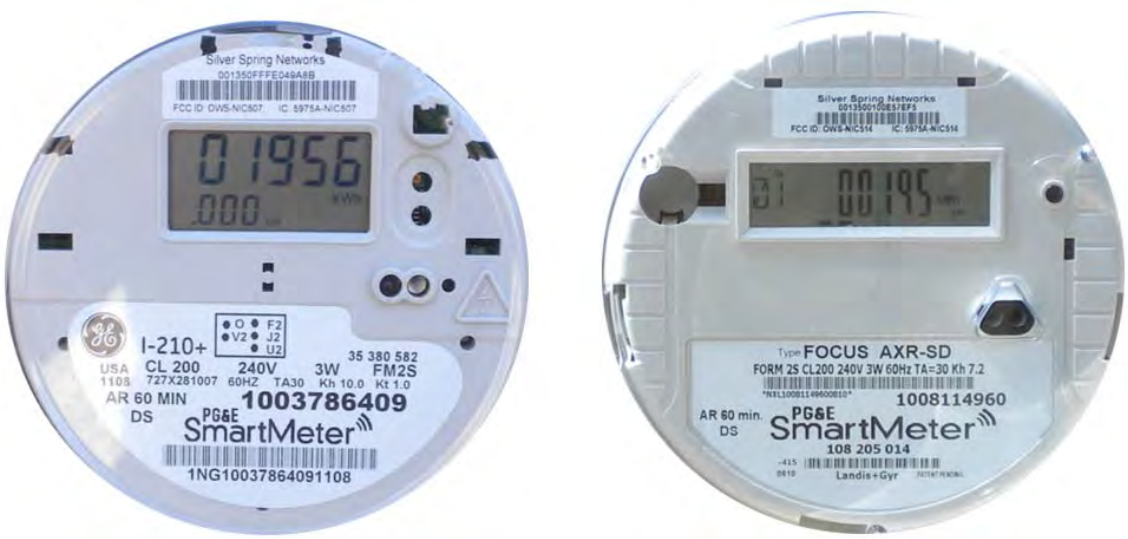

Figure 2-1
Photographs of the GE I-210 and Landis-Gyr Focus AXR-SD smart meters

Based on FCC reports prepared for SSN[1,2], Table 2-2 provides the following maximum transmitter output powers and antenna gains.

Table 2-2
Summary of operational parameters for the NIC507 and NIC514 radios taken from FCC test reports

Radio	902-928 MHz band		2,400-2,450 MHz band	
	Power (dBm)	Antenna gain (dBi)	Power (dBm)	Antenna gain (dBi)
NIC507	+29.5	2.4	+20.05	1.5
NIC514	+29.86	4	+21.7	1

The above parameters indicate that the maximum effective isotropic radiated power (EIRP) for the 900 MHz band is between +31.9 dBm (1,549 mW) and +33.9 dBm (2,455 mW) and for the 2.4 GHz band is between +21.5 dBm (141.3 mW) and +22.7 dBm (186.2 mW). The indicated antenna gains are the maximum values; antenna gains in directions other than the main beam would be less, resulting in a lower transmitted power density.

Characteristics Relevant to Assessing Potential Exposure

Several factors determine the magnitude of RF fields that can be produced by any source. These include the 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 (that is, the ratio of the time that the transmitter actually transmits a signal to some reference time). For evaluating compliance with RF exposure standards, the time-averaged value of plane wave equivalent power density is usually the most fundamental aspect of 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; 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, the metal electrical box that contains the meter socket interacts with the RF fields to distort what the antenna pattern would be in the absence of the meter box. The meter box can 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 to the front of the meter.

The 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 such that exposure levels over a body's dimensions are also highly non-uniform. Since exposure limits are based on spatial averages over the body as well as 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 greatest. Nonetheless, for purposes of the evaluation reported here, measurements of RF fields at the height of the meter were obtained for locations near the meter exterior to the residence. Limited data were also obtained to document the variation in field over a distance from ground level to six feet (1.8 m) above ground so that spatial average values of field could be calculated from the fields' measured spatial peak value.

Because the transmitted fields from smart meters can exhibit such a strong dependency on distance and azimuthal- and elevation-angles, mounting locations can 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 weak RF fields. If the meter is mounted lower,

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[1] Emissions Test Report for a Low Power Transmitter. Report No. 09PRO001 Rev.3. Compliance Certification Services, 47173 Benicia Street, Fremont, CA 94538, 6 March 2009.

[2] Emissions Test Report for a Low Power Transmitter. Report No. 09PRO009. Compliance Certification Services, 47173 Benicia Street, Fremont, CA 94538, 22 August 2009.

more of the body may be subjected to the maximum fields since the body may intercept most of the transmitted fields within the elevation plane. This is illustrated in Figure 2-2. The field's non-uniformity across the body 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 be also. As an example, for a 900 MHz horizontal dipole antenna, the spatially averaged power density over the vertical extent of a six-foot tall person standing at 12 inches (0.3 m) in front of the lower antenna would be expected to result in approximately a 26 percent greater body-averaged exposure for a meter mounted at 48 inches (1.22 m) above the ground compared to a meter mounted at 66 inches (1.68 m) above the ground. The influence of the ground on the RF power density along the body axis is represented by the oscillations in the two curves of Figure 2-2.

Finally, exposures are characterized in terms of the time-averaged values of power density to which the body is exposed because all of the applicable exposure limits are based on averages over time. For the smart meters used by PG&E, this is determined by the duty cycle of emissions, as discussed above, and one's proximity to a meter.

RF Exposure Limits: See Appendix A.

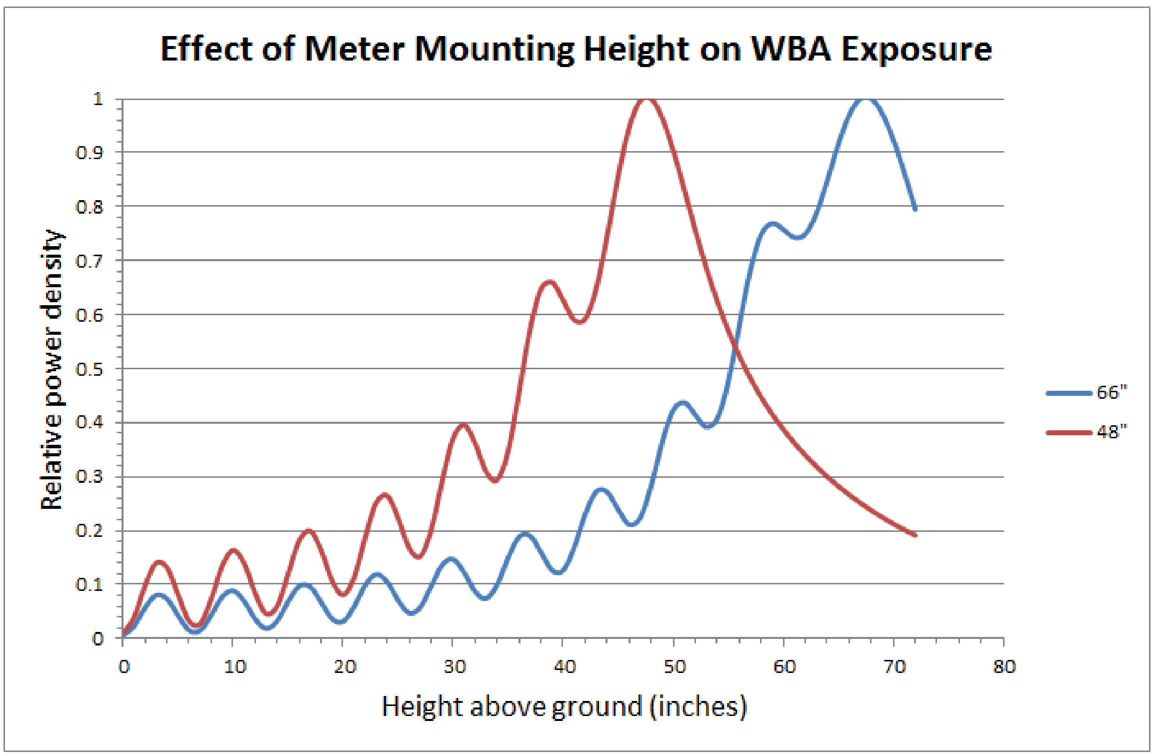

Figure 2-2
Calculated values of relative power density, using a method of moments technique, along the body axis of a person standing 12 inches (0.3 m) in front of a 1 watt horizontal dipole with realistic ground for two smart meter mounting heights of 48 inches (1.22 m) and 66 inches (1.68 m). Oscillations in the power density are caused by ground reflections.

Section 3: Technical Approach Used in This Project

Basic Features

Many elements were included in this evaluation of RF fields of smart meters deployed by PG&E. A series of measurements on four smart meters provided by PG&E was carried out in Colville, WA to become familiar with their operation. This element consisted of:

- Measuring the RF fields of the 900 MHz radio vs. distance in an outdoor setting
- Measuring the meters' 900 MHz transmitting pattern
- Observing their 900 MHz pulse characteristics
- Determining the 900 MHz RF field attenuation afforded by a simulated stucco wall
- Measuring the vertical spatial distribution of 900 MHz fields adjacent to a meter
- Measuring any low frequency emissions that might result from meter clock circuits or switching power supplies operating in the frequency range of 0 to 100 kHz.

In addition, measurements were conducted in California on installed smart meters including:

- Measurements at six residences including outside and inside the homes
- Measurements at three apartment complexes that included meter banks of 12, 13 and 112 meters in close proximity to one another including short term duty cycle measurements
- Measurements at an access point installed on a light pole

At a laboratory at the PG&E San Ramon Technology Center, measurements were performed of RF fields produced by a smart meter with the 2.4 GHz HAN radio activated for test purposes. A measurement of the duty cycle that would be associated with a smart meter transmission during a firmware download via an access point to a meter was conducted in the PG&E laboratory to determine what the maximum possible duty cycle could be for a data transmission presumed to represent the highest duty cycle at which a smart meter would transmit.

In an earlier study of frequency-hopping spread-spectrum smart meters[3], it had been found that programming of the radios to operate in continuous wave (CW) mode greatly facilitated field characterization since the emissions of such programmed meters could be uniquely identified against the backdrop of other meters that were hopping across the 902-928 MHz band. Such was not the case with the meters provided for measurements in Colville. All of the meters, as delivered, when powered on, immediately began frequency hopping, providing considerable challenge when attempting to determine their transmitting patterns. Using spectrum analyzer based instrumentation, see below, the frequency-hopping characteristic of the meter emissions made it virtually impossible to meaningfully assess directional variations in the strength of the emitted pulses. To increase the activity of the smart meters, and, thereby, enhancing the ability to capture the brief, emitted signals, a field service unit (FSU) was used to "ping" the meter, causing it to transmit pulses on a repetitive basis.

Instrumentation

RF Fields

The primary concern in this study was the magnitude of RF fields emitted by smart meters in PG&E's territory. Due to the frequency-hopping nature of the smart meter transmitters, a spectrum analyzer based detector was used for most of the measurements (Narda model SRM-3006 Selective Radiation Meter,

[3] *An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter*. EPRI, Palo Alto, CA: 2010. 1021126.

SN D-0069). Figure 3-1 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 correcting the measured field for the frequency dependency of the FCC MPEs. Calibration certificates for the SRM and probe are provided in Appendix B.

Figure 3-1
The Narda SRM-3006 Selective Radiation Meter is based on FFT spectrum analyzer technology and uses a probe/antenna to measure the absolute magnitude of incident RF fields across the frequency range of 27 MHz to 3,000 MHz and digitally converts the detected field to the equivalent percentage of the FCC MPE.

Besides providing measurements of the frequency spectrum of detected fields, 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 extremely wide resolution bandwidth (RBW) so that detected signals can be measured in the time domain. This facilitated capture of the brief pulses of RF that occurred across the entire 900 MHz band regardless of the specific frequency of each individual emission. For the measurements performed in scope mode, a RBW of 32 MHz was used when centered on 915 MHz. This permitted capture of all signals within the 902-928 MHz band so that the peak, instantaneous power of the emissions could be viewed. In this way, pattern measurements could be obtained by rotating the meter for approximately a minute while recording the peak signal levels.

The SRM-3006, with an accompanying probe/antenna, is capable of performing narrowband spectrum measurements of signals from 27 MHz to 3,000 MHz. For measurements of the 900 MHz band smart meter emissions, an RBW of 100 kHz was used. 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 of 100 kHz, 200 kHz and 300 kHz. Measurement of emissions in the 2.4 GHz band made use of a 200 kHz RBW.[4]

[4] Tests were conducted to determine the difference in measured peak power of the smart meter signals with RBWs of 100, 200 and 300 kHz. The 200 and 300 kHz RBWs yielded 2.5% and 3.5% greater indicated powers than the 100 kHz RBW. In the interest in finer frequency resolution, the 100 kHz RBW was used for the 900 MHz band measurements.

In Colville, measurements were made of the RF field at 0.3 m, 0.6 m, 1 m, 2 m, 3 m, 4 m, 5 m, 10 m and 15 m in front of each smart meter using the spectrum mode of operation. Measurements were performed in an outdoors environment free of any nearby reflective objects over a gravel driveway. The measurements were performed by allowing the SRM-3006 to acquire a maximum hold spectrum of the emitted signals from the smart meter for approximately two minutes. The peak value of detected field across the spectrum was then used as a measure of the RF field produced at that distance by the meter. Figure 3-2 shows a representative measured spectrum acquired at 0.3 m in front of an L+G Focus AXR-SD meter. Smart meters were installed in a meter box (Milbank Type 3R enclosure) supported by a PVC pipe inserted in an antenna rotator.

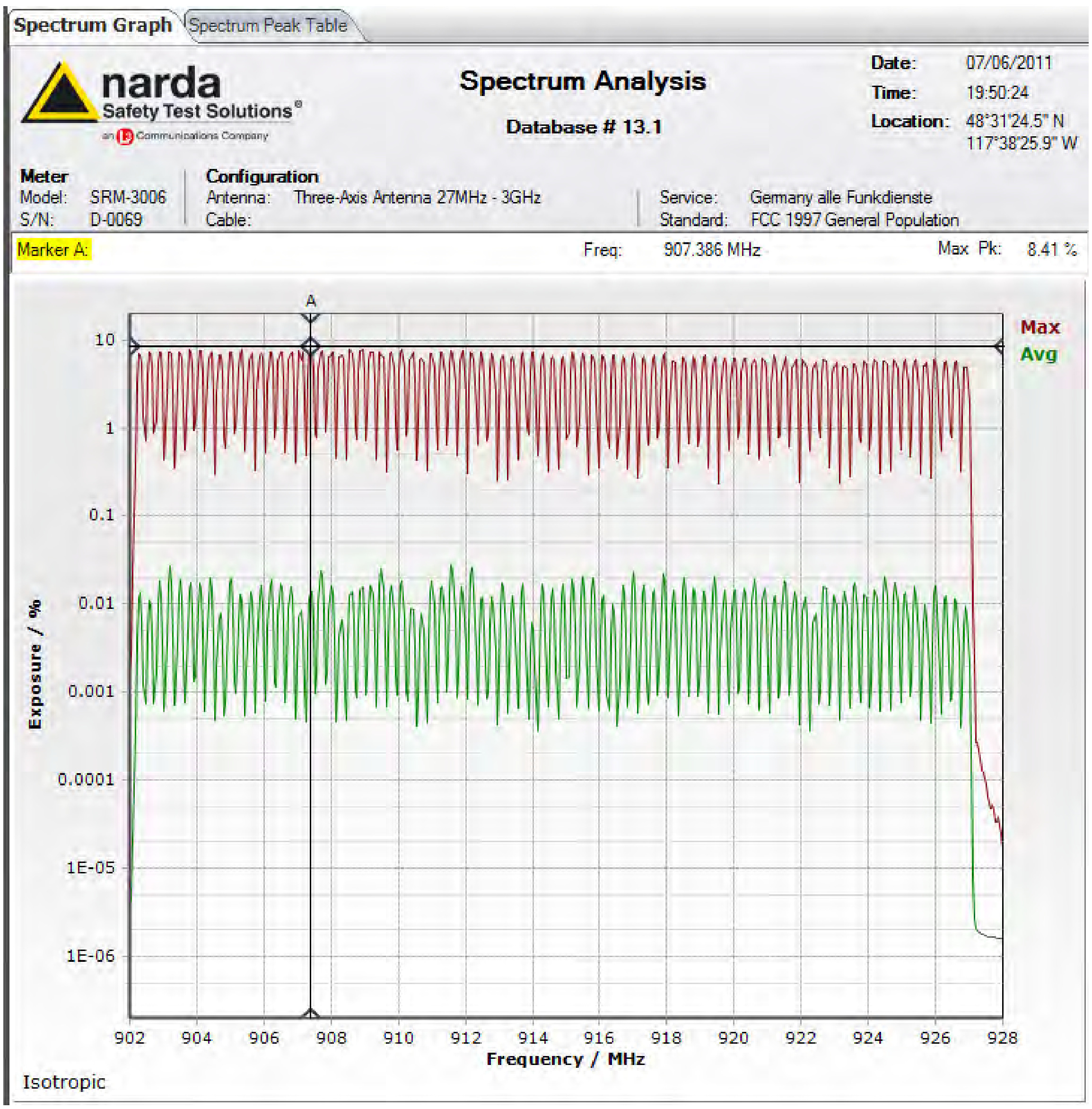

Figure 3-2
Example SRM-3006 spectrum measurement of the spread-spectrum frequency-hopping signals produced by a L+G Focus AXR-SD smart meter at 0.3 m showing the 83 hopping channels used by the meter. The marker is set on the maximum peak value of field representing 8.41% of the FCC MPE for the general public.

Low Frequency Fields

The electronic circuits contained within the smart meter have the potential for producing weak, low frequency fields associated with, for example, electronic clocks, switching power supplies and other digital circuitry. Limited measurements were conducted to detect low frequency fields using an electric and magnetic field analyzer (Narda model EHP-50C, SN 352WN01203). This device, shown in Figure 3-3 during measurements near one of the smart meters, senses both electric and magnetic fields using a time domain sampling approach, similar to that employed in the SRM-3006, and FFT technology for displaying the measured amplitude spectrum of the electric field strength or magnetic flux density. The EHP-50C is specified to measure magnetic fields as weak as nominally 1 nT and electric field strengths as weak as 0.01 V/m over the frequency range of 5 Hz to 100 kHz. The device permits detection of three orthogonal polarization components of the fields through a sequential process. Sweep times are determined by the frequency span that is selected. Figure 3-4 is an illustrative spectral plot of magnetic field obtained by the EHP-50C when placed at 0.3 m in front of a L+G Focus AXR-SD smart meter over a six-minute period of time during which the root-mean-square (RMS) value of the field was measured. The magnetic field flux density is given in the unit microtesla (μT). Calibration certification for the EHP-50C is provided in Appendix C.

Figure 3-3
Using the Narda EHP 50C electric and magnetic field analyzer

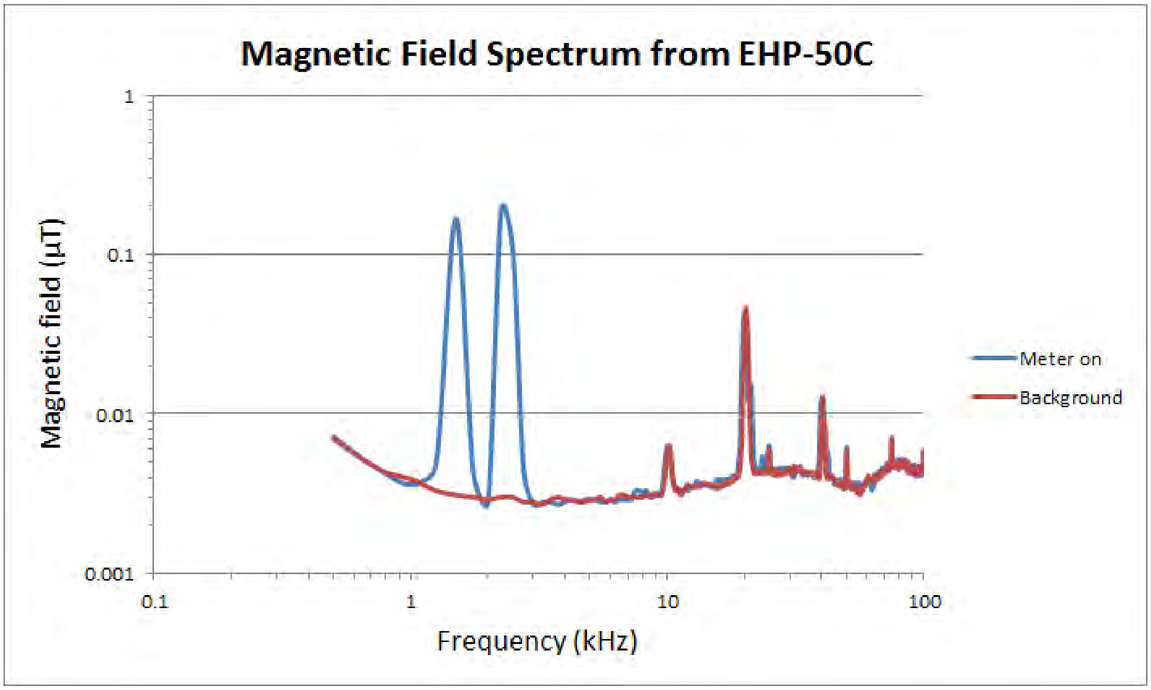

Figure 3-4
Illustrative root-mean-square (RMS) magnetic field spectrum observed near a L+G Focus AXR-SD smart meter over a six-minute period of time. The background spectrum was acquired while the meter was off and the test meter box was unpowered from the AC mains.

Rotator System for Pattern Measurements

Evaluating smart meter patterns was accomplished by rotating each meter, when plugged into the test meter socket/box, using a light-duty TV antenna rotator. The smart meter was supported 51 inches above the ground by a PVC pipe inserted into the bottom of the meter box and the top of the rotator. Patterns were acquired by pinging the meter to transmit pulses across the 902-928 MHz band while the meter was rotated 360 degrees in slightly less than one minute. The scope mode of the SRM-3006 was used, as described above, to record the instantaneous peak value of detected pulses, regardless of their specific frequency within the 900 MHz smart meter band as the meter was rotated. Observation of the resulting pattern of pulsed fields allowed a determination of the transmitting pattern of the meter as installed in the meter box. The rotator with meter box and an installed smart meter are shown in Figure 3-5. AC power was provided to the meter box via a long extension cable connected to a 220 volt source in a shop located about 100 feet from the test location.

Figure 3-5
Smart meter installed in a Milbank type 3R meter box and supported above a rotator for measurement of the transmitting pattern of the meter. The SRM-3006 was positioned at 0.3 meters from the front of the smart meter for all pattern measurements.

Section 4: Results

Field vs. Distance in Colville

Peak RF fields expressed as a percent of the FCC MPE for general public exposure are tabulated for the range of distances used in Table 4-1. The peak field was obtained by using a marker feature on the SRM-3006 following approximately two minutes of continuous measurement during which the SRM-3006 had performed approximately 1500 scans of the 902-928 MHz band. While each of the 83 spread spectrum channels on which the meter operates exhibited virtually the same peak field, the single greatest channel value was used in Table 4-1. Each measurement was made with the SRM-3006 positioned on a tripod at the specified distance with the instrument at the same height as the smart meter. A laser level was used to insure that the detection probe of the SRM-3006 was set at the same height as the display screen on each smart meter regardless of slight variations in the ground surface elevation.

Table 4-1
Summary of peak 900 MHz RF field values at nine distances from four smart meters measured in Colville (field expressed as percentage of FCC MPE for general public) (Narda SRM-3006 w/100 kHz RBW).

	GE-I210		**L+G Focus AXR-SD**	
Radio Distance (m)	NIC-507	NIC-514	NIC-507	NIC-514
0.3	9.628	8.272	9.216	8.410
0.6	3.522	2.444	3.730	2.861
1.0	1.384	1.285	1.084	0.783
2.0	0.488	0.311	0.502	0.451
3.0	0.201	0.082	0.159	0.129
4.0	0.136	0.116	0.106	0.102
5.0	0.095	0.029	0.058	0.051
10.0	0.013	0.008	0.00622	0.0084
15.0	0.021	0.018	0.022	0.016

Field measurements were made no closer to a smart meter than 1 ft (0. 3m). IEEE Standard C95.3-2002 (IEEE, 2002) recommends a minimum measurement distance of 20 cm to minimize nearfield coupling and field gradient effects that occur with commonly used broadband field probes, including the Narda. Meter recordings 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 amplitude of the field being measured over the volume of space occupied by the measurement probe elements. Nearfield coupling can be particularly important when employing field probes in the reactive near field of dimensions comparable to the size of the source antenna. The elements inside the SRM-3006 probe/antenna are approximately 10 cm long. Based on the potential for significant probe coupling with the smart meter's internal transmitting antenna, measured values with surface contact between the probe/antenna and a smart meter should be considered suspect and, likely, substantially overestimates the true field. Thus, the appropriate minimum distance at which fields would be measured with the SRM-3006 was determined as nominally 30 cm, equivalent to 0.9 wavelengths at 915 MHz.

The data in Table 4-1 are graphically displayed in Figure 4-1. For comparison to the decrease in RF field magnitude (percent of MPE) that would be expected for a free-space environment, the straight black line labeled "$1/R^2$ decay" is shown. Variations in the measured value of fields are expected to be caused by measurement uncertainty (for example, small temporal fluctuations) and the real world presence of uneven ground over which the measurements were performed and that undoubtedly introduced ground reflections and possibly interference that resulted in the observed interference patterns.

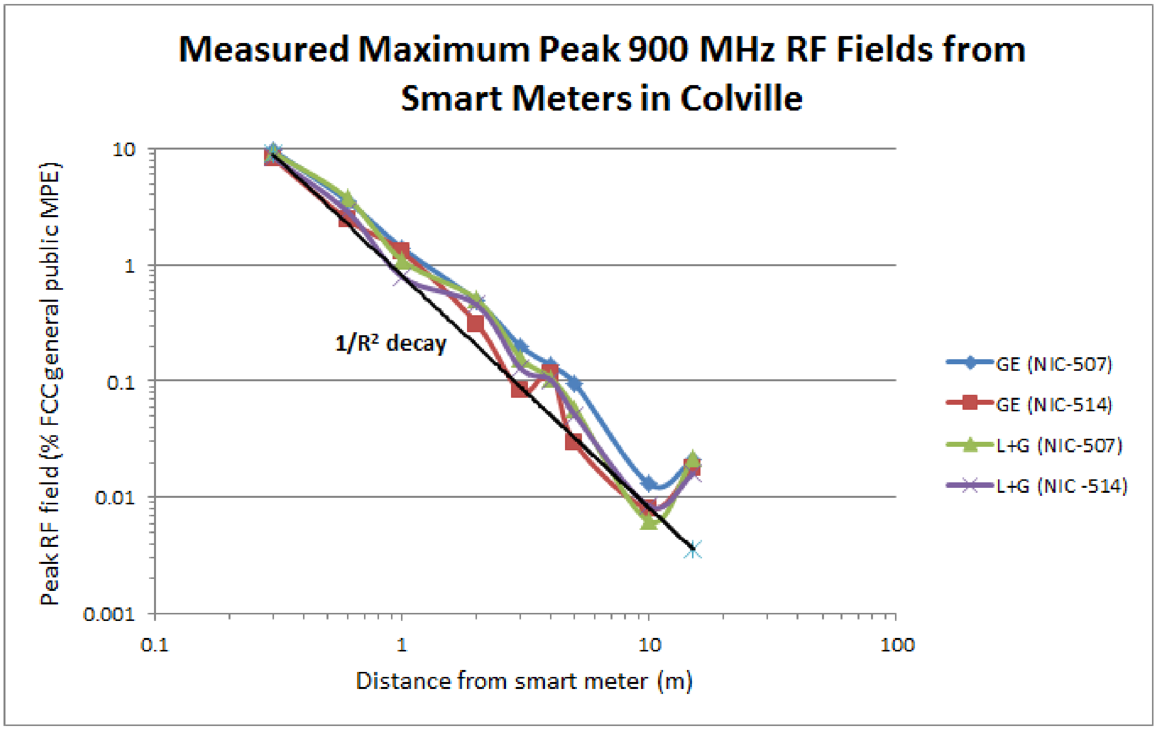

Figure 4-1
Measured maximum peak RF fields from four smart meters obtained in Colville, WA. RF field is expressed as a percentage of the FCC MPE for general public exposure and represents the instantaneous peak value of field during the brief transmissions from the meters. Time-averaged values of field are obtained by applying the duty cycle for the meter (see section on duty cycles). An "inverse distance squared decay line" is shown in black that would represent the expected decrease in RF field in free space. (Narda SRM-3006 w/100 kHz RBW)

Throughout the RF field measurements, checks were frequently made to ensure that the measurement process yielded consistent results. To evaluate the ability to repeat field measurements, three separate measurements of RF fields taken in front of a GE-I210 meter at 0.3 m, separated in time by other measurements, were evaluated. This exercise resulted in the following:

Measurement repeatability evaluation	
Trial	% MPE
1	9.628
2	9.970
3	10.400
Average	9.999
Std deviation	0.387
% Std deviation	3.89

Hence, the results are suggestive that the measurement process could be repeated within about 10% over time[5].

Field vs. Distance at Installed Smart Meter Locations in California

The primary focus of RF field measurements conducted in California was to determine RF field values inside residences that were equipped with smart meters. Nonetheless, at each of the homes, measurements were also performed, as circumstances would permit, of RF fields outside the residence and close to the smart meter. In some cases, however, the environment made it impossible to measure beyond a few feet from a meter due to the presence of fences or

[5] Given the fact that the standard deviation includes nominally 2/3 of the range of values and that only three values are used in computing the standard deviation, a provisional estimate of some 10% for measurement repeatability is proposed.

vegetation. Table 4-2 summarizes these results for the six residences and a PG&E warehouse at which a single smart meter was installed. The outdoors residential data are plotted in Figure 4-2.

Table 4-2
Measured 900 MHz peak RF fields in front of six residential installed smart meters and one meter installed on a PG&E warehouse. Field is expressed as a percentage of the FCC MPE for general public exposure. (Narda SRM-3006 w/100 kHz RBW).

Distance (ft)	Distance from front of smart meter (ft/m)				
Residence	1/0.3	2/0.6	3/1.0	5/1.5	10/3.0
A	14.69				
B	4.547	1.166	0.526	0.468	0.087
C	12.36	4.394	2.117	1.818	0.667
D	14.72	3.772	2.877	1.17	0.225
E	13.94	6.905	4.523		
F	8.79	2.611	1.237		
Warehouse	4.217	1.292	0.815	0.317	0.164

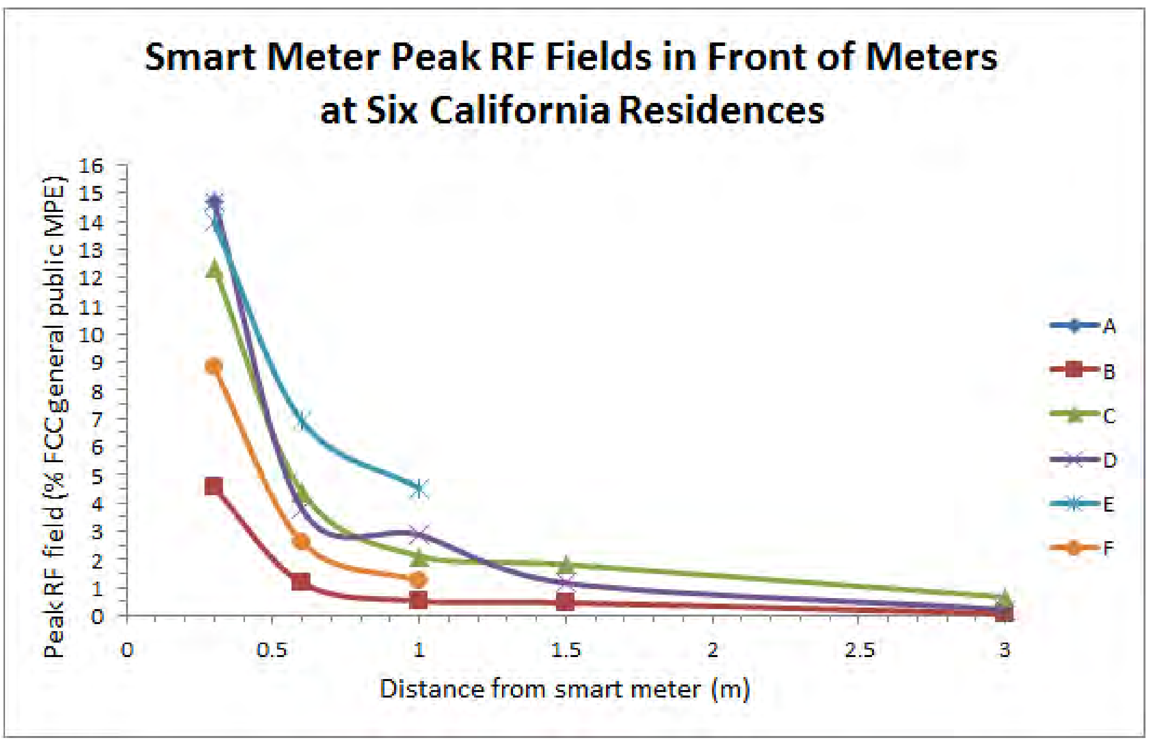

Figure 4-2
Measured maximum peak RF fields in front of smart meters at six California residences. RF field is expressed as a percentage of the FCC MPE for general public exposure and represents the instantaneous peak value of field during the brief transmissions from the meters. Time-averaged values of field are obtained by applying the duty cycle for the meter (see section on duty cycles).

Pattern Measurements

Normally, antenna pattern measurements are conducted in an anechoic chamber to prevent reflections from the measurement environment that may distort the actual free space pattern. In this investigation, the directional patterns of the four test meters provided for preliminary measurements were estimated from measurements in an outdoors environment. The primary purpose of these pattern estimates was to quantify the degree of RF field reduction behind the meter. This pattern information provides insight to the level of RF fields that may be directed into a home with a smart meter mounted on an exterior wall. Following the measurement procedure described above, pattern data were collected for the 900 MHz band transmitter for each of the four meters.

With the Narda SRM-3006 set to scope mode, Figures 4-3 through 4-6 present the relative patterns determined for the GE-I210 and L+G Focus AXR-SD smart meters respectively obtained as a distance of 0.3 m from the meters. Each pattern is the result of sampling the 900 MHz RF field pulses as the meter was rotated through 360 degrees in the azimuth plane. Because the meters emit pulses intermittently, a continuous field is not present for detection during the entire meter rotation. This aspect of the smart meter operation results in the anomaly of the pattern raggedness. Had the transmitter been able to be operated in continuous wave (CW) mode, the pattern would have appeared smooth from beginning to end of the rotation. Nonetheless, the resulting data provide useful information on the directivity of transmitted fields from the smart meters.

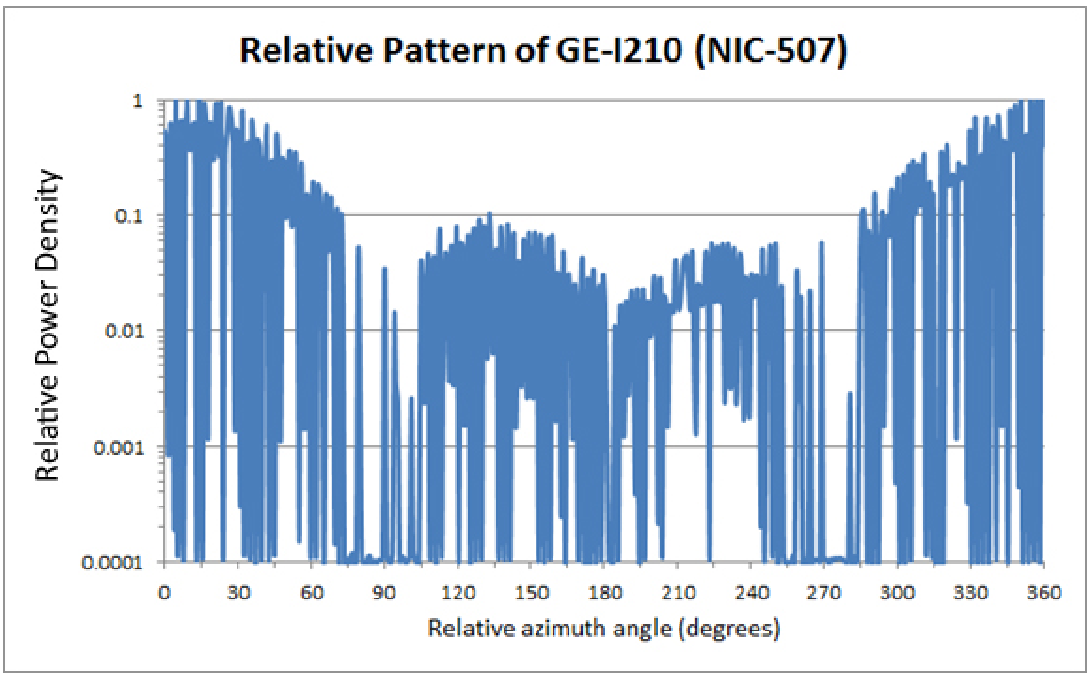

Figure 4-3
Measured relative pattern of the GE-I210 smart meter with the NIC-507 radio. The ratio of the rearward directed field is nominally 10.4 times less than the maximum in the forward direction. The forward directed field is seen near the region of 0 and 360 degrees on the graph. A direction of 180 degrees is toward the rear of the meter. The apparent raggedness of the pattern is a measurement anomaly caused by the intermittent pulses emitted by the meter as captured by the detector over the rotation time of approximately 1 minute. (Narda SRM-3006 w/100 kHz RBW)

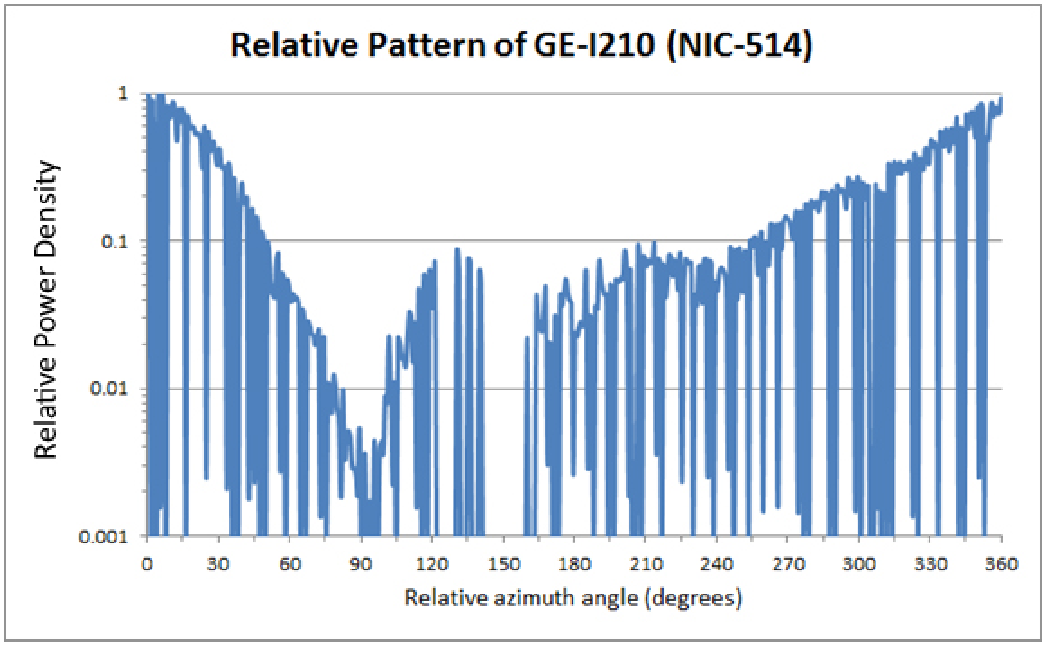

Figure 4-4
Measured relative pattern of the GE-I210 smart meter with the NIC-514 radio. The ratio of the rearward directed field is nominally 10.6 times less than the maximum in the forward direction. The forward directed field is seen near the region of 0 and 360 degrees on the graph. A direction of 180 degrees is toward the rear of the meter. The apparent raggedness of the pattern is a measurement anomaly caused by the intermittent pulses emitted by the meter as captured by the detector over the rotation time of approximately 1 minute. (Narda SRM-3006 scope mode)

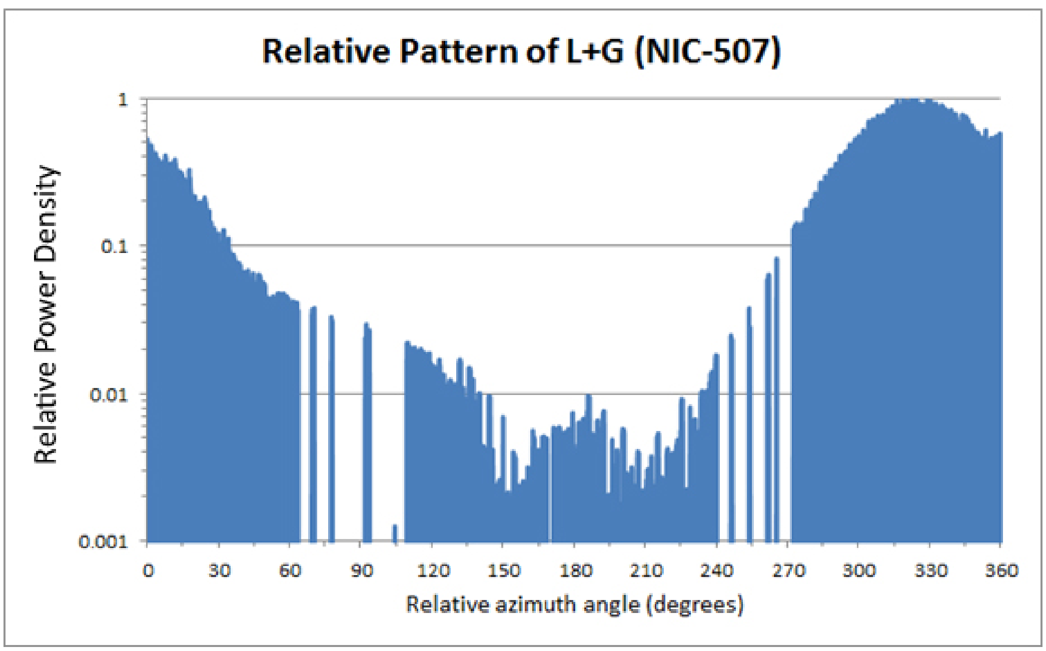

Figure 4-5
Measured relative pattern of the L+G Focus AXR-SD smart meter with the NIC-507 radio. The ratio of the rearward directed field is nominally 62.5 times less than the maximum in the forward direction. The forward directed field is seen near the region of 0 and 360 degrees on the graph. A direction of 180 degrees is toward the rear of the meter. The apparent raggedness of the pattern is a measurement anomaly caused by the intermittent pulses emitted by the meter as captured by the detector over the rotation time of approximately 1 minute. (Narda SRM-3006 scope mode)

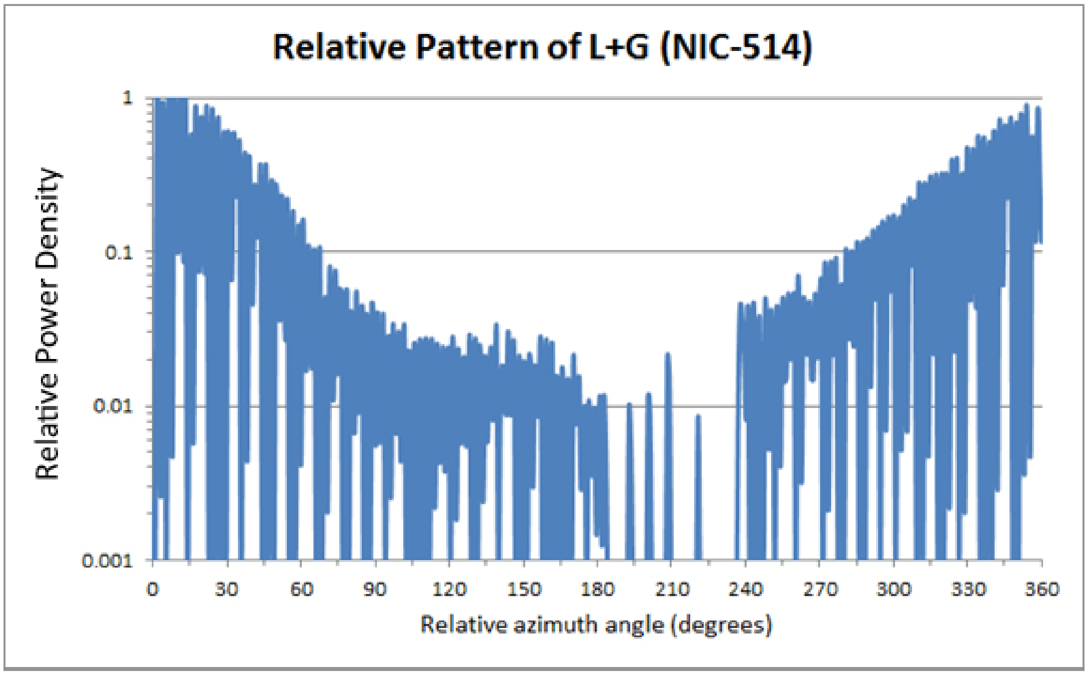

Figure 4-6
Measured relative pattern of the L+G Focus AXR-SD smart meter with the NIC-514 radio. The ratio of the rearward directed field is nominally 33.3 times less than the maximum in the forward direction. The forward directed field is seen near the region of 0 and 360 degrees on the graph. A direction of 180 degrees is toward the rear of the meter. The apparent raggedness of the pattern is a measurement anomaly caused by the intermittent pulses emitted by the meter as captured by the detector over the rotation time of approximately 1 minute. (Narda SRM-3006 scope mode)

Each pattern was characterized in terms of a factor that conservatively expresses the reduction in RF field directed generally toward the rear of the meter compared to that directed toward the front of the meter. These factors were 10.4 and 10.6 for the GE meters and 33.3 and 62.5 for the L+G meters. These pattern differences are likely reflective of the different physical makeup of the GE and L+G meters including the housing and other conductive structures of the meters. In a practical sense, a conservative value of 10 dB (a factor of 10 fold relative to the RF field when expressed in terms of the exposure limit) is appropriate to the meters with the L+G meters exhibiting greater factors. This means that rearward directed RF energy is at least ten-fold less intense than that directed away from the front of the meter.

Spatial Average Measurements

The RF exposure limits set by all of the scientifically based standards, guidelines or regulations presently in effect (including those of the FCC) are expressed in terms of RF power density that is spatially averaged over the body dimensions. To explore how the RF fields from the PG&E smart meters are distributed along a vertical axis, near the meter, measurements were performed in Colville by using the SRM-3006 in scope mode to capture the pulsed emissions of two of the test meters. Acquisition of the spatial variation of fields was accomplished by standing adjacent to the smart meter (mounted at 51 inches above ground to the center of the display screen on the meter) on one side, holding the SRM-3006 such that the probe/antenna would be approximately 12 inches (0.3 m) in front of the meter as the instrument was slowly and uniformly raised from ground level to a height of six feet (72 inches) (1.83 m). After experimenting with this procedure, a probe/antenna vertical transit time of about 15 seconds was determined to yield useful data. Four successive trials acquired measures of the RF field as a function of height above ground as displayed in Figures 4-7 and 4-8 for the GE-I210 (NIC-514) and the L+G Focus AXR-SD (NIC-507) smart meters respectively.

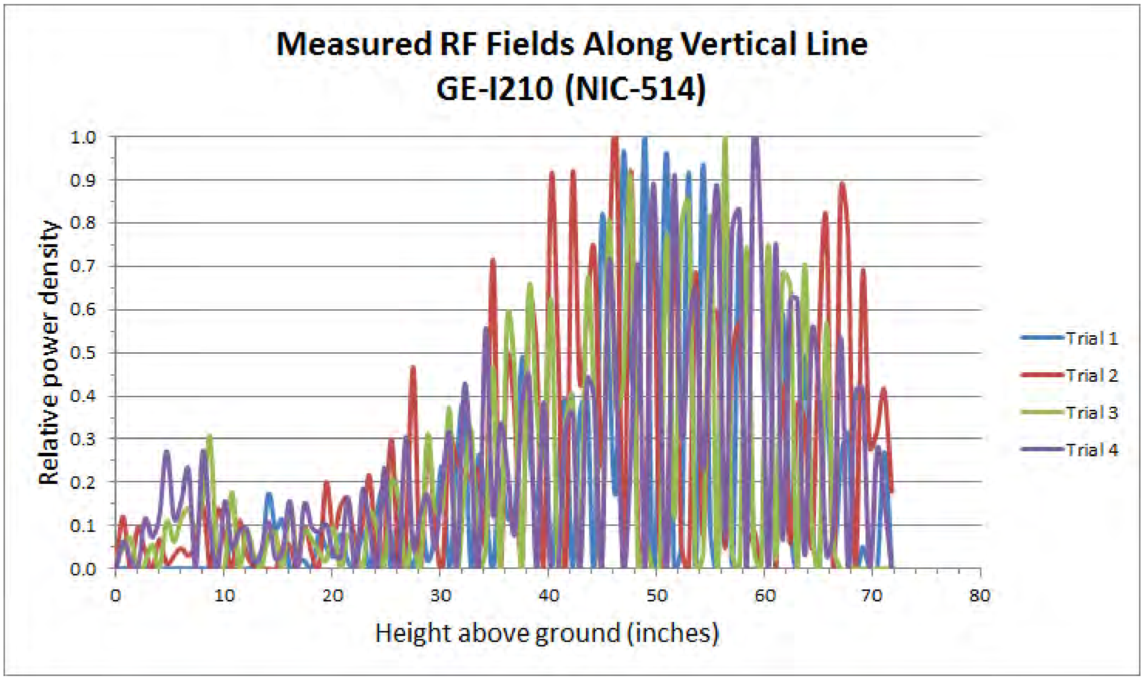

Figure 4-7
Relative measured RF fields along a vertical line from ground surface to a height of 6 feet (72 inches) (1.83 m) at approximately 12 inches (0.3 m) in front of a GE-I210 (NIC-514) smart meter. The maximum field is observed near the mounting height of the meter (51 inches). The overall spatial average is 21% of the spatial maximum value of field. (Narda SRM-3006 scope mode)

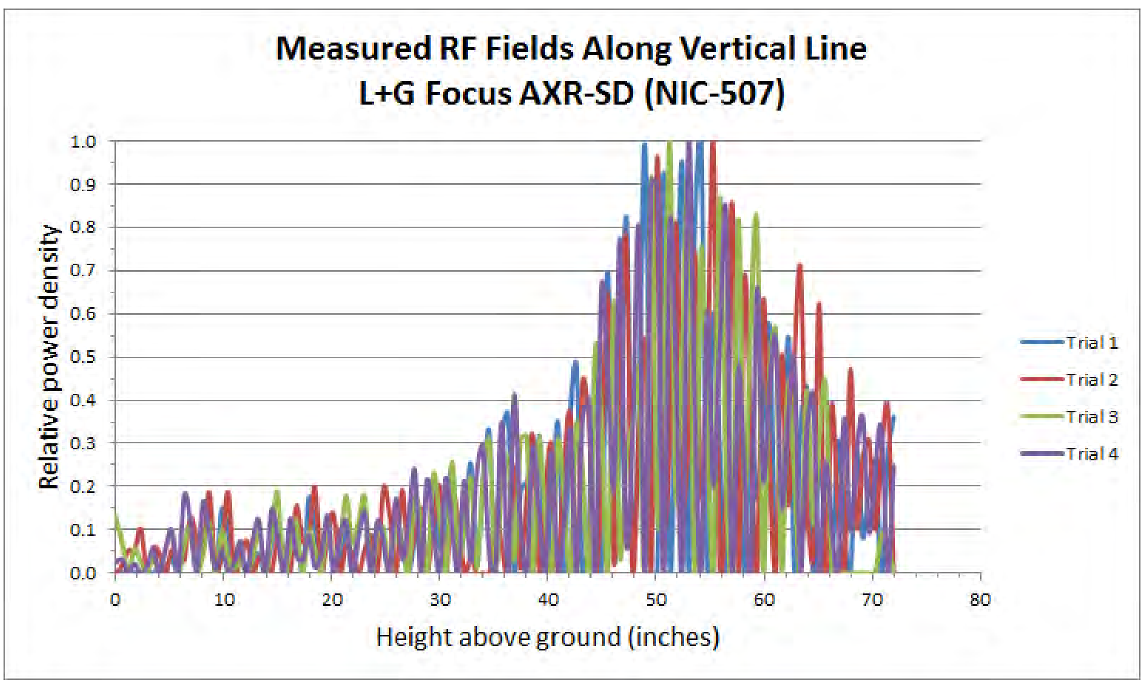

Figure 4-8
Relative measured RF fields along a vertical line from ground surface to a height of 6 feet (72 inches) (1.83 m) at approximately 12 inches (0.3 m) in front of a L+G Focus AXR-SC (NIC-507) smart meter. The maximum field is observed near the mounting height of the meter (51 inches) (1.29 m). The overall spatial average is 18% of the spatial maximum value of field. (Narda SRM-3006 scope mode)

The measured values were normalized to the maximum value observed near the mounting height of the meters and used to compute the ratio of the spatial average of RF field to the maximum value. Table 4-3 summarizes the results from the four trials of measurements from each of the two smart meters. These data indicate that for exposures occurring very close (at approximately 12 inches) to either of the smart meters, the spatially averaged exposure ranges from about 0.18 to 0.21 of the greatest value found directly in front of the meters.

Table 4-3
Estimated ratio of spatially averaged RF fields to the spatial maximum field for the GE-I210 (NIC-514) and the L+G Focus AXR-SD (NIC-507) (Narda SRM-3006 scope mode).

Trial	GE-I210 (NIC-514)	L+G Focus AXR-SD (NIC-507)
1	0.171	0.173
2	0.237	0.181
3	0.194	0.173
4	0.235	0.189
Overall average ratio	0.209	0.179

Wall Attenuation of 900 MHz Smart Meter Fields

Virtually all electric power meters are installed on an exterior wall of a home or business building. Interior RF fields will typically be substantially weaker than those directly in front of a meter simply due to the directional characteristics of the antenna/meter.

In addition, the attenuation afforded by common construction materials can also reduce the strength of RF fields inside the structure. To assess the magnitude of RF field reduction that can be provided by a common wall construction found in California, two of the smart meters were mounted on the surface of a simulated stucco wall. The 900 MHz band RF fields were then measured on the "interior" side of the simulated wall with and without the wall present. These data would then provide insight to how effective such a wall might be in reducing the strength of the RF fields emitted by the smart meters.

The simulated wall (4 ft by 8 ft) has been described previously[6]. Figure 4-9 shows the measurement arrangement for the simulated wall attenuation measurements. The smart meter box was placed against the stucco side of the wall with the center of the display screen on the meter at 51 inches above the ground, the same as used for all of the other Colville measurements of fields. The SRM-3006 was positioned directly behind the smart meter but on the sheetrock side of the wall. Following measurement of the field with the wall present, the wall was carefully removed without disturbing the meter or the probe/antenna. The distance between the back side of the meter box and the front surface of the probe/antenna was 20 cm and was kept the same for both measurements. By using the SRM-3006, the measured attenuation includes all possible polarization components because of the isotropic characteristic of the probe/antenna. 900 MHz attenuation factors of 2.4 and 2.7, equivalent to 3.8 dB and 4.3 dB, were determined with this approach for the GE-I210 (NIC-507) and the L+G Focus AXR-SD (NIC-514) respectively.

[6] *An Investigation of Radiofrequency Fields Associated with the Itron Smart Meter*. EPRI, Palo Alto, CA: 2010. 1021126.

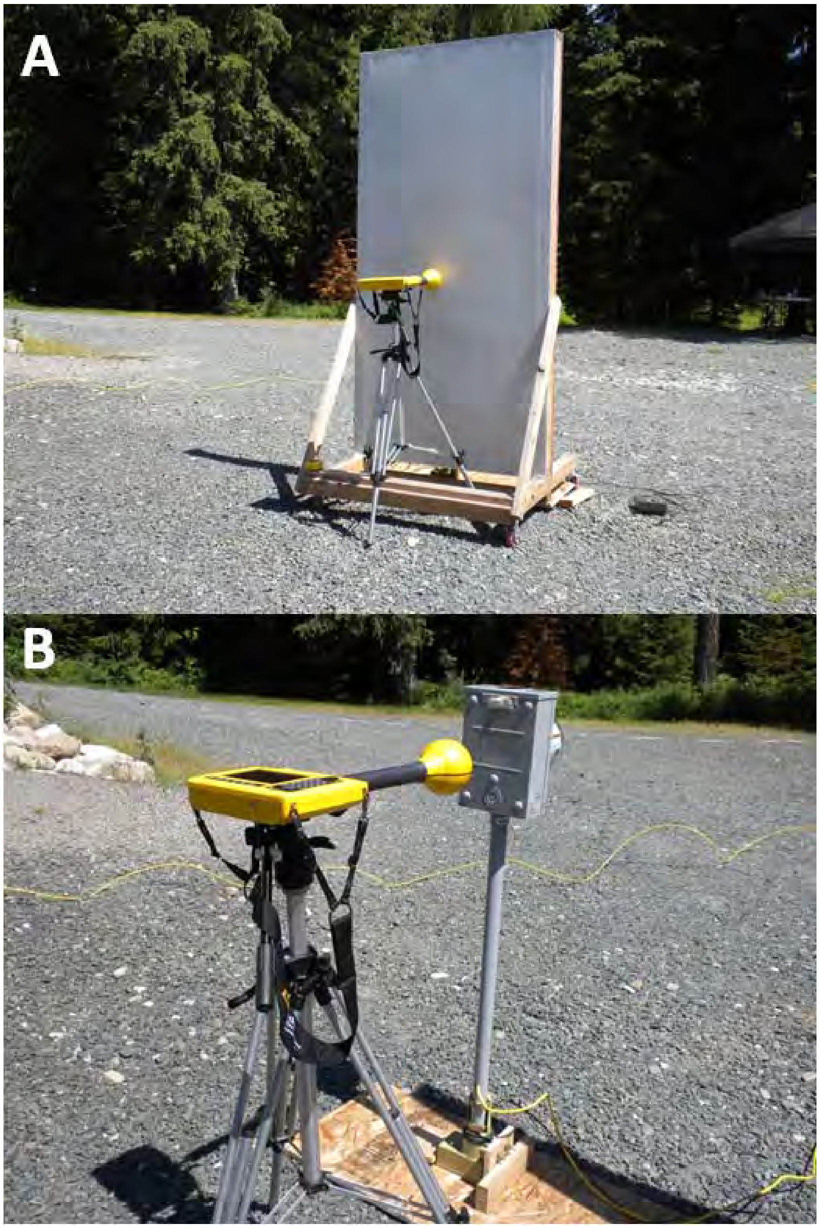

Figure 4-9
Measurement setup for determining the attenuation of 900 MHz RF fields introduced by the presence of a simulated stucco wall. Measurements of the maximum field at the same distance behind the smart meter were conducted with (A) and without (B) the simulated wall present. The separation distance between the rear surface of the meter box and the closest surface of the probe/antenna was 20 cm and was kept the same for both measurements.

Pulse Characteristics

The signals emitted by frequency-hopping spread-spectrum type smart meters consist of short bursts that occur intermittently. The exact nature of these emissions will vary depending on what the meter is doing, establishing a network connection with neighboring meters, transmitting electrical usage data at specified times or being updated with new firmware that controls its operation. During preliminary measurements performed in Colville, the waveform of the signals emitted by the smart meters was determined by using the SRM-3006 in scope mode. To facilitate the measurement of the pulsed waveforms, the SRM-3006 was set for measurement with only one of the probe/antenna axes active rather than the normal isotropic mode in which each of the three elements in the probe/antenna are sequentially connected for sensing of three orthogonal polarizations of the incident field. This setting permitted a greater time resolution and the ability to better define the exact shape of the pulses. [7]

Pulse waveforms for the four smart meters are provided in Figures 4-10 through 4-13. These figures show a repetitious pulse of approximately 103 ms in width. Examination of the digital representation of these waveforms resulted in pulse widths of 102.8 ms for the GEI-210 (NIC-507) and L+G Focus AXR-SC (NIC-507 and 714); the GE-I210 (NIC-514) exhibited a pulse width of 103.3 ms. These were preceded by two short pulses of approximately 2-3 ms in width.

7 This procedure may possibly underestimate the pulse magnitude, but the purpose of these measurements was to identify temporal characteristics of the waveshapes recorded.

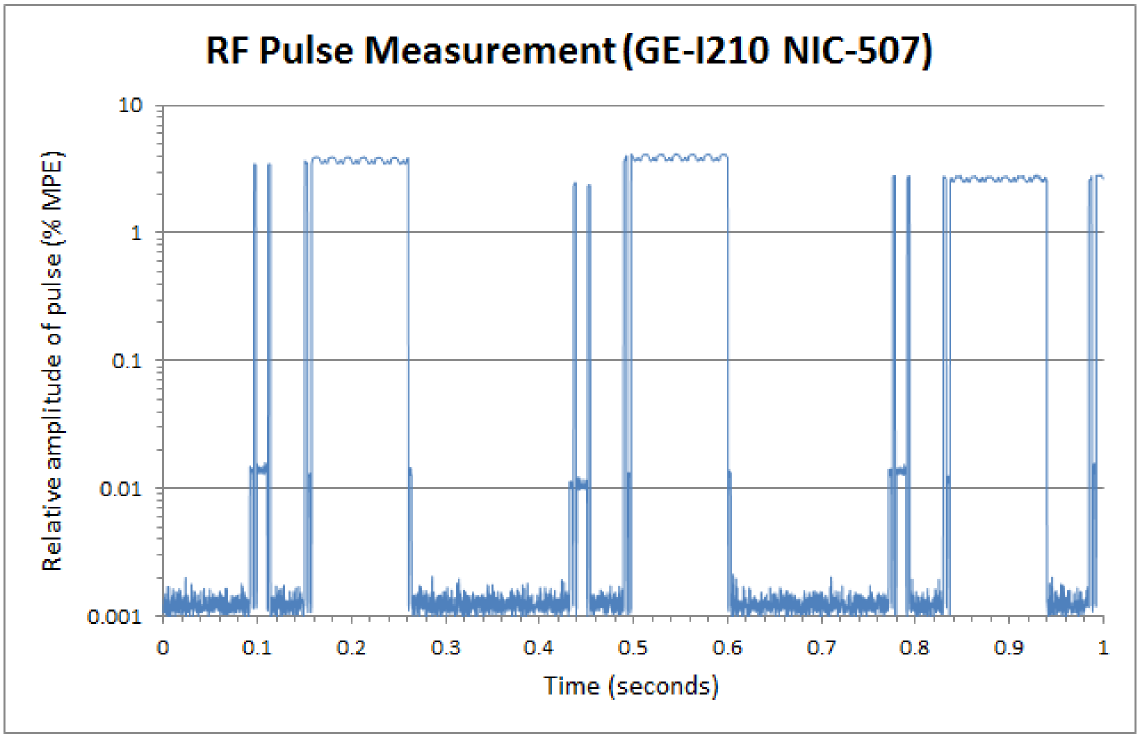

Figure 4-10
Measured RF pulse waveform produced by the GE-I210 (NIC-507) smart meter. The widest pulse width was approximately 102.8 ms in duration. (Narda SRM-3006 scope mode, single axis)

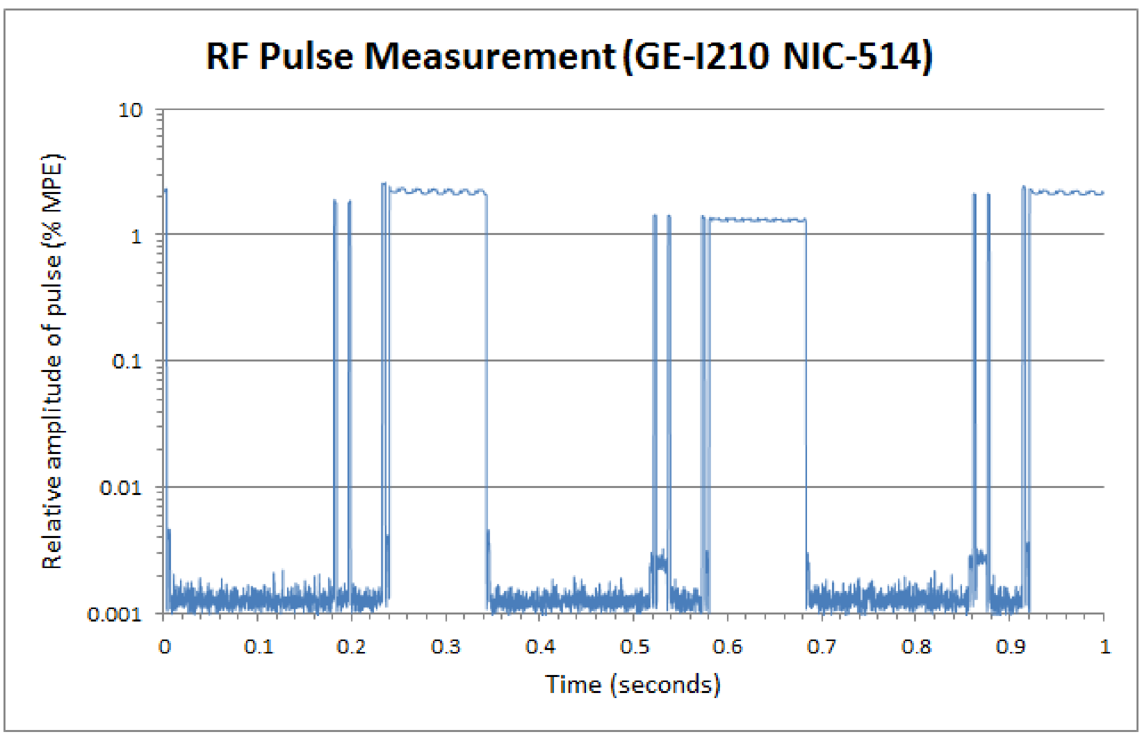

Figure 4-11
Measured RF pulse waveform produced by the GE-I210 (NIC-514) smart meter. The widest pulse width was approximately 103.3 ms in duration. (Narda SRM-3006 scope mode, single axis)

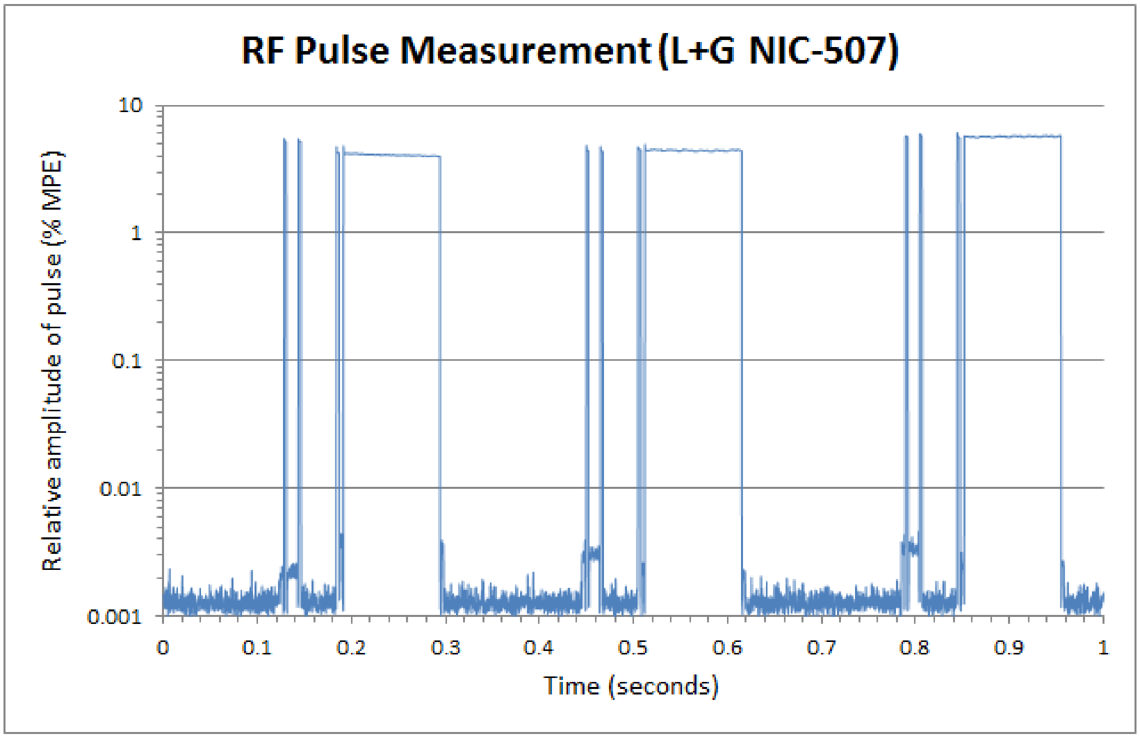

Figure 4-12
Measured RF pulse waveform produced by the L+G Focus AXR-SD (NIC-507) smart meter. The widest pulse width was approximately 102.8 ms in duration. (Narda SRM-3006 scope mode, single axis)

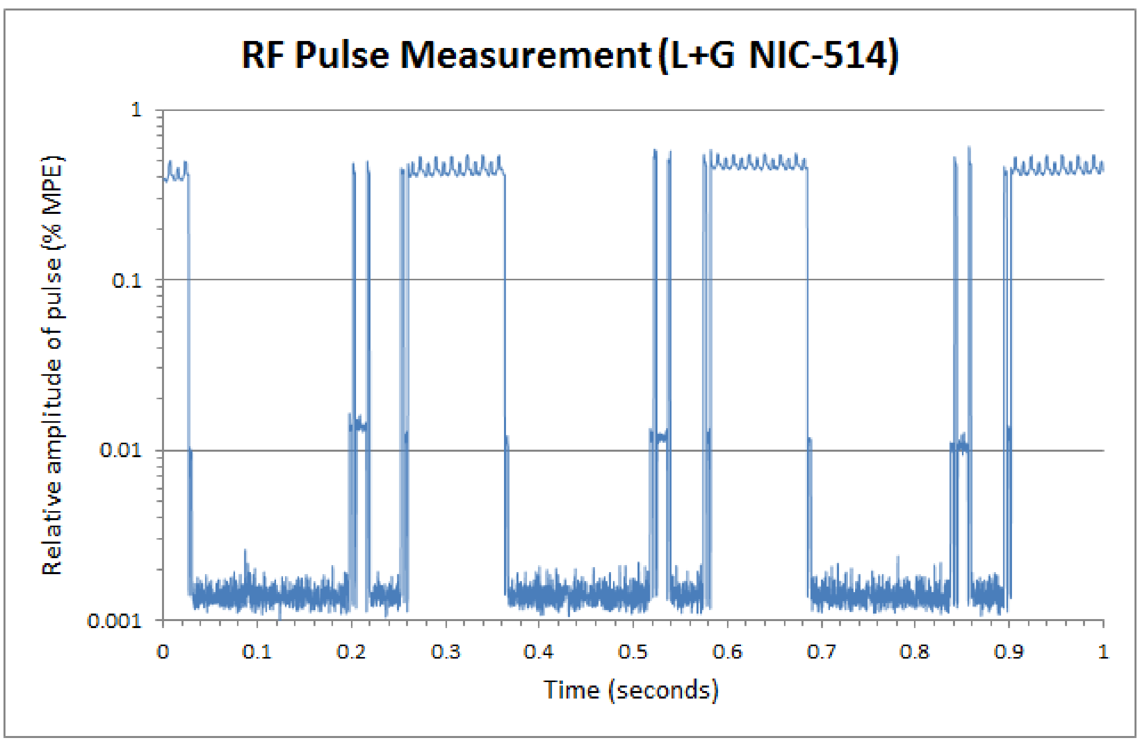

Figure 4-13
Measured RF pulse waveform produced by the L+G Focus AXR-SD (NIC-514) smart meter. The widest pulse width was approximately 102.8 ms in duration. (Narda SRM-3006 scope mode, single axis)

Low Frequency Emissions

The Narda EHP-50C was used to measure low frequency emissions in the range of 5 Hz to 100 kHz. Electric field strength and magnetic flux density, expressed in microtesla (μT), are determined by the instrument. Two smart meters, the GE-I210 (NIC-514) and the L+G Focus AXR-SD (NIC-507), were used in these measurements of both electric and magnetic fields. For each measurement, the meter box was disconnected from power for acquiring a measurement of background fields. The meter box was then powered on and the measurement taken while the FSU was used to ping the meter. In each instance, the instrument was allowed to run for six minutes to yield the RMS value of the fields detected over that time. The results of these measurements are provided in Figures 4-14 through 4-17.

Wideband values are also reported by the EHP-50C instrument by computing the root of the sum of squared signal magnitudes, taking into account the applicable resolution bandwidth, filter characteristics and elimination of the bottom 1.2% of the spectral lines (based on manufacturer recommendations). The difference in wideband values for electric and magnetic fields relative to the background measurements is shown in the title of each measurement. Generally, measurements with the smart meter operating were not materially different from the background measurement except for the case of the GE-I210 where two peaks in the magnetic field spectrum were observed at approximately 1 and 2 kHz. However, during a second run of the magnetic field measurement with the same meter, these two peaks were not observed. This suggests that their appearance is intermittent. This finding was not pursued.

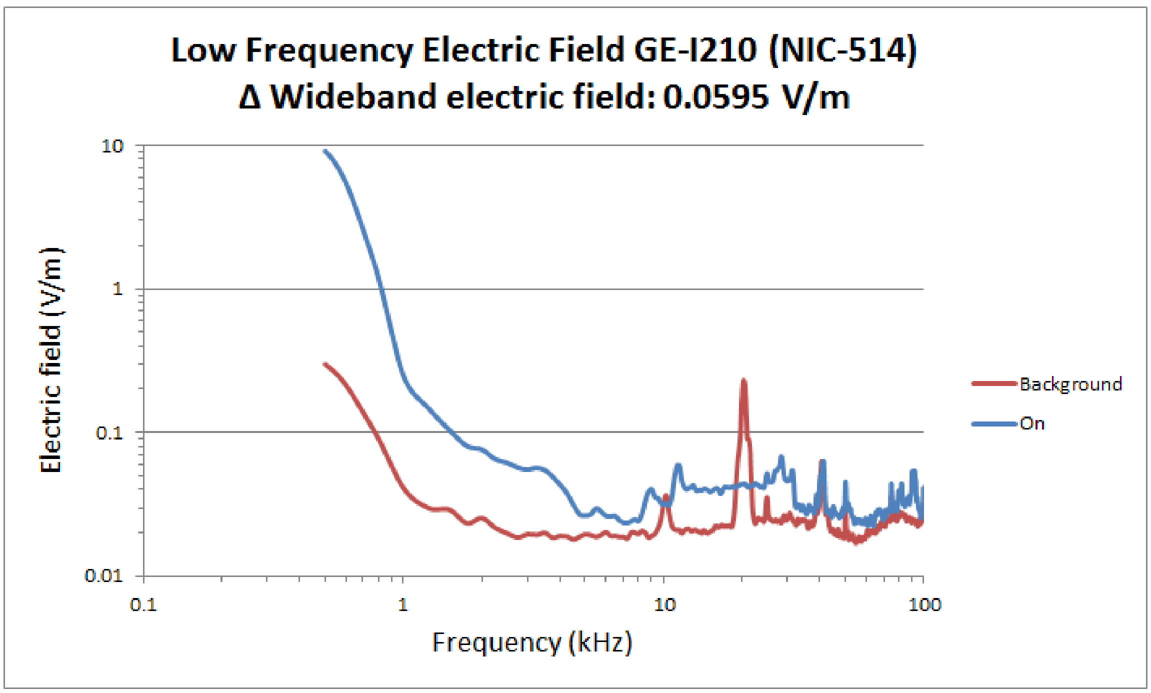

Figure 4-14
Measured low frequency electric field strength of the GE-I210 (NIC-514) smart meter. The wideband electric field strength, accounting for background, was 0.0595 V/m.

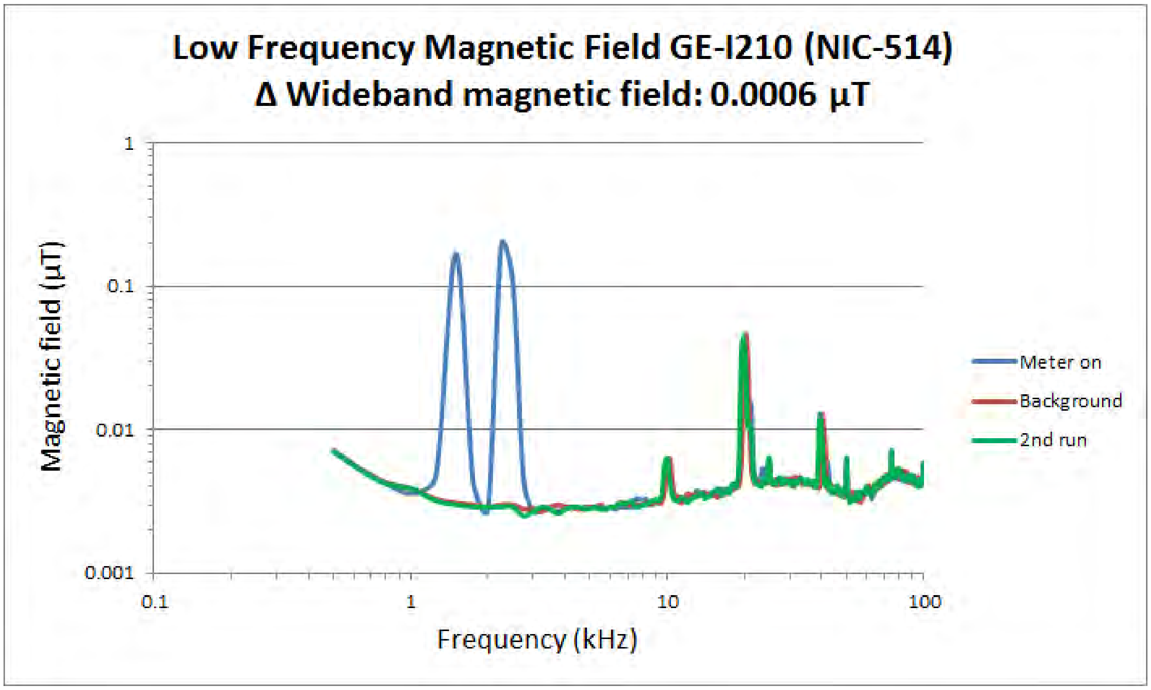

Figure 4-15
Measured low frequency magnetic field flux density of the GE-I210 (NIC-514) smart meter. The wideband magnetic field flux density, accounting for background, was 0.0006 µT. The two low frequency peaks at about 1 and 2 kHz were not present on a second 6-minute run, suggesting that they were intermittent.

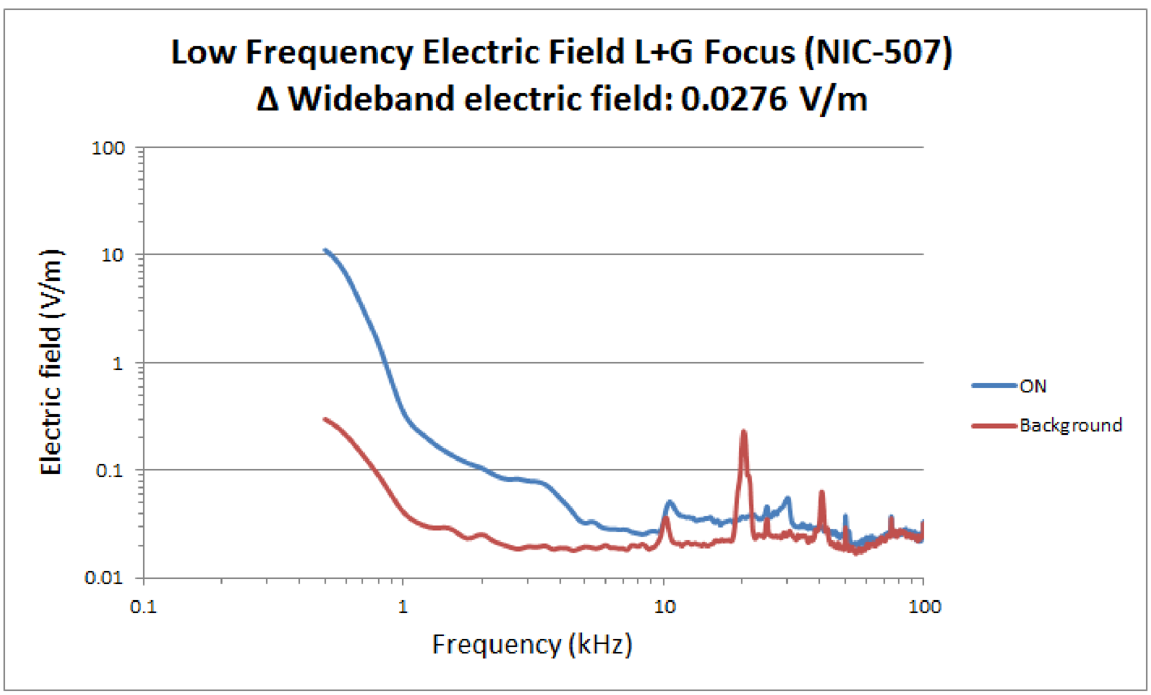

Figure 4-16
Measured low frequency electric field strength of the L+G Focus AXR-SD (NIC-507) smart meter. The wideband electric field strength, accounting for background, was 0.0276 V/m.

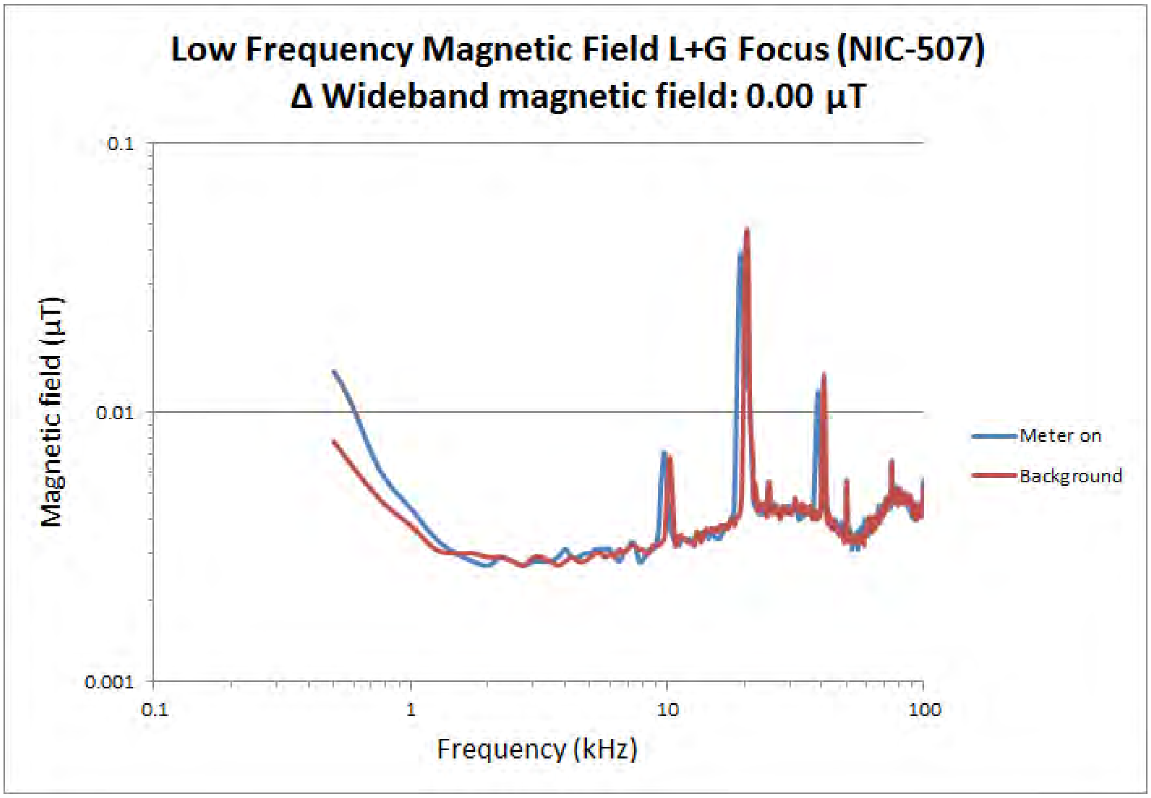

Figure 4-17
Measured low frequency magnetic field flux density of the L+G Focus AXR-SD (NIC-507) smart meter. The wideband magnetic flux density, accounting for background, was 0.00 μT.

Residential Interior Measurements

In California, measurements of 900 MHz RF emissions were performed in six different residences, designated earlier as A-F, and inside a warehouse, designated G. The measurement approach used in each case was, first, to establish connection with the smart meter using the FSU to ping the meter repeatedly. Each room of the house, typically including the garage and, in some cases, outdoor areas, was then swept (at 100 kHz bandwidth) 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 4-4 through 4-10 contain the residential and warehouse measurement values.

Table 4-4
Interior RF field measurements in residence A. L+G (NIC-507), SSN 00135002009D74AD. (Narda SRM-3006 w/100 kHz RBW).

Area in Residence	% MPE
Inside living room behind meter	0.15
Inside living room	0.128
Inside dining room and kitchen	0.773[A]
Inside family room	0.021
Inside laundry room farthest from meter first floor	0.00809
Inside office	0.013
Inside 2nd floor master bed/bath	0.00794
Inside 2nd floor 2nd bedroom	0.00382
Inside 2nd floor front bedroom	0.00015
Inside 2nd floor back bedroom	0.00009
Inside 2nd floor master bed/bath	0.00145
Inside family room	0.017
Inside office	0.00393
Inside living room	0.105
Inside dining room	0.335
Outside backyard	0.00408

[A] This higher value was subsequently determined to be caused by the placement of the FSU device on the dining room table in the home and proximity to the FSU when sweeping the area of the room. Following this observation, a similar incident was observed at residence B. Subsequently, the FSU was relocated outside of residence B and each of the other homes to avoid the contribution of the weak RF fields associated with the FSU in close proximity to the SRM-3006.

Table 4-5
Interior RF field measurements in residence B. GE-I210 (NIC-514), SSN 0013500100D20699. (Narda SRM-3006 w/100 kHz RBW).

Area in Residence	% MPE
Inside office	0.00011
Inside living room dining room	0.00004
Inside garage (closest to meter)	0.018
Inside front bedroom 1st floor	0.0003
Inside master bed/bath and hall 1st floor	0.00007
Inside family room and kitchen	0.00001
Inside 2nd floor upstairs landing	0.00017
Inside 2nd floor bedroom	0.00082
Inside 2nd floor bedroom 2	0.0003
Outside backyard pool deck	0.00009

Table 4-6
Interior RF field measurements in residence C. GE-I210 (NIC-507), SSN 001350010088493. (Narda SRM-3006 w/100 kHz RBW).

Area in Residence	% MPE
Inside garage (directly behind meter location)	0.532
Inside family room	0.0002
Inside kitchen	0.00085
Inside dining room	0.00078
Inside office	0.00072
Inside bedroom 5	0.00113
Inside bath laundry	0.00393
Inside bottom of stairs	0.00129
Inside 2nd floor game room	0.00641
Inside 2nd floor bath	0.0024
Inside 2nd floor master bedroom	0.00014
Inside 2nd floor master bath	0.0003
Inside 2nd floor loft	0.0001
Inside 2nd floor bedroom #4	0.00015
Inside 2nd floor bedroom #3	0.00105
Inside 2nd floor au pair bedroom	0.00075
Outside backyard pool area	0.00287
Outside front yard	0.848

Table 4-7
Interior RF field measurements in residence E. L+G (NIC-507), SSN 001350010014FE3D. (Narda SRM-3006 w/100 kHz RBW).

Area in Residence	% MPE
Inside living room	0.00029
Inside kitchen family room	0.00009
Inside master bedroom/bath	0.00126
Inside middle bedroom meter side	0.00168
Inside front bedroom	0.045
Inside laundry room	0.00364
Inside bath room	0.00217
Inside garage	0.055

Table 4-8
Interior RF field measurements in residence E. L+G (NIC-507), SSN 00135001001645D5. (Narda SRM-3006 w/100 kHz RBW).

Area in Residence	% MPE
Inside child's bedroom front	0.041
Inside child's bedroom front run #2	0.078
Inside Front bedroom	0.00089
Inside living room	0.00076
Inside dining room	0.00008
Inside Kitchen dinette family room	0.00006
Inside wine cellar	0.00001
Inside guest room farthest from meter	0.00001
Inside garage farthest from meter	0.00001
Inside bedroom	0.00033
Inside office	0.00148
Inside master bed and bath	0.034
Outside backyard pool area	0.00016

Table 4-9
Interior RF field measurements in residence F. GE-I210 (NIC-507), SSN 0013500200A6248D. (Narda SRM-3006 w/100 kHz RBW).

Area in Residence	% MPE
Inside office	0.00005
Inside living room dining room	0.00154
Inside kitchen	0.00044
Inside family room	0.00104
Inside garage	0.074
Inside 2nd floor master bed	0.00194
Inside 2nd floor master bath	0.00009
Inside 2nd floor mid bedroom	0.00643
Inside 2nd floor bonus room	0.00078
Inside 2nd floor front bedroom/bath	0.0003
Inside 2nd floor tech room	0.00043

Table 4-10
Interior RF field measurements in warehouse office G. GE-I210 (NIC-514), SSN 0013500100D9E878. (Narda SRM-3006 w/100 kHz RBW).

Location in office immediately behind meter	% MPE
Inside office behind meter	0.00611

The tabular data indicate that the peak RF fields at the six residences included in this survey as well as the warehouse office are generally substantially less than 1% of the general public MPE. In a few instances, peak fields nearing the 1% value were associated with interference caused by either sweeping the area immediately near the FSU as described in footnote A of Table 4-3 or being located immediately behind where the smart meter was mounted. Of the 77 measured field values in Tables 4-3 through 4-9, most were determined at interior locations within the home. Figure 4-18 illustrates an cumulative percentile analysis of the measurement data. The highest value was 0.848% of the FCC general public MPE and this was on the opposite side of a fence located immediately next to the installed smart meter. Figure 4-18 shows 99% of the measured values are less than 0.791% of the MPE.

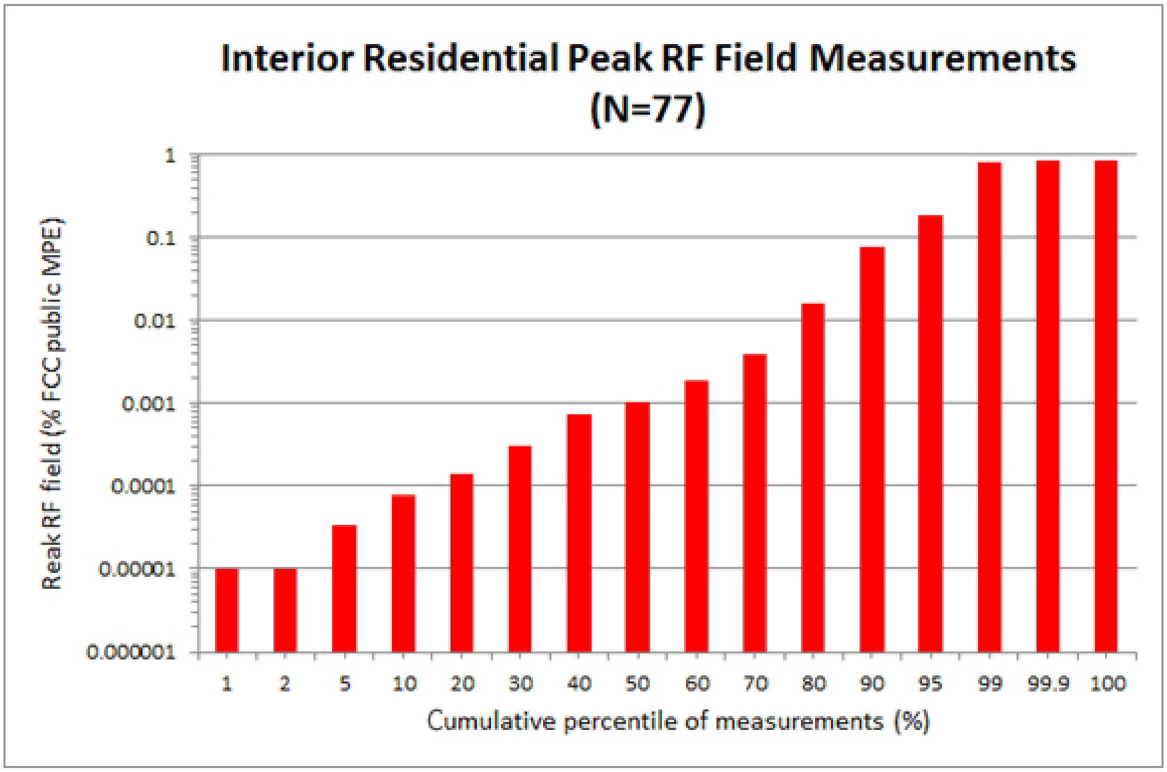

Figure 4-18
Cumulative percentile analysis of 77 peak RF field measurements in six California residences and one warehouse office equipped with smart meters installed by PG&E. The greatest measured peak value of field was equivalent to 0.848 % of the FCC MPE for the general public. (Based on data from Narda SRM-3006 w/100 kHz RBW)

Appendix D provides photographs of the six residences and installed smart meter included in these measurements and the PG&E warehouse.

RF Field Measurements of Multiple Smart Meters

Besides residential measurements of smart meter RF emissions at residences where single smart meters are installed, measurements were also performed at three apartment locations where multiple meters were installed. At each of these locations, the meters were configured in a tight rectangular layout consisting of 12 (Apartment Complex A), 13 (Apartment Complex B) and 112 (Apartment Complex C) smart meters. These three meter installations are shown in Figures 4-19, 4-20, and 4-21 and represent apartment complexes in San Ramon and Berkeley, CA. The block of meters in Figure 4-20 are installed in a below grade parking structure that is part of the apartment complex. The large group of meters in Figure 4-21 have sliding metal doors that are normally closed to offer environmental protection to the meters. Field measurements at this site were performed with the sliding doors open and closed as shown in Figure 4-22.

Figure 4-19
Performing measurements of the peak RF field in front of a block of 12 smart meters located on an apartment in San Ramon, CA. Measurements were made without the use of the FSU to ping any of the meters. This site is designated at Apartment Complex A.

Figure 4-20
Performing measurements of the peak RF field in front of a block of 13 smart meters located in an apartment complex in San Ramon, CA. Measurements were made without the use of the FSU to ping any of the meters. These meters are located in a below grade parking structure at the apartment complex. This site is designated as Apartment Complex B.

Figure 4-21
Performing measurements of the peak RF field in front of a block of 112 smart meters located on an apartment complex in Berkeley, CA. Measurements were made without the use of the FSU to ping any of the meters. Sliding metal doors are used to normally cover the meters and were opened for most of the measurements. This site is designated as Apartment Complex C.

Figure 4-22
Performing measurements of the peak RF field in front of a block of 112 smart meters located on an apartment complex in Berkeley, CA with sliding metal doors closed. Measurements were made without the use of the FSU to ping any of the meters.

Apartment Complex A

RF field measurements at Apartment Complex A with 12 smart meters were accomplished without the use of the FSU to ping any of the meters. The measurement results represent what the RF fields were at the time of the visit without any prior arrangements that would necessarily result in transmissions specific to any of the meters at the site.

Measurements at Apartment Complex A, similar to those performed at Complexes B and C, consisted of walking parallel to the bank of meters, holding the SRM-3006's probe/antenna approximately at a fixed distance from the front surface of the meter bank but moving the probe/antenna across a projection of the bank plane at that distance. During this process, the instrument was set to the Max Hold mode so that the maximum field amplitudes were stored in memory. This process resulted in a measure of the greatest peak RF field that existed at the time in front of the meters at the designated separation distance. Table 4-11 lists the relevant measurement data obtained in front of the smart meters at Apartment Complex A.

Table 4-11
Peak RF field measurements at different separation distances within a vertical plane parallel to the bank of 12 smart meters at Apartment Complex A. All values are in percent of the FCC MPE for general public exposure (Narda SRM-3006 w/100 kHz RBW).

Distance from front of meters (ft/m)	Peak RF field (% FCC public MPE)
1/0.3	9.468
2/0.6	2.75
5/1.5	1.109
10/3	0.272

Apartment Complex B

Table 4-12 summarizes similar RF field measurements conducted at Apartment Complex B.

Table 4-12
Peak RF field measurements at different separation distances within a vertical plane parallel to the bank of 13 smart meters at Apartment Complex B. All values are in percent of the FCC MPE for general public exposure (Narda SRM-3006 w/100 kHz RBW).

Distance from front of meters (ft/m)	Peak RF field (% FCC public MPE)
1/0.3	6.756
2/0.6	2.319
3/1.0	1.269

Apartment Complex C

This apartment complex presented the possibility to measure RF emissions from a collection of 112 smart meters. Similar to the previous two apartment complexes, measurements were performed along a line running parallel to the bank of meters at the nearest practical distance of 2 feet. This closest practical distance of approach related to the inset nature of the smart meters within the overall enclosure that had sliding doors on the front. Table 4-13 summarizes similar RF field measurements conducted at Apartment Complex C.

Table 4-13
Peak RF field measurements at different separation distances within a vertical plane parallel to the bank of 112 smart meters at Apartment Complex B. All values are in percent of the FCC MPE for general public exposure (Narda SRM-3006 w/100 kHz RBW).

Distance from front of meters (ft/m)	Peak RF field (% FCC public MPE)
2/0.6	4.526
10/3	0.717
2/0.6 (doors closed)	0.098

RF fields measured at the three apartment complexes are illustrated graphically in Figure 4-23. The shielding effect of the sliding metal doors on the magnitude of the emitted RF fields is evident in the figure. The doors were observed to offer a reduction of RF field of 46.2 times, equivalent to 16.6 dB.

Short Term Duty Cycle Measurements

The PG&E smart meters do not transmit continuously; rather, the 900 MHz band RF signals are emitted intermittently throughout the day. Were the smart meter to continuously transmit, it would be said to have a duty cycle of 100%, i.e., the emitted signal exists all the time. In reality, most wireless smart meters only transmit for a small fraction of time. For sources that produce a fixed amplitude of RF field, duty cycle can be defined as the ratio of time that the signal is on to the total time of the observation. For example, if the signal exists for one-fourth of the observation time, the duty cycle would be 25%. For the more realistic and complex case of smart meter fields, the duty cycle is defined of the average power collected from the detected fields divided by the peak power observed. Hence, for the scenario of multiple meters associated with a meter bank, as found on the apartments discussed above, the duty cycle depends on the magnitude of the average signal level determined by the composite of all signals arriving from all meters. Since at any given physical point RF fields are potentially arriving from many different directions with different intensities, the average value of the composite detected signals becomes more complex to determine. With the SRM-3006, this determination is made readily since the instrument provides, in its scope mode of operation, a direct assessment of the duty cycle by computing the measured average power (or average percentage of MPE) and electronically dividing this value by the magnitude of the greatest value of instantaneous peak power. This means that a simple visual observation of the acquired maximum hold of peak power may not immediately reveal the apparent duty cycle since a crucial aspect of the measurement is the ratio of the true average value of power obtained over the observation, or averaging time, to the absolute peak value of power.

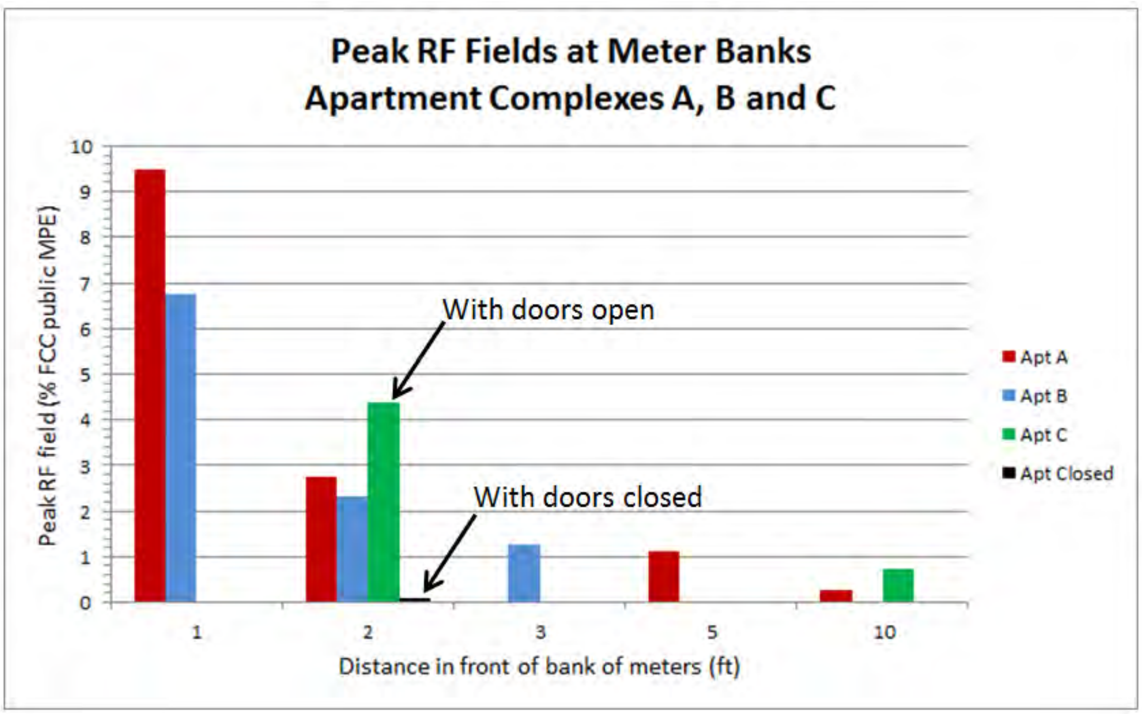

Figure 4-23
Peak RF fields measured at several distances in front of meter banks at Apartment Complexes A, B and C. At complex C, measurements are shown for the doors open vs. doors closed conditions. (Narda SRM-3006 w/100 kHz RBW)

At the three apartment complexes, the SRM-3006 was used in scope mode to measure the apparent duty cycle of the composite RF field produced by the bank of multiple meters, albeit, over short times of only one or three minutes. Figure 4-24 shows the result of a time domain waveform capture of the peak RF field, as a percent of the MPE, standing in front of the meters at Apartment Complex A over a period of one minute. The duty cycle associated with this brief observation was 0.00052 or 0.052%.

Figure 4-25 shows a similar time domain waveform capture standing in front of the meters at Apartment Complex B over a period of one minute. The duty cycle associated with this brief observation was 0.00206 or 0.206%.

Finally, Figure 4-26 shows a time domain waveform capture over a three-minute period with the computed duty cycle of 0.00292 or 0.292% for the large group of smart meters at Apartment Complex C. In this three minute data acquisition, the measurement extended from 12:00 pm to 12:03 pm local time. Meters within the service territory are programmed to transmit data on energy use at six times per day, uniformly distributed with one of the six times beginning at 12:00 o'clock noon. The intent of selecting this time was to enhance the probability of observing greater smart meter activity than might occur at other times.

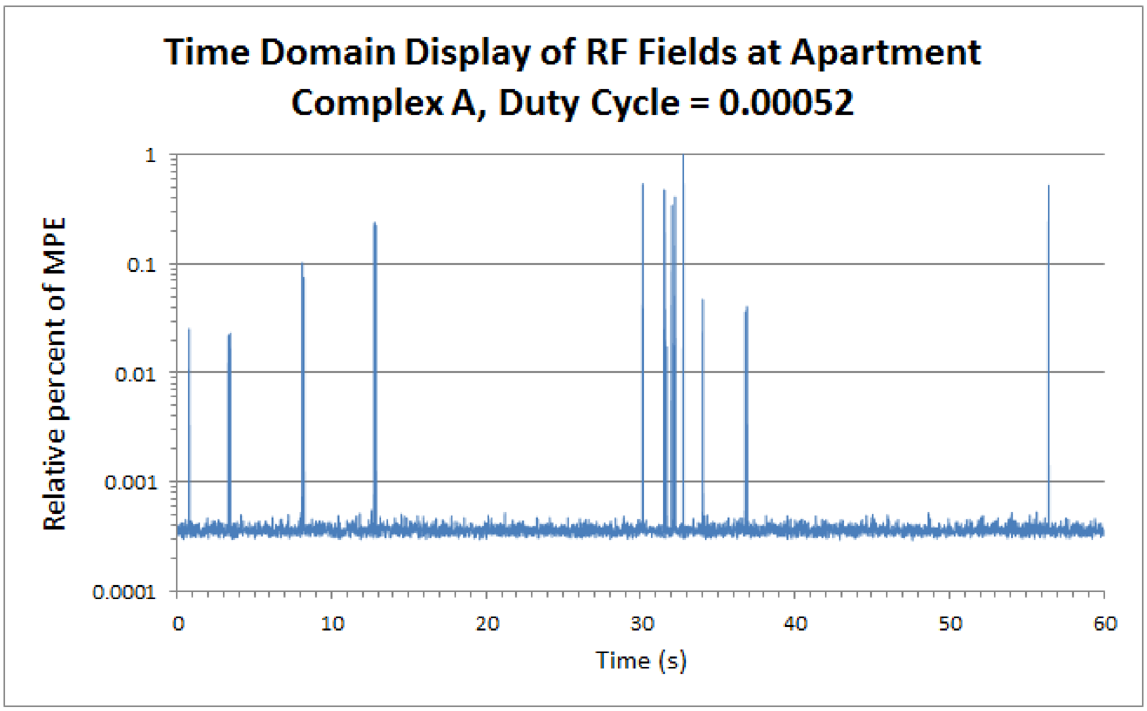

Figure 4-24
Time domain waveform of peak RF fields emitted from bank of 12 smart meters at Apartment Complex A. The duty cycle averaged over the 1 minute observation time was 0.00052 or 0.052%. (Narda SRM-3006 scope mode)

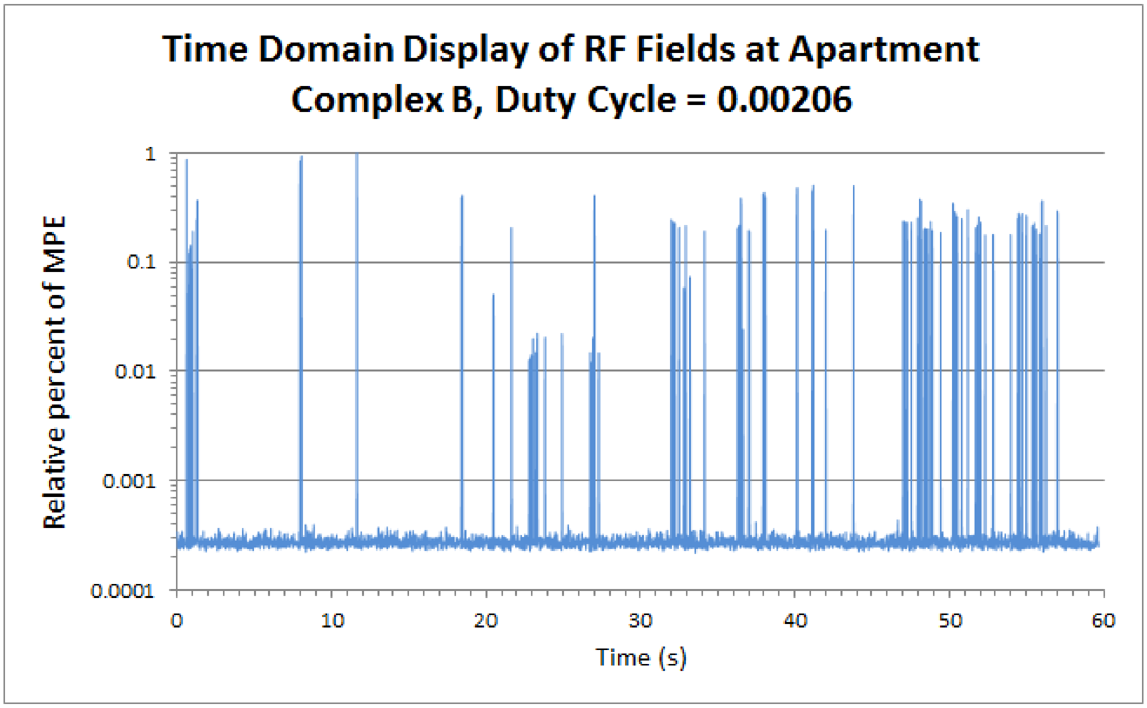

Figure 4-25
Time domain waveform of peak RF fields emitted from bank of 13 smart meters at Apartment Complex B. The duty cycle averaged over the 1 minute observation time was 0.00206 or 0.206%. (Narda SRM-3006 scope mode)

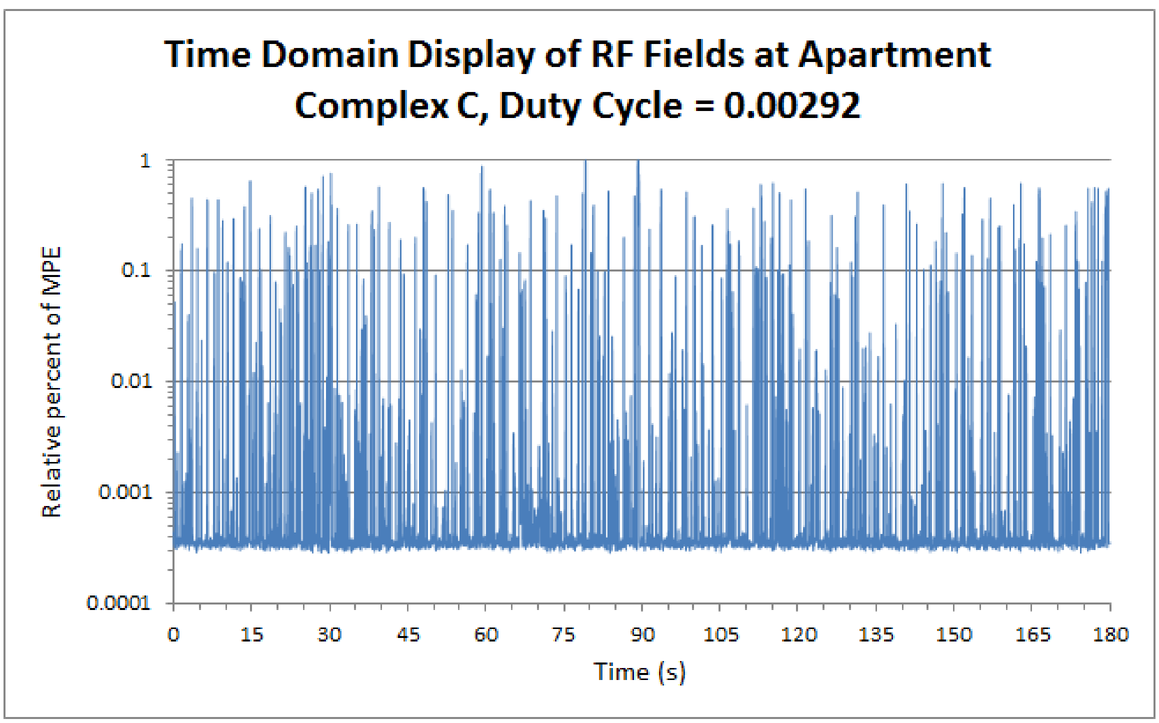

Figure 4-26
Time domain waveform of peak RF fields emitted from bank of 112 smart meters at Apartment Complex C. The duty cycle averaged over the 3 minute observation time was 0.00292 or 0.292%. (Narda SRM-3006 scope mode)

While the typical duty cycle of the smart meters is quite small, discussions were held with PG&E laboratory personnel familiar with the details of the smart meter network. The focus of these discussions was to determine what conditions might be expected to lead to the greatest duty cycle for smart meters throughout the PG&E service territory. It was pointed out that on a very infrequent basis, roughly two to three times annually, smart meter firmware revisions can be propagated wirelessly throughout the network. Because this process can lead to the most data intense traffic in the system during the relatively short period of time that such a process exists, the maximum duty cycle of a smart meter would be expected. To put a value on this elevated, short-term duty cycle, a firmware download was simulated in a laboratory at the PG&E San Ramon Technology Center.

In this test, the SRM-3006 was used like a conventional spectrum analyzer, without its accompanying probe/antenna, to measure the RF power delivered to a smart meter antenna (i.e., conducted RF) during a firmware download. While the firmware download proceeded, the peak and average power of the RF signal internal to the smart meter was directly measured over a period of 10 seconds. Figure 4-27 is one of several measurements showing the time domain capture of the peak and average power as displayed with the SRM-3006 in scope mode.

Invoking the duty cycle feature of the instrument, a maximum duty cycle of 0.4099 or 40.99% was measured. A second trial measurement yielded a duty cycle value of 0.4008 or 40.08%. According to laboratory personnel, the duration of the firmware download would be approximately 2-3 minutes. If the download condition were to last for 3 minutes, and the duty cycle was 41% during the download, this would result in a 30-minute averaged duty cycle, relevant to FCC MPE compliance, of 4.1%.

An alternative approach to estimating the duty cycle was pursued using the normal spectrum analysis feature of the SRM-3006 in which the instrument sampled the peak and average value of detected power across the 902-928 MHz band. Each of the 83 hopping frequencies are apparent as seen in Figure 4-28 which was the result after continuous measurement over approximately 5 minutes (during this time, a total of 16,152 scans of the spectrum were performed). The maximum detected peak power was -21.11 dBm and the maximum detected average power was -44.25 dBm as seen in Figure 4-28. The ratio of these values would normally yield the duty cycle. However, because the 83 hopping channels are essentially randomly distributed in terms of when they occur, this means that, on average, any given hopping frequency will be undervalued by 19.19 dB [10×log(83)] simply because the signal will not, on average, be present on all sweeps of the analyzer. Hence, the duty cycle, based on this approach, would be given by the difference between -21.11 dBm and -44.26 dBm + 19.19 dB = -3.96 dB. This is equivalent to a power ratio of 0.4018 or a duty cycle of 40.18%, in excellent agreement with the more direct time domain approach to duty cycle assessment.

Laboratory Measurement of the HAN Radio Emission

Although the HAN feature in the smart meters installed by PG&E is not currently used, and could not be activated in either the test meters sent to Colville or in the normally installed meters in the PG&E service territory, a single meter with the HAN feature was activated in the PG&E San Ramon Technology Center laboratory. The SRM-3006 was adjusted to scan the 2.4 to 2.5 GHz band. Figure 4-29 shows the measured spectrum at 1 foot (0.3 m) from a HAN activated smart meter (observed peak on right side of display). The broad signal seen to the left of the HAN radio signal was caused by a wireless router in the laboratory room. The peak field of the HAN radio emission corresponds to 0.13% of the FCC general public MPE. Figure 4-30 plots the measured RF field values for the HAN radio as observed in the PG&E laboratory room. For measurements in the laboratory, the meter with the operating HAN radio was positioned near the center of a larger group of meters as shown by the arrow in Figure 4-31. A time domain measurement of the pulsed RF field of the HAN radio is shown in Figure 4-32. The associated duty cycle during this observation was 0.00615 or 0.615%. Actual duty cycles will depend on the extent of data communications between the HAN radio and other HAN components within the home.

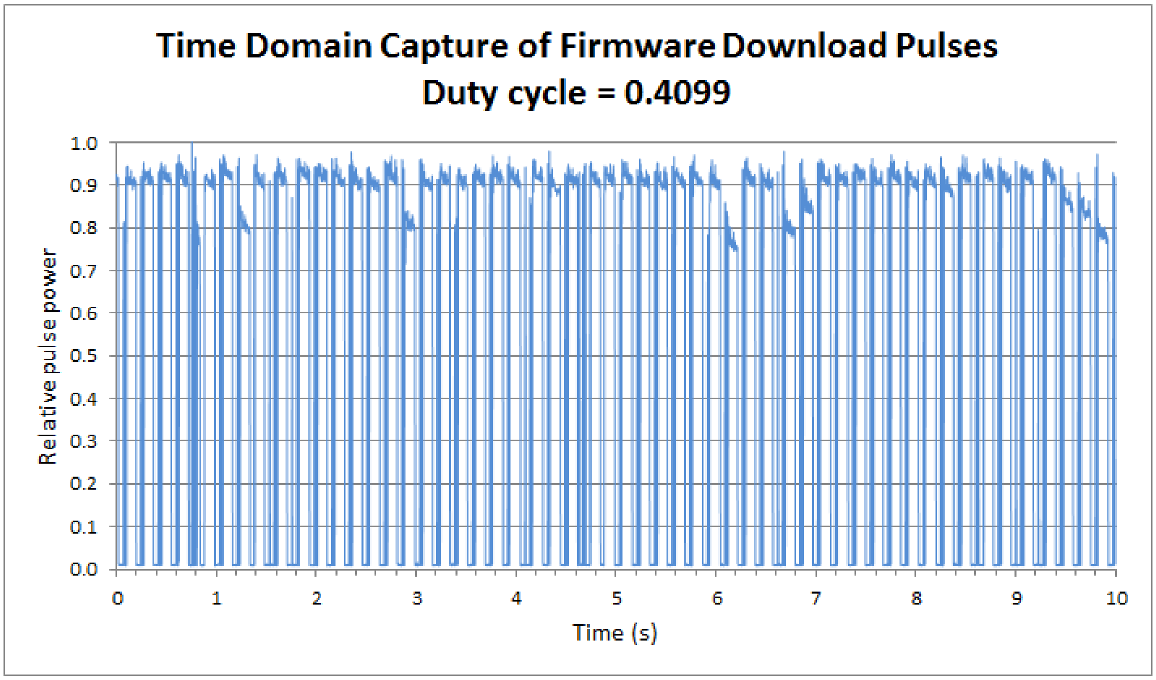

Figure 4-27
Representative time domain capture of pulse power during a simulated firmware download through a smart meter. The duty cycle was measured to be 0.4099 or 40.99%. This condition would last for between 2-3 minutes resulting in a 30 minute time-averaged duty cycle of about 4.1%. (Narda SRM-3006 scope mode)

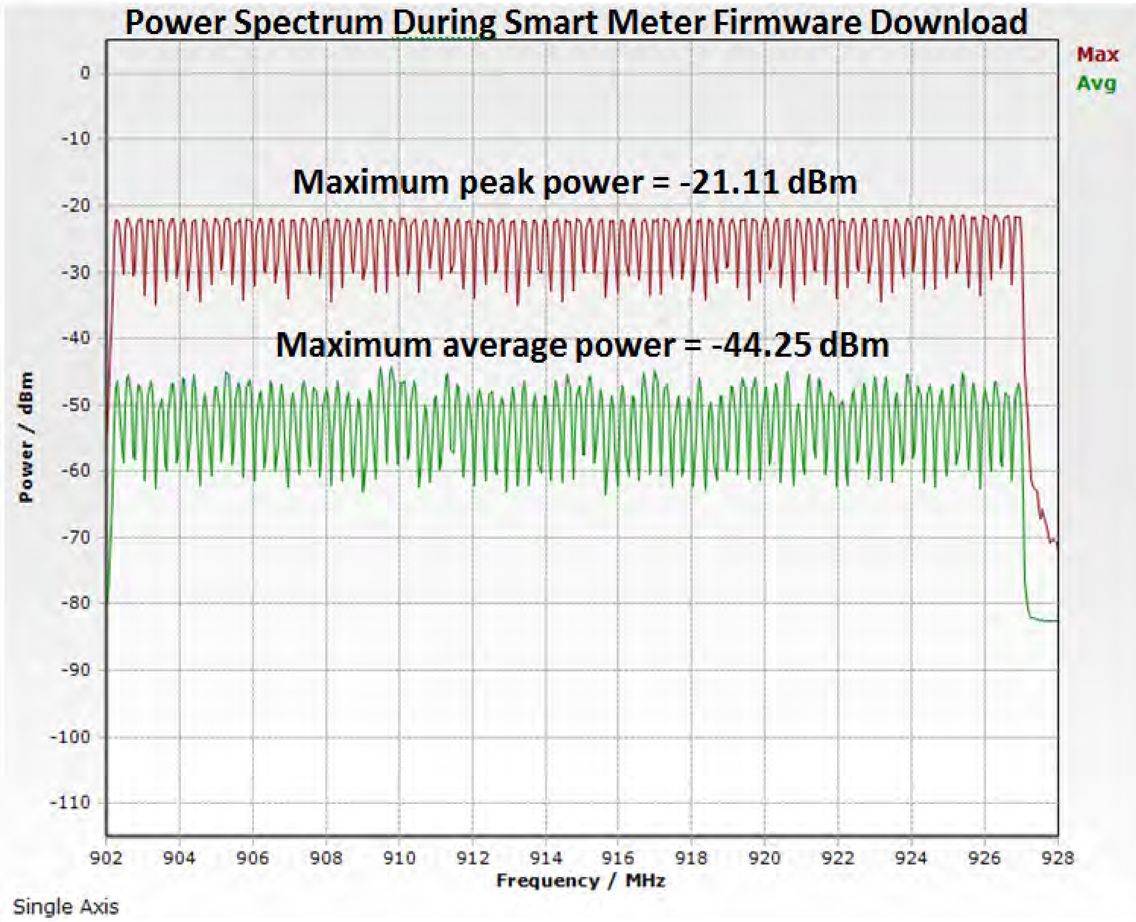

Figure 4-28
Measured 900 MHz power spectrum of smart meter RF signal during simulated firmware download. (Narda SRM-3006 w/100 kHz RBW)

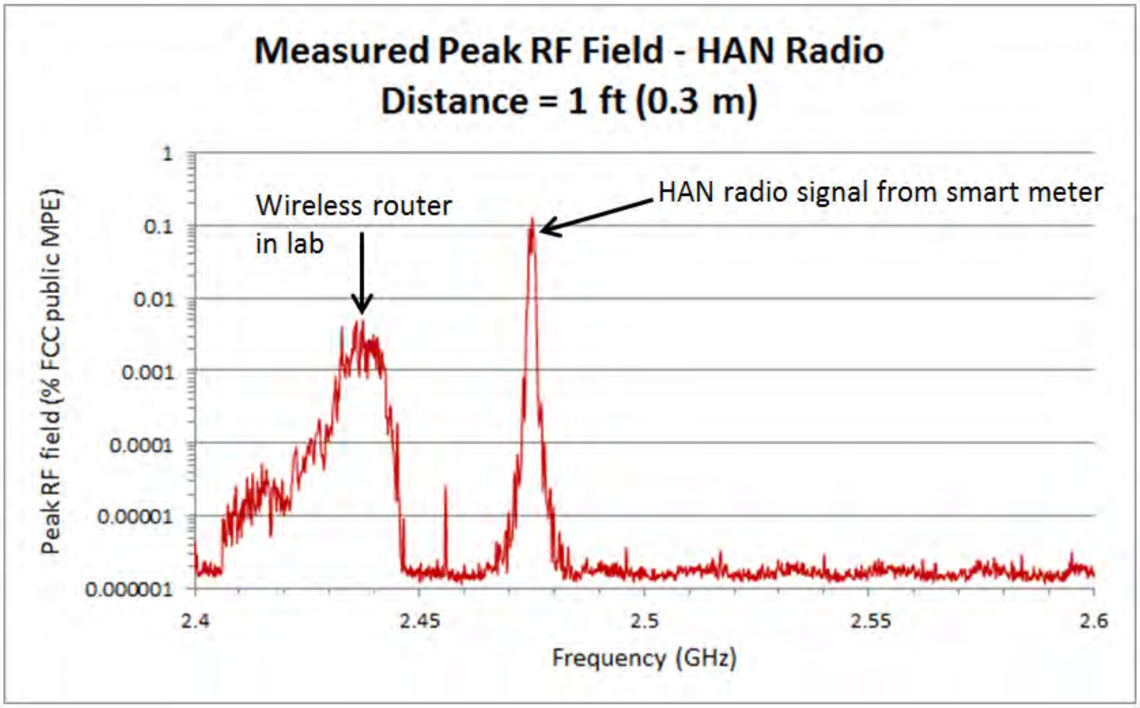

Figure 4-29
Measured 2.4 GHz peak power spectrum of smart meter in PG&E laboratory at a distance of 1 foot (0.3 m) directly in front of the meter. Peak field value of the HAN radio emission corresponds to 0.13% of the FCC general public MPE. (Narda SRM-3006 w/200 kHz RBW)

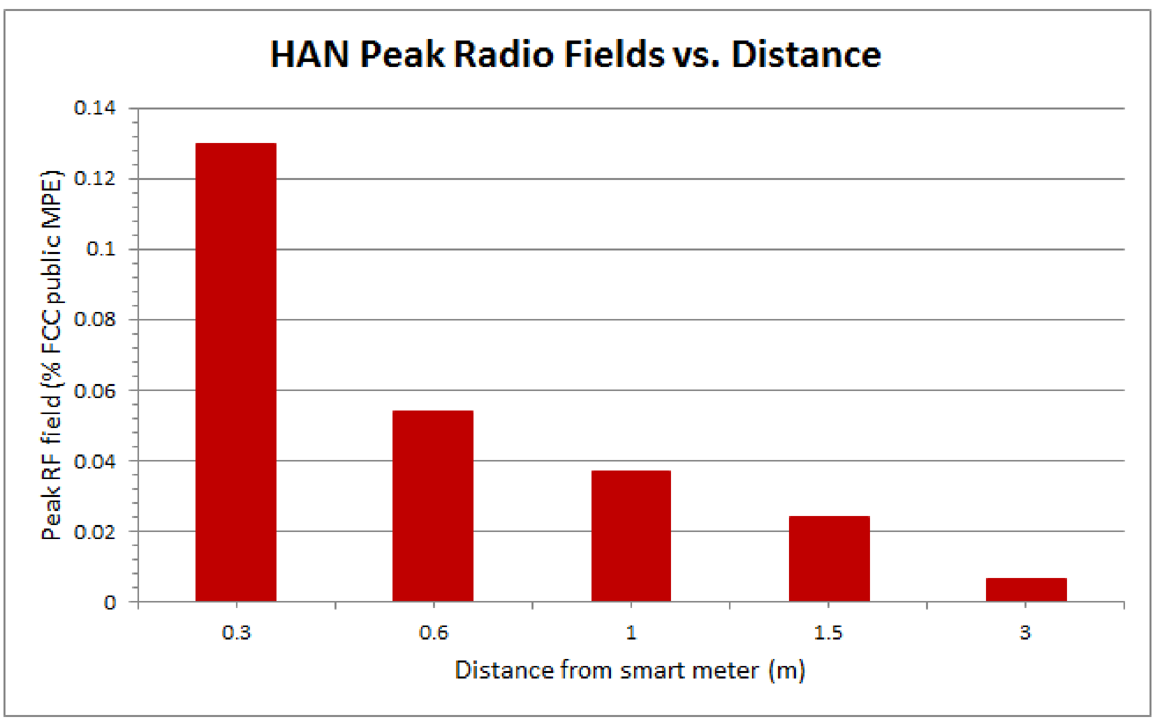

Figure 4-30
Measured 2.4 GHz peak RF fields produced by HAN radio in a smart meter vs. distance. Measurements were conducted inside a PG&E laboratory at the San Ramon Technology Center. (Narda SRM-3006 w/200 kHz RBW)

Figure 4-31
Arrangement of smart meters in the PG&E laboratory where measurements of RF fields produced by a HAN radio were conducted. The only meter with an operating HAN radio is indicated by the arrow.

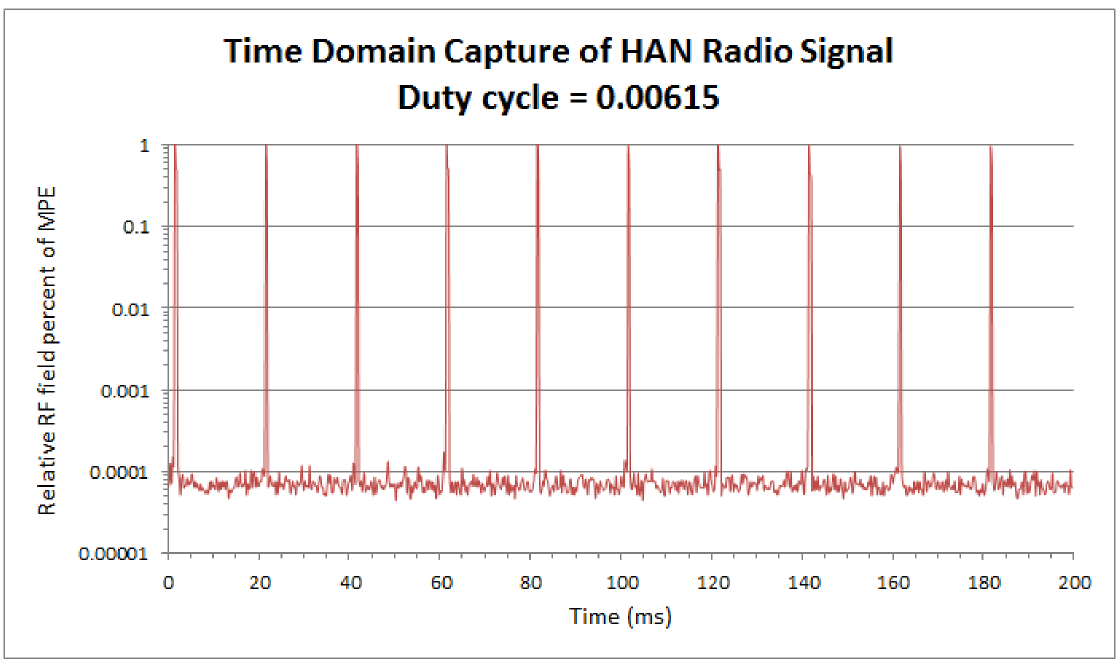

Figure 4-32
Time domain measurement of pulses from a HAN radio in the PG&E laboratory. The HAN radio was operating on a frequency of 2475.062 MHz. The duty cycle was observed to be 0.00615 or 0.615%. (Narda SRM-3006 scope mode)

Access Point Measurements

A component of the mesh networks deployed by PG&E is the access point (AP) which acts as a collector of data from multiple smart meters.[8] The AP is elevated above ground to enhance signal coverage of the area, commonly installed on light poles within a community at a height of approximately 25-30 feet above ground. The AP can receive and transmit in the 900 MHz band for communication with endpoint meters but it also contains a transceiver that operates in a wireless band, similar to cellular telephone base stations in the frequency range of 950 MHz or 1900 MHz, depending on the wireless carrier contracted for wireless wide area network (WWAN) service in a particular geographic region. The WWAN provides a wireless link back to PG&E for conveying all of the data reported by the many endpoint smart meters. Table 17 provides measurement data obtained near the AP and on the ground.

Table 4-14
Peak RF field measurements near an access point (AP) associated within a PG&E mesh network in San Ramon, CA (Narda SRM-3006 w/100 kHz RBW).

Distance from access point (ft/m)	Peak RF field (% FCC public MPE)
1/0.3	8.046
2/0.6	3.825
On ground, below access point	0.010

A three-minute time domain data acquisition was performed at the AP from which an estimate of the duty cycle of the 900 MHz radio could be made. Figure 4-33 provides a plot of the observed peak RF field vs. time. The duty cycle of the AP, during this 3-minute period was 0.02408 or 2.408%. This elevated duty cycle, compared to other measurements at endpoint meters, is likely due to the increased data traffic between the AP and the many endpoint meters that the AP services. Figure 4-34 shows a representative lamp pole installed AP. The inverted antenna, extending below the transmitter housing, is considerably larger than that contained within endpoint meters and is designed to enhance signal coverage of the region of some thousands of endpoint meters distributed across a relatively large geographic area. Although the AP 900 MHz transmitter power is the same as endpoint meters, i.e., 1 watt, and the antenna is larger, providing more gain for better signal coverage of the area, the near-field peak intensity is not materially different from that of an endpoint meter. Despite greater far-field antenna gain associated with the larger antenna, this observation is because the RF field is distributed over a larger antenna aperture. Hence, for measurements very close to the AP, where the RF field is greatest, the peak magnitude of field is not substantially different from that of an endpoint meter at the same distance.

A wide spectrum measurement performed at the AP did not reveal, within the sensitivity of the instrumentation and during the 1.5 minute observation, any significant RF fields outside of the frequency bands in which the smart meters or APs operate. Figure 4-35 illustrates the result of this measurement with the SRM-3006 probe/antenna positioned at approximately 1 ft (0.3 m) from the AP antenna.

[8] In some cases, the term "cell relay" refers to a smart meter equipped with an additional antenna that collects and relays the data from a group of endpoint meters within a mesh network back to the utility. In the case of the system under study in this report, the purpose of the relay is simply to facilitate data transmissions from endpoint meters either to other endpoint meters or directly to the access point (AP). It is like an endpoint meter with a modified antenna but without the meter that measures electricity consumption. A Relay contains the same 900 MHz transmitter that is inside of endpoint meters but uses the same kind of antenna (slightly greater gain) as installed on APs and is typically installed on tall poles to enhance its coverage area within a region of endpoint meters.

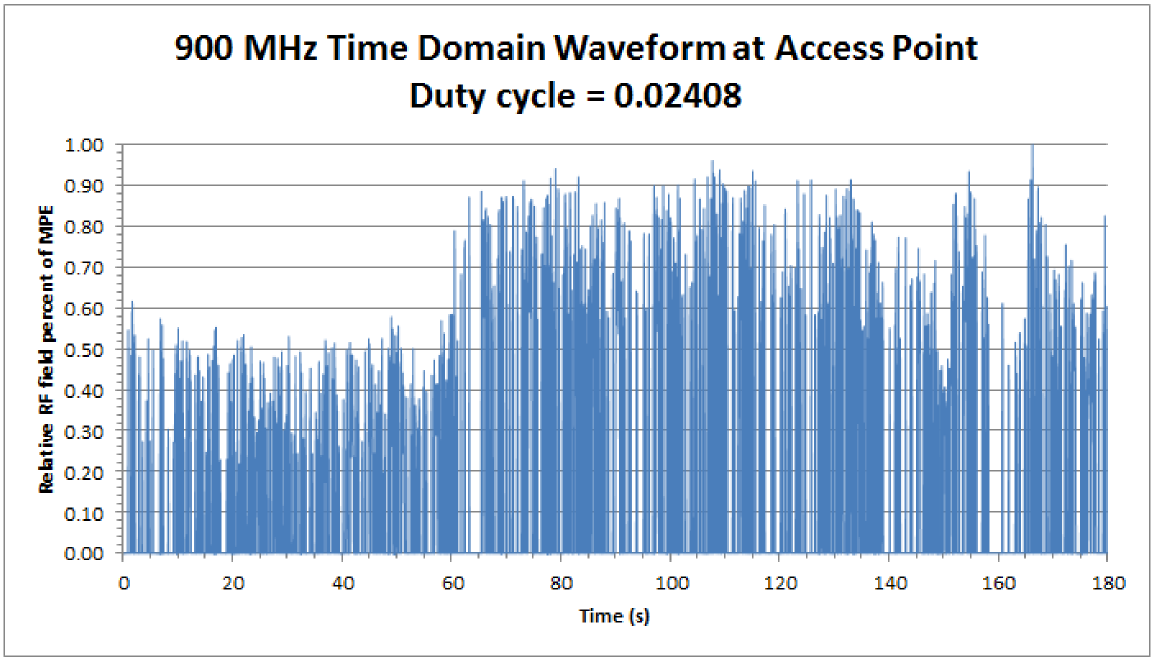

Figure 4-33
Time domain measurement of the 900 MHz band RF field emitted by an access point. The observed duty cycle during this three minute data acquisition was 0.02408 or 2.408%. This higher value supposedly reflecting the greater activity of the smart meter 900 MHz transmitter in handling communications with a large number of endpoint meters. (Narda SRM-3006 scope mode)

Figure 4-34
Typical access point installation on a street lamp pole. The inverted antenna, extending below the transmitter housing, is considerably larger than that contained within endpoint meters and is designed to enhance signal coverage of the region of some thousands of endpoint meters distributed across a relatively large geographic area.

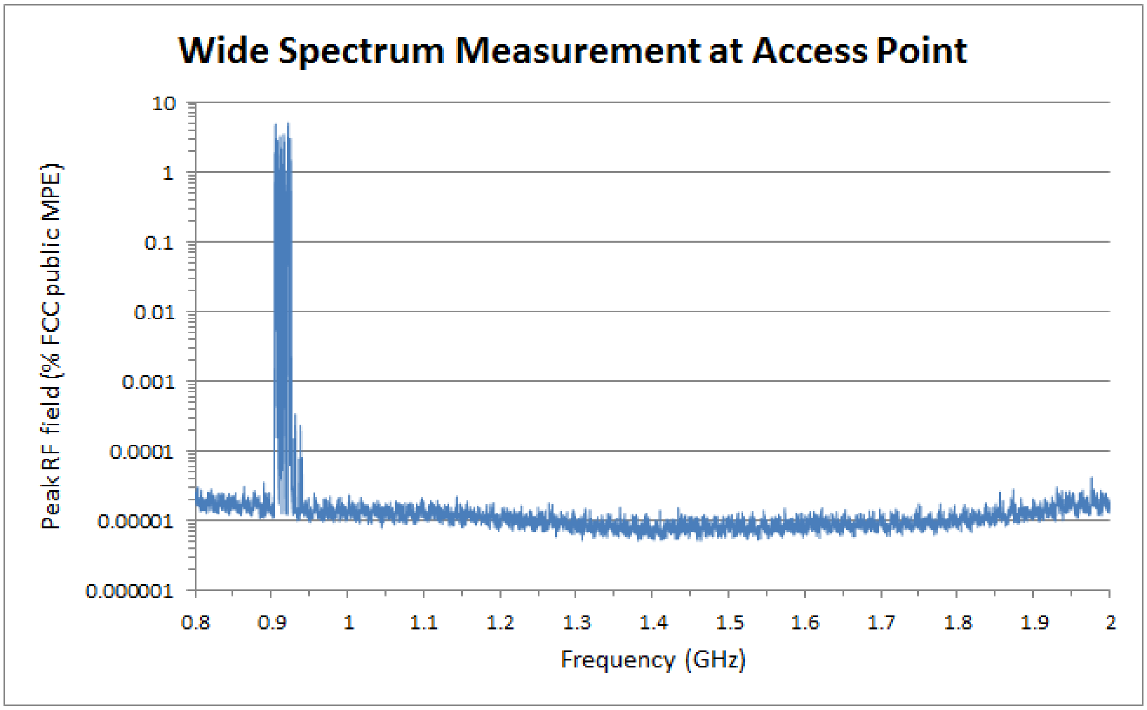

Figure 4-35
Wide spectrum measurement at an access point. The primary emission frequencies detected were in the 902-928 MHz band used by the smart meters deployed by PG&E. (Narda SRM-3006 w/300 kHz RBW)

Section 5: Duty Cycle Analysis

RF exposure associated with the operation of wireless spread-spectrum frequency-hopping smart meters consists of intermittent RF fields. While the peak value of the field strength or power density near smart meters is typically 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 an accurate 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 any 30-minute window of time. With knowledge of the smart meter duty cycle, the peak value of RF fields can be corrected 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 in the process, making it extremely time consuming to characterize exposure over a wide range of environments and varying proximity to the smart meters. Secondly, because the network activity of any given endpoint meter varies from moment-to-moment and day-to-day, depending on network conditions and reporting times for the meters to transmit electrical usage data, any direct RF field measurement that might be successfully completed will be subject to the normal activity of meter transmissions over time. This imposes an uncertainty on how well a measurement of average exposure actually represents actual exposure at other times. Such challenges suggest that attempts to directly measure overall time-averaged smart meter exposures are prohibitively time consuming and not likely to yield definitively quantifiable estimates.

An alternative approach to the question of smart meter duty cycles and the range of duty cycle values 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. On July 14, 2010, SSN conducted a study to interrogate a large sample of the endpoint meters to obtain the number of transmitted bytes of data over a "nominal" 30-minute window. Initially, 100,000 active meters were randomly selected for inclusion in this study. The data transmit rate for the SSN radios within the smart meters is 100 kbps (kilobits per second). With knowledge of the number of bytes of data transmitted during a known time interval, the amount of time that the radio actually emitted as signal (RF field) can be calculated. Data from this study were subsequently analyzed to examine the range of apparent duty cycles for endpoint meters.

Figure 5-1 illustrates the results of this analysis. The number of meters for which valid data were ultimately obtained was 88,296. The data set was sorted to find the number of meters associated with sample intervals ranging from 1 minute to as long as 126 minutes. Transmit data for each subset of meters was then analyzed to determine the maximum, minimum, average and standard deviation of the duty cycles for each one-minute range of sample interval. An interesting observation is the remarkably uniform average duty cycle over the range of sample intervals ranging from 0.044% to 0.13% with an overall average value of 0.068%. Of the total sample, the absolute highest duty cycle found was 13.9%, this occurring for one out of the 88,296 meters that were studied.[9]

An analysis of the fraction of meters in the study exhibiting various duty cycles is given in Figure 5-2. Here the cumulative percentile of endpoint meters with averaged duty cycles up to the maximum is provided. Figure 5-2 indicates that half of the meters exhibited duty cycles less than 0.0465%. 99% of meters had duty cycles of no more than 0.355%, 99.9% had duty cycles less than 1.12% and 99.99% of meters had duty cycles of less than 4.53%.

[9] The sampling period for each of the 88,296 meters varied from 1 to 126 minutes, with a single value of duty cycle provided for each meter. Thus, for example, the duty cycle for 1,887 meters was based on 42-43 minutes of observation. During this interval one of the 1,887 meters transmitted for 13.9% of the time (~5.9 minutes), the maximum observed across the meters for the 42-43 minute time slot, as well as over all 88,296 meters. The data are not available describing the duty cycle for this meter over a longer period of operation. For example, the data available for this analysis may represent this meter through an exceptionally active period.

These data, collected from normally operating meters, provide a comprehensive view of the likely range of duty cycles in the PG&E deployment of smart meters and show that most meters, most of the time exhibit rather small duty cycles, usually less than 1%. From the duty cycle study, those meters with duty cycles exceeding 1% are displayed in Figure 5-3.

Endpoint meters communicate with pole-mounted access points (APs). However, Relay devices (typically pole mounted devices that act purely as relays for endpoint meters) may also be involved in some areas to facilitate this communication. An additional analysis of duty cycle data for APs and Relays is shown in Figure 5-4. This figure shows for example that the APs, which are also pole mounted, exhibit a median duty cycle of 3.59%. In some cases, APs can apparently operate with duty cycles as large as 18%, this duty cycle associated with only 0.05% of the APs monitored for transmit activity. Relay devices exhibited a median duty cycle more in line with endpoint meters with a value of 0.48%. However, Relays can also operate at higher duty cycles than endpoint meters with the highest value observed of 21% for 0.005% of all Relays. These higher duty cycles mean that the time-averaged RF fields near them are more likely to exceed that of common endpoint meters. The fact that both APs and Relays are normally located high above ground, however, substantially reduces ground level exposure to the fields emitted by these two components of the mesh networks.

Although it is not possible to definitively declare that the absolute maximum duty cycle of the smart meters deployed by PG&E will not exceed 13.9%, these data support the position that an extremely small portion of all meters would be expected to exceed about 1%. Importantly, the relatively uniform duty cycles observed over varying sample intervals means that it is reasonable to apply these data to estimating the 30-minute time- averaged RF fields near smart meters and that such estimates can be confidently used to support FCC exposure limits compliance assessments for smart meters. These duty cycle data reinforce the position that time averaging is applicable to the source based intermittent operation of smart meters.

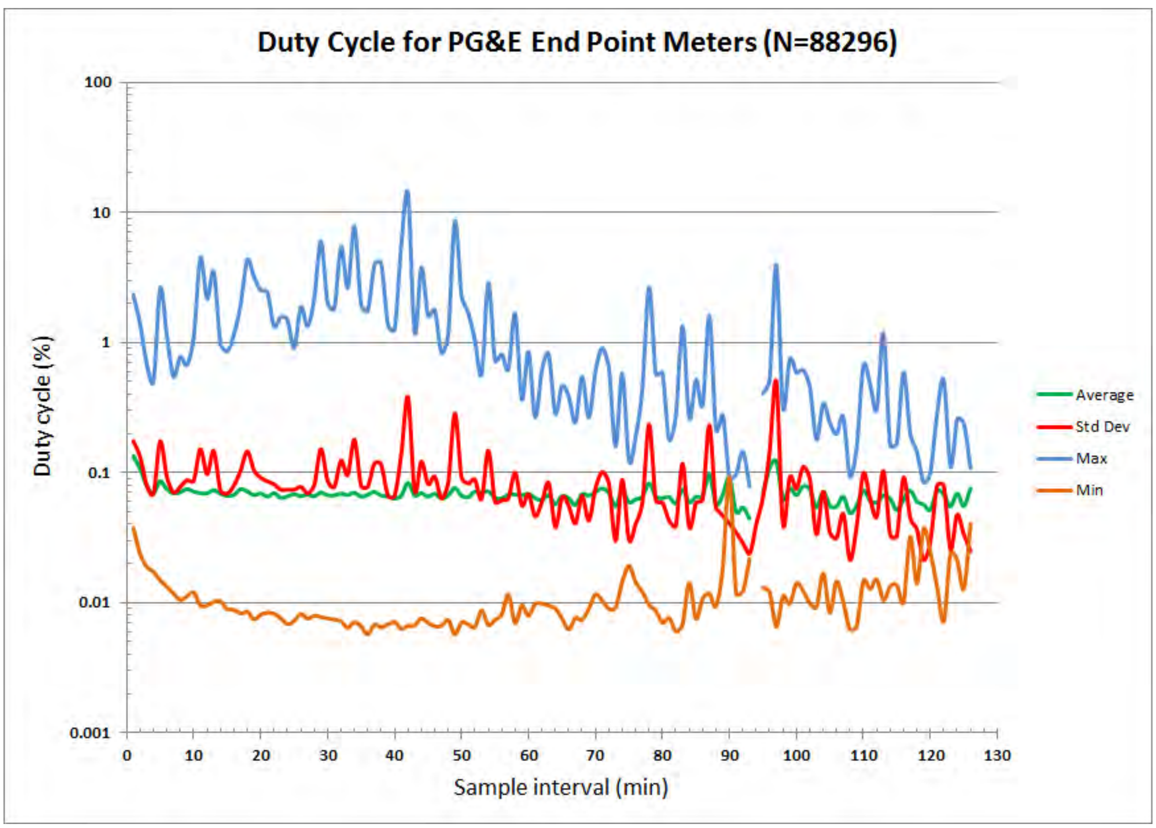

Figure 5-1
Duty cycle based on a study of 88,296 endpoint smart meters in which a range of sample intervals (averaging times) was used ranging from 1 to 126 minutes.

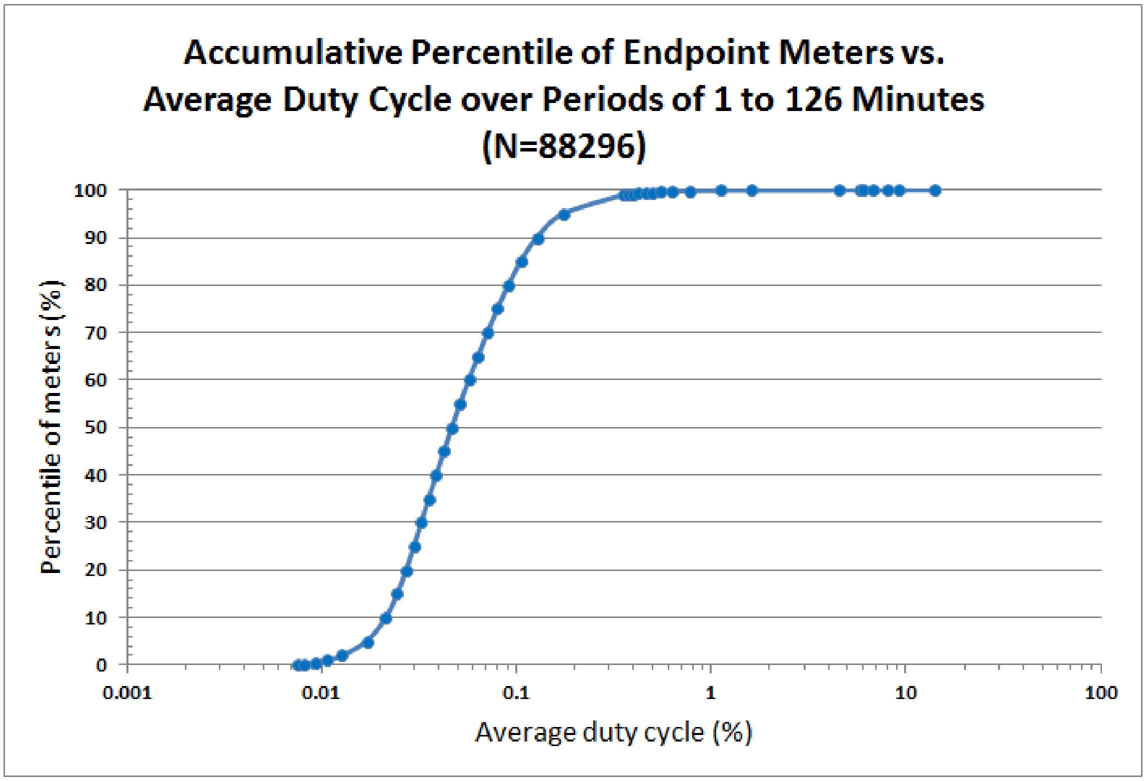

Figure 5-2
Result of a percentile analysis of 88,296 endpoint meters exhibiting various duty cycles over sample periods of 1 to 126 minutes.

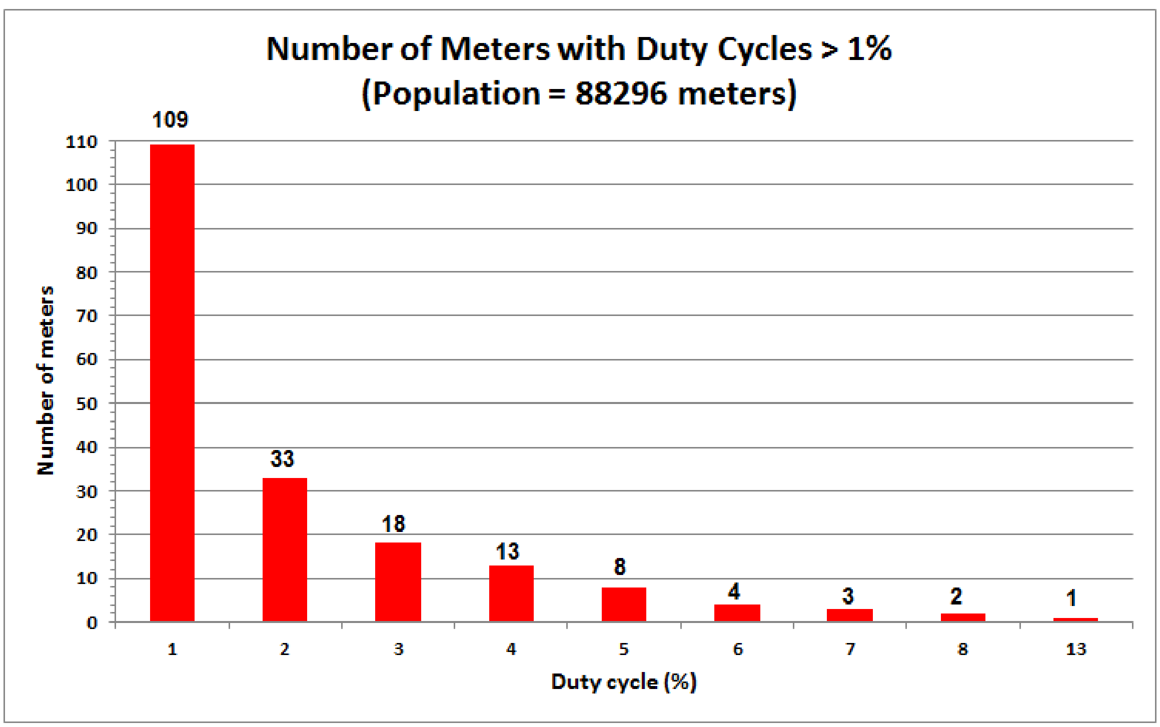

Figure 5-3
Numbers of smart meters from study population of 88,296 endpoint meters exhibiting duty cycles equal to the value on the horizontal axis.

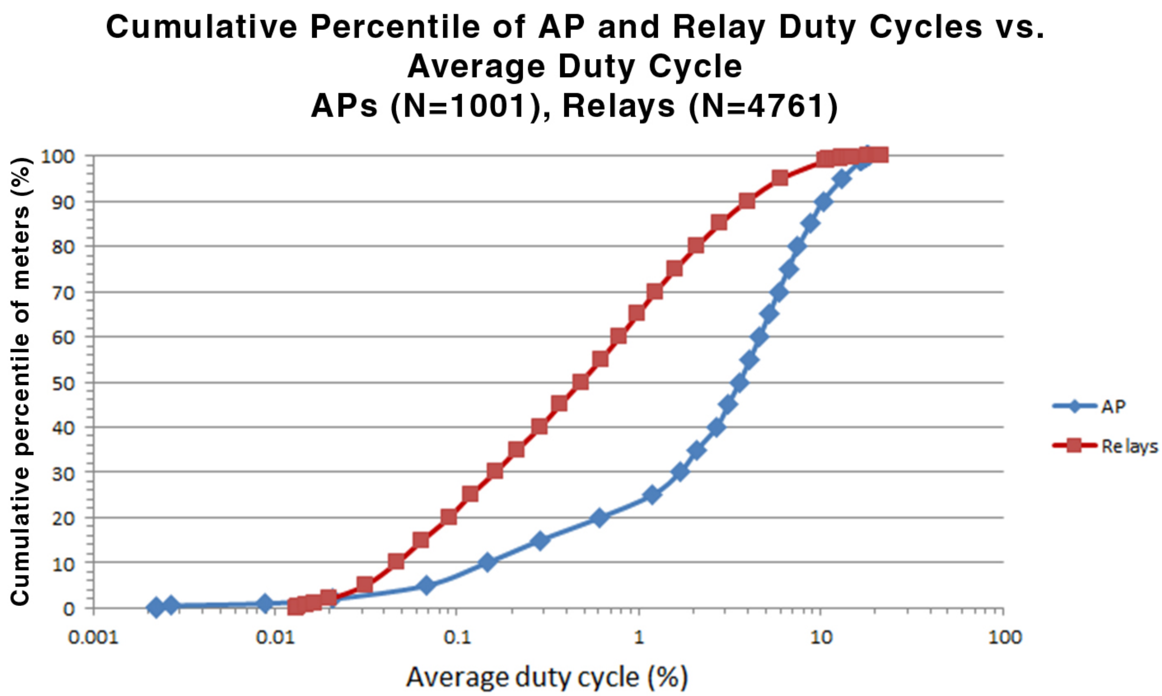

Figure 5-4
Result of a percentile analysis of 1001 APs and 4761 Relays exhibiting various duty cycles over a sample interval of nominally 47 hours.

Section 6: Discussion

An inclusive approach has been pursued for characterizing possible exposure of individuals to the RF emissions that can be produced by the wireless smart meters deployed by PG&E. When taken collectively, the RF data presented in this report show common exposures to the smart meters investigated comply by a wide margin with the applicable human exposure rules of the FCC. Irrespective of whether RF power densities are quantified in terms of their instantaneous peak magnitude, their time-averaged value or their spatially averaged value, the fields comply with the exposure limits. For example, at a distance of 1 ft (0.3 m) directly in front of a smart meter, the greatest peak RF power density measured in this study was 14.7% of the FCC public MPE found at a single meter. If this peak field value is corrected for the 99.99th percentile duty cycle (4.53%) observed among the actual installed endpoint smart meter population and for spatial averaging (a factor of 0.209), the resulting exposure value for comparison with the FCC MPE would be 0.14% of the MPE. This would be deemed a conservative estimate of the exposure that an individual might experience if standing very close to and in front of one of the smart meters.

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 readings. 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 14.7%, could be expected to be as great as 33.1% 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 20 cm 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 1.5% (0.3% with spatial averaging included) of the public MPE would be projected at 20 cm using the 99.99th percentile duty cycle found for smart meters in the PG&E 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.

AP and Relay duty cycles can be greater than those of endpoint meters. However, the potentially greater time-averaged RF fields associated with these devices have little to no effect with respect to compliance with the FCC MPEs. The normally elevated mounting points for APs and Relays result in exposure levels on the ground below that are substantially less than the RF levels near endpoint meters.

The data also show that the PG&E smart meter deployment results in only very weak RF fields inside the residences measured. 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 indoor exposures of less than 1% of the MPE with 95% of measurements less than 0.2% of the MPE were found. If these values are corrected for duty cycle, the resulting potential exposures are less than 0.045% of the public MPE for all of the interior measurements..

A conservative value of the rearward directed RF energy was determined to be approximately one-tenth of the field, expressed in term of a percentage of the MPE, found directly in front of the meter. Actually, in some angular directions behind the meters, the RF field may be substantially less and closer to a hundred times less.

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 three locations. The peak levels of RF fields measured are not different from those measured at a single smart meter. To illustrate this point the peak readings from the multiple meters in the three apartment complexes (Figure 4-23) are displayed with the data from the single residences (Figure 4-23) in Figure 6-1. This is consistent with the manner in which the mesh network functions; multiple meters competing at the same exact time for communicating with the access point results in data packet collisions with the result that the data must be repeated on successive trials until the message is correctly received. 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 little likelihood that the instantaneous RF field will be represented by the superposition of signals arriving from a multiplicity of meters. This insight was supported by acquiring time domain measurements of the broadband waveform of multiple smart meter emissions. A difference in the resulting RF fields with large aggregations of smart meters in one location can be reflected in greater time-averaged values of field since, during any given time period, more meter emissions can occur. So, while the peak value of field stays essentially the same as with a single meter, the time-averaged value can be greater. However, in the measurements reported here, there was no clear evidence that the composite duty cycle of the collection of meters as a whole was uniquely different. For instance, at the apartment setting with 112 smart meters, the measured duty cycle during a period in which it was expected that most meters would be communicating with the access point, was about 0.3% corresponding to the value found in the top 1% of endpoint meters. While there will be differences in the average value of the composite RF field produced by large groups of smart meters, compared with a single meter, time-averaged exposures that may result when individuals stand immediately next to the array of meters is not expected to exceed the MPEs simply due to the very low duty cycles of the individual endpoint meters. The data obtained in this study do not suggest that multiple meter locations present an exposure limit compliance issue.

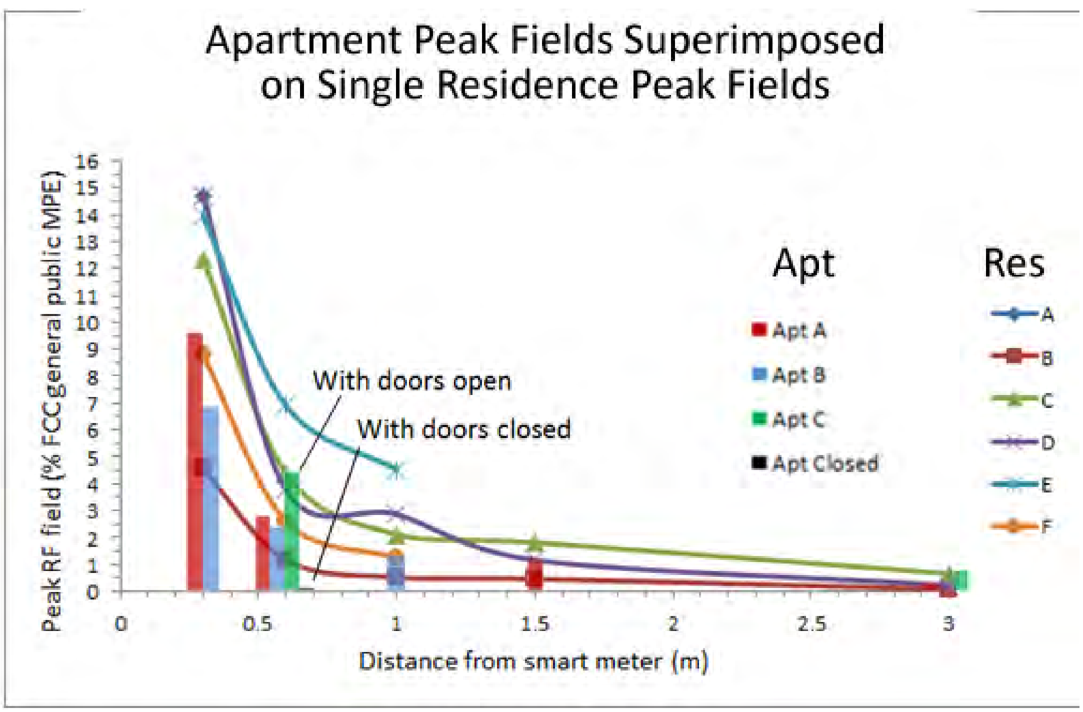

Figure 6-1
Apartment peak fields superimposed on single residence peak fields

PG&E has not activated the HAN feature that exists within its smart meters. But, the HAN radio was characterized as to the RF field level that could be produced near a HAN radio-activated smart meter. The significantly lower power of the HAN transmitter and greater MPE value at the HAN's operating frequency results in much lower RF fields (relative to the MPE) than those produced by the 900 MHz transmitter. At 1 ft (0.3 m), the HAN radio resulted in a peak RF field corresponding to 0.13% of the FCC MPE for public exposure. Spatial averaging and correcting for duty cycle (which will be dependent on the extent of data communications between the HAN radio and the HAN devices within the home) will result in lower values when applied to characterizing exposure.

Electric and magnetic field measurements over the frequency range of 5 Hz to 100 kHz did not reveal the presence of any particular fields that were consistently and significantly greater than background values except in the case of the observation of a magnetic field component in the region of 1 and 2 kHz that proved to be inconsistent upon subsequent measurements.

The influence of reflections, such as produced by the ground and/or other reflective surfaces, to result in extremely high values of resultant RF fields near smart meters has been claimed with the argument that reflections can enhance the power density of fields by as much as 400 times[10] over the free space value. Measurements of peak RF fields taken close to the PG&E smart meters and reported here, where the field is the greatest and potential exposure would be maximized, were found to be commonly in the range of about 10% of the MPE for public exposure. This finding stands in strong contrast to the claim in the referenced report and supports the conclusion that such a claim is unrealistic and not supported by real world measurements.

[10] Sage Associates (2011). Assessment of Radiofrequency Microwave Radiation Emissions from Smart Meters. 1396 Danielson Road, Santa Barbara, CA.

Measurements documented in this report suggest that simplistic calculations of peak RF fields based on the maximum EIRP[11] 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 is given in dBm, R is distance in cm and the frequency is 915 MHz, the percent of the FCC public MPE, S(%), is given by:

$$S(\%) = 13.05 \times \frac{10^{(dBm/10)}}{R^2}$$

This formula adjusts the calculated power density for the FCC public MPE at 915 MHz. Using the specified EIRP for the 900 MHz (NIC-514) radio in Table 2-2 (29.9 dBm power with 4 dBi gain) , the RF field at 30 cm is projected to be 35.6% of the public MPE. Two issues are noteworthy; (1) the computed RF field is between two and three times greater than that measured for the PG&E smart meters of this power level and (2) the above formula includes no corrections that would correct for possible reflections. The inclusion of a ground reflection factor in FCC OET-65[12] formulas is based on measurements of FM radio broadcast fields in the 100 MHz frequency range and is applicable when the distance between the source antenna and the point of interest is sufficient to allow for relatively uniform exposure of the body. The FCC ground reflection factor is also only applicable to estimating the spatial peak values of RF field, not body-averaged values.

[11] EIRP is equal to the product of transmitted power and antenna gain (relative to an isotropic source).

[12] Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, FCC OET Bulletin 65, Edition 97-01, August 1997. [Page 21 discusses the use of a ground power reflection factor of 2.56.]

The experience gained in this investigation showed that the most practical method for measurement of frequency-hopping smart meter fields is the use of a spectrum analyzer based detection system. The Narda SRM-3006 proved reliable and consistent throughout the measurements conducted for this study that spanned approximately six months. The sensitivity of the instrument and the ability to identify emissions on specific frequencies provided a straightforward means for measurement of the smart meter fields compared to less sensitive, broadband probe devices. Access to the scope option on the SRM-3006 was indispensible for measurement of short term smart meter duty cycles.

Section 7: Conclusions

Measurements were performed to characterize possible RF fields produced by four different combinations of electric smart meters and internal 900 MHz radio transmitters being deployed by PG&E. The measurements included a preliminary investigation of the meter characteristics in Colville, WA and subsequent measurements in the PG&E service territory. The study shows that the subject smart meter fields are 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 typical peak fields of about 10% of the MPE. Time- and spatially-averaged values were concluded to be, at most, about 0.14% of the FCC MPE, depending on the activity of the meter.

Directional emission patterns for the meters were investigated and found to favor the forward direction with a conservative reduction factor of approximately 10 dB for rearward directed fields with some specific angles exhibiting reduction factors of approximately 20 dB.

Large aggregations 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 transmitters. Such higher average composite duty cycles do not, however, change the conclusion that such exposures are compliant with the established FCC limits.

Although not presently implemented, the HAN radio inside the smart meter, when activated, results in substantially weaker RF fields due to its lower EIRP and, also, complies with the FCC exposure limits.

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 in six California residences, 99% of the measured peak values were less than 0.8% of the MPE with 90% of the measured values being less than 0.1% of the exposure limit.

Smart meter exposure produced by wireless frequency-hopping transmitters is constrained by the low power of the transmitter and low antenna gain. 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.

Section 8: References

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Appendix A: RF Exposure Limits

In the United States, the controlling limits for human exposure are those adopted by the FCC. While the FCC maximum permissible exposures (MPEs) strictly apply to FCC licensees, it has become common practice for manufacturers of many smart meters, which operate as unlicensed sources, to apply the FCC MPEs in their certifications before the FCC. Hence, the FCC's limits are for assessing compliance. However, in addition to the FCC MPEs, the IEEE has published standards for safe exposure limits (IEEE, 2005). Table A-1 summarizes the MPEs from the FCC and the IEEE pertinent to the emission frequencies associated with smart meters.

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 of source-based exposures 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. 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. For smart meter emissions, a precise determination of compliance with the FCC exposure rules requires both the assessment of time-averaged RF fields and an assessment of the average RF field across the dimensions of the body. In practice, and as found in virtually all of the certification reports filed with the FCC for smart meter emissions by manufacturers, the simplistic assumption is made that if the maximum, instantaneous field[13], 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.

The MPEs listed in Table A-1 are based on limiting the underlying basic restriction of RF energy absorption averaged both across the body and across a local 1 gram mass of tissue. The energy absorption rate is referred to as the specific absorption rate (SAR) which is expressed in units of 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 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.

[13] 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.

Table A-1
FCC and IEEE MPEs pertinent to smart meter RF fields. MPE values are in terms of power densities averaged over 6 minutes for occupational exposure and 30 minutes for exposure of the general public.

	FCC MPE (mW/cm^2)		**IEEE MPE (mW/cm^2)**	
Frequency	General public	Occupational	General public	Occupational[A]
902	0.601	3.01	0.451	3.01
928	0.619	3.09	0.464	3.09
2400	1.000	5.000	1.000	8.00
2450	1.000	5.000	1.000	8.17

[A]The IEEE standard refers to an upper tier of MPEs for persons in controlled environments. For practical purposes, this can be thought of as for occupational exposure.

Appendix B: 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

CALIBRATED BY:
Paul Geyer

AUTHORIZED SIGNATORY:

MANAGEMENT SYSTEM

DQS

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

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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 (2^{nd} and 3^{rd} order):	passed
10	INPUT RETURN LOSS:	passed

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APPENDIX

FREQUENCY RESPONSE (RF)

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

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

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

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

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

Appendix C: Calibration Certification of the Narda EHP-50C

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narda Safety Test Solutions
an L3 Communications Company

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)

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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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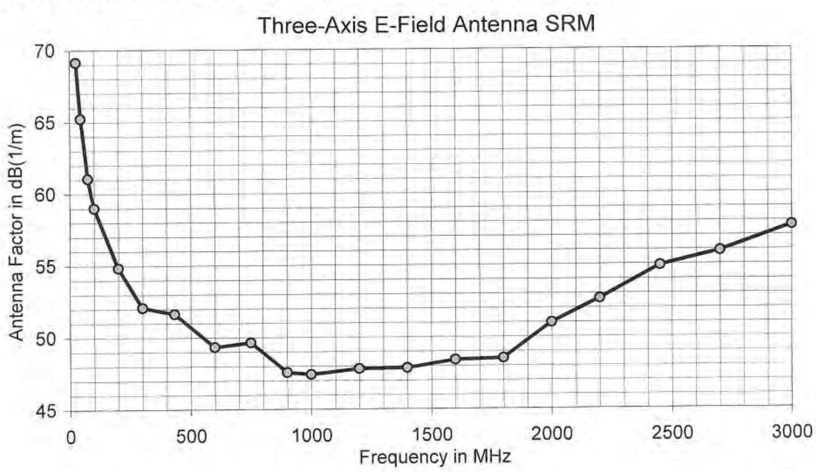
Results

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 D: Residential and Warehouse Photographs

Figure D-1
Residence A, Walnut Creek, CA

Figure D-2
Residence B, Concord, CA

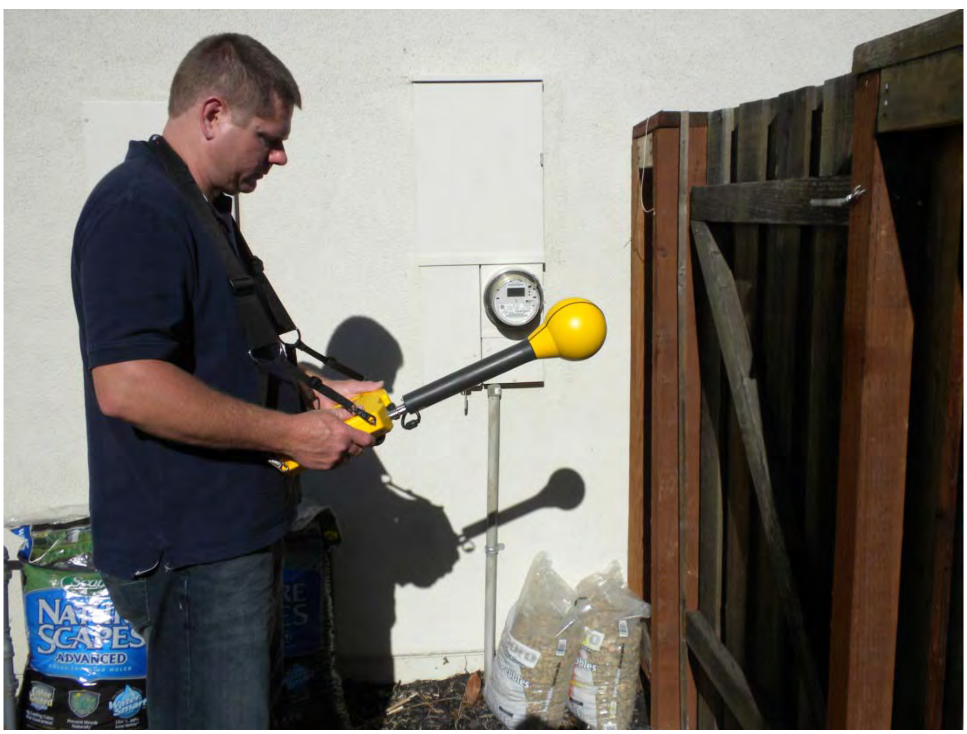

Figure D-3
Residence C, Brentwood, CA

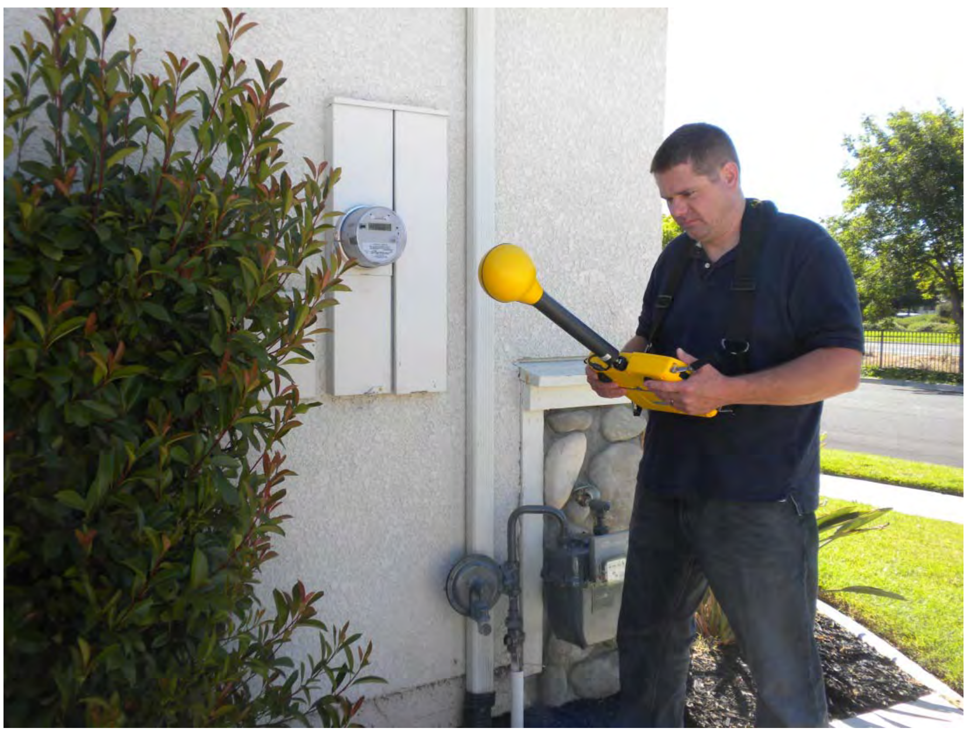

Figure D-4
Residence D, Brentwood, CA

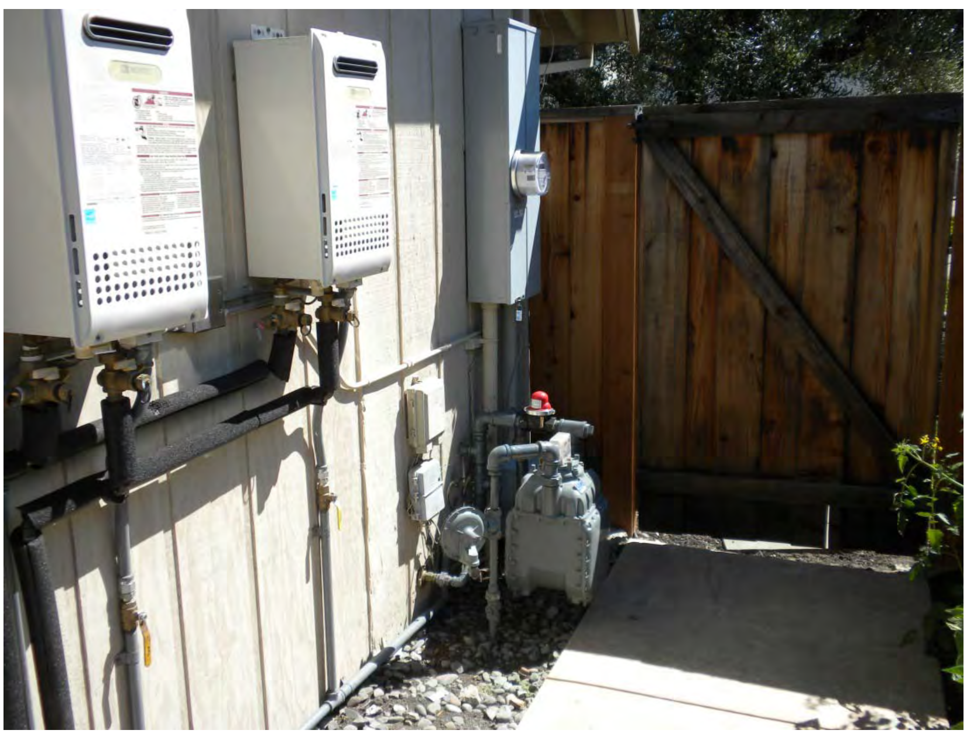

Figure D-5
Residence E, Danville, CA

Figure D-6
Residence F, San Ramon, CA

Figure D-7
Warehouse G, San Ramon, CA

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