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Characterization of Radio Emissions from Advanced Metering Infrastructure Revenue Meters (Smart Meters) in CPS Energy Residential Installations

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Characterization of Radio Emissions from Advanced Metering Infrastructure Revenue Meters (*Smart Meters*) in CPS Energy Residential Installations

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ABSTRACT

This technical report presents the results of electromagnetic (EM) emission measurements in the radio frequency (RF) range from advanced metering infrastructure (AMI) utility meters (smart meters) employed by CPS Energy in its territory of operation. The study is focused on the determination of the maximum possible level of emissions, the typical population exposure conditions, and a comparative set of measurements from other RF sources that are present in a common household. The results indicate that the maximum possible human exposure would occur at RF emission levels about 10%, or less, of international standard safety guidelines for continuous exposure. Smart meters RF emissions also were found to be lower than those from other devices to which consumers are typically exposed.

Keywords

Advanced Metering Infrastructure

Smart Meters

Electromagnetic Field Exposure

EXECUTIVE SUMMARY

As part of the development of the Advanced Metering Infrastructure (AMI), electric utilities are increasingly deploying revenue meters (smart meters) with two-way telecommunication capabilities that utilize radio-frequency (RF) transmitters. Health and safety concerns regarding potential adverse affects on humans due to exposure to the electromagnetic (EM) fields generated during these radio transmissions have been raised by various individuals and organizations.

To assess the situation more extensively, CPS Energy commissioned a data collection and analysis study to provide a quantitative description of the RF emissions from smart meters being deployed in the CPS Energy service territory.

The study is considering the specific meters models planned for deployment, measurements in actual residential installations that were provided through an already operational pilot project, and laboratory measurements designed to investigate the maximum RF exposure scenarios, regardless of how improbable they may be.

From the data presentation perspective, the basic information is provided while avoiding technical language that may sound obscure to a large part of the public (thus missing the main communication target) and at the same time maintaining a scientific rigor by providing reproducible and accurate results. Technical details are presented in the report appendix.

Analysis and conclusions from an epidemiological perspective are outside the scope of this study and are being actively pursued at the international research level. Instead, the present effort was focused on presenting the EM emissions in the radio-frequency (RF) range from smart meters in comparison with other common devices that are generating electromagnetic fields and to which the public is routinely exposed.

The metric to quantify and compare the technical findings is consistent with both published standards and previous investigations. A synthesis of the results is shown in Figures ES-1 and ES-2. Figure ES-1 provides a pictorial representation of the measured RF emission levels from a smart meter in the vicinity of the transmitting antenna; this is a qualitative drawing of a contour map representing the actual measured emission levels as a function of distance from the meter. The measurements are expressed as percentage of the reference level defined in the most conservative international standard, published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP, [3], [4]).

The Figure ES-1 refers to a horizontal cross section plane, located at the same elevation from the ground as the meter, where the maximum level of emissions has been found.

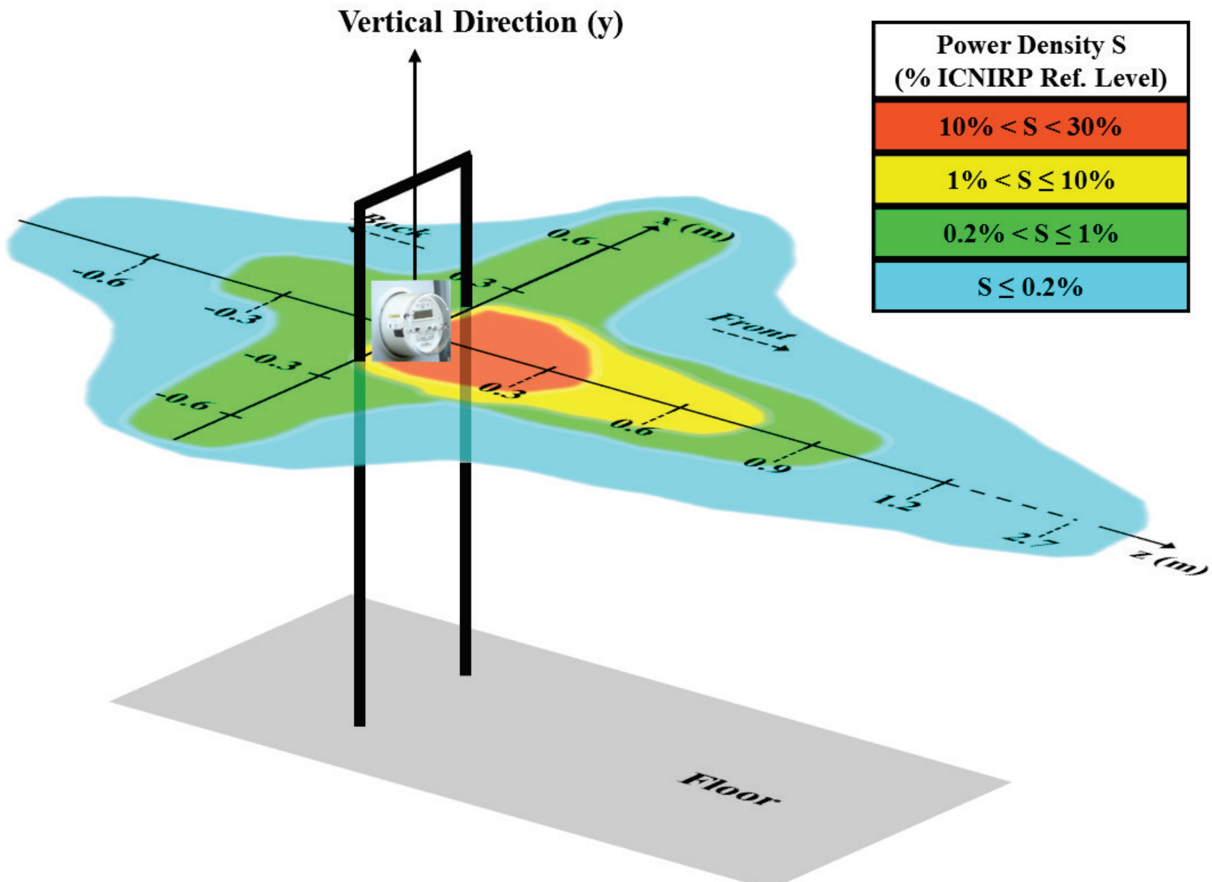

Figure ES-1 – Pictorial representation of the measurements data for the maximum RF emission scenario (continuous transmission) from the tested smart meters.

Measured power density expressed as % of the reference level as prescribed in the ICNIRP international standard [3].

Figure ES-2 (details are discussed in Section 3) provides a comparison of RF emissions from smart meter radios with respect to other common RF emission sources. The figure is constructed by plotting the emission levels expressed as percent of the ICNIRP reference limit (as in Figure ES-1), while an approximate uninterrupted exposure time estimated for typical consumer's use is presented on the horizontal axis.

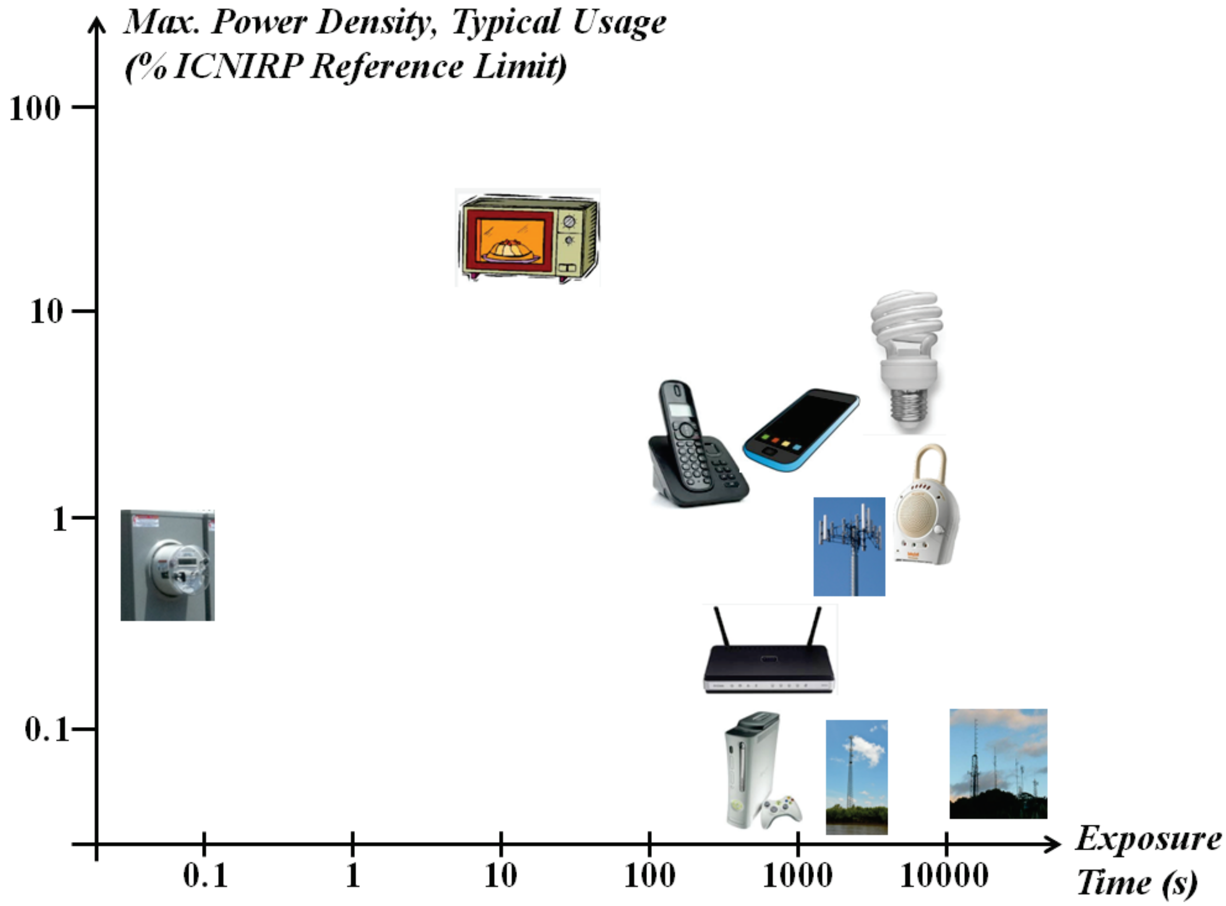

Figure ES-2 – Qualitative comparison of EM emissions for different sources present in common households *vs*. an approximate uninterrupted exposure time estimated for typical consumer's use (both axes are on a logarithmic scale).

In conclusion, the measurements of this study find that the CPS Energy smart meters that have been tested generate RF emission that:

- For any possible exposure conditions produce instantaneous power density levels always less than 30% of the reference level specified by the ICNIRP safety guideline.
- For typical consumer exposures in residential settings, exposure levels are one order of magnitude less, or lower, than the ICNIRP reference limits. These results are also consistent with previous similar studies.
- Are lower, in terms of combined exposure time and RF power density level, than a variety of common devices that generate RF fields.

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1
DESCRIPTION OF THE TECHNOLOGY

Introduction

This report presents the results of radio-frequency (RF) emission measurements from power revenue meters equipped with wireless communication radios that are being considered for a large-scale installation in the service territory of CPS Energy in San Antonio, Texas.

These devices, to be deployed as part of the Advanced Metering Infrastructure (AMI) implementation and commonly referred to as “smart meters”, have transmitting and receiving capabilities for integration in a mesh-network environment and operate in the same radio frequency range as cellular telephones. There have been concerns raised both in the public domain and in the technical community about possible adverse health consequences due to the human exposure to low-level EM fields, including those emitted by smart meters.

The general issue of impact of EM fields on living organisms, and on human health in particular, is outside the scope of this investigation. However, the results that are here presented provide a perspective on exposure levels from smart meters relative to established health and safety-based exposure limits.

Currently, RF exposure safety standards are based on thermal effects due to absorption of RF energy in living tissues: for this case the power density is the reference exposure quantity to be considered. This relates to the rate of deposition of thermal energy in tissue per unit mass, a quantity called the Specific Absorption Rate (SAR), expressed as watts per kilogram (W/kg).

Organization of the Report

The report main body provides a narrative description that includes the background information and testing approach, a synthesis of the measurements, and a presentation of the level of emissions from the meters in comparison with other common sources of RF. A set of technical appendixes is provided that contain the details of the measurement process and the data collection, a discussion about data analysis and verification, and ancillary information.

Scope and Objectives

Health and safety concerns have been raised by individuals and organizations in relation to the potential adverse effects due to human exposure to the electromagnetic fields generated during the radio transmission operation of smart meters. In order to help address these concerns, CPS Energy commissioned a study with EPRI to provide a quantitative characterization of the electromagnetic emissions from the radios installed in the smart meters planned for deployment in its service territory.

The study is considering the specific meters models planned for deployment, measurements in actual residential installations that were made available through an already operational pilot project, and laboratory measurements designed to investigate the maximum RF exposure scenarios, regardless of how improbable they may be.

Background

The common trend towards the development of a "smart grid" infrastructure calls for an enhanced interaction among different components of the electric power system: at the generation level, the proper response to the load variations needs to be in place; at the utilization level, the customer must be provided with a nominal level of power quality (within a set variance range), a high level of dependable service, and rapid recovery from power outages. Between generation and end-use, the transmission and distribution infrastructure represents the key of ensuring this functionality.

The communication to and from the consumer level is going to play a critical role in the overall planning and managing of grid operations. The ability to collect timely data on the levels and patterns of end-usage—once supported by an adequate information technology infrastructure comprised of telecommunication, data storage/processing, and data analytics—would allow for an "intelligent" management of the grid's resources, with overall improvement of reliability, energy efficiency, and hopefully, customer satisfaction (both in terms of quality of service and economy). Within this large-scale picture, the smart meters—the upgraded version of the revenue meters—represent the natural interface with customer installations across the service territory.

An infrastructure has been already designed and tested, and in many areas is implemented and operational, allowing a large number of smart meters to operate and communicate in a mesh-network environment. In the United States, the typical implementation of this network relies on wireless communication, organized in a similar fashion to the cellular telephone network. The smart meters designed for this application utilize radios operating in the high-frequency region of the EM spectrum, at frequencies near to those allocated for cellular telephones.

The smart meters can communicate directly with a receiving concentrator node or with another smart meter present in its neighborhood, depending on the radio wave propagation condition that may favor one connection versus another. This design allows for maximum flexibility in the functional quality of the network, providing high reliability for communication in both high-density urban environments and rural, sparsely populated areas.

Historical Perspective on EPRI Research

The deployment of wireless-based smart meter networks, initially through pilot projects and later on a larger scale, has generated a wide spectrum of reactions in the public domain. As concerns were raised about the potential impact of RF emissions on people living in the vicinity of the smart meter installations (including apartment complexes where arrays of meters may be present), utilities are actively supporting related exposure characterizations.

Previous EPRI-supported measurement studies (as well as more general perspective discussions) about RF emissions from AMI meters are published in the peer-reviewed literature ([6] and [7]), and in EPRI Technical Reports and Resource Papers ([8], [9], [10], [11], [12]).

The work in [8] summarizes the EPRI perspective on smart meters focused on two main research activities: an analysis of the amount of RF energy deposited in persons exposed to smart meter emissions and a study of RF emissions from one particular type of smart meter model, under controlled conditions at the manufacturer's facility.

The technical report [9], discusses the details of Automatic Metering Infrastructure (AMI) as a summary white paper. The analysis proceeds in defining the typical operational conditions at low duty cycles, the expected level of exposure in comparison with the FCC guidelines, and a discussion about the comparison with EM emission from other common devices (like cellular telephones).

A technical report [10] provides a detailed description of the RF emission data collection on smart meters that was carried out in a laboratory setting in the state of Washington and at residences in California. The study analyzed the EM emission and compared them with the FCC standard, finding that it was less than 1% of the FCC maximum permitted exposure (MPE) for typical duty-cycle operating conditions. At 100% duty cycles, measured power densities were less than 10% of the FCC limits. The indoors shielding effect from typical home construction materials was also investigated, showing that the field levels decrease by an additional order of magnitude compared with ones measured outdoors.

Measurements on typical indoor values of the RF fields were reported in [11] for six residential locations in the service territory of the PG&E electric utility company. In addition, measurements were performed to examine the composite RF field environment from arrays of smart meters installed and operating next to each other in three different apartment complexes, including one with 112 co-located smart meters. Analysis of data transmissions from 88,296 smart meters, collected via the PG&E data-management system, was utilized to provide a statistical distribution of meter duty cycles to be included in the determination of time-averaged emission levels.

The study reported in [11] also provided data on the home area network at 2.4 GHz (although not utilized) that has substantially weaker fields due to lower RF power emitted, and that was reported well within the FCC exposure limits. In summary, in all these studies, the smart meter emissions were shown to be small in comparison to the applicable FCC exposure limits.

Two EPRI workshops that were conducted to study the electromagnetic environments created by emerging technologies and on their potential health effects associated with radio-frequency (RF) emissions are summarized in [12]. The workshops concluded that acquiring more data concerning the characterization of exposure to EM fields is a top priority.

In all the reported studies, the RF emission from smart meters in typical conditions of utilization and exposure have been determined to be well below both the thresholds from established and recognized safety standards (like those issue by Institute of Electrical and Electronics Engineers, IEEE, the Federal Communications Commission, FCC, and the International Commission on Non-Ionizing Radiation Protection, ICNIRP).

Specific Focus: the CPS Energy Smart Meter Deployment Plan

The present study is focused on characterizing RF emissions from all the models of smart meters expected to be deployed by CPS energy in its service territory. The study accounts for the specific installation environment and hardware that characterize CPS Energy's planned deployment in San Antonio, Texas. In addition to testing within several typical communities, Laboratory tests were conducted with smart meters in a continuous operation mode to facilitate the measurements for maximum RF exposure conditions.

The study was conducted both in reference to meters in the standard residential installation setup and in a “test mode”, where the radio transmission was set in a continuous mode, without any reference to a “duty cycle” from a particular communication data pattern that can lower the average time of exposure to RF.

The measurements have been also conducted to determine the maximum field levels generated all the way to the surface of the meter, near the transmission antenna (that is located inside the meter enclosure), thus addressing possible very atypical conditions of exposure (such as for animals, or children at play in a backyard). However, due the sensitivity of these measurements to detector position within about 20 cm from the transmitting antenna of the meter, these measurements may only provide general approximations. More details are discussed in the Appendix A.

2
ELECTROMAGNETIC FIELD EXPOSURE LIMITS

Limits for exposure to EM fields have been established by the US Federal Communications Commission (FCC), the Institute of Electrical and Electronics Engineers (IEEE), and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Each of these organizations aims to protect against potentially adverse effects associated with excessive heating of tissues within the body. They are also all based on the same body of literature in which food-motivated behavior in experimental animals (monkeys, rats) was compromised at a threshold dose rate of about 4 W/kg, a quantity referred to as the specific absorption rate or SAR. This SAR was associated with about a 1°C rise in body temperature. FCC, IEEE and ICNIRP established exposure limits restrict whole body SAR to 0.4 W/kg for occupational or "controlled" circumstances, which is a factor of 10 lower than the mentioned nominal effect threshold.

For the general public an additional factor of 5 led to a dose rate limit of 0.08 W/kg or a 50-fold factor below nominal threshold. Both of these SAR quantities are expressed as whole-body averages.

Because the exposure limits are established to protect against excessive heating, a process that does not occur instantaneously in the case of field exposures, exposure levels may exceed those stated above provided their time average remains below those values. For FCC and IEEE limits, the averaging duration is 6 minutes for controlled environments, and 30 minutes for the general public; for ICNIRP limits, 6 minutes applies for all.

For localized exposures, the IEEE and ICNIRP permit up to 10 W/kg over 10 grams of tissue for controlled environments and 2 W/kg for the general public. The FCC permits, respectively, 8 W/kg and 1.6 W/kg over 1 gram of tissue.

The relationship of SAR to exposure, as expressed by the power density (W/m^2), is a function of frequency and the physical dimensions and dielectric tissue properties of the exposed subject. The coupling efficiency of an RF field to a human may be maximal from anywhere between about 50 MHz (large adults) to 130 MHz (small children).

The limits to exposure are accordingly "trough-shaped" with upper and lower frequency limits specified to encompass all persons: FCC, 30-300 MHz; IEEE, 30-400 MHz (Controlled) and 40-400 MHz (General Public); ICNIRP, 10-400 MHz. In these frequency ranges, all limits are 1.0 mW/cm^2 for controlled circumstances, and 0.2 mW/cm^2 for the general public. Above these bounds the exposure limits (but not permissible SAR, which remains the same) rise as the deposition of thermal energy starts to concentrate closer to the body surface (skin effect); the limits also rise to the left of the trough because of frequency-dependent dielectric tissue properties. For example, for a smart meter operating in the license-free band of 902-928 MHz, the FCC's general public exposure limit is about 0.6 mW/cm^2.

The following Figures 2-1 to 2-4 report the general public maximum exposure guidelines adopted by the FCC, IEEE, and ICNIRP, respectively.

Frequency Range (MHz)	Electric Field Strength (E) (V/m)	Magnetic Field Strength (H) (A/m)	Power Density (S) (mW/cm^2)	Averaging Time $\|E\|^2$, $\|H\|^2$ or S (minutes)
0.3-1.34	614	1.63	(100)*	30
1.34-30	824/f	2.19/f	$(180/f^2)$*	30
30-300	27.5	0.073	0.2	30
300-1500	--	--	f/1500	30
1500-100,000	--	--	1.0	30

f = frequency in MHz *Plane-wave equivalent power density

Figure 2-1
FCC guidelines for maximum permitted exposure RF levels for the general public from [2]

Frequency range (MHz)	RMS electric field strength (E) (V/m)	RMS magnetic field strength (H) (A/m)	RMS power density (S) E-field, H-field (W/m^2)	Averaging time $\|E\|^2$, $\|H\|^2$ or S (min)	
0.1–1.34	614	$16.3/f_M$	$(1000, 100\,000/f_M^2)$	6	6
1.34–3	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	$f_M^2/0.3$	6
3–30	$823.8/f_M$	$16.3/f_M$	$(1800/f_M^2, 100\,000/f_M^2)$	30	6
30–100	27.5	$158.3/f_M^{1.668}$	$(2, 9\,400\,000/f_M^{3.336})$	30	$0.0636\,f_M^{1.337}$
100–400	27.5	0.0729	2	30	30
400–2000	–	–	$f_M/200$	30	
2000–5000	–	–	10	30	
5000–30 000	–	–	10	$150/f_G$	
30 000–100 000	–	–	10	$25.24/f_G^{0.476}$	
100 000–300 000	–	–	$(90f_G-7000)/200$	$5048/[(9f_G-700)f_G^{0.476}]$	

NOTE—f_M is the frequency in MHz, f_G is the frequency in GHz.

Figure 2-2
IEEE Guideline for Maximum Permitted Exposure RF levels for the general public, from [5]

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

Figure 2-3
ICNIRP reference levels (equivalent to the maximum permitted exposure levels of IEEE) for general public exposure to time-varying electric and magnetic fields from [3]

The frequency *f* is expressed as indicated in the "Frequency range" column (e.g. for 900 MHz, that is in 400-2000 MHz range, *f*=900). The levels refer to RMS values, for an average over 6 minutes.

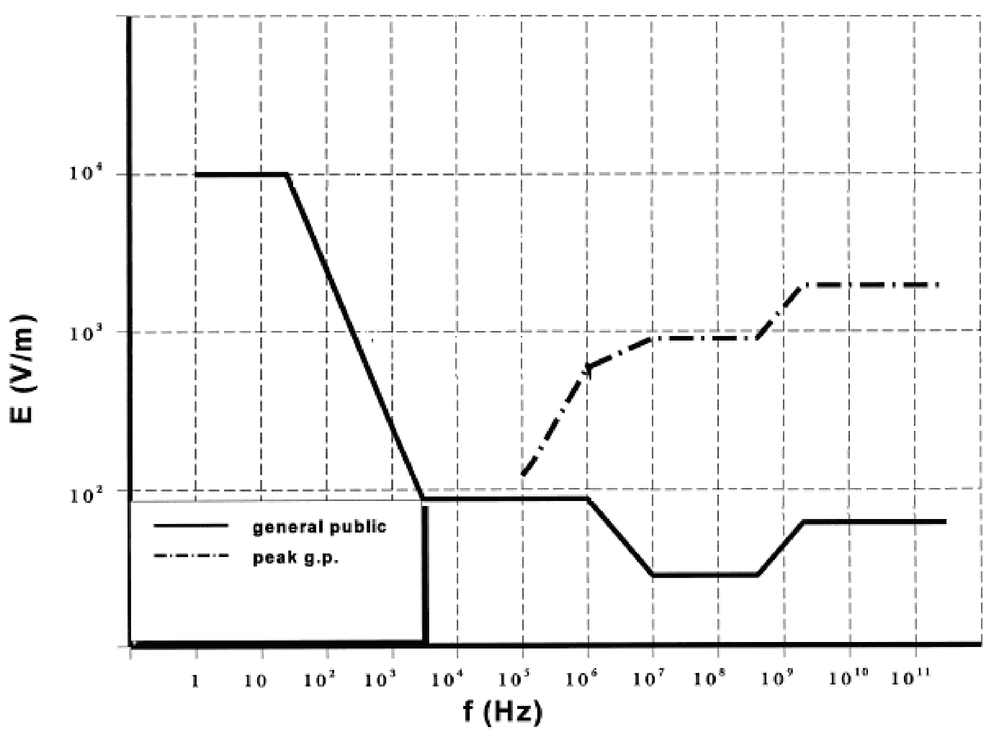

Figure 2-4
ICNIRP Guidelines of Figure 2-3 presented in graphical form

The solid line corresponds to the levels of Figure 2-3, the dashed line is an additional prescription for maximum instantaneous level of field exposure, still for general public (from [3]) without any time averaging reference.

At the frequency f=915 MHz, the IEEE specifies a maximum permissible exposure (MPE) corresponding to an average power density S_{IEEE}=f/200 W/m^2=4.575 W/m^2 (corresponding to RMS fields computed over a 30-minute period).

The ICNIRP standard for the general public reference level prescribes the same level as in the IEEE standard, but the exposure time is up to six minutes. The ICNIRP also specifies maximum separate electric and magnetic fields for this frequency range. For the 915 MHz frequency, the corresponding RMS maximum permissible electric field is 41.6 V/m.

The FCC standard for the general public MPE prescribes a level of $S_{FCC}=f_{MHz}/1500$ mW/cm^2 $=f_{MHz}/150$ W/m^2. For f_{MHz}=915, this yields S_{FCC}=6.1 W/m^2, which is a larger (i.e. less stringent) value than the IEEE/ICNIRP standard.

For the object of this study, referring to for devices like smart meters utilized in the US, the FCC exposure limits apply. While IEEE and ICNIRP are widely cited (e.g., NATO is in the process of adopting IEEE standards from 0 to 300 GHz), the FCC maximum permissible exposure (MPE) is the primary reference for commercial devices. The ICNIRP provides reference levels that are a bit more conservative than the FCC, thus they are utilized as benchmarks in this study (FCC levels can be easily related to the ICNIRP via a numeric factor).

3
TEST METHODS

This section describes the results of the measurements conducted on three smart meters models that cover the current and near future installation plans for CPS Energy. The procedure for assessing the RF emission is discussed, in the context of RF exposure standards. The testing methodology is described, with the definition of the relevance of both the maximum ambient RF scenario and "typical" exposure conditions.

Establishing a Figure of Merit for the Assessment of EM Fields Impact on the Human Health

For RF exposure characterization, the chosen metric is the surface power density (power per area unit, W/m^2 or mW/cm^2), which, at the frequencies of interest in this study, is directly proportional to the square of the electric field. The FCC, IEEE and ICNIRP exposure standards specify the time over which exposure may be averaged to limit the total thermal energy absorbed (W/m^2 x time (sec) = energy (Joules)) to a level that the body can easily dissipate.

Testing Methodology

Maximum RF Emissions Scenario

The "maximum RF emissions scenario" has been here defined as that referring to the following conditions: a) smart meter with its radio continuously transmitting at its rated power and b) RF emissions measured as close to the meter case as possible (and while ensuring that a valid measurement is provided).

In practice, these conditions correspond to a smart meter transmitting constantly with a 100% duty cycle and with an exposure target in physical contact with the meter enclosure case. It can be argued that this scenario is quite far from any practical reality: the duty cycle of a typical smart meter utilization pattern is very low (nominal average of 0.1% as reported in [6] and [7]) while occupants in residential dwellings are unlikely to remain even close to a meter box location. Nevertheless, this is considered appropriate for a study that is meant to investigate safety conditions for consumers.

Typical Exposure Scenario

The definition of "typical" exposure conditions is more complex, because it should be representative of a large set of possible situations.

The smart meter utilization pattern may vary considerably depending on the topology on the network and the type of data that the utility chooses to transmit and receive, and it is reasonable to assume that, in the future, functionality will expand with a possible increase in duty cycle, as the implementation of smart grid technologies becomes more common. For these reasons, the issue of the actual duty cycle is not considered here, and a continuous transmission is still assumed, always at the maximum power level. This is a conservative choice and a continuous emission level multiplied by the duty cycle would be more accurate and appropriate to represent actual exposure conditions.

The distance of exposure shall take into account both indoor and outdoor conditions. The former is of a considerably less concern, because the metal box that is housing the meter provides shielding in the rear direction, and additional shielding is provided by the walls [9].

The outdoor exposure is here considered in reference to a "casual presence" in the area where the meter is installed, without including the case of deliberate contact, as, for example, in the case of a utility worker doing maintenance (for which occupational or "controlled" limits would apply).

Based on these considerations, it will be conservatively assumed that the "typical" exposure scenario is that of a continuous transmission at 1 m (about 3 ft) distance directly in front of the smart meter case.

Time of Exposure

An additional consideration shall be given to the issue of exposure time. Published safety standards prescribe an average power level referred to a defined exposure time (six minutes for the ICNIRP guidelines, as discussed in the Appendix F).

For example, the ICNIRP maximum average exposure at 900 MHz is prescribed as a 4.5 W/m^2 RF power density averaged over any contiguous period of six minutes, for the general public. Then, for the ICNIRP standard, the exposure of an individual that is spending three minutes in a 4.5 W/m^2 power density environment would be considered equivalent to the case of exposure to a six-minute average power density of 2.25 W/m^2, that is corresponding to 50% of the ICNIRP maximum permitted exposure.

Testing Equipment

The measuring equipment utilized was a NARDA SRM 3006 RF analyzer (Figure 3-1) with a 9 kHz to 6 GHz frequency range, both single-axis and isotropic sensor capabilities and a large dynamic range (electric field levels from 50 μV/m to 200 V/m). This analyzer has the ability of performing a frequency-selective maximum instantaneous field detection that allows capturing also fast, pulsed transmission patterns (like frequency-hopping operation of smart meters in typical installation conditions).

Figure 3-1
NARDA SRM-3006 analyzer utilized for the EM field measurements

Device under Test

To address the utility-specific character of this study, the tests were performed on three different smart meter models that have been or will be utilized in the CPS Energy service territory in San Antonio. The specific models that were chosen in these tests are shown in the Appendix B for residential installations, and C, D and E, for laboratory measurements.

Laboratory Environment Measurements

Tests were conducted in a laboratory environment by operating the meter radio transmitter both in the standard residential operation mode (characterized by short pulses separated by a period of inactivity and with transmission in a set of adjacent frequency channels) and in a continuous operation/single frequency mode, in order to generate a RF emission constantly at the maximum level, independent of any duty cycle. As it is discussed in Appendix G, the purpose of this continuous operation mode was to eliminate any ambiguity related to the detection of the short, aperiodic pulse transmission pattern and to provide a conservative estimate of the RF field level, without any time averaging.

Residential Installation Measurements

Measurements were performed in the actual area of deployment, on three customer installations in residential areas (single-family homes) chosen within the San Antonio, Texas city limits. These residences are part of a CPS Energy pilot program implemented on a volunteer basis.

The measurements refer to three single-family homes in different neighborhoods. All the meters were of the same make and model and had identical factory setup. The meters were in the standard, mesh-network operation mode as installed by CPS. Therefore, the measurements represent a realistic scenario of RF exposure.

In these conditions, in practice, the radio transmitter in the meter is being activated for a short pulse every few tens of seconds (variable with the surrounding conditions of the mesh-network interconnection). This mode can be programmed and does not reflect any particular standard; it mainly relates to the amount of data that are being transmitted and whether or not the meter is used as “bridge” to convey information from other meters in nearby residences to the concentrator receiving node.

4
RESULTS

Measurement Results

Measurements in Residential Installations - Smart meter installations in three single-family homes were tested. The details of each set of measurements (one for each separate residence) are presented in Appendix B. The measurements were conducted by recording the maximum instantaneous level of the RF emissions, regardless of the duty cycle, pulse sequence and frequency hopping pattern. Thus these results can be used as a representation of a maximum RF field to which anyone could be exposed.

The results are summarized in Figure 4-1, where an average of the measurements over all three residential locations is reported. This averaging partially compensates for the inaccuracies that derive from the measuring process, such as errors of positioning, antenna orientation, and stray reflections.

In comparing with the ICNIRP guidelines, one must consider that the values in the standard are referred to a root-mean-squared (RMS) emission averaged over six-minute period of time. In the present study, conservatively, the maximum instantaneous RF power density levels are measured and utilized to compare with of ICNIRP reference levels.

Laboratory Measurements - Three different AMI meter models were tested in a laboratory setup. The meters were operated both in the standard mode for residential installations and in a special test mode that allowed them to operate continuously on a single frequency. A custom fixture (Figure 4-2) reproducing conditions similar to those for residential installations was utilized. The meters were inserted in a standard metal socket enclosure, as it is utilized in residential installations.

The details of the measurements for the three different meters are presented in Appendixes C, D, and E, respectively for the Landis & Gyr, Silver Spring, and Consert-GE models. The first two meters are both operating at a RF power level of 1 W and are generating comparable emission levels (small differences being related to the antennas). The third model, Consert-GE, can operate up to at a maximum RF power of 0.25 W and has a similar antenna pattern as the previous two, thus resulting in lower emission levels.

x	y	z	% ICNIRP Power Density
-0.1	0	0	14.05
0	0	0.2	13.12
0.1	0	0	23.16
-0.4	0	0	0.77
0	0	0.5	3.62
0.4	0	0	1.16
-0.6	0	0	0.2
0	0	0.7	1.73
0.6	0	0	0.58
0	-0.4	0	1.66
0	0.4	0	2.69
-1.1	0	0	0.19
0	0	1.2	0.7
1.1	0	0	0.07
-1.7	0	0	0.04
0	0	1.8	0.61
1.7	0	0	0.03
0	-0.7	-0.3	0.17
0	-0.3	-0.3	0.21
0	0	-0.3	0.31
0	0.3	-0.3	0.13
0	0	-1.3	0.04
0	0	-1.8	0.03

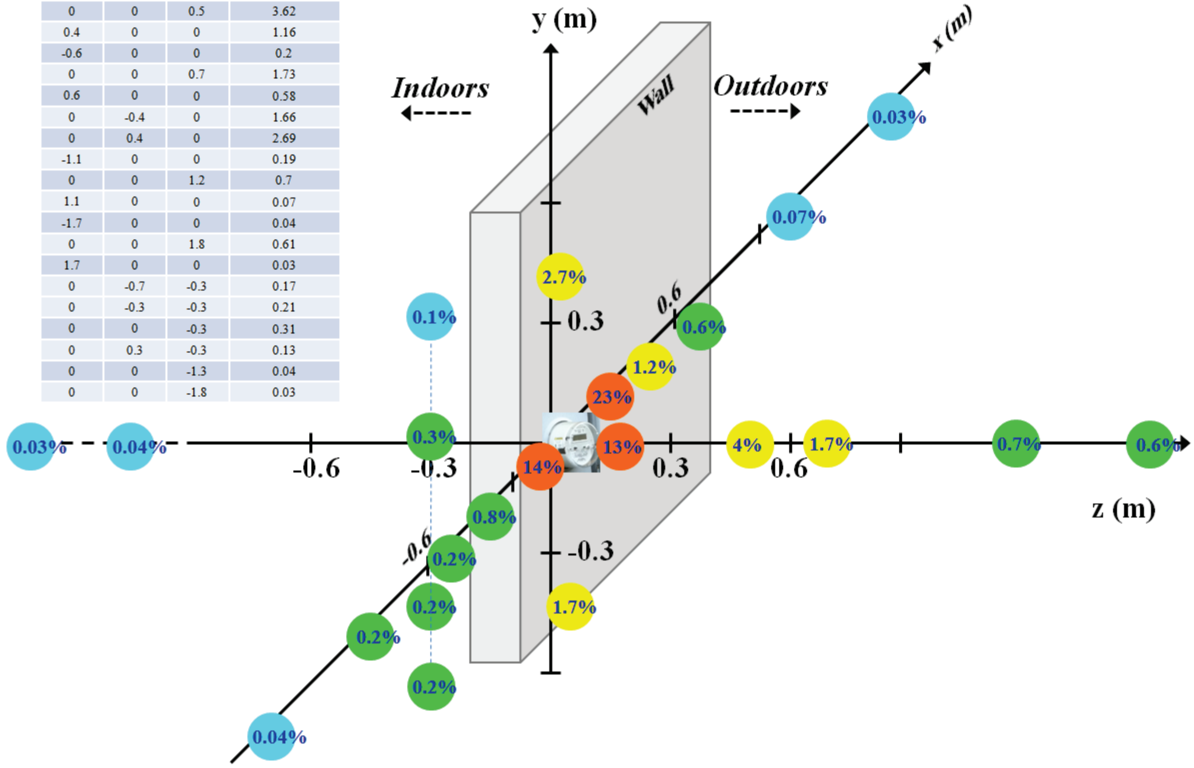

Figure 4-1
Smart Meter RF emissions averaged over the measurements in three different residential locations

The measured maximum RF power density levels are shown as a percentage of the reference level in the ICNIRP standard [3]. Three different level ranges are shown color-coded: blue for equal or less than 0.1%, green between 0.1% and 1%, yellow between 1% and 10%, and orange for more than 10% and less than 30%.

Figure 4-2
Laboratory setup utilized for testing the RF emission from different meter models

The setup is shown with all three meters installed; tests were actually performed with one meter at the time.

A summary of the laboratory results obtained for the Landis & Gyr meter in continuous transmission mode is shown in Figure 4-3. Similar emission levels were found for Silver Spring meter as well (details are found in the Appendixes C and D). All the emissions from the Consert-GE meters are well below the levels in Figure 4-3. The figure is a qualitative drawing of a color filled-contour map based on the measured data. The data are collected in a set of positions, and the measured levels are color-coded; then a qualitative drawing is produced by encircling the values within the same color band.

The contour map is referred to a horizontal cross-section, at the same elevation above ground as the meter, as sketched in Figure 4-4. Measurements were also performed in few positions at different elevations, and it has been verified that the field levels are always less than the corresponding ones measured in the horizontal plane at the same elevation as the meter (the plane here shown).

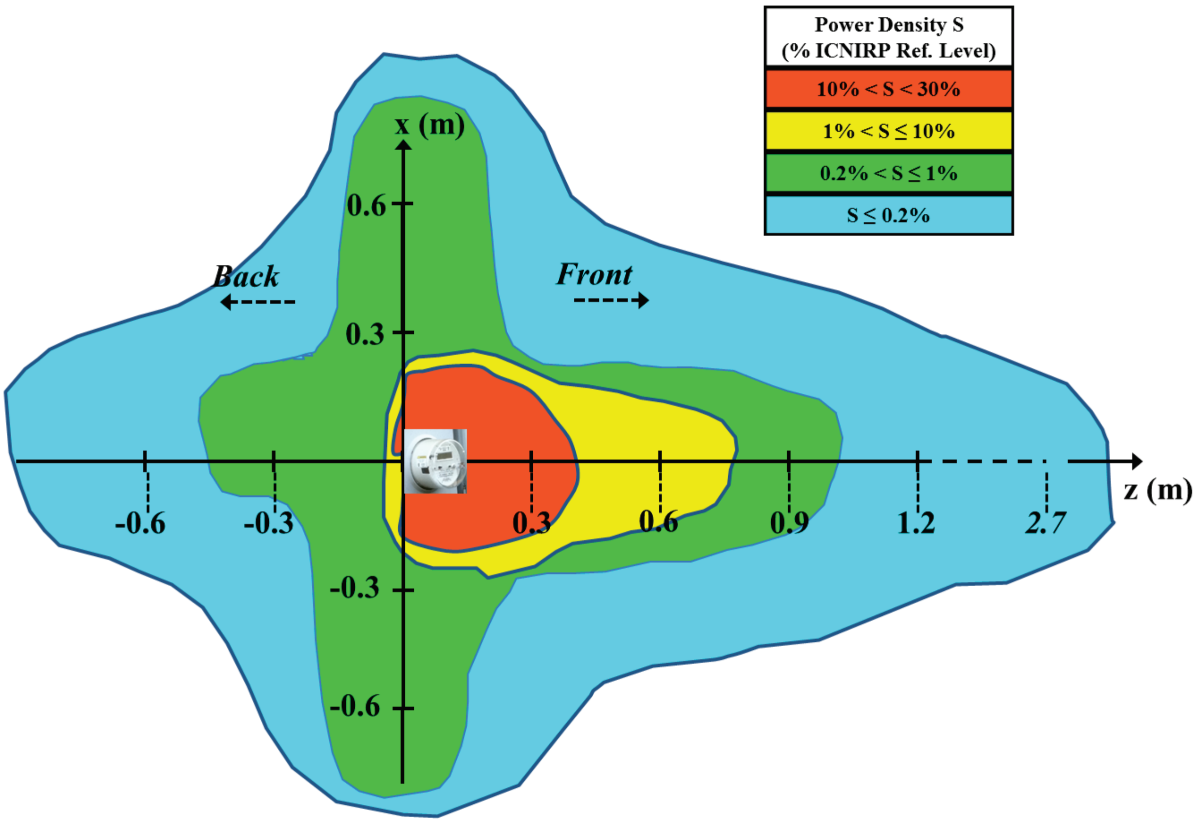

Figure 4-3
Qualitative drawing of a color map from the data in Figure C-2 in Appendix C.

The map is a qualitative representation of the actual measured data of the RF power density level for a Landis and Gyr meter model operated in continuous RF emission mode at the fixed frequency of 902 MHz. The measured RF power density level is expressed as % of the ICNIRP international standard reference level [3].

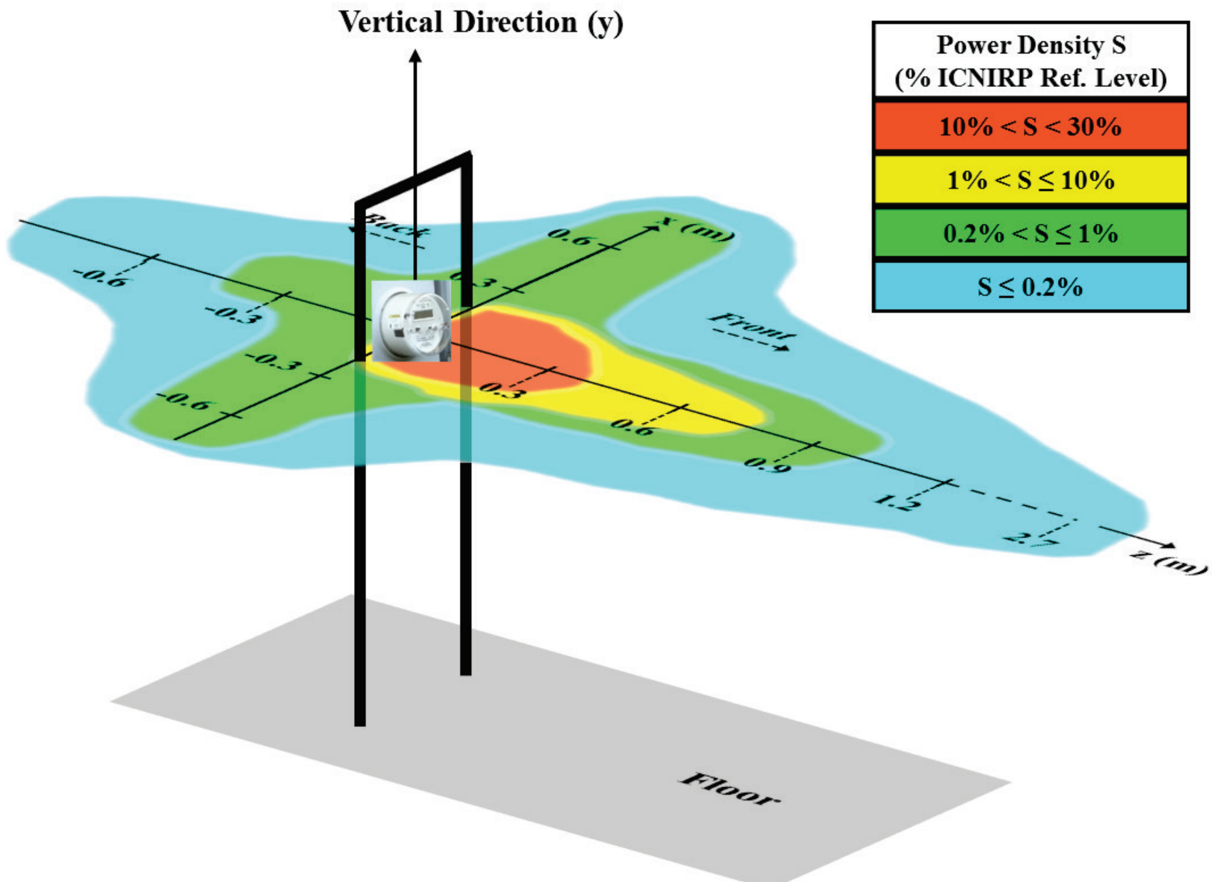

Figure 4-4
Frame of reference for the drawing of Figure 4-3, referring to the data in Figure C-2 in Appendix C.

Data Accuracy and Validation

Error Analysis - An error analysis on the measurement data that have been presented needs to address the accuracy of two fundamental physical quantities: the EM field level and the position where the field is measured. For the objectives of this study, this analysis is providing the levels of confidence for the measurements that have been presented.

Ultimately, the safety considerations are made on the basis of the reference levels published in the ICNIRP standard. These levels are considered as safety guidelines, with a safety margin derived from specific studies on verified thermal effects occurring during exposure to RF fields in animal experiments.

These considerations point to the fact that the safety thresholds themselves are affected by tolerances that are even harder to quantify.

Positional Errors - The positional errors are related to the determination of the probe location; this was always referred to the surface of the NARDA SRM-3006 analyzer spherical probe (Figure 3-1), expressed as distance from the front surface of the smart meter enclosure.

Table 4-1
Positional Error Determination

The same RF Electric Field measurement are repeated four times by moving the analyzer probe and then placing it back in the same position, as determined by a laser distance measurer tool.

Repeated Measurements at 0.454 m Distance	Measured Max. Electric Field (V/m)
1^{st}	16.0
2^{nd}	15.6
3^{rd}	15.1
4^{th}	15.0
Average	15.425
Maximum Deviation	0.575
Maximum Error	3.7%

All the measurements were, for the most part, executed with a laser distance measurer tool, with a precision down to the millimeter range. The actual errors were mainly due to the hand positioning of the tool near the probe (estimated better than 1 cm accuracy) and of the probe small angular misalignments.

To capture the overall effect of these positional errors, the same measurement of the electric field was repeated four times by moving the tripod-mounted probe away from the established location and then placing it back in a position determined by using the laser distance measurer tool (no ground marks were utilized). The results are shown in Table 4-1; the maximum error is 3.7%, and will be considered as approximated to 4%.

RF Field Errors - The determination of the field values is affected by several potential sources of errors; for the type of tests that have been performed, the most important are:

- Far-field conditions uncertainty
- Stability of the RF source and other random fluctuations due to the environment
- Multiple RF reflection paths
- Antenna gain pattern

Table 4-2
Potential Impact of Ground Paths Preliminary Estimates

Measurements at the same horizontal distance are repeated with the smart meter placed at two different elevations (about 5 and 6 feet), with respect to the ground level. The values in italic font are interpolated.

Horizontal Distance (m)		**Measured** Maximum Instantaneous Electric Field (V/m)			
	Elevation 1.5 m	**Elevation** 1.8 m	**Average**	**Variation from Average**	**% Error**
0.454	16	12.4	14.2	1.8	12.6%
1.4	*5*	5.7	5.35	0.35	6.5%
2	*4*	4	4	0	0
2.7	2.6	3.8	3.2	0.6	19%
3.5	1.5	2.5	2	0.5	25%
Average Error					12%
Maximum Error					25%

The far-field conditions are relatively well established except for the locations immediately close to the meter enclosure (a detailed discussion is presented in Appendix A). The near-field boundary is formally set to that distance where the phase errors become less than 22.5 degrees, corresponding to a 1/16 of the wavelength [1]. Thus, assuming the case of a measurement at the near-field boundary (that yields the largest phase error), there will be a 22.5-degree phase difference between the contributions to the field from the two extremities of the antenna (the locations on the antenna that are further apart).

A detailed calculation of the EM field pattern in the near field region is not relevant for the scope of this analysis; an approximate estimate of the error upper limit is presented in Appendix A and yields a field error of 3%, at the considered distance corresponding to the near field boundary.

The source stability is reflected in the fluctuations of the measured field level. The measurements have been performed with a sufficient "dwelling time" (about a minute) enough to observe a stable value of the maximum field. Therefore, the maximum RF emission scenario (the maximum field due to the RF fluctuations) is always considered, and this source of error is not a factor for the results that have been presented.

The reflection paths were minimized by performing the test in a relatively open area. The effect of possible ground path was tested by collecting data with the meter at two different elevations (as it could be the case in actual residential installations). The results are shown in Table 4-2) and show an average error of 12%.

The errors due to the antenna pattern are different in nature because they do not affect the accuracy of the actual electric field measurement, but they may cause an underestimation of the maximum field level that can be found in the region surrounding the antenna. These errors will be considered separately for the "closest" and the "typical" exposure conditions (the "typical exposure region", following the discussion in Section 3, is considered at about one meter distance from the source).

To account for these variations, a manual scan of the electric field amplitude was performed at selected radial distances. These estimates are valid within few wavelengths from the antenna, which is a distance within the estimated typical range of exposure, in the order of about one meter from the antenna. In all these cases, it was confirmed that the measurements directly in front of the meter yield the maximum RF emission level. From the antenna pattern manufacturer's data, positioning errors within a 30 degrees span from the antenna main axis yield a gain variation less than 0.5 dB, which correspond to field errors less than 6%.

For measurement in locations close to the antenna, the RF electric field level becomes very sensitive to small angular variations of probe position (both in azimuth and elevation, examples for the antenna patterns of the smart meters under tests are shown in Appendix D and E). Thus, close to the smart meter enclosure, that is closer to the near-field zone, larger variations are expected.

Higher resolution scans of the emission levels right on the surface of the enclosure were performed for the Landis & Gyr and Silver Spring meters and reported in Appendix C and D; for these cases, the approximate maximum electric field level variations from the average, over the region near the meter enclosure, were estimated at about 31% and 10%, respectively.

Overall Error Assessment - An estimate of the total error can be done based on the different error sources that have been considered: because the different errors are due to statistically independent variations, the different error terms are added to compute the total RMS error.

For a near exposure to the smart meter (the maximum RF emission scenario), relevant sources of error are those related to the far-field conditions assumptions (estimated at 3%) and those due the antenna pattern (estimated up to 31%, close to the near field region), thus the RMS error is still about in the 30% range.

For a typical exposure scenario, where a distance in the order of 1 meter from the source is considered, the relevant errors are the multiple RF reflection paths (estimated at 12%), the antenna gain pattern (estimated at 6%) and the positional errors (4%). The combined RMS total error is then about 14%.

Data Validation - The instrument utilized for the data collection is a widely used, high-end RF analyzer (NARDA SRM-3006, described in Section 3) provided with a current calibration certificate. Nevertheless, as a further check of the reliability of the results, an independent verification of the field levels was performed. This is particularly significant for the measurements of the field near the meter enclosures, where the uncertainty is larger.

A first data-consistency check was obtained by successfully comparing the RF analyzer measurements with the predictions of the field profile from an isotropic radiator (Appendix C and D).

A simple test was also performed by utilizing a near-field probe, essentially a quarter-wavelength monopole antenna, consisting of a small conductor connected to a shielded cable. The advantage of the near-field probe is the minimal perturbation of the field conditions and the relatively precise sampling of the field in a particular location.

The shielded cable was connected to a spectrum analyzer set for time-domain equivalent power measurements (in *dBm*) at the selected frequency (thus set in a zero-scan mode). Because this is a relative measurement, the actual absolute values of the field measured by the near-field probe-antenna are not important.

The test was conducted with the L&G smart meter (as utilized for the results in Appendix B) by measuring the power level at different distances from the source, plotting the corresponding field profile versus distance, and comparing it with the similar profile obtained from the NARDA analyzer readings in the same positions.

If the NARDA analyzer was being affected by near-field errors, then the two measurements would diverge as the location was getting closer to the source: the data were collected all the way to the surface of the meter, where the highest values of the electric field have been measured.

The results are shown in Figure 4-5. A very good agreement was obtained between the voltage profile on the probe, proportional to the local electric field (red trace labeled "V_{probe}") and the electric field from the NARDA analyzer (labeled "E", blue trace). The far-field profile (labeled "1/x", green trace) is also plotted, showing the expected inverse-distance dependence and a good agreement with the measurements as well.

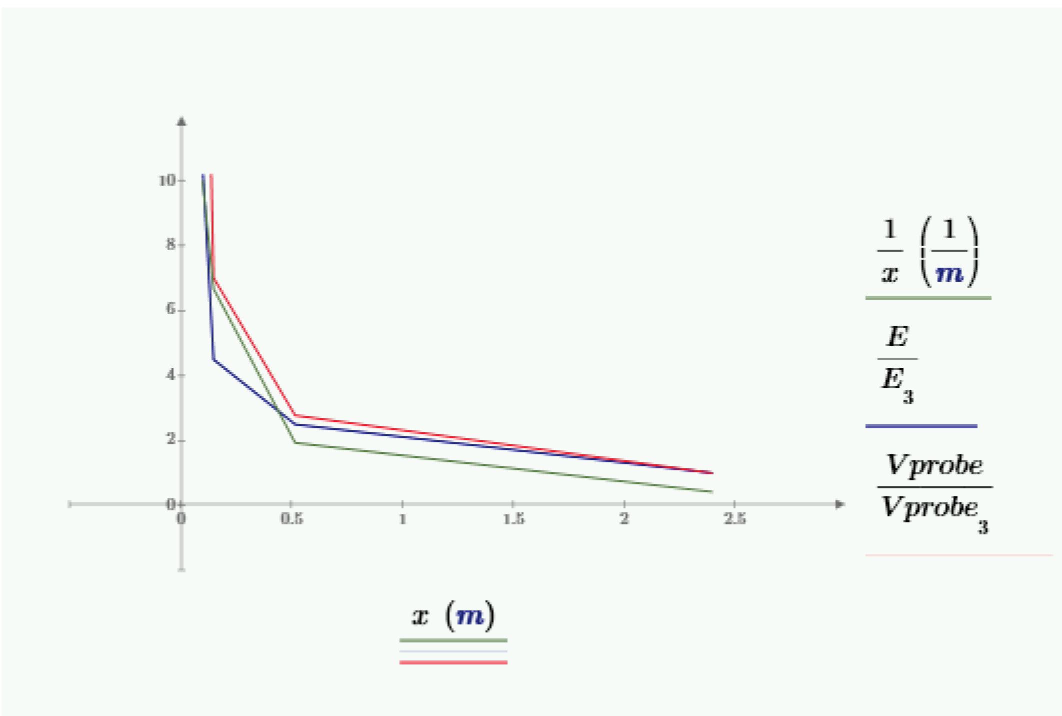

Figure 4-5
Comparison between a small, near-field electric field probe and the calibrated RF analyzer

The measurements and the expected far-field inverse-distance profile are in good agreement, indicating the reliabilitly of the measurements perfomed all the way up to the surface of the meter enclosure

5 CONCLUSIONS

Three different smart meter models currently utilized or planned for installation in the CPS Energy service territory in San Antonio, Texas, were tested to measure the RF emissions generated by the radio transmitter in the smart meter that provides a two-way communication link between a residence and the utility company. The purpose of the study is to obtain an accurate characterization of these emissions and to benchmark these levels against established exposure standards and guidelines.

While the results of this report have a fairly general relevance in the context of current AMI technology development, the data have been collected with a particular focus on the CPS Energy meter deployment: measurements of smart meter RF emissions were performed in installations in San Antonio, and extensive laboratory tests were conducted to cover all the different models that are currently in the CPS Energy smart meter pool.

A further safety margin was introduced in the choice of the data-collection methodology in that the smart meter typical time utilization pattern (a low "duty cycle" consisting typically in very short pulses followed by a long period of inactivity) was not factored in as a mitigating factor to ameliorate the impact of the RF exposure level. This is meant to provide consumers' confidence in the CPS Energy safety-oriented approach: the data presented here are referring to the instantaneous maximum RF power density that can be measured in all possible exposure conditions, from the physical contact with the meter to locations further away. For a more realistic exposure assessment, an additional significant reduction of the average power level should be considered by taking into account the effective duty cycle resulting for any particular meter installation.

The findings of this investigation show that the CPS Energy smart meters that have been tested generate RF emissions field levels that:

- For any possible exposure conditions produce instantaneous power density levels always less than 30% of the reference levels specified by the ICNIRP safety guideline.
- For typical consumer exposures in residential settings, exposure levels are one order of magnitude less, or lower, than the ICNIRP reference limits. These results are also consistent with previous similar studies.
- Are lower, in terms of combined exposure time and RF power density level, than a variety of common devices that generate RF fields.

6
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A
INSTRUMENTATION AND FIELD REGIONS

Basic Terminology

In this study, standard terms have been used to define the details of measurement data that have been introduced. For sake of clarity, a brief summary is here presented.

- **EM field.** In a region of space an EM field is said to be present if forces of EM origin can manifest on an electric charge. In general, the "field" is fundamental concept in physics and relates to how the known fundamental forces in nature are able to act and propagate energy through space. The EM field exists regardless of the presence of a detector in a particular location (and, in general, is perturbed by the detector presence itself, albeit typically by a small amount) .

- **Electromagnetic (EM) Emissions.** An EM field is always associated with energy. "EM Emissions" refer to the generation and propagation of electromagnetic fields and thus of EM energy. EM emissions are describing the process of the EM field being generated where there was none before and of a wave of EM energy being formed (or EM wave) that moves from its source and travels through space at the speed of light.

- **EM radiation. "**Radiation" refers to the actual EM energy being sent away, radiated as a wave. While used almost interchangeably, technically, it is different from "emission" in the sense that it refers to the EM energy that actually leaves the source region unlike, for example, the energy in the induction field generated near a magnetic coil. Typically, the terminology "EM radiation" is used in reference to the emissions from antennas.

- **RF (Radio-Frequency). "**Radio-frequency" is that frequency range of EM waves that is typically used in radio communications (typically as low as the 100 kHz range). Thus "RF emission" or "RF radiation" is just a short for "EM emission in the radio frequency range".

Near Field and Far Field Conditions

In this study, the EM field has been measured up to the closest accessible region to the antenna (that is on the smart meter protective enclosure) in order to characterize the locations where the highest emission levels may be detected.

Typically, the field "very close" to the transmitting antenna (the *near field* region, [1]) has a more complex pattern than that found further away (in the *far field* region [*ibid*.]), because the magnetic and electric components of the wave are not linked by a constant proportionality factor (the wave impedance), and the reactive character of the electric and magnetic fields is dominant over the radiative EM field typical of a propagating wave.

Measuring the EM fields in the far-field region simplifies the determination of the power density from the electric field level, because an independent determination of the magnetic component of the wave (typically more difficult at higher frequencies) is not required.

On the other hand, in the near field region, the electric and magnetic components of the wave need to be determined independently; furthermore, the field intensity is strongly dependent on the position with respect the antenna surface. Thus a measurement close to the antenna needs be done through a careful scanning, because the field amplitude can change significantly with small changes of the measuring probe position. The choice of the probe itself is also important: the measuring probe (a receiving antenna) should be small enough so that perturbations of the transmitting field are minimized and reflections avoided.

In order to get a quantitative assessment for the scenario that is being tested, the basic parameters to be considered are the size of the antenna compared to the transmitting wavelength, the distance from the antenna where the measurements are performed, and the size of the receiving probe.

The analysis of the near field conditions can be simplified by referring to a small dipole antenna [*ibid.*], with dimensions much smaller than the wavelength. In this case, the near field outer boundary can be set at distance of $\lambda/2\pi$ from the antenna λ. For distances further away, the radiating EM wave pattern begins to form (in conditions where the size of the antenna is larger than the wavelength, this transition has a somewhat more complex character).

For distances close to the near field boundary, errors may be introduced if a field distribution that follows the far-field antenna pattern was assumed. An approximate estimate of this error can be computed for the purpose to this analysis without resorting to the exact solution of the EM field generated by the antenna. This result is used in Section 4 for the estimate of the overall error on the measurement data.

By assuming that the smart meter antenna is about a quarter-wavelength long (≈8 cm corresponding to a 900 MHz frequency, λ=33 cm, for this case) the sinusoidal current distribution along the antenna will be approximated by four equal segments of $\lambda/16\approx2$ cm length, with a constant current along each segment.

For reference, it is considered that the contribution to the total EM field (the electric field component, for instance) in the chosen observation point due to one of the four segments is equal to one (E_1=1, in arbitrary units) when the current is at the peak (zero phase angle, since cos(0)=1). Thus, if there were a negligible phase difference among the contributions of the four segments of the antenna, the total field would be close to four (E_{tot}=4, same arbitrary units).

If, instead, there is a phase error as large as 22.5 degrees, only the first segment will contribute to the field at the peak current level: E_1=1. The fourth segment will have a current equal to cos(22.5) ≈0.92, and the other two segments in between will have currents equal to cos(22.5/3) ≈0.99 and cos(22.5·2/3) ≈0.97. Thus the total field will proportionally be smaller, equal to $E_{tot}= E_1+ E_2 +E_3 +E_4=1+0.99+0.97+0.92=3.88$.

Compared to the case with no phase error (E_{tot}=4), the error is then (4-3.88)/4≈3%. This is the error that is expected for using the far-field assumption in proximity of the near-field boundary.

Application to the Smart Meter Testing

As it was mentioned, the AMI meters that are being tested operate in the 900 MHz frequency band, corresponding to a wavelength $\lambda=c/f_0=33$ cm. The largest dimension of the printed circuit board (PCB) antenna of the meter transmitter is (approximately) D=10 cm; thus for this particular setup D< λ.

In this condition, the antenna is technically considered *electrically short* (however, the dimensions of the antenna are still somewhat comparable with the wavelength, and for this reason the far-field conditions will be better approximated at larger distances). As previoulsy mentioned in this appendix, in reference to the small dipole approximation, the *near-field* outer boundary can be set at distance of $\lambda/2\pi\approx5$ cm from the antenna [1].

The Smart Meter antenna is a PCB element that is placed inside the meter, at approximately 10 cm from the edge of the protective case. The isotropic RF analyzer probe antenna (NARDA SRM-3006, in Figure 3-1) that has been utilized for these measurements has a spherical enclosure of approximately 5" (0.127 m) diameter.

Thus, the closest measurable distance from the source can be placed at about 16 cm, that is well past the 5 cm near-field region boundary, and all measurements are then considered outside of the near-field region.

For this reason, all the comparisons with the ICNIRP standards can be done only for the electric field component: the standard provides separate limits for the magnetic field as well, but in this case the measurement of the smart meter emissions electric field can provide the magnetic component as well through a simple proportionality factor.

B
MEASUREMENTS IN RESIDENTIAL INSTALLATIONS

Data on smart meter*s* emissions were collected in three different locations in the CPS service territory in San Antonio, Texas. The measurements refer to three single-family homes in different neighborhoods. All the meters were of the same make and model (Landis & Gyr, shown in Figure B-1) and had identical setup, with a nominal maximum RF power set to 1 W.

Figure B-1
Landis+Gyr Gridstream smart meter utilized in the test, as installed in the CPS energy residential pilot project.

The measurements corresponding to three residential locations are reported in Tables B-1, B-2, and B-3. The frame of reference for the spatial coordinates is shown in Figure B-2.

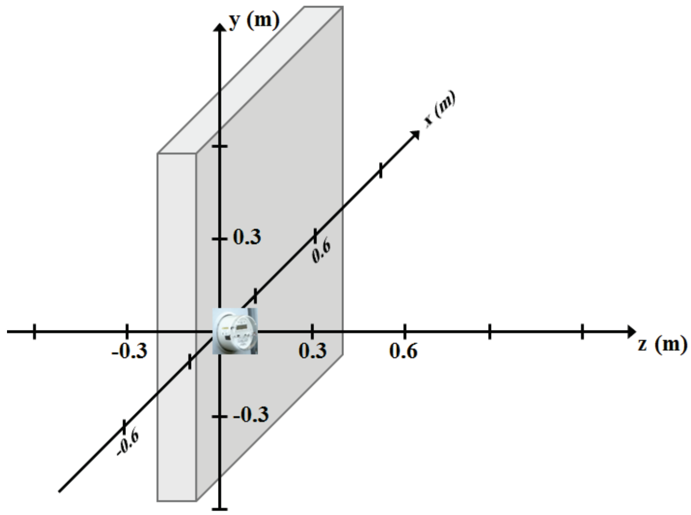


Figure B-2
Frame of reference for the spatial coordinate system utilized in the measurements.

Table B-1
Residence 1 data (*Hollow Circle* Location)

Measurement	x (m)	y (m)	z (m)	E-field (V/m)
1	-0.1	0	0	17.3
2	0	0	0.2	15.6
3	0.1	0	0	17.3
4	-0.4	0	0	6.7
5	0	0	0.5	10
6	-0.4	0	0	6.9
7	0	0	0.7	8
8	0	-0.7	-0.3	2.4
9	0	0	-0.3	4.4
10	0	1.6	-0.3	1.6
11	0	0	-1.3	1.2
12	0	0	-2.3	0.8
13	0	0	-3.1	0.5

An example of the measurement setup is shown in Figure B-3 for an outdoors location and in Figure B-4 for an indoor location (chosen in correspondence to the meter box position, that was located outside, on the opposite side of the wall).

A synoptic qualitative drawing from the average of the measurements taken over all the three residences is shown in Figure 4-1, in Section 4 of this report.

Figure B-3
Measurements near the meter in a residential installation

Figure B-4
Indoor measurements in a location corresponding to the position of the meter box installation.

Table B-2
Residence 2 Data (*Centro Grande St.* Location)

Measurement	x (m)	y (m)	z (m)	E-field (V/m)
1	-0.1	0	0	23
2	0	0	0.2	25.1
3	0.1	0	0	39.6
4	-0.4	0	0	4
5	0	0	0.5	13.2
6	-0.4	0	0	5.6
7	-0.6	0	0	2.6
8	0	0	0.7	8.6
9	0.6	0	0.	2.8
10	0	-0.4	0.	6.4
11	0	0.4	0.	11.3
12	-1.1	0	0	1.6
13	0	0	1.2	5.6
14	1.1	0	0	1.2
15	-1.7	0	0	1.3
16	0	0	1.8	4.6
17	1.7	0	0	1
18	0	-0.3	-0.3	3.1
19	0	0.	-0.3	1.6
20	0	0.3	-0.3	2.3
21	0	0	-1.3	1.3
22	0	0	-1.8	1.2
23	0	0	-2.3	1.1

Table B-3
Residence 3 Data (*Everton St.* Location)

Measurement	x (m)	y (m)	z (m)	E-field (V/m)
1	-0.1	0	0	25
2	0	0	0.2	22
3	0.1	0	0	23
4	-0.4	0	0	4.3
5	0	0	0.5	10
6	-0.4	0	0	6.4
7	-0.6	0	0	2.6
8	0	0	0.7	6.4
9	0.6	0	0.	5.7
10	0	-0.4	0.	8.6
11	0	0.4	0.	7.6
12	-1.1	0	0	3.2
13	0	0	1.2	4.1
14	1.1	0	0	1.7
15	1.7	0	0	1.2
16	0	-0.3	-0.3	2.2
17	0	0.	-0.3	3.1
18	0	0.3	-0.3	1.9
19	0	0	-1.3	1.3
20	0	0	-1.8	1
21	0	0	-2.3	1

C

LABORATORY TEST: LANDIS & GYR METER IN CONTINUOUS TRANSMISSION MODE

A Landis+Gyr *Gridstream* model (Figure C-1) was tested in a laboratory setup with a continuous transmission mode at 902 MHz and 1 W of RF power.

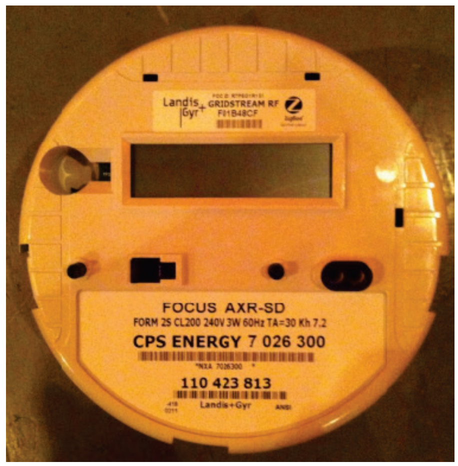


Figure C-1
Landis & Gyr *Gridstream* meter utilized in the laboratory test

The RF power density emissions measured on a horizontal plane at the meter elevation are illustrated in Figure C-2, with the orientation as shown in the figure inset.

As expected, the field is more intense in the region surrounding the protective case (the antenna is located on the printed circuit board immediately under the face plate. A value of about 50% of the equivalent ICNIRP reference level is measured right in front of the meter, in contact with the protective case.

The consistency of the measurements with the expected *1/r* dependence in the far-field (for the electric field) is shown in Figure C-3 for a series of values measured directly on the axis in front of the meter. The curve labeled “1/r” is derived by imposing the matching in one arbitrary point along the “z” coordinate. It was verified that the choice of this point is not critical and is not affecting the overall good level of matching between the two curves.

By expressing these results in terms of the electric field limits prescribed by the ICNIRP, the outlook changes considerably, because the power density is proportional to the square of the electric field (in far-field conditions), and falls off as $1/r^2$. Figure C-4 is the equivalent of Figure C-2 but is showing a map of the instantaneous maximum electric field.

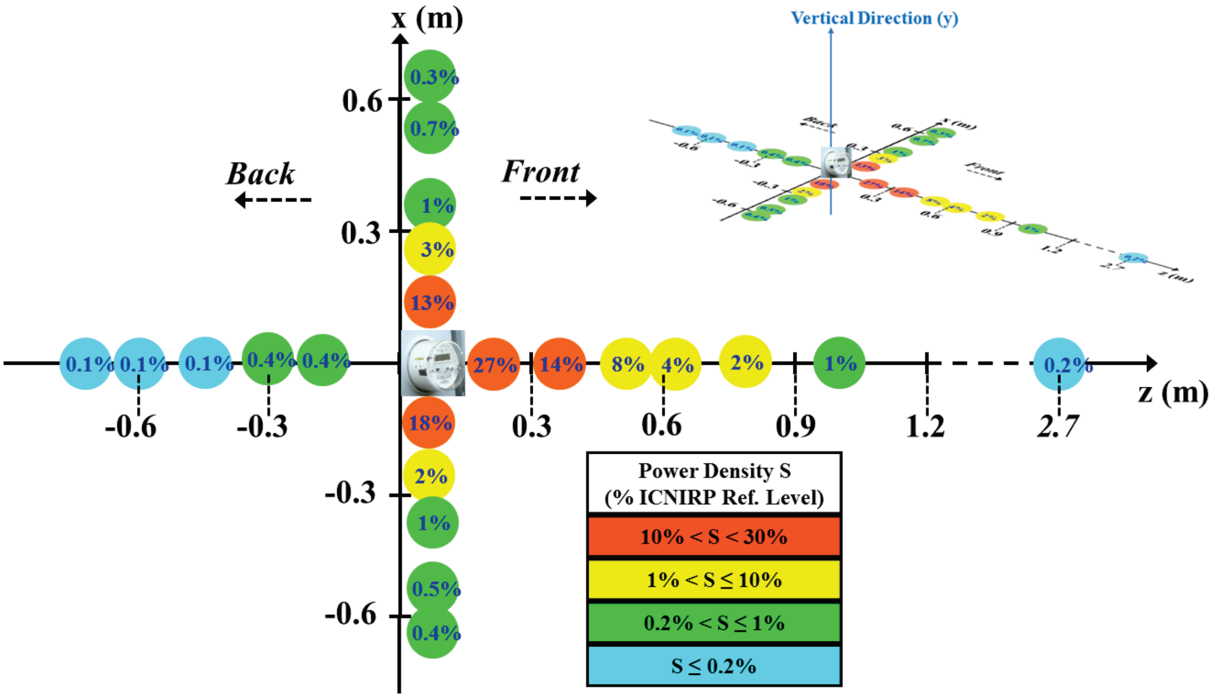


Figure C-2
RF power density measurements in the horizontal plane at the meter elevation for a Landis+Gyr meter in continuous operation at the maximum nominal RF power (1 W)

The power density measurements are expressed as a percentage of the corresponding reference level in the ICNRIP standard.

If the field is measured even 30 or 50 cm away from the meter, the pattern is fairly regular and no sudden variations have been determined (consistent with the typical antenna pattern utilized, similar, for example, to that shown in Figures D-5 and D-6).

However, as discussed in the Appendix A, significant variations of the field measurements are expected in close proximity of the antenna, due both to the size of the measuring probe (comparable with the wavelength) and to the fact that the probe itself is closer to the near field region.

In this case, the measure of the electric field is still fairly accurate, but a careful scanning of the region surrounding the meter needs to be performed in order to identify the possible locations where the electric field reaches a highest level.

The Figure C-5 shows the result of this panning measurement approach where a maximum instantaneous electric field corresponding to an RMS value of 39 V/m was detected, equivalent 96% of the corresponding ICNIRP reference level.

This represents the maximum level that could be detected, although it is located in a position that realistically is of no concern in terms of exposure in “normal” utilization and installation patterns (to achieve this level of exposure, a prolonged physical contact in that particular location of the protective case under the meter would be required).

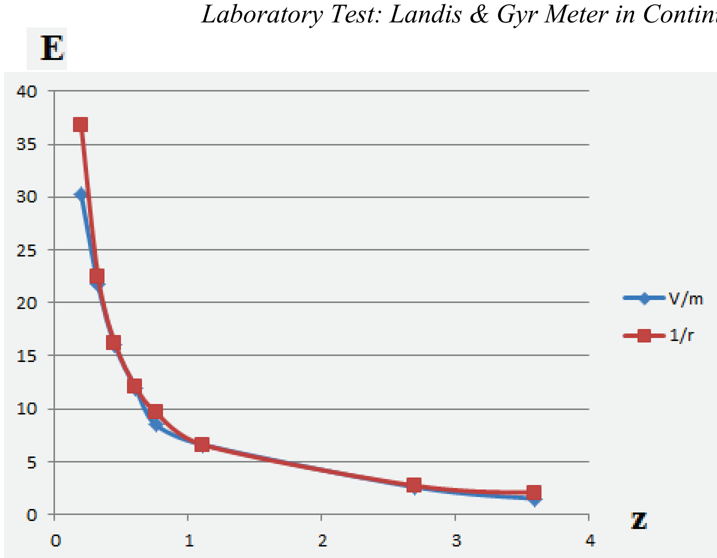


Figure C-3
Measured the electric field E (in V/m, blue curve) vs. the "z" coordinate (in m)

The electric field profile follows the "1/r" variation with the distance expected for the radiated field outside the near field region (red curve).

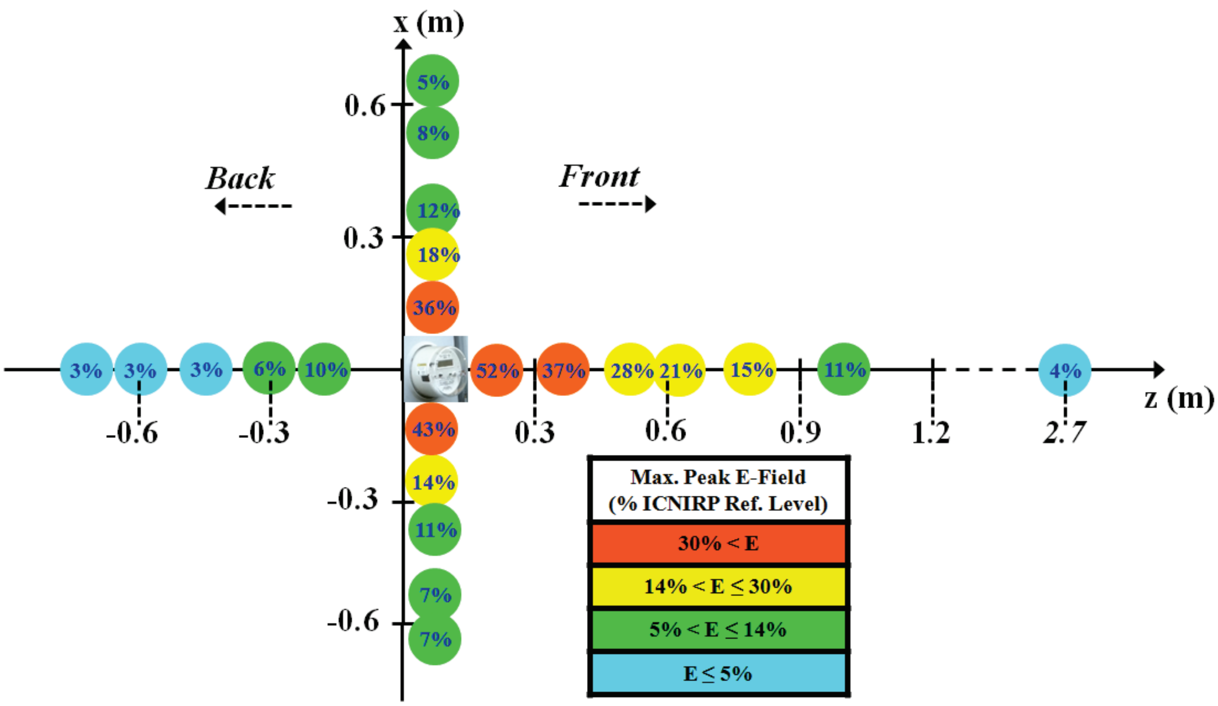


Figure C-4

RF maximum instantaneous electric field from measurements in the horizontal plane at the meter elevation for a Landis & Gyr meter in continuous operation

The values are expressed as a percentage of the corresponding electric field reference level in the ICNRIP standard.

Figure C-5
Maximum detected value of the electric field in the vicinity of the meter.

The indicated maximum value of 56.47 V/m, corresponding to an RMS value of 39.5 V/m, or 96% of the ICNIRP corresponding limit value, was found in the precision scanning of the region immediately surrounding the meter enclosure.

D

LABORATORY TEST: SILVER SPRING METER IN CONTINUOUS TRANSMISSION MODE

Test Setup

A Silver Spring Networks utility meter with a custom setup providing a continuous (100% duty cycle), single-frequency transmission mode was tested in the laboratory setup. The meter under test was a FOCUS AXR-SD (Figure D-1) with nominal RF output power of 30 dBm (1 W) at 915 MHz and inverted-F PCB, dual-polarization antenna. Radiation pattern details are provided in Figure D-5 and D-6 in this appendix.

The results collected with the RF analyzer were found in agreement (within small errors due to the positioning of the probe) with those for the standard residential operation mode characterized by short pulses separated by a period of inactivity and with transmission switching constantly through in a set of adjacent frequency channels ("frequency hopping").

As it is discussed in Section 3, the purpose of the continuous operation setup is to eliminate any ambiguity related to the detection of the short, aperiodic pulse transmission mode and to provide the most conservative estimate of the EM field transmission level, without reliance on any mitigation effect of a reduced duty cycle.

Figure D-1
FOCUS AXR-SD Silver Spring Networks utility meter utilized in the laboratory test.

Test Results

The measured RMS value corresponding to the maximum instantaneous electric field was E_{RMS}=19V/m, near the surface of the meter protective case. This value is less than half of the RMS level of 41 V/m recommended in the ICNIRP standard.

The typical exposure conditions, as discussed in Section 2, are more likely to occur at larger distances from the utility meter location. At 1 m from the source, the RMS electric field is about 3 V/m, less than an order of magnitude smaller than the ICNIRP guideline.

The maximum field that could be detected was with the sensor positioned in close proximity to the front cover of the meter. RMS values corresponding to the maximum instantaneous electric fields between 22 V/m and 27 V/m (46% of the corresponding ICNIRP level) were detected while scanning different positions near the surface of the meter enclosure (the larger values were found near the edge of meter face).

Figure D-2 shows an excellent agreement comparison between the measured data (red curve) and the theoretical *1/r* far-field dependence: a proportionality coefficient is computed by imposing the matching on the point furthest away from the meter. The maximum electric field instantaneous level measured in the front of the meter had a RMS corresponding value of 22.3 V/m, or 38% of the equivalent ICNIRP limit.

While operating in the single-frequency continuous operation mode, the transmitter power can be controlled by the operator. In this case, a test for data consistency was performed by decreasing the power in 3 dB steps from the 30 dBm level and measuring the electric field at a fixed position near the meter. The expectation is that the electric field values decrease proportionally to the square root of the power.

The correlations between power and measured electric field are presented in Table D-1 and Figure D-3. The figure shows satisfactory agreement with the theoretical expression (blue trace) of power computed from the electric field and an effective area A_{eff} derived by the measured values at the 1 W maximum power level.

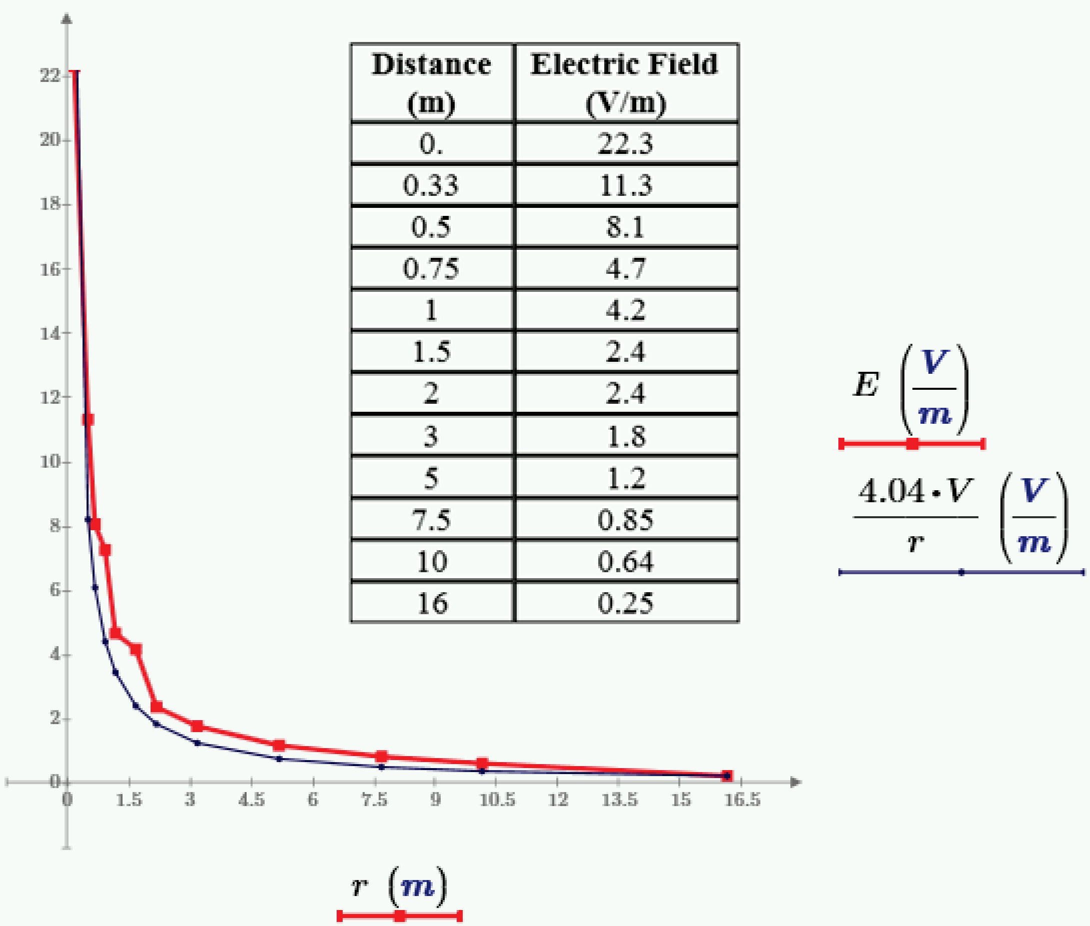
Measurements in the open environment were performed up to a distance of 16 meters from the source, with the setup shown in Figure D-4. The results are reported in Figure D-5 (the distance data in the plots include the 16 cm offset that corresponds to the minimum distance that can be reached between the antenna and the analyzer sensor, as discussed in Appendix A).

In summary, in the laboratory measurements on the Silver Spring smart meter, the highest value of the measured electric field yielded a corresponding RMS value of E_{RMS} =19 V/m, or about 50% of the reference level recommended in the ICNIRP standard. The corresponding average power density will then be S_{AV}=0.967 W/m^2 ≈ 1 W/m^2. This is less than one-fourth of the ICNIRP limit (4.575 W/m^2). It should be noted that this is just a value for a particular point in space where the emission level is the largest and overestimates (this providing a conservative safety margin) a real exposure absorbed by a person. The Table D-2 summarizes the comparison of the measured levels with available safety guidelines.

It should be emphasized again that the safety standards are actually referred to a cumulative (6 minutes for ICNIRP an 30 minutes for IEEE and FCC) exposure over time, while the measured values are just indicative on an instantaneous maximum pulse that does not take into account any duty-cycle.

As discussed in Section 1, typically, "common exposure" outdoors locations can be considered as placed at 1 m or further away from the utility meter.

By considering the maximum electric field measured at 1 m distance from the source, the corresponding RMS field is found to be ≈3 V/m, less than an order of magnitude compared with the 41 V/m level specified in the ICNIRP guidelines.



Distance (m)	Electric Field (V/m)
0.	22.3
0.33	11.3
0.5	8.1
0.75	4.7
1	4.2
1.5	2.4
2	2.4
3	1.8
5	1.2
7.5	0.85
10	0.64
16	0.25

Figure D-2
Measured electric field vs. distance (in red) and theoretical 1/r far-field dependence (in blue).

The 4.04 V coefficient in the 1/r plot is computed from the measured data to impose matching on the position furthest away (16 m). The value listed in the table are maximum fields (the corresponding RMS values are smaller by a factor of √2).

Table D-1
Correlation Between Trasmitter Power and Electric Field Measured in a Fixed Position Near the Meter

TX Power W (dBm)	Electric Field (V/m)
1.0 (30)	22.3
0.501 (27)	17
0.25 (24)	12.3
0.125 (21)	10
0.063 (18)	8
0.031 (15)	6

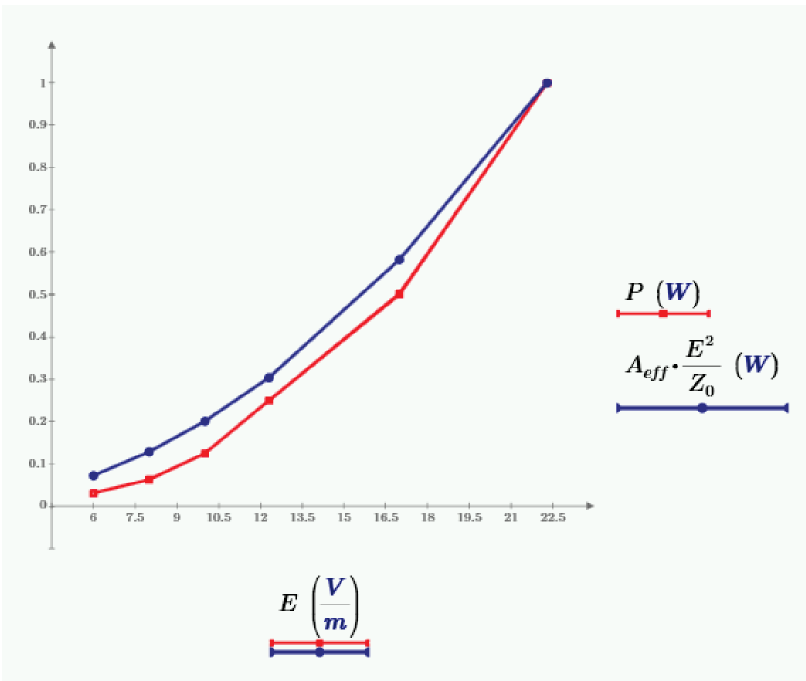


Figure D-3
Applied Power Vs. Measured Electric Field (in Red) and Theoretical Correlation Curve (in Blue)

Figure D-4
Measurements with the Silver Spring Meter in open-air test setup.

Table D-2
Comparison of measured RF power density and electric field levels from ICNIRP/IEEE and FCC safety guidelines

Quantity	Measured Maximum	IEEE/ICNIRP MPE	FCC MPE
S_{AV} (W/m^2)	1	4.575	6.1
E_{RMS} (V/m)	19	41	47.6

Data Consistency Check: Comparison with the Isotropic Transmitter Model

For an ideal isotropic radiator emitting a power P, the power density (power per unit area) at a radial distance r from the source is $S=P/4\pi r^2$.

At a P=1 W and a distance of r=16 cm, the power density will be $S=3.1\ W/m^2=0.31\ mW/cm^2$. The corresponding electric field amplitude, assuming the far-field conditions, is E=34.2 V/m.

The AMI meter is equipped with an inverted-F, dual polarization antenna. The antenna pattern characteristics as reported by the manufacturer are shown in Figure D-5 and D-6.

For a reference measurement with the analyzer antenna positioned in front of the meter, a zero degrees azimuth and elevation is considered. In this position, based on the data reported in Figures D-5 and D-6, the minimum attenuation due to the antenna pattern is approximately between 1 and 4 dB on the vertical polarization.

With a 4 dB antenna pattern attenuation, the source power level of 30 dBm (1 W) is reduced to 26 dBm (0.4 W), corresponding to an electric field of 21.6 V/m, while at 2 dB of attenuation, the power level becomes 28 dBm (0.63 W), which gives an electric field of 27 V/m.

It can then be concluded that, within the tolerances of experimental measurements (due to positioning, estimates of the antenna location, and provided data of the antenna pattern), the field level emissions based on a simple antenna theory model are consistent with the measured data, reporting fields between 22 V/m and 27 V/m.

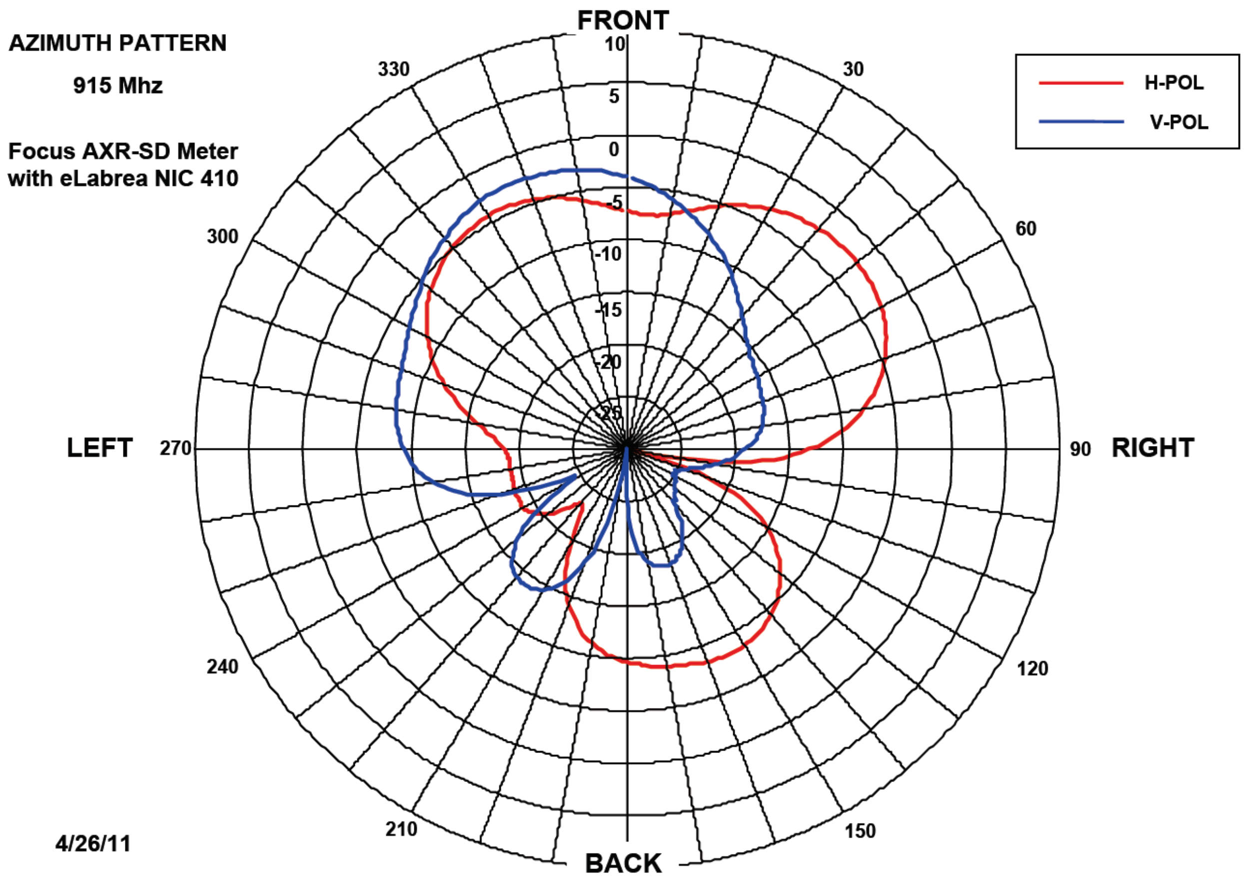


Figure D-5
FOCUS AXR-SD Silver Spring Networks manufacturer's data for the antenna azimuth pattern.

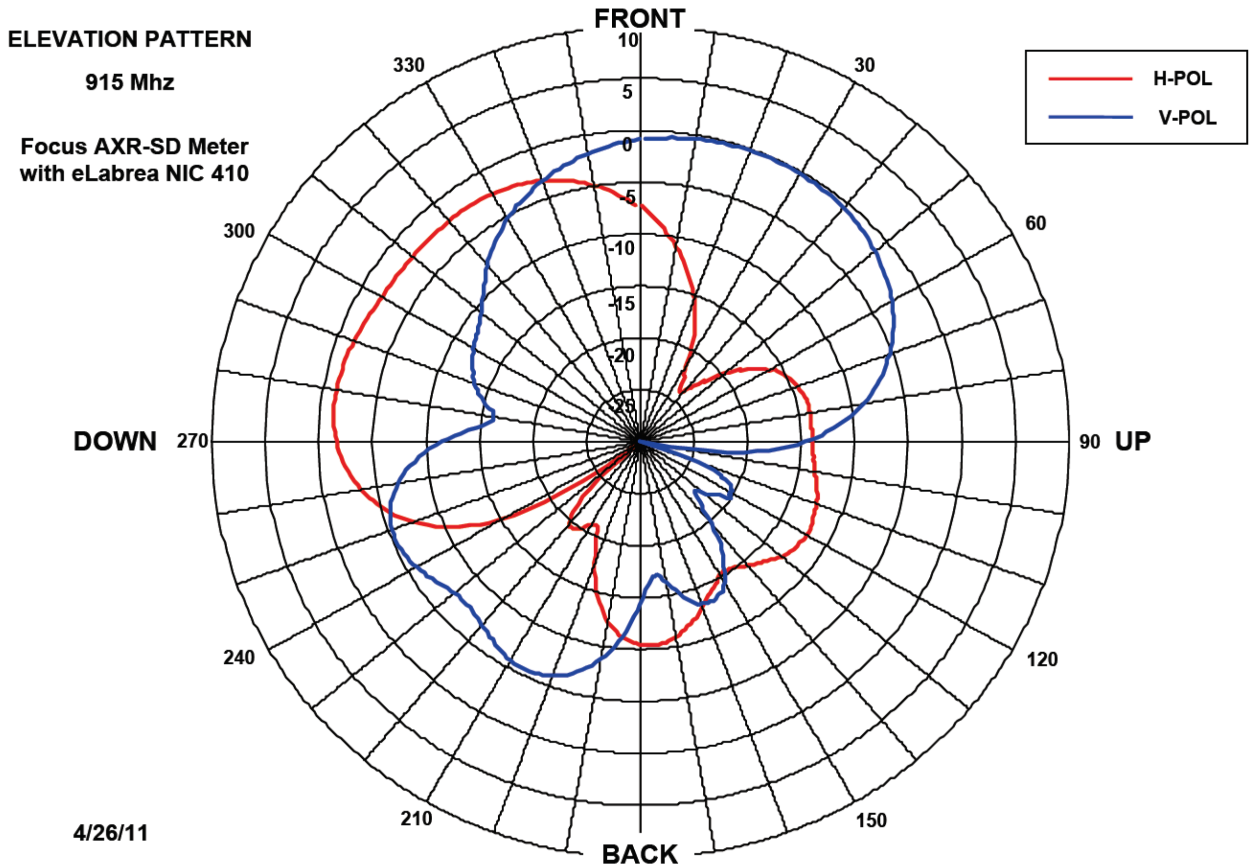


Figure D-6
FOCUS AXR-SD Silver Spring Networks manufacturer's data for the antenna elevation pattern.

E
LABORATORY TEST: CONSERT GE METER IN CONTINUOUS TRANSMISSION

The RF emissions from a Consert-GE smart meter, shown in Figure E-1, were measured in the laboratory setup: the meter was remotely controlled by the manufacturer via cellular network.

The testing conditions were set to reproduce a scenario corresponding to a large duty cycle (close to 100%) by transmitting a large data file. This setup would represent a hypothetical condition where the utility is requesting a large amount of data (close to the maximum throughput allowed by the hardware) to be transmitted from the customer installation. The transmission was still performed in the standard frequency-hopping mode, as it would be in residential installations.

The meter is equipped with a low-power transmitter (24 dBm or 0.25 W maximum) suitable for small cellular coverage areas (as in a dense urban environment) near the 830 MHz frequency.

Figure E-1
GE-Consert smart meter utilized in the laboratory test

The radiation pattern of the PCB antenna mounted inside the meter produce a significant anisotropy with respect to variations of the angular position of the detector (Figure E-2). With the particular mounting of the PCB antenna inside the meter and for a reference frame centered on the antenna with the choices indicated in Figure E-2 (left inset), a detector positioned in horizontal plane and aligned with the meter mid-position (as most of the measurements that have been performed) corresponds to the z-y plane.

The measured maximum electric field had a corresponding to an RMS value of 1.9 V/m, near the edge of the meter. This corresponds to electric field levels up 5% of the equivalent ICNIRP reference level.

The measured electric field values further away from the meter (up to about 1 m distance) decrease rapidly below the 1 V/m level. An example of the measured output, with the typical frequency hopping pattern, is shown in Figure E-3.

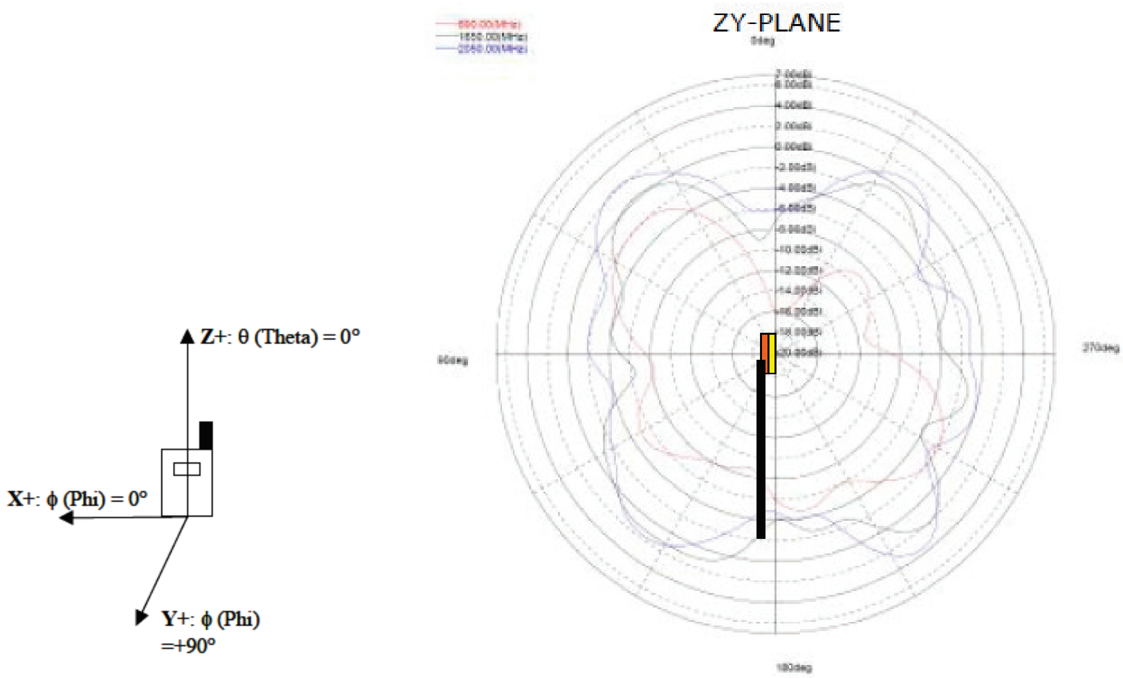


Figure E-2
GE-Consert Meter Antenna Pattern as per Manufacturer's Specifications

The red curve is for the 800-MHz band utilized in the test. The antenna gain varies from -0.7 to 1.5.

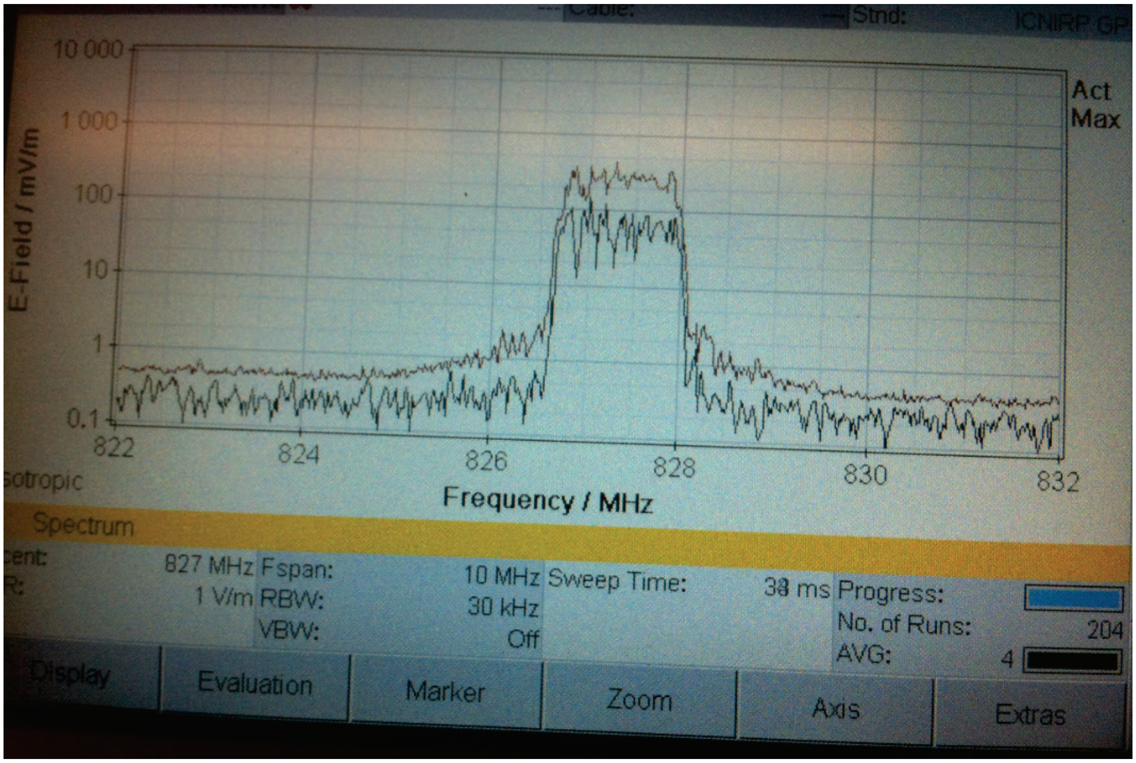


Figure E-3
Measurement with the NARDA SRM-3006 analyzer showing the typical frequency hopping pattern during the transmission test on the GE-Consert Meter

F

COMPARISON WITH OTHER EM EMISSION SOURCES

Comparing Different Common Household EM Sources

The RF emissions from the smart meters have been characterized in the context of other RF sources that the general public can be exposed to in typical residential dwellings. For this purpose, the data collected from the smart meters were compared with the RF emissions from several other sources; these data are not meant to cover all the possible conditions of exposure but are considered representative of typical conditions encountered in residential households.

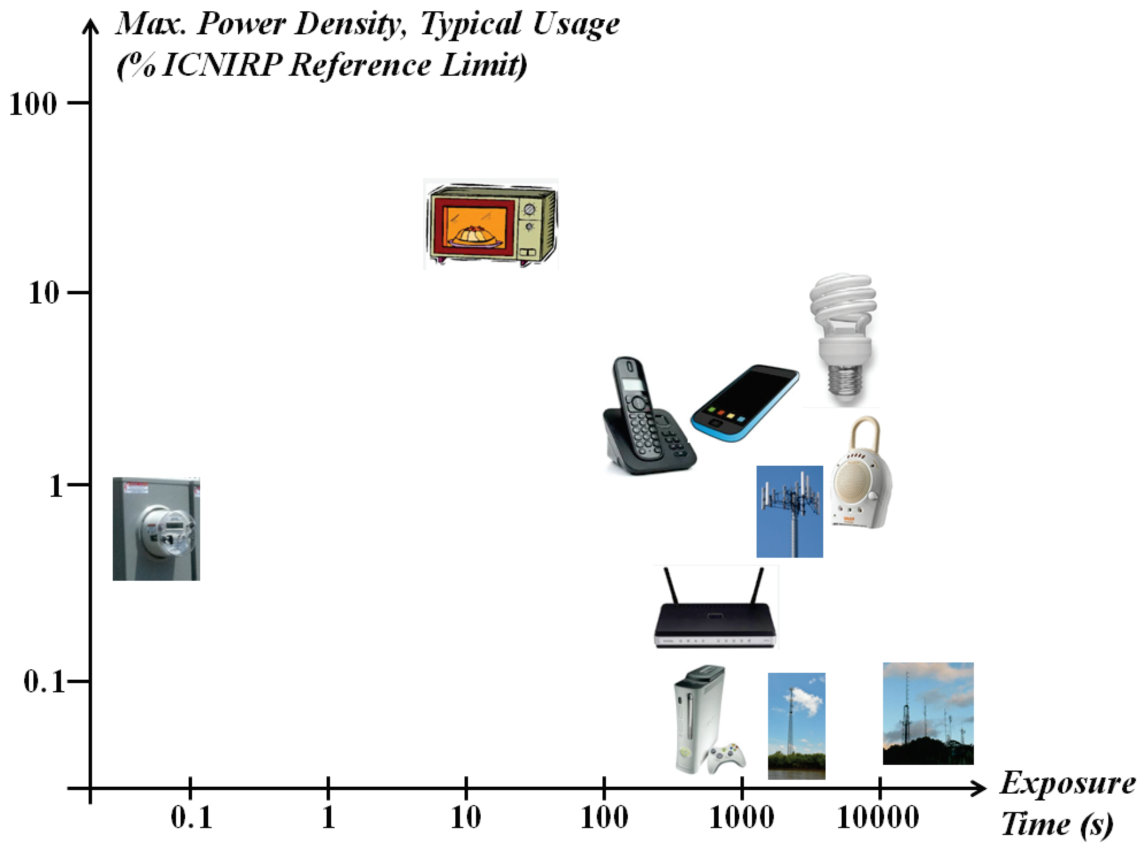


Figure F-1
Comparison of EM emissions for different sources present in common households *vs*. an approximate uninterrupted exposure time estimated for typical consumer's use (both axes are on a logarithmic scale).

Device	Smart Meter 	µwave Oven 	DECT Phone 	Smart Phone 	Wi-Fi Router 	CFL Bulb 	TV Antenna 	Baby Monitor 	Video Game 	Cell Tower (Near) 	Cell Tower (Average) 
Approx. Frequency (MHz)	900	2400	1800	900	2400	0.15	400	900	2400	900	900
ICNIRP Power Density Ref. Limit (W/m^2)	4.5	10	9	4.5	10	20	2	4.5	10	4.5	4.5
Power Density from Typical Use (W/m^2)	0.033	3.316	0.133	0.107	0.012	1.194	0	0.048	0	0.048	0
Approx. % ICNIRP Limit	0.74	33.16	1.47	2.39	0.12	5.97	0.02	1.06	>0.01	1.06	>0.01
Typical Exposure Time (s)	<0.1	10	$>10^2$	10^3	$>10^3$	$>10^3$	$>10^4$	10^4	$>10^3$	$>10^3$	$>10^3$

Figure F-2
Numeric values utilized for Figure F-1: approximated EM emission power density levels and typical exposure times compared to the ICNIRP reference level.

Selected common household items that produce RF emissions were considered: a microwave oven, a “WiFi” router for domestic use, and two “smart phones” were tested (with verified emission patterns, without other interfering devices). Data for other devices were also compared as found in published literature.

The RF emission was measured in the closest available position next to the RF source that corresponds to the considered typical exposure. It should be taken into account that the RF analyzer detector head has a 5-inch diameter protective enclosure. Therefore, the actual distance from the RF source was practically limited to 2.5 inches, or about 6 centimeters.

The results in Figure F-1 show a qualitative comparison of RF emissions for different common devices in relation to their typical, estimated continuous time of exposure for consumer utilization. Data for direct measurements on selected devices are shown in Table F-1, with power density values computed directly from the instantaneous maximum field level. Some direct measurements are reported in Table F-2: for example, a microwave oven was found generating a maximum electric field in excess of 50 V/m next to the door; a Wi-Fi router produced 34 V/m close to the antennas, and up to a 9-V/m pulse was measured for cellular phones in the closest proximity of the antenna.

Table F-1
Basis of Estimate for the electric fields values listed in Figure F-2

Smart Meter

Measured: less than 5 V/m at the one meter (3 ft) from the front surface of the smart meter case

Microwave Oven

Measured: 52 V/m at the door surface

DECT Phone

Measured: 15 V/m at the surface. Maximum measured field: 111 dBμV/m=0.355 V/m at 1.8 GHz at 3 m. Extrapolated at 0.3 m to 3.5 V/m.

Reference: M. Ganley et al. "Permitted Noise above 1 GHz: Final Report", ERA Technology Report 2006-0450 (2006) [http://stakeholders.ofcom.org.uk/binaries/research/technology-research/a1-a6.pdf, Figure 58, page 130]

Smart Phone

Measured: 9 V/m near the antennas

Wi-Fi Router

Measured: 34 V/m near the antennas, less than 3 V/m at 1 m.

CFL bulb

Measured: 30 V/m near the surface

UHF TV Antenna Tower

Digital signal strength in a residential area from http://transition.fcc.gov/mb/engineering/dtvmaps/. Here a typical signal of -21 dBm corresponding to 0.58 V/m is considered

Baby Monitor

Estimated considering the upper limit of a typical power range: 900 MHz transmitter at 100 mW (20 dBm) at 30 cm producing 5.77 V/m (isotropic radiator) [from http://www.qsl.net/pa2ohh/jsvpm.htm]

Video Game

XBox 360 Core system. Tested in normal operating mode – Using a demo game that exercises the CPU, graphic cards and input and output ports. Maximum measured field: 98 dBμV/m=0.079 V/m at 3 m, 2.4 GHz. Extrapolated at 0.3 m to 0.79 V/m.

Reference: M. Ganley et al. "Permitted Noise above 1 GHz: Final Report", ERA Technology Report 2006-0450 (2006) [http://stakeholders.ofcom.org.uk/binaries/research/technology-research/a1-a6.pdf, Figure 56, page 127]

Cell Phone Tower (near distance)

Assume 10 W power, 20 dB antenna, 30 m distance. This corresponds to an effective radiated power P_{ERP}=1000 W and a power density (at 30 m) of $p_{ERP}=1000/(2\pi d^2)=0.088$ W/m^2. The corresponding electric field is found then from $E = \sqrt{Z_0 p_{ERP}}$=5.77 V/m, where Z_0=377 Ω.

Cell Phone Tower (average distance)

A 4-bar Android signal at -91 *dBm* corresponds to 0.00018 *V/m*, or 0.18 *mV/m*.

The field levels in Figure F-2 are approximately considering a distance from the source in average utilization conditions and are reported as a percentage of the maximum permitted exposure level from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, for the pertinent frequency.

These data may obviously vary for different brands and models; this comparison is here provided for the purpose of putting the smart meter RF emissions in the proper context of consumer's RF exposure.

Table F-2
RF emissions for selected common household sources (measured after scanning different locations near the object)

Device	RMS Value Corresponding to Measured Max. Instantaneous Electric Field E_{RMS} (V/m)	Typical Operation Pattern
900 MHz ICNIRP Limit	41	
Microwave Oven (Door Surface)	37	Continuous
Wi-Fi Router (Near Antennas)	24	Pulsed, Infrequent
AMI Meter (Front Surface Contact)	19	Pulsed, Infrequent
Smart Phone (Surface Contact)	6.4	Almost Continuous

Correlation with Past Comparable Studies

Investigations on different smart meter installations were conducted in the past by EPRI (see "Historical Perspective on EPRI Research" in Section 1). A synoptic view of comparable results, along with the original references, is presented in Table F-3, showing that the past results are consistent with the ones obtained in this study.

Table F-3
Measured RF Emissions from Smart Meters in different previos EPRI published studies

Device (902 MHz, 1 W)	Itron, CL200	GE-I210	L+G Focus AXR-SD
Reference	[9] Page 9-4	[11] Page 4-1	[11] Page 4-1
% FCC MPE (Front Surface)	65.3%		
E_{RMS} (V/m)	31		
% FCC MPE (0.3 m)	5.5%	9.6%	9.2%
E_{RMS} (V/m)	2.6	4.6	4.4

To show consistency of the data utilized in Figure F-2 for different RF sources commonly utilized by the general population, similar measurement from past EPRI reports are also shown in Table F-4.

Table F-4
Data on RF Emissions of Common Household Devices From Previous Surveys Published in the Literature

Device	Power Density S (W/m^2)	% FCC MPE	RMS Electric Field E_{RMS} (V/m)	Reference
900 MHz FCC MPE	6.01	100%	47.6	
Microwave Oven at 0.3 m		12%	7.3	[11] Page 13-2
2.4 GHz Wi-Fi Router Public Area	0.003		1.1	[8]
2.4 GHz Wi-Fi Router Home at 0.3 m		0.24%	0.15	[9] Page 13-3
Smart Phone (Surface Contact)	5		43.4	[10] Page 9

G
COMPARISON WITH PUBLISHED SAFETY GUIDELINES

As shown in Appendix F, safety standards are based on the RMS values for the field, or equivalent power density levels, computed from an average over several minutes (for the public exposure, 6 minutes for the ICNIRP, and 30 minutes for FCC and IEEE). These guidelines are derived essentially from the point of view of protecting living tissue from adverse thermal effects deriving from exposure to the EM fields.

In this study, data are collected for the purpose of comparing with safety standards: the ICNIRP is considered for this purpose, given its more conservative prescriptions in terms of maximum permissible field exposure.

During the measurement process, random fluctuations (for example, of thermal nature or induced by transient reflections) may produce variation of the instantaneous field. Following a conservative approach, the maximum instantaneous value is here always considered as representative of the field intensity. This maximum is taken over a sufficient dwelling time (typically in the order of a minute) after observing that a stable value is held as the maximum level measured by the analyzer.

For the purpose of comparison with the safety standard, all the measured data are considered as if the smart meter were emitting radio frequency power with an unperturbed sinusoidal waveform corresponding to the maximum measured instantaneous value. The RMS value (and then the corresponding power density) is computed as this maximum value divided by a factor √2 (Figure G-1) for direct comparison with the chosen reference standard.

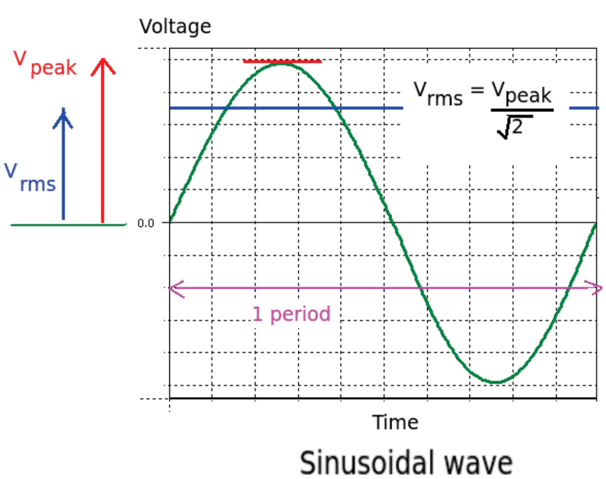


Figure G-1
Peak vs. RMS value for a sinusoidal function

For example, a measurement in a certain location would yield a level corresponding to 10% of the ICNIRP reference level. This means that an equivalent RMS value, corresponding to the measured maximum instantaneous value divided by $\sqrt{2}$, is equal to 10% of the level that the ICNIRP guideline requires to be held for the prescribed averaging time of six minutes.

This approach does not then intentionally include any mitigating factor for the emission level due to pulsed or infrequent transmission pattern (i.e. at a low duty cycle) and represents a conservative scenario, to cover any present and future possible setting of the smart meter transmission duty-cycle and operation mode.

The issue of limiting exposure to maximum instantaneous values of EM fields is also considered, in the ICNIRP standard (Figure 2-4), to some approximation, by extending the time-averaged reference level by a certain heuristic factor, with a frequency dependence (dashed curve in Figure 2-4).

H
EM SURVEY MEASURING PROTOCOL

The following form has been developed and utilized for the data collection during the survey of the smart meters in the CPS Energy service territory in San Antonio, Texas, to maintain a systematic and reproducible approach in the measuring process.

The layout is fairly general and easy to customize. As written, it applies to single and two-story residences.

Smart Meter EM Survey - Measurement Protocol

1. Identification and Location

Location [ ] **Date** [ ]

1.1 Verify that the meter is active (numeric display on)

Number of Units: [ ] Meter(s) Status: ON [ ] OFF [ ]

Make/Model: [ ]

Comments

[ ]

1.2 Position

Meter Height: [ ]

Meter Horizontal Reference: [ ]

Meter Horizontal Displacement from Reference: [ ]

Comments

[ ]

2. <u>Preliminary Test</u>

2.1 Verify RF Transmission

SRM-3006 Spectrum Range Set-up:

Approximate Frequencies

Approximate E-Field Level:

Approximate Periodicity:

Comments

HF Spectrum Range Set-up:

Approximate Frequencies

Approximate E-Field Level:

Approximate Periodicity:

Comments

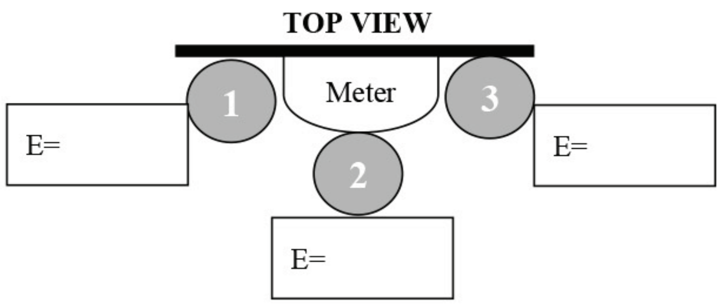
3. <u>Detailed Test</u>

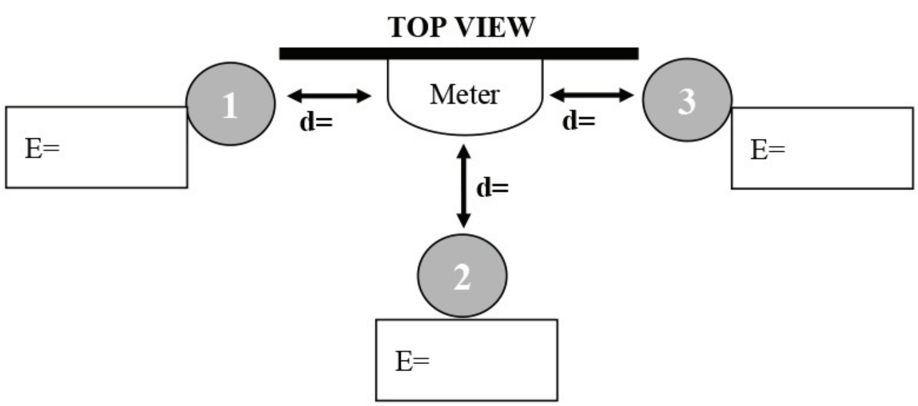
3.1 Outdoors Measurement

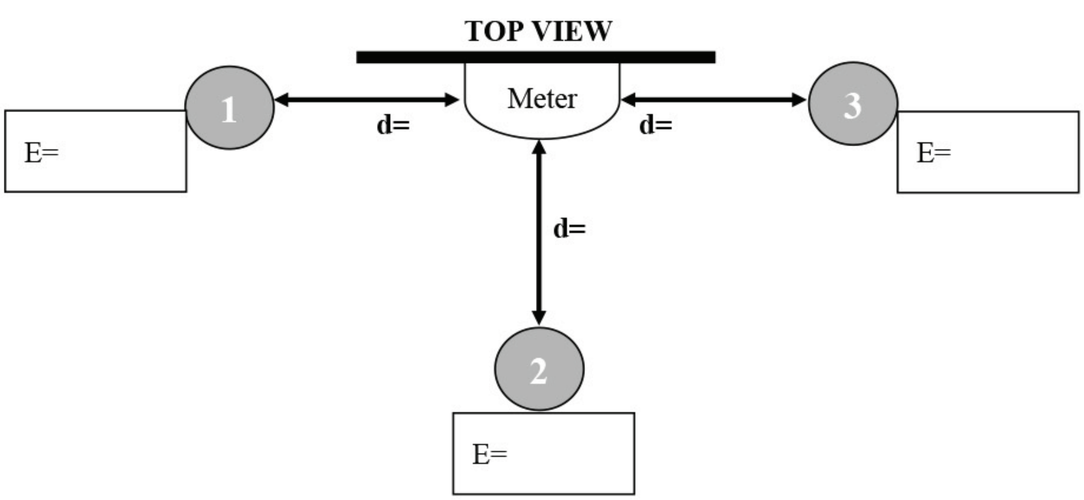
3.1.1 Close Range

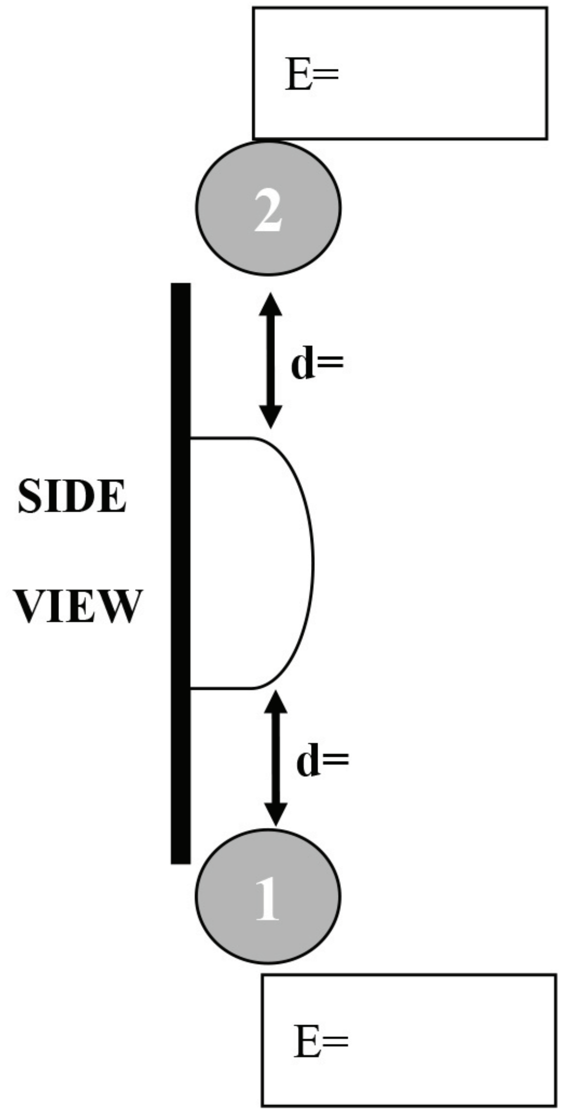
SRM-3006 Signal Level Set-up: Baseline: ______

Center Frequency: ______ RBW: ______ Max Range: ______





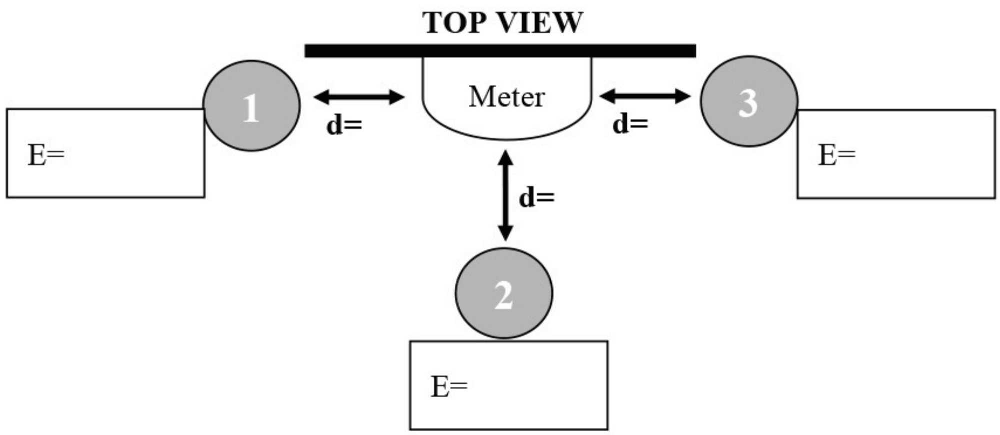


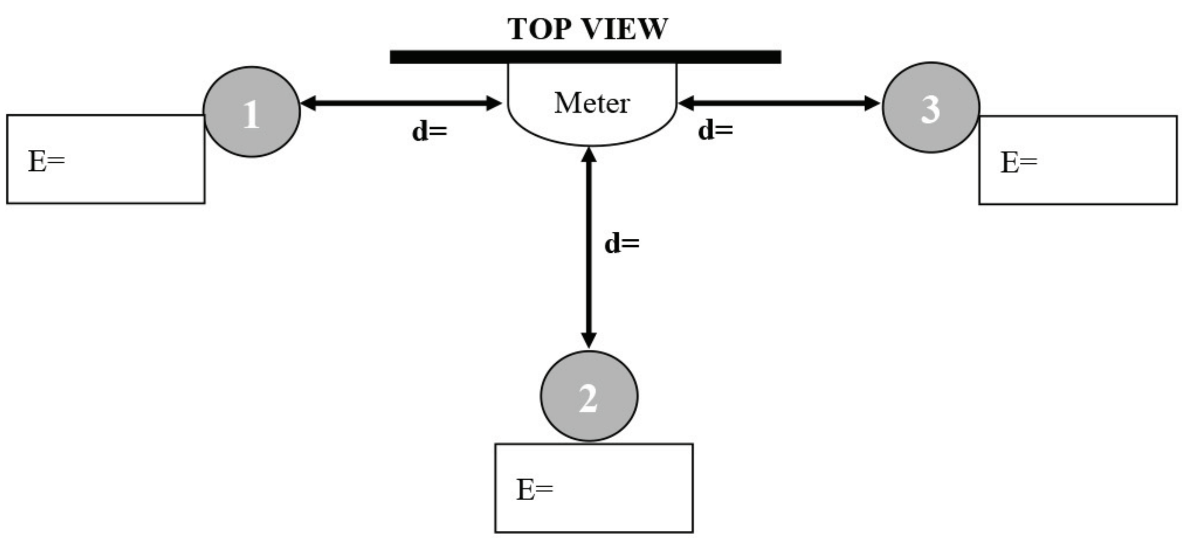

E=
2
d=
SIDE
VIEW
d=
1
E=

3.1.2 Long Range

SRM-3006 Signal Level Set-up

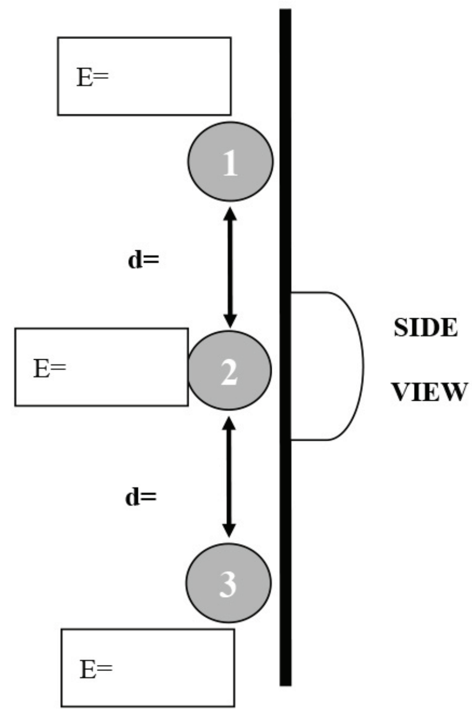
Center Frequency: RBW: Max Range:



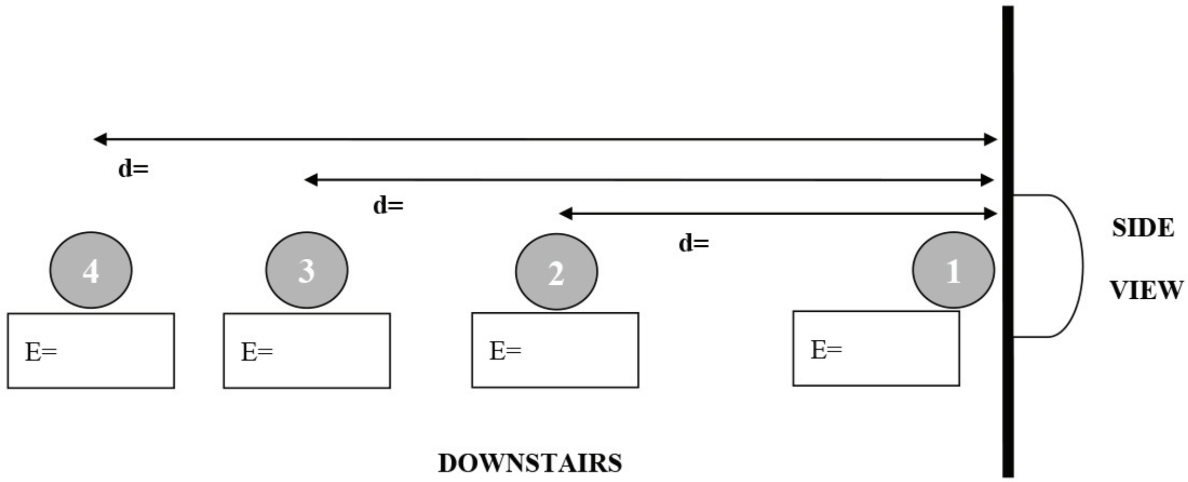


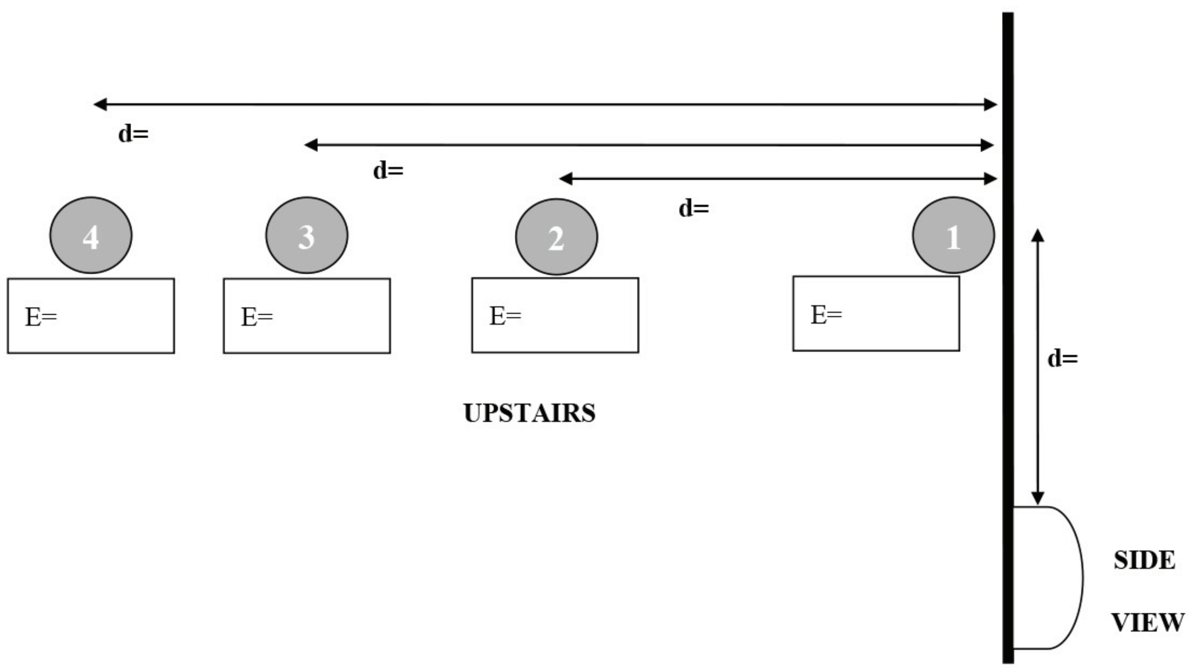
3.2 Indoors Measurement

3.2.1 Close Range



3.2.1 Long Range





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