

City of Naperville
Naperville Smart Grid Initiative (NSGI)
Pilot 2 RF Emissions Testing – Summary Report – V2.0

Smart Meters, Household Equipment, and the General Environment

November 10, 2011

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Revision History

Version 1.0	09/16/2011	Original Document
Version 2.0	11/10/2011	Added Section 5 describing the impacts of Near Field effects when measuring power density at 1 wavelength or less from a transmitter. Also made notes in measurement results tables where near field effects could have influenced some of the measurements.

Executive Summary

In early 2011, a group of Naperville utility customers expressed concerns regarding the RF emissions levels from smart grid equipment that will be deployed as part of the Naperville Smart Grid Initiative (NSGI). To address these concerns, additional testing procedures were included in the Pilot 2 of the NSGI scope to obtain detailed RF measurements from the smart grid equipment, common household devices and the ambient Naperville RF environment. Department of Public Utilities (DPU-E) engineers performed the RF testing utilizing a NARDA power density meter, which is a sophisticated RF measurement device commonly used to measure the RF power density of devices. This device is also used to compare a device's performance against Federal Communications Commission (FCC) specifications for power density allowed.

This *RF Emissions Testing Summary Report* contains a high-level description of the test scope, excerpts of the key RF measurements with illustrations and conclusions. A separate more detailed document titled *RF Emissions Testing Plan and Results* contains the RF test plan scope, overall approach, detailed test procedures and the complete set of test data. The comprehensive testing resulted in the following key findings which are documented and explained in the above referenced documents:

- The NSGI smart grid equipment emitted RF power densities that are below the FCC guidelines.
- Measurements of the smart meter equipment's instantaneous or peak RF power densities ranged between 1% and 3.2% of FCC limits at 20 cm in front of the meter. Please note that the measurements observed were from a specially programmed continuously transmitting meter. Based on the standard operation of the smart meters that will be deployed throughout Naperville, as well as these measurements observed in testing, one would need to stand 20 cm in front of the smart meter for 30 minutes to experience this small amount of RF energy relative to the FCC standard.
- Measurements of the smart meter equipment average RF power densities ranged between 0.002% and 0.003% of FCC limits at 20 cm in front of the meter over a 30-minute period.
- The maximum Tropos (mid-tier backhaul equipment) measured instantaneous or peak RF power density observed was 0.0277% of the FCC limit (measured 20 cm directly in front of the antenna).
- The smart grid equipment average RF power densities were lower than typical household devices such as microwaves, cell phones, and Wi-Fi routers.

1. Radio Frequency Testing Motivation

One significant source of public concern regarding smart grid technology is that the radio frequency (RF) emissions from smart meters could potentially be harmful. While all smart grid equipment manufacturers are required to adhere to all Federal Communications Commission (FCC) guidelines, quantifying the actual RF emissions from installed smart meters, and associated telecommunications equipment, plays a critical role in public understanding and opinion regarding the potential health impacts of smart grid technologies.

2. Radio Frequency Test Methodology

The City of Naperville Department of Public Utilities - Electric (DPU-E) has developed a comprehensive scientific methodology for the RF emissions testing of smart grid equipment and common household devices (See *Pilot 2 RF Emissions Testing Plan and Results* for full methodology and raw data).

This RF study completed by the City of Naperville resulted in the:

- Measurement of baseline RF observations from various public environments throughout the City (e.g. “ambient RF”)
- Collection of both “lab” and “in-the-field” radio frequency test data from the Elster REX2 Residential smart meter and related equipment that will be deployed
- Quantification of the RF output of common household devices such as cell phones, wireless routers, and other devices typically found in Naperville residences.

The testing was led and completed by Naperville Engineering Staff between August 22nd and September 7th 2011. All testing was completed using the Narda SRM-3006 Selective Radiation Meter which is a sophisticated measurement device commonly used to measure RF Power Density of devices. The meter was calibrated by the manufacturer at 21 reference points and has an uncertainty of +2.2/-2.9 dB for 750-1600 MHz.

It should be noted that although there will be 10 different meter types installed in Naperville, the RF testing conducted by the utility is applicable to all meter types. This is because, while these meters differ in their functionality, they all utilize the same communications radio.

3. FCC Limit

The FCC Document 47CFR1.1310 sets the rules concerning Maximum Permissible Exposure (MPE) to humans. The criteria used by the FCC to evaluate the MPE for RF emissions are listed in Table 1 below. Key limits pertaining to the smart grid are listed in Table 2 below.

Table 1: FCC Limits for Radio Frequencies

Frequency range (MHz)	Power density (mW/cm ²)	Averaging time (minutes)
(A) Limits for Occupational/Controlled Exposures (See Note 1)		
0.3-3.0	*(100)	6
3.0-30	*(900/f ²)	6
30-300	1.0	6
300-1500	f/300	6
1500-100,000	5	6
(B) Limits for General Population/Uncontrolled Exposure (See Note 2)		
0.3-1.34	*(100)	30
1.34-30	*(180/f ²)	30
30-300	0.2	30
300-1500	f/1500	30
1500-100,000	1.0	30
f = frequency in MHz ; * = Plane-wave equivalent power density		

Table 2: Key FCC Limits

Device	FCC Limit [$\mu\text{W}/\text{cm}^2$]***
Elster Smart Meter*	~601
Elster Gatekeeper*	~601
Tropos 7320 Mesh Router**	1,000

*As the FCC limit is variable with the frequency (f [MHz]/1500 when under 1GHz), 601 was used in the calculations because it will produce the largest (worst possible) percent of FCC limit.

**While two different routers will be deployed throughout Naperville (Tropos 7320 and 6320) only the 7320 was tested, as it is the more powerful of the two devices.

***Note that these values are shown in microwatts per centimeter squared which would require division by 1000 to directly compare to the milliwatt values shown in Table 1.

4. Results

The results of the Naperville RF testing have been broken into four distinct parts. Each of the aforementioned parts is shown below along with a listing of the devices measured for each test:

4.1 Lab Data

- a. Elster REX2 Smart Meter
 - i. Standard Configuration
 - ii. 100% Packet Rate
 - iii. 100% Transmit Rate
- b. Elster A3 Smart Meter – Standard Configuration
- c. Elster Gatekeeper – Standard Configuration
- d. Tropos 7320 Mesh Router – Standard Configuration
- e. Microwave – Standard Configuration
- f. Cell Phone
 - i. While Making Phone Call
 - ii. While Streaming Video
- g. Wireless Router (Wi-Fi)
 - i. Idle
 - ii. While Streaming Video

4.2 Home Measurements

- a. Existing Home RF Environment Prior to Smart Meter Installation
- b. Elster REX2 Smart Meter
 - i. Standard Configuration
 - ii. Standard Configuration with Meter Specially Programmed to Send Data Once Per Minute

4.3 Tropos 7320 Mesh Router and Elster Gatekeeper Field Measurements

- a. Standard Configuration Tropos 7320 Mesh Router
- b. Standard Configuration Elster Gatekeeper

4.4 Ambient Environments in Naperville

4.1. Lab Data

This section shows the RF measurements of the smart grid devices and household devices that were captured in the lab setting at the Naperville DPU-E. We can be certain that values in Table 3 and Table 4 are attributable mainly to the sources noted in each column because the room used for this lab testing had negligible RF background levels. The results of the tests conducted are shown in Table 3 below. It should be noted that the values in this table are instantaneous maximum measured peaks and are not reflective of the average power density over time. It should also be noted that the Elster REX2 meter was measured in three different modes: normal configuration (maximum of ~0.1% duty cycle), 100% packet rate (~50% duty cycle) and 100% transmit rate (~100% duty cycle). Every smart meter installed in Naperville is programmed with the standard configuration, which will result in the smart meter transmitting data for less than two minutes per day. The 100% packet rate and 100% transmit rate modes were specially programmed to generate more frequent RF emissions so that the instantaneous or peak smart meter power density could more easily be measured. Please note that the duty cycles shown for the 100% packet rate and 100% transmit rate do not represent the expected transmission frequency during standard meter operations.

Table 3: Measured Instantaneous Peak Values of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Pilot II											
(All values in $\mu\text{W}/\text{cm}^2$ and are an instantaneous maximum measured peak)											
Distance from source [m]	Elster REX2 Meter			Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (WiFi) Router	
	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	100% Packet Rate [$\mu\text{W}/\text{cm}^2$]	100% Transmit Rate [$\mu\text{W}/\text{cm}^2$]	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Call [$\mu\text{W}/\text{cm}^2$]	YouTube Stream [$\mu\text{W}/\text{cm}^2$]	Idle [$\mu\text{W}/\text{cm}^2$]	YouTube Stream to Laptop [$\mu\text{W}/\text{cm}^2$]
-3	n/a	0.15	0.00076	n/a	n/a	n/a	0.13986	0.00616	0.00384	0.005702	0.00252
-1	n/a	0.11	0.2512	n/a	n/a	n/a	0.3758	0.0154	0.03968	0.02044	0.064
-0.23	n/a	2.27	0.24332	n/a	n/a	n/a	0.5454	0.32	0.13126	0.03648	0.88
-0.2	n/a	2.45	0.451	n/a	n/a	n/a	0.63576	0.336	0.18638	0.044684	0.8988
0.2	9.248	15.46	19.214	11.7416	5.93102	0.2776	81.386	0.957	0.783	0.2685	0.9846
0.23	3.7452	13.88	15.932	3.7582	2.88303	0.16357	35.644	0.7364	0.2166	0.032782	0.899
1	0.429	2.01	1.4064	4.6254	1.37581	0.037026	6.9834	0.022838	0.0638	0.01878	0.0632
3	0.148	0.69	0.6728	0.1618	0.27842	0.0013	1.3626	0.00941	0.00324	0.00299	0.00228
5	0.0274	0.08	0.2048	0.12556	0.118232	0.019974	0.28348	0.0024	0.001068	0.005412	0.00144

Notes:

1. Measurements behind the Standard Configuration REX2 Meter and the Standard Configuration A3 meter were not recorded as peak measurements because they could not be detected due to the signal attenuation through the meter box. It should also be noted that the exterior walls and siding of a home would provide additional signal strength reductions.
2. Measurements behind the Gatekeeper and Mesh Router were not recorded as these devices use omnidirectional antennas, which transmit uniform signals in all horizontal directions.
3. The negative distance measurements for the Wi-Fi router and cell phone were taken on the opposite side of the device relative to the positive distance measurements. In actuality there is no negative distance for the cell phone and Wi-Fi router because the antennas in these devices are omnidirectional.
4. The standard configuration smart meter, 100% packet rate smart meter, and 100% transmit rate smart meter results are from three unique meters in three unique meter sockets.
5. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
6. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.
7. Please note that measurements taken at 0.23, 0.2, -0.2, and -0.23 m can be influenced by near-field effects (See Section 5)

Table 4 shows the percent of the FCC’s emission limit that each Smart Grid and household device reached during instantaneous maximum peak measurements. As shown in Table 4, the highest percent of the FCC limit that any smart grid equipment attained was 3.197%, which occurred at 0.2 meters (~8 inches) away from an Elster REX2 meter that was programmed to transmit 100% of the time.

Table 4: Percent of FCC Limit of Measured Instantaneous Peak Values of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Pilot II											
(All values in % of FCC limit and are an instantaneous maximum measured peak)											
Distance from Source [m]	Elster REX2 Meter			Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (WiFi) Router	
	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	100% Packet Rate [$\mu\text{W}/\text{cm}^2$]	100% Transmit Rate [$\mu\text{W}/\text{cm}^2$]	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Call [$\mu\text{W}/\text{cm}^2$]	YouTube Stream [$\mu\text{W}/\text{cm}^2$]	Idle [$\mu\text{W}/\text{cm}^2$]	YouTube Stream to Laptop [$\mu\text{W}/\text{cm}^2$]
-3	n/a	0.02507%	0.00013%	n/a	n/a	n/a	0.01399%	0.00062%	0.00038%	0.00057%	0.00025%
-1	n/a	0.01802%	0.04180%	n/a	n/a	n/a	0.03758%	0.00154%	0.00397%	0.00204%	0.00640%
-0.23	n/a	0.37804%	0.04049%	n/a	n/a	n/a	0.05454%	0.03200%	0.01313%	0.00365%	0.08800%
-0.2	n/a	0.40742%	0.07504%	n/a	n/a	n/a	0.06358%	0.03360%	0.01864%	0.00447%	0.08988%
0.2	1.53877%	2.57171%	3.19700%	1.95368%	0.98686%	0.02776%	8.13860%	0.09570%	0.07830%	0.02685%	0.09846%
0.23	0.62316%	2.31015%	2.65092%	0.62532%	0.47971%	0.01636%	3.56440%	0.07364%	0.02166%	0.00328%	0.08990%
1	0.07138%	0.33361%	0.23401%	0.76962%	0.22892%	0.00370%	0.69834%	0.00228%	0.00638%	0.00188%	0.00632%
3	0.02463%	0.11488%	0.11195%	0.02692%	0.04633%	0.00013%	0.13626%	0.00094%	0.00032%	0.00030%	0.00023%
5	0.00456%	0.01271%	0.03408%	0.02089%	0.01967%	0.00200%	0.02835%	0.00024%	0.00011%	0.00054%	0.00014%

Notes:

1. Measurements behind the Standard Configuration REX2 Meter and the Standard Configuration A3 meter were not recorded as peak measurements because they could not be detected due to the signal attenuation through the meter box. It should also be noted that the exterior walls and siding of a home would provide additional signal strength reductions.
2. Measurements behind the Gatekeeper and Mesh Router were not recorded as these devices use omnidirectional antennas, which transmit uniform signals in all horizontal directions.
3. The negative distance measurements for the Wi-Fi router and cell phone were taken on the opposite side of the device relative to the positive distance measurements. In actuality there is no negative distance for the cell phone and Wi-Fi router because the antennas in these devices are omnidirectional.
4. The standard configuration smart meter, 100% packet rate smart meter, and 100% transmit rate smart meter results are from three unique meters in three unique meter sockets.
5. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
6. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.
7. Please note that measurements taken at 0.23, 0.2, -0.2, and -0.23 m can be influenced by near-field effects (See Section 5)

4.2. Home Measurements

An RF study of a home with an operational REX2 smart meter captured the power density in a real world environment. Measurements were taken both before and after smart meter installation to demonstrate the RF power density contributions made to the home environment by the smart grid equipment. The results of these tests are shown in Figures 1, 2, 3 and 4, which display measured instantaneous peak energies outside, on the first floor, second floor, and in the basement of the home respectively. Data was taken under three different cases:

1. Prior to smart meter installation

2. After smart meter installation under normal operational configurations
3. After smart meter installation with the meter specially configured to send data packets once every minute (note that this configuration is atypical and has been used only for testing purposes)

Testing prior to the smart meter installation demonstrated that there are numerous different sources of RF present in this particular residential neighborhood in Naperville. These signals emanate from sources such as television broadcasts, cell phone towers, two-way public safety radios, Wi-Fi systems, terrestrial radio broadcasts, and numerous others. Based on preconfigured settings from the manufacturer, along with Naperville programming of the smart meter, the measurements taken under normal operation of a smart meter confirmed that the instantaneous maximum pulses detected from the smart meter were still less than the FCC's limit. Furthermore, the transmission pulses were captured over an extended period, confirming that the duty cycle for the NSGI smart meters is less than 0.1%. The term duty cycle is used to describe the amount of time a device is active and operating, as a percentage of total time.

Due to the extremely low duty cycle of RF emissions from the NSGI smart meters, it can be difficult to capture a consistent power density measurement in a field environment. Therefore, a smart meter in this field environment was specially programmed to broadcast data packets once per minute, over a sixty minute period, to allow another set of data to be collected around and inside the home. This set of data is in addition to the data collected with a standard configuration smart meter as well as the data collected in and around the home prior to smart meter installation. In all, there were three sets of data captured around the home. All measurements taken during the once per minute broadcasts were instantaneous, or peak RF Power Density measurements, and were well below FCC limits. In fact, the largest instantaneous peak measurement recorded in the field from the smart meter was still less than 1% of the FCC's limit for average power density at 20 cm from the face of the meter. (Note: the average power density can be calculated by taking the instantaneous RF power density times the transmit duty cycle, which is no more than 0.1% for the NSGI system.)

With the smart meter specially configured to transmit once per minute, the worst-case instantaneous or peak power density of the smart meter measured at the home was 0.913478% of the FCC limit when measured at 20 cm from the face of the meter. The average power density of this smart meter would be 0.0009% of the FCC limit at 20cm from the front of the meter over a period of 30 minutes for normal operation. The strongest instantaneous peak measurements taken in the residence were from the home's microwave and wireless router, which were measured at 51.1. $\mu\text{W}/\text{cm}^2$ and 2.2 $\mu\text{W}/\text{cm}^2$ respectively. A detailed list of the microwave and wireless router measurements, in addition to the other in-home devices measured, can be found in Figure 2 and Figure 3. A summary of the measurements taken at points adjacent to the meter, both in and outside the home, are shown in Table 5.

Please also note that REX2 smart meter used at the home was a different physical meter than the smart meters used during the previously described Lab RF power density tests. Therefore, the power density values in this test are not expected to be the same as the values in the previous tables.

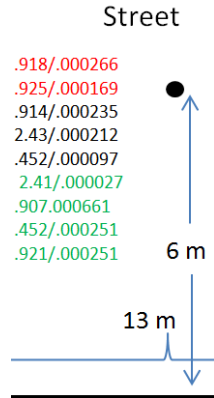
Table 5: Maximum Instantaneous Measured Peaks at selected locations in home

Instantaneous Maximum Measured Peaks Data Calls Once per Minute		
Location	Measured Instantaneous Maximum Peak ($\mu\text{W}/\text{cm}^2$)	Percent of FCC Limit
Outside Home (20 cm from meter)	5.490000	0.913478%
Inside Home (at face of wall directly behind meter at a location ~1.5 m above meter)	0.000158	0.000026%
Second Floor Hallway (~4.5 m above meter)	0.000158	0.000026%
Basement (at face of wall directly below meter ~1.5 m below meter)	0.000958	0.000159%

On the following pages, Figures 1, 2, 3, and 4 show all frequencies observed in and around this Naperville home constructed with wood siding. These figures show measurements observed before a smart meter is installed (in red), after a standard configuration smart meter is installed (in black), and while a standard configuration meter was specially scheduled to send a signal once per minute (in green). Please note that the standard configuration meter specially scheduled to send a signal once per minute has a frequency of transmission significantly greater than the frequency of transmission of a meter in normal operations, this special schedule was necessary to allow large volumes of data collection for this test. Figure 1 shows the measured instantaneous peak energy at various points around the outside of the home. Figure 2 shows the measured instantaneous peak energy at various points on the first floor of the home. Figure 3 shows the measured instantaneous peak energy at various points on the second floor of the home. Figure 4 shows the measured instantaneous peak energy at various points in the basement of the home.

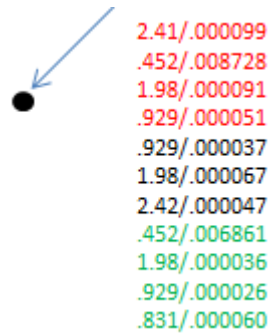
It is important to note that the RF readings that are shown in these figures were the most frequently observed and had the largest amplitude during our testing sessions. Many other frequencies were present during this testing but only the strongest measurements observed are shown in these figures. It should be noted that the operating frequency range of an Elster REX2 smart meter is 902 MHz – 928 MHz which is equivalent to 0.902 GHz – 0.928 GHz. Additionally the ZigBee antenna within the smart meter operates between 2.412GHz and 2.485 GHz which are frequencies also used by Wi-Fi and other typical household devices.

When analyzing this data it is important to compare the pre smart grid data (shown in red) to the post smart grid data under normal operation (in black) to determine the true impact of the smart meter, and associated smart grid hardware, on this home. As an example, the following is an excerpt of data from Figure 1. The pre-smart meter data (shown in red) had the strongest readings at 0.918 GHz and 0.925 GHz. It is then reasonable to assume that the 0.907 GHz frequency observed, when the smart meter was communicating once per minute (shown in green), is associated with the communication of the smart meter. The power density measurement associated with the 0.907 GHz frequency observed in this test was $0.000661 \mu\text{W}/\text{cm}^2$ which is equivalent to 0.00011% of the FCC limit.



Clipped from Figure 1

In another example, which is also clipped from Figure 1, the pre-smart meter data (shown in red) had some of the strongest readings from the 0.452 GHz and 1.98 GHz frequencies. It is reasonable to assume that the 0.452 GHz frequency observed, when the smart meter was communicating once per minute (shown in green), is NOT associated with the communication of the smart meter or related smart grid equipment as that frequency falls outside of the operating range of the devices. The additional frequencies gathered show the other non-smart grid related RF signals, and their power density, already present inside and outside of this Naperville home.



Clipped from Figure 1

Figure 1: Measured Instantaneous Peak Energy Outside Naperville Home

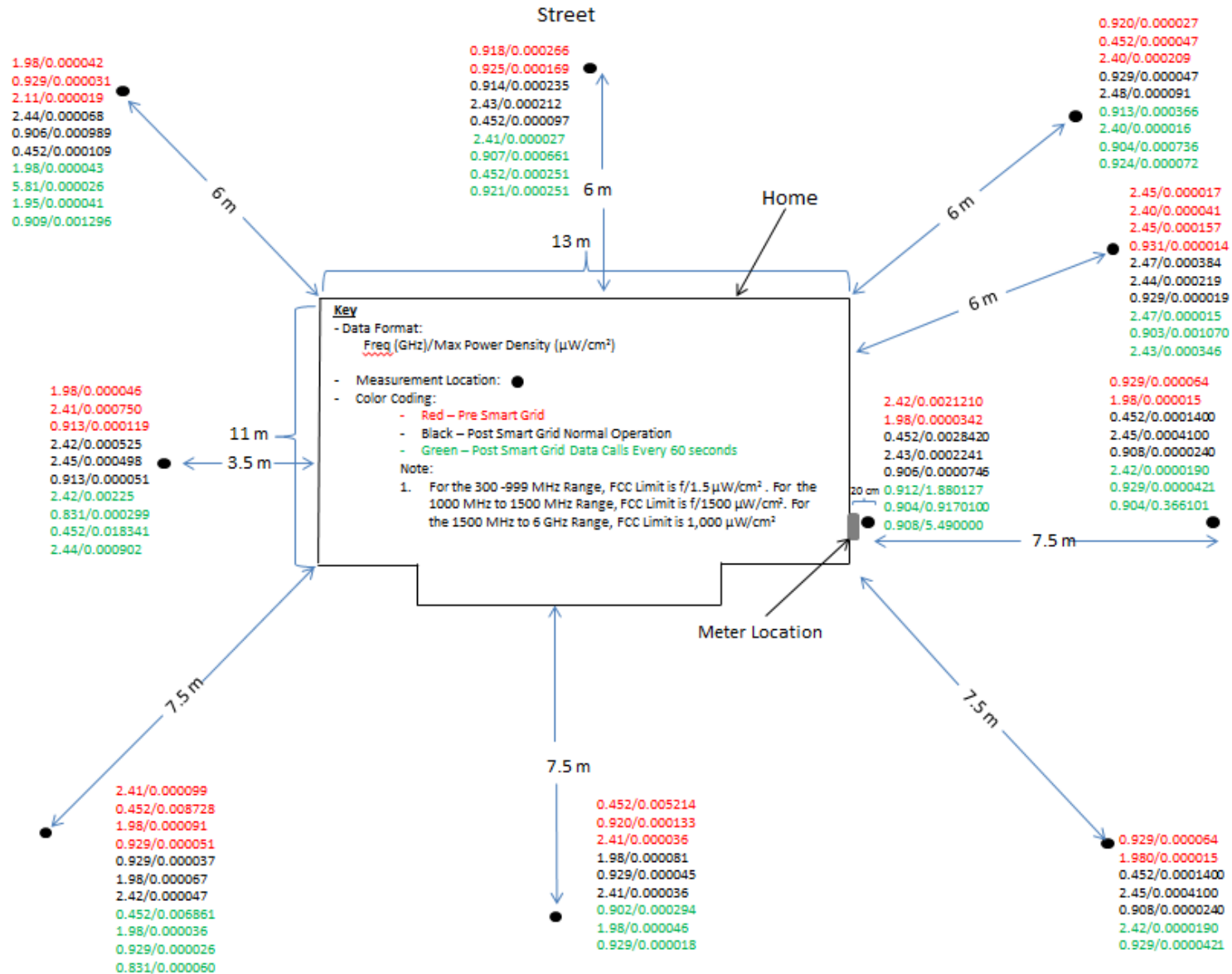


Figure 2: Measured Instantaneous Peak Energy on First Floor of Naperville Home

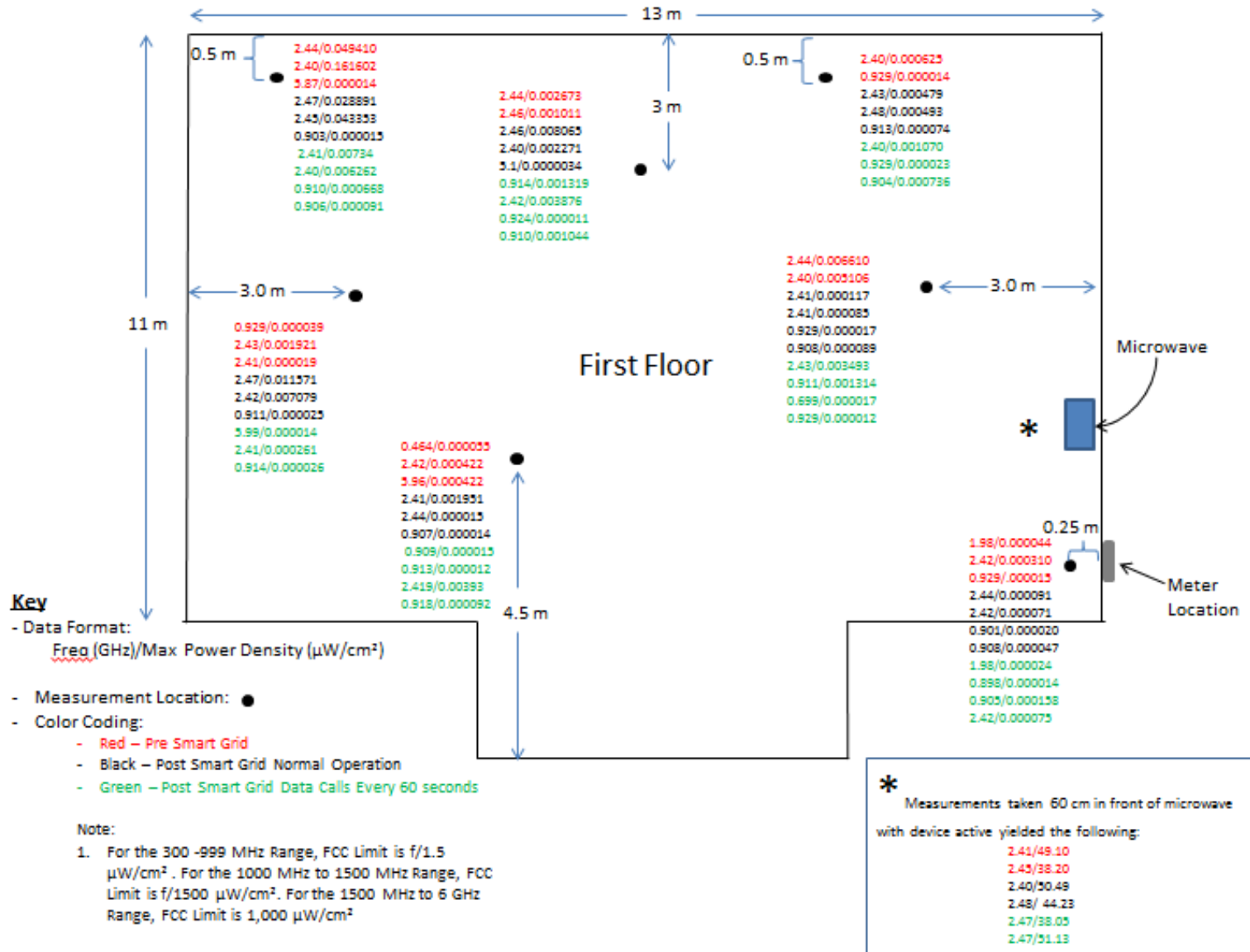


Figure 3: Measured Instantaneous Peak Energy on Second Floor of Naperville Home

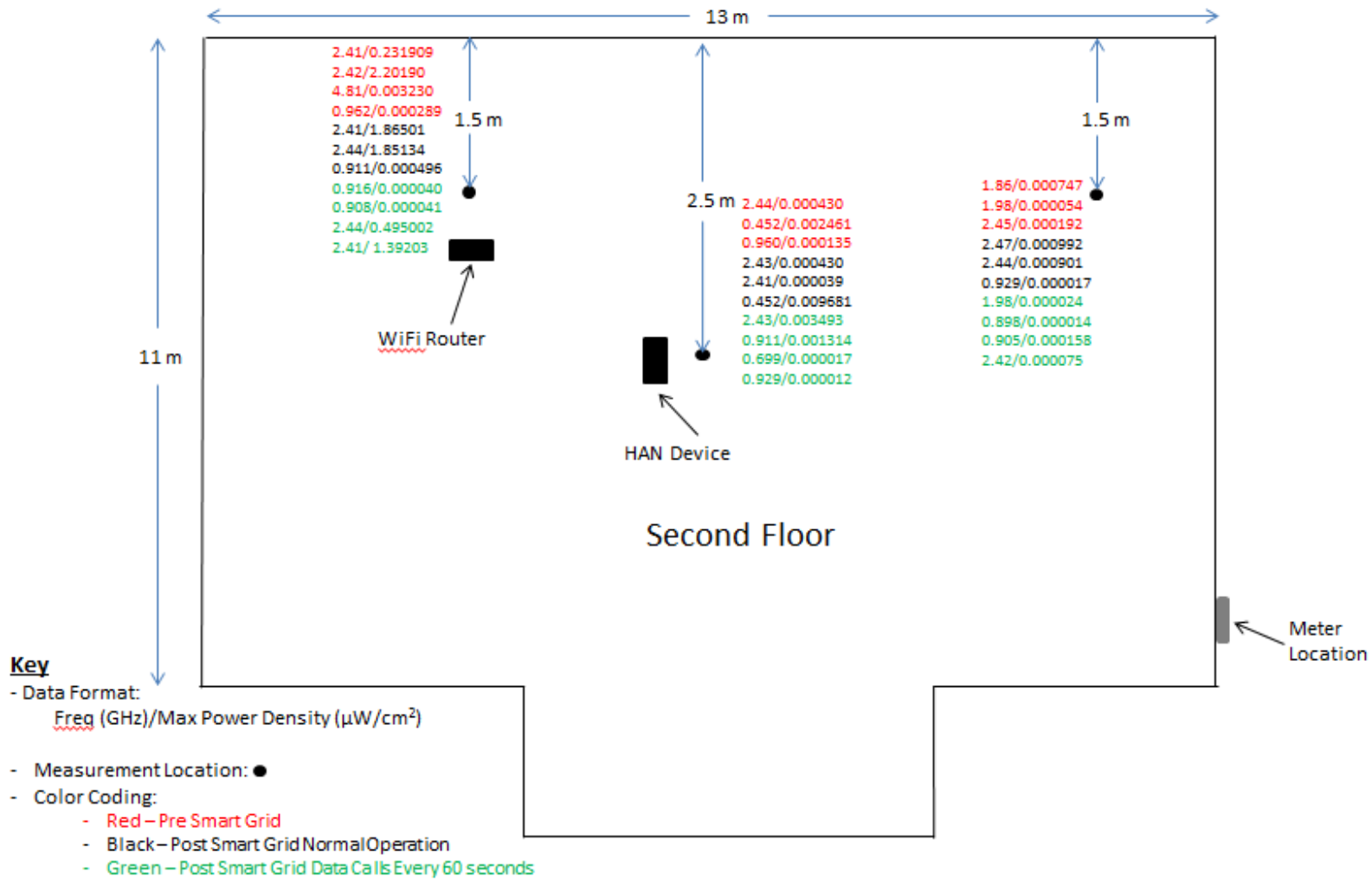
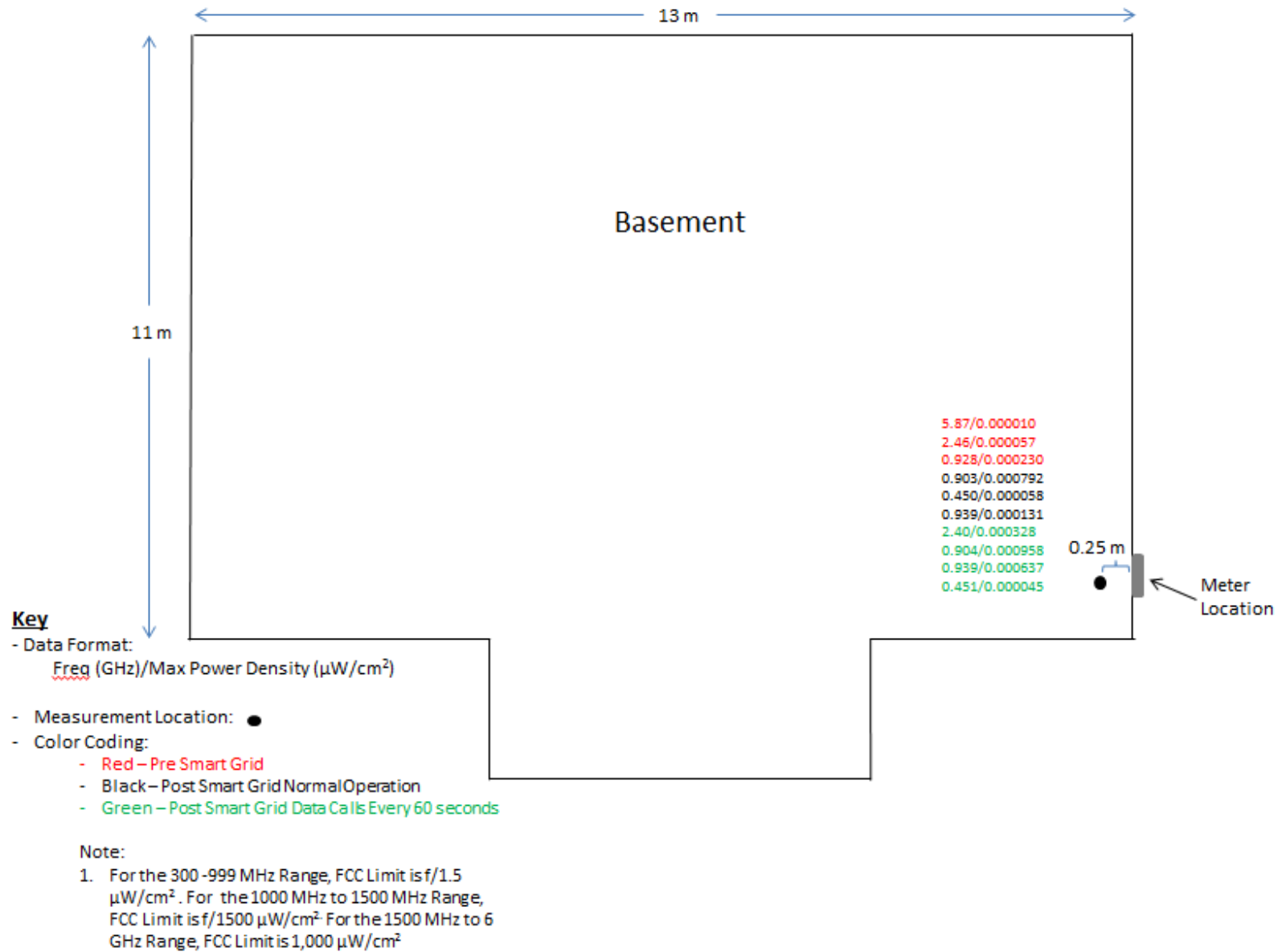


Figure 4: Measured Instantaneous Peak Energy in Basement of Naperville Home



4.3. Tropos 7320 Mesh Router and Elster Gatekeeper Field Measurements

Field measurements were observed at an operational Tropos 7320 mesh router and Elster Gatekeeper. The objective of this portion of the testing was to capture the RF contribution from this equipment to the Naperville RF environment directly underneath the devices mounted on the light pole. Measurements of the Tropos 7320 Mesh Router (the Tropos 6320 Mesh Router was not tested as it is the weaker of the two devices that will be used in Naperville) and Elster EnergyAxis Gatekeeper were taken with the devices installed and configured in a field setting (street lights used for Tropos and Gatekeeper mounting will average between 7.6 to 12.2 m in height). The Narda RF measurement antenna was mounted on a tripod with a height of 1.8 m and measurements were taken at 0m, 1.5m, 3m, and from 5m up to 30m in 5m increments away from the pole on a horizontal plane. Measurements were also taken 0m, 1.5m, 3m, and from 5m up to 30m in 5m increments away from the base of the pole at 90°, 180°, and 270° angles from the plane of the Gatekeeper device (total of 36 test points). See Figure 6 for example measurement locations and Figure 7 for typical device mounting locations.

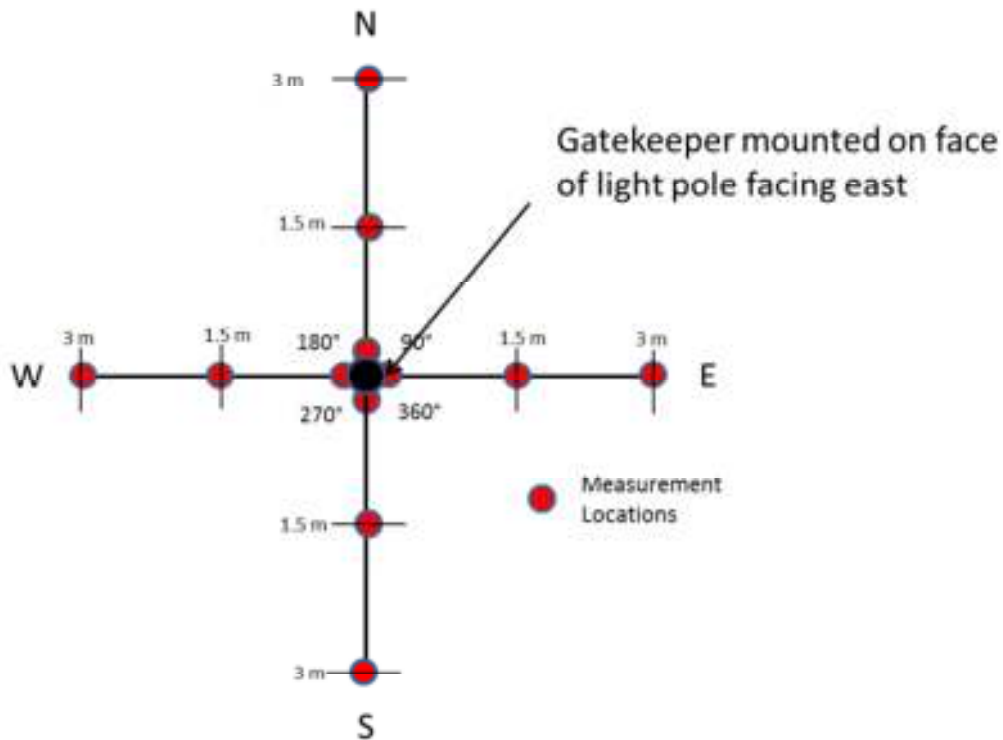


Figure 6. Select Measurement Locations (Top Down View)

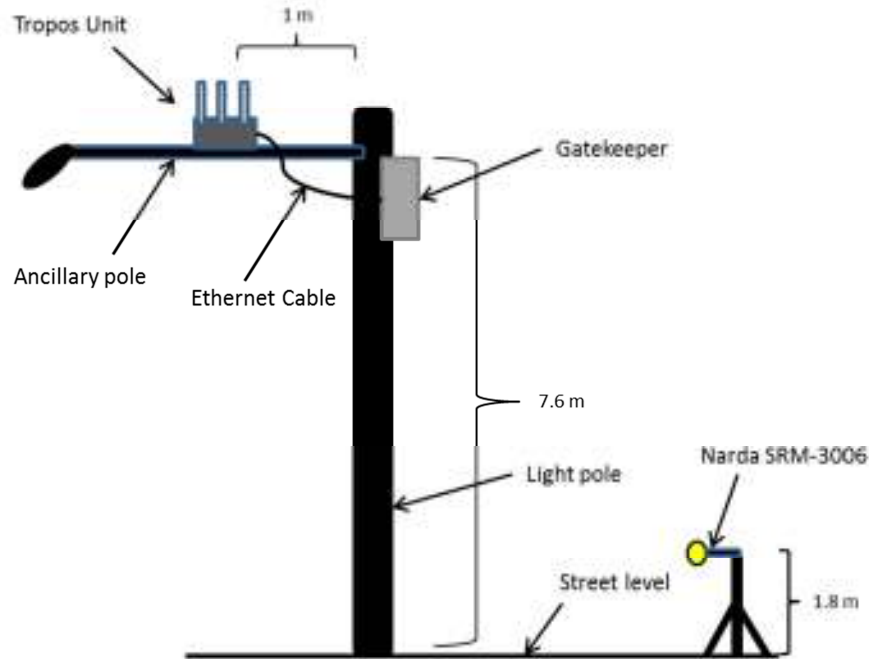


Figure 7. Device Mounting Locations (Side View)

The results of these tests confirmed lab testing and manufacturer’s specifications as all measurements fell below FCC limits. Instantaneous peak measurements of the Elster Gatekeeper ranged between $0.0000129 \mu\text{W}/\text{cm}^2$ and $0.0225400 \mu\text{W}/\text{cm}^2$ (Please see *RF Emissions Testing Plan and Results* for full test data results). Instantaneous peak measurements of the Tropos 7320 Mesh Router ranged between $0.0000076 \mu\text{W}/\text{cm}^2$ and $0.0001711 \mu\text{W}/\text{cm}^2$ (Please see *RF Emissions Testing Plan and Results* for full test data results).

The Tropos device uses a higher gain omnidirectional antenna with a vertical beam width of 30 degrees. Since the Tropos device that was being measured was located more than 20 feet off the ground, the measured RF Power under the radio was not from main lobe of the antenna. As the distance from the Tropos radio was increased, the effective gain of the antenna increased and in some cases the measured power density from the Tropos unit actually increased. The Tropos unit was nearly un-measurable when located on the light pole and measurements taken at the 2.4 GHz and 5.4 GHz frequencies, could just as likely have been from a resident’s Wi-Fi router (Please see *RF Emissions Testing Plan and Results* for full test data results).

The below table contains a portion of the field RF measurements related to the Tropos 7320 and Elster Gatekeeper (the full set of data can be found in the document titled *RF Emissions Testing – Plan and Results*). The objective of this portion of the testing was to capture the RF contribution from this equipment to the Naperville RF environment directly underneath the devices mounted on the light pole.

Table 6: Tropos and Gatekeeper Measurements Observed Near Light Pole

Angle (Degrees)	Distance (m)	Frequency (GHz)	Max Instantaneous Power Density ($\mu\text{W}/\text{cm}^2$)	Percent of FCC Limit	Equipment
0	0	0.903	0.000404	0.000067%	Gatekeeper
0	0	0.911	0.000166	0.000027%	Gatekeeper
0	0	0.914	0.0000997	0.000016%	Gatekeeper
0	0	2.46	0.000116	0.000012%	Tropos
0	0	2.45	0.0001711	0.000017%	Tropos
0	1.5	0.903	0.0095	0.001578%	Gatekeeper
0	1.5	0.908	0.0084	0.001388%	Gatekeeper
0	1.5	0.904	0.0083	0.001377%	Gatekeeper
0	1.5	0.911	0.0075	0.001235%	Gatekeeper
0	1.5	2.42	0.0000395	0.000004%	Tropos
0	1.5	2.41	0.0000335	0.000003%	Tropos
0	3	0.903	0.003012	0.000500%	Gatekeeper
0	3	0.913	0.00178	0.000292%	Gatekeeper
0	3	0.911	0.001255	0.000207%	Gatekeeper
0	3	0.904	0.00154	0.000256%	Gatekeeper
0	3	2.41	0.0000761	0.000008%	Tropos
0	3	2.42	0.0000222	0.000002%	Tropos
90	0	0.911	0.0009857	0.000162%	Gatekeeper
90	0	0.903	0.0007783	0.000129%	Gatekeeper
90	0	0.914	0.0007558	0.000124%	Gatekeeper
90	0	2.43	0.000011	0.000001%	Tropos
90	1.5	0.904	0.00206	0.000342%	Gatekeeper
90	1.5	0.91	0.009259	0.001526%	Gatekeeper
90	1.5	0.914	0.009428	0.001547%	Gatekeeper
90	1.5	2.42	0.0000118	0.000001%	Tropos
90	1.5	2.41	0.0000107	0.000001%	Tropos
90	1.5	5.47	0.0000815	0.000008%	Tropos
90	3	0.911	0.02009	0.003308%	Gatekeeper
90	3	0.909	0.0000162	0.000003%	Gatekeeper
90	3	0.904	0.0000129	0.000002%	Gatekeeper
90	3	0.908	0.02254	0.003724%	Gatekeeper
90	3	2.42	0.0000287	0.000003%	Tropos
90	3	2.41	0.000046	0.000005%	Tropos
90	3	2.41	0.0000456	0.000005%	Tropos

Angle (Degrees)	Distance (m)	Frequency (GHz)	Max Instantaneous Power Density ($\mu\text{W}/\text{cm}^2$)	Percent of FCC Limit	Equipment
180	0	0.906	0.0005715	0.000095%	Gatekeeper
180	0	0.907	0.0002904	0.000048%	Gatekeeper
180	0	0.902	0.0001945	0.000032%	Gatekeeper
180	0	5.52	0.0000078	0.000001%	Tropos
180	0	2.42	0.0000076	0.000001%	Tropos
180	0	5.58	0.0000078	0.000001%	Tropos
180	1.5	0.91	0.008973	0.001479%	Gatekeeper
180	1.5	0.906	0.002906	0.000481%	Gatekeeper
180	1.5	0.907	0.003098	0.000512%	Gatekeeper
180	1.5	0.908	0.00254	0.000420%	Gatekeeper
180	1.5	2.4	0.0000148	0.000001%	Tropos
180	1.5	5.48	0.0000908	0.000009%	Tropos
180	3	0.913	0.0002083	0.000034%	Gatekeeper
180	3	0.909	0.0000538	0.000009%	Gatekeeper
180	3	0.904	0.000044	0.000007%	Gatekeeper
180	3	2.42	0.0000204	0.000002%	Tropos
180	3	2.41	0.0000158	0.000002%	Tropos
180	3	2.42	0.0000131	0.000001%	Tropos
270	0	0.913	0.0002083	0.000034%	Gatekeeper
270	0	2.11	0.00002037	0.000002%	Tropos
270	0	2.41	0.00001584	0.000002%	Tropos
270	0	2.42	0.00001308	0.000001%	Tropos
270	1.5	2.41	0.00001891	0.000002%	Tropos
270	1.5	2.41	0.00001876	0.000002%	Tropos
270	1.5	2.42	0.0000154	0.000002%	Tropos
270	3	2.41	0.000098	0.000010%	Tropos
270	3	2.41	0.00003154	0.000003%	Tropos

4.4. Ambient Environments in Naperville

Field measurements were taken at two heavily trafficked Naperville intersections (Chicago Avenue and Washington Street as well as Jefferson Avenue and Main Street) on 9/2/2011 during the afternoon. Also, measurements were taken at Neuqua Valley High School in the afternoon both during and after school on 9/6/2011 and 9/7/2011 respectively. The data shows that there are multiple sources of RF currently present in Naperville including cell phone towers, Wi-Fi, radio communications, television broadcasts, and many others. All of these frequencies are present prior to mass-market deployment of smart meters and smart grid related hardware. These ambient RF levels all fell well below the FCC

mandated limits and are in the same instantaneous maximum power density range as smart meter related equipment.

Table 7: Ambient RF Field Measurements at the Naperville intersection of Chicago and Washington

Ambient RF Field Measurements		
Location: Chicago and Washington		
SE Corner	Frequency [GHz]	Max Instantaneous Peak [$\mu\text{W}/\text{cm}^2$]
1	0.939	0.0387
2	0.938	0.0111
3	0.865	0.007934
4	0.864	0.00312
5	0.903	0.001789
6	2.415	0.0000071
NE Corner	Frequency [GHz]	Max Instantaneous Peak [$\mu\text{W}/\text{cm}^2$]
1	0.938	0.1394
2	0.939	0.008768
3	0.865	0.004679
4	0.864	0.003545
5	0.905	0.003155
6	2.417	0.0006591
NW Corner	Frequency [GHz]	Max Instantaneous Peak [$\mu\text{W}/\text{cm}^2$]
1	2.42	0.004469
2	2.416	0.004113
3	0.938	0.003963
4	2.417	0.003929
5	2.419	0.003489
SW Corner	Frequency [GHz]	Max Instantaneous Peak [$\mu\text{W}/\text{cm}^2$]
1	0.939	0.02605
2	0.938	0.01413
3	0.865	0.00855
4	2.415	0.006219
5	2.414	0.006098

Table 8: Ambient RF Field Measurements at Neuqua Valley High School

Location	Non-school Day 9/6/2011		School Day 9/7/2011	
	Frequency [GHz]	Max Instantaneous Peak [$\mu\text{W}/\text{cm}^2$]	Frequency [GHz]	Max Instantaneous Peak [$\mu\text{W}/\text{cm}^2$]
Main Entrance (Outside)	0.881	0.002959	-	-
	0.882	0.002398	-	-
	1.94	0.002061	-	-
	1.966	0.001874	-	-
	0.886	0.001548	-	-
Main Entrance/Foyer (Inside)	0.845	0.000587	-	-
	1.88	0.000534	-	-
	2.413	0.000266	-	-
	2.414	0.000261	-	-
	2.412	0.000255	-	-
Wireless Access D100	2.413	0.007461	0.819	0.0931
	2.412	0.009431	2.463	0.05023
	2.41	0.009308	2.462	0.04766
	2.411	0.01245	2.461	0.04627
	2.41	0.01117	2.46	0.04422
	1.866	0.0000972	1.901	0.00931
	2.4	0.01774	-	-

5. Near-Field Effects

When measuring the RF emissions from smart grid equipment and common household devices, it is important to understand the near field effects that can influence these measurements. Near field effects generally take place at approximately one wavelength or less from the emitting antenna, which is extremely close to the equipment transmitting the signal. They are caused by the electric and magnetic field effects from the currents and charges within the antenna as well as absorption of the electromagnetic field by the measurement device or any other objects in the vicinity. This means that for measurements taken at one wavelength or less, there will be a higher degree of inaccuracy relative to those taken outside of two wavelengths where near field effects are no longer of concern. The area between one and two wavelengths is generally referred to as the transition zone as this is the region where near-field effects still come into play, however they are not dominant. Therefore, in order to fully demonstrate the worst case scenario maximum power density of smart meters, it is important to conduct measurements at distances less than two wavelengths as well as to observe measurements taken at greater than two wavelengths. Additionally, it is important to obtain theoretical values at distances where near-field effects are of concern and compare the theoretical values to the observed values. The following are the mathematical steps necessary calculate the wavelength of the standard configuration smart meter equipment in Naperville.

Wavelength is calculated using the relation:

$$v = c / \lambda$$

where,

v = frequency,

c = the speed of light (3×10^8 m/s) and

λ = wavelength

For smart grid (Elster REX2 Meter and Elster Gatekeeper) equipment we use:

$$v = 902 \text{ MHz}$$

Solving for λ we get:

$$\lambda = (3 \times 10^8 \text{ m/s}) / (902 \times 10^6 \text{ Hz}) = 0.33 \text{ meters (1.082 feet)}$$

Based on these calculations for the smart grid equipment in Naperville, measurements taken at 20 and 23 cm, which are less than one wavelength, could have a higher level of inaccuracy due to near-field effects. Fortunately, we are able to determine the power density at these distances by utilizing a field measurement observed from a distance of greater than two wavelengths, along with the inverse square law. The inverse square law states that an electromagnetic wave's power density is proportional to the inverse square of the distance from a point source.

$$I = P/A = P/(4 \times \pi \times r^2)$$

Where,

I = Intensity (power/unit area)

P = Antenna Power

r = distance from the point source (in this case the antenna)

By applying the inverse square law to the measurements taken at 1 meter (~3X the wavelength of the smart meter and therefore well outside of the area where near field effects come into play; and also equivalent to the distance at which the Narda SRM-3006 device is calibrated) the theoretical values shown in Tables 9, 10, and 11 were calculated for all smart grid equipment and common household devices tested.

These calculations demonstrate that even under the worst-case scenario, the instantaneous peak measurements observed from a smart meter are below the FCC Maximum Permissible Emission (MPE) limit. Furthermore, since the FCC allows time averaging over a 30 minute period for "source-based" equipment which has an inherent transmit duty cycle, the power density is further reduced by a factor of 1/"Transmit duty cycle". Since the worst case transmit duty cycle is 0.1%, the average power density is calculated by taking the worst case peak measurement and reducing this by a factor of 1000 due to the lower transmit duty cycle. It is interesting to note that the low transmit duty cycle is directly correlated to the infrequent number of times that the NSGI smart grid devices are transmitting per day.

Table 9 shows the measured and calculated instantaneous peak values of smart grid equipment and household devices. Table 10 shows the measured and calculated instantaneous peak values as a percentage of the MPE. Table 11 shows the measured and calculated average power density as a percentage of MPE. Table 11 accounts for the fact that the smart meters are transmitting at a maximum of 0.1% of the day. Again, the FCC's exposure guidelines allow for the use of 30 minute time averaging for average power density calculations of smart meters because the RF electromagnetic fields associated with smart meters are source-based, meaning they can be associated with a specific emitter or set of

emitters, and also because the devices behave based on an inherent property or duty cycle (FCC, 1997).

The results of these calculations show that at worst case power levels, the Elster REX2 meter's average power density is approximately 12,000 times lower than the FCC limit for a person sitting 20 cm in front of a smart meter for a 30 minute time period.

Table 9: Measured and Calculated Instantaneous Peak Values of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Part II											
(All values in $\mu\text{W}/\text{cm}^2$ and are an instantaneous maximum peak)											
Distance from source [m]	Elster REX2 Meter			Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (WiFi) Router	
	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	100% Packet Rate [$\mu\text{W}/\text{cm}^2$]	100% Transmit Rate [$\mu\text{W}/\text{cm}^2$]	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Call [$\mu\text{W}/\text{cm}^2$]	YouTube Stream [$\mu\text{W}/\text{cm}^2$]	Idle [$\mu\text{W}/\text{cm}^2$]	YouTube Stream to Laptop [$\mu\text{W}/\text{cm}^2$]
0.2	10.7250	50.1250	35.1600	115.6350	34.3953	0.9257	174.5850	0.5710	1.5950	0.4695	1.5800
0.23	8.1096	37.9016	26.5859	87.4364	26.0077	0.6999	132.0110	0.4317	1.2060	0.3550	1.1947
1	0.4290	2.0050	1.4064	4.6254	1.3758	0.0370	6.9834	0.0228	0.0638	0.0188	0.0632

Notes:

1. Values at 1 meter were measured during lab and field testing using the Narda SRM-3006 device. Values at 0.25, 0.23, and 0.2 meters were calculated by applying the $1/r^2$ law to the 1 meter values.
2. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
3. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.

Table 10: Percent of FCC Limit of Measured and Calculated Instantaneous Peak Values of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Part II											
(All values in % of FCC limit and are an instantaneous maximum peak)											
Distance from source [m]	Elster REX2 Meter			Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (WiFi) Router	
	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	100% Packet Rate [$\mu\text{W}/\text{cm}^2$]	100% Transmit Rate [$\mu\text{W}/\text{cm}^2$]	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Call [$\mu\text{W}/\text{cm}^2$]	YouTube Stream [$\mu\text{W}/\text{cm}^2$]	Idle [$\mu\text{W}/\text{cm}^2$]	YouTube Stream to Laptop [$\mu\text{W}/\text{cm}^2$]
0.2	1.7845%	8.3403%	5.8502%	19.2404%	5.7230%	0.0926%	17.4585%	0.0571%	0.1595%	0.0470%	0.1580%
0.23	1.3494%	6.3064%	4.4236%	14.5485%	4.3274%	0.0700%	13.2011%	0.0432%	0.1206%	0.0355%	0.1195%
1	0.0714%	0.3336%	0.2340%	0.7696%	0.2289%	0.0037%	0.6983%	0.0023%	0.0064%	0.0019%	0.0063%

Notes:

1. Values at 1 meter were measured during lab and field testing using the Narda SRM-3006 device. Values at 0.25, 0.23, and 0.2 meters were calculated by applying the $1/r^2$ law to the 1 meter values.
2. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
3. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.

Table 11: Measured and Calculated Average Power Density as a Percentage of MPE of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Part II											
(All values in % of FCC limit and are an instantaneous maximum peak)											
Distance from source [m]	Elster REX2 Meter			Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (WiFi) Router	
	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	100% Packet Rate [$\mu\text{W}/\text{cm}^2$]	100% Transmit Rate [$\mu\text{W}/\text{cm}^2$]	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Call [$\mu\text{W}/\text{cm}^2$]	YouTube Stream [$\mu\text{W}/\text{cm}^2$]	Idle [$\mu\text{W}/\text{cm}^2$]	YouTube Stream to Laptop [$\mu\text{W}/\text{cm}^2$]
0.2	0.0018%	0.0083%	0.0059%	0.0192%	0.0057%	0.0926%	17.4585%	0.0571%	0.1595%	0.0470%	0.1580%
0.23	0.0013%	0.0063%	0.0044%	0.0145%	0.0043%	0.0700%	13.2011%	0.0432%	0.1206%	0.0355%	0.1195%
1	0.0001%	0.0003%	0.0002%	0.0008%	0.0002%	0.0037%	0.6983%	0.0023%	0.0064%	0.0019%	0.0063%

Notes:

1. Values at 1 meter were measured during lab and field testing using the Narda SRM-3006 device. Values at 0.25, 0.23, and 0.2 meters were calculated by applying the $1/r^2$ law to the 1 meter values.
2. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
3. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.

6. Conclusions

This report demonstrates that even under the worst-case scenario, the instantaneous peak measurements observed from a smart meter are far below the FCC Maximum Permissible Emission (MPE) limit, which is the allowed average power density over a 30-minute interval. It is even more important to note the infrequent number of times that the NSGI smart grid devices are transmitting per day. Table 12 shows the measured average power density of smart grid equipment and household devices. Table 13 shows the measured average power density as a percentage of the MPE. Tables 12 and 13 both account for the fact that the smart meters are transmitting at a maximum of 0.1% of the day. The FCC's exposure guidelines allow for the use of 30 minute time averaging for average power density calculations of smart meters because the RF electromagnetic fields associated with smart meters are source-based, meaning they can be associated with a specific emitter or set of emitters, and also because the devices behave based on an inherent property or duty cycle (FCC, 1997).

The column labeled "REX 2 Meter: Worse Case" in Table's 12 and 13 represent the highest power densities measured in this report. The results of this report show that at worst case power levels the Elster REX2 meter's measured average power density is approximately 31,000 times lower than the FCC limit for a person sitting 20 cm in front of a smart meter for a 30 minute time period. The results of our calculations based on measurements taken at 1m (outside of the area where near field effects come into play) show that at worst case power levels, the Elster REX2 meter's average power density is approximately 12,000 times lower than the FCC limit for a person sitting 20 cm in front of a smart meter for a 30 minute time period.

Table 12: Average Power Density of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Part II									
(All values in $\mu\text{W}/\text{cm}^2$, are an average power density, and normalized to the ambient RF)									
Distance from source [m]	REX2 Meter	Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (WiFi) Router	
	Worst Case [$\mu\text{W}/\text{cm}^2$]	Standard Config. Smart Meter [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Standard Config. [$\mu\text{W}/\text{cm}^2$]	Call [$\mu\text{W}/\text{cm}^2$]	YouTube Stream [$\mu\text{W}/\text{cm}^2$]	Idle [$\mu\text{W}/\text{cm}^2$]	YouTube Stream to Laptop [$\mu\text{W}/\text{cm}^2$]
-3	0.000151	n/a	n/a	n/a	0.139860	0.006160	0.003840	0.005702	0.002520
-1	0.000108	n/a	n/a	n/a	0.375800	0.015400	0.039680	0.020440	0.064000
-0.23	0.002272	n/a	n/a	n/a	0.545400	0.320000	0.131260	0.036480	0.880000
-0.2	0.002449	n/a	n/a	n/a	0.635760	0.336000	0.186380	0.044684	0.898800
0.2	0.015456	0.011742	0.005931	0.277600	81.386000	0.957000	0.783000	0.268500	0.984600
0.23	0.013884	0.003758	0.002883	0.163570	35.644000	0.736400	0.216600	0.032782	0.899000
1	0.002005	0.004625	0.001376	0.037026	6.983400	0.022838	0.063800	0.018780	0.063200
3	0.000690	0.000162	0.000278	0.001300	1.362600	0.009410	0.003240	0.002990	0.002280
5	0.000076	0.000126	0.000118	0.019974	0.283480	0.002400	0.001068	0.005412	0.001440

Notes:

1. Measurements behind the Standard Configuration REX2 Meter and the Standard Configuration A3 meter were not recorded as peak measurements because they could not be detected due to the signal attenuation through the meter box. It should also be noted that the exterior walls and siding of a home would provide additional signal strength reductions.
2. Measurements behind the Gatekeeper and Mesh Router were not recorded as these devices use omnidirectional antennas, which transmit uniform signals in all horizontal directions.
3. The negative distance measurements for the Wi-Fi router and cell phone were taken on the opposite side of the device relative to the positive distance measurements. In actuality there is no negative distance for the cell phone and Wi-Fi router because the antennas in these devices are omnidirectional.
4. The standard configuration smart meter, 100% packet rate smart meter, and 100% transmit rate smart meter results are from three unique meters in three unique meter sockets.
5. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
6. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.
7. Please note that measurements taken at 0.23, 0.2, -0.2, and -0.23 m can be influenced by near-field effects (See Section 5)

Table 13: Average Power Density as a Percentage of MPE of SG Equipment and Household Devices

City of Naperville: NSGI - RF Emissions Testing Pilot II									
(All values in Average % of FCC limit and are an instantaneous maximum measured peak)									
Distance from source [m]	REX2 Meter	Elster A3 Meter	Elster Gatekeeper	Tropos 7320 Mesh Router	Microwave	Cell Phone		Wireless (Wi-Fi) Router	
	Worst Case	Standard Config. Smart Meter	Standard Config.	Standard Config.	Standard Config.	Call	YouTube Stream	Idle	YouTube Stream to Laptop
-3	0.000025%	n/a	n/a	n/a	0.013986%	0.000616%	0.000384%	0.000570%	0.000252%
-1	0.000018%	n/a	n/a	n/a	0.037580%	0.001540%	0.003968%	0.002044%	0.006400%
-0.23	0.000378%	n/a	n/a	n/a	0.054540%	0.032000%	0.013126%	0.003648%	0.088000%
-0.2	0.000407%	n/a	n/a	n/a	0.063576%	0.033600%	0.018638%	0.004468%	0.089880%
0.2	0.003197%	0.001954%	0.000987%	0.027760%	8.138600%	0.095700%	0.078300%	0.026850%	0.098460%
0.23	0.002651%	0.000625%	0.000480%	0.016357%	3.564400%	0.073640%	0.021660%	0.003278%	0.089900%
1	0.000234%	0.000770%	0.000229%	0.003703%	0.698340%	0.002284%	0.006380%	0.001878%	0.006320%
3	0.000112%	0.000027%	0.000046%	0.000130%	0.136260%	0.000941%	0.000324%	0.000299%	0.000228%
5	0.000034%	0.000021%	0.000020%	0.001997%	0.028348%	0.000240%	0.000107%	0.000541%	0.000144%

Notes:

1. Measurements behind the Standard Configuration REX2 Meter and the Standard Configuration A3 meter were not recorded as peak measurements because they could not be detected due to the signal attenuation through the meter box. It should also be noted that the exterior walls and siding of a home would provide additional signal strength reductions.
2. Measurements behind the Gatekeeper and Mesh Router were not recorded as these devices use omnidirectional antennas, which transmit uniform signals in all horizontal directions.
3. The negative distance measurements for the Wi-Fi router and cell phone were taken on the opposite side of the device relative to the positive distance measurements. In actuality there is no negative distance for the cell phone and Wi-Fi router because the antennas in these devices are omnidirectional.
4. The standard configuration smart meter, 100% packet rate smart meter, and 100% transmit rate smart meter results are from three unique meters in three unique meter sockets.
5. Standard configuration meter (<0.1% duty cycle), 100% packet rate meter (~50% duty cycle), 100% transmit rate meter (100% duty cycle).
6. Please note that while the measurement results for the standard configuration meter, the peak power for the 100% packet rate meter, and the 100% transmit rate meter appear to be inconsistent, the results were repeatable. These measurement inconsistencies could be due to many factors including, the near field effects associated with RF Power measurements below a distance of two wavelengths from the source, the different antenna gain characteristics of each meter socket, and finally the different RF reflection characteristics of the room when the two different meters were measured.
7. Please note that measurements taken at 0.23, 0.2, -0.2, and -0.23 m can be influenced by near-field effects (See Section 5)

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