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MEASUREMENTS OF EM RADIATION FROM IN-HOUSE POWER LINE TELECOMMUNICATION (PLT) DEVICES OPERATING IN A RESIDENTIAL ENVIRONMENT

FIELD TEST REPORT

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North American Broadcasters Association (NABA)

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1. Introduction

The North American Broadcasters Association (NABA) contracted the Communications Research Centre (CRC) to carry out Measurements of Electromagnetic (EM) radiation from Power Line Telecommunication (PLT) devices operating in a residential environment. This document describes the test procedure and results for the measurement of EM radiation to determine the extent of potential interference from PLT devices to broadcast services operating in a residential environment. The tests were carried out by CRC from November 2008 to January 2009.

Commercially available PLT devices considered for field trial are first presented in Section 2. A laboratory evaluation of these devices is presented in Section 3, which aims at characterizing conducted emissions of these devices as a reference point for EM radiation measurements. Section 4 contains the field trial methodology and results analysis. A conclusion with general comments on the field trial report is presented in Section 5.

The results of the laboratory evaluation are presented in Appendix A. The results of the RF field strength measurement with the visited sites description are presented in Appendix B.

2. PLT Devices Description for Field Trial

A total of eight (8) commercially-available devices representing the various PLT standards were considered for field trial. These PLT devices, shown in the table below, were evaluated in the CRC laboratory prior to the field tests.

Device #	Manufacturer	Model	PLT Standard	Manufacturer Specification		
				Data Rate (Mbps)	Operating Frequency Range (MHz)	Region
1	TrendNet	TPL-202E	HomePlug 1.0 Turbo	85	4.5 – 21.0	North America
2	Panasonic	BL-PA100	HD-PLC	190	4.0 – 28.0	North America
3	Linksys	PLK200	HomePlug AV	100	Not Specified	North America
4	NetGear	XE102GNA	HomePlug 1.0	14	4.3 – 20.9	North America
5	NetGear	XE103G-100NAS	HomePlug 1.0	85	4.3 – 20.9	North America
6	NetGear	HDX101-100NAS	UPA	200	2.0 – 30.0	North America
7	Logitec	LPL-TX/S	UPA	200	2.0 – 30.0	Japan
8	CNC	CNC-1000	HomePlug 1.0	85	4.3 – 20.9	Japan

Table 2-1 List of PLT available for the field test

As can be seen in Table 2-1, many of the PLT devices use the same standard or different versions of a standard. Following the laboratory evaluation, it was decided to limit the number of PLT devices at one per standard for the field trial.

3. Laboratory Evaluation

The eight PLT devices from Table 2-1 were evaluated in the CRC laboratory prior to field trial. The primary objective of these tests was to characterize and compare all PLT devices on the following criteria:

- Operating frequency range
- Conducted power within the operating frequency range as specified by the manufacturer, see Table 2-1
- Conducted power up to 110 MHz
- General spectrum shape
- Quantify the radiated emission differences between data transfer mode and idle mode
- Quantify the difference between measurements using a peak detector and a quasi-peak detector

Moreover, the laboratory evaluation allowed us to understand the operation of these devices, more specifically:

- Practice measurement procedure and how the devices operate
- Study PLT devices data transfer mode and idle mode of operation
- Quantify PLT devices output power level

The laboratory characterization was done in two parts.

The first part of the laboratory evaluation was to assess the use of a quasi-peak detector for field trial. Quasi-peak detection is usually used for EM radiated emissions measurements in the frequency of operation of PLT devices. However, early work with a quasi-peak detector showed that this type of detector is meant to measure narrow band signals and will be inadequate to measure the wide band signals of PLT devices. This first part of this section explains this issue and will determine the relationship between measurements using peak and quasi-peak detectors.

The second part of the laboratory evaluation was to characterize and compare the PLT devices using conducted power measurements. This section contains the laboratory results for the three PLT devices that were chosen for field trial as well as the selection criteria.

3.1 Laboratory Tests Setup

The laboratory setup for the conducted power measurement is presented in Figure 3-1.

The AC electrical source came from the CRC main power through a step up transformer and a breaker box to isolate and convert the AC to 110-120 single phase voltage. Two outlets, used to plug in the PLT device pairs, were linked with a grounded 14/2 electrical cable of 1.75 meters.

In order to measure low signal levels above the operating frequency range of the PLT devices with better precision, a high-pass filter was used to attenuate the main PLT signal carriers present in the operating frequency range. This was necessary to measure the emissions up to 110 MHz without overloading the spectrum analyzer. As shown in Figure 3-1, two laboratory setups were used, one without and one with the high-pass filter. The high-pass filter was supplied by Tin Lee Electronics Ltd., model number HP7 30/33(40) B50, with a -3 dB cut-off frequency of 32 MHz. Only measurements above 35 MHz were done and recorded using this high-pass filter.

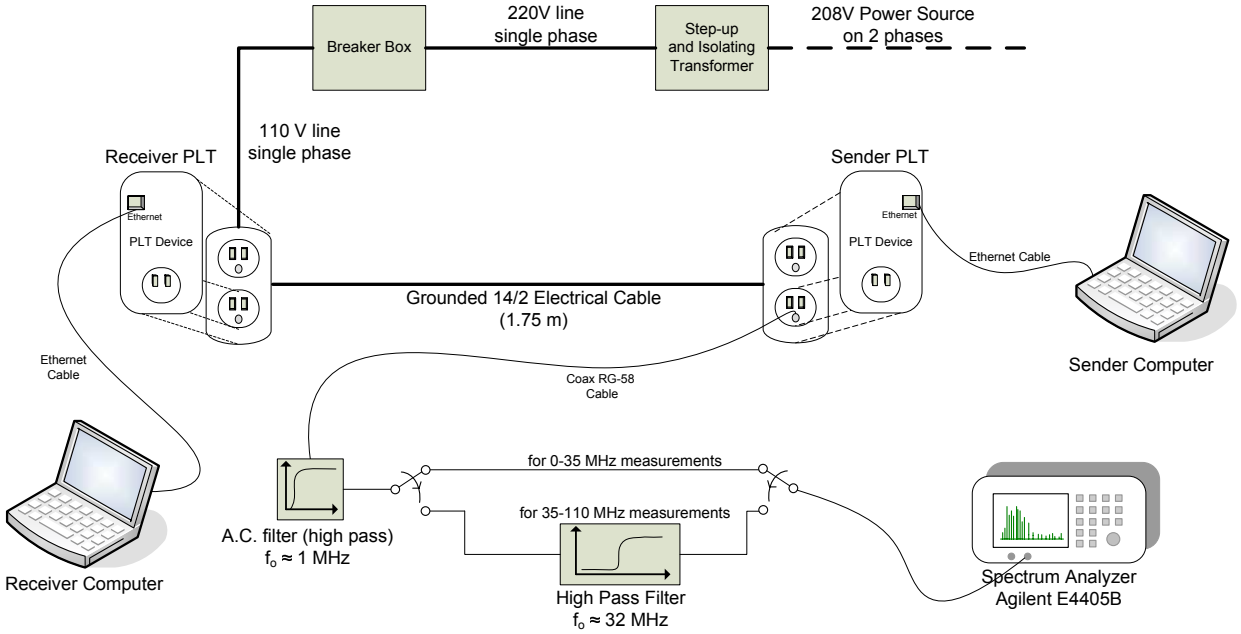


Figure 3-1: PLT Devices Conducted Power Measurements Test Bed

3.2 Peak vs. Quasi-Peak detector measurements in the context of PLT emissions

Electro-magnetic compatibility measurements in the frequency of operation of PLT devices are normally done using a quasi-peak detector. A quasi-peak detector consists of a peak detector followed by a lossy integrator that has a longer falling time than rising time. This type of detector is meant to measure the annoyance factor of impulse signals to other devices. Due to the complexity of its implementation, the quasi-peak detector available for the spectrum analyzer has an extremely slow response time. Measuring signals in the 1-108 MHz range could take up to two hours for a measurement that would take a few seconds using a regular peak detector. Therefore, peak detection was selected for the field trial measurements.

3.2.1 Test Methodology

Conducted power measurements were performed to compare peak versus quasi-peak detectors. The measurements were done over a small 100 kHz bandwidth at a 15 MHz center frequency. An average power measurement was performed in this 100 kHz band for each of the three PLT device pairs, and for each of the two detectors. The difference in average power was considered to be the difference between peak and quasi-peak detection. It was shown in the laboratory that this small 100 kHz bandwidth was wide enough so that results will be repeatable with other center frequencies.

This test was done for the three devices chosen for field trial, and the measurements were done while the PLT devices were sending data.

3.2.2 Test Results

The measurements shown in Table 3-1 revealed that the difference between peak and quasi-peak power was in the order of 6 to 7 dB. There was a slight variation between the devices which was expected since quasi-peak detection power will vary according to the signal burst rate, which was certainly not the same across all standards.

Device #	Average Peak Signal Level (dBµV)	Average Quasi-Peak Signal Level (dBµV)	Difference between Peak and Quasi-Peak detectors (dB)
2	83.2	75.8	**7.4**
3	92.1	85.9	**6.2**
6	92.5	86.7	**5.8**

Table 3-1: Peak vs. Quasi Peak Results

All the results presented in this report are done using peak detection due to limitations that are explained in the introduction of this section. Furthermore, the field trial results of this report do not include the signal level difference between quasi-peak and peak detection. The values of Table 3-1 were determined so that the field trial results could be compared to other emission studies.

3.3 Conducted Power Measurements

The conducted power measurements were done for the frequency range of 0 to 110 MHz using two modes of operation: Data Transfer mode and Idle mode.

The goal of the tests was to determine the output level injected into electrical lines up to 110 MHz in both modes and the bandwidth and spectral shape of these devices as specified by the manufacturer. The operating frequency range depends on the PLT standard as presented in Table 2-1.

3.3.1 Test Methodology

The test setup for these measurements is presented in Figure 3-1. In order to obtain good precision, the measurements were done from 0 to 110 MHz in consecutive frequency spans of 10 MHz wide with the spectrum analyzer set to a resolution bandwidth of 9 kHz and using peak detection. In general, the reference level of the spectrum analyzer was adjusted as low as possible without creating spectral overload. As explained in Section 3.1, a high-pass filter was used to obtain a better measurements precision for frequencies above 35 MHz. Because of this, a discontinuity in the noise floor can be observed in the results at 35 MHz.

A first measurement was done to evaluate the ambient noise level of the system. In this instance, no PLT devices were connected to the test bed.

Following this, the output level of each PLT device was measured from 0 to 110 MHz while the devices were transferring data at full data rate (data transfer mode). Finally, a third set of measurements was done while the devices were not actively transferring data (idle mode). The PLT output power level during the tests was the factory pre-set power, which was not found to be adjustable.

3.3.2 Test Results

The conducted power measurements for devices 2, 3 and 6, selected for field trials, are presented in this section. The detailed results of these tests for all the devices are available in Appendix A.

The measurement of the test bed noise floor is presented in Figure 3-2. The first observation is that our laboratory electrical line setup acts as an antenna that captures signals from other radiocommunication systems. The spikes between 85 MHz and 108 MHz are from local FM radio stations, while other spikes at other frequencies were intermittent and probably caused by other radiocommunication systems. It was necessary to take this into account when looking at the conducted emission results.

Another observation made during laboratory tests was that short wave radio reception was severely impaired by the proximity of active PLT devices. No measurement was done during field trial to quantify that observation.

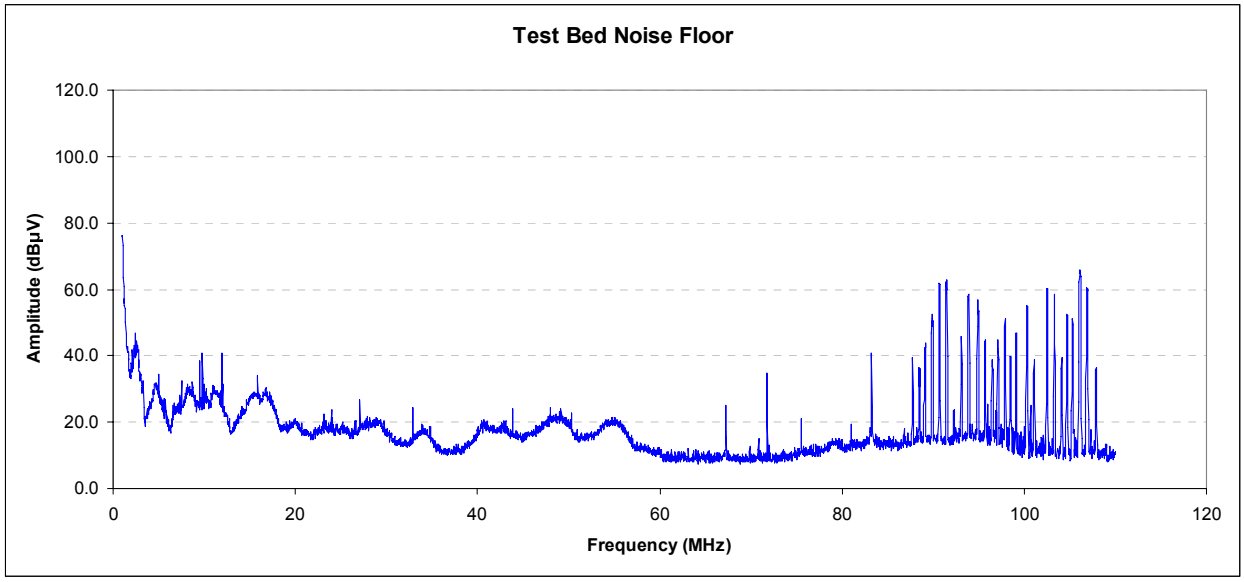


Figure 3-2: Conducted Measurements Test Setup Noise Floor

The results for devices 2, 3 and 6 are presented Figures 3-3, 3-4 and 3-5 respectively. The measurements, in dBµV, were made with the spectrum analyzer using peak detection and a 9 kHz resolution bandwidth. In each figure, the blue curve shows the conducted signal during data transfer and the green curve shows the conducted signal in idle mode. In each case, the measurements are made using maximum hold for a ten second duration.

As can be seen in the figures, the signal level in idle mode does not exceed the signal level in data transfer

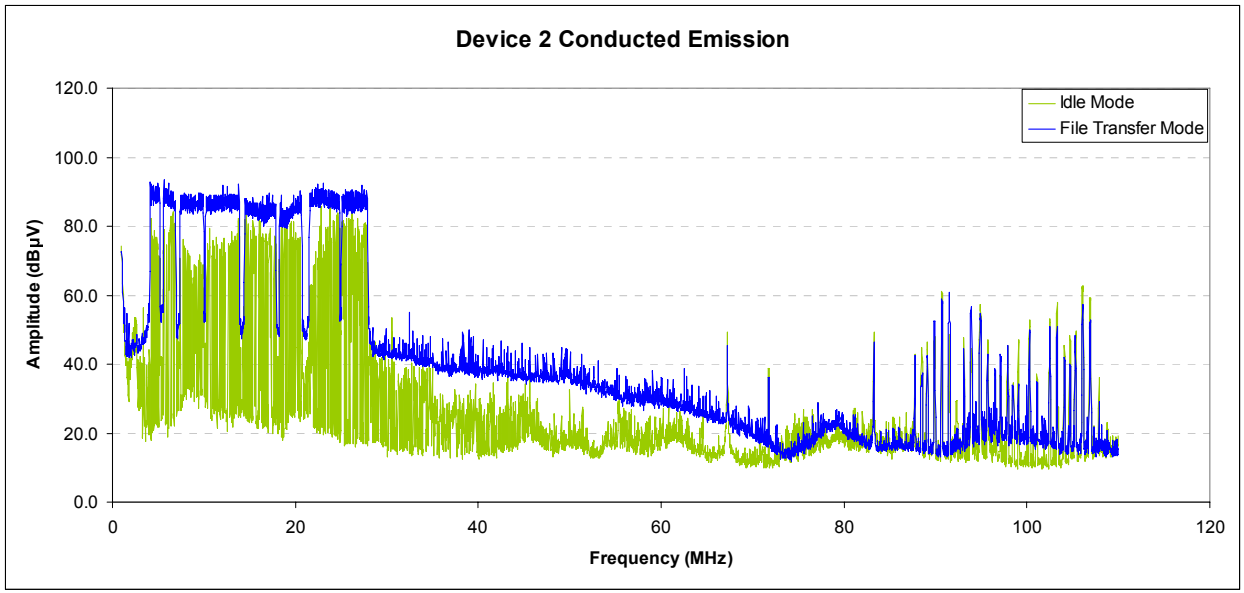


Figure 3-3: Conducted Power from Device 2 (HD-PLC standard)

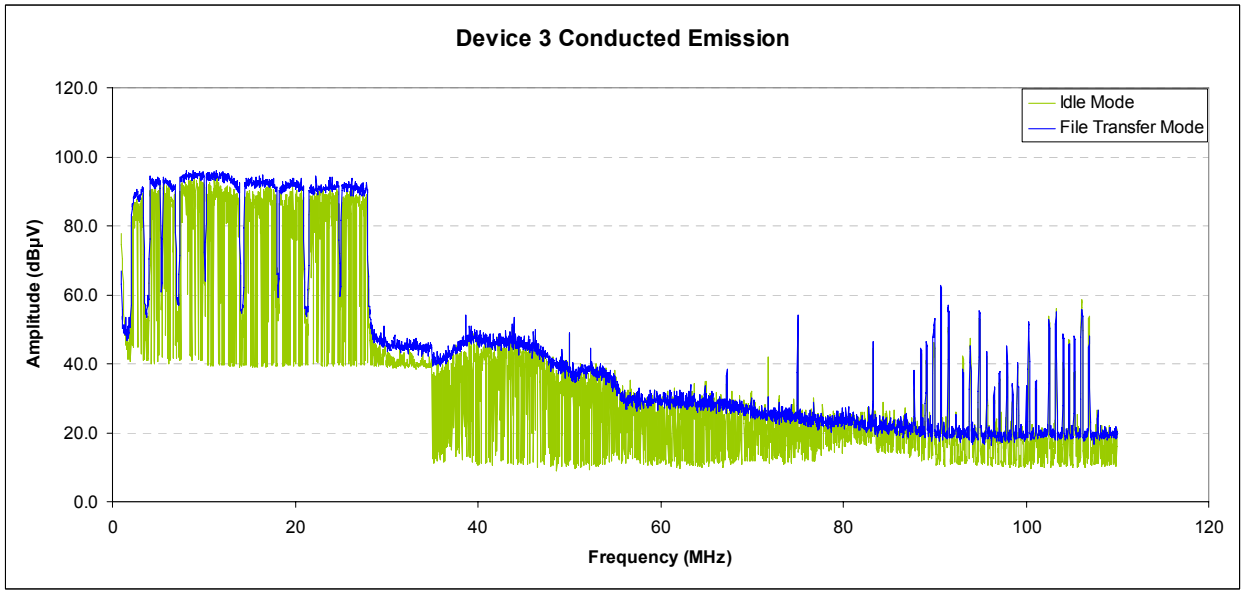


Figure 3-4: Conducted Power from Device 3 (Homeplug AV standard)

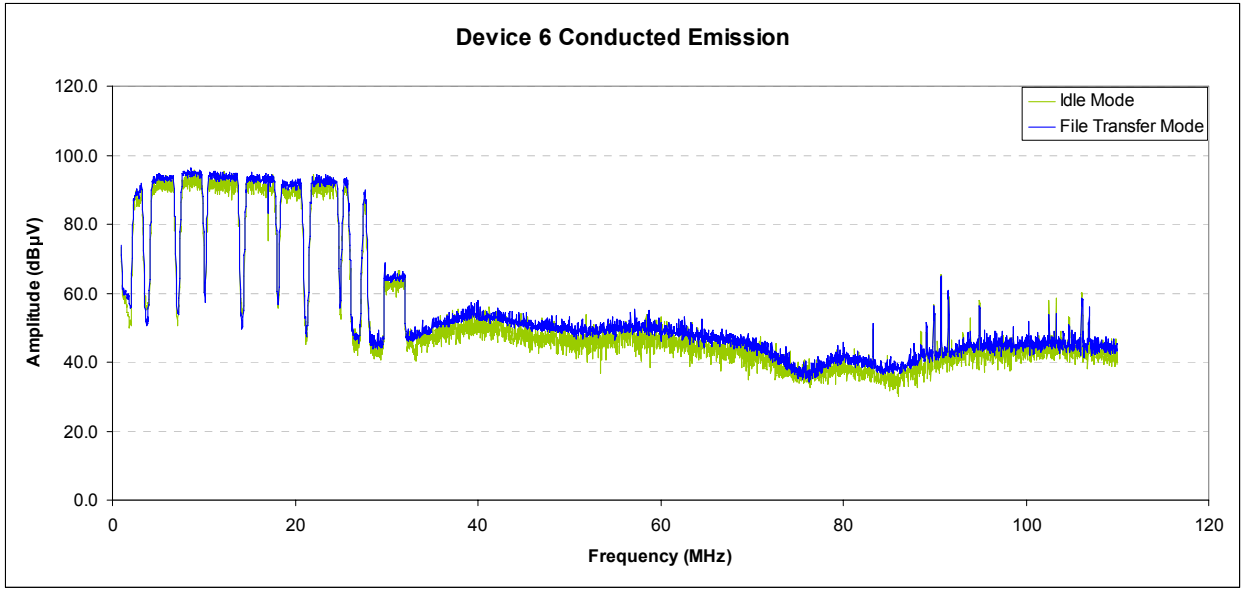


Figure 3-5: Conducted Power from Device 6 (UPA standard)

The conducted signal level for the three PLT devices chosen was representative of the worse case conditions for the output signal level and the bandwidth usage for their respective standards.

The following table is a summary of the calculated transmission power of the eight PLT devices under test within their operating frequency range with RBW of 9 kHz and Max Hold traces. The average power should be around 10 to 12 dB below the "Max Hold" power.

Table 3-2: PLT Devices Transmission Power with RBW 9 kHz and Max Hold Traces

PLT Device	PLT Transmission Power (dBm)	PLT Signal Voltage (dBµV)
1	16.4	123.4
2	13.3	120.3
3	19.4	126.4
4	14.9	121.9
5	14.3	121.3
6	19.1	126.1
7	15.5 (f < 15 MHz) 3.3 (f > 15 MHz)	122.5 (f < 15 MHz) 110.3 (f > 15 MHz)
8	-15.1	91.9

3.4 Laboratory Evaluation Conclusions

The laboratory evaluation of the PLT devices provided a good understanding on the operation of the eight candidate devices for field trial. Following this evaluation, device 2 (HD-PLC), device 3 (Homeplug AV) and device 6 (UPA) were chosen for field trial. The three devices were chosen according to the following criteria:

- Different PLT standard
- Wide bandwidth usage
- Strong signal levels for their respective standard

Observations made during this evaluation lead to the following conclusions:

- Power outside operating frequency range is at least 40 dB lower than the maximum power within the operating frequency range. **It may be likely that radiated emissions outside the operating frequency range will not be measurable during field trial.**
- Power transmitted in idle mode does not exceed the power transmitted in file transfer mode. **Therefore, idle mode measurements will not give any additional information.**

These conclusions allowed the field trial to be streamlined by removing unnecessary measurements. Measurements of radiated emissions outside the operating frequency range require an additional calibrated dipole antenna tuned for the frequencies of 30 MHz to 108 MHz, which adds more measurement and manipulations. Also, measuring radiated power in idle mode is redundant if no new information can be acquired from these measurements.

However, for the first few field test sites, full measurements were performed in order to confirm the conclusions reached from the laboratory evaluation. Results from these tests are presented in Sections 4.4.4 and 4.4.5.

4. EMI Field Tests Results and Analysis

The RF field strength measurements were done using one and two-story residential houses. Most of the houses are connected to the electricity distribution grid (220 volts single phase) through underground AC lines, but some were connected using overhead AC lines. The front and the back of the houses have enough clearance to make field strength measurements at three and ten meters from the outer walls, thus these two distances were selected for RF field strength measurements.

4.1 Field Tests Methodology

A total of 17 houses were selected for the measurement of RF field strength, as presented in Table 4-1. The PLT devices were tested in pairs of the same model, connected to AC outlets inside the houses. Three pairs of PLT devices were selected as per the laboratory tests discussed in Section 3.4 (devices 2, 3 and 6). During field tests, the devices were positioned inside the house to be far apart from each other, representing a realistic home network. The devices were positioned as to have one device from a PLT pair in a room near the front of the house and the other device near the back of the house. In the case of two-story homes, one PLT device was on the first floor and one was on the second floor. The PLT output power level during the tests was the factory pre-set level, which was not found to be adjustable.

Each PLT device was connected to a personal computer. Two modes of PLT operation were tested: Data Transfer mode for all the houses and Idle mode for a few selected houses. For the data transfer mode, measurements were made while a large file was transferred between the two computers. Reference measurements of the ambient noise were also performed at each measurement location.

The RF field strength was measured using a calibrated loop antenna for the frequency range of 0 to 30 MHz and a calibrated dipole antenna for the frequencies of 30 to 108 MHz (see Section 4.2 for antenna specifications). The antenna factor of these antennas was precisely calibrated to yield RF field strength measurements in dBμV/m. The antennas were positioned at two meters above ground level. The measurements were done at three meters and ten meters from the front and back outer walls of the houses.

The measurements in idle mode and in the frequency range of 30-108 MHz (dipole antenna) were done only for some of the 17 houses to confirm the conclusions made in the laboratory evaluation (see Section 3.4).

There were 4 measurement locations at each of the 17 houses:

- Front of the house, three meters distance
- Front of the house, ten meters distance
- Back of the house, three meters distance
- Back of the house, ten meters distance

The following measurements were done at each location:

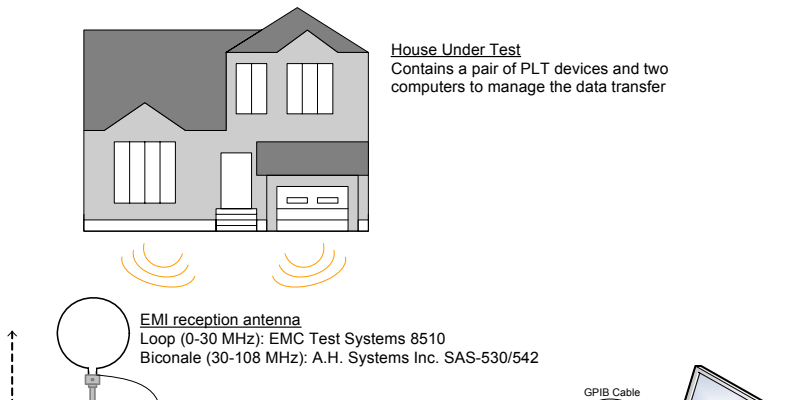
- Ambient noise level between 0-30 MHz (loop antenna)
- RF field strength between 0-30 MHz in data transfer mode for each of the three PLT device pairs

4.2 Field Tests Setup

The measurement of the RF field strength required calibrated components and measuring equipment for the frequency range of 0-108 MHz. The following lists the equipment that was used for the field tests:

- Agilent E4405B spectrum analyzer
- Loop Antenna (Passive)
  - Brand: EMC Test Systems
  - Model number: 6512
  - Operating Range: 10 kHz – 30 MHz
- Dipole Antenna (Passive)
  - Brand: A.H. Systems Inc.
  - Model number: SAS-530 (balun) and SAS-542 (folding elements)
  - Operating Range: 20 MHz – 330 MHz
- Low-Pass RF filter
  - Brand: Tin Lee Electronics Ltd.
  - Model: LP7E-30-37 B50
  - -1dB Cut-off frequency: 31 MHz
  - -40dB Cut-off frequency: 35 MHz
- PLT device pairs 2, 3 and 6 (see Table 2-1)
- Two computers used to transfer data over the PLT network
- One computer used to store the field strength measurements

Figure 4-1 shows the test setup for RF field strength measurements. As discussed previously, there were four antenna locations at each house where the field strength was measured (front and back, three and ten meters). The antenna was positioned at two meters above ground level. A low pass filter connected between the antenna and the spectrum analyser was used to remove high-powered VHF signals (FM and TV stations) when measuring below 30 MHz, so as not to overload the spectrum analyser. A laptop computer was used to control the spectrum analyser and store the measurements.



The following procedure was used at each house and for each measurement location. A first measurement was performed to record ambient noise level. Then, a pair of PLT devices was connected and a file transfer was initiated to carry out the RF field strength measurement. The same process was repeated for the two other PLT device pairs. The antenna was then moved to another location and another set of measurements was carried out.

Additional tests for idle mode, dipole antenna (30-108 MHz) and overhead electrical lines were done as explained in Section 3.4 for a few selected houses.

The spectrum analyser measurements were made using peak detection instead of quasi-peak, as explained in Section 3.2. The low-pass filter, cable and antennas were calibrated to measure the EMI in dBμV/m. The following settings were used on the spectrum analyser for the measurements:

For frequencies 0-30 MHz (using loop antenna):

- Resolution Bandwidth = 9 kHz
- Peak Detector
- Max Hold Trace (10 seconds)
- One trace point every 50 kHz (601 points total)

For frequencies 30-108 MHz (using dipole antenna):

- Resolution Bandwidth = 120 kHz
- Peak Detector
- Max Hold Trace (10 seconds)
- One trace point every 50 kHz (1561 points total)

4.3 Test Sites Summary

A total of 17 houses were visited during field trial. Table 4-1 summarises the test sites, including the type of house, the material of the outer walls and the type of electrical line used to connect the house to the electricity grid of the neighbourhood (underground or overhead lines). Appendix B of this report contains the full description of the 17 test sites, including pictures and a diagram of each house.

Site #	Type of House	Exterior Wall Material				Electrical Line
		Front Wall		Back Wall		
		1st Floor	2nd Floor	1st Floor	2nd Floor	
1	Two-story single-detached	Brick	Vinyl	Vinyl	Vinyl	Underground
2	Two-story semi-detached	Brick	Brick/Canaxel	Brick	Canaxel	Underground
3	Two-story single-detached	Brick	Brick/Vinyl	Vinyl	Vinyl	Underground
4	Two-story single-detached	Brick	Brick	Brick	Aluminum	Underground
5	Two-story single-detached	Brick	Brick	Brick	Aluminum	Underground
6	Two-story townhouse	Brick	Brick/Vinyl	Vinyl	Vinyl	Underground
7	Two-story single-detached	Brick	Brick	Vinyl	Vinyl	Underground
8	Two-story single-detached	Brick	Brick	Vinyl	Vinyl	Underground
9	Bungalow single-detached	Brick	N/A	Vinyl	N/A	Underground
10	Two-story townhouse	Brick	Aluminum	Aluminum	Aluminum	Underground
11	Bungalow single-detached	Stucco	N/A	Stucco	N/A	Underground
12	Two-story single-detached	Brick	Vinyl	Vinyl	Vinyl	Overhead
13	Sides split single-detached	Brick	Brick	Brick	Vinyl	Underground
14	Two-story single-detached	Brick	Shingle	Brick	Shingle	Overhead
15	Two-story single-detached	Brick	Aluminum	Brick	Aluminum	Overhead
16	Two-story single-detached	Brick	Brick/Shingle	Vinyl	Vinyl	Underground
17	Two-story single-detached with loft	Brick	Brick/Vinyl	Vinyl	Vinyl	Underground

Table 4-1: Description of the test sites

4.4 RF Field Strength Test Results

This section presents the test results for RF field strength measured from the selected PLT devices. The results are divided in five sections:

1. **RF field strength measurement analysis**

   This statistical analysis includes measurements of the RF field strength from 0-30 MHz, at three and ten meters distances from the front and back of the houses for each pair of PLT devices.

2. **RF field strength measurements from 30-108 MHz**

   This section contains the observations relative to emissions from 30 to 108 MHz to study the amount of emissions outside the operating frequency range.

3. **PLT emission propagation analysis between three meters and ten meters**

   This section studies the ratio of the RF field strength between three meters and ten meters to understand propagation loss in the frequencies used by PLT devices.

4. **Effect of overhead power lines on RF field strength**

   It is known that PLT device conducted signal extends outside a house's electrical wiring up to the residential distribution transformer. Measurements were done to quantify the impact of overhead electrical line on overall field strength coming from the houses.

5. **Idle mode emission analysis**

   This section contains the observations relative to idle mode operation in comparison to data transfer mode, as was done during laboratory evaluation.

4.4.1 RF Field Strength Measurement Analysis

This section provides a statistical analysis of the measurements of the RF field strength from 0-30 MHz, at three and ten meters distances from the front and back of the houses for each pair of PLT devices. See Appendix B for the complete set of results. **Test Site 3 has been discarded from this result analysis because it was found that PLT devices were in use in an adjacent house during the tests, distorting the results.**

Prior to each set of measurements, the ambient noise was recorded to characterise the frequency range of interest. This characterisation was required to discriminate the PLT devices emission from other radiocommunication systems and environmental noise.

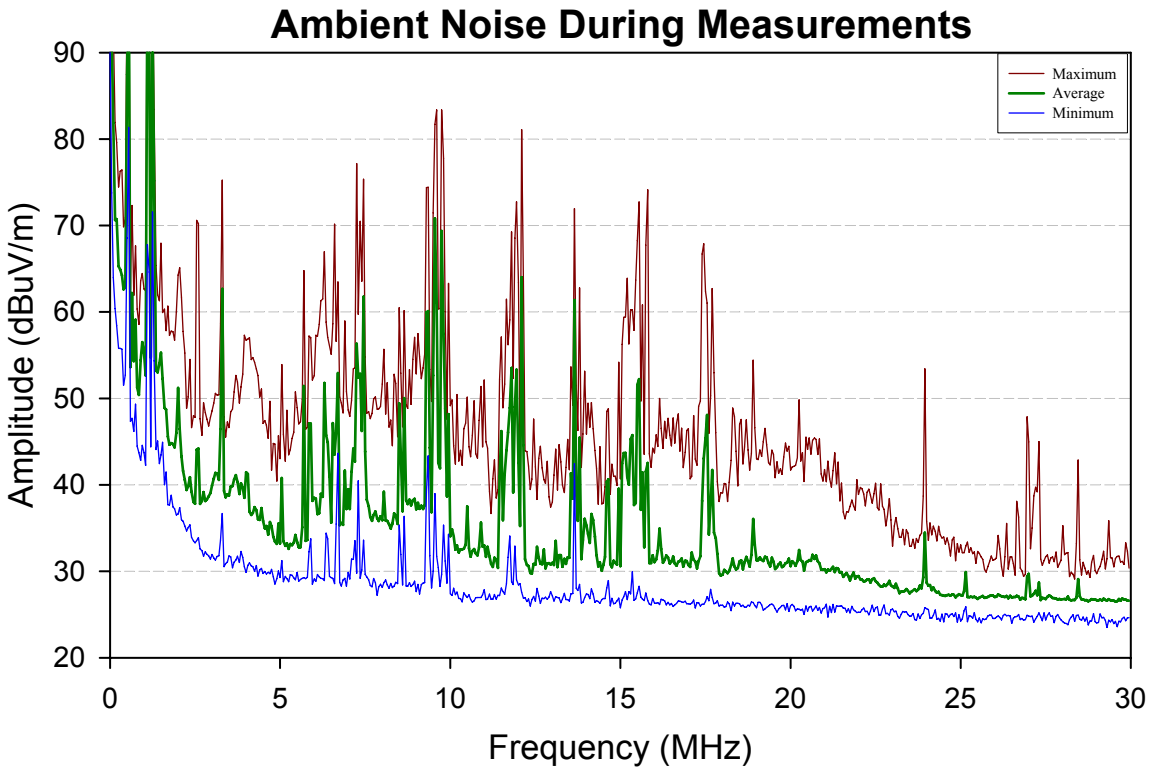


Figure 4-2: Ambient noise distribution at 3 and 10 meters

The contribution of the ambient noise in the field strength measurement was not negligible. Most of the strong signal spikes were believed to be from amateur or short wave band stations. Other noise sources such as electric motors (furnace, refrigerator and other appliances) may have contributed in raising the ambient noise.

For the purpose of analysing the measured RF field strength, all measurements done on the 16 houses were grouped by their respective devices and distance from the houses. Note that Test Site 3 is not included in this statistical analysis. Figure 4-3 to Figure 4-8 show statistical analyses for the three devices.

There are two figures per device, one showing the results for all measurements done at three meters and one showing all measurements done at ten meters. The figures show the linear voltage average (converted back in dB scale), minimum and maximum RF field strength measured for each device. Furthermore, the study uses the measurements from the 16 houses to calculate a confidence interval that should represent the expected field strength from PLT devices radiated from typical houses. A 95 % confidence interval of the RF field strength is calculated from the standard deviation of the 16 houses sampled, given a normal distribution. The lower bound of this 95 % confidence interval is in dark blue

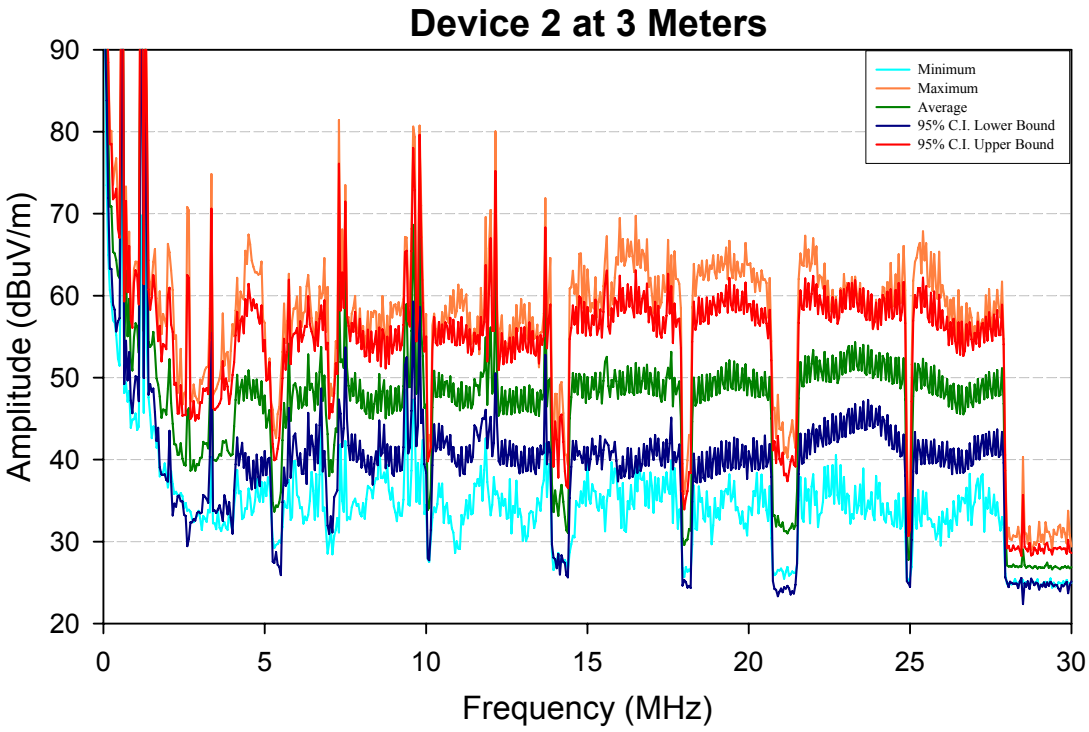
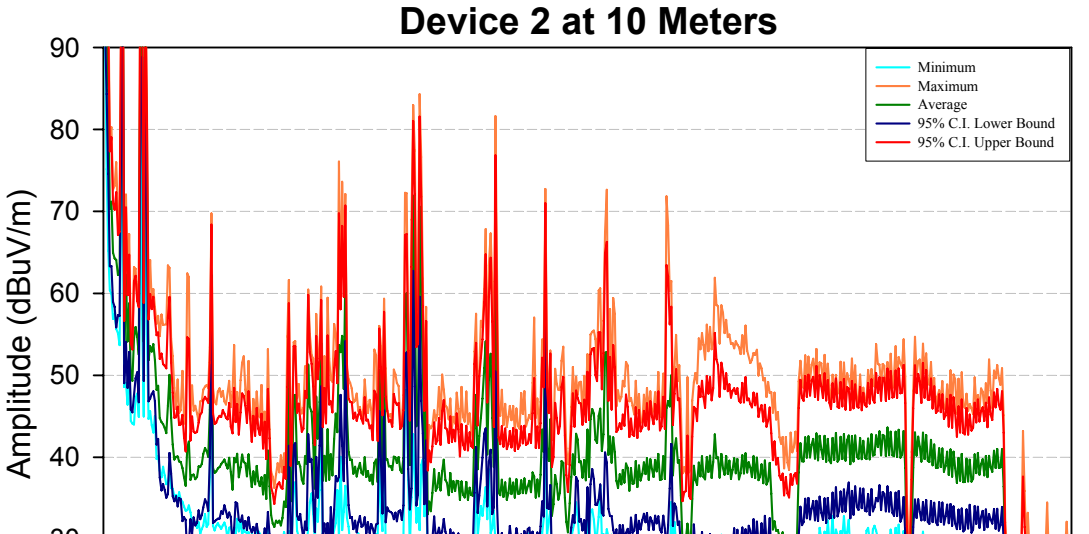


Figure 4-3: RF field strength distribution, device 2 (HD-PLC) at 3 meters



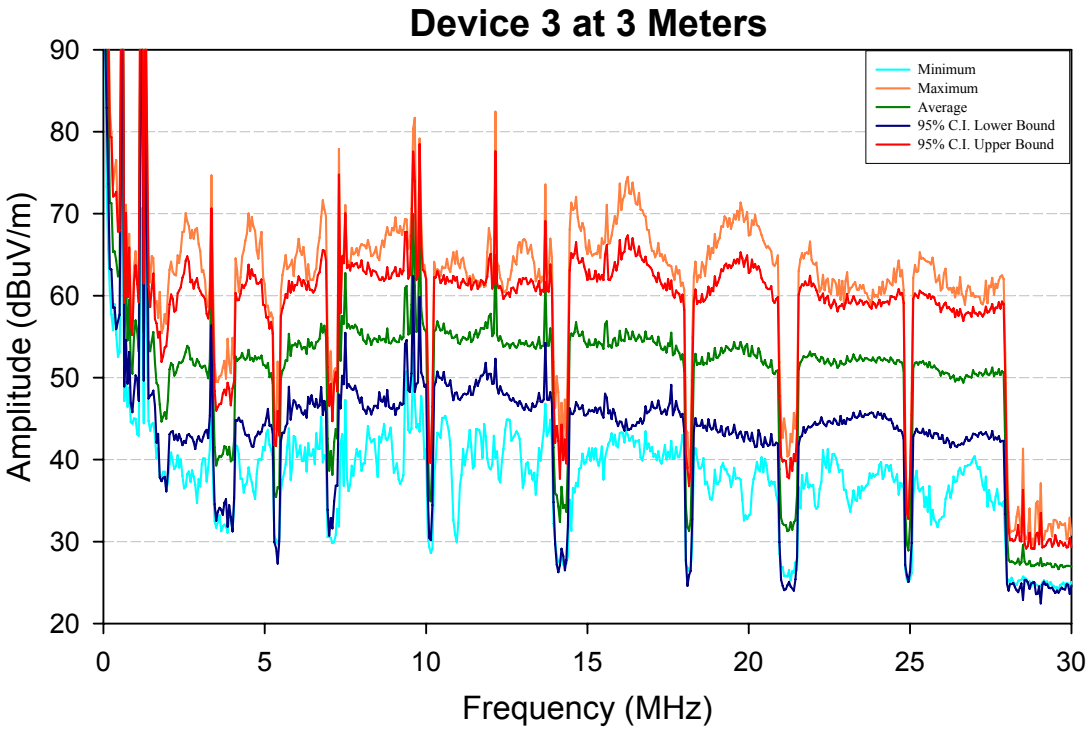
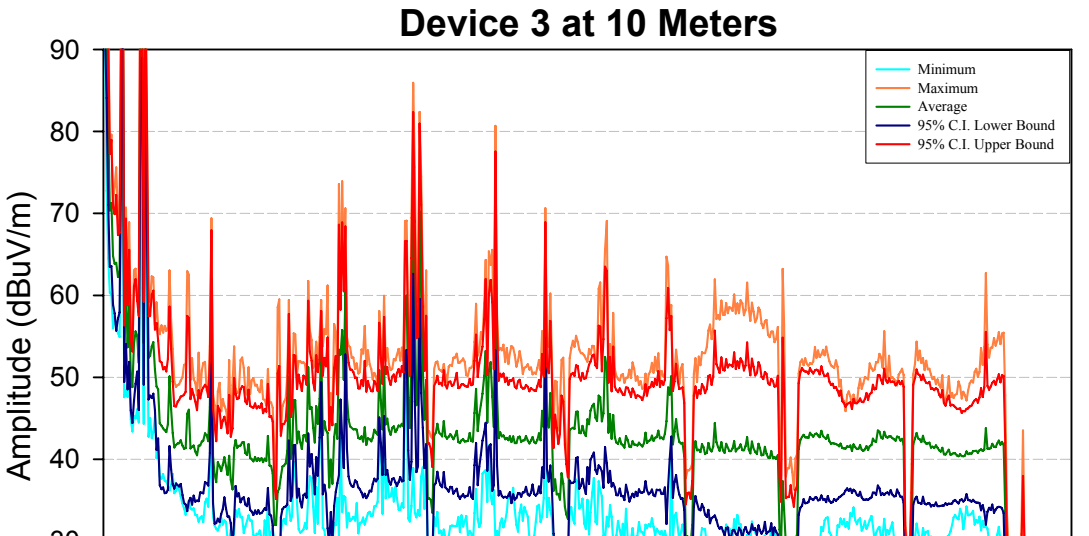


Figure 4-5: RF field strength distribution, device 3 (Homeplug AV) at 3 meters



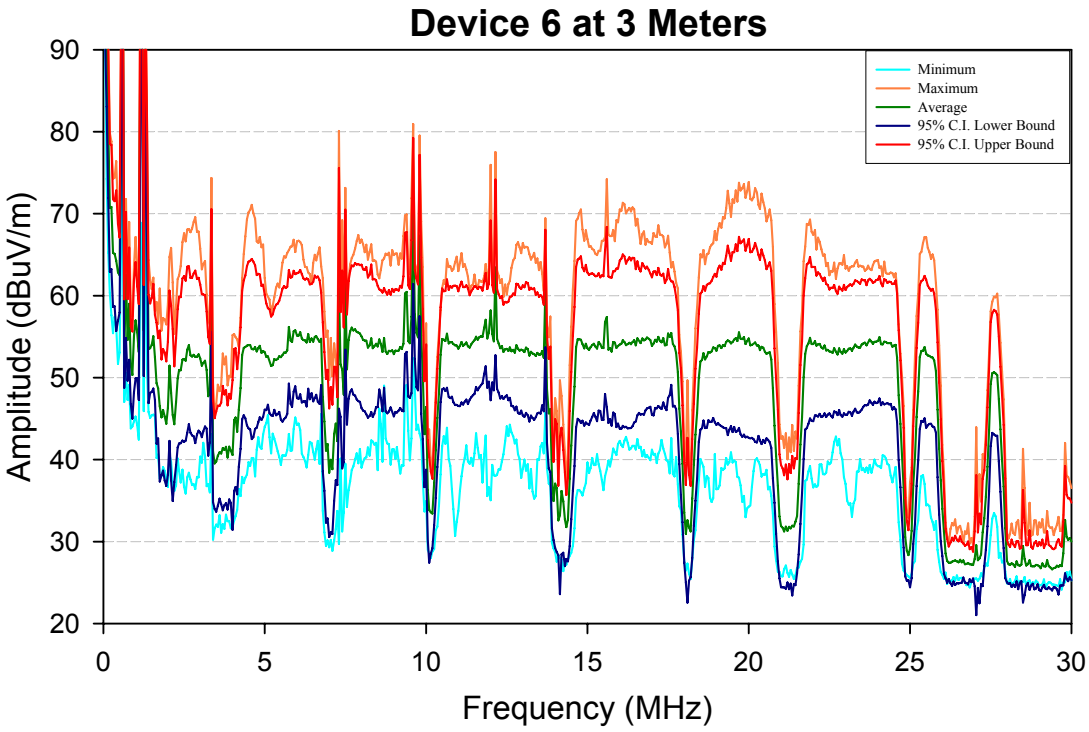
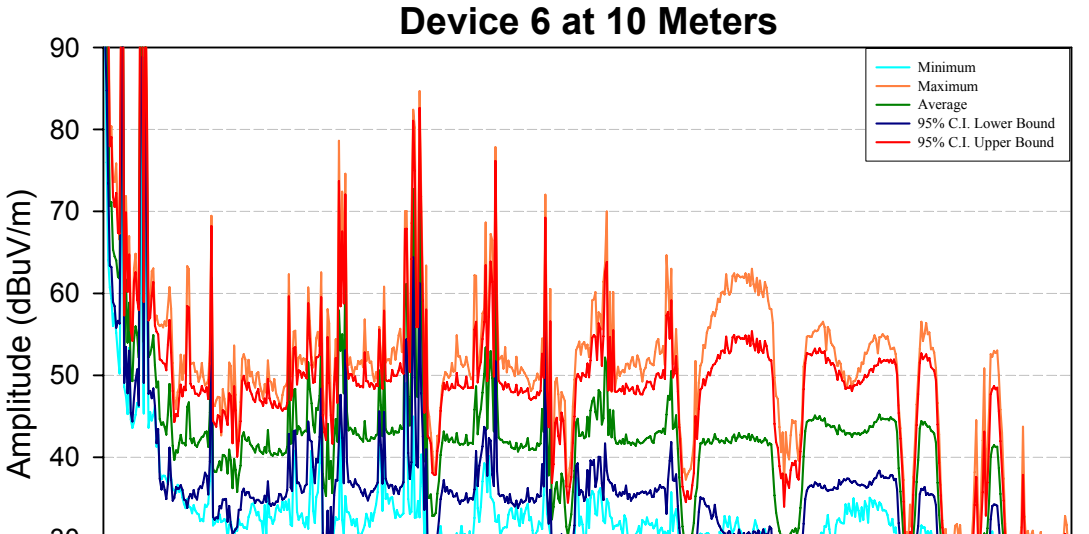


Figure 4-7: RF field strength distribution, device 6 (UPA) at 3 meters



From the figures above, it can be seen that the average signal level varies generally from 45 to 55 dBµV/m for measurements at three meters and 35 to 45 dBµV/m for measurements at ten meters. The 95% confidence interval bounds indicate that overall signal level can vary greatly (10 dB to 20 dB) from house to house and over the frequency range. Construction materials, electrical wiring and PLT location within the houses may be factors that contribute to this wide variation of results.

4.4.2 RF Field Strength Measurements between 30-108 MHz

This section presents the field test results of emissions from 30 to 108 MHz. The goal was to determine if PLT devices create interference in these frequencies compared to ambient noise level. Because strong FM and analog TV station signals are present in this frequency range, extra precaution had to be taken to avoid spectrum analyser overload causing measurement distortion.

The distribution of the ambient noise measurement from 30 to 108 MHz done for all sites where these measurements were made is presented in Figure 4-9. This figure contains three curves. The green curve is the average of all ambient noise measurements done during the field trial. The red and blue curves are respectively the envelopes of the maximum and minimum measurements.

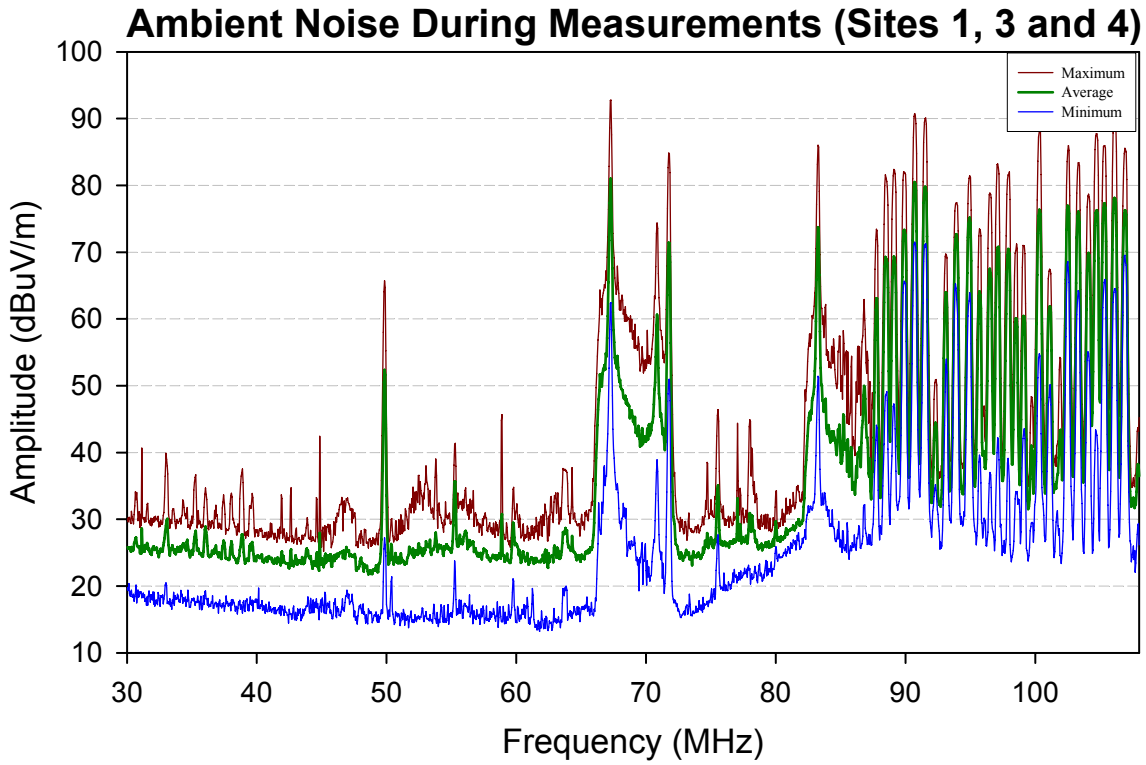


Figure 4-9: Ambient noise distribution from 30 to 108 MHz

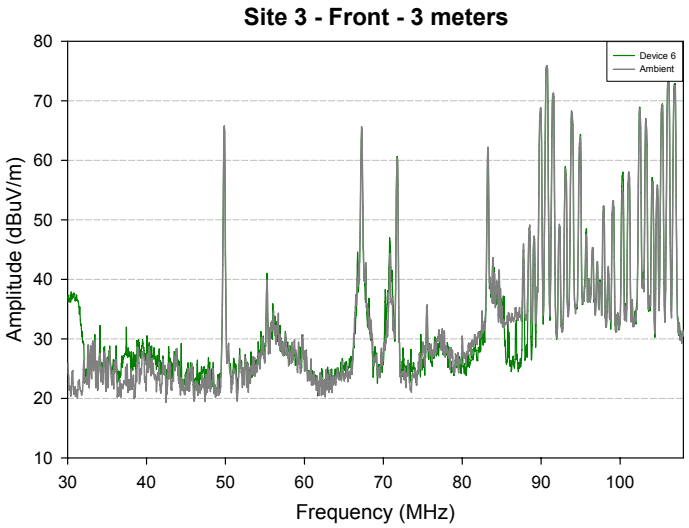


Figure 4-10: Emission Field Strength at Site 3 Front - 3 meters

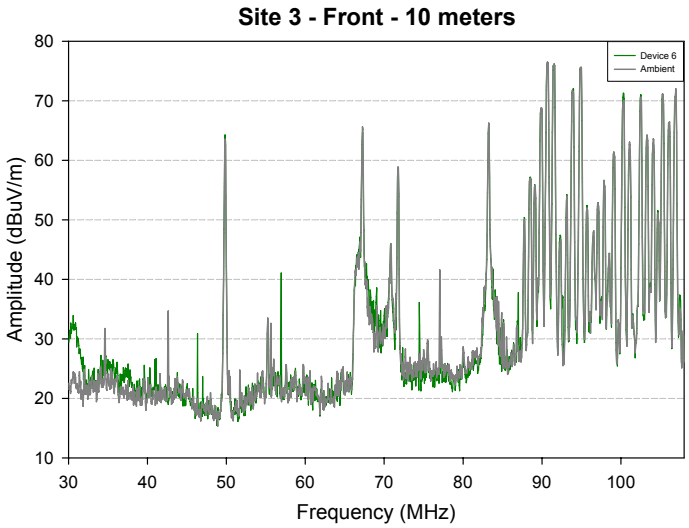


Figure 4-11: Emission Field Strength at Site 3 Front - 10 meters

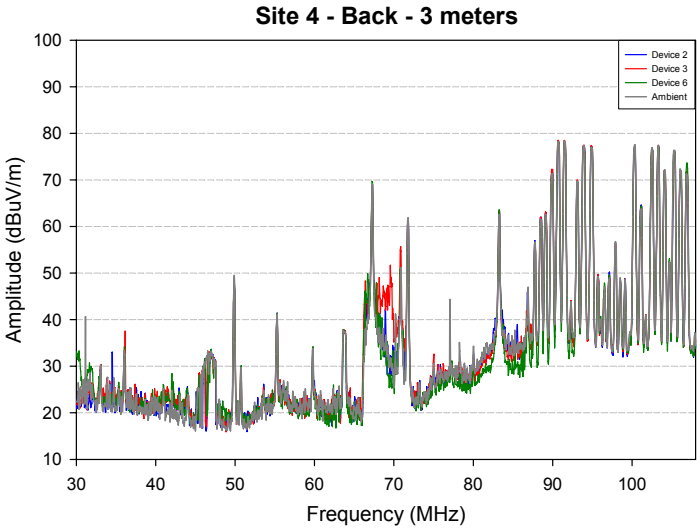


Figure 4-12: Emission Field Strength at Site 4 Back - 3 meters

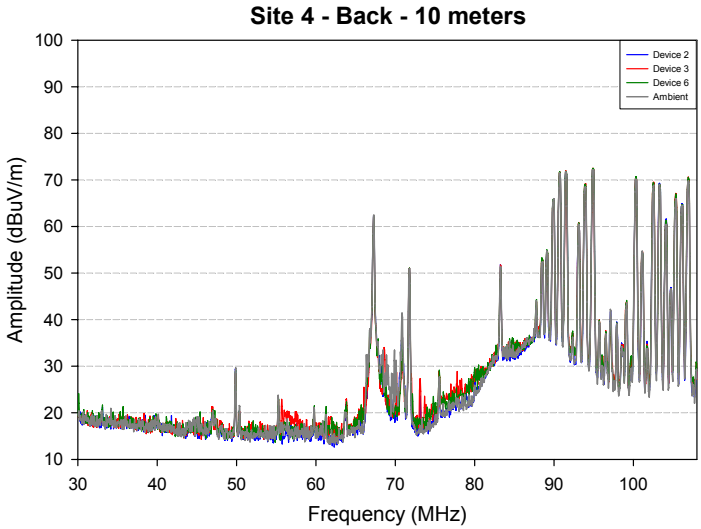


Figure 4-13: Emission Field Strength at Site 4 Back - 10 meters

The results presented in this section show that there is no meaningful emission above ambient in the 30 to 108 MHz frequency range. It should be noted that in Figure 4-12, the high emission from device 3 around 70 MHz were due to change of video content in the NTSC off-air Channel 4 signal. The emission anomalies from PLT devices seen in the figures above can be explained by changes in spurious ambient noise, as shown in Figure 4-9. These results agree with the conclusion from the laboratory evaluation in

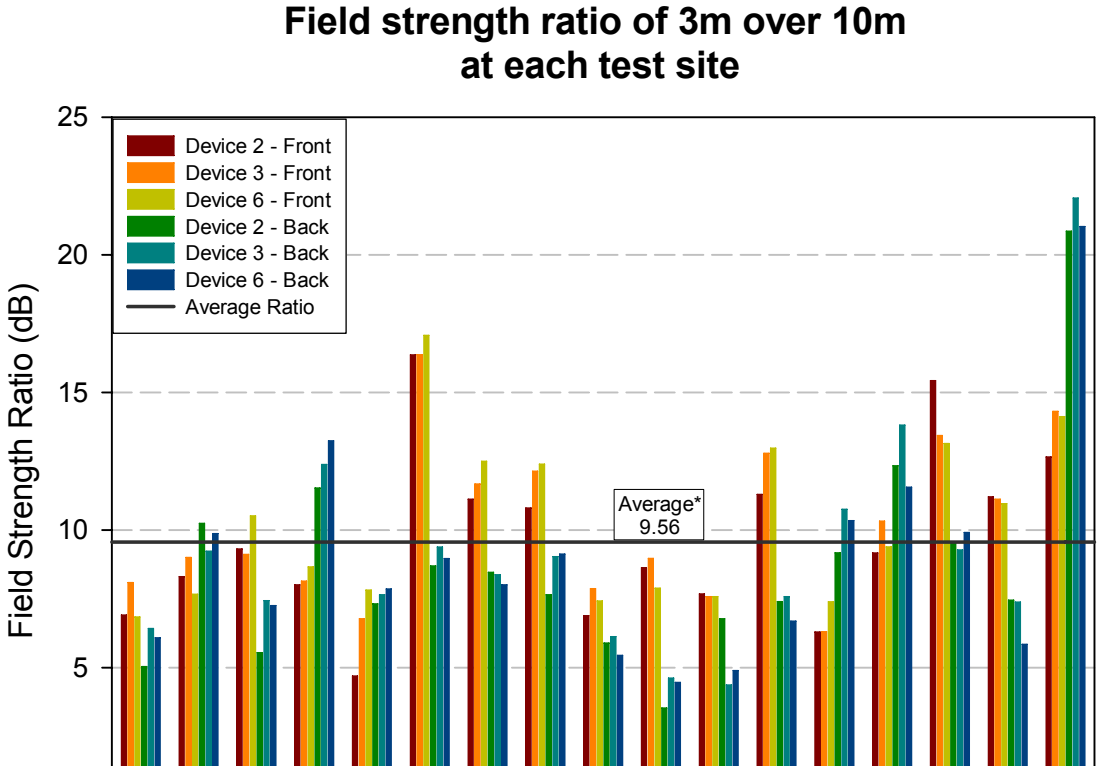
4.4.3 PLT Emissions Propagation Analysis between 3 Meters and 10 Meters

This section studies the ratio of the RF field strength between three meters and ten meters to understand propagation loss in the operating frequencies of PLT devices. The theoretical field strength ratio between measurements at three meters over ten meters can be derived from the free space loss propagation equation. Since it is a ratio, the equation can be simplified to:

$$Field\ Strength\ Ratio_{(dB)} = 20 * Log\left(\frac{10\,meters}{3\,meters}\right) \approx 10.5\ dB$$

The equation above assumes an extrapolation factor of 20 dB per decades of distance for free space propagation. Thus, there should theoretically be 10.5 dB more power at three meters than at ten meters from the houses.

The Figure 4-14 below shows the field strength ratio of three meters over ten meters for each device at each test site. To reduce the effect of the ambient noise, the calculations were done from 16 to 28 MHz only. The average field strength ratio over all the devices and test sites is 9.56 dB, 1 dB lower than the theoretical value. Based on these test results, the extrapolation factor was actually 18.2 dB per decade of distance.



The following figure is the field strength ratio average for all test sites, over the 0-30 MHz frequency range. This analysis shows also a ratio of around 10 dB for each device. It should be noted that only spectrum flat top should be considered. The notches seen in the spectrum are required to avoid interference with amateur radio and should not be considered since PLT devices do not transmit power within these notches.

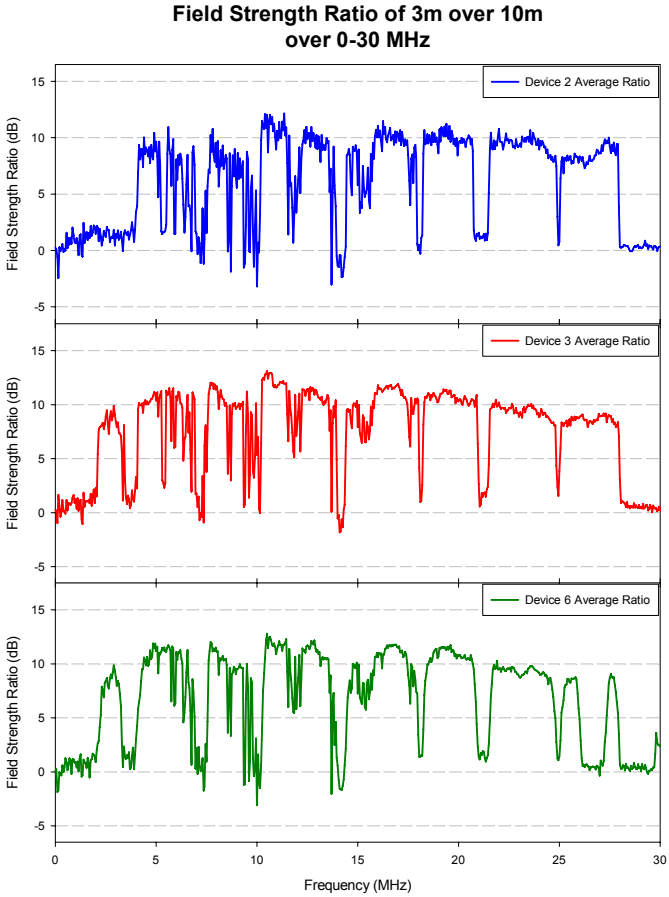


Figure 4-15: Field strength average ratio of 3 m over 10 m measurements over 0-30 MHz for each PLT device

4.4.4 Effect of Overhead Power Lines on RF Field Strength

It is known that PLT device conducted signal extends outside a house's electrical wiring, past the electric meter, and up to the residential distribution transformer. This section presents measurements done to quantify the impact of overhead electrical line on overall field strength coming from the houses.

Figure 4-16 to Figure 4-21 compare the measurements done at sites 12, 14 and 15 with the measurements

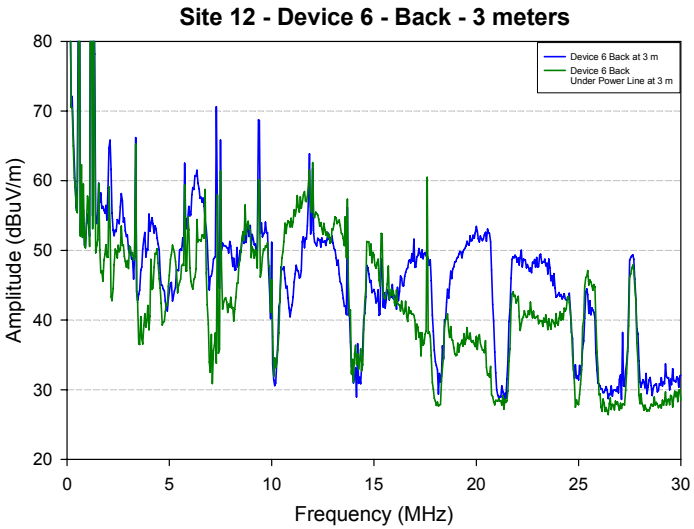


Figure 4-16: Under overhead electrical lines at 3 meters for site 12

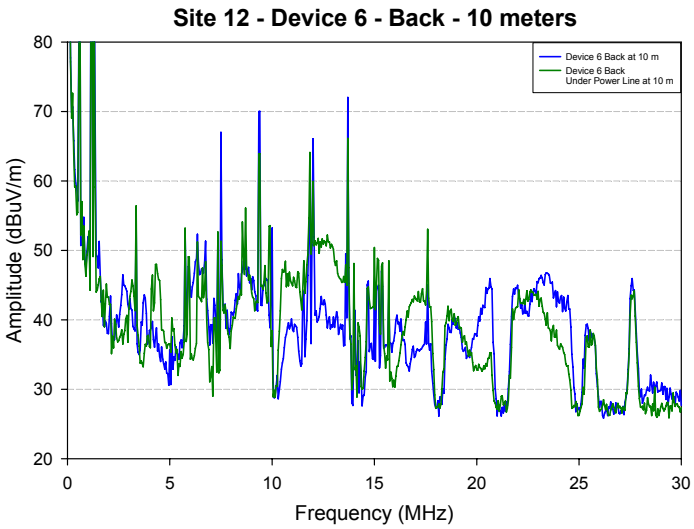


Figure 4-17: Under overhead electrical lines at 10 meters for site 12

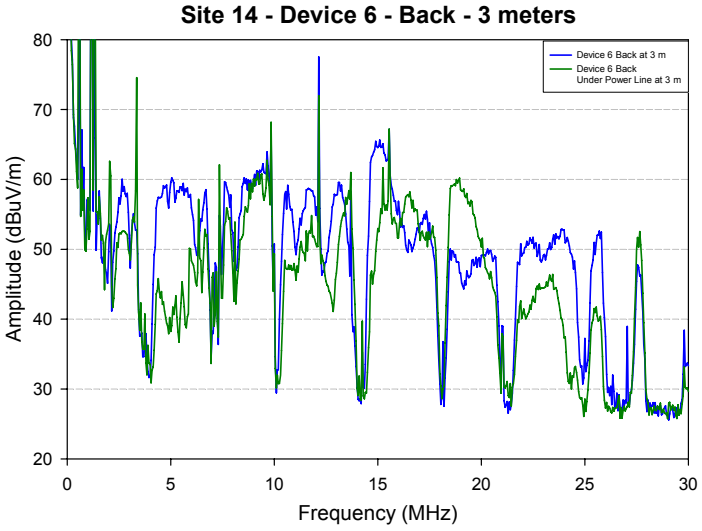


Figure 4-18: Under overhead electrical lines at 3 meters for site 14

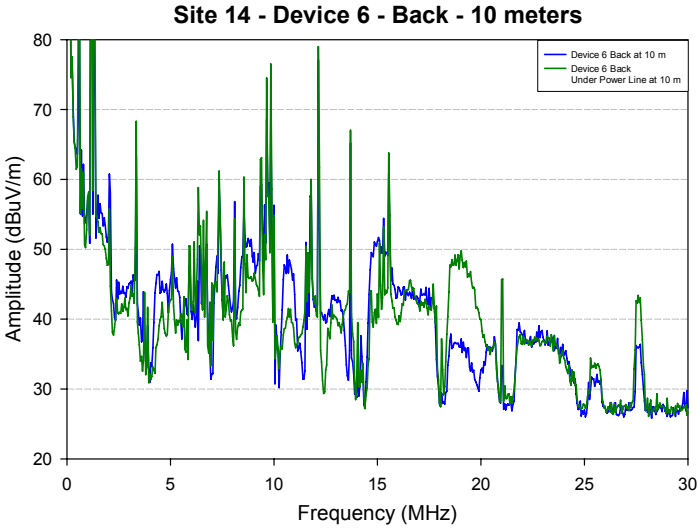


Figure 4-19: Under overhead electrical lines at 10 meters for site 14

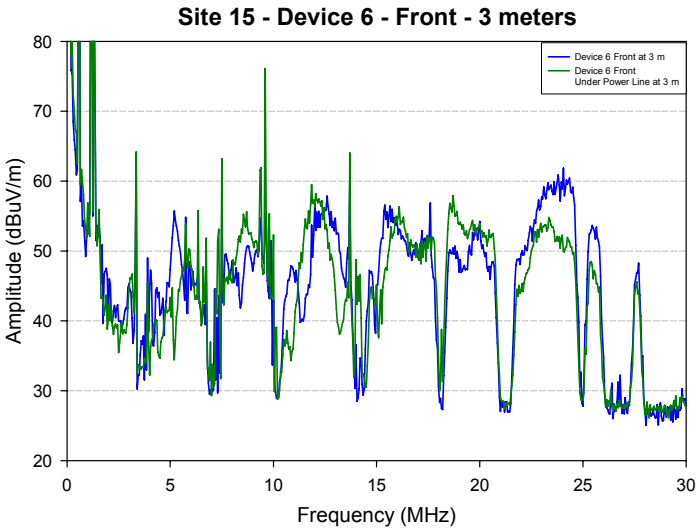


Figure 4-20: Under overhead electrical lines at 3 meters for site 15

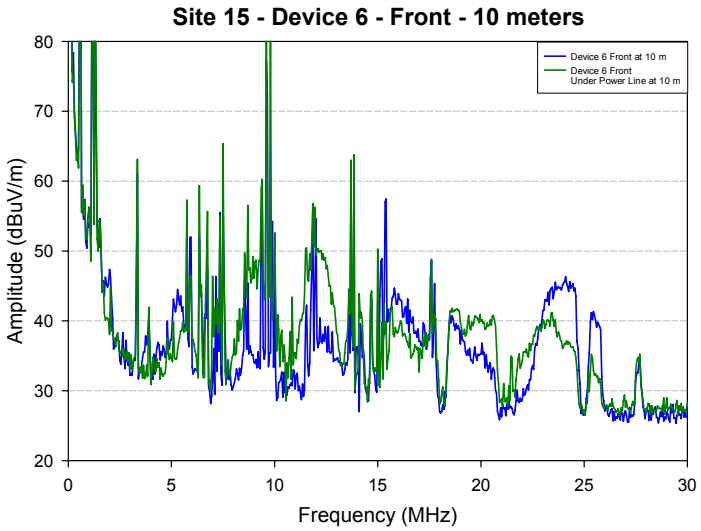


Figure 4-21: Under overhead electrical lines at 10 meters for site 15

The figures above do not indicate that there is a significant contribution to overall field strength due to the presence of an electrical line over the measuring antenna. The signal level variations seen in the plots are frequency dependent and mostly due to the fact that the measurement location is different when measuring under the electrical lines.

4.4.5 Idle Mode Emissions Analysis

This section contains the observations relative to idle mode operation in comparison to data transfer mode, as was done during laboratory evaluation.

Figures 4-22, 4-23 and 4-24 show the idle mode emission compared to data transfer mode emission for the three devices used during field trial. These figures were chosen because these particular measurements have minimal impact from ambient noise. The relationship between idle mode and file transfer mode can then be clearly observed.

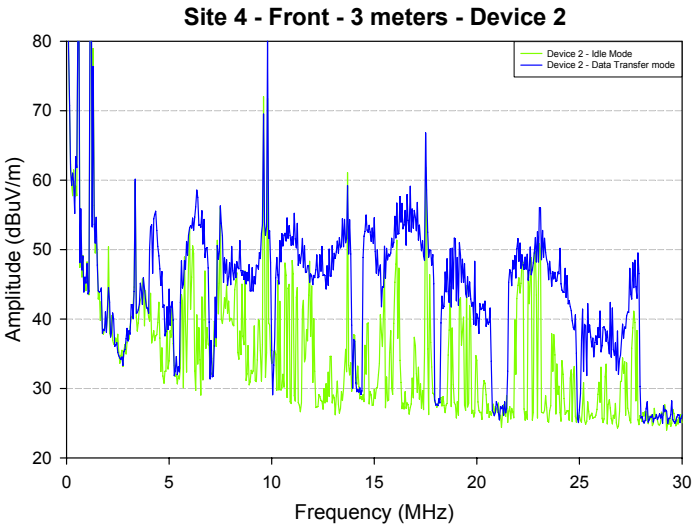


Figure 4-22: Data Transfer mode versus Idle mode for Device 2

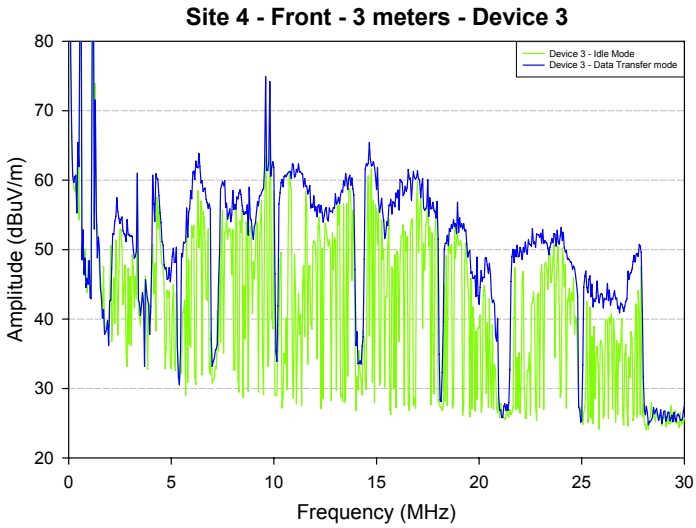


Figure 4-23: Data Transfer mode versus Idle mode for Device 3

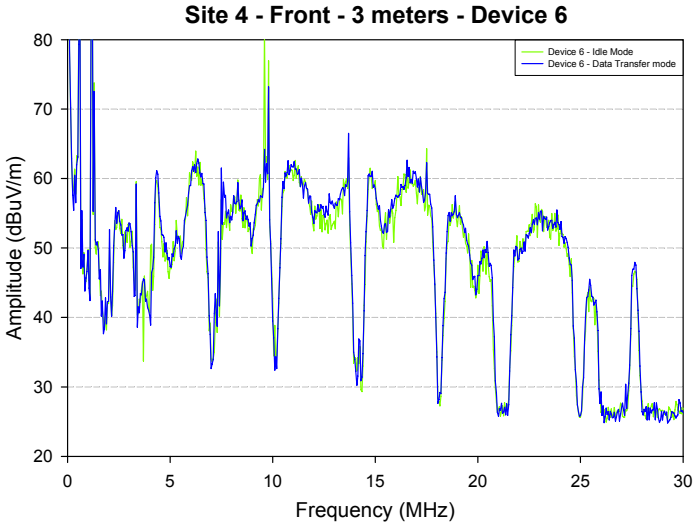


Figure 4-24: Data Transfer mode versus Idle mode for Device 6

The figures above confirm the observations made during the laboratory tests. Idle mode emission from PLT devices does not exceed data transfer emission. However, it should be noted that there is always

5. CMI and DMI Field Test Results

The Common Mode Current (CMI) and Differential Mode Current (DMI) measurements were done in two selected houses (Site 1 and Site 4). The purpose of measuring CMI and DMI was to determine if there is a relationship between these two measurements and EMI caused by PLT devices.

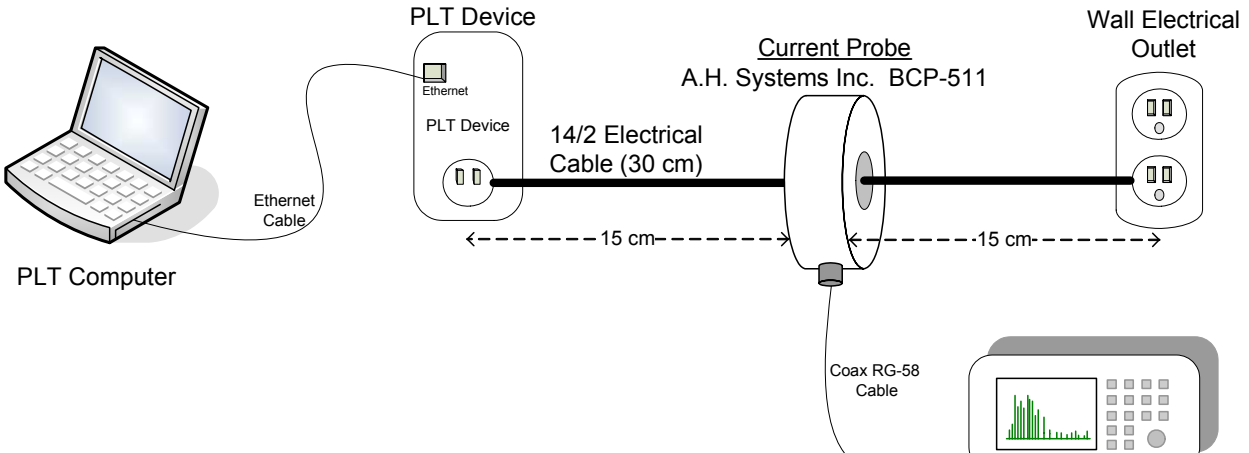
5.1 CMI and DMI Field Tests Setup

The measurements were done on four electrical outlets in each house. Two of these outlets were the same outlets that were used to connect the PLT devices during EMI field tests. The CMI and DMI were measured at these two outlets by inserting a short extension cable between the PLT device and the outlet. Two additional outlets were tested, one on each floor of the houses. An open ended extension cable was used to measure the CMI and DMI at these outlets. Consequently, there were two different test setup used for these measurements, as is described below.

CMI and DMI measurements required the following equipment:

- Agilent E4405B spectrum analyzer
- Current Probe
  - Brand: A.H. Systems Inc.
  - Model number: BCP-511
  - Operating Range: 20 kHz – 100 MHz
- 2 x 14/2 grounded electrical cable (30 cm and 3 meters cables)
- PLT device pairs 2, 3 and 6 (see Table 2-1)
- Two computers used to transfer data over the PLT network

Figure 5-1 and Figure 5-2 show the test setups and equipment used for the configurations of tests. Figure 5-1 shows the test setup when testing on an outlet that had a PLT device connected, while Figure 5-2 is the setup that was used to test at other outlets in the houses (no PLT device connected).



During CMI measurements, the current probe encircles all the wires in the electrical cable (Live, Neutral and Ground). For DMI measurements, the electrical cable sheath was removed and only the Live wire is placed in the current probe, while the Neutral and Ground are looped outside the probe.

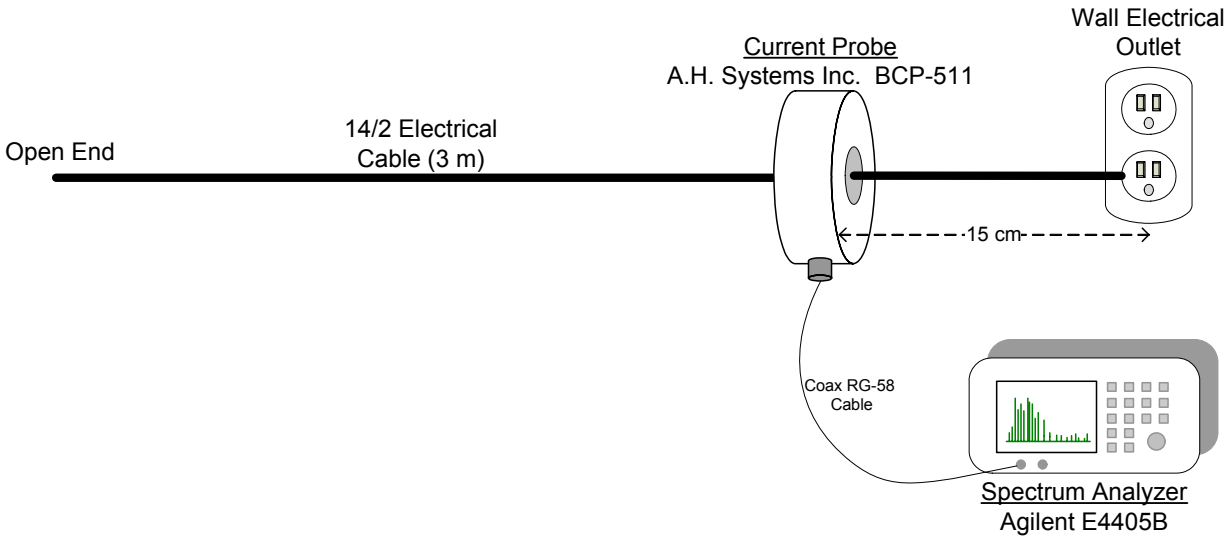


Figure 5-2: CMI and DMI Test Setup at Other Outlet

Figure 5-2 shows the test setup when testing on outlets that had no PLT devices connected. As can be seen in the figure, an open ended extension cable of 3 meters was used to place the current probe. The pair of PLT devices was still connected to their original outlets in the house, and the data transfer was initiated.

The measurements were done over the frequency range of 0-30 MHz for configurations. The following settings were used for the spectrum analyzer:

- Resolution Bandwidth = 10 kHz
- Average Detector
- Max Hold Trace (10 seconds)
- One trace point every 50 kHz (601 points total)

5.2 CMI & DMI Field Tests Measurements

The results for CMI and DMI field test measurements are presented in this section. Only the results from one of the two sites (Site 4) are presented here since the observations and conclusions are the same for both sites. The results for Site 1 are available in Appendix C.

5.2.1 CMI Measurements and Observations

The CMI measurements made on the four electrical outlets for Site 4 and the three PLT devices are shown in Figure 5-3 to Figure 5-6.

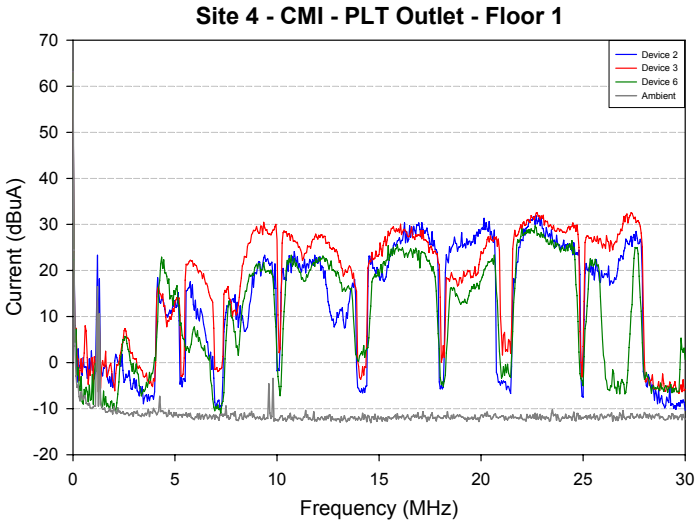


Figure 5-3: CMI at PLT Outlet on Floor 1

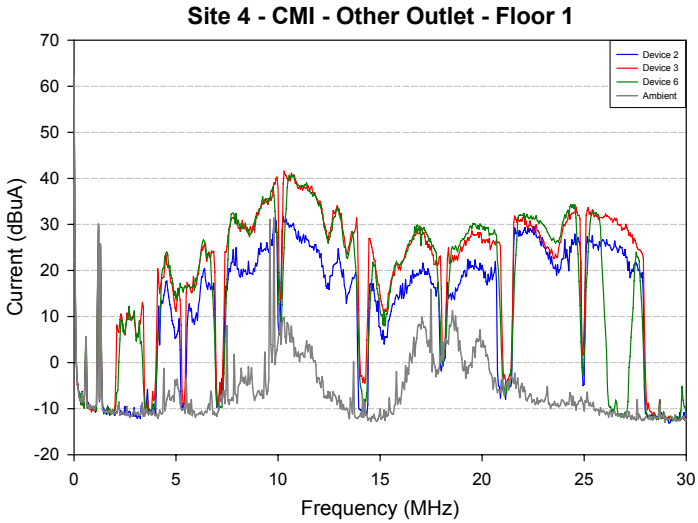
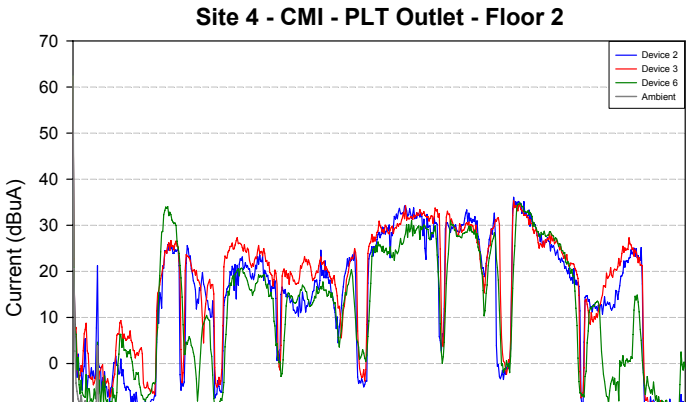
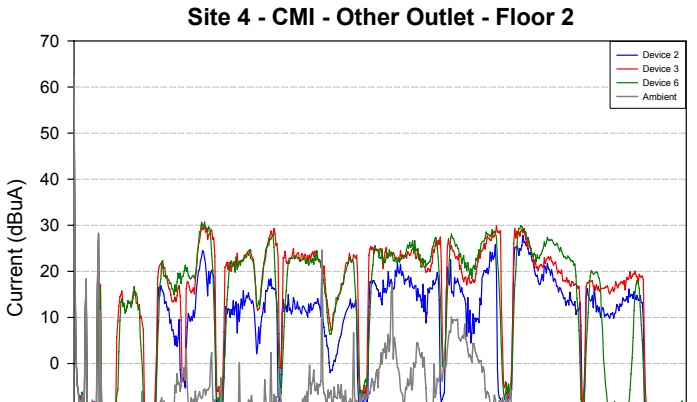


Figure 5-4: CMI at Other Outlet on Floor 1





In the figures above, the term "PLT Outlet" refers to an electrical outlet that had a PLT device connected to it, while the term "Other Outlet" refers to an outlet that didn't have a PLT outlet, as explained in the test setup description of Section 5.1.

Figure 5-7 shows a comparison of CMI between the four electrical outlets under test, but only for a single PLT device (Device 3).

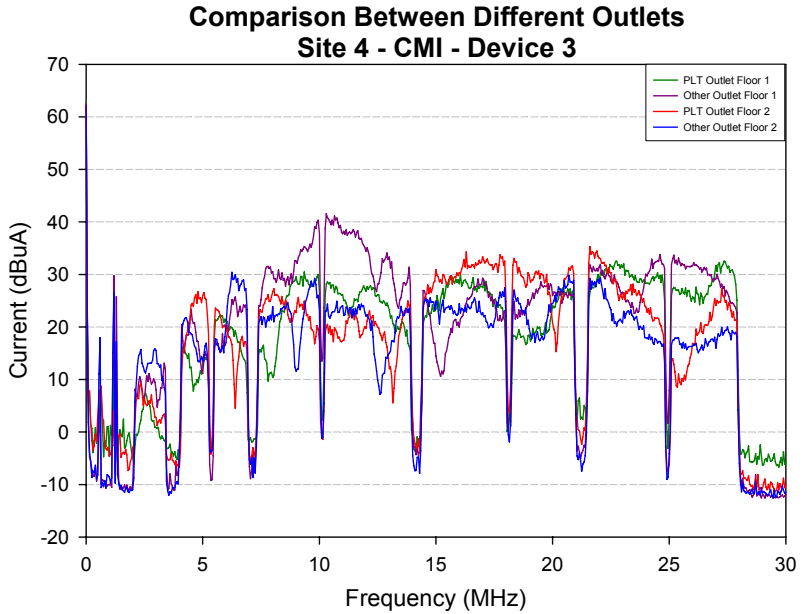


Figure 5-7: Comparison of CMI for a Single Device on the Four Electrical Outlets

From the CMI measurements presented in this section, the following observations were made:

- For a single device and outlet, CMI level vary greatly depending on the frequency range (it's not flat over the frequency range).
- When comparing different devices on a single outlet, devices that transmit stronger conducted power don't necessarily have stronger CMI over all the frequency range. Devices that transmit lower conducted power can have higher CMI than other devices at certain frequencies.
- From outlet to outlet, the CMI is completely different.
- **There is no discernable relationship between EMI and CMI.** A CMI measured is only valid for a single point on the electrical network. The EMI would be a summation of CMI over the whole house network as seen from the EMI antenna point of view. Because of this, the in-house EMI might be different from room to room. This is similar to the near field effect of an antenna. Being further away would stabilize that effect.

5.2.2 DMI Measurements and Observations

The DMI measurements were done on the same conditions as CMI. The DMI was measured only on the Live wire. Figure 5-8 to Figure 5-11 show the DMI for the four electrical outlets under test.

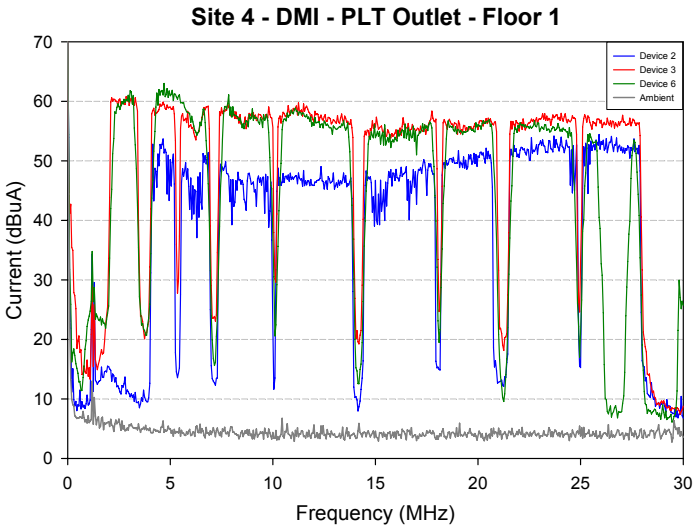


Figure 5-8: DMI at PLT Outlet on Floor 1

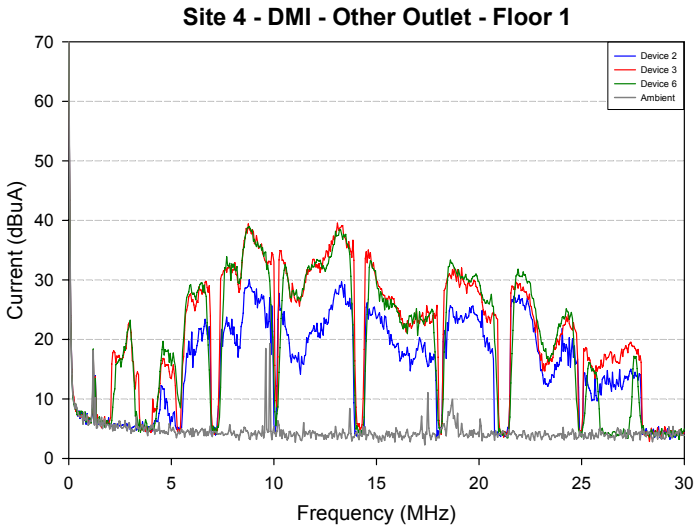


Figure 5-9: DMI at Other Outlet on Floor 1

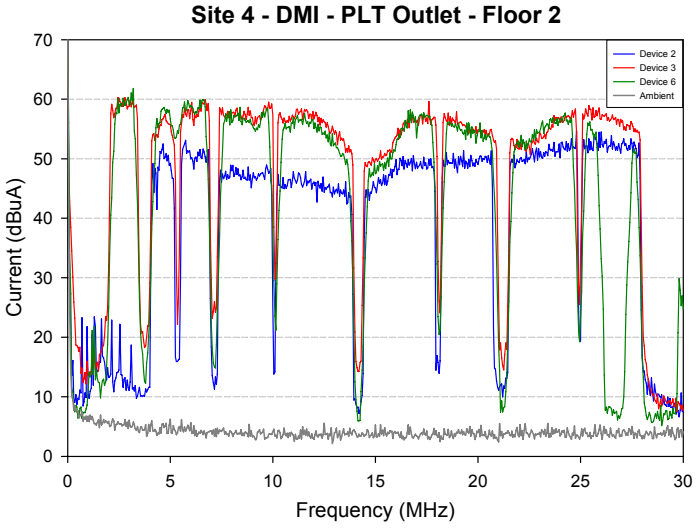


Figure 5-10: DMI at PLT Outlet on Floor 2

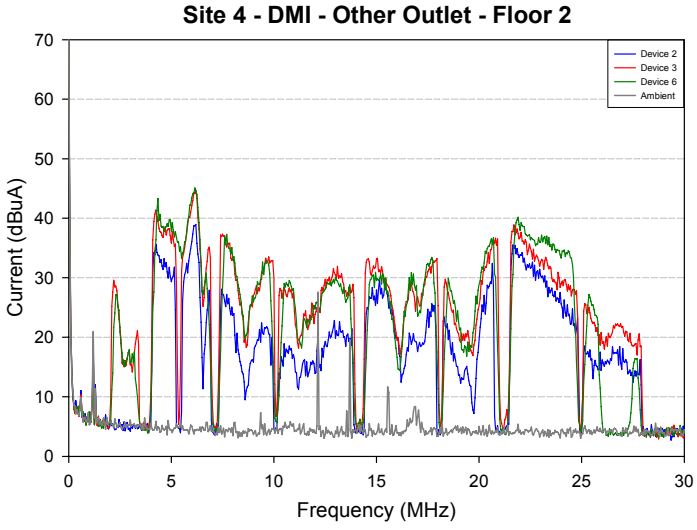


Figure 5-11: DMI at Other Outlet on Floor 2

The DMI measurements done during field trials can be summarized by the following points:

- In contrast to CMI, DMI measured at PLT outlets show more consistent results with the devices' conducted power. So devices with stronger output power show stronger current readings.
- The DMI measured at other outlets (where no PLT is connected) exhibit wide amplitude differences over the frequency range. This is good to show what a PLT signal looks like when received from another device. It shows that the home electrical network has a very severe frequency response.
- Some DMI measured at other outlets (non-PLT outlets) show much lower current level probably due to the outlet being connected to a different live wire than the PLT devices are using (in North America, most houses have two phases AC power).
- There's no observable relationship between CMI and DMI

6. LCL Field Test Results

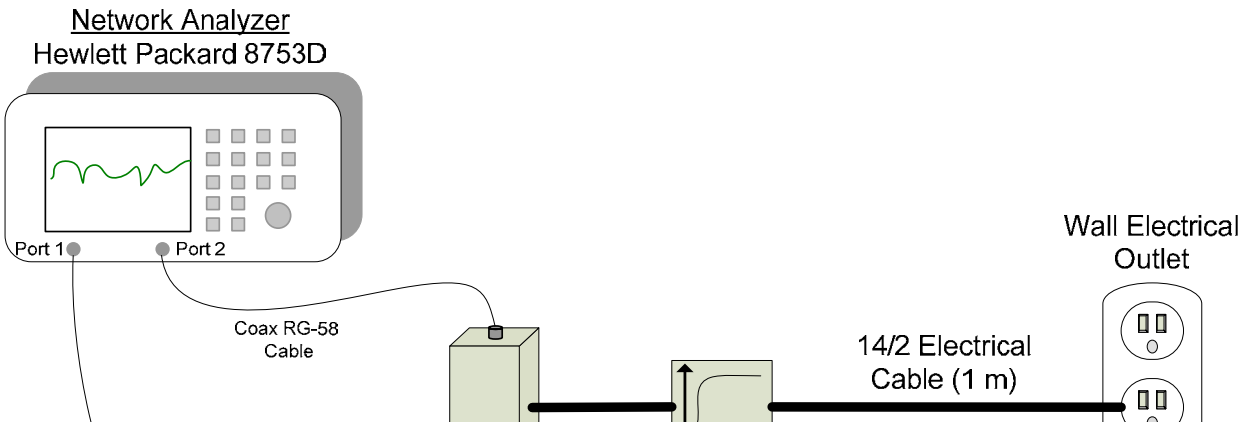
The longitudinal conversion loss (LCL) is a parameter that measures the balance of a line. It defines the conversion ratio of differential mode signal to common mode signal in a communication network. The LCL was measured at the same houses and electrical outlets where CMI and DMI were measured in the previous section. The purpose of these tests is to obtain LCL in typical household electrical outlets and see if there's an observable correlation with the CMI and DMI measurements.

6.1 LCL Measurements Tests Setup and Methodology

The LCL measurements were done in conjunction with the CMI and DMI measurements. At each of the four PLT outlets used to measure the CMI and DMI (see section 5), the LCL was measured over the frequency range of 0-30 MHz. Performing the LCL measurements required the following list of equipment:

- Hewlett Packard 8753D Network Analyser
- LCL Probe (Longitudinal Balance Bridge)
  - Brand: North Bridge
  - Model number: 52100LBB
  - Operating Range: 0.1 – 100 MHz
- 14/2 grounded electrical cable (1 m)
- High-Pass AC filter (built into the 30 cm electrical cable connector)
  - Brand: CRC custom made
  - -1dB Cut-off frequency: 1 MHz

Figure 6-1 shows the test setup for the LCL measurements. The Network Analyser's ports 1 and 2 were connected to their respective ports 1 and 2 on the LCL probe, while the 1 m electrical cable was connected to the LCL probe's test port and into the wall outlet. To protect the equipment from the main 60Hz AC voltage, an AC high pass filter was placed between the LCL probe and the electrical cable.



Prior to doing a measurement, calibration was performed on the network analyzer for a S_{21} measurement with a calibration load that was supplied with the LCL probe. Afterwards, the LCL probe was connected as in Figure 6-1 and the LCL was measured.

6.2 LCL Field Tests Measurements and Observations

The LCL measurements for Site 4 are presented in this section. Full results for Site 1 are available in Appendix C. Figure 6-2 to Figure 6-5 show the LCL measurements for each individual outlet, while Figure 6-6 shows the LCL for the four outlets on the same figure.

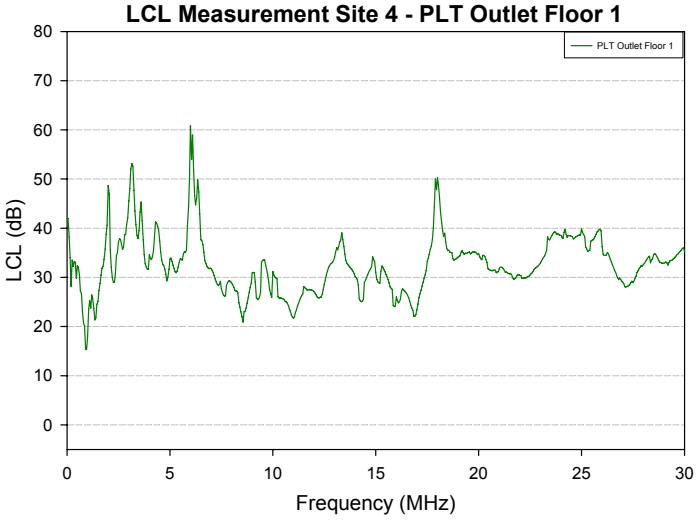


Figure 6-2: LCL at PLT Outlet on Floor 1

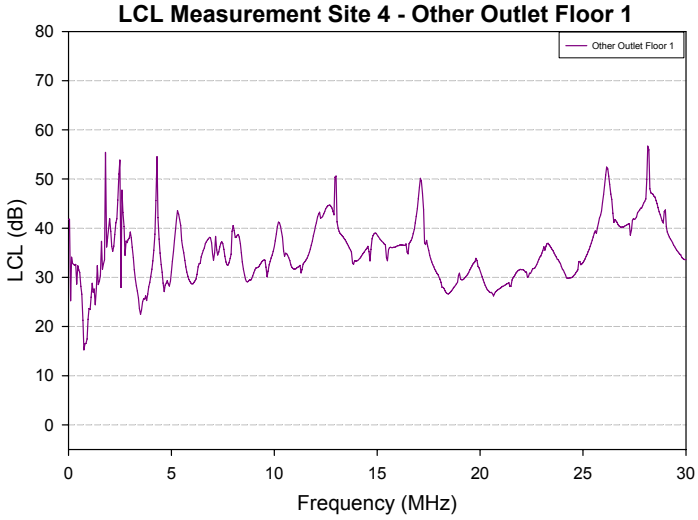
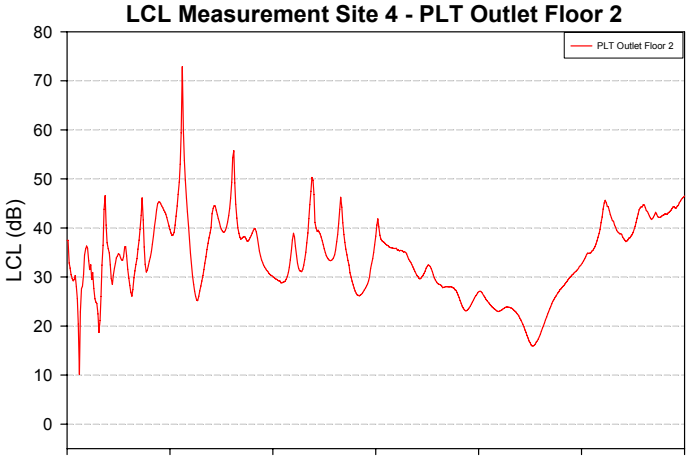
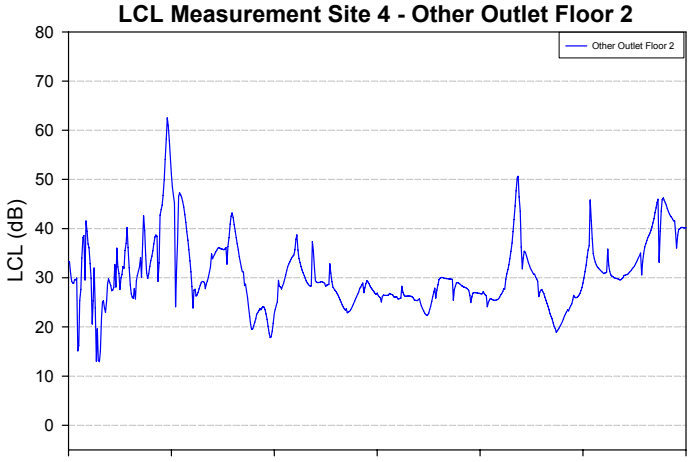


Figure 6-3: LCL at Other Outlet on Floor 1





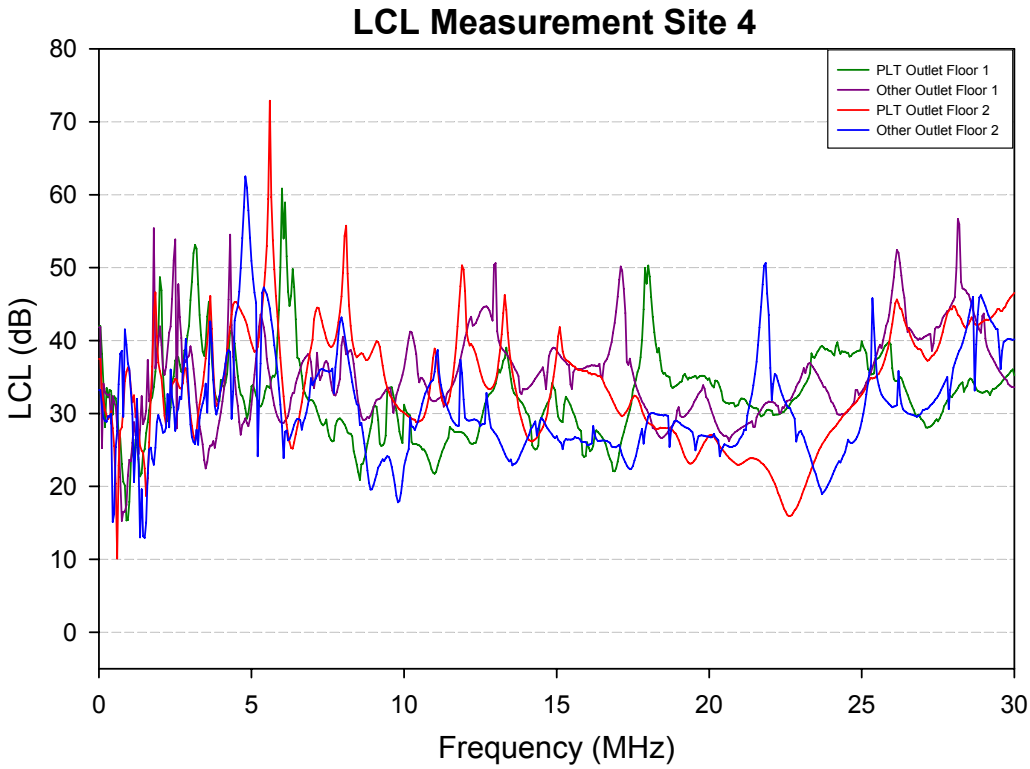


Figure 6-6 Comparison of LCL on the Four Electrical Outlets

From the figures above and the additional results for Site 1 (see Appendix C), the following observations were made on LCL at the electrical outlets of typical houses:

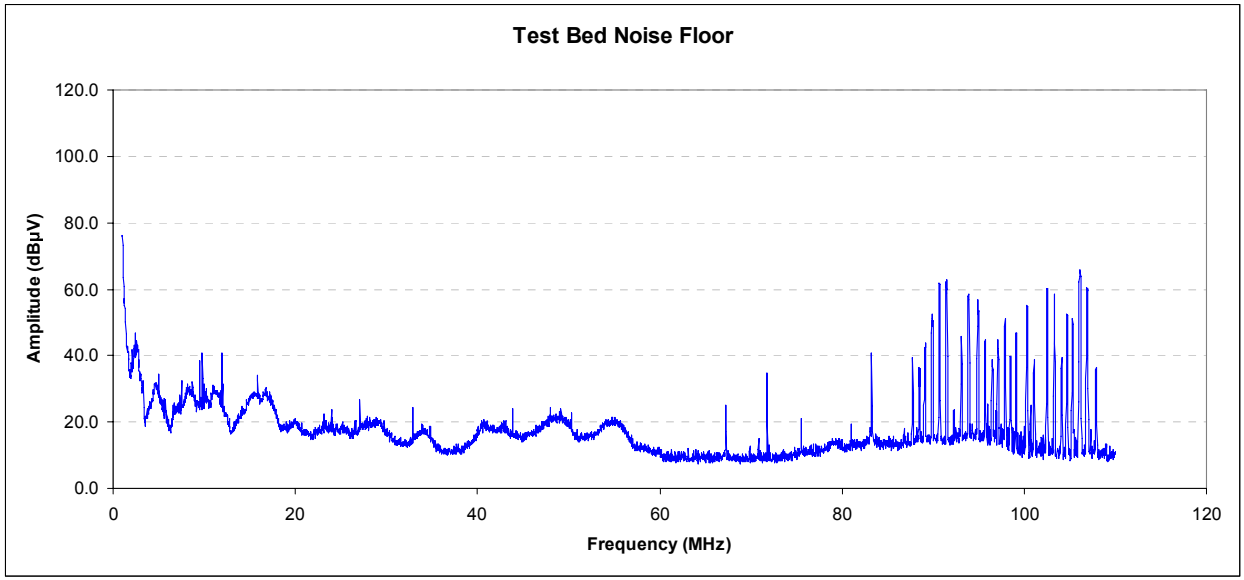
- LCL is generally 20 dB or greater, which is consistent with the Japanese ITU-R submission 2007[1] which assumed a value of 16 dB for the test bed.
- The LCL varies greatly over the frequency range. There are differences of more than 40 dB depending on frequency.
- LCL is very different between different outlets of a single home.
- There is no observable relationship between CMI/DMI and LCL.
- It was observed during field tests that LCL is very sensitive to house appliances and electric devices depending on whether these appliances and devices are powered on or not.

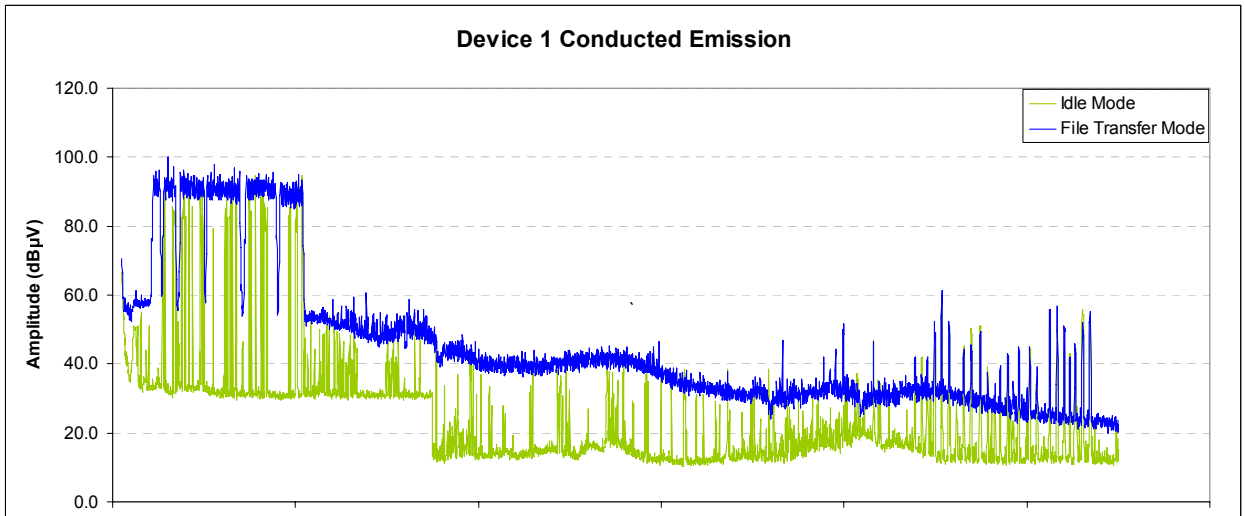
7. Field Trial Conclusions

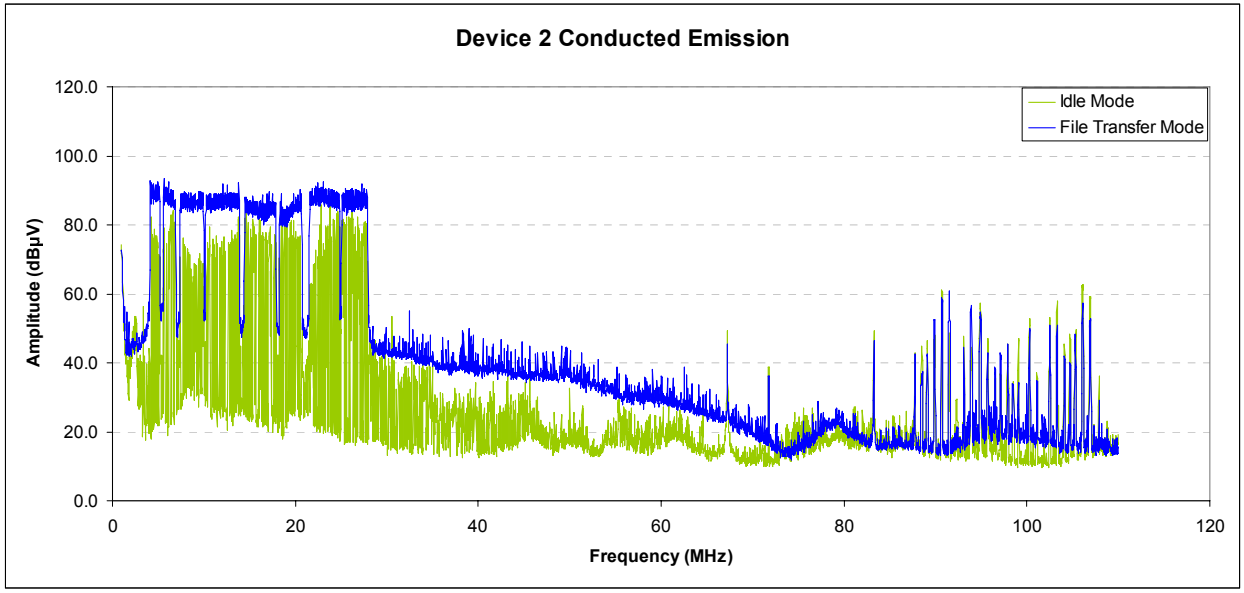
- The extrapolation factor for field strength attenuation over distance is 18.2 dB based on field test results, which is much lower than the 40 dB per decade assumption used by some spectrum authorities.
- Very low emission levels above ambient were observed for the frequencies from 30 to 108 MHz. Test scenarios with more than two PLT devices in a home could result in stronger emission.
- Test results show that emission levels in the operating frequency range can vary over a 20 dB range for any pair of device, depending on the house under test.
- Measured emission level is linearly proportional to the output power of a PLT device (e.g. 10 dB higher output power will result in 10 dB higher emission level).
- Idle mode emission level is not higher than data transfer mode as observed in laboratory conducted tests.
- There are transmission activities during idle mode, resulting in the same interference potential present in data transfer mode.
- Residential buildings connected by overhead electrical lines do not seem to have a significant increase in total emissions due to the potential emission coming from these overhead lines.

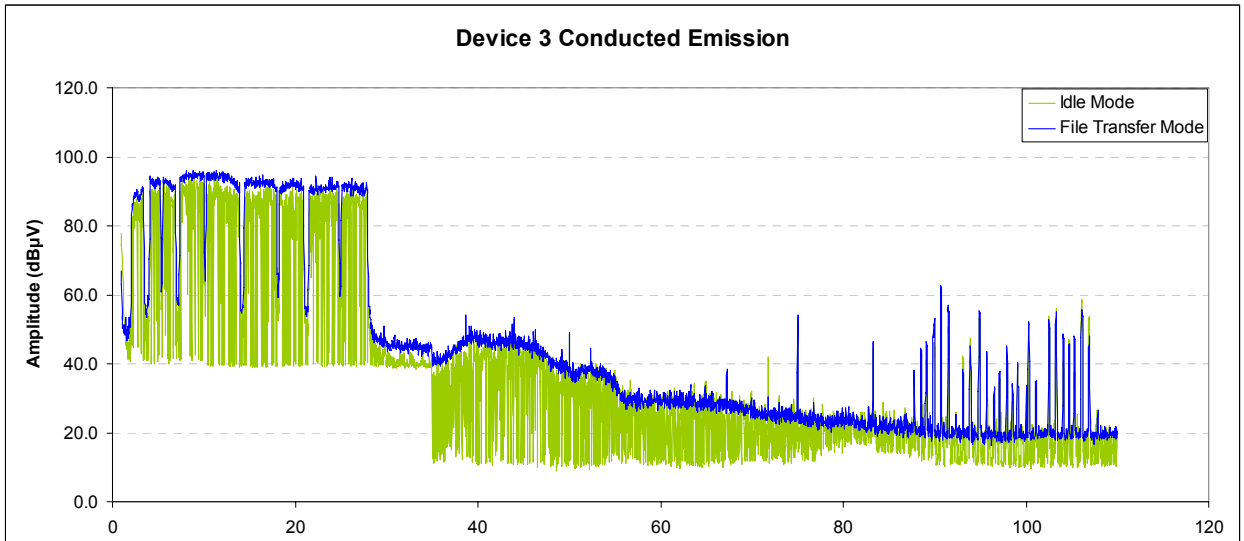
Appendix A: Laboratory Test Results

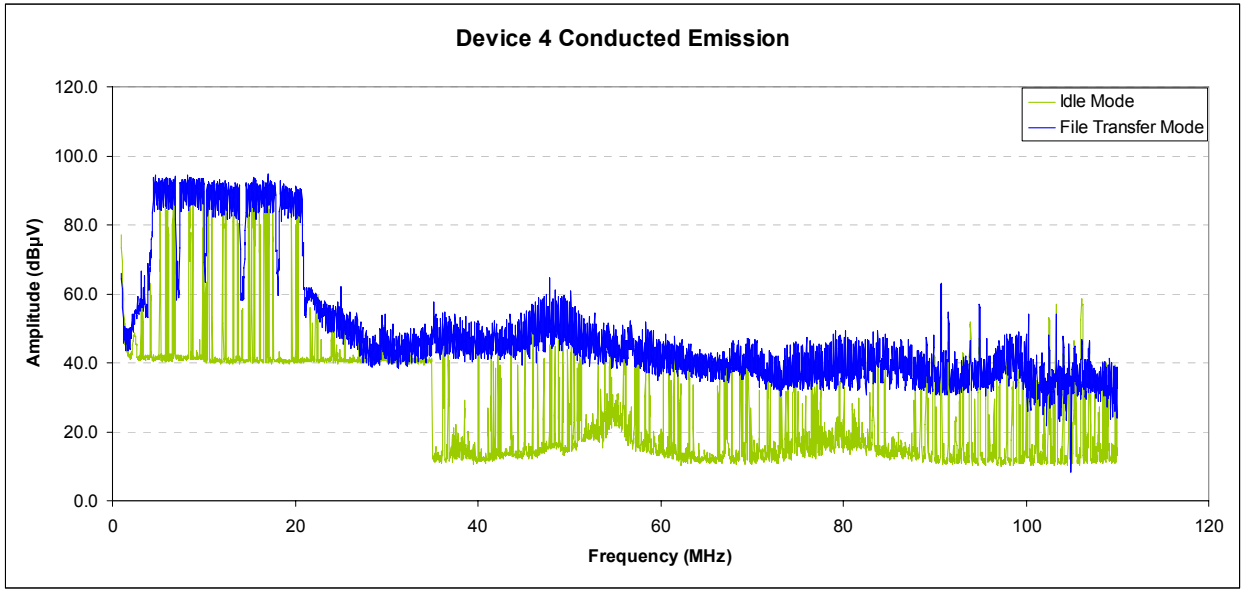
The following figures show the conducted power from the eight PLT devices considered for field trial. The measurements are done as per the laboratory test setup presented in Section 3.1 and the methodology of Section 3.3.1.

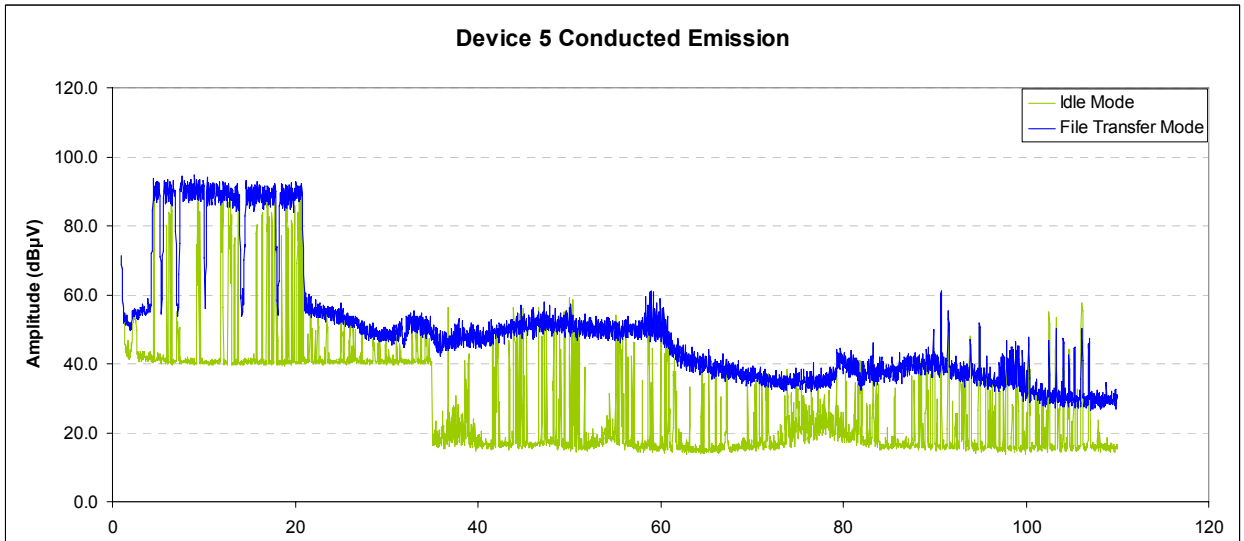


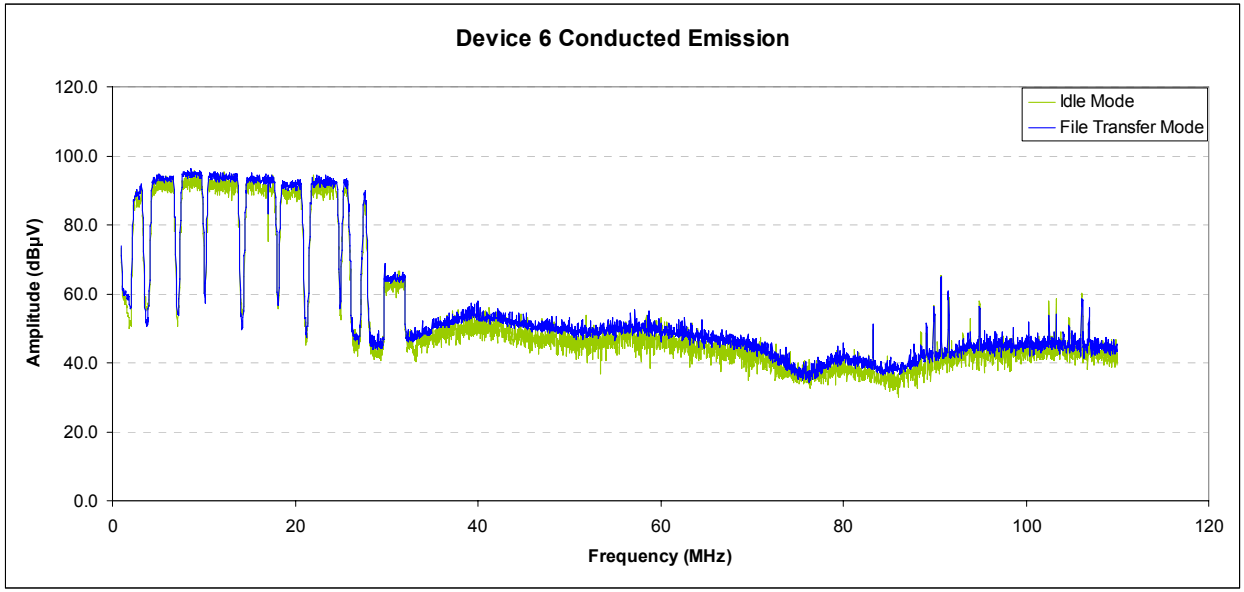


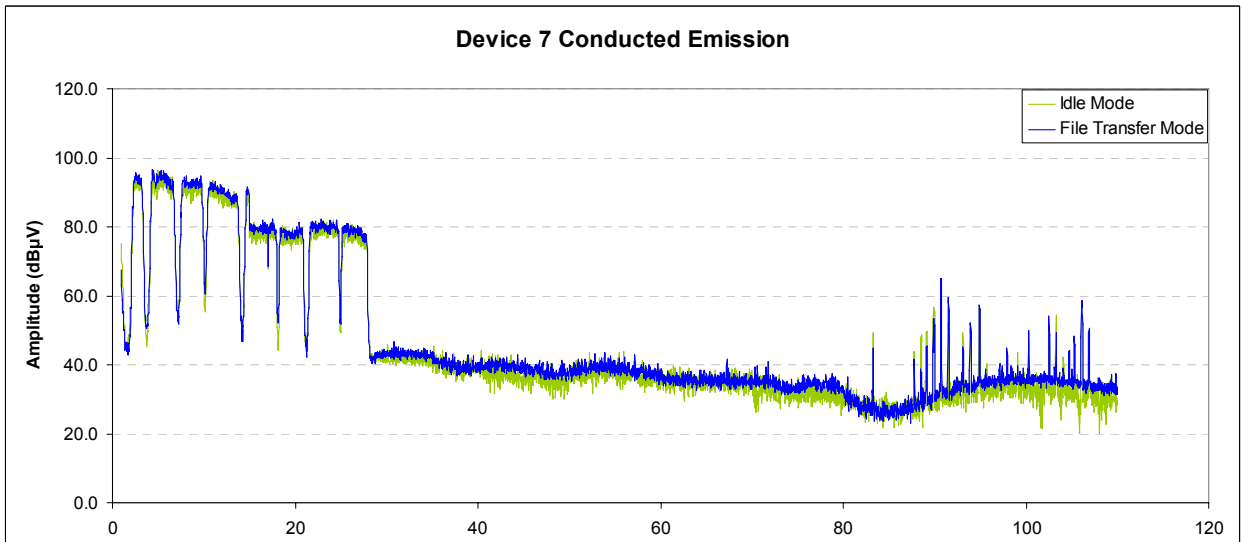

Device 2 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Frequency (MHz)

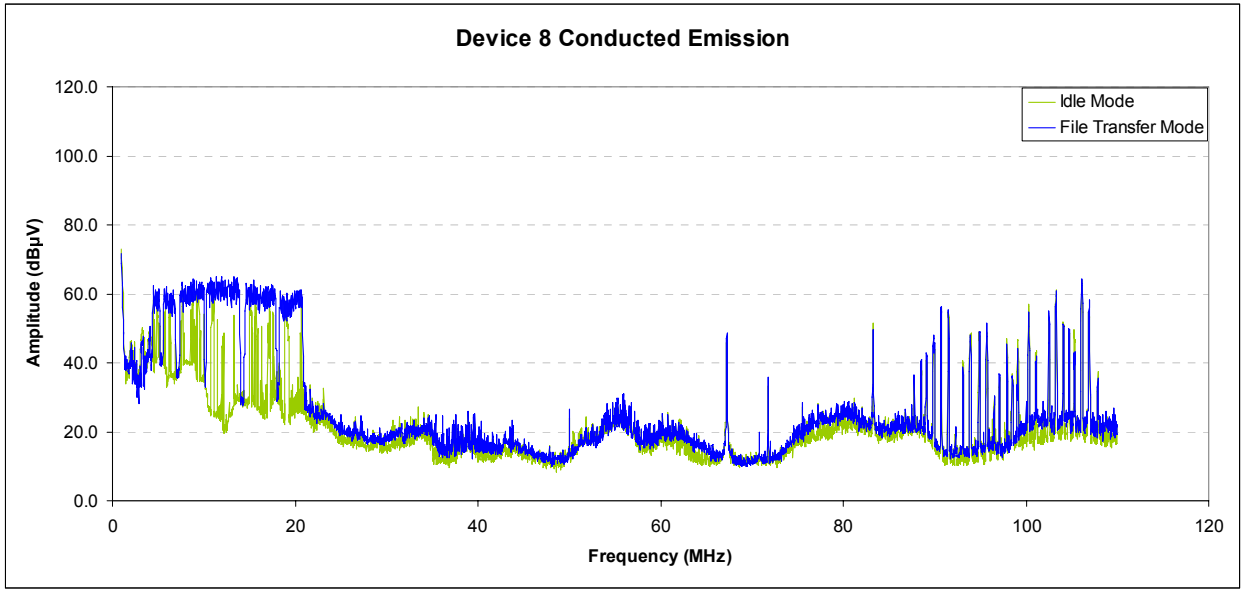

Device 3 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120


Device 4 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Frequency (MHz)


Device 5 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120


Device 6 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Frequency (MHz)


Device 7 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120


Device 8 Conducted Emission
Idle Mode
File Transfer Mode
Amplitude (dBµV)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0
20
40
60
80
100
120
Frequency (MHz)

Appendix B: Site Descriptions and RF Field Strength Tests Results

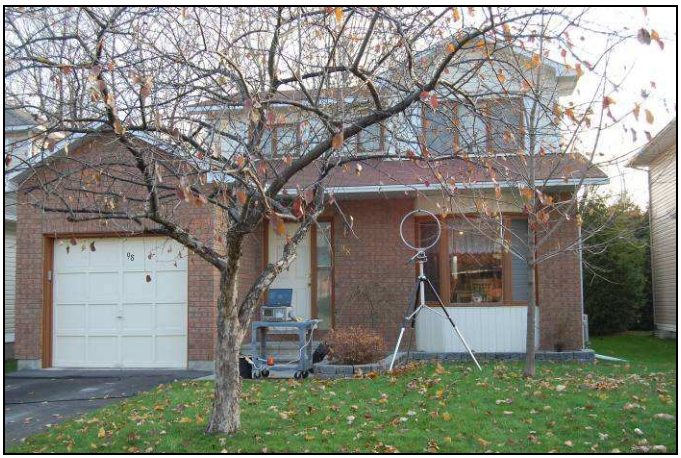
RF Field Strength Specific Test Conditions					
Site #	Loop Antenna (0-30 MHz)			Dipole Antenna (30-108 MHz)	
	File Transfer Mode	Idle Mode	Under Overhead Electrical Lines	File Transfer Mode	Idle Mode
1	X	X		X	X
2	X	X			
3	X	X			
4	X	X		X	X
5	X				
6	X				
7	X				
8	X				
9	X				
10	X				
11	X				
12	X		X		
13	X				
14	X		X		
15	X		X		
16	X				
17	X				

Test Site 1

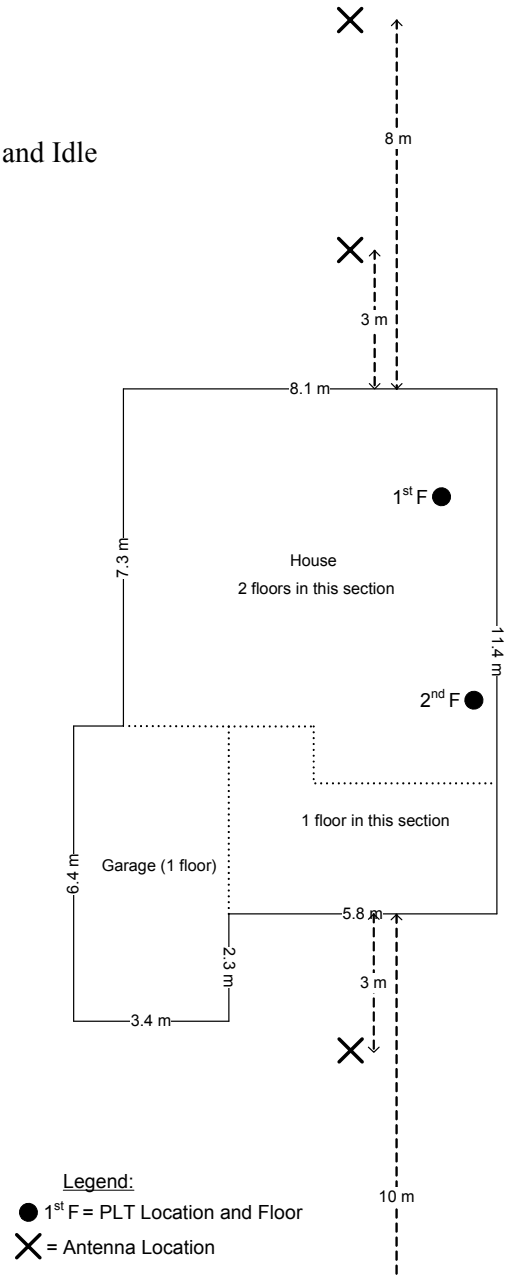
Type of House: Two-story single-detached
Electrical Lines: Underground

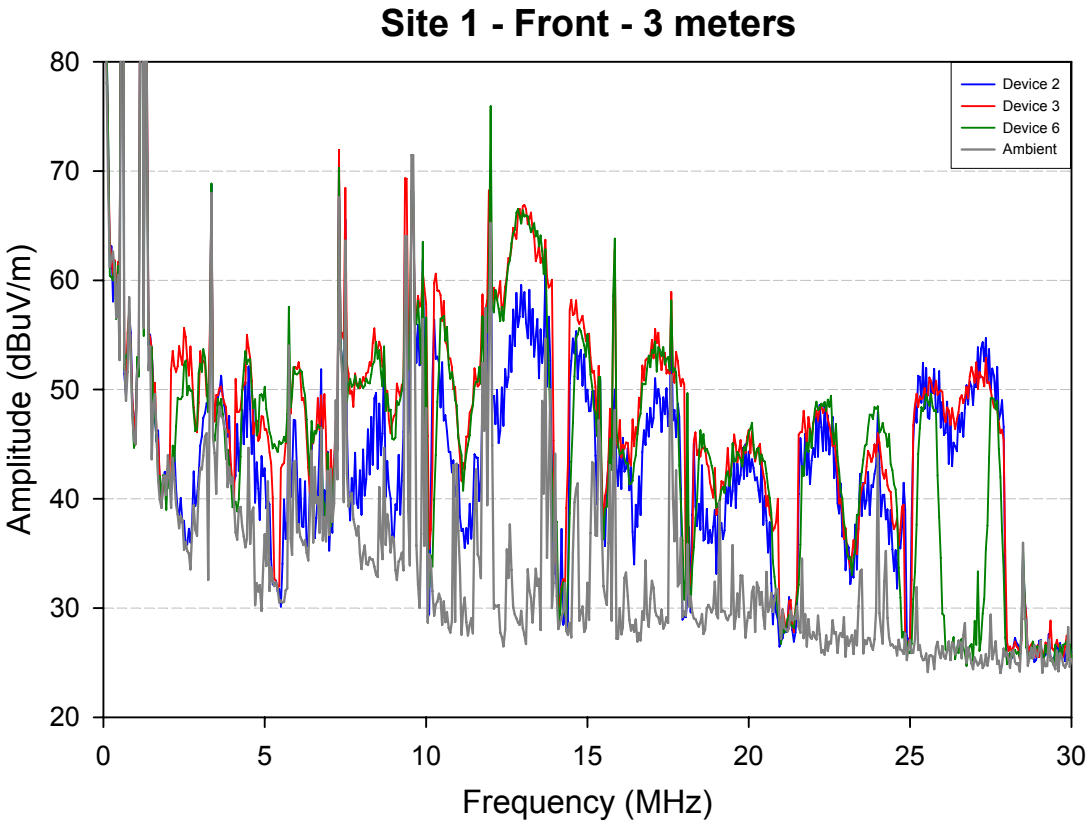
Front Wall Materials: Brick, Vinyl
Back Wall Materials: Vinyl

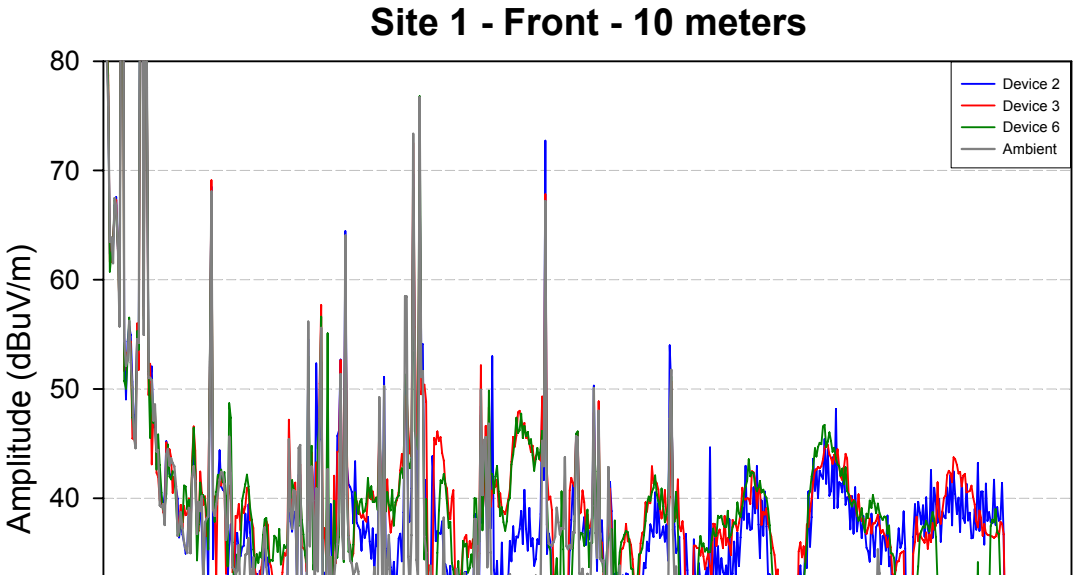
Tests Performed: EMI 0-108 MHz: Data Transfer and Idle
LCL
CMI/DMI

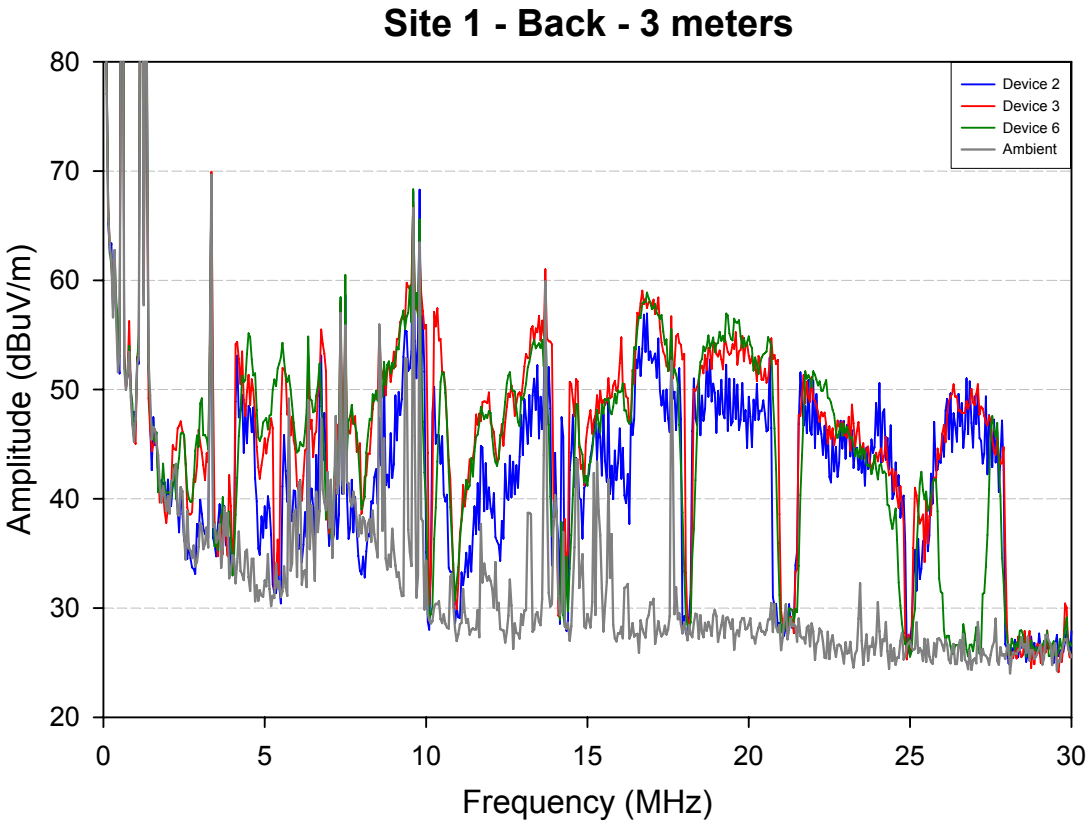


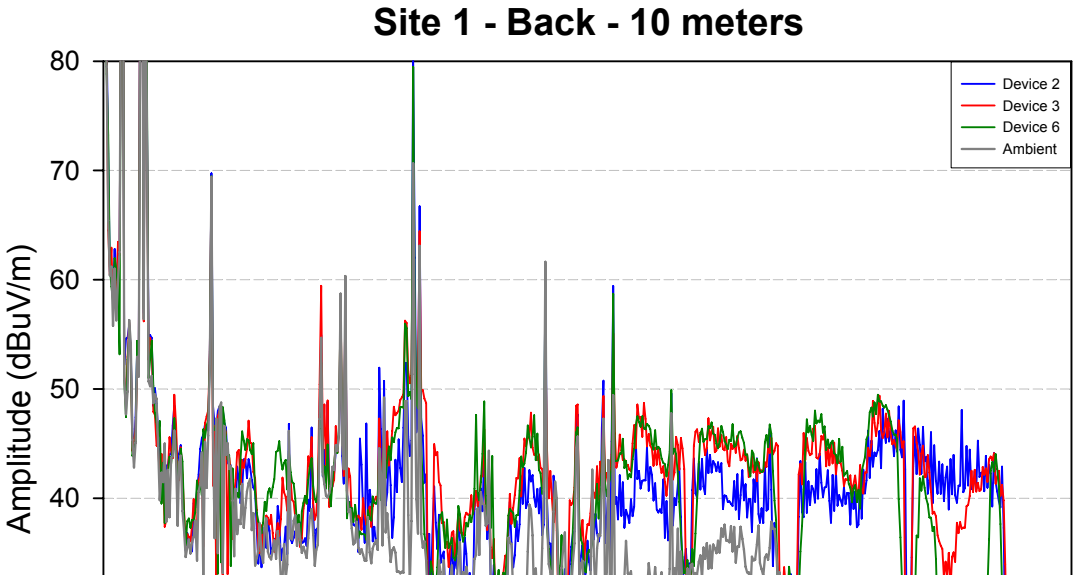
Test Site 1 - Front




Site 1 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 1 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 1 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 1 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

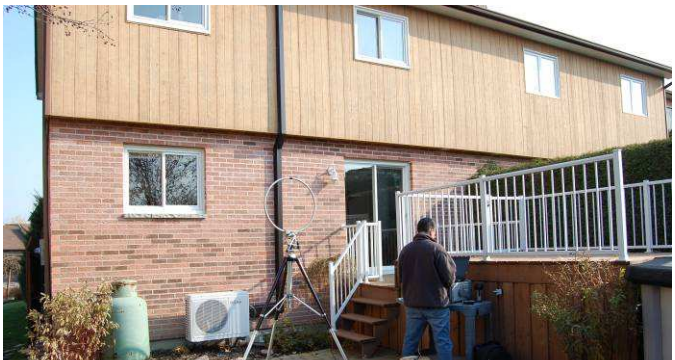
Test Site 2

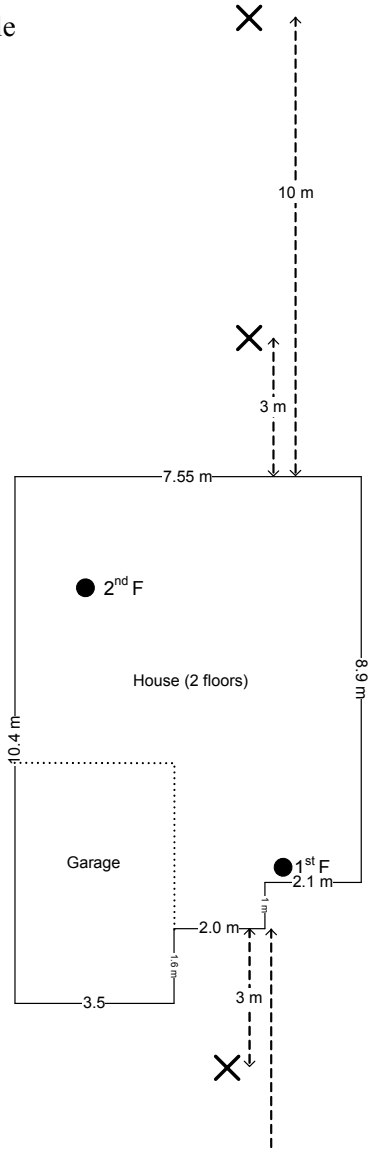
Type of House: Two-story semi-detached
Electrical Lines: Underground

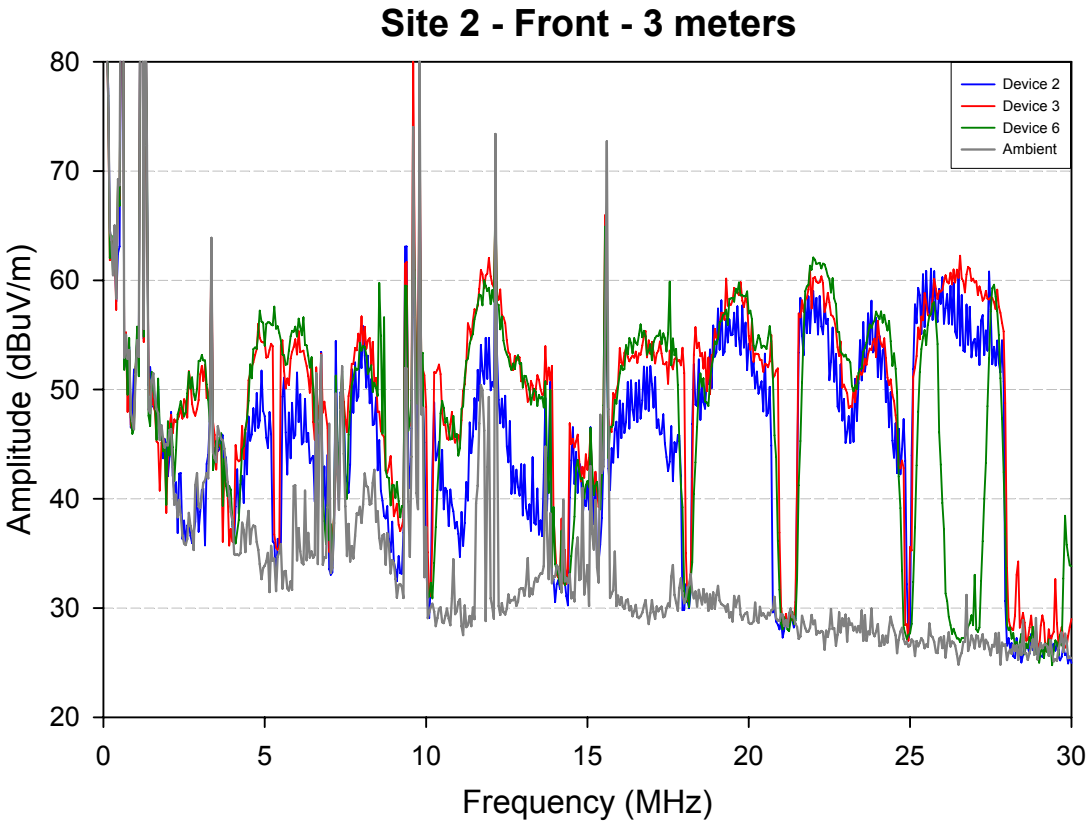
Front Wall Materials: Brick, Canexel
Back Wall Materials: Brick, Canexel

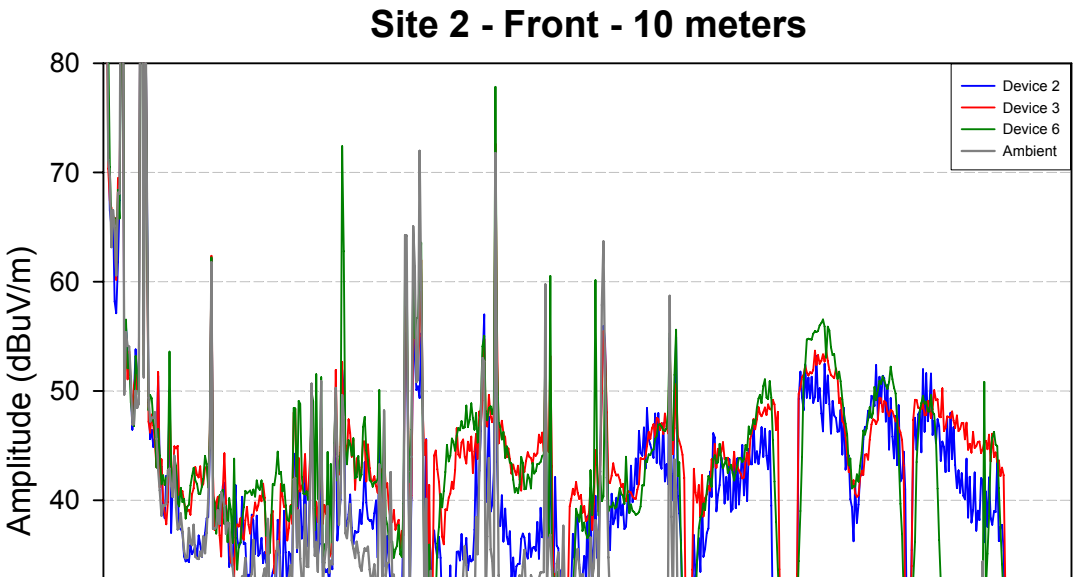
Tests Performed: EMI 0-30 MHz: Data Transfer and Idle

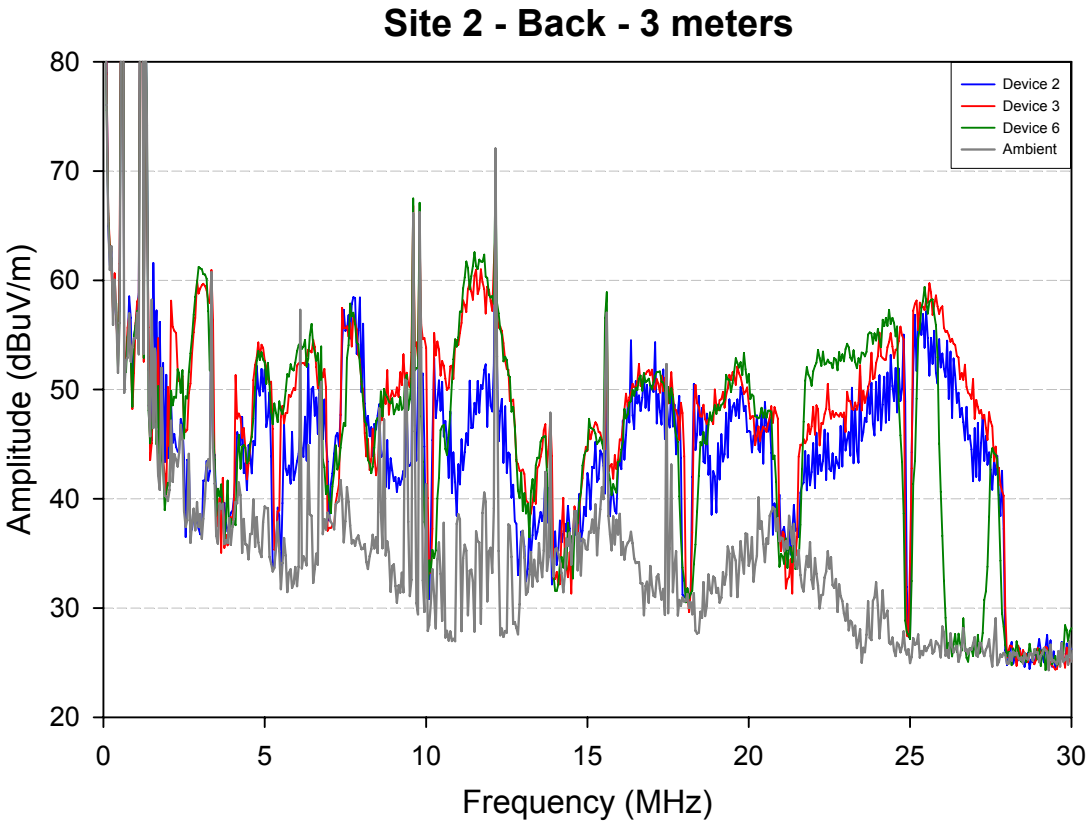
Test Site 2 - Front

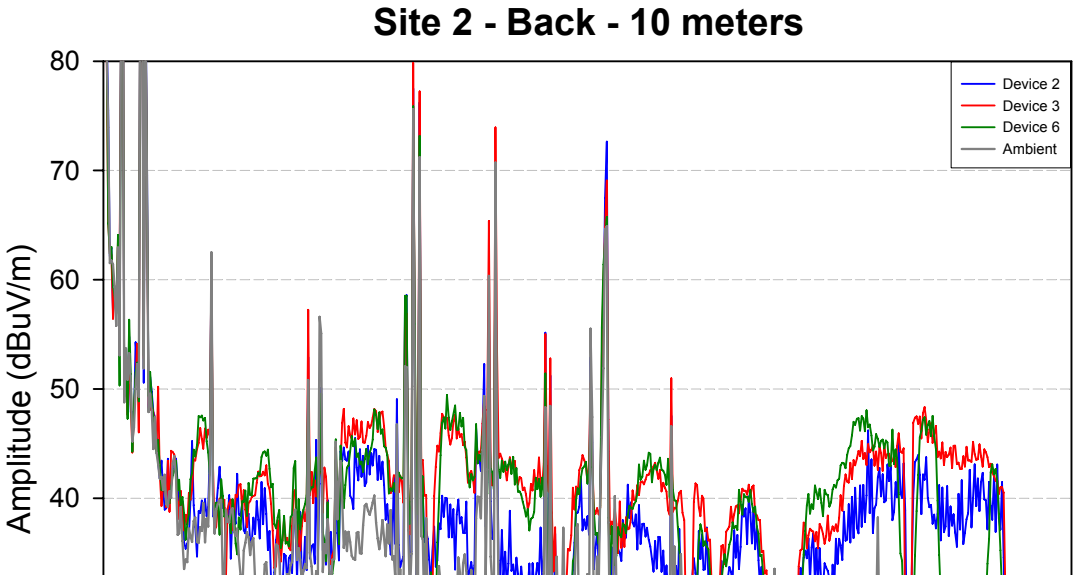





Site 2 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 2 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 2 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 2 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

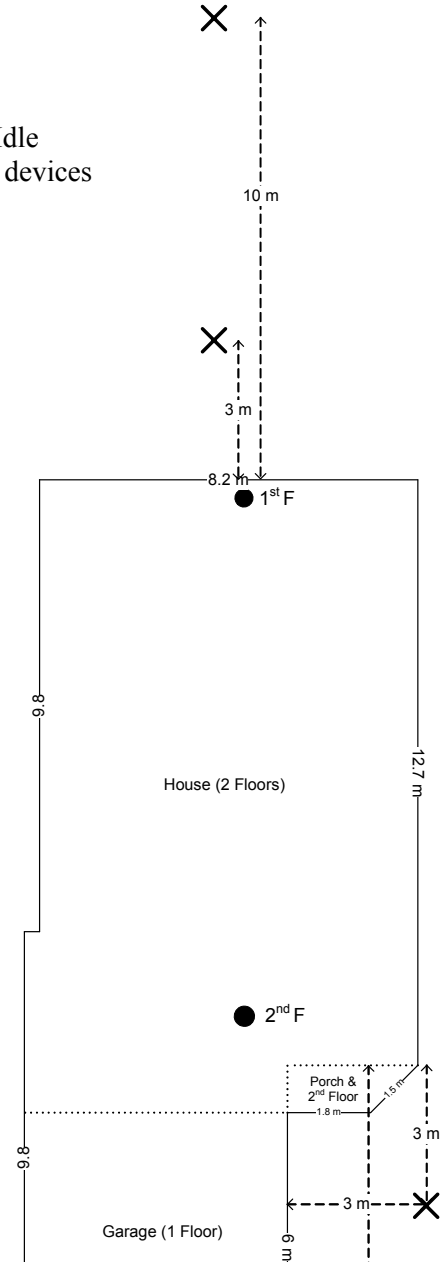
Test Site 3

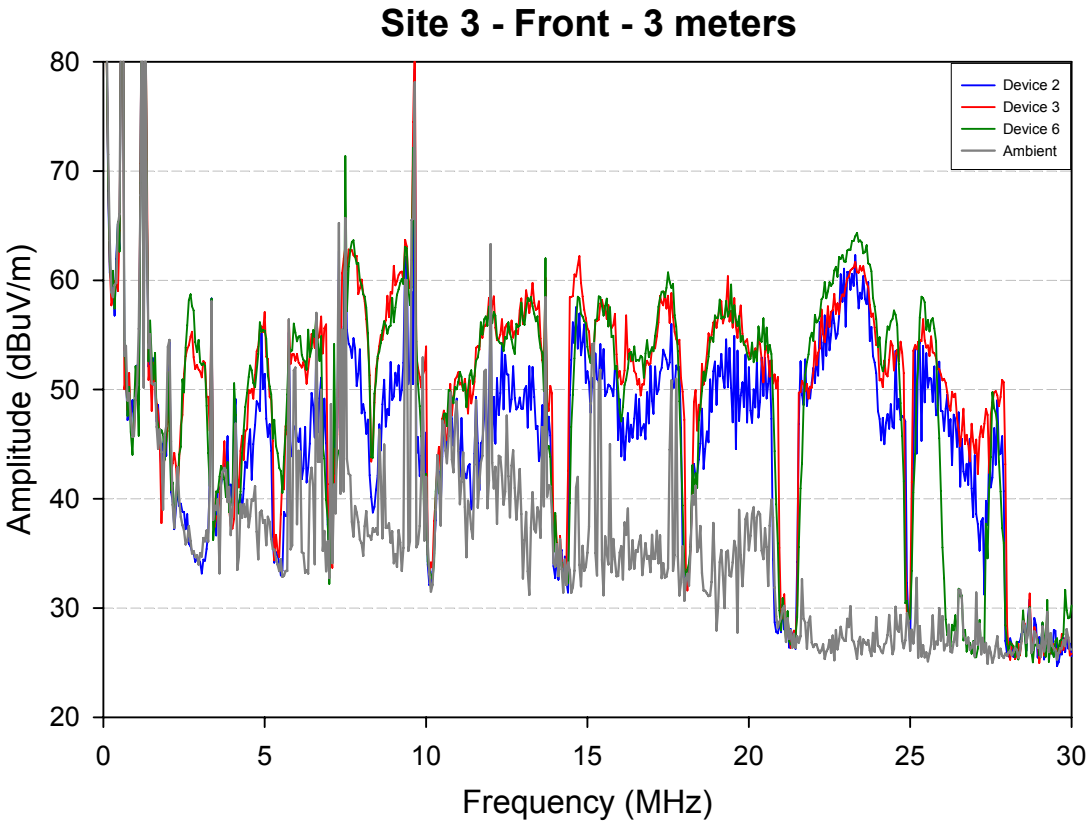
Type of House: Two-story single-detached
Electrical Lines: Underground

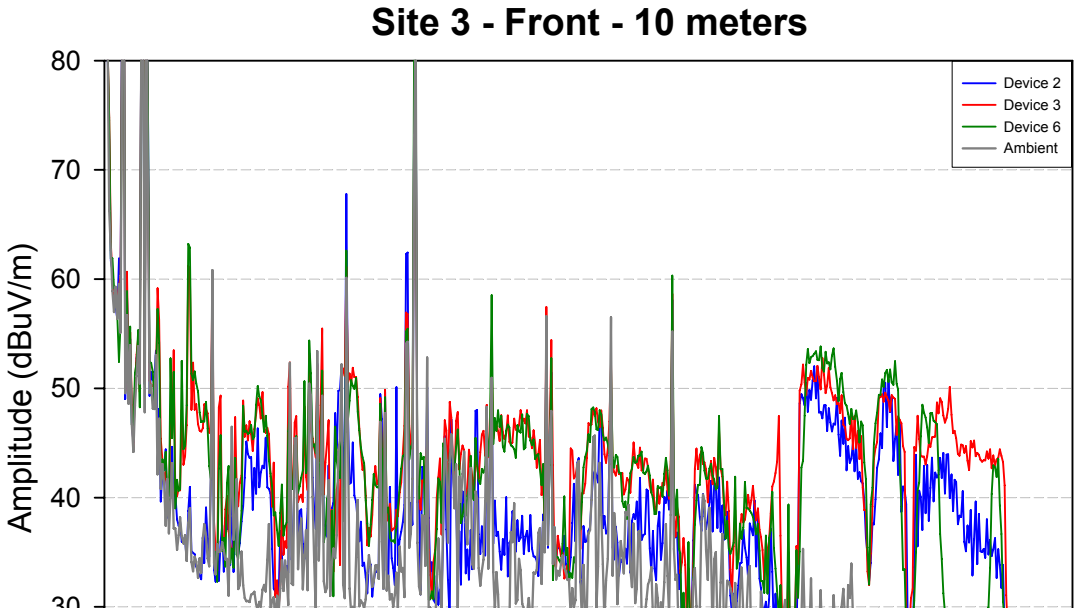
Front Wall Materials: Brick, Vinyl
Back Wall Materials: Vinyl

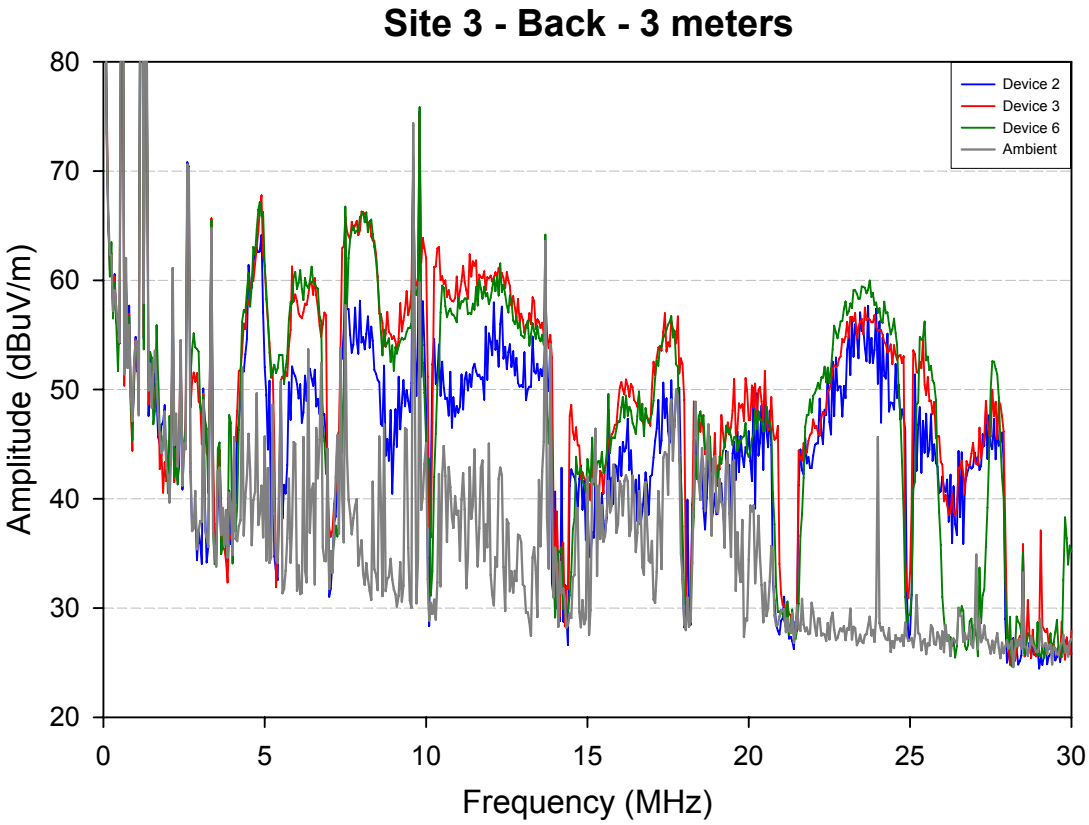
Tests Performed: EMI 0-30 MHz: Data Transfer and Idle
Comments: Right door neighbor was using PLT devices for home network

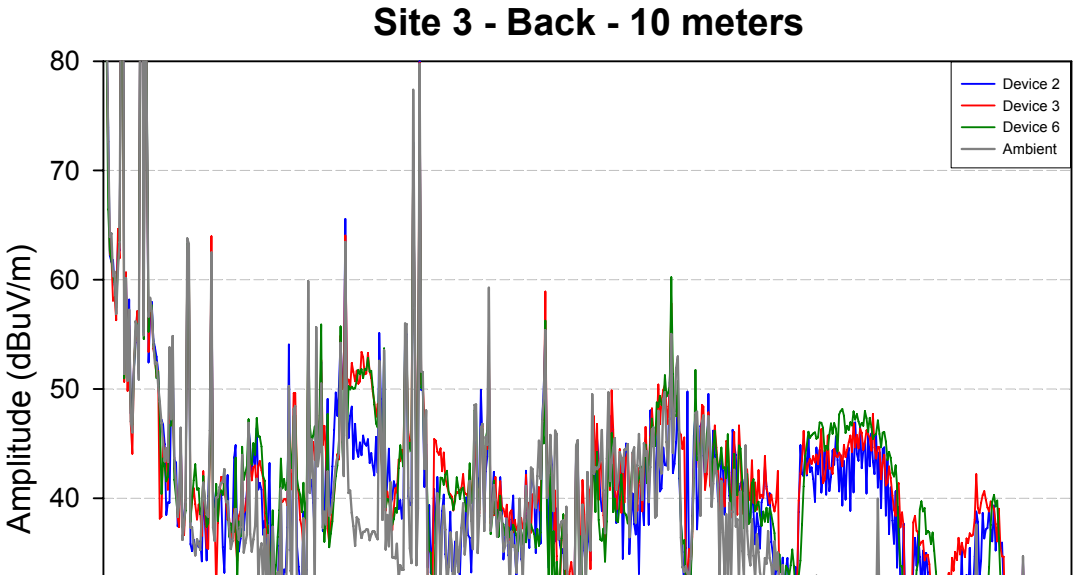
Test Site 3 - Front




Site 3 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 3 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30


Site 3 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 3 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

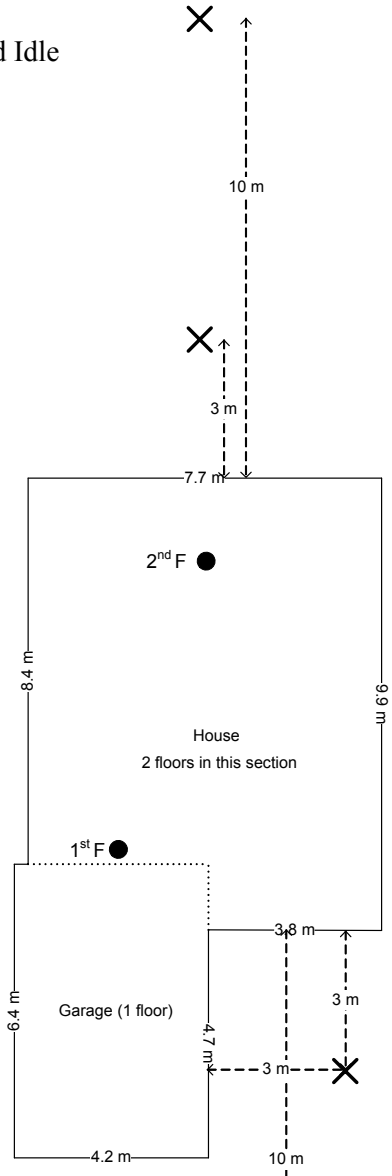
Test Site 4

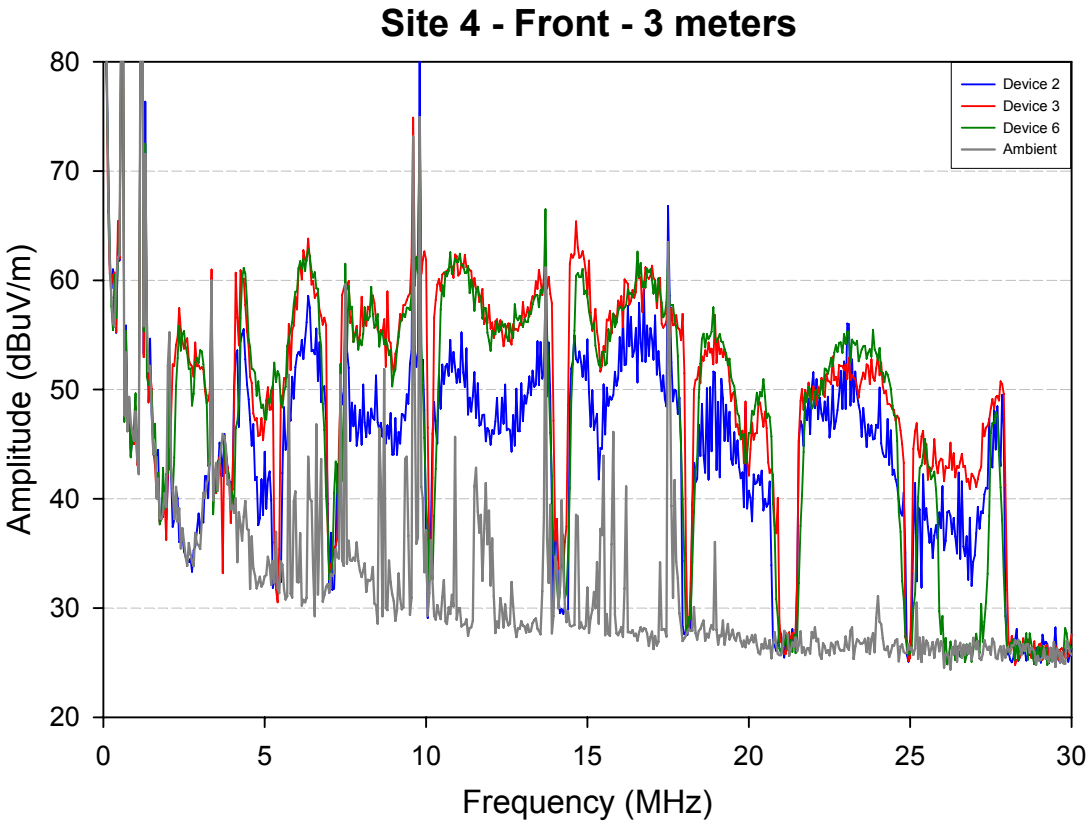
Type of House: Two-story single-detached
Electrical Lines: Underground

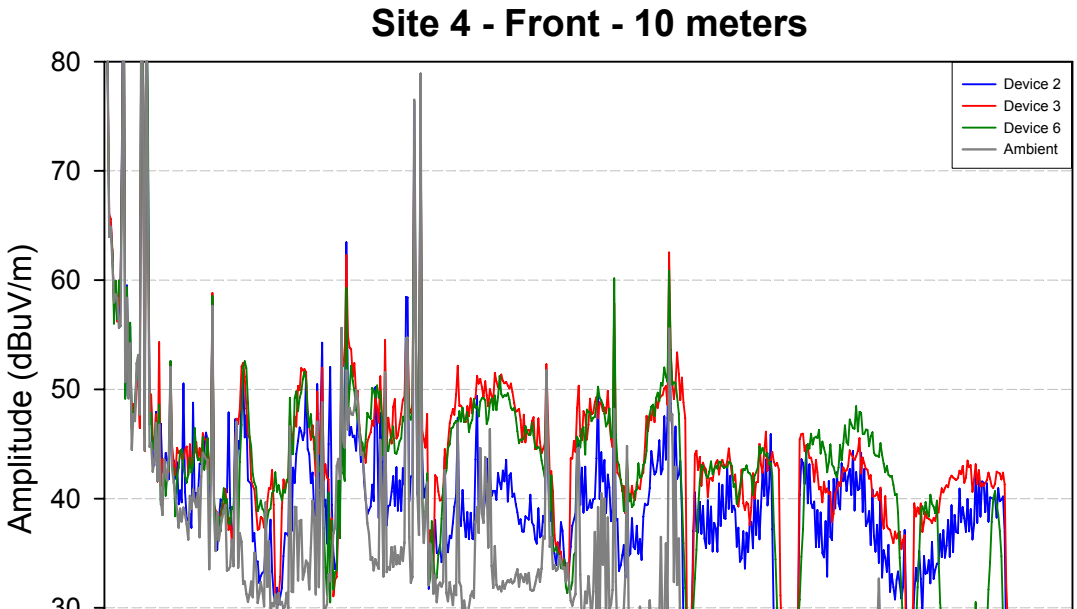
Front Wall Materials: Brick
Back Wall Materials: Brick/Aluminum

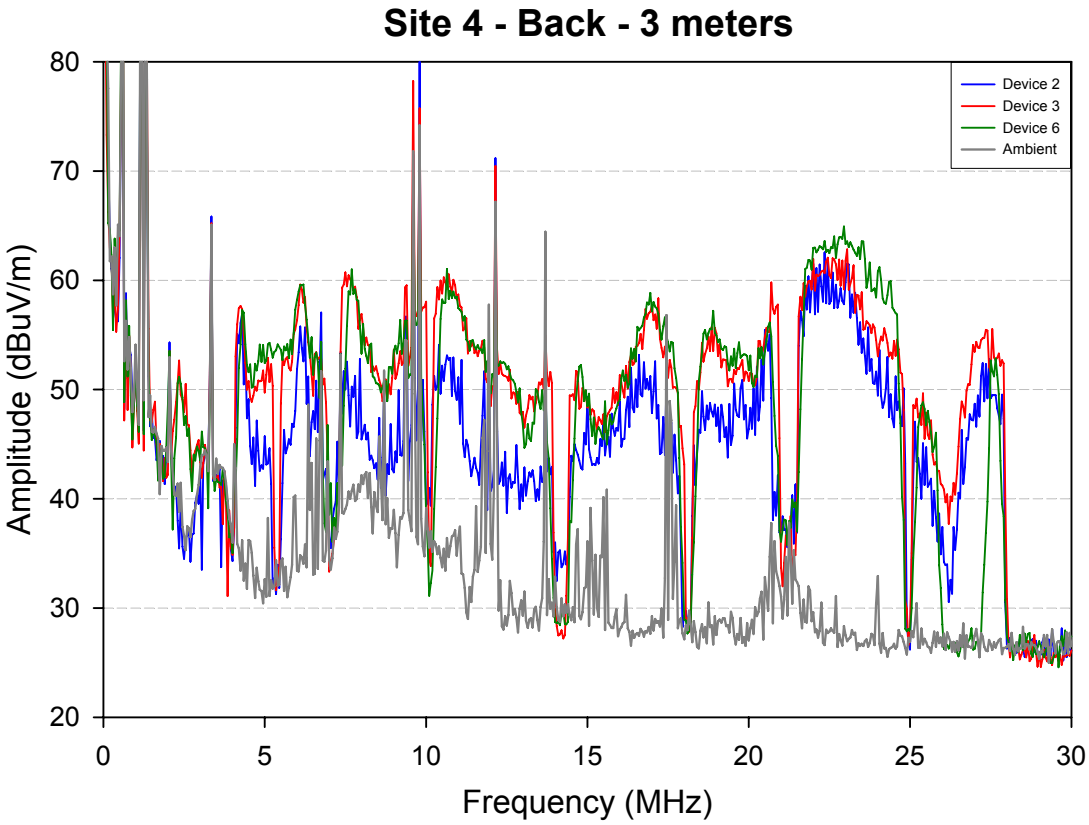
Tests Performed: EMI 0-108 MHz: Data Transfer and Idle

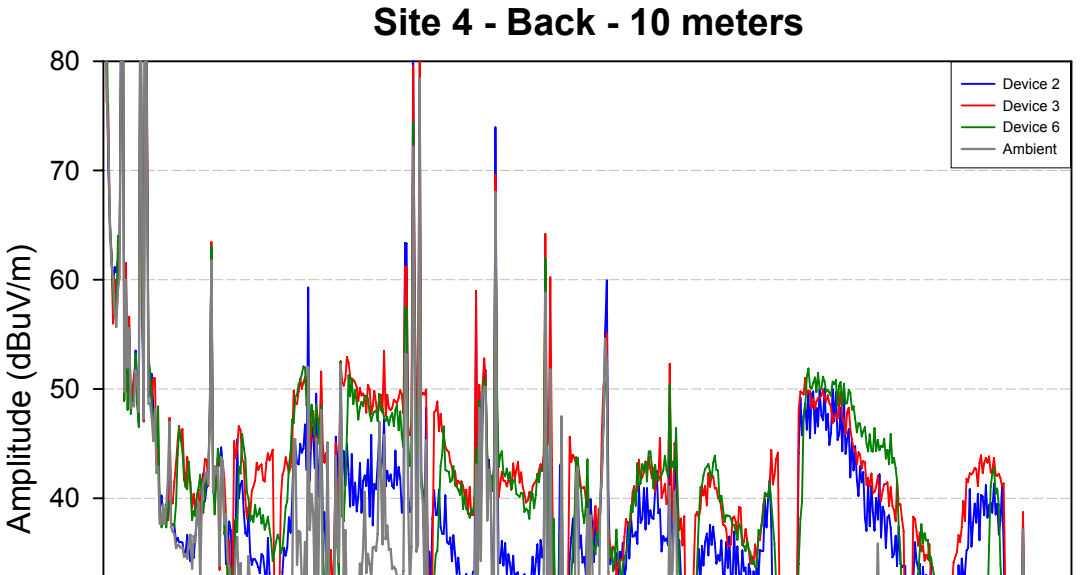
Test Site 4 - Front




Site 4 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 4 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30


Site 4 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 4 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

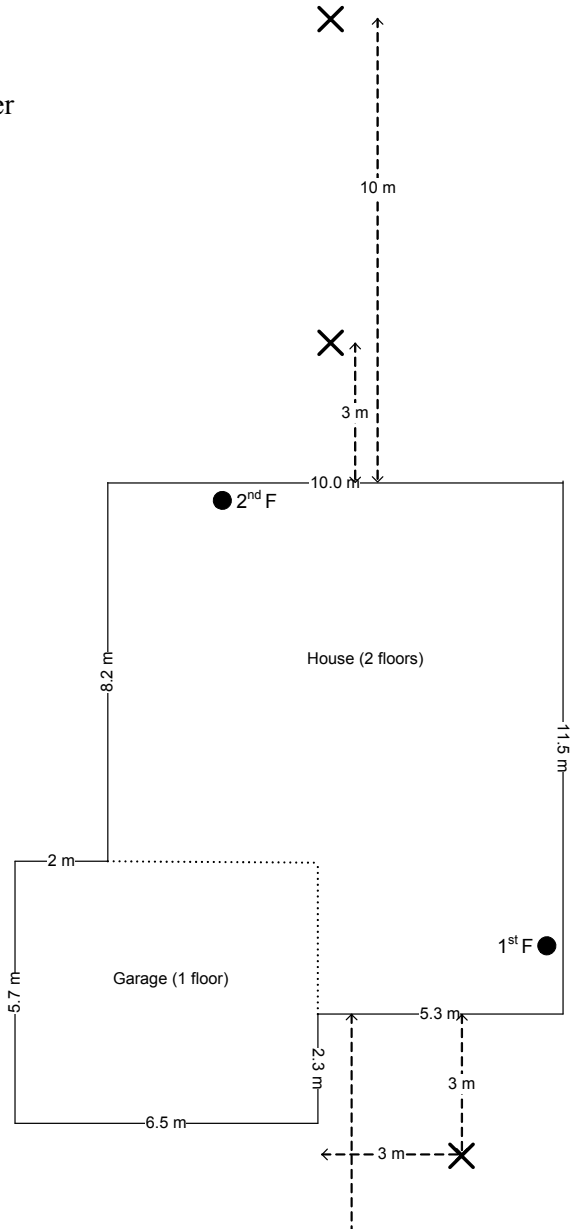
Test Site 5

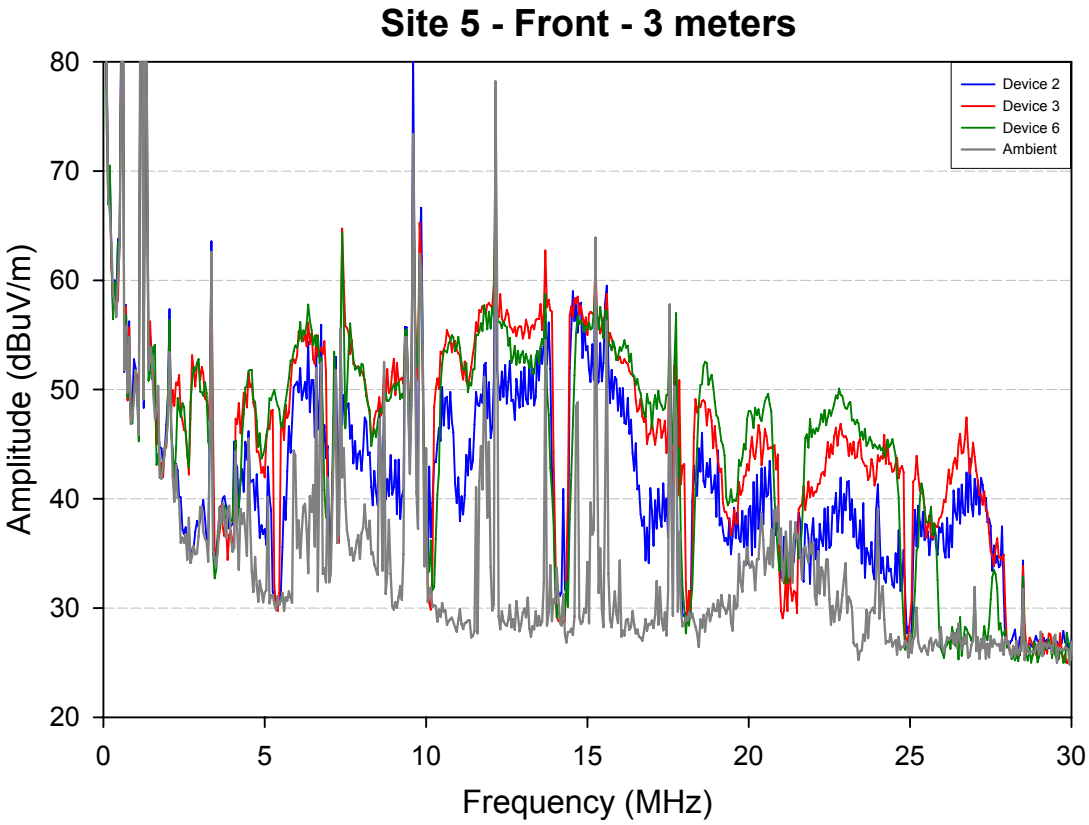
Type of House: Two-story single-detached
Electrical Lines: Underground

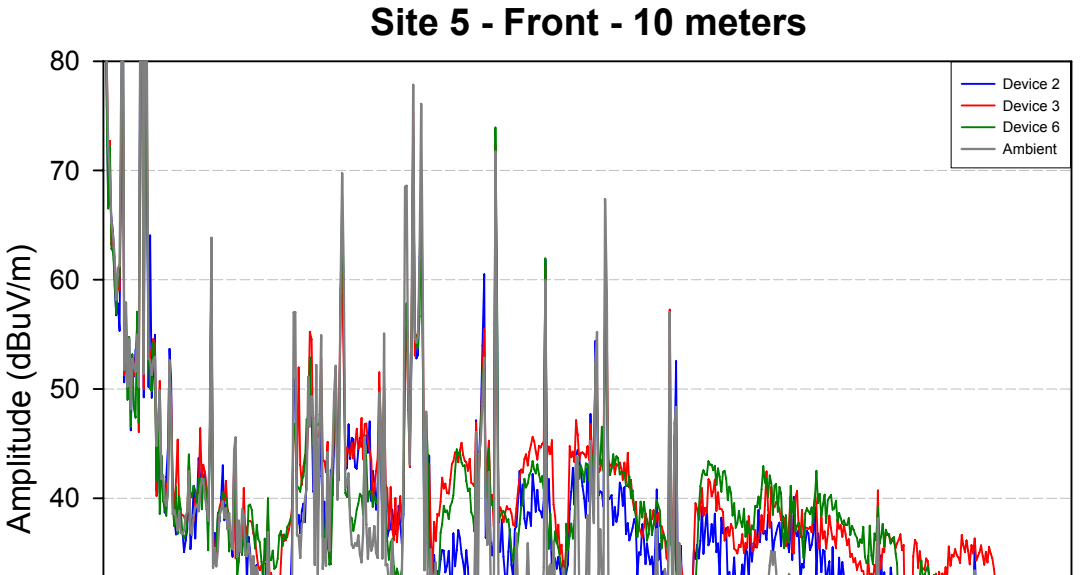
Front Wall Materials: Brick
Back Wall Materials: Brick/Aluminum

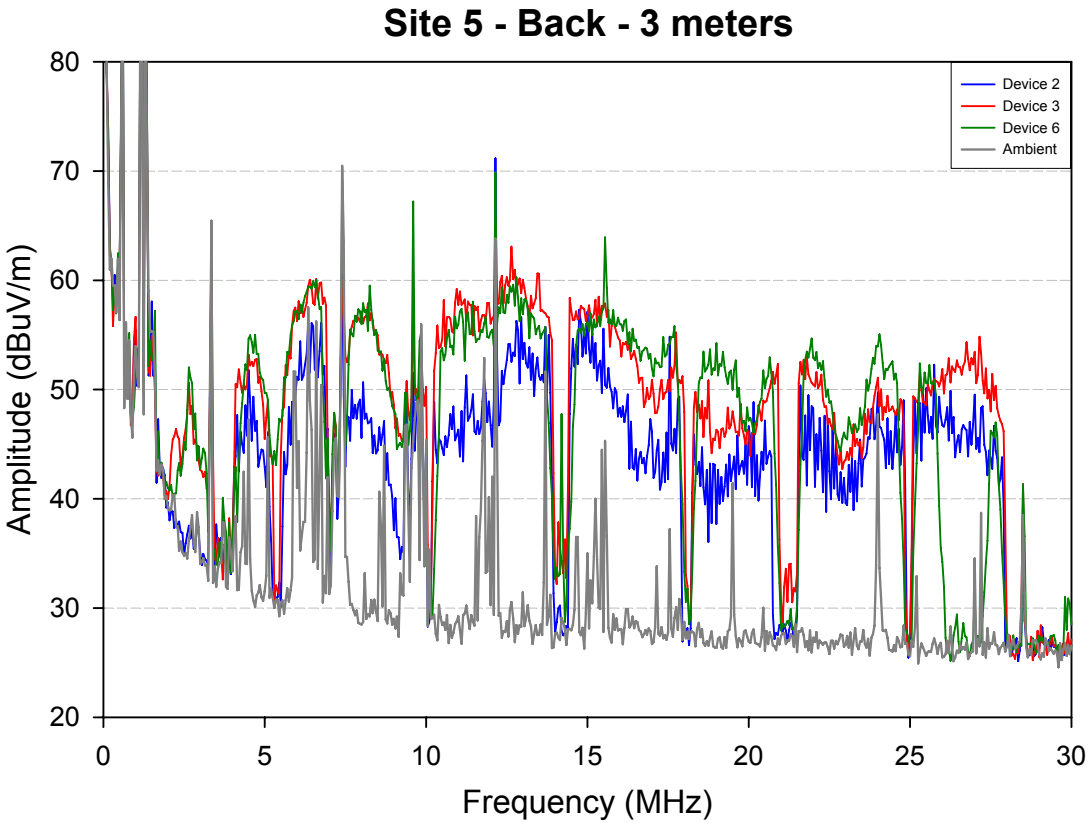
Tests Performed: EMI 0-30 MHz: Data Transfer

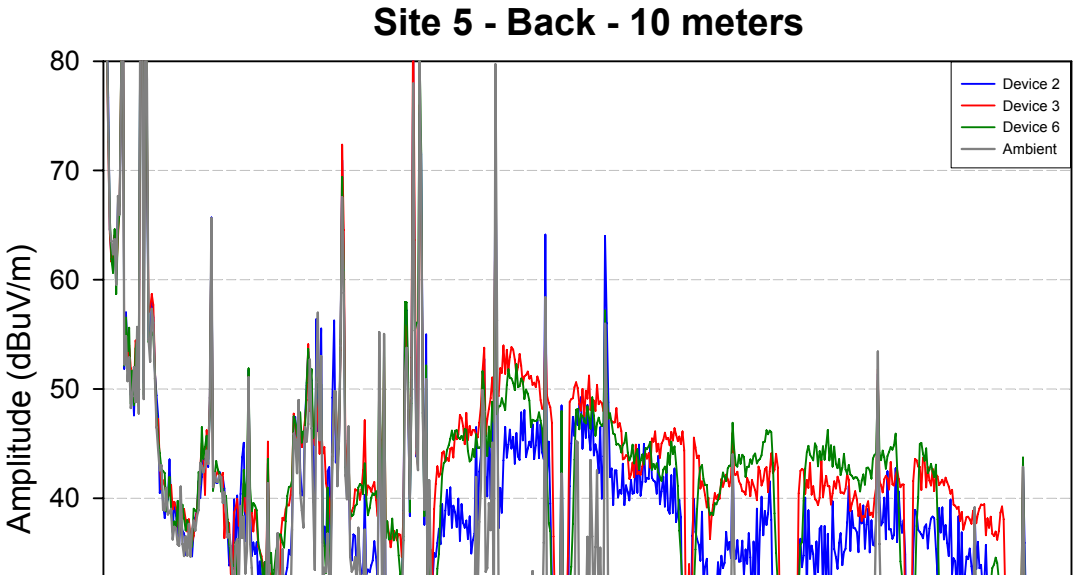
Test Site 5 - Front




Site 5 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 5 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 5 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 5 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

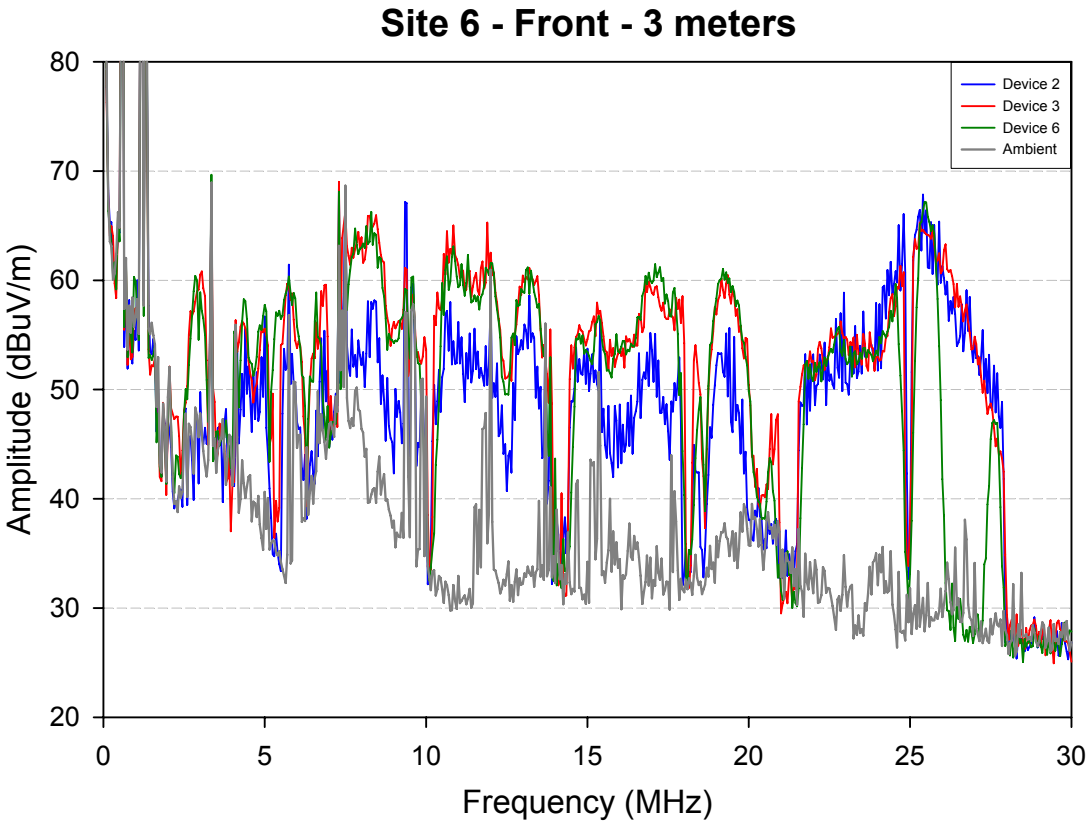
Test Site 6

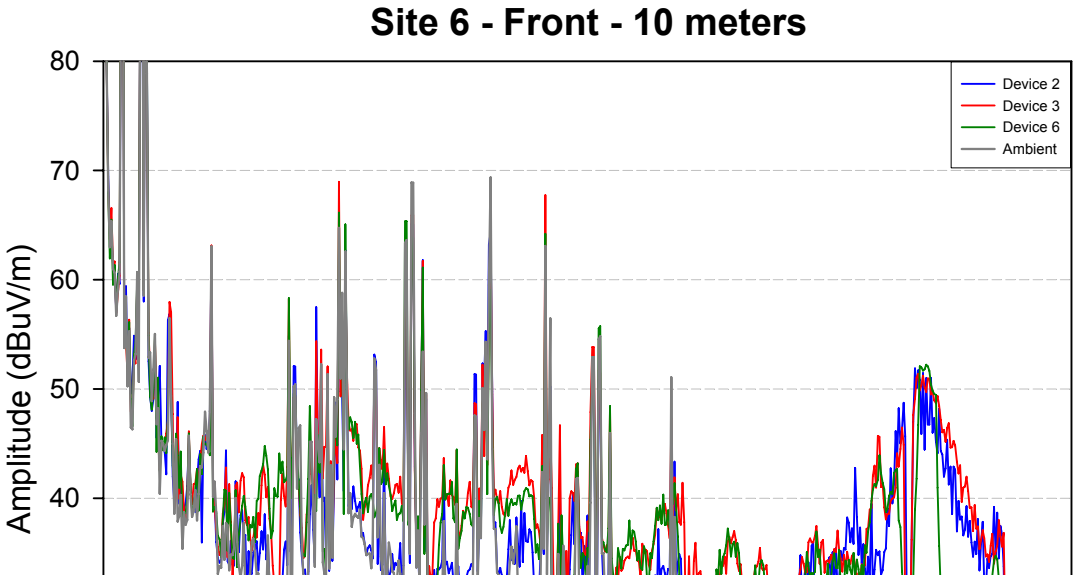
Type of House: Two-story townhouse
Electrical Lines: Underground

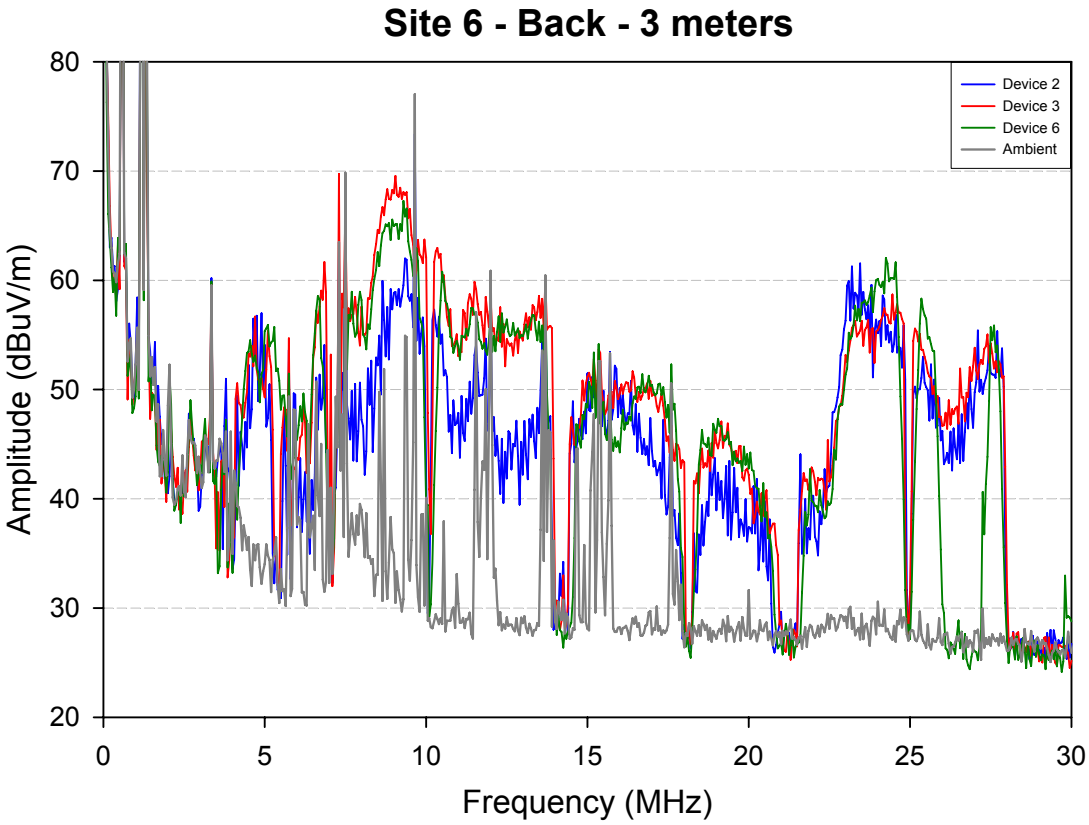
Front Wall Materials: Brick/Vinyl
Back Wall Materials: Vinyl

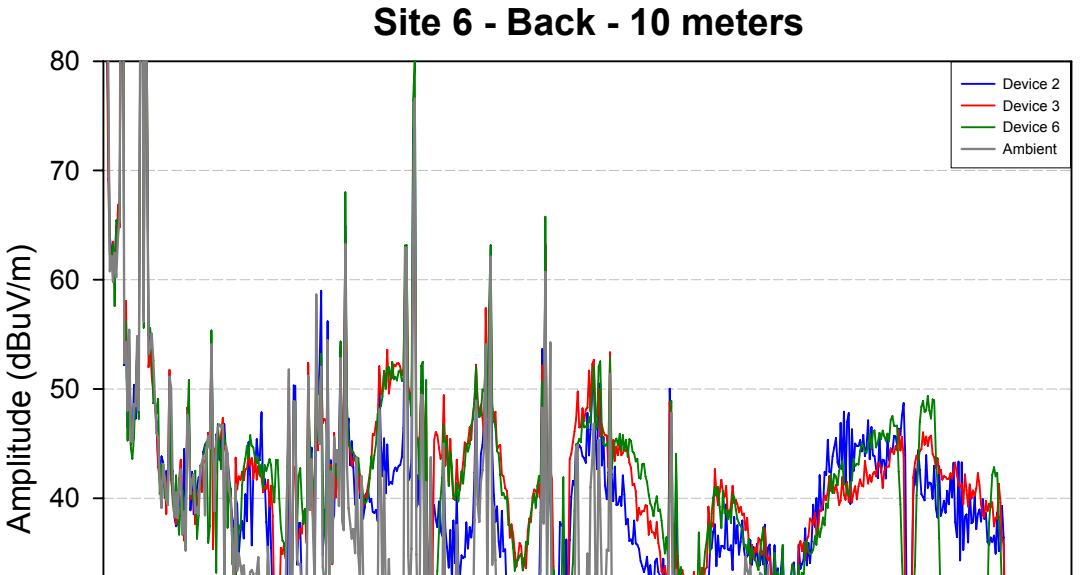
Tests Performed: EMI 0-30 MHz: Data Transfer

Test Site 6 - Front


Site 6 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 6 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 6 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 6 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

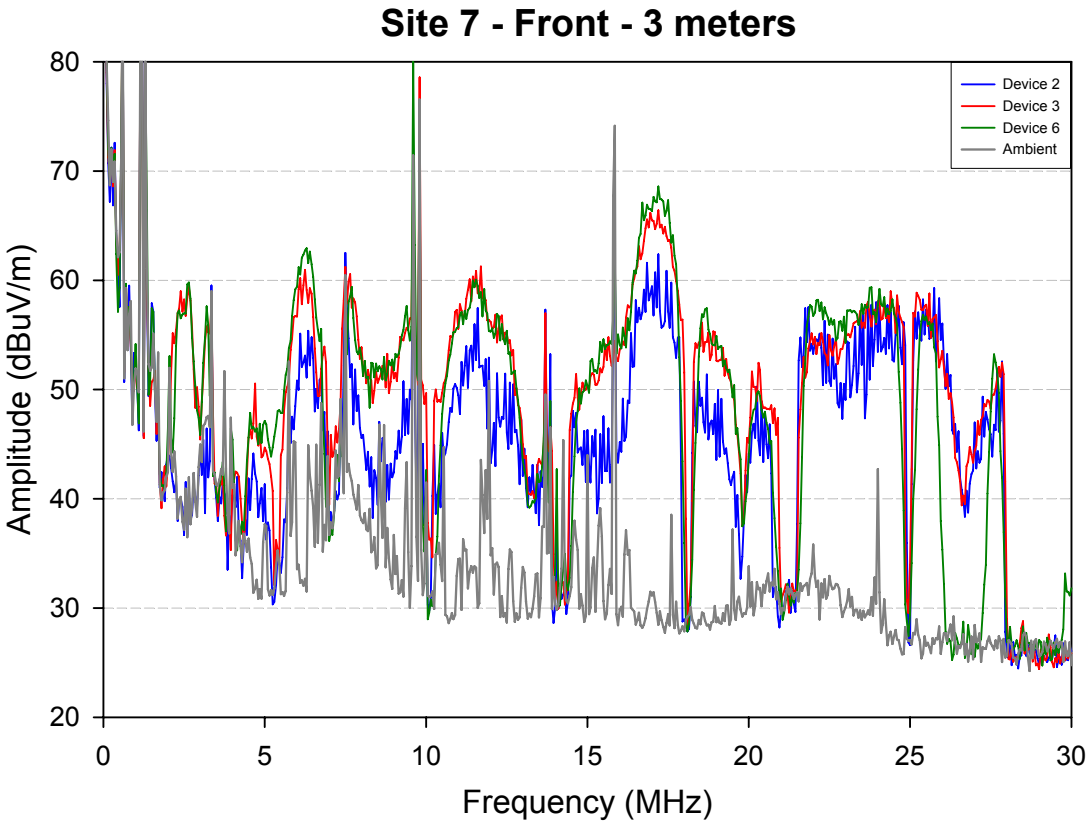
Test Site 7

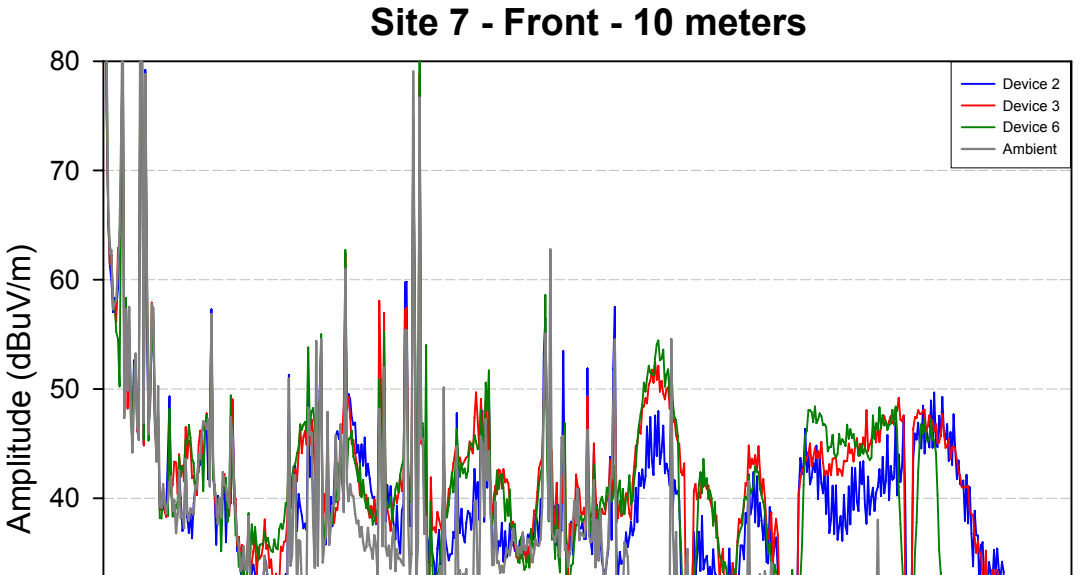
Type of House: Two-story single-detached
Electrical Lines: Underground

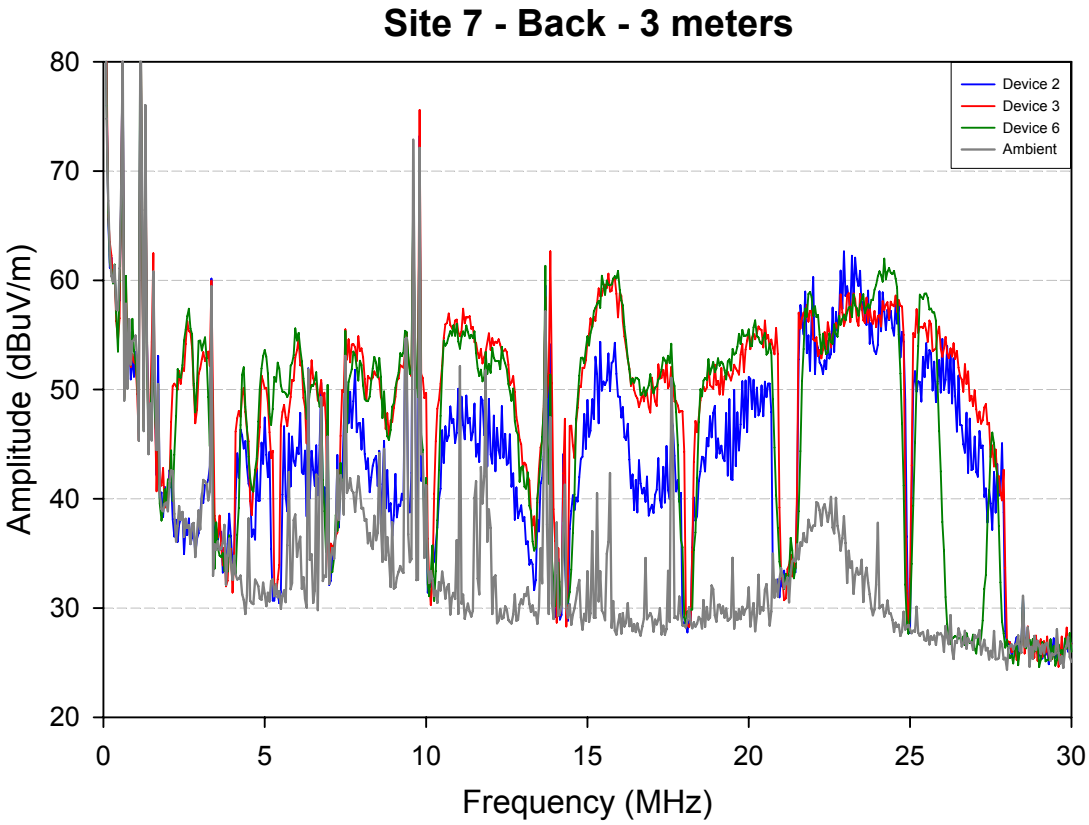
Front Wall Materials: Brick
Back Wall Materials: Vinyl

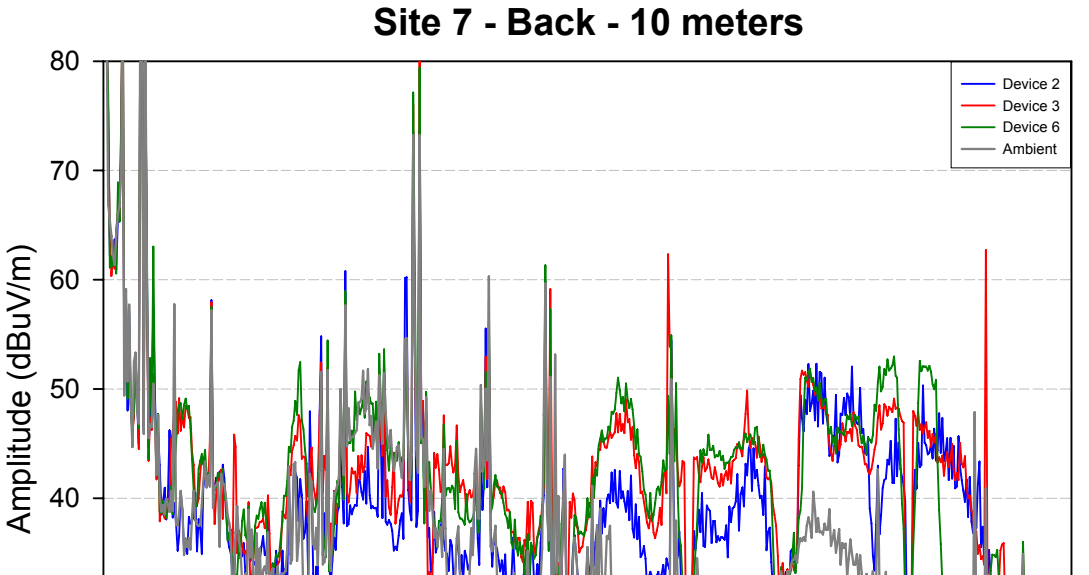
Tests Performed: EMI 0-30 MHz: Data Transfer

Test Site 7 - Front


Site 7 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 7 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 7 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 7 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

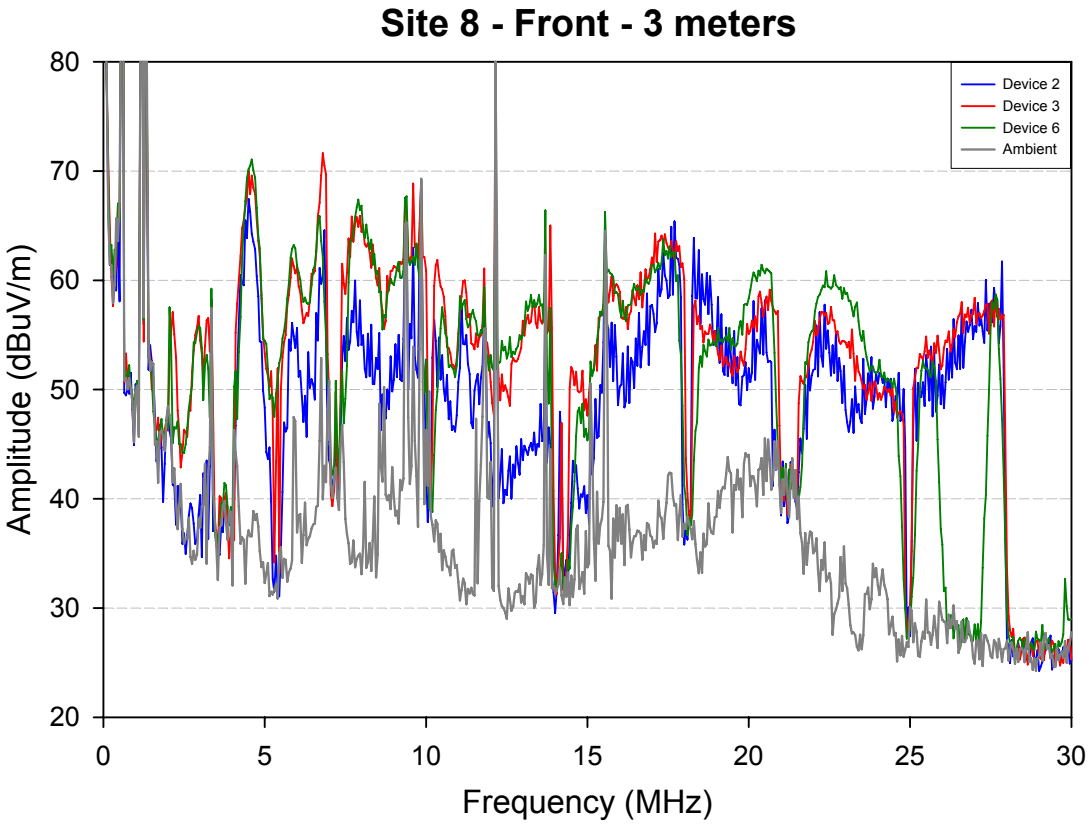
Test Site 8

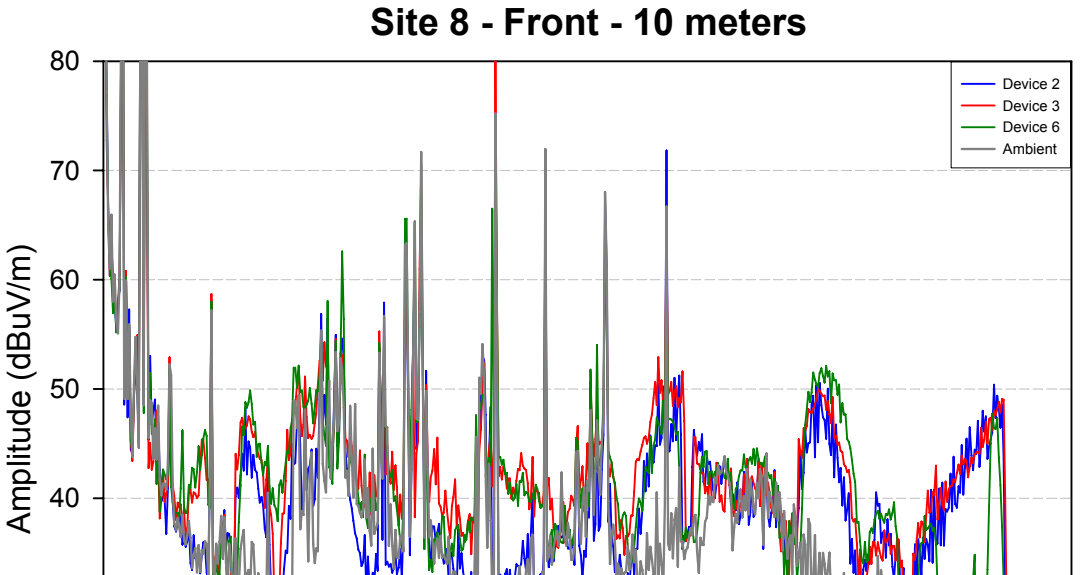
Type of House: Two-story single-detached
Electrical Lines: Underground

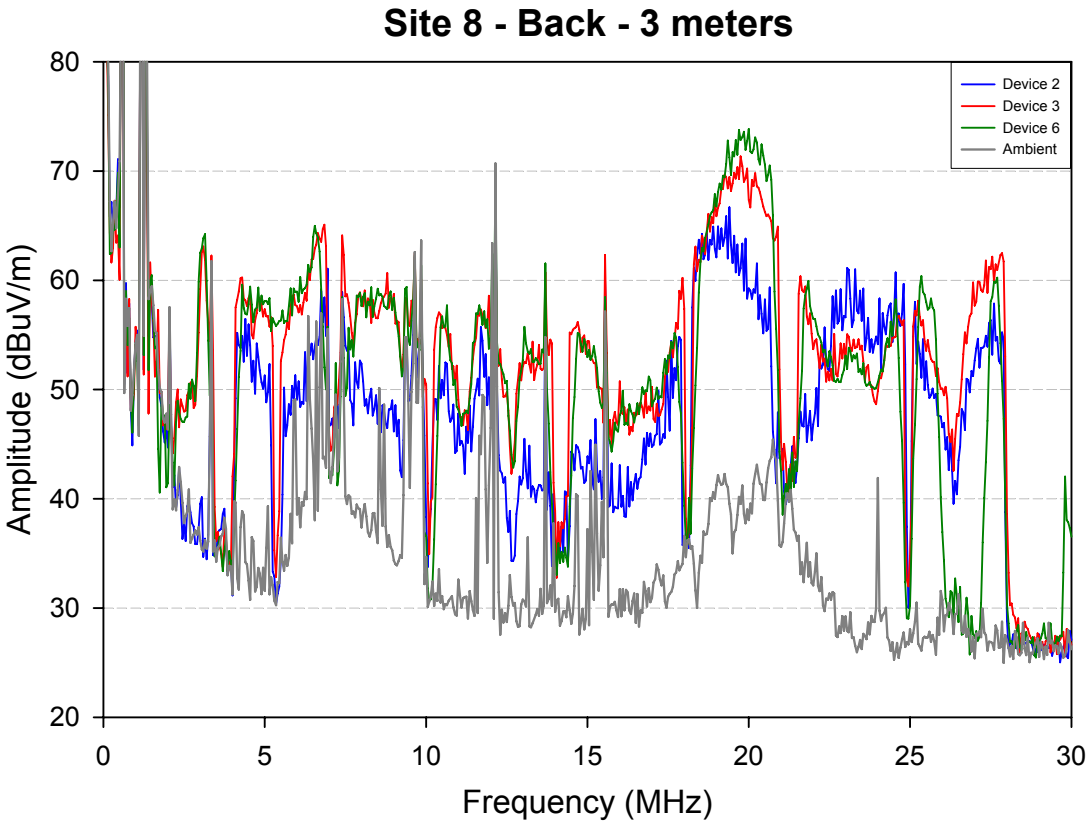
Front Wall Materials: Brick
Back Wall Materials: Vinyl

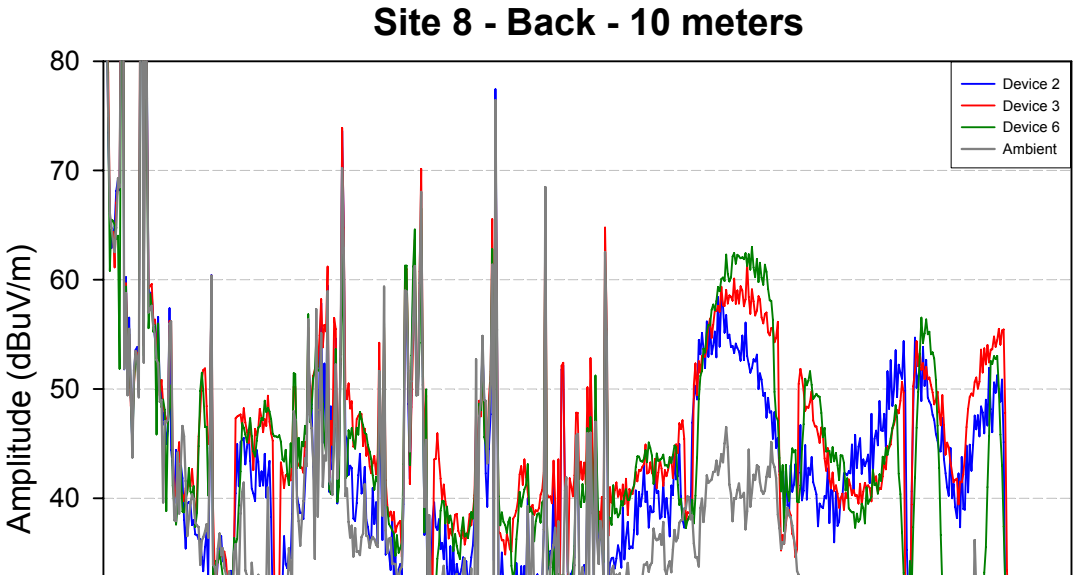
Tests Performed: EMI 0-30 MHz: Data Transfer

Test Site 8 - Front


Site 8 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 8 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 8 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 8 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

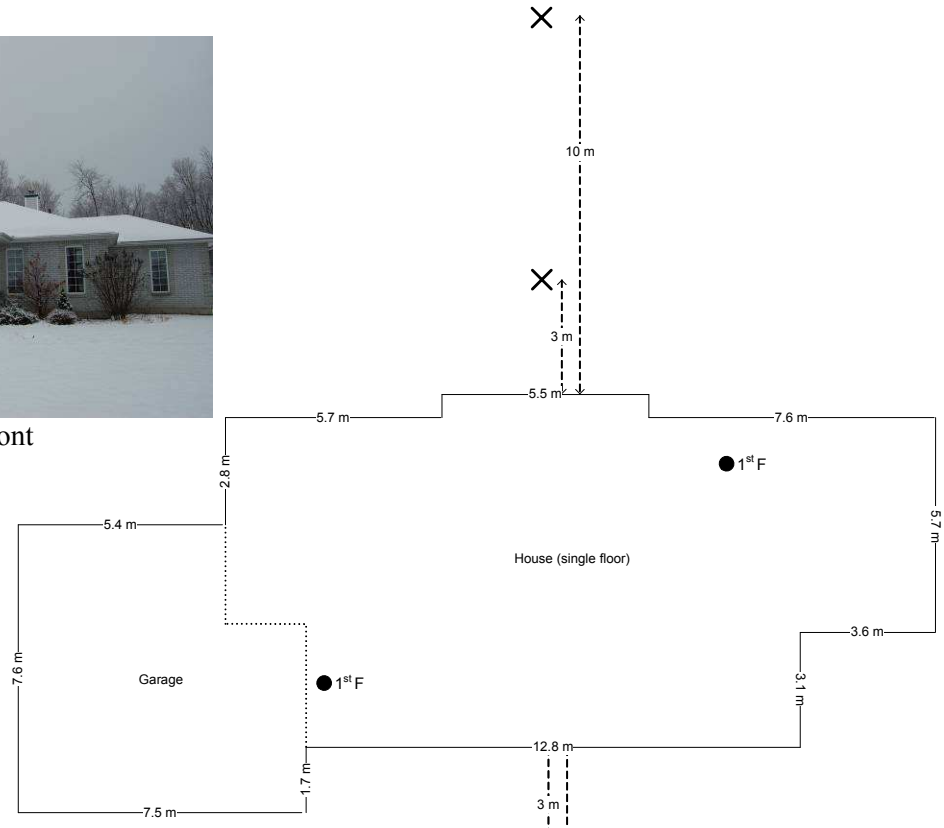
Test Site 9

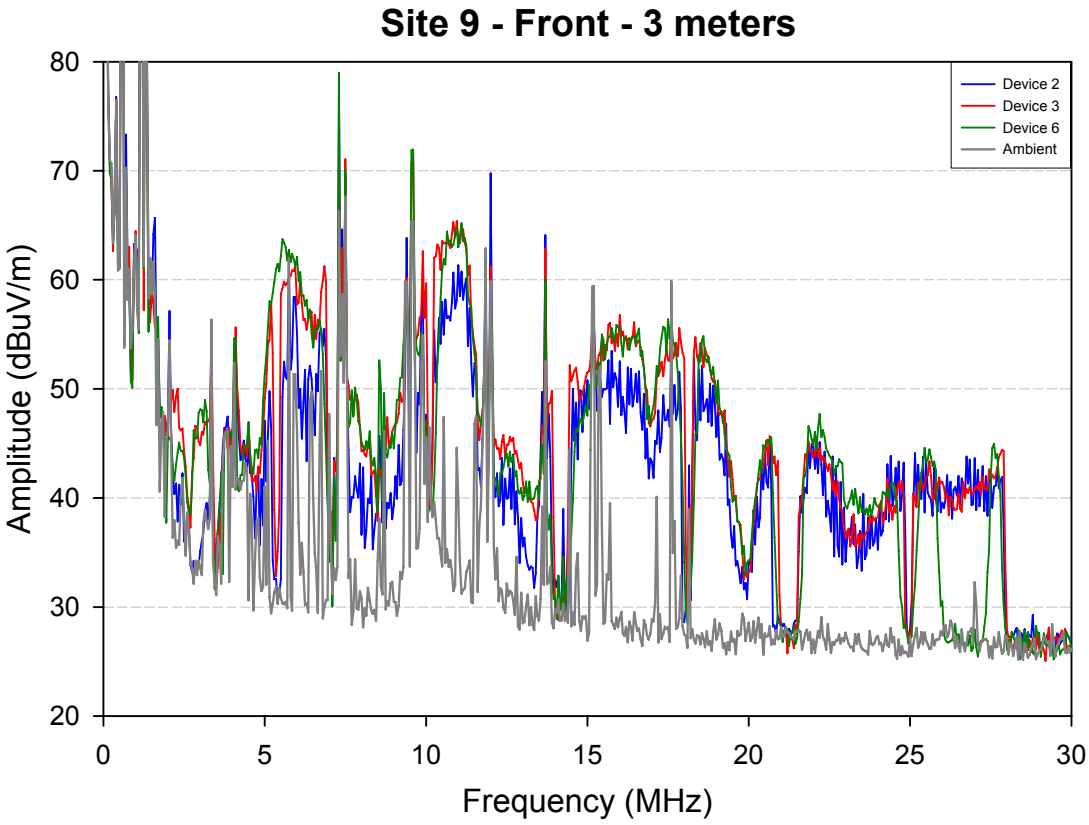
Type of House: Bungalow single-detached
Electrical Lines: Underground

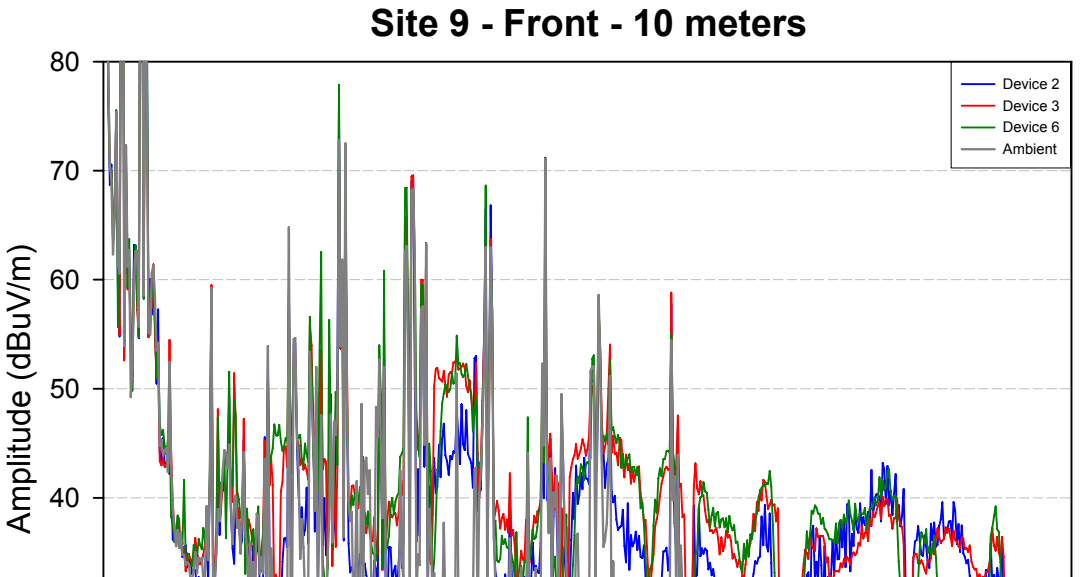
Front Wall Materials: Brick
Back Wall Materials: Vinyl

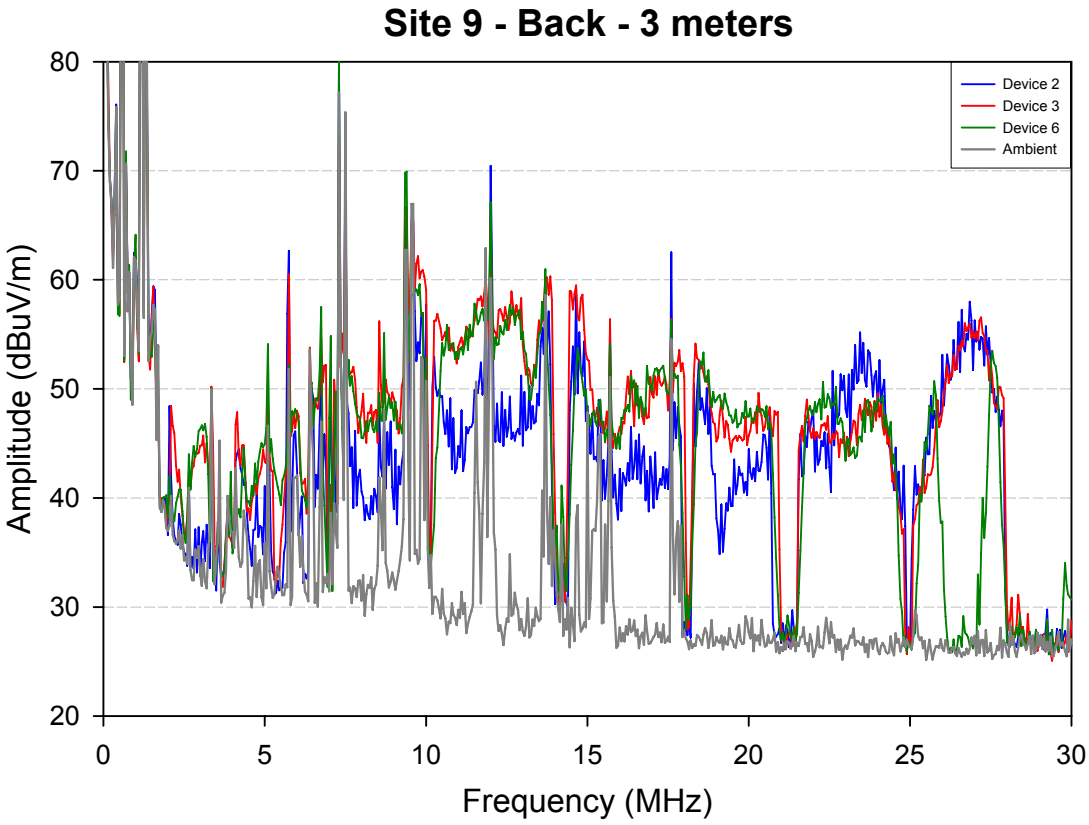
Tests Performed: EMI 0-30 MHz: Data Transfer

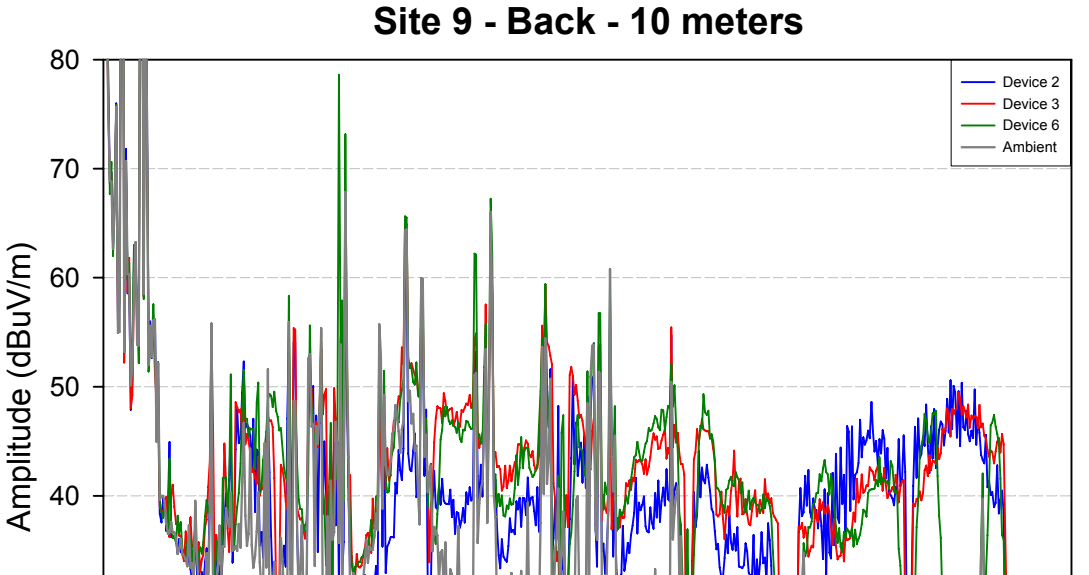
Test Site 9 - Front




Site 9 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 9 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

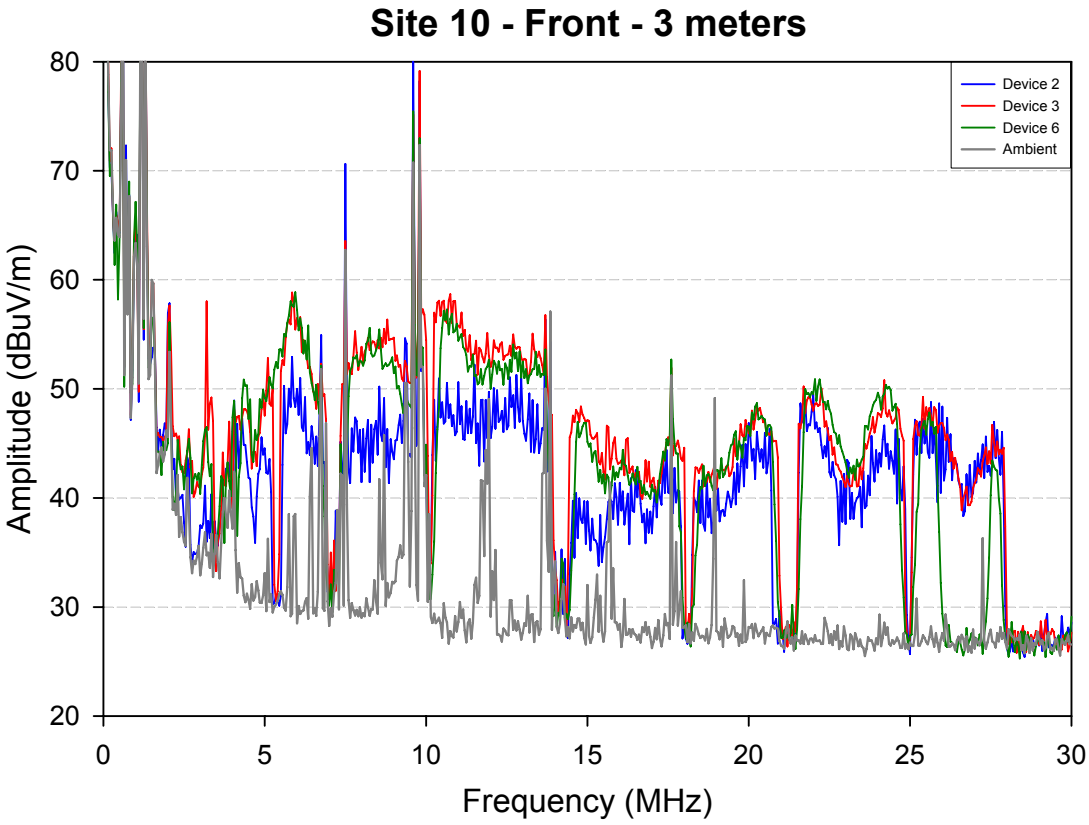

Site 9 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30

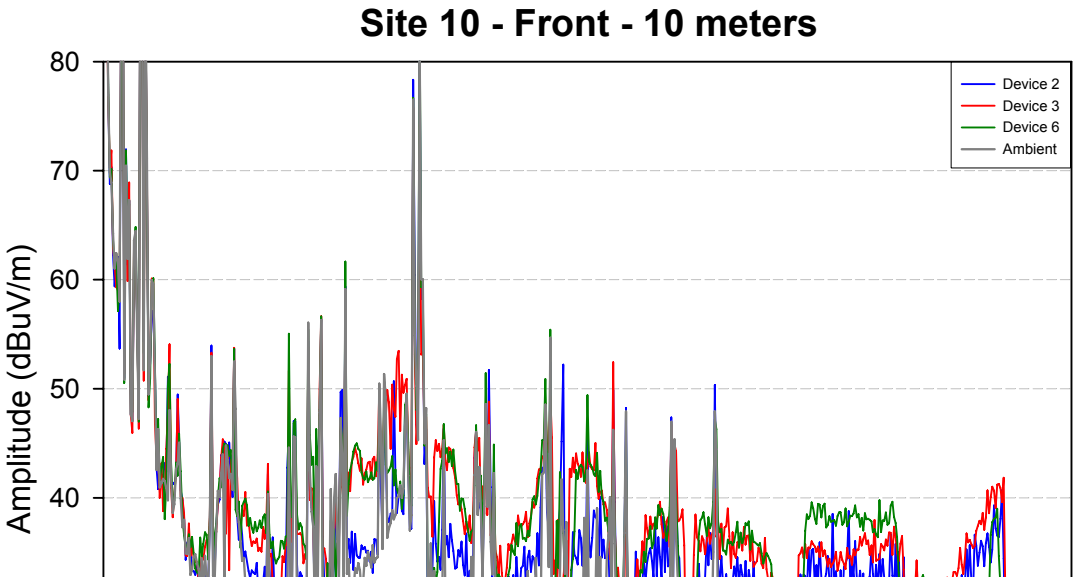

Site 9 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

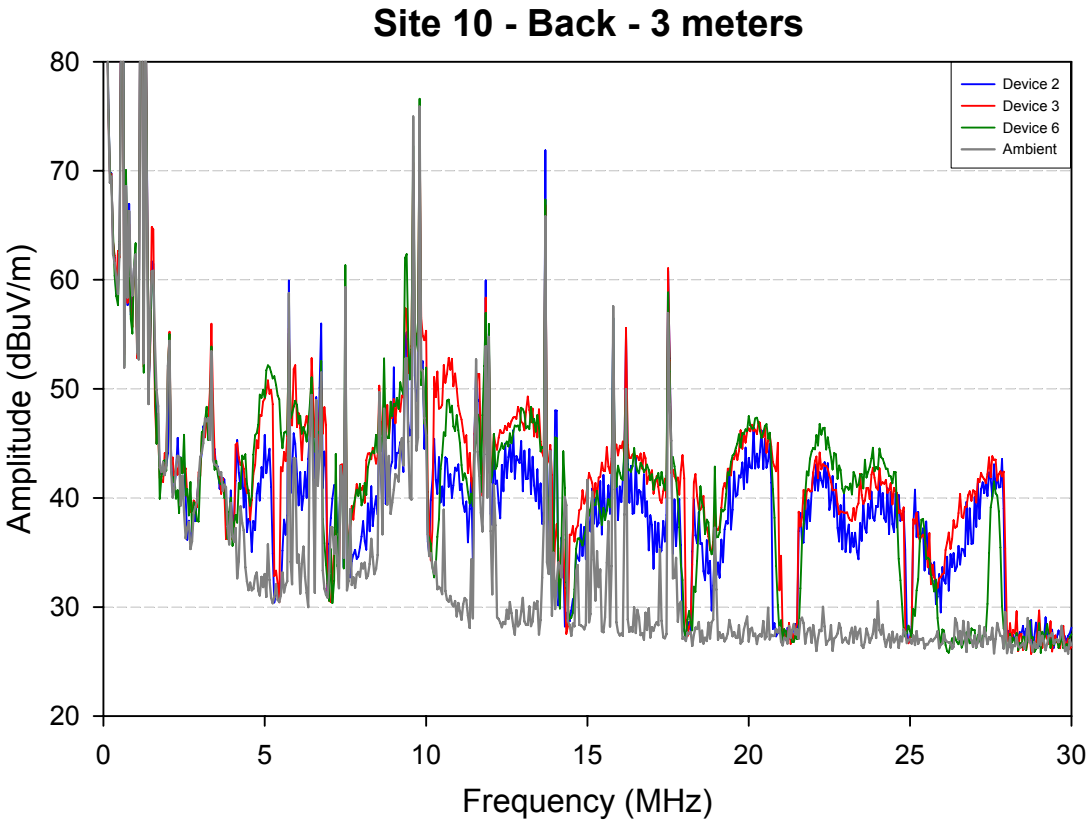
Test Site 10

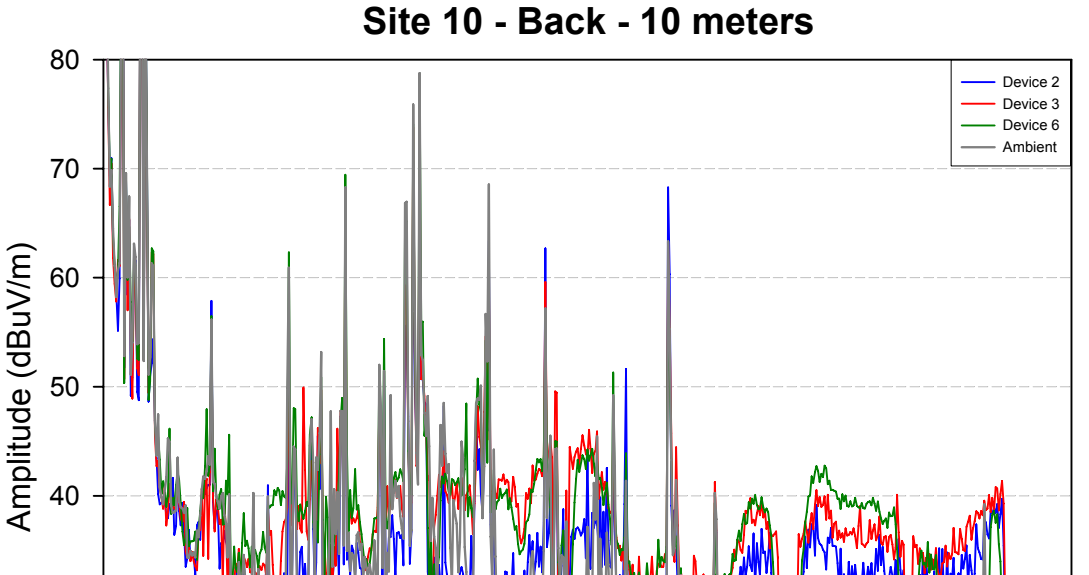
Type of House:	Two-story townhouse
Electrical Lines:	Underground
Front Wall Materials:	Brick/Aluminum
Back Wall Materials:	Aluminum
Tests Performed:	EMI 0-30 MHz: Data Transfer

Test Site 10 - Front


Site 10 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 10 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 10 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 10 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

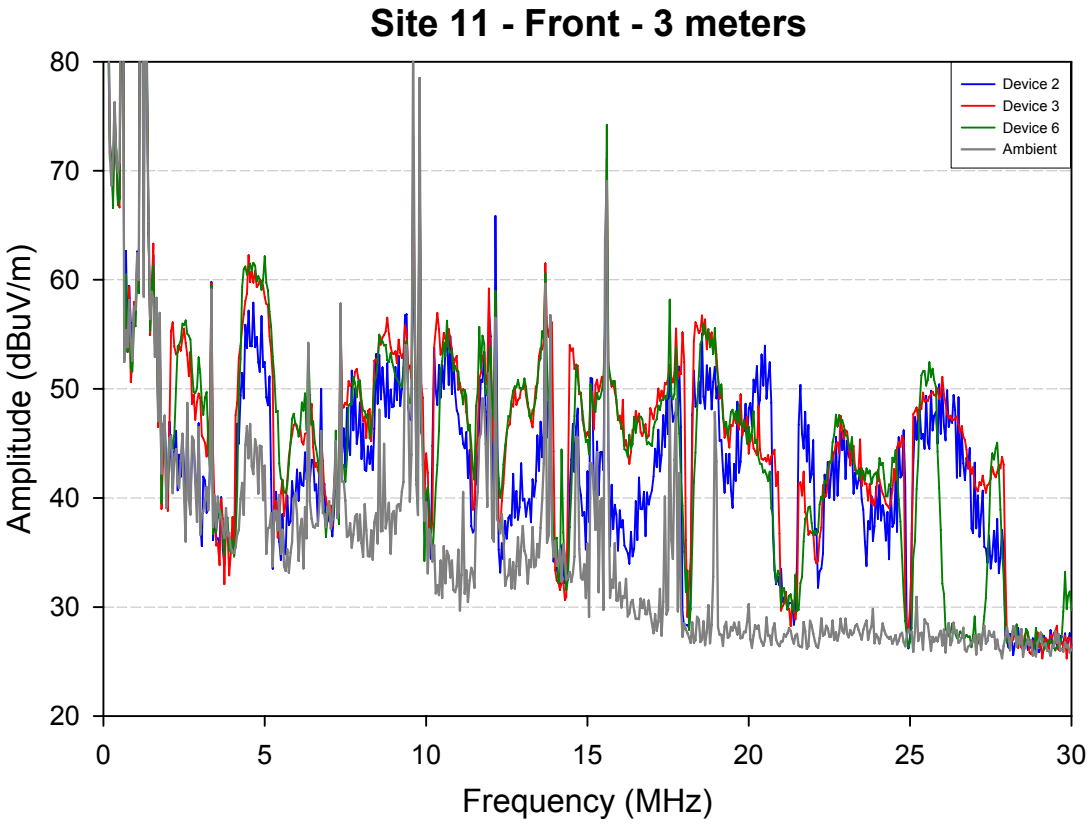
Test Site 11

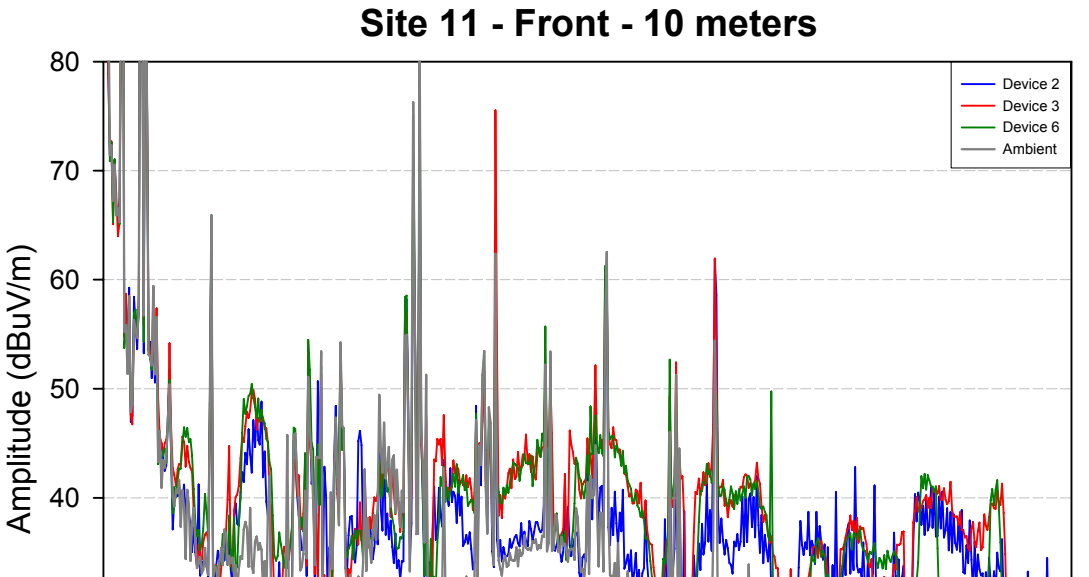
Type of House: Bungalow single-detached
Electrical Lines: Underground

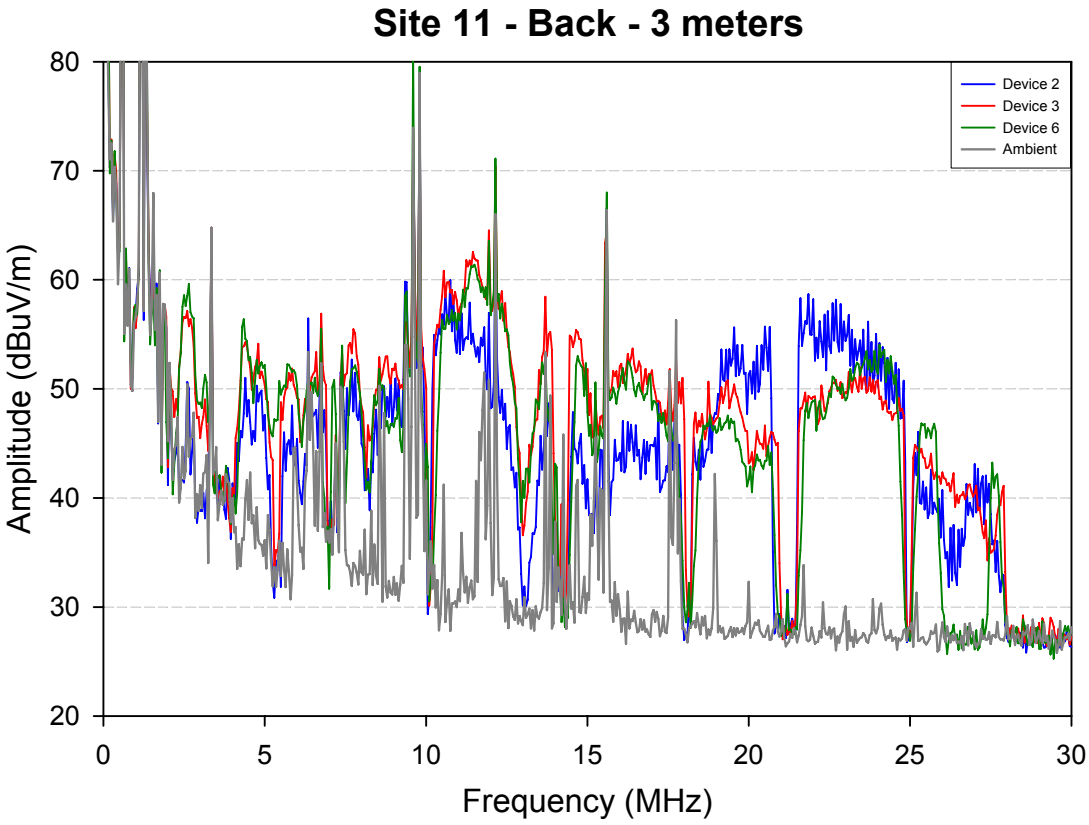
Front Wall Materials: Stucco
Back Wall Materials: Stucco

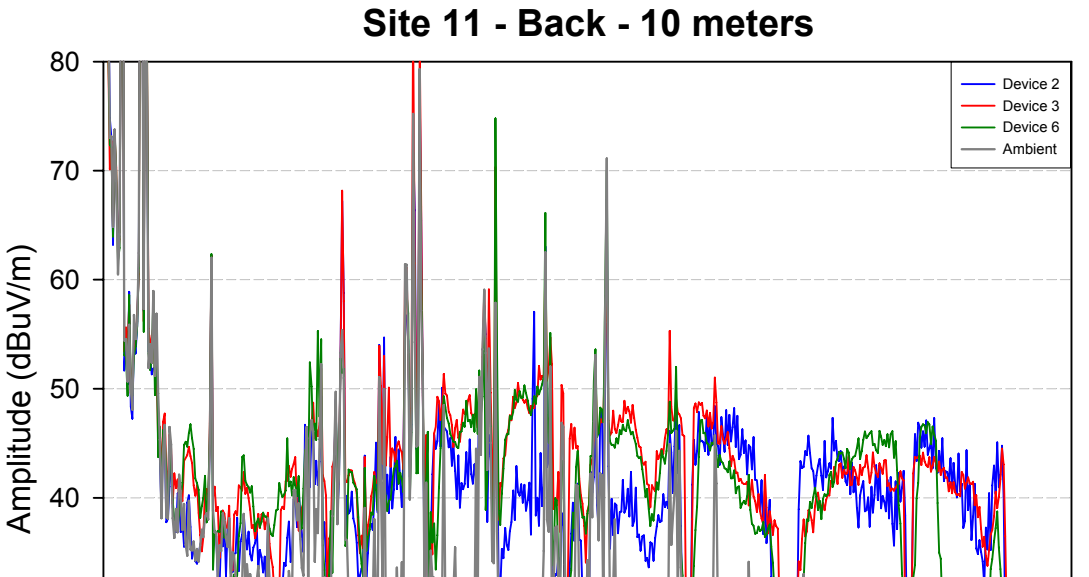
Tests Performed: EMI 0-30 MHz: Data Transfer

Test Site 11 - Front


Site 11 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 11 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 11 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 11 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

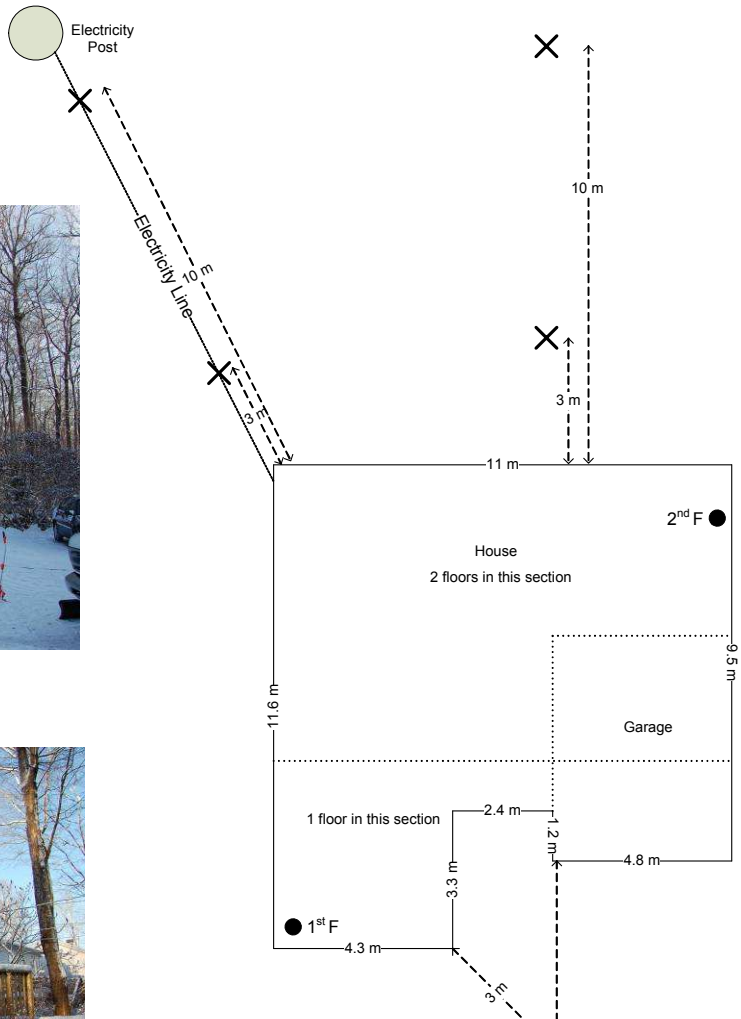
Test Site 12

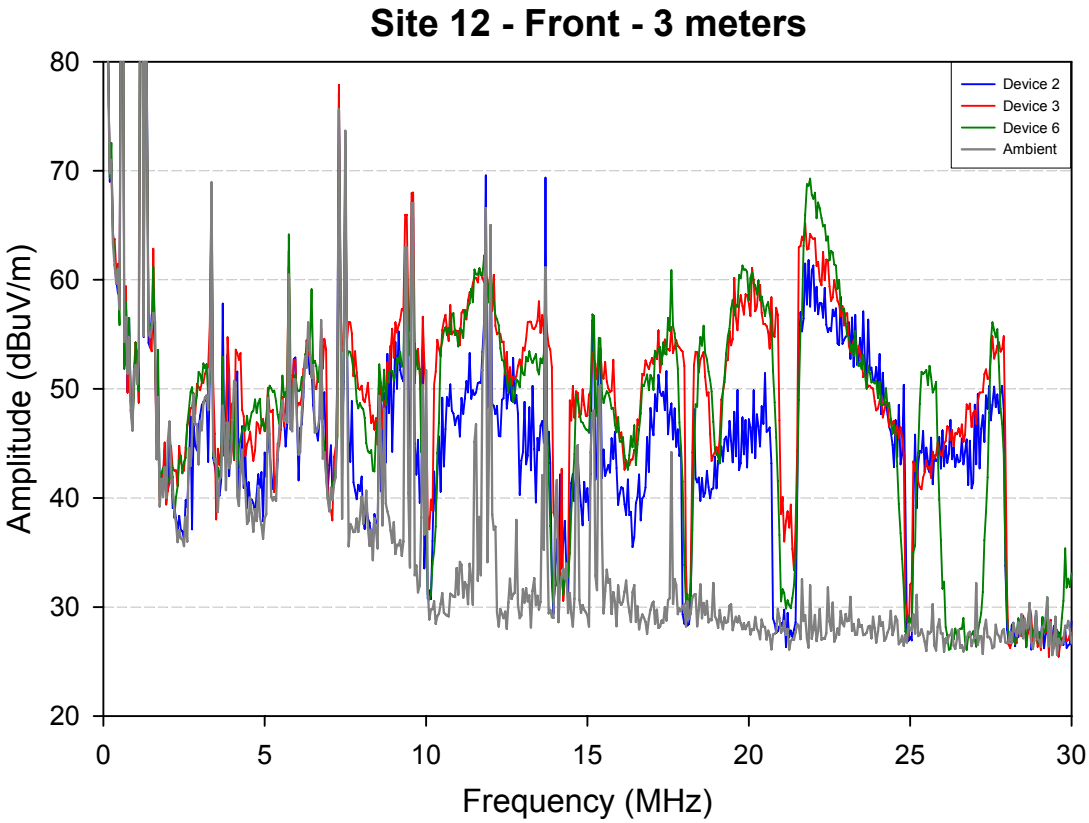
Type of House: Two-story single-detached
Electrical Lines: Overhead

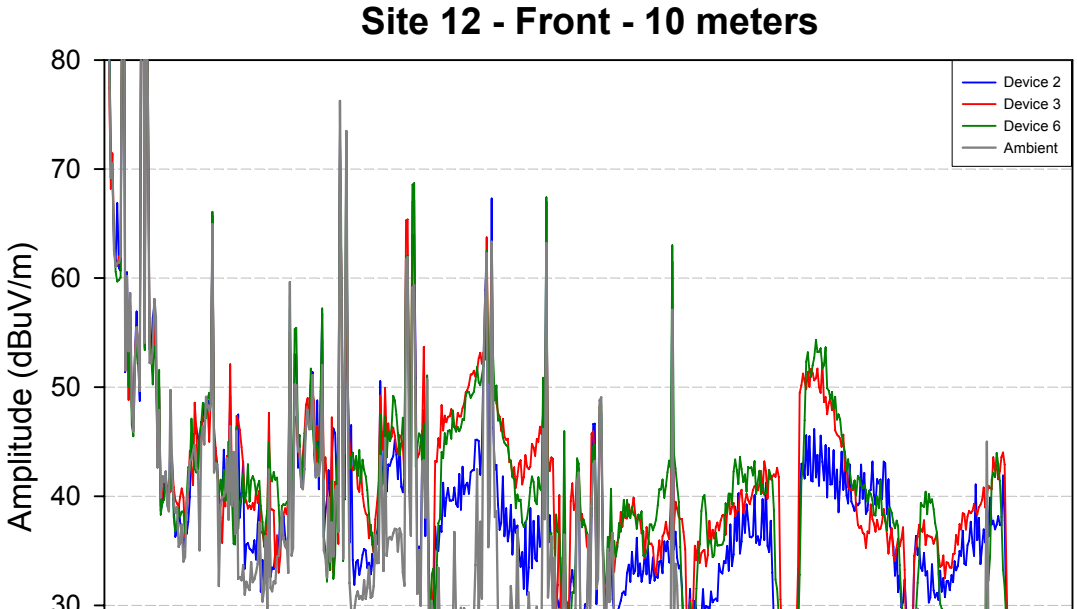
Front Wall Materials: Brick/Vinyl
Back Wall Materials: Vinyl

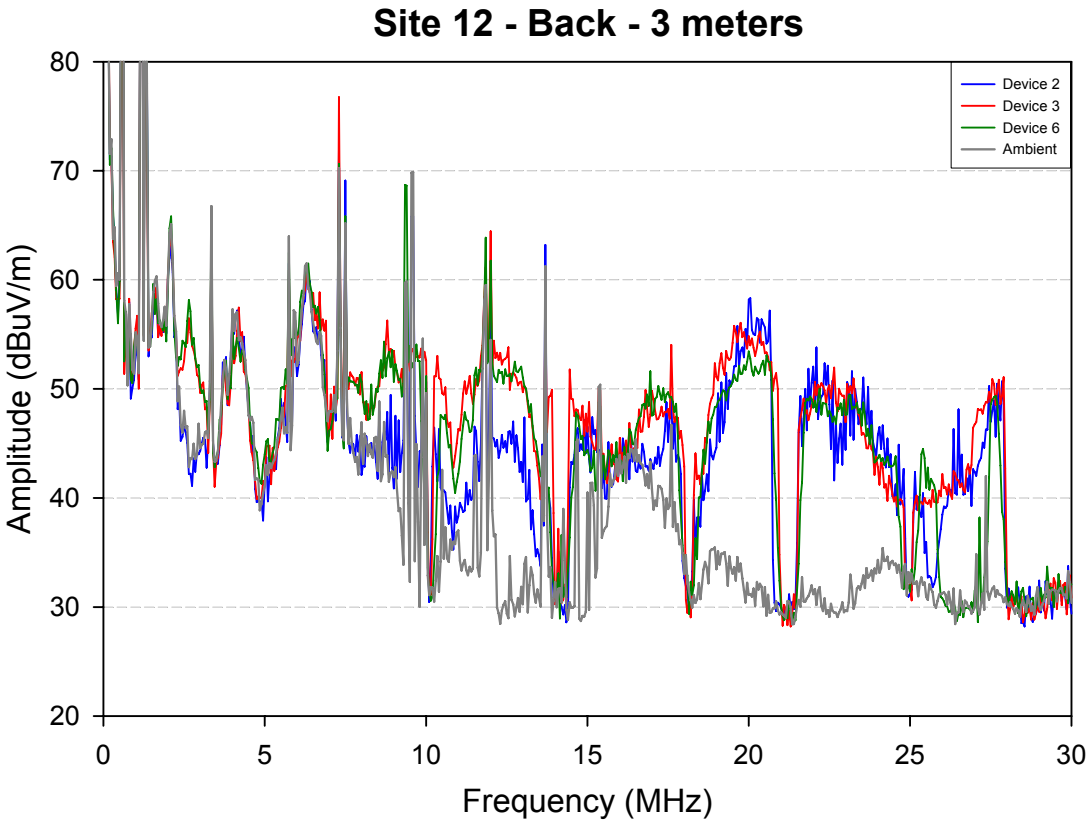
Tests Performed: EMI 0-30 MHz: Data Transfer
Under Electrical Lines Measurements

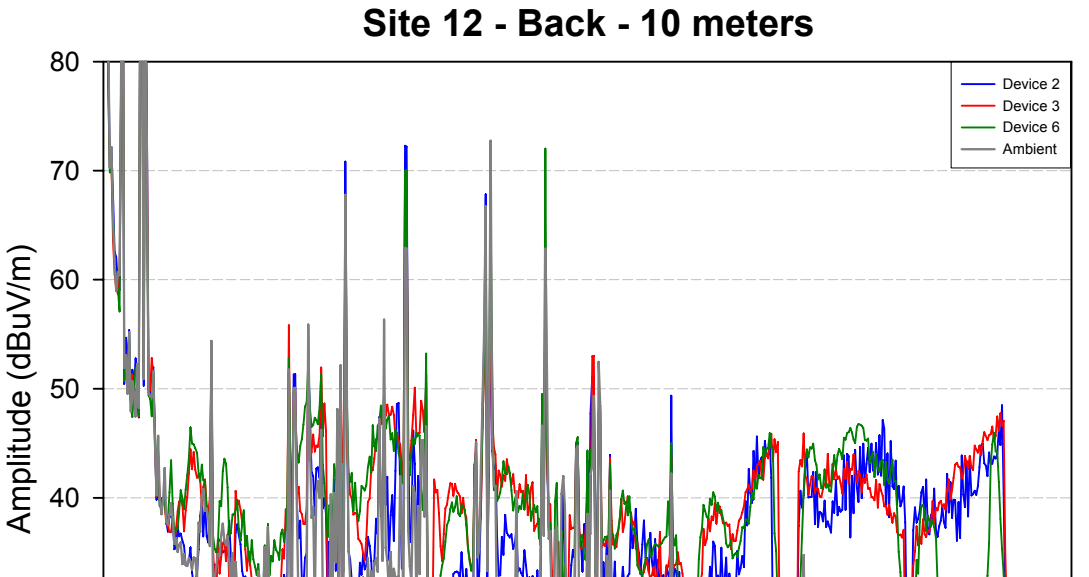
Test Site 12 - Front




Site 12 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 12 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30


Site 12 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 12 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

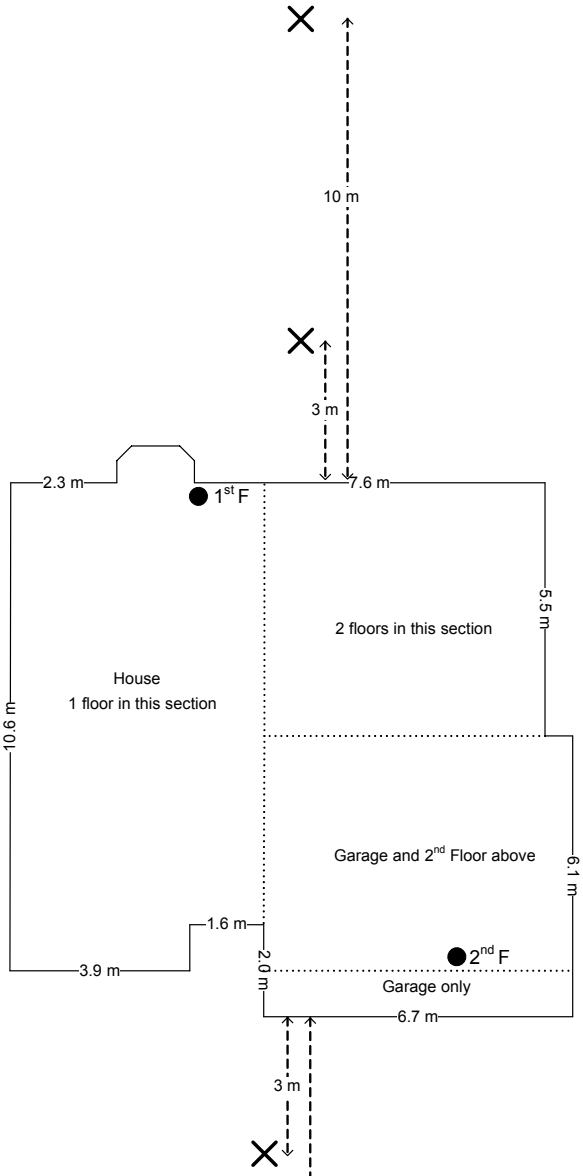
Test Site 13

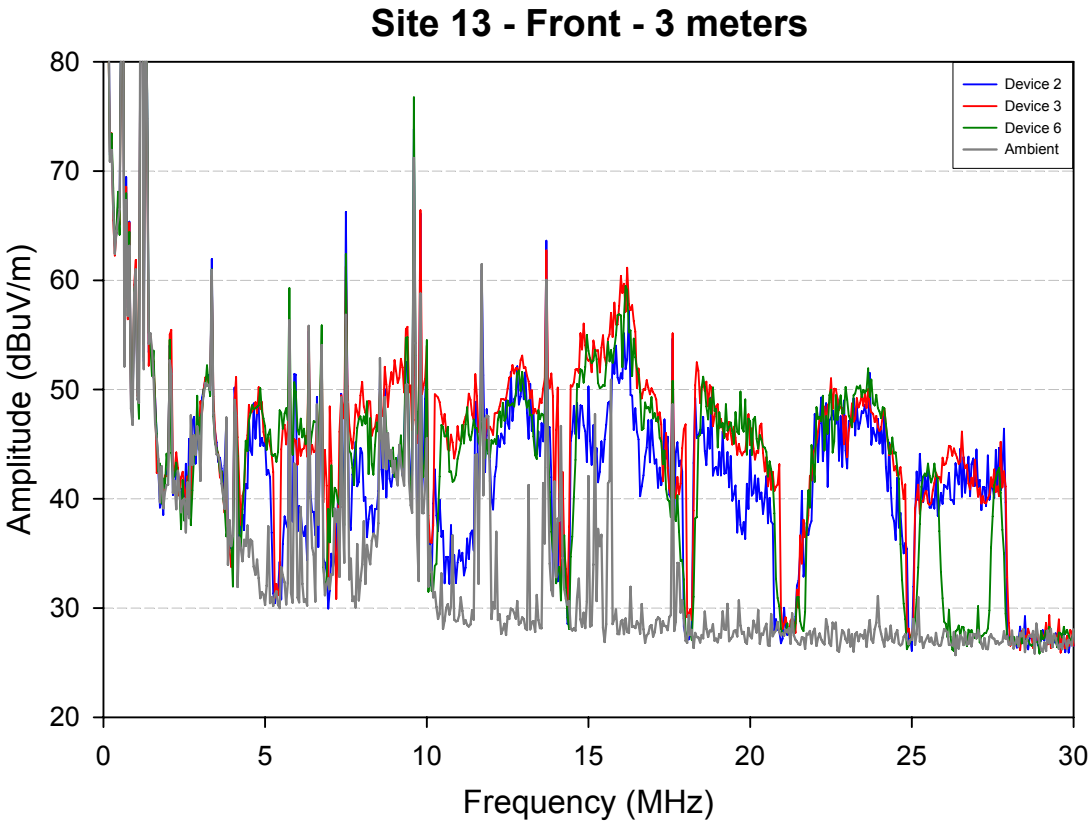
Type of House: Sidesplit single-detached
Electrical Lines: Underground

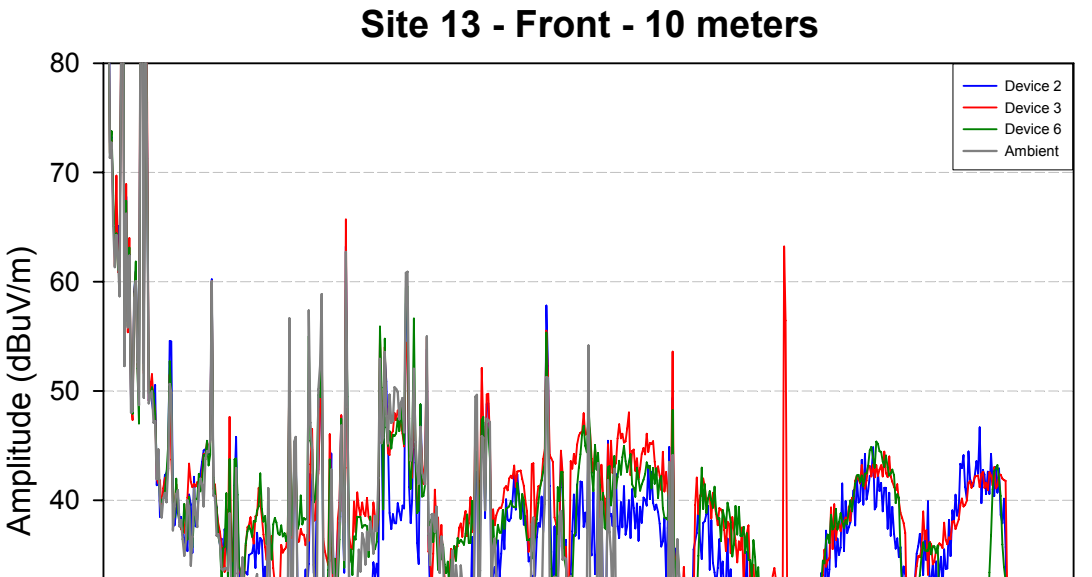
Front Wall Materials: Brick
Back Wall Materials: Brick/Vinyl

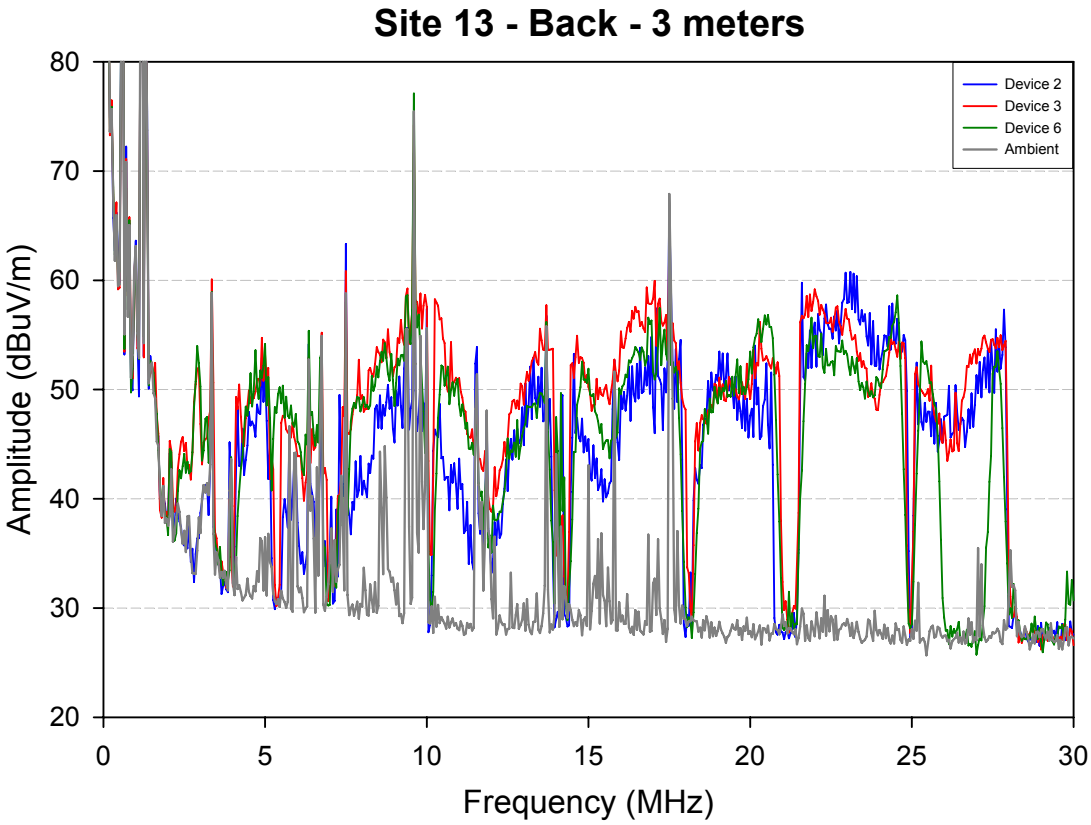
Tests Performed: EMI 0-30 MHz: Data Transfer

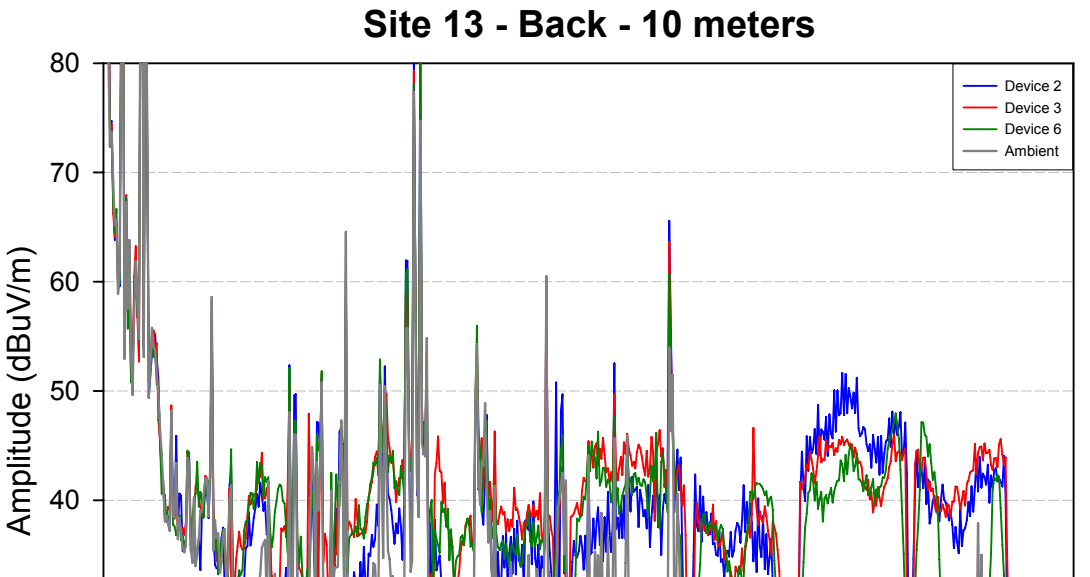
Test Site 13 - Front




Site 13 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 13 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 13 - Back - 3 meters
Device 2
Device 3
Device 6
Ambient
Amplitude (dBuV/m)
Frequency (MHz)
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 13 - Back - 10 meters
Device 2
Device 3
Device 6
Ambient
Amplitude (dBuV/m)
80
70
60
50
40

Test Site 14

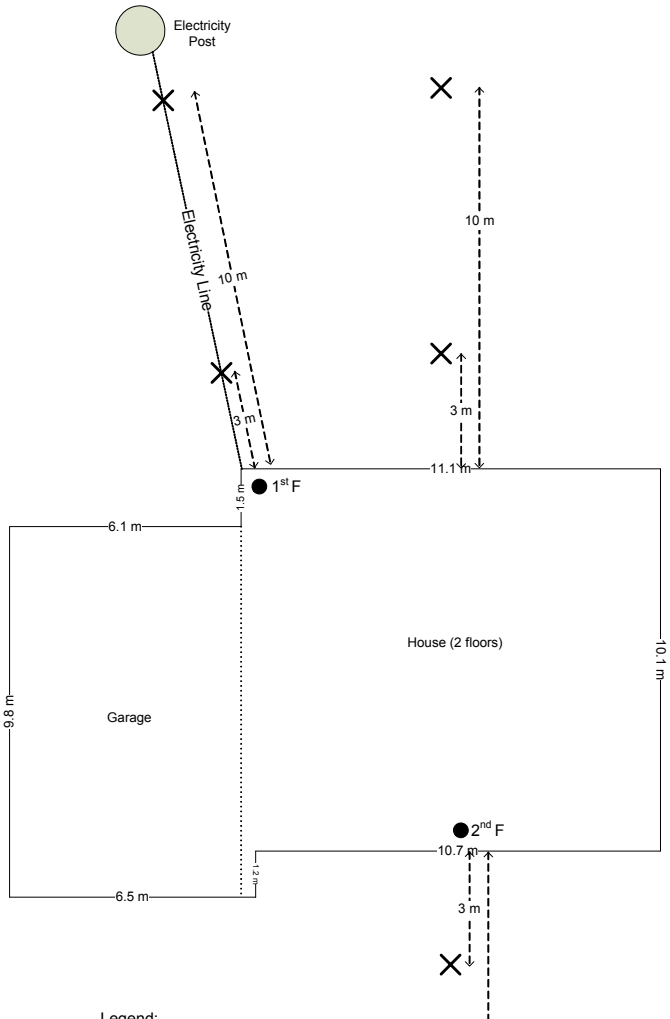
Type of House: Two-story single-detached
Electrical Lines: Overhead

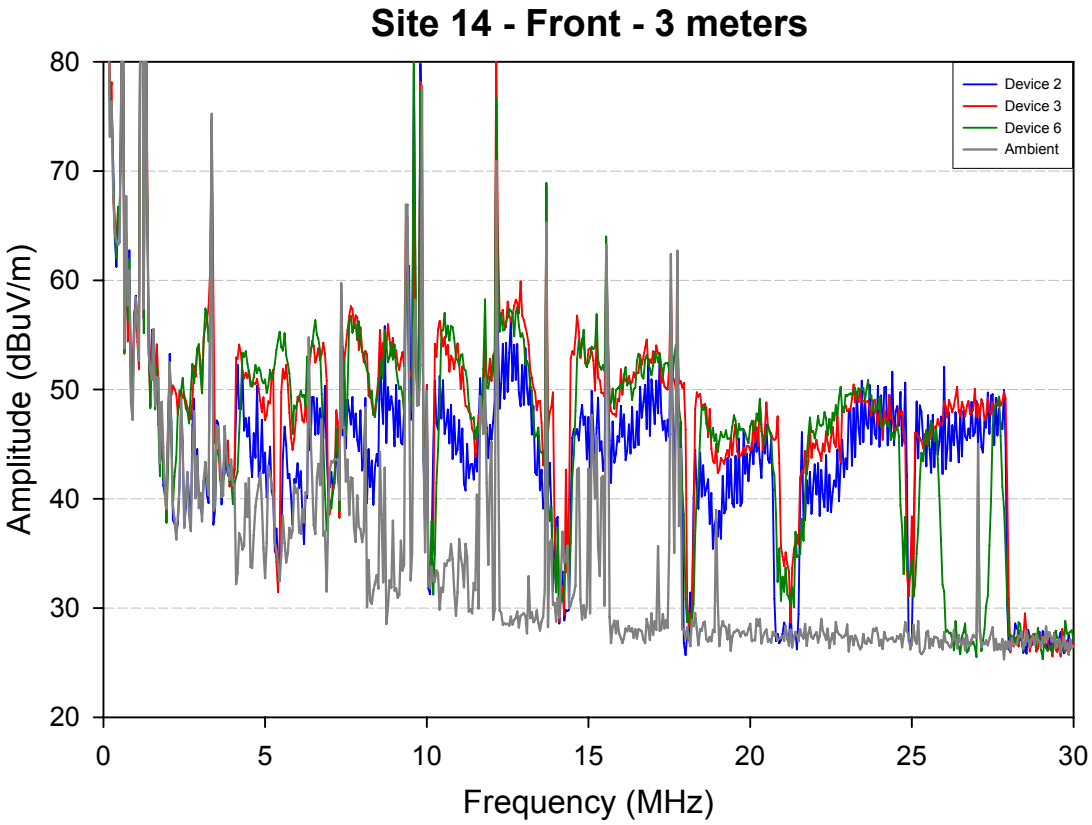
Front Wall Materials: Brick/Shingle
Back Wall Materials: Brick/Shingle

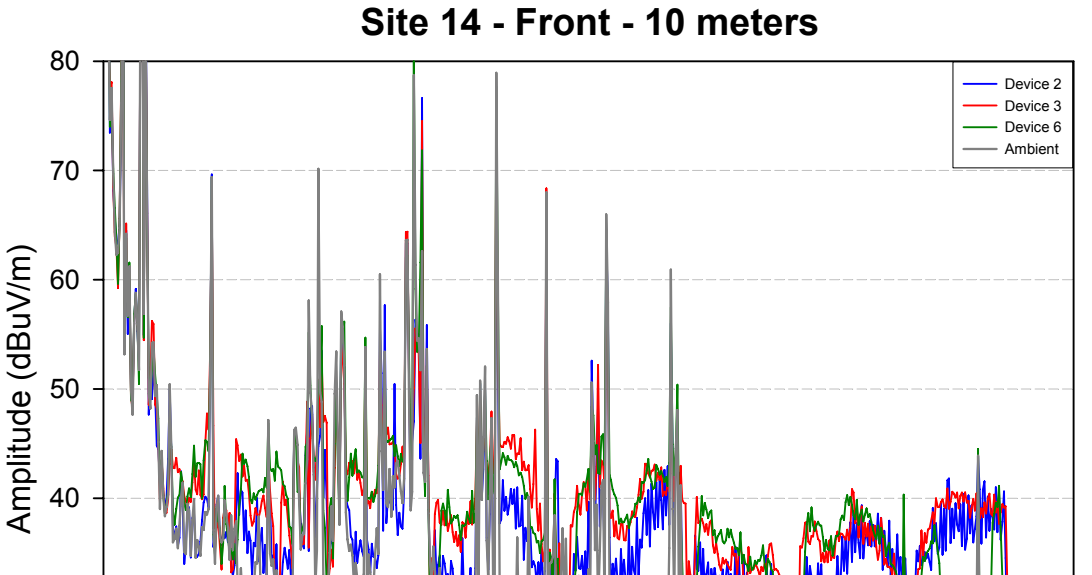
Tests Performed: EMI 0-30 MHz: Data Transfer
Under Electrical Lines Measurements

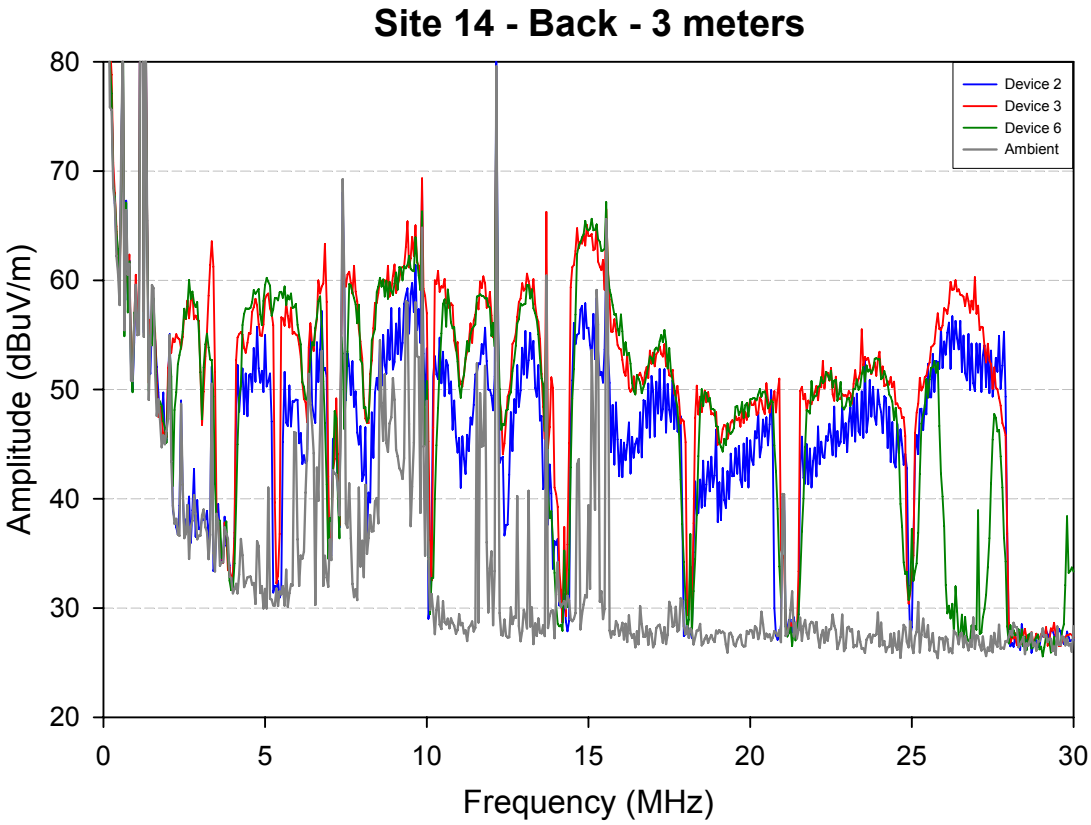
Test Site 14 - Front

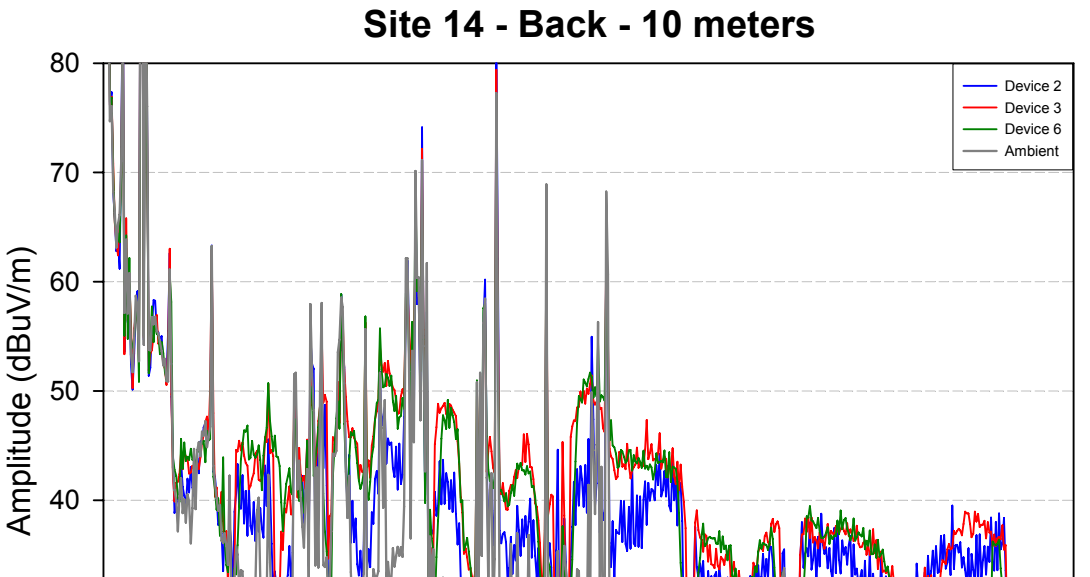
Test Site 14 - Back




Site 14 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 14 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

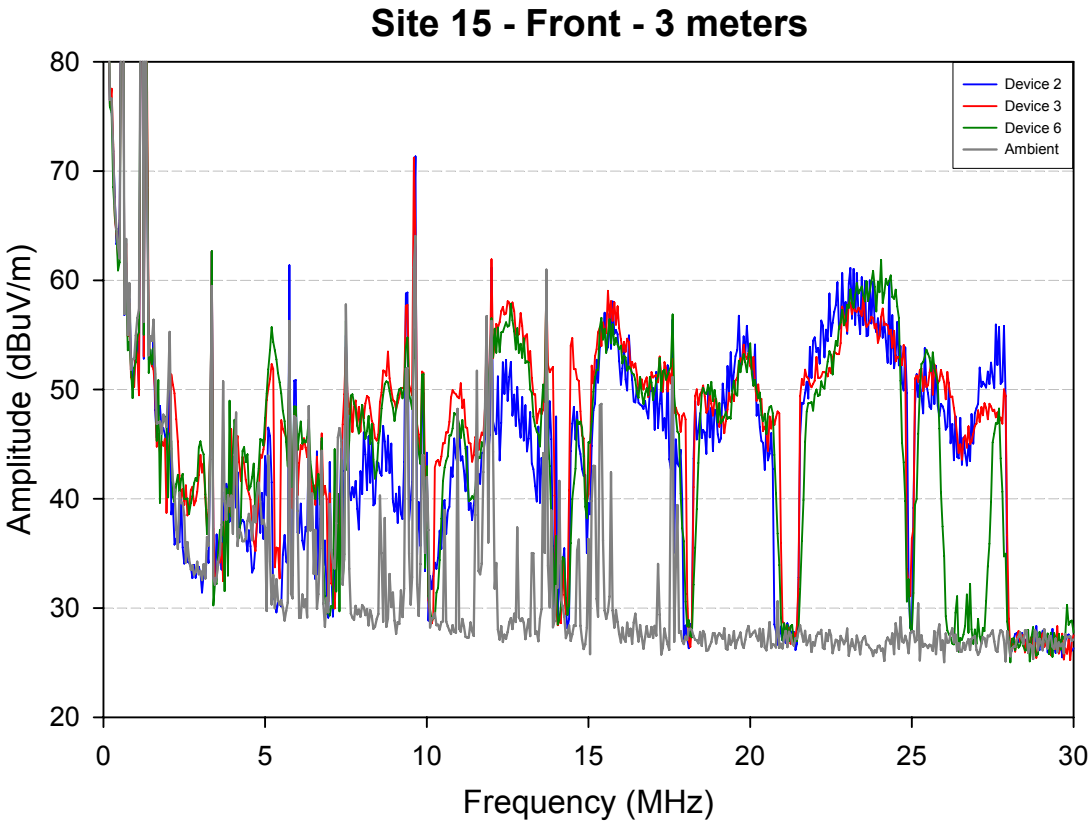

Site 14 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30

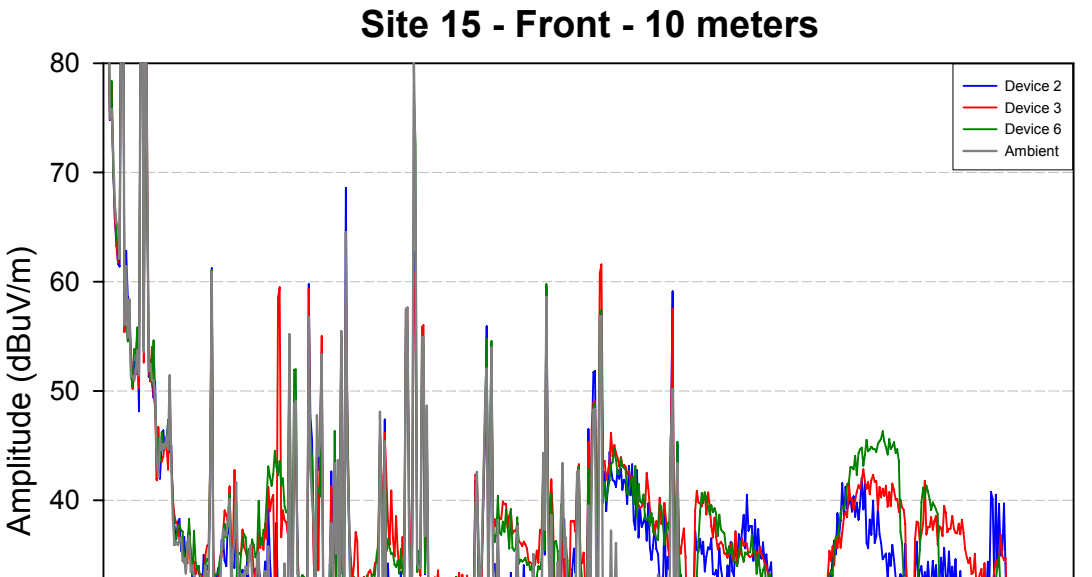

Site 14 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

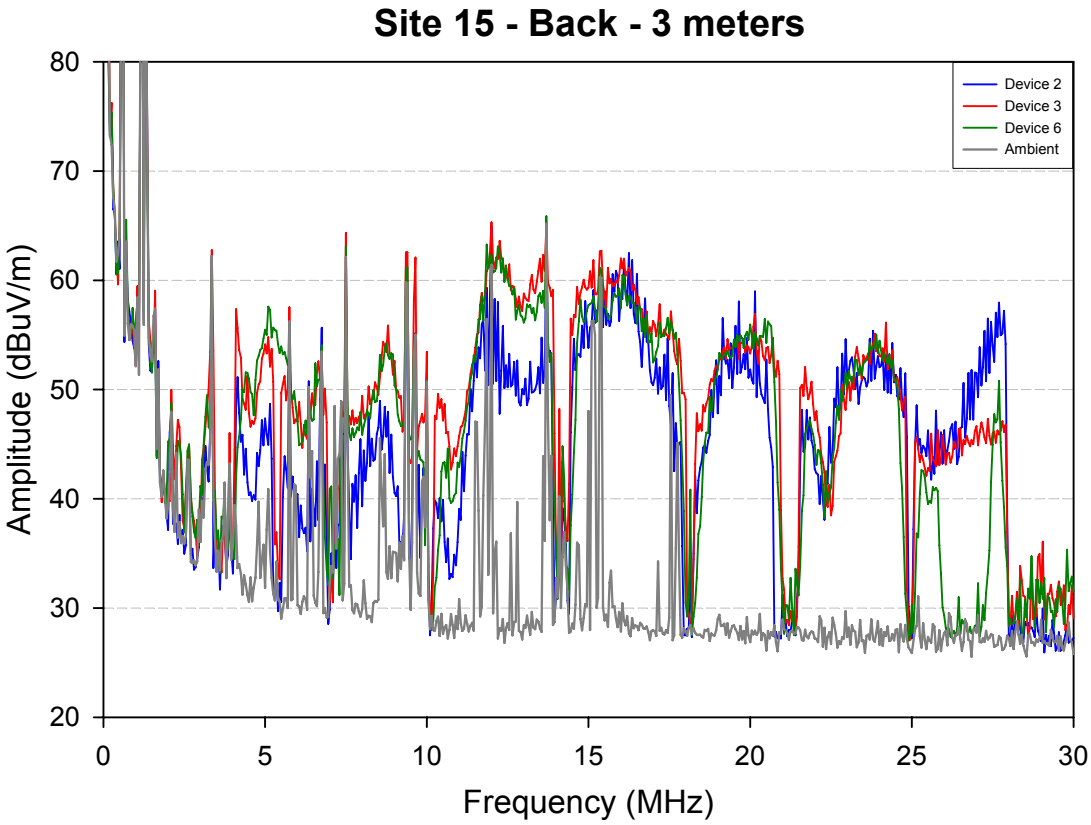
Test Site 15

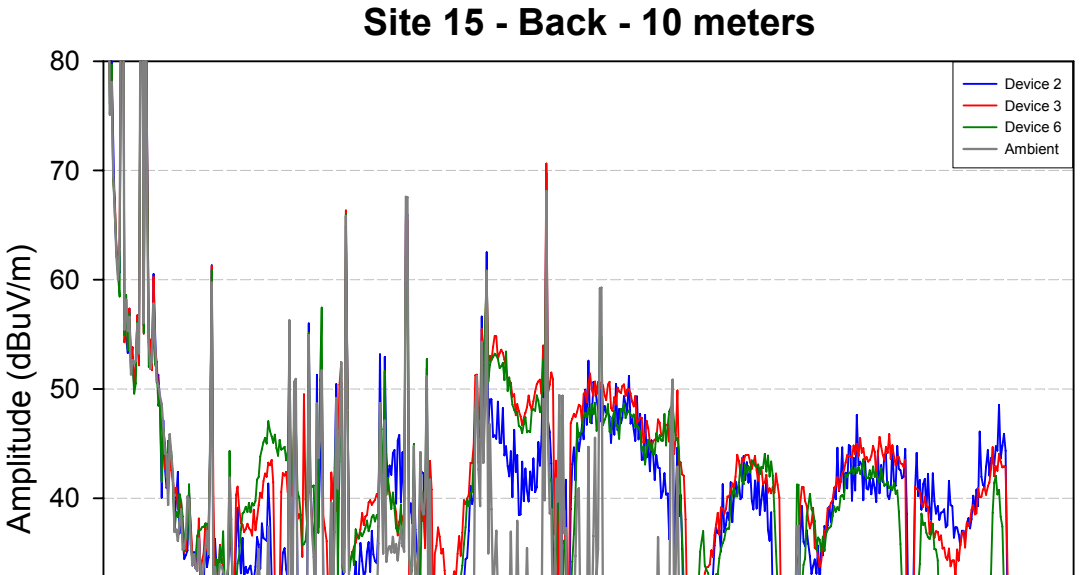
Type of House:	Two-story single-detached
Electrical Lines:	Overhead
Front Wall Materials:	Brick/Aluminum
Back Wall Materials:	Brick/Aluminum
Tests Performed:	EMI 0-30 MHz: Data Transfer Under Electrical Lines Measurements

Test Site 15 - Front


Site 15 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 15 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 15 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 15 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

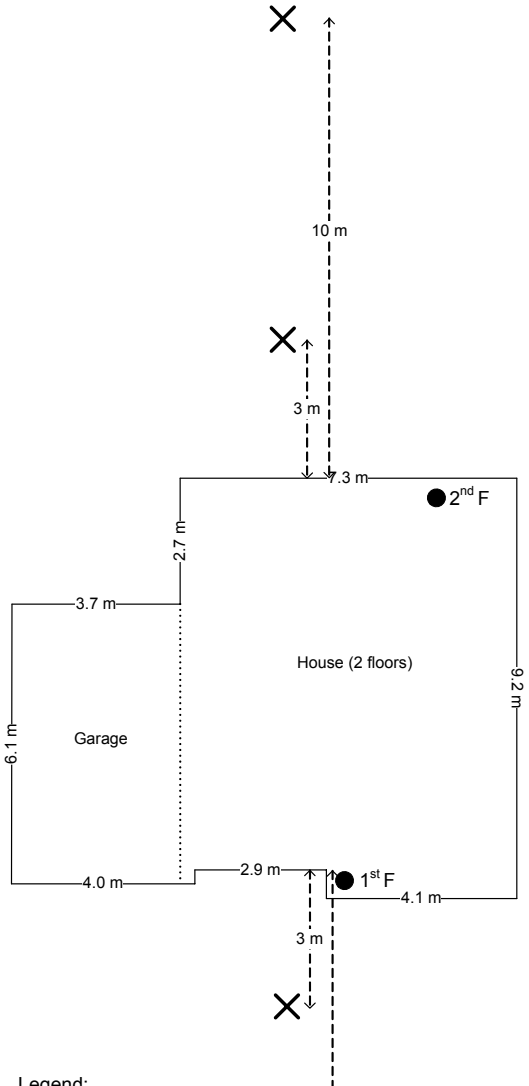
Test Site 16

Type of House: Two-story single-detached
Electrical Lines: Underground

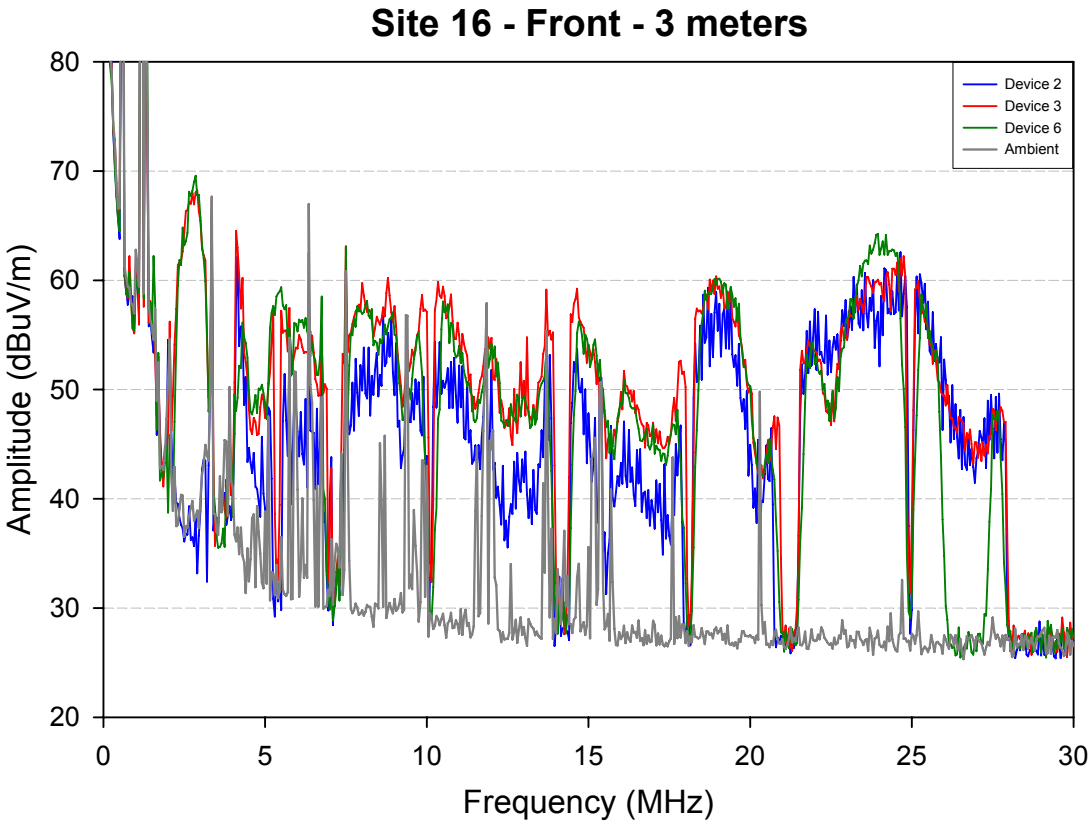
Front Wall Materials: Brick/Shingle
Back Wall Materials: Vinyl

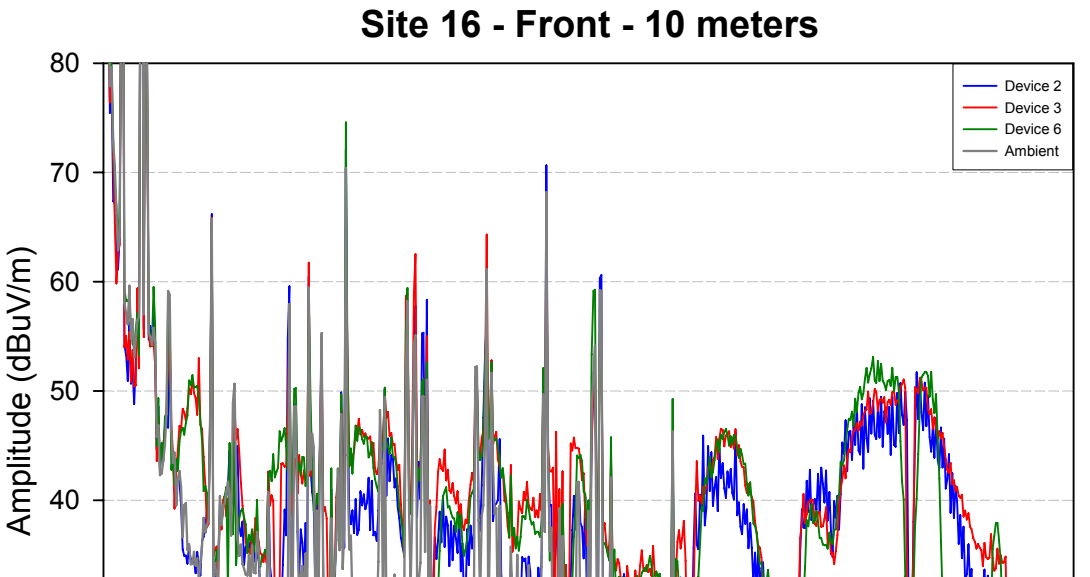
Tests Performed: EMI 0-30 MHz: Data Transfer

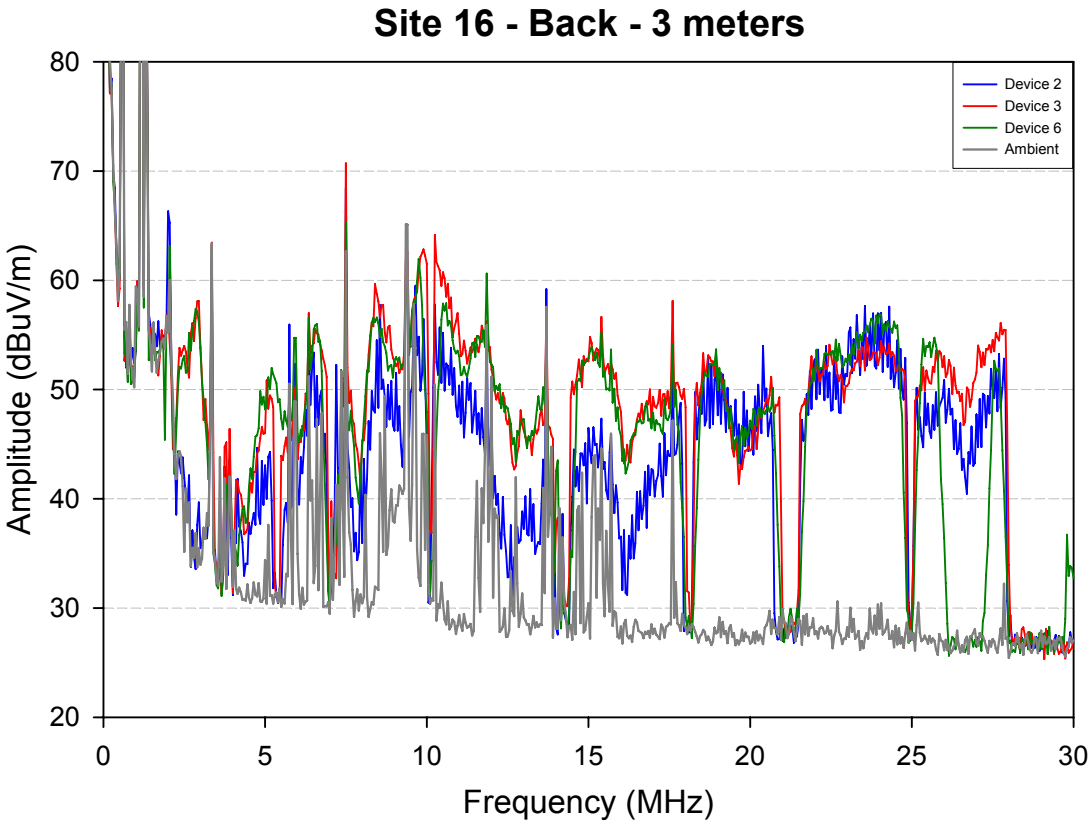
Test Site 16 - Front

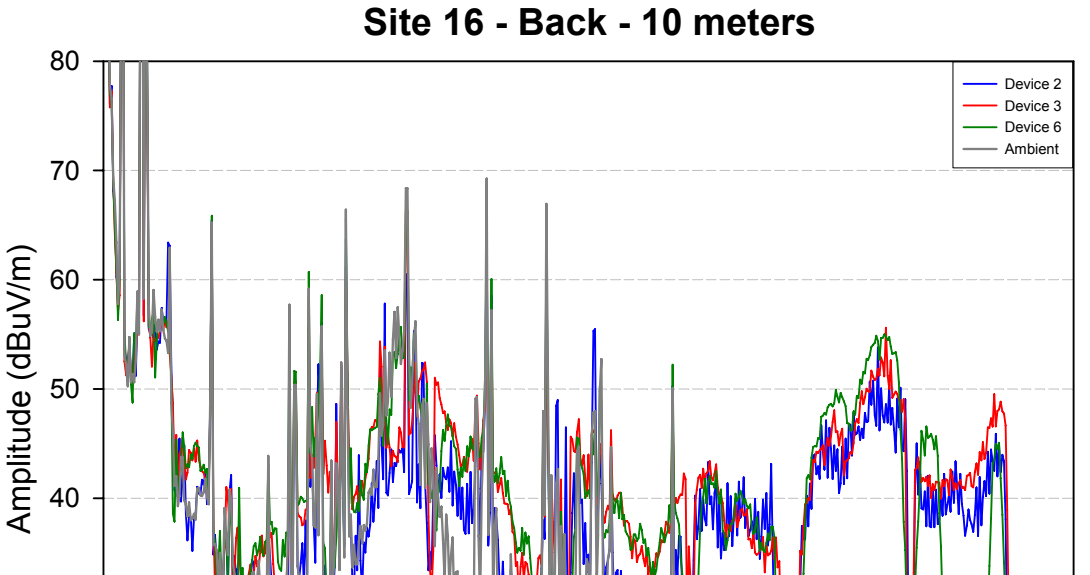


Legend:


Site 16 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 16 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40


Site 16 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30


Site 16 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

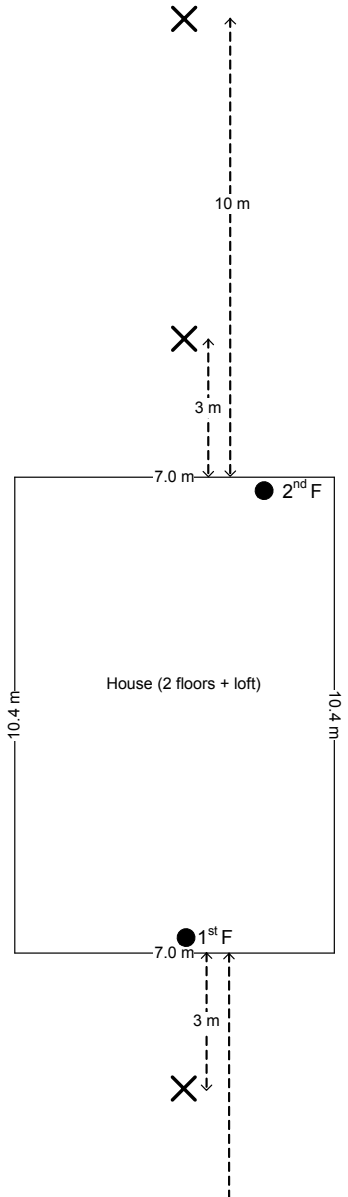
Test Site 17

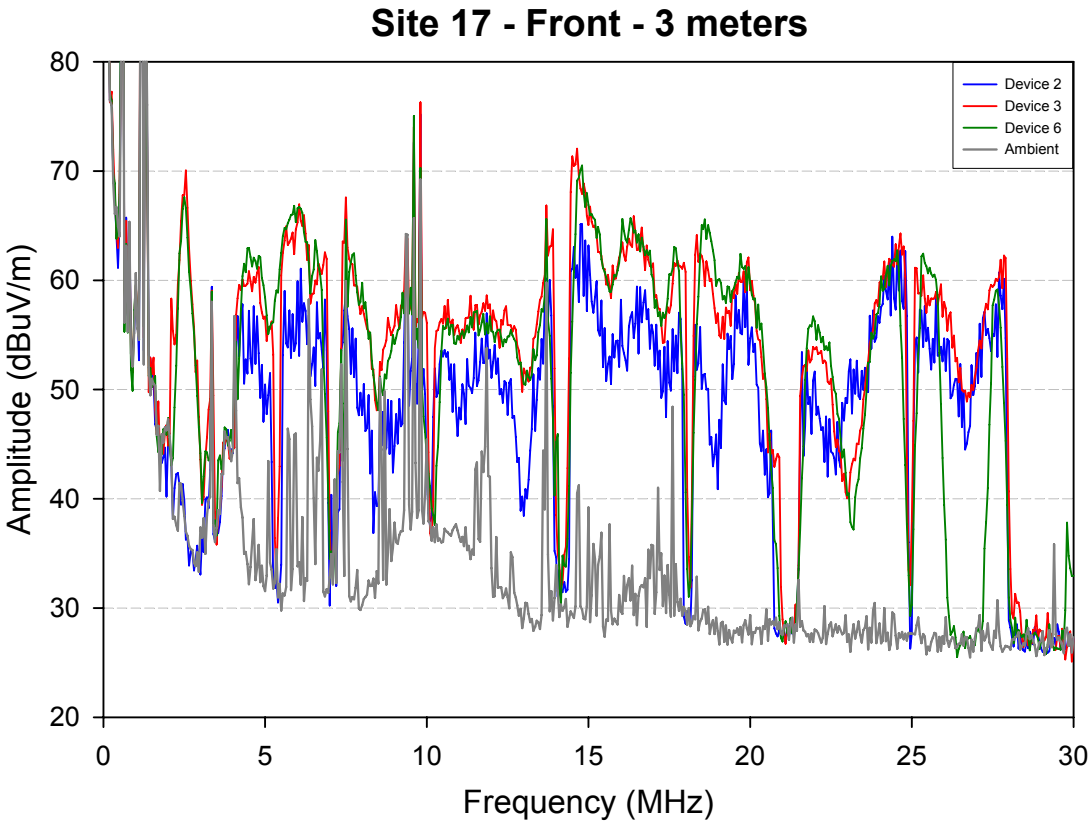
Type of House: Two-story single-detached with loft
Electrical Lines: Underground

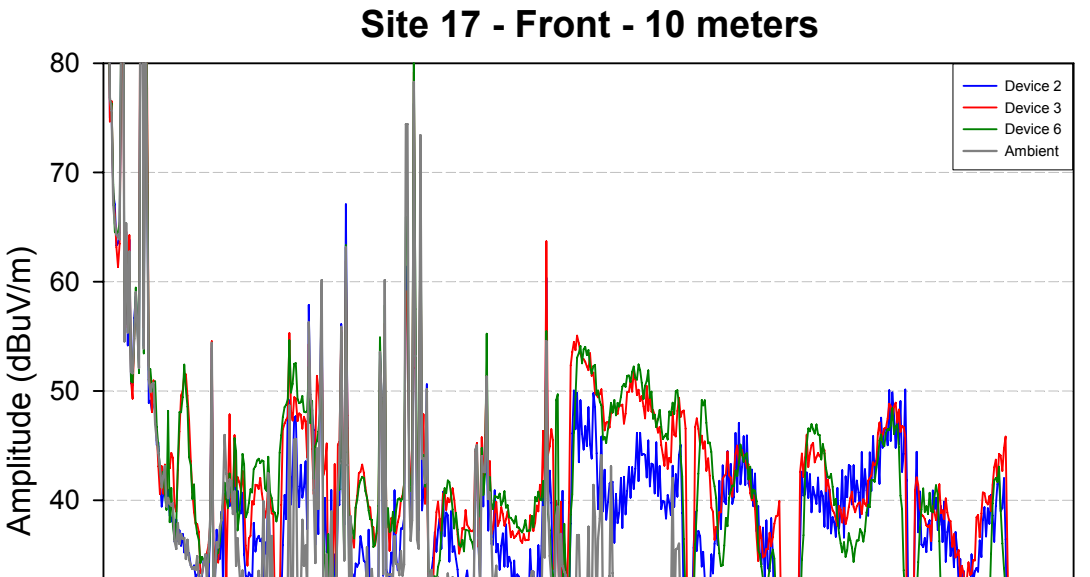
Front Wall Materials: Brick/Vinyl
Back Wall Materials: Vinyl

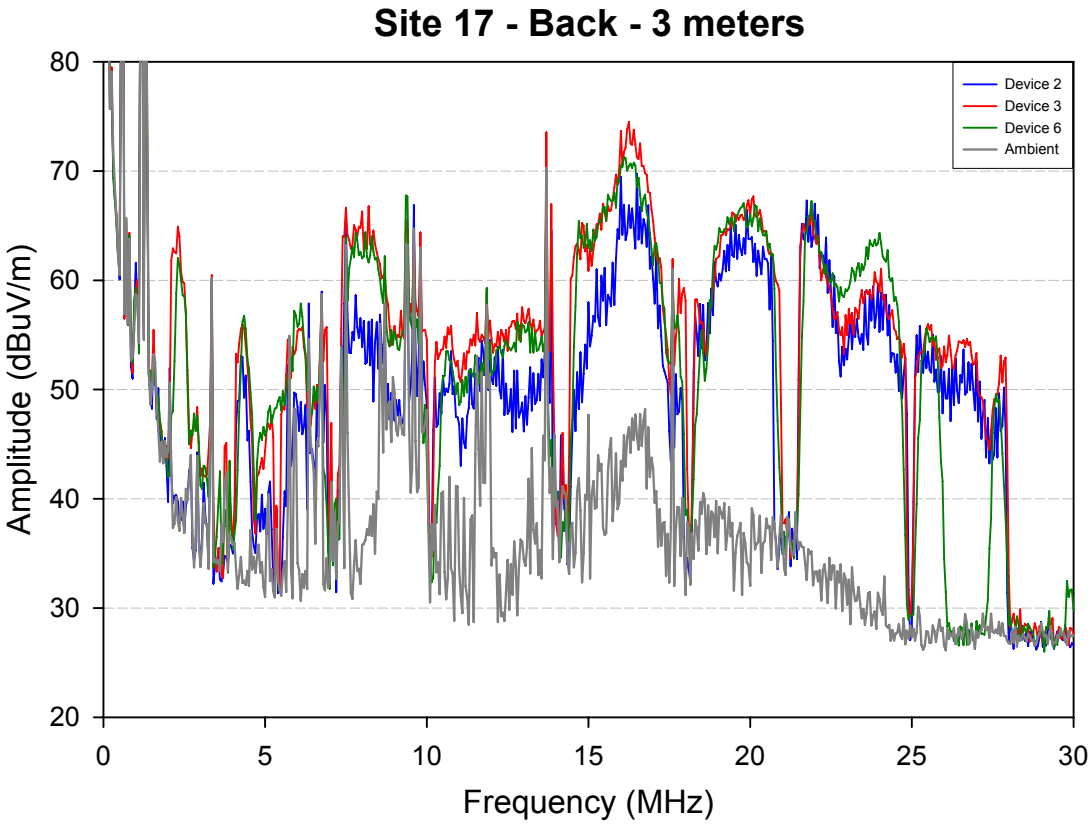
Tests Performed: EMI 0-30 MHz: Data Transfer

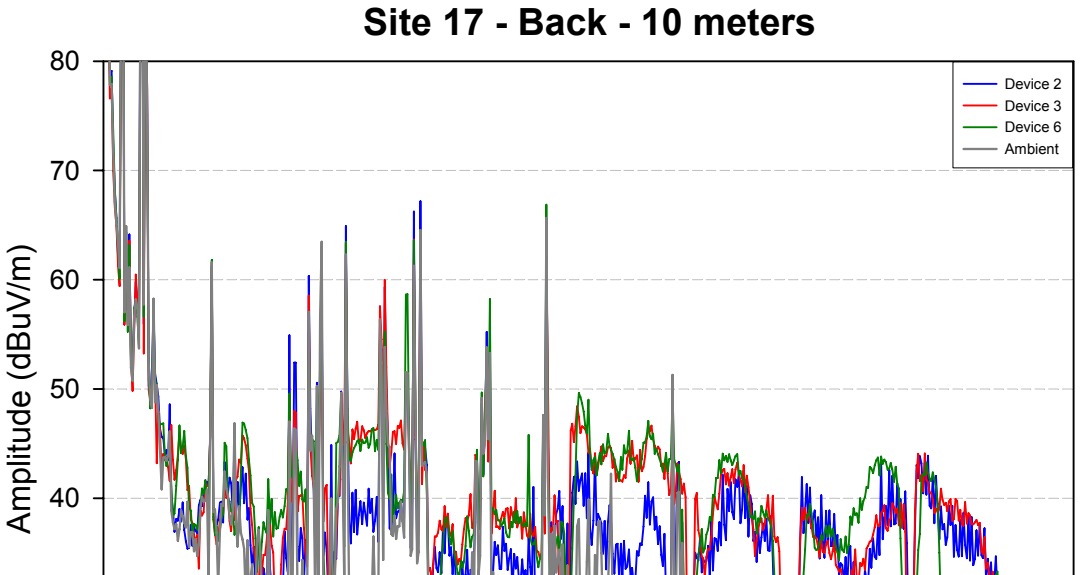
Test Site 17 - Front



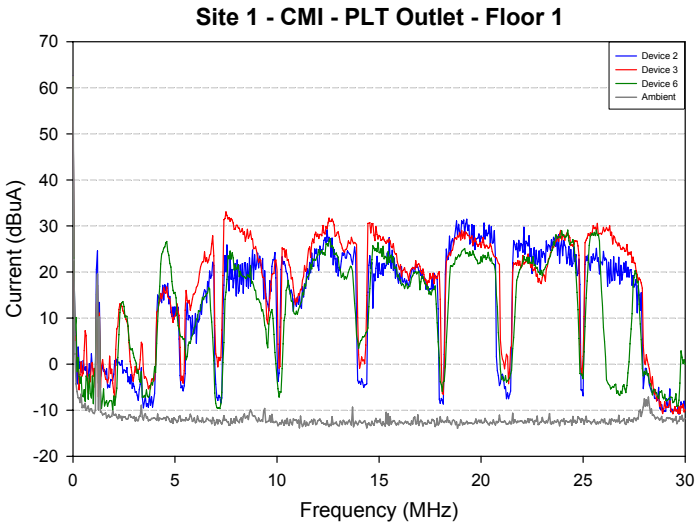

Site 17 - Front - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30

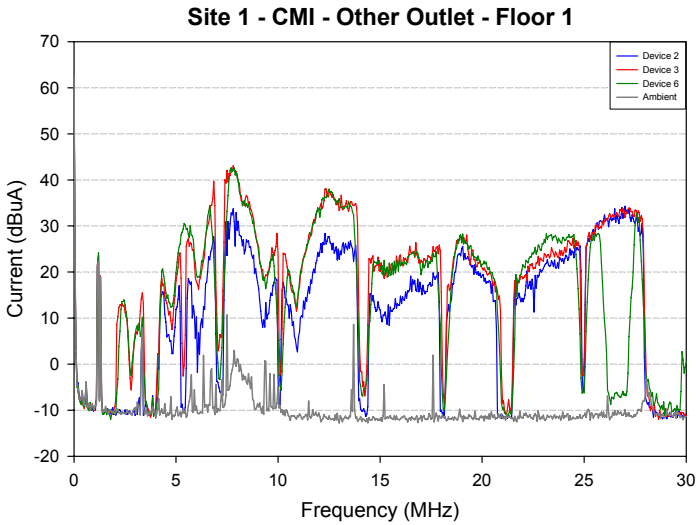

Site 17 - Front - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

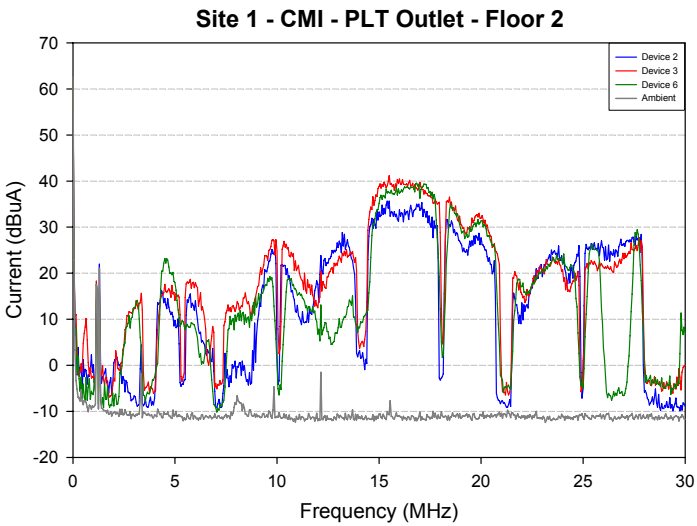

Site 17 - Back - 3 meters
Amplitude (dBuV/m)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40
30
20
0
5
10
15
20
25
30

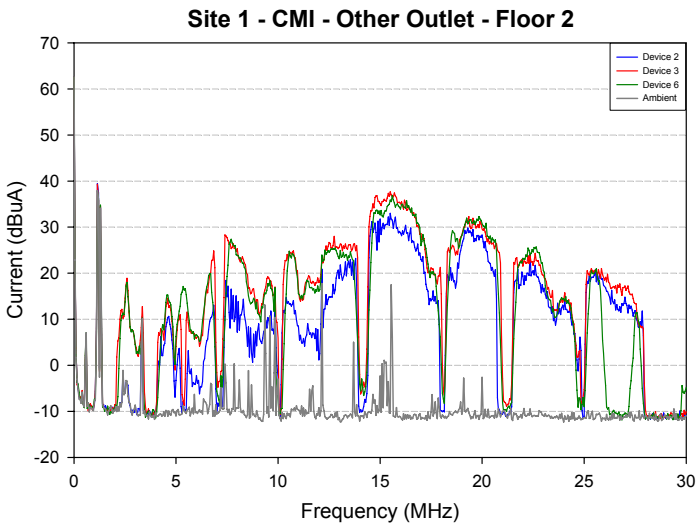

Site 17 - Back - 10 meters
Amplitude (dBuV/m)
Device 2
Device 3
Device 6
Ambient
80
70
60
50
40

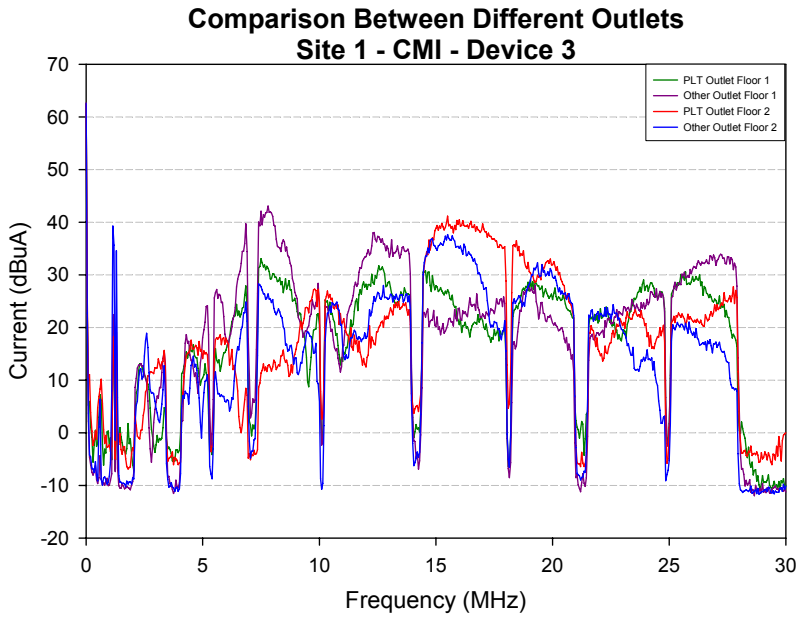
Appendix C: Additional Test Results for CMI, DMI and LCL (Site 1)

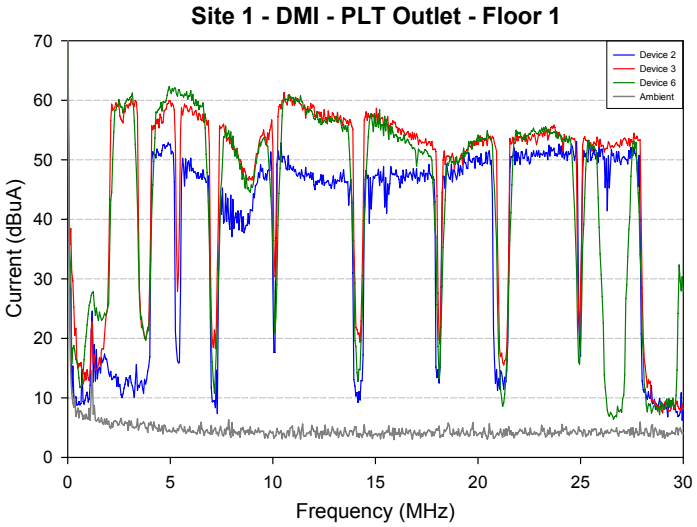


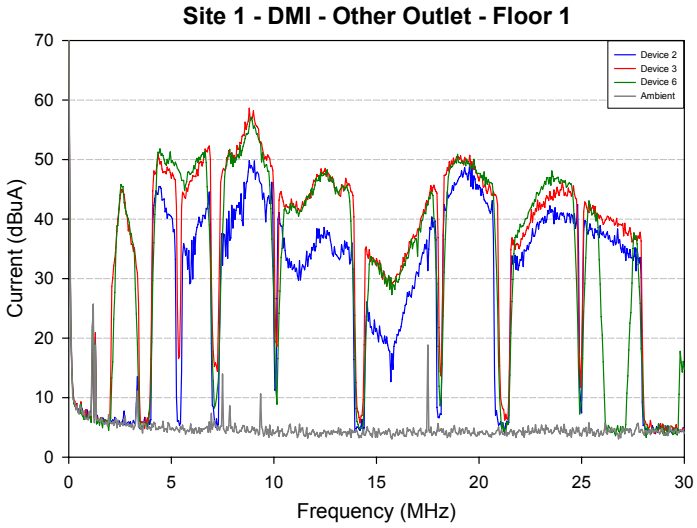


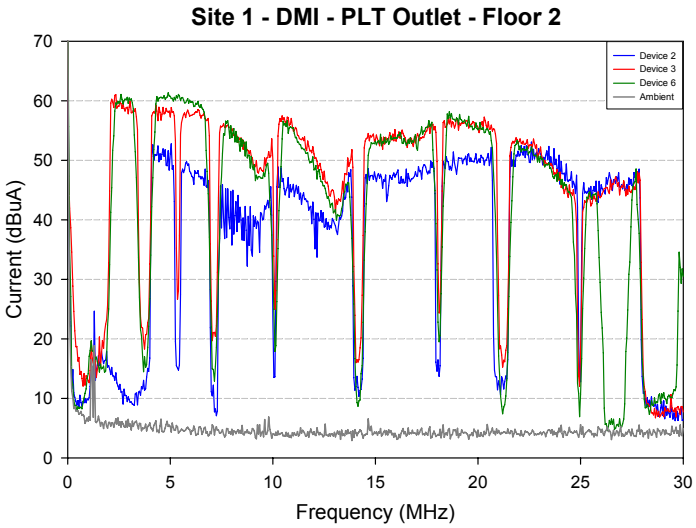


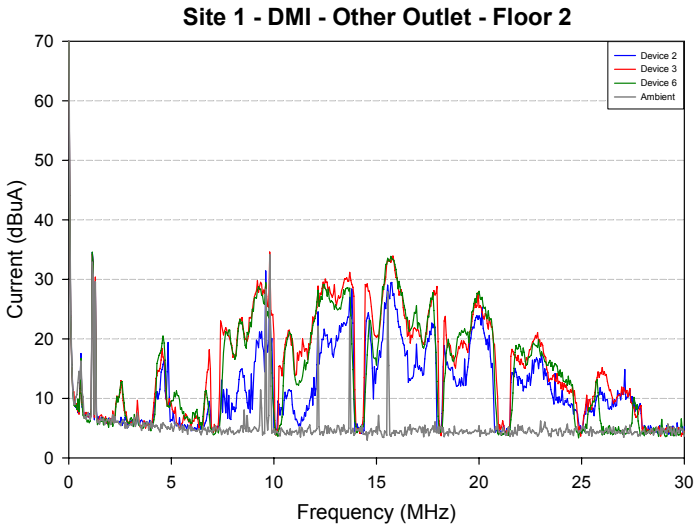


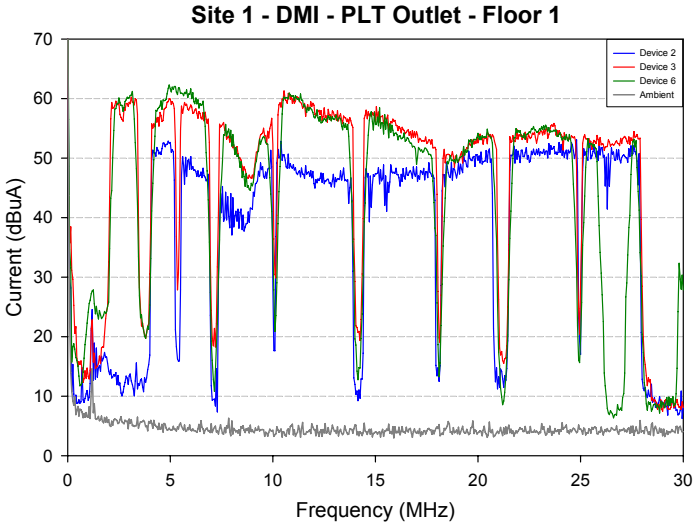

Comparison Between Different Outlets
Site 1 - CMI - Device 3
PLT Outlet Floor 1
Other Outlet Floor 1
PLT Outlet Floor 2
Other Outlet Floor 2
Current (dBuA)
Frequency (MHz)

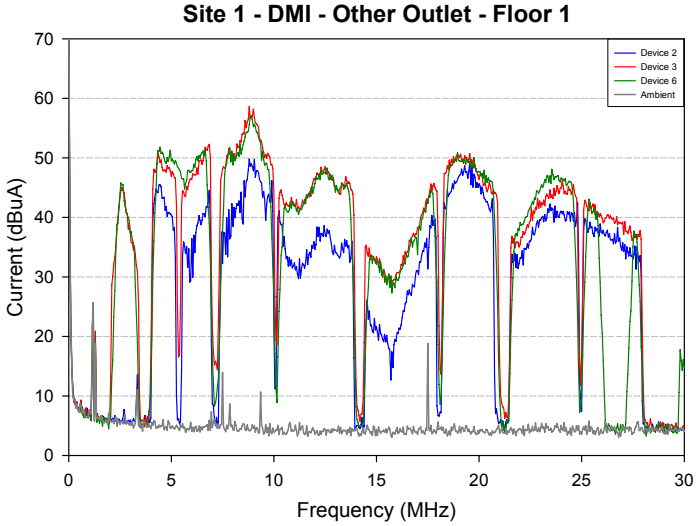

Site 1 - DMI - PLT Outlet - Floor 1
Device 2
Device 3
Device 6
Ambient
Current (dBuA)
Frequency (MHz)

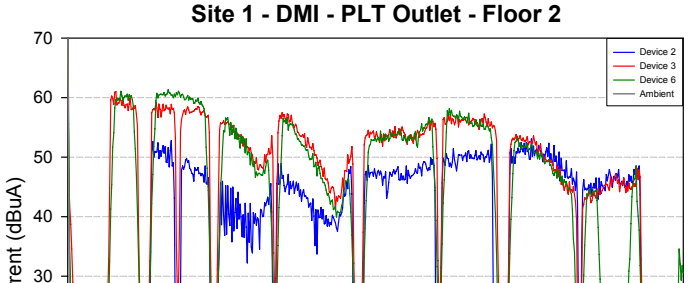

Site 1 - DMI - Other Outlet - Floor 1
Device 2
Device 3
Device 6
Ambient
Current (dBuA)
Frequency (MHz)

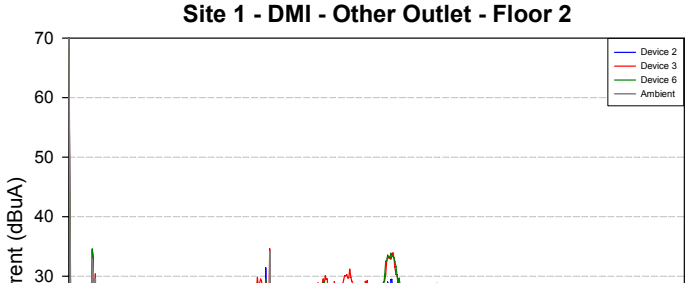

Site 1 - DMI - PLT Outlet - Floor 2
Current (dBuA)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient

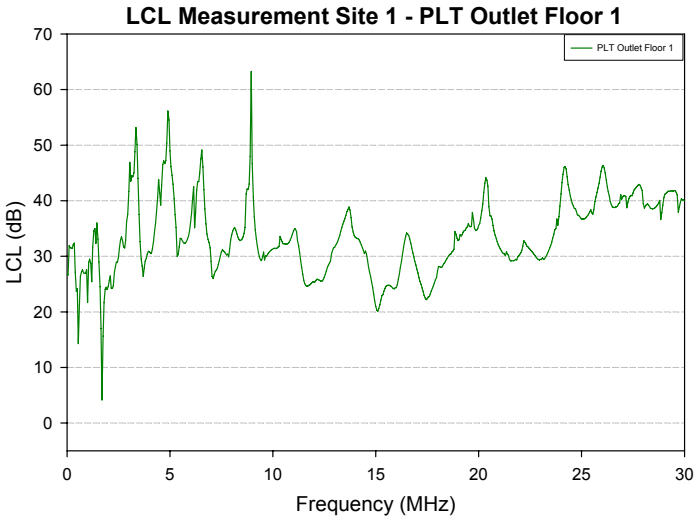

Site 1 - DMI - Other Outlet - Floor 2
Current (dBuA)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient

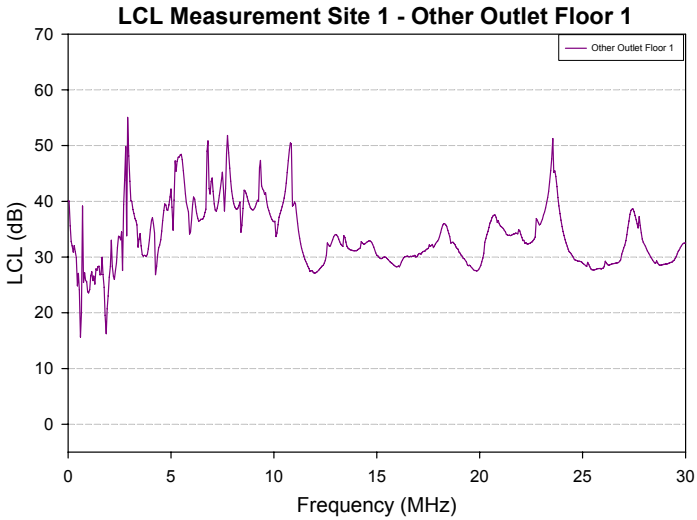

Site 1 - DMI - PLT Outlet - Floor 1
Current (dBuA)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient

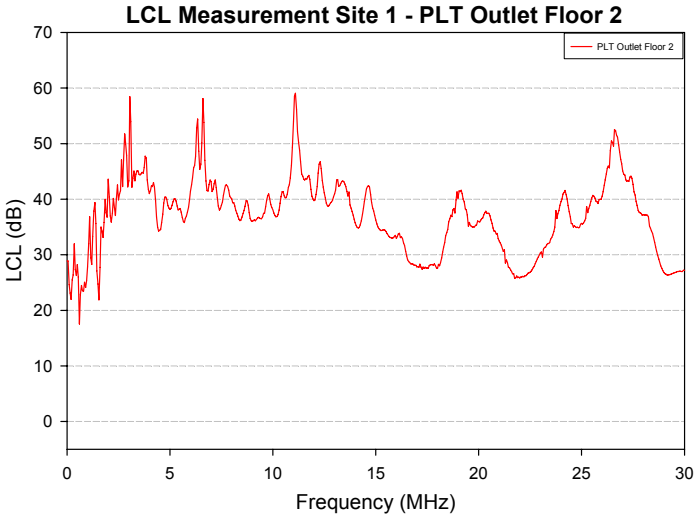

Site 1 - DMI - Other Outlet - Floor 1
Current (dBuA)
Frequency (MHz)
Device 2
Device 3
Device 6
Ambient

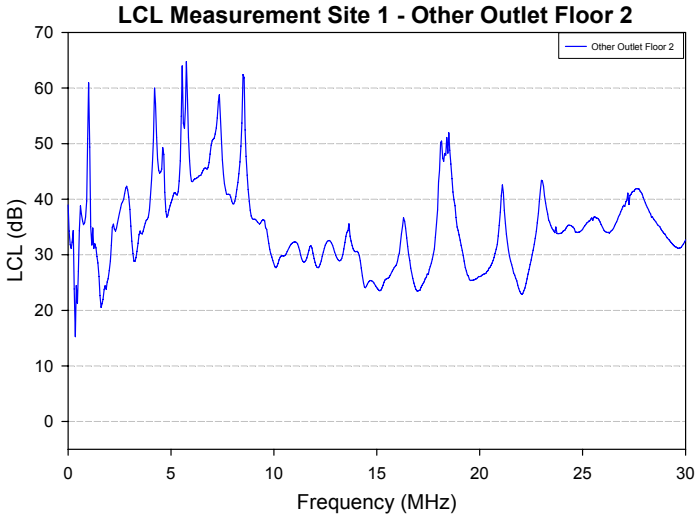

Site 1 - DMI - PLT Outlet - Floor 2
Device 2
Device 3
Device 6
Ambient

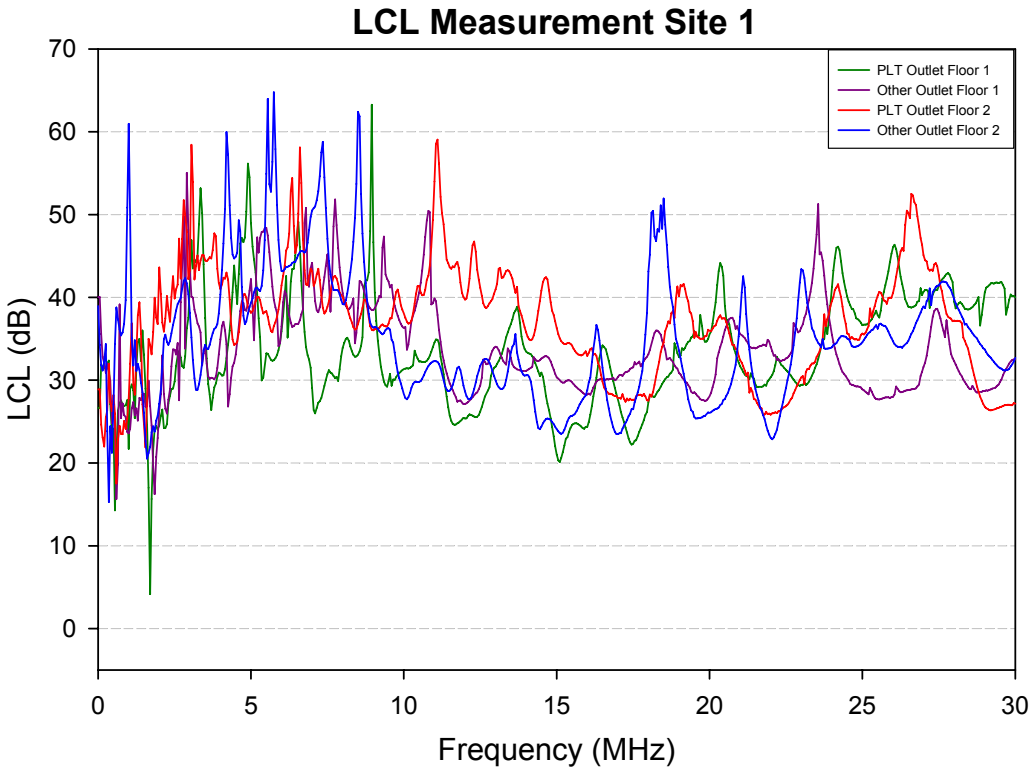

Site 1 - DMI - Other Outlet - Floor 2
Device 2
Device 3
Device 6
Ambient


LCL Measurement Site 1 - PLT Outlet Floor 1
PLT Outlet Floor 1
LCL (dB)
Frequency (MHz)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30


LCL Measurement Site 1 - Other Outlet Floor 1
Other Outlet Floor 1
LCL (dB)
Frequency (MHz)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30


LCL Measurement Site 1 - PLT Outlet Floor 2
PLT Outlet Floor 2
LCL (dB)
Frequency (MHz)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30


LCL Measurement Site 1 - Other Outlet Floor 2
Other Outlet Floor 2
LCL (dB)
Frequency (MHz)
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30


LCL Measurement Site 1
PLT Outlet Floor 1
Other Outlet Floor 1
PLT Outlet Floor 2
Other Outlet Floor 2
LCL (dB)
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Frequency (MHz)