Chapter 5 – MEASUREMENT OF PLT SYSTEMS

5.1 BACKGROUND

Until recently, carrier current systems most often operated within a dwelling to perform simple remote control functions or to provide an audio monitoring capability. These systems were generally unable to propagate past the first electrical transformer. Furthermore, they operated at frequencies below 2 MHz using narrowband analogue transmissions. For the most part, there was not a concentration of these devices nor were they pervasive. All of these things combined resulted in minimal impact on the allocated users of the spectrum they shared. Internet access via the power line was not feasible with these systems.

Present day Access systems use wideband digital signals that are capable of travelling well over several kilometres along the electrical lines. They have the ability to overcome the barriers previously imposed by electrical transformers and other line discontinuities. Some systems have repeaters that offer signal reconstruction, amplification and frequency translation. The use of wide bandwidths in the order of several MHz is commonplace to provide a higher data rate and better noise immunity. The frequencies used are commonly between 2 and 50 MHz although they may be capable up to 80 MHz and beyond. The Access systems have the capability to serve a neighbourhood, a city section or an entire city. Rural deployment is a strong possibility where no other high speed internet access is economically feasible.

The In-House systems available today are no longer based on simple analogue technology. Although they do not provide internet access, they may be capable of video transmission to home entertainment devices using the home owner's electrical wiring. Some In-House systems may be interoperable with Access systems with a special modem. Again, these are high bandwidth and high data rate systems spread over several MHz. As a general consideration, the In-House system emissions are mostly contained within the connected building or its immediate environs. However, the potential for leaked emissions remains high and would become more problematic if the popularity of these systems increases.

5.2 MEASUREMENT EVOLUTION

The initial measurements of Access PLT systems were generally investigative in nature. These measurements were conducted by interested parties, both pro and con, to assess the impact of leaked emissions on the incumbent users below 80 MHz. An example of a suite of investigative measurement is provided in Section 5.9. From these measurements came the basis of regulation and the attendant measurements to demonstrate compliance.

5.2.1 Investigative Measurements for Access Systems

Administrations in North America authorized several entrepreneurs to establish experimental PLT Access systems in selected cities. The regulatory agencies visited these installations and conducted measurements. Where no regulations exist, the nature of the measurements was to establish system operation characteristics, radiated power levels, spectral signature, and finally, interference mitigation capability.

Wideband digital emissions present as noise like emissions. Of interest is the width of the emission, the total power in the emission and the power spectral density over selected segments corresponding to an allocated channel in the spectrum of interest. These measurements were to be made with a RMS detector to obtain true power levels.

The investigation also established the measurement locations, separation distance, the spectral content, and the equipment needed. Of particular interest was determining the location of radiation nodes caused

by standing waves or discontinuities on the electrical lines. There was also interest in establishing the rate of decay with distance from the power line. Several computer models of power line systems required verification by measurement.

5.2.2 Regulatory Measurements for Access Systems

Regulatory measurements differ from investigative ones in many regards:

- They may be constrained by existing rules with respect to detectors, measurement bandwidths and separation distance.
- They treat the signal as an interfering source rather than a fundamental emission.
- Separation distance and elevation searches were never envisaged for sources that are elevated to over 10 metres.
- Measurement procedures below 30 MHz are not mature in many regulations.
- They may represent a compromise between advocates and detractors.

An example of a typical suite of regulatory measurements for North America is shown in Section 5.10. European variations may include differences in the measurement location and require measurements in three orthogonal planes. However, the general technical approach is very similar to the North American methods.

5.3 OBSERVATIONS

Regulatory measurements are useful only for the demonstration of compliance to an administration's rules. The evaluation of harm to a specific system will not be evident. There is an assumption that potential victims will continue to operate with minimal obstruction. The rules state emission limits. With the extrapolation of the maximum emission by calculation, one could estimate the field at a distance. However, the potential for interference must be assessed differently. These measurements are taken in close proximity to the radiator and the sky wave is not considered for the purpose of interference. Some PLT systems are power agile and alter the power across the emission bandwidth in order to maintain a signal to noise ratio of between 25 and 30 dB above the line noise. Anything less would result in data throughput reduction. Essentially, the emission is never constant, exasperating the measurement process when the PLT system is not under the explicit control of the investigator.

5.4 RECOMMENDATIONS

In order to assess the potential performance degradation of a communications system due to PLT presence, the entire system must be considered. For the most part, wideband digital emissions will present as noise to the victims and be perceived as a rise in the noise floor. Some PLT systems may operate in a burst or packet mode which will make the emission more audible and potentially more harmful. Analogue systems such as amplitude modulated or single sideband (SSB) voice channels will be most affected, and frequency modulated systems to a lesser extent. Systems that transmit digital information have an inherent advantage due to error correction algorithms and the processing gain associated with spread spectrum transmissions.

The Canadian experience with interference to HF communications revealed that SSB analogue voice transmissions in a 3 kHz channel are the most affected by systems attempting to share the spectrum. The thought was that if a SSB channel could be protected, then it would follow that other more advanced technologies would also be protected. For an interfering source consisting of a low rate burst emission,

laboratory tests have shown that a 3 kHz SSB communications channel will not tolerate more than 9 dB of interference above the ambient noise. At the 9 dB point, the conversation intelligibility is lost.

5.5 A PROCEDURE TO EVALUATE PLT IMPACT ON MILITARY SYSTEMS

Figure 5.5-1 shows the measurement arrangement. The noise generator simulates the ambient noise at the location of interest. Its presence provides a realistic measurement. The PLT source can be one of several configurations. A digital generator may be programmed to produce a PLT emission. Two arbitrary waveform generators (I and Q) may be combined and modulated by a suitable RF generator, or the most economical and least troublesome approach would be to acquire a PLT modem and couple it to the measurement system.

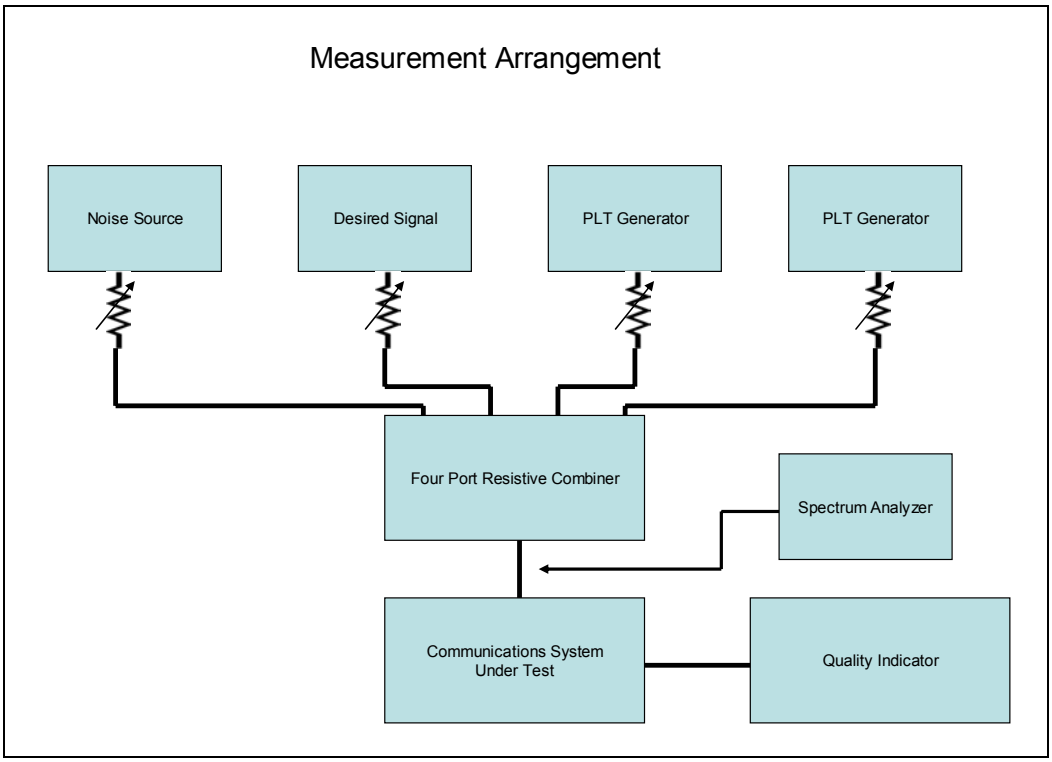

Figure 5.5-1: Measurement Arrangement.

Interference from multiple PLT emissions may be simulated by adding one or more PLT sources.

The procedure for communications systems is then as follows:

- Determine the bandwidth (B_{com}) of the communications channel.
- Set the noise generator to produce the local ambient noise as seen in B_{com}. This value is established from published values or may be measured locally.
- The PLT emission is off.
- Establish a communication link at a level that is deemed acceptable in terms of intelligibility or bit/frame error rate.
- Increase the level of the PLT emission(s) until the link has degraded to the minimum acceptable.

- Care shall be taken that the inputs to the four port combiner do not produce intermodulation products at the output of the combiner. Should intermodulation be present, the levels must be reduced or a hybrid combiner employed.
- A measurement of the level of the PLT emission is then taken by summing the total power in the bandwidth B_{com} using a spectrum analyzer.

From this measurement, the field strength of a PLT emission required to cause impairment of the communications link may be established.

Further it can be calculated/modelled based on the known locations of PLT systems and the victim communications equipment whether a potential for interference exists.

5.6 EVALUATION OF PLT IMPACT ON MILITARY INTELLIGENCE SYSTEMS

Military intelligence gathering systems are designed to operate in electromagnetically quiet areas to receive low level signals. Any increase in ambient noise levels anywhere in the HF band will adversely affect their operations.

Any evaluation procedure dealing with intelligence systems is beyond the scope of this unclassified report. However, in Chapter 8, relevant techniques are presented to predict cumulative effects of PLT emissions.

5.7 ELECTRICAL SAFETY

MV and higher electrical distribution lines may cause serious injury or death through inadvertent contact. The labour laws regarding electrical workers are to be respected for each jurisdiction where measurements are made. For example, Canadian labour laws forbid non-electrical workers from approaching within three metres of a MV distribution line, and the distance increases with voltage. Should conducted measurements be made, the coupling device should bear the clearly visible mark of an electrical regulatory authority. No unlabeled equipment should be connected to the lines. It is advisable to contact the electrical utility operator in advance of the measurements.

5.8 NORTH AMERICAN AND EUROPEAN MEASUREMENT DIFFERENCES

The following table compares the measurement requirements of the United States and Germany for overhead systems (NOTE: In Germany, overhead PLT systems are not in use, but the table applies to telecommunications systems).

Table 5.8-1: Measurement Requirements Comparison

Item	United States	Germany
Power Level	Maximum	Maximum
Duty Cycle	Maximum	Maximum
Detectors	Burst rate >20 Hz Quasi-Peak Burst rate <20 Hz Peak	Quasi-Peak
Measurement Distance	10 metres horizontal corrected for slant distance	3 metres standard
Measurement Distance Correction >30 MHz	20*log(slant range/10)	Complex antenna substitution method … no correction
Measurement Distance Correction< 30 MHz	40*log(slant range/30)	N/A
Measurements < 3 metres and < 30 MHz	N/A	Correct as 20*log(d/3)
Measurements > 3 metres and < 30 MHz	N/A	Curve fitted over numerous measurements
Antenna < 30 MHz	Loop	Loop
Antenna > 30 MHz	Linear Polarized E Field	Dipole
Antenna Height > 30 MHz	1 to 4 metres Optional 1 metre and add 5 dB correction	1 to 4 metres
Antenna Height < 30 MHz	1 metre Optimized in azimuth	1 metre
Measurement Location Access Systems	Every ¼ λ for 1 λ from injection point/discontinuity Supplements measurements may be required	3 metres from the lines Local conditions allow for variation
Number of Measurements	Variable – report minimum of 6 highest	
Quasi Peak Correction	N/A	Correction if (S+N)/N >20 dB
Peak Correction	N/A	Correction if (S+N)/N >20 dB
Measurement Axis > 30 MHz	Vertical and Horizontal	XY
Measurement Axis < 30 MHz	Vertical Optimized in azimuth	XYZ (vector sum)

5.9 TYPICAL ACCESS SYSTEM INVESTIGATIVE MEASUREMENTS

5.9.1 Background

The PLT technology is an unintentional radiator communications system that has the potential to degrade the performance of receptors due to radio frequency energy escaping from the power lines over which it is propagated. All of the measurement efforts to date on PLT systems have focused on the issue of compliance and the subject of interference to other spectrum users. Some interest groups have advocated measurements that undoubtedly will present the technology in the worst light. While others attempt to apply techniques that are best used in a laboratory, under controlled conditions, that are unsuited to a field environment.

Others have suggested measurements be made in situations that present a physical danger to the testers.

Here is presented a measurement regimen that will be applicable to all PLT technology field measurements.

5.9.2 Measurement Considerations

A careful consideration of the emission characteristics is required first and foremost.

- Measure the input emission to the power line in advance of transmission for:
  - Spectral signature – total power in the emission.
  - 99% occupied bandwidth.
  - Power spectral density (PSD) 10 kHz spectral segment below 30 MHz and 25 kHz spectral segment above 30 MHz over the 99% width of the emission.
  - CISPR detected values over the 99 % width of the emission.
  - The presence of spectral lines.
  - Peak emissions above the average.
  - Power agility.
  - Minimum power required to communicate.

5.9.2.1 Measurement Questions

Has the presence of concentrators, injectors, extractors and band translators promoted spectral growth or distortion from the quantities measured before transmission?

Has the PSD been distorted by the environment? i.e., reflections, absorptions.

5.9.2.2 Measurement Rationale

Receivers respond very poorly to spectral lines within their channel. They will fare better in a whitened spectrum.

A peak emission that exceeds the average level may prove devastating to a receptor while the average emission power may not. This is a consideration that is only determined by measurement of the PLT system characteristics.

It is quite likely that the CISPR detected measurements will become the accepted method to demonstrate compliance. Essentially, the CISPR values are the most likely values to be used for demonstration of compliance. The other measurements are used to provide insight to the emission and its characteristics.

5.9.3 Equipment

5.9.3.1 Antennas

Below 30 MHz a passive loop is required. The compelling reasons for a passive loop are two fold. The rod antenna factors are not valid unless the rod is placed on a ground plane having a diameter of 1.2 metres which makes it impractical to use in an elevated position. An active loop is prone to undetected overload which will void the measurement.

Above 30 MHz any linearly polarized antenna is acceptable. However, it is wise to use a commonly available device that is generally accepted within the EMC community such as a biconical antenna. There has not been demonstrated a need to measure above an upper limit of 80 MHz.

5.9.3.2 Indicating Instrument

It is important that the indicating instrument be commercially available and conventionally equipped. For wideband evaluations, signature analysis and power spectral density measurement, a spectrum analyzer is the most desirable.

For CISPR measurements, a test receiver is required. Most receivers have a fixed pre-set suite of conditions that are enabled when the CISPR detector is selected, making the measurements ultimately defendable. A test receiver is better able to target a specified event than a spectrum analyzer. A CISPR enabled spectrum analyzer should not be used as the test results can be misleading without an intimate knowledge of how the instrument conducted the measurement in a swept environment.

5.9.3.3 Recommended Test Equipment for Measurements below 30 MHz

- A CISPR 16-1 compliant test receiver with General Purpose Interface Bus (GPIB) capability (9 kHz and 10 kHz IF bandwidth).
- A swept tuned spectrum analyzer with GPIB capability.
- A calibrated magnetic loop antenna.

5.9.3.4 Recommended Test Equipment for Measurements above 30 MHz

- A CISPR 16-1 compliant test receiver with GPIB capability.
- A swept tuned spectrum analyzer with GPIB capability.
- A calibrated biconical antenna.

5.9.3.5 General Test Equipment

- GPIB controller – laptop computer preferred.
- Cables and connectors.

5.9.4 Measurement Geometry

5.9.4.1 Basic Premise

- There are no receptors located directly underneath a power line.
- There are limited receptors located within 3 metres horizontally of a power line.

- There are no receptors less than 1 metre above the ground.
- A measurement distance of 3 metres or less separation from the power line presents a safety of life issue.
- 10 metres horizontal separation is the next generally accepted measurement distance when 3 metres is discounted.
- Propagation is generally along the direction of the power line with lobes at the standing wave points.
- Impedance discontinuities on the power line will radiate and generate standing waves on the line.
- Horizontal and vertical polarizations are to be measured above 30 MHz.

5.9.4.2 Recommended Measurement Points

- The preliminary measurement is at an injector site test point for a wired connection.
- The first radiated measurement is at the power line next to the injector.
- Continue downstream for approximately 2 wavelengths, examining for nodes every ¼ wavelength.
- Measure at line discontinuities and operator installed equipment.

5.9.5 Practical Measurements

- Horizontal separation is 10 metres (or best fit if on a city street).
- Normalize the measurement to 10 metres.
- The sight to the power line is to be reasonably unobstructed.
- The height scan begins at 2 metres below the power line to 2 metres above the power line.
- First measurement is at an injector site.
- Determine the polarization and direction of the emission and record the largest value.
- The plane of the magnetic loop is to remain vertical.
- Measure at each ¼ wavelength down the power line for up to 2 wavelengths.
- Measure at impedance discontinuities such as transformers or other PLT equipment.
- Record the following parameters at each measurement site:
  - 99% occupied bandwidth (99% of the power contained within the bandwidth).
  - Power spectral density (PSD) 10 kHz spectral segment below 30 MHz and 25 kHz spectral segment above 30 MHz over the 99% width of the emission.
  - CISPR detected values over the 99% width of the emission.
  - Total power in the 99% emission width.
  - Distance with respect to an injector/extractor or other line discontinuity.
  - Height of the receive antenna feed point.
  - Horizontal separation from the power line.
  - Antenna polarization above 30 MHz.

5.9.6 Measurement Records

The details of the measurements are to be recorded such that they may be reproduced by anyone reading the report. They should include, but not be limited to, these items below:

- GPS position or location on a city map.
- List of all equipment and calibration dates.
- People in attendance.
- Height of the antenna with respect to the power line, where the measurement was taken.
- Numerical spectrum analyzer data. Trace values to re-confirm results.
- Analyzer settings including detector.
- Table of system gains and losses with respect to frequency.
- Photographs of a typical test setting.
- Antenna polarization.

5.10 TYPICAL ACCESS SYSTEM REGULATORY MEASUREMENTS

This Section presents an example of compliance measurements of Power Line Telecommunications (PLT) devices. For PLT systems, the measurement principles are based on the current understanding of PLT technology. Modifications may be necessary as measurement experience is gained.

5.10.1 General Measurement Principles for Access PLT and In-House PLT

1) Testing shall be performed with the power settings of the Equipment Under Test (EUT) set at the maximum level.

2) Testing shall be performed using the maximum RF injection duty factor (burst rate). Test modes or test software may be used for uplink and downlink transmissions.

3) Measurements should be made at a test site where the ambient signal level is 6 dB below the applicable limit.

4) If the data communications burst rate is at least 20 bursts per second, quasi-peak measurements shall be employed. If the data communications burst rate is 20 bursts per second or less, measurements shall be made using a peak detector.

5) For frequencies above 30 MHz, an electric field sensing antenna, such as a biconical antenna is used. The signal shall be maximized for antenna heights from 1 to 4 metres, for both horizontal and vertical polarizations. For Access PLT measurements only, as an alternative to varying antenna height from 1 to 4 metres, these measurements may be made at a height of 1 metre provided that the measured field strength values are increased by a factor of 5 dB to account for height effects.

6) For frequencies below 30 MHz, a passive magnetic loop is used. The magnetic loop antenna should be at 1 metre height with its plane oriented vertically and the emission maximized by rotating the antenna 180 degrees about its vertical axis.

7) The six highest radiated emissions relative to the limit and independent of antenna polarization shall be reported.

8) All operational modes should be tested including all frequency bands of operation.

5.10.2 Access PLT Measurement Principles

5.10.2.1 Test Environment

1) The Equipment Under Test (EUT) includes all PLT electronic devices, e.g., couplers, injectors, extractors, repeaters, boosters, concentrators and electric utility overhead or underground medium voltage lines.

2) *In-situ* testing shall be performed on three typical installations for overhead line(s) and three typical installations for underground line(s).

5.10.2.2 Radiated Emissions Measurement Principles for Overhead Line Installations

1) Measurements should normally be performed at a horizontal separation distance of 10 metres from the overhead line. If necessary, due to ambient emissions, measurements may be performed at a distance of 3 metres. Distance corrections are to be made.

2) Testing shall be performed at distances of 0, ¼, ½, ¾ and 1 wavelength down the line from the PLT injection point on the power line. Wavelength spacing is based on the mid-band frequency used by the EUT. In addition, if the mid-band frequency exceeds the lowest frequency injected onto the power line by more than a factor of two, testing shall be extended in steps of ½ wavelength of the **mid-band** frequency until the distance equals or exceeds ½ wavelength of the **lowest** frequency injected. (For example, if the device injects frequencies from 3 to 27 MHz, the wavelength corresponding to the mid-band frequency of 15 MHz is 20 metres, and wavelength corresponding to the lowest injected frequency is 100 metres. Measurements are to be performed at 0, 5, 10, 15 and 20 metres down line – corresponding to zero to one wavelength at the mid-band frequency. Because the mid-band frequency exceeds the minimum frequency by more than a factor of two, additional measurements are required at 10-metre intervals until the distance down-line from the injection point equals or exceeds ½ of 100 metres. Thus, additional measurement points are required at 30, 40 and 50 metres down line from the injection point).

3) Testing shall be repeated for each Access PLT component (injector, extractor, repeater, booster, concentrator, etc.).

4) The distance correction for the overhead-line measurements shall be based on the slant range distance, which is the line-of-sight distance from the measurement antenna to the overhead line. (For example, if the measurement is made at a horizontal distance of 10 metres with an antenna height of 1 metre and the height of the PLT-driven power line is 11 metres, the slant range distance is 14.1 metres [10 metres vertical distance and 10 metres horizontal distance]. [At frequencies below 30 MHz, the measurements are extrapolated to the required 30-metre reference distance by subtracting 40 log(30/14.1), or 13.1 dB from the measured values. For frequencies above 30 MHz, the correction uses a 20 log factor and the reference distance is specified in regulation].

Note: In cases where Access PLT devices are coupled to low-voltage power lines (i.e., HomePlug or modem boosters), apply the overhead-line procedures as stated above along the low-voltage lines.

5.10.2.3 Radiated Emissions Measurement Principles for Underground Line Installations

1) Underground line installations are those in which the PLT device is mounted in, or attached to, a pad-mounted transformer housing or a ground-mounted junction box and couples directly only to underground cables.

2) Measurements should normally be performed at a separation distance of 10 metres from the in-ground power transformer that contains the PLT device(s). If necessary, due to ambient emissions, measurements may be performed at a distance of 3 metres. Distance corrections are to be made.

3) Measurements shall be made at positions around the perimeter of the in-ground power transformer where the maximum emissions occur. A minimum of 16 radial angles surrounding the EUT is required (In-ground transformer that contains the PLT device(s)). If directional radiation patterns are suspected, additional azimuth angles shall be examined.

5.10.2.4 Conducted Emissions Measurement Principles

1) Conducted emissions testing is not required for Access PLT.

5.10.3 In-House PLT Measurement Principles

1) *In-situ* testing is required for testing of the functions of the In-House PLT device.

5.10.3.1 Test Environment and Radiated Emissions Measurement Principles for *In-Situ* Testing

1) The Equipment under Test (EUT) includes In-House PLT modems used to transmit and receive carrier PLT signals on low-voltage lines, associated computer interface devices, building wiring and overhead or underground lines that connect to the electric utilities.

2) *In-situ* testing shall be performed with the EUT installed in a building on an outside wall on the ground floor or first floor. Testing shall be performed on three typical installations. The three installations shall include a combination of buildings with overhead-line(s) and underground line(s). The buildings shall not have aluminium or other metal siding, or shielded wiring (e.g., wiring installed through conduit, or BX electric cable).

3) Measurements shall be made at positions around the building perimeter where the maximum emissions occur. A minimum of 16 radial angles surrounding the EUT (building perimeter) are to be measured. If directional radiation patterns are suspected, additional azimuth angles shall be examined.

4) Measurements should normally be performed at a separation distance of 10 metres from the building perimeter. If necessary, due to ambient emissions, measurements may be performed a distance of 3 metres. Distance corrections are to be made.

5.10.3.2 Additional Measurement Principles for *In-Situ* Testing with Overhead Lines

1) In addition to testing radials around the building, testing shall be performed at three positions along the overhead line connecting to the building (i.e., the service wire). It is recommended that these measurements be performed starting at a distance 10 metres down the line from the connection to the building. If this test cannot be performed due to insufficient length of the service wire, a statement explaining the situation and test configuration shall be included in the technical report.

2) Measurements should normally be performed at a horizontal separation distance of 10 metres from the overhead line connecting to the building. If necessary, due to ambient emissions, measurements may be performed a distance of 3 metres. Distance corrections are to be made using the slant range distance.

3) The distance correction for the overhead-line measurements shall be based on the slant range distance, which is the line-of-sight distance from the measurement antenna to the overhead line.