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Methodologies to relate radiation from power line telecommunication installations to power line telecommunication modem output

SM Series

Spectrum management

International Telecommunication Union

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REPORT ITU-R SM.2269

Methodologies to relate radiation from power line telecommunication installations to power line telecommunication modem output

(Question ITU-R 221-1/1)

(2013)

CONTENTS

Page

1 Introduction

A key element in the studies on the impact of power line telecommunication (PLT) above 80 MHz is to develop means of assessing how much of the RF energy injected into mains wiring by PLT modems is radiated. Such tools will provide the basis for:

– assessing compliance with electromagnetic compatibility (EMC) limits on radiated emissions;

– determining the resulting increase in the noise floor; and

– assessing the potential to cause interference to radiocommunication services.

If it proves possible to relate the radiated emissions from PLT installations to directly measurable quantities of PLT modem power spectral density and total output power, then the task of providing guidelines on the deployment of PLT through ITU-R and ITU-T Recommendations becomes easier. The ITU-T family of G.9960 Recommendations incorporates a toolkit that allows national regulators to tailor the power spectral density (PSD) spectrum mask and total output power in accordance with local market conditions. What is missing is a means of relating limits for unacceptable levels of radio-frequency noise and interference to radiocommunication services to the injected power and spectral density of PLT modems.

In order to use the PSD level as a reference for assessing and controlling radiated emissions from PLT installations, some means of determining representative coupling losses in typical PLT installations is required. That would then allow the amount of radiation from typical PLT installations to be linked directly to the modem PSD and total output power.

Several ITU-R studies have been included in Report ITU-R SM.2158 that demonstrate the techniques and effort involved when carrying out measurements on the impact of radiation from PLT systems on broadcasting systems operating below 80 MHz. The following studies contained in the Appendices to Report ITU-R SM.2158 measured PLT radiation in the HF bands:

– Study A3.1 (Brazil) – Reports radiated electric field measurements from a single access PLT system. This concluded that the interfering field strength should not exceed

16 dB(μV/m) at the receiving location, which may be lower than the ambient background noise, rather than the measured 60 dB(μV/m).

– Study A3.2 (NABA/CRC) – Reports radiated electric field measurements from in-premises PLT system and shows PLT signals are received at around 50-60 dB(μV/m) at 3 to 10 m distance.

– Study A3.5.3 (IUCAF) – Reports radiated electric field measurements from a PLT system in an isolated house and shows PLT signals are received at around 50 dB(μV/m) at 10 m distance.

This Report brings together studies supporting the aim to establish a methodology for relating the radiated emissions from PLT installations to the modem power output and spectral density.

2 Coupling loss methodology

This study carried out by Norddeutscher Rundfunk (NDR) and Zweites Deutsches Fernsehen (ZDF) aims to assess the radiated emissions from PLT installations by considering the coupling losses involved. The intention is to develop a method whereby a figure for the total coupling loss can be determined in a typical situation, with the aim of extending the technique to a range of representative situations.

This study follows up on the interference measurements reported here in § 3.2.1 so as to explore ways of simplifying the assessment of radiated emissions from PLT installations. There are many steps involved in assessing how the radiation from PLT systems will be experienced as additional noise or interference by a receiver. Unfortunately, none of the steps involved are amenable to easy modelling or measurement. The quantity that is measurable with certainty and repeatability is the PSD injected by a PLT modem into the mains wiring.

The task of administrations, regulators and standards organizations would be simpler if the injected PSD level could be used as the reference when setting limits for unacceptable levels of noise and interference. This would require a means of assessing the representative coupling losses in typical PLT installations that would then allow the amount of radiation from typical PLT installations to be linked directly to the modem PSD and total output power.

The object of the NDR/ZDF study was to model the coupling losses all along the chain from the RF energy injected into the mains wiring, then into the fraction radiated, and finally into the fraction receivable within a building. If these can be combined into a representative total coupling loss then the interference potential of PLT devices can be assessed from a knowledge of their total output power and PSD characteristics.

For the purpose of setting a repeatable basis for modelling, this study uses a DVB-T modulator to establish a broadband RF signal with known spectral characteristics.

2.1 Measurement philosophy

It is difficult to measure the level of the radiated emissions from a PLT installation using antennas, because the power injected by the PLT modems into the power lines varies in time. On idle mode, there are only some signal spikes present. Maximum power is transmitted only during data transfer, which is mostly unsteady.

The PLT modem output power is known to the device manufacturer. The interference power level on the output of a defined reception antenna can be calculated, if the coupling loss between the PLT modem plugged into a mains wall socket and the antenna output is known. The coupling loss can also be used to calculate the maximum allowed PLT modem output power or PSD, if the maximum interference level at a receiver input is given.

Adequate measurements of the coupling loss are very time consuming, because different types of buildings, of mains wirings, different antenna positions, etc. have to be considered. A more efficient approach is to model several building types, with different power line wirings, connect a PLT modem to the power line at different locations and use electromagnetic radiation calculation tools, to find the coupling loss between the PLT modem and the received signal level of an antenna in the building. The antenna has to be placed in many different locations and positions. A large number of coupling loss values, for different wiring models and assumptions can be calculated, generating a good statistical approach. The values can be verified by some exemplary measurements.

In order to find some experimental values for the coupling loss in the VHF-frequency band, measurements were made by the IRT[1] in a laboratory and in a typical non-detached house in a rural region of Germany.

2.2 Measurement setup

The first coupling loss measurements were made in an IRT laboratory just to get some feeling for it. However, a laboratory is not typical for a broadcast reception site. Realistic coupling loss measurements were made in a typical non-detached house in a rural region of Germany. The house is made of bricks, has a ground floor and two stories with concrete floors/ceilings, see Fig. 1.

FIGURE 1

Non-detached house (centre) where the coupling loss from PLT modem to dipole antenna was measured

Report SM.2269-01

To measure the radiated and received interference power, a stable signal with known level has to be injected into the power lines. PLT modem output is not directly suitable because it is unsteady. As PLT systems use COFDM signals for data transmission, we used a similar signal for measurements, a DVB-T signal. A Rohde & Schwarz (R&S) SFQ signal generator fed a 7 MHz bandwidth DVB-T signal at a frequency of 198.5 MHz into the house mains, see Fig. 2.

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[1] The IRT (Institut für Rundfunktechnik GmbH) is the Research and Development institution of the public service broadcasters of Germany, Austria and Switzerland. It is located in Munich, Germany.

FIGURE 2

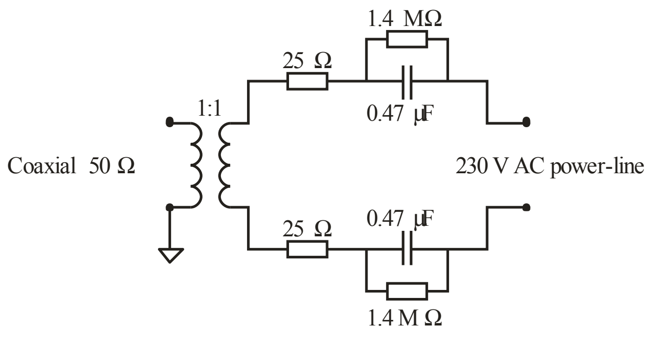
Signal generator SFQ feeding DVB-T signal into the mains

Report SM.2269-02

The matching from the coaxial 50 Ohm generator output to the symmetrical power lines and the 230-V isolation was done by the circuit shown in Fig. 3.

FIGURE 3

Matching and isolating circuit



Report SM.2269-03

The circuit can attenuate the generator signal significantly, if the line impedance is lower than 1 000 Ohm (i.e. 3.5 dB at 100 Ohm). The line impedance depends on several parameters which cannot be controlled. For the purpose of the associated calculations here, the matching circuit is considered to attenuate the DVB-T signal by 3 dB.

A vertically polarized ground-plane antenna was used for the signal reception, as shown in Fig. 4. The antenna was placed at 1.5 m above ground and was connected to a spectrum analyser in order to measure the received channel power. The ground-plane antenna gain is 0 dB_d, the same as for a $\lambda/2$-dipole.

FIGURE 4

Vertically polarized ground-plane measurement antenna

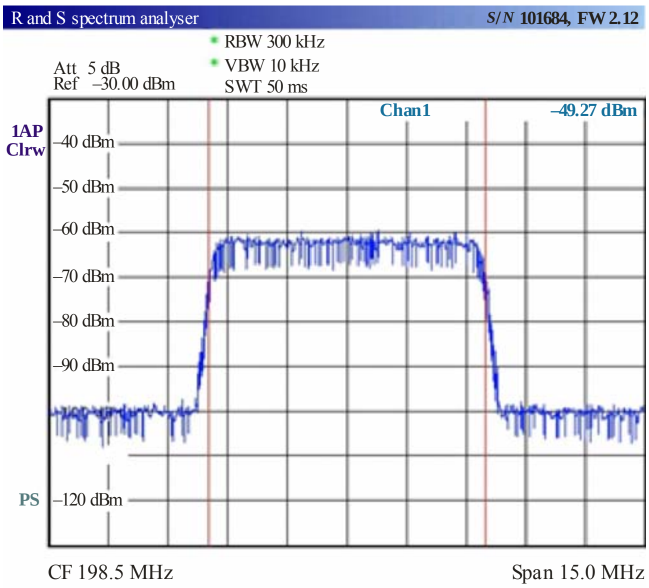
Report SM2269-04

The spectrum analyser used was an R&S ETL, which can measure the power in a given bandwidth. For the calibration of the measurement set-up, the SFQ-signal generator was set at –50 dBm power level and was connected directly to and measured by the ETL set to 7 MHz channel bandwidth. The spectrum measured is shown in Fig. 5, the channel power measured was –49.27 dBm. That means that the measurement error was below 1 dB.

The settings of the spectrum analyser were let unchanged for all following measurements.

FIGURE 5

Spectrum of the DVB-T signal used for measurements
(–50 dBm level at generator)



Report SM2269-05

2.3 Measurement results

2.3.1 Measurements results in the IRT-laboratory

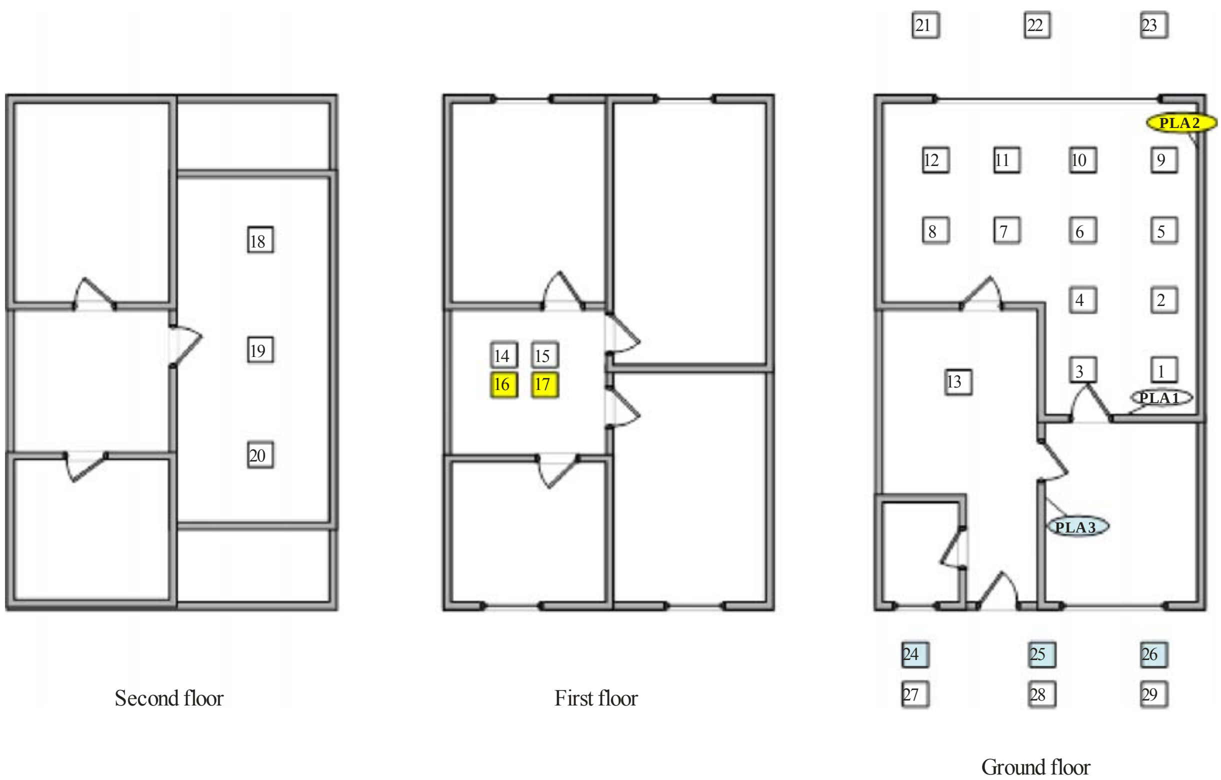
The DVB-T signal generator was plugged into a mains wall outlet. The signal power at the ground-plane antenna output, set at 1.5 m above ground, was measured in six positions in the laboratory.

2.3.2 Measurement results in a non-detached house

The house, where the measurements were done, was made of bricks, had a ground floor and two stories, with concrete floors/ceilings, see Fig. 1. Actually, there are three adjacent houses, left, centre and right. The centre house outline is given in Fig. 6, the left adjacent house outline in Fig. 7. The measuring signal was connected to a wall outlet in the centre house, in the ground floor.

FIGURE 6

Centre house outline

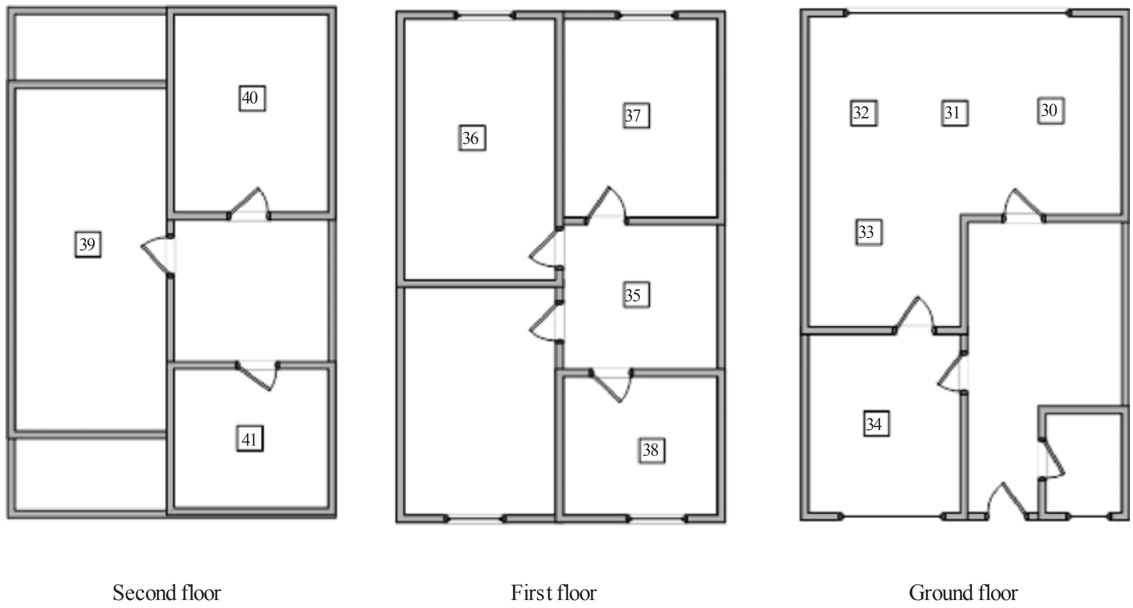


Report SM.2269-06

The DVB-T generator was set to 0 dBm output power and was plugged successively to the wall outlets in the points PLT modem 1 (white), PLT modem 2 (yellow) and PLT modem 3 (blue) in the ground floor. Measurements were made in the points 1 to 29 in the centre house and the points 30 to 41 in the left adjacent house. The measurement-point colour corresponds to the generator coupling position, when measured (PLT modem 1, 2 or 3).

FIGURE 7

Left adjacent house outline

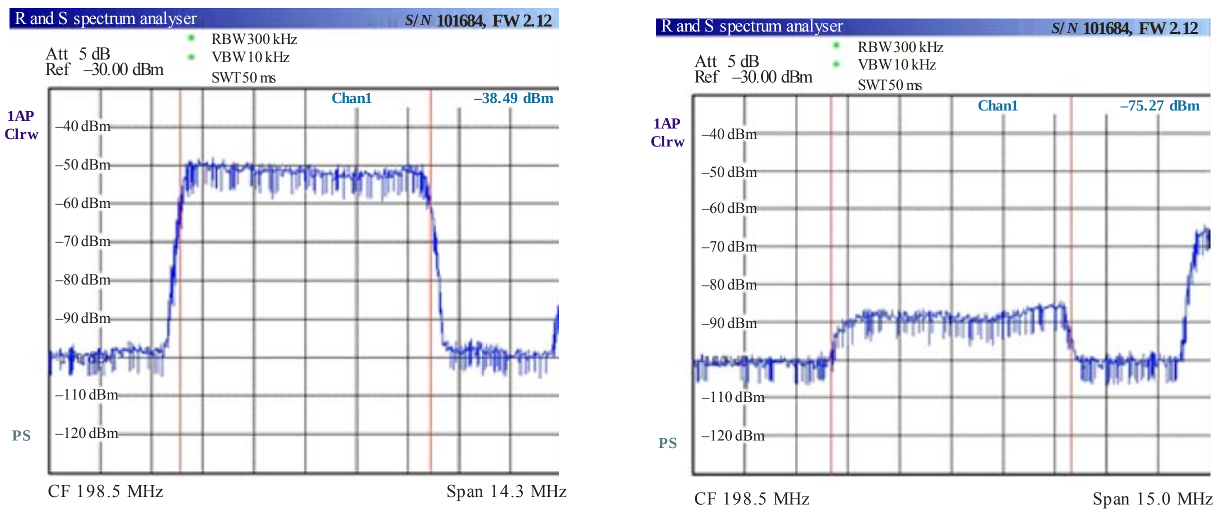


Report SM.2269-07

The antenna was placed at the measuring points indicated as numbered squares in Figs 6 and 7. For each measuring point, the spectrum on the ETL-SA was recorded. In addition, the received channel power was indicated. As an example, in Fig. 8, the results are shown for a potentially high PLT interference-level point and a potentially low PLT interference-level point.

FIGURE 8

Spectrum at two measuring points, with high and low level interference



Report SM2269-08

a. Measuring point 1; high interference b. Measuring point 39; low interference

The signal on the right edge in Fig. 8b, outside the DVB-T measurement bandwidth, is a DAB signal transmitted in the region.

Measurements were done in the centre house in the ground floor in the room the signal was injected into mains, in the neighbouring room, on the first and on the second floor and outside the house.

Measurements were also done in the left adjacent house in the ground floor, on the first and on the second floor.

2.4 Measurement results for the coupling loss

2.4.1 Results from the IRT laboratory

The average coupling loss calculated from the six measurement point values is –47 dB. The standard deviation of the values is 6 dB.

2.4.2 Results from measurements within the centre house

The coupling loss between the PLT modem output and the receiving-antenna output varies in the same house in the range from 48 dB to 57 dB. The fluctuation of the measured values is high, with a standard deviation of about 6 dB. Outside the building, the coupling loss to points at a distance of 4 m from the house wall in front of the building is 57 dB, the coupling loss to points at a distance of 10 m at the rear of the house is 60 dB. The actual coupling loss average values measured are:

– into the same room: 48 dB
– to neighbouring room 44 dB
– to floor above 54 dB
– to two floors above 57 dB
– to points outside the building at a distance of 4 m 57 dB
– to points outside building at a distance of 10 m 60 dB

2.4.3 Results from measurements in the adjacent house

The coupling loss between the PLA 1 output in the centre house and the receiving-antenna output in the left adjacent house varies in a range from 62 dB to 70 dB, depending on distance and floor. The average values measured are:

– on the same floor 62 dB
– on the floor above 62 dB
– on two floors above 70 dB

2.5 Illustration calculation for the maximum allowed PLT modem output power

The maximum allowed power at the output of a PLT modem in order to avoid interference to DAB reception will be calculated starting from the following premises:

– the interference to DAB reception at 200 MHz should not increase by more than 1% with respect to the total receiving noise power;
– the PLT installation is transmitting its power evenly distributed in the spectrum from 30 MHz to 300 MHz;
– the DAB-receiver noise figure (F) is 8 dB;
– the DAB-reception antenna gain is –2.2 dBd;
– the man-made noise (MMN) allowance at 200 MHz with the above-mentioned antenna is 2 dB;
– the DAB reception takes place in an adjacent apartment, where the coupling loss is 62 dB.

The COFDM signal of the PLT modem disturbs like white noise. If the initial interfering level should not be increased by more than 1%, the PLT modem interfering power should be 20 dB below the equivalent total receive noise level at the receiver input.

The equivalent noise level at the receiver input is the thermal noise level plus the receiver noise figure plus MMN, the allowance due to the man-made noise received by the antenna. The result does not depend on the signal bandwidth if PSD is used instead of power.

The thermal noise PSD at 20°C is –174 dBm/Hz. After adding F and MMN, the noise floor PSD at the receiver input is –164 dBm/Hz.

The PLT interference should be at least 20 dB below, i.e. at –184 dBm/Hz.

The coupling loss from a PLT modem to a dipole antenna is assumed as 62 dB. The DAB-receiving antenna has a gain of –2.2 dB relative to a dipole, so the total coupling loss from PLT modem to the DAB receiver is 64.2 dB. Adding the coupling loss to the noise floor PSD, we find that the PLT modem output PSD should be lower than –119.8 dBm/Hz.

Consequently, the total output power from 30 MHz to 300 MHz should not exceed –35.5 dBm.

2.6 Conclusions

The interfering power at a receiver input can be calculated on the basis of the PLT modem output PSD if the coupling loss between the PLT modem output and the receiver antenna output is known. Vice versa, by setting the maximum allowed interference level at the receiver input, the maximum allowable PLT modem output signal PSD can be calculated using the coupling loss.

The coupling loss from a PLT modem connected to a power outlet, to the output of a vertically-polarized dipole antenna in the VHF-frequency band was measured in a laboratory and in a typical non-detached house in a rural region of Germany. The values found were in the range from 48 dB to 57 dB within the house and 62 dB to 70 dB between adjacent houses.

Based on the measurement results, if the interfering power in an adjacent apartment should not increase the total receiving system noise power for DAB reception in the VHF-frequency band by more than 1%, the maximum PLT modem output signal PSD should not exceed –120 dBm/Hz.

The coupling loss values measured and the maximum PLT modem output signal PSD level calculated are valid for houses similar to the ones where the measurements were done, having similar power-line wiring. For other house types and power-line wirings, the values can differ significantly.

3 Radiating point source methodology

This section considers the impact of PLT on mobile cellular communications in the 450-470 MHz band. The complicated behaviour of mains wiring as a distributed radiating source has been a complicating factor in all the experimental and theoretical assessments of the impact of PLT at frequencies less than around 250 MHz. However, at some frequencies, it must be the case that a PLT modem connected to a length of wiring will come to behave more as a point source.

The “skin effect” ensures that attenuation along wiring increases with frequency. Therefore, as the operating frequency rises, only a short length of wiring close to the injection point will be capable of radiating and the problem of PLT radiated emissions reduces to that several PLT modems radiating as point sources from a short length of wiring at each connection point. By the same token, it may be that communication over the mains wiring then owes more to radiation and reception at each connection point than through the attenuated PLT signals conducted along the whole length of the mains wiring.

No information is available on when such a transition in behaviour along typical mains wiring takes place, but clearly the use of a simple point source model for assessing the coupling losses involved with PLT radiated emissions will become more appropriate as the frequency rises.

3.1 Methodology and calculations to protect cellular mobile services

Recommendations ITU-R M.1767 and ITU-R F.1670 were referenced in the GE06 Regional Agreement in order to protect the mobile and the fixed services from digital TV. The calculation method shown in § 3.2 below is based on the same methodology and provides the interfering thresholds and PLT radiated emission masks.

Taking into account the distances (PLT to victim; see distances in parenthesis in Table 1 row 3) and assumptions specified previously, the following trigger levels and max allowed PLT peak-power values can be derived:

TABLE 1

Trigger levels and max PLT peak-power for different victim receivers 80-470 MHz

Power and field strength per 1 MHz	Indoor Cellular terminal or home base station	Outdoor Macrocellular/micro-cellular base-station and fixed station	Outdoor Radiolocation station
Power trigger level (dBm)	–129	–141	–149
Field-strength trigger level (dBμV/m)	1.5	–10.5	–18.5
Max PLT peak-power (dBm)	–103 (1 m)	–95 (10 m)	–83 (100 m)

This analysis of interference caused by PLT radiated emissions to the reception of one of the terrestrial services commonly used in the home could also be used to protect the broadcasting services in the VHF and UHF bands. Moreover, this methodology may also provide a useful basis for studying the protection of radiocommunication services from the unintended emissions of industrial, scientific and medical (ISM) and cable TV distribution installations.

The tolerated desensitization of the terrestrial receivers is 0.05 dB; the allowed interfering signal is 20 dB below the noise threshold; the trigger level is KTBF – 20 dB. If the tolerated desensitization of the terrestrial services receivers is 0.5 dB, the allowed interfering signal is 10 dB below the noise threshold, and all the values in Table 1 will be higher in 10 dB.

The worst-case scenario to protect the indoor terrestrial services from PLT is a cellular handset, as the cellular phone is only 1 m from PLT. To provide adequate protection to weak-signal operations by the terrestrial services in the VHF/UHF frequency range, radiation from PLT devices or installations should not exceed a maximum of 1.5 dBμV/m in a 1 MHz BW, measured indoor at a distance of 1 m from the PLT installation; see additional values in Table 1. The field-strength is independent of frequency, assuming free-space propagation and no-wall attenuation. The power depends on RF; at a RF of 460 MHz, the maximum allowed PLT peak-power is –103 dBm/MHz. To get a degradation in fade margin of 0.5 dB (not 0.05 dB), the values are 11.5 dBμV/m in a 1 MHz BW, measured indoor at a distance of 1 m from the PLT installation; and at RF of 460 MHz, the PLT allowed peak-power is –93 dBm/MHz.

The worst-case scenario to protect the outdoor terrestrial services from PLT is a cellular base-station or fixed station, 10 m from PLT. For this case the max PLT peak-power is –95 dBm/MHz for degradation in fade margin of 0.05 dB and –85 dBm/MHz for degradation in fade margin of 0.5 dB.

3.2 Calculation method assessing the radiated emissions from PLT

In order to calculate the power and field-strength triggers involved when assessing their vulnerability to interference, radiocommunication systems can be characterized by their noise figure, G_i and L_F parameters. Note that the allowable PLT radiated emission mask depends on the frequency of the wanted frequency, R_F, as propagation varies with frequency.

The following parameters are employed in the calculations:

F: receiver noise figure of the terrestrial mobile station receiver (dB);

B: the reference bandwidth (BW) of the PLT interfering system (MHz);

g_i: the receiver antenna gain of the terrestrial station (handset or B) (numeral);

G_i: the receiver antenna gain of the cellular station (handset or B) (dBi);

L_F: antenna cable feeder loss (dB);

f: reference frequency (MHz);

$P_{handset}$: Power Trigger Level/MHz at cellular handset (dBm);

P_{BS}: Power Trigger Level/MHz at terrestrial base station (BS) (dBm);

P_{RL}: Power Trigger Level/MHz at radiolocation station (RL) (dBm);

$E_{handset}$: Field-strength Trigger Level/MHz at cellular handset (dBμV/m);

E_{BS}: Field-strength Level/MHz at terrestrial base station (dBμV/m).

3.2.1 Trigger levels to protect terrestrial services from PLT radiation

The receiver thermal noise power KTBF[2] at non-loss isotropic antenna for a BW = 1 MHz and a typical noise figure (F) of 5 dB equals:

$$\text{KTBF/1 MHz} = -114 + 5 = -109 \text{ dBm/MHz} \tag{1}$$

$$\text{KTBF} - 20 \text{ dB (1 MHz)} = -109 \text{ dBm} - 20 \text{ dB} = -129 \text{ dBm/MHz} \tag{2}$$

As no antenna gain is applicable to handsets, the protection criterion for cellular handsets is that PLT radiated emissions for a 1 MHz bandwidth reference signal should not exceed:

$$P_{handset} \text{ (1 MHz)} = -129 \text{ dBm/MHz} \tag{3}$$

For cellular network base stations, the parameter of G_i = 15 dBi and L_F = 3 dB are appropriate for determining the protection requirements against PLT radiated emissions. Thus, the power trigger level at the base station antenna input is given by:

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[2] For k: Boltzmann's constant 1.38×10^{-23} J/K, T~300 Kelvin and B = 1 MHz the KTB factor equals –114 dBm.

$$P_{BS}\ (1\ \text{MHz}) = -129\ \text{dBm/MHz} - 15\ \text{dB}\ (G_i) + 3\ \text{dB}\ (L_F) = -141\ \text{dBm/MHz} \qquad (4)$$

By way of comparison, for a radiolocation receiver, the parameter of G_i = 23 dBi and L_F = 3 dB are appropriate for determining the protection requirements against PLT radiated emissions. Thus, the power trigger level at the radiolocation antenna input is given by:

$$P_{RL}\ (1\ \text{MHz}) = -129\ \text{dBm/MHz} - 20\ \text{dB} = -149\ \text{dBm/MHz} \qquad (5)$$

Using the standard equation:

$$P_r = \frac{E^2\ g\lambda^2}{Z_0\,4\pi} = \frac{E^2\ gc^2}{480\pi^2 f^2}$$

the conversion formula between the electrical field strength (dBμV/m) at the antenna input to power (dBm) is:

$$P\ (\text{dBm}) = E(\text{dB}\mu\text{V/m}) - 77.21 - 20\log f\,(\text{MHz}) + G_i - L_F \qquad (6)$$

As the equivalent noise level at the receiver input (i.e. with noise figure, 1 MHz reference and frequency R_F of 460 MHz) is identical, the difference in field strengths is derived from the different gains and losses at the receiving antenna.

For the reference frequency R_F of 460 MHz, the conversion formula (6) gives:

$$-129\ (\text{dBm}) = E(\text{dB}\mu\text{V/m}) - 77.21 - 53.25 \qquad (7)$$

Thus:

$$E_{handset}\ (1\ \text{MHz}) = 1.5\ (\text{dB}\mu\text{V/m}) \qquad (8)$$

$$E_{BS}\ (1\ \text{MHz}) = E_{fixed}(1\ \text{MHz}) = 1.5\ (\text{dB}\mu\text{V/m}) - 12\ \text{dB} = -10.5\ (\text{dB}\mu\text{V/m}) \qquad (9)$$

$$E_{RL}\ (1\ \text{MHz}) = E = 1.5\ (\text{dB}\mu\text{V/m}) - 20\ \text{dB} = -18.5\ (\text{dB}\mu\text{V/m}) \qquad (10)$$

3.2.2 Allowed PLT radiated emission level mask to protect terrestrial services

Assuming free space propagation from PLT radiated emissions, considered as a point source, to terrestrial radio receivers using equation (4) of Recommendation ITU-R P.525 and distance d in metres (not km).

$$L_{bf} = -27.6 + 20\log f + 20\log d\ (\text{dB}) \qquad (11)$$

The maximum allowed PLT peak-power P_{PLT} at f = 460 MHz for the protection of a cellular handset 1 m from a PLT source is therefore:

$$P_{PLT}\ (\text{dBm/MHz}) = P_{handset}\ (\text{dBm/MHz}) + L_{bf} = -129 - 27.6 + 20\log f + 20\log d$$

$$= -129 - 27.6 + 20\log 460 + 20\log 1 = -129 - 27.6 + 53.3 \approx -103\ (\text{dBm/MHz}) \qquad (12)$$

Likewise, the maximum allowed PLT peak-power P_{PLT} at f = 460 MHz for the protection of a IMT/cellular base station 10 m from a PLT source is:

$$P_{PLT}\,(\text{dBm/MHz}) = P_{BS}\,(\text{dBm/MHz}) + L_{bf}$$
$$= -141 - 27.6 + 53.3 + 20\log 10 \approx -95\ (\text{dBm/MHz}) \quad (13)$$

And the maximum allowed PLT peak-power P_{PLT} at f = 460 MHz for the protection of a radiolocation receiver 100 m from a PLT source is:

$$P_{PLT}\,(\text{dBm/MHz}) = P_{RL}\,(\text{dBm/MHz}) + L_{bf}$$
$$= -149 - 27.6 + 53.3 + 20\log 100 \approx -83\ (\text{dBm/MHz}) \quad (14)$$

3.3 Calculation method for assessing the aggregated radiated emission from PLT installations

This subsection deals with the assessment related to the aggregated radiated emission from PLT installations in a situation where multiple PLT modems are simultaneously turned on. Since PLT installations consist of a number of PLT modems that individually emit at a common frequency, the superposition of these multiple emissions has the potential for harmful interference from PLT installations to radiocommunication services. In this connection, the multiple radiated emissions from PLT modems have different phases with a random variation at a specific measuring distance, respectively. This random characteristic leads to the phenomenon that constructive and destructive interferences are stochastically occurring at a victim receiver.

Although multiple PLT modems have the same transmitted powers, the radiated emissions from these PLT modems can be different at the same distance according to the PLT installations' environment. So, the field strength should be considered in evaluating the impact of PLT installations on radiocommunication services. In many countries, the radiated emissions from PLT systems are also allowed in the domain of electric field strength as illustrated in Recommendation ITU-R SM.1879. In order to assess the electric field strength of the aggregated radiated emission from PLT installations, the probabilistic approach presented in Recommendation ITU-T K.62 is applied considering the electric field changes caused by the random phase differences of multiple interfering signals at a victim receiver. Thus, this subsection provides a calculation method for assessing the aggregated radiated emission from PLT installations in the viewpoint of probabilistic approach.

3.3.1 Mathematical model

Consider that there are radiated emissions from PLT installations consisting of multiple PLT modems surrounding a victim receiver as shown in Fig. 9. Here, in Fig. 9, r_i is the distance between the ith PLT source and the measuring point, and d_i is the distance between the ith PLT source and the victim receiver. The amplitude of the aggregated radiated emission from the PLT installation at the victim receiver can be mathematically written in the following:

$$E_o(t) = \sum_{i=1}^{N} E_{oi}\cos(\omega_c t + \theta_i) = E_o\cos(\omega_c t + \alpha) \quad (15)$$

where

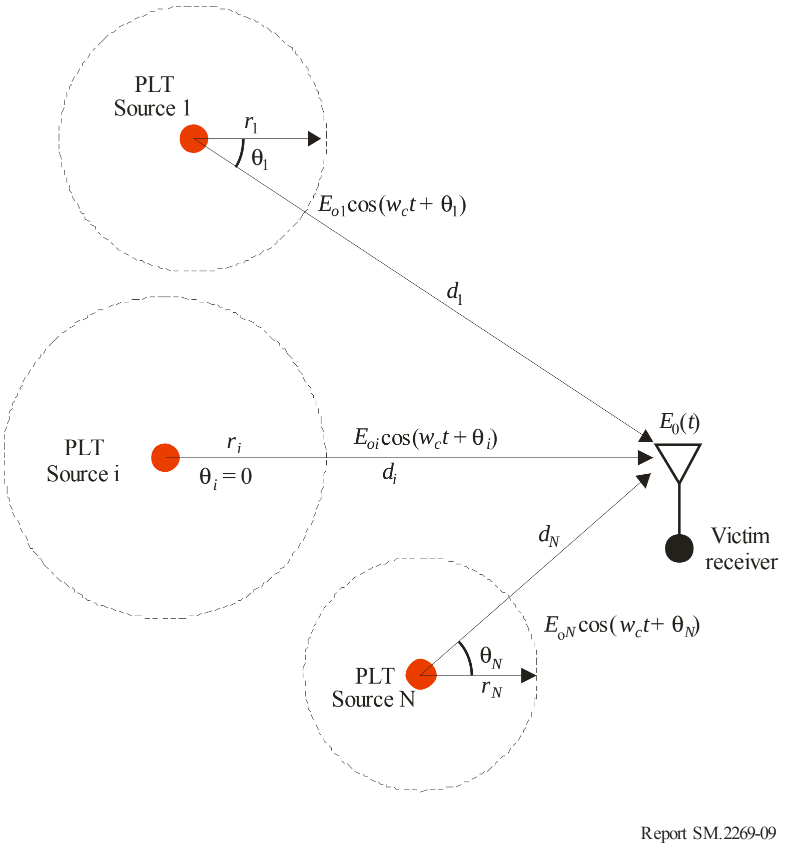
- E_o : amplitude of the aggregated radiated emission at a victim receiver (μV/m)
- N : number of PLT source
- E_{oi} : amplitude of the radiated emission from the ith PLT source at the measuring distance (μV/m)
- ω_c : radian frequency (Hz)
- θ_i : phase difference between the radiated emission from the ith PLT source and some agreed reference at a victim receiver (radian)

α : phase difference between the aggregated radiated emission and some agreed reference at a victim receiver (radian).

The objective of this subsection is to compute the probability of the interference event $\{E_o > E_{PR}\}$ occurring in case the amplitude of the aggregated radiated emission from PLT installations, E_o, is greater than the level required to protect the victim receiver, E_{PR}.

FIGURE 9

Geometry of the aggregated radiated emission from PLT installations at a victim receiver



To compute the probability of interference event, $P_r\{E_o > E_{PR}\}$, θ_i is statistically modelled by the uniform random variable (RV) with the probability density function $1/2\pi$ over $[-\pi, \pi]$ as was done in Recommendation ITU-T K.62. Using the simple far-field propagation, the amplitude of radiated emission from the ith PLT source at the distance d_i, $E_{oi}^{dB}(d_i)$, is computed in terms of logarithm unit (dBμV/m) as:

$$E_{oi}^{dB}(d_i) = E_{oi}^{dB}(r_i) - 20 \cdot \beta \cdot \log_{10}(d_i/r_i) \quad (16)$$

where $E_{oi}^{dB}(r_i)$ is the amplitude of the radiated emission $E_{oi}(r_i)$ at the distance r_i in logarithm unit (dBμV/m) and β is the wave propagation coefficient. In the case of free-space propagation, β is 1. The amplitude of the aggregated radiated emission from PLT installations at the victim receiver, E_o, is obtained by using equation (3) of Recommendation ITU-T K.62 as:

$$E_o = \sqrt{\sum_{i=1}^{N} E_{oi}^2(d_i) + 2\sum_{j>i}^{N}\sum_{i=1}^{N} E_{oi}(d_i)E_{oj}(d_j)\cos(\theta_i - \theta_j)},\ i < j \le N \quad (17)$$

Thus, the probability of the interference event, $P_r\{E_o > E_{PR}\}$, is computed by using equation (17) and the random generation of uniform RV θ_i; i = 1,…, N.

3.3.2 Example

As an example for computing $P_r\{E_o > E_{PR}\}$, we consider the outdoor base station as a victim receiver with the protection level E_{PR}= 0.3 μV/m (= –10.5 dBμV/m) in the presence of PLT installation. The protection level is equal to the value derived in the previous § 3.1.1. The parameters of the PLT installation are described in Table 2.

TABLE 2

Summary of parameters

Parameters	**Value**	**Remarks**
Number of PLT sources (N)	5	Assumed PLT installation environment
Field strength from PLT sources at a measuring distance 10 m $((E_{oi}^{dB}\ (r_i))$	37 dBμV/m*	Five PLT sources having common emission amplitudes
Common frequency	460 MHz	See equation (9)
Wave propagation coefficient (β)	2	Non-line of sight
Distances between PLT sources and the victim receiver (d_i)	100, 150, 200, 250 and 300 m	Assumed PLT installation environment

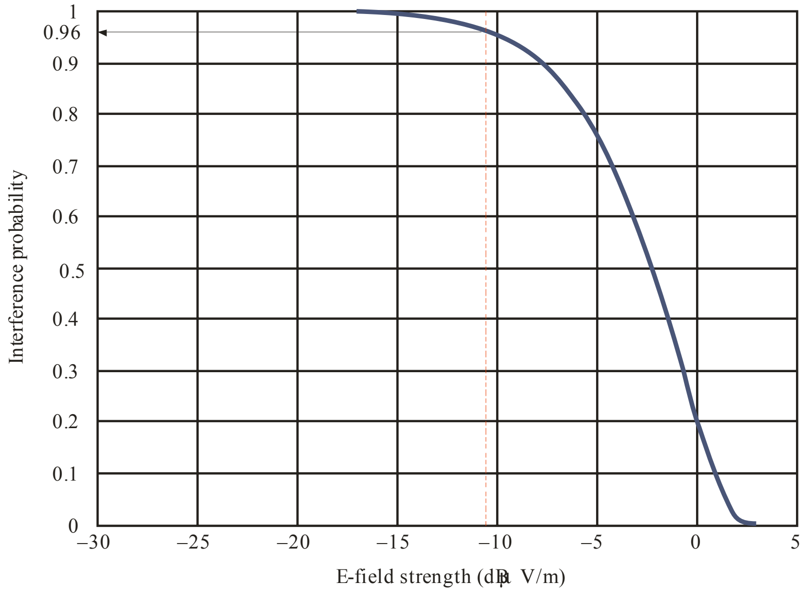
* The value is the class B emission limit of information technology equipment described in the International Special Committee on Radio Interference (CISPR) Publication 22.

As shown in Fig. 10, the interference probability of a base station in the presence of PLT installation, $P_r\{E_o > 0.3\ \mu\text{V/m}\ (= -10.5\ \text{dB}\mu\text{V/m})\}$, is about 0.96. Comparing the interference probability 0.96 at the victim receiver with the 80% confidence level of CISPR, $P_r\{E_o > E_{PR}\}$= 0.2 or $P_r\{E_o < E_{PR}\}$ = 0.8. It is realized that the PLT installation described in Table 2 causes interference to the outdoor base station with the protection level of –10.5 dBμV/m.

The example demonstrates that the presented calculation method can be applied to assess the aggregated radiated emission of PLT installations.

FIGURE 10

Interference probability of a base station in the presence of PLT installations



Report SM2269-10

4 Experimental determination of circulating RF currents on mains wiring, the RF disturbance and equivalent antenna characteristics of an in-house PLT installation

Measured RF disturbance, CM and DM currents caused by PLT systems, and antenna characteristics of in-house power-line network

Chapter 2 of Report ITU-R SM.2158 notes that the antenna like effects of radiating power-line wiring and shielding effects of buildings are complicated and differ from house to house and country to country according to local building constructions and power wiring practices. If modelling methodologies based on theoretical or statistical considerations are developed for the purpose of managing the interference potential of PLT installations then validation of their predictions and scope should be carried out by means of experiments and measurements in real situations. This section provides results of field experiments carried out in Japan.

4.1 Measured RF disturbance from a PLT system[3]

A major concern of radiocommunication services is the field strength of the disturbance, relative to the ambient noise level, outside buildings where PLT systems have been installed. In these experiments, the field strength is measured by using a passive loop antenna located at a distance of 10 m from the outer wall of a house where a PLT system is installed.

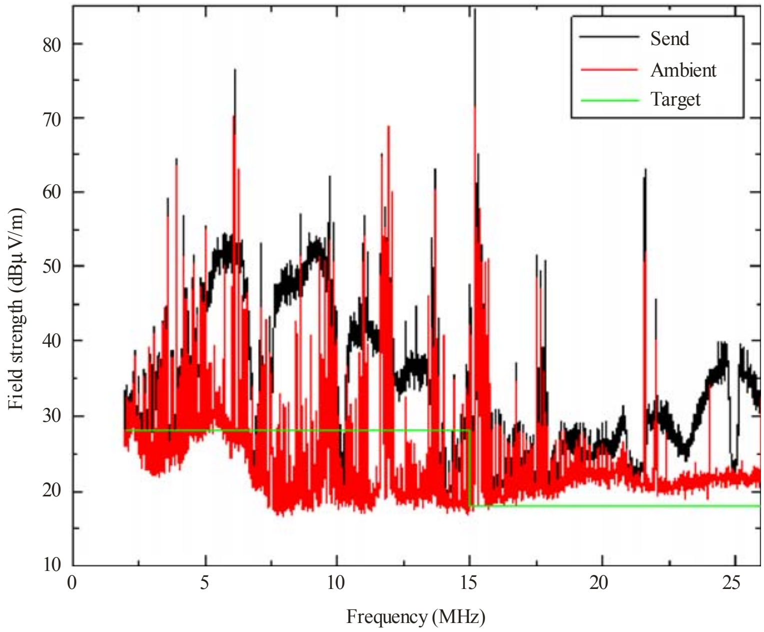
The field strength of PLT disturbance (“Send”) is measured when the PLT system is in use. The field strength of the ambient noise (“Ambient”) is measured when the PLT system is not in use. The results are shown in Fig. 11. The field strength of the disturbance from the PLT system is much larger than the ambient noise level over most of the HF spectrum, and reaches up to 55 dBμV/m (BW = 10 kHz). This is more than 30 dB larger than the ambient noise level. By way of

[3] Kitagawa, M. and Ohishi, M. [September 2008] – Measurements of the Radiated Electric Field and the Common Mode Current from the In-house Broadband Power Line Communications in Residential Environment, Proc. 8th Int. Symposium on Electromagnetic Compatibility (EMC Europe 2008), pp. 433-438, Hamburg, Germany.

comparison, the field strength limits set by the applicable national regulations at the measurement location are 28 dBµV/m (below 15 MHz) and 18 dBµV/m (above 15 MHz). The measured field strengths were larger than the set limits. Moreover, below 15 MHz with the PLT installation operating, the measured field strength is about 10 dB larger than the actual measured ambient noise level.

FIGURE 11

RF disturbance caused by a PLT system



Report SM.2269-11

4.2 Measured RF currents at a power socket outlet[3]

In order to locate the origin of the RF disturbance for this PLT installation, the common mode (CM) and the differential mode (DM)[4] RF currents were measured at the power socket outlet into which the PLT signal is fed. The results are shown in Fig. 11.

In Fig. 12, the CM current (the lower plot) meets the permitted current levels (20 dBµA below 15 MHz and 10 dBµA above 15 MHz) over most of the HF spectrum. The DM current is 60 dBµA below 15 MHz and 50 dBµA above 15 MHz. The DM current is 40 dB larger than the CM current, while it was intended to be only 16 dB larger than the CM current. There is a discrepancy of 24 dB between the measured DM current and the intended DM current, which can explain most part of the 27 dB discrepancy between the measured field strength (55 dBµV/m) and the target level (28 dBµV/m).

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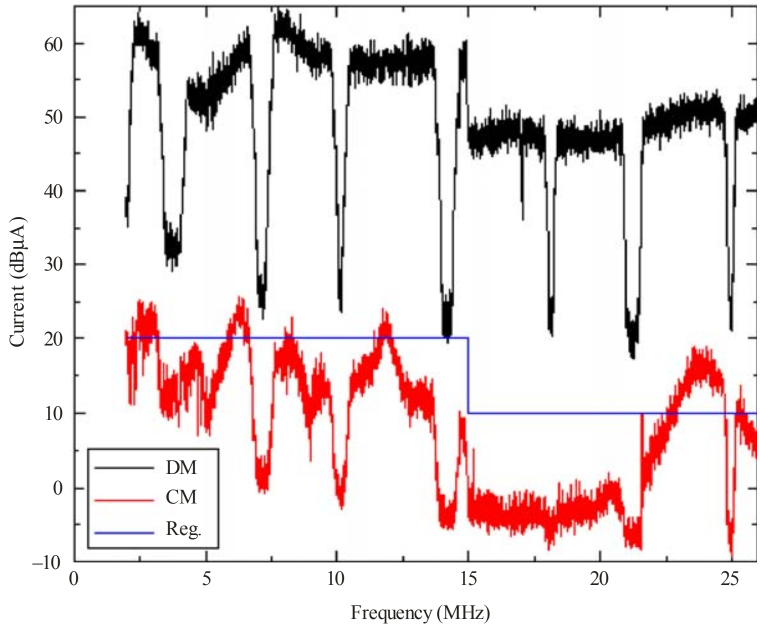
[4] See Chapter 2 of Report ITU-R SM.2158 for an explanation of the mechanism whereby CM and DM RF currents are produced on mains wiring.

FIGURE 12

Differential mode and common-mode currents at the power socket outlet into which the PLT modem is inserted



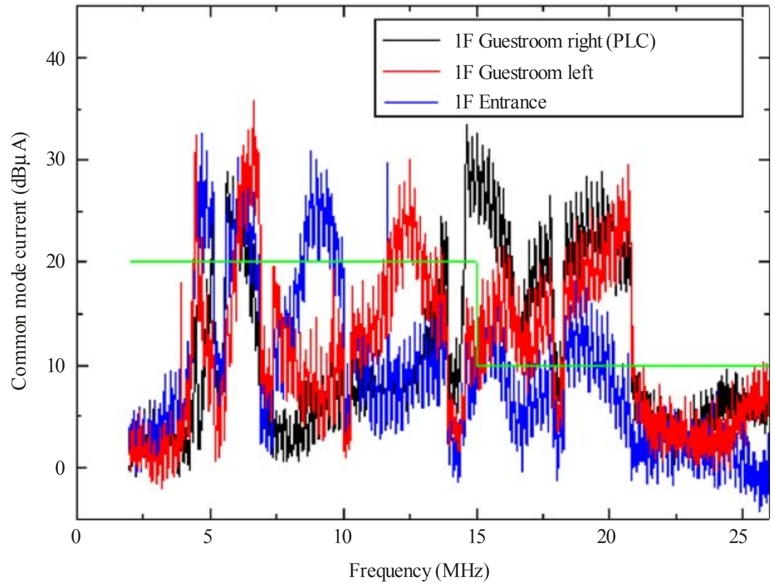
Report SM2269-12

4.3 Measured CM currents along the mains power wiring[3]

The CM currents along the power line can be very different from that measured at the power socket outlet into which the PLT signal is fed. However, it is difficult to measure the CM current along the power-line wiring already installed. By connecting a short (3 m) power-line cable to an unused socket outlet, it is possible to measure the CM current flowing near the unused outlet. The results of CM current measurements at various outlets are shown in Fig. 13. The CM current near unused outlets could be more than 20 dB larger than that measured at the power socket outlet where PLT signal is injected and is seen to exceed the CM current limit by more than 10 dB. A possible explanation for why the CM currents exceed the target limit is that the DM current is much larger than intended.

FIGURE 13

Common-mode currents at a power socket outlet where NO PLT modem is connected (measured by the short extension cable method)



Report SM.2269-13

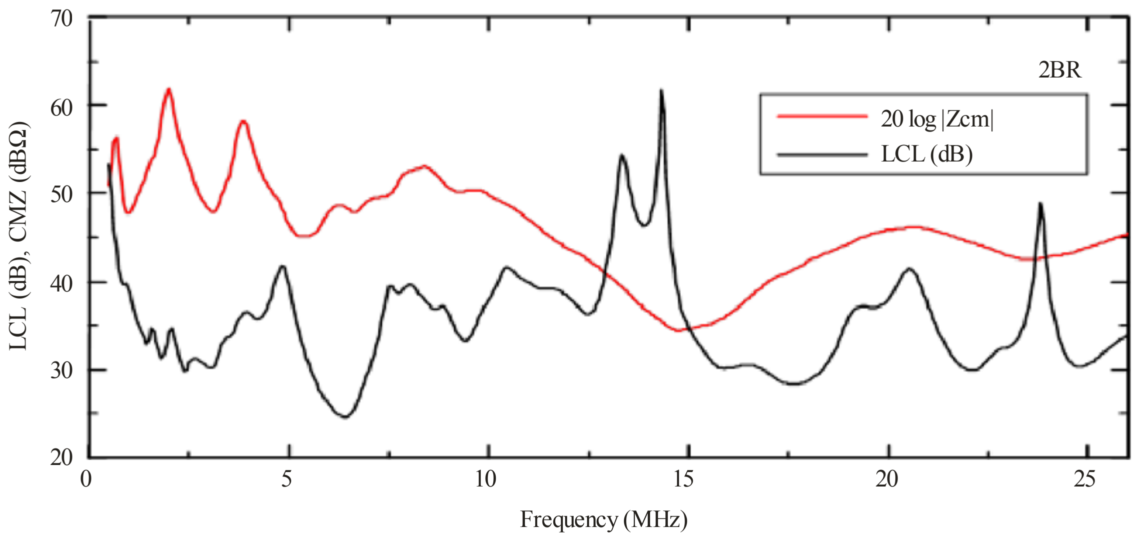
4.4 LCL measured at an outlet

The limit for the CM current level was set by assuming that the Longitudinal Conversion Loss (LCL) is 16 dB or greater. If the LCL of the power line of the house is smaller than 16 dB (i.e. worse performance, through greater conversion of DM current into CM currents), then it may be expected that the CM current will be larger than the intended limit. In order to examine this possibility, the LCL was measured.

The result is shown in Fig. 14. The minimum LCL found is 24 dB, which is larger (i.e. better performance) than 16 dB. There is no negative correlation found between the measured LCL and the measured field strength of the PLT disturbance.

FIGURE 14

LCL and common-mode impedance measured at an outlet



Report SM.2269-14

4.5 Equivalent antenna gain of an in-house PLT installation[5]

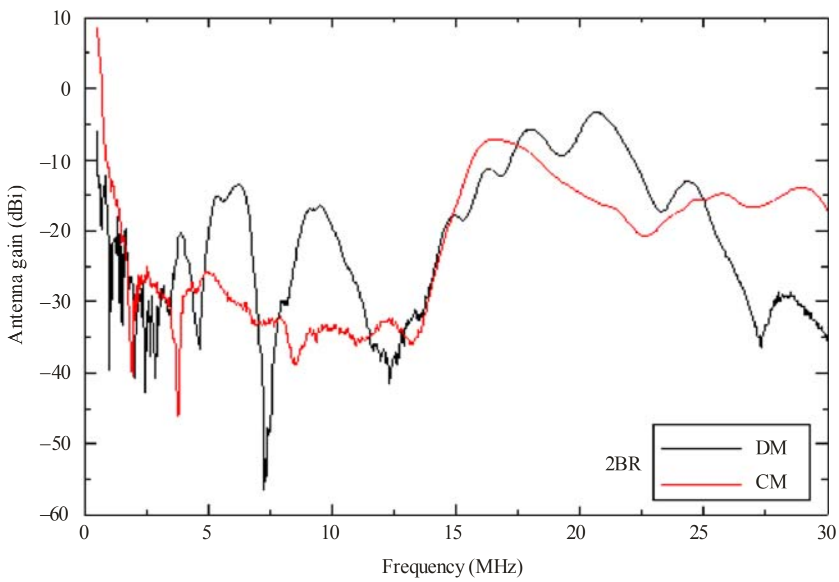
A smaller than expected shielding effect by the building could explain why the measured RF disturbance is larger than the intended limit. Moreover, the RF disturbance from the power line also depends on the geometrical structure of wiring, given the same amount of the CM current along the power line. Such information is not likely to be extracted from the quantities such as the LCL measured at power socket outlets alone.

The most direct and reliable quantity which represents the overall conversion factor from the PLT signal strength (PSD) to the field strength of the RF disturbance is the antenna gain of the whole PLT installation, as seen from the DM currents of the socket outlet where the PLT DM signal is injected, into the receiving antenna outside the building. This figure includes both the antenna effect of the power-line wiring and the shielding effect of the building. The DM and the CM at the injection point (socket outlet) are selectively excited by using an LCL probe circuit; then the transmittance from the selected mode of the outlet to the reference antenna (passive loop) at a distance of 10 m from the outer wall of the house is measured with a network analyser.

The results are shown in Fig. 15. Over most of the lower HF spectrum, the antenna gain of the DM is larger than that of the CM. Moreover, the DM antenna gain and the field strength of the disturbance have a strong positive correlation. This explains the strong RF disturbances at around 6 and 9 MHz, where the equivalent gain of the house wiring is around –15 dBi. Over the higher part of the HF spectrum, the DM and the CM have comparable antenna gains as high as –10 to –5 dBi.

FIGURE 15

Antenna gain of in-house power-line installation, with RF fed into a power socket outlet in either differential mode or common mode



Report SM.2269-15

[5] Kitagawa, M. [October 2007] – In-situ Measurement of the Antenna Factor of in-house Power Lines, IEICE Tech. Rep., Vol. 107, EMCJ2007-54, pp. 7-12 (in Japanese).