

International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Report ITU-R SM.2158-3
(06/2013)

**Impact of power line telecommunication
systems on radiocommunication systems
operating below 80 MHz**

SM Series
Spectrum management



International
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Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.

Electronic Publication
Geneva, 2018

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REPORT ITU-R SM.2158-3*

Impact of power line telecommunication systems on radiocommunication systems operating below 80 MHz,**, ******

(Question ITU-R 221/1)

(2009-2010-2011-2013)

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* Radiocommunication Study Group 1 made editorial amendments to this Report in the year 2018 in accordance with Resolution ITU-R 1.

** The Administration of Japan reserves its position on this Report, pending further contributions on specific issues to be submitted at the next meeting(s) of Working Party 1A.

*** The Administration of Syrian Arab Republic reserves its position on this Report.

**** See also Report ITU-R SM.2157.

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1 Introduction

As part of the studies on the compatibility between radiocommunication systems and high data rate telecommunication systems using electricity power supply or telephone distribution wiring (Question ITU-R 221/1), this Report covers the use of the radio spectrum and associated protection requirements of radiocommunication services in respect to impact of power line telecommunications (PLT). PLT systems make use of radio frequency signals applied on the power lines used for the distribution of mains electricity. Because electrical power lines are not designed for the transmission of high data rate signals, PLT signals on electrical power lines have the potential of causing interference to radiocommunication services.

RR No. 15.12 requires that: “Administrations shall take all practicable and necessary steps to ensure that the operation of electrical apparatus or installations of any kind, including power and telecommunication distribution networks, but excluding equipment used for industrial, scientific and medical applications, does not cause harmful interference to a radiocommunication service and, in particular, to a radionavigation or any other safety service operating in accordance with the provisions of these Regulations¹.”

This Report covers the use of PLT systems at frequencies below 80 MHz. This new family of applications is sometimes referred to as PLC (power line communications), BPL (broadband over power lines) as well as PLT (power line telecommunications). In this Report we shall use the generic term PLT.

1.1 Data communication over electrical power lines

Signalling over the mains network has existed for many years operating at VLF and LF, and many applications of low data rate transmission over the mains are currently in operation, including signaling by power companies in respect of their distribution networks.

Since 1998, new developments in data modem technology have demonstrated the possibility to use higher frequencies and wider bandwidths to communicate along the mains distribution network, using frequencies up to 80 MHz.

There are presently two main families of PLT applications:

- Access PLT whose target market is the last mile (i.e. 1.2 km) between the electricity supply substation and the subscriber and could therefore be an alternative means of access to the telecommunication local loop.
- Indoor PLT whose aim is to distribute signals (coming for example from access PLT or from DSL) to the mains electricity socket outlets inside buildings.

In addition, ITU-R and ITU-T are studying Smart Grid[†].

PLT potentially offers a transmission rate of several Mbit/s via the normal electrical power wiring inside every building. In the case of access PLT, this data rate is shared among a number of simultaneous users. As PLT uses the Internet protocol (IP), the main application of PLT could be also described as Internet from the power socket. The benefit of PLT is that it uses the already existing and widely deployed low voltage electricity network, permitting new services without the

¹ **15.12.1** and **15.13.1** In this matter, administrations should be guided by the latest relevant ITU-R Recommendations.”

[†] Smart Grid is under study by the ITU-T Focus Group on Smart Grid (FG Smart). One task of this Focus Group is to provide a definition of the term “smart grid.” For further details, see <http://www.itu.int/en/ITU-T/focusgroups/smart>.

need for additional wiring. The implementation of PLT systems and their technical characteristics can vary considerably according to application and the country of use.

In some circumstances, there may be significant attenuation of RF signals along low voltage power lines where multiple line-pole transformers fed from a medium voltage distribution network within a locality feed a small number of consumers each at low voltage (as is common with 110 V bi-phase supplies to home and business premises) or where electrical metering equipment uses inductive and capacitive components networks.

However, in 220/240 volt 3-phase distribution network there may be over 100 consumers per phase fed from a high voltage transformer. In the case of underground networks, there may be very little isolation from meters as electronic metering becomes standard. In these circumstances multiple PLT systems could end up sharing the bandwidth and thus may effectively reduce the data throughput rate available over the electrical mains of several streets or throughout a large building with little attenuation between the systems.

Examples of how PLT systems are designed and have been implemented around the world are given in Annex 4 to this Report.

2 Fundamental elements related with radio-frequency radiations from PLT systems

2.1 Introduction

Power lines consist of two or three conducting wires. It is well known that in-house power-line network configuration is complex and different from house to house and from country to country. In a PLT system, signal power is fed at an outlet from PLT equipment (modem) into power lines, where the RF signal current in each wire is designed to be equal in magnitude and opposite in direction. In most cases, however, the currents in two wires have components flowing in the same direction. Those in-phase components behave like antenna currents that become primary sources of RF disturbances caused by PLT systems.

In distribution networks, in-phase RF current components in power-line conductors can be regarded as primary radiation sources, if a distance between the conductors is much less than the wavelength of the PLT signals. When the length of a power-line network is similar to the wavelength of the in-phase RF signal, the power line may act as a good antenna.

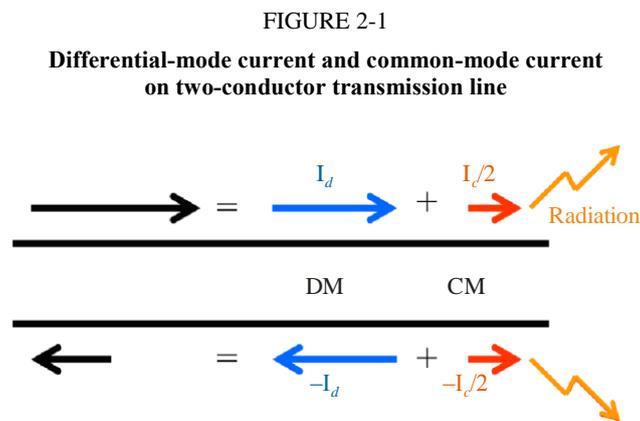
Considering that power-line network configurations are different from house to house, it may be possible to describe and analyse individual power-line wiring using numerical electromagnetic codes such as NEC2 or NEC4[‡], and illustrate the in-phase RF current distributions and disturbances. However it is impractical to derive quantitative results that can be applied to all cases. Therefore, in this chapter, only the fundamental elements and concepts are introduced towards understanding of disturbances caused by PLT systems.

2.2 Differential-mode and common-mode currents

As is described in § 2.1, PLT signal currents in two power-line conductors are designed to be equal in magnitude, and flow in opposite directions to each other. This fundamental current mode is referred to as differential-mode (DM) in the transmission line theory. However, if the signal source, power lines, or loads are not electrically balanced with respect to the ground and nearby objects or

[‡] An example is found in: ZHANG, M. and LAUBER, W. [2008] Evaluation of the Interference Potential of In-Home Power Line Communication Systems. IEEE International Symposium on Power Line Communications and its Applications. p. 263-268.

the power-line wires are geometrically not parallel, the currents in the line conductors have components flowing in the same direction. This in-phase current mode is called as common-mode (CM). Thus, the PLT signal current in each conductor can be expressed as a vector sum of DM and CM components, i.e. I_d and I_c , as shown in Fig. 2-1. These two mode currents propagate independently along the power lines if they are balanced. However they are coupled at unbalanced elements on the power-line network. Since DM PLT currents on two closely-aligned conductors flow in opposite directions, generated electromagnetic waves can be cancelled out, resulting in no significant radiation at positions distant from the power lines. In contrast, generated electromagnetic waves by the CM PLT currents cannot be cancelled out. At the HF range and above, they may radiate electromagnetic waves in a similar way to monopole antennas or folded dipole antennas.



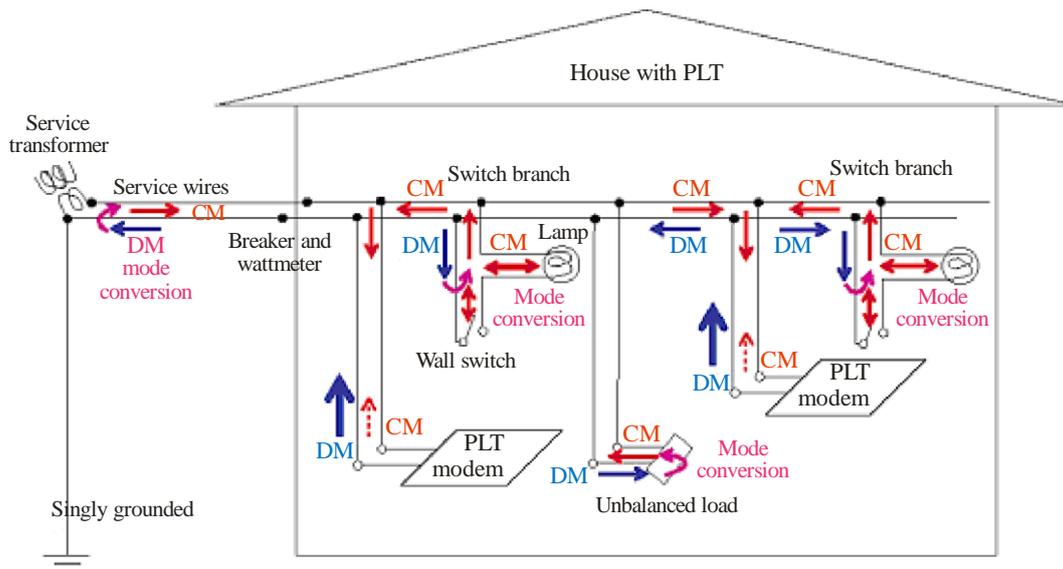
When PLT modems feed DM signal into highly unbalanced power-line network, the DM and CM are strongly coupled. It should be noted that entire CM currents flowing along a power-line network are the source of PLT disturbance. Therefore it is essential to understand distribution of CM currents in the power-line network and how they radiate disturbances to what extent. However power-line wirings are very complicated and different from house to house. Further power-line wirings are often hidden in walls, ceilings, floors or pipes, and it is generally difficult to measure the CM currents along the wirings. It is apparent that more measurements are required for better understanding of radiation characteristics from power lines.

2.3 Generation of common-mode current

DM PLT signal currents may be transformed into CM currents by two major mechanisms: imbalance of a PLT modem itself and imbalance in power lines. The imbalance in a power-line network includes (i) unbalanced load connected to an outlet, (ii) switch branches which consist of ceiling lamp(s) and single-pole wall switches, and (iii), in some countries, singly grounded service wires, as shown in Fig. 2-2. Note that unbalanced elements on a power-line network are usually remote from PLT modems, separated by several metres to a few tens of metres. Therefore the CM currents generated at remote unbalanced elements need be treated by means of the distributed constant circuit or the transmission line theory. In practice, it is hard to identify and quantitatively investigate every unbalanced element in a power-line network. It is also impossible to detect every unbalanced element in a power-line network through measurement at any single point on a network, as shown in the next subsection.

FIGURE 2-2

Differential-mode and common-mode currents on a power-line network



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2.4 Folded-dipole antenna effect of a switch branch

There are many branch circuits connected in parallel with backbone power lines in houses and buildings. At some specific frequencies where the length of a branch approaches half a wavelength (the resonant condition), the branch circuit behaves like a folded dipole antenna, as illustrated in Fig. 2-2. Then, a resonant branch radiates electromagnetic waves strongly. In such a resonant folded-dipole antenna, DM currents entering at the feed point are completely converted into CM currents in folded elements. Since a folded-dipole antenna is balanced at the feed point, this type of mode-conversion (unbalance) cannot be, in principle, detected away from the folded antenna. It should be noted that the folded-dipole antenna is well-known as a wideband antenna, and the folded-dipole effect occurs with lower radiation efficiency even when the resonant condition is not met.

2.5 Shielding effectiveness of exterior walls of a house

Electromagnetic waves radiated from power lines may be shielded to some extent by exterior walls and ceiling of a house and/or a building. Shielding effects vary depending on wall and ceiling materials and building structures, consequently they are different from house to house and difficult to measure quantitatively. The vertical shielding effect through ceilings and roofs may differ considerably from the horizontal shielding effect through walls even for the same building. Generally wooden walls may have lower shielding effect whereas concrete walls may show higher shielding effect.

2.6 Leakage from an in-house power line to service wires outside the house

Service wires outside houses/buildings are unshielded, may extend several tens of metres in length at a height of nearly ten metres above the ground. Thus CM current on the service wires has high potential in causing interferences to the radiocommunication services in the MF and HF bands. Furthermore, in some countries, the service wires are singly grounded at service transformers, are highly unbalanced, and may convert the DM current on the service wires into the CM current quite efficiently. Therefore leakages of both the CM and the DM currents from the power-line network inside the house to the service wires outside the house need be carefully investigated.

3 Radio system characteristics, protection criteria, and impact of PLT systems on radiocommunication systems

3.1 Broadcasting

3.1.1 General characteristics of analogue[§] LF, MF and HF broadcasting

The following physical characteristics and technical parameters are used in planning analogue broadcasting services below 10 MHz.

3.1.1.1 Bandwidth

The bandwidth of a typical modern AM receiver is 4.4 kHz, but a range may be encountered, with several modern receivers having selectable bandwidth.

3.1.1.2 Receiver noise

In addition to atmospheric and man-made noise, the intrinsic noise of the receiver must also be taken into account. This is described here.

The intrinsic receiver noise level E_i^0 , is calculated by:

$$E_i^0(\text{dB}(\mu\text{V/m})) = E_C(\text{dB}(\mu\text{V/m})) + 20 \log M - SNR_{af}$$

where:

E_C : noise limited sensitivity of the receiver

M : modulation depth

SNR_{af} : audio-frequency signal-to-noise ratio.

According to Recommendation ITU-R BS.703, the minimum sensitivity of an AM sound broadcasting sound receiver is:

	LF	MF	HF
E_C dB(μ V/m)	66	60	40

Thus:

	LF	MF	HF
M	0.3	0.3	0.3
SNR_{af} (dB)	32	32	26
E_i^0 dB(μ V/m)	23.5	17.5	3.5

3.1.1.3 Minimum usable field strength

The noise floor used in the calculation of the required minimum field strength is determined by the largest of atmospheric noise, man-made noise and intrinsic receiver noise. The resulting values for noise (whatever the cause), E_n , usually lies between 3.5 and 7 dB(μ V/m) in the frequency bands

[§] Studies of planning parameters suitable for digital HF broadcasting are underway.

under consideration. The RF signal-to-noise ratio, SNR_{RF} , is taken to be 34 dB for the HF and 40 dB for the LF/MF bands. Thus the minimum usable field strength, F_{min} , is calculated as:

	LF	MF	HF
E_n dB(μ V/m)	20	20	3.5-7
SNR_{RF} (dB)	40	40	34
F_{min} dB(μ V/m)	60	60	37.5-41

3.1.1.4 Protection ratios

The co-channel and adjacent protection ratios given below are applicable for protecting AM broadcast transmissions against other AM transmissions and do not apply to protection from other services.

Co-channel protection ratios

Quality grade	LF	MF	HF
3 (fair)	27 dB	27 dB	17 dB
4 (good)	30 dB	30 dB	27 dB

Adjacent channel protection ratios

ΔF_{kHz}	LF	MF	HF
0	0-9 ⁽¹⁾	0-9	0
± 2	+10	+10	+10
± 5	-3	-3	-3
± 10	-35	-35	-35

⁽¹⁾ The range of values corresponds to various degrees of modulation compression and bandwidths (e.g. 4.5 kHz/10 kHz).

3.1.2 General characteristics of DRM digital** LF, MF and HF broadcasting

The following physical characteristics and technical parameters are used in planning digital broadcasting services below 10 MHz. They are the characteristics specifically developed for the Digital Radio Mondiale (DRM) system. In the DRM system, various robustness modes, spectrum occupancy types, modulation schemes, and protection levels are specified in order provide adequate service in a multitude of propagation and interference conditions. The possible combinations of these characteristics give rise to a range of values for S/N , minimum usable field strength, etc. These ranges will be indicated briefly in the following sections.

3.1.2.1 DRM robustness modes

In the DRM specification four robustness modes with different parameters (sub-carrier number and spacing, useful symbol and guard interval length, etc.) for the OFDM (orthogonal frequency division multiplex) transmission scheme are defined for the various propagation conditions in the LF, MF, and HF bands:

** Studies of planning parameters suitable for digital HF broadcasting are underway.

Robustness mode	Typical propagation conditions	Preferred frequency band
A	Ground-wave channels, with minor fading	LF, MF
B	Time- and frequency-selective channels, with longer delay spread	MF, HF
C	As robustness mode B, but with higher Doppler spread	Only HF
D	As robustness mode B, but with severe delay and Doppler spread	Only HF

3.1.2.2 Spectrum occupancy types

For each robustness mode the occupied signal bandwidth can be varied dependent on the frequency band and on the desired application.

Robustness mode	Occupied signal bandwidth (kHz)			
	Spectrum occupancy type			
	0	1	2	3
A	4.208	4.708	8.542	9.542
B	4.266	4.828	8.578	9.703
C	–	–	–	9.477
D	–	–	–	9.536
Nominal bandwidth (kHz)	4.5	5	9	10

3.1.2.3 Modulation and protection levels

For all robustness modes two different modulation schemes (16-QAM or 64-QAM) are defined which can be used in combination with one of two (16-QAM) or four (64-QAM) protection levels, respectively.

Modulation	Protection level	Average code rate
16-QAM	0	0.5
16-QAM	1	0.62
64-QAM	0	0.5
64-QAM	1	0.6
64-QAM	2	0.71
64-QAM	3	0.78

3.1.2.4 Receiver noise

In addition to atmospheric and man-made noise, the intrinsic noise of the receiver must also be taken into account and is described in § 3.1.1.2.

3.1.2.5 Minimum usable field strength

To achieve a sufficiently high quality of service for a DRM digital audio service, a bit-error ratio (BER) of about 10^{-4} is needed. The SNR required at the receiver input to achieve this BER is

dependent, apart from the system parameters, also on the wave propagation conditions in the different frequency bands.

A range of relevant values for minimum usable field strength are given in the table below. The given ranges cover for the possible modulation schemes and protection levels. Only a few combinations of possibilities are indicated, sufficient to give an idea of the wide range of values that can arise.

Robustness mode	LF	MF	HF
Robustness mode A (Ground wave propagation)	39.1-49.7	33.1-43.7	
Robustness mode A (Ground-wave plus sky-wave propagation)		33.9-47.4	
Robustness mode B (Sky-wave propagation)	–		19.1-30.4

Planning parameter values for DRM system below 30 MHz

Band	LF		MF		HF	
	4.5 kHz	9 kHz	4.5 or 5 kHz	9 or 10 kHz	5 kHz	10 kHz
Bandwidth (kHz)	4.5 kHz	9 kHz	4.5 or 5 kHz	9 or 10 kHz	5 kHz	10 kHz
Required S/N (dB) ⁽¹⁾	8.8-22.9	8.6-22.0	8.8-31.2	8.6-30.9	9.5-31.2	9.3-35.5
Receiver intrinsic noise (dB(μ V/m))	27.5	30.5	21.5	24.5	1.5	4.5
Minimum usable field strength (dB(μ V/m)) ⁽¹⁾	39.3-49.7	39.1-49.2	33.3-47.4	33.1-46.5	19.2-30.4	19.1-29.9

⁽¹⁾ The values depend on the modulation scheme (16-QAM or 64-QAM), the coding rate (0.5-0.78), and the propagation channel models (ground-wave and/or sky-wave).

3.1.2.6 Required signal-to-noise ratios for DRM reception

The following signal-to-noise ratios (SNR) are required to achieve a BER of about 10^{-4} are given below for typical propagation conditions on the relevant frequency bands.

	LF	MF	HF
Ground wave propagation (9, 10 kHz BW)	8.6-21.4	8.6-21.4	
Robustness mode A, B (4.5, 5 kHz BW) (Ground-wave propagation)	8.8-19.5	8.8-19.5	
Robustness mode B (Ground-wave plus sky-wave propagation)	–	9.4-22.8	14.6-30.9
Robustness mode C (Ground-wave plus sky-wave propagation)	–	–	14.6-33.3
Robustness mode D (Sky-wave propagation)	–	–	16.0-35.0

3.1.2.6.1 Protection ratios

The combination of spectrum occupancy types and robustness modes lead to several transmitter RF spectra, which cause different interference and therefore require different RF protection ratios (PR).

The differences in protection ratios for the different DRM robustness modes are quite small. Therefore, the RF protection ratios presented in the following tables are restricted to the robustness mode B.

3.1.2.6.2 Co-channel protection ratios

Wanted signal	Unwanted signal	Co-channel PR range
AM	DRM	23.0-23.6
DRM	AM	4.8-7.8
DRM	DRM	12.8-16.4

3.1.2.6.3 Adjacent channel protection ratios

Values of adjacent channel protection ratio range over -20 kHz to $+20$ kHz frequency separation, but are not reproduced here.

3.1.3 LF, MF, HF and VHF radio broadcasting frequency ranges

The following frequency bands below 80 MHz are allocated to for broadcasting in RR Article 5:

Band	Frequencies
LF	148.5-283.5 kHz (Region 1)
MF	526.5-1 605.5 kHz (Regions 1, 3)
	525-1 705 kHz (Region 2)
HF	3 950-4 000 kHz (Regions 1, 3)
	5 900-6 200 kHz
	7 100-7 350 kHz WRC-03: 7 200-7 350 (03-2007) and $-7 400$ (03-2009)
	9 400-9 900 kHz
	11 600-12 100 kHz
	13 570-13 870 kHz
	15 100-15 800 kHz
	17 480-17 900 kHz
	18 900-19 020 kHz
	21 450-21 850 kHz
	25 670-26 100 kHz
VHF	47-68 MHz (Region 1)
	54-72 MHz (Region 2)
	47-50 MHz, 54-68 MHz (Region 3)
	76-108 MHz (Region 2)
Tropical bands (used for national broadcasting by tropical countries):	
	2 300-2 498 kHz (Region 1, Tropical)
	2 300-2 495 kHz (Regions 2+3)
	3 200-3 400 kHz (All Regions)

Band	Frequencies
	4 750-4 995 kHz
	5 005-5 060 kHz

3.1.4 Protection criteria and acceptable interference

The Radio Regulations, various ITU-R Recommendations, and Reports provide specifications and useful information that can be used in order to derive the protection requirements for reliable broadcasting reception. This section summarizes the relevant information and attempts to derive the protection requirements for HF analogue sound broadcasting. Because most of the PLT modems employ OFDM and spread spectrum (SS) for their modulation method, interference from PLT is treated as random noise in the analysis below.

3.1.4.1 Recommendations ITU-R BS.1786 and ITU-R BT.1786 – Criterion to assess the impact of interference to the terrestrial broadcasting service

Description	Acceptable criterion for the total interference to the broadcasting service resulting from devices and systems without a frequency allocation in the Radio Regulations
Derived value	At no time should exceed one percent of the total receiving system noise power

3.1.4.2 Recommendation ITU-R BS.560-4 – Radio-frequency protection ratios in LF, MF, and HF broadcasting

Description	Minimum usable field strength: 34 dB plus the greater of 3.5 dB($\mu\text{V}/\text{m}$) (receiver intrinsic noise) and atmospheric noise
Derived value	C/N : 34 dB Minimum usable field strength ≥ 37.5 dB($\mu\text{V}/\text{m}$)

3.1.4.3 Recommendation ITU-R BS.703 – Characteristics of AM sound broadcasting reference receivers for planning purposes

Description	Noise-limited sensitivity: 40 dB $\mu\text{V}/\text{m}$, based on an AF signal-to-unwanted noise (r.m.s.) ratio of 26 dB, related to a modulation of 30%
Derived value	C/N : 26 dB – 20 log(0.3) dB = 26 + 10.5 = 36.5 dB Field strength: 40 dB($\mu\text{V}/\text{m}$)

3.1.4.4 Report ITU-R BS.1058 – Minimum AF and RF signal-to-noise ratio required for broadcasting in band 7 (HF)

Description	AF signal-to-noise ratio for planning purpose: 24 dB
	AF signal-to-noise ratio corresponding to grade 4 on the ITU-R scale (perceptible but not annoying): 31 dB
	AF signal-to-noise ratio corresponding grade 3 on the ITU-R scale (slightly annoying): 20-21 dB
Derived value	C/N : 24 dB – 20 log(0.3) dB = 24 + 10.5 = 34.5 dB

3.1.4.5 Annex 2 to Recommendation ITU-R BS.1615 – “Planning parameters” for digital sound broadcasting at frequencies below 30 MHz – RF protection ratios for DSB (DRM system) at frequencies below 30 MHz

Description	Relative RF protection ratio for AM interfered with by Digital: 6 to 6.6 dB for AF protection ratio of 0 dB as an reference value
Derived value	C/N : 6 dB + 17 dB = 23 dB, for AF protection ratio of 17 dB ⁽¹⁾

⁽¹⁾ The value of 17 dB is used as an example to derive the C/N in absolute values.

3.1.4.6 Derivation of acceptable range of field strength incident from the wired telecommunication systems

Summary of the derived value	Minimum usable field strength of HF broadcasting: 37.5 to 40 dB(μ V/m) C/N : 30 to 36.5 dB
Derived field strength	Range of field strength incident from the wired systems: 1 to 10 dB(μ V/m)

3.1.4.7 Receiver noise level and acceptable interference level

For estimation of receiver sensitivity deterioration due to co-channel interference, or for estimation of an acceptable co-channel interference level, it is important to know the receiver noise level rather than the receiver sensitivity, since receiver sensitivity deteriorates due to increase of receiver noise by co-channel interference power. For example, if the co-channel interference receiving power is the same level as the original receiver noise, resultant noise power increases by a factor of 2 (3 dB) (neglecting the difference of noise waveforms), and the sensitivity deterioration is 3 dB.

Receiver external noise level and interference level are usually expressed in terms of field strength. Accordingly, it is convenient to express the receiver internal noise by equivalent field strength for ease of comparison (in place of actual noise existing in the receiver, an equivalent noise is assumed received through the antenna with noise-less receiver.)

Receiver noise level can be calculated as shown in § 3.1.1.2. Although this receiver noise is estimated using analogue receiver sensitivity, these results also apply to digital receivers when bandwidth differences are taken into account.

The above receiver noise estimation is made on condition that external noise is absent. However, receiver noise usually includes external noise that is received through receiving antenna besides receiver internal (intrinsic) noise, which is generated in the receiver. The external noise for receivers operating at below 30 MHz includes atmospheric, man-made, and cosmic noise.

Recommendation ITU-R P.372-9 expresses each of average strength of atmospheric noise, man-made noise, and cosmic noise comparing with the thermal noise level kT_0b when they are received through a lossless short vertical monopole with perfectly grounded plane. Therefore, it is convenient to convert the receiver internal noise level into equivalent field strength (E_{ri}), as mentioned above, based upon the identical antenna.

Equivalent field strength of the receiver (overall) noise (E_{rt}) is expressed by the field strength corresponding to the power sum of the above E_{rt} and average field strength of the external noise (E_{re}). That is:

$$E_{rt}^2 = E_{ri}^2 + E_{re}^2 \quad (3-1)$$

When co-channel interference field strength, E_u , superposes to E_{rt} , the equivalent field strength of the receiver noise power increases up to E_{rtu} which corresponds to the power sum of E_{rt} and E_u . That is:

$$E_{rtu}^2 = E_{rt}^2 + E_u^2 \quad (3-2)$$

For example:

- When E_u is equal to E_{rt} , overall receiver noise increases by 3 dB, that is, receiver sensitivity deteriorates by 3 dB.
- When E_u is 6 dB lower than E_{rt} , receiver sensitivity deteriorates by 1 dB.
- When E_u is 10 dB lower than E_{rt} , receiver sensitivity deteriorates by 0.5 dB.
- When E_u is 20 dB lower than E_{rt} , receiver sensitivity deteriorates by 0.05 dB.

That is, in order to limit receiver sensitivity deterioration due to co-channel interference (E_u) to within 0.05 dB, E_u should be 20 dB lower than equivalent field strength of the receiver (overall) noise (E_{rt}).

3.1.4.8 Equivalent field strength of receiver noise

Receiver internal noise in § 3.1.1.2 is calculated using the receiver sensitivity with a built-in antenna. However, the sensitivity figures in § 3.1.1.2 are significantly improved by using an external antenna, such as a short wire extended in the room. Taking this improvement and low loss performance in the antenna matching of VHF receivers into account, external noise, whose minimum value is determined by the man-made noise, is considered the major component of receiver noise in receivers operating below 80 MHz.

With the above antenna condition defined in Recommendation ITU-R P.372, a lossless short vertical monopole antenna with perfect ground plane, the received power (P_r) from a field strength E is expressed by:

$$P_r = E^2 \lambda^2 / (640\pi^2) \quad (3-3)$$

where:

- P_r : maximum available received power (W)
- E : field strength (V/m)
- λ : wavelength (m) = $3 \times 10^2 / f$
- f : frequency (MHz).

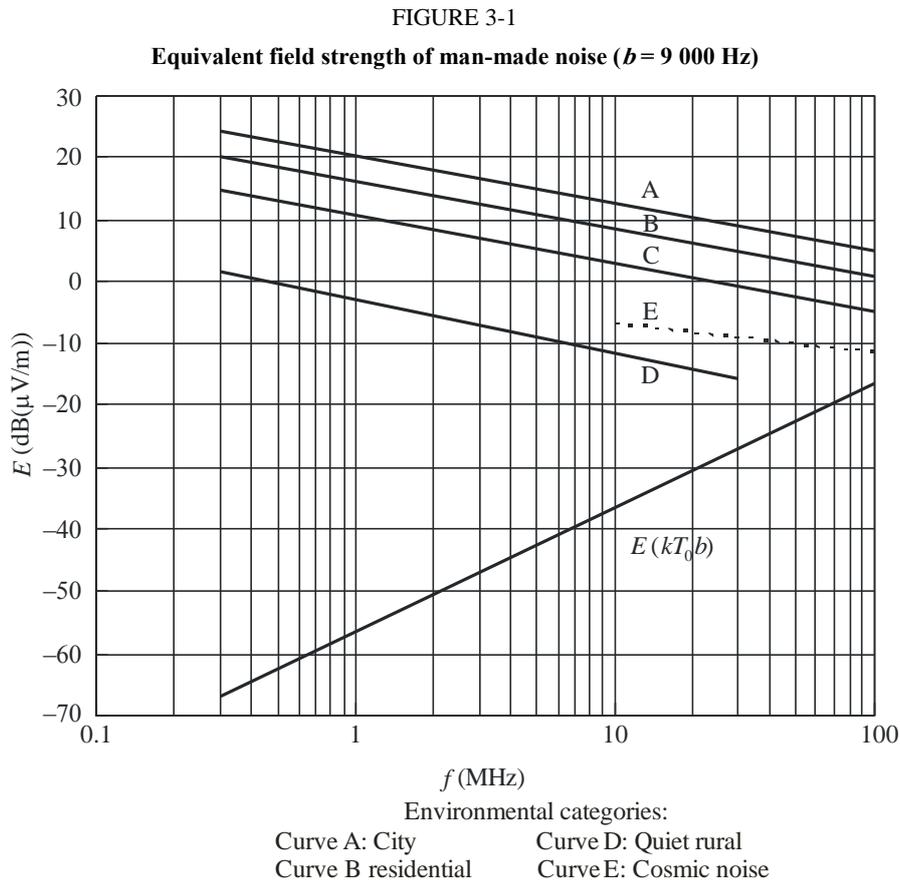
Substituting kT_0b (–164.5 dBW) into the above P_r , equivalent field strength of the thermal noise; $E(kT_0b)$ for ($b = 9\,000$ Hz) is given by:

$$E(kT_0b) = 20 \log f - 56 \quad \text{dB}(\mu\text{V/m}) \quad (3-4)$$

where:

- $E(kT_0b)$: equivalent field strength of the thermal noise kT_0b dB(μ V/m)
- k : Boltzmann's constant = 1.38×10^{-23} J/K
- T_0 : reference temperature = 288 K
- b : receiver effective noise bandwidth (Hz)
- $kT_0b = -164.5$ dBW (for $b = 9\,000$ Hz (the bandwidth b is to be adjusted in accordance with the necessary bandwidth of the transmitter system)).

The value of $E(kT_0b)$ is shown in Fig. 3-1. Recommendation ITU-R P.372 expresses the average strength of each kind of external noise by comparing it with the thermal noise level (F_{am} dB relative to kT_0). That is, each field strength is obtained as F_{am} (dB) above $E(kT_0b)$ dB(μ V/m).



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3.1.4.9 External noise

Recommendation ITU-R P.372 expresses each of average strength of atmospheric noise, man-made noise, and cosmic noise comparing with the thermal noise level (F_{am} dB relative to kT_0) when they are received through a lossless short vertical monopole with a perfectly grounded plane.

3.1.4.9.1 Man-made noise

Figure 3-1 shows a summary of man-made noise in various environments. Equivalent field strengths are shown for $b = 9\ 000$ Hz.

3.1.4.9.2 Comparison between man-made noise and atmospheric noise

The minimum level of external noise is determined by the man-made noise as this is the dominant factor when the atmospheric noise fades.

3.1.4.10 Permissible interference field strength

From the above, it is concluded that:

- When an external antenna is used, external noise is the major receiver noise.
- With a built-in-antenna, external noise is the major factor in business and residential areas. Even in rural areas the external noise is significant;

- Since the minimum value of external noise is determined by the man-made noise, the permissible interference field strength is also determined by man-made noise;
- It is assumed in this analysis that the Fig. 3-1 for man-made noise in quiet rural areas be used as a reference.

3.1.4.11 Protection criteria for the broadcast service

- In order to protect the broadcasting service from radiated noise arising from PLT systems operating over the electrical infrastructure wiring and from electrical equipment connected to a power socket, protection levels between the values shown as line F in Fig. 3-2 (r.m.s. value) and those shown as line G in Fig. 3-2 (peak value) should not be higher the value at any place where a receiver might be located. The values in Fig. 3-2 recognize the noise floor limitation of the broadcast receiver above 30 MHz.
- The protection levels necessary to protect a broadcasting receiver using an a.c power supply from interference through a receiver power cable is the equivalent value given in Fig. 3-1, including the case when an external long wire antenna is used or when a power line is used as an antenna by grounding the external antenna terminal.

Median values of man-made noise power for a number of environments are shown in Fig. 3-1. The figure also includes a curve for galactic noise.

In all cases results are consistent with a linear variation of the median value, F_{am} , with frequency f of the form:

$$F_{am} = c - d \log f \quad \text{dB} \quad (3-5)$$

With f expressed in MHz, c and d take the values given in Table 3-1. Note that equation (3-5) is valid in the range 0.3 to 250 MHz for all the environmental categories except those of curves D and E as indicated in Fig. 3-1.

Since the above are received values with lossless short vertical monopole above a perfect ground plane, the vertical component of the r.m.s. field strength is obtained as F_{am} (dB) above $E(kT_0b)$ (dB) given by equation (3-4).

For $b = 9\,000$ Hz:

$$E_n = F_{am} + 20 \log f - 56 \quad \text{dB}(\mu\text{V/m}) \quad (3-6)$$

where:

- E_n : field strength in bandwidth b , and
- f : centre frequency (MHz)
- b : receiver effective noise bandwidth (Hz).

Median values of man-made noise field strength for a number of environments obtained from equation (3-6) are shown in Fig. 3-1.

By substituting F_{am} expressed by equation (3-5) into equation (3-6),

$$E_n = c - d \log f + 20 \log f_{\text{MHz}} - 56 \quad \text{dB}(\mu\text{V/m}) \quad (3-7)$$

$$= c' + d' \log f \quad \text{dB}(\mu\text{V/m}) \quad (3-8)$$

where:

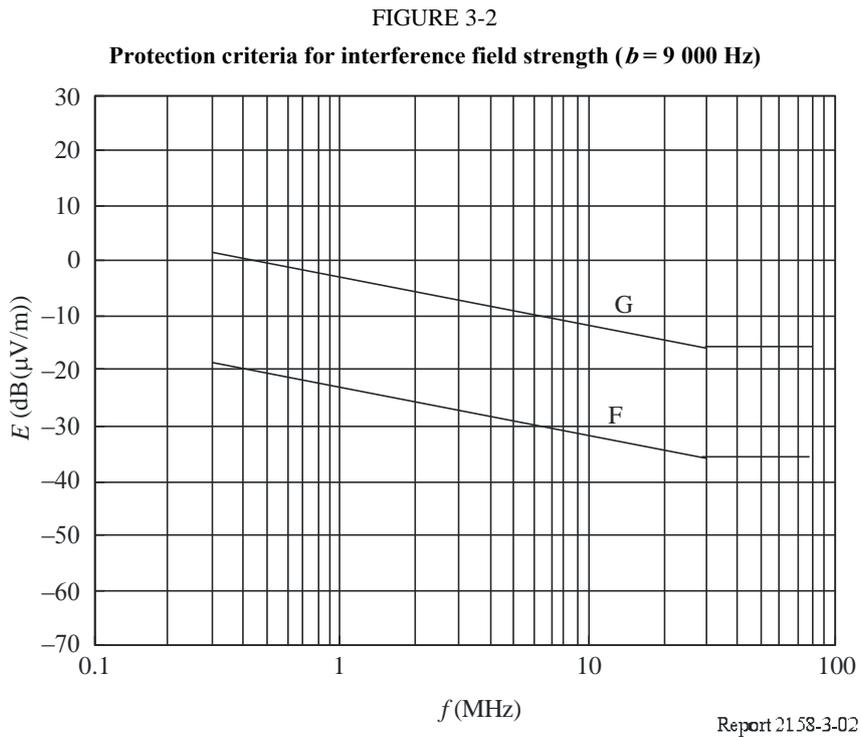
$$c' = c - 56$$

$$d' = 20 - d$$

c' and d' take the values given in Table 3-1.

TABLE 3-1
Values of the constants c' and d'

Environmental category	c'	d'
Business (curve A)	20.8	-7.7
Residential (curve B)	16.5	-7.7
Rural (curve C)	11.2	-7.7
Quiet rural (curve D)	-2.4	-8.6
Galactic noise (curve E)	-4	-3.0



Curves F: Protection criteria for an r.m.s value of interference field strength (20 dB below curve D in Fig. 3-1 at or below 30 MHz)

G: Protection criteria for a peak value of interference field strength (same as curve D in Fig. 3-1 at or below 30 MHz)

c' and d' for curves F and G take the values given in Table 3-2.

TABLE 3-2
Values of the constants c' and d' at below 30 MHz

Environmental category	c'	d'
Curve F	-22.4	-8.6
Curve G	-2.4	-8.6

3.2 Amateur and amateur satellite

3.2.1 General characteristics

The RR defines the amateur radio service as:

«**1.56** *amateur service*: A radiocommunication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.

1.57 *amateur-satellite service*: A radiocommunication service using space stations on earth *satellites* for the same purposes as those of the *amateur service*.»

The maximum permitted transmitter power is dependent on national regulations, varying from around 100 W to 1.5 kW output power. The amateur services are the only potential user of relatively high transmitter power in residential areas. However many users choose to operate using low transmit powers on the order of a few watts. A wide variety of antennas and equipment, depending on location and financial means is used. Consequently, there is no standard amateur radio station.

Users of the amateur services do not generally have the opportunity to position antennas far away from electric wiring. They must install their antennas within the boundaries of their homes, which generally means in close proximity to mains and telephone wiring. Other sources of localized interference can be minimized by the amateur choosing not to use equipment such as luminaries, switch-mode power supplies, and other equipment generating interference when operating. That choice is not available in the case of many cable-borne cable transmission systems, where the emissions are present all the time.

Amateur service stations communicate over long distances on the HF bands, making optimum use of propagation windows. Amateurs frequently operate at or near to the minimum signal-to-noise ratio for effective communication. Limits of communication are generally determined by the received signal strength in relation to the background noise. Amateurs manage to communicate effectively with a signal-to-noise ratio of some 6 dB for voice communications in a nominal 2.4 kHz bandwidth and as low as minus 6 dB (related to the same bandwidth) for Morse code or spectrum-efficient data modes.

Many users of the amateur services provide disaster relief communications. In many countries, amateur radio is seen as a valuable back-up service in case of breakdown or overload of normal communications systems. Governments rely on this capability at times of emergency. Amateur service HF and VHF allocations are used for this purpose.

3.2.1.1 Operational characteristics

Amateur stations and amateur-satellite earth stations generally do not have assigned frequencies but dynamically select frequencies within an allocated band using listen-before-talk (LBT) techniques. Terrestrial repeaters, digital relay stations and amateur satellites use frequencies selected on the basis of voluntary coordination within the amateur services. Some amateur frequency allocations are exclusive to the amateur and amateur-satellite services. Many of the allocations are shared with other radio services and amateur operators are aware of the sharing limitations.

Operating protocols vary according to communications requirements and propagation. MF and HF bands are used for near-vertical-incidence-sky wave (NVIS) to global paths. VHF, UHF and SHF bands are used for short-range communications. Amateur satellites afford an opportunity to use frequencies above HF for long-distance communications.

3.2.2 Amateur frequency allocations

Details of frequency bands allocated to the amateur services in the range 1.8 to 80 MHz vary from Region to Region. Table 3-3 gives an indication of the frequency distribution of the allocations.

3.2.3 The protection requirements of the HF amateur radio service

Stations in the amateur services often work at very low signal to noise ratios (SNR). The available SNR is usually limited by environmental factors, such as antenna efficiency, but because the majority of amateur stations are in residential areas, the usual limitation is external man made noise.

TABLE 3-3

Frequency bands allocated to the amateur service in the range 3 to 80 MHz

Approximate frequency (MHz)
1.8
3.5
7
10.1
14
18.1
21
24.9
28
50
70

3.2.3.1 Fade margin and the 0.5 dB protection criterion of HF amateur radio

In professional broadcasting, ample fade margins are taken into account to guarantee a high degree of availability of the signal. This, coupled to the lower sensitivity of broadcast receivers, leads to the high power levels used in HF broadcasting. In the amateur radio service, the permitted transmitter powers are relatively low and in long-distance communications the remaining fade margin above the minimum required field strength of a long-distance signal is around 0 to 1 dB. Given the form of the signal strength versus time curve of a narrow-band HF signal with fading, this means that in some long-distance communication links, parts of the transmissions will be missed due to fading, necessitating repeat transmissions. Increasing the ambient noise floor by only a few dB would have a tremendous impact on the long distance communication capability of an amateur station.

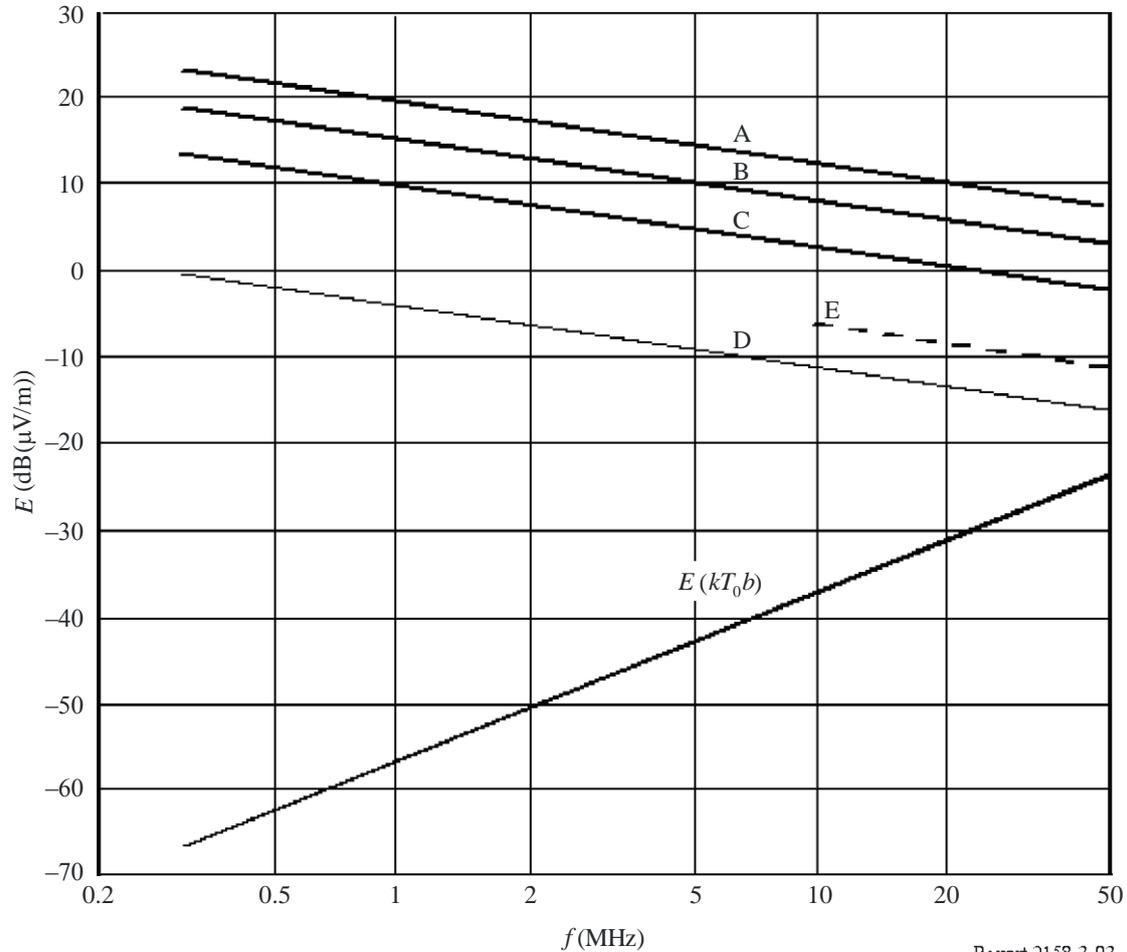
For this reason, the maximum allowable increase in the total noise floor due to PLT emissions should be 0.5 dB. For the increase not to exceed 0.5 dB, the average noise field strength radiated by the power network at 10 m distance must be 9.14 dB below the pre-existing noise level.

3.2.3.2 The noise floor in amateur radio bands

In common with other HF services, the ability to achieve satisfactory amateur communications depends on the ratio between the wanted signal and the noise. The noise consists of four components, (internally generated) receiver noise, atmospheric, man-made and cosmic. Figure 3-3

were derived from Recommendation ITU-R P.372 using a graph that represents the 99.5% of time value exceeded situation, measurement bandwidth is 6 kHz, and f is frequency (MHz).

FIGURE 3-3
Equivalent field strength of man-made noise ($b = 6$ kHz)



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Curve designations:

- | | |
|----------------------|----------------------|
| Curve A: Business | Curve D: Quiet rural |
| Curve B: Residential | Curve E: Cosmic |
| Curve C: Rural | |

3.2.3.3 Acceptable noise floor levels

From the criteria in § 3.2.3.1, the acceptable increase in noise floor generated by PLT is 0.5 dB greater than the figures derived from the graph in Fig. 3-3. It should be noted that the requirement is independent of the bandwidth of the received signal: to correlate with the usual measurement bandwidth of 9 kHz, the figures can be increased by 1.8 dB. Table 3-4 lists the field strength acceptable at 10 m from a PLT installation to meet. Figures for 70 MHz are obtained by extrapolation from Fig. 3-3.

TABLE 3-4

**Total protection requirements based on the 0.5 dB criterion –
maximum field strength at 10m from a PLT installation**

Frequency band (MHz)	dB(μ V/m) in 6 kHz			
	Business	Residential	Rural	Quiet rural
1.8	18.5	13.5	8.5	-7.5
3.5	16.5	12.5	5.5	-8.5
7	14.5	9.5	4.5	-9.5
10	12.5	8.5	3.5	-5.5
14	11.5	7.5	2.5	-6.5
18	11	7	2	-7
21	10	6	0.5	-8.5
24	9.5	5.5	0	-9
28	9	5	-0.5	-9.5
50	8.5	4.5	-1.5	-10
70	8	4	-2	-10.5

3.3 Aeronautical mobile and radionavigation

For compatibility assessments it is essential to have available at least the following characteristics of the victim radio services:

- the type of service;
- used frequency range;
- the minimum wanted field strength;
- the horizontal and vertical extension of the designated operational coverage (DOC).

For aeronautical radio services, which could potentially suffer interference due to cable TV leak radiation in the frequency range above 30 MHz, this information can be found in Table 3-5.

Many of military HF radios are located on airborne platforms. Therefore, they may suffer interference due to the low propagation loss of interfering signals and the large radio horizon distance (RHD) of airborne radios.

HF radio is used in the aerospace environment as the primary beyond-line-of-sight (BLoS) communication means to aircraft, land and maritime mobile platforms. Information is exchanged via HF radio in voice, message, and data link formats.

HF communications are used between air command and control ground elements and aircraft for exchanging mission control and surveillance/sensor data at extended ranges and when other communications are not available due to equipment failure or interference. HF is also used for air traffic control (ATC) purposes when beyond the range of VHF facilities.

TABLE 3-5

Aeronautical and radionavigation system characteristics

Frequency band	Application abbreviation	Type of service, short description	Designated operational coverage (DOC)	Interference threat	Receiving bandwidth (kHz)	Minimum wanted field strength (dB(μ V/m))
90-110 kHz	LORAN C			DSL		
255-526.5 kHz	NDB	Non-directional beacons		DSL		
2.8-22 MHz	HF Communications	HF Communications		PLT, DSL, CATV		
3 023 kHz	Distress/emergency			PLT, DSL		
5 680 kHz	Distress/emergency			PLT, DSL, CATV		
74.8-75.2 MHz	ILS/MKR	Aeronautical radionavigation service (ARNS) marker beacon belonging to the ILS system, provides a signal to the pilot or flight management system (FMS), when the plane is passing certain fixed points during final approach and landing.	Horizontal: a circle of approximately 100 m radius around the position of the beacon. Vertical: from 30 m to 1 km, depending on the position of the beacon. Position of the beacon: 2 or 3 points on the extended centre line of the runway, between 100 m and 7.5 km from threshold.	CATV		63

HF communications are used between air command and control elements and ground elements mainly in a back-up mode when primary and higher capacity means are not available.

This includes:

- backup to governmental communications systems;
- links to PfP and non-governmental elements;
- links to deployed/mobile entities;
- links to tactical formations.

For system characteristics and required protection criteria for the maritime and aeronautical mobile services, there is no single document that consolidates the information for systems operating below 80 MHz. Review of current texts reveals that some of the information on characteristics is contained in the following Recommendations: ITU-R M.257*, ITU-R M.488*, ITU-R M.541, ITU-R M.627, ITU-R M.688, ITU-R M.822, ITU-R M.1081, ITU-R M.1082, ITU-R M.1173 and ITU-R M.1458, and provisions of the RR.

In addition, no formal Recommendations for protection of maritime mobile or aeronautical mobile systems exist.

* *Note by the Secretariat* – These Recommendations have been suppressed on 28/04/2011 (CACE//537).

Annex 2.6 contains a compatibility analysis which assesses possible interference to airborne receivers due to summation effects from PLT sources.

3.3.1 Results

The following table was generated using a methodology similar to that contained in the UWB Report ITU-R SM.2057 with the multiple technology limit modified from 6 dB to 20 dB to take into account that PLT is not an intentional radiator and therefore in the view of Working Party 5B should only be allowed 1% of the interference margin.

TABLE 3.6

Signal level to be protected at the receive antenna

System	Frequency band	Receiver location	Minimum level of desired signal		Required D/U (Note 1)	Receiver bandwidth	Aviation safety margin	Multiple technology limit	Signal level to be protected at the antenna input
			($\mu\text{V/m}$)	(dBm)	(dB)	(kHz)	(dB)	(dB)	(dBm/Hz)
NDB	190-535 kHz	Airborne	70	-31	15	2.8	6	20	-107
HF communications	2.85-22 MHz	Airborne			15	3	6	20	
		Ground			15	3	6	20	
Marker beacon	74.8-75.2 MHz	Airborne	1 500	-51	20	22	6	20	-143

NOTE 1 – Value taken here are the Intra System D/U ratio or in the case of radar the system I/N ratio and are provided as an interim value.

3.4 General protection criteria considerations HF fixed and land mobile

This section considers the protection requirements necessary to ensure that HF fixed and land mobile radiocommunication services, particularly those supporting radionavigation or other safety related functions do not experience harmful interference from PLT installations or networks, as would be required by RR No. 15.12.

Land forces need HF communications to ensure effective consultation, command and control, both within NATO and with PFP Nations. In addition, HF Combat Net Radio communications are used at lower echelons as primary or secondary means where terrain, distance, or mobility requirements preclude reliance on Tactical Area Communications Systems.

The vast majority of usage of the land mobile service are for: national defense, law enforcement; management and preservation of national resources; search and rescue; and emergency and safety communications operations in national seashores, lakes, forests, water resources, and wildlife refuge. The areas of operation for these radios include the urban, suburban, and rural areas, both off-shore and in-land. Operation of these land mobile radios typically occurs near power lines that may be used for PLT systems.

3.4.1 Protection criteria and protection requirement

3.4.1.1 Protection criteria

In order to ensure HF communications, the interference protection criteria is based on the levels of thermal, man-made, cosmic and atmospheric noise levels defined in Annex 1. Information on updated noise measurements including long-term observations of man-made noise below 30 MHz are also contained in Annex 1.

0.5 dB degradation of sensitivity

Generally speaking, the criterion of acceptable interference is based on a maximal sensitivity degradation of **0.5 dB**. It means that the total noise and interference (generated by PLT) should not be more than 0.5 dB higher than the total noise at the HF receiver without interference from PLT.

In other words:

$$(\text{Total } I \text{ and } N) \text{ (dBm/Hz)} < N \text{ (dBm/Hz)} + 0.5$$

where:

I: interference generated by PLT (dBm) in a bandwidth of 1 Hz

N: total of receiver noise and man-made noise (dBm) in a bandwidth of 1 Hz.

The above 0.5 dB sensitivity degradation criterion is selected based on the fact that military radio systems are operated close to their sensitivity level.

Basic parameters of HF radios required for the calculations

The required parameters of the victim HF radios are as follows:

- Receiver noise figure: 10 dB
- Antenna gain Rx: 0 dBi⁶
- Thermal noise: -174 dBm/Hz

⁶ The antenna gain of HF systems is normally around 0 dBi. A positive antenna gain will reduce the relative influence of the thermal noise.

With this approach further parameters of HF radios are **not** required.

3.4.1.2 Protection requirement

Based on the above protection criteria, the protection requirement of HF radio systems are as follows:

- a) The increase of background noise and interference per Hz should not exceed 0.5 dB due to the unwanted emissions of cable transmission networks (CTN) including unwanted emissions from PLT systems;
- b) The reference noise level, depending on the area, can be either that for quiet rural, rural, residential or business;
- c) The minimal separation between cable and victim HF Rx is assumed to be 10 m.

3.4.2 A possible protection criteria

PLT systems use radio frequency energy on unshielded, unbalanced transmission lines, resulting in the unavoidable radiation of RF energy. The radiated from PLT networks could cause harmful interference to radio communications. Consequently, limits on radiated emissions will be necessary to ensure protection of the existing licensed HF fixed service.

PLT systems are not recognized as a class of emission or a service and must be treated as a source of extraneous radiation source.

The proposed protection criterion for the HF fixed service from PLT systems is provisionally based on a degraded performance objective of 1% for unwanted emissions when compared with average values as given in Recommendation ITU-R F.1094 developed by former WP9A. The peak value of PLT emissions should be taken into consideration.

The level of an aggregate interfering signal at the receiving antenna with respect to the quiet rural noise level as specified in Recommendation ITU-R P.372 should also be considered. Certain mitigation techniques such as implementation procedures for PLT systems could mitigate the potential compatibility issue resulting from the use of these objectives.

3.4.3 Automatic link establishment systems

Experience with military missions shows that HF communications is sometimes the only way to distribute missions and progress reports without delays, and without the danger of signal jamming. In addition, in case of a nuclear explosion SATCOM links will be disrupted. By contrast, the HF links would still be available. Disruptions on HF links would be only for a short time.

In general, adaptive radio systems are used which can automatically choose the best frequencies in relation to the best propagation conditions and the maximum data throughput, but only if the *noise floor is low enough* (i.e. below the decision threshold of the systems). Higher noise levels will reduce the performance of ALE-based systems, as well as the general performance of digital radios.

3.5 Maritime mobile

In this chapter, the various frequency bands allocated for maritime communications and maritime mobile service are reviewed.

3.5.1 Background

Maritime radiocommunications, of which the most important is distress and safety communications, are heavily based on the use of MF and HF frequency bands primarily due to the unique propagation conditions of the MF/HF bands.

Maritime communications are defined as a *service* under the ITU Radio Regulations. Communications can be between coast stations and ships, or between ships; survival craft stations and emergency radio beacons may also participate in this service. It also includes port operations service and ship movement service.

Safety service is defined under RR No. 1.59:

«**1.59** *safety service*: Any *radiocommunication service* used permanently or temporarily for the safeguarding of human life and property.»

The maritime community also uses *radionavigation*, which is also a defined service having exclusive allocations as defined in the RR.

Terms for use of maritime radiocommunications are agreed under the Constitution and Convention of the ITU, which is complemented by the decisions of the World Radiocommunication Conferences (WRC) published as the Radio Regulations (RR). The RR also has binding provisions for all administrations to take all necessary actions to protect these radio frequencies from harmful interference.

3.5.2 Frequencies allocated for maritime communications

Distress and safety communications

RR Appendix 13 defines frequencies to be used for non-GMDSS distress and safety communications. Although it was the intention that GMDSS system would globally replace the Appendix 13 by 1 February 1999, it has been noted that certain administrations and vessels, not subject to the SOLAS, 1974 agreement as amended may still wish to continue to use provisions of Appendix 13 for distress and safety communications for some time after 1 February 1999.

The following paragraphs detail the regulations governing the protection of Distress and Safety Frequencies.

“Section II – Protection of Distress and Safety Frequencies

A – General

§ 13 Except as provided for in these Regulations, any emission capable of causing harmful interference to distress, alarm, urgency or safety communications on the frequencies 500 kHz, 2 174.5 kHz, 2 182 kHz, 2 187.5 kHz, 4 125 kHz, 4 177.5 kHz, 4 207.5 kHz, 6 215 kHz, 6 268 kHz, 6 312 kHz, 8 291 kHz, 8 376.5 kHz, 8 414.5 kHz, 12 290 kHz, 12 520 kHz, 12 577 kHz, 16 420 kHz, 16 695 kHz, 16 804.5 kHz, 121.5 MHz, 156.525 MHz, 156.8 MHz or in the frequency bands 406-406.1 MHz, 1 544-1 545 MHz and 1 645.5-1 646.5 MHz (see also Appendix 15) is prohibited. Any emission causing harmful interference to distress and safety communications on any of the other discrete frequencies identified in Part A2, Section I of this Appendix and in Appendix 15 is prohibited.”

Global maritime distress and safety system

Global maritime distress and safety system (GMDSS) is fully defined in the International Convention for the Safety of Life at Sea (SOLAS, 1974). Resolution 331 (Rev.WRC-97)* states that all ships subject to IMO SOLAS convention shall be fitted for the GMDSS by 1 February 1999.

* This Resolution was subsequently revised at WRC-03 and WRC-07.

The frequencies to be used for the GMDSS are contained in RR Appendix 15. The distress and safety frequency allocations are shown in Table 3-7. In addition to frequencies listed in Appendix 15, coast stations should use other appropriate frequencies for the transmission of safety messages.

TABLE 3-7

Table of distress and safety frequencies in maritime mobile service below 30 MHz

	Distress			Safety	
	DSC	RTP-COM	NBDP-COM	MSI/MSI-HF	AERO-SAR
	kHz	kHz	kHz	kHz	kHz
MF	2 187.5	2 182.0	2 174.5	490.0	3 023.0
				518.0	
HF	4 207.5	4 125.0	4 177.5	4 209.5	5 680.0
				4 210.0	
	6 312.0	6 215.0	6 268.0	6 314.0	
	8 414.5	8 291.0	8 376.5	8 416.5	
	12 577.0	12 290.0	12 520.0	12 579.0	
	16 804.5	16 420.0	16 695.0	16 806.5	
				19 680.5	
				22 376.0	
				26 100.5	
				MSI	
				MSI-HF	

Legend:

AERO-SAR These aeronautical carrier (reference) frequencies may be used for distress and safety purposes by mobile stations engaged in coordinated search and rescue operations.

DSC These frequencies are used exclusively for distress and safety calls using digital selective calling in accordance with No. 32.5 (see Nos. 33.8 and 33.32).

MSI In the maritime mobile service, these frequencies are used exclusively for the transmission of maritime safety information (MSI) (including meteorological and navigational warnings and urgent information) by coast stations to ships, by means of narrow-band direct-printing telegraphy.

MSI-HF In the maritime mobile service, these frequencies are used exclusively for the transmission of high seas MSI by coast stations to ships, by means of narrow-band direct-printing telegraphy.

NBDP-COM These frequencies are used exclusively for distress and safety communications (traffic) using narrow-band direct-printing telegraphy.

RTP-COM These carrier frequencies are used for distress and safety communications (traffic) by radiotelephony.

Frequencies allocated to maritime mobile service

The Table of Frequency Allocations (RR Article 5) shown in Table 3-8 contains the following frequencies below 30 MHz allocated exclusively for maritime mobile service in Region 1. These frequencies should also be protected from harmful interference within the sense of RR No. 15.12.

TABLE 3-8

Frequencies allocated to the maritime mobile service

14-19.95 kHz		2 625-2 650 kHz	19 680-19 800 kHz
20.05-70 kHz	415-495 kHz 505-526.5 kHz	4 000-4 438 kHz	22 000-22 855 kHz
72-84 kHz	1 606.5-1 625 kHz	6 200-6 525 kHz	25 070-25 210 kHz
86-90 kHz	1 635-1 800 kHz	8 100-8 815 kHz	26 100-26 175 kHz
110-112 kHz		12 230-13 200 kHz	
117.6-126 kHz	2 045-2 160 kHz	16 360-17 410 kHz	
129-148.5 kHz	2 170-2 173.5 kHz 2 190.5-2 194 kHz	18 780-18 900 kHz	

3.5.3 Receiver parameters for the maritime mobile service in MF and HF bands

For system characteristics and required protection criteria for the maritime and aeronautical mobile services at frequencies below 80 MHz, there is no single document that consolidates the requested information for systems operating below 80 MHz. Review of current texts reveals that some of the information on characteristics is contained in the following Recommendations: ITU-R M.257*, ITU-R M.488*, ITU-R M.541, ITU-R M.627, ITU-R M.688, ITU-R M.822, ITU-R M.1081, ITU-R M.1082, ITU-R M.1173 and ITU-R M.1458, and provisions of the RR.

In addition, no technical studies related to protection criteria nor formal Recommendations for such protection of maritime mobile or aeronautical mobile systems exist. However, the following information has been collated, which may serve as a basis for deriving protection requirements.

3.5.3.1 NAVTEX receivers – 424, 490 and 518 kHz

Report ITU-R M.910-1 provides that:

- Receiver sensitivity = 18 μ V/m (25 dB(μ V/m));
- S/N = 8 dB (300 Hz);
- Co-channel protection ratio = 8 dB.

3.5.3.2 Maritime MF/HF receivers

MF/HF distress and safety communications in the GMDSS use the following frequencies:

Digital selective calling (DSC) (kHz)	Radiotelephony (R/T) (kHz)	Narrow-band direct-printing (NBDP) (kHz)
2 187.5	2 182	2 174.5
4 207.5	4 125	4 177.5
6 312	6 215	6 268
8 414.5	8 291	8 376.5
12 577	12 290	12 520
16 804.5	16 420	16 695

* Note by the Secretariat – These Recommendations have been suppressed on 28/04/2011 (CACE/537).

Maritime safety information (MSI) (kHz)	Coordination with SAR aircraft (kHz)	MF/HF general communications in the GMDSS use the following frequency bands (kHz)
4 210 6 314 8 416.5 12 579 16 806.5 19 680.5 22 376 26 100.5	3 023 5 650	1 606.5-1 625 1 635-1 800 2 045-2 160 2 170-2 173.5 2 173.5-2 190.5 2 190.5-2 194 2 625-2 850 4 000-4 063 4 063-4 438 6 200-6 525 8 100-8 195 8 195-8 815 12 230-13 200 16 360-17 410 18 780-18 900 19 680-19 800 22 000-22 855 25 070-25 210 26 100-26 175

Co-channel protection ratios:

- Radiotelephony = 9 dB
- Digital selective calling = 12 dB
- Narrow-band direct-printing = 16 dB.

The ETSI Standard 300 373 contains the following values.

Maximum usable sensitivity:

In 1 605-4 000 kHz: 5 dB(μ V)

In 4 000-27 500 kHz: 0 dB(μ V)

Adjacent signal selectivity:

–500 Hz +500 Hz: 40 dB (with a narrow-band filter)

–1 kHz, +4 kHz: 40 dB

–2 kHz, +5 kHz: 50 dB

–5 kHz, +8 kHz: 60 dB

Automatic gain control time constants:

Attack time = 5 to 10 ms

Recovery time = 1 to 4 s

Cross modulation:

\pm 20 kHz: max level of unwanted signal = +90 dB(μ V)

Intermodulation:

+70 dB(μ V)

Spurious response rejection:

70 dB

* ETSI Standard 300 373

3.5.4 Hyperbolic radionavigation systems

For use in the bands 285.4-285.6 kHz, 285.6 and 315 kHz and 405 and 415 kHz (see RR No. 466A), Recommendation ITU-R M.631-1* provides that:

- minimum wanted received signal level = 3 $\mu\text{V/m}$;
- bandwidth ± 10 Hz;
- co-channel protection ratio = 20 dB.

For use band 70-130 kHz (LORAN), Recommendation ITU-R M.589-3 provides that:

- The S/N at the boundary of the coverage area is typically, e.g. if the expected noise level is 55 dB($\mu\text{V/m}$), a wanted minimum signal level of 45 dB($\mu\text{V/m}$) is needed throughout the coverage area.
- A typical protection ratio for the maximum wanted-to-unwanted signal level is 20 dB, meaning that the unwanted field strength at a Loran-C receiver should be below ~ 25 dB($\mu\text{V/m}$) in order to prevent interference.

3.5.5 LF/MF maritime radionavigation beacons

For use in the frequency band 275-415 kHz, Recommendations ITU-R M.823-3 and ITU-R M.588* provide that:

- Frequency assignments to maritime radio beacons are based on multiples of 100 Hz.
- The maximum permitted occupied bandwidth in Region 1 is 230 Hz.
- The receiver operates at a maximum bit error ratio of 1×10^{-3} in the presence of Gaussian noise at a signal-to-noise ratio of 7 dB in the occupied bandwidth.
- The required protection ratio for an on-channel interfering signal is 15 dB.

3.6 Radiolocation

The radiolocation service is a radiodetermination service used for detection and positional location of distant objects (targets).

Frequencies in the range 3-50 MHz are used for a variety of uses including area surveillance of aircraft and shipping movements, early warning missile detection and oceanographic observations providing data on wave heights and related wind conditions.

3.6.1 Oceanographic radar systems in the bands 3-50 MHz

Protection requirements for the various systems in use are given in Table 3.8*bis*.

3.6.2 System characteristics

The following system characteristics have been taken from Recommendation ITU-R M.1874.

* *Note by the Secretariat* – These Recommendations have suppressed on 28/04/2011 (CACE/537).

TABLE 3-8bis

Protection requirements for oceanographic radar systems in the bands 3-50 MHz

Receiving characteristics	Oceanographic radar systems (Recommendation ITU-R M.1874)					
	1 (5 MHz) 2 (13 MHz) 3 (25 MHz) 4 (42 MHz)	5 (8 MHz) 6 (12 MHz) 7 (16 MHz) 8 (25 MHz) 9 (42 MHz)	10 (9.2 MHz)	11 (24.5 MHz)	12 (24.5 MHz)	13 (41.9 MHz)
Antenna pattern type	Electric and magnetic dipoles	Directional with beamwidth of $\pm 3^\circ$ to $\pm 15^\circ$	Directional	Directional	Directional	Directional
Antenna type	2 crossed loops + monopole as single unit	Monopole array (4-16 elements)	16 sets of 2-element Yagi	8 sets of 3-element Yagi	8 sets of 3-element Yagi	8 sets of 3-element Yagi
Antenna polarization	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical
Antenna main beam gain	5 dBi	10 to 18 dBi	16 dBi	15 dBi	15 dBi	15 dBi
Antenna elevation beamwidth	45°	35°	30°	25°	25°	25°
Antenna azimuthal beamwidth	90-360°	6 -30° depending on array size	8-10°	15°	15°	15°
Antenna horizontal scan rate	Fixed antenna	Fixed antenna	Fixed antenna with digital beam forming	Fixed antenna phased array 60 min per 12 direction	Fixed antenna with digital beam forming	Fixed antenna with digital beam forming
Antenna height	4 m	$\sim \frac{1}{4}\lambda$	feed point 10 m above ground level	feed point 2-14 m above ground level	feed point 2-14 m above ground level	2 feed point 2-14 m above ground level
IF 3 dB bandwidth	500 Hz	No IF used. (baseband bw is 1 500 Hz)	200 Hz	200 Hz	200 Hz	200 Hz
Noise figure	12 dB with pulsing	8 dB	17 dB with pulsing	12 dB with pulsing	12 dB with pulsing	13 dB with pulsing
Initial maximum tolerable value of interference	-147 dBm	-142 dBm	-157 dBm	-162 dBm	-162 dBm	-161 dBm
Resolution bandwidth	500 Hz	1 500 Hz	1 Hz	1 Hz	1 Hz	1 Hz

NOTE 1 – The initial maximum tolerable value of interference is specified for the aggregate level from all interference sources and hence an apportionment factor will need to be developed.

3.7 Fixed

Signal intelligence (SIGINT) activities are important to the military. Therefore, listening to (very weak) signals is done by the military and this activity can be disturbed by low-level interference.

Military HF radio stations are also supplied by public power lines. The power supply system might not be provided with special filters to remove HF signals. Filtering out PLT signals on power lines might not be practical.

3.7.1 Fixed system characteristics

Review of current texts reveals that some of the information on characteristics is contained in Recommendations ITU-R F.758 and ITU-R F.764, parts of which are outdated and due for revision or deletion during the current ITU-R work cycle, and provisions of the RR. In addition, Recommendation ITU-R F.339 provides information on bandwidths, signal-to-noise ratios and fading allowances for complete HF systems characteristics.

3.7.2 Protection criteria

The level of an aggregate interfering signal at the receiving antenna with respect to the ITU quiet rural noise level as specified in Recommendation ITU-R P.372 may be considered, however neither technical studies relating to protection criteria nor formal Recommendations for such protection of HF fixed service systems exist at this time.

A deterministic analysis is generally the preferred methodology when considering the protection of the primary fixed service in the HF range from interference caused by high data rate communication applications using the electricity supply wiring.

3.8 Radio astronomy

Threshold interference levels for interference detrimental to the operation of the radio astronomy service (RAS) are given in Recommendation ITU-R RA.769. As noted there, the values represent detrimental threshold levels for typical observations, using an integration (observations) time of 2 000 s and an antenna gain of 0 dBi. Recommendation ITU-R SA.509 provides the antenna gain pattern of the radio astronomy antenna.

The radio astronomy service (RAS) has frequency allocations at 13.36-13.41 MHz and 25.55-25.67 MHz on a primary basis. In terms of total input interference power into the bands, the threshold interference levels from Recommendation ITU-R RA.769 are -185 dBW and -188 dBW respectively, and the corresponding spectral power flux densities within the bands are -248 and -249 dB(W/(m² · Hz)).

All frequency bands below 80 MHz currently allocated to and intensively used by the radio astronomy service are indicated in Table 3-8 which reproduces the protection criteria for the frequency range where cable signal can be found. These are as given in Recommendation ITU-R RA.769.

Protection of bands in this frequency range is of great importance for future radio astronomy because of the construction of a new generation of radio telescopes such as the MWA, the eVLA, the low frequency array (LOFAR) and the square-kilometer array (SKA).

TABLE 3-9

Frequency band (MHz)	European Common Allocation (ECA) allocation status	Reference bandwidth for spurious emissions (MHz)	Level of detrimental interference (continuum observations) (dB(μV/m))	Level of detrimental interference (spectral line observations) (dB(μV/m))
13.36-13.41	Primary shared (5.149)	0.05	-55.2	
25.55-25.67	Primary (passive exclusive) (5.149)	0.12	-53.2	
37.5-38.25	Secondary (5.149)		-50.2	
73.0-74.6	Secondary (5.149)	1.60	-50.2	

NOTE 1 – RR No. 5.149 states for the bands 13.36-13.41 MHz, 25.55-25.67 MHz, 37.5-38.25 MHz, and 73.0-74.6 MHz, that “... administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service”.

3.9 Standard frequency and time

ITU-R Working Party 7A notes that interference analyses may not predict accurately the effect of possible PLT interference on specialized services such as the reception of standard-frequency and time signals by radio-controlled clocks.

Table 3-10 is derived from the Table in Annex 1 to Recommendation ITU-R SM.1138.

TABLE 3-10

Properties of Standard frequency and time signals

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
1 High frequency (voice)			
Voice announcements, double-sideband	$B_n = 2M$	Speech $M = 4\ 000$ Bandwidth: 8 000 Hz = 8 kHz	8K00A3XGN
2 High frequency (tone bursts)			
Ticks used for epoch measurement	$B_n = 2/t_R$	$t_R = 1\ \text{ms}$ Bandwidth: 2 000 Hz = 2kHz	2K00K2XAN
3 High frequency (time code)			
Time code as telegraphy	$B_n = BK + 2M$	$B = 1/\text{s}$ $M = 1$ $K = 5$ Bandwidth: 7 Hz	7H00A2XAN

TABLE 3-10 (*end*)

Description of emission	Necessary bandwidth		Designation of emission
	Formula	Sample calculation	
4 Low frequency (time code)			
Time code leading edge used for epoch measurement	$B_n = 2/t_R$	$t_R = 1$ ms Bandwidth = 2 000 Hz = 2 kHz	2K00K2XAN
Time code as telegraphy	$B_n = BK + 2M$	$B = 1/s$ $M = 1$ $K = 3$ Bandwidth: 5 Hz	5H00A2XAN

4 Potential means for preventing or eliminating interference

To prevent interference, the administration of Japan decided in October 2006 to permit only indoor PLT, that is, not to allow access PLT.

Another way to prevent, or at least sufficiently mitigate, interference is to define suitable emission limits of PLT systems and devices at a level low enough to ensure the protection of a radiocommunication or radio astronomy service.

Electrical power systems could be designed for high speed data transmission through complete radiation shielding, RF blocking filters at transition points, or other means.

4.1 Mitigation factors and methods for power line communications

There is increasing demand for and use of broadband access to the Internet throughout the world and PLT systems may provide one means of such access. But such systems are unintentional emitters of RF radiation, and may cause interference to radio receivers.

PLT system may use internal low voltage house wiring to carry communications signals, or outside (overhead or buried) LV wiring, or outside MV wiring, or a combination.

Some radio receivers, such as HF broadcast receivers with internal antennas that use the electric power cord as part of the antenna subsystem, may suffer interference through conducted emissions, but the interference coupling path to most other victim receivers may be by means of radiated emissions.

In adopting regulations applicable to PLT, national administrations may rely solely on limits on emission levels to protect against interference, or they may rely on a combination of emission limits and mitigation factors. This section provides guidance on mitigation factors that may be considered by national administrations.

4.1.1 Attenuation of conducted signals

A primary concern of some administrations is the protection of HF broadcast receivers in one apartment or home when a neighbour in an adjacent apartment or home uses PLT. In this case, conducted emissions might be the primary interference coupling mechanism.

Some studies have included measurements showing that attenuation of PLT signals, from the electric socket in the premises, through an electric meter and through a breaker panel, is on the order of 30 dB to 40 dB. This is understood to be due to a combination of loss through the meter itself, plus the complex electrical behaviour of in-building electric networks. Electric meters that

contain electronic circuitry to provide for remote control and monitoring have been found to attenuate PLT signals by as much as 20 dB at some frequencies, and the frequency dependence of the attenuation is quite complex. Consequently, in an apartment building where one neighbour is using PLT technology and an adjacent neighbour has an HF broadcast receiver connected to the mains network, the total attenuation of conducted PLT signals could be on the order of 60 to 80 dB from one neighbour to the other.

These results may or may not be applicable in all countries, because building construction methods vary and electrical network configurations vary from country to country. Consequently, in considering whether to take this attenuation into account as a mitigation factor in adopting national regulations, administrations should study the attenuation in typical buildings within each country.

Moreover, attenuation may be increased by adding a filter to the electric power network. Such a filter could be inserted between a radio receiver's mains cord plug and the electrical socket where it is connected. Because the physical configuration of plugs and sockets varies from one country to another, administrations should investigate the feasibility of this mitigation approach and the availability of such filters within each country. For further information on separation distance see § A3.5.

4.1.2 Frequency band exclusions

Administrations may require that PLT systems exclude (place no carrier frequencies in) certain designated bands. This requirement might be applied solely to overhead outdoor MV wires, to outdoor MV and LV wires, or to underground wires (LV or MV).

For example, one administration has imposed such a requirement on some bands between 2 MHz and 22 MHz as well as 74.8-75.2 MHz. This protects bands allocated to aeronautical mobile and radionavigation services that are used to provide aeronautical safety of life services. In this case, the requirement was applied only to overhead outdoor MV wires, not to LV or underground MV wires.

4.1.3 Geographical exclusion zones

Administrations may prohibit PLT operators from using certain frequency bands within specified distances of licensed radio stations in particular services.

For example, one administration has prohibited PLT use of the frequency band 2.1735-2.1905 MHz (global maritime distress band) within 1 km of about 110 designated maritime radio stations. It also prohibited PLT operators from using 73.0-74.6 MHz (radio astronomy frequencies) within 65 km of one radio astronomy (RA) observatory (applicable only to overhead MV) or within 47 km of the RA observatory (applicable to underground MV and overhead LV lines).

Such distance-based regulations would apply to companies operating PLT systems to provide Internet access service, but not to in-home networks using customer-owned PLT equipment.

The distances at which harmful interference from PLT systems might occur is highly dependent upon factors such as the characteristics of the local power grid and the design and topology of the particular PLT system. Since these factors vary significantly from one location to another, conclusions drawn from one system and configuration cannot reliably be applied to dissimilar cases. Administrations should take care to base regulatory decisions only on analyses that accurately reflect the national situation.

4.1.4 Consultation area requirements

In order to make the detection and mitigation of interference more efficient, administrations may require PLT system operators to give advance notice of installations to certain radio service licensees.

For example, one administration has required PLT operators to give 30 days advance notice of installations in the following bands and locations:

- on 1.7-30 MHz, if within 4 km of certain specified administration monitoring stations and about 60 aeronautical and land HF radio stations;
- on 1.7-80 MHz, if within 4 km of about 16 radio astronomy sites;
- on 1.7-30 MHz, if within 37 km of three specified radar receive sites;
- on 1.7-80 MHz, if within 1 km of certain other specified administration sites;
- to frequency coordinators for police, fire and emergency medical agencies licensed to operate mobile radio services in the area.

For planned operations within the consultation areas defined above, PLT operators must supply the following information:

- 1 name of the PLT operator;
- 2 frequencies of the PLT operation;
- 3 postal codes served by the PLT operation;
- 4 the manufacturer of and type of PLT equipment being deployed;
- 5 point of contact information (both telephone and e-mail address); and
- 6 the proposed or actual date of initiation of PLT operation.

4.1.5 Adaptive interference techniques

Administrations may require PLT operators to employ equipment with adaptive interference mitigation techniques under the control of the operator. This would permit PLT operators to notch or decrease signal strength to mitigate interference at particular locations in particular bands when it is reported. Administrations could require that notches reduce emissions by a fixed amount (for example, 10 dB or 20 dB) below applicable emission limits.

It may also be feasible to develop PLT equipment that senses radio signals in certain radio services and adaptively automatically applies notches to protect those radio signals. If such equipment is feasible, administrations could specify radio services or frequency bands that are to be protected in this manner.

Administrations may also require that PLT operators employ equipment with a last resort remote-controllable RF transmission shutdown feature for deactivation of any unit found to cause harmful interference.

4.1.6 Interference complaint procedures

Administration should assure that procedures exist for submission of and response to PLT interference complaints.

For example, the complainant should first take reasonable steps to confirm that interference exists, and is caused by a PLT system. The complainant should notify the PLT operator. The PLT operator should investigate within a time that is reasonable for the service suffering interference. For example, the PLT operator might be allowed 24 h to investigate and mitigate complaints from public safety licensees, but longer to investigate interference to HF broadcast services. If the interference cannot be mitigated in this manner, the licensee could then file a complaint with the appropriate administration agency, which would then assign its technical and legal resources to mitigating the interference.

4.1.7 PLT operator database

Administrations could require PLT operators to establish a publicly accessible database of PLT operations to make interference mitigation more efficient. Such a database could be managed by an industry trade association, by the administration itself, or by an independent third party. The database could contain the following information, for example:

- 1 name of the PLT operator;
- 2 frequencies of the PLT operation;
- 3 postal codes served by the PLT operation;
- 4 the manufacturer of and type of PLT equipment being deployed;
- 5 point of contact information (both telephone and e-mail address); and
- 6 the proposed or actual date of initiation of PLT operation.

The database manager need have no role in any interference complaint or investigation, but information in the database could be used in such investigations.

4.2 Studies of mitigation techniques

4.2.1 Study of mitigation techniques in Brazil

4.2.1.1 Introduction and general information

This section presents the results obtained through field measurements of broadband power line telecommunication (PLT) systems reported by the Brazilian Administration. The tests were performed in order to evaluate the effectiveness of mitigation techniques implemented in second-generation PLT systems. Aspects of radio interference and levels of radiated emissions from the network were considered. These emissions were both compared with the limits of Recommendation ITU-T K.60⁷ as well with the limits of one administration.

4.2.1.2 Test configuration

The tests were performed on a typical low voltage installation of overhead lines with a length of 240 m. The network consisted of public lighting poles so that the noise produced by motors and electrical appliances would be minimized.

The methodology applied was based on Recommendation ITU-T K.60⁶ and FCC 04-245 procedures.

In order to get the highest readings of disturbance emissions, the PLT equipment was set at the maximum output power level (around -58 dBm/Hz) to maximize disturbance emissions.

A calibrated loop antenna, a tripod and a spectrum analyser were used to measure the magnetic component of the radiated emissions below 30 MHz (according to Recommendation ITU-T K.60 measurement procedure, CISPR 16-1-1 a quasi-peak detector could also be used instead of the spectrum analyser). The setup is displayed in Fig. 4-1.

⁷ Clause 1 (Scope) of Recommendation ITU-T K.60 – Emission levels and test methods for wireline telecommunication networks to minimize electromagnetic disturbance of radio services (2008-02) states: “The purpose of this Recommendation is to guide administrations when considering complaints of interference between telecommunication systems and is not intended to set compliance requirements or recommendations for protecting the radio spectrum.”

FIGURE 4-1

Distribution network and loop antenna

Report 2158-4-01

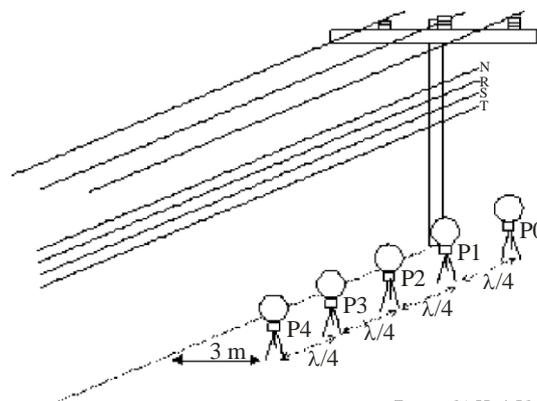
The spectrum analyser was set at a resolution bandwidth (RBW) of 9 kHz with a peak detector. Comparing these values with those obtained with a quasi-peak detector indicated a difference of less than 4 dB.

Measurements were performed at a horizontal separation distance of 3 m. The distance was taken as a straight line from the projection of the power line to the floor level to the measuring antenna reference point.

As Fig. 4-2 illustrates, testing was performed along the line from the PLT injection point at 0, $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 wavelength spacing, based on the mid-band frequency used by the equipment. The positions correspond to points P0, P1, P2, P3 and P4, respectively.

At each position, three measurements were taken; one for each orientation of the magnetic loop antenna to evaluate the three orthogonal field components.

FIGURE 4-2

Measurement positions

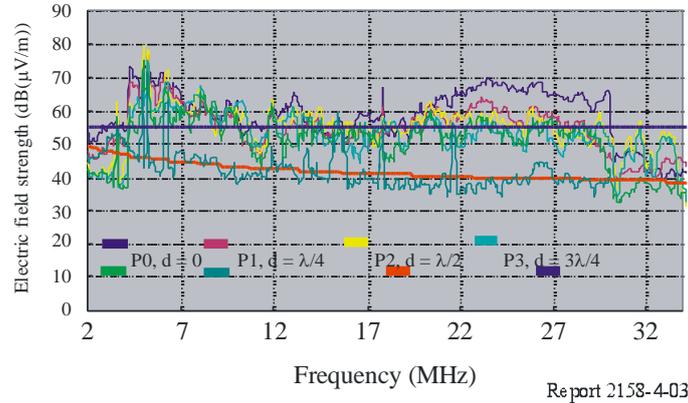
Report 2158-4-02

Figure 4-3 shows that when the equipment is set at maximum injected power, the electric field is far above the quasi-peak limits used by one administration. Distance correction was applied to the limit value according to the extrapolation factor adopted by one administration (see Annex 3.6). When scanning the spectrum with and without the presence of PLT, it can be noted that the PLT signal

interferes in the existing services. However, there is a considerable reduction in the radiated power when moving down the line from the injection point.

FIGURE 4-3

Measurement in all positions



Report 2158-4-03

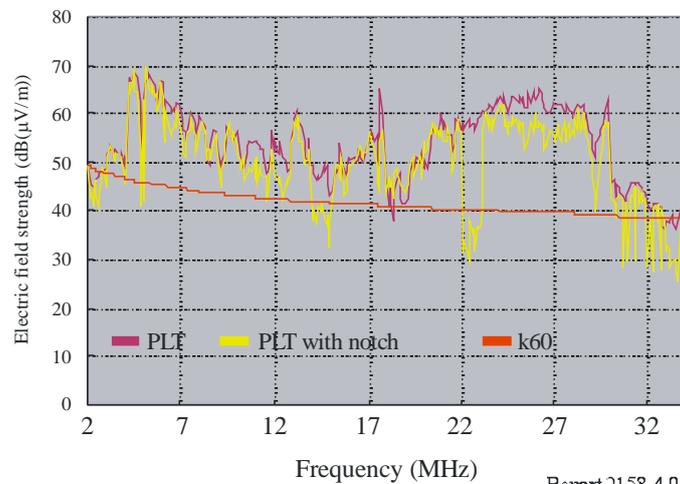
Regarding interference mitigation, three configurations were analysed.

4.2.1.3 Notch filters

Initially, notch filters were configured to attenuate the signal level on predetermined frequency bands. In Fig. 4-4, one can observe three notches at the bands 4.8-4.9 MHz, 14-15 MHz and 22-23 MHz. In all three ranges, the emission strength falls below the levels given in Recommendation ITU-T K.60⁶. Moreover, demodulation of the radio signal confirmed the effectiveness of this mitigation technique in preset exclusion bands.

FIGURE 4-4

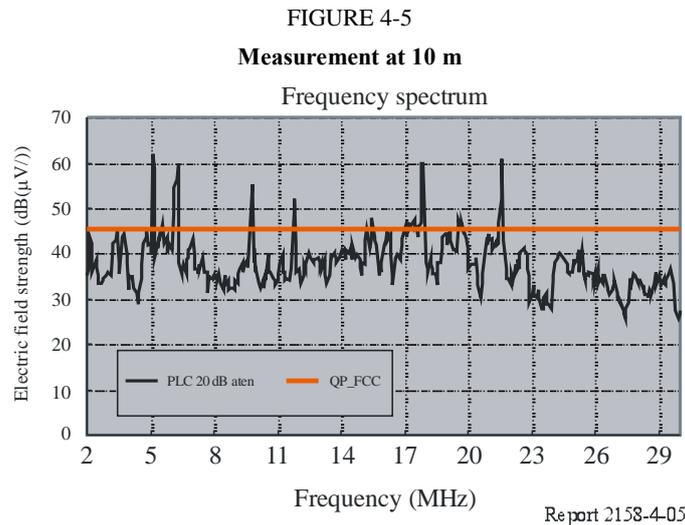
Measurement with notches



Report 2158-4-04

4.2.1.4 Power reduction

Finally, the injected power was attenuated until the radiated emission reached the FCC limits. This test was performed in a small section of the network where it was possible to have measurement distances of 10 metres. Figure 4-5 illustrates a small increase in background noise due to PLT. The spikes represent RF signals that were not affected by PLT emissions.



4.2.1.5 Conclusion

The tests showed that the implementation of mitigation techniques such as notch filters and output power control should offer the effective protection to HF systems.

Considering the results of these tests, the lack of infrastructure to provide for broadband access, and the need to promote digital inclusion, the Brazilian Administration is considering regulation, rules and necessary requirements to enable the coexistence of PLT systems, operating over low voltage (LV) and medium voltage (MV) power lines on the frequency band of 1 705 kHz to 50 MHz, with HF licensed systems.

4.2.2 Intermodulation effects on the depth of spectrum notches in PLT systems

The interference to stations in the amateur and amateur-satellite services from PLT in the HF range has led to a mitigation technique known as spectral notching to be introduced. However, measurements have shown that intermodulation effects in other equipments connected to the mains wiring can lead to a marked reduction in the effectiveness of this approach.

4.2.2.1 Measurement technique

Two PLT devices were set up to communicate between them, with a line impedance stabilization network (LISN) feeding into a unit designated as “remote”: the 20 dB attenuation at RF simulates a remote PLT in another room. Hence the remote PLT only makes a small contribution to the measured emission. The devices are referred to as power line adaptors (PLA).

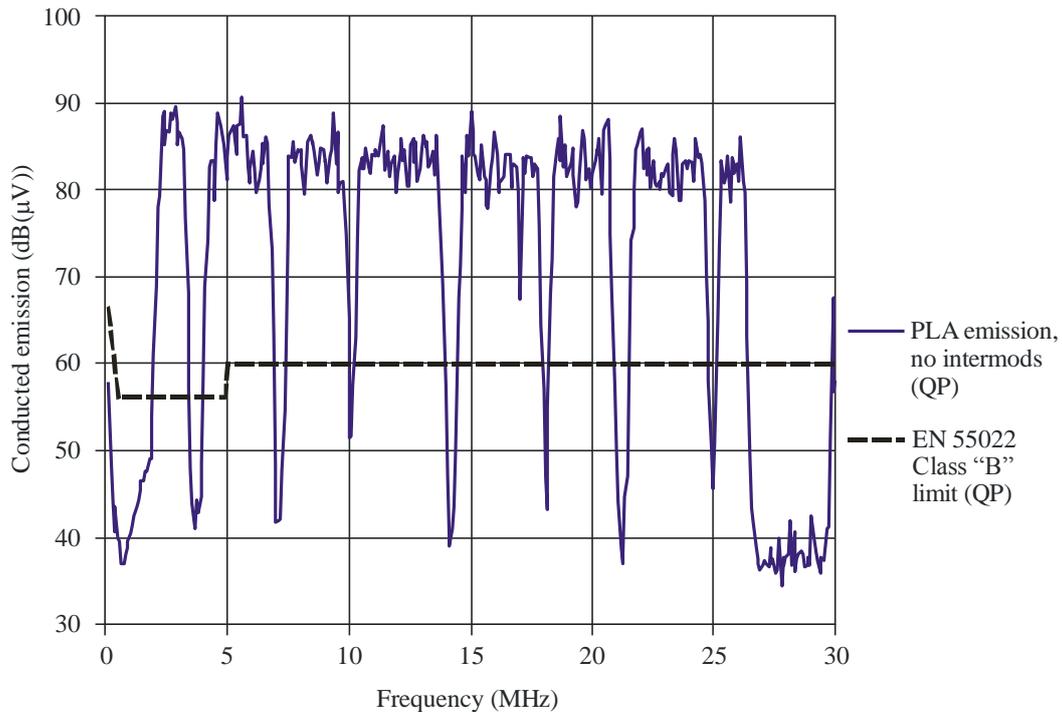
The local and remote PLAs are communicating but no data is being sent. Measurements were made at 400 spot frequencies with a 9 kHz measurement bandwidth and a quasi-peak (QP) detector. The results are shown in Fig. 4-6, with the EN55022 Class B QP at 60 dB(μ V) limit shown for comparison.

Because of the frequency step size, the narrower notches such as 10 MHz, 18 MHz and 24 MHz amateur bands are not be shown with their full depth but all are at least 30 dB deep and some are over 40 dB deep at the centre.

A non-linear device using the circuit in Fig. 4-7 was connected to the mains. This is very similar to a number of small mains power supplies examined: there are variations in component values between various models.

FIGURE 4-6

The spectrum showing the spectral notches



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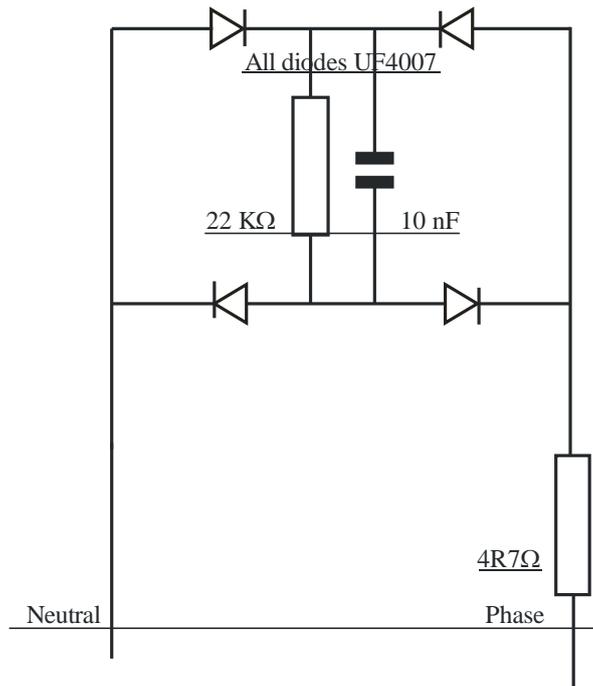
4.2.2.2 Results

Figure 4-8 shows the effect of connecting the rectifier shown in Fig. 4-7 to an adjacent mains socket. It can be seen that the depth of the 3.5, 14, 18, 21, 24 and 28 MHz notches is reduced to about 20 dB. There is also a significant increase in out-of-band products with peak amplitude that is significantly higher than the QP level. The increase in emissions in the range 0.5-2 MHz includes the 1.8 MHz amateur band and the MF broadcast band. There are also increased emissions above 27 MHz that could affect the 28 MHz and 50 MHz amateur bands, although the emissions above 30 MHz are not shown in Fig. 4-8.

Figure 4-9 shows the composite plot of Fig. 4-7 and Fig. 4-8 overlaid.

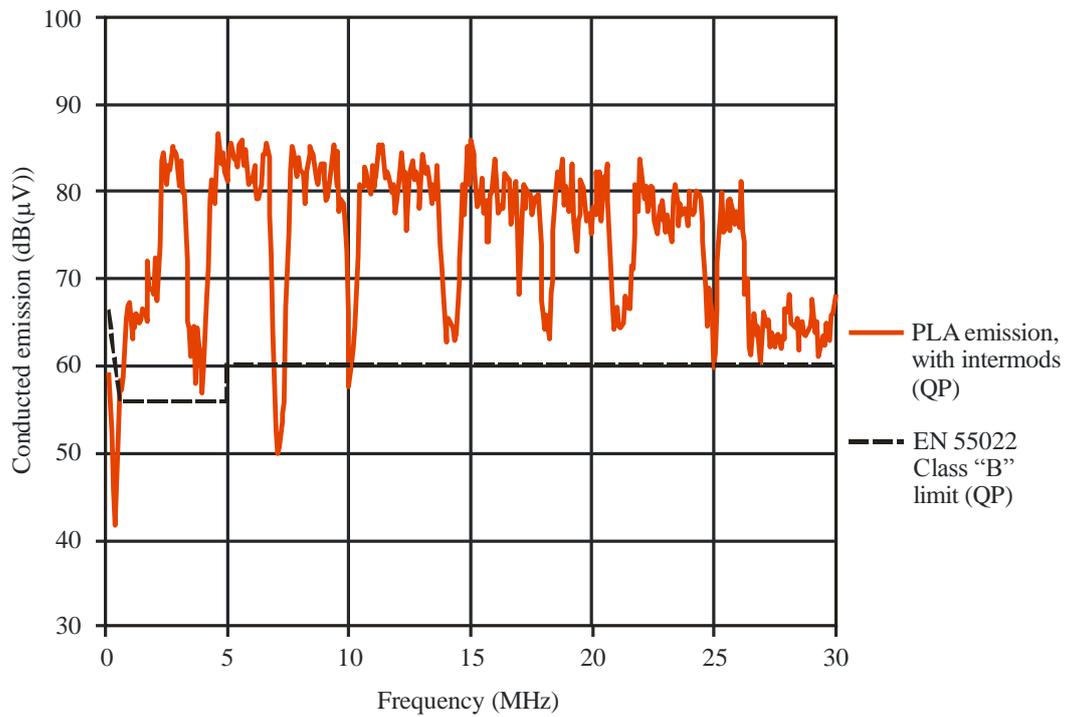
A small plug-in switch-mode mains PSU was dismantled, and it was found that the rectifier part was similar to Fig. 4-6, apart from a larger smoothing capacitor and different diodes. The mains input is connected directly to the bridge rectifier via a 5.6 Ω resistor, and the RF interference filtering is after the rectifier. This means that RF signals from a nearby PLA can get straight into the bridge rectifier, and any intermodulation products and harmonics generated by the bridge rectifier can get straight out again, onto the mains.

FIGURE 4-7
Simulated small power supply



Report SM.2158-4-07

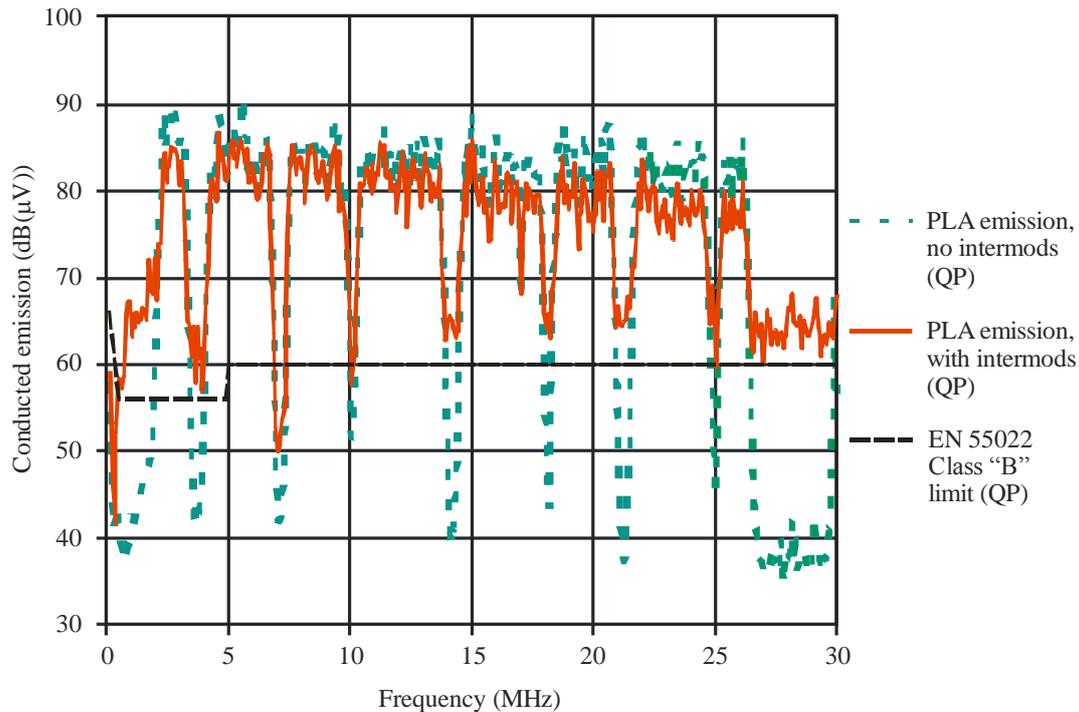
FIGURE 4-8
The effects of intermodulation on the notches



Report SM.2158-4-08

FIGURE 4-9

Composite plot of Figs 3 and 4 overlaid



Report SM.2158-4-09

Some tests were also performed with one PLA on its own. This may be a “worst-case” situation where it is constantly calling while searching for another PLA but it may also be representative of the case where two PLAs are plugged in close together, as sometimes happens. In either case, the QP level of the intermodulation products is higher than the results shown in Fig. 4-8 (where a local PLA is communicating with a remote PLA). At a spot frequency of 14.182 MHz, inside the 14 MHz “notch”, the QP emission levels for one PLA on its own were as follows:

- No rectifying load, 44 dB μ V.
- With PSU on load, 60 dB μ V.
- With PSU off load, 65 dB μ V.
- With rectifier shown in Fig. 4-7, 73 dB μ V.

The 14 MHz notch is quite deep and goes well below the EN55022 Class B limit of 60 dB μ V QP but in this situation, it was found that the PSU on load can bring the level up to the limit. It was found that the same PSU disconnected from its PLA, i.e. unloaded, can generate intermodulation products that are about 5 dB over the limit. The PSU on its own is relatively quiet in the HF bands so the above emissions appear to be caused by the rectifier of the PSU generating intermodulation products from the PLA signals.

A charger for a mobile phone was also tested, and it also generated intermodulation products, particularly when off-load, although these were about 2 dB less than the PLA PSU when off-load. Clearly there are many different types of switch-mode power supply that can be plugged in to the mains and some of these may cause significantly more intermodulation than the two types mentioned above.

4.2.2.3 Conclusions

Although the introduction of spectral notches into PLT systems shows a very useful improvement in reducing the interference potential to the amateur and amateur satellite services of in house PLT

systems, the measurements resulting from these experiments have demonstrated that the effects of non-linearity in other devices can have a major effect in significantly reducing the depths of the notches. Nevertheless, the notches still perform a valuable function even when intermodulation is present, but the effects of intermodulation can be best minimized by a reduction of the power levels applied to the mains distribution system.

5 Overall conclusions

This Report illustrates the potential for interference to various radiocommunication services in the presence of emissions from PLT systems and devices. The Report describes the radio frequency emission characteristics of PLT systems as well as the characteristics and protection criteria of radiocommunication systems that are impact by PLT systems. Additionally, potential methods for mitigating interference from PLT emissions are discussed.

Annex 1

Noise, radiation and propagation considerations

A1 Noise, radiation and propagation considerations

A1.1 Noise level in the HF band

This section provides a general explanation of noise in the HF band (3-30 MHz). More detailed reference is made to noise levels in the individual radio spectrum users' sections of this Report.

The sensitivity of a high-grade radio receiver is determined by the noise generated in its low-level signal stages. This noise is generated by active components within the equipment. This noise level defines the ultimate sensitivity of the receiver. In the HF radio spectrum however, communication is not generally limited by the internal noise in the receiver, but by other noise sources external to the receiver itself. These noise sources, taken together, comprise the *ambient noise environment*.

A1.1.1 The ambient noise environment

In the HF band the external noise environment consists of two parts: the irreducible residual ambient noise which is predictable and which may vary with season, time and location, and incidental noise from local man-made sources. The combination of these two determines the minimum usable signal level. These have been termed the ambient noise floor and incidental noise, respectively.

The incidental noise generated by devices compliant with relevant EMC standards can greatly exceed the noise floor. Despite this, reception of low-level HF signals is possible because of the random and therefore probabilistic nature of the incidental noise. Many devices radiate near the limit of their standard on only a few discrete frequencies, or on a narrow-band of frequencies. In addition, most incidental noise is relatively short lived.

HF communication services have to take account of the variable nature of HF propagation. The operating frequency and time of transmission need to be chosen so as to optimize the probability of achieving a satisfactory signal to noise ratio. Some systems in the fixed and mobile services have sufficient flexibility in their operating protocols that the transmission is repeated at a later time

when the interference has ceased if incidental noise prevents radiocommunication at a particular time. In the case of automatic or adaptive systems this functionality may be built into the operating protocol. In contrast the HF broadcasting service typically has to maintain a satisfactory quality of services on a particular frequency, to a particular target area, for periods ranging from half an hour to several hours duration in the face of variable propagation conditions.

Natural noise sources

- a) Atmospheric noise, a major source of which is almost continuous lightning activity around the equator from which interference is propagated to the rest of the world by ionospheric reflection. The overall noise level depends on frequency, time of day, season of the year and location. In temperate zones, noise from this source is relatively low, although there will be short bursts of noise from local electrical atmospheric activity at certain times.
- b) Cosmic noise, originating from outer space, mainly the Sun and the Milky Way (the latter contribution also known as galactic noise). In the HF band, the cosmic noise reaching the antenna depends on the screening effect of the ionosphere and will generally be at levels below that of man-made noise. At lower HF frequencies it is impractical to distinguish between cosmic noise and the general background noise from other sources.

Man-made noise sources

Man-made noise is composed of two parts:

The first results from a large number of relatively distant sources. This is effectively white noise and one of the constituents of the ambient noise floor. The environments are often classified as city, residential, rural and quiet rural. Man-made noise derives from electrical, electronic or radio equipment. From the radio user's point of view, the difference between these environments is the level of the noise and the length of time for which it persists.

Secondly there is incidental noise from local sources, the level of which varies depending on the type of environment and the density of usage of nearby equipment. In rural and quiet rural locations incidental noise may be expected to be rare, and HF communication is optimal.

A1.1.2 Measuring the ambient noise floor

Measurements of the ambient noise floor have been carried out by a number of organizations including the MASS Consultants, BNetzA, BBC, Qinetiq⁸ and the RSGB⁹. Making these measurements requires great care. In particular it is essential to select a radio frequency that is not occupied by an existing radio signal. Intentional radio signals around any particular frequency must not be confused with noise.

Because of high occupancy levels in the HF bands, and the necessary method of measurement a simple frequency sweep within an HF band using a typical EMC measuring receiver with a standard 9 kHz bandwidth will not provide a true measure of the background noise level. Furthermore, measurements made with a typical loop EMC measuring antenna may be limited by the noise of the receiver system, not the environmental noise.

To carry out a swept measurement of the true ambient noise floor at HF, a much narrower bandwidth than 9 kHz – something on the order of 100-200 Hz – should be used. This is then converted to a 9 kHz bandwidth for comparison purposes.

⁸ Qinetiq is the [British defence technology company](#), formed from the greater part of the former government [Defence Evaluation & Research Agency \(DERA\)](#), June 2001.

⁹ Radio Society of Great Britain.

Usually it is impractical to measure the ambient noise floor in industrial or business locations where the incidental noise will exceed the noise floor all the time. In a residential location it is usually quite practical to choose a period when there is no significant incidental noise. This assumes that measurements are taken at a reasonable distance (greater than 10 m) from any building or dwelling, and that the measuring antenna is suitably located. In interpreting published plots of the ambient noise floor, it is important to take into account the conditions of measurement, particularly the bandwidth, the detector used, peak, quasi-peak or average, and the type of antenna.

A1.1.3 Determination of the noise level

The following are relevant extracts from Recommendation ITU-R P.372. Data on atmospheric radio noise from lightning were obtained in an extensive CCIR study undertaken in the 1960s, although global warming may lead to changes in the incidence and intensity of thunderstorm activity, and although a re-examination of the analysis might be beneficial to provide evidence whether these data may have changed with time, there is no basis for expecting that these data have changed with time. Data on man-made noise is based on an analysis undertaken in the USA, largely in USA environments, in the 1970s.

The levels contained in the Recommendation are used as a reference throughout this Report although the question remains whether they represent levels present today in Europe. CEPT has undertaken a noise floor measurement campaign in Europe to evaluate if the noise floor levels in the LF, MF and HF bands given in Recommendation ITU-R P.372 are representative or not of the levels present today in Europe.

A1.1.3.1 Thermal, man-made, cosmic and atmospheric noise levels

In order to be able to deal with the major types of modulation used in HF radios, the interference calculations of noise and interference are based on a reference bandwidth of 1 Hz.

The noise sources considered are thermal noise inherent to radios and man-made as well as radio noise mentioned in Recommendation ITU-R P.372.

Thermal noise per Hertz:

$$N_0/\text{Hz} = kT_0 \text{ W/Hz}$$

where:

$$k: \text{ Boltzman's constant} = 1.38 \times 10^{-23} \text{ (J/K)}$$

$$T_0 = 290 \text{ K}$$

The radio noise described in Recommendation ITU-R P.372 is used for the calculations. It contains man-made, cosmic and atmospheric noise components. The details are as follows:

The median value above kT_0 is as follows:

$$F_{am} = c - d \log (f) \quad \text{dB}$$

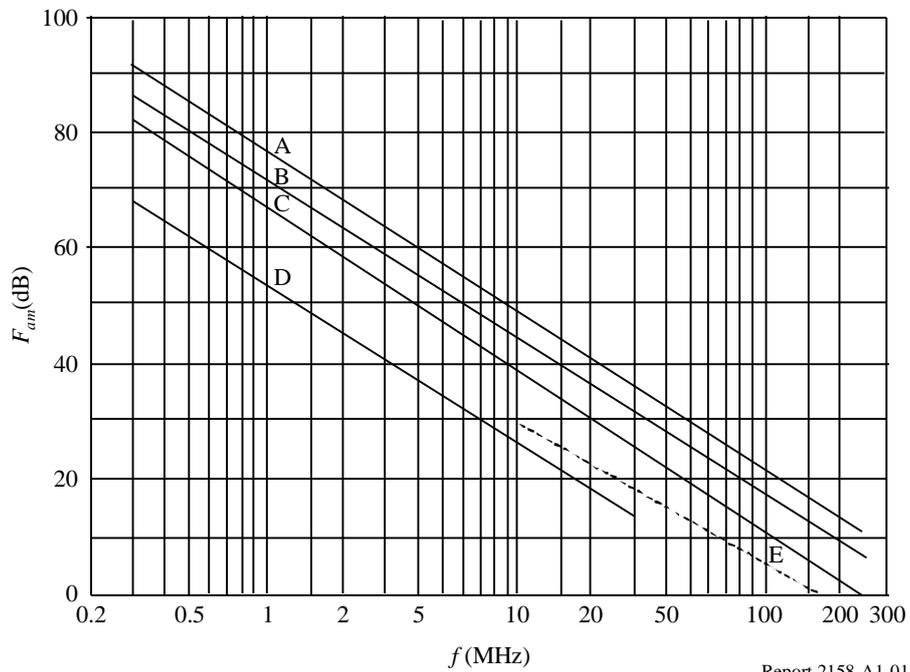
The values for c and d can be found in the above ITU-R reference and f is frequency (MHz). The values are as follows:

TABLE A1-1
The constants c and d of Recommendation ITU-R P.372 for various types of area

Type of area	c	d
City	76.8	27.7
Residential	72.5	27.7
Rural	67.2	27.7
Quiet Rural	53.6	28.6
Cosmic (10-80 MHz)	52.0	23.0

The corresponding levels are given in Fig. A1-1:

FIGURE A1-1
Median values of man-made noise power for a short vertical loss less grounded monopole antenna (Recommendation ITU-R P.372, Fig. 10)



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Environmental categories: Curve A: City Curve D: Quiet rural
 Curve B: residential Curve E: Cosmic noise
 Curve C: Rural

The atmospheric noise is modelled as follows:

TABLE A1-2

Formulae reflecting the level of the atmospheric noise, 99.5% value exceeded

Frequency range (MHz)	Formulae
1.5-10	$F_a = 27.8 - 0.35 (8.2 - f(\text{MHz}))^2 \text{ dB}$
10-15	$F_a = 46.4 - 1.98 f(\text{MHz}) \text{ dB}$
15-20	$F_a = 66.8 - 3.34 f(\text{MHz}) \text{ dB}$
20-30	0

These formulae were derived from Recommendation ITU-R P.372 using a graph that represents the 99.5% of time value exceeded situation and f is frequency (MHz). The above formulae were derived for this exercise only. Therefore, although the formulae do not fully match the original graph at points where the influences of other components are dominant, the final results are in practical terms correct and valid.

A1.1.3.2 Updated noise measurements for Europe

In June 2002, CEPT/ECC WGSE asked ECC FM22 in a liaison statement to conduct a European measurement campaign in the LF, MF and HF bands to evaluate the noise floor levels given in Recommendation ITU-R P.372-8. The question was asked to help its Project team SE35 in its technical work concerning the compatibility between cable transmission systems and radio services.

Recommendation ITU-R P.372-9 was most recently updated in 2007 although the noise floor figures are unchanged. The man made noise results continue to be based on analysis in the 1970s, largely of measurements made in the USA. There are some proposals which assume a limited increase of the existing noise floor and therefore it is essential to have correct values of the present noise floor level.

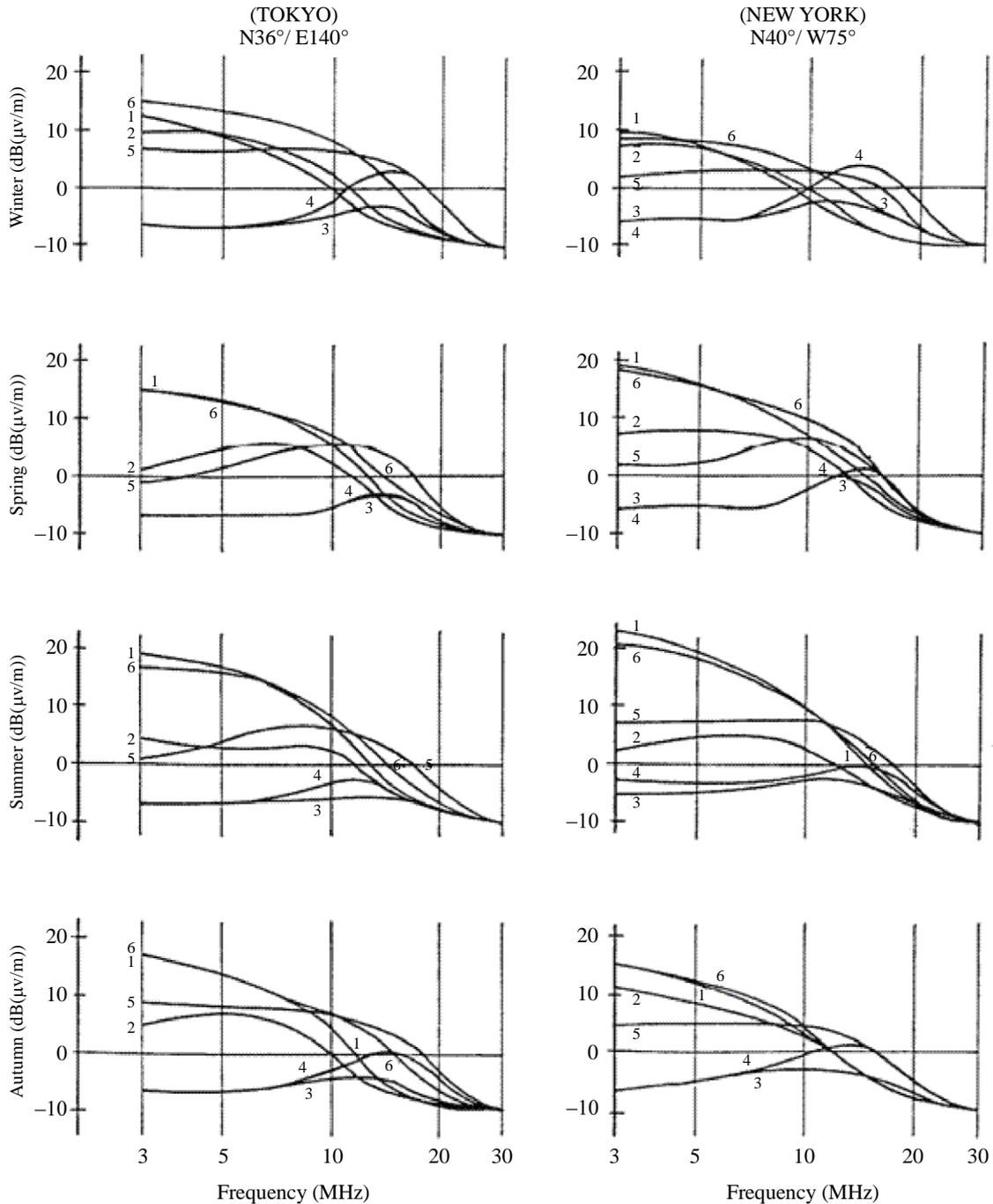
FM22 organized a measurement campaign in Europe in November 2002 and used the SE35 proposals for the measuring method and procedures as mentioned in the liaison statement. PT SE35 individual members and organizations such as NATO and the European Radio amateur Association indicated their willingness to contribute to the study. The results of the European measurement campaign were ambiguous and it became clear that the goal of obtaining comparable results was much more complicated than it seemed at the start of the campaign.

In The Netherlands, a group of experts from military bodies, industry, amateurs and the Radio Communication Agency started a study. In parallel, a study was carried out in FM22.

Soon it was clear that the measurement method and procedures used in the United States of America in the 1970s could not be reproduced, and that a properly described measuring method should be developed.

FIGURE A1-3

Examples of atmospheric noise field strength (Tokyo, New York)



- 1 0000-0400LT
- 2 0400-0800LT
- 3 0800-1200LT
- 4 1200-1600LT
- 5 1600-2000LT
- 6 2000-2400LT

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Recent studies undertaken by MASS consultants in the United Kingdom used modern technology to obtain large data sets enabling good statistical analysis. Methods have been developed for obtaining the noise figure, producing data for the eventual modification of the information in the Recommendation. A method was also developed for determining the statistical characteristics of the impulsive component; see Report ITU-R P.2089. These results have been entered into the

Radiocommunication Study Group 3 noise databank along with similar results from studies carried out in Germany.

The levels of man-made noise found in both these studies are of the same order of level as those in the Recommendation, leading to the view that there have not been major changes in the past 30 years – perhaps increased electrical usage has been compensated by improved suppression techniques. However more results are needed before any revision to the Recommendation could be considered with confidence.

Recommendation ITU-R P.372 provides estimates of noise levels across the spectrum for man-made, atmospheric and cosmic radio noise. At HF, in most situations, it is man-made noise that dominates, although there are situations at low-noise radio sites, for example, where atmospheric and cosmic noise may be the limiting noise level. It is not expected that the noise level caused by natural sources will have changed since the advent of the models in Recommendation ITU-R P.372. However, man-made noise may change according to industrial activities.

A1.1.4 Long-term man-made noise measurements in Germany

Description of the measurement campaign

Since 2008, a measurement campaign covering 23 locations in Germany has been carried out. The campaign has been focused on the protection of safety-related receiving stations from interference caused by wired telecommunication installations and networks in the frequency range below 30 MHz. The locations are spread relatively evenly over the territory of Germany.

The detailed measurement method is described in Report ITU-R SM.2155. Within the local MMN (man-made noise), the MMN components – i.e. WGN (white Gaussian noise), IN (impulse noise) and SCN (single carrier noise) – have been analysed separately. Once a year, measurements over 24 hours are made and recorded. The individual annual records have been analysed for significant changes in the location-based noise value. Furthermore, the annual records of all safety-related locations have been compared to identify a medium-term trend of the general noise values at these locations.

This study has been focused on measuring the increasing noise and on concrete interference caused by wired telecommunication installations and networks in the frequency range below 30 MHz. The wired telecommunication installations and networks in question include CATV (upstream), PLC, LAN/WAN, and VDSL. The frequency ranges 5.3 MHz, 12.7 MHz and 20.2 MHz represent the assessment frequencies of the above-mentioned technologies.

For the assessment of interference at the location of the operator, it is important to know whether the interference comes from local sources or from far away via the sky wave. Therefore, time synchronized measurements were carried out at the safety-related location, at a location at the nearest locality (town or village) and at a reference location (RF-quiet position, 1 to 20 km away).

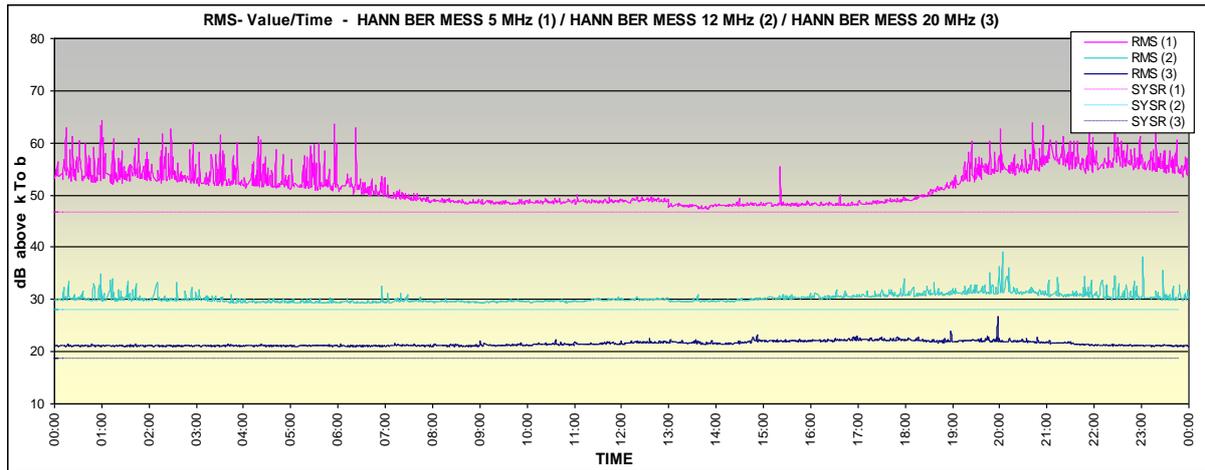
Example of a 24-hour record of the local WGN (5 MHz, 12 MHz and 20 MHz)

Figure A1-4 shows an example of the recorded WGN (scale: dB above kTB) over 24 hours. The WGN graph depends on the time of the day due to different propagation conditions. The dotted lines represent the sensitivity of the measurement equipment.

FIGURE A1-4

Example of a 24-hour record of the local WGN (5 MHz, 12 MHz and 20 MHz)

HANN BER MESS – Start: 06.04.2011 – 13:00 Stop: 07.04.2011 – 13:00



Summary of the results

The MMN measurements on the representative frequencies (5 MHz, 12 MHz and 20 MHz) of the wired telecommunication installations and networks carried out from 2008 to 2012 in Germany have led to the following preliminary results:

- In the current campaign, no clear trend towards increased WGN values has become evident so far at the observed locations in Germany.
- On average, in all measurements, the highest WGN values were found in the years 2008 and 2009, while the lowest WGN values were found in the years 2010 and 2011. The results for 2012 are in the mid-range of all results obtained in the previous years.
- The variation of the WGN values determined in the annual measurements ranges in most cases from 5 dB to 10 dB. In some cases, variation ranges of more than 10 dB were observed.
- The general trend of the measurement results is largely independent of the environment category of the safety-related receiver station or the environment category of the nearest locality (city, residential or rural area).
- Interference to safety-related receivers caused by wired telecommunication systems could not be found at all of the 23 operator locations in Germany.

A1.2 Propagation mechanisms

A1.2.1 Near-field and ground-wave propagation

The occurrence of line sources in the case of PLT will require the estimation of radiation from a generic portion of the total network tied to one injection point. The estimation can be achieved at distances up to at least 1 km through the application of a modeling package such as numerical electromagnetic code (NEC). To estimate radiated power levels at distances of 1 km or greater where ground wave propagation will occur, the field strength levels may be calculated using the curves in Recommendation ITU-R P.368¹⁰ at frequencies up to 30 MHz. GRWAVE may be used

¹⁰ Available at <http://www.itu.int/rec/R-REC-P.368/recommendation.asp?lang=en&parent=R-REC-P.368-9-200702-1>.

for the entire frequency range under consideration up to at least 80 MHz. A copy of GRWAVE may be obtained from the Radiocommunication Study Group 3 software page.¹¹

For larger distances within line-of-sight, both under or above the power line, Recommendation ITU-R P.525 will be appropriate, and Recommendation ITU-R P.1546 may be used at higher frequencies.

A1.2.2 Sky wave propagation

At HF, the ionosphere is an important factor in allowing relatively weak signals to propagate over long distances, most importantly, through both reflection and refraction from the higher regions - the E and F layers. Absorption can also be a significant factor, particularly in the D-region, the lowest part of the ionosphere, so this mode of propagation can both enhance and attenuate the signals strengths received at large ranges. Because ionization is driven by the Sun, the ionosphere shows diurnal and seasonal variation, depending upon the level of solar activity.

ITU-R Working Party 3L considered that highly geometric arrangements of power lines bearing PLT systems could cause higher and more directional emissions in aggregate than more random distributions.

It may be found necessary to estimate the total radiated power through the aggregation of all of the generic portions for an area, e.g. a city. If cumulative effect(s) of multiple access PLT systems occur, they could contribute to or be the origin of skywave propagation which goes to long distances depending on the frequency. A methodology has been provided for further study at Annex of document, which is intended to provide a means of estimating the effects of cumulative emissions from a large population of PLT sources by skywave propagation.

Based on assumptions made in studies contained in this Report and on additional material that has been considered, the following range of assumptions may be used in skywave aggregation calculations.

Range of assumptions for use in skywave aggregation calculations	
e.i.r.p. per PLT modem ⁽¹⁾	-74 dBm/Hz to -103 dBm/Hz
PLT modems per household	2 to 4
Duty cycle (fraction of time that each modem is transmitting)	0.005 to 0.50
Market penetration (PLT modems divided by total number of households)	0.02 to 0.30

⁽¹⁾ Some studies have used measured values of e.i.r.p. as high as -74 dBm/Hz, while other studies have used radiated power levels as low as -103 dBm/Hz derived from injected power levels and a theoretical conversion factor.

A1.2.3 Examples of propagation calculations and studies

The following list contains examples of work done on relevant radio wave propagation modes:

- 1 NTIA Report 04-413 – Potential interference from broadband over power line (BPL) systems to Federal Government Communications at 1.7-80 MHz – Phase 1 Study. Can be obtained from <https://www.ntia.doc.gov/report/2004/broadband-over-powerline-report>.

¹¹ <http://www.itu.int/oth/ROA0400000F/en>.

- 2 Recommendation ITU-R P.368 – Ground wave propagation curves for frequencies between 10 kHz and 30 MHz.
- 3 Recommendation ITU-R P.834 – Effects of tropospheric refraction on radio wave propagation and Recommendation ITU-R P.1546 – Method for point to area predictions for terrestrial services in the frequency range 30 MHz-3 000 MHz.
- 4 Recommendation ITU-R P.533 – Method for the prediction of the performance of HF circuits.

Annex 2

Analyses of potential interference

A2 Analyses of potential interference

A2.1 A modelling analysis for the radio astronomy service

“The potential of harmful interference from PLT systems is highly dependent upon factors such as the characteristics of the local power grid and the design and topology of the particular PLT system. Since these factors vary significantly from one location to another, conclusions drawn from one system and configuration cannot reliably be applied to dissimilar cases. Administrations should take care to base regulatory decisions only on analyses that accurately reflect the national situation.”

PLT systems inject broadband radio frequency energy into a conductor system, which is inherently unbalanced and globally can be found in a variety of configurations, even within one administration. As a consequence of several measurement campaigns it is apparent that a combination of both point and line sources of radiation will occur. The occurrence of line sources will require the estimation of radiation from a generic portion of the total network tied to one injection point.

Estimation of radiation can be achieved at distances up to at least 1 km through the application of a modeling package such as Numerical Electromagnetic Code (NEC). To estimate radiated power levels at distances of 1 km or greater where ground wave propagation will occur, the field strength levels may be calculated using the curves in Recommendation ITU-R P.368¹² at frequencies up to 30 MHz. GRWAVE may be used for the entire frequency range under consideration up to at least 80 MHz. A copy of GRWAVE may be obtained from the Study Group 3 software page¹³.

It may be found necessary to estimate the total radiated power through the aggregation of all of the generic portions for an area, e.g. a city. It is also possible that the power line sources will initiate a sky wave component. In such cases the sky wave field strengths can be estimated using Recommendation ITU-R P.533¹⁴.

¹² <http://www.itu.int/rec/R-REC-P.368/en>.

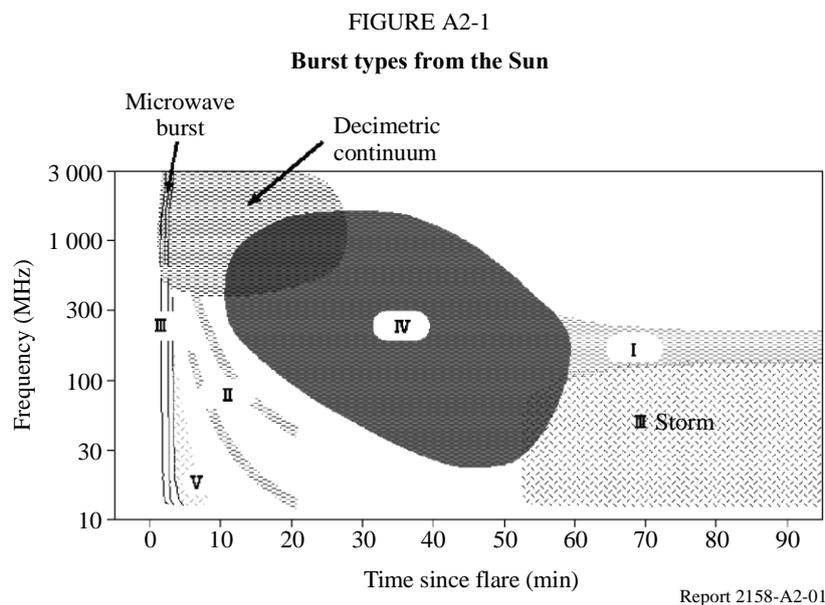
¹³ <http://www.itu.int/ITU-R/index.asp?category=documents&mlink=rsg3&lang=en>.

¹⁴ <http://www.itu.int/rec/R-REC-P.533/en>.

It should be noted that in developing criteria for PLT systems measurement of both E and H fields is necessary owing to the unknown relationship between these fields in the near field to these radiation sources.

A2.1.1 Uses of HF bands by the RAS

The protected bands at 13.36-13.41 and 25.55-25.67 MHz are extensively used by radio astronomers to observe electromagnetic waves emitted by the Sun, Jupiter, pulsars, and many other types of celestial objects. These emissions are mainly produced through synchrotron emission and wave-particle interactions driven by electrons accelerated near to the speed of light, and are distributed continuously across a relatively wide range of frequencies.



The Sun produces radio emissions of many kinds. However, those studied in the HF range are emissions produced by flares and other transient events. The characteristics and classification of these emissions are shown in Fig. A2-1¹⁵. The emissions have a variety of characteristics and occur over a wide frequency range, exceeding 10 MHz to 3 GHz. The Type III bursts and storms are the most frequently observed solar radio emissions in the HF range, although all types occur on occasion, with varying degrees of rarity. Some bursts of solar radio emission are strong enough to interrupt terrestrial radio communications. Since HF bands have many critical applications, such as long-distance aeronautical communications, an ability to predict solar-induced degradation of communication conditions in the HF bands is very important. To address such needs, the National Institute of Information and Communications Technology (NICT) of Japan has been operating the “space weather forecast” for many years.

Additionally, some aspects of the evolution of the Universe just after the Big Bang which are of the greatest current interest can best be studied in the HF and VHF/UHF bands. New radio telescopes such as low frequency array (LOFAR), long wavelength array (LWA) and square kilometer array (SKA) are currently planned to explore this region of the spectrum.

¹⁵ <http://hiraiso.crl.go.jp/>.

A2.1.2 Separation distances between a RA antenna and a PLT system in the HF region

A2.1.2.1 The PLT system used for the study

A High frequency PLT system using the frequency band 2-30 MHz has been proposed in several countries. Since power lines are not designed with HF communication applications in mind, transmissions are highly attenuated. To compensate for the losses, the proposed systems use high transmitted powers (e.g. -50 dBm/Hz, which is the value used in this study). Consequently power lines carrying PLT signals will radiate significant power in the HF bands.

The gain of the antenna formed by the power line is assumed to be -20 dBi¹⁶.

A2.1.2.2 Calculations

A generally-applicable calculation of the power received from a PLT system by a radio telescope antenna would be very difficult. The geometry of the wire(s) carrying the signals and their distances from conducting and dielectric structures need to be considered. In addition, compared with the wavelengths, the “antenna” may be close to the ground. At frequencies below about 30 MHz, the ionosphere may be a major factor in the propagation of the emissions.

Equation to calculate received power by a RAS antenna

The received power by a radio astronomy antenna is calculated by:

$$P_r = P_t - L_{bf} + G_r \quad (\text{A2-1})$$

where:

P_r : received power by the radio astronomy antenna (dBW)

P_t : transmitted power at a distance of 30 m from the transmitter (dBW)

G_r : antenna gain of the radio astronomy antenna toward the transmitter (dBi)

L_{bf} : propagation loss beyond 30 m from the transmitter (dB).

Given the radio astronomy antenna gain (0 dBi) and gain of power line (-20 dBi), it is necessary to evaluate P_t and L_{bf} before calculating the power received by the radio astronomy antenna. Establishing P_t will be difficult. Estimating L_{bf} will require consideration of many factors in addition to the geometric path loss, such as the role of nearby conducting and dielectric structures, wave interference and ionospheric propagation.

We assume a distance of 30 m. We therefore show here a calculation for that distance, and then discuss the application of such a model to other distances.

Calculations of transmitted power at a distance of 30 m from the transmitting antenna

It is possible to calculate the transmitted field strength at a distance of 30 m, E , from a transmitter by using equation (1) in § 2 of Recommendation ITU-R P.525 as follows:

$$\begin{aligned} E &= \frac{\sqrt{30G_t P}}{d} \\ &= 408 \text{ } (\mu\text{V/m}) \text{ (in the 13 MHz band)} \end{aligned} \quad (\text{A2-2})$$

and

$$E = 633 \text{ } (\mu\text{V/m}) \text{ (in the 25 MHz band)}$$

¹⁶ MUTO, K., MANABE, K. and MORIMOTO, T. [2001] On the EMI / EMC issues in the Power Line Communication. 12-6, Records of Shikoku Sections Joint Convention of Institutes of Electrical Engineering of Japan (in Japanese).

G_t and d denote antenna gain of the PLT system (dBi) and distance from the transmitter, respectively. Then the field strength is converted into power by using equation (8) in § 4 of Recommendation ITU-R P.525:

$$P_r = E - 20 \log f - 167.2 \quad (\text{A2-3})$$

where:

- P_r : expressed in dBW
- E : dB(μ V/m), and
- f : GHz..

Therefore the received power by a radio astronomy antenna with the gain of 0 dBi and located 30 m from the transmitting antenna (power line) is given as:

$$P_r = -77.52 \text{ dBW (in the 13 MHz band)}$$

and

$$P_r = -79.34 \text{ dBW (in the 25 MHz band)}$$

These values are far above the protection criteria of the RAS receivers. This calculation, even for this small separation distance, is worthy of consideration because in general, radio telescopes are connected to power lines. However, this result underlines the need to keep PLT systems as far as possible from radio telescope antennas.

Received power at distances exceeding 30 m from the transmitting antenna

Calculation of the power received at distances exceeding 30 m from the transmitting antenna is difficult. In general, the calculation of received power at large distances from antennas is based upon the assumption that characteristic size scales in the antenna are small compared with the range, or else that they have a uniform distribution to infinity, as in the case of an infinite, straight wire). In general, PLT systems will not satisfy these assumptions. However, the free-space calculation has value for illustrative purposes.

Recommendation ITU-R P.525 provides a model for free-space propagation loss between a PLT system and the antenna of a radio telescope. This model does not include the effect due to atmospheric attenuation. The atmospheric attenuation is only 2.5×10^{-2} dB/km (Fig. 1 of Recommendation ITU-R P.676), therefore we neglected this attenuation.

The free-space propagation loss between isotropic antennas, L_{bf} , is given in equation (4) in § 2.2 of Recommendation ITU-R P.525 as:

$$L_{bf} = 32.4 + 20 \log f + 20 \log d \quad (\text{dB}) \quad (\text{A2-4})$$

where:

- f : frequency (MHz)
- d : distance between the RAS antenna and the PLT system (km).

However, a more realistic approach would be to use a more deterministic analysis, such as that being developed within Working Party 9C. This will include modeling emissions received from power lines over ranges from 10 to 1 000 m.

Calculations of separation distances

In the estimation of separation distances, at least two main propagation modes need to be considered: direct path propagation, including terrain effects, and ionospheric propagation.

a) *Direct path calculation*

Using the arguments above, we can estimate the separation distance, d .

At the 13 MHz band, $L_{bf} = 107.48$ dB and $d = 424$ km. Similarly at the 25 MHz band, $L_{bf} = 108.66$ dB and $d = 253$ km.

In this propagation mode, a separation distance of up to 424 km is needed to protect the HF radio astronomy antenna from interference caused by a single PLT system. More realistically, multiple transmitters should be considered, some of which are driven with the same signals but at different distances from the radio telescope antenna.

b) *Ionospheric propagation*

At HF frequencies, the ionosphere is an important factor in allowing relatively weak signals to propagate over long distances, through both reflection and refraction. Absorption can occur in the D-region, the lowest part of the ionosphere. So this mode of propagation can both enhance and attenuate the signals strengths received at large ranges. The ionosphere is driven by the Sun, and also shows diurnal and seasonal variation, so depending upon the level of solar activity, the signal strength received at large distances may vary by more than 60 dB. Therefore, this propagation mode becomes the dominant factor in the reception of PLT emissions at large distances, and may, on occasion, provide world coverage.

A2.1.3 Discussion

Realistic assessments of the interference potential of PLT systems on radio telescopes are not easy to make. There is initial value in simplified instances and case studies, as discussed in this section.

A2.1.3.1 Multiple PLT systems

It is clear that the PLT system consists of multiple modems to communicate. Thus it is necessary to consider a case where there are a significant number of PLT modems. The ADSL system has been introduced and more than 1 000 000 systems are already used in many countries. Therefore we assume that 10 000 PLT modems are deployed in an area. In this case the aggregate transmitted power from the PLT system becomes 10 000 (= 40 dB) higher than the case for a single system, and, even in the simple case of direct path reception, the necessary separation distance to protect the RAS antenna becomes 20 dB larger, i.e. the distance is larger than the radius of the Earth.

A2.1.3.2 Diffraction propagation

Diffraction around the curved surface of the Earth is an important factor in the propagation of radio waves over large distances. Recommendation ITU-R P.526 provides guidance for the development of a diffraction propagation model, and its Annex provides monographs to get propagation loss due to diffraction relative to the free-propagation case. For example, Fig. 2 of Recommendation ITU-R P.526 provides diffraction loss due to the spherical Earth as a function of distance.

The figure shows that the diffraction loss is larger for distances of 38 km or more (at 25 MHz and $k = 1$, where k is the effective Earth radius factor, defined in Recommendation ITU-R P.310), and that additional loss of about 20 dB is obtained for a distance of 100 km. However these monographs also suggest that diffraction does not give very much additional loss if the separation distance is not so large.

A2.1.3.3 Reduction of leaked emission from the PLT system

It cannot be ruled out that there will be technical and operational methods available that may significantly reduce the emission of radio signals by power lines below the levels assumed here. This could have significant ramifications for discussions of compatibility. For example, assuming direct-path, free-space propagation, reducing the leaked emission by 60 dB, the separation distance

between the HF RAS antenna and the PLT system becomes about 0.4 km, reducing the separation distance needed by a factor of about 1 000. In such a case it would be possible to deploy 10 000 PLT modems by establishing an exclusion zone of a radius of 40 km around each RAS telescope. If the degree of reduction is less than 60 dB, the radius of the exclusion zone becomes larger accordingly.

A2.1.3.4 Radiation at higher frequencies

Power distribution systems have not been designed with the carrying of HF signals in mind. In addition to the various resistive and reactive components, there are almost certainly non-linear characteristics, for example oxide layers, coatings on insulators, discharges in humid atmospheres etc., which will generate harmonics and intermodulation components that could extend too much higher frequencies than the frequency of the PLT. These should also be considered. However, in these cases the propagation issues may be less complicated.

A2.1.4 Conclusions

Models for assessing the impact of HF emissions from PLT systems upon the operation of radio telescopes are still at a rudimentary stage. Adequate separation distances will be an important factor in the protection of radio telescopes from these emissions. A simple, direct-path, free-space propagation model indicates a maximum protection distance of about 420 km. However, this could be changed by local terrain effects and by the ionosphere, which may, under some conditions, enable emissions to propagate over continental distances, or even world-wide. In a more realistic assessment, multiple sources, at least some of which are driven with the same signals and at differing distances from the radio telescope, would need to be considered. If methods become available that would reduce the emission by about 60 dB, the compatibility issue between PLT and radio observatories would become much less difficult, so that band sharing between radio astronomical observations and PLT systems could become more demonstrably viable.

The radiation of intermodulation products and harmonics due to non-linearities (at radio frequencies) in the power line components may produce emissions at frequencies much higher than the fundamental PLT frequency. These also need to be studied, although in this case simple propagation models may be applicable.

PLT systems may be widely deployed, and once this has occurred, it will be difficult to address compatibility issues with the radio astronomy service and other communication services. This underlines the need for comprehensive studies, including combinations of single and multiple signals, the radiation properties of large, connected networks in environments like those in which PLT systems will operate, and for appropriate measurements of real systems and components. At this point it is not possible to report compatibility; more study is needed.

A2.2 Overview of power line telecommunication systems interference to the broadcasting service

A2.2.1 Introduction

The promise of high speed data communications utilizing the existing electric power infrastructure is an attractive alternative to providing Internet services especially in rural areas. Power Line Telecommunication (PLT) systems use existing medium-voltage and low-voltage power distribution systems to guide the propagation of radio frequency signals and thus, provide access to broadband services. Since power lines are not shielded, emissions along the power distribution lines may occur. PLT emissions by devices without a corresponding frequency allocation in the Radio Regulation are the concern of this overview.

Radiocommunication Study Group 6 has made it clear that the broadcasting service must be protected from interference by devices without a corresponding frequency allocation in the Radio Regulations that produce fundamental emissions in the frequency bands allocated to the broadcasting service. Numerous studies have been made using simulations to determine the potential for PLT interference to various radiocommunication systems^{17,18}. This overview considers two recent studies that are directly applicable to the HF and low VHF broadcast bands.

A2.2.2 Interference effects into low VHF television

Caldwell and Wetmore¹⁹ studied the potential for interference from PLT into the low VHF television band (54-88 MHz). Their analysis simulated different locations in the Los Angeles, California area of the United States. The areas were modelled using the numerical electromagnetic code (NEC) program. One area was a residential neighbourhood in West Los Angeles served by a 12 kV three-phase distribution system with no medium voltage neutral where the transformer primaries are connected between phases. Typical distribution poles (designated as 2 and 6) are illustrated in Fig. A2-2. The overall area covered by the simulation is illustrated in Fig. A2-3. The locations of distribution poles 2 and 6 illustrated in Fig. A2-2 are identified. The PTL point of excitation, E, is located at pole 1.

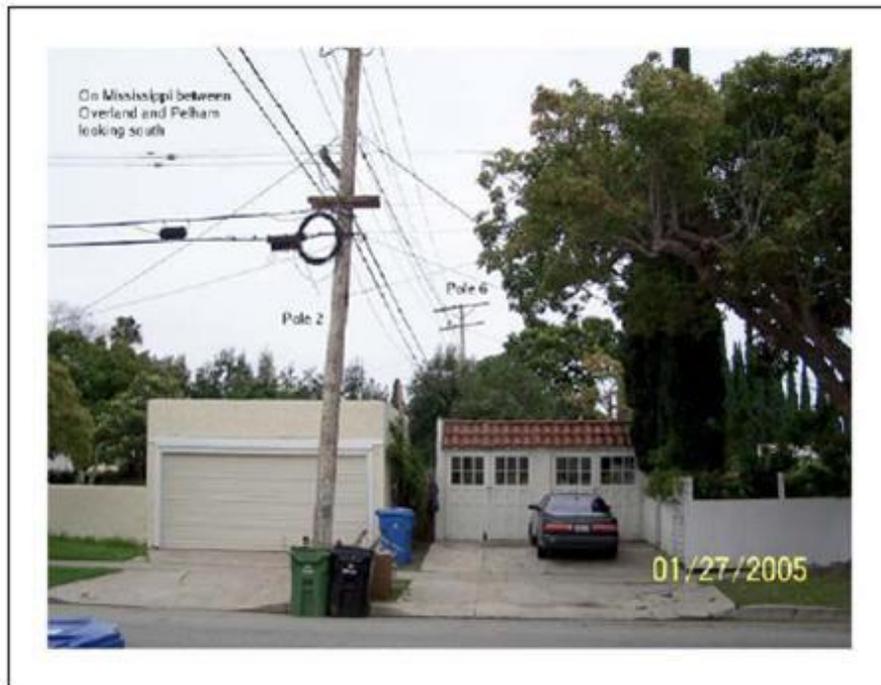
¹⁷ NTIA [April 2004] Potential Interference from Broadband over Power Line (BPL) Systems to Federal Government Radiocommunications at 1.7-80 MHz, Phase I Study. Vols. I and II, NTIA Report 04-413.

¹⁸ HENRY, P.S. [April 2005] Interference Characteristics of Broadband Power Line Communication Systems Using Aerial Medium Voltage Wires. *IEEE Comm. Mag.*, p. 92-98.

¹⁹ WINSTON CALDWELL, M. and WETMORE EVANS, R. [3 February 2005] Fox Technology Group. Interference Effects into Low VHF Television Arising From Broadband Over Power Line. (Filed in FCC ET Docket 03-104 by the Association for Maximum Service Television on 7 February 2005 and available at www.mstv.org/docs/feb72005tech.pdf).

FIGURE A2-2

Example of a power line distribution system in a residential area used in the PLT model with pole 2 in the foreground and pole 6 in the background



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The NEC model used a single frequency tone with an input power level of -56 dBm in a 6 MHz television band. The study considered both direct sequence spread spectrum (DSSS) and orthogonal frequency division multiplexing (OFDM) modulations. If OFDM modulation with 50 evenly spaced carriers is assumed, a compliance measurement using the recommended resolution bandwidth of 120 kHz would measure 1/50th of the existing signal power in the 6 MHz channel. Therefore, $10 \log_{10}(50) = 17$ dB should be added to properly reflect the aggregated increase to the signal power due to the multiple OFDM carriers.

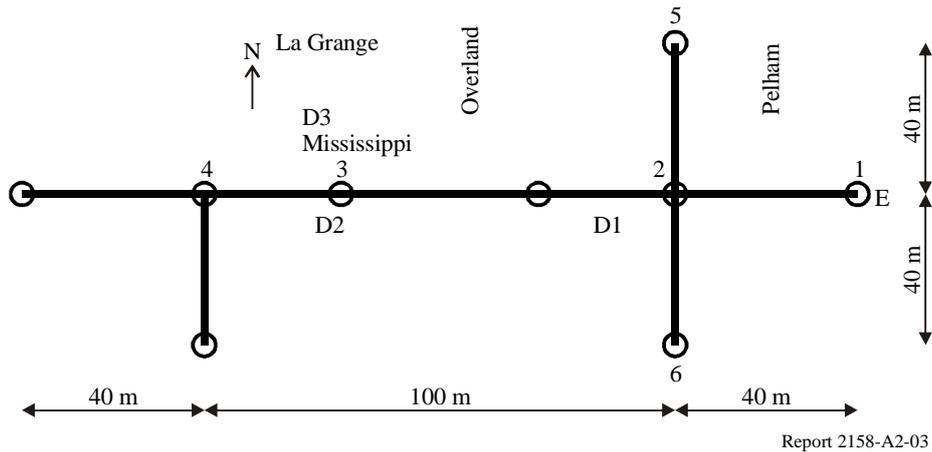
Three half-wave dipoles were placed at locations at a height of 9.1 m above ground level. The placement of the dipoles simulated television receive-antennas placed on houses located within the neighbourhood. The received field strength at the dipoles in the presence of the 50 carrier OFDM PLT signal as a function of the television channel (low VHF channels 2, 3, 4, and 5) is illustrated in Fig. A2-4. The signal strength ($\text{dB}(\mu\text{V}/\text{m})$) is compared with the noise threshold at the edge of coverage for an ATSC digital television signal. The noise threshold of $13 \text{ dB}(\mu\text{V}/\text{m})$ is the FCC defining field strength of $28 \text{ dB}(\mu\text{V}/\text{m})$ less the 15 dB SNR required for ATSC²⁰ digital television. The FCC Defining field strength is the value of the field strength required to delineate the coverage area for a digital television station²¹. The FCC planning factors requires the Desired-to-Undesired (D/U) ratio for co-channel interference of ATSC digital television to be greater than +15 dB and +23 dB at the fringe of coverage. Therefore, a PLT signal strength greater than $13 \text{ dB}(\mu\text{V}/\text{m})$ (or $5 \text{ dB}(\mu\text{V}/\text{m})$ at the fringe of coverage) in the presence of a $28 \text{ dB}(\mu\text{V}/\text{m})$ digital television signal will render the television signal unusable.

²⁰ ATSC – Advanced Television Systems Committee.

²¹ FCC [2 July 1997] Longley-Rice Methodology for Evaluating TV Coverage and Interference. OET Bulletin No. 69. Federal Communication Commission, United States of America.

FIGURE A2-3

Layout of power line distribution system in West Angeles, California used to evaluate PLT emissions into the VHF band. The PLT excitation, E, occurs at pole 1

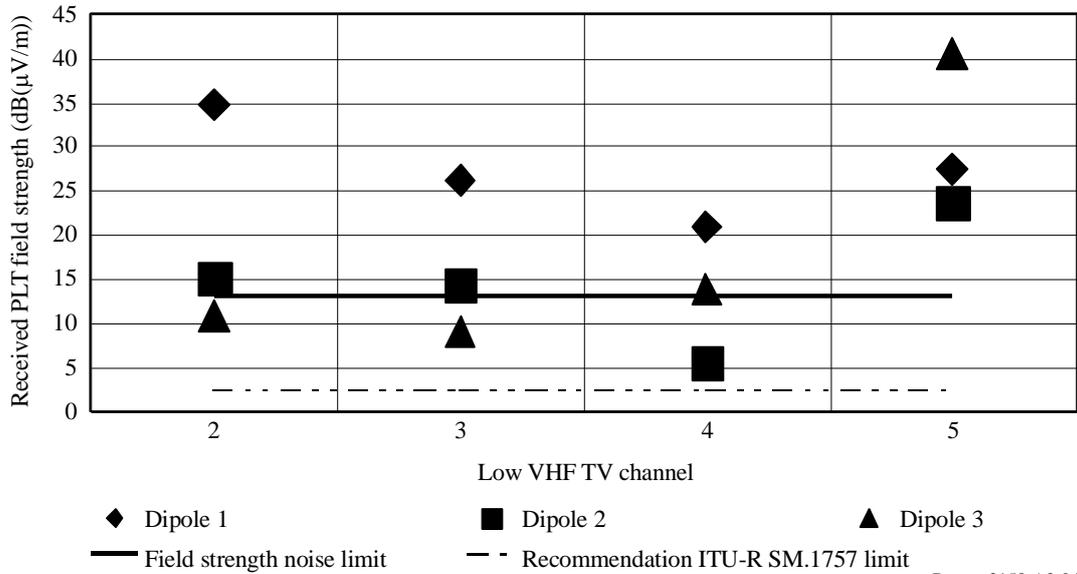


The PLT signal field strength also exceeds the limit set in Recommendation ITU-R SM.1757 for interference from any device without an allocation in the RR (e.g. ultra wideband devices). This recommendation specifies that the power emitted 3 m from the device should not exceed -114.2 dBm over 6 MHz. The equivalent field strength is a maximum of 2.5 dB(μ V/m). The PLT emissions significantly exceed these limits.

In addition, to determining the field strength at discrete points, the study includes plots of field strength (μ V/m) over the entire area of interest. Figures A2-5 and A2-6 illustrate the field strength (μ V/m) of PLT emissions in TV channels 2 and 5 at 4 m above ground level, respectively, over an area of approximately $2\,500$ m². Field strength values over 90 (μ V/m) are considered non-compliant. Points within 10 m of the PLT conductor are not included. It should be noted that the PLT emission, in many locations, exceeds both the FCC and the ITU-R limits for digital TV reception. This study shows that PLT signals although compliant with FCC Part 15 rules will cause material interference to low VHF digital television and render these channels unusable by the broadcasting service.

FIGURE A2-4

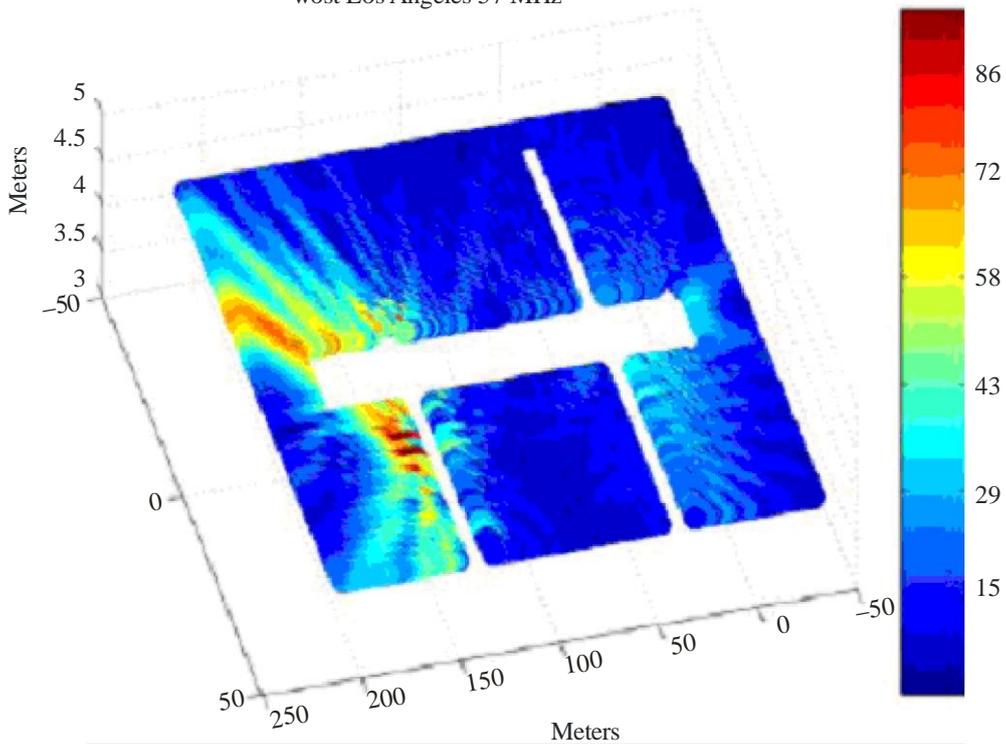
The field strength of a PLT signal received at three locations for the low VHF channels in the West Los Angeles study. The PLT signal simulates an OFDM modulation of 50 carriers with an excitation power of -56 dBm per carrier integrated over the 6 MHz TV band. The plot illustrates that the PLT signal significantly exceeds the field strength used by the FCC to define the area of coverage for a digital television station and the limits of reception



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FIGURE A2-5

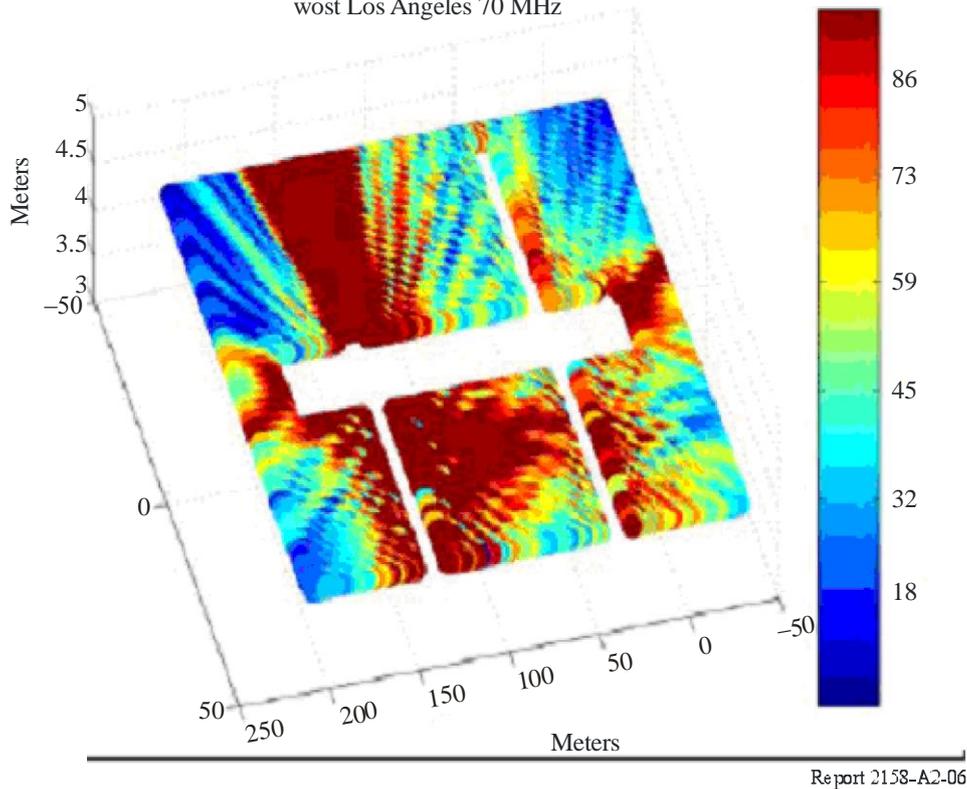
PLT emission field strength (μ V/m) in TV channel 2 at 4 m AGL. Note the strong emissions particularly occurring at the various power line discontinuities west Los Angeles 57 MHz



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FIGURE A2-6

PLT emission field strength ($\mu\text{V}/\text{m}$) in TV channel 5 at 4 m AGL.
 Note the strong emissions vary significantly with respect to the TV channel
 west Los Angeles 70 MHz



A2.2.3 Interference effects into the HF band

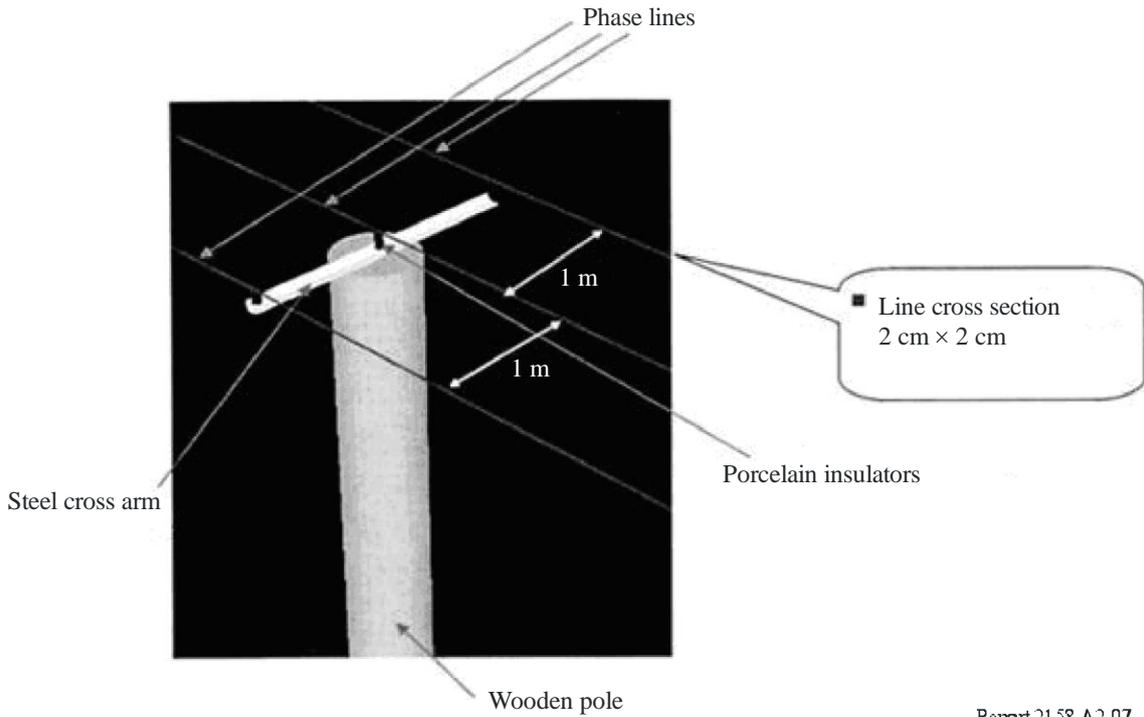
Zhang and Lauber²² have modelled a similar situation in the 5 to 35 MHz band but have included the effects of distribution transformers. They have characterized the PLT system using a three-phase medium voltage line with a neutral line. The lines were spaced 1 m apart at a height of 10 m with the neutral line 0.9 m above the centre phase line. The pole configuration is illustrated in Fig. A2-7.

The electric power distribution system is illustrated in Fig. A2-8. The power line consists of a 360 m straight section with a second 180 m straight section at a 60° angle. Both ends of the line are terminated with transformers in a wye-configuration. For the case presented here the line was also loaded by transformers at two additional locations. The PLT excitation was injected 60 m from the end of the line using a broadband Gaussian source with a power spectral density of -50 dBm/Hz. Zhang and Lauber show that the introduction of inductive reactance of transformers increases the impedance discontinuities and subsequently, undesirable resonances and emissions from the power lines. Their results confirm the observations of Caldwell and Wetmore above that emissions are more prevalent where discontinuities exist in the power distribution system.

²² ZHANG, M. and LAUBER, W. [26-29 March, 2006] Evaluation of Interference Potential of PLT Systems. Proc. 2006 IEEE International Symposium on Power Line Communications and its Applications (ISPLT), Orlando, Florida, United States of America.

FIGURE A2-7

Electric power distribution pole configuration for the Zhang and Lauber* simulation of power line telecommunication interference into the 5 to 30 MHz HF band

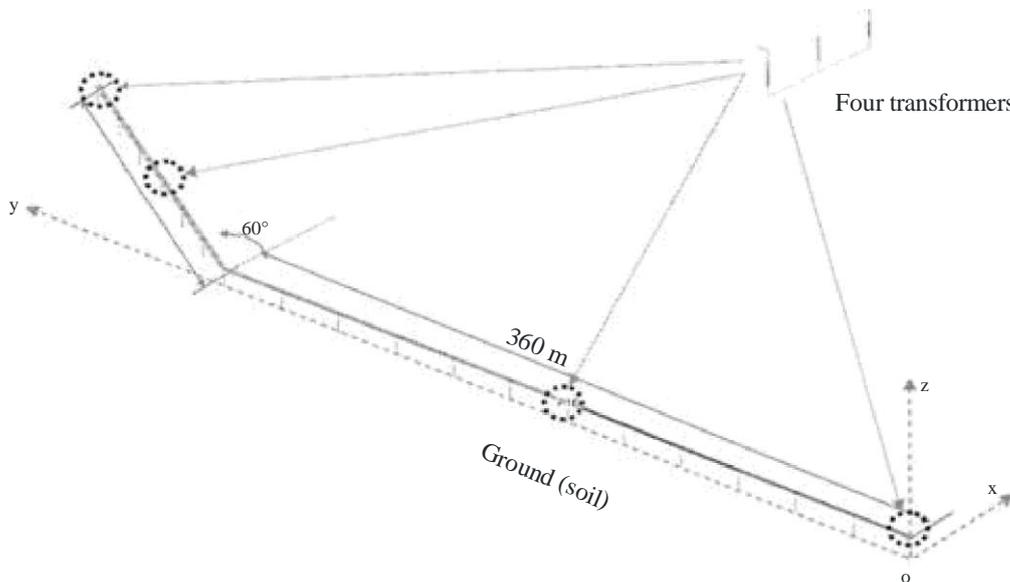


Report 2158-A2-07

* ZHANG, M. and LAUBER, W. [26-29 March, 2006] Evaluation of Interference Potential of PLT Systems. Proc. 2006 IEEE International Symposium on Power Line Communications and its Applications (ISPLT), Orlando, Florida, United States of America.

FIGURE A2-8

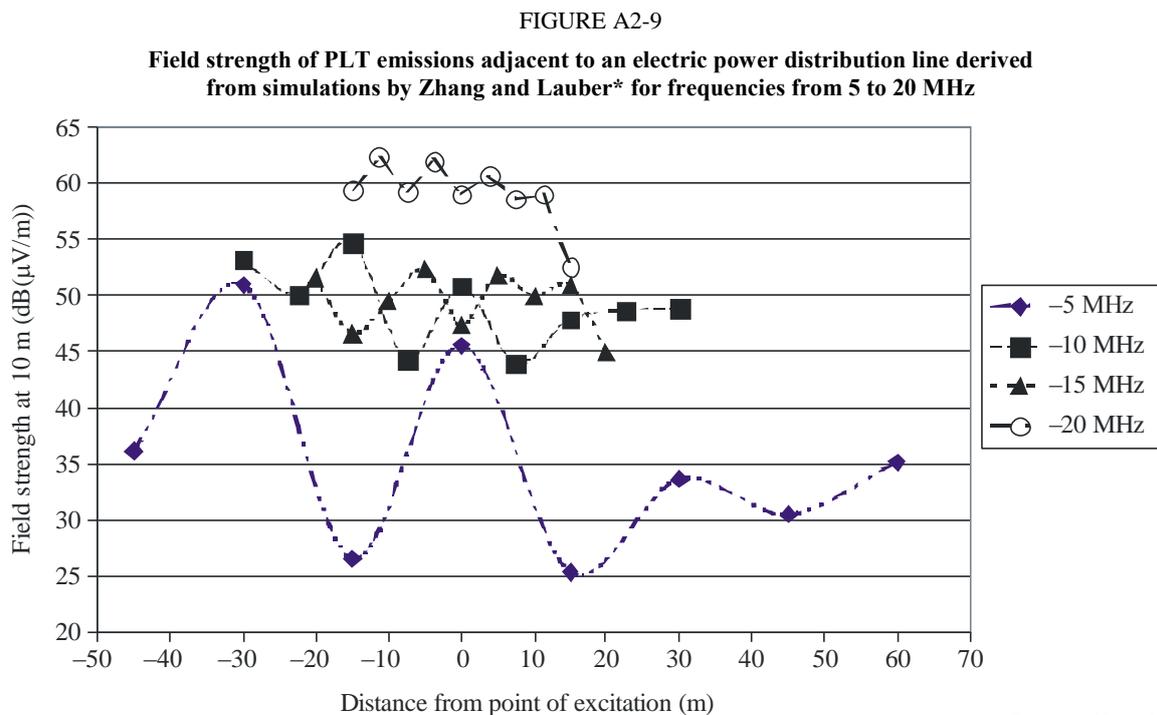
Zhang and Lauber* model for an electric power distribution network containing transformer loading and terminations. The lines are located 10 metres above a good soil ground



Report 2158-A2-08

* ZHANG, M. and LAUBER, W. [26-29 March, 2006] Evaluation of Interference Potential of PLT Systems. Proc 2006 IEEE International Symposium on Power Line Communications and its Applications (ISPLT), Orlando, Florida, United States of America.

Using this model, Zhang and Lauber²³ simulated measurement points at quarter-wavelength distances from the point of excitation. Vertically-polarized measurements were made at a height of 2 m above ground level and at a horizontal distance of 10 m from the nearest conductor. The results are reduced by 3 dB to compensate for the difference between the peak values in the simulation and a quasi-peak detector specified by the FCC limit values²⁴. Figures A2-9 and A2-10 show the simulation results as a function of distance from the point of excitation for 5-20 MHz and 25 to 35 MHz, respectively. Note that standing waves are present on the power line. These standing waves in the presence of impedance discontinuities result in significant resonances at various frequencies and distances along the power line. Figure A2-11 illustrates the net effect of these resonances showing that PLT emissions well in excess of the FCC limits occur along the power line.



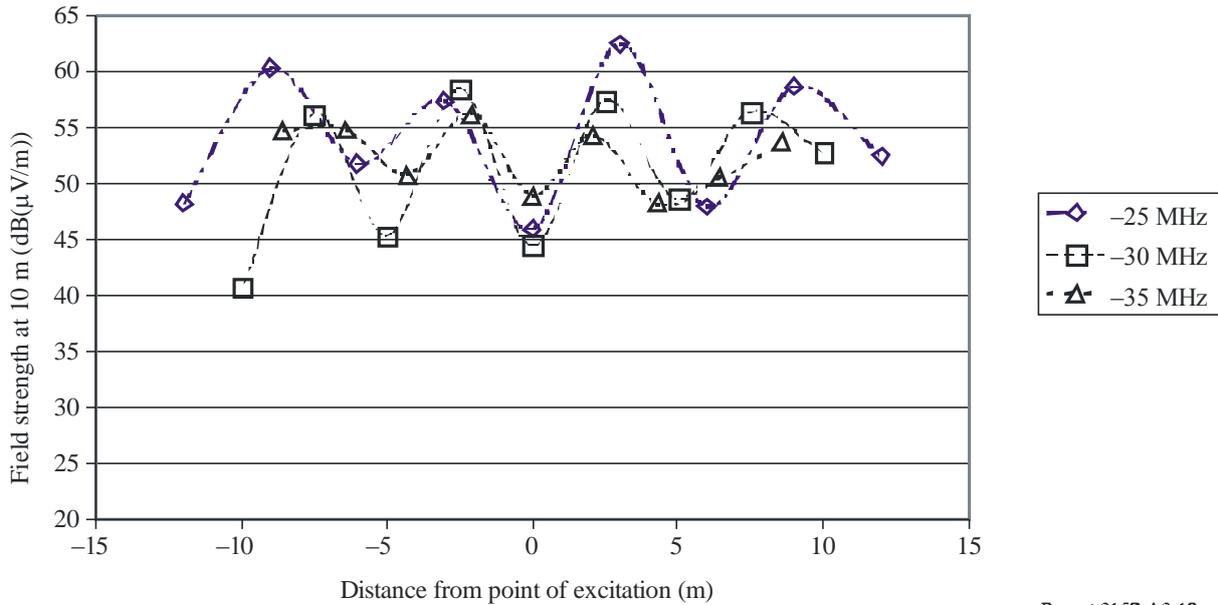
* ZHANG, M. and LAUBER, W. [January, 2006] Evaluation of the interference potential of power line communication systems. CRC Technical Rep. Phase II, VWS-TM-05-06-02, Ottawa, Canada.

²³ ZHANG, M. and LAUBER, W. [January, 2006] Evaluation of the Interference Potential of Power Line Communication Systems. CRC Technical Report Phase II, VWS-TM-05-06-02, Ottawa, Canada.

²⁴ FCC [2004] Report and Order, In the Matter of Amendment of Part 15 regarding new requirements and measurement guidelines for Access Broadband over Power Line (BPL) Communication Systems. Adopted in October 14, 2004 and Released 28 October 2004. Federal Communications Commission, United States of America.

FIGURE A2-10

Field strength of PLT emissions adjacent to an electric power distribution line derived from simulations by Zhang and Lauber* for frequencies from 25 to 30 MHz

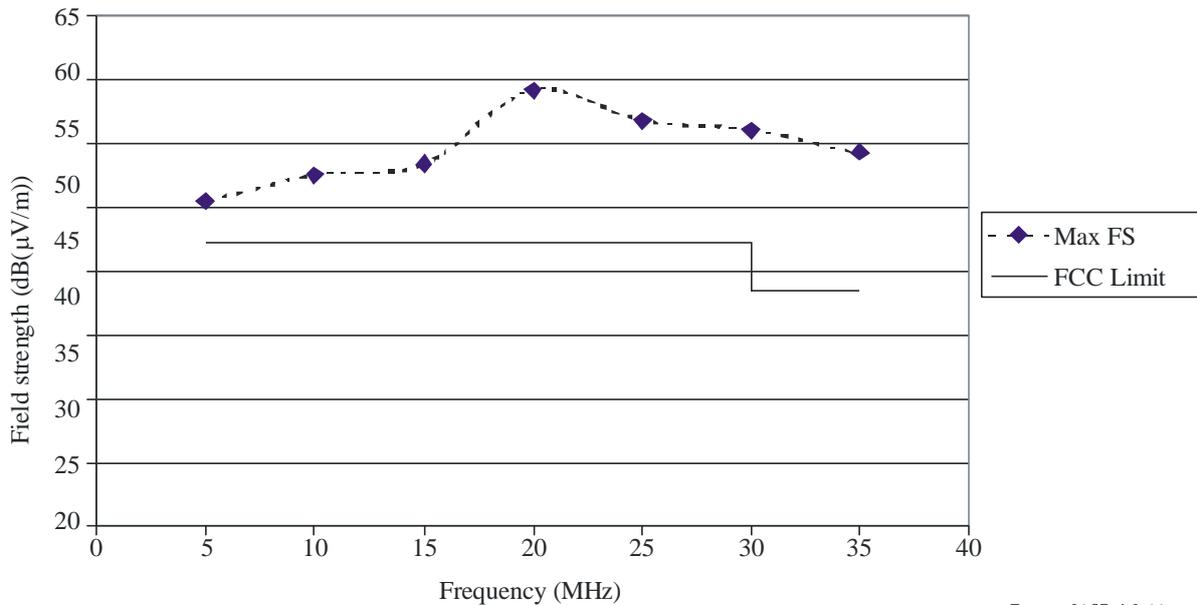


Report 2158-A2-10

* ZHANG, M. and LAUBER,W. [January, 2006] Evaluation of the interference potential of power line communication systems. CRC Technical Rep. Phase II, VWS-TM-05-06-02, Ottawa, Canada.

FIGURE A2-11

Maximum Field Strength of PLT emission occurring along the electric power distribution system simulated by Zhang and Lauber*



Report 2158-A2-11

* ZHANG, M. and LAUBER,W. [January, 2006] Evaluation of the interference potential of power line communication systems. CRC Technical Rep. Phase II, VWS-TM-05-06-02, Ottawa, Canada..

A2.2.4 Summary and conclusions

It is clear that the broadcasting service and its range of operation are limited by the noise floor of the receiving equipment. Consequently, broadcasting services are particularly susceptible to noise emanating in the vicinity of the receive antenna. This overview has illustrated the issue with PLT and the need to restrict the operation of PLT devices within the frequency bands allocated to the broadcasting service.

A2.3 Effects of interference from PLT into the broadcasting service below 30 MHz

The following information is one illustration of the effects of interference from PLT into the broadcasting service below 30 MHz.

Demonstrations of PLT impact on the HF Broadcasting services can be seen and heard on: <http://www.ebu.ch/en/technical/publications/userguides/index.php>. The demonstration called “The digital Haze” is a presentation including an audiovisual demonstration of the interference²⁵.

The demonstration shows that interference from PLT devices and networks affects the reception of the HF analogue services. Moreover, the Broadband interference radiated by the PLT networks can cause the complete failure of the digital services, using DRM system^{26,27}. Because of the trans-border nature of these services, the listeners who suffer interference will not know to whom they should complain. With the expected increase of number of listeners with DRM, this problem may become more frequent and could jeopardize the development of the new digital services. Consequently, the attempts to roll out PLT without taking this into account are of serious concern to the Broadcasting Community.

The only way to prevent, or at least sufficiently mitigate, this problem is to define suitable emission limits of PLT networks, to a level low enough to ensure the protection of the broadcasting service.

A2.4 Methodology for calculation of cumulative HF skywave interference from power line telecommunication systems

This section contains four studies of Skywave aggregation of PLT emissions. In order to determine the aggregate received power level one must first assume the power output and the density of the PLT devices and systems. The cumulative effect of PLT systems from different locations on a given receiver location can then be aggregated, by adding the available received powers²⁸. The four studies include:

²⁵ Download the zip file and keep all files in the same folder after unzip. Run the demonstration in slide show mode with Power point.

²⁶ The Digital Radio Mondiale (DRM) consortium, which has 90 members, including 36 European companies, has developed a new digital broadcasting technology to improve the quality and enhance the capabilities of LF, MF and HF broadcasting compared to those offered by existing analogue systems in these bands. This system is also described in Recommendation ITU-R BS.1514-1.

²⁷ Demonstrations of DRM can be watched and heard on: <http://www.drm.org/system/watchandhear.php>. Many broadcasters have already started live broadcasts in DRM. Their schedule is available on: <http://www.drm.org/livebroadcast/livebroadcast.php>. Comprehensive material on DRM with up-to-date news and events can be found on: <http://www.drm.org/newsevents/pressrelease.php>.

²⁸ It should be noted that in the example calculations included in the studies, results are directly related to the input assumptions.

1 A study done by the governmental Research & Technology Organisation Information Systems Technology (IST) Panel Research Task Group (RTG) on “HF Interference, Procedures and Tools IST-050/RTG-022” calculates the potential impact of world-wide distribution of in-house PLT systems or devices to a specified test location (area-to-point model). It also provides example calculation using Winnipeg, Canada as the specified receiving location.

2 A study done by NTIA analysed the interference potential due to aggregation of ionospheric signals using propagation software, method of moment electromagnetic simulation models of PLT energized power line.

3 A study done by Japan used skywave propagation model specified in Recommendation ITU-R P.533 – HF propagation prediction model (point-to-area model). It provides example calculations involving high angle propagation in the vicinity of Japan.

4 A study done by IUCAF contains compatibility study in relevant to the radio astronomy service in the HF band, based on extraction from the above study done by Japan.

A2.4.1 Governmental skywave interference example into Winnipeg, Canada

A2.4.1.1 Introduction

This section presents the results of the work carried out by the Governmental Research & Technology Organisation Information Systems Technology (IST) Panel Research Task Group (RTG) on “HF Interference, Procedures and Tools IST-050/RTG-022”²⁹, to address the concerns raised by the potential for unintentional radio interference by the widespread operation of broadband wire-line telecommunication systems, such as power line telecommunications (PLT, PLC). The Research Task Group started their studies in 2004, with the participation of an international group of experts, and the final report was published in 2006 for unlimited public use.

A2.4.1.2 Method of calculation for cumulative HF skywave interference from PLT systems

A comprehensive methodology is proposed to predict the cumulative effect of far field (skywave) PLT interference at a receiver location. Given knowledge of all relevant input parameters, the methodology would give accurate predictions. It is well established and easy to explain that the cumulative signal power from large number of unintentional radiators (e.g. PLT installations), as received at a receiver site, can be written:

$$P_{cum}(f, t) = \iint_{x, y} \frac{g_{RX}(x, y, f)}{L(x, y, f, t)} P_{TX}(f) D_A(x, y) \eta_{PEN}(x, y) \eta_{USAGE}(t) dA \quad (A2-5)$$

- $P_{cum}(f, t)$ is the total received power spectral density (W/Hz), at frequency f and time instant t .
- The integral is done over an area with geographical coordinates (x, y) .
- The integral (summation) is performed incoherently, i.e. on a power basis, rather than on an amplitude basis.
- $g_{RX}(x, y, f)$ is the receiver antenna directivity in the direction (azimuth and elevation) of signals originating from a transmitter at point (x, y) . It is important to use directivity rather than gain, in order to be able to compare the result to established background noise levels.

²⁹ The Report and “Cumulative PLT calculation Tool” can be downloaded from:
<http://www.rta.nato.int/Pubs/RDP.asp?RDP=RTO-TR-IST-050>.

- $L(x, y, f, t)$ is the basic transmission loss from point (x, y) to the receiver site. For each frequency it varies with time (as function of solar activity and time of day and year). It is proposed to use the median transmission loss “LOSS” as predicted by ICEPAC³⁰, which calculates a prediction of the amount that the PLT signal will be attenuated under *median* propagation conditions for the given input parameters.
- Note that ICEPAC can estimate $\frac{L(x, y, f, t)}{g_{RX}(x, y, f)}$ directly, if the receiver antenna characteristics are given, which in this case should be normalized by the antenna efficiency to give antenna directivity rather than gain. In the absence of knowledge of receiver antenna, an isotropic antenna can be assumed $g_{RX}(x, y, f) = 1$.
- $P_{TX}(f)$ is the average e.i.r.p. spectral density (W/Hz) of a single PLT installation.
- $D_A(x, y)$ is the population density (persons per unit area). Such demographic data (actual numbers from 2005 and predicted numbers for 2010 and 2015) can be downloaded free of charge from the database “Gridded population of the world”³¹. It is recommended to download “Population Grid” data, which contains the number of people in each grid square, at a grid resolution of 0.25° in BIL format. These data implicitly take into account the different areas of grid squares at different latitudes (and that some grid squares have smaller land areas since they contain partly sea), and hence contain $D_A(x, y)dA$ directly.
- $\eta_{PEN}(x, y)$ is the market penetration (PLT installations per capita).
- $\eta_{USAGE}(t)$ is the duty cycle; the average fraction of time each PLT installation is transmitting. This will be different for different times of day and week; for home installations it is likely to be larger when people are not at work. When considering in-house PLT systems, the market penetration would refer to the number of modems installed, while the duty cycle be averaged over the number of modems (and hence will not exceed 50%, considering that there always will be at least one modem listening to a transmitting modem).
- To estimate the potential of cumulative effect of PLT interference at a receiver site, Working Party 5C recommends the following methodology:
 - Step 1:* Download and import population density data $D_A(x, y)dA$.
 - Step 2:* Estimate $\eta_{PEN}(x, y)$ based on available market information.
 - Step 3:* Select a number of representative operating frequencies, times of day and year, sunspot numbers (SSN) and levels of geomagnetic activity³². For each combination of these, do the remaining steps.
 - Step 4:* Run ICEPAC (ICEAREA_INV) to obtain median values of $\frac{L(x, y, f, t)}{g_{RX}(x, y, f)}$.

³⁰ ICEPAC is part of the IONCAP family of HF prediction programs, which are considered, according to Recommendation ITU-R F.1611, as related models to that contained in Recommendation ITU-R P.533.

ICEPAC is available for download from:

<http://www.itu.int/ITU-R/index.asp?category=documents&link=rsg3&lang=en>.

³¹ Socioeconomic Data and Applications Center (SEDAC), Columbia University, which can be downloaded from the following web site <http://sedac.ciesin.columbia.edu/gpw>.

³² Geomagnetic activity input (Q-index) which represents the effective geomagnetic activity index if the planetary magnetic index K_p is known. Q-index has a range of [0-8], 0 being quiet, 5 is active and 8 is a major storm condition.

Step 5: Estimate values of $P_{TX}(f)$ and $\eta_{USAGE}(t)$, based on available information.

Step 6: Evaluate the integral numerically.

Step 7: Compare the result with the background noise level.

A2.4.1.3 Cumulative PLT tool

The user interface of ICEAREA INVERSE only allows sweeping over 9 different combinations of input parameters, which makes it cumbersome to perform comprehensive analyses. The number of input parameters is five (month, time of day, sunspot number, geomagnetic Q-index and frequency), such that the total number of parameter combinations easily exceeds 1 000, even with a modest number of alternatives for each parameter.

To overcome this problem, the Task Group has developed a MATLAB-based tool “cumulative PLT tool” which will bypass the ICEAREA INVERSE user interface and execute the program directly in batch mode for an arbitrarily large number of parameter combinations. The PLT Tool performs this by modifying the input files before issuing the DOS command in order to start the ICEPAC program without a user interface.

For each parameter combination, the cumulative PLT tool will perform items 1, 4, 6 and 7 in the methodology outlined in the previous section, and save the resulting cumulative PLT signal level to a text file which can easily be imported into Excel, MATLAB, or any other program for post-processing and display. The text file will also contain Recommendation ITU-R P.372 noise levels and the absolute protection requirement (APR) level. The task group proposed an absolute protection requirement of $-15 \text{ dB}(\mu\text{V}/\text{m})$ per 9 kHz bandwidth is converted to (dBm/Hz) with the following equation for the protection of radio services from PLT generated interference:

$$APR(f) = -15 \text{ dB}(\mu\text{V}/\text{m}) - 20 \log_{10}(f) - 10 \log_{10}(b) + 95.5 - 174 \quad \text{dBm}/\text{Hz} \quad (\text{A2-6})$$

where:

f : frequency (MHz)

b : noise power bandwidth (Hz).

Also, under certain rare circumstances ICEPAC predicts path losses smaller than 30 dB from certain regions to the receiver site. This is clearly physically not possible, and is likely to be due to a flaw in ICEPAC. The cumulative PLT tool will discard any ICEPAC runs which predict the path loss to any region smaller than 50 dB, and tag the predicted cumulative PLT signal level as NaN (Not a Number) to indicate missing data. During testing of this tool NaN occurred at 107 out of a total of 7 992 ICEPAC runs.

Before running the tool, ICEAREA INVERSE should be run once in order to define receiver location and transmitter location grid, and set up the input files (which the tool will later modify) accordingly. The transmitter location grid must be a Latitude/Longitude grid with 0.25° resolution in both directions, and the result should be saved in the “default\” subdirectory. The tool is equipped with a text-based user interface rather than a graphical user interface (GUI). Also $P_{TX}(f)$, $\eta_{PEN}(x, y)$ and $\eta_{USAGE}(t)$ are constant input parameters, such that variation in these parameters over frequency, location and time is not implemented.

A2.4.1.4 Cumulative PLT tool – Instructions on use

Software files for the cumulative PLT tool can be downloaded from <http://www.rta.nato.int/Pubs/RDP.asp?RDP=RTO-TR-IST-050>, and steps on how to use the tool are shown below.

To start using the tool, do the following:

- 1 Run ICEAREA INVERSE once in order to set up the receiver location and transmitter location grid:
 - a) Start ICEAREA INVERSE.
 - b) Push “Parameters” LOSS (predicts the path loss directly).
 - c) Push “Method” Auto select.
 - d) Coefficients: URSI88 (no difference observed when using CCIR coefficients, but recommend using URSI88 since these are the newest).
 - e) Push “Receiver” to select a receiver location.
 - f) Push “Plot Center”, → “Set to receiver”, and select the X-range and Y-range for the transmitter grid. Ensure that the X-range and Y-range covers the same number of degrees. A grid of $-4\ 000$ km to $+4\ 000$ km should be sufficient, which is approximately the maximum distance for single-hop propagation, limited by the Earth’s curvature, unless interference from farther-away regions is of particular interest. (Examine the map to find proper values of minimum/maximum latitude and longitude. Ensure that the difference between maximum and minimum value is the same for latitude and for longitude such that the angular resolution becomes identical in both directions).
 - g) Push “Grid”, select Grid Type = “1 Lat/Lon”, and select the grid size such that each grid cell is $0.25 \times 0.25^\circ$, e.g. if X-range and Y-range cover $70 \times 70^\circ$, select a grid size of 281×281 . Lat/Long grid is convenient when used in conjunction with gridded population density data.
 - h) Select “Run” → “Map only” in order to see the extent of the transmitter grid.
 - i) Ensure that there is only one parameter combination under “Groups” (the actual parameter values here are irrelevant).
 - j) Push “System parameters”, Min. angle = 0.1° , multipath power tolerance = 10 dB, maximum tolerable time delay = 15 ms (the latter two values are increased from the defaults in order to account for different propagation paths). The other system parameters, including transmitter power, are irrelevant when predicting path loss only.
 - k) Push “Fprob” Keep default values.
 - l) Push “TX antenna” default/isotrope³³.
 - m) Push “RX antenna” default/isotrope, or insert knowledge about antenna at the receiver location if required.
 - n) Select “Run” → “Calculate” → “Save/Calculate/Screen”.
 - o) When prompted for input file name, go to the subfolder named “default” and enter a meaningful file name.
 - p) The program should now perform calculations and produce a plot on the screen. Close the program and all windows it has generated. The files generated by the program will be used by the cumulative PLT tool.

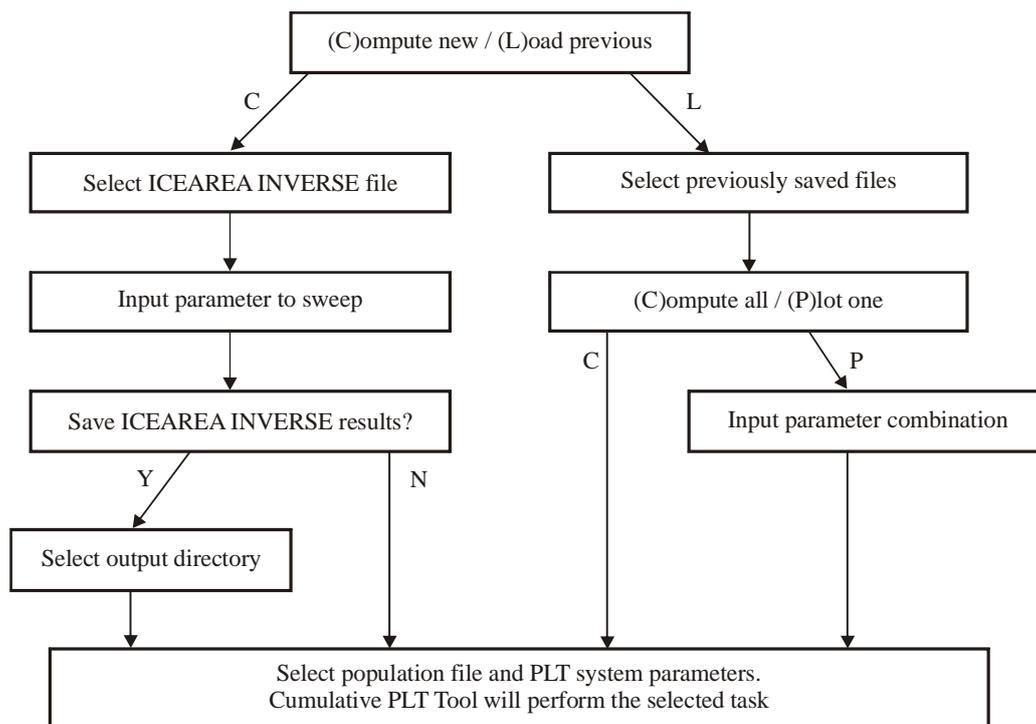
NOTE 1 – If only one case is selected under “Groups”, run “Save/Calculate/Screen”. The result will be output to a map on screen and saved to a file xxx.ig1. If several cases are selected under “Groups”, run “Save/Calculate”. The results will be saved to files xxx.ig1, xxx.ig2, xxx.ig3 and so on. The output files xxx.igx are text files which can be used in further post-processing to evaluate cumulative effects.

³³ Isotrope antenna: omnidirectional antenna.

- 2 Start MATLAB, go to the installation folder and enter “cumulative_plt_tool” in order to start the tool. Follow the on-screen instructions.
- The input procedures are intended to be relatively failsafe; in case of unexpected inputs the tool should repeat the question.
 - The options of the text-based user interface are illustrated in Fig. A2-12.
 - When prompted to select population data file, note that, e.g. the file name glp05ag15.bi corresponds to population data from 2005, and glp10ag15.bi to 2010 (the middle digits of the file name denotes year).
 - Be aware that large amounts of processing time and hard disk space may be required if running a large number of parameter combinations.

FIGURE A2-12

Flowchart of the available options in the user interface of the cumulative PLT tool



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The tool has three different modes of operation:

- “Compute new”: The tool will go through a number of parameter combinations and do the following for each parameter combination:
 - Call ICEAREA INVERSE.
 - Store the result file generated by ICEAREA INVERSE for later use (optional).
 - Estimate the cumulative PLT signal level and compare with ITU-R noise curves and with the absolute protection requirement.
 - Write the resulting numbers to a text file.
- “Load previous/Compute all”: The tool will go through files previously generated by ICEAREA INVERSE under mode 1, and do the following for each file:
 - Load ICEAREA INVERSE result file into memory.

- b) Estimate the cumulative PLT signal level and compare with ITU-R noise curves with the absolute protection requirement.
 - c) Write the resulting numbers to a text file.
- 3 “Load previous/Plot one”: The tool will prompt the user to select one of the previously computed parameter combinations and produce the type of figure/map shown in Fig. A2-13.

The following files are produced when running the tool:

- 1 “xxx_summary.txt”: Text file containing the estimated cumulative PLT signal level compared to background noise curves for each parameter combination.
- 2 “xxx_swept_parameters.mat”: MATLAB data file containing information on which parameter combinations were simulated (to be used in the “Load previous” modes).
- 3 (Optional) “xxx_00001.ig1”, “xxx_00002.ig1”, and so on: Results generated by ICEAREA INVERSE (one file per parameter combination).

A2.4.1.5 Calculation of HF radio noise from PLT systems

In this section an example where the cumulative PLT tool is used to evaluate the interference potential at a hypothetical receiver location. The location was selected on the basis that it should be a city for easy reference. The input parameters are given as an example in § A2.1.

Example receiver location in Winnipeg, Canada

In this example, a hypothetical receiver location at Winnipeg Canada (49.53N and 97.09W) was used. It was noted that Winnipeg located in the Province of Manitoba is a rural area of Canada with a population density less than two persons per km² and that the use of the “quiet rural” noise level from Recommendation ITU-R P.372 is appropriate in the calculation. In addition, it is noted that CBC Radio-Canada, utilizes many of the frequencies allocated to the broadcasting service in the HF bands below 80 MHz.

The analysis is performed under the following assumptions:

Average e.i.r.p. per PLT installation is $P_{TX} = -80$ dBm/Hz (e.g. -50 dBm/Hz HomePlug modems and equivalent antenna gain from wiring of -30 dBi). The value of -80 dBm/Hz used in this example calculation is consistent with the median levels in the CRC findings (see § A3.2) but may not represent the potential for higher peak levels which were found to be 20 dB higher.

Market penetration is $\eta_{PEN} = 0.05$ PLT modems per capita. Other studies shown in § A2.4.3 have used market penetration (PLT systems per household) ranging from 20% to 35% with an average of 30%.

Duty cycle of each modem is $\eta_{USAGE} = 0.3$. The CRC tests found that the in-house modem would continue to operate and emit RF signal even when no data was being transferred. Some modems may be operating at a 50% duty cycle (100% per modem pair). In an access PLT system individual modems may operate with a much lower duty cycle.

The transmitter location grid used extends from -120° to -50° longitude and -15° to 55° latitude, and PLT modems outside this area are disregarded. No knowledge of receiver antenna characteristics is assumed, hence an isotropic receiver antenna is used in the analysis.

A population data prediction from 2010 is used.

Cumulative PLT tool execution within MATLAB is shown below:

 Cumulative PLT Tool
 Roald Otnes, Norwegian Defence Research Establishment (FFI), October 2006

NATO RTO IST-050/RTG-022 on HF Interference, Procedures and Tools

 This program will estimate the cumulative effects from PLT,
 based on ICEPAC sky wave path loss predictions and population data
 from "Gridded population of the world" (gpwv3) database

The program has been tested on MATLAB versions 6.5 and 7.1,
 and with ICEPAC version 05.0119WW

Please run ICEAREA INVERSE one time as normal to set up all parameters, before
 running this program to sweep some of the parameters.
 ICEAREA INVERSE will then be called (batch mode) for all chosen parameter combinations.

Use of text-based interface:

 Enter will provide default parameters.
 Use MATLAB syntax for the parameters to be swept.
 Be aware that using default values for all swept parameters will take very long time to run.
 Ctrl-C in MATLAB window to abort.
 Do NOT close down the ICEPAC window that pops up; that will make Windows confused.
 ICEAREA INVERSE batch calculation: (C)ompute new or (L)oad previous? c
 ICEPAC installation directory [c:\itshfbc\]:
Select the input file created from the initial setup run (e.g. WINNIPEG.ice)
 ICEPACfile =
 WINNIPEG
 Swept months [2:2:12]: 2:2:12
 Swept UTCs [0:4:20]: 0:4:20
 Swept SSNs [50 100 200]: [50 100 200]
 Swept Qs [0 5]: [0 5]
 Swept freqs [2 4 8 16 24]: [2 4 8 12 16 20 24]
 Total number of ICEAREA INVERSE runs planned: 1 512
 Save ICEAREA INVERSE results for later use (disk space required: 20 267.1 MB). [Y]/N? Y
 Output directory [.\ICEPAC\]:
 Select population file (eg. glp10ag15.bil for 2010 data)

 EIRP per PLT modem (dBm/Hz) [-80]:
 Market penetration (PLT modems per capita) [0.05]:
 Duty cycle (fraction of time each PLT modem is transmitting) [0.3]:
 Market factor (penetration * duty cycle): -18.2 dB
 EIRP per capita: -98.2 dBm/Hz

 Results will be saved to file .\icepac\WINNIPEG_summary.txt
 Modifying ICEAREA INVERSE input files
 copy c:\itshfbc\run\temp1.txt c:\itshfbc\run\iceareax.da1
 1 file(s) copied.
 copy c:\itshfbc\run\temp2.txt c:\itshfbc\area_inv\default\WINNIPEG.ice
 1 file(s) copied.
 c:\itshfbc\bin_win\icepacw.exe c:\itshfbc\ INV CALC default\WINNIPEG.ice
 copy c:\itshfbc\area_inv\default\WINNIPEG.ig1 .\icepac\WINNIPEG_00001.ig1
 1 file(s) copied.

Integral of population / loss over entire area: -31.4 dB
 Received PLT noise: -129.7 dBm/Hz

Atmospheric noise lower limit: -159.7 dBm/Hz
 Man-made, rural: -115.0 dBm/Hz
 Man-made, quiet rural: -129.0 dBm/Hz
 Absolute protection requirement: -139.1 dBm/Hz

and so on for 1 511 other parameter combinations.

The MATLAB command window presented above starts with documentation and usage explanation followed by user input parameters and brief reports from individual ICEPAC runs. The first of 1 512 runs (for 6*6*3*2*7 parameter combinations) is shown above, The 1 512 ICEPAC runs with the 281 × 281 grid used in this example took a total of about 22 hours on a standard desktop computer circa 2006, and filled 20 GB of disk space when the detailed ICEPAC results were saved (optional) for later use.

As the input value “EIRP per PLT modem” is bandwidth normalized and given in units of dBm/Hz, the resulting estimate of the cumulative PLT signal is also given in units of dBm/Hz. The results are saved to a tab-separated text file, one line per ICEPAC run, similar to the WINNIPEG example given in § 5.1. (NOTE – In the case of discarded ICEPAC runs, the number in the “PLT noise” column will be replaced by “NaN”):

WINNIPEG [ISOTROPE], 2010 population data, e.i.r.p. = -98.2 dBm/Hz per capita

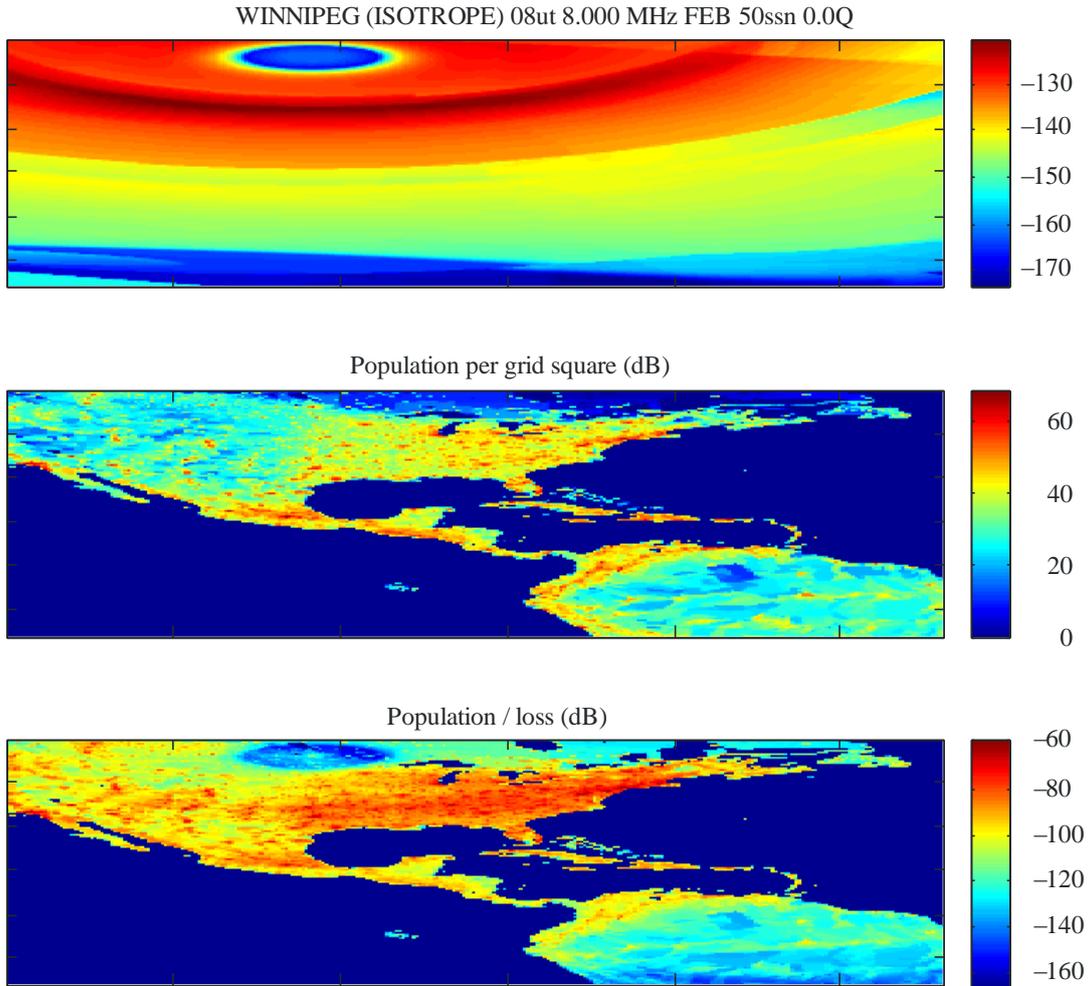
Month	UTC	SSN	Q	Freq	PLT noise	Atm (low)	Rural	Quiet rural	Abs. prot. req.
2	0	50	0	2.000	-129.69	-159.65	-114.99	-129.01	-139.06
2	0	50	0	4.000	-134.53	-152.37	-123.18	-137.62	-145.08
2	0	50	0	8.000	-139.32	-146.21	-131.36	-146.23	-151.10
2	0	50	0	16.000	-149.54	-160.64	-139.55	-154.84	-157.12
2	0	50	0	24.000	-165.75	-187.36	-144.34	-159.87	-160.65

Cumulative PLT output maps

The cumulative PLT tool also provides the option of plotting maps illustrating the correspondence between ICEPAC path loss and population density. This requires that the detailed ICEPAC results have been saved to disk. An example for a case where the predicted PLT signal exceeds the median quiet rural man-made noise by more than 6 dB is shown in Fig. A2-13. In general, high predicted PLT signal levels correspond to cases where there is low path loss from densely populated regions. It was concluded by some Sector Members that the parameters used in the example calculation are reasonable and that the results correctly indicate that the PLT signal levels exceed the median “quiet rural” man-made noise by at least 6 dB.

FIGURE A2-13

Top plot: Median path loss (dB) as predicted by ICEPAC for a combination of input parameters for a receiver in Winnipeg; Middle plot: Population per $0.25^\circ \times 0.25^\circ$ grid square in dB ($10 \log_{10}$ (population)); bottom plot: Product (dB-sum) of the top two plots



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The maps in Fig. A2-13 are generated using the MATLAB cumulative PLT tool as shown below:

ICEAREA INVERSE batch calculation: (C)ompute new or (L)oad previous? L

ICEPACfile =

WINNIPEG

(C)ompute cumulative PLT noise for all files, or (P)lot One? p

Select UTC, one of (0 4 8 12 16 20): 8

Select Freq, one of (2 4 8 16 24): 8

EIRP per PLT modem (dBm/Hz) [-80]:

Market penetration (PLT modems per capita) [0.05]:

Duty cycle (fraction of time each PLT modem is transmitting) [0.3]:

Market factor (penetration * duty cycle): -18.2 dB

EIRP per capita: -98.2 dBm/Hz

Month: 2 / UTC: 8 / SSN: 50 / Q: 0 / Freq: 8.00

Integral of population / loss over entire area: -41.3 dB

Received PLT noise: -139.6 dBm/Hz

Atmospheric noise lower limit: -146.2 dBm/Hz

Man-made, rural: -131.4 dBm/Hz

Man-made, quiet rural: -146.2 dBm/Hz

Absolute protection requirement: -151.1 dBm/Hz

A2.4.1.6 Wire-line system antenna gain

The antenna gain of a wire-line transmission system is defined as the ratio between e.i.r.p. and injected power. For PLT systems, several measurement results were reported in the literature and RTG report recommends following antenna gains:

- –30 dBi for in-house systems;
- –15 dBi for overhead access systems;
- –50 dBi for underground access systems.

It should be recognized that there are uncertainties in these numbers of the order of ± 5 to ± 10 dB due to statistical spread. Furthermore, in the case of overhead Access system power lines, at resonant frequencies the antenna gain may be higher by 10-13 dB.

A2.4.1.7 Current PLT market penetration estimation

In § 5.6.5 an estimated value of market penetration of $\eta_{PEN} = 0.05$ was used for the example calculations. Market information is generally difficult to obtain and hard to predict into the future, since vendors do not disseminate this information readily, and the technology is still in development. An attempt to predict the market development for PLT³⁴ predicts that by 2010 there will be between 2.5 and 5 million Access PLT (BPL) subscribers in USA. This corresponds to a market penetration of 0.9-1.7% of the population. In Germany, the number of HomePlug devices “on the market” in February 2005 was 300 000, and in February 2006 was 800 000³⁵. This information was given to the Task Group from the German BITKOM (industry) via the German Ministry of Commerce. The population in Germany was 82 million, thus the HomePlug market penetration as of February 2006 is 0.01 modems per capita. As of April 2006, Intellon had sold 10 million HomePlug chipsets worldwide and shipped 5 million³⁶. (Intellon, DS2 and Panasonic are major vendors of PLT chipsets). Users of the cumulative PLT tool can enter an appropriate value for this parameter.

A2.4.1.8 Conclusions

The absolute protection requirement is a term developed by the research task group, and has been retained in this text to preserve the integrity of the cumulative PLT tool. The absolute protection level does not affect the calculations and it is used only for comparison, similar to how the various environmental noise levels are used. Working Party 5C has not concluded studies on protection levels for terrestrial radio services from PLT systems. The methodology presented in this document is based on the ICEPAC propagation prediction method, and can be used to predict cumulative HF skywave interference from PLT systems. This technique can be utilized to analyze impact of PLT signals received at a receiver location for terrestrial radiocommunication interference studies.

A2.4.2 NTIA study on ionospheric propagation and aggregation of Access PLT emissions

A2.4.2.1 Introduction

The purpose of this study is to review and analyze the potential effect of a large scale Access PLT deployment on aggregate noise levels over a national scale. An aggregate effect from PLT interference, if any, would occur due to ionospheric or “sky wave” propagation. Since current PLT systems make use of HF frequencies, and since modeling of PLT-energized power lines indicates much of the PLT emissions appear to radiate in an upward direction, these HF PLT emissions have

³⁴ HELD, J. [2006] *Understanding Broadband over Power Line*. Auerbach Publications.

³⁵ BITKOM-Informationen zu Anwendungen der Powerline-Technologie, Stand März 2006.

³⁶ BPL Today, April 11, 2006, p.3.

the potential to travel many miles from their source. Moreover, because a given listening point may receive radiated PLT emissions from many sources, it is conceivable that an aggregation of signals could occur, raising the receiver noise floor level and rendering weak, desired signals unintelligible. In general, ionospheric propagation occurs for frequencies between 1.7 MHz and 30 MHz, as discussed in the NTIA PLT Phase 1 Study³⁷.

A2.4.2.2 Analytical modeling of sky wave propagation

Background

The analysis presented here employed the VOACAP HF statistical propagation prediction software³⁸ and overhead and underground power line models using the NEC software³⁹.

NTIA used VOACAP in its “area” mode to calculate aggregate emissions received at multiple points from widespread PLT deployments. In the geographic center of every county in the United States, NTIA placed effective PLT emitters, each representing the total PLT emissions from its respective county. Propagation simulations were sequentially run for each effective emitter to a fixed grid of receive points covering the continental United States, and the results were summed in the power domain. NTIA ran these simulations over a large set of time and frequency conditions.

Approach

Power line models

For this report, NTIA determined radiated power levels for each effective PLT emitter using an elaborate overhead power line model. These power levels were calculated using the measurement guidelines adopted in the FCC’s PLT Report and Order⁴⁰. NTIA calculated the radiated power output from the power line model which would result in electric fields that met Part 15 limits, and the result was scaled by NTIA’s deployment model and county population to arrive at the power output of each effective PLT emitter (Table A2-1).

The overhead model was based upon an actual power line structure at which NTIA conducted measurements of PLT emissions (Figs A2-14 and A2-15). The model was created with the help of *in-situ* observations and measurements, and was designed for simulation using NEC-4.1. As closely as possible and within program constraints, this model was designed to conform to the actual features of the power grid, including the use of catenary wires, correct placement of transformers loads, wire height and placement on power poles, grounding wires, riser, pole placement and wire junctions.

The overall extent of the model was approximately 328 m in the x-axis direction, and 435 m in the y-axis direction. The modelled power line height was 12 m. The power line spacing was 0.6 m with a multi-grounded neutral line 1 m below the other lines. All wires were 12.6 mm in diameter and given the conductivity of copper (5.8×10^7 S/m). The ground plane for the model (a flat earth structure beneath the wires) had characteristics typical of “good” ground (dielectric constant of 15.0, conductivity of 0.005 S/m).

³⁷ NTIA Phase 1 Study, Vol. I, at section 5.2.2, available from <http://www.ntia.doc.gov/ntiahome/fccfilings/2004/bpl/index.html>.

³⁸ NTIA/ITS ionospheric propagation software package available for download from <http://www.greg-hand.com/hfwin32.html>.

³⁹ Numeric Electromagnetic Code method-of-moments electromagnetic modeling software is available through Lawrence Livermore National Laboratory: <https://ipo.llnl.gov/technologies/nec>.

⁴⁰ BPL Report and Order, at Appendix C, Measurement Guidelines 2.b.

FIGURE A2-14
Angle view of the elaborate overhead power-line model

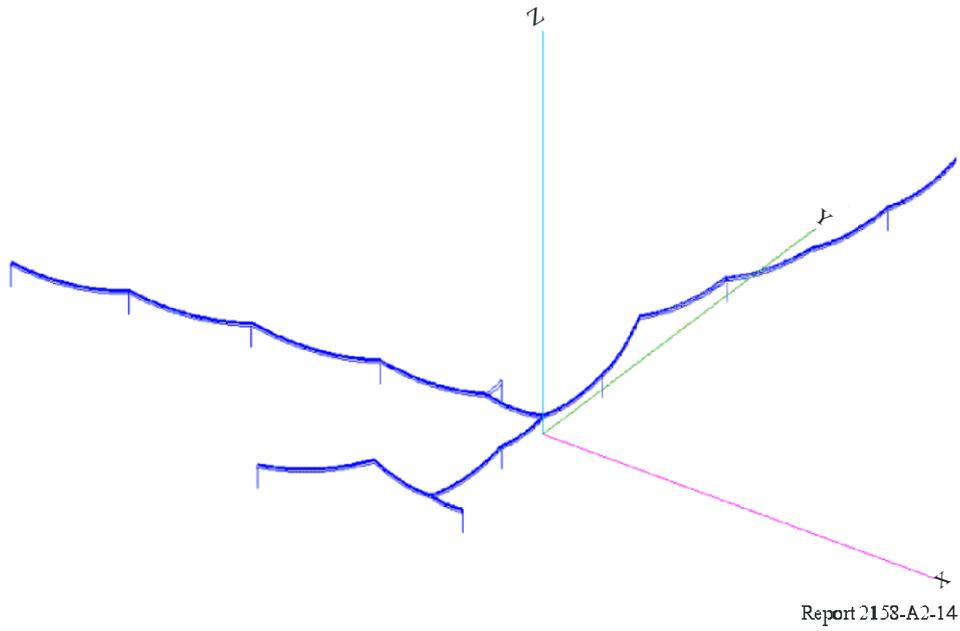
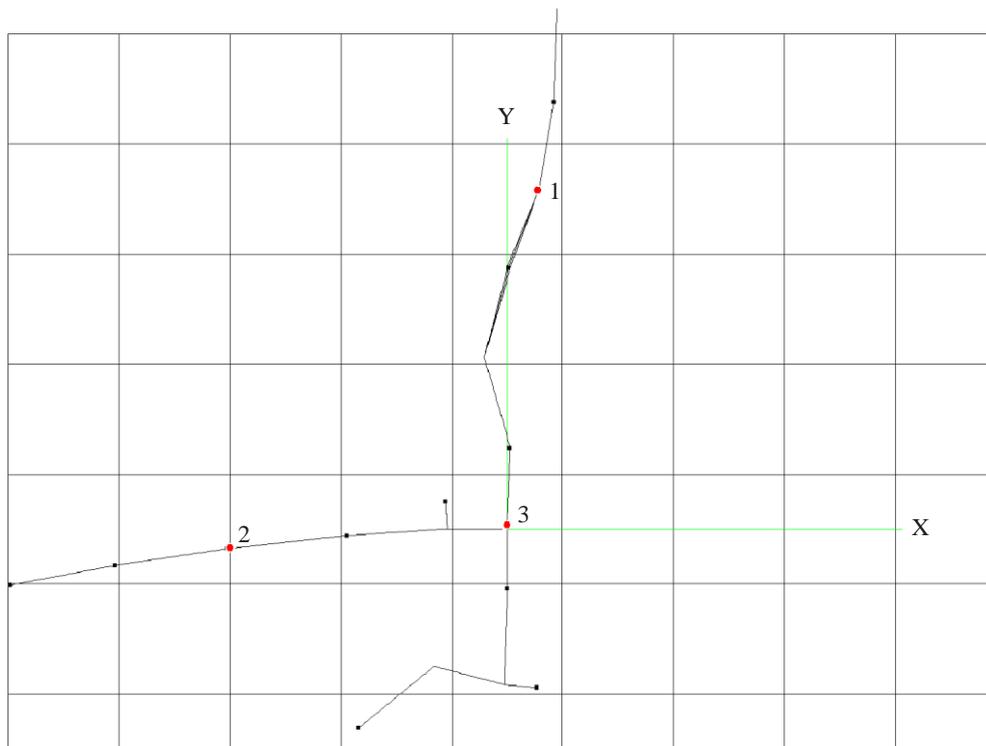


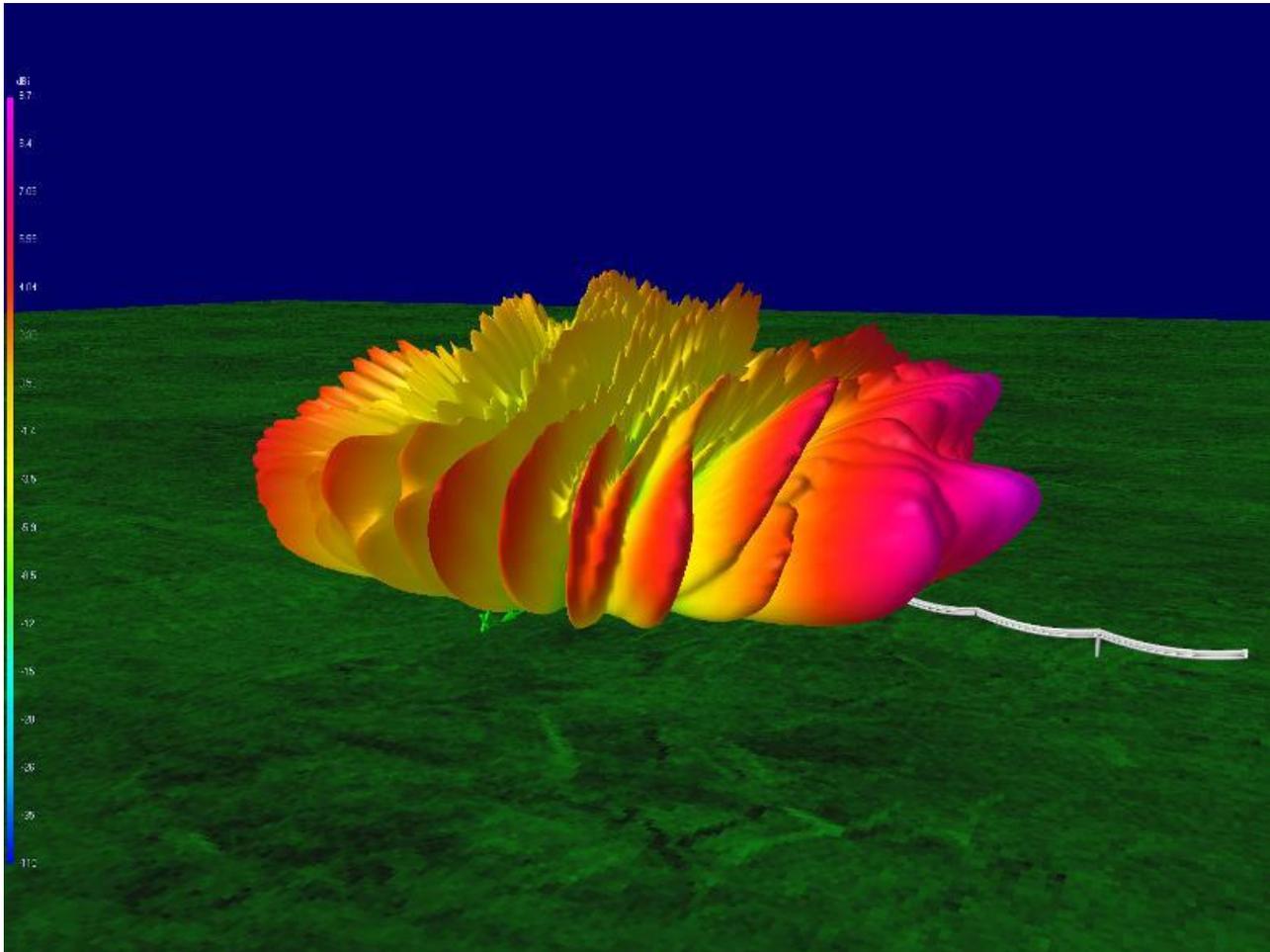
FIGURE A2-15
Overhead view of the power line model depicting PLT injection points (red dots).
Injection point 3 was used for this analysis. Distribution transformers
(impedance loads to neutral) are shown by black dots.



An example radiation pattern calculated with the use of this model is presented in Fig. A2-16. This radiation pattern was calculated for 16 MHz.

FIGURE A2-16

Example far-field directive gain radiation pattern at 16 MHz, using signal injection at injection point 3



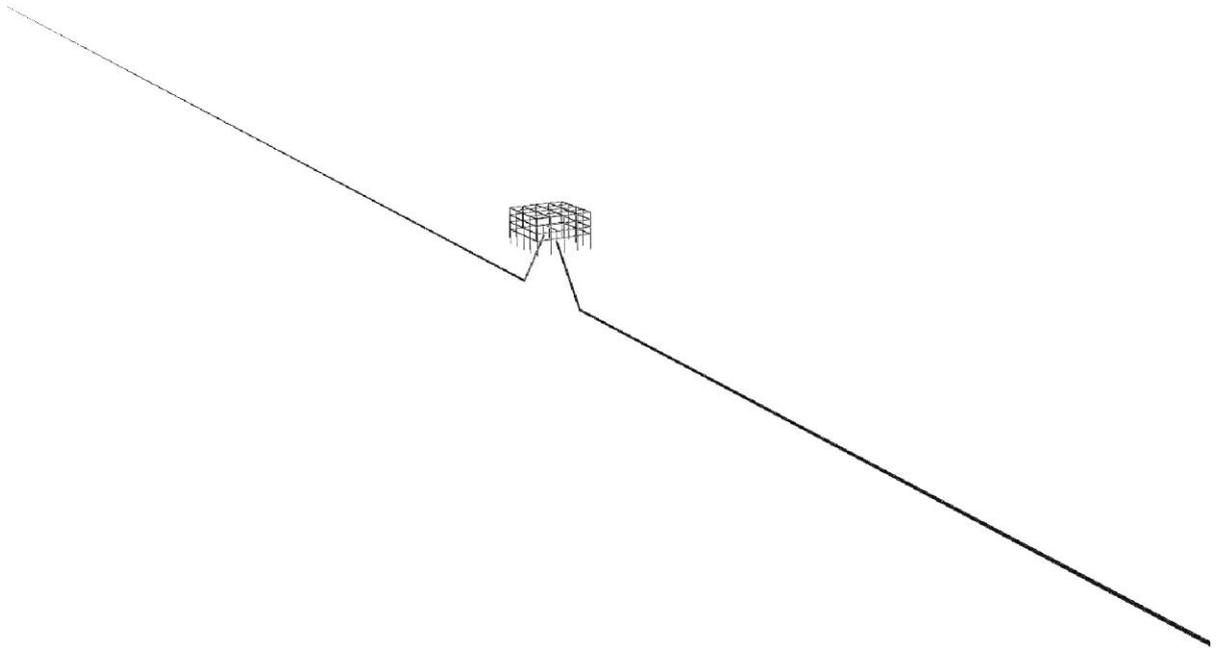
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NTIA created an additional NEC model of an underground PLT system (Figs A2-17 and A2-18). As with the overhead model, NTIA used NEC to derive frequency-dependent directive-gain radiation patterns and radiated power necessary to meet Part 15 limits from the underground model. Radiated power calculations were again performed using the new PLT measurement guidelines in the PLT Report and Order⁴¹. The radiated power levels are listed in Table A2-1.

⁴¹ BPL Report and Order, at Appendix C, Measurement Guidelines 2.b.

FIGURE A2-17

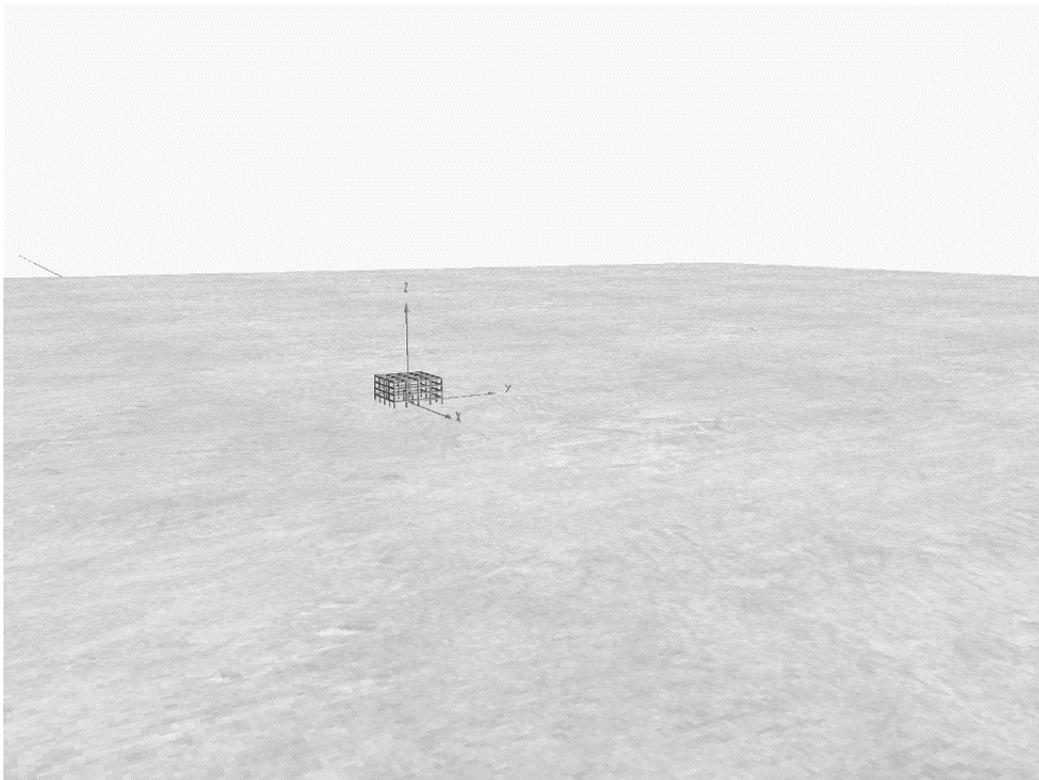
Underground power line model with ground removed. The underground line, comprised of three neutral wires surrounding a dielectric-insulated central wire, extends 340 m end to end



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FIGURE A2-18

Underground power line model with ground included. The visible wire frame box represents a pad-mounted transformer, in which the PLT source is installed



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TABLE A2-1

PLT structural radiated power at Part 15 limit

Frequency (MHz)	Radiated power (dBW/Hz)	
	Overhead	Underground
2	-103.04	-94.26
4	-106.71	-87.84
6	-104.38	-84.66
8	-102.99	-82.73
10	-102.89	-83.29
12	-102.93	-79.38
14	-104.06	-78.43
16	-106.32	-74.75
18	-97.48	-75.16
20	-103.48	-79.52
22	-104.29	-81.67
24	-101.04	-82.24
26	-105.71	-82.45
28	-100.98	-83.47
30	-98.04	-84.28

Greater NEC-calculated radiated power from underground structures is not unexpected, as ground losses in NEC-calculated directive gain patterns subsequently attenuate this power significantly. Thus, it is to be expected that NTIA's underground model radiated significantly more power than overhead systems while meeting Part 15 limits. With both the overhead and underground models, increased variability of radiated power with frequency is largely due to the vast increase in complexity of the model used over previous work.

The PLT Report and Order specified that compliance measurements should take place at $\frac{1}{4}$ wavelength intervals down the power line from the PLT device, to a distance of one wavelength of the mid-band frequency, at a measurement height of 1 m⁴².

The radiated power levels were derived by exciting the NEC models in question using a unit voltage source, finding the magnetic or electric field values through NEC simulation at appropriate points around the models as specified in the PLT measurement guidelines, and scaling all subsequent electric field values by the dividend of calculated electric field divided by the Part 15 limit. To translate the scaling to the power domain, NEC-calculated radiated power levels were scaled by the square of this factor.

Use of voice of America coverage analysis program

NTIA calculated PLT interference and man-made noise power values using VOACAP's area mode in a fixed 31 × 31-point grid of receiving points covering CONUS and centered on Kansas City, Missouri⁴⁰. NTIA assumed PLT deployment densities based in part on U.S. Census data to simulate

⁴² BPL Report and Order, at Appendix C, Measurement Guidelines 2.b.2, for a description of additional measurements that may be required if the mid-band frequency of the PLT signal is two or more times greater than the lowest PLT signal injected onto the power line.

effective PLT emitters in the geographic center of each county in the United States of America (including Alaska and Hawaii)⁴³. These emitters were given frequency-dependent directive-gain radiation patterns calculated using the elaborate NEC overhead power line model or the underground model and located in the geographic center of each county. The radiation patterns used were arithmetically averaged in azimuth to simulate the random orientation of multiple PLT-energized power lines represented by each effective emitter.

For the elaborate overhead power line model, NTIA ran full ionospheric aggregation simulations over a comprehensive set of more than 8,500 sets of conditions (including all months of the year, hours of the day, low and high levels of solar activity and frequencies from 2 to 30 MHz in 2 MHz increments). NTIA used these simulations to calculate the Interference-plus-Noise-to-Noise ratio, or $(I + N)/N$, conditions due to large numbers of deployed PLT devices⁴⁴. The results presented here were examined in terms of sets of conditions producing worst-case increases to the local receiver noise floor.

Similar propagation analyses were completed for the underground model over a large sample of hours of the day, frequencies, months of the year and solar conditions (more than 1,300 sets of conditions), including the same conditions that resulted in the greatest aggregated interference-to-noise ratios using the overhead power line model as an emitter.

VOACAP reports results of propagation in terms of signal-to-noise ratio (SNR). Table A2-2 indicates how the SNR values reported by VOACAP translate into noise floor increases.

TABLE A2-2

Noise floor increase $(I + N)/N$ as a function of SNR

Noise floor increase, $(I + N)/N$ (dB)	SNR (dB)
3	0
1	-5.868
0.5	-9.135
0.1	-16.327
0.05	-19.363
0.01	-26.373
0.005	-29.386

A2.4.2.3 Simulation characteristics

NTIA ran simulations both with the Smoothed Sunspot Number (SSN) parameter set to a high value (150) to simulate excellent propagation characteristics during the peak of the 11-year solar cycle, and to a low value (25) to simulate depressed propagation characteristics at the low point in the solar cycle. Because of software design, all receive points used VOACAP's quarter-wave vertical monopole antenna (type 22) over ground with dielectric constant $\epsilon_r=15$ and conductivity σ set to

⁴³ NTIA Comments, at Technical Appendix, section 4.2, available from:

http://www.ntia.doc.gov/ntiahome/fccfilings/2004/BPLTechAppdx_06042004.doc. See also County and City Data Book: 2000, U.S. Census Bureau, National Data Summary File 1, Table P-15.

⁴⁴ In this Report, $(I + N)/N$ is also referred to as noise floor increase.

0.005 S/m⁴⁵. In reality, ground characteristics vary in the United States of America, ranging from very poor ($\epsilon_r = 3$ and $\sigma = 0.001$ S/m) to excellent ($\epsilon_r = 20$ and $\sigma = 0.030$ S/m).

The man-made noise level was set to remote or quiet rural levels (−164 dBW/Hz at 3 MHz) at all receive points, to best address receiving conditions at many U.S. Government sites⁴⁶. As with receive-point antennas, software design allows one manmade noise level to be assigned to all receive points in VOAAREA's calculation grid. Actual man-made noise levels in the United States of America can vary from quiet rural conditions to the very high noise levels that can be found in industrial areas.

NTIA individually scaled the NEC-calculated radiated power levels of each county's effective emitter by the number of active PLT devices expected to serve the urban households in that county. Urban households (as defined by the U.S. Census Bureau) were used in this analysis as they present greater deployment densities than rural households, and as such, are more likely to be the bulk of early deployments of Access PLT service. As in the earlier analysis, NTIA assumed that a PLT injector had the data handling capacity to support an average of 30 customers, and 1 of 4 urban households was a PLT customer. In other words, one PLT injector was assumed per 120 urban households. With nearly 85 million urban households in the United States of America, this assumption resulted in a total of over 705,000 modelled PLT devices in this analysis⁴⁷.

Several other factors were taken into consideration when predicting the receiver noise floor increase. First, NTIA considered that not all PLT devices will operate at the Part 15 limit; therefore, the average radiated signal was assumed to be 4 dB below the Part 15 limit. Second, the VOAAREA analysis was based on root-mean-square (RMS) values; therefore an adjustment was made to convert the quasi-peak PLT signal level, as measured for FCC limit compliance, to an RMS level⁴⁸. Third, since the devices in the system do not all operate at the same frequency⁴⁹, an allowance of 6 dB was given (i.e. 1 in 4 PLT injectors are assumed to be co-frequency). Finally, the assumed duty cycle of PLT devices was set at a mean of 55%. These adjustments to the PLT radiated power levels are listed in Table A2-3.

⁴⁵ VOAAREA allows one to set the length of the vertical antenna either to a fixed value in meters or to allow it to vary with frequency. In this analysis, it was assumed that a receiver subject to potential interference at any given frequency would make use of an antenna designed for that frequency; therefore, the antenna in this case was set to quarter-wave length for each frequency (e.g. 7.5 m at 10 MHz). VOACAP automatically adjusts this length such that the receive pattern stays the same regardless of frequency. As is appropriate for a monopole antenna, the maximum gain for the antenna at any height was set to 3 dB above that of a dipole.

⁴⁶ Noise level used in this analysis is based on Recommendation ITU-R P.372, implemented in VOACAP/VOAAREA.

⁴⁷ NTIA Comments, at Technical Appendix, § 4.

⁴⁸ The choice of quasi-peak-to-r.m.s conversion factor was based on the measurement data from the NTIA Phase 1 Study, which indicated that the PLT signal power measured using a quasi-peak detector typically exceeded the level measured using an average detector by 0 – 5 dB. NTIA Phase 1 Study, at Volume II, section D.3.4.

⁴⁹ NTIA Phase 1 Study, Vol. I, a section 2.2.

TABLE A2-3

Adjustment factors for access PLT devices

Factor	Adjustment (dB)
Devices operating at levels below Part 15 limits	-4
Quasi-peak to r.m.s conversion	-3
Co-frequency distribution factor	-6
Duty cycle	-2.6
Total	-15.6

The receive points in the VOAAREA calculation grid used 1 Hz bandwidths (set by adjusting the radiated interfering PLT signal power of each transmitting point to the power (dB(W/Hz)). The noise power levels provided by VOAAREA were in dB(W/Hz). The received signal power from all effective PLT emitters at a given receive point was summed in the power domain independent of the noise power level, and the resulting summed PLT interfering power and the noise power at that point were used to calculate interference-to-noise. Thus, the aggregate interference-to-noise ratio at a point was into a 1 Hz bandwidth.

Table A2-4 summarizes the assumptions listed above as they were applied to this simulation.

TABLE A2-4

Simulation conditions

Effective PLT emitters	Overhead	Underground
Excitation	Voltage source on single line, centrally located	Voltage source in pad-mounted transformer, centrally located
Far field pattern		
Source	NEC-4.1 overhead model	NEC-4.1 underground model
Variability	Averaged over azimuth, variable by elevation and frequency	
Type	Directive gain	
Power level		
Source	NEC-4.1 overhead model	NEC-4.1 underground model
Structure emissions limits	Limited by Part 15 limits, as measured using PLT measurement guidelines	
County-level scaling	Scaled by urban households in county	
Parameter used	NEC-4.1 "radiated power" value (specified as output power after structure losses, but not ground losses, are considered)	
Placement	Geographic centers of all counties in the United States of America	
Antenna type	Quarter-wave monopole (VOACAP type 22)	
Ground conditions	"Average" ground	
Conductivity	0.005 S/m	
Relative permittivity	15	
Placement	31 × 31 grid of receive points throughout CONUS	
Noise	"Quiet rural" noise conditions at 3 MHz (-164 dB(W/Hz))	

TABLE A2-4 (*end*)

Effective PLT emitters	Overhead	Underground
Simulation		
Frequencies	From 2 to 30 MHz in 2 MHz steps	
Times of day	From 0 to 23 hours UTC in 1-hour increments	
Months of year	From January to December	
Solar conditions	Smoothed Sunspot Numbers (SSN) 25 and 150	
Primary path geometry	Short path	
Calculation methodology	Short/long path smoothing	
Calculated parameters	Received signal strength (SDBW), received noise (NDBW)	
Power adjustment factor	-15.6 dB (detailed in Table A2-3)	

A2.4.2.4 Simulation results

In order to gauge whether a given aggregated PLT signal level presents a risk of harmful interference to U.S. government radiocommunication receivers, NTIA considered two threshold values of $(I + N)/N$, or receiver noise floor increase⁵⁰. The lower threshold, a 1 dB increase in the noise floor (corresponding to a PLT interference-to-noise ratio of approximately -5.9 dB), was chosen as the level at which some harmful interference might occur. The higher threshold, increasing the noise floor by 3 dB (a PLT interference-to-noise ratio of 0 dB), was selected as a level at which harmful interference was considered to be a significant risk.

Analysis of the impact of PLT aggregation was done by combining the PLT signal levels of the modelled overhead and underground PLT systems with the background noise levels, such that the combination met the noise floor increase thresholds listed above. This analysis enabled NTIA to examine the ionospheric aggregation effects while varying the relative numbers of overhead and underground systems.

Comparison of overhead and underground analysis results

The simulations found overhead systems produced aggregated signal levels greatly in excess of underground systems, even when both classes of systems were adjusted to meet Part 15 limits. The median value for overhead aggregated PLT signal level was approximately 20 dB higher than that of an equal number of underground systems, given the same ionospheric propagation characteristics, over all the conditions modelled. This finding suggests that, where feasible, installation of PLT devices operating in the 1.7 to 30 MHz frequency range on underground wiring could have significant advantages over the same devices operating on overhead systems, from the standpoint of signal aggregation due to ionospheric propagation.

The relative impact of overhead and underground PLT aggregation can be seen graphically in the following results. Figures A2-19 and A2-20 illustrate the number of overhead plus underground devices needed to cause a worst-case 1 or 3 dB increase in the noise floor at any geographic location in the United States under best propagation and lowest local noise floor conditions.

For these graphs, ionospheric aggregation modelling was used to derive sets of conditions for both low and high solar activity during which the greatest ratios of signal-to-noise level due to aggregated PLT was produced. For all other sets of conditions and geographic locations, calculated aggregation resulted in less impact to the noise floor. Thus, for most calculated conditions, more

⁵⁰ The term “I” refers to the interfering signal power associated with radiated PLT emissions.

PLT devices would be required to produce the same impact on the local noise floor as that illustrated in Figs A2-19 and A2-20.

Calculations for periods of high solar activity indicated that maximum aggregated PLT signal levels occur primarily at higher frequencies in the HF band (18-30 MHz) during mid-to-late afternoon hours in the fall and winter. Calculations using low solar activity conditions found maximum aggregated PLT signal levels primarily at lower frequencies in the HF band (4-8 MHz). As was indicated by calculations assuming high solar activity conditions, maximum aggregated PLT signal levels were found during late afternoon hours during the fall and winter.

Figure A2-19 depicts combinations of underground and above-ground PLT devices that produce increases in the noise floor of 1 dB (lower curve) and 3 dB (upper curve). This figure is generated for the combination of ionospheric propagation and noise conditions (15:00 UTC during November at 30 MHz, with high-level solar activity) that produce the highest aggregate PLT signal relative to the local noise floor at any geographic point. Under these conditions, more than 1.35 million overhead PLT devices alone could be deployed before realizing a 1 dB increase in the noise floor at any geographic location. This number increases to 5.23 millions overhead PLT devices for a 3 dB aggregate noise floor increase. By reducing the number of overhead devices and adding underground PLT devices, the total number of deployed PLT devices can be greatly increased, while meeting the same levels of noise floor increase.

FIGURE A2-19

Number of underground PLT devices compared to the number of overhead PLT devices that would result in the same increase in the noise floor under high SSN conditions

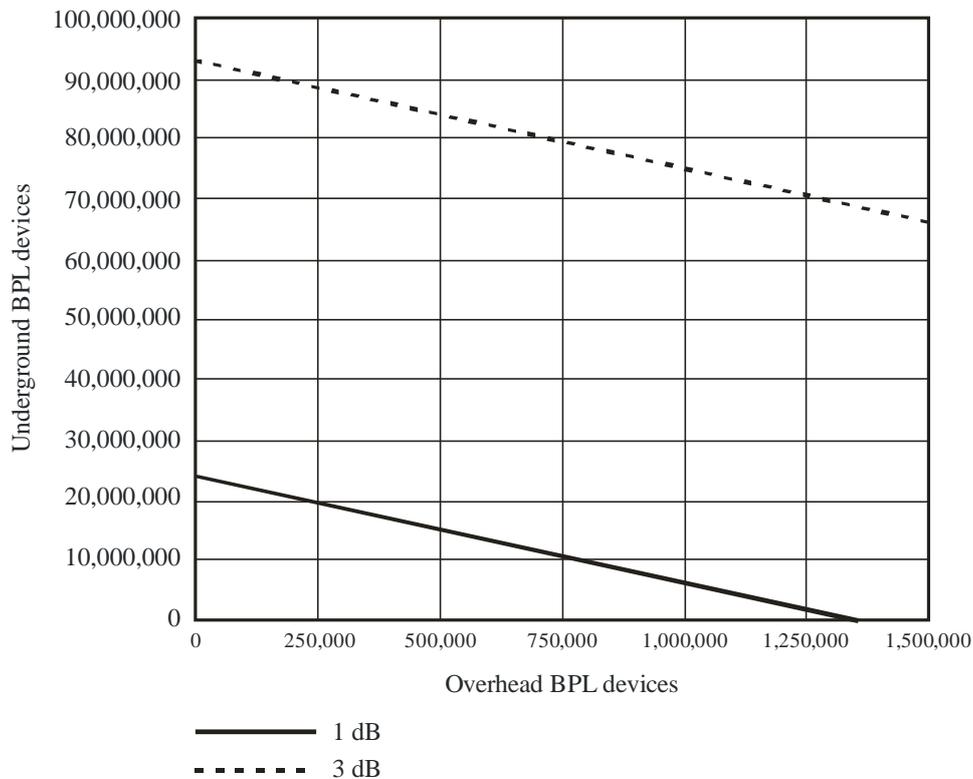
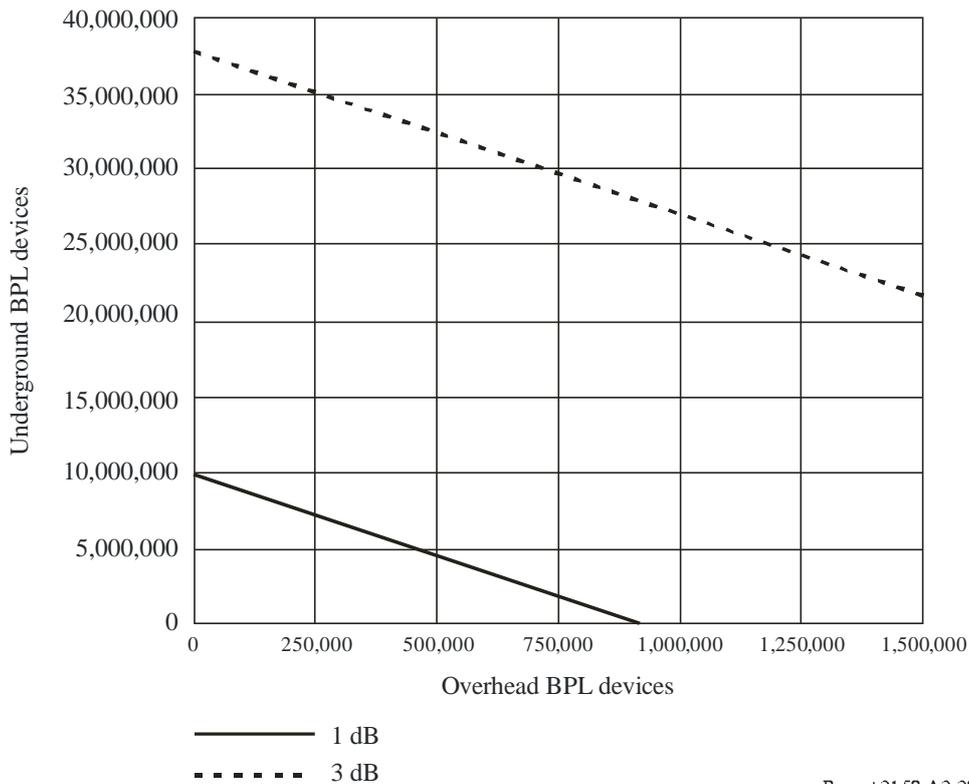


Figure A2-20 depicts numbers of overhead PLT devices compared to the number of underground PLT devices that would result in a 1 dB and 3 dB increase in the receiver noise floor under low solar cycle conditions. As with solar cycle maxima results, the fewest overall PLT devices necessary to meet the thresholds occurs when overhead PLT devices are used exclusively. For these conditions, approximately 916 000 overhead PLT devices would be required to raise the noise floor by 1 dB. By contrast, the exclusive use of underground PLT devices in the 1.7 to 30 MHz frequency range would allow nearly 10 million PLT devices to be deployed before producing a 1 dB noise floor increase.

FIGURE A2-20

Number of underground PLT devices compared to the number of overhead PLT devices that would result in the same increase in the noise floor under low SSN conditions



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A2.4.2.5 Maps of Ionospheric Aggregation

Figures A2-21 through A2-33 depict aggregated PLT interference-to-noise ratio (labelled as signal-to-noise) contour maps across the continental United States of America (CONUS) for a number of PLT deployment cases. These maps combine the aggregate power contributions of overhead and underground PLT devices distributed by population throughout the United States in various ratios such that the maximum aggregate PLT SNR encountered at any geographic point produces an approximate 1 dB or 3 dB increase in the noise floor.

Because of the way VOACAP produces output, only signal-to-noise ratios are indicated in the legends of the contour maps. To aid in interpreting Figs A2-22 through A2-33, a sample contour map is provided in Fig. A2-21. Figure A2-21 illustrates the translation of the values in these legends to the respective increases in the noise floor. The lighter shaded regions correspond to greater levels of noise floor increase due aggregation of PLT emissions. The peak location or locations are identified on the contour maps by a circular symbol having a cross inside it.

FIGURE A2-21

Sample VOAAREA output map detailing the increase in the noise floor for each signal-to-noise value in the map legend

15ut 30.000 MHz Nov 150ssn above: 1510000 underground: 26,770,000

Tx location to grid of Rx

AREADATA \ HIGH_2_2\OUT477.V14 SNR

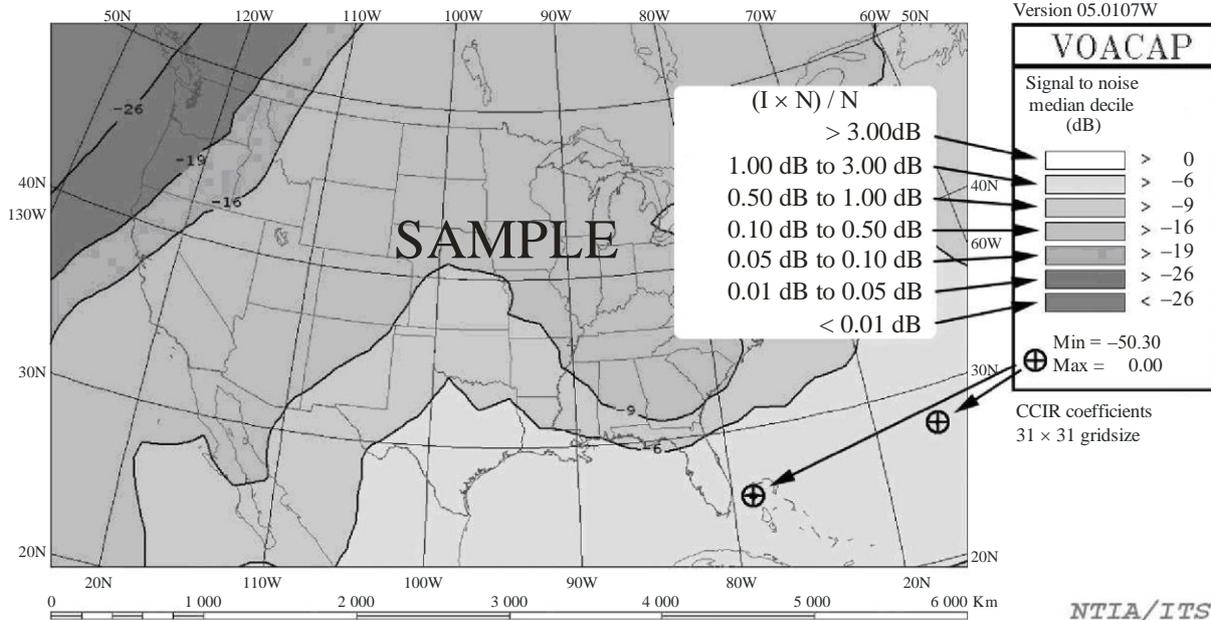


FIGURE A2-22

Aggregation under high SSN conditions due to 24 095 730 underground devices and no overhead devices with maximum noise floor increase of 1 dB

15ut 30.000 MHz Nov 150ssn overhead: 0 underground: 24, 095, 730

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_7.V11 SNR

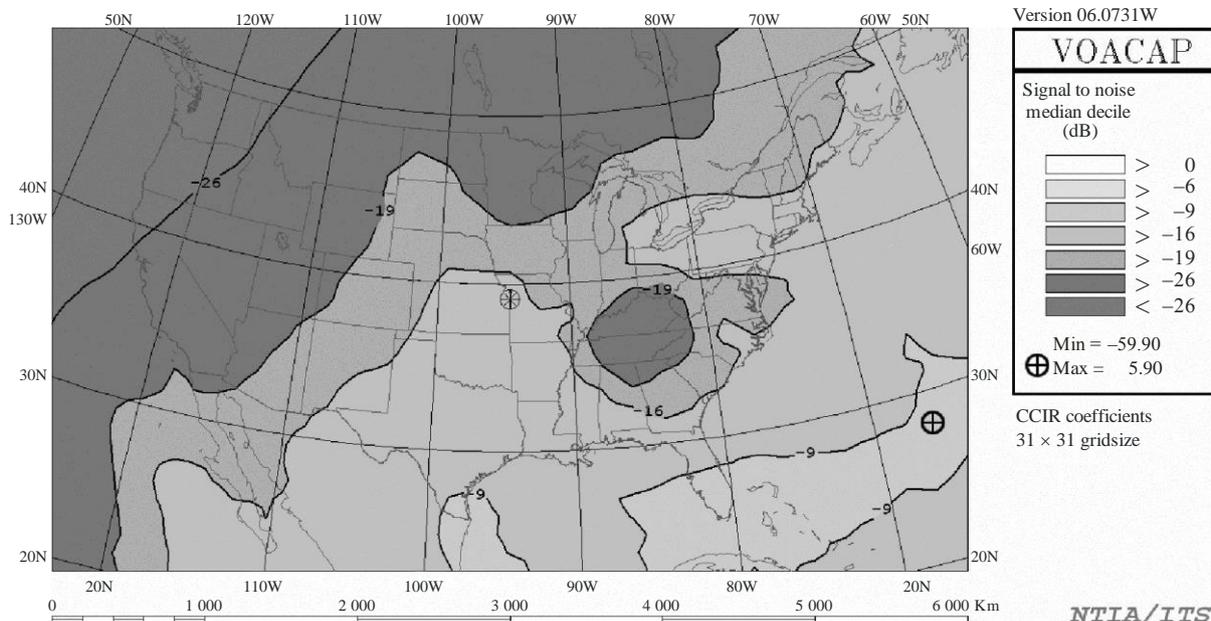


FIGURE A2-23

Aggregation under high SSN conditions due to 12 047 865 underground devices and 760 168 overhead devices with maximum noise floor increase of 1 dB

15ut 30.000 MHz Nov 150ssn overhead: 760,168 underground: 12, 047, 865

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_9.V11 SNR

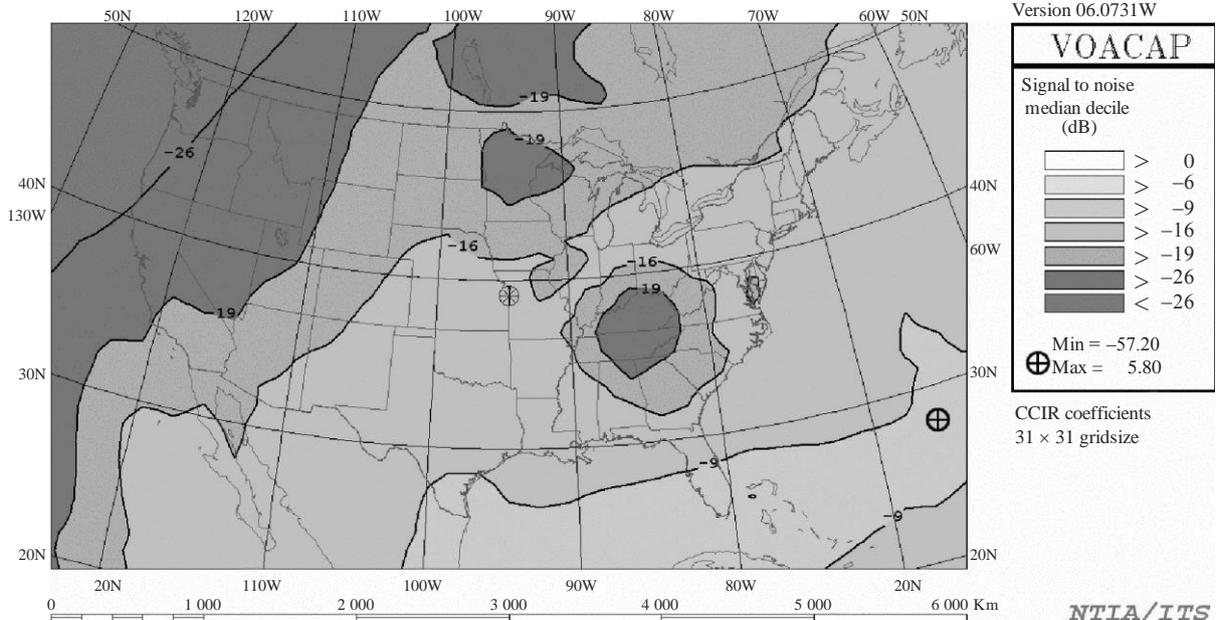


FIGURE A2-24

Aggregation example under high SSN conditions due to no underground devices and 1 355 002 overhead devices with maximum noise floor increase of 1 dB

15ut 30.000 MHz Nov 150ssn overhead: 1,355,002 underground: 0

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_11.V11 SNR

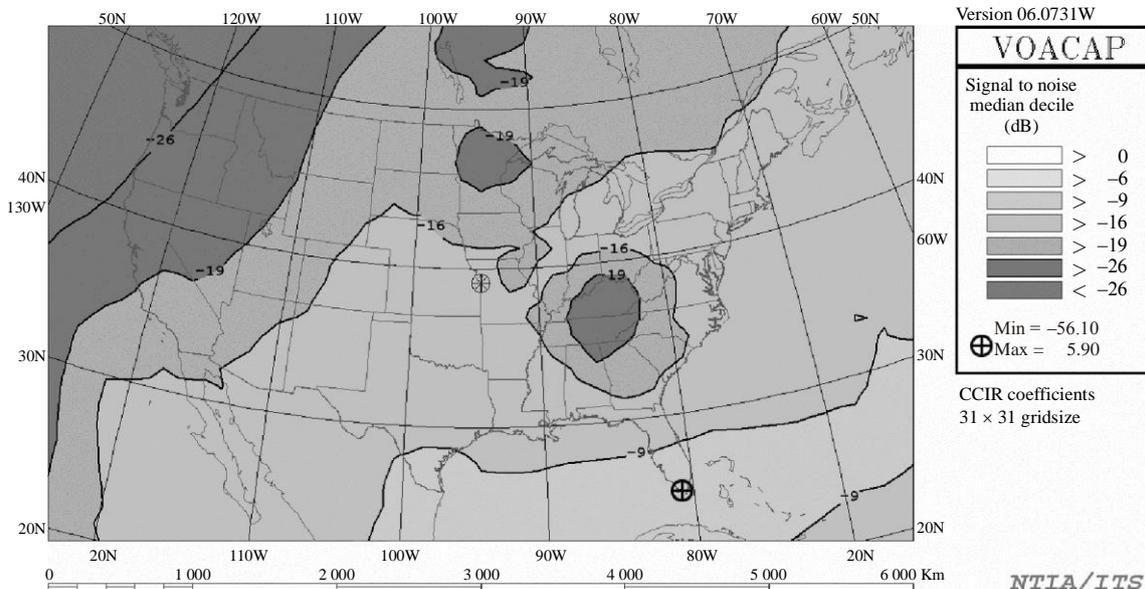


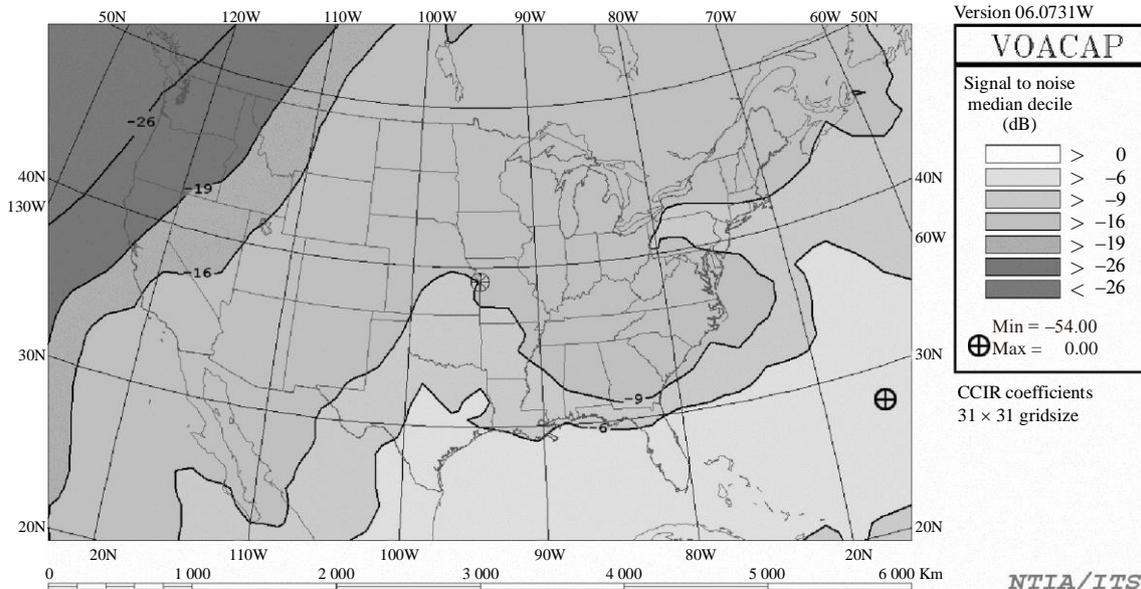
FIGURE A2-25

Aggregation example under high SSN conditions due to 93 055 084 underground devices and no overhead devices with maximum noise floor increase of 3 dB

15ut 30.000 MHz Nov 150ssn overhead: 0 underground: 93,055,084

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_8.V11 SNR



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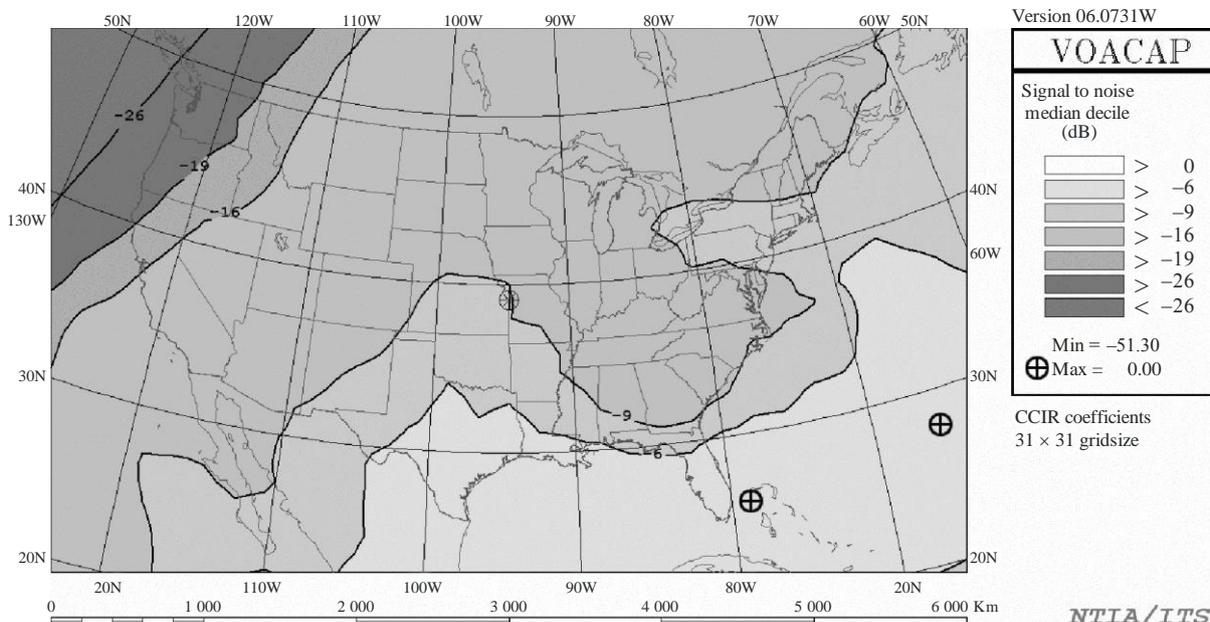
FIGURE A2-26

Aggregation example under high SSN conditions due to 46 527 542 underground devices and 2 935 689 overhead devices with maximum noise floor increase of 3 dB

15ut 30.000 MHz Nov 150ssn overhead: 2,935,689 underground: 46,527,542

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_10.V11 SNR



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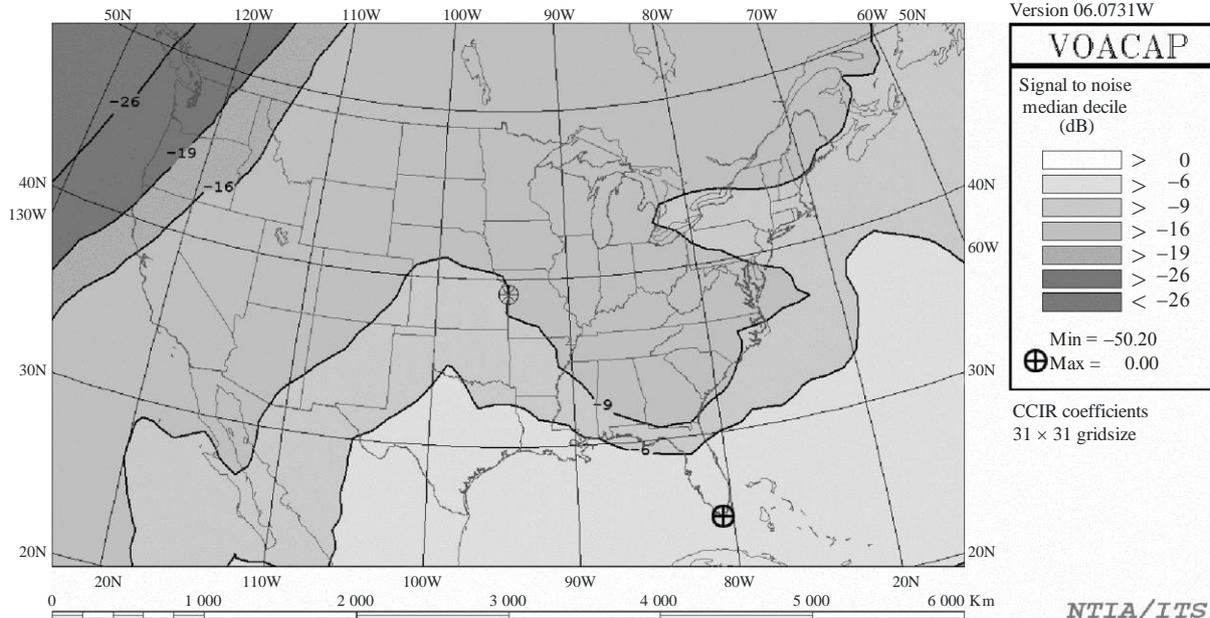
FIGURE A2-27

Aggregation example under high SSN conditions due to no underground devices and 5 232 871 overhead devices with maximum noise floor increase of 3 dB

15ut 30.000 MHz Nov 150ssn overhead: 5,232,871 underground: 0

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_12.V11 SNR



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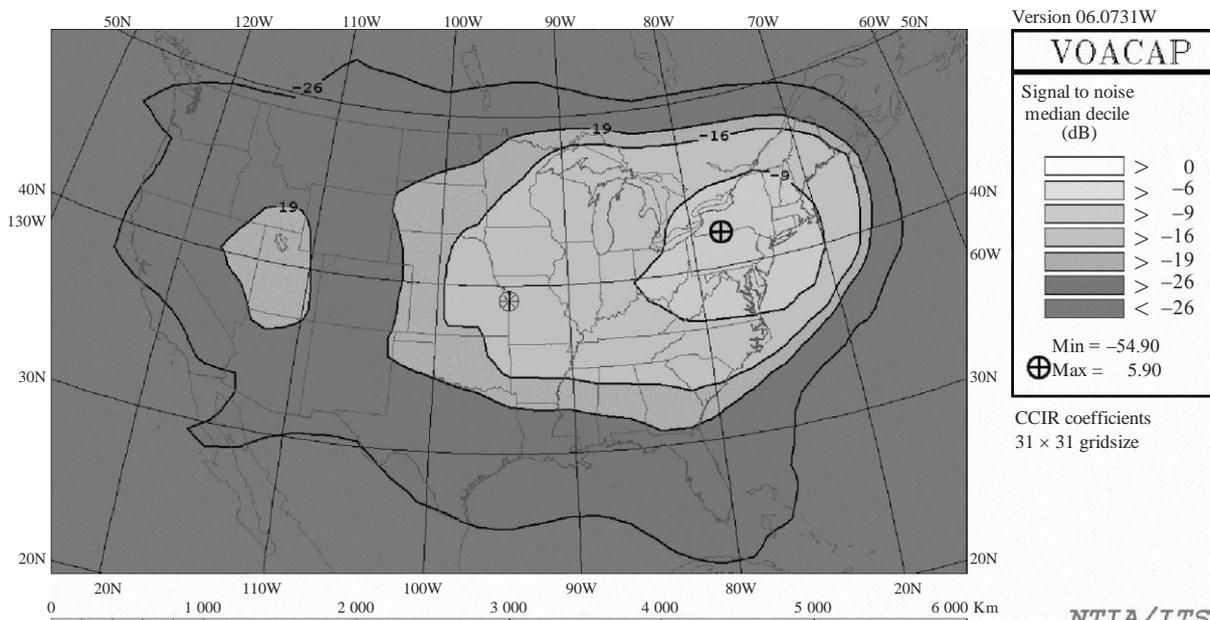
FIGURE A2-28

Aggregation example under low SSN conditions due to 9 816 125 underground devices and no overhead devices with maximum noise floor increase of 1 dB

15ut 6.000 MHz Dec 25ssn overhead: 0 underground: 9,816,125

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_1.V11 SNR



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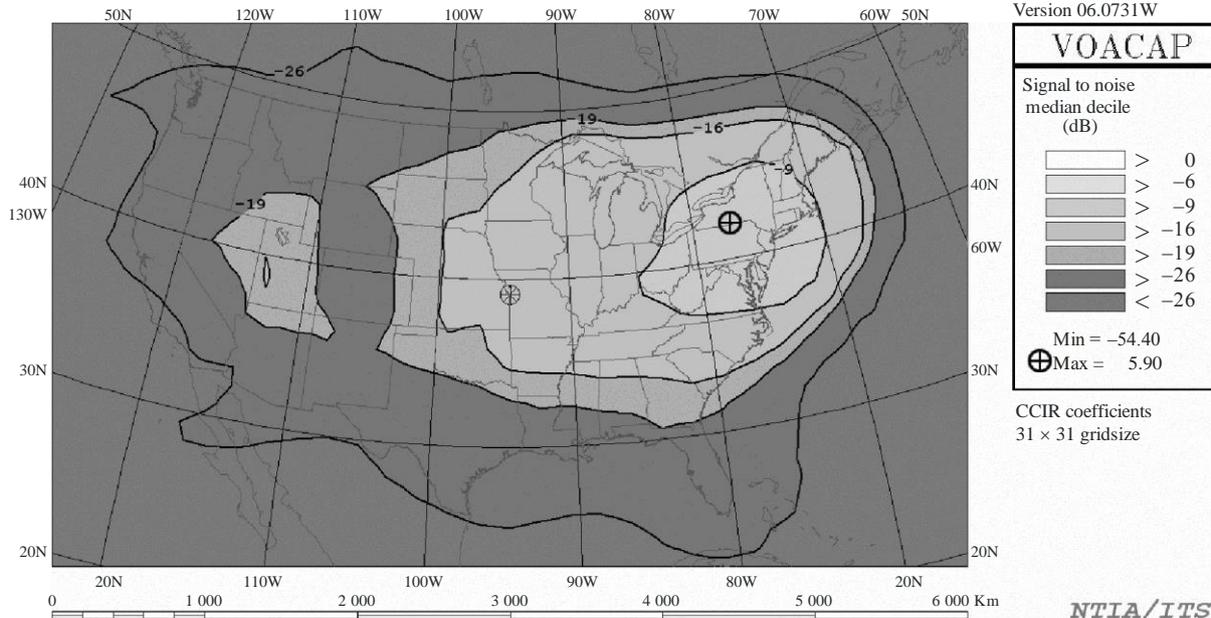
FIGURE A2-29

Aggregation example under low SSN conditions due to 4 908 062 underground devices and 458 047 overhead devices with maximum noise floor increase of 1 dB

15ut 6.000 MHz Dec 25ssn overhead: 458,047 underground: 4,908,062

Tx location to grid of Rx

SNR
AREADATA \ AGGS\AGGOUT_3.V11



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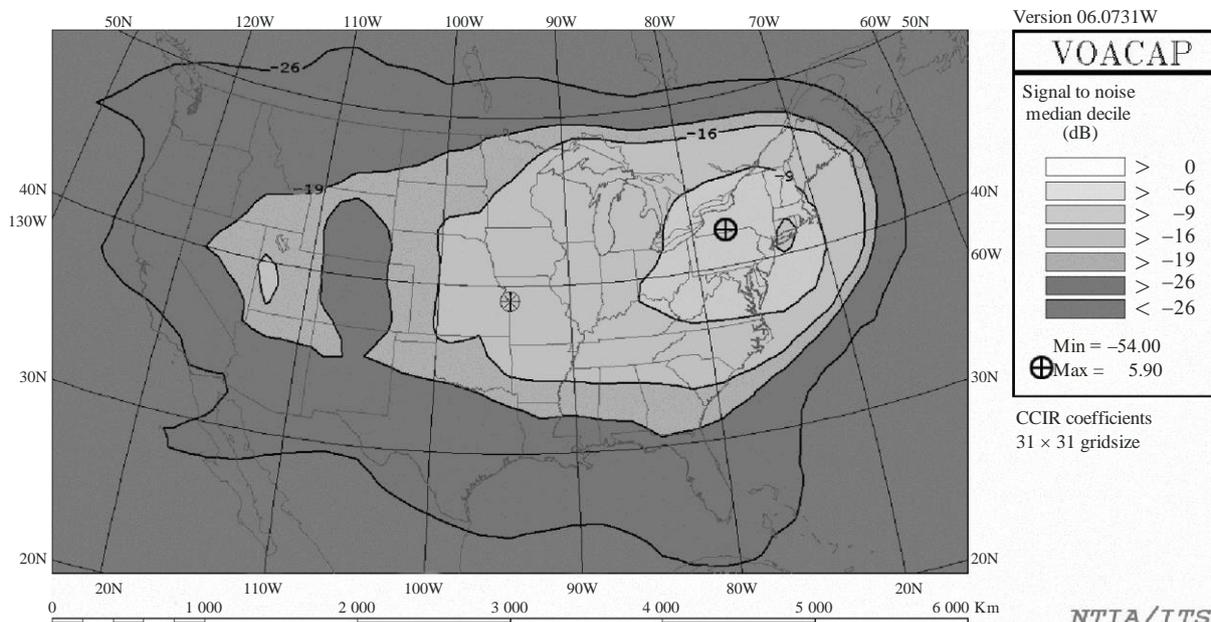
FIGURE A2-30

Aggregation example under low SSN conditions due to no underground devices and 916 094 overhead devices with maximum noise floor increase of 1 dB

15ut 6.000 MHz Dec 25ssn overhead: 916,094 underground: 0

Tx location to grid of Rx

SNR
AREADATA \ AGGS\AGGOUT_5.V11



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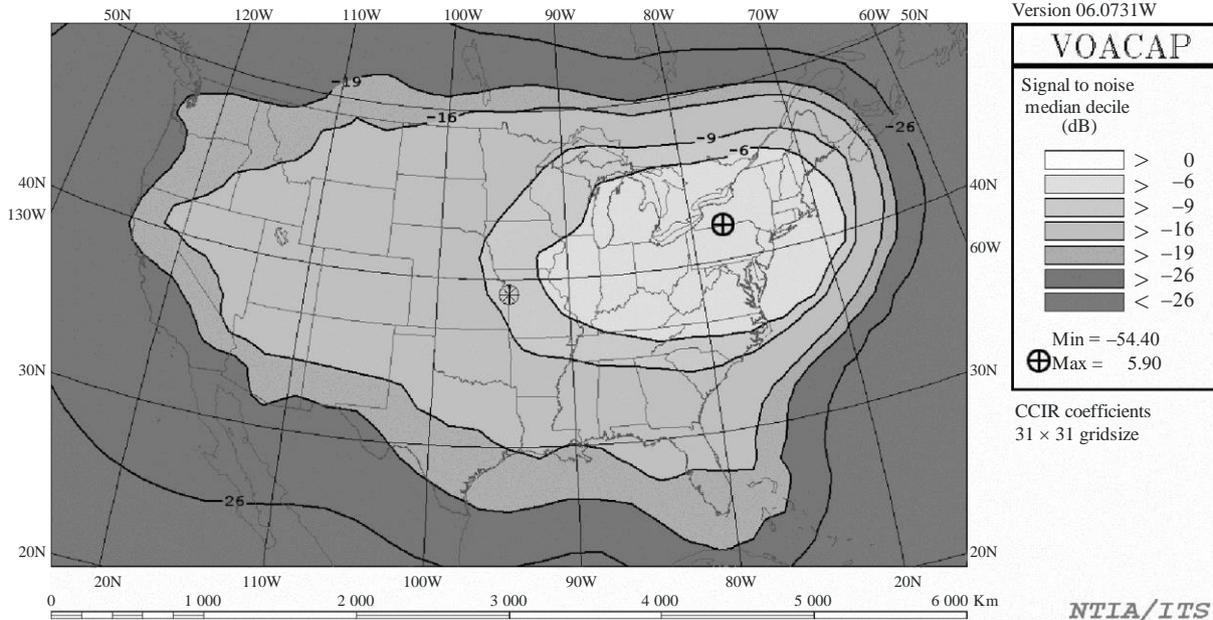
FIGURE A2-31

Aggregation example under low SSN conditions due to 37 908 805 underground devices and no overhead devices with maximum noise floor increase of 3 dB

15ut 6.000 MHz Dec 25ssn overhead: 0 underground: 37,908,805

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_2.V11 SNR



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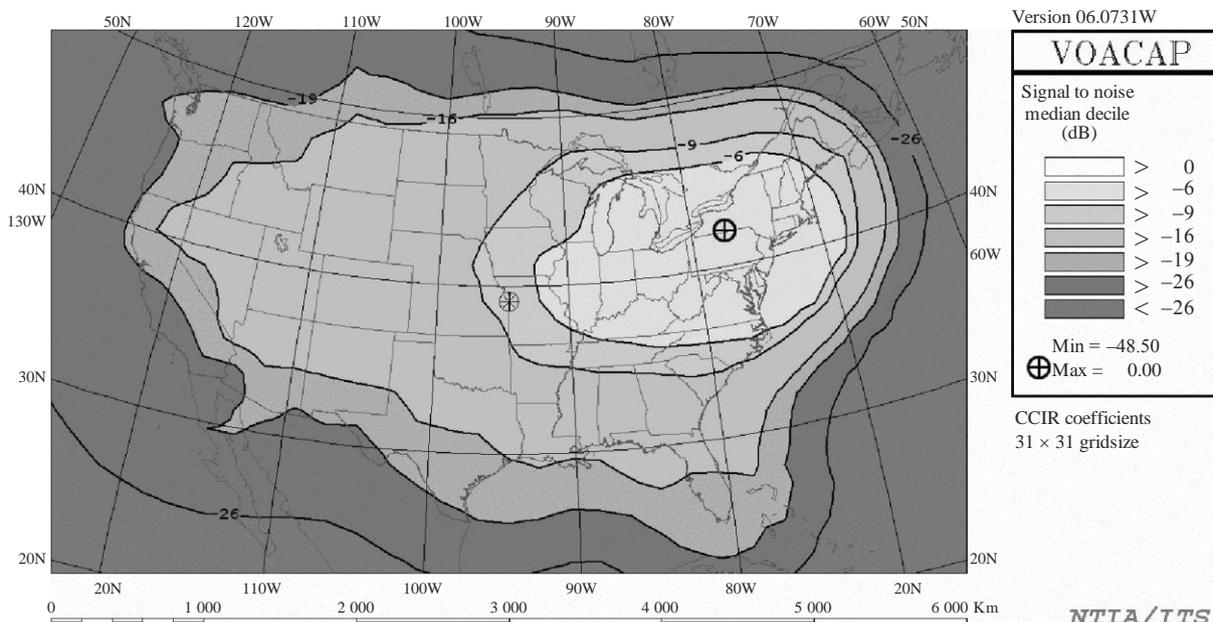
FIGURE A2-32

Aggregation example under low SSN conditions due to 18 954 402 underground devices and 1 768 927 overhead devices with maximum noise floor increase of 3 dB

15ut 6.000 MHz Dec 25ssn overhead: 1,768,927 underground: 18,954,402

Tx location to grid of Rx

AREADATA \ AGGS\AGGOUT_4.V11 SNR

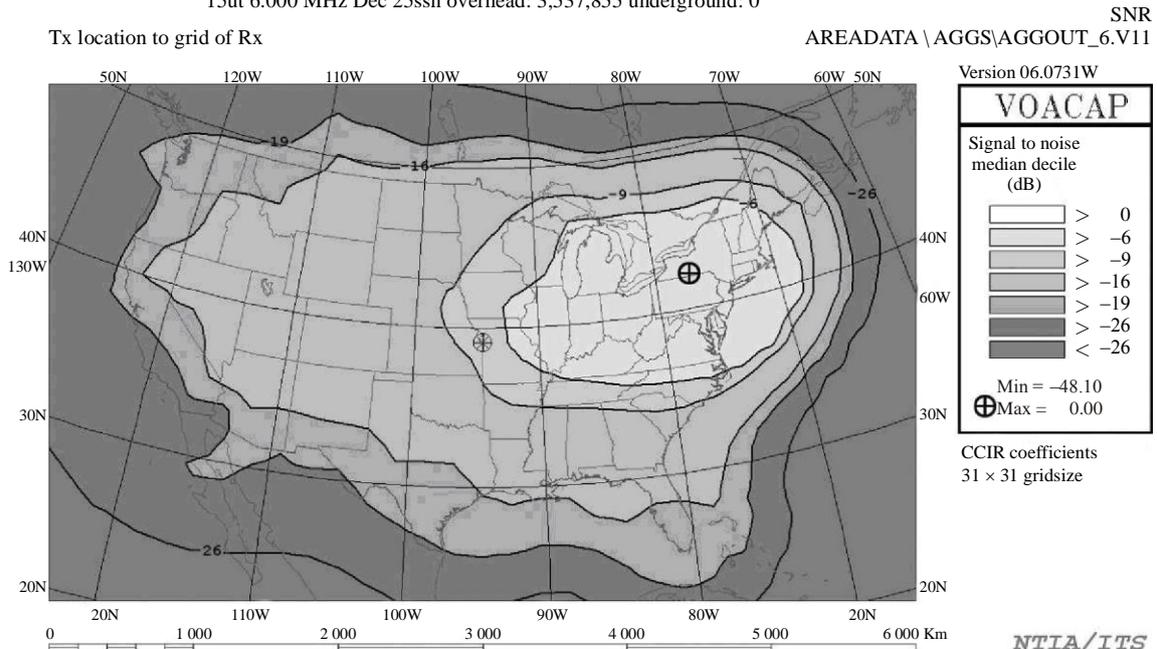


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FIGURE A2-33

**Aggregation example under low SSN conditions due to no underground devices
and 3 537 855 overhead devices with maximum noise floor increase of 3 dB**

15ut 6.000 MHz Dec 25ssn overhead: 3,537,855 underground: 0



The aggregation examples of Figs A2-21 through A2-32 depict the two circumstances (one for low solar cycle activity and one for high) in which the fewest devices are needed to reach the thresholds indicated at any geographic point and across all conditions of time and frequency simulated. As can be seen from the figures, under these conditions of best propagation/lowest noise and using the assumptions developed in this study, more than 916,000 overhead PLT devices deployed nationwide would be necessary to produce increases in the noise floor of 1 dB at any geographic point – well above the 705,000 PLT devices expected in NTIA’s deployment model for passing 100 percent of the urban households in the United States of America. Far more devices could be deployed without reaching either 1 dB or 3 dB thresholds if a significant percentage are deployed on underground power lines.

In the vast majority of cases modelled (other times of day, months of the year and frequencies), many more devices, both underground and above ground, were required to produce the stipulated increases in the noise floor.

A2.4.2.6 Summary

NTIA modelled two power line structures and conducted comprehensive aggregation studies using VOAAREA propagation software to determine the potential for harmful interference to U.S. Government radiocommunication systems in the 1.7 to 30 MHz frequency range due to PLT signals propagated via the ionosphere.

The simulation results conducted by the United States of America for the deployment of Access PLT on MV overhead power lines operating in the 1.7 to 30 MHz band show that, for a wide scale deployment of overhead PLT devices (such that PLT services passes 100 percent of the urban households in the United States of America) and under the assumptions in this study, the noise floor increase is expected to be less than 1 dB for the worst case propagation conditions. In reality, approximately 20% of the MV power lines are underground and many PLT systems operate in the VHF band. From these results, a widespread deployment of Access PLT systems in the United States of America is not expected to pose a problem for U.S. Government radiocommunication

systems (land-mobile and fixed-service systems represented by quarter-wave dipoles) operating in the 1.7 to 30 MHz band due to ionospheric propagation and aggregation of signals.

A2.4.3 Results on calculation of cumulative HF sky-wave interference caused by power line telecommunication systems

A2.4.3.1 Introduction

This section describes examples of calculation of the cumulative electric field strength caused by PLT systems due to the sky-wave propagation that is modelled in Recommendation ITU-R P.533 – HF propagation prediction method.

In this calculation, the following assumptions were made:

- The territory of Japan is divided into nine areas, each having an imaginary radiation source with a power proportional to the sum of the assumed number of PLT systems.
- A total of 1.5×10^7 PLT systems corresponding to the coverage of 30% households are used.
- 100% Duty cycle (All PLT systems are up and running but only a single PLT modem in a system output power at a time) is used.

A2.4.3.2 Calculation of the cumulative PLT sky-wave field

Calculation procedures

1 *Power radiated from a single PLT system*

The radiation power was estimated as follows:

- for a PLT modem, the power radiated from power lines is calculated from a signal power of -60 dBm/Hz (r.m.s. value) and the longitudinal conversion loss (LCL) of the power lines to be 30 dB;
- in addition, considering the bandwidth of an interfered receiving system, the radiation power from a single PLT system is evaluated for the radio service bands as shown in Table A2-5;
- therefore the following formula was used:
Radiated power (dBW) = Signal power (dBm/Hz) $-30 + 10 \log$ (bandwidth (Hz)) $- LCL$ (dB); and
- receiver points are assumed to be far enough from the PLT systems and therefore the radiation source can be treated as a point source.

TABLE A2-5

Radiation power of a single PLT system

	Frequency band	Radiation power
Radio astronomy	13 MHz band (Center frequency: 13.385 MHz)	-73.0 dBW (r.m.s. value, bandwidth 50 kHz)
	25 MHz band (Center frequency: 25.610 MHz)	-69.2 dBW (r.m.s. value, bandwidth 120 kHz)
Amateur radio	3.5 MHz band (Calculation frequency: 3.538 MHz)	-86.2 dBW (r.m.s. value, bandwidth 2.4 kHz)
	7 MHz band (Calculation frequency: 7.050 MHz)	-86.2 dBW (r.m.s. value, bandwidth 2.4 kHz)

2 *Cumulative treatment of distributed PLT systems*

In the calculation, the territory of Japan was divided into 9 areas as shown in Table A2-6, each having an imaginary radiation source of a power estimated from the following formula:

$$\begin{aligned} & \text{Radiation power of an imaginary source in an area (dBW)} \\ & = \text{Power radiated from a single PLT system (dBW)} + 10 \log (\text{number of PLT systems}) - \\ & \text{Shielding effect (dB)} \end{aligned}$$

where:

$$\text{Number of PLT systems} = \text{Number of households in the area} * \text{PLT penetration rate}$$

with:

Number of households based on government data (as of 2004 March),
in the area:

PLT penetration rate: estimated from the broadband service penetration rate at the prefectural and city levels (as of 2005 March) under the condition of the nationwide average of 30%,

Shielding effect: assumed to be 0 dB (no effect).

For each PLT modem, a duty cycle of 100% was assumed for the worst case analysis. It means all PLT modems are up and running.

3 *Calculation of the cumulative field strength distribution through HF sky-wave propagation*

The electric field strength distribution (median value) through the HF sky-wave propagation radiated from a total of 1.5×10^7 PLT systems was calculated in the following way:

- for each area the electric field strength distribution from an imaginary radiation source was calculated through the HF sky-wave propagation;
- the nine calculation results above were summed in terms of the power.

Actual calculation using the propagation model in Recommendation ITU-R P.533

Calculation of the field strength distribution was made using the public domain free software, RECAREA⁵¹, published by Radiocommunication Study Group 3, with the following parameters:

a) *Radiation power*

Because of a constraint of the software, calculations were made for certain levels of the radiation power above 0 dBW. Then, the results were corrected corresponding to the radiation power listed in Tables A2-5 and A2-6.

b) *Transmit antenna*

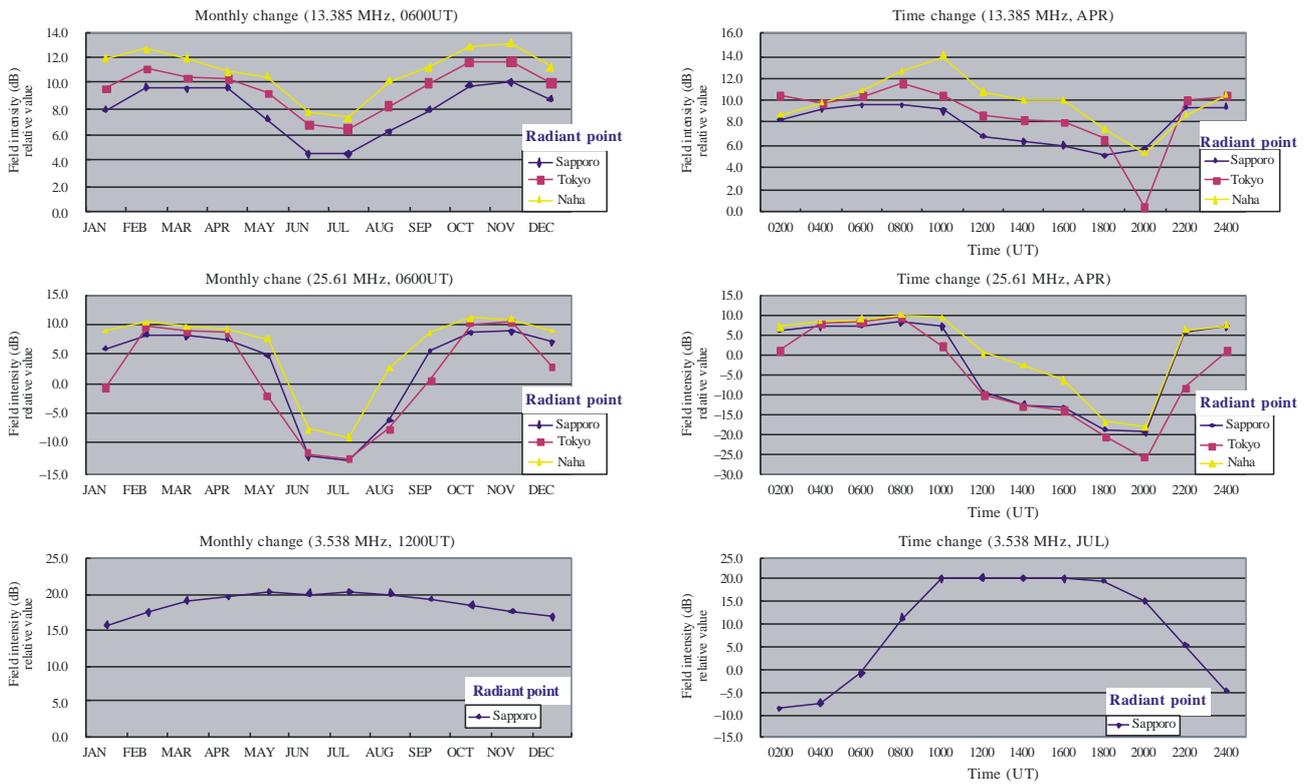
Antenna type was set to the isotropic antenna.

c) *Conditions in the ionosphere*

Various characteristics of the ionosphere change by month and time. Electric field strength and its distribution also change because of this characteristics variation. The maximum electric field strength in the plot area shown in f) varies according to the month and time used for the calculation, as shown in Fig. A2-34. In this calculation, parameters “Month: April, time: 0600UT” were used, which corresponded to approximately the maximum electric field strength.

⁵¹ This software is downloadable from http://elbert.its.bldrdoc.gov/pc_hf/hfwin32.html.

FIGURE A2-34
 Example of the field intensity changed with month/time



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d) *SSN (Sun spot number)*

Figure A2-35 shows an example of maximum electric field strength variation for various SSN. SSN = 100 was set for the calculation. (Solar activity is relatively active.)

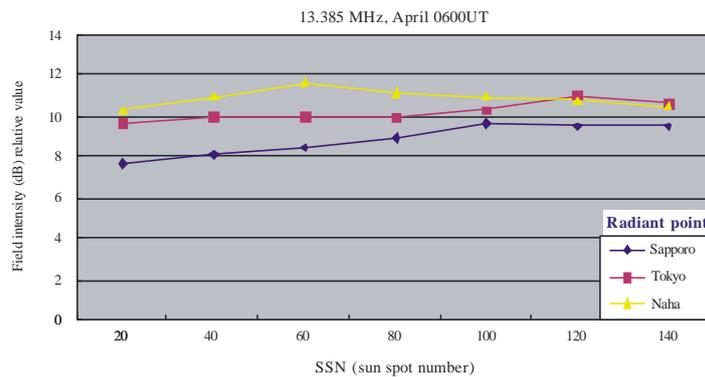
e) *Receiving antenna / receiver bandwidth*

It is an irrelevant parameter in the calculation of electric field strength.

f) *Plot area*

The reference point of the plot was set to Tokyo, and the plot area covered an area around Japan: 700 km East, 1 300 km West, 1 200 km North and 1 000 km south relative to the reference point.

FIGURE A2-35
 Example of the field intensity changed with SSN



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TABLE A2-6

Radiation power of the imaginary radiation sources

	Area	Location of the imaginary source	Number of households (x 10 ⁴)	PLT Penetration	Number of PLT systems (x 10 ⁴)	Radiation power of the imaginary source (dBW)
1	Hokkaido	Sapporo (43.06N, 141.33E)	252	20%	50.4	13MHz band: -16.0 25MHz band: -12.2 3.5MHz/7MHz band: -29.2
2	Touhoku	Sendai (38.26N, 140.90E)	341	25%	85.3	13MHz band: -13.7 25MHz band: -9.9 3.5MHz/7MHz band: -26.9
3	Kanto	Tokyo (35.67N, 139.77E)	1,717	35%	600.9	13MHz band: -5.2 25MHz band: -1.4 3.5MHz/7MHz band: -8.4
4	Shinetsu, Hokuriku	Kanazawa (36.59N, 136.63E)	263	25%	65.8	13MHz band: -14.8 25MHz band: -11.0 3.5MHz/7MHz band: -28.0
5	Toukai	Nagoya (35.17N, 136.97E)	536	35%	187.5	13MHz band: -10.3 25MHz band: -6.5 3.5MHz/7MHz band: -23.5
6	Kinki	Osaka (34.68N, 135.52E)	829	30%	248.7	13MHz band: -9.0 25MHz band: -5.2 3.5MHz/7MHz band: -22.2
7	Chugoku, Shikoku	Hiroshima (34.40N, 132.46E)	464	25%	116.0	13MHz band: -12.4 25MHz band: -8.6 3.5MHz/7MHz band: -25.6
8	Kyushu	Fukuoka (33.58N, 130.38E)	531	25%	132.9	13MHz band: -11.8 25MHz band: -8.0 3.5MHz/7MHz band: -25.0
9	Okinawa	Naha (26.21N, 127.69E)	50	20%	10.0	13MHz band: -23.0 25MHz band: -19.2 3.5MHz/7MHz band: -36.2

A2.4.3.3 Calculation results

Figure A2-36 shows calculation results of radiation from a single PLT system. The electric field strength by the sky-wave propagation may have a maximum value point far away from the radiation point and the maximum value point varies by month, time and frequency, and so on.

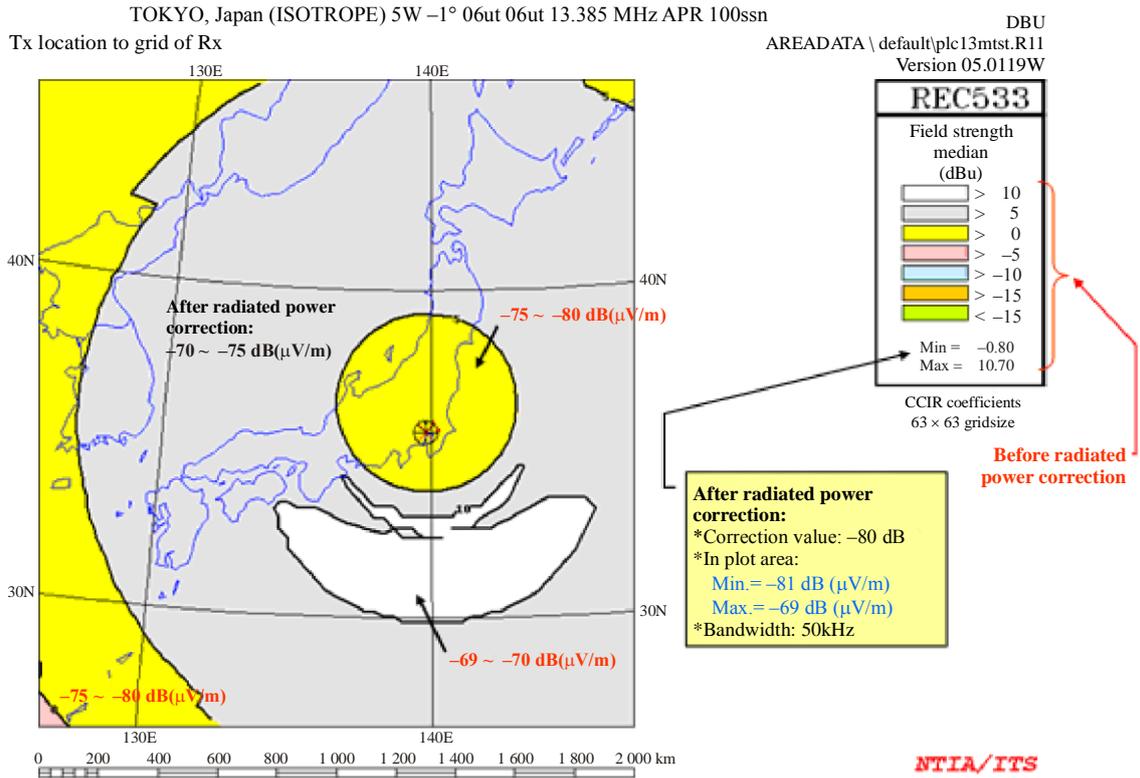
However the absolute value of the electric field strength from a single PLT system is extremely low. Additionally, as the distance from the radiation point increases, the interference electric field strength decreases as illustrated in Fig. A2-37.

Figures A2-38 and A2-39 shows calculation results of the cumulative electric field strength distribution (median value) from a total of 1.5×10^7 PLT systems in Japan.

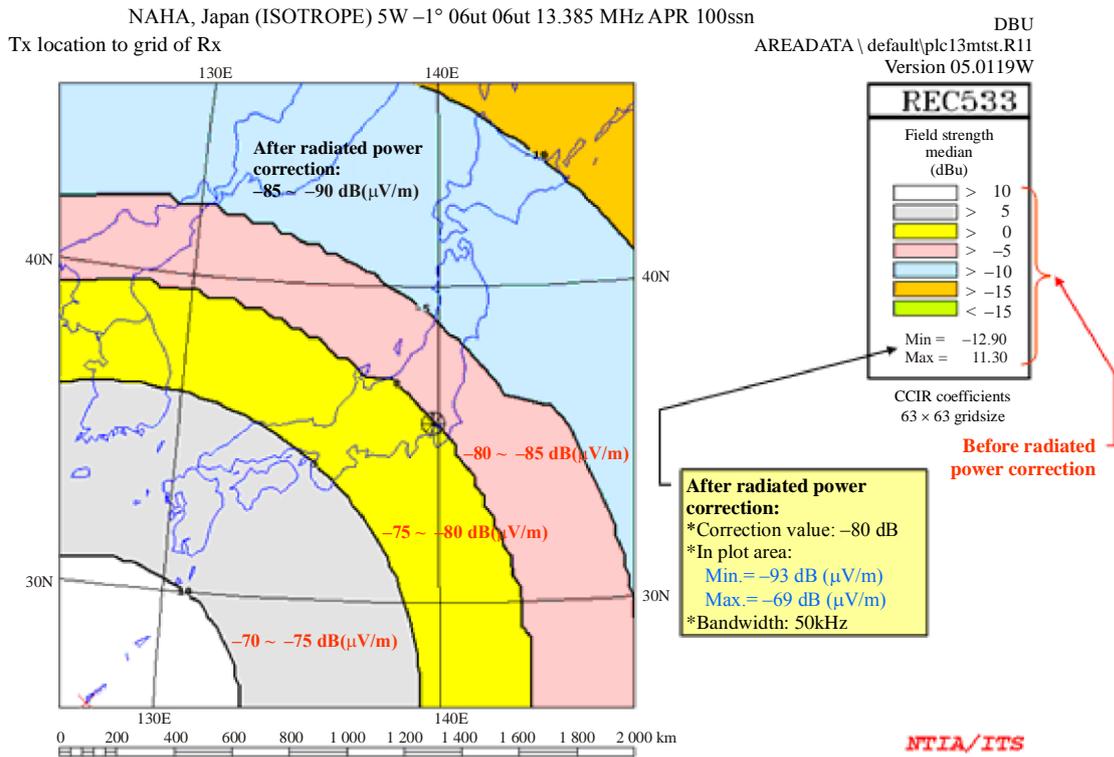
According to the calculation results, similarly to the case of a single PLT system, the electric field strength by the sky-wave may have a maximum value point far away from the radiation point. However, the cumulative electric field strength generated by all PLT systems is found to be low and that is less than rural-area noise level.

FIGURE A2-36

Example of HF sky wave field strength distribution caused by a single PLT system



a) 13 MHz band, radiant point: Tokyo



b) 13 MHz band, radiant point: Naha

FIGURE A2-37

**Example of HF sky wave field strength distribution caused by a single PLT system
(13 MHz band, radiant point: Tokyo)**

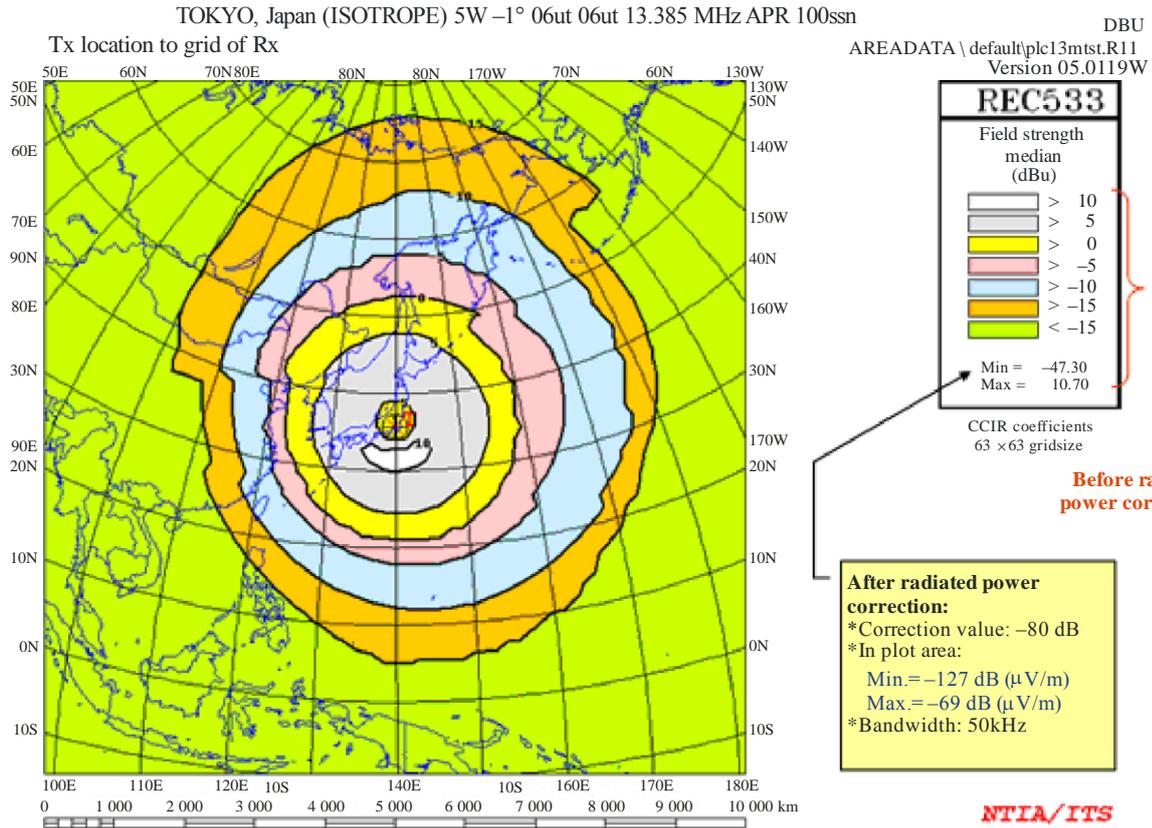
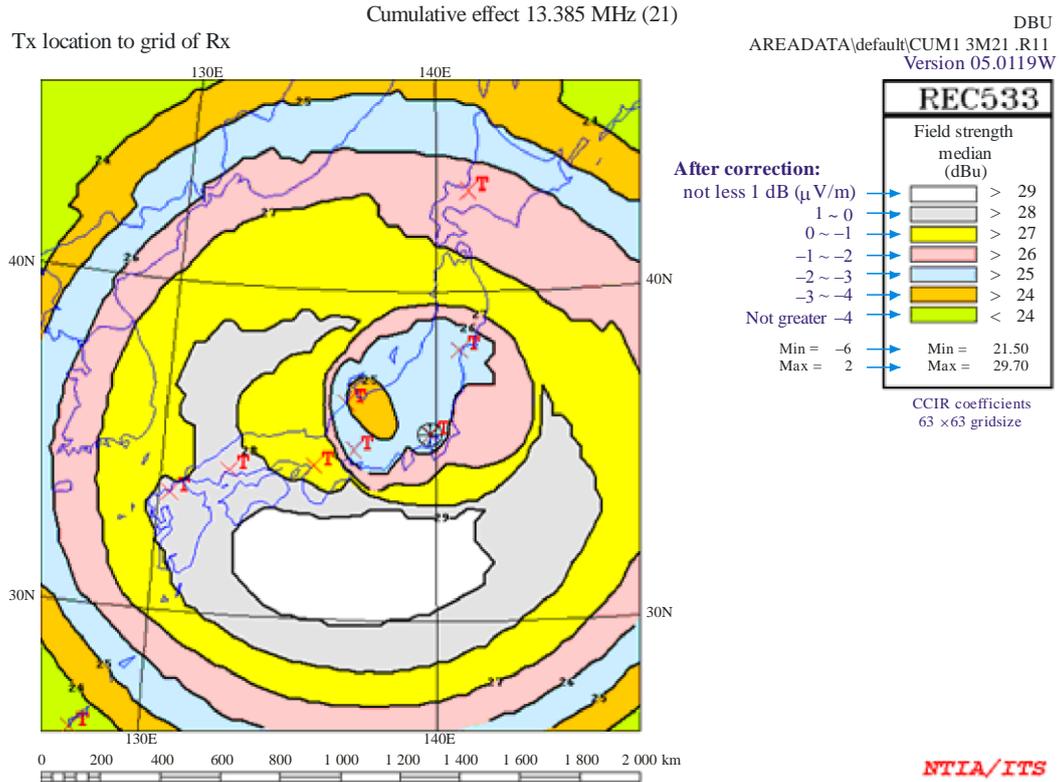
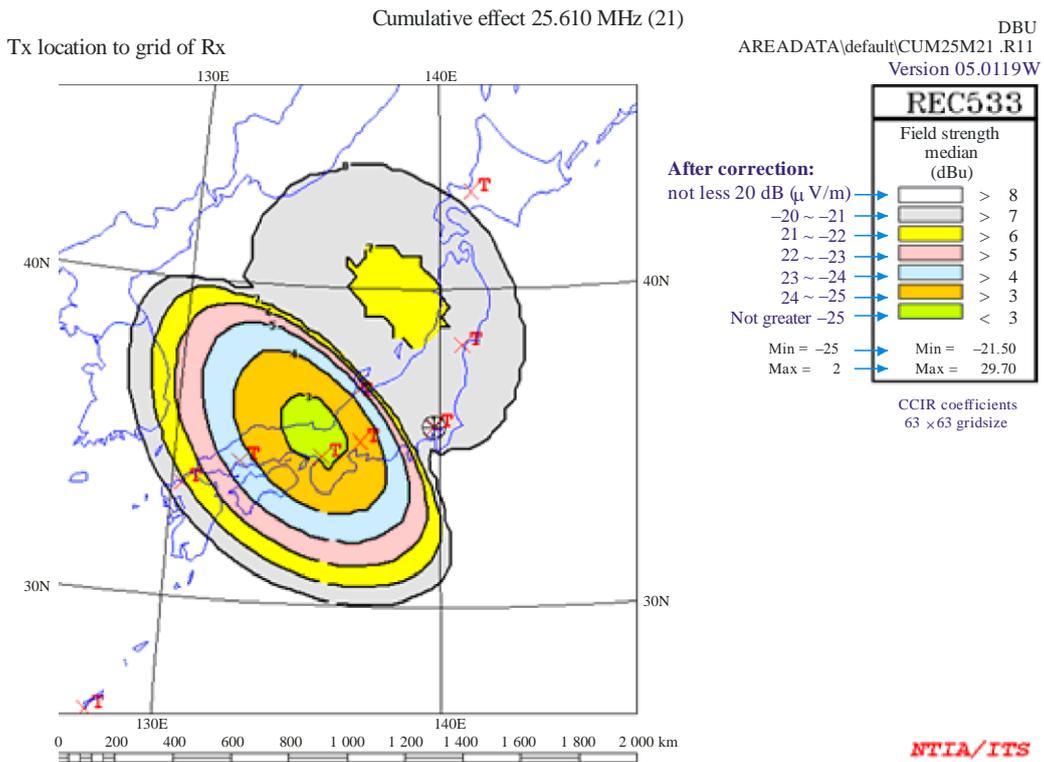


FIGURE 2A-38

Example of the cumulative field strength distribution of HF sky waves radiated by all PLT systems (for 13 MHz band and 25 MHz band)



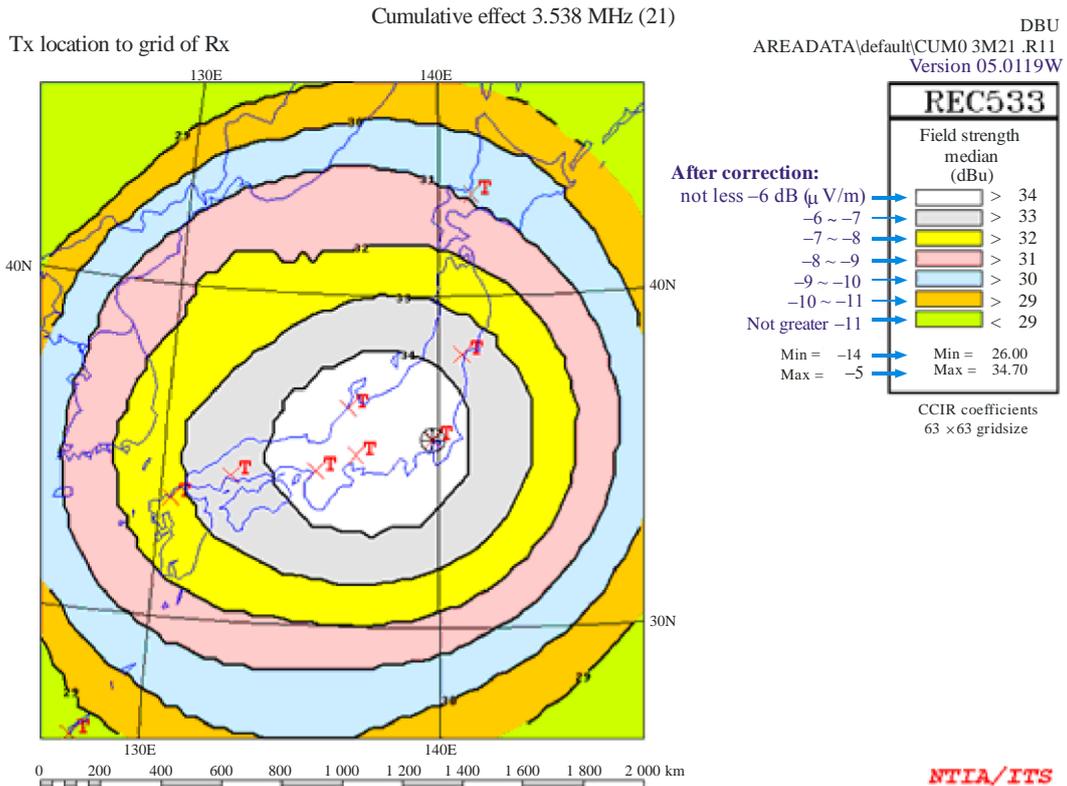
a) Sky-wave 13 MHz band, bandwidth: 50 kHz



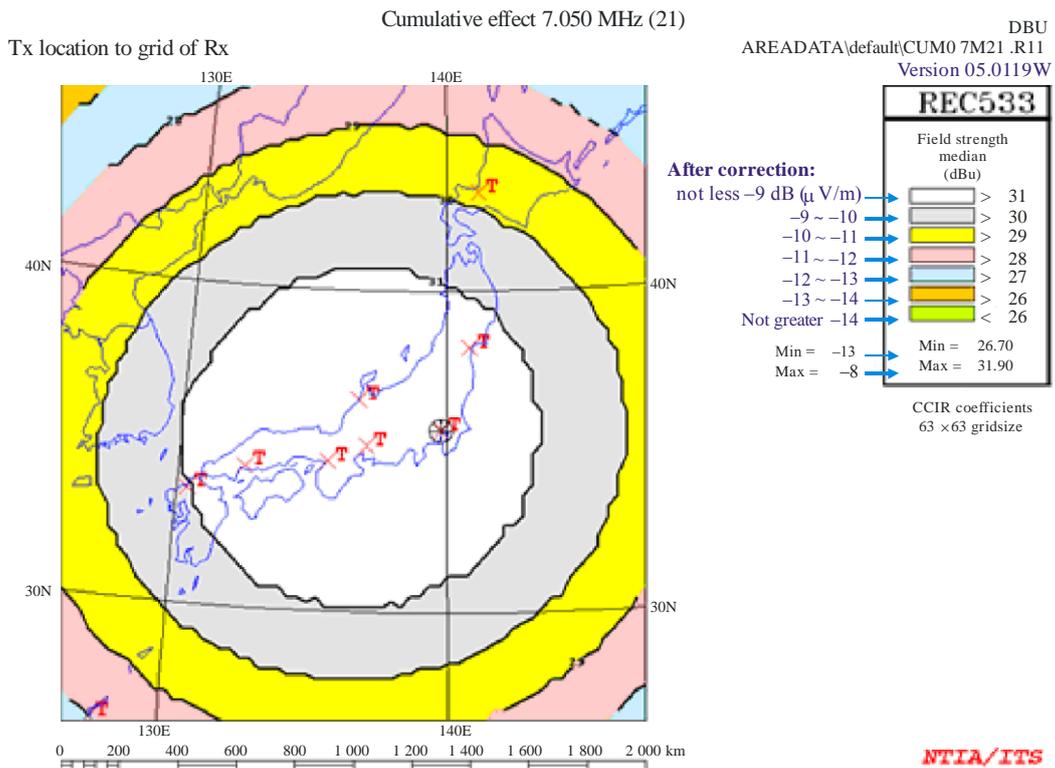
b) Sky-wave 25 MHz band, bandwidth: 120 kHz

FIGURE 2A-39

Example of the cumulative field strength distribution of HF sky waves radiated by all PLT systems (for 3.5 MHz band and 7 MHz band)



a) Sky-ware: 3 MHz band, bandwidth: 2.4 kHz



b) Sky-ware: 7 MHz band, bandwidth: 2.4 kHz

A2.4.4 Compatibility study results between the radio astronomy observations in the HF band and cumulative HF sky-wave interference caused by in-house power line telecommunication systems

A2.4.4.1 Introduction

The radio astronomy service has frequency allocations in the HF band on a primary basis: 13.36-13.41 MHz and 25.55-25.67 MHz. The threshold levels of interference detrimental to the radio astronomy observations in these bands, expressed in terms of the electric field strength shown in Report ITU-R RA.2131, are -55.2 dB(μ V/m) for the 13 MHz band and -53.2 dB(μ V/m) for the 25 MHz band, respectively.

A2.4.4.2 Calculation results

Figure A2-38 shows calculation results of radiation from a single PLT system. The electric field strength through the sky-wave propagation may have a maximum value point far away from the radiation point and the maximum value point varies by month, time and frequency, and so on. Figure 2A-39 shows calculation results of the cumulative electric field strength distribution (median value) from a total of 1.5×10^7 PLT systems. According to the calculation results, similarly to the case of a single PLT system, the electric field strength by the sky-waves may have a maximum value point far away from the radiation point.

In Fig. 2A-39 the maximum electric field strengths are 2 dB(μ V/m) for the 13 MHz band and -2 dB(μ V/m) for the 25 MHz band, which are far above the threshold levels of interference detrimental to the radio astronomy observations in these bands, -55.2 dB(μ V/m) for the 13 MHz band and -53.2 dB(μ V/m) for the 25 MHz band. The discrepancies are about 57 dB for the 13 MHz and about 51 dB for the 25 MHz band. Since the calculated field strengths are approximately proportional to the total radiated power, such discrepancies could be resolved by reducing the number of PLT systems from 1.5×10^7 to 30. However, such a situation would not be realistic.

A2.4.4.3 Possible mitigation measures for protecting the radio astronomy service in the HF band

It is found that the frequency sharing between the radio astronomy observations in the HF band and large number of PLT systems would not be feasible. Possible mitigation measures to avoid interference detrimental to the radio astronomy observations in the HF band would be:

- implementation of fixed notch filters to the radio astronomy bands, i.e. a PLT system do not use the frequency bands allocated to the radio astronomy service in the HF band; or
- reduction of the radiation power from a single PLT system by more than 50 dB.

Since the radio astronomy observations are quite sensitive and cannot escape from radiation caused by the PLT systems, a permanent reduction of the power spectral density of PLT devices (i.e. permanent notching) should be implemented to the frequency bands allocated to the radio astronomy service.

A2.5 Experimental results of the subjective assessment test on HF analogue broadcast reception interfered with by PLT

This section reports the subjective assessment test on interference of PLT with HF broadcast reception conducted in Japan. This test was carried out with two steps; acquisition of HF broadcast reception audio samples interfered with by PLT and subjective assessment test using the audio samples. To acquire the audio samples, an HF signal modulated by audio signals (30% modulation) was generated at 6.055 MHz in a shielded room (GTEM cell). HF broadcast signal, PLT noise and Gaussian noise were generated inside the isolated GTEM cell.

Two types of PLT modems with different modulation technologies were used, that is, spread spectrum (SS) and OFDM.

With respect to the test frequency, the middle frequency band in three frequency bands used by Nikkei Radio Broadcasting Co. was selected.

The subjective assessment test was performed according to the DSIS (double stimulus impairment scale) method described in Recommendation ITU-R BS.1284.

These tests were performed in the following dates and the venues:

- 29 August 2005 (Acquisition of audio samples): NICT
- 15 September 2005 (Subjective assessment test): NHK STRL

A2.5.1 Test methods

A2.5.1.1 Acquisition of audio samples

Figure A2-40 and Table A2-7 show the test configuration and the test conditions, respectively.

The following three signals were combined and injected to TEM cell.

- PLT modem signal via V-LISN (V-Line Impedance Stabilization Network).
- Noise generator output to simulate man-made noise.
- AM standard signal generator output to simulate HF broadcasting signal (30% modulation).

Field strength of man-made noise (N_{ext}) was set to a value for the assumed noise environment, and field strength of HF broadcasting signal (E_{sig}) was set to the minimum value required. (See Table A2-7) By varying field strength of PLT signal (E_{plc}), audio samples were acquired.

The audio output signals through a headset port were recorded as audio samples to be tested.

A2.5.1.2 Subjective assessment test

Figure A2-42 and Table A2-8 show the test configuration and the test condition, respectively.

The subjective assessment test was performed according to Recommendation ITU-R BS.1284. Twenty-four non-expert listeners joined the listening tests after a short training. The quality of the audio samples was evaluated using the double stimulus impairment scale (DSIS) method with the five-grade impairment scale:

- 5: Imperceptible.
- 4: Perceptible but not annoying.
- 3: Slightly annoying.
- 2: Annoying.
- 1: Very annoying, where the quality of audio signal with both the Gaussian background noise and the PLT noise was compared with that of the audio signal with the background noise only (reference).

FIGURE A2-40
Audio sample test condition

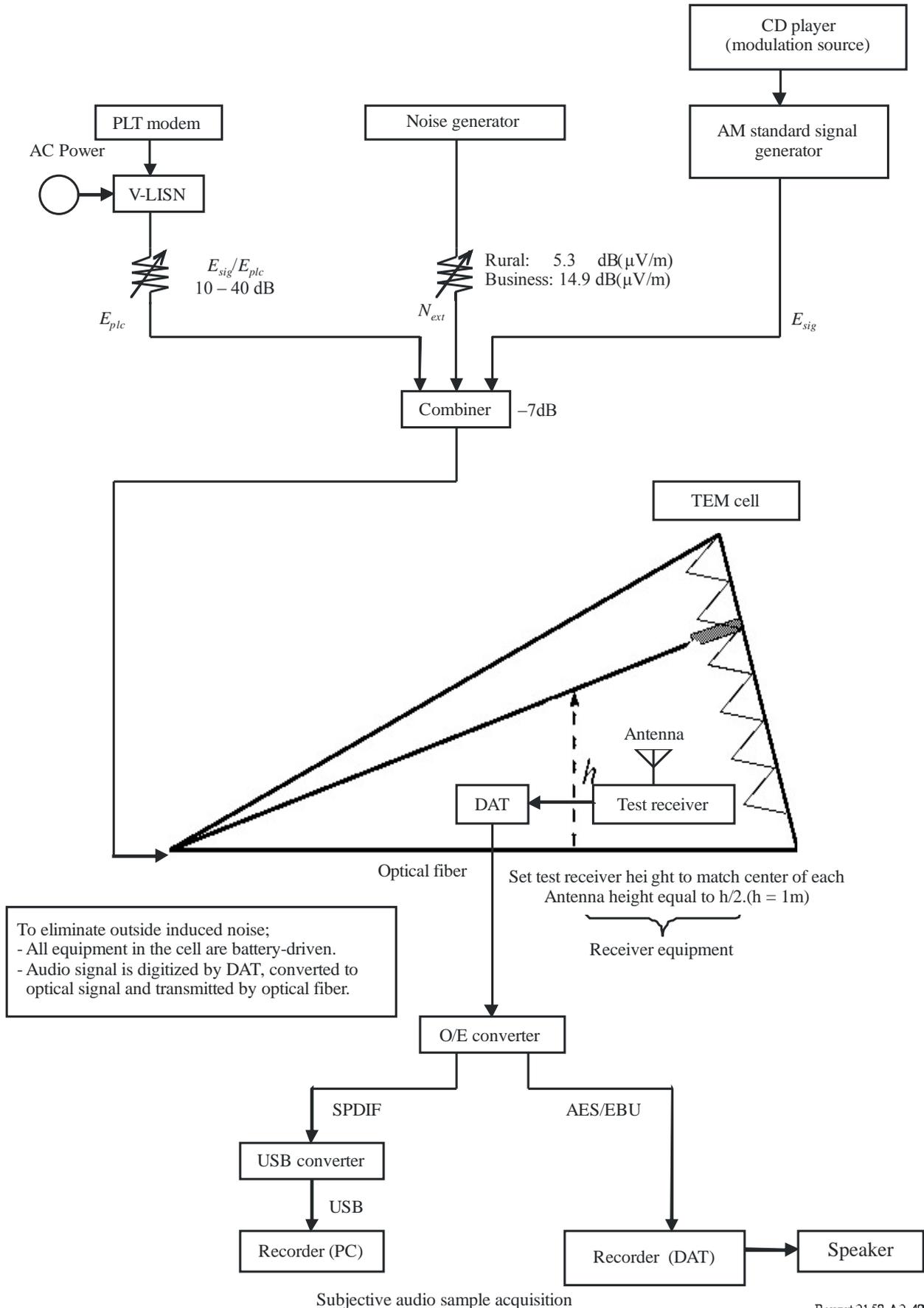


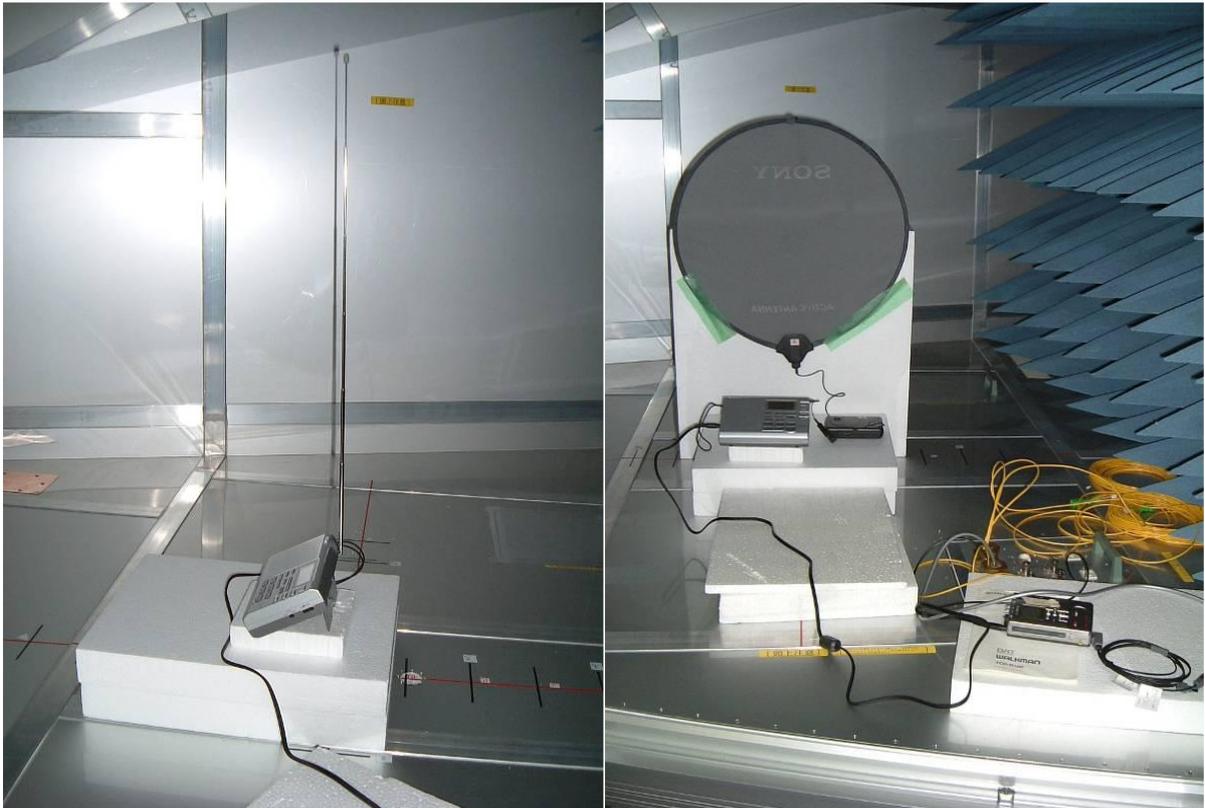
TABLE A2-7

HF broadcasting receiver condition

Receiver	Antenna	Field strength of HF broadcasting signal (E_{sig}) ^{(1), (4)}	Field strength of man-made noise (N_{ext}) ^{(2), (4)}	Field strength of PLT modem signal (E_{plc}) ^{(3), (4)}
Table top receiver ⁽⁵⁾	Rod antenna	40 dB(μ V/m)	5.3 dB(μ V/m) (Rural)	E_{sig}/E_{plc} ratio between 10 and 40 dB at 2 dB steps (See Table A2-6)
			14.9 dB(μ V/m) (Business)	
Table top receiver ⁽⁵⁾	Loop antenna ⁽⁶⁾	30 dB(μ V/m)	5.3 dB(μ V/m) (Rural)	
			14.9 dB(μ V/m) (Business)	

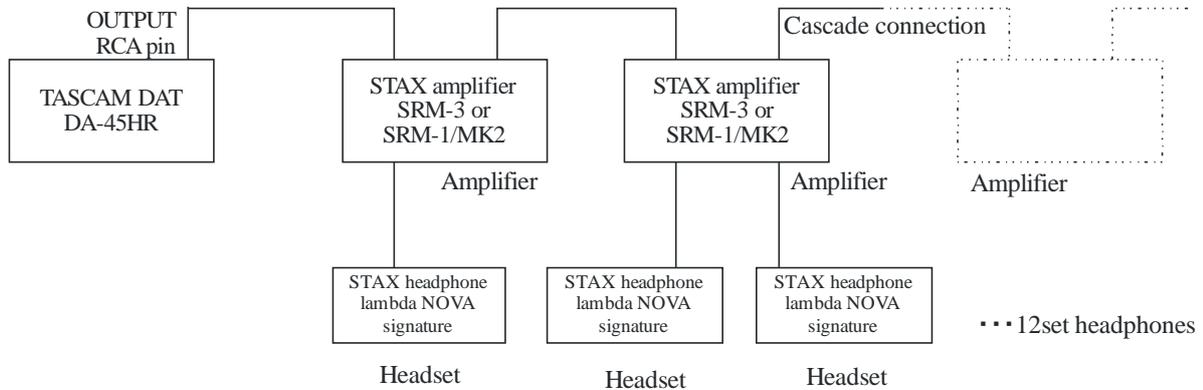
- (1) Field strength of HF broadcasting signal corresponds to the minimum field strength required for HF broadcasting signal. 40 dB(μ V/m) is for international (The WARC HFBC(2), Geneva 1987), 30 dB(μ V/m) is for Japan. The field strength is measured for non-modulated carrier signal.
- (2) Field strength of man-made noise is 5.3 dB(μ V/m) (BW = 9 kHz) for rural, or 14.9 dB(μ V/m) (BW = 9 kHz) for business as described in Recommendation ITU-R P.372-8.
- (3) Field strength of PLT modem signal is measured for 9 kHz bandwidth, which is minimum required frequency bandwidth for HF broadcasting. Two different types of PLT modems were used in the experiments, that is, OFDM and SS systems.
- (4) Gaussian noise (background) and PLT noise were superposed to the HF signal in the GTEM cell.
- (5) A Sony HF receiver installed inside the cell received the HF signals interfered with by the noises and reproduced audio signals to be assessed. The receiver intrinsic noise was as low as it yielded a ratio of the audio signal to noise (S/N) better than 26 dB for a signal field strength of 40 dB(μ V/m).
- (6) AN-LP1 by Sony Co. is used in case of the field strength of 30 dB(μ V/m).

FIGURE A2-41
Receiver in GTEM cell



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FIGURE A2-42
Subjective assessment test configuration



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TABLE A2-8

Subjective assessment test condition

Method	Double Stimulus Impairment Scale (DSIS) Reference Sound (11 s)-Evaluation Sound (11 s)
Reference sound	Received HF broadcasting signal with man-made noise only with the condition of Table A2-7
Evaluation sound	Received HF broadcasting signal with man-made noise and PLT modem signal with the condition of Table A2-7
Grading scale	Five-grade impairment scale 5: Imperceptible 4: Perceptible, but not annoying 3: Slightly annoying 2: Annoying 1: Very annoying
Audio content	P1: Speech (Female) P2: Music (Male vocal and music accompaniment)
Average modulation depth	30% (Equivalent to Recommendation ITU-R BS.703)
Man-made noise	By noise generator
PLT modem	SS and OFDM
Field strength of PLT modem signal	E_{sig}/E_{plc} ratio was varied from 10 dB to 40 dB at 2 dB steps to cover all the evaluation grades from 1 through 5
Evaluator	24 non-expert listeners
Listening method	Open-air headset

A2.5.2 Test results

Figures A2-43 through A2-46 show the results of the subjective assessment test for the HF broadcast signal field strength of 30 dB(μ V/m) and 40 dB(μ V/m) in simulated rural and business noise environments. Each graph shows the assessment results for two types of PLT modems.

As described in Table A2-8, this subjective test employed the double stimulus impairment scale for investigating the permissible level of PLT noise in comparison with the environmental man-made noise. The reference sound for Grade 4.5 was presented to the test listeners where the HF broadcast signal was interfered with by the environmental noise only. Then, the HF broadcast signal was presented with the environmental noise and the PLT noise. The radio receiver employed in the test had an S/N ratio better than 26 dB for a broadcast signal of 40 dB(μ V/m).

For example, in Fig. A2-43, the reference sound was a broadcast signal of 40 dB(μ V/m) with a rural noise of about 5 dB(μ V/m). Hence the listening condition for rating score better than Grade 4 but less than Grade 5 with a carrier-to-noise (C/N) ratio of about 35 dB.

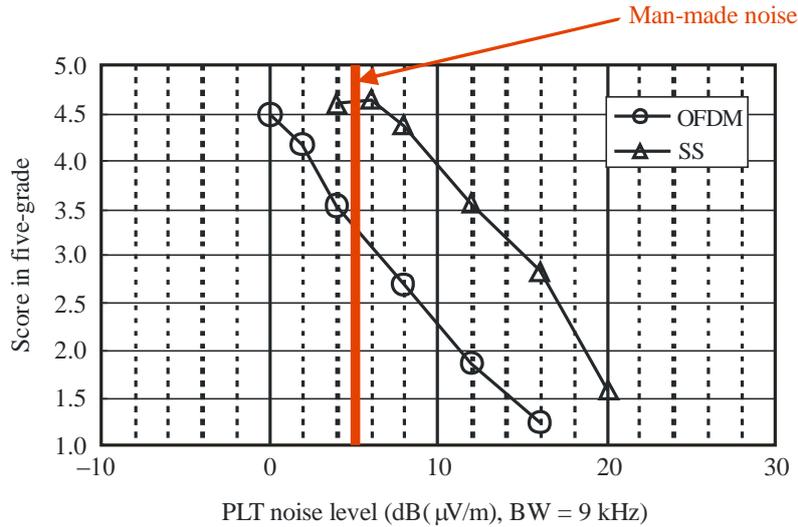
On the other hand, in Fig. A2-44, the environmental noise level was increased up to the business area noise level of about 15 dB(μ V/m). Accordingly the reference listening condition was not good but slightly annoying with a C/N ratio of 25 dB. However, we assumed that, even under such a poor listening condition, people accustomed to noisy sound might score the broadcast signal with Grade 4.5 as shown in this figure.

It is summarized from these test results that PLT noise could degrade the perceived audio quality of HF broadcasting and that the impact depends on the noise environment (field strength of man-made noise), field strength of the broadcast signal, total receiving power, and the type of PLT modem.

FIGURE A2-43

Degradation in sound quality caused by PLT noises

(Signal 40 dB(μ V/m) + Rural-area noise)

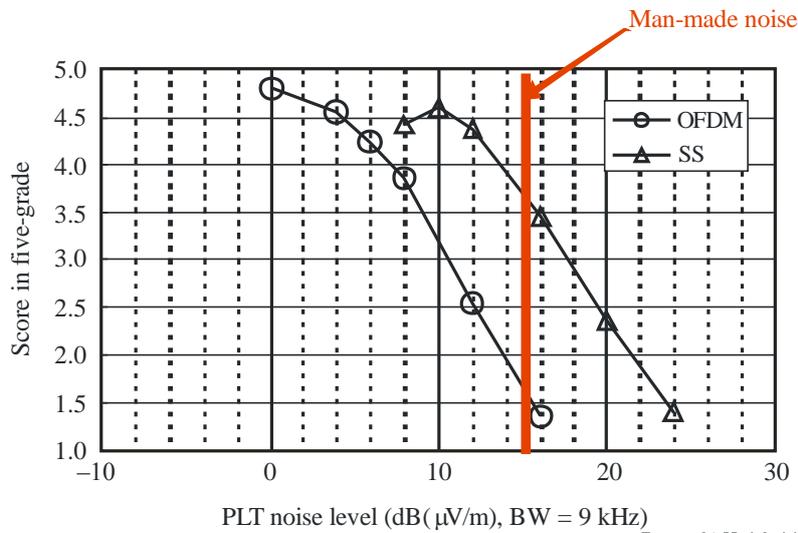


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FIGURE A2-44

Degradation in sound quality caused by PLT noises

(Signal 40 dB(μ V/m) + Business-area noise)

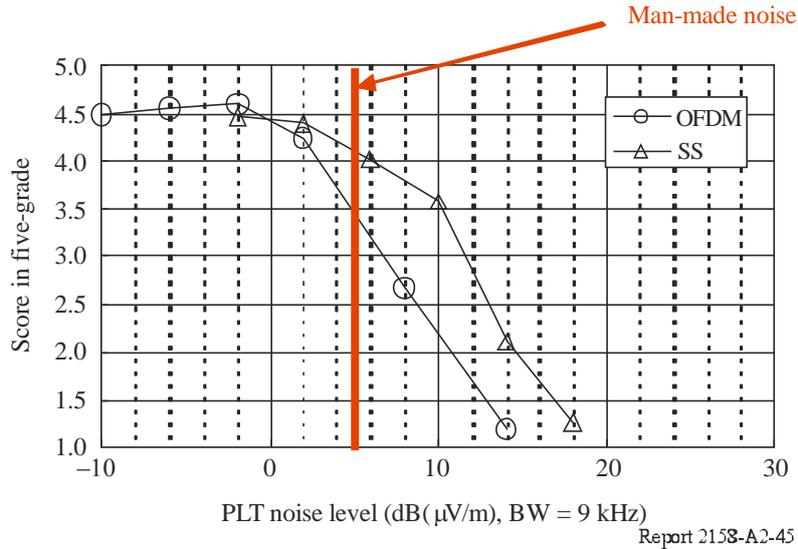


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FIGURE A2-45

Degradation in sound quality caused by PLT noises

(Signal 30 dB(μV/m) + Rural-area noise)

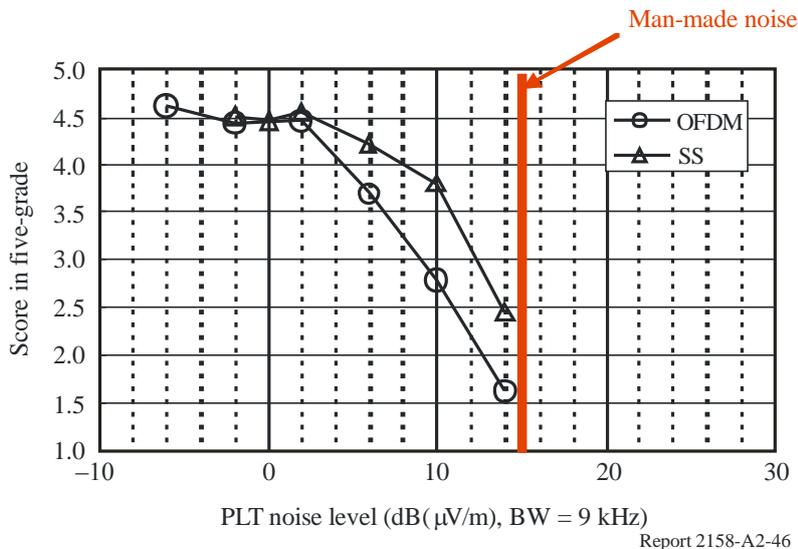


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FIGURE A2-46

Degradation in sound quality caused by PLT noises

(Signal 30 dB(μV/m) + Business-area noise)



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A2.5.3 Test equipment

TABLE A2-9

List of test equipment

Equipment	Specification or Part No.	Quantity
TEM Cell EGT-1100 (ELENA ELECTRONICS CO., LTD)	Frequency range: 3.9-26.1 MHz Noise floor: 0 dB(μ V/m) or less Max. EUT size: 600 cubic mm or larger	1
PLT modem	(OFDM)	1
PLT modem	(SS)	1
V-LISN	V-LISN	1
Adjustable attenuator	2 – 3 dB step	2
Noise generator	Agilent E4438C	1
Modulation signal source	CD Player	1
Standard signal generator	Panasonic VP-8121B	1
Sending signal combiner		1
Spectrum analyser		1
HF radio	SONY ICF-SW35	1
Antenna for HF radio	SONY AN-LP1	1
DAT	SONY TCD-D100	1
O/E converter	MOTU 308	1
USB converter	M.Audio Audiophile USB	1
Recorder	DAT (TASCAM DA45HR) PC (IBM THINKPAD R51)	1 1
Speaker for monitor	FOSTEX 6301B	1
Subjective listening test equipment	Player, Headset (TASCAM DAHR) STAX Lambda Nova Signature STAX SRM-3, SRM-1/MK2	24
Evaluator	Non-expert	24
Cable, etc.		As needed

A2.6 Compatibility analysis regarding protection requirements of HF aeronautical mobile radio in relation to PLT in-house devices

A2.6.1 Introduction

For broadband communications within LV AC mains grids and in-house installations, modern PLT systems use the frequency range 1 705 kHz to 30 MHz.

Since such networks and installations were not constructed to ever carry wanted signals at frequencies much higher than the power frequency (i.e. 50 or 60 Hz), the level of radiated RF disturbances from such installations will significantly increase with utilization of PLT in the field. There is no doubt that such an increase of the radio noise may result in a much higher probability of interference with radio reception in general, in locations well populated with operational PLT appliances.

This compatibility analysis focuses on the protection of airborne receivers in the aeronautical mobile service.

The calculations in this text are intended to show the extent to which PLT applications may interfere with the aeronautical mobile receiver and which possibilities there are to avoid or at least mitigate this interference.

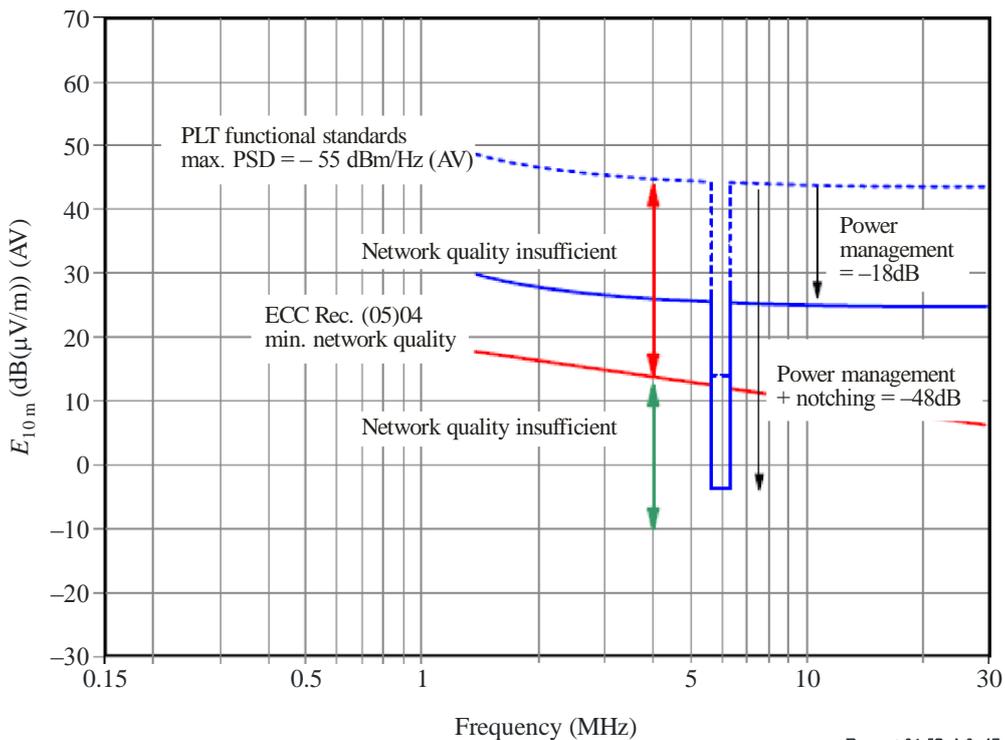
A2.6.2 Study assumptions

According to the functional standards, PLT devices for in-house communications operate with a maximum power spectral density (PSD) of -55 dBm/Hz or -73 dBm/Hz, respectively. Typical utilization of frequencies in the cable presently covers the range from 1 705 kHz to 30 MHz. All commercially available systems operate with multi-carrier transmission and use OFDM (orthogonal frequency division multiplex) in combination with CSMA/CA (carrier sense multiple access/collision avoidance) modulation schemes.

Taking into account statistically proven HF properties of typical AC mains in-house installations in Europe one is able to estimate the level of radiated RF disturbances which emanate from buildings where PLT communication is active. For consideration of the impact of these disturbances on airborne receivers, a point source was developed using finite-element modelling. The resulting radiation characteristics of this source are shown in Fig. A2-47 (blue curves).

FIGURE A2-47

Non-access PLT appliances, true electric component of radiated RF disturbances from AC mains installations in a building carrying PLT (10 m distance from the outer wall or roof of the building), effect of power management and notching (at around 6 MHz) (situation in Europe where the ECC Rec. (05)04 applies, end-to-end loss of the PLT communications link = 20 dB)



$$f[x] = \frac{1}{4\pi l^2}$$

$$l = \sqrt{R_E^2 - 2 \cos\left[\frac{x}{R_E}\right] R_E (h + R_E) + (h + R_E)^2}$$

where the values of x and l are physically constrained not to exceed:

$$x_{max} = R_E \arccos[R_E/(R_E + h)] \text{ and } l_{max} = \sqrt{h(h + 2R_E)} \text{ respectively}$$

$$f[x] = \frac{1}{4\pi \left(R_E^2 - 2 \cos\left[\frac{x}{R_E}\right] R_E (h + R_E) + (h + R_E)^2 \right)}$$

$$PFD = \frac{p_{TX} g_{TX} D R_E}{2} \int_{x_1}^{x_2} \frac{\sin\left[\frac{x}{R_E}\right]}{\left(R_E^2 - 2 \cos\left[\frac{x}{R_E}\right] R_E (h + R_E) + (h + R_E)^2 \right)} dx$$

and, for the normalized form:

$$PFD_{\text{for unit EIRP density}} = \frac{R_E}{2} \int_{x_1}^{x_2} \frac{\sin\left[\frac{x}{R_E}\right]}{\left(R_E^2 - 2 \cos\left[\frac{x}{R_E}\right] R_E (h + R_E) + (h + R_E)^2 \right)} dx$$

This model considers the summation effects of a specific interferer surface in relation to the interferer density (interferer/km²). The corresponding interfering field strength is derived from the power flux density which may then be compared with various evaluation thresholds. The calculations were carried out using the arithmetic program Mathcad.

A2.6.4 Evaluation threshold for the aeronautical radio

As evaluation thresholds for interference:

- the maximum permissible interfering field strength for the airborne receiver measured in the laboratory;
- the noise floor measured during measuring flights;

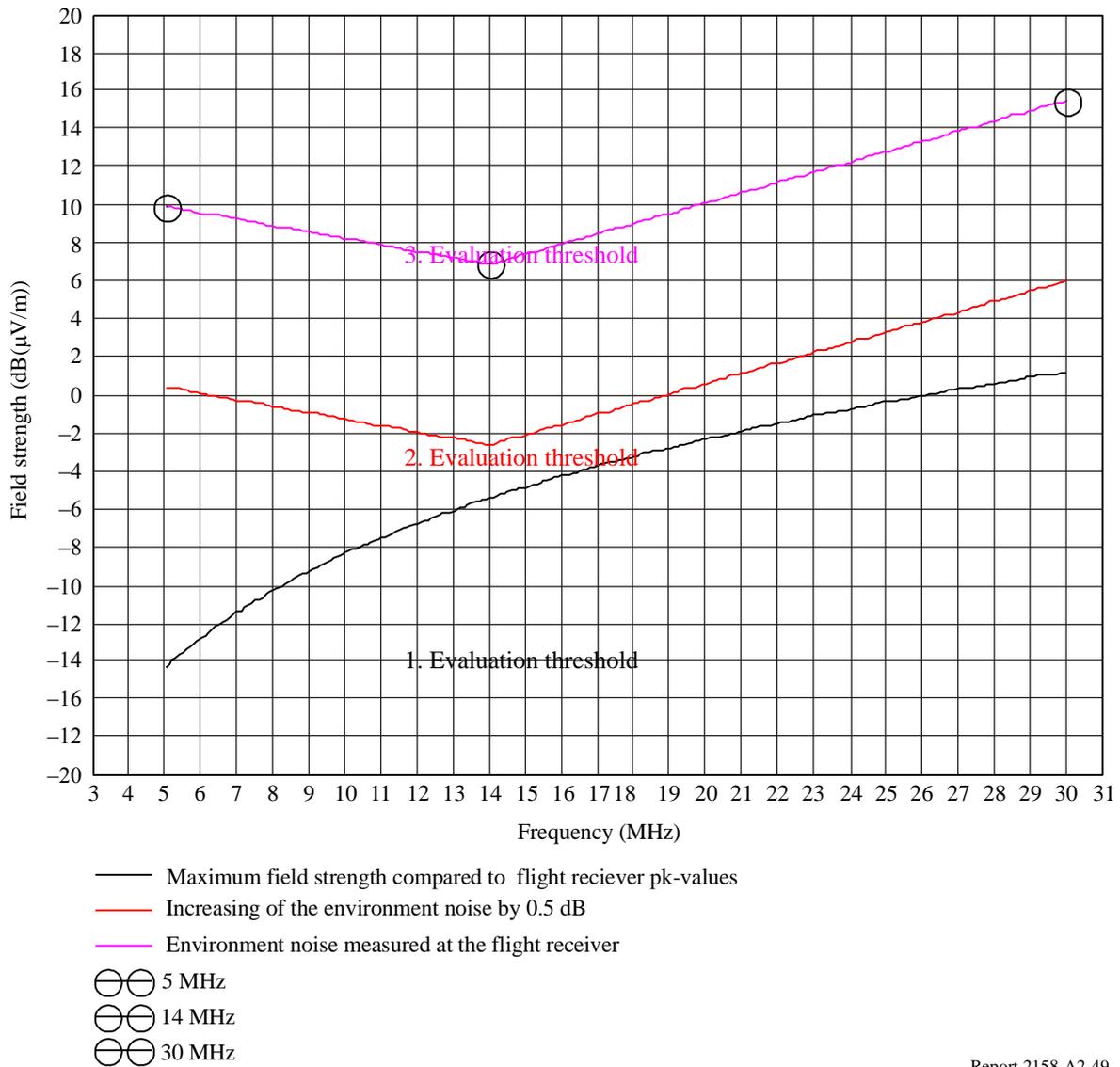
are used (shown in Fig. A2-49).

The measuring flights were carried out within the scope of a working group of the BNetA in cooperation with the NARFA (National Allied Radio Frequency Agency), the air force shipyard Landsberg and the association of German cable net operator (ANGA). Three measuring flights took place at various altitudes and the respective noise floor was measured at the frequencies 5 MHz, 14 MHz and 30 MHz. These measuring values constitute, beside the maximum permissible interferer field strength (black curve in Fig. A2-49), a second evaluation threshold (magenta curve

in Fig. A2-49). As a third threshold on Fig. A2-49 (red curve) an around 9.5 dB decreased curve is illustrated, in that a noise similar interference signal generates a total noise which would increase the measured noise floor by not more than 0.5 dB.

An increase of the noise floor by 0.5 dB is considered just still admissible to a radio service relevant for safety such as aeronautical mobile radio.

FIGURE A2-49
Evaluation threshold regarding the compatibility between PLT and aeronautical radio



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A2.6.5 Results of the analysis

The field strengths generated by PLT application in relation to the three evaluation thresholds were examined. The following tables illustrate by how many dB the PLT interfering signal needs to be decreased to achieve compatibility in relation to the relevant evaluation criterion. The cases involving power management and notching as well as the case involving a combination of these two mitigation measure are listed.

The presented calculations are based on an interferer density of 250 interferers/km², an aircraft altitude of 1 km and a radius of the interfering area of 10 km. For the radiation characteristics of these interferers see Fig. A2-47. Tables A2-10, A2-11, and A2-12 specifying for different criteria (receiver sensitivity, noise increase by 0.5 dB, noise increase by 3 dB) by how many dB the interfering field surface radiated from all PLT point sources needs to be decreased (for the cases outlined above), to ensure a compatibility at the airborne receiver. A compatibility is even not given when using power management and notching. Table A2-13 sets out the relevant correction values for different interferer densities.

TABLE A2-10

250 interferers/km², interferer field surface radius 10 km, flight altitude 1 km

Receiver sensitivity	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz
PLT (-55 dBm/Hz)	-65 dB	-59 dB	-55 dB	-52 dB	-50 dB	-49 dB
PLT (power management)	-47 dB	-41 dB	-37 dB	-34 dB	-32 dB	-31 dB
PLT (notch)	-35 dB	-29 dB	-25 dB	-22 dB	-20 dB	-19 dB
PLT (power management + notch)	-17 dB	-11 dB	-7 dB	-4 dB	-2 dB	-1 dB

For maximum increase by 0.5 dB of the noise compared with the noise caused by the PLT interference signals, a power management and notching of the relevant frequencies of all PLT devices ensures a compatibility only above 20 MHz (green highlighted fields in the bottom line of the Table A2-11). Below 20 MHz the calculated values are higher with a maximum of 3.5 dB.

TABLE A2-11

250 interferers/km², interferer field surface radius 10 km, flight altitude 1 km

Noise increase by 0.5 dB	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz
PLT (-55 dBm/Hz)	-50.5 dB	-51.5 dB	-51.5 dB	-49 dB	-46.5 dB	-45.5 dB
PLT (power management)	-32.5 dB	-33.5 dB	-33.5 dB	-31 dB	-28.5 dB	-27.5 dB
PLT (notch)	-20.5 dB	-21.5 dB	-21.5 dB	-19 dB	-16.5 dB	-15.5 dB
PLT (power management + notch)	-2.5 dB	-3.5 dB	-3.5 dB	-1 dB	1.5 dB	2.5 dB

In case of the 3rd evaluation threshold (noise increasing maximum 3 dB) only a power management in combination with a notching across the relevant frequency range would be sufficient (green highlighted fields of the Table A2-12). However, this evaluation threshold should be deemed unrealistic, because of a doubling of the noise power, so the requirements of the safety-relevant radio services are not fulfilled.

TABLE A2-12

250 interferers/km², interferer field surface radius 10 km, flight altitude 1 km

Noise increase by 3 dB	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz
PLT (-55 dBm/Hz)	-41 dB	-42 dB	-42 dB	-39.5 dB	-37 dB	-36 dB
PLT (power management)	-23 dB	-24 dB	-24 dB	-21.5 dB	-19 dB	-18 dB
PLT (notch)	-11 dB	-12 dB	-12 dB	-9.5 dB	-7 dB	-6.5 dB
PLT (power management + notch)	7 dB	6 dB	6 dB	8.5 dB	11 dB	12 dB

For other interferer densities than 250 interferer/km² the following correction values can be used.

TABLE A2-13

Disturber density correction

Interferer density (interferer/km²)	Correction value (dB)
50	7
100	4
150	2
200	1
250	0
300	-1

A2.6.6 Other determinants

In the above examination the interferer density was used as the most relevant compatibility parameter. Investigations with other parameters like flight altitude, the radius of the considered interferer surface or so-called Hot Spots proved a negligible influence on the calculations.

A2.6.7 Requirements toward PLT devices for protecting the HF aeronautical mobile service

Adequate protection of aeronautical mobile airborne receivers from interference is indisputable. The question is up to which extent and by which means this can be guaranteed without compromising the evolving PLT technology.

The CISPR is considering whether at sensitive radio frequencies, mitigation measures such as notching can be used in order to reduce the PSD of the wanted PLT signal either permanently or, in adaptation to the local conditions of radio reception and the type of radio service, dynamically.

Annex 3**Radio frequency emissions from PLT systems****A3 Radio frequency emissions from PLT systems****A3.1 Measurement of access PLT non intentional radiated RF levels on HF bands****A3.1.1 Introduction**

Power Line Telecommunication systems (PLT) have being widely used to provide new facilities to customers as data transmission, Internet services and last mile connecting solution. Nevertheless, energy not intentionally radiated, generated by PLT, can cause harmful interference on neighbour systems operating from 1 700 kHz to 80 MHz, which include HF bands.

A3.1.2 Objective

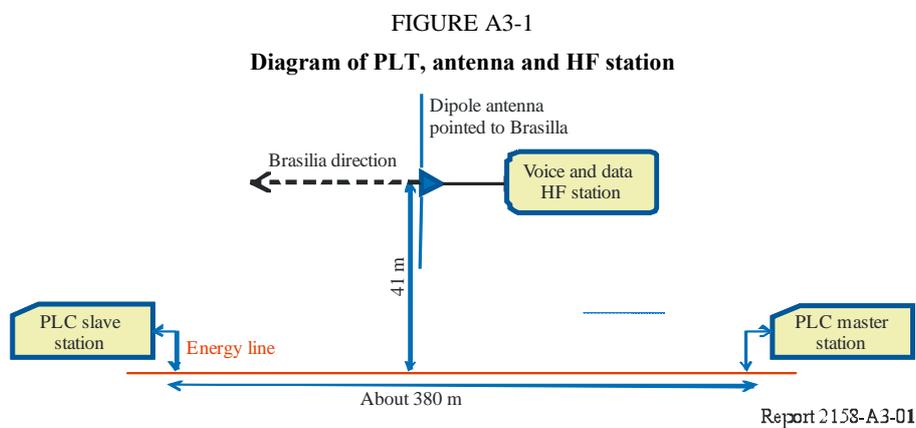
Elaborate a comprehensive and practical analysis of PLT radiated levels and potential interference on HF systems.

A3.1.3 Interference concept

The basic interference concept is explained by devices, which irradiate enough energy to interrupt or disturb the operation of other regulated systems. Then, as a first approach it is important to have an idea about the maximum RF levels from interference sources that are possible to be supported by HF communication systems without causing any disturb.

A3.1.4 Test description

In order to do a preliminary investigation on the radiated levels, in HF bands, some tests were performed in Brazil. The tests were developed in Campinas, Sao Paulo, using the configuration showed on Fig. A3-1. A PLT equipment of second generation operating in a low voltage electrical line (380 m) and a HF antenna located 41 m from it were installed. Campinas's station was connected with Brasilia's by a HF link to transmit and receive voice and data. Due to the dimension of HF antenna (wide band dipole), it was not possible to relocate the position easily, so it remained on a unique position.



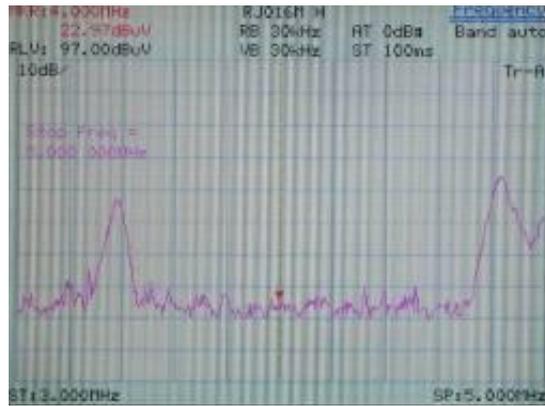
In the beginning some environmental noise measurements were collected in order to obtain spectrum occupation data without the PLT operation. Measurements were taken in blocks of 2 MHz bandwidth from 3 to 30 MHz, as the example indicated on Fig. A3-2.

On Fig. A3-3 we can see the spectrum from 3 to 12 MHz without PLT operation and in Fig. A3-4 with the presence of PLT energy in the same band.

Figure A3-5 shows PLT spectrum operation from 7.98 to 12.5 MHz and Fig. A3-6 shows other PLT equipment operating in a wide band from almost 3 to 30 MHz.

FIGURE A3-2

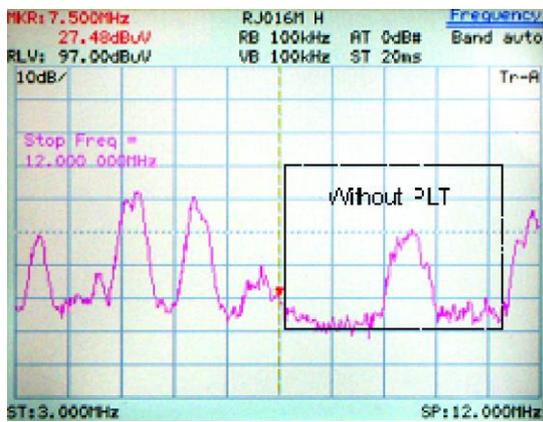
Environment spectrum occupation



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FIGURE A3-3

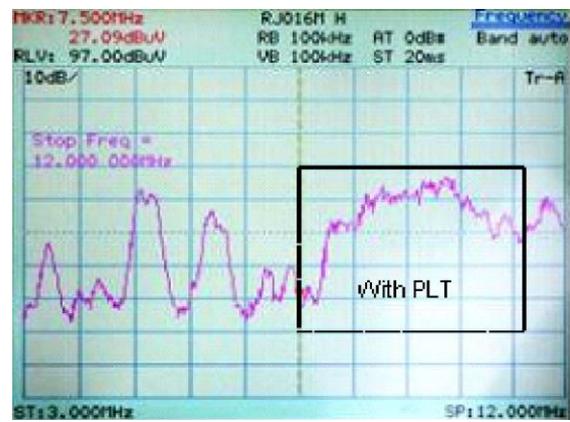
3 to 12 MHz without PLT operation



Report 2158-A3-03

FIGURE A3-4

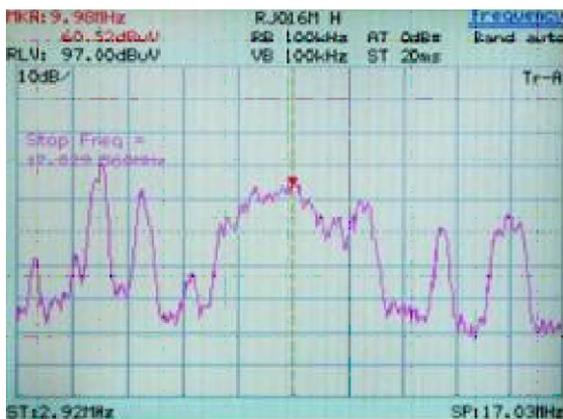
PLT spectrum operation



Report 2158-A3-04

FIGURE A3-5

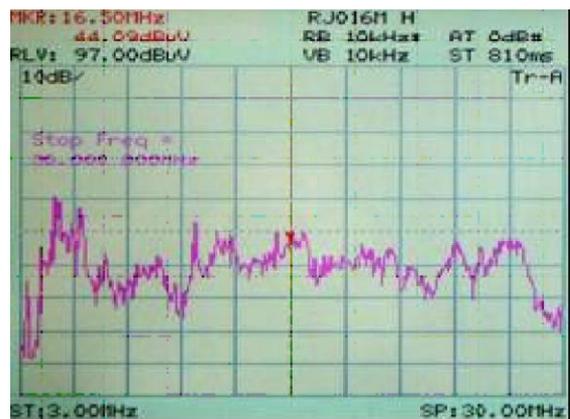
PLT operation from 7.98 to 12.5 MHz



Report 2158-A3-05

FIGURE A3-6

PLT operation in wide band



Report 2158-A3-06

The PLT levels were captured by HF antenna to provide the same information received by HF system. The PLT operation indicated levels greater than 60 dB(μ V) in some parts of the spectrum.

The HF link provided reception levels in Campinas from approximately 13 to 49 dB(μ V) (measurements based on 1 kHz test tone). When PLT was operating, HF data transmission was blocked and there was a strong noise on the audio receiver, totally disturbing the voice reception.

The PLT level in the concerned distance had enough intensity to cause harmful interference. The PLT level was reduced in steps to verify the interference threshold. However, in this distance, in any PLT level, the data transmission was blocked, so it was not possible to reach the threshold.

A3.1.5 Comments

The energy irradiated by PLT systems has potential capacity to cause interference in HF communications and in other bands as clearly demonstrated in the tests. Therefore, it is necessary to apply some mitigation techniques in order to make possible the shared use of the HF spectrum.

Theoretically, if we consider the HF equipment sensibility parameters it could be possible to estimate a maximum acceptable PLT level that would avoid interference. For example, to 10 dB SINAD to 0.5 μ V, that is equivalent to -6 dB(μ V) (HF minimum input levels), the maximum level generated by PLT had to be -16 dB(μ V), which can be lower than background noise level in some places.

An irradiating model for electrical lines that develop an analogy with antenna faces some complex questions like how to consider geometry irregularities, different neighbour environments, rural and residential areas, etc. These aspects can change dramatically the wave propagation behaviour and provide no confident results. Besides that, the neighbour areas will be on near fields (reactive or Fresnel zone), and then the task to predict the levels of irradiated radiofrequency using a general model becomes a challenge.

These considered aspects conduct to empirical tests in order to have a practical idea about the required coordination minimum distances to PLT from HF systems. Therefore, more tests were performed in Porto Alegre, Rio Grande do Sul, Brazil, where there is a PLT system working.

A HF link between Porto Alegre and Rio de Janeiro stations was established. The tests were conducted on April 2008, using a mobile HF station with a whip antenna. The procedures were basically the same as performed in Campinas, the difference was the HF station capacity to move far from the PLT source and collect more data continuously.

The harmful interference from PLT on HF systems occurred and was minimized in distances greater than 450 m from electrical lines. It is important to say that it is considered a short distance HF link (one hop on ionosphere) that generally has a stronger signal than a long distance link, so the minimum distance from PLT probably would have to be increased to avoid interferences.

A3.1.6 Possible mitigation technique

Using as criteria an average of HF receiver levels to long (more than 1,500 km) and short links (up to 1 500 km), it is feasible to consider some practical distances from PLT systems to HF stations to mitigate or minimize interferences.

- a) HF long distance link: 1 000 m; and
- b) HF short distance link: 500 m.

The geographical separation is necessary to guarantee the minimum confidence to avoid interference from PLT to HF.

A3.1.7 Conclusions

Modelling techniques to estimate RF levels irradiated by electrical lines from PLT will be useful only around linear lines.

The PLT levels estimated with loop antennas can give us a rough estimation about the potential interference, however it is not possible to consider accuracy threshold levels because of the drastic HF levels variation during the day and the night.

In the PLT proximities the AM broadcast services probably will be interfered when PLT operate in the same frequency.

A collection of measurements in PLT neighbour sites with HF systems can provide a good idea about signal level propagation in practical terms and seems to be the most appropriated way to determine interference distances.

A practical mitigation approach can be to consider the worst situation of interference where an HF station was installed in the proximities of an operating PLT system, and use the distances indicated on item 6 as a protection criteria to stations that are used to short and long HF links.

A3.2 Measurements of the radiated emissions from in-house power line telecommunications devices into the residential environment in Canada

A3.2.1 Introduction

Subsequent to the measurements made by Kitagawa and Ohishi⁵², the North American Broadcasters Association (NABA) contracted the Communications Research Centre, Canada (CRC) to carry out emission measurements from Power Line Telecommunications (PLT) devices operating in a residential environment. This section describes the test procedures and results of field strength measurements of PLT emissions to determine the possibility of interference from PLT devices. The CRC report⁵³ is attached in Appendix 1. The measurements clearly demonstrate the need to provide interference protection to the broadcasting service (BS). Since PLT devices operate without a frequency allocation in the ITU Radio Regulations, the appropriate protection criterion for the broadcasting service can be found in Recommendation ITU-R BT.1786.

A3.2.2 Conducted power measurement – Test procedure and results

A total of eight commercially-available PLT devices representing the various PLT standards were considered for testing. These devices were readily available in the United States of America, Canada, and Japan. The PLT devices, shown in the Table A3-1, were evaluated in the CRC laboratory prior to the field tests.

As can be seen in Table A3-1, many of the PLT devices use the same standard or different versions of the same standard. Following the laboratory evaluation, it was decided to limit the number of PLT devices at one per standard for the field test. PLT devices 2, 3, and 6 were chosen for field tests.

⁵² KITAGAWA, M. and OHISHI, M. [March 2008] Measurements of the radiated electric field and the common mode current from the in-house broadband power line communications in residential environment I. IEICE Tech. Rep., Vol. 107, **533**, EMCJ2007-117, p. 1-6.

⁵³ <http://www.nabanet.com/nabaweb/members/pdf/itur/CRCReport.pdf>.

The laboratory setup for the conducted power measurement is presented in Fig. A3-7. The a.c electrical source came from the CRC main power through a step up transformer and a breaker box to isolate and convert the a.c to 110 to 120 V, 60 Hz 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 m typical of residential construction. A computer was assigned to each PLT device for the transfer of data. One computer sent a large file to a receiving computer.

The power measurements for signals below 30 MHz were made using an Agilent E4405B spectrum analyser, set with a resolution bandwidth of 9 kHz and using peak detection and a maximum hold trace of 10 s. In order to measure the conducted signal from the PLT devices with the spectrum analyser, an a.c filter was required to remove the 60 Hz, 110 to 120 V component. The a.c filter was a 2nd order LC filter with a cut-off frequency of 1 MHz.

TABLE A3-1

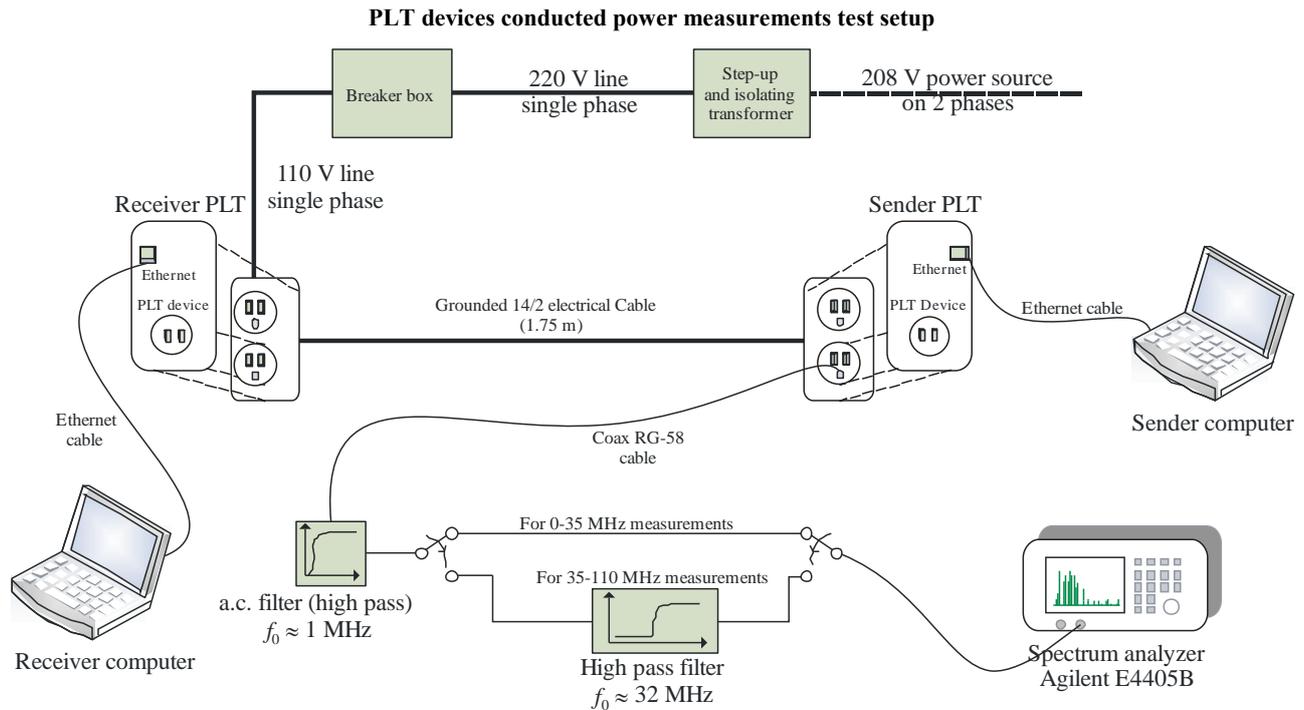
List of PLT devices evaluated for the field tests

Device No.	Manufacturer	Model	PLT Standard	Manufacturer specification		
				Data rate (Mbit/s)	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	Logitech	LPL-TX/S	UPA	200	2.0-30.0	Japan
8	CNC	CNC-1000	HomePlug 1.0	85	4.3-20.9	Japan

In order to measure low signal levels above 30 MHz 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 analyser. As shown in Fig. A3-7, 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. The resolution bandwidth for these measurements was 120 kHz.

The conducted power measurements were made over the frequency range from 0 to 110 MHz using two modes of operation: Data Transfer mode and Idle mode (no active data transfer). 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 the PLT devices.

FIGURE A3-7



In order to achieve good precision, the measurements were made from 0 to 110 MHz in consecutive frequency spans of 10 MHz wide with the spectrum analyser set to a resolution bandwidth of 9 kHz and using peak detection. In general, the reference level of the spectrum analyser was adjusted as low as possible without creating spectral overload. Since a high-pass filter was used to obtain improved measurement precision for frequencies above 35 MHz, a discontinuity in the noise floor can be observed in the results at 35 MHz.

The measurement of the test bed noise floor is shown in Fig. A3-8. The figure illustrates that the electrical line test setup acted as an antenna that captured 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.

The results for PLT devices 2, 3 and 6 are shown in Figs A3-9, A3-10, and A3-11 respectively. The blue curve shows the conducted signal during data transfer and the green curve (generally, the lower trace) shows the conducted signal in the idle mode. As can be seen in the figures, the signal level in idle mode does not exceed the signal level in data transfer mode. Additionally, the devices tested don't operate identically in idle mode. PLT devices 2 and 3 were transmitting occasional carriers to keep the channel open and synchronized, while device 6 was constantly transmitting its full signal bandwidth. The results of conducted measurements for the other PLT devices are shown in Appendix A of the CRC Report contained in Appendix 1 to this Annex.

FIGURE A3-8
Conducted measurements test setup noise floor

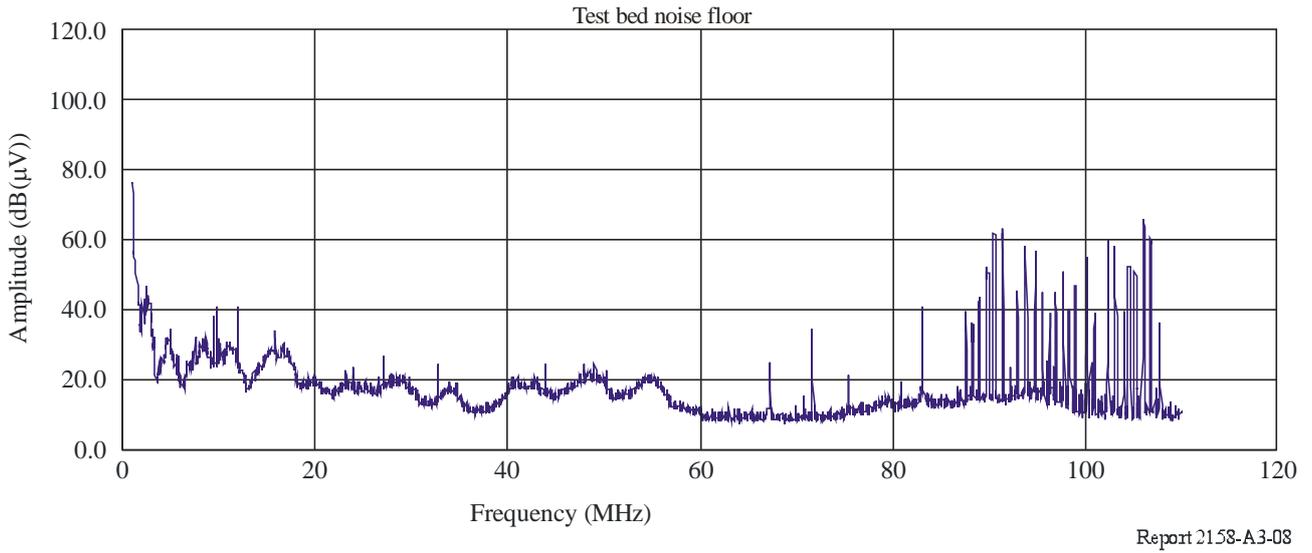


FIGURE A3-9
Conducted power from Device 2 (HD-PLC standard)

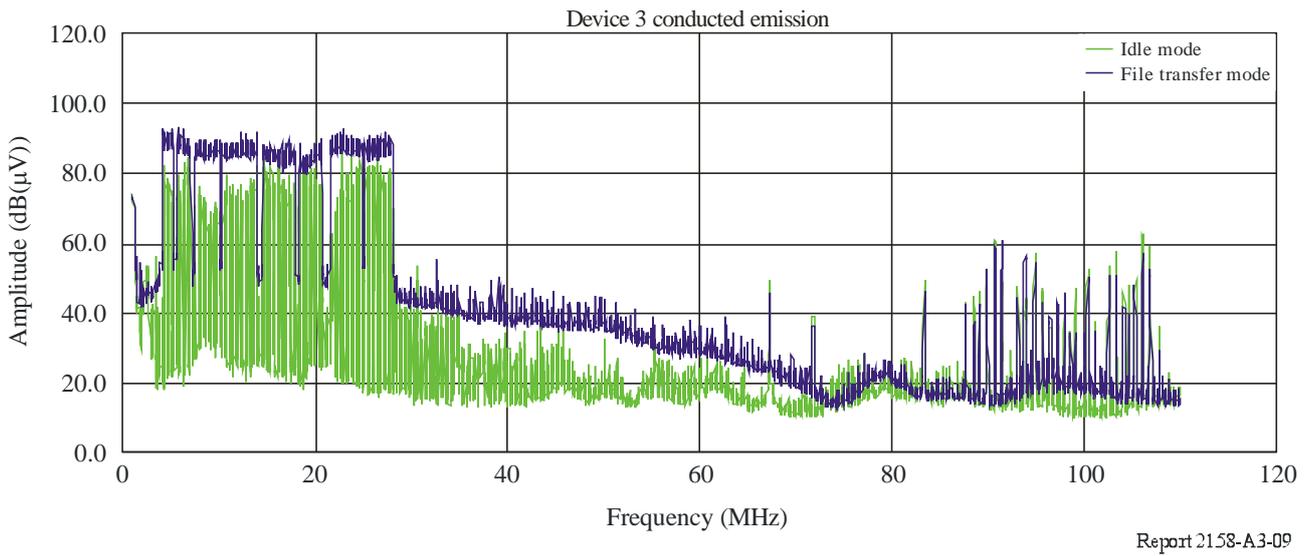
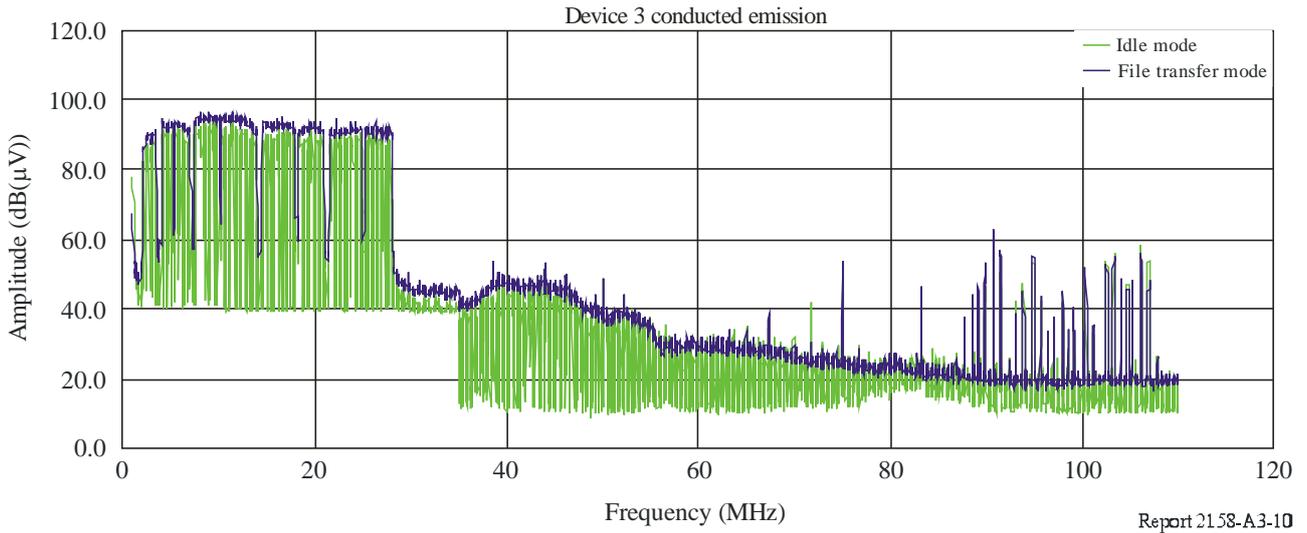
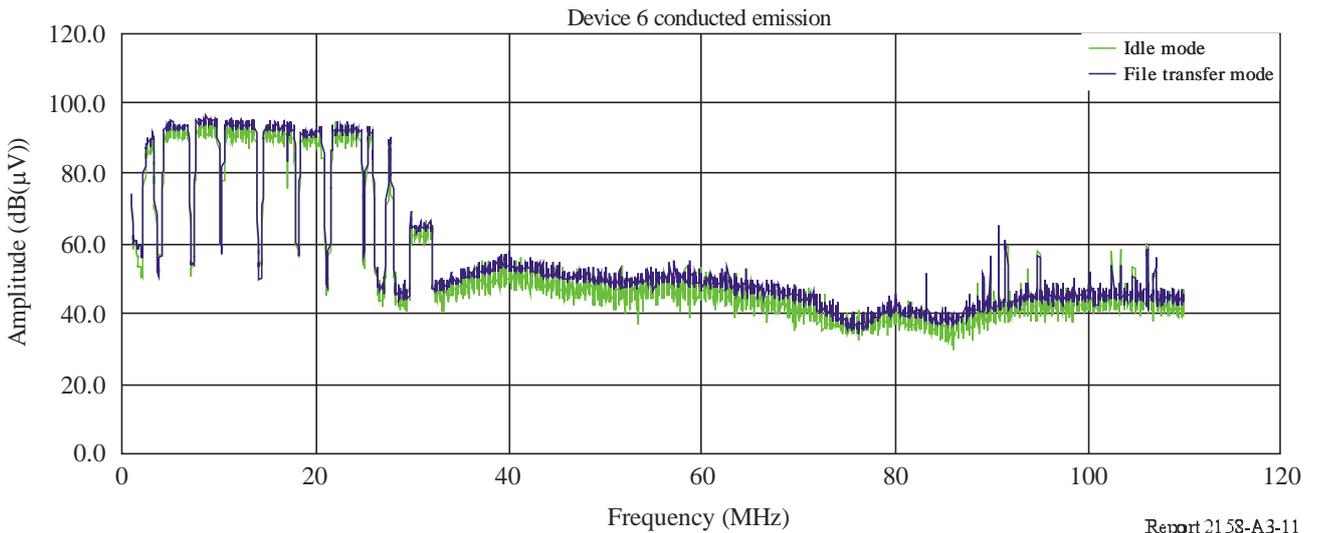


FIGURE A3-10
Conducted power from Device 3 (Homeplug AV standard)



Report 21.58-A3-10

FIGURE A3-11
Conducted power from Device 6 (UPA standard)



Report 21.58-A3-11

These results illustrate that even if the PLT device is not transmitting data, the device is actively generating emissions. It is also observed that even if the PLT device operates below 30 MHz, the device has emissions to at least 80 MHz.

A3.2.3 Field strength measurements – Procedure and results

RF field strength measurements were made using one and two-story residential houses near Ottawa, Canada. Most of the houses are connected to the electricity distribution grid (220 V single phase) through underground lines, but some were connected using overhead lines. The front and the back of the houses had enough clearance to make field strength measurements at three and ten metres from the outer walls, thus these orientations were selected for the measurements.

A total of 17 houses were selected for the field tests as shown in Table A3-2 representing various layouts and construction materials. The table summarizes each test site, 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 the CRC Report contained in the Attachment to this Annex provides the full description of all 17 test sites, including pictures and a diagram of each house.

TABLE A3-2
Description of the field test sites

Site No.	Type of house	Exterior wall material				Electrical line
		Front wall		Back wall		
		1 st floor	2 nd floor	1 st floor	2 nd floor	
1	Two-story single-detached	Brick	Vinyl	Vinyl		Underground
2	Two-story single-detached	Brick	Brick/Canaxel	Brick	Canaxel	
3 ⁽¹⁾	Two-story single-detached	Brick	Brick/Vinyl	Vinyl		
4	Two-story single-detached	Brick	Brick	Brick	Aluminium	
5	Two-story single-detached	Brick		Brick	Aluminium	Underground
6	Two-story townhouse	Brick	Brick/Vinyl	Vinyl		
7	Two-story single-detached	Brick		Vinyl		
8	Two-story single-detached	Brick		Vinyl		
9	Bungalow single-detached	Brick	N/A	Vinyl	N/A	
10	Two-story townhouse	Brick	Aluminium	Aluminium	Aluminium	
11	Bungalow single-detached	Stucco	N/A	Stucco	N/A	
12	Two-story single-detached	Brick	Vinyl	Vinyl		Overhead
13	Sides split single-detached	Brick		Brick	Vinyl	Underground

TABLE A3-2 (*end*)

Site No.	Type of house	Exterior wall material				Electrical line
		Front wall		Back wall		
		1 st floor	2 nd floor	1 st floor	2 nd floor	
14	Two-story single-detached	Brick	Shingle	Brick	Shingle	Overhead
15	Two-story single-detached	Brick	Aluminium	Brick	Aluminium	
16	Two-story single-detached	Brick	Brick/Shingle	Vinyl		Underground
17	Two-story single-detached with loft	Brick	Brick/Vinyl	Vinyl		

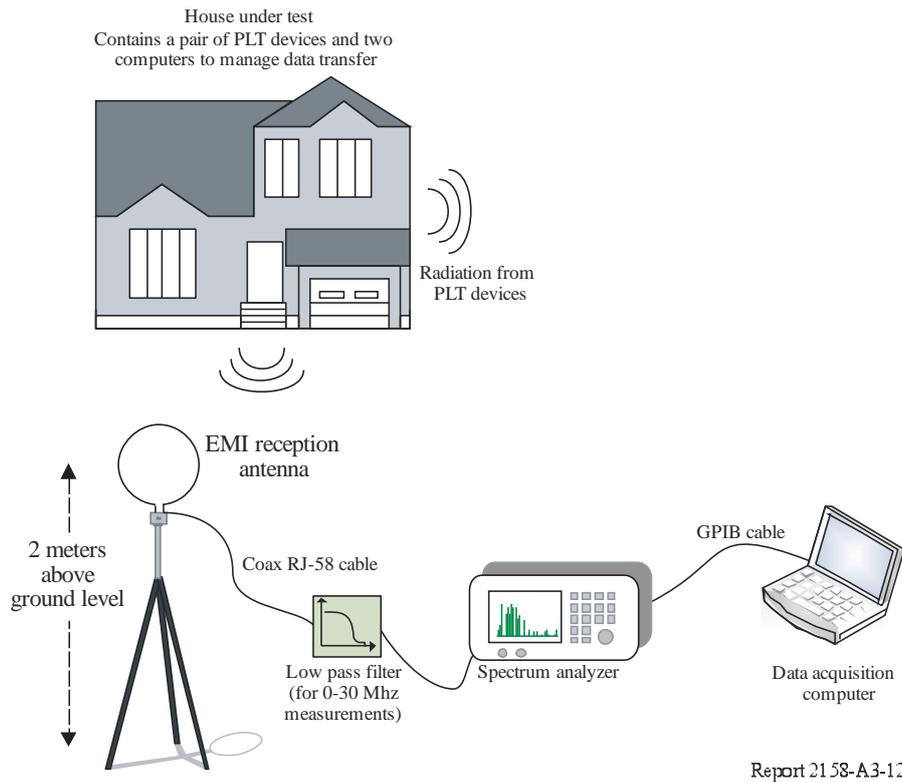
⁽¹⁾ The data from Test site 3 was not used in the analysis. It was found that PLT devices in use in an adjacent house during the tests interfered with the results.

The PLT devices (2, 3, and 6) were tested in pairs of the same model, connected to AC outlets inside the houses. 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. Each PLT device was connected to a personal computer. Two modes of PLT operation were tested: Data Transfer mode for all the houses and the 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 passive loop antenna for the frequency range of 0 to 30 MHz (EMC Test Systems, Model 6512) and a calibrated passive dipole antenna for the frequencies of 30 to 108 MHz (A.H. Systems Inc. Model SAS-530 balun and SAS-542 folding elements). The antenna factor of these antennas was precisely calibrated to yield RF field strength measurements (dB(μ V/m)). The antennas were positioned at 2 m above ground level. The measurements were made at three metres and ten metres from the front and back outer walls of the houses.

Figure A3-12 shows the test setup for RF field strength measurements. A low pass filter (Tin Lee Electronics Ltd. Model LP7E-30-37 B50, -1 dB cut-off at 31 MHz, -40 dB cut-off at 35 MHz) 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.

FIGURE A3-12

RF field strength measurement test setup

The minimum, maximum average ambient noise measurement (linear voltage average converted back to a dB scale) for 16 test sites is shown in Fig. A3-13. The contribution of the ambient noise in the field strength measurement was not negligible at certain frequencies. 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 because of interference from neighbouring PLT devices. Figure A3-14 through Fig. A3-19 show the statistical analyses for the three devices. Each figure shows the maximum, minimum, and average RF field strength measured for each device. Furthermore, the study used the measurements from the 16 houses to calculate a confidence interval that should represent the expected maximum 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 upper and lower bound of this 95% confidence interval is shown. The calculations in this statistical analysis were done with linear values. As explained above, the contribution of interference from sources other than PLT devices was not negligible and cannot be removed from the statistical analysis.

FIGURE A3-13

Average ambient noise distribution at 3 and 10 m for 16 test sites

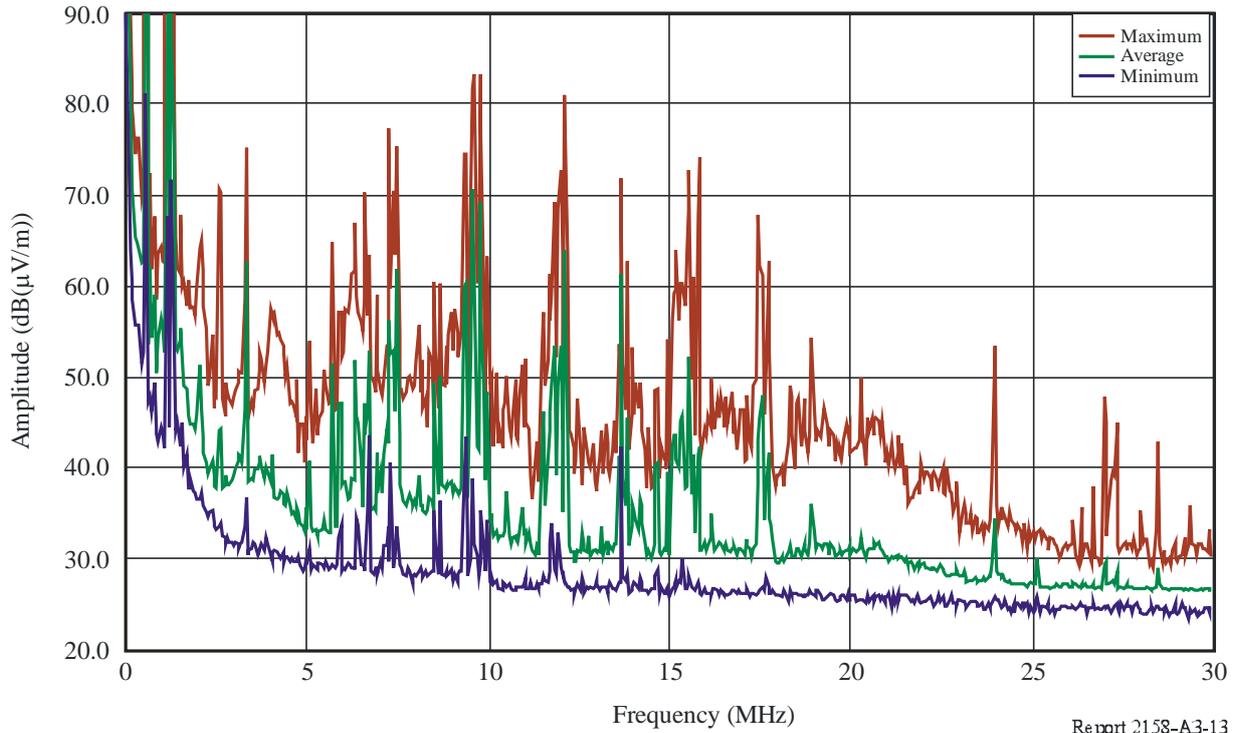


FIGURE A3-14

RF field strength distribution, PLT Device 2 (HD-PLC) at 3 m

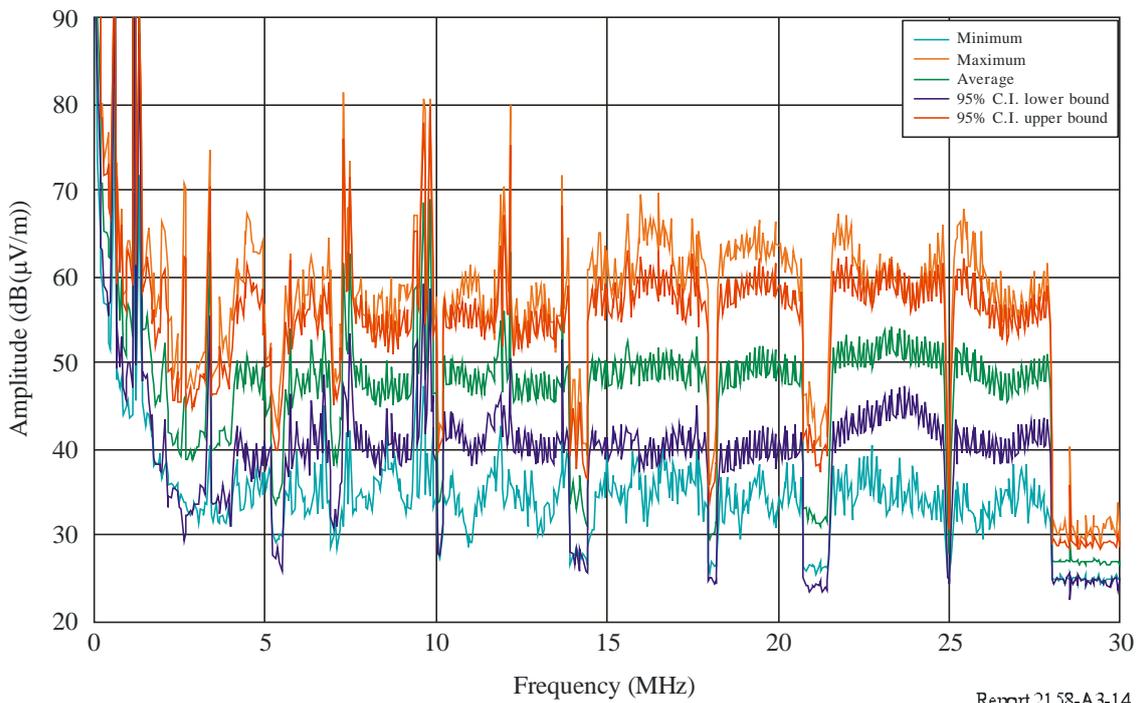


FIGURE A3-15

RF field strength distribution, PLT Device 2 (HD-PLC) at 10 m

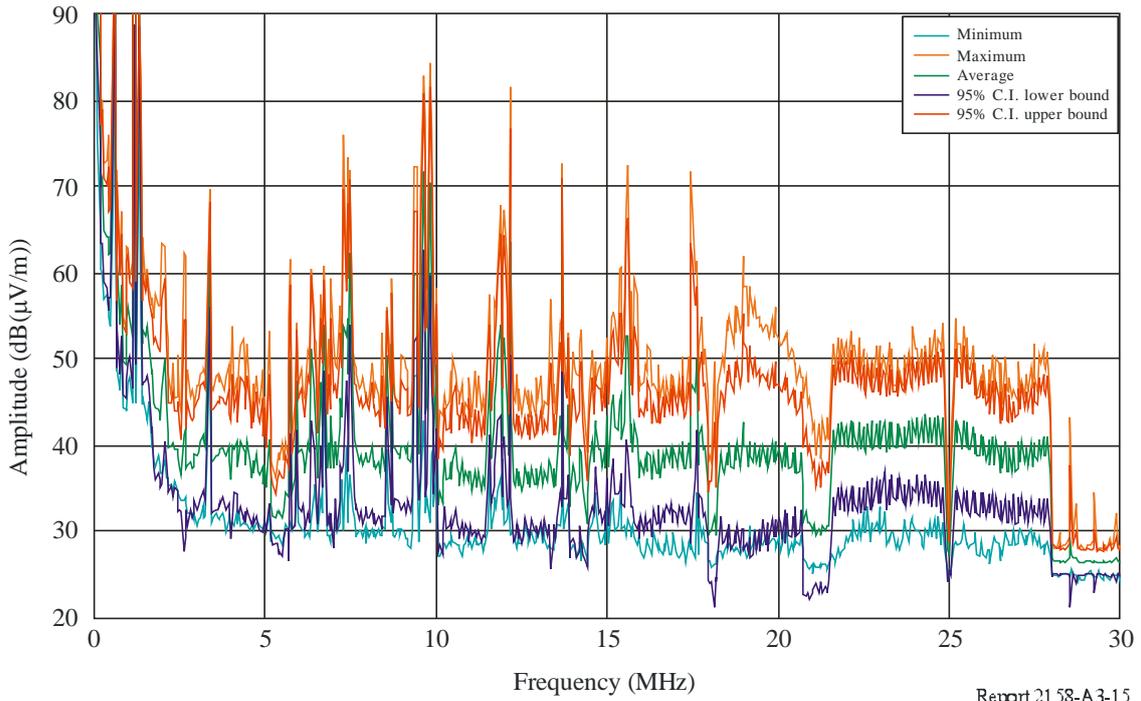


FIGURE A3-16

RF field strength distribution, PLT Device 3 (Homeplug AV) at 3 m

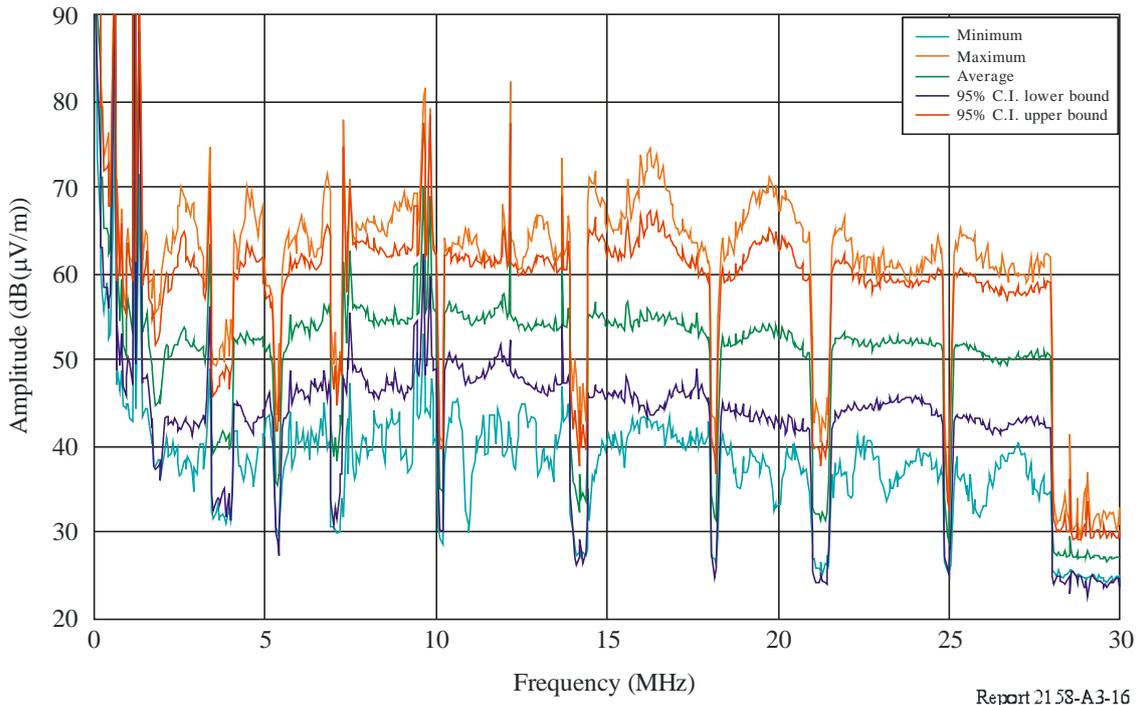


FIGURE A3-17

RF field strength distribution, PLT Device 3 (Homeplug AV) at 10 m

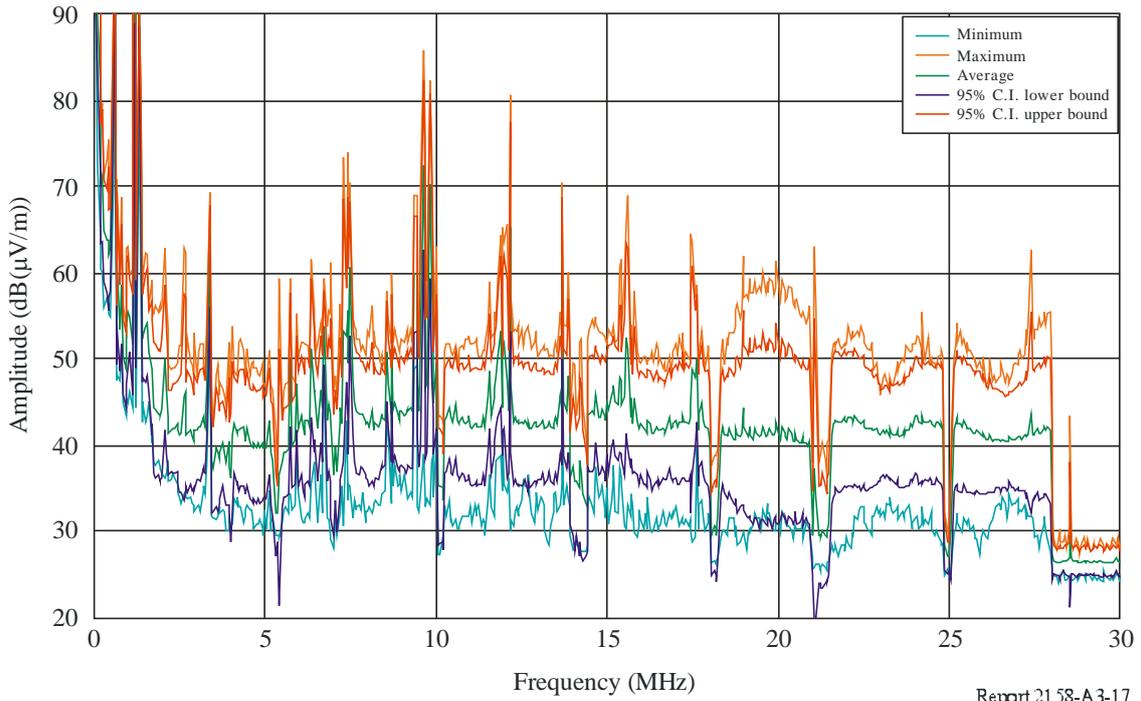


FIGURE A3-18

RF field strength distribution, PLT Device 6 (UPA) at 3 m

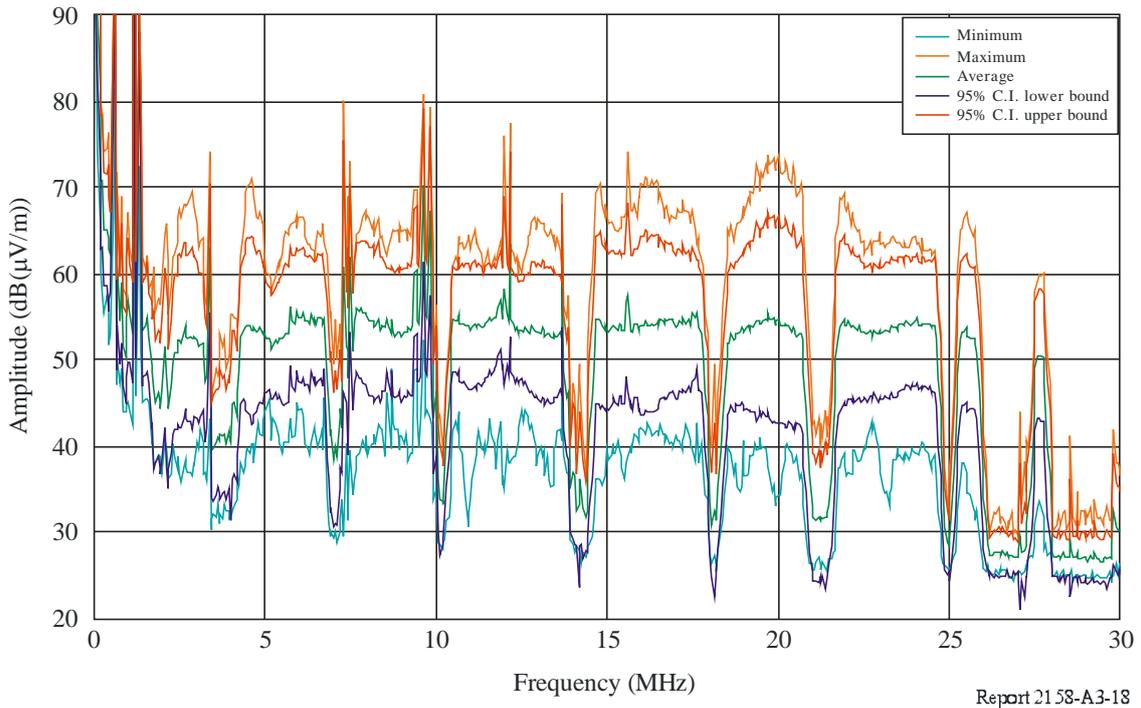
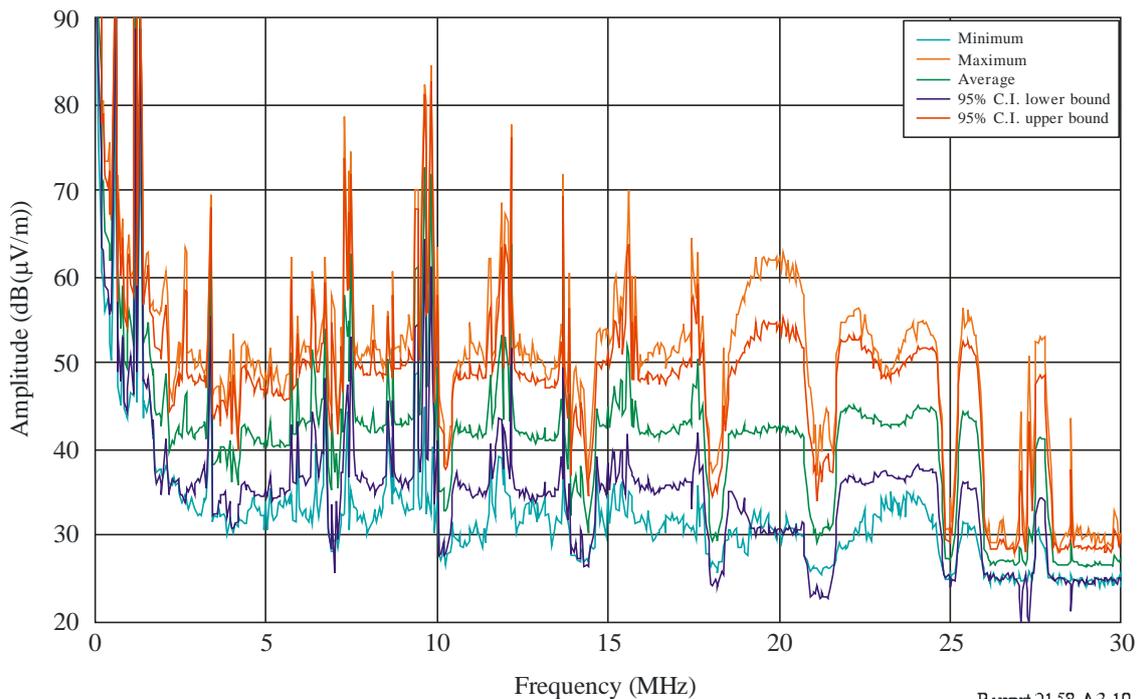


FIGURE A3-19

RF field strength distribution, PLT Device 6 (UPA) at 10 m



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A3.2.4 Conclusions

The results of laboratory and field testing by the CRC show that maximum emissions from PLT devices in a typical residential house exceeded the average ambient noise levels by more than 30 to 40 dB at a distance of 10 to 3 m, respectively, from the outer wall of the house. At 10 m, the average PLT emissions exceeded the average ambient noise by about 5 to 10 dB. At some frequencies and distances, the PLT emission levels are intentionally notched and were below the ambient noise. Thus, as observed by the CRC, PLT devices are capable of interfering with radiocommunication services, especially those services operating on a noise-limited basis. The broadcasting service is particularly vulnerable to interference from PLT devices. The planning factors for the BS support reception at much lower field strengths than may be possible in the presence of emissions from PLT devices. For example, Recommendation ITU-R BS.703 sets the minimum useable field strength for an average HF broadcast receiver at 40 dB(μV/m). The CRC test results presented here show that PLT devices will generate interference levels 20 to 30 dB higher than the signal levels for which an HF broadcast receiver is expected to receive, depending on frequency, separation distance, receiver antenna configuration and other factors.

A3.3 Measurement results of the radiated emissions from in-house power line telecommunications systems into the residential environment in the test conducted in Japan

A3.3.1 Introduction

This section reports measurement results of the radiated emissions from in-house power line telecommunication systems into the residential environment conducted in Japan.

A3.3.2 Measurement method

Radiated emission from the in-home PLT devices measured at surrounding area of house by following conditions. Two different types of PLT devices were used in the experiments, that is, OFDM and Spread Spectrum devices.

- a) Measurement equipments
- *Antenna*: Loop antenna which calibrated
 - *Spectrum analyser*: Spectrum analyser should have ability of following setup and battery operation (see Note 1).

NOTE 1 – At field measurement, noise from power cable of measurement equipments or cable which is using for measurement will lose reproducibility. Battery operation is desirable. If they could not use a battery, power supply should be provided by independent source and care about placement of power line cable.

- b) Placement of measurement equipments
- Measurement points are 5m from external wall of house and the points are 8 directions from house. (If measurement points cannot set because of land features or less space than 5 m, 4 points are minimum).
 - Distance of 5 m is from nearest external wall toward to the house.
 - Height of antenna (bottom of loop antenna) is 1m from land surface.
- c) Measurement frequency range
- 1 to 30 MHz.
- d) Setup of measurement equipment (Spectrum analyser)
- RBW = 10 kHz, VBW = 100 kHz, Span = 29 MHz, Centre frequency = 15.5 MHz
 - Point = around 1 000 points, Sweep = Auto
 - Detect mode: RMS mode.
 - Averaging: More than 20 times with above detect mode.

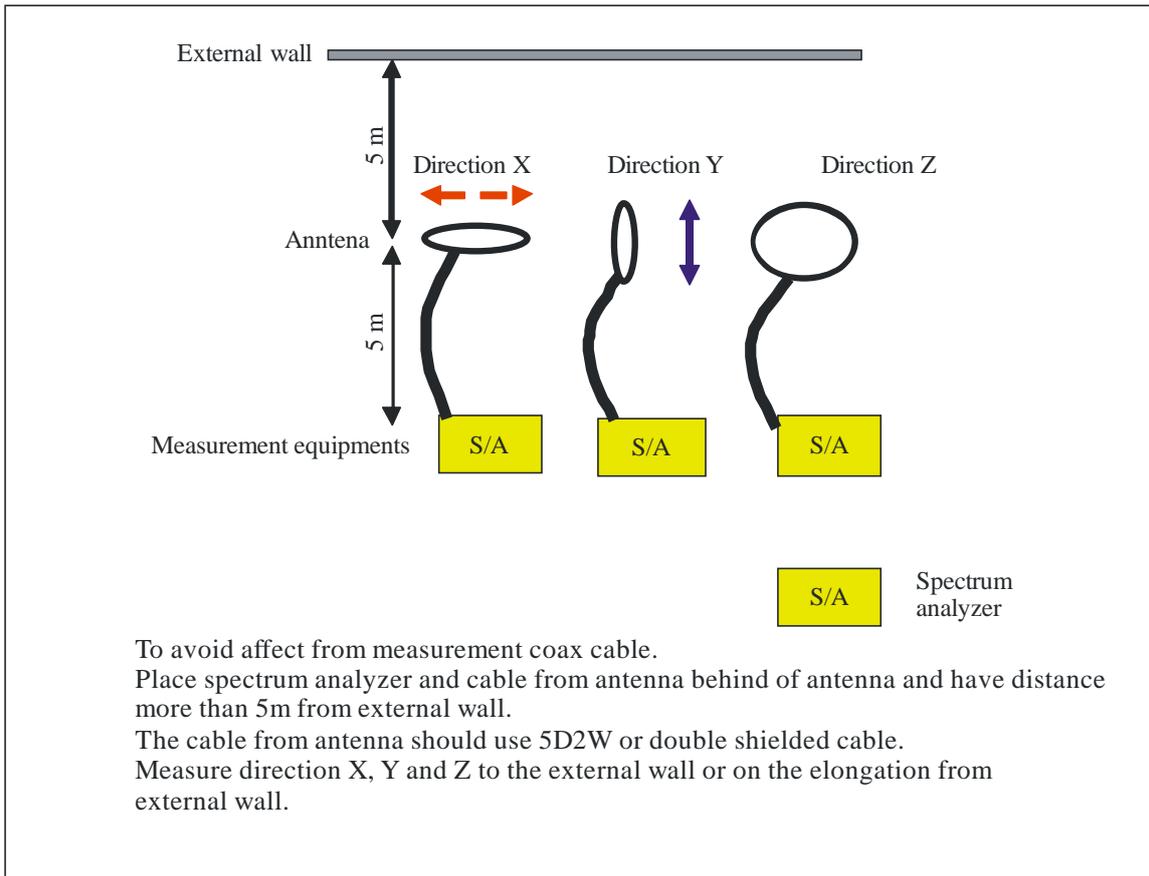
A3.3.3 Condition of PLT communication

- a) House
- Use typical house.
- Describe wooden construction/non-wooden construction, single family home (floor number)/apartment.
 - Measure the PLT system which is not a house use, measure at actual environment.
- b) Measure more than 2 distribution paths at one house (see Fig. A3-21)
- If the house has more than 2 floors, it is recommended using the path which is distributed to other floor.
- c) Measurement condition
- Condition 1: no PLT system in the house.
 - Condition 2: Install PLT system and communicate at maximum speed with UDP by application software like FTP. (Uni-direction.)
- d) Other condition

Measure noise at actual usage environment and other consumer electronics or lighting equipment are not removing from home for measurement. And also those are not on/off during measurement.

FIGURE A3-20

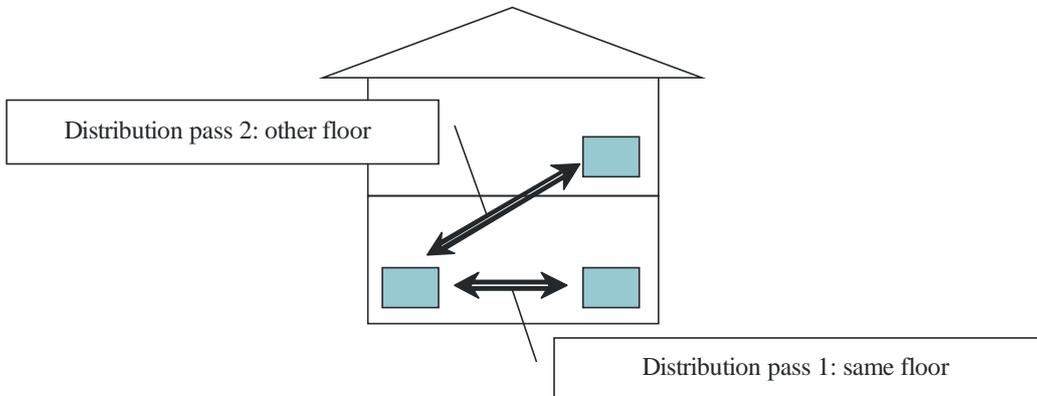
Placement of measurement equipments



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FIGURE A3-21

Example of distribution pass



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A3.3.4 Measurement result

TABLE A3-3
Measurement condition

	Type of PLT devices	OFDM	SS
Measurement conditions	House classification	wooden construction	Non-wooden construction
	Single family home/ apartment	Single family home / 2 floors	Building (School 4 floors)
	AC outlet which install PLT system	See Fig. A3-22	See Fig. A3-23
	Frequency range of PLT system	4 MHz-28 MHz	4 MHz-20 MHz
	Application of PLT system	For consumer	For industrial
Measurement equipments	Spectrum analyser	Agilent E7401A	Agilent E4402B
	Loop antenna	EMCO 6502	EMCO 6502

Figures A3-24 and A3-25 show measurement result of OFDM system and Figs A3-26 and A3-27 show result of SS system.

Figures A3-24 to A3-27 show result of direction-X and direction-Y at point which detected radiated emission by OFDM system and SS system. And also show result of neighbourhood point.

Spectrums of pulse are broadcasting wave or noise from consumer electronics. And those are observable any time even if PLT system is not operated. Those PLT systems transmit all the time and using frequency range of 2 to 30 MHz (Except frequency ranges which are used by armature radio.) So that, the transmitting spectrum from PLT system is not pulse and observed as wide range noise.

From this measurement result, radiated emission of direction-X and direction-Y of same point were different. And the radiated emission measured in the adjacent measurement points is different.

As shown by measurement result, radiated emission from PLT system and mains line is not transmitting to any direction and it has directional characteristics. Only specific direction can see radiated emission.

FIGURE A3-22

Measurement condition (1)

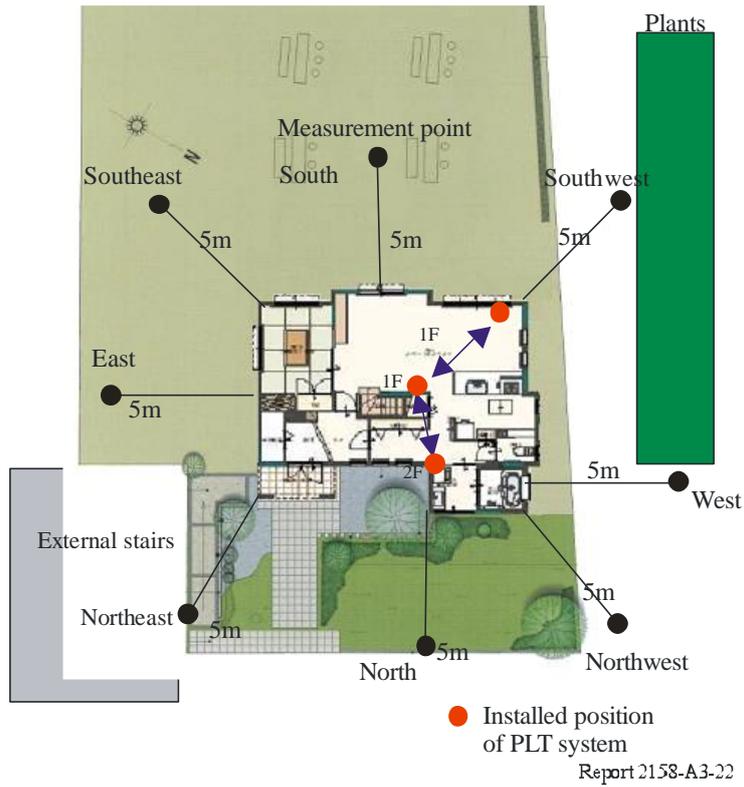


FIGURE A3-23

Measurement condition (2)

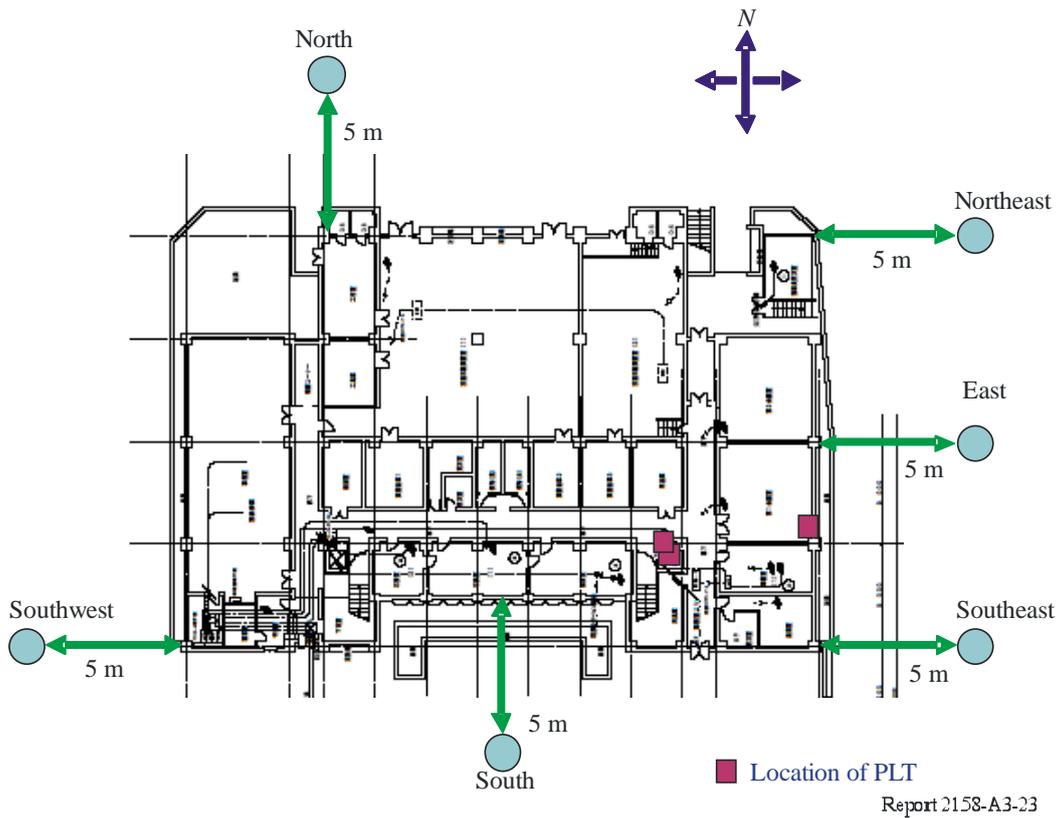


FIGURE A3-24

OFDM Distribution path 2 East 5 m

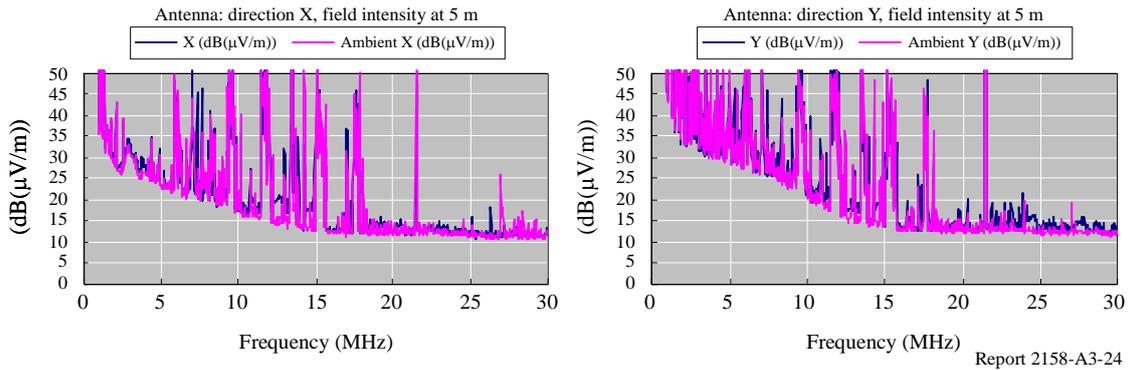


FIGURE A3-25

OFDM Distribution path 2 Southeast 5 m

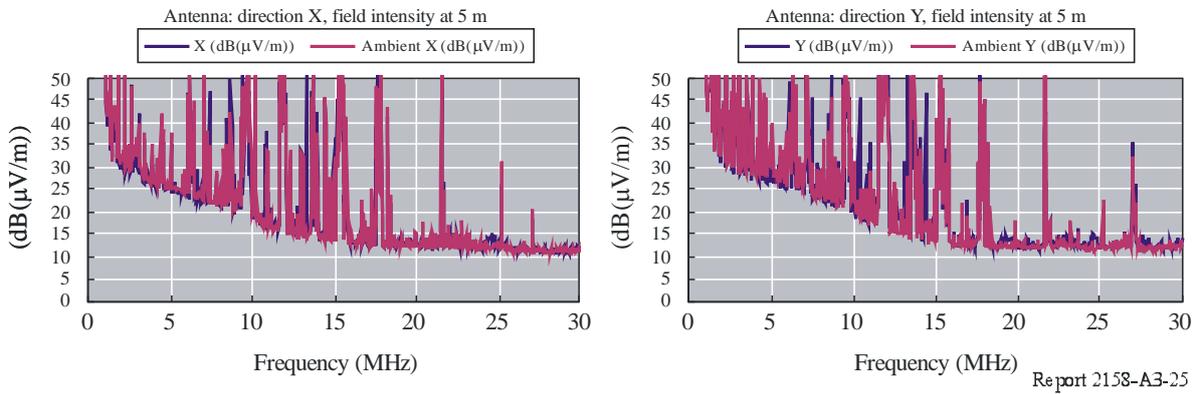


FIGURE A3-26

SS Distribution path 4 Northeast 5 m

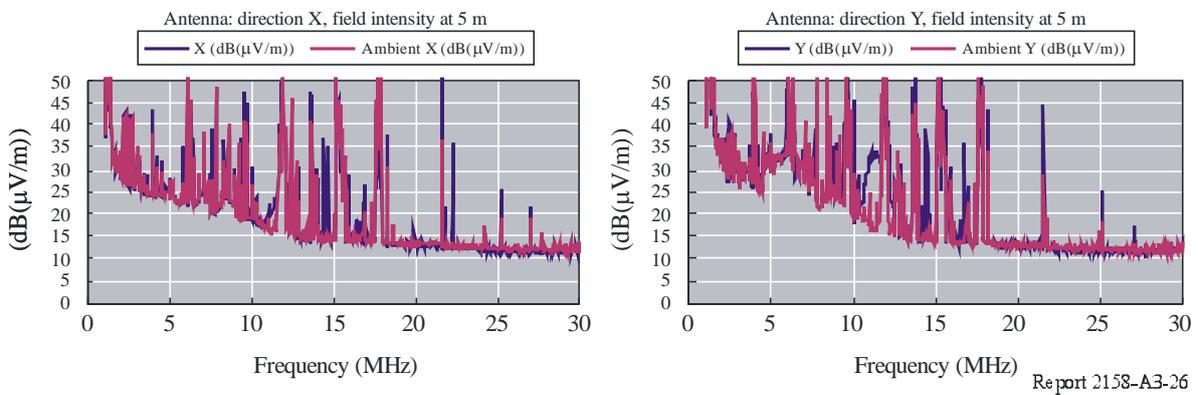
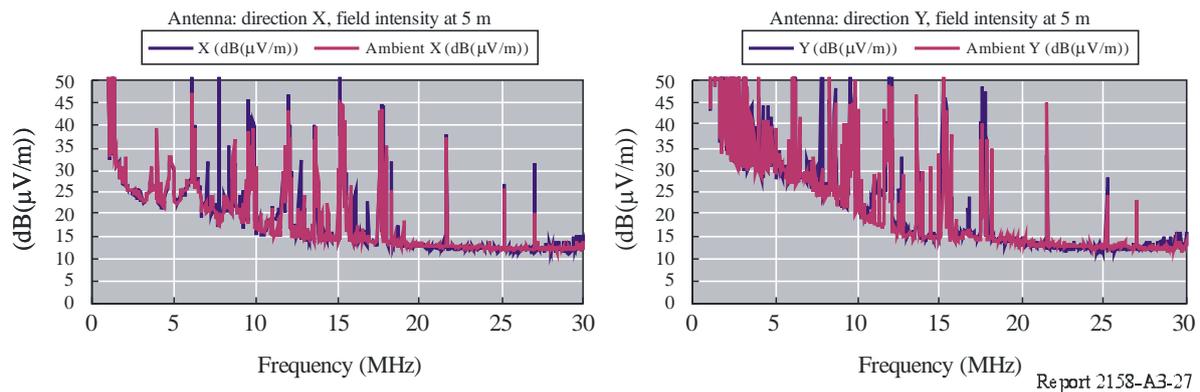


FIGURE A3-27

4-4 SS Distribution path 4 North 5 m



A3.4 Measurement results of leaked emissions by access PLT system in the HF and the UHF bands

A3.4.1 Introduction

Recently, high speed power line telecommunication equipments to archive data rates of several to ~200 Mbit/s have been developed, and broadband PLT systems with extending the available frequency bandwidth up to 80 MHz have been available. However, because power lines are designed not for telecommunication purpose but for the 50/60 Hz power distribution, the power lines may emit substantial level of electromagnetic noise. In the HF and VHF bands below 80 MHz, there are a lot of radio stations for the broadcasting service, the amateur service, the aeronautic service, the radio astronomy service, and so on. If the PLT modems using the frequency range below 80 MHz are widely used, large portion of the HF/VHF spectrum may become unusable. The HF band is also worth for scientific observations to research the earth's environments and astronomical objects. Because the received signal levels from astronomical sources are usually very weak, it could be a serious damage to conduct sensitive radio astronomical observations not only in the frequency range below 80 MHz but in higher frequency bands, including the UHF bands, due possibly to the harmonics and/or intermodulation effects of the PLT wanted signals.

The problems described above were investigated from April to July in 2002 by the PLT study group organized by the Ministry of Internal Affairs and Communications (MIC) of Japan. The study group held a working group on the field experiments, and executed collaborative field experiments on the PLT facility. In July 8-9 and 22-23, 2002, the field experiments were carried out at Mt. Akagi in Gunma Prefecture, Japan. In the experiments, we measured leaked emissions caused by the PLT modems in the HF and the UHF bands in order to evaluate impact of the expansion of PLT bandwidth on the radio astronomical observations and examine the presence of spurious emissions over higher frequency. In this text, we report the experimental results in the field experiments, and compare the PLT noise levels with the interference thresholds detrimental to radio astronomical observations, which are given in Recommendation ITU-R RA.769.

A3.4.2 Field experiment at Mt. Akagi, Japan, in July 23, 2002

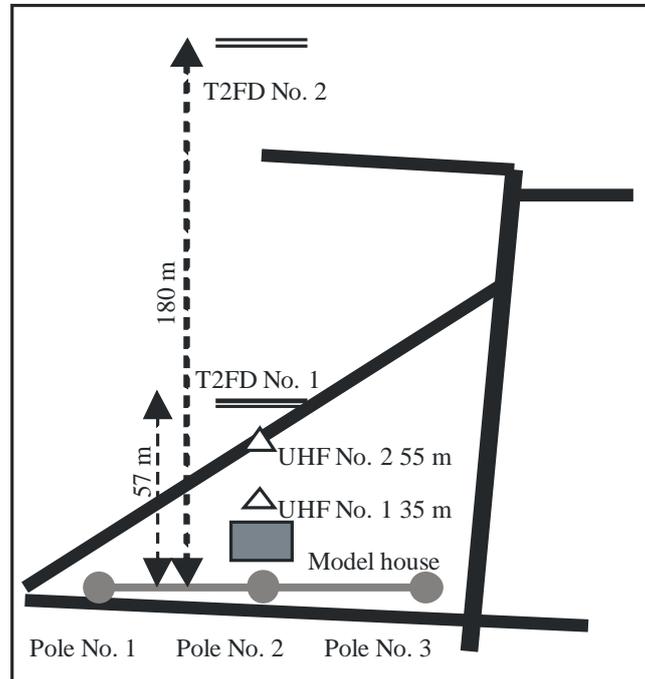
Figure A3-28 shows the configuration of the field experiment. Power lines used for the experiment were extended between electric poles (poles No. 1, No. 2, and No. 3 in Fig. A3-28) and a model house. Two pairs of PLT modems listed in Table A3-4 were used, and we carried out measurements of the leaked emissions in the HF and the UHF bands. The PLT modems and laptop computers

connected at the outdoor side of the power lines were set on the pole No. 2. The output powers of the PLT modems 1/2 and 3/4 are shown in Figs A3-29 and A3-30, respectively⁵⁴.

It is noted that three pairs of in-house PLT modems were also prepared at the experiment site, however they were not used for the measurements reported in this text.

FIGURE A3-28

Map of the experiment site



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TABLE A3-4

Access PLT modems used for the field experiments

No.	Modulation form	Frequency range (MHz)	Nominal output power (dBm/Hz)	Nominal output impedance (Ω)	Notch frequency (MHz)
1/2	OFDM	4.3-20.9	-50	100 \leq	7.000-7.300 10.100-10.150 14.000-14.350 18.068-18.168 21.000-21.450
3/4	SS	4.0-20.0	-50	50 \leq	7.000-7.300 9.800-10.300 13.900-14.400 17.850-18.350

⁵⁴ Attachment 3 to Technical Report of the High-Speed Power Line Communications Study Group, Ministry of Internal Affairs and Communications (MIC) of Japan, August 2002.

FIGURE A3-29

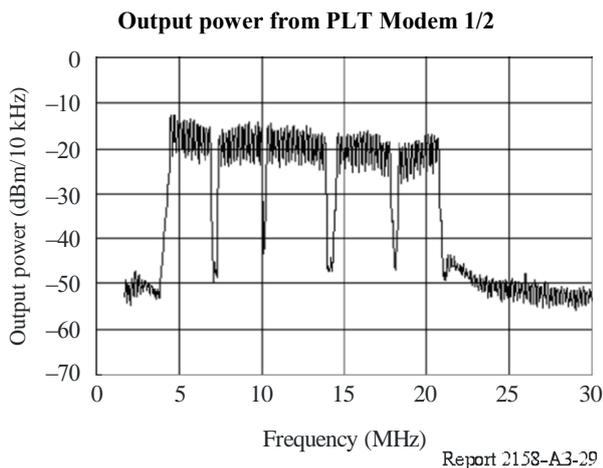
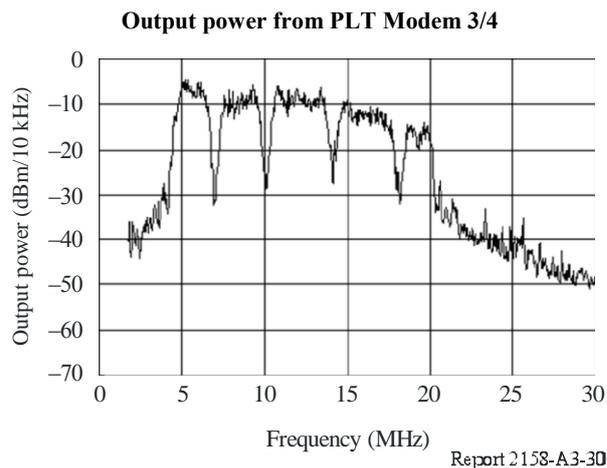


FIGURE A3-30



For the purpose of the experiment in the HF band, two sets of equivalent T2FD antennas of 25 m long were set up at distances of 57 m and 180 m apart from the pole No. 2 (T2FD No. 1 and No. 2 in Fig. A3-28, respectively). Height of each antenna from the ground was about 5 m. It is noted that these T2FD were not sensitive to the vertically polarized component of the electric field because they were set horizontally. Therefore, the T2FD might not have received the total power of the PLT noise. Output from the T2FD antennas were directly connected with spectrum analysers which measured electric power up to 30 MHz. For the quantitative measurements, we obtained 10 spectral traces for one spectrum measurement, and we evaluated the deviations of the measurements.

In order to examine the spurious emissions from the PLT facility, a log-periodic antenna (Create Design, CLP-5130-1) and a receiver were set up at a distance of 55 m apart from the pole No. 2 (UHF No. 2 in Fig. A3-28), which were moved to a distance of 35 m (UHF No. 1) for some occasions. The receiver consisted of a high pass filter, a low noise pre-amplifier, and a wide band amplifier. The pre-amplifier had a power gain of 40 dB at the centre frequency of 327 MHz, the bandwidth of about 20 MHz, and the minimum noise figure of 0.8 dB. The high pass filter which had a cut-off frequency at 260 MHz prevented saturation of the pre-amplifier by strong broadcasting signals in the VHF range. Spectra around 327 MHz were measured by spectrum analysers, and automatically recorded by a personal computer via the GPIB interface. In order to check that the spurious emissions were actually originated from the PLT facility, we measured the HF spectra simultaneously and examined dependences of spurious emission on distance and direction from the PLT facility.

A3.4.3 Leaked emissions in the HF band

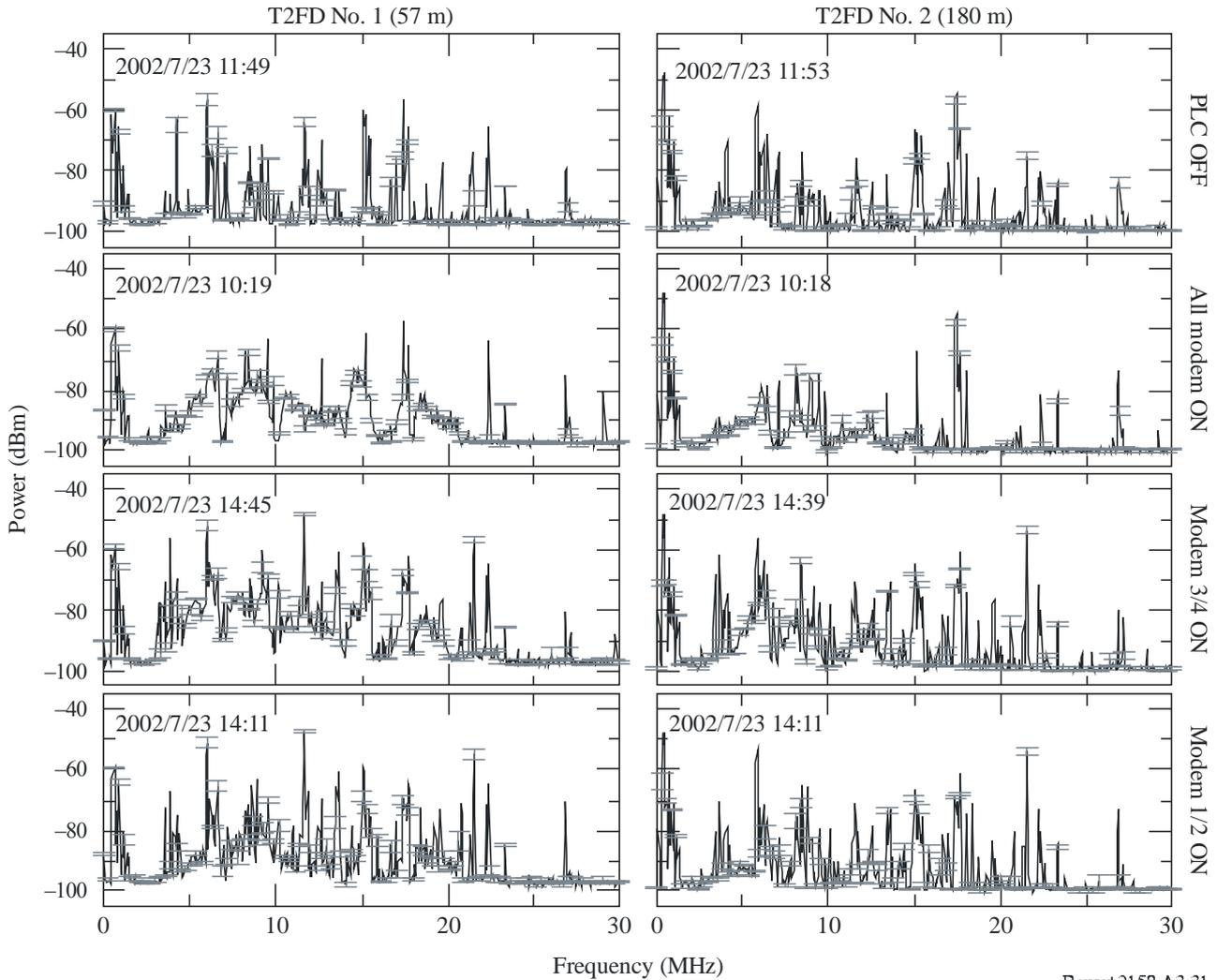
Figure A3-31 shows the results of the spectral measurements in the HF band. When the PLT modems were not in operation, many broadcasting signals showed up over a flat noise floor which represented a noise level of the spectrum analyser. After the modems were turned on, the noise floor level significantly increased in the frequency range from 4 to 20 MHz. There were some narrow drops in the increased noise floor at frequencies around 7, 10, 14, and 18 MHz, which were identical with the notch frequencies of the modems (see Table A3-4). These characteristics indicated that the increased noise level was caused by the PLT modems. Both OFDM (No. 1/2) and SS (No. 3/4) modems produced large increases of the noise floor, and the noise level due to the SS modems was about 5 dB larger than that of the OFDM modems. As shown in Fig. A3-31, many broadcasting signals were interfered with and some of them were completely masked by the PLT noise.

FIGURE A3-31

HF spectra measured by T2FD No.1 (left) and #2 (right)

When the PLT system was not in operation (top panels), all modems were turned on (second panels), only modem 3/4 were running (third panels), and only modem 1/2 were running (bottom panels).

Error bars represent the standard deviation



Distance dependence of the PLT noise level was examined assuming that the leakage electric field E is proportional to the power law of distance r , that is:

$$E \propto r^{-\alpha} \tag{A3-1}$$

where α is an attenuation coefficient. The coefficients were calculated based on the measurements with two T2FD antennas. The calculated coefficients scattered depending on frequency but distributed around 1.0.

In order to evaluate the leaked emission level quantitatively, the T2FD antennas were calibrated. A standard loop antenna (Anritsu MP414B) was set just below the T2FD antenna, and we measured electric field strengths of some broadcasting frequencies simultaneously. The antenna factor K of T2FD was calculated by:

$$K = E/V \tag{A3-2}$$

where V (μV) and E ($\mu\text{V}/\text{m}$) are output from the T2FD antenna and the standard loop, respectively. For example, the antenna factor of the T2FD antenna at the frequency of 9.6 MHz was derived to be -8.0 ± 2.5 dB. The T2FD antenna was also analysed based on the moment method and an antenna gain G_a was calculated to be 2.3 dBi at 9.6 MHz. The antenna factor is also derived from the antenna gain by:

$$K = \sqrt{\frac{4\pi\eta_0}{Z_0 G_a \lambda^2}} \quad (\text{A3-3})$$

where η_0 is the wave impedance and equal to 120π , Z_0 is 50Ω , and λ is the wavelength. By using equation 3 and considering a transmission loss through a coaxial cable to be 0.8 dB, the antenna factor was calculated to be -5.8 dB, which is consistent with the value estimated by the calibration.

Figure A3-32 shows a comparison between the PLT noise and the Galactic level calculated by referring to known Galactic spectra⁵⁵ and the calibrated antenna factors. The PLT noise exceeded the level of the Galactic noise by more than 30 dB.

A3.4.4 Spurious emission in the UHF band

The UHF band is an atmospheric window for the radio astronomical observations, and high sensitive measurements of weak radio sources are possible. Although the broadband PLT modems do not use such a higher frequency band, it is necessary to examine the spurious emissions levels due to the PLT modems.

FIGURE A3-32

HF spectrum measured by T2FD No. 1 when all the PLT modems were running (upper line) and estimated Galactic emission level (lower line)

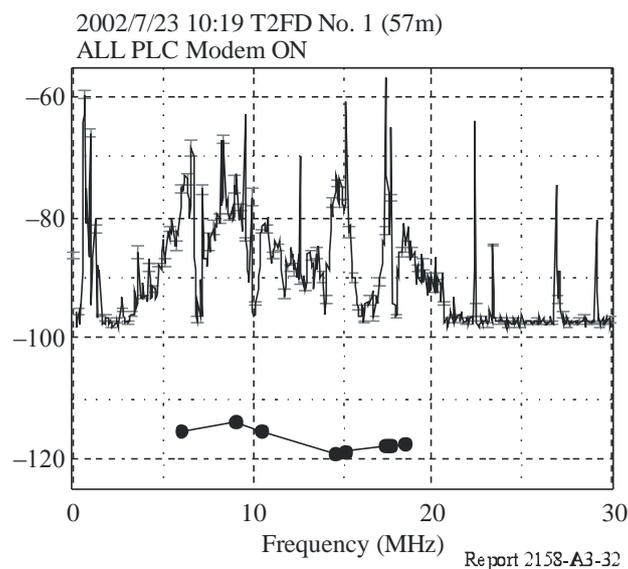


Figure A3-33 shows a dynamic spectrum in the frequency range from 297 to 357 MHz during an operation of PLT modem 3/4. When the modems were turned off at 15:04, it is clearly observed that the broadband noise and some narrow-band emissions disappeared. In other words, spurious emissions due to the PLT modems were clearly observed.

⁵⁵ ALEXANDER J.K., BROWN L.W., CLARK T.A., STONE R.G., and WEBER R.R. [1969] The Spectrum of the Cosmic Radio Background between 0.4 and 6.5 MHz. *Astrophys. J.*, 157, L163.

There was no obvious cause for the spurious emissions generated by the modems under test. Further studies would be required to investigate the production of harmonics and/or intermodulation products in PLT modems. Moreover, when PLT modems employ notching, the presence of non-linear elements in the mains wiring may result in the generation of intermodulation products and filling of notches.

FIGURE A3-33

Dynamic spectrum at around 327 MHz
As soon as the modem 3/4 were turned off at 15:04, the broadband noise and some narrow-band emissions disappeared

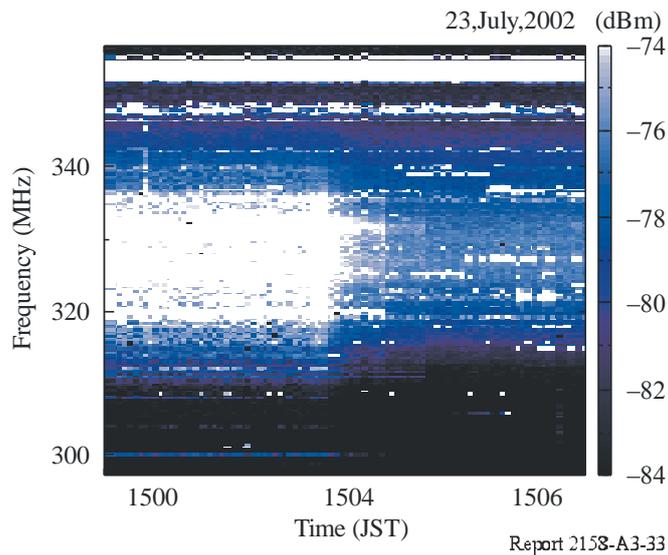
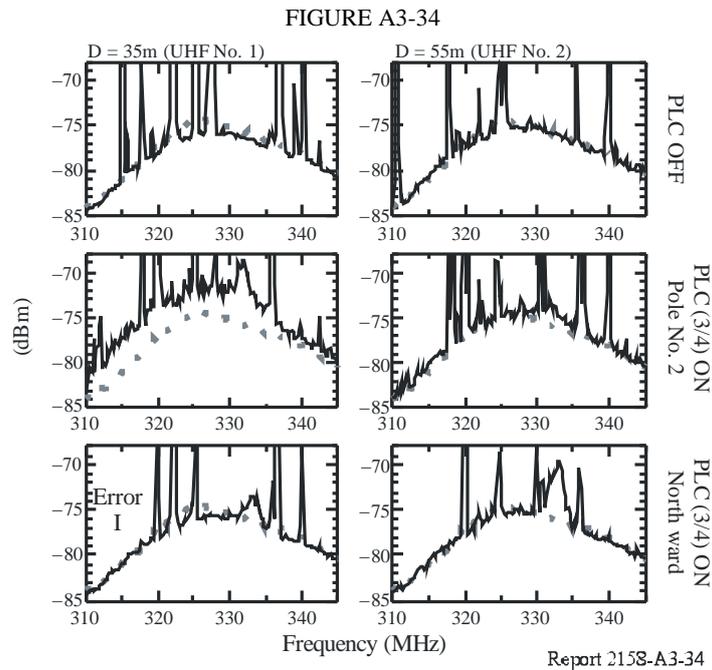


Figure A3-34 shows dependence of the spurious emission level on the distance and direction of the log-periodic antenna with respect to the PLT facility. When the all PLT modems were turned off or the antenna did not direct to the PLT facility, no spurious emissions were detected. On the other hand, the strong spurious emissions were received when the antenna was close to the PLT facility and was directed toward it. At the position of UHF No. 1, the increase of the noise floor reached about 4 dB. These results indicate the presence of spurious emissions from the PLT modems in the UHF band.



Distance dependence of the PLT noise level was also evaluated in the UHF band. By using equation 1, the attenuation coefficient was calculated to be 1.3, which was close to but somewhat larger than the far field value.

Distance dependence of spurious emissions and direction of the log-periodic antenna with respect to the PLT facility measured at 35 m point (left) and at 55 m point (right). Top: PLT modems were not operational. Middle: PLT modems 3/4 were running and the antenna was directed to the pole No. 2. Bottom: Same as middle panels but the antenna pointed the opposite direction. In each panel, solid lines are averaged spectra around the frequency of 327 MHz and gray dotted line shows a spectrum when input of the receiver was terminated. Some environmental noises which were not related to PLT were also identified as narrow-band emissions which were received when the PLT modems were turned off and the antenna was directed northward. A typical error bar in the measurements is indicated in the left-bottom panel.

A3.4.5 Comparison of the PLT noise level with Recommendation ITU-R RA.769 at 327 MHz

Threshold levels for interference detrimental to the radio astronomy service are given in Recommendation ITU-R RA.769. At 327 MHz we derived the spurious emission levels from the PLT facility at both frequencies, and compared them with the threshold levels. The band around 327 MHz is allocated to the radio astronomy service on a primary basis, and the threshold level of interference detrimental to the radio astronomy observations is given to be -258 (dB(W/(m² · Hz))) in Recommendation ITU-R RA.769. From Fig. A3-34, the noise levels at the UHF No. 1 at around 327 MHz were -72.1 dBm when the PLT modem 3/4 were operational and -75.9 dBm when they were turned off. Considering the system gain of 51.2 dB, measured bandwidth of 100 kHz, and the antenna gain of 12 dBi, the spectral power flux-density of the spurious emission was estimated to be -206 (dB(W/(m² · Hz))). Applying the far-field attenuation coefficient of 1.0, the separation distance needed to protect radio astronomical observatories were estimated to be about 12 km (see Table A3-5).

TABLE A3-5

Separation distance to protect the RAS from PLT at 327 MHz

Frequency (MHz)	327
Threshold level (dB(W/(m ² · Hz)))	-258
Spurious PLT Emissions (dB(W/(m ² · Hz)))	-206
Distance from pole No. 2 (m)	35
Separation distance (km)	12

We also intended to make similar calculations at 13.5 MHz, however, the measured leaked emission levels at the distance of 180 m (T2FD No. 2) were too close to the noise floor to conduct reliable calculations.

A3.4.6 Conclusions

From the spectral measurements in the HF band, it was shown that the noise floor levels were significantly increased due to Access PLT modems. The leaked emission levels were found to be much higher than that of the radio astronomical signals. From the experiments in the UHF band, it was found that the spurious emissions were generated from the PLT modems. In both frequency bands, the leaked emissions due to the PLT modems were much greater than the interference threshold levels detrimental to the RAS given in Recommendation ITU-R RA.769. The separation distance at 327 MHz appropriate to protect the radio astronomical observatories from the spurious emissions caused by a single pair of the Access PLT modems was found to be about 12 km. If the Access PLT modems were widely deployed, the aggregated leaked emission levels would be increased much more and the separation distance would become much longer.

For the purpose of establishing limits on the output power of PLT modems, these studies clearly demonstrate that leaked emissions from PLT modems with a power spectral density of -50 dBm/Hz raise the ambient noise floor by a great amount and are capable of causing severe interference. An effective practical limit would have to take account of factors such as the cumulative impact of multiple PLT units, distance and propagation paths to potential victim receivers and the characteristics of mains wiring systems encountered in real life.

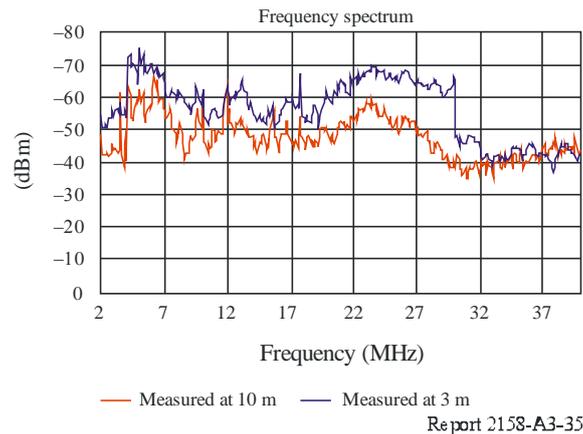
A3.5 Distance separation measurements**A3.5.1 Distance separation measurements in Brazil**

The relation between field strength and distance was investigated to define both the size of the exclusion zone required to protect HF stations from PLT interference and the extrapolation factor to be used in the measurements. Figure A3-35 shows the field strength measured at horizontal distances of 3 and 10 m.

As the distance increases, there is an average measured field strength reduction of 11.7 dB for frequencies between 4 MHz and 30 MHz.

The results demonstrated that a 40 dB/decade extrapolation factor represents a good first approximation once the average calculated field strength reduction would lead to 9.47 dB (2.3 dB difference) for line-of-site attenuation.

FIGURE A3-35

Measurement at 10 m and 3 m**A3.5.2 Distance separation measurements in Canada**

The ratio of the RF field strength between 3 m and 10 m was studied by the Canadian Communications Research Centre to understand propagation loss in the operating frequencies of PLT devices. The theoretical field strength ratio between measurements at 3 m over 10 m can be derived from the free space loss propagation equation. Since it is a ratio, the equation can be simplified to:

$$\text{Field strength ratio}_{(\text{dB})} = 20 \log\left(\frac{10\text{ m}}{3\text{ m}}\right) \approx 10.5 \text{ dB}$$

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 metres than at ten metres from the houses.

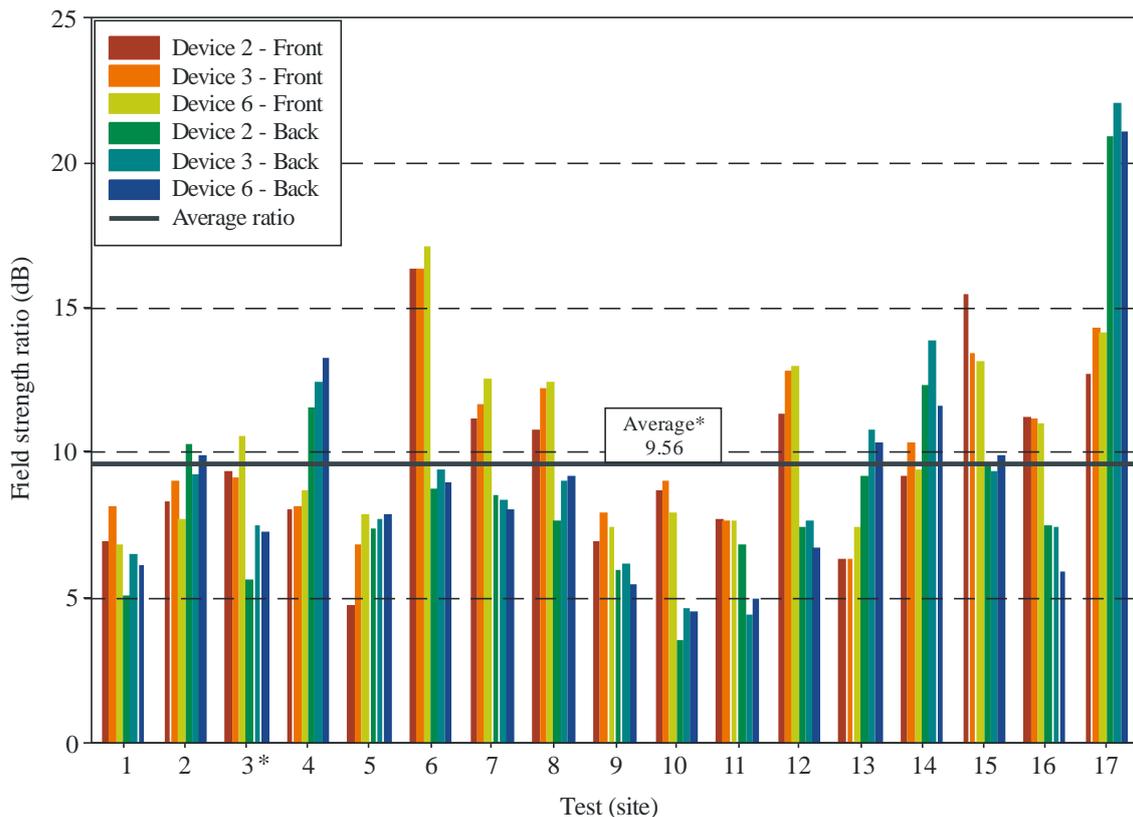
Figure A3-36 shows the field strength ratio of 3 m over 10 m for each device at each test site. To reduce the effect of the ambient noise, the calculations were done from 16 to 28 MHz only. The average field strength ratio over all the devices and test sites is 9.56 dB, 1 dB lower than the theoretical value. Based on these test results, the extrapolation factor was actually 18.2 dB per decade of distance.

A3.5.3 Distance dependence of the leaked electric field caused by in-house PLT systems separation measurement in Japan**A3.5.3.1 Introduction**

Information on the distance dependence (decrease of the electric field as a function of distance from a house where in-house PLT modems are operating) would be important to study and derive compatibility conditions toward the coexistence between the radiocommunications systems that are operating in accordance with the Radio Regulations and the PLT systems. In this regard a study was made to measure the leaked electric field at a distance of 5, 10 and 30 m from the outer wall of a house where in-house PLT systems operate, and succeeded to derive the distance dependence of the field strength as a function of distance and wavelength.

FIGURE A3-36

Field strength ratio of 3 m over 10 m at each test site



*Test site 3 is shown on the graph but not taken into consideration for the calculation of the average due to PLT interference from an adjacent house.

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A3.5.3.2 Measurement⁵⁶

The measurements were performed in an actual rural environment using a single-story wooden house shown in Fig. A3-37. The coordinate of the house is 37° 42' N and 140° 40' E. The house is located in a remote, mountain area. Although the house is surrounded by forest, there is sufficient clearance toward west, south and southeast from the house.

For the leaked electric field, the measurement points were located at a distance of 5, 10 and 30 m from the outer wall of the house toward west, south and southeast. We used a passive loop antenna (ETS-Lindgren 6512; 60 cm ϕ) at a height of 1 m (lower edge). The antenna output was measured by a spectrum analyser (NEC SpeCAT2) over a frequency span of 2 to 26 MHz at every 8 kHz, with a resolution bandwidth of 8 kHz. The measurements were conducted in the rms mode and recorded in the MAXHOLD. Because the leaked electric field has three independent components (x-, y-, z-directions), we measured three components at every measuring point, which were then synthesized into the total electric field strength.

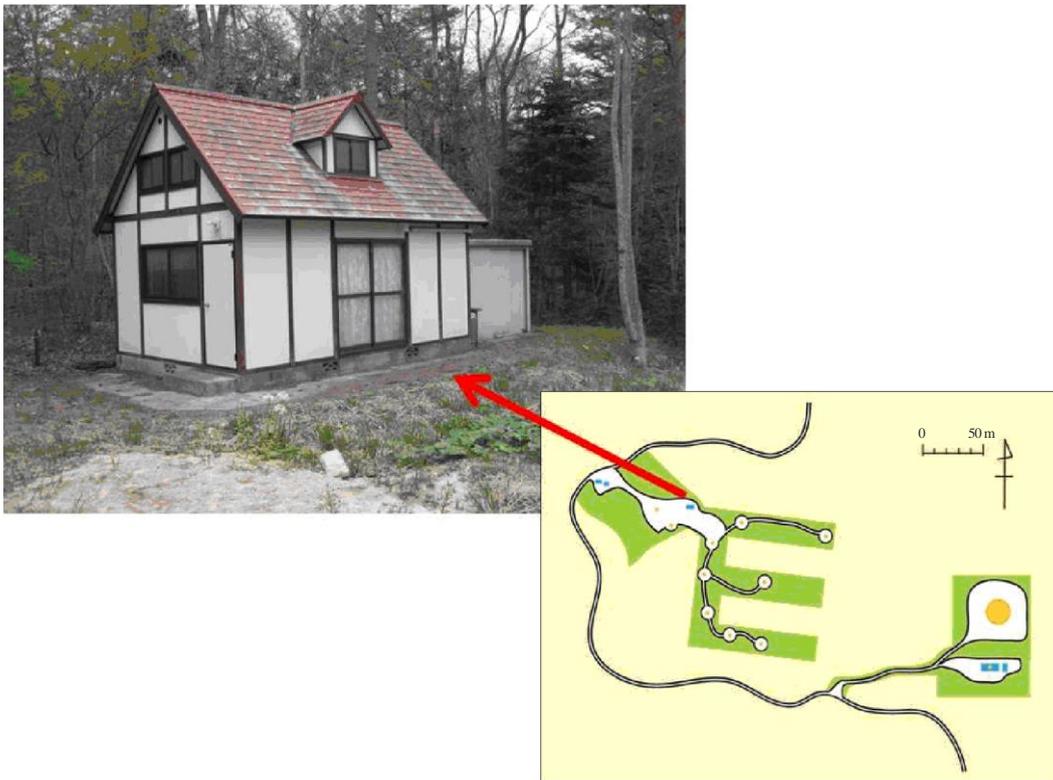
We also measured the common-mode current inside the house. Because the in-house power lines of this measurement house were exposed on its inner wall, it was possible to conduct direct measurements of the common-mode current at several points along the power lines by using a current probe. The output power from the current probe was measured by the same spectrum

⁵⁶ OHISHI, M., KITAGAWA, M., MISAWA, H. and TSUCHIYA, F. [September, 2009] Leaked emissions due to the in-house broadband power line communications (1) – Measurement of the electric field strength at a distance and direct measurements of the common-mode current-. IEIEC Tech. Rep., EMCJ2009-40.

analyser as that used for the field measurements, with the same frequency span, measurement points, frequency resolution and measurement mode. The common-mode current was then derived from the output of the current probe. The differential- and common-mode currents flowing from the PLT modems were measured with the same procedure.

FIGURE A3-37

The house used for the measurements and the map around the house



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Table A3-6 shows details of the in-house PLT modems used, which are commercially available in Japan. A pair of PLT modems was plugged into the in-house outlets. Each modem was connected to a personal computer. Data was transmitted by sending a large file from one computer to the other through the PLT modems. Measurements of the leaked electric field strength and the currents were made during the file transfer. For the measurements of the ambient noise, the PLT modems were plugged off from the outlets.

TABLE A3-6

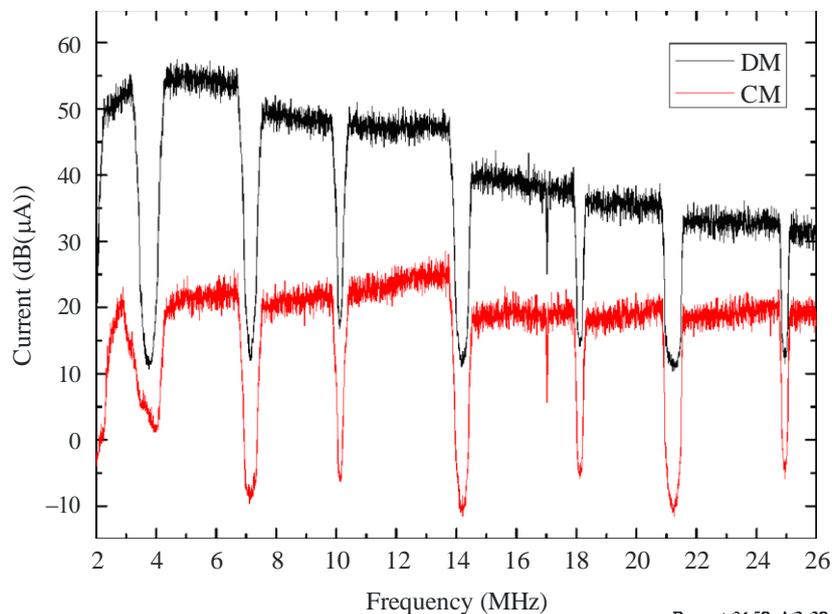
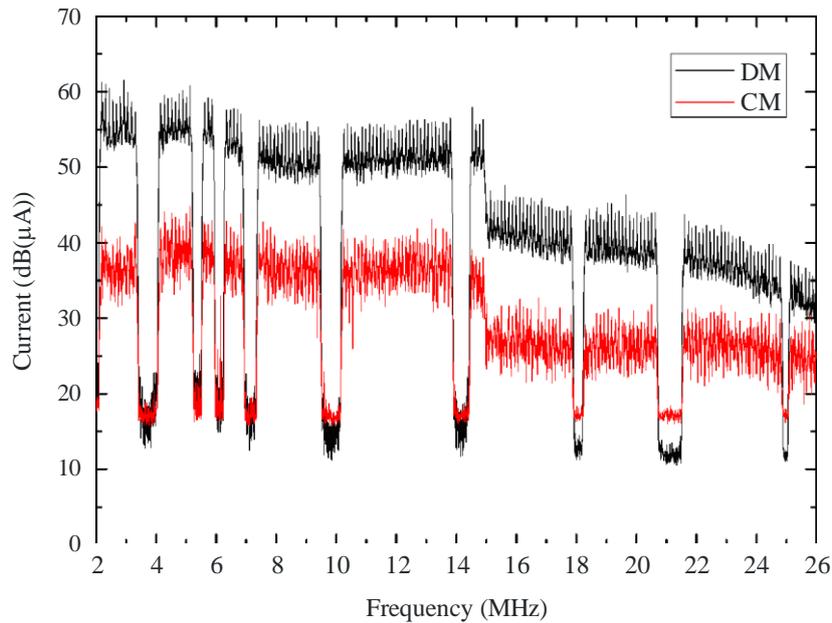
PLT Modems used for the measurements

PLT standard	Frequency range (MHz)	Data rate (PHY layer) (Mbit/s)
HD-PLC	2-28	210
UPA	2-30	200

A3.5.3.3 Measured data

Figure A3-38 illustrates the differential mode and common mode currents immediately after the PLT output port. A PLT modem injects the differential mode current into the power line for the data transfer, and a fraction of the differential mode current would be converted to the common mode current at unbalanced elements that are distributed on the power line. The degree of the conversion depends on the unbalanced elements. The common mode currents shown in Fig. A3-38 are not the converted common mode current, but are those generated in the PLT modem (injected or launched common mode current).

FIGURE A3-38
**Differential mode (DM) and common mode (CM) Currents
 for the HD-PLC modem (upper panel) and the UPA modem (lower panel)**



Figures A3-39 through A3-41 illustrate the leaked electric field strength for the HD-PLC modem toward the south, southeast and west direction, respectively.

FIGURE A3-39
Leaked electric field strength (dB(μ V/m)) for the HDPLC modem toward south

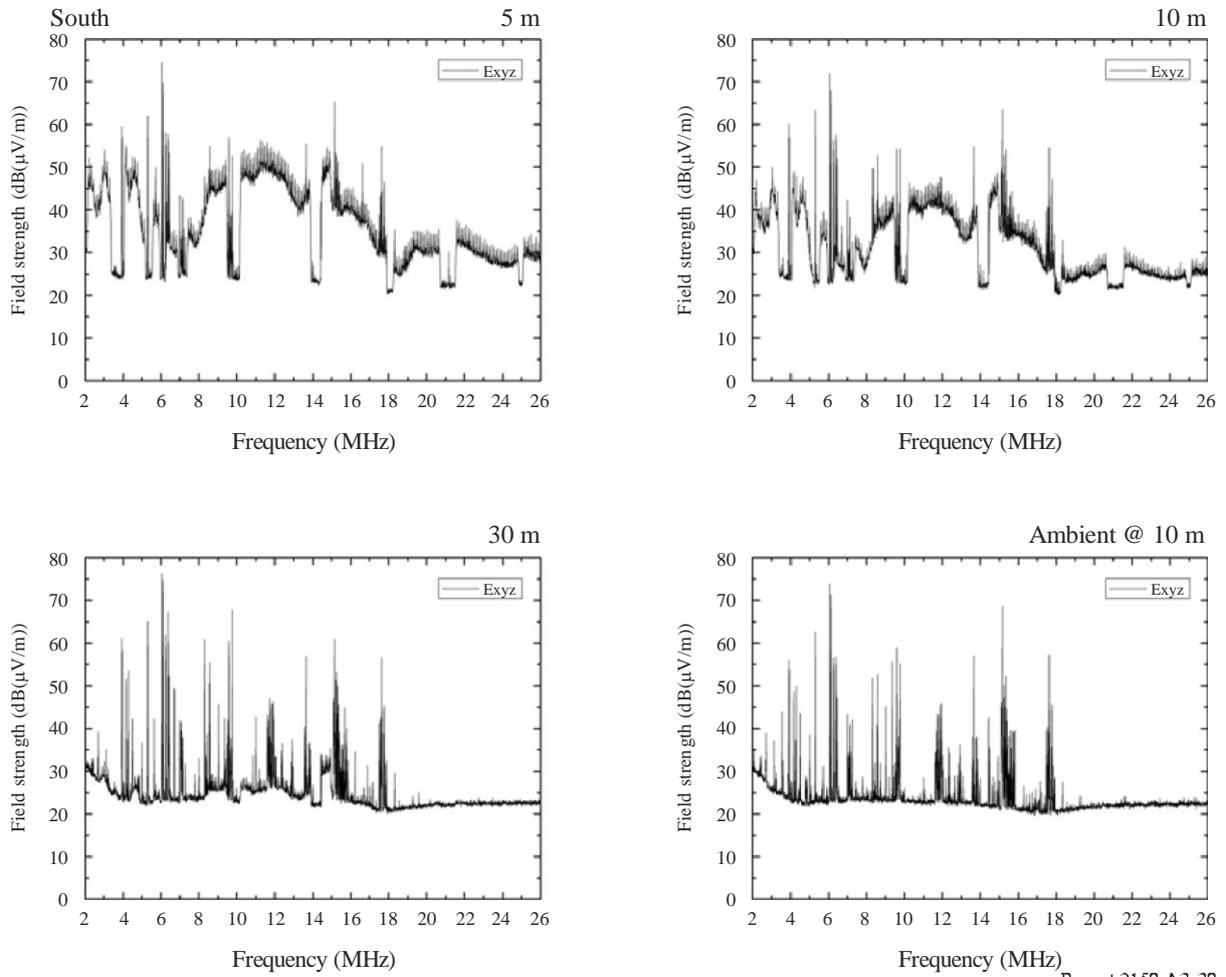


FIGURE A3-40
Leaked electric field strength (dB(μ V/m)) for the HDPLC modem toward southeast

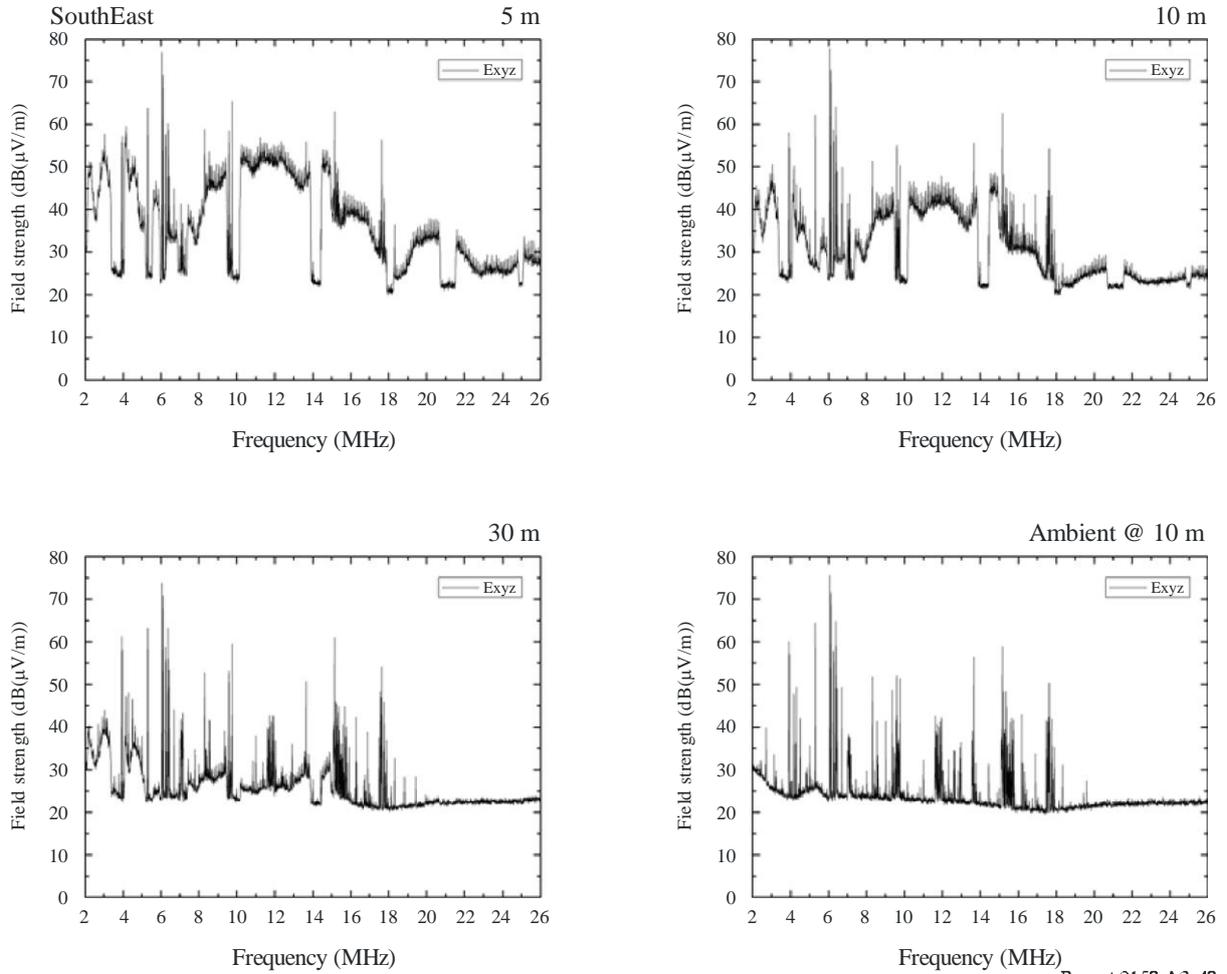
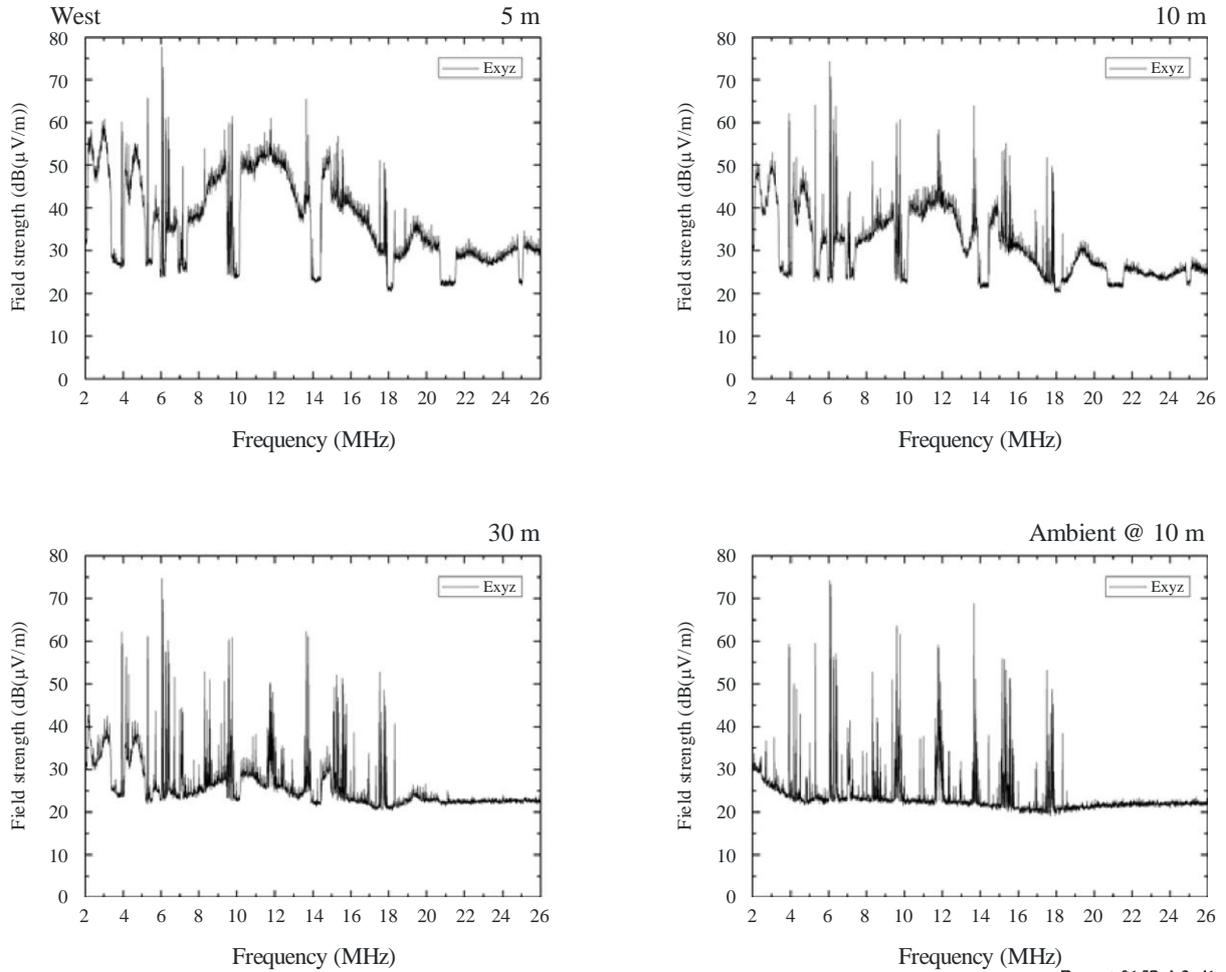


FIGURE A3-41

Leaked electric field strength (dB(μ V/m)) for the HDPLC modem toward west



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Figures A3-42 through A3-44 illustrate the leaked electric field strength for the UPA modem toward the south, southeast and west direction, respectively. Note that we are unable to include the electric field data at a distance of 5 m toward south due to measurement error.

FIGURE A3-42

Leaked electric field strength (dB(μ V/m)) for the UPA modem toward south

South

5 m

No measurement data

10 m

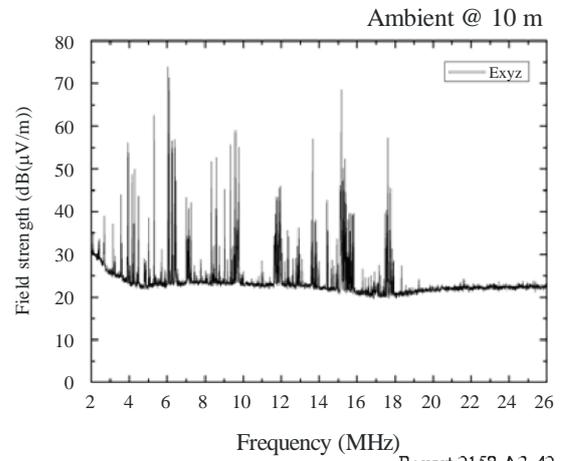
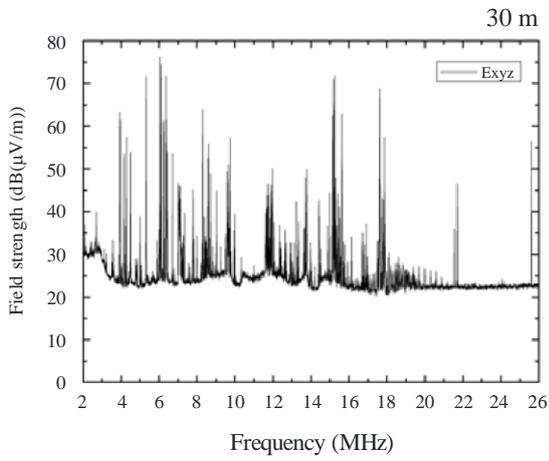
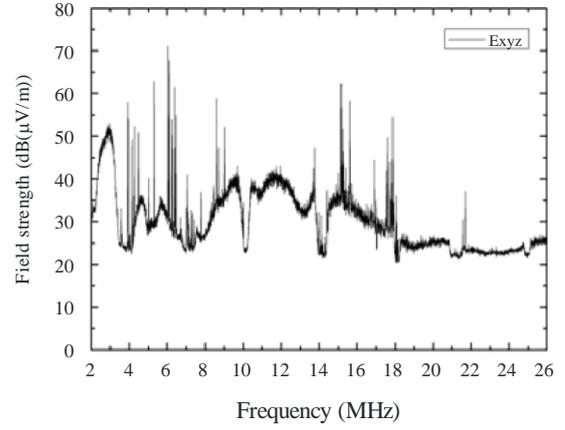


FIGURE A3-43

Leaked electric field strength (dB(μ V/m)) for the UPA modem toward southeast

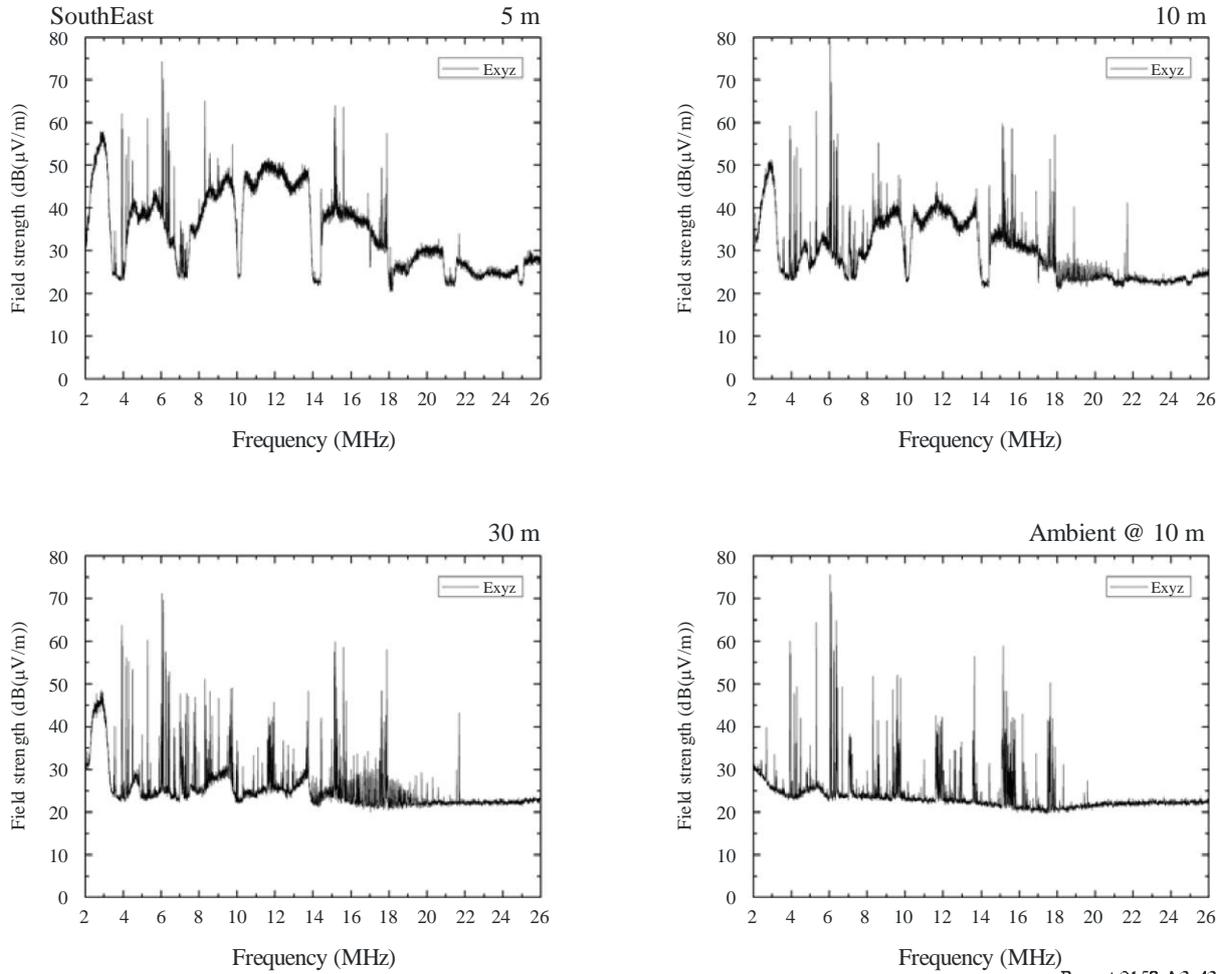
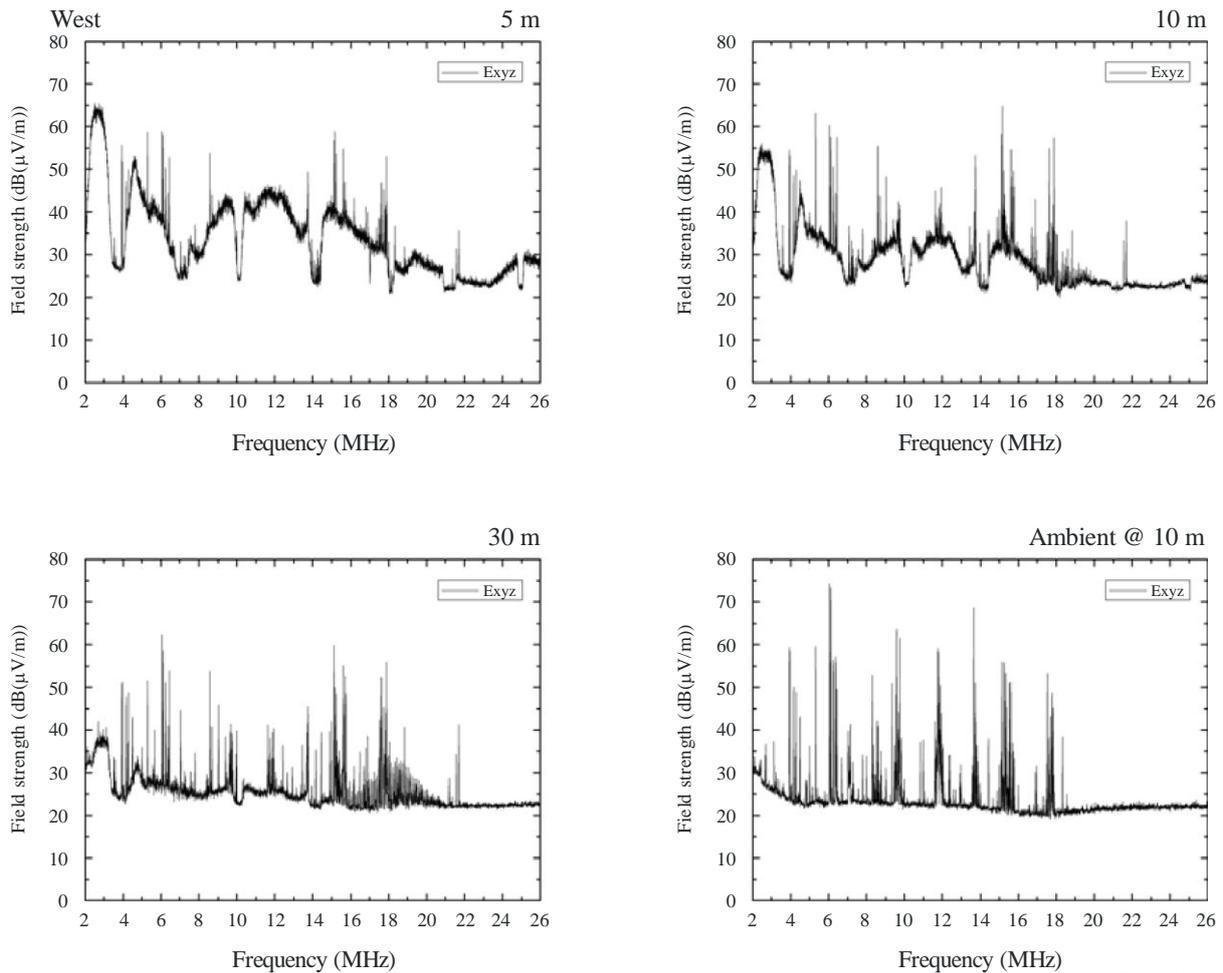


FIGURE A3-44

Leaked electric field strength (dB(μ V/m)) for the UPA modem toward west

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Figure A3-45 shows the distribution of the in-house power line of the measurement house together with the points where we made direct measurements of the common-mode current. The dimension of the house was 5.4×3.6 m. The power line distribution network of the measurement house was a simple one; the main part of the power lines is extended horizontally from the switchboard. We chose three points:

- line 1 is a location where a power line is branched into two,
- line 2 is another branch where a lamp is connected, and
- line 3 is close to the end point of a power line.

Figure A3-46 shows the measured common-mode currents at three points. It is clearly seen that the common-mode current varies from point to point along the power line. In this example the maximum common-mode current of about 40 dB(μ A) was measured at around 2.8 MHz at line 2 and line 3. It should be noted that several broadcasting signals are clearly observed (e.g. around 6 MHz). This, in turn, means that the power line would be a good receiving antenna.

FIGURE A3-45

Distribution of the in-house power line network of the measurement house

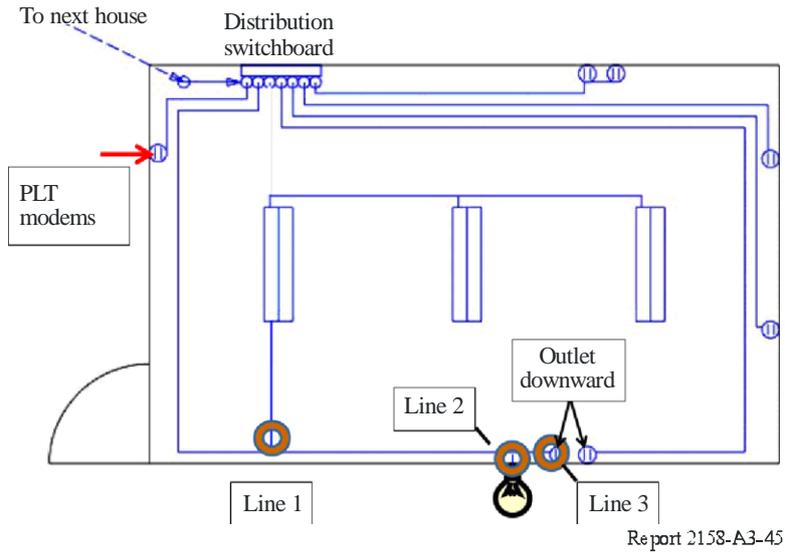
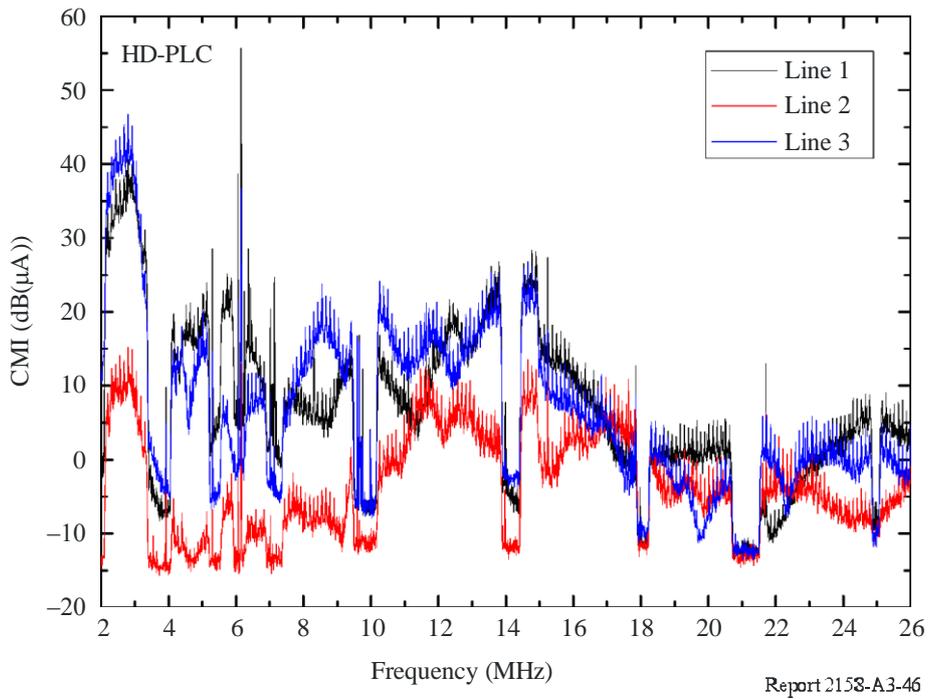


FIGURE A3-46

Example of direct measurement of common-mode current on the in-house power line



A3.5.3.4 Derivation of the distance dependence

In order to derive the distance dependence, we selected three frequency ranges: 2 896-3 200 kHz, 10 304-10 592 kHz and 14 502-14 792 kHz. These were selected because there are no distinct signals for the radiocommunications services judged from the actually measured ambient data (Figs A3-39 through A3-44). For each frequency range we calculated the averaged field strength and its standard deviation, which are plotted in Fig. A3-47.

In the HF range the boundary between the near-field and the far-field ($\lambda/2\pi$) is about 25 (for 2 MHz) to 1.5 (for 30 MHz) m. Therefore it is required to take this fact into account to find an appropriate model to explain the measured field strength distributions. We have found that the dipole radiation model will give a good approximation:

$$E = \frac{Z_0 I L}{2\pi D} \sqrt{1 - \left(\frac{\lambda}{2\pi D}\right)^2 + \left(\frac{\lambda}{2\pi D}\right)^4} \quad (\text{A3-4})$$

where:

- E : field strength
- Z_0 : impedance of the space
- I : current
- L : length of the wire
- λ : wavelength
- D : distance.

Assuming $L = 5$ m, it was possible to derive the current, I , by comparing the model curve and the measured field strengths. The derived (common-mode) current values were 42 dB(μ A) for the 3 MHz range, 24 dB(μ A) for the 10 MHz range and 20 dB(μ A) for the 14 MHz range, respectively. The model curves are also plotted in Fig. A3-47.

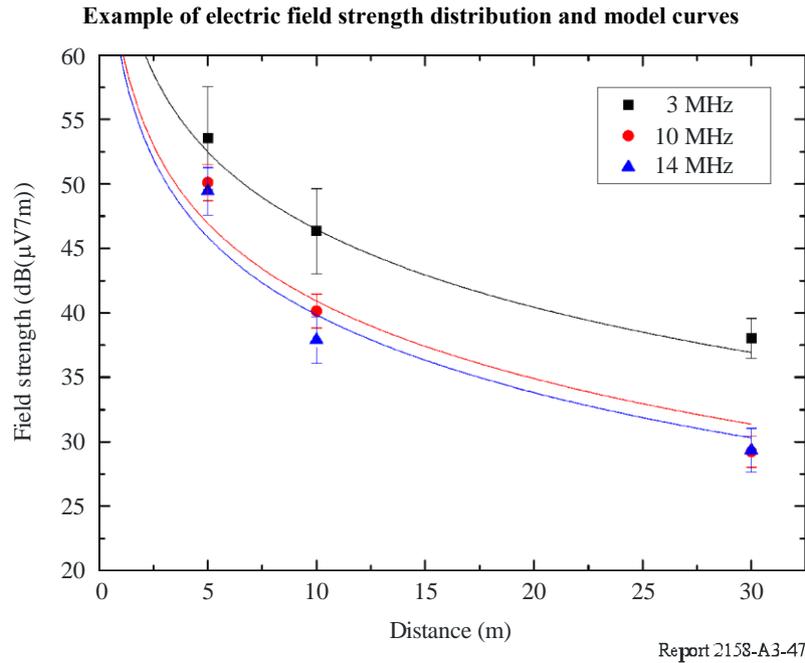
The derived common-mode current values in Fig. A3-47 are slightly less than the measured ones in Fig. A3-46. When we take the wall attenuations into account, it would be possible to reconcile the differences between the direct measurement values and the estimated ones of the common-mode current. The simple power line structure (Fig. A3-45) would be consistent with the dipole radiation approximation⁵⁷.

A3.5.3.5 Summary

The leaked electric field strengths and the common-mode currents along the power line were measured with the in-house PLT modems. Based on these measured data, it was found that the dipole radiation model would be a good approximation to express a relation between the field strength and the distance from the radiation source.

⁵⁷ VICK, R. Estimating the radiated emissions of domestic main wiring caused by power-line communication systems. EMC Zurich Conf., (February, 2003), p.87-92.

FIGURE A3-47



Equation (A3-4) can be expressed for the near-field case as

$$E \approx Z_0 \frac{IL\lambda}{8\pi^2 D^3} \quad \text{for} \quad \frac{\lambda}{2\pi D} \gg 1$$

and for the far-field case as

$$E \approx Z_0 \frac{IL}{2\lambda D} \quad \text{for} \quad \frac{\lambda}{2\pi D} \ll 1$$

Therefore the distance dependence would not be a simple one (e.g. 20 dB/decade or 40 dB/decade), and should be carefully chosen according to the ratio of the wavelength to the distance.

A3.6 Impact on radioastronomy observations by leaked radiation caused by in-house PLT systems

A3.6.1 Introduction

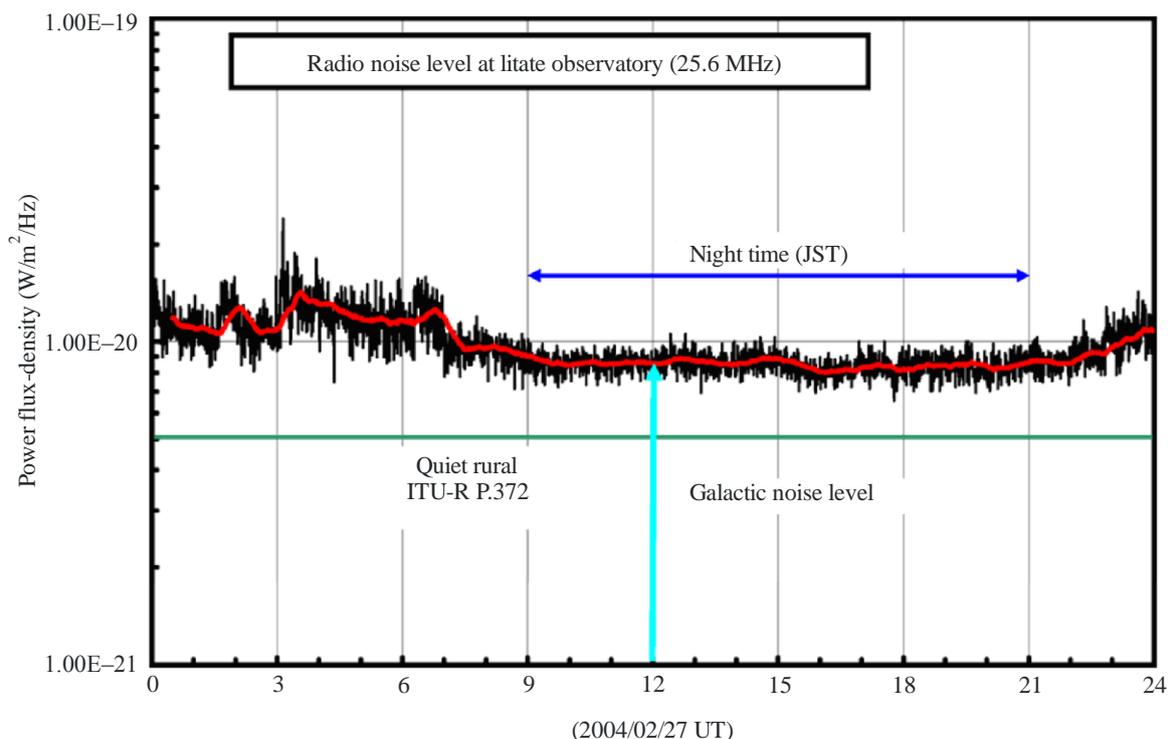
The radio signals from celestial sources detected by radio astronomical telescopes and, consequently, interference thresholds detrimental to the radio astronomy service (RAS) given in Recommendation ITU-R RA.769 are far below the man-made noise levels given in Recommendation ITU-R P.372. Thus radio astronomers have built their observatories in remote areas, and developed techniques to observe very weak signals from celestial sources under conditions where interference is almost constant and non-polarized.

Since the disturbances from PLT systems are time-variable and polarized, radio astronomers have serious concerns about PLT systems. However, until now there have been no actual measurement data taken by radio telescopes operating in the HF band in assessing the impact on RAS observations by PLT systems. To correct this lack we have used actual radio telescopes to measure the disturbance caused by PLT systems.

A3.6.2 Radio noise environment at the measurement location

The measurements were performed at the Iitate radio observatory of the Tohoku University, Japan. The observatory is located in a remote, mountain area, and its coordinates are 37° 42' N and 140° 40' E. The observatory is surrounded by a forest, and there are no residences within 1.2 km around the observatory. Thus the radio noise environment is suitable for radio astronomy observations in the HF and VHF/UHF bands. Measured radio noise by using a radio telescope at the Iitate radio observatory is shown in Fig. A3-48. It is seen that the radio noise is dominated by the Galactic noise, but some man-made noise is seen during day-time. The radio noise level is between the rural and the quiet rural ones defined in Recommendation ITU-R P.372.

FIGURE A3-48
Measured radio noise at the Iitate radio observatory in February 2004



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A3.6.3 Measurement⁵⁸

Table A3-7 shows details of the in-house PLT modems used, which are commercially available in Japan. These PLT modems were installed at a single-story wooden house inside the observatory. Although the house is surrounded by a forest, there is sufficient clearance to the west, south and southeast from the house (see Fig. A3-49). A pair of PLT modems was plugged into the in-house outlets. Each modem was connected to a personal computer. Data was transmitted by sending a large file from one computer to the other through the PLT modems. Measurements of the leaked

⁵⁸ Further details are described in OHISHI, M., KITAGAWA, M., MISAWA, H., and TSUCHIYA, F. [September, 2010] Impact of the PLT Disturbance against Radio Astronomy in the HF Band, AP-RASC 2010 held in Toyama, Japan, E1-3.

radiation were made during the file transfer. For the measurements of the ambient radio noise, the PLT modems were unplugged from the outlets. The injected currents are found in § A3.5.3.3 of this Report.

TABLE A3-7

PLT modems used for the measurements

PLT standard	Frequency range	Data rate (PHY layer)
HD-PLC	2-28 MHz	210 Mbit/s
UPA	2-30 MHz	200 Mbit/s

FIGURE A3-49

Configuration of the test house and the RAS antennas

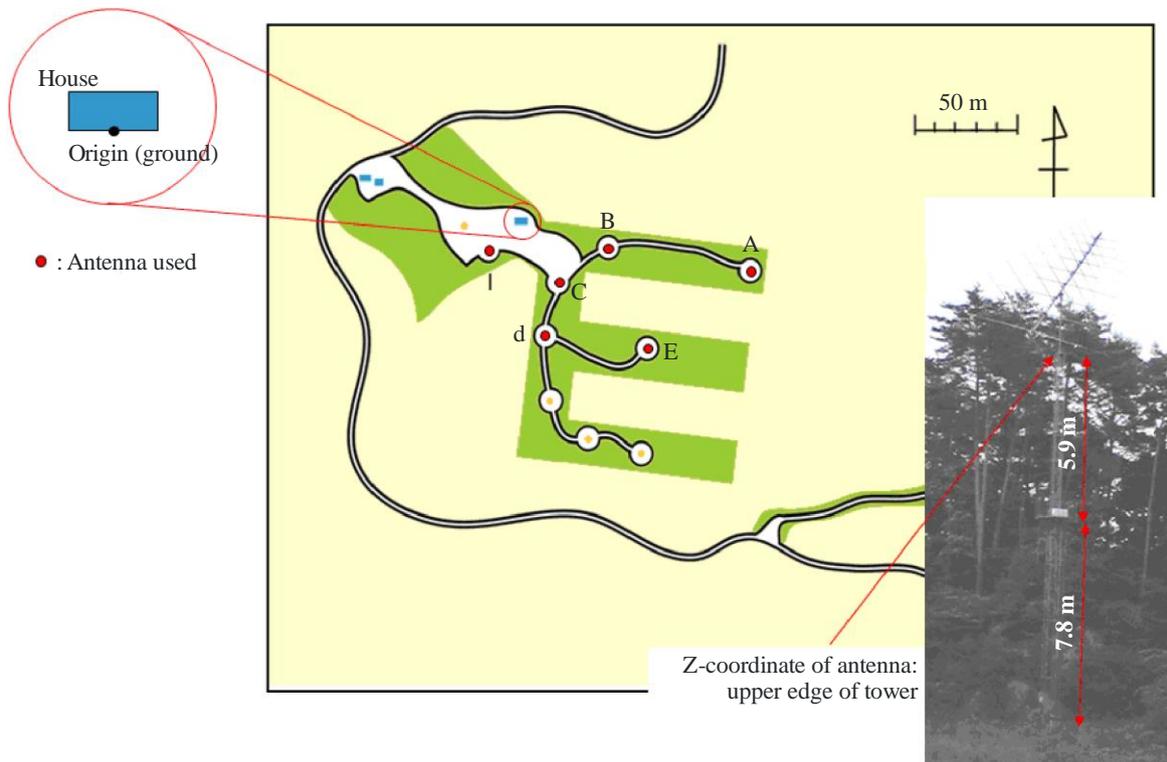


TABLE A3-8

Relative coordinate with regard to and distance from the origin (the test house)

Antenna	X (m)	Y (m)	Z (m)	R (m)
A	126.0	-11.5	7.5	126.5
B	43.5	-9.0	10.0	45.5
C	23.5	-29.0	12.5	39.5
D	16.0	-59.0	11.5	62.0
E	73.5	-59.0	7.5	94.5
I	-19.0	-22.0	13.5	32.0

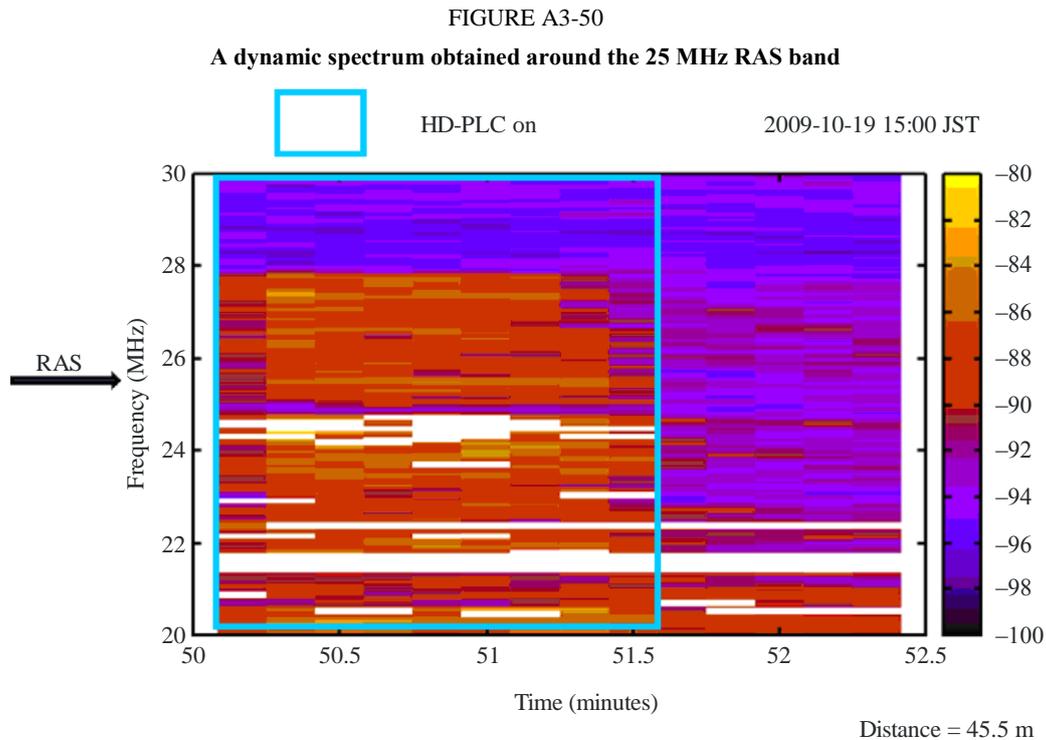
NOTE 1 – X denotes the E-W direction whose positive sign corresponds to the East, Y the N-S direction with positive sign corresponds to the North, and Z the height. R denotes the distance between the origin and an antenna.

For the leaked radiation, radio astronomy antennas built in the Iitate radio observatory were used. The antenna consists of two orthogonal log-periodic antennas with the maximum antenna gain of 12-13 dBi. Six antennas shown in Fig. A3-49 and Table A3-8 were used; the distance from the test house to an antenna ranges between 32 and 126.5 m. Each antenna is equipped with a front end receiver (R&K A-11) with the noise figure of 1.5 dB. Furthermore, each front end is equipped with a high pass filter (cut-off frequency of 12.5 MHz) to avoid saturation of the receiver due to strong signals in the MW range. The detected signals were transferred through underground coaxial cables, and fed into a backend (Advantest R3131) that was controlled by a PC through the GPIB. After 10 seconds of sampling, the data was obtained by the PC.

During the experiments the common mode current (CMI) running through the underground co-axial cables were also measured. The measured CMI was below 0 dB μ A, and it was confirmed that the contribution of re-radiation from the co-axial cables to the radiation observed by the RAS antennas was negligible.

A3.6.4 Measured data

Figure A3-50 shows a dynamic spectrum around the 25 MHz RAS band (25.55-25.67 MHz) at a distance of 45.5 m from the test house. The spectrum was taken after averaging 10 seconds with the resolution bandwidth (RBW) of 10 kHz. The RAS band is indicated by an arrow. It is clearly seen that the PLT disturbance is above the ambient noise level by about 10 dB and RAS band is masked while the PLT modem is on.



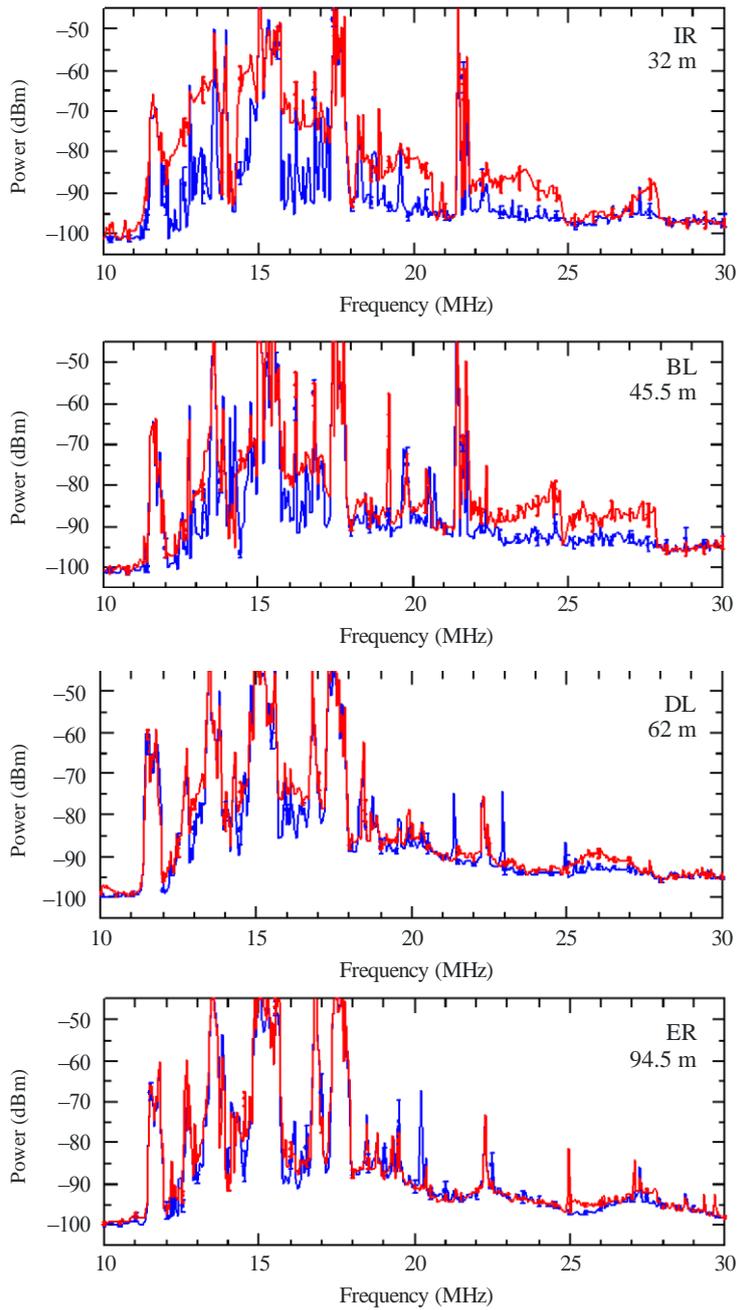
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Figure A3-51 illustrates observed wideband spectra at distances of 32, 45.5, 62 and 94.5 m. The red curves show data when the HD-PLC PLT modems are transmitting data, and the blue curves are those when the PLT modems are plugged off. The PLT disturbance can be observed even at a distance of 94.5 m with an excess above the background level of about 2-3 dB. The excess observed by the antenna I (distance = 32 m) is about 30 dB which is much higher than that observed by a loop antenna (about 10 dB; see § A.3.5.3.3). This may suggest that there would be a height pattern or that the antenna gain of the mains would be higher for higher elevation angles.

It is seen that the excess around the 25 MHz RAS band does not decrease monotonically; the excess observed by the antenna I (distance = 32 m) is less than that observed by the antenna B (distance = 45.5 m). This finding may be taken into account in future studies of interference to the radiocommunication services by PLT systems.

Figure A3-52 shows expanded spectra around or near the 25 MHz RAS band that were observed in distances between 45.5 and 126.6 m. The red curves show data when the HD-PLC PLT modems are transmitting data, and the blue curves are those when the PLT modems are plugged off. The spectra were taken after averaging 1 minute with the resolution bandwidth (RBW) of 10 kHz. The PLT disturbance can be observed even at a distance of 126.5 m with an excess of about 1 dB. The excesses at or near the 25 MHz RAS band are summarized in Table A3-9.

FIGURE A3-51
Observed wideband spectra



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Note 1 – The RBWs were 10 kHz (antennas I and B) and 30 kHz (antennas D and E).

FIGURE A3-52

Expanded spectra near the 25 MHz RAS band

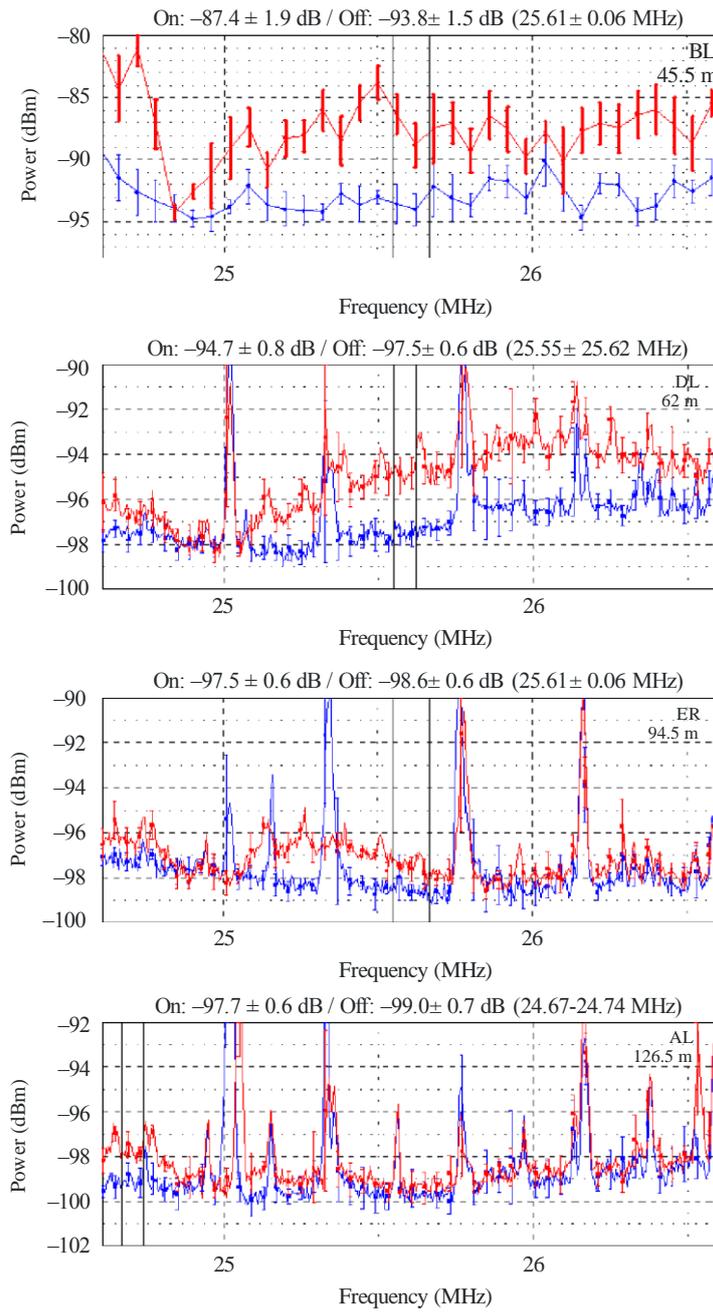


TABLE A3-9

Excesses of the PLT disturbance and comparison with Rec. ITU-R RA.769

Antenna	Distance (m)	Excess (dB)	Excess (K)	Ratio
A	126.5	1.3 ± 0.9	5 276	5.4 × 10 ⁴
E	94.5	1.1 ± 0.8	4 358	4.4 × 10 ⁴
D	62.0	2.8 ± 0.9	13 690	1.4 × 10 ⁵
B	45.5	6.4 ± 2.4	50 880	5.2 × 10 ⁵

A3.6.5 Assessment of the PLT disturbance through comparison with Rec. ITU-R RA.769

The excesses in Table A3-9 can be expressed in terms of temperature by using the following equation:

$$T = T_{sys}(10^{excess/10} - 1)$$

where T_{sys} denotes the system temperature (the sum of background noise (the Galactic noise) and the receiver noise temperature converted from the noise figure). Since the noise figure of the receiver is 1.5 dB, the corresponding receiver noise temperature is 120 K. The Galactic noise temperature is 15 000 K at 25.6 MHz (Recommendation ITU-R RA.769). Thus the system temperature, T_{sys} is 15 120 K. The converted results of the excesses are shown in the 4th column in Table A3-9.

Interference thresholds detrimental to the RAS can be calculated from statistical fluctuation of the radio astronomy receiver noise with the equation below:

$$\Delta T = \frac{T_{sys}}{\sqrt{B\tau}}$$

where:

ΔT : the statistical noise fluctuation

B : the bandwidth

τ : the integration time (see Recommendation ITU-R RA.769 for details).

Interference thresholds detrimental to the RAS are defined 10% of the noise fluctuation for the integration time of 2 000 s. For this case, $T_{sys} = 15\,120$ K, $B = 120$ kHz, and $\tau = 2\,000$ s, the threshold value is calculated to be 97.2 mK. Column 5 of Table A3-9 provides ratios of the excess due to the PLT disturbance expressed in K to the interference threshold (97.2 mK). It is seen that the ratios are larger than 10⁴.

It is now apparent that a single pair of PLT modems severely impairs radio astronomy observations in the HF band.

A3.6.6 Mitigation of PLT disturbance against radio-astronomy observations in the HF band

Radio astronomy observations can detect much weaker signals than background noise by utilizing several techniques. The first one is to integrate for a long time to average the noise fluctuations. If the background noise behaves like the random noise, the averaging will result in a much lower noise level. The second one is subtraction of the background noise through signal processing. These techniques are valid only if the unnecessary noise is constant in time and is not polarized.

PLT disturbances are usually polarized and variable in time. Therefore the techniques described above cannot be used to mitigate PLT disturbances.

A third, often used technique, is to keep a separation distance between the antenna and sources of interference so as to avoid harmful interference. If we assume free-space propagation loss, and base the calculation on the received power of the PLT disturbance by a RAS antenna, a separation distance of about 33 km for a single pair of PLT modems is needed to protect radio astronomy observations in the HF band. It would be unrealistic to expect a PLT user to be aware of their interference to any nearby radio astronomy observatory operating in the HF band. Since PLT modems are used on a non-licensed basis, their deployment would be unworkable even if an exclusion zone around a radio astronomy observatory was established.

An effective mitigation technique to protect the radio astronomy service in the HF band would be to install deep permanent notches (a depth of at least 50 dB) for the RAS bands. This conclusion is consistent with that described in § A2.4.4.3.

A3.6.7 Conclusions

PLT disturbances caused by in-house PLT modems were measured by radio astronomy antennas, and were detected by them at distances out to 130 m. The PLT disturbances are found to be between 4.4×10^4 and 5.2×10^5 higher than the interference threshold detrimental to the radio astronomy service. A minimum coordination distance of 33 km between an HF RAS antenna and a single pair of PLT systems is indicated by these results, though it would not be feasible to keep this minimum separation distance from non-licensed PLT systems. Permanent notch filters with a depth of at least 50 dB are needed to avoid harmful interference to radio astronomy observations conducted in the RAS bands.

Appendix 1 to Annex 3

Measurements of EM radiation from in-house PLT devices operating in a residential environment – Field Test Report

“Measurements of EM radiation from in-house Power Line Telecommunication (PLT) devices operating in a residential environment – Field Test Report”, Communications Research Centre (Canada), 24 March 2009 at URL:

<http://www.nabanet.com/nabaweb/members/pdf/itur/CRCReport.pdf> or see Annex 1 of Document 1A/176.

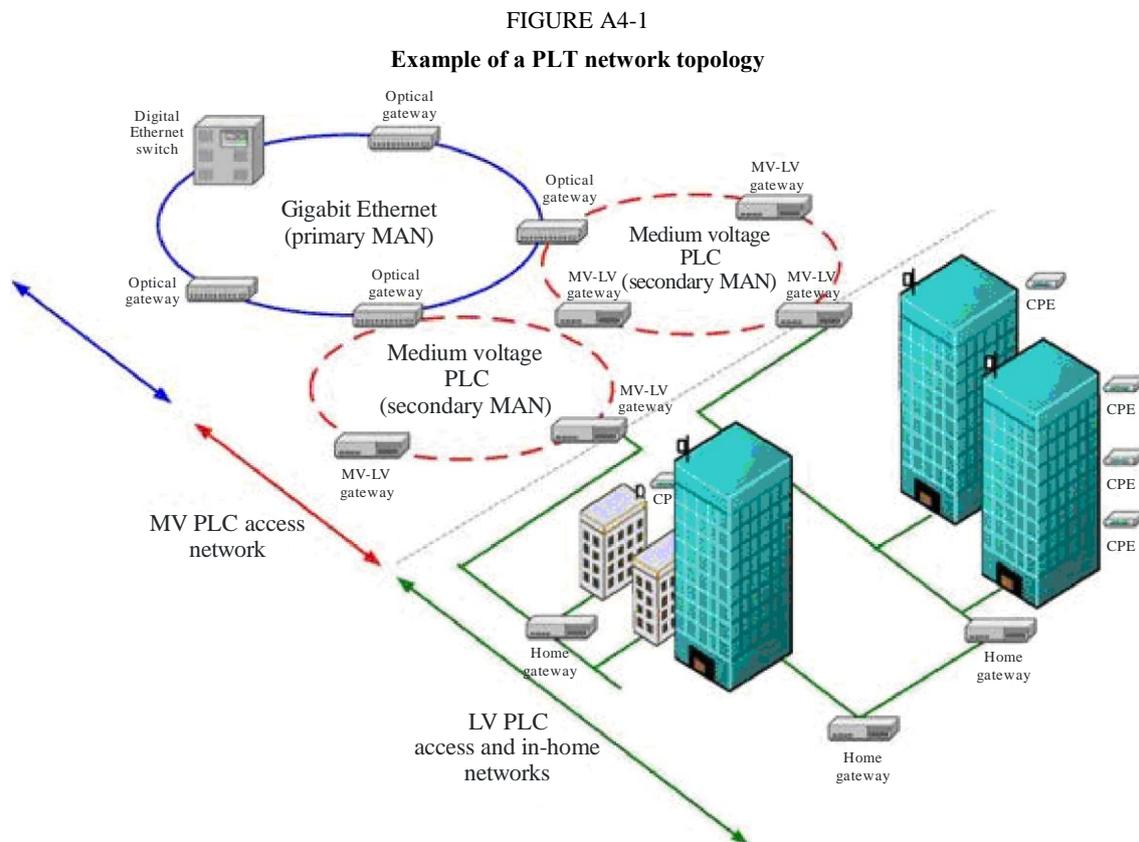
Annex 4

Design examples of PLT technology

A4 Design examples of PLT technology

A4.1 Examples of a PLT network topology

Figure A4-1 shows an example of a PLT network topology. In this example, the optical backhaul is connected to MV electrical distribution lines or rings through optical-PLT gateways. MV rings are connected to the LV electrical distribution network, where the customer premises equipments (CPE) are connected, through MV-LV PLT gateways. Data flows between terminals located at customer premises (CPE) through home gateways to and from head ends (not shown) that might be connected to the network at MV/LV gateways (transformer stations).



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The PLT network architecture can be split in three main parts, each one having its own architecture:

- A backhaul, ideally an optical ring.
- A MV PLT ring, either in frequency division or time division scheme.
- A LV PLT ring, normally with a tree topology or a star topology.

A4.2 General design considerations

A4.2.1 Media access control

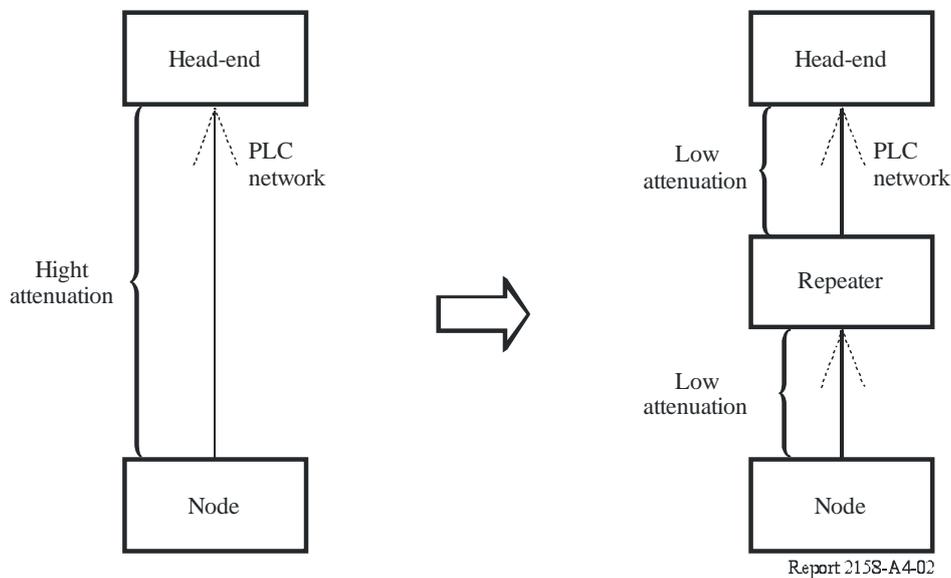
The goal of the media access control (MAC) is to distribute the access among the different users. It has to be able to cope with different architectures and it has to allow:

- A master-slave approach, where there is a data connection between the head end equipment (HE) and the customer premises equipment (CPE). This is the normal approach for LV networks.
- A Central Controller approach, allowing a direct communication between two devices of the network, and normally used in MV rings.

A4.2.2 Repeaters

Due to the high attenuation in power line channels, the use of repeaters (both in MV and LV networks) is sometimes necessary to achieve the full coverage of the electrical network. These repeaters are not explicitly shown in Fig. A4-2 and may be installed in an as-needed basis in order to guarantee that the signal arriving at each node is adequate.

FIGURE A4-2
Typical use of a repeater



A4.2.3 Multiplexing and multiple access approaches

PLT systems may be designed with different multiplexing and multiple access approaches:

- Frequency division.
- Time division.

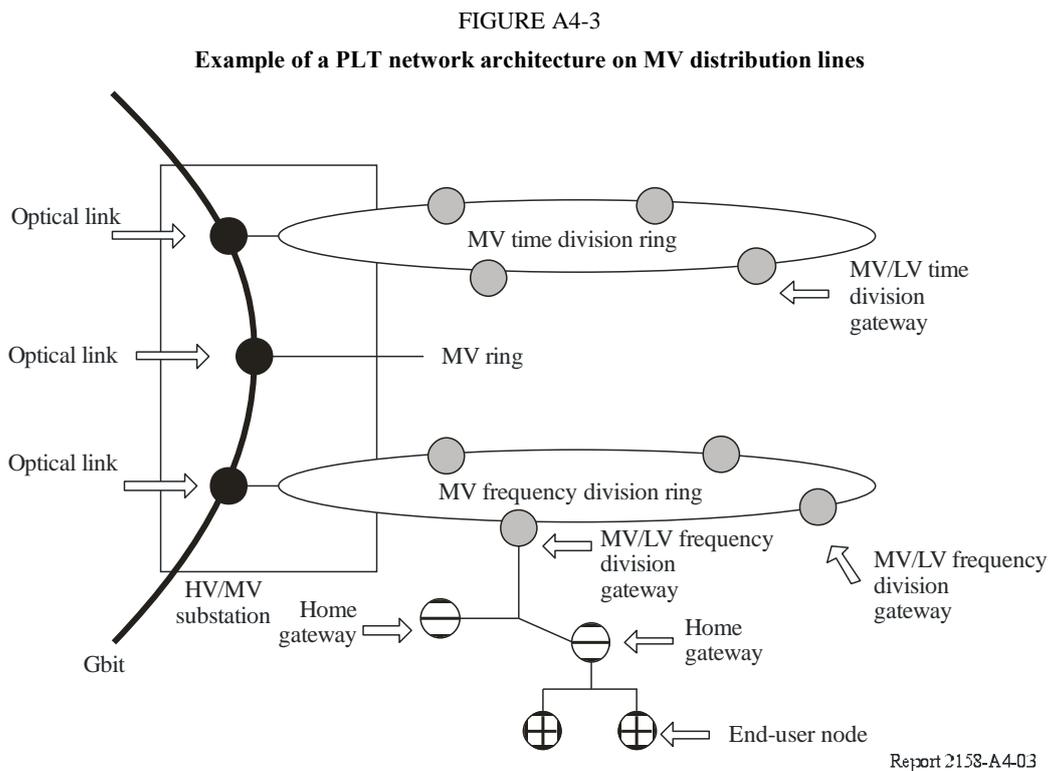
In order to avoid interferences between MV and LV, each of the PLT networks can use a different frequency range. This is also true in the LV/in-home border. In general, frequency division is used between MV and LV. Frequency division can also be used in LV repeaters placed at the bottom of buildings, which allows reusing frequencies in different buildings. If PLT devices are deployed only on LV or only on MV, time division multiple access (TDMA) may be used.

A4.2.4 Distance

The distance between two nodes of the PLT network (in a ring topology) or between the head-end (master) and the home gateway (slave) is sometimes too big and the receiving equipment may not be able to correctly get the data. In this case, the use of repeaters is necessary.

A4.3 PLT network architectures on MV distribution lines

Figure A4-3 shows an example of a MV-PLT architecture where MV rings are connected to an optical backhaul. These rings can either use Time Division either Frequency Division, depending on the latency required and characteristics of the installation. Each node of the ring can be connected to an LV-PLT network.



A4.4 PLT network architectures on low voltage distribution lines

The PLT network on LV distribution lines is the final step of the network connecting the backhaul to the customer. It is directly affected by the characteristics of the mains network within the customer premises. These are the main factors influencing the LV PLT architecture:

Network Location – A PLT network can be placed in a residential, industrial or business area. Furthermore, there is a difference between rural, suburban and urban residential areas. Industrial and business areas are characterized by a higher number of customers which are potential users of the PLT services. It is also expected that subscribers from the business areas have different requirements than industrial and especially the subscribers from the residential areas. Similar differences can be found between urban and rural application areas, as well.

Subscriber density – The number of users/subscribers in a LV network as well as user concentration may vary from network to network. The subscribers can be mostly placed in single houses (low subscriber density), which is typical for the rural and suburban application areas, with small blocks including several individual customers (e.g. urban residential area), in buildings with a larger number of flats or offices, or within apartment or business towers (very high subscriber density), such as in big commercial quarters.

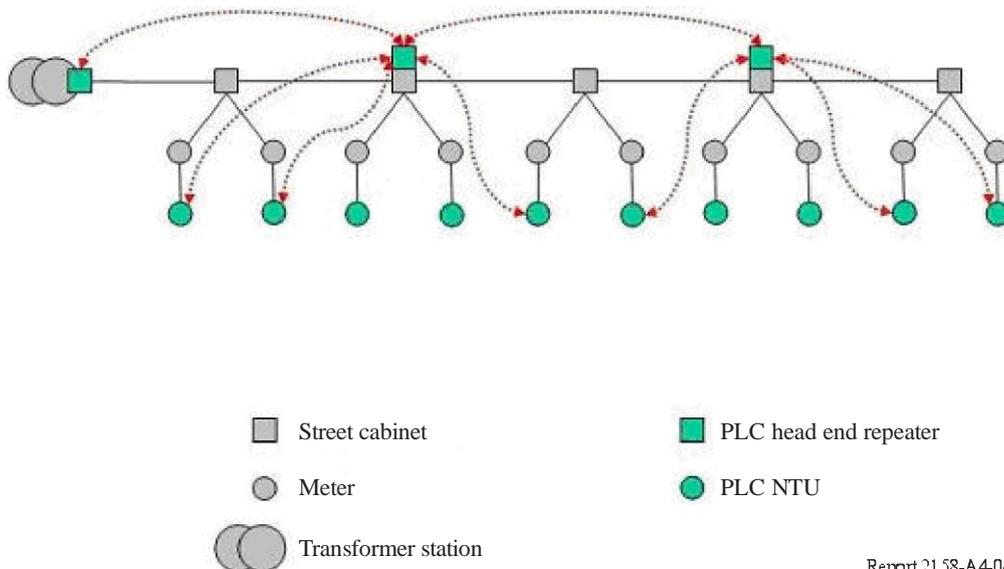
Network length – The longest distance between the transformer unit and a customer within a LV network also differs from place to place. Usually, there is a significant network length difference between the urban and rural application areas.

Network design - Low-voltage networks usually consists of several network sections (branches) of varying number, which differs from network to network, as well.

A4.4.1 Low density PLT network topology

This topology corresponds to low density residential areas, mainly with single houses. A head end must be installed in the transformer station. Then, in order to get good performance, the distance between repeaters (or the head end and one repeater) should not be more that 100 m. This normally means that between two repeaters there are not more than two street cabinets. Another requirement is the distance between the repeaters and the network termination units (NTUs). In some places is necessary to install additional repeaters in intermediate street cabinets to increase the performance of some customers. An example of deployment in this topology is shown in Fig. A4-4. Normally there are three to four repeaters in a feeder of 300 m long. In Fig. A4-4, the dotted lines show that data from some NTUs must transit though a second street cabinet before reaching a repeater.

FIGURE A4-4
Low density PLT network topology

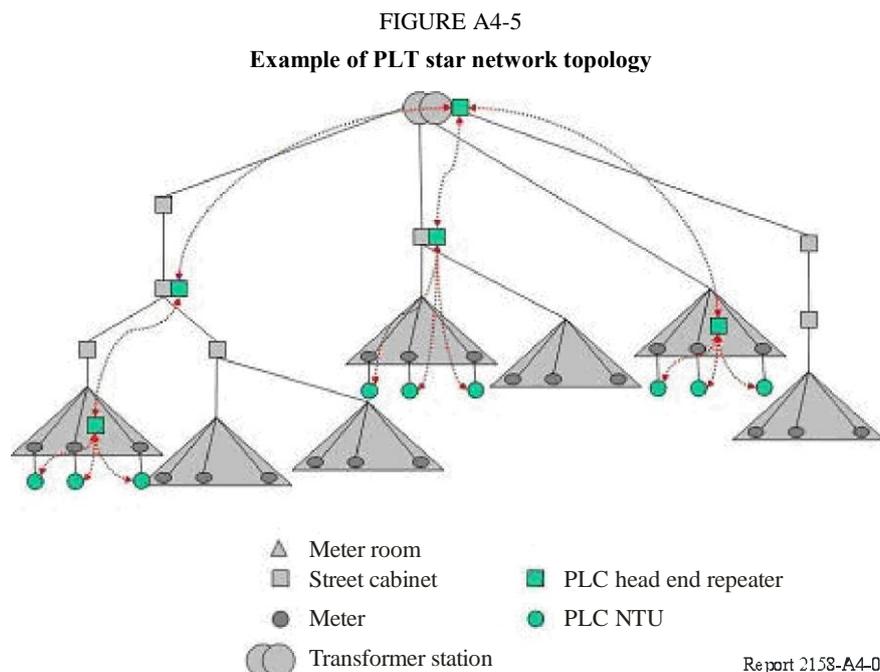


A4.4.2 High density PLT network topologies

These topologies correspond to high-density area with buildings. The meters may be grouped in a meter room. There is a direct connection from the transformer to the meter room. There are two cases: the feeder goes directly to the meter room (tree topology) or there is more than one meter room connected to each feeder (star topology). These two different topologies are presented in the following sections. There may also be a single meter between the transformer and the building wiring.

A4.4.3 PLT star network topology

A head end must be installed in the transformer station. The repeaters are normally installed in the meter rooms but in those cases where the distance between the transformer and the meter room is too big additional repeaters should be installed in the intermediate street cabinets.



A4.4.4 PLT tree network topology

With this topology, a head end must be installed in the transformer station and a repeater in each meter room.

A4.4.5 PLT multi-floor network topology

This topology corresponds to high-density area with buildings where meters may be distributed in different floors.

A head end must be installed in the transformer station. Normally one repeater is installed inside each building. The repeater should be as centered in the building as possible in order to cover the all building, but always there should be visibility with the master or other repeater. For example, in a building of six floors, the repeater should be at floor three, but it can be put in floor two to increase the throughput with the head end. As shown in Fig. A4-7, in a building of three floors the repeater should be between floor one and floor two.

FIGURE A4-6
Example of PLT tree network topology

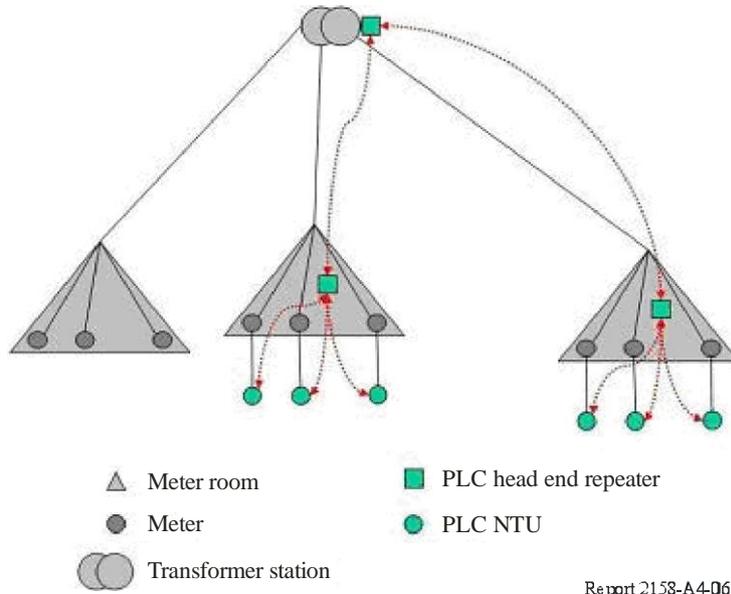


FIGURE A4-7
Example of PLT multi-floor network topology

