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(06/2011)

Impact of power line telecommunication systems on radiocommunication systems operating in the VHF and UHF bands above 80 MHz

SM Series

Spectrum management

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REPORT ITU-R SM.2212

Impact of power line telecommunication systems on radiocommunication systems operating in the VHF and UHF bands above 80 MHz

(Question ITU-R 221-1/1)

(2011)

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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) in the VHF and UHF bands. It complements Report ITU-R SM.2158 which already provides information and guidance for the frequency bands from the LF bands up to about 80 MHz.

Recent developments of PLT technology show that PLT systems can use frequencies going far beyond 80 MHz. Future technological developments may even make the use of frequencies in the UHF bands possible for PLT.

There are presently two main families of PLT applications:

- Access (outdoor) PLT whose target market is the last mile (i.e. 1.2 km) between the electricity supply substation and the subscriber and could be therefore an alternative means of access to the telecommunication local loop.
- Indoor PLT whose aim is to distribute signals (coming for example from access PLT from DSL or even from data sources within homes and without connection to an access network) to the mains electricity socket outlets inside buildings.

According to the information available, frequencies above 80 MHz are currently only used by indoor PLT systems.

The ITU-T Recommendation G.9960 (06/2010) – Unified high-speed wire-line based home networking transceivers – System architecture and physical layer specification, contained a physical layer specification for such PLT systems using frequencies up to 100 MHz. This version merged 3 previously approved ITU-T Recommendations: G.9960 Foundation (2009), ITU-T G.9960 Amendment 1 (2009) and ITU-T G.9960 Corrigendum 1 (2009). The 100 MHz power line base-band profile has been modified to reduce the upper frequency limit from 100 MHz to 80 MHz. It is expected that further cooperation between ITU-R and ITU-T should allow a reconsideration of this frequency limitation in ITU-T Recommendation G.9960.

It should be noted that there are already indoor PLT systems on the market which follow other specifications than Recommendation ITU-T G.9960 and use frequencies going up to about 300 MHz or even beyond.

Such PLT indoor systems potentially offer transmission rates of several hundred Mbit/s via the normal electrical power wiring inside every building. HD-film streaming and online-gaming in the home are applications which may require such transmission rates. The implementation of such PLT systems and their technical characteristics can vary considerably.

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.

Radio Regulations (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 Regulations[1]".

This ITU-R Report provides in its Chapter 3 information on radio system characteristics and protection criteria for a lot of possibly impacted radiocommunication systems operating between 80 and 470 MHz. It is intended to extend this ITU-R Report step by step, eventually covering all radiocommunication systems concerned in this frequency range. Depending on the future development of PLT systems, it might become necessary to consider also possible impacts on radiocommunication systems operating above 470 MHz.

2 Characteristics of radio-frequency radiation from PLT systems in the VHF and UHF bands

2.1 Interference radiation from PLT modem systems

The following is an example of interference radiation that emanates from a power line used to interconnect two high-speed PLT modems communicating with a data rate of up to 250 Mbit/s. The measurements were made using a reference antenna at a distance of three (3) m from the power line. The following peak field-strength values were measured and recorded in the 30-320 MHz frequency range in horizontal and vertical polarization:

– System noise of the measuring receiver (lower reference of measuring system).

– Environmental noise.

– Interference with modems in idle mode.

– Interference with modems during data transfer with up to a 250 Mbit/s data rate.

Details on the test procedure can be found in Annex 3. As an upper reference, the limits given in Table 6 of Standard EN 55022 (April 2007)[2] are entered in the diagrams. The limit values are indicated in quasi-peak values. Quasi-peak values are usually up to 4 dB lower than the peak values (see Report ITU-R SM.2158).

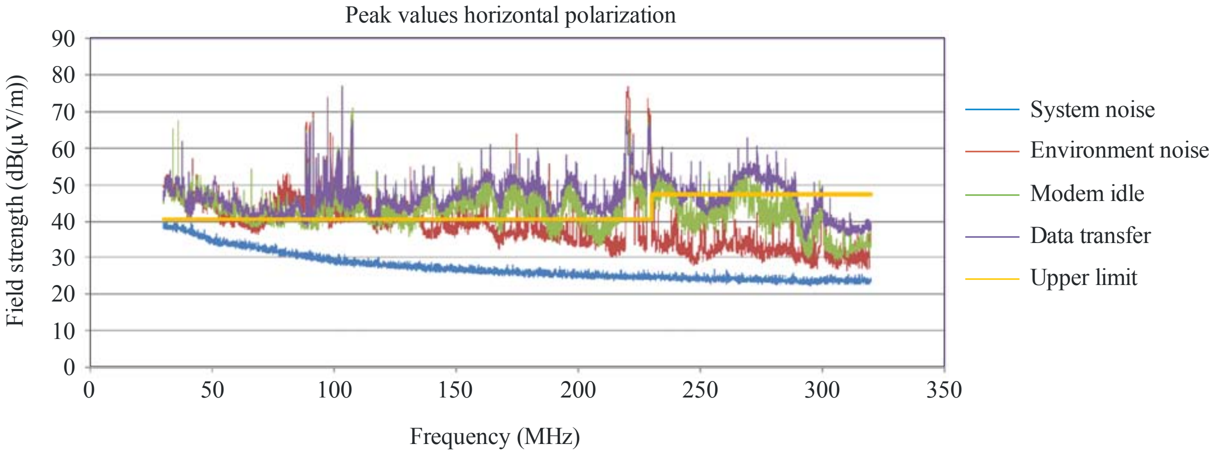
"[1] **15.12.1** and **15.13.1** In this matter, administrations should be guided by the latest relevant ITU-R Recommendations."

[2] CENELEC EN 55022:2006; Information technology equipment – Radio interference characteristics – Limits and methods of measurement (CISPR 22: 2005 (modified)).

2.2 PLT interference field strength with horizontal polarization

FIGURE 1

Peak values of the horizontally polarized field strength in dB(μV/m)



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The blue line in Fig. 1 represents the smallest measurable field strength that equals the measuring receiver's system noise. The red line represents the course of the environmental noise (man-made noise) in absence of the modems. Since the measurements were made at the IRT, where many electrical and electronic systems are operating, the environmental noise is rather high (red line); below 150 MHz it is even above the upper limit value line. The peaks of the field-strength values in the 87.5-108 MHz range match the FM signals, those around 220 and 229 MHz range match the DAB signals that can be received at the IRT.

When the modems are switched on, the interference field strength increases, as indicated by the green line. During data transfer, the interference field strength again climbs, indicated by the violet line. Above 130 MHz, the level of the interference field strength caused by the modems is some dB above the environmental noise; this means the measured values are correct. The peak values of the modem's interference during data transfer as well as in idle mode are in excess of the CISPR limit values of up to approximately 20 dB. The applicable CISPR limits are shown in Table 1.

TABLE 1

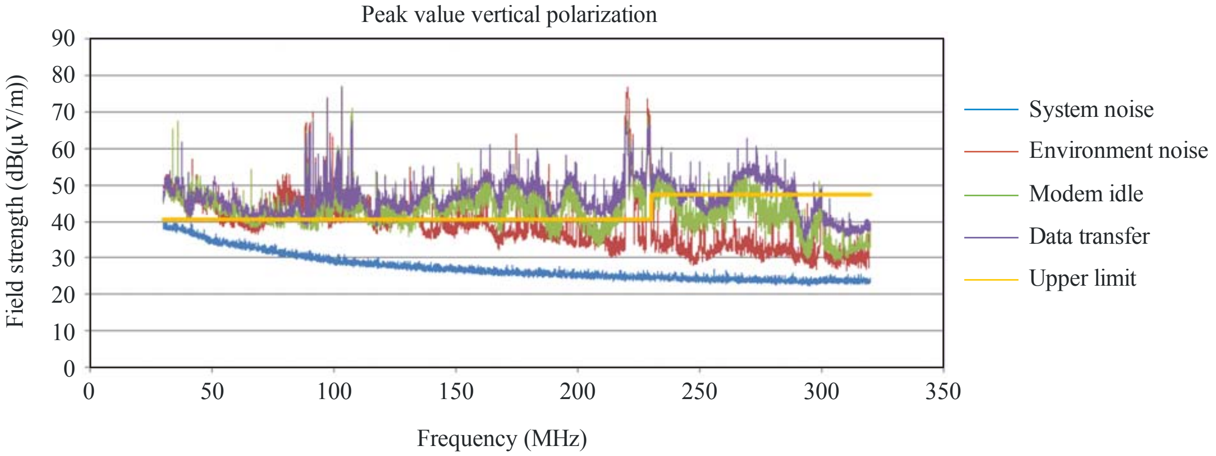
CISPR 22 edition 6, emission limits for information technology equipment (120 kHz bandwidth)

Frequency range	**Radiated emissions (quasi-peak, antenna at 10 m distance)**	
	Class A (not intended for domestic use)	**Class B (intended for domestic use)**
30-230 MHz	40 dB(μV/m)	30 dB(μV/m)
230-1 000 MHz	47 dB(μV/m)	37 dB(μV/m)

2.3 PLT interference field strength with vertical polarization

FIGURE 2

Peak values of vertically polarized field strength in dB(μV/m)



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The values in Fig. 1 also apply for the field-strength values in Fig. 2. The DAB signals at 220 MHz and 229 MHz are higher since they are transmitted at a vertical polarization. The peak values of the modem’s interference during data transfer as well as in idle mode are above the limit values in the entire frequency range.

2.4 PLT interference into FM and DAB systems

The BBC Research & Development Department made spectral measurements of the radiation from high-speed PLT modems in comparison with the wanted signals from Band II FM transmitters and Band III DAB transmitters. These measurements were carried out in two representative home locations together with proof of procedure and calibration tests under laboratory conditions. The results in Annex 3 show that the radiation from PLT are comparable to the wanted field-strengths for reception used in the established planning methods. In effect, PLT raises noise floor to a level that means that a previous good coverage areas now become borderline coverage. In effect the SNR is reduced to near to the acceptable threshold and audio quality can quickly degrade from noisy to unintelligible with only a small variation in factors such as receiver location and tropospheric propagation conditions.

2.5 Conclusion

The spectral measurements made on high-speed PLT modems show interference radiation occurring at frequencies up to 305 MHz, which includes the FM band as well as the DAB band. The measurements also show that interference due to the modems is stronger than the EN 55022 standard allows in the 30-300 MHz frequency range. It is also expected that as the data rate of high-speed modems increases, a corresponding increase in the interference radiation will occur at frequencies above 300 MHz.

3 Radio system characteristics, protection criteria, and impact of PLT systems on radiocommunication systems in the VHF and UHF bands

3.1 Broadcasting

3.1.1 Minimum usable field strength of broadcast systems with regard to PLT systems at frequencies above 80 MHz

This section provides some basic information concerning the minimum usable field strength of broadcast systems in the frequency range above 80 MHz up to about 1 GHz. 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. The following section lists the values from the relevant Recommendations to give a short overview on the relevant values for the different broadcast systems operating above 80 MHz.

In RR Article 5 for Region 1 the following frequency bands above 80 MHz are allocated to for broadcasting:

TABLE 2

Frequency bands for broadcasting

Band	Frequencies
VHF	87.5-100 MHz 100-108 MHz
	174-223 MHz 223-230 MHz
UHF	470-790 MHz 790-862 MHz

Recommendation ITU-R BS.412-9 – Planning standards for terrestrial FM sound broadcasting at VHF

For a satisfactory FM sound service in the presence of interference from industrial and domestic equipment (for limits of radiation from such equipment refer to Recommendation ITU-R SM.433*, which gives the relevant CISPR recommendations) a median field strength (measured at 10 m above ground level) is required to be not lower than the values given in Table 3:

TABLE 3

FM median field strength measured at an antenna height of 10 m (Source: Rec. ITU-R BS.412-9, Table 1)

Areas	Services	
	Monophonic dB(μV/m)	Stereophonic dB(μV/m)
Rural	48	54
Urban	60	66
Large cities	70	74

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* *Note by the Secretariat* – Recommendation ITU-R SM.433 has been suppressed on 06/06/2003 (RA-03).

Often FM sound broadcasting is received by portable or mobile equipment with an antenna height of about 1.5 m, but the service is only planned for an antenna height of 10 m. A portable receiver used with a built-in antenna is expected to have the same sensitivity as the receiver assumed for the planning. Hence the same values for the usable field strength can be assumed.

Recommendation ITU-R BS.1660-3 – Technical basis for planning of terrestrial digital sound broadcasting in the VHF band

This Recommendation is the technical basis for planning of terrestrial digital sound broadcasting System A (T-DAB) in the VHF Band III. Table 4 contains values with the inclusion of a correction of 13 dB for location percentage and of 10 dB for height gain. The below given minimum median equivalent field strength represents the minimum wanted field strength used for planning. The values shown in Table 4 are applied to mobile reception.

TABLE 4

T-DAB minimum median equivalent field strength (dB(µV/m))
at an antenna height of 10 m
(Source: Rec. ITU-R BS.1660-3, Table 1)

Frequency band	**Band III**
Minimum equivalent field strength (dB(µV/m))	35
Location percentage correction factor (50% to 99%) (dB)	+13
Antenna height gain correction (dB)	+10
Minimum median equivalent field strength for planning (dB(µV/m))	58

For portable reception using an indoor antenna the value of 35 dB(µV/m) may be regarded as the minimum equivalent field strength which has to be taken into account.

Recommendation ITU-R BT.1368-8 – Planning criteria for digital terrestrial television services in the VHF/UHF bands

The figures given in Table 5 are calculated for Rice channel.

TABLE 5

Minimum field strengths for terrestrial digital television DVB-T 8 MHz system
(Source: Rec. ITU-R BT.1368- 8, Table 44)

Frequency (MHz)	**200**			**550**			**700**		
System variant guard interval 1/4	QPSK 2/3	16-QAM 2/3	64-QAM 2/3	QPSK 2/3	16-QAM 2/3	64-QAM 2/3	QPSK 2/3	16-QAM 2/3	64-QAM 2/3
Minimum field strength for fixed reception, E_{min} (dB(µV/m))	27	33	39	33	39	45	35	41	47

For portable reception using an indoor antenna the values given in Table 5 may be regarded as the minimum equivalent field strength which has to be taken into account.

3.1.2 Maximum interference field-strength densities at the broadcast receiving system

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. The minimum level of external noise is determined by the man-made noise as this is the dominant factor when the atmospheric noise fades. Since the minimum value of external noise is determined by the man-made noise, the protection requirement for field strength is also determined by man-made noise.

With respect to unintentional emissions in the broadcasting bands above 80 MHz, the Recommendations ITU-R BS/BT.1895 *recommends*:

"**1** that the values in *recommends* 2 and 3 be used as guidelines, above which compatibility studies on the effect of radiations and emissions from other applications and services into the broadcasting service should be undertaken;

2 that the total interference at the receiver from all radiations and emissions without a corresponding frequency allocation in the Radio Regulations should not exceed 1% of the total receiving system noise power[3];

3 that the total interference at the receiver arising from all sources of radio-frequency emissions from radiocommunication services with a corresponding co-primary frequency allocation should not exceed 10% of the total receiving system noise power."

In order to limit receiver sensitivity deterioration within 1% or 0.05 dB, the requirement for protecting the broadcasting service should be 20 dB lower than E_n, where E_n is the equivalent field strength of the man-made noise in bandwidth b. Furthermore, the protection requirement can be expressed in terms of a maximum field strength density of dB(µV/m/MHz) with $b = 1$ MHz.

The protection requirement is expressed by:

$$\text{Maximum field strength density} = g + h \log f \qquad \text{dB}(\mu\text{V/m/MHz}) \qquad (1)$$

where:

$$g = c - 55.5$$
$$h = 20 - d$$

and where constants c and d are given in Table 1 of Recommendation ITU-R P.372, therefore g and h take the values given in Table 6.

TABLE 6

Values of the constants *g* and *h*

Environmental category	*g*	*h*
City	21.3	–7.7
Residential	17.0	–7.7
Rural	11.7	–7.7
Quiet rural	–1.9	–8.6

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[3] Except radiation from PLT devices below 30 MHz.

The protection requirement for the terrestrial broadcasting service in terms of maximum field strength density at the broadcast receiver antenna is tabulated in Table 7. Since the external noise for quiet rural above 30 MHz is exceeded by the receiver noise floor, the values for quiet rural above 30 MHz are derived from equation (3-4) in Report ITU-R SM.2158 and a –20 dB protection criterion. Similarly, the receiver noise floor exceeds the man-made noise above 470 MHz. Therefore, all values above 470 MHz are derived from equation (3-4) in Report ITU-R SM.2158 and a –20 dB protection criterion.

TABLE 7

Maximum interference field-strength densities at the broadcast receiving system

Broadcast frequency band(1)	**Maximum interference field-strength density dB(μV/m/MHz)**(2)			
	City	**Residential**	**Rural**	**Quiet rural**
47-72 MHz	8.4	4.1	–1.2	–22.1
76-88 MHz	6.8	2.5	–2.8	–17.9
88-108 MHz	6.3	2.0	–3.3	–16.6
174-230 MHz	4.0	–0.3	–5.6	–10.7
470-960 MHz	–2.1	–2.1	–2.1	–2.1
1 452- 1492 MHz	7.7	7.7	7.7	7.7

(1) Broadcast frequency bands do not include regional variations given in Article 5 of the Radio Regulations.

(2) Values derived from Recommendations ITU-R P.372, ITU-R BS/BT.1895 except for quiet rural above 30 MHz and all cases above 470 MHz whose values are derived from the receiver internal noise floor, Recommendations ITU-R BS/BT.1895.

3.2 Amateur and amateur satellite

The amateur bands in the 80-450 MHz range are the 144-148 MHz band (144-146 MHz in ITU Region 1), 220-225 MHz in Region 2 and portions of 420-450 MHz in all regions. As well as being heavily used for relatively local coverage by analogue FM and related modes, supported in most countries by an extensive network of repeaters, these bands have literally a worldwide scope in supporting long-distance communication at very low (and even negative) signal/noise ratios. It is these weak-signal applications that require interference protection, although the other forms of communication will also benefit.

Amateur weak-signal communication at VHF is making systematic use of transient modes of propagation such as extended troposcatter, tropospheric ducting, and in the case of 144 and 220 MHz, trans-equatorial propagation, as well as reflections from aurora, meteor trails and the moon, which other services generally dismiss as “unreliable” and are therefore receiving relatively little professional attention. In contrast, amateurs are using these modes of propagation for communication over distances 1 000 km and more, while moon-bounce communication spans all three ITU Regions. This type of operation uses SSB and Morse in a similar manner to HF, but makes more regular use of extremely weak and fading signals, often at signal/noise ratios down to 0 dB and using special protocols to capture information from any brief enhancements. Newer digital modes are now capable of communication at 10-20 dB below the audible threshold.

These unique features make amateur VHF weak-signal communication extremely sensitive to any increase in the background noise level. The degree of protection required is comparable to radio astronomy, although relatively few amateur stations are located in such remote areas as are radio astronomy observatories.

3.2.1 Background noise levels in the 144-148 MHz band

Recommendation ITU-R P.372-10 establishes that, in "quiet rural" areas, background noise at these frequencies is dominated by sky noise, particularly from the Sun which appears as a quasi-point source, and from our own galaxy (the Milky Way), which appears as a broad belt of strong emission. From Recommendation ITU-R P.372, the median noise figure for galactic noise varies from about 0 dB relative to *kTb* at 144 MHz to –9 dB at 432 MHz. From equation (2) in Recommendation ITU-R P.372, these levels correspond to field strengths of –23.4, –27.4 and –32.4 dB(μV/m) respectively for the 144, 225 and 432 MHz bands.

3.2.2 Characteristics of amateur stations in the 144-148 MHz band

From Recommendation ITU-R P.372, the noise field strength is –23.4 dB(μV/m).

Degradation of the noise floor of 0.5 dB would require the noise field strength from PLT to be no stronger than –34 dB(μV/m).

Assuming that the antenna is external to the building, has an effective gain in the direction of the PLT of 2 dBi (side lobe gain), and is separated by 10 m from the PLT installation, then allowing for a 16 dB wall loss and a reference bandwidth of 120 kHz, the field strength of the PLT fundamental or harmonics should not exceed 6 dB(μV/m) in 120 kHz at 3 m.

3.2.3 Protection requirements for amateur stations in the 220-225 MHz band

From Recommendation ITU-R P.372 , the noise field strength is –27.4 dB(μV/m).

Degradation of the noise floor of 0.5 dB would require the noise field strength from PLT to be no stronger than –38 dB(μV/m).

Assuming that the antenna is external to the building, has an effective gain in the direction of the PLT of 2 dBi (side lobe gain), and is separated by 10 m from the PLT installation, then allowing for a 20 dB wall loss and a reference bandwidth of 120 kHz, the field strength of the PLT fundamental or harmonics should not exceed 6 dB(μV/m) in 120 kHz at 3 m.

3.2.4 Protection requirements for amateur stations in the 420-450 MHz band

From Recommendation ITU-R P.372 , the noise field strength is –32.4 dB(μV/m).

Degradation of the noise floor of 0.5 dB would require the noise field strength from PLT to be no stronger than –43 dB(μV/m).

Assuming that the antenna is external to the building, has an effective gain in the direction of the PLT of 1 dBi (side lobe gain), and is separated by 10 m from the PLT installation, then allowing for a 24 dB wall loss and a reference bandwidth of 120 kHz, the field strength of the PLT fundamental or harmonics should not exceed 6 dB(μV/m) in 120 kHz at 3 m.

3.2.5 Other services operating in the domestic environment with similar requirements

With an aging population, there are growing requirements for the use of radio in medical monitoring in the domestic environment, and Recommendation ITU-R RS.1346 established use of the band 401-406 MHz on a secondary, non-protected, non-interference causing basis for medical implant communication systems (MICS). The standards for this require that a “listen before talk” (LBT) threshold of (–150 dBm + 10 log*B* + *G*), where *B* is the system bandwidth and *G* the antenna gain relative to isotropic, be used to establish this threshold. As an SNR of 11 dB is usually taken as providing the acceptable level at which a signal can be reliably detected. If referred to a 120 kHz bandwidth, the MICS LBT threshold equates to 16.6 dB(µV/m): the noise field strength cannot exceed about 5.5 dB(µV/m) measured at the MICS programmer (which is the equipment establishing the communication link) for a 3 dB degradation in SNR Should the PLT noise exceed 10 dB(µV/m), the LBT threshold will be exceeded because detection of the signal with such a SNR is not readily achieved, and no transmissions will be made to interrogate the implanted device. It may therefore be seen that the levels of protection required for the amateur service are not out of line with those required for other important services likely to be found in the domestic environment.

Other short-range devices (SRDs) used in the domestic environment includes alarms for intrusion and fire detection, as well as personal alarms. One standard used widely internationally is EN300-220: this effectively requires the noise level to be of the order of 9 dB(µV/m) at 400 MHz measured at 3 m in 120 kHz. These levels also apply to harmonics and intermodulation products from lower frequency PLT operation.

It should be noted that these levels apply equally to harmonics and intermodulation products from lower frequency PLT devices.

It can be seen that the requirements of the amateur services are not out of line with those of other devices likely to be found within the domestic environment.

3.3 Aeronautical mobile

Aeronautical mobile services are particularly susceptible to cumulative interference from a dense population of sources of radio-frequency radiation from the ground due to the line-of-sight nature of the radio path. This issue is being exacerbated where such dense populations are under the approach/departure paths of an airport.

TABLE 8

Initial maximum tolerable value of interference for systems operating in aeronautical services
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	Initial maximum tolerable value of interference
				(μV/m)	(dBm)	(dB)	(kHz)	(dB)	(dB)	(dBm/Hz)
VHF Comms	25 kHz	117.975-137 MHz	Airborne	75	–82	20	16	6	20	–170
		117.975-137 MHz	Ground	20	–93	20	16	6	20	–181
	8.33 kHz	117.975-137 MHz	Airborne	75	–82	20	5.6	6	20	–165
		117.975-137 MHz	Ground	20	–93	20	5.6	6	20	–177
	VDL Mode 2 and 3	117.975-137 MHz	Airborne	75	–82	20	8	6	20	–167
		117.975-137 MHz	Ground	20	–93	20	16	6	20	–181
	VDL Mode 4	108-137 MHz	Airborne	75	–81	20	5.56	6	20	–165
		108-137 MHz	Ground	20	–93	20	6	6	20	–177

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 initial value.

Annex A2.2 contains a study dealing with the compatibility of aeronautical mobile and aeronautical radionavigation services and PLT systems in the frequency range of 30 to 380 MHz.

TABLE 9

Initial maximum tolerable value of interference for systems operating in airborne radiodetermination services
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**	**Initial maximum tolerable value of interference**
			(μV/m)	**(dBm)**	**(dB)**	**(kHz)**	**(dB)**	**(dB)**	**(dBm/Hz)**
ILS localizer	108-112 MHz	Airborne	40	–86	20	30	6	20	–177
ILS glideslope	328.6-335.4 MHz	Airborne	400	–76	20	42	6	20	–168
GBAS	108-117.975 MHz	Airborne	215	–72	26	14	6	20	–165
VOR	108-117.975 MHz	Airborne	90	–79	20	36	6	20	–171
Aeronautical radionavigation	200-225 MHz								
Radiolocation	216-220 MHz								
Aeronautical radionavigation	420-460 MHz								
Radiolocation	430-450 MHz								

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 initial value.

3.4 Maritime mobile

Maritime VHF receivers – 154-174 MHz

Recommendation ITU-R M.489-2 provides that:

- the reference sensitivity should be equal to or less than 2.0 µV, e.m.f., for a given reference signal-to-noise ratio at the output of the receiver;
- the adjacent channel selectivity should be at least 70 dB;
- the spurious response rejection ratio should be at least 70 dB;
- the radio-frequency intermodulation rejection ratio should be at least 65 dB;
- the power of any conducted spurious emission, measured at the antenna terminals, should not exceed 2.0 nW at any discrete frequency. In some radio environments lower values may be required.

Automatic identification of ships (AIS) receivers

AIS receivers operate on two frequencies, 161.975 and 162.025 MHz, for the purpose of meeting a wide range of marine safety and security objectives developed by IMO, which include managing ship movements along congested shipping lanes, collision avoidance, improving the SAR response to distress incidents, protecting against oil pollution and maintaining a secure environment for ships and ports.

- AIS minimum receiver sensitivity specification level (for a 20% permitted error rate) = –107 dBm;
- typically, AIS base stations have a receiving sensitivity of –115 dBm or better.

3.5 Radiodetermination service

Airborne radiodetermination services are particularly susceptible to cumulative interference from a dense population of sources of radio-frequency radiation from the ground due to the line of sight nature of the radio path. This issue is being exacerbated where such dense populations are under the approach/departure paths of an airport.

3.6 Land mobile

There are no generally applicable protection criteria covering the case of interference caused to the land mobile service by sources of unintended radiation such as PLT systems. Further work is needed in order to establish a basis for developing protection requirements that should be met by PLT systems.

In any event though, the protection criteria for radiation from PLT systems should be no less stringent than the protection criteria that have been established in respect of sharing studies between the land mobile service and other primary and secondary radiocommunication services. Examples of the protection requirements that have been developed for the land mobile service in the requested frequency range 80-470 MHz may be found in the following ITU-R Recommendations:

- Recommendation ITU-R M.1808 – Technical and operational characteristics of conventional and trunked land mobile systems operating in the mobile service allocations below 869 MHz to be used in sharing studies. It contains considerations on interference and performance criteria (§§ 2.1 and 2.2 of Annex 1) and a full set of technical characteristics for the bands 138-174 MHz and 406.1-470 MHz;

- Recommendation ITU-R M.1824 – System characteristics of television outside broadcast, electronic news gathering and electronic field production in the mobile service for use in sharing studies. It provides system characteristics of television outside broadcast (TVOB), electronic news gathering (ENG) and electronic field production (EFP) in the mobile service. In particular, Tables 2 and 3 contain technical characteristics of talkback/walkie-talkie and audio links respectively, some of them being within the frequency range 80-470 MHz.

In addition Resolution 646 (WRC-03) identifies portions of the band 380-470 MHz that may be used for the purposes of public protection and disaster relief.

Radiocommunication systems operating above 470 MHz in the land mobile service include cellular systems and IMT systems. In some countries cellular systems are also deployed below 470 MHz. With regard to cellular systems, some information on protection requirements is available in Recommendation ITU-R M.1823 – Technical and operational characteristics of digital cellular land mobile systems for use in sharing studies.

3.7 Radio astronomy

The radio astronomy service (RAS) has frequency allocations in three bands between 80 and 470 MHz on a primary basis (shown in Table 10), where footnote RR No. 5.149 applies. The 150 and 410 MHz bands are used for continuum observations (i.e. total power mode) only, and the 327 MHz band is used for the continuum and the spectral line modes. The interference threshold levels detrimental to the RAS are given in Recommendation ITU-R RA.769 and their equivalent electric field values are given in Report ITU-R RA.2131. Those threshold values are also included in Table10.

TABLE 10

Equivalent electric field interference thresholds for the radio astronomy service

RAS band (MHz)	Threshold pfd dB(W/m^2)	Threshold spfd dB($W/m^2/Hz$)	Threshold electric field dB(μV/m)
150.05-153	–194 in 2.95 MHz	–259	–48.2 in 2.95 MHz
322-328.6	–189 in 6.6 MHz for cont. mode –204 in 10 kHz for line mode	–258 for cont. mode –244 for line mode	–43.2 in 6.6 MHz for cont. mode –58.2 in 10 kHz for line mode
406.1-410	–189 in 3.9 MHz	–255	–43.2 in 3.9 MHz

3.8 Mobile-satellite service

The following details the frequency bands below 470 MHz that are allocated to the mobile-satellite service (MSS) as well as the protection criterion and system parameters.

3.8.1 Frequency bands

Below 470 MHz, various bands are allocated to the mobile-satellite service (MSS):

- the band 137-138 MHz is allocated to the MSS in the space-to-Earth direction;
- the band 148-150.05 MHz is allocated to the MSS in the Earth-to-space direction;
- the bands 161.9625-161.9875 MHz and 162.0125-162.0375 MHz are allocated to the MSS in the Earth-to-space direction (see RR No. 5.227A).

- the band 235-322 MHz is allocated to the MSS (see RR No. 5.254);
- the band 312-315 MHz is allocated to the MSS in the Earth-to-space direction;
- the band 335.4-399.9 MHz is allocated to the MSS (see RR No. 5.254);
- the band 387-390 MHz is allocated to the MSS in the space-to-Earth direction;
- the band 399.9-400.05 MHz is allocated to the MSS in the Earth-to-space direction;
- the band 400.15-401 MHz is allocated to the MSS in the space-to-Earth direction;
- the band 406-406.1 MHz is allocated to the MSS in the Earth-to-space direction, limited to low power satellite emergency position-indicating radio beacons (see RR No. 5.266). Any emission capable of causing harmful interference to the authorized uses of the band 406-406.1 MHz is prohibited (see RR No. 5.267).

3.8.2 Protection criterion

Good spectrum engineering practice will ensure that radiation produced by PLT devices will be kept to the minimum technically achievable levels. This being said, for radiation as produced by PLT devices, a $\Delta T/T$ criterion of 1% is the permissible level of interference into MSS receivers (either space-borne, airborne or on the ground). This criterion is considered appropriate by analogy with the fixed-satellite service (FSS) where Recommendation ITU-R S.1432-1 recommends such a value for sources of interference other than in the FSS or in co-primary services.

3.8.3 System parameters

The detailed system parameters of MSS systems using the bands 137-138 MHz, 148-150.05 MHz, 399.9-400.05 MHz and 400.15-401 MHz are contained in Annex 2 of Recommendation ITU-R M.1184-2 – Technical characteristics of mobile satellite systems in the frequency bands below 3 GHz for use in developing criteria for sharing between the mobile-satellite service (MSS) and other services. For ease of use, Tables 11 and 12 summarize the relevant system parameters required to ensure the protection of MSS receivers from PLT radiations.

TABLE 11

Characteristics of mobile earth station receivers in the band 137-138 MHz

Receiving mobile earth station antenna gain (dBi)	5.7	0.5	–3	3
Receiving mobile earth station antenna pattern	Omnidirectional	Omnidirectional	Omnidirectional	Omnidirectional
Receiving mobile earth station noise temperature (K)	4 467	813	66	1 565
Receiving mobile earth station deployment	Worldwide	Worldwide	Worldwide	Worldwide
Receiving mobile earth station polarization	RHCP	RHCP	LHCP	RHCP

TABLE 12

Characteristics of MSS satellite receivers in the band 148-150.05 MHz

Receiving satellite altitude (km)	950	775	800	893	1 000
Receiving satellite antenna gain (dBi)	–2	0	0	5.6	6
Receiving satellite antenna pattern	Isoflux	Toroidal	10 log (cos 2 θ)	10 log (cos 2 θ)	Isoflux
Receiving satellite noise temperature (K)	309	400	1 000	1 480	940
Receiver polarization	Linear	Linear	RHCP	LHCP	Linear

With regard to the mobile-satellite service allocations above 200 MHz, particular aggregation effects from PLT radiations in the band 406-406.1 MHz need to be carefully controlled. This is the frequency used by search and rescue satellites, and Radio Regulations Nos 5.266 and 5.267 apply.

TABLE 13

Characteristics of MSS satellite receivers in the band 399.9-400.05 MHz

Receiving satellite altitude	667 km
Receiving satellite antenna gain	7 dBi
Receiving satellite antenna pattern	Cardioid
Receiving satellite noise temperature	389 K
Receiver polarization	RHCP

TABLE 14

Characteristics of mobile earth station receivers in the band 400.15-401 MHz

Receiving mobile earth station antenna gain (dBi)	5.7	3	3	7
Receiving mobile earth station antenna pattern	Omnidirectional	Omnidirectional	Omnidirectional	Omnidirectional
Receiving mobile earth station noise temperature (K)	4 467	229	505	550
Receiving mobile earth station deployment	Worldwide	Worldwide	Worldwide	Worldwide
Receiving mobile earth station polarization	RHCP	RHCP	RHCP	LHCP

With regard to the MSS allocation in the 454-456 MHz band, the following characteristics are extracted from the ITU database and correspond to existing systems operating in this band:

– receiving satellite altitude: 650 km;

– receiving satellite antenna gain: 0 dBi;

– receiving satellite antenna pattern: omnidirectional;

– receiving satellite noise temperature: 590 K;

– receiving satellite polarization: LHCP.

No specific information is available on the 459-460 MHz band but it is suggested that the characteristics for the 454-456 MHz band are also valid for the 459-460 MHz band.

3.8.4 Specific case of the band 406-406.1 MHz

This band is allocated to the MSS in the Earth-to-space direction for use only by low-power satellite emergency position-indicating radio beacons (see RR No. 5.266). Any emission capable of causing harmful interference to the authorized uses of the band 406-406.1 MHz is prohibited (see RR No. 5.267). This band is notably used by the Cospas-Sarsat global satellite-based search and rescue system. All information about the satellite systems using this band is contained in the Recommendation ITU-R M.1478 – Protection criteria for Cospas-Sarsat search and rescue instruments in the band 406-406.1 MHz. This specific need to ensure an interference-free environment for these systems is emphasized because they provide a safety service.

3.9 Radionavigation-satellite service

The following details the frequency bands below 470 MHz that are allocated to the radionavigation-satellite service (RNSS) as well as the protection criterion and system parameters.

3.9.1 Frequency bands

Below 470 MHz, two bands are allocated to the radionavigation-satellite service (RNSS):

– the band 149-9-150.05 MHz is allocated to the RNSS;

– the band 399.9-400.05 MHz is allocated to the RNSS.

3.9.2 Protection criterion

Good spectrum engineering practice will ensure that radiations produced by PLT devices will be kept to the minimum technically achievable levels. This being said, it is considered that, for radiations as those produced by PLT devices, a $\Delta T/T$ criterion of 1% is the permissible level of interference into RNSS receivers (either space-borne, airborne or on the ground). This criterion is considered appropriate by analogy with the fixed-satellite service (FSS) where Recommendation ITU-R S.1432-1 recommends such a value for sources of interference other than in the FSS or in co-primary services.

3.9.3 System parameters

With regard to the RNSS allocation in the 149.9-150.05 MHz band, the following characteristics are extracted from the ITU database and correspond to existing systems operating in this band:

– RNSS receiving earth station antenna gain: 0 dBi;

– RNSS receiving earth station antenna pattern: omnidirectional;

– RNSS receiving earth station noise temperature: 200 K;

– RNSS receiving earth station deployment: worldwide.

With regard to the RNSS allocation in the 399.9-400.05 MHz band, the following characteristics are extracted from the ITU database and correspond to existing systems operating in this band:

- RNSS receiving earth station antenna gain: 0 dBi;
- RNSS receiving earth station antenna pattern: omnidirectional;
- RNSS receiving earth station noise temperature: 200 K;
- RNSS receiving earth station deployment: worldwide.

3.10 Other radiocommunication systems/applications

This section deals with radiocommunication systems/application which cannot be directly attributed to a specific radiocommunication service. Besides the subsection on wireless medical implant communication systems, other systems/applications might be added in a future revision to this ITU-R Report.

3.10.1 Wireless medical implant communication systems

Wireless medical implant communication systems operate in the band 401-406 MHz, and are used for such applications as monitoring and programming of medical implants such as pacemakers, neural stimulators and the like. With the increasing aging population, the demands made on health care services are increasing in complexity and cost, and to these ends, the requirements for electronic monitoring will increase.

Because the band used for Ultra Low Power Active Medical Implants (ULP-AMI) is shared with a primary radiocommunication services, a comprehensive channel access mechanism is used. For home monitoring, a monitor is used (ULP-AMI-P) where the listen before talk (LBT) threshold is +16 dB(μV/m) field strength with a typical 0 dBi antenna gain. Such monitors are mains powered and usually located in close proximity to other devices with mains leads, such as clocks, bedside lamps, electric blankets, etc. Such mains leads will of course have the PLT signal radiated from them. To allow operation, the noise level from future PLT systems operating in bands up to and beyond 470 MHz is required to be, in the band 401-406 MHz, no more than +16 dB(μV/m) measured in a 300 kHz bandwidth, or about +12 dB(μV/m) in a 120 kHz bandwidth.

4 Potential means for preventing or eliminating interference

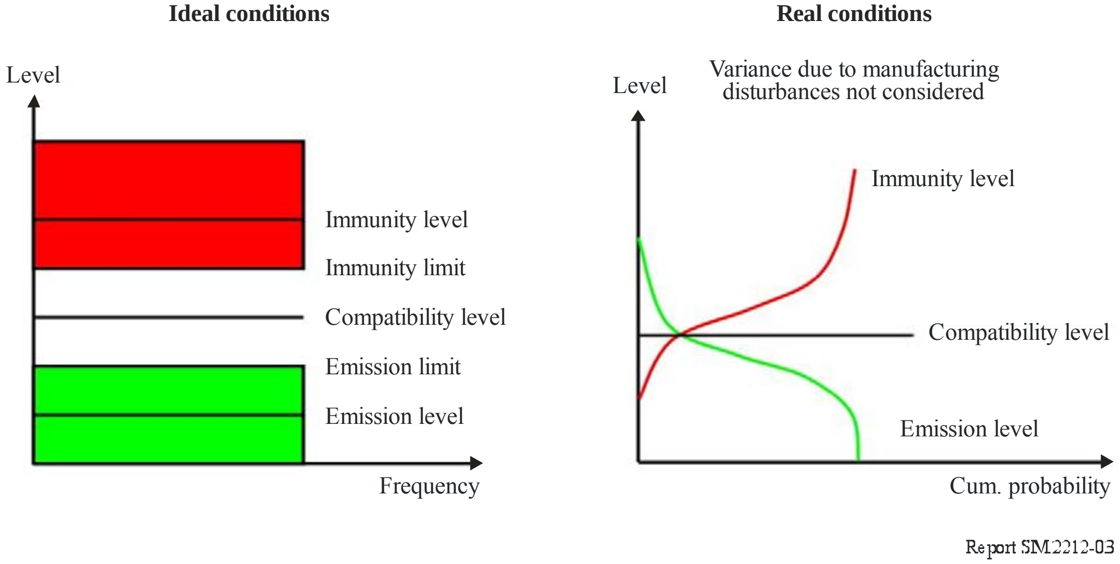
4.1 Adaptive EMC measures

The classical concept of EMC requires constant emission and immunity limits against high frequency signals. The emission limit of all devices and their own immunity threshold defines the operating range. Devices working within this range operate without producing any interference in their environment. This classical concept of guaranteeing EMC, as shown on the left side of Fig. 3, has the drawback that some resources are left unused. Furthermore, devices may need costly shielding, even though there may be no signals causing disturbance. All frequencies are shielded by the device, independent of where and when the device is operated. In short, the resources may not be used efficiently.

In some cases, the reception of a low-power signal is disturbed despite the fact that surrounding devices comply with the relevant EMC standards. Unfortunately, this is the real condition shown on the right side of Fig. 3. From both an economic and a technical point of view this is not satisfactory. In this case, stricter limits should have been chosen.

FIGURE 3

EMC considerations, ideal and real conditions



Since radio systems (e.g. land mobile, TV, analogue or digital radio) receive a large range of signal amplitudes, they are typically the most sensitive devices in the home and office environment. Therefore, radio signal protection dominates the process of EMC in the area of high frequency signals. EMC has been performed for several decades by simply defining limits for electromagnetic emissions produced by equipment. In the past, this simple approach was adequate. Classical disturbance sources such as commutator machines or switched power supplies occasionally produce emissions in a wide frequency band. A selective and at the same time flexible suppression was not possible. Therefore, suppression was designed by limiting the maximum emission to a value a few dB below the limit. The established limits are increasingly discussed by the radio people, since the limits were designed under certain conditions regarding spatial, time and frequency probability of disturbance sources. Today, a larger number of modern disturbance sources produce continuous emissions in a broad frequency band without an allocation in the Radio Regulations, so that the original preconditions may not necessarily be valid.

Modern wired communication systems based on OFDM technology (e.g. ADSL, VDSL, PLT) are able to integrate adaptive EMC measures into their design. They can control their undesired radiation emissions in a very flexible way. Cognitive radio technologies may also be able to adapt their spectral emissions according to their actual environment.

For example, power line communication modems as specified in ETSI TS 102578 use the adaptive approach. Compared to conventional PLT modems, which could interfere with radio services, the modems using the concept of “Smart Notching” do not disturb radio receivers.

The frequency range of PLT modem emissions overlaps with radio broadcast frequencies. Power line wires in private homes are not shielded and are structured with a certain amount of asymmetry. If a radio receiver is operated in the vicinity of where a power line communication is active, the radio reception quality might suffer. Having communication systems in the same frequency range and coupling paths in between – conducted as well as radiated – makes disturbance situations inevitable.

Due to the antenna properties of the low voltage distribution grid, the electricity cables in a building receive signals from radio broadcast services. PLT modems equipped with “Smart Notching” (as specified in ETSI TS 102 578) detect the existence of such radio services by measuring the signal’s spectrum on the mains network. After an analysis of this spectrum, the PLT modems exclude frequencies receivable by SW radio devices. This process is called “notching”. Thanks to the adaptive OFDM transmission with a high number of carriers, “Smart Notching” causes only a minor decrease in the transmission bit-rate as only low SNR carriers are lost. Continuous analysis allows the system to minimize interference and to optimize throughput depending on the current conditions.

Electromagnetic compliance is achieved in a different way in such adaptive systems: instead of rigid constraints, “Smart Notching” devices can comply and improve EMC. According to the definition of the International Electrotechnical Vocabulary (IEV), a product is electromagnetically compatible if it works satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything else.

4.2 Permanent notching

Permanent notching has been accepted generally in respect of the amateur bands.

The FM band is too important to listeners as the primary means of broadcast-radio listening, for any risk of disturbance from uncontrolled power line communication systems to be contemplated. Hence the preferred option would clearly be for the frequency range of PLT etc. to be capped at 80 MHz, as previously advised by ITU-T SG 15. Failing that, permanent notching the whole band from 87.5 to 108 MHz ought to be adopted.

Concerning DAB, where the field strengths encountered are generally lower than for FM reception, there are even greater doubts about reliably detecting DAB signals from ingress along the mains wiring and protecting services. Permanent notching is recommended for DAB bands.

4.3 Dynamic notching

The dynamic notching standard of ETSI TS 102578 (for HF broadcasting) has been proposed as a model for use above 30 MHz, together with suggested changes/extensions. However, the ETSI TS was developed with close oversight and cooperation from HF broadcasters, and was only accepted, as a compromise to resolve the particular problems of HF coexistence of broadcasting and PLT. Note also that acceptance was only possible once the technique had been demonstrated in operation, albeit in a fairly limited form with only one prototype system available for testing.

It is far from clear that it will be a simple task to extend this technique to broadcasting in the VHF bands. There are many differences:

- the FM band is used for domestic services, a mainstream form of radio listened to in the majority of homes, for extended periods;
- the quality expectations of listeners in this situation are much greater – FM broadcasting readily delivers a very much better quality of reception than AM shortwave, close to CD quality in a normal domestic environment – and listeners will therefore be highly intolerant of lapses in quality;
- technically, FM is very different from AM;
- the wavelength of the FM-band signal is close to or shorter than typical lengths of mains-wiring features (as opposed to the situation at HF), thus increasing the efficiency with which PLT interference is radiated into the environment.

It is far from clear that a dynamic notching scheme could necessarily work at all, certainly in terms of adequately and reliably sensing the presence of broadcasts that need to be protected by notching. Note that in an urban environment some 30 FM transmissions can often be received. Then, with a notch width of at least 800 kHz being required, that would mean having to notch out the entire band in practice.

It is therefore questionable whether it would be worth the trouble involved, considering the likely return in PLT capacity. In many (indeed most) European countries the FM band is very intensively used, with regulators having to handle constant demand for more frequencies for more FM services. FM stations are already as close in frequency as is acceptable and are planned not only on the basis of avoiding co-channel interference, but also taking account of adjacent channel use within ±400 kHz.

The question of notch width is of particular concern. It was suggested that a notch of 200 kHz would be satisfactory. The rationale for this appears to be an error, being based on applying Carson's rule to MONO FM to give a suggested 200 kHz. However this is more appropriate as an indication of where the bulk of the transmitted energy falls (IN MONO), and thus the minimum bandwidth for a receiver that would pass the bulk of the signal (and thus give reasonably limited amounts of distortion due to spectrum truncation). However this neglects that nearly all FM broadcasts are made in stereo, with additional RDS signalling, in which the baseband frequencies extend a very long way beyond 15 kHz, more like 60 kHz in fact. It is essential that the PLT notch extends beyond the actual analogue or digital FM channel width and shall include the adjacent channels.

More importantly, it neglects that the key factor is the susceptibility of receivers to interference, something which is much more dependent on details of receiver design – where the designs to be taken into account are the millions of receivers already in service in listener's homes. Only testing (in effect a kind of protection ratio measurement, at various frequency offsets) of a broad selection of receivers can establish the necessary notch characteristics, both the width at full depth and also the equally important shape of the sides. Note that both of these were taken into account for HF receivers in TS 102578. The extent of the notch from one set of contiguous (i.e. un-notched) PLT sub-carriers on one side of a detected FM station carrier would need to be 400 kHz, plus another 400 kHz the other side to the next set of contiguous PLT sub-carriers. Thus the notches in PLT sub-carriers at full depth would have to be 800 kHz in width, i.e. ±400 kHz from each detected FM carrier, with additional sloping sides. In many urban locations the consequence would then surely amount to notching of the full band anyway.

In the case of applying dynamic notching in order to protect radiocommunication services other than broadcasting it must be recognized that the technique can only be effective if the sensing is carried out in the same location where the interference can cause harm. Where reception is only expected to take place outside buildings, no purpose is served by sensing signals within buildings because the results will not be representative of the aggregate interference receivable in the operational environment. Moreover, if signals intended for reception outside buildings are receivable within a building the implication is that the mains wiring is acting as an efficient antenna and in consequence can contribute to increased levels of interference outside.

4.4 Geolocation notching

This technique would require a database of services that the national administration considers would be protected for reception at any particular location. On a simplistic basis this could use be based on the franchised area for commercial broadcasters or the predicted service area in other case. However, actual coverage usually extends beyond the notional franchise or service area and the national administration would be faced with the dilemma of restricting listener choice in favour of PLT use. This may give rise to legal challenges on the legitimacy of restricting access to previously receivable services.

Other problems are also evident when taking the idea at face value. Some entity would have to be responsible for setting up and maintaining the geolocation database. Even without the prospect of legal difficulties when mistakes are made affecting coverage and commercial profitability, this would be a time-consuming and expensive proposition. Who would carry the work and pay for it?

Also, the technique would amount to denial of spectrum for expansion of broadcast service offerings. PLT service providers should therefore make appropriate payments for spectrum thus reserved for their use.

In the case of the FM band, the above comments on notch width and the amount of spectrum that could usefully be refarmed for PLT use will also apply.

4.5 Transmit power control in ITU-T Recommendation G.9960

ITU-T Recommendations G.9960/G.9961 (a.k.a. G.hn) {1, 2} for home networking specify various tools to control PLT transmit power of an individual G.hn device (node) in the network (domain). These tools allow a node to meet various regulations (e.g. CISPR, CENELEC) as well as power consumption requirements (e.g. European Code of Conduct). This section illustrates the procedure of setting the transmit PSD mask that applies to all nodes in the domain. It also illustrates the mechanism to independently control transmit power of an individual node.

Currently the upper effective frequency limit in ITU-T Recommendation G.9960 has been set to 80 MHz (aligned with Report ITU-R SM. 2158). The toolkit provided in ITU-T Recommendation G.9960 is in principle also applicable to prevent or eliminate interference, if frequencies above 80 MHz are used by PLT systems.

4.5.1 Construction of transmit PSD mask

In a G.hn domain, all nodes shall obey the transmit PSD mask (TxPSD) set by a master node (domain master). At any time, a node is not allowed to transmit signals above this mask. TxPSD is described in § 7.1.5 {1}, and it is constructed by the following components:

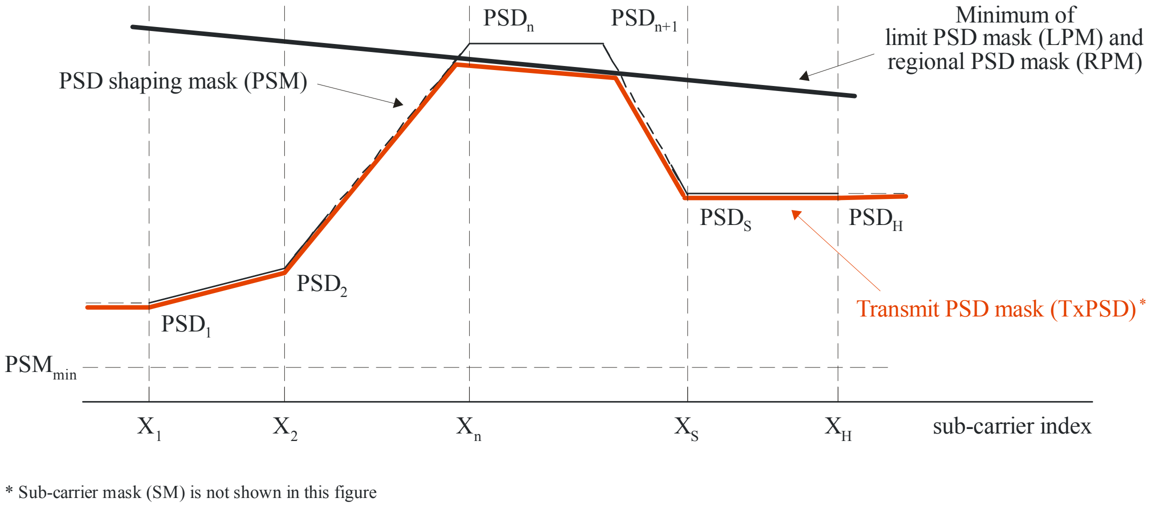
1. Limit PSD mask (LPM, § 7.1.5 {1}): PSD mask defined for each band plan (e.g. 100 MHz power line baseband)
   – LPM is specified in the main body of the Recommendation (e.g. see Fig. 7-32 in § 7.2.2.3 {1} for 100 MHz power line baseband);
   – LPM defines the absolute PSD limit that reflects the maximum allowable limit (i.e. maximum of all regional regulations);
   – LPM gives a guideline to design a device that can be deployed in all regions.
2. Regional PSD mask (RPM, § 7.1.5 {1}): PSD mask defined for each band plan for each region
   – RPM may be specified in separate annexes to reflect different regional regulations. So far, no RPM is defined (North American RPM was considered, but not included in the final approved draft);
   – If RPM does not exist in a specific region, then LPM is used as RPM.
3. Sub-carrier mask (SM, § 7.1.5.1 {1}): Masked bands defined for a given LPM or RPM
   – SM denotes frequency notching. The domain master can specify up to 32 masked bands (§ 8.8.5.5 {2}). This information is broadcast to all nodes via a MAP message (periodic message transmitted by the domain master to indicate media access plan), and can be changed dynamically.
4. PSD shaping mask (PSM, § 7.1.5.2 {1}): PSD breakpoints defined for a given LPM or RPM
   – The domain master can specify up to 32 PSD breakpoints (§ 8.8.5.5 {2}). This information is broadcast to all nodes via a MAP message, and can be changed dynamically.

5. International amateur radio bands (§ 7.1.5.3 {1})
   - Several of the amateur radio bands in 0 to 100 MHz range are specified in Annex D {1}. The domain master can notch one or more of these bands (§ 8.8.5.5 {2}). This information is broadcast to all nodes via a MAP message, and can be changed dynamically.

The transmit PSD mask (TxPSD) is constructed by these five components as specified in § 7.1.5.2 {1} and Fig. 4.

FIGURE 4

Construction of transmit PSD mask (TxPSD)



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4.5.2 Notification of transmit PSD mask

The domain master advertises the TxPSD periodically so that all nodes in the domain (including new nodes about to join the domain) know the TxPSD before they start transmitting any signals on the line. The domain master can even change this information dynamically (§ 8.8.5{2}). This feature may be used to implement dynamic notching.

A new node shall detect and decode the MAP transmitted by the domain master to get TxPSD applied to the current domain. It shall obey this mask as long as it is a member of the domain. A node is allowed to transmit lower power than this mask.

The domain master can change some of these components on the fly (SM, PSM, HAM bands on/off). G.hn specifies a mean to synchronize all nodes in the domain to a new TxPSD.

4.5.3 PSD ceiling

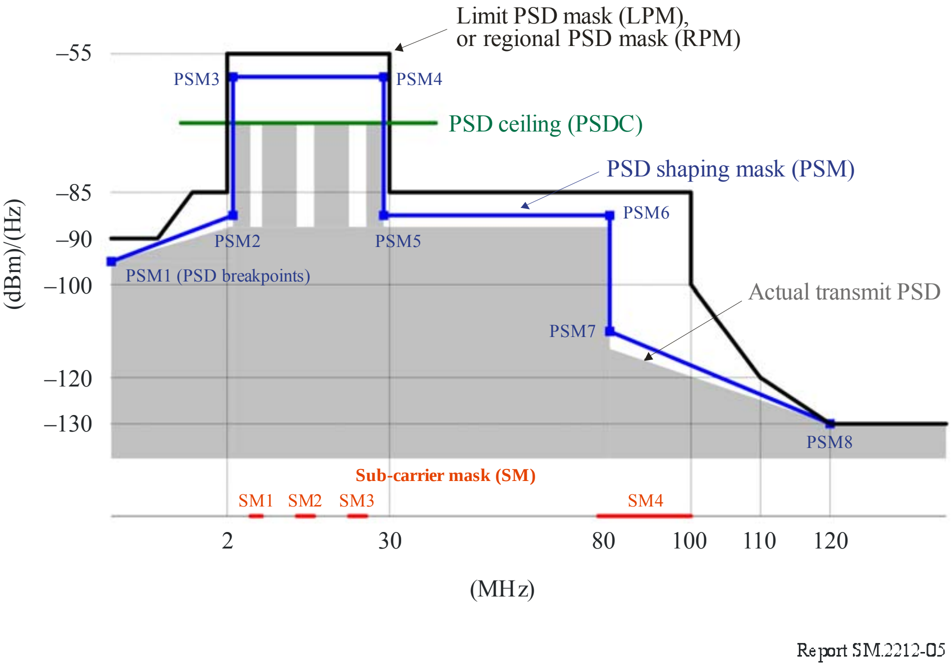
PSD ceiling (PSDC, § 7.1.5.4 {1}) denotes the ceiling of the PSD value applied to signals transmitted between nodes. Whereas TxPSD applies to all nodes in the domain, PSDC applies to an individual node. Different values can be applied per each connection, and the value can change over time to adapt to a changing channel. This value is carried in the PHY-frame header (APSDC-M field, § 7.1.2.3.2.2.11{1}) so that the receiver knows the maximum transmit level of the signal that it received.

During the channel estimation process, the receiver notifies the transmitter the optimal value of PSDC (Table 8-93 in § 8.11.7.3 {2}). This mechanism can be used to cutback the transmit power, and/or minimize the receive power, which reduces not only total power consumption of the network but also interference to other networks.

Figure 5 illustrates the relationship between TxPSD and PSDC.

FIGURE 5

Transmit PSD mask and PSD ceiling



4.5.4 References

{1} ITU-T Recommendation G.9960 (2010): Unified high-speed wire-line based home networking transceivers – System architecture and physical layer specification, Prepublished.

{2} ITU-T Recommendation G.9961 (2010): Unified high-speed wire-line based home networking transceivers – Data link layer specification, Prepublished.

4.6 Conclusion for preventing or eliminating interference

There should be an effort to demonstrate the feasibility and effectiveness of mitigation techniques for particular services in particular bands. If such techniques are applied without proper evaluation and safeguards, and an inadequately specified PLT equipment version is placed on the market then national administrations may potentially be left facing widespread reactions and complaints.

5 Overall conclusions

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

Annex 1

Noise radiation and propagation considerations in the VHF and UHF bands

A1 Detailed analysis of mode conversion at the switch branch

The switch branches consisting of ceiling lights and wall switches commonly found in domestic power line wirings are highly unbalanced at radio-frequency range, and they convert the differential-mode signals into the common-mode or antenna currents that cause the radiated radiation from the power line. Although these facts are well recognized among radiocommunication community, they seem poorly recognized in PLT community. In the § 2.1.4.3 of Report ITU-R SM.2158, it is shown that the differential and common modes are strongly coupled over a broad spectral range, not just at a resonance frequency, based on the theoretical analysis which models a series short stub as an unbalanced phase shifter. Although the essential physical mechanism of the mode conversion is well represented in the phase shifter model, more general analyses would be desirable. Also when the wall switch is turned off, the switch branch constitutes a series open stub which may not be modelled as a phase shifter. Instead the branch terminated by a cold light bulb with a resistance as low as a few ohms was modelled as a series short stub in the previous analysis. General series stub analysis that treats both short and open stubs would be desirable.

In the following, such general analysis of series stubs is given based on a recent study[4].

A1.1 Mixed-mode scattering matrix of a balanced transmission line unilaterally loaded with a stub in series

A1.1.1 Theoretical formulations

Unilateral series stub circuits in which an open or a short stub made of a balanced transmission line is inserted in series with the one side of the other balanced transmission line as shown in Fig. 6 have been theoretically analyzed. Their mixed-mode scattering matrices have been derived to reveal the distinct mode-conversion characteristics.

Power line telecommunications (PLT) feed RF signals into the odd mode of power line network inside the house. Since switch branch circuits consisting of ceiling lights and single-pole wall switches form unilateral series stubs, the theory is useful in predicting EMC problems caused by PLT systems using the HF and/or VHF regions.

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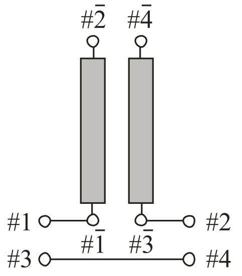
[4] KITAGAWA, M. and OHIRA, T. [July 2010] Mixed-mode scattering matrix of a balanced transmission line unilaterally loaded with a stub in series − Pencil-and-paper formulation. IEICE Tech. Rep. MW.

FIGURE 6

A balanced transmission line unilaterally loaded with a series stub

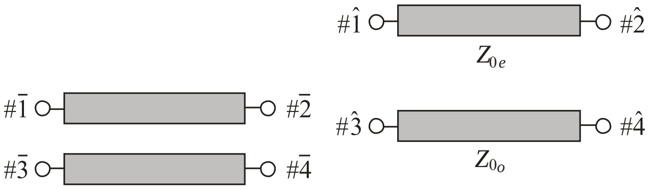


(a) A series short stub (b) A series open stub

Report SM.2212-06

FIGURE 7

A balanced transmission line which constitutes a stub



(a) coupled lines (b) even-odd modes

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Two conductors of a balanced transmission line in Fig. 7 (a) which constitutes a stub in Fig. 6 are coupled. The even and odd modes are decoupled and can be treated independently as shown in Fig. 7 (b). The even mode and the odd mode have the following impedance matrices respectively,

$$\hat{\mathbf{Z}}_e = \frac{Z_{0e}}{j\sin\phi_e}\begin{bmatrix} \cos\phi_e & 1 \\ 1 & \cos\phi_e \end{bmatrix}, \quad \hat{\mathbf{Z}}_o = \frac{Z_{0o}}{j\sin\phi_o}\begin{bmatrix} \cos\phi_o & 1 \\ 1 & \cos\phi_o \end{bmatrix}$$

where Z_{0e} and Z_{0o} denote the characteristic impedances of the even and the odd modes, ϕ_e and ϕ_o denote the phase rotations of the even and the odd modes through the stub, i.e. $\phi_e = \beta_e l$ and $\phi_o = \beta_o l$ for a lossless transmission line of the length l. For a transmission line with loss, they are replaced with $\phi_e = \beta_e l(1 - j\alpha_e/\beta_e)$ and $\phi_o = \beta_o l(1 - j\alpha_o/\beta_o)$for given propagation constants $\gamma_e = \alpha_e + j\beta_e$ and $\gamma_o = \alpha_o + j\beta_o$.

Then the voltages and the currents of the mode terminals in Fig. 7 (b) are connected as follows:

$$\begin{bmatrix} \hat{v}_1 \\ \hat{v}_2 \end{bmatrix} = \hat{\mathbf{Z}}_e \begin{bmatrix} \hat{i}_1 \\ \hat{i}_2 \end{bmatrix}, \quad \begin{bmatrix} \hat{v}_3 \\ \hat{v}_4 \end{bmatrix} = \hat{\mathbf{Z}}_o \begin{bmatrix} \hat{i}_3 \\ \hat{i}_4 \end{bmatrix}$$

The transformation matrix between a pair of input (or output) physical terminals in Fig. 7 (a) and the corresponding mode terminals in Fig. 7 (b) is given by:

$$\mathbf{C}_2 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

The transformation matrix between all physical terminals and all mode terminals is given by:

$$\mathbf{C}_4 = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & -1 & 0 \\ 0 & 1 & 0 & -1 \end{bmatrix}$$

The impedance matrix of the mode terminals of the transmission line in Fig. 7 (b) is given by:

$$\hat{\mathbf{Z}}_{\mathrm{TL}} = \begin{bmatrix} \hat{\mathbf{Z}}_e & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{Z}}_o \end{bmatrix}$$

Therefore the impedance matrix of the physical terminals of the transmission line in Fig. 7 (a) is calculated to be:

$$\mathbf{Z}_{\mathrm{TL}} = \mathbf{C}_4 \hat{\mathbf{Z}}_{\mathrm{TL}} \mathbf{C}_4 = \begin{bmatrix} z_{11} & z_{12} & z_{13} & z_{14} \\ z_{12} & z_{11} & z_{14} & z_{13} \\ z_{13} & z_{14} & z_{11} & z_{12} \\ z_{14} & z_{13} & z_{12} & z_{11} \end{bmatrix}, \quad \begin{aligned} z_{11} &= -\tfrac{j}{2}(Z_{0e}\cot\phi_e + Z_{0o}\cot\phi_o) \\ z_{12} &= -\tfrac{j}{2}(Z_{0e}\operatorname{cosec}\phi_e + Z_{0o}\operatorname{cosec}\phi_o) \\ z_{13} &= -\tfrac{j}{2}(Zo_e\cot\phi_e - Zo_o\cot\phi_o) \\ z_{14} &= -\tfrac{j}{2}(Z_{0e}\operatorname{cosec}\phi_e - Z_{0o}\operatorname{cosec}\phi_o) \end{aligned}$$

In the case of a short stub in Fig. 6 (a), the terminal conditions are given by:

$$\bar{v}_4 = \bar{v}_2, \bar{i}_4 = -\bar{i}_2$$

Therefore the input and output voltages and currents have the relationship:

$$\begin{bmatrix} \bar{v}_1 \\ \bar{v}_3 \end{bmatrix} = \begin{bmatrix} z_{11} - \star & z_{13} + \star \\ z_{13} + \star & z_{11} - \star \end{bmatrix} \begin{bmatrix} \bar{i}_1 \\ \bar{i}_3 \end{bmatrix}, \quad \star = -\frac{jZ_{0o}}{2\cos\phi_o \sin\phi_o}$$

which can be expressed by the impedance matrix:

$$\mathbf{Z}_{ss} = -\frac{j}{2} \begin{bmatrix} Z_{0e}\cot\phi_e - Z_{0o}\tan\phi_o & Z_{0e}\cot\phi_e + Z_{0o}\tan\phi_o \\ Z_{0e}\cot\phi_e + Z_{0o}\tan\phi_o & Z_{0e}\cot\phi_e - Z_{0o}\tan\phi_o \end{bmatrix}.$$

In the case of an open stub in Fig. 6 (b), the terminal condition is given by:

$$\bar{i}_2 = \bar{i}_4 = 0$$

Therefore the input and output voltages and currents have the relationship:

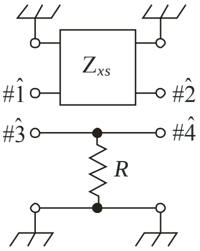
$$\begin{bmatrix} \bar{v}_1 \\ \bar{v}_3 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{13} \\ z_{13} & z_{11} \end{bmatrix} \begin{bmatrix} \bar{i}_1 \\ \bar{i}_3 \end{bmatrix}$$

which can be expressed by the impedance matrix:

$$\mathbf{Z}_{os} = -\frac{j}{2} \begin{bmatrix} Z_{0e}\cot\phi_e + Z_{0o}\cot\phi_o & Z_{0e}\cot\phi_e - Z_{0o}\cot\phi_o \\ Z_{0e}\cot\phi_e - Z_{0o}\cot\phi_o & Z_{0e}\cot\phi_e + Z_{0o}\cot\phi_o \end{bmatrix}$$

FIGURE 8

Analysis with virtual shunt resistance to the ground



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To analyze a transmission line unilaterally loaded with a series stub as shown in Fig. 6, the other conductor is grounded through the resistance *R* as shown in Fig. 8. Then the impedance matrix of the conductor is given by:

$$\mathbf{R} = \begin{bmatrix} R & R \\ R & R \end{bmatrix}$$

and the impedance matrix of the whole circuit in Fig. 8 is given by:

$$\mathbf{Z}_{xs4} = \begin{bmatrix} \mathbf{Z}_{xs} & \mathbf{0} \\ \mathbf{0} & \mathbf{R} \end{bmatrix}$$

where subscript is $x = o$ for an open stub and $x = s$ for a short stub. It is translated into the mixed-mode impedance matrix:

$$\hat{\mathbf{Z}}_{xs} = \mathbf{C}_4 \mathbf{Z}_{xs4} \mathbf{C}_4 = \begin{bmatrix} \hat{z}_{11} & \hat{z}_{12} & \hat{z}_{13} & \hat{z}_{14} \\ \hat{z}_{12} & \hat{z}_{11} & \hat{z}_{14} & \hat{z}_{13} \\ \hat{z}_{13} & \hat{z}_{14} & \hat{z}_{11} & \hat{z}_{12} \\ \hat{z}_{14} & \hat{z}_{13} & \hat{z}_{12} & \hat{z}_{11} \end{bmatrix}$$

The mixed-mode scattering matrix of the series stub circuit shown in Fig. 6 is calculated by taking the limit:

$$\hat{\mathbf{S}} = \lim_{R\to\infty} \frac{\hat{\mathbf{W}}_0^{-1/2}\hat{\mathbf{Z}}_{xs}\hat{\mathbf{W}}_0^{-1/2} - \mathbf{1}_4}{\hat{\mathbf{W}}_0^{-1/2}\hat{\mathbf{Z}}_{xs}\hat{\mathbf{W}}_0^{-1/2} + \mathbf{1}_4} = \begin{bmatrix} \hat{s}_{11} & \hat{s}_{12} & \hat{s}_{13} & \hat{s}_{14} \\ \hat{s}_{12} & \hat{s}_{11} & \hat{s}_{14} & \hat{s}_{13} \\ \hat{s}_{13} & \hat{s}_{14} & \hat{s}_{33} & \hat{s}_{34} \\ \hat{s}_{14} & \hat{s}_{13} & \hat{s}_{34} & \hat{s}_{33} \end{bmatrix}$$

where:

$$\hat{\mathbf{W}}_0 = \begin{bmatrix} W_e & 0 & 0 & 0 \\ 0 & W_e & 0 & 0 \\ 0 & 0 & W_o & 0 \\ 0 & 0 & 0 & W_o \end{bmatrix}$$

W_e and W_o denote the reference impedances of the even and the odd modes respectively, and $\mathbf{1}_4$ is the identity matrix of four dimension.

A1.1.2 Results

The mixed-mode scattering matrix elements of a transmission line unilaterally loaded with a series short stub are given as follows:

$$\begin{aligned}
\hat{s}_{11} &= \frac{(W_e^2 - W_o^2)Z_{0o}\sin\phi_e\sin\phi_o + 2jW_o(Z_{0e}Z_{0o}\cos\phi_e\sin\phi_o - W_e^2\sin\phi_e\cos\phi_o)}{[2Z_{0e}\cos\phi_e + j(W_o + W_e)\sin\phi_e][2W_eW_o\cos\phi_o + j(W_o + W_e)Z_{0o}\sin\phi_o]} \\
\hat{s}_{12} &= \frac{2W_e[2W_oZ_{0e}\cos\phi_e\cos\phi_o + j(Z_{0e}Z_{0o}\cos\phi_e\sin\phi_o + W_o^2\sin\phi_e\cos\phi_o)]}{[2Z_{0e}\cos\phi_e + j(W_o + W_e)\sin\phi_e][2W_eW_o\cos\phi_o + j(W_o + W_e)Z_{0o}\sin\phi_o]} \\
\hat{s}_{13} &= \frac{2j\sqrt{W_eW_o}(Z_{0e}Z_{0o}\cos\phi_e\sin\phi_o - W_eW_o\sin\phi_e\cos\phi_o)}{[2Z_{0e}\cos\phi_e + j(W_o + W_e)\sin\phi_e][2W_eW_o\cos\phi_o + j(W_o + W_e)Z_{0o}\sin\phi_o]} \\
\hat{s}_{14} &= \frac{2\sqrt{W_eW_o}[(W_o + W_e)Z_{0o}\sin\phi_e\sin\phi_o - j(Z_{0e}Z_{0o}\cos\phi_e\sin\phi_o + W_eW_o\sin\phi_e\cos\phi_o)]}{[2Z_{0e}\cos\phi_e + j(W_o + W_e)\sin\phi_e][2W_eW_o\cos\phi_o + j(W_o + W_e)Z_{0o}\sin\phi_o]} \\
\hat{s}_{33} &= \frac{-(W_e^2 - W_o^2)Z_{0o}\sin\phi_e\sin\phi_o + 2jW_e(Z_{0e}Z_{0o}\cos\phi_e\sin\phi_o - W_o^2\sin\phi_e\cos\phi_o)}{[2Z_{0e}\cos\phi_e + j(W_o + W_e)\sin\phi_e][2W_eW_o\cos\phi_o + j(W_o + W_e)Z_{0o}\sin\phi_o]} \\
\hat{s}_{34} &= \frac{2W_o[2W_eZ_{0e}\cos\phi_e\cos\phi_o + j(Z_{0e}Z_{0o}\cos\phi_e\sin\phi_o + W_e^2\sin\phi_e\cos\phi_o)]}{[2Z_{0e}\cos\phi_e + j(W_o + W_e)\sin\phi_e][2W_eW_o\cos\phi_o + j(W_o + W_e)Z_{0o}\sin\phi_o]}
\end{aligned}$$

where:

$s_{11} = s_{22}$	are even-mode reflections
$s_{12} = s_{21}$	are even-mode transmissions
$s_{13} = s_{31} = s_{24} = s_{42}$	are backward mode-conversions
$s_{14} = s_{41} = s_{23} = s_{32}$	are forward mode-conversions
$s_{33} = s_{44}$	are odd-mode reflections
$s_{34} = s_{43}$	are odd-mode transmissions.
Z_{0e} and Z_{0o}	denote the characteristic impedances of the even and the odd modes
ϕ_e and ϕ_o	denote the phase rotations of the even and the odd modes
W_e and W_o	are the reference impedances of the even and the mode ports, respectively. They are the most general expressions.

The mixed-mode scattering matrix of a series open stub is obtained by substituting $\phi_o + \pi/2$ into ϕ_o of the above expressions while ϕ_e is intact. Therefore the general expressions for a series open stub are omitted for brevity.

In the following, the reference impedances are chosen to be equal to the characteristic impedances, i.e. $W_e = Z_{0e}$ and $W_o = Z_{0o}$, so that there is no false reflection at the interfaces and no artifact resonance.

Then the mixed-mode scattering matrix elements of a series short stub are given by:

$$
\begin{aligned}
\hat{s}_{11} &= \frac{(Z_{0e}^2 - Z_{0o}^2)\sin\phi_e \sin\phi_o + 2jZ_{0e}(Z_{0o}\cos\phi_e \sin\phi_o - Z_{0e}\sin\phi_e \cos\phi_o)}{[2Z_{0e}\cos\phi_e + j(Z_{0o}+Z_{0e})\sin\phi_e][2Z_{0e}\cos\phi_o + j(Z_{0o}+Z_{0e})\sin\phi_o]} \\
\hat{s}_{12} &= \frac{2Z_{0e}[2Z_{0e}\cos\phi_e \cos\phi_o + j(Z_{0e}\cos\phi_e \sin\phi_o + Z_{0o}\sin\phi_e \cos\phi_o)]}{[2Z_{0e}\cos\phi_e + j(Z_{0o}+Z_{0e})\sin\phi_e][2Z_{0e}\cos\phi_o + j(Z_{0o}+Z_{0e})\sin\phi_o]} \\
\hat{s}_{13} &= \frac{2j\sqrt{Z_{0e}Z_{0o}}Z_{0e}\sin(\phi_o - \phi_e)}{[2Z_{0e}\cos\phi_e + j(Z_{0o}+Z_{0e})\sin\phi_e][2Z_{0e}\cos\phi_o + j(Z_{0o}+Z_{0e})\sin\phi_o]} \\
\hat{s}_{14} &= \frac{2\sqrt{Z_{0e}Z_{0o}}[(Z_{0o}+Z_{0e})\sin\phi_e \sin\phi_o - jZ_{0e}\sin(\phi_e + \phi_o)]}{[2Z_{0e}\cos\phi_e + j(Z_{0o}+Z_{0e})\sin\phi_e][2Z_{0e}\cos\phi_o + j(Z_{0o}+Z_{0e})\sin\phi_o]} \\
\hat{s}_{33} &= \frac{-(Z_{0e}^2 - Z_{0o}^2)\sin\phi_e \sin\phi_o + 2jZ_{0e}(Z_{0e}\cos\phi_e \sin\phi_o - Z_{0o}\sin\phi_e \cos\phi_o)}{[2Z_{0e}\cos\phi_e + j(Z_{0o}+Z_{0e})\sin\phi_e][2Z_{0e}\cos\phi_o + j(Z_{0o}+Z_{0e})\sin\phi_o]} \\
\hat{s}_{34} &= \frac{2Z_{0e}[2Z_{0e}\cos\phi_e \cos\phi_o + j(Z_{0o}\cos\phi_e \sin\phi_o + Z_{0e}\sin\phi_e \cos\phi_o)]}{[2Z_{0e}\cos\phi_e + j(Z_{0o}+Z_{0e})\sin\phi_e][2Z_{0e}\cos\phi_o + j(Z_{0o}+Z_{0e})\sin\phi_o]}
\end{aligned}
$$

The above expressions are general enough when the same two conductor lines are used for both a stub and the transmission lines around the stub.

The losses of the transmission line can be incorporated as the imaginary part of the phase rotations. For example, the even-mode loss can be incorporated as $\phi_e = \beta_e l(1 - j\alpha_e/\beta_e)$ if the even-mode propagation constant is given by $\gamma_e = \alpha_e + j\beta_e$.

The simplest case

If we let $Z_{0e} = Z_{0o}$ and $\phi_e = \phi_o$, then the scattering matrix elements of a series short stub become:

$$
\begin{aligned}
\hat{s}_{11} &= \hat{s}_{13} = \hat{s}_{33} = 0, \\
\hat{s}_{12} &= e^{-j\phi}\cos\phi, \\
\hat{s}_{14} &= -je^{-j\phi}\sin\phi
\end{aligned}
$$

which reproduce the description in § 2.1.4.3 of Report ITU-R SM.2158 based on the simple phase shifter model. Since $Z_{0e} = Z_{DM}/2$and $Z_{0e} = 2Z_{CM}$, the above conditions coincide with $Z_{CM} = Z_{DM}/4$.

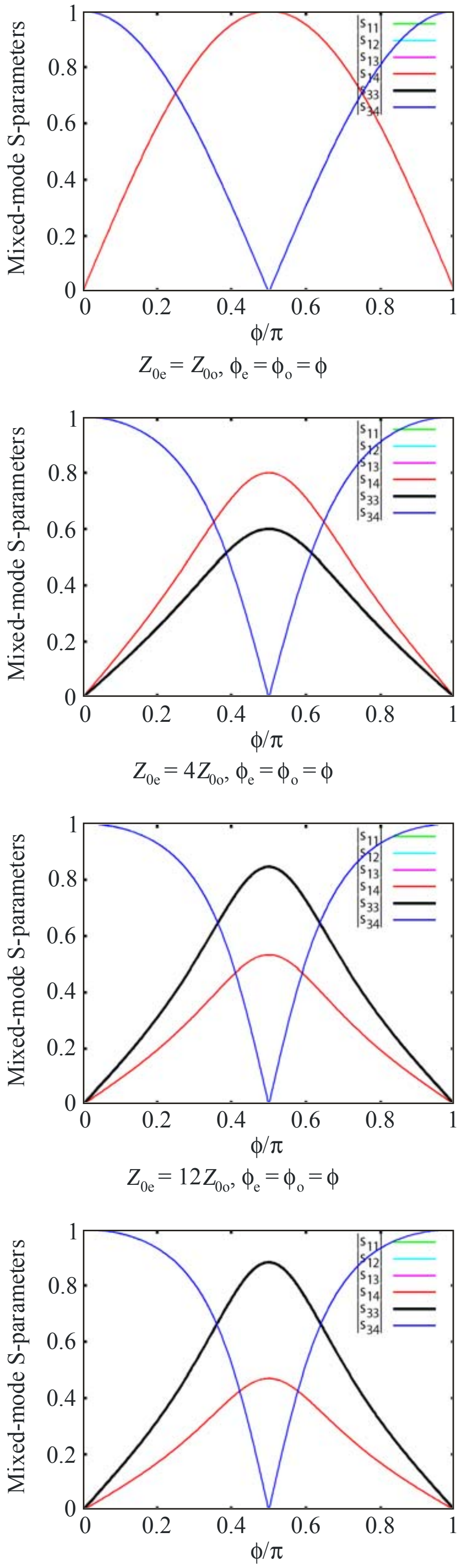
Numerical results

In the following, various numerical examples are calculated using the general expressions for both series short stubs and series open stubs to study the effects of characteristic impedances, mode dispersion (phase velocity difference between the even and the odd modes) and/or loss. In Figs 9 through 14, the horizontal axis is the odd-mode phase rotation ϕ_o divided by π. At the centre (0.5) of the horizontal axis, $\phi_o = \pi/2$. If the stub length l corresponds to a quarter wavelength of the odd-mode at the frequency f_0, then $\phi_o = \beta_o l = \pi f/2f_0$. Therefore the horizontal axis is regarded as $f/2f_0$, the frequency f normalized by $2f_0$, and the centre (0.5) represents $f = f_0$.

The vertical axis is the absolute value of the mixed-mode scattering matrix elements. As far as mode conversions at the stub are concerned, only $s_{13} = s_{31}$ (red curves) which represent inter-mode forward scatterings and $s_{14} = s_{41}$ (magenta curves) which represent inter-mode backward scatterings are relevant. Other elements represent reflections or transmissions within the same modes.

FIGURE 9

A series short stub (lossless) with various characteristic impedances Note that $s_{13}=0$, $|s_{11}|=|s_{33}|$, $|s_{12}|=|s_{34}|$ since $\phi_e=\phi_o$



$Z_{0e} = Z_{0o}$, $\phi_e = \phi_o = \phi$

$Z_{0e} = 4Z_{0o}$, $\phi_e = \phi_o = \phi$

$Z_{0e} = 12Z_{0o}$, $\phi_e = \phi_o = \phi$

$Z_{0e} = 16Z_{0o}$, $\phi_e = \phi_o = \phi$

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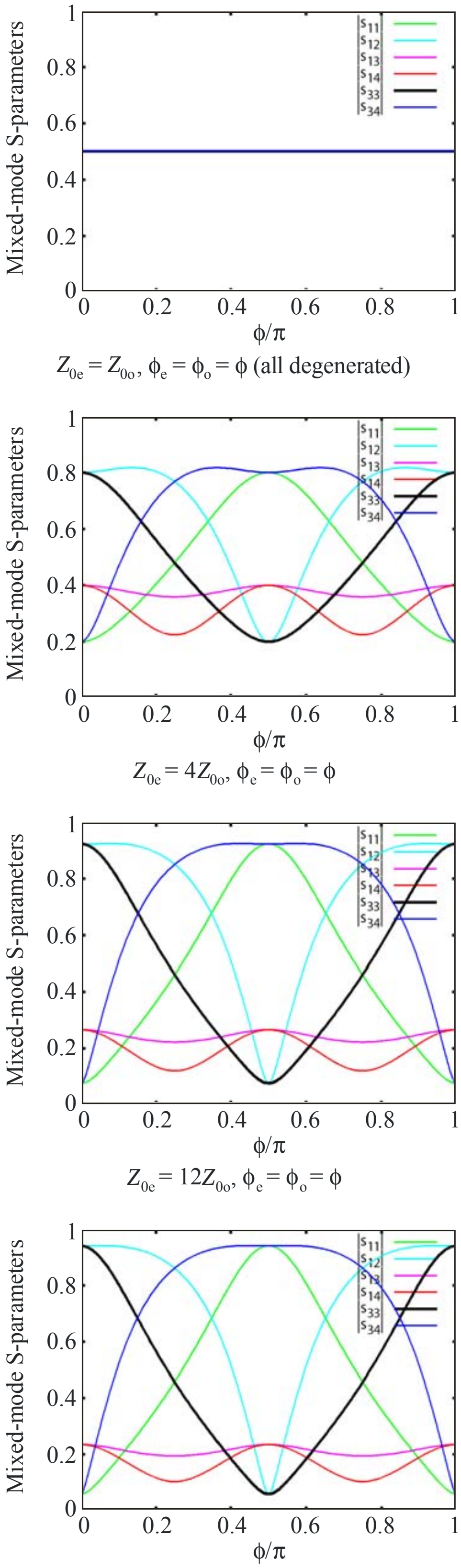
FIGURE 10

A series open stub (lossless) with various characteristic impedances



$Z_{0e} = Z_{0o}$, $\phi_e = \phi_o = \phi$ (all degenerated)

$Z_{0e} = 4Z_{0o}$, $\phi_e = \phi_o = \phi$

$Z_{0e} = 12Z_{0o}$, $\phi_e = \phi_o = \phi$

$Z_{0e} = 16Z_{0o}$, $\phi_e = \phi_o = \phi$

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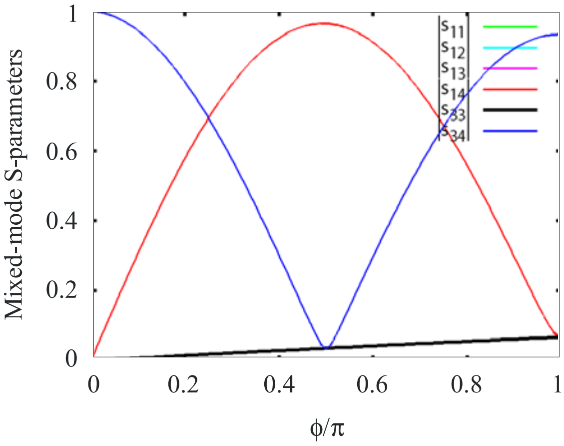
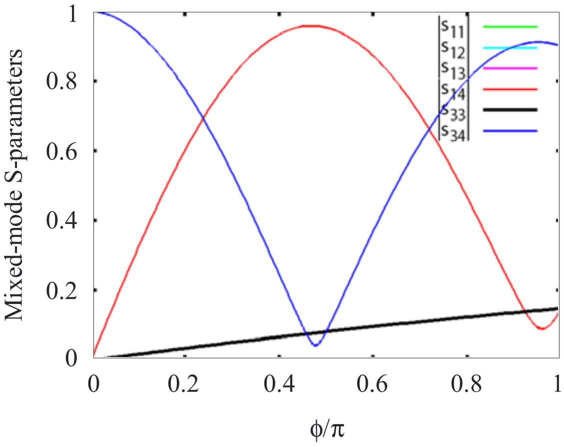
FIGURE 11

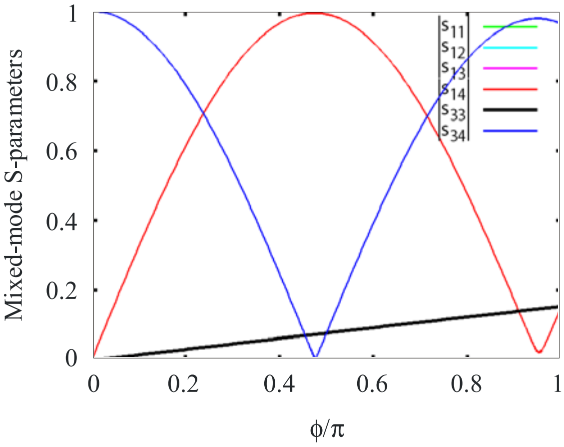
A series short stub with mode dispersion and/or loss (Z_{0e}=Z_{0o})



Lossy even-mode $\phi_e = \phi_o = \phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive, lossy even-mode
$\phi_e = 1.1\phi_o = 1.1\phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive $\phi_e = 1.1\phi_o = 1.1\phi$

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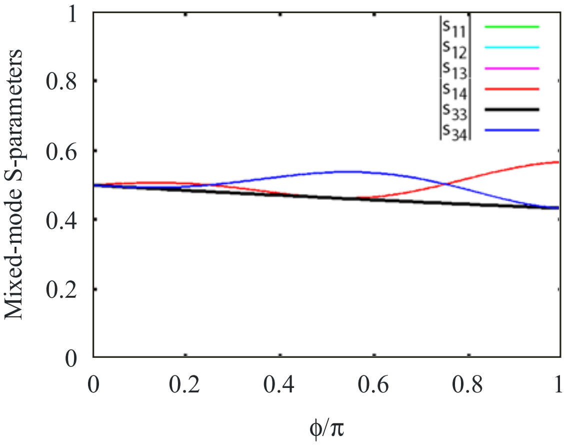
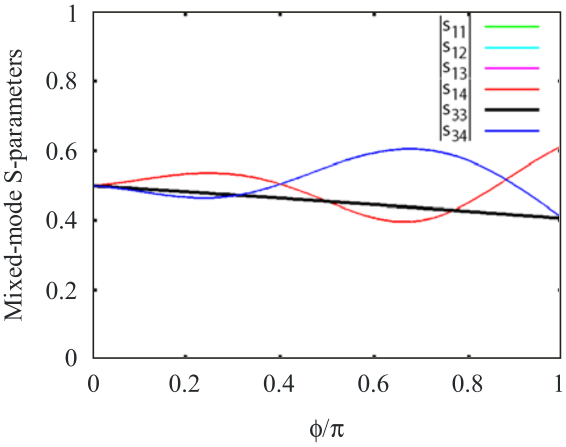
FIGURE 12

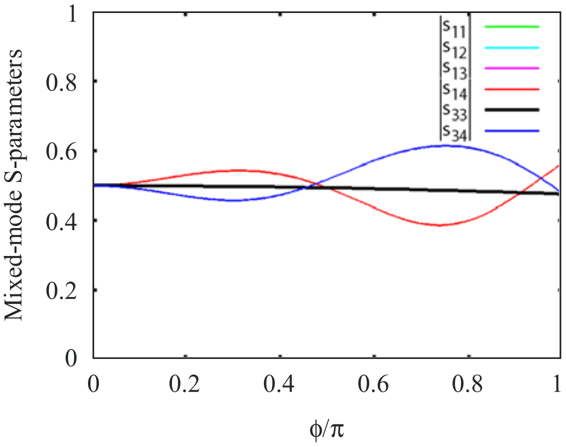
A series open stub with mode dispersion and/or loss (Z_{0e}=Z_{0o})



Lossy even-mode $\phi_e = \phi_o = \phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive, lossy even-mode
$\phi_e = 1.1\phi_o = 1.1\phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive $\phi_e = 1.1\phi_o = 1.1\phi$

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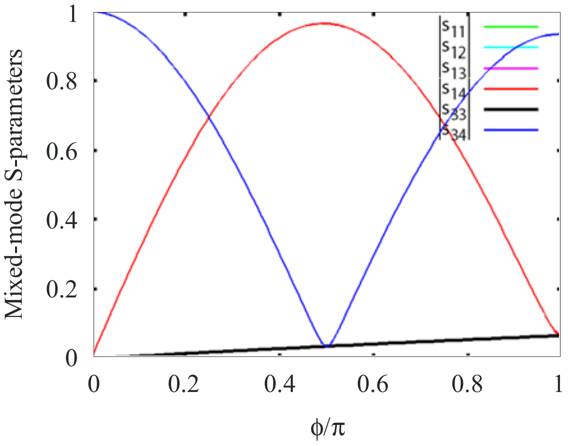
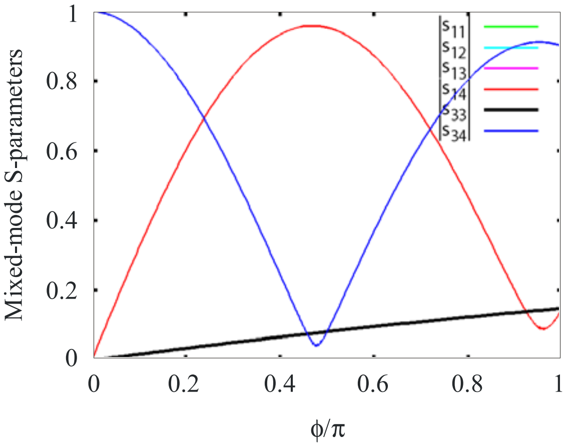
FIGURE 13

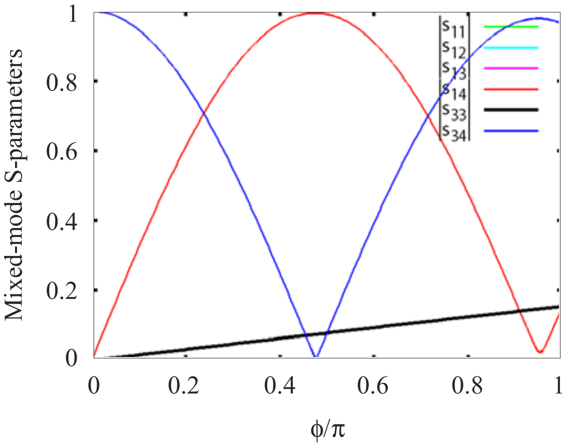
A series short stub with mode dispersion and/or loss ($Z_{0e} = 12Z_{0o}$)



Lossy even-mode $\phi_e = \phi_o = \phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive, lossy even-mode $\phi_e = 1.1\phi_o = 1.1\phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive $\phi_e = 1.1\phi_o = 1.1\phi$

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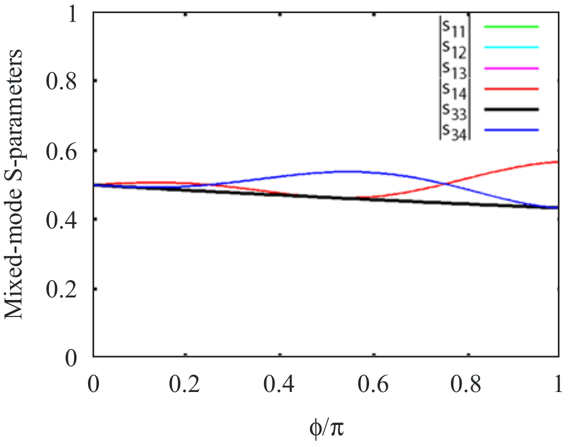
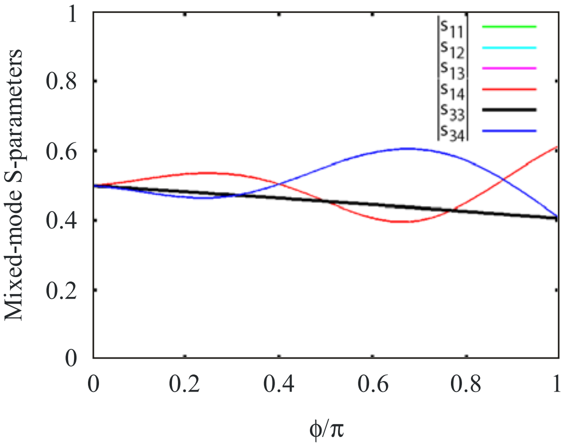
FIGURE 14

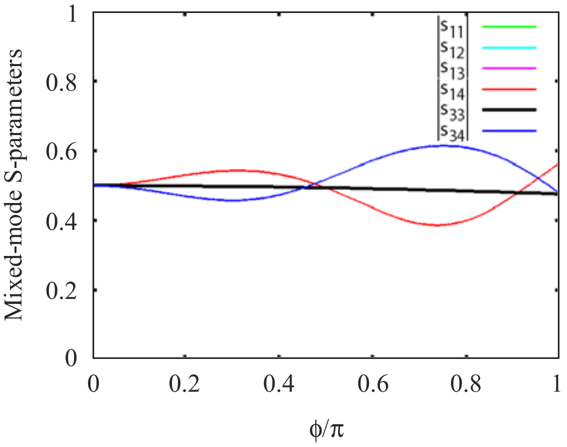
A series open stub with mode dispersion and/or loss ($Z_{0e} = 12Z_{0o}$)



Lossy even-mode $\phi_e = \phi_o = \phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive, lossy even-mode $\phi_e = 1.1\phi_o = 1.1\phi$, $\alpha_e/\beta_e = 0.05$



Mode-dispersive $\phi_e = 1.1\phi_o = 1.1\phi$

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A1.1.3 Conclusions

The general expressions for the mixed-mode scattering matrix elements of a balanced transmission line unilaterally loaded with a stub in series have been formulated. The simple unilateral phase shifter model of a series short stub used in the analysis in § 2.1.4.3 of Report ITU-R SM.2158 has been verified as the simplest case of the general expressions. The general expressions for the mixed-mode scattering matrix elements which represent inter-mode scatterings between even and odd modes and the numerical calculations under various conditions suggest that the even and the odd modes are strongly coupled over a wide range of spectrum, not just at the frequencies where the stub length corresponds to a multiple of the quarter wavelength of the odd-mode.

The results suggest that the even-mode currents as large as the odd-mode signal currents are generated in domestic power line wirings which usually contain as many switch branches as the number of rooms and that the power spectral density of the odd-mode signal must be regulated as low as that of the even-mode.

Annex 2

Analyses of potential interference in the VHF and UHF bands

A2 Interference to VHF/UHF radio systems from harmonics of power line telecommunication systems operating in the VHF bands between 80 and 200 MHz

The study of protection requirements of radio services in the range up to 80 MHz from the effects of PLT has been extensively carried out. However, there so far appears to have been little consideration of the effects of the harmonics of PLT systems on VHF and UHF radio systems.

A2.1 Domestic radio systems

Several radio systems operating in the 88-800 MHz range are used in domestic situations. These include as well as amateur radio, broadcast radio and television, paging, personal alarms for the elderly or incapacitated persons, medical implant monitoring and medical implant control.

The field strengths required by such systems varies over a very wide range, as does the level at which harmful interference can occur. Further, it has been shown (Ref. 1) that intermodulation in the mains distribution system can reduce the depth of spectral notches provided in the PLT system, and non-linearities (such as the “rusty bolt” effect) will also result in the generation of harmonics. From PLT systems operating up to 200 MHz, the harmonics will be probably not be much of a problem above about 500 MHz, but sensitive systems operating below that may well suffer harmful interference.

The amateur services operating in the 220 MHz band in Region 2, and additionally, the amateur and amateur-satellite services in the 432 MHz band in all regions, are particularly likely to be affected by such harmonics: sensitivities down to the order of –40 dB(μV/m) are used in these services. However, the antennas are usually external to the building and frequently some distance away, so a separation of 10 m from the PLT distribution network is not an unreasonable assumption. A wall attenuation of 10 dB is also usually assumed.

Broadcast services generally have reasonably large field strengths available, even indoors. This has, of course, led to the use of poor antennas, often indoors and very close to mains wiring, so that the possibility of interference becomes relatively high.

Other services likely to be affected include medical implants, operating in the 401 to 406 MHz band following the guidelines in Recommendation ITU-R RS.1346. Such devices are of increasing importance in the field of "e-health", especially in view of the health costs of serving an increasingly ageing population. In this case, devices operate indoors, in close proximity to the mains – indeed, "programmers" as the fixed units are known, will almost certainly be mains powered, and thus see a high level of PLT signal (including intermodulation products and harmonics) on their mains leads, and thus radiated to their antennas.

To avoid interference to the primary user (meteorological aids), a sophisticated "listen before talk" mechanism is mandated in the product standards for these equipments, e.g. EN301 839, requiring a threshold of as low as +11 dB(μV/m), above which transmission is inhibited. Thus interference from the PLT exceeding this level will prevent the programmer from initiating communication with the implant. A spacing of 30 cm between the radiating mains wiring and the programmer is quite likely, and thus a loss of 30 dB less than in the amateur case may be expected. Without the benefit of the wall attenuation that the amateur station can expect, or the possible advantages in terms of rejection by antenna radiation pattern, the protection requirements for the medical implants in terms of radiated PLT power can be seen to be very similar to those required by the amateur services.

Although VHF paging services are not quite as popular as once was the case, they are still used, as in many situations, they are cheaper than using alternatives such as cellular telephones. Mainly operating in the VHF region, they will be subject to harmonic and fundamental interference from PLT equipment operating up to 200 MHz.

Personal alarms operating in either the VHF or 400 MHz region are used by the elderly and disabled, especially those living alone or in sheltered accommodation to call for assistance in the case of an emergency. Because the transmitters have to be small and light – frequently worn attached to a neckband – and have small and inefficient antennas as well as powers of only a few milliwatts, receiver sensitivities are of necessity high. The case of someone collapsing such that the body is over the antenna will give an appreciable increase in attenuation, but again, the receiver will be close to the mains wiring, and the wanted signal received signal strength may well be as low as 0 dB(μV/m).

A2.1.1 Conclusion

Although the level of harmonics and intermodulation products falling outside the operational frequency band of a PLT system may be expected to decrease with frequency, the effects of equipment mains leads becoming resonant with a resultant increase in the local field strength is much more likely to occur than at lower frequencies. It has been shown that the level of protection required by the amateur and amateur satellite services at VHF/UHF from the fundamental and harmonics of PLT systems is similar to that required by other systems likely to be found in the domestic environment, the communications failure of which, caused by harmful interference from PLT radiation, could have serious consequences.

A2.2 Compatibility between aeronautical radio and PLT in-house devices in the frequency range 30 MHz-380 MHz

For broadband communications within low voltage AC mains grids and in-house installations, some PLT equipment uses the frequency range up to 300 MHz.

This compatibility analysis focuses on the protection of radio reception for airborne receivers in the aeronautical radio service using the frequency range 30 to 380 MHz.

The compatibility requirements at the airborne receiver for the aeronautical services in the frequency range 80 to 380 MHz are listed in § A2.2.5.1. Applying these requirements results in an interference threshold to be met by PLT (see § A2.2.5.2). To show whether these limits can be met by PLT, the maximum power spectral density as defined in the various PLT systems for above 30 MHz was converted into radiated power/field strengths from buildings which carry PLT broadband communications, in § A2.2.5.3. In § A2.2.5.4 it is shown to which extent PLT may interfere with the aeronautical receiver.

A2.2.1 Compatibility analysis for interferences in aeronautical radio

BNetzA has performed extensive measurements in 2000 on digital cable signals to determine the "wanted minimum field strength" required by VHF COM, UHF COM, VOR, ILS LOS and VDL Mode 2). These values can be converted into the "maximum permissible interference field strengths at the airborne receiver" by applying the system dependent C/I. The values are listed in Table 15.

TABLE 15

Compatibility requirements at the airborne receiver for COFDM signals measured by a quasi-peak (QP) detector having a bandwidth of 120 kHz

	Wanted minimum field strength (dB(μV/m))	***C/I* (dB)**	**Maximum permissible interference field strength (dB(μV/m))**
VHF COM 8.3 kHz Raster 117.975-137 MHz	16	10	6
VHF COM 25 kHz Raster 117.975-137 MHz	16	10	6
UHF COM 25 kHz Raster 230-380 MHz	24	7	21
VOR 40 kHz Raster 108-117.975 MHz	39	13	26
ILS –LOC 40 kHz Raster 108.1-111.95 MHz	32	9	23
VDL Mode 2 118-138 MHz	39	9	30

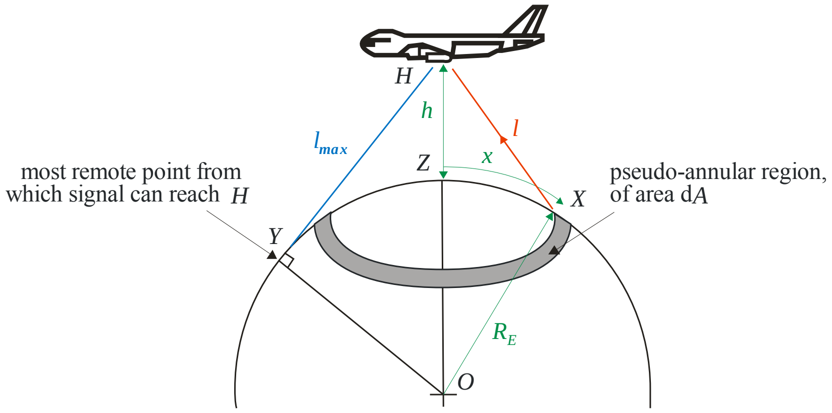
A2.2.2 Calculation of interference threshold for PLT due to aeronautical requirements

A2.2.2.1 Compatibility model

To assess possible interference to airborne receivers due to aggregate effects from PLT sources the compatibility model from *ECC Rep 024 Annex 7*[5] is used. This model considers the summation effects of a specific interferer surface in relation to the interferer density (interferer per square kilometre). The geometry is sketched in Fig. 15. The receiver in the aircraft sees an increased area of the apparent noise due to the aggregation.

FIGURE 15

Model for determination of the aggregate effect of interference



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For single interference which hits the receiver directly (free space propagation), the path length *l* can be determined by:

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

$$l = \sqrt{R_E^2 - 2\,\mathrm{Cos}[\tfrac{x}{R_E}]\,R_E\,(h + R_E) + (h + R_E)^2}$$

Where the values of *x* and *l* are physically constrained by the Earth curvature:

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

$$f[x] = \frac{1}{4\pi\,(R_E^2 - 2\,\mathrm{Cos}[\frac{x}{R_E}]\,R_E\,(h+R_E) + (h+R_E)^2)}$$

$$\mathrm{PFD} = \frac{p_{\mathrm{TX}}\,g_{\mathrm{TX}}\,D\,R_E}{2} \int_{x_1}^{x_2} \frac{\mathrm{Sin}[\frac{x}{R_E}]}{(R_E^2 - 2\,\mathrm{Cos}[\frac{x}{R_E}]\,R_E\,(h+R_E) + (h+R_E)^2)}\,dx$$

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[5] ECC Report 024 (2003), PLT, DSL, Cable Communications (including Cable TV), LANs and their effect on Radio Services, http://www.erodocdb.dk/doks/doccategoryECC.aspx?doccatid=4&alldata=1.

and, for the normalized form:

$$\mathrm{PFD}_{\text{for unit EIRP density}} = \frac{R_E}{2}\int_{x_1}^{x_2} \frac{\mathrm{Sin}[\frac{x}{R_E}]}{(R_E{}^2 - 2\,\mathrm{Cos}[\frac{x}{R_E}]\,R_E\,(h+R_E)+(h+R_E)^2)}\,dx$$

A2.2.2.2 Assumptions

To illustrate the impact on the airborne receiver, Berlin and its statistical data were used as example:

> The city has an area of 900 km²; the average area for a building is 1.16*10^{-3} km². 40% of the area is covered with buildings (360 km²), so you have 860 buildings/km². On average a building has 6 flats that mean 5 200 interferer/km². As an assumption 10% of the flats are featured with broadband Internet access via PLT, the interferer are reduced to 500 interferer/km². Not all PLT modems will be used at the same time. For that point we reduce the interferer density by 50%. That means, the interferer density is about 250 interferer/km² for a city like Berlin.

A2.2.2.3 Calculation

Using the maximum permissible interference field strength in Table 15, the permitted power flux-density, *PFD*, at the receiver can be calculated:

$$PFD = \frac{E^2}{120\pi}$$

where:

PFD: power flux-density (W/m²)

E: maximum permissible interference field strength field (V/m).

By using the compatibility model described in § A2.2.2.1 the permitted radiating power of one PLT noise source can be calculated then.

$$h = 1\ \text{km} \qquad R_E = 6\,371\ \text{km} \qquad D = \frac{250}{\text{km}^2} \qquad G_{TX} = 1.64 \qquad \text{dBi}$$

$$\mathrm{P_{TX}} := \frac{2\cdot \mathrm{PFD}}{\mathrm{D}\cdot \mathrm{R_E}\cdot \mathrm{G_{TX}}\cdot \displaystyle\int_{x_1}^{x_2(h)} \frac{\sin\left(\frac{x}{R_E}\right)}{\left[R_E{}^2 - 2\cdot\cos\left(\frac{x}{R_E}\right)\cdot R_E\cdot(h+R_E) + (h+R_E)^2\right]}\,dx}$$

$$\mathrm{p_{TX}} := 10\cdot\log\left(\frac{\mathrm{P}_{TX}}{10^{-3}\,\mathrm{W}}\right)$$

h: flight altitude (km)

R$_E$: Earth's radius (km)

G$_{TX}$: antenna gain of an isotropic source (dBi)

D: interferer density in interferer/km²

PFD: power flux-density (W/m²).

The calculations also were made for the flight altitudes 300 m, 1 000 m and 10 km. The difference between 300 m and 10 km is only 2 dB which means the flight altitude is irrelevant for the consideration.

The results for the altitude of 1 km and interferer density of 250 interferer/km² are summarized in the following Table 16. This table contains the maximum permissible interference field strength from Table 1, the calculated maximum PFD determined at the airborne receiver and the resulting maximum permissible radiating power of one PLT noise source at the ground.

TABLE 16

Maximum permissible radiating power of one PLT noise source measured by a quasi-peak (QP)detector having a bandwidth of 120 kHz

	Maximum permissible interference field strength at the airborne receiver (dB(μV/m))	**PFD Maximum permissible power flux-density at the airborne receiver (pW/m^2)**	**PTX Maximum permissible radiating power of one PLT noise source**
VHF COM 8.3 kHz raster 117.975-137 MHz	6	0.0106	–80 dBm / 10 dB(pW)
VHF COM 25 kHz raster 117.975-137 MHz	6	0.0106	–80 dBm / 10 dB(pW)
UHF COM 25 kHz raster 230-380 MHz	21	0.334	–65 dBm / 25 dB(pW)
VOR 40 kHz Raster 108-117.975 MHz	26	1.056	–60 dBm / 30 dB(pW)
ILS-LOC 108.1-111.95 MHz	23	0.529	–63 dBm / 27 dB(pW)
VDL Mode 2 118-138 MHz	30	2.653	–56 dBm / 34 dB(pW)

The values for the maximum permissible radiating power of one PLT noise source vary for the different services between 10 and 34 dB(pW).

A2.2.3 Calculation of power flux-density caused by limits provided by PLT system standards

The maximum power spectral density is standardized for PLT devices for in-house communications, e.g. by ITU-T and IEEE.

TABLE 17

Maximum power spectral density by different organizations

	Maximum power spectral density for PLT devices above 30 MHz
Amendment 1 to ITU-T Rec. G.9960	–85 dBm/Hz (r.m.s.)
Draft standard IEEE P1901	–85 dBm/Hz (AV)

For noise-like communication signals, the relation between the readings of the measurement receiver obtained from different detectors is the following:

a)	peak (PK)	0 dB	reference value
b)	quasi peak (QP)	–2 dB	
c)	root mean square (r.m.s.)	–10 dB	
d)	average (AV)	–12 dB	

In the following calculation a maximum transmit PSD level of –85 dB/Hz (r.m.s.) is used. The maximum power spectral density is assumed to be constant for frequencies above 30 MHz. The conversion into the aggregated radiated field strength at 10 m from the building (measured with a peak detector) was performed by the same method (finite-element modelling). Assuming an isotropic antenna, the field strength can be converted into power by:

$$P_t = E + 20 \log d - 74.8$$

where:

E: field strength dB(μV/m)

P_t: power (dBm)

d: distance (km).

The same assumptions as in § A2.2.2.2 were used: an interferer density of 250 interferer/km² and a flight altitude of 1 km.

TABLE 18

Maximum power flux-density at the airborne receiver

Maximum power spectral density for PLT devices above 30 MHz	Aggregated radiated field strength at 10 m distance from the building	Aggregated power corresponding to the field strength	PFD Aggregated power flux-density at the airborne receiver
–85 dBm/Hz (r.m.s.)	33 dB(μV/m) (PK)	4 nW (PK)	3.903 pW/m² (PK)

In Table 18 it can be seen that a PLT device, with a maximum power spectral density of –85 dBm/Hz (r.m.s.), causes a radiation of a field strength of 33 dB(μV/m) measured with a peak detector.

A2.2.4 Comparison of interference threshold required for airborne receiver and interference caused by PLT systems

The maximum permissible interference field strength and power flux-density at the airborne receiver are listed in Table 16. The corresponding aggregated power flux-density at the airborne receiver radiated by PLT is contained in Table 18. This value is converted into the maximum radiated field strength at the airborne receiver.

The permissible field strength and PFD (see § A2.2.2) are compared with the radiated values (see § 4) in Table 19. For better comparison the peak values used for the PLT interference in Table 18 are referred to quasi-peak in following considerations, i.e. reduction of 2 dB.

TABLE 19

Comparison of maximum permissible and aggregated radiated field strength at the airborne receiver and margin required for protection (all values given in terms of QP)

	Maximum permissible interference field strength (dB(μV/m))	Maximum permissible power flux-density (pW/m²)	Aggregated radiated field strength (dB(μV/m))	Aggregated radiated power flux-density (pW/m²)	Margin required for protection (dB)
VHF COM 8.3 kHz raster 117.975-137 MHz	6	0.0106	30	2.512	–24
VHF COM 25 kHz raster 117.975-137 MHz	6	0.0106	30	2.512	–24
UHF COM 25 kHz raster 230-380 MHz	21	0.334	30	2.512	–9
VOR 40 kHz Raster 108-117.975 MHz	26	1.056	30	2.512	–4
ILS-LOC 108.1-111.95 MHz	23	0.529	30	2.512	–7
VDL Mode 2 118-138 MHz	30	2.653	30	2.512	0

The last column in Table 19 shows the margin which is needed to reduce the interference caused by PLT devices. Assuming a maximum power spectral density for PLT devices of –85 dBm/Hz (r.m.s.), a reduction of 24 dB would be necessary for the VHF systems. The margins vary between 0 and –24 dB depending on the system.

These calculations were made for an interferer density of 250 interferer/km². The correction depends linearly on the interferer density (see also Document 1A/157).

TABLE 20

Interferer density correction values

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

A2.2.5 Conclusions

Assuming a maximum power spectral density for PLT devices of –85 dBm/Hz (r.m.s.) as currently defined e.g. in ITU-T Recommendation G.9960, all investigated aeronautical radio systems in the frequency range above 80 MHz, except VDL Mode 2, would be interfered at the airborne receiver by PLT. The concerned systems are VHF COM, UHF COM, VOR and ILS LOC.

The margin required for protection of the aeronautical systems reaches up to 24 dB for the VHF systems. Or with other words, the maximum power spectral density for PLT has to be reduced by this margin.

A2.3 PLT aggregation model applicable for aircraft radiocommunication and radionavigation systems

Assuming free-space path loss the minimum coupling loss can be translated into a minimum separation distance for a single source using the following formula:

$$L_{bf} = 32.4 + 20\log(f) + 20\log(d)$$

where:

L_{bf} = free-space basic transmission loss (dB)

f = frequency (MHz)

d = distance (km).

Aggregating all of the single point source can be achieved using the following formula:

$$A = \frac{W_{eirp}\lambda^2 G_r \rho R_e}{16\pi(R_e + h)} \bullet \ln\left(\frac{\left(2(R_e + h)H + h^2\right)}{h^2}\right)$$

where:

A = average aggregate interference (watts per unit bandwidth)

W_{eirp} = equivalent average PLT device EIRP (watts per unit bandwidth)

λ = wavelength (m)

Gr = victim receiver antenna gain (dB)

ρ = average density of PLT emitters (emitters per metre^2)

R_e = effective earth radius (m)

R = radius of the observed zone or the radio horizon

h = height of the receive antenna above the ground (m)
H = $R_e(1 - \cos(R/R_e))$.

Annex 3

Radio-frequency radiation from PLT systems in the VHF and UHF bands

A3 Radio-frequency radiation from PLT systems in the VHF and UHF bands

This Annex addresses the impact on radiocommunication services from radiation of wired-telecommunication systems including power line telecommunication (PLT) systems and the criteria required for protection. Initially, PLT systems operated at frequencies below 30 MHz and so the resulting radiation was also in this range. Unfortunately, increased use is being made of mains electrical wiring for the transmission of wideband data. Mains electrical wiring is, typically, neither designed nor engineered for the transmission of high bandwidth data and incidental radiation from the wiring is a consequence. Any broadcast receiver operated in the vicinity of a mains conductor carrying PLT will perceive this radiation as an increase in the noise floor. This impacts the receiver's ability to resolve low-level signals. Measurements of PLT devices reveal that radiation occur well beyond 300 MHz. These findings and the impact on radiocommunication services are summarized in this Report.

This Annex is supplemented with data from analyses, laboratory tests, field tests, and various measurement programmes that can be found in Reports ITU-R SM.2158 and ITU-R SM.2157.

A3.1 Institut für Rundfunktechnik GmbH measurements of PLT modems

This section provides technical information concerning the performance and the radiation characteristics of some PLT systems. The information includes the results of measurements of spectrum usage of modern power line telecommunications (PLT) modems carried out at the Institut für Rundfunktechnik GmbH (IRT), the central research and development institution of the public service broadcasting organizations in Germany, Austria and Switzerland. The information is intended to assist in the assessment of interference stemming from PLT devices.

A3.1.1 Overview of the measurements

The typical frequency range for the two legacy PLT technologies currently used throughout Europe until 2010 is 2-30 MHz for Homeplug AV and 2-32 MHz for UPA. Frequency notching is used to minimize interference to signals within the frequency bands used by amateur radio operators. In addition, the transmit power in various frequency ranges is reduced by approximately 30 dB in order to reduce interference with other users in these parts of the frequency spectrum. Since the end of 2009, adapters have been available on the market that are supposed to enable gross transmission rates of up to 1 Gbit/s (peak rate). Unlike Homeplug AV, ITU-T Recommendation G.9960 (06/10) and the standard IEEE-1901(also called Homeplug AV2), they use a considerably broader frequency range (2 MHz to 30 MHz and 50 MHz to 305 MHz), which includes the VHF band II (FM) as well as the band III (DAB). Measurements of spectrum usage of these PLT technologies, in particular by a representative of mediaxtream, the newest Gigabit chip set from Gigle[6], aim to

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[6] In December 2010 Broadcomm acquired Gigle Networks Inc.

capture the performance under realistic load conditions on the power lines as well as possible radiation levels. It remains to be clarified to what extent interference or adverse effects may occur in the broadcast bands due to the use of these PLT adapters.

A3.1.2 PLT performance

Despite the fact that the identical Intellon INT6300 chip set is used in the products by Allnet, Devolo, and Zyxel and the identical DS2 DSS9010 chip set in the products by AcBel and Conceptronic, differences in performance can be detected. The measured values show very good performance of all power line devices operating in accordance with the transmission control protocol (TCP). Even at a distance of 22 m and different current phases, data rates of 50 to 74 Mbit/s are achieved, that, for example, allow for the streaming of two HD signals while still having sufficient reserve to manage a transfer rate of 10 Mbit/s for other purposes. The adapters by Allnet, Devolo, and Zyxel as well as adapters by AcBel and Conceptronic have a nominal maximum transmission rate of 200 Mbit/s, which equals a maximum net data rate of approximately 80 Mbit/s. The Belkin Gigabit power line HD[7] adapters with the mediaxtream chip set by Gigle (GGL541) have to be individually analyzed since they are the only ones with a Gigabit network connection and have a nominal maximum transmission rate of 1 000 Mbit/s. Under real operating conditions, the maximum net data rate may be significantly lower. Nevertheless, in using the 50-305 MHz spectrum, the Gigle GGL541 chip set enables a clearly higher data rate than the chip sets from Intellon (2-30 MHz) and DS2 (2-32 MHz). Belkin adapters were able to demonstrate this, for example, at a distance of 2.3 m. At "shorter distances" the performance of the Gigle chip set outperforms the Intellon and DS2 chip sets by a factor of 3.5. At a distance of 22 m, the performance of the Belkin adapters deteriorates. Starting at a line length distance of approximately 10 m or with higher attenuation between the two Belkin adapters, the devices only operate in the Homeplug AV spectrum (lower frequency band: 2-30 MHz). The data throughput of 50 Mbit/s is then approximately 30% lower than that of the Intellon and DS2 adapters.

Since December 2010, power line adapters using the Power line standard IEEE-1901have been available. The Atheros[8] AR7400 chip set is the first on the market to comply with this standard. It uses a broader frequency range (2 MHz to 68 MHz) than the Homeplug AV standard (2 MHz to 30 MHz), whereas the globally used FM radio bands between 76 and 108 MHz and the DAB radio bands between 174 and 240 MHz are not used. The expanded frequency range and a more efficient modulation method up to 4096 QAM aim to enable AR7440-based Power line products to communicate with a data rate exceeding 500 Mbit/s PHY (peak rate). Renowned power line adapter manufacturers such as Netgear, Trendnet, TP-Link, Devolo, D-Link, AVM, Billion, MSI, Allnet have already announced or introduced Power line devices that comply with the IEEE-1901 standard.

Table 21 tabulates the technical characteristics of power line adapters measured. Three pairs of the Power line standard Homeplug AV by the manufacturers Allnet, Devolo, and Zyxel as well as two UPA devices by AcBel and Conceptronic were tested. As a third version, the Gigabit power line adapters by Belkin were tested and reported herein; they are the only ones with a maximum nominal transmission rate of 1 000 Mbit/s. As fourth version, a pair of Netgear adapters with a maximum nominal transmission rate of 500 Mbit/s was tested.

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[7] Gigabit Power line HD F5D4076 S v1, F5D4076 S v1 and MSI ePower 1000HD use the Giglechip set (GGL541) and have similar measurement results.

[8] Qualcomm acquired Atheros having acquired Intellon shortly before.

TABLE 21

Specifications of tested power line adapters

Manufacturer	Allnet	Devolo	Zyxel	Belkin	AcBel	Conceptronic	Netgear
Product	ALL168203	dLAN 200 Avplus	PLA-400 v2	Gigabit Power line HD	DH10PF	Homeplug 200 Mbit/s	Power line AV 500 XAVB5001
Standard	Homeplug AV			HPAV2 mediaxtream	UPA		IEEE-1901
Transmission speed (nominal)	200 Mbit/s			1 000 Mbit/s	200 Mbit/s		500 Mbit/s
Spectrum	2-30 MHz			2-30 MHz 50-300 MHz	2-32 MHz		2-68 MHz
Protocols	CSMA/CA			CSMA/CA TDMA MAC	TDMA MAC		
Modulation	OFDM – 1 155 carrier, 1 024/256/64-QAM, QPSK, BPSK				OFDM – 1 536 carrier		OFDM – 4 096 carrier

A3.1.3 Frequency spectrum measurements

For the realization of the measurements, one lead of the power cable that was transmitting the data traffic was placed in a R&S MDS 21 absorbing clamp and the remaining leads were left outside (see Fig. 16). The attenuation of the measuring clamp is indicated with 17 dB in the range between 30-1 000 MHz; therefore this value has to be added to the indicated levels in order to determine the correct HF level on the power line. To be representative for the power line standard, AcBel, Allnet and Belkin devices were used for the measurements. A data transfer that pushed the devices to their performance limits was generated between two identically built power line adapters. During the active performance measurement, the spectrum analyzer FSEA recorded the frequency spectrum.

FIGURE 16

Measuring set-up with absorbing clamp

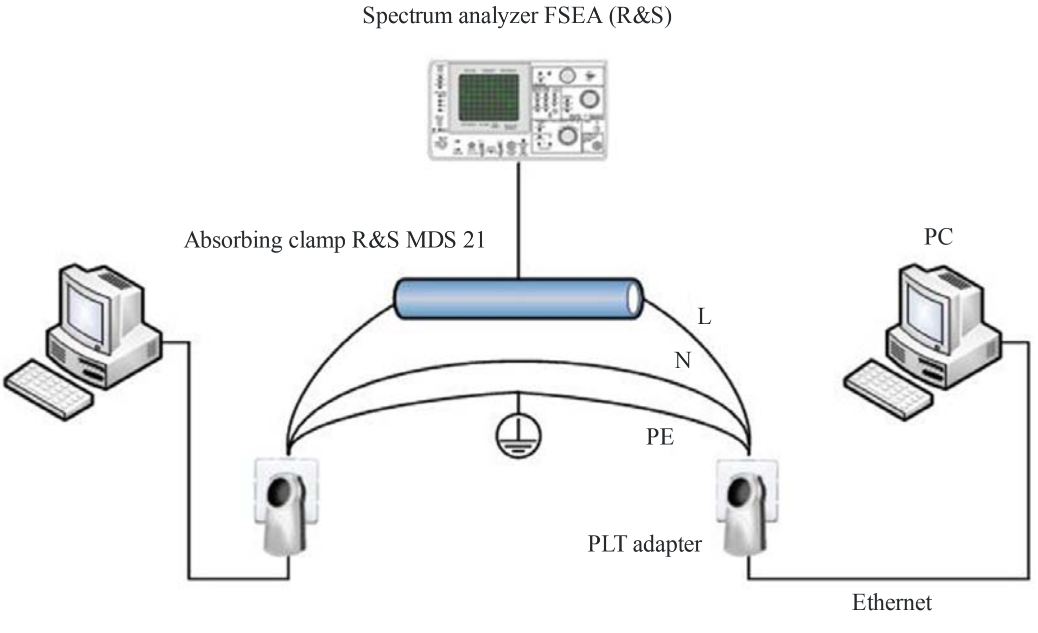

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FIGURE 17

On-air signals and ambient noise at measuring site visible are (*inter alia*): SW, FM (87.5-108 MHz), DAB (around 215 MHz))

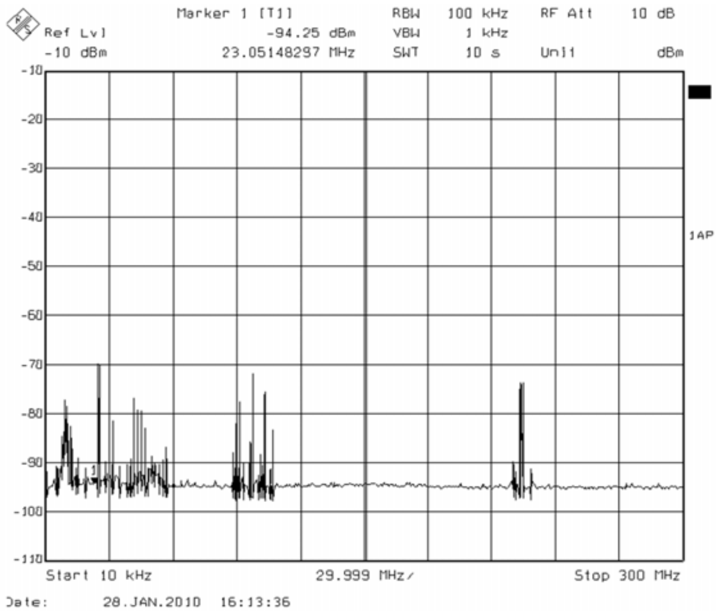

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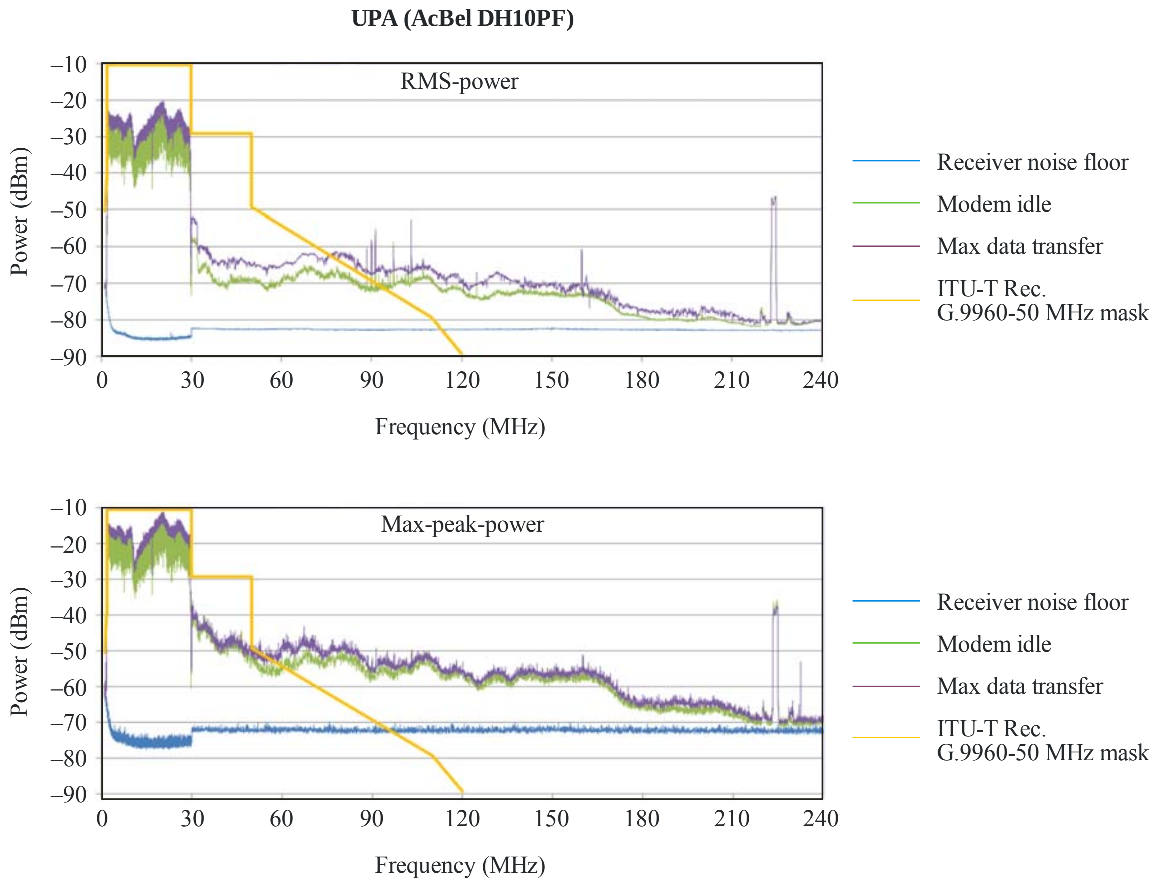
FIGURE 18

Power spectrum of AcBel UPA in idle mode and for maximum data throughput



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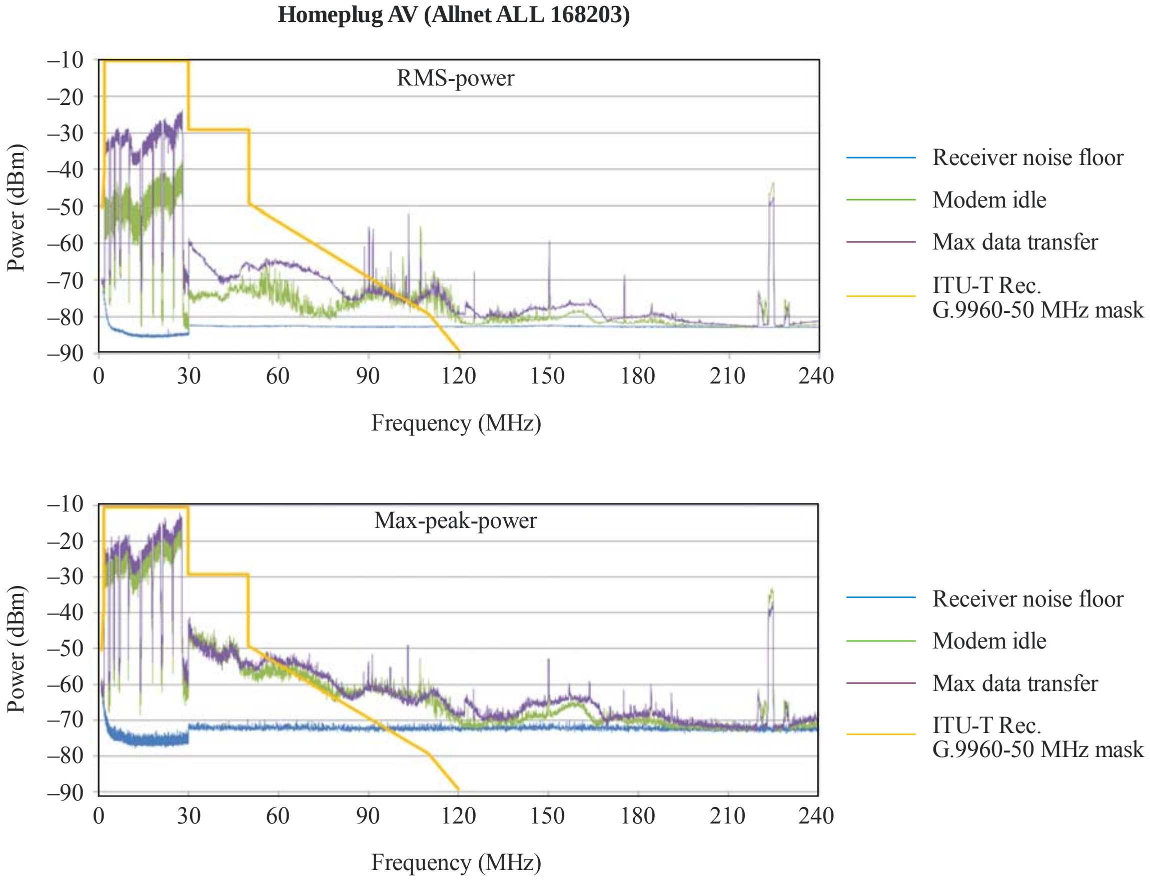
According to the manufacturer, power line adapters in compliance with the UPA standard use a frequency range of 2-32 MHz. The spectrum analysis, however, shows (see Fig. 18) that UPA still generates spectral components beyond 32 MHz up to almost 190 MHz, although clearly attenuated by approximately 50 dB. The levels in the actual working range are approximately –15 dBm (attenuation of the absorbing clamp included).

According to the manufacturer, power line adapters in compliance with the Homeplug AV standard use a spectrum of 2-30 MHz. Although Homeplug AV and UPA indicate the same maximum transmission rate of 200 Mbit/s, their frequency spectrums differ. Homeplug AV has similarly high levels in the lower frequency range; the levels of the higher spectral components, however, are lower than those in UPA devices (see Fig. 19). Spectral components range up to approximately 70 MHz.

FIGURE 19

Power spectrum of Allnet Homeplug AV in idle mode and for maximum data throughput



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According to the manufacturer, Power line adapters with mediaxtreme chip sets can communicate in the frequency range of 2-30 MHz (HPAV) and 50-300 MHz. However, the simultaneous use of both spectrum ranges is not (yet) possible. In the case of a data transfer with several TCP connections, it became clear that the communication between two adapters takes place in the 50-305 MHz spectrum range (upper band), (see Fig. 20). The levels in this frequency range are approximately 25-30 dB lower than those of the devices from AcBel and Devolo (2-30/32 MHz). Despite the communication in the upper band, power line devices in compliance with the mediaxtream standard simultaneously show spectral components in the lower band.

FIGURE 20

Power spectrum of the Belkin adapter in idle mode and for maximum data throughput

Mediaxtream – (Belkin gigabit power line HD)

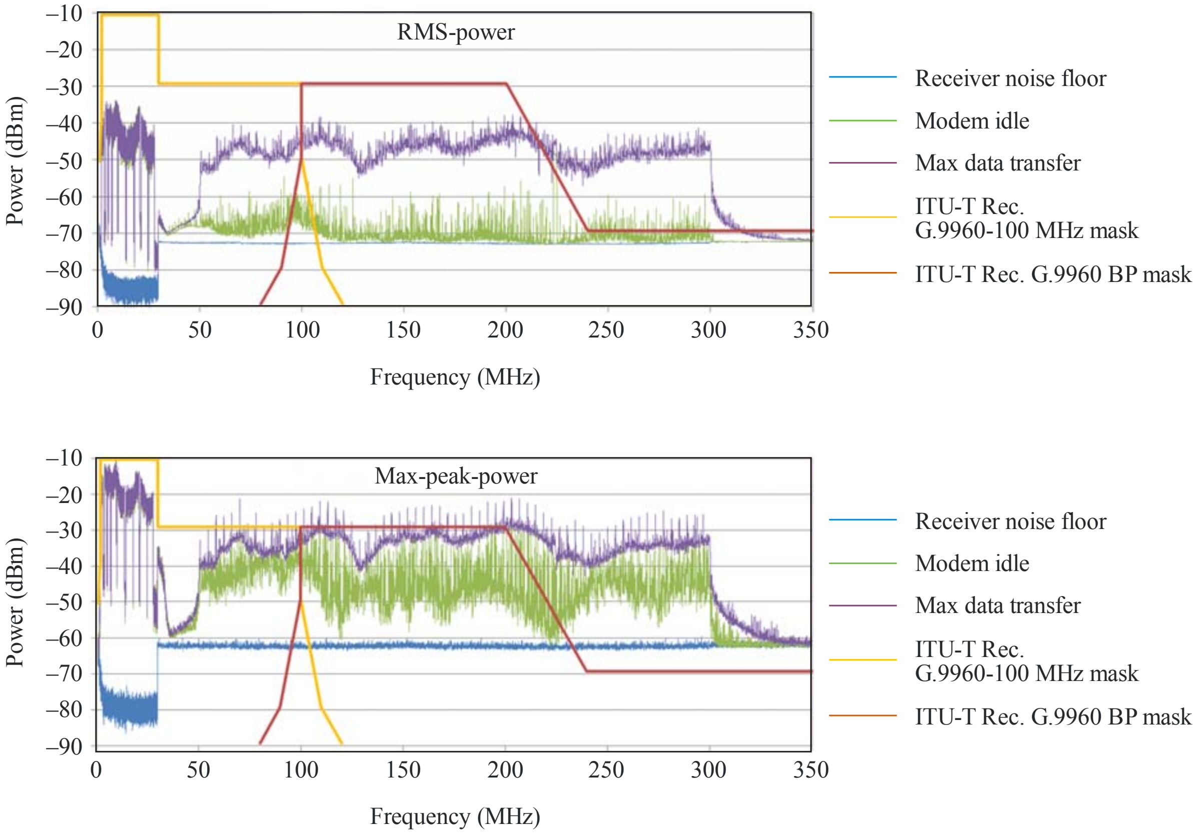

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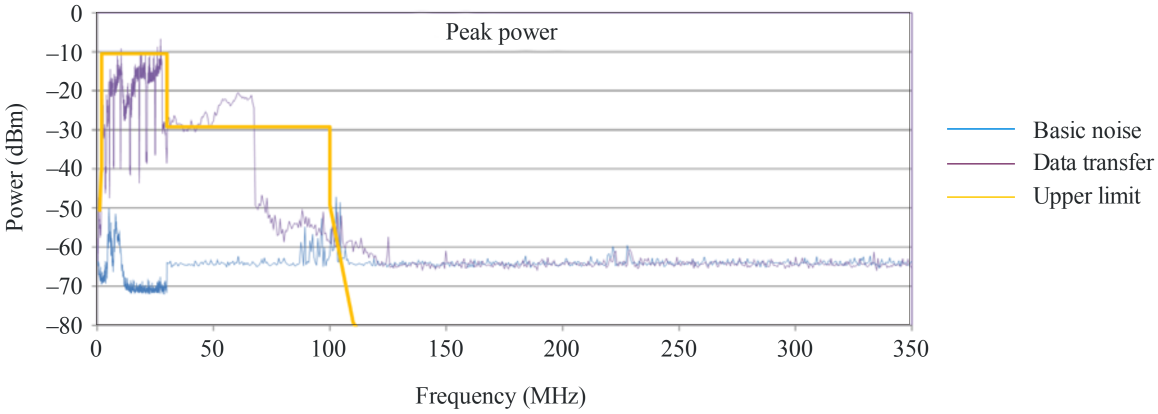
FIGURE 21

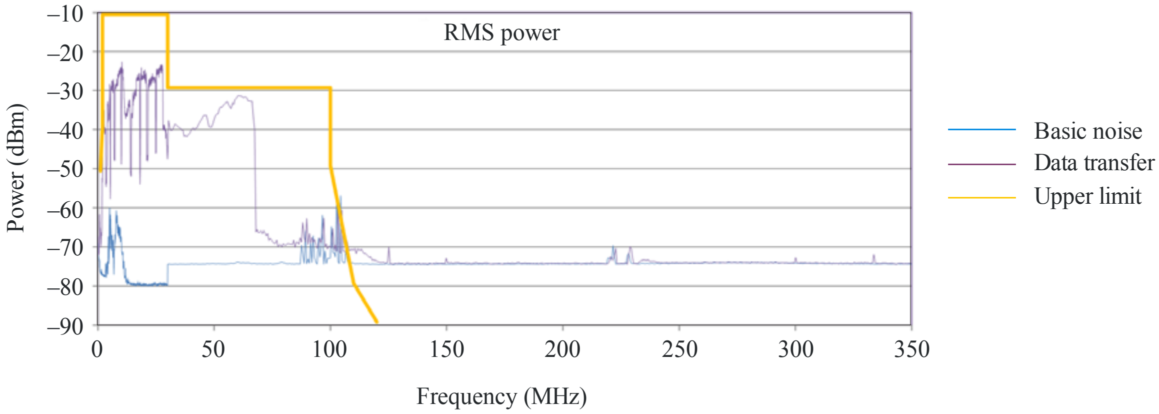
Peak power spectrum of the Netgear AV500 adapter for maximum data throughput (dBm)
Upper limit (yellow) corresponding to ITU-T Rec. G.9960



Report SM.2212-21

FIGURE 22

RMS power spectrum of the Netgear AV500 adapter for maximum data throughput (dBm)



Report SM.2212-22

A3.1.4 Interference radiation of the Belkin PLT modem "Power line Gigabit" F5D4076-S v1

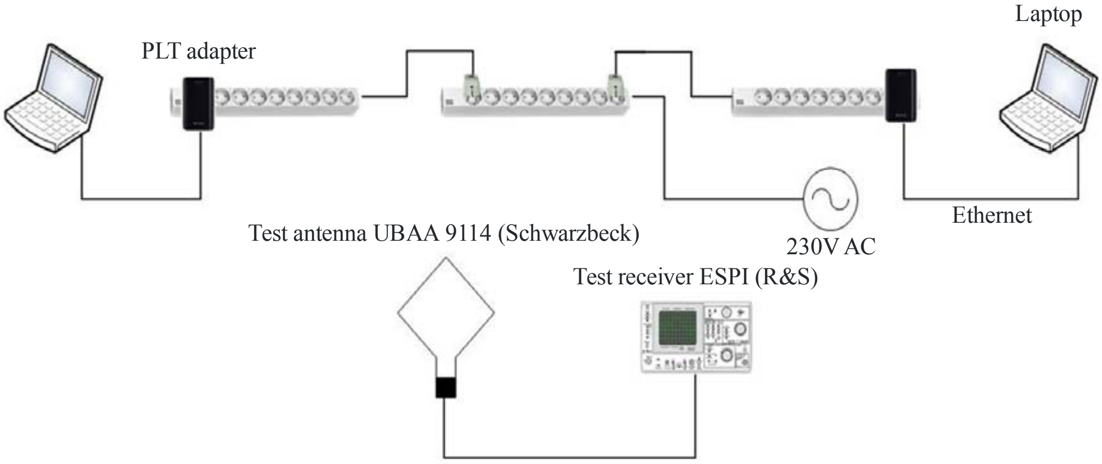
Two mains extension leads, each with a 1.5 m long power cable, were connected left and right to a mains extension lead connected to the mains wall socket (230 V), allowing for the two extensions to be placed at a distance of 3 m on a table (ref. measurement setup in Fig. 23). The Belkin modems were plugged into the outer sockets and connected with two notebooks. Then, data with a net rate of up to 250 Mbit/s (TCP) were transmitted by using the IxChariot software tool. A Schwarzbeck UBAA 9114 antenna was placed at a distance of 3 m and a height of 1.5 m. The horizontally and vertically polarized field strength was captured in the 30-320 MHz frequency range. The measurements were taken with the EMC test receiver R&S ESPI. The settings of the test receiver were as follows:

- Measuring bandwidth: 120 kHz;
- Measuring step: 40 kHz;
- Measuring time: 100 ms;
- With pre-amplifier;
- Attenuation: 10 dB;
- Measuring detectors: Peak and r.m.s. (root mean square).

The conversion rate (antenna factor) of the broadband antenna UBAA9114 was entered into the receiver as a value table depending on the reception frequency in order, for the measuring results, to be directly recorded in dB(µV/m). During two measuring runs the peak value and r.m.s. value of the field strength were measured for each frequency. Measurements with a quasi-peak detector were not made because such a measuring run would take many hours for a single measurement value. Instead, the quasi-peak value detector was intentionally used to replicate the influence of impulse interferences on the human ear during reception of an analogue radio programme. Except for the FM band, interference above 30 MHz has its effect on digital services for which the interference effect can be better described with r.m.s. and peak values.

FIGURE 23

Set-up for the interference radiation measurements



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Following field-strength values were measured and recorded in horizontal and vertical polarization:

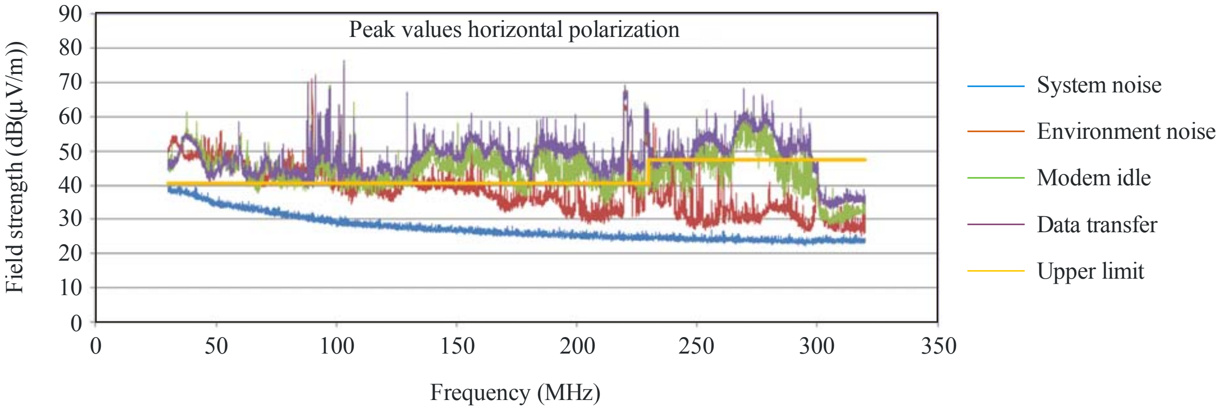
- System noise of the measuring receiver (lower reference of measuring system);
- Ambient noise;
- Interference with modems in idle mode;
- Interference with modems during data transfer with up to 250 Mbit/s gross data rate.

As upper reference, the limits given in Table 6 of Standard EN 55022[9] are entered in the diagrams. The limits are indicated in quasi-peak values. Quasi-peak values are usually lower than the peak values, but in any case higher than the r.m.s. values.

A3.1.5 Field strength with horizontal polarization

FIGURE 24

Peak values of the horizontally polarized field strength (dB(µV/m))



Report SM.2212-24

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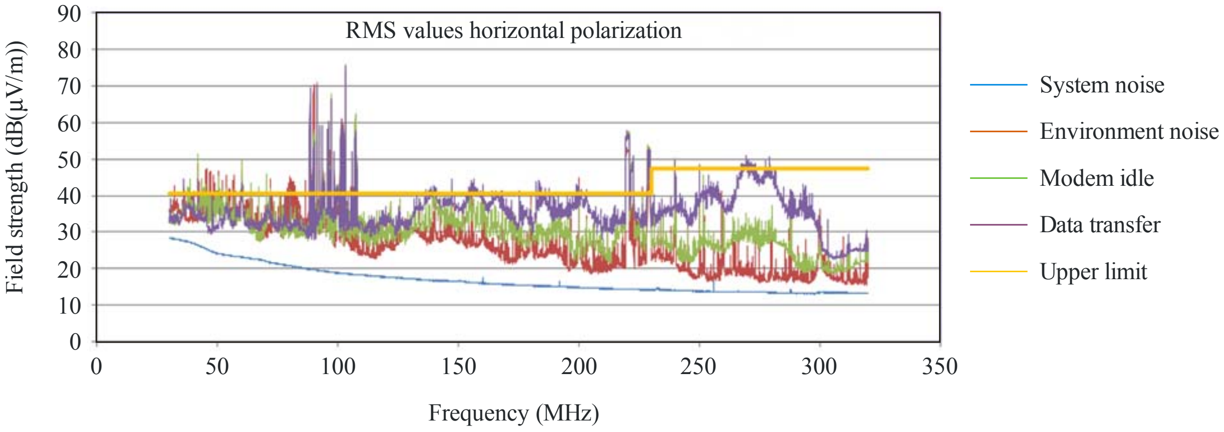
[9] CENELEC EN 55022: 2006; Information technology equipment − Radio interference characteristics − Limits and methods of measurement (CISPR 22: 2005 (modified)).

The blue line in Fig. 24 represents the lowest measurable field strength that equals the measuring receiver's system noise. The red line represents the ambient noise (man-made noise) in absence of the modems. Since the measurements were made at the IRT, where many electrical and electronic systems are operating, the ambient noise is rather high (red line); below 150 MHz it is even above the upper limit value line. The peaks of the field-strength values in the 87.5-108 MHz range match the FM signals, those around 220 and 229 MHz match the DAB signals that can be received at the IRT.

When the modems are switched on, the interference field strength increases, as indicated by the green line. During data transfer, the interference field strength again increases, indicated by the violet line. Above 130 MHz, the level of the interference field strength caused by the modems is some dB above the ambient noise; this means the measured values are correct. The peak values of the modem's interference during data transfer as well as in idle mode exceed the limit up to approximately 20 dB.

FIGURE 25

Root mean square (r.m.s.) values of the horizontally polarized field strength (dB(μV/m))



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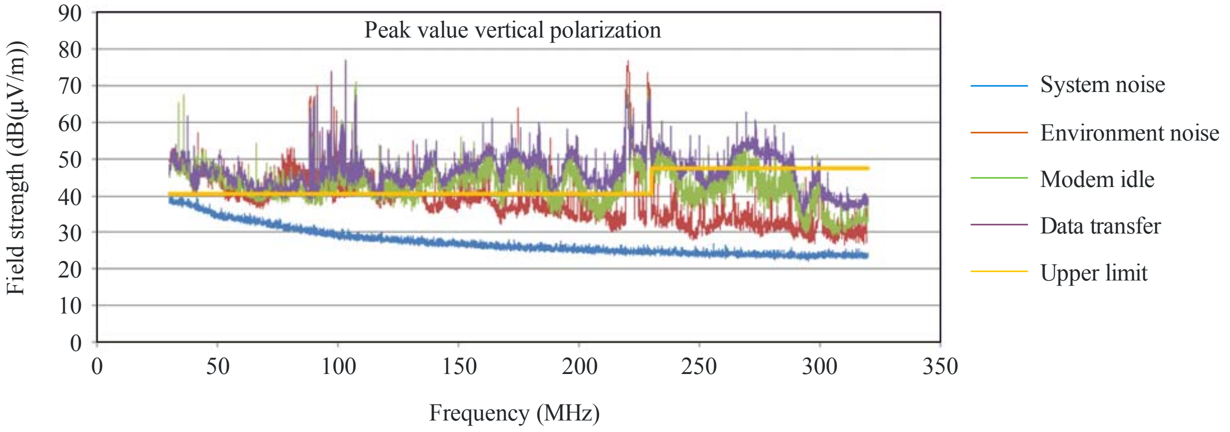
The r.m.s. values in Fig. 25 are approximately 10 dB lower than the respective peak values for permanent interference such as the system noise of the test receiver (blue) and the interference of the modems in operation (violet). The interference of the modems in idle mode is pulsed, which explains why the difference between peak value and r.m.s. values increased (green lines). The r.m.s. values of the interference of the modems during data transfer are in part also above the limit.

A3.1.6 Field strength with vertical polarization

FIGURE 26

Peak values of vertically polarized field strength (dB(µV/m))



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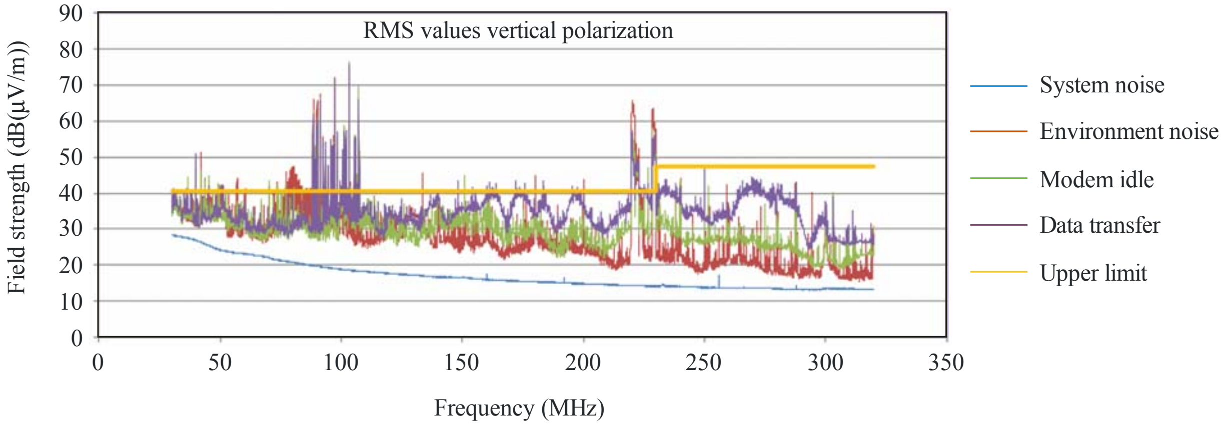
The values in Fig. 24 also apply for the field-strength values in Fig. 26. The DAB signals at 220 MHz and 229 MHz are higher since they are transmitted at a vertical polarization. The peak values of the modem's interference during data transfer as well as in idle mode are above the limit in the entire frequency range.

FIGURE 27

Root mean square (r.m.s.) values of the vertically polarized field strength (dB(µV/m))



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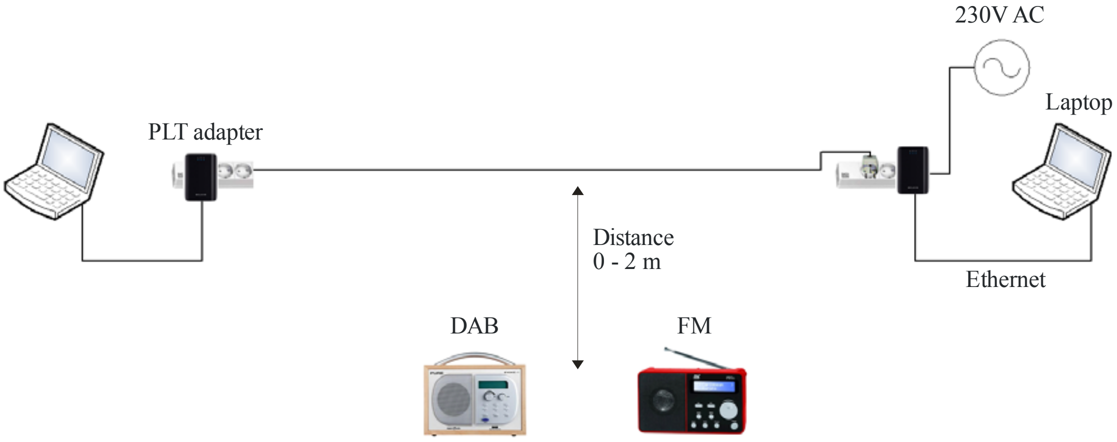
The comment on Fig. 25 also applies to Fig. 27. The r.m.s. values of the modem's interference during data transfer touch the limits in the 30-200 MHz range, the quasi-peak values are above this limit at any rate.

A3.1.7 Real interference of the FM and DAB reception

In order to be able to evaluate whether the measured part of the spectrum of the adapters with the mediaxtream standard influence the reception of FM and/or DAB, a simple test setup in a "normal" working environment was made at the IRT, equalling the reception in a private home or apartment (see Fig. 28).

FIGURE 28

Setup for the measurement of real interference of the FM and DAB reception



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Each Belkin-F5D4076 adapter was plugged into a triple outlet, whereas the supply power cable of a triple outlet with a length of 3 m was oriented at table height on the room's side wall. An FM radio (DNT) and a DAB radio (PURE) were placed on the table in front of the cable. The distance to the cable was varied during the measurements in several steps between 0 and 2 m in order to investigate the interference.

During each step the FM radio and then the DAB radio were set on "loud", while the data flow generated with IxChariot (250 Mbit/s) was repeatedly switched on and off via the power line.

The radios were positioned close (approximately 1 m) to a large window in the room allowing for "good" reception.

Results of FM test

When set to a strong local station (Bayern3, Bayern5, band II 100 MHz), a subjective interference during PLT activity could not be determined. However, when set to a weak station (Ö3), additive noise from the speakers could be clearly identified during PLT activity up to a distance of approximately 1 m between radio and balanced power cable. In the case of greater distances, interference was no longer audible.

Results of DAB test

The audible interference during DAB reception (e.g. Bayern3, band III 220 MHz) was much more serious. Interference occurred even to stations with good receiving conditions at a distance between the radio and data-transmitting power cable up to 1.5 m during PLT activity. The interference ranged from twittering and knocking to "complete" blackout of the audio signal.

Audible effects were eliminated only at distances above 1.5 m.

A3.1.8 Conclusion from the IRT measurements

The spectral measurements made on the PLT adapters “Power line Gigabit” F5D4076 S by Belkin on the one hand show the occupation of frequencies up to 305 MHz, which includes the FM band as well as the DAB band. On the other hand, the interference measurements show that interference due to the modems is stronger than the EN 55022 standard allows in the 30-300 MHz frequency range.

It should be noted that these tests used a relatively symmetrical power cabling, so these results do not represent the worst case, but have to be regarded as a less critical configuration.

One possible solution would be the use of frequency notching in the affected bands. The manufacturer of the mediaxtream chip set, Gigle, has already offered such consequential actions in case of appropriate feedback.

A3.2 Communication Research Centre (Canada) measurements of PLT modems

The Communications Research Centre (CRC, Canada) evaluated a total of eight commercially-available PLT devices representing the various PLT standards. These devices were readily available in the United States of America, Canada, and Japan. The test measurement details and results can be found in the 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:
http://www.nabanet.com/nabaweb/members/pdf/itur/CRCReport.pdf or see the Attachment to the Annex of Document 6A/160.

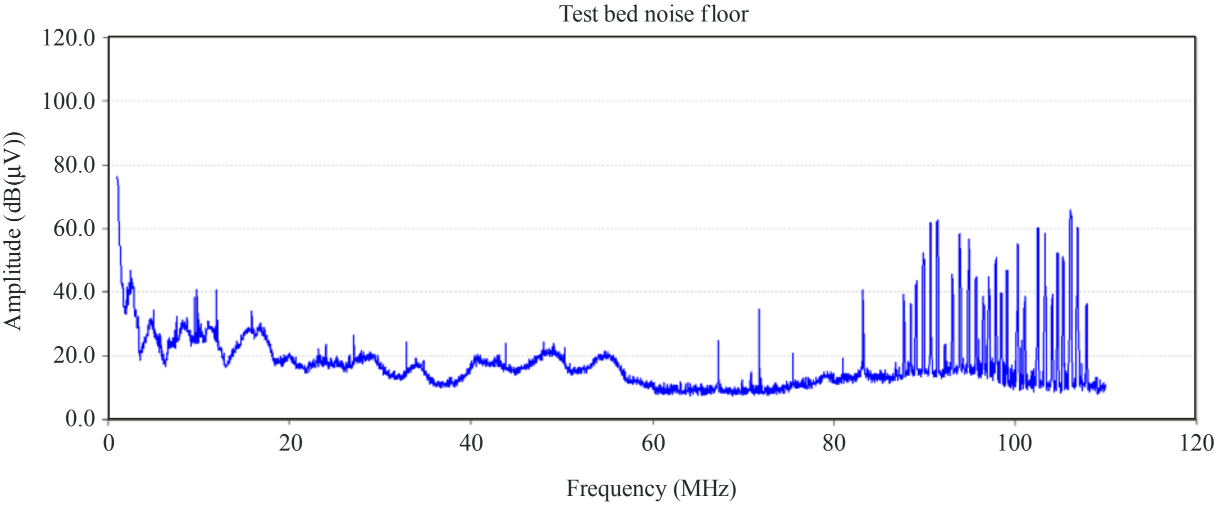
A summary is available in Report ITU-R SM.2158. The tests included measurements up to 110 MHz in order to determine the impact of the PLT devices on the FM broadcasting band.

A3.2.1 CRC measurement procedure and conducted emission results

The measurement of the test bed noise floor from 50 kHz to 110 MHz is shown in Fig. 29. 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.

FIGURE 29

Conducted measurements test setup noise floor

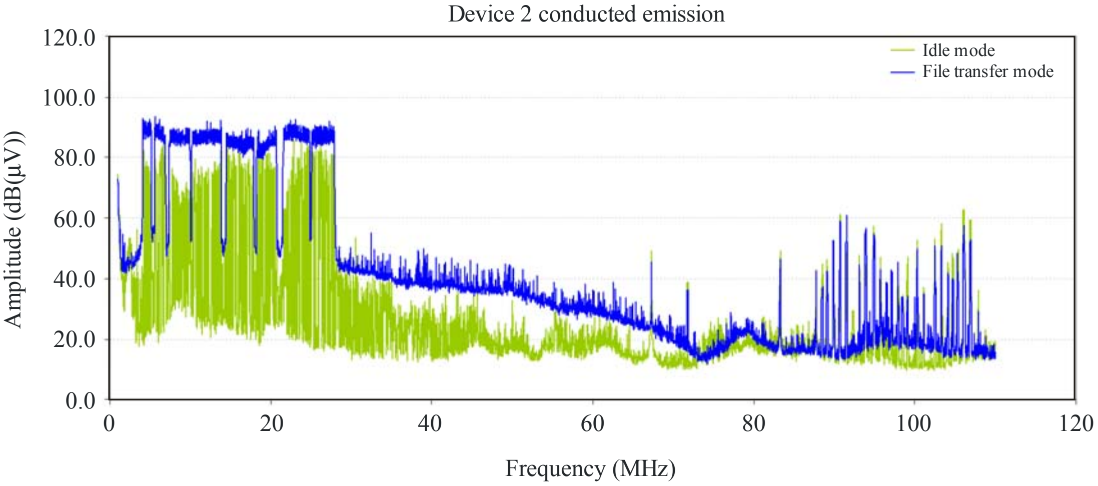


Report SM.2212-29

The results for PLT devices 2, 3 and 6 are shown in Figs 30, 31 and 32 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 do not 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.

FIGURE 30

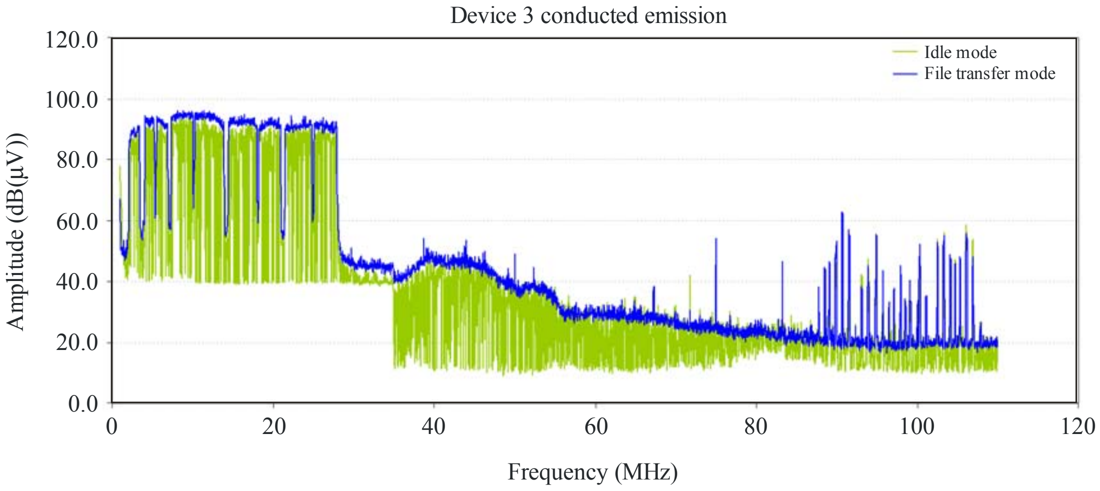
Conducted power from Device 2 (HD-PLC standard)



Report SM.2212-30

FIGURE 31

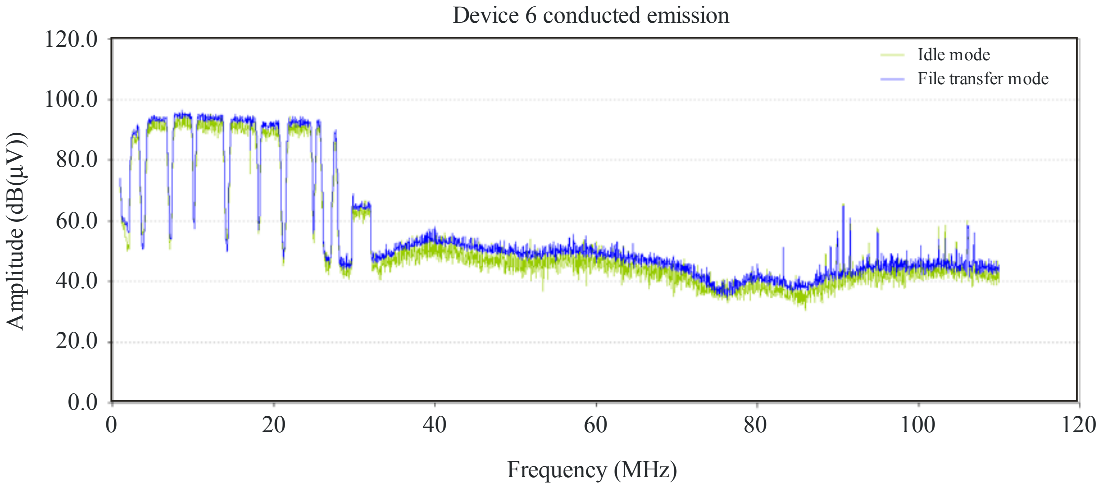
Conducted power from Device 3 (Homeplug AV standard)



Report SM.2212-31

FIGURE 32

Conducted power from Device 6 (UPA standard)



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A3.2.2 Conclusions from the CRC measurements

These results illustrate that even if the PLT device is not transmitting data, the device is actively generating radiation. It is also observed that even if the PLT device operates below 30 MHz, the device has radiation at least 20 dB above the noise floor up to 110 MHz.

A3.3 CBS Broadcasting and National Public Radio measurements of a "Gigabit" PLT modem

CBS Broadcasting and National Public Radio (NPR) conducted a series of measurements at the NPR Labs similar to those of IRT described in § A3.1. Measurements of conducted emissions were made from a pair of Belkin "Gigabit Power line HD" F5D4076-S v2 PLT modems.

A3.3.1 Measurement procedure

A pair of Belkin "Gigabit Power line HD" PLT modem adapters (Model: F5D4076-S v2) were connected with a two-wire 1.8 m extension cord and placed within a shielded test box as illustrated in Fig. 33. The shielded box provided AC power line filtering and RF coaxial connections. The PLT adapters were connected to a desktop computer and an Ethernet router to a server. File transfers were initiated from the server to the computer.

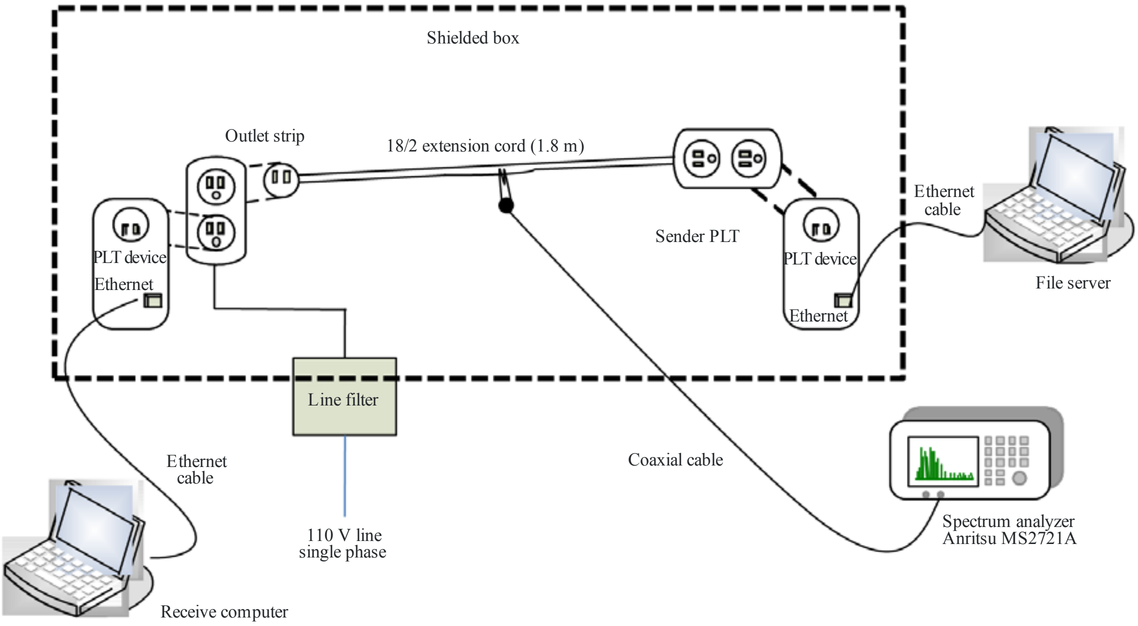
An Anritsu spectrum analyzer Model MS2721A was used to record the frequency spectrum. The spectrum analyzer settings were as follows (unless otherwise noted):

– Resolution bandwidth (RBW): 1 MHz;
– Number of measurement steps: 551/sweep;
– Without preamplifier;
– Attenuation: 0 dB;
– Measurement detector: Peak;
– Trace: Max hold.

A double wire loop provided coupling from the hot side of the power line to the spectrum analyzer. The following results illustrate the signal power as a function frequency as measured by the spectrum analyzer.

FIGURE 33

Measurement setup using a shielded box



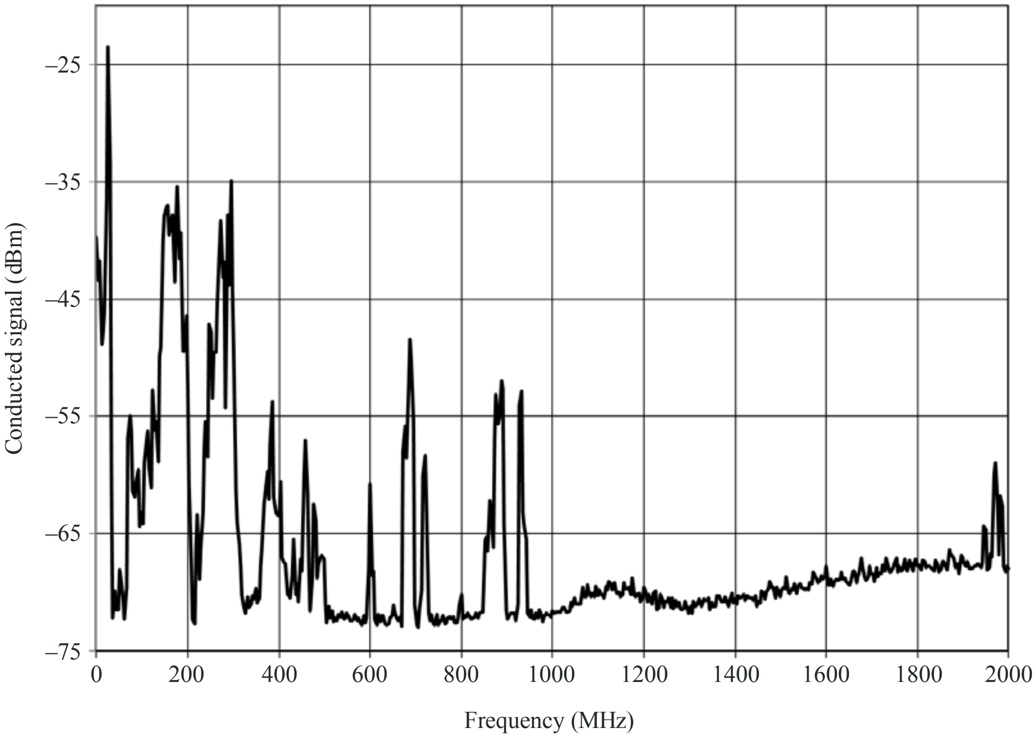
Report SM.2212-33

A3.3.2 Conducted emission measurement results for the Belkin "Gigabit power line HD" F5D4076-S v2 PLT modem

Figure 34 illustrates the signals being carried by the power line between two Belkin "Gigabit power line HD" PLT modems (Model: F5D4076 S v2) in the idle state (no data being transferred). It is noted that the adapters have a substantial output up to 300 MHz as was reported by IRT. However, the emissions extend well beyond 300 MHz up to 930 MHz with an additional signal obvious at 1 970 MHz.

FIGURE 34

Conducted emission from a pair of Belkin “Gigabit power line HD” PLT modems (Model: F5D4076-S v2) – Note that emissions occur up to 1 GHz and beyond at 1.9 GHz (RBW: 3 MHz, Reference level: –30 dBm)

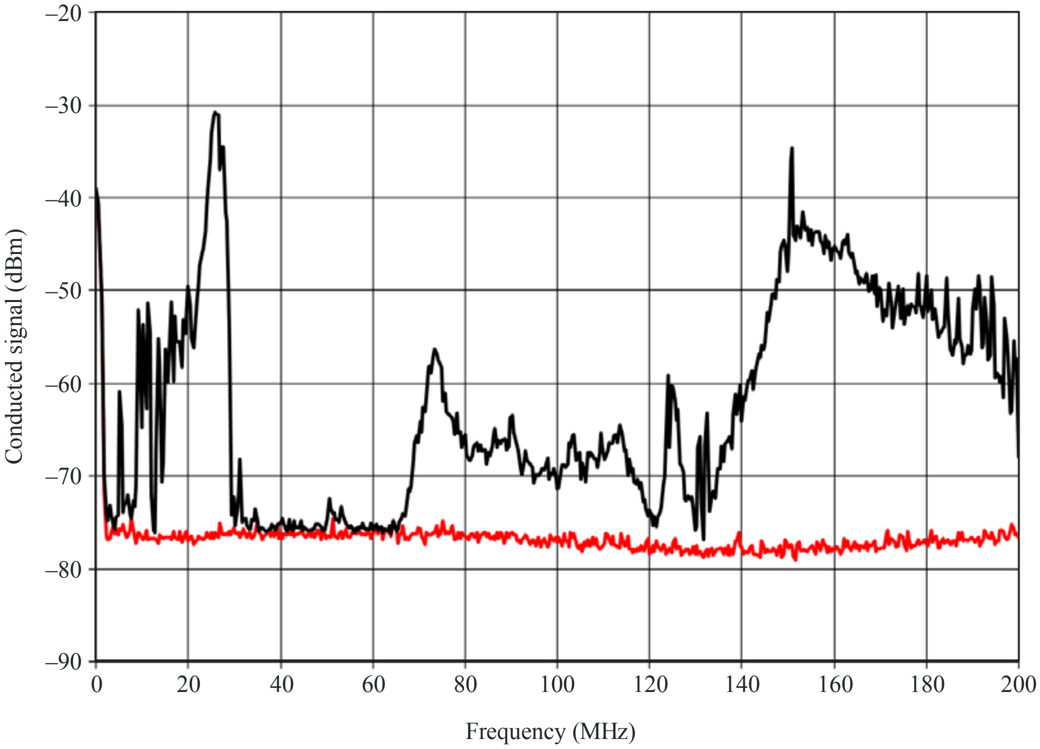


Report SM.2212-34

Figure 35 illustrates the conducted emissions from a pair of Belkin “Gigabit power line” PLT modems (Model: F5D4076-S v2) up to 200 MHz with the PLT modems in the idle state (no data being transferred). The upper trace (black) is compared to the noise floor (lower trace in red) of the shielded test box. Note that the PLT modems have substantial emissions up to 27 MHz and again above 70 MHz.

FIGURE 35

Conducted emissions from a pair of Belkin "Gigabit power line" PLT modems (Model: F5D4076-S v2) over a frequency range up to 200 MHz. The upper trace (black) represents the emission of modems while idle (no data transfer); the lower trace (red) illustrates the noise floor of the shielded test box

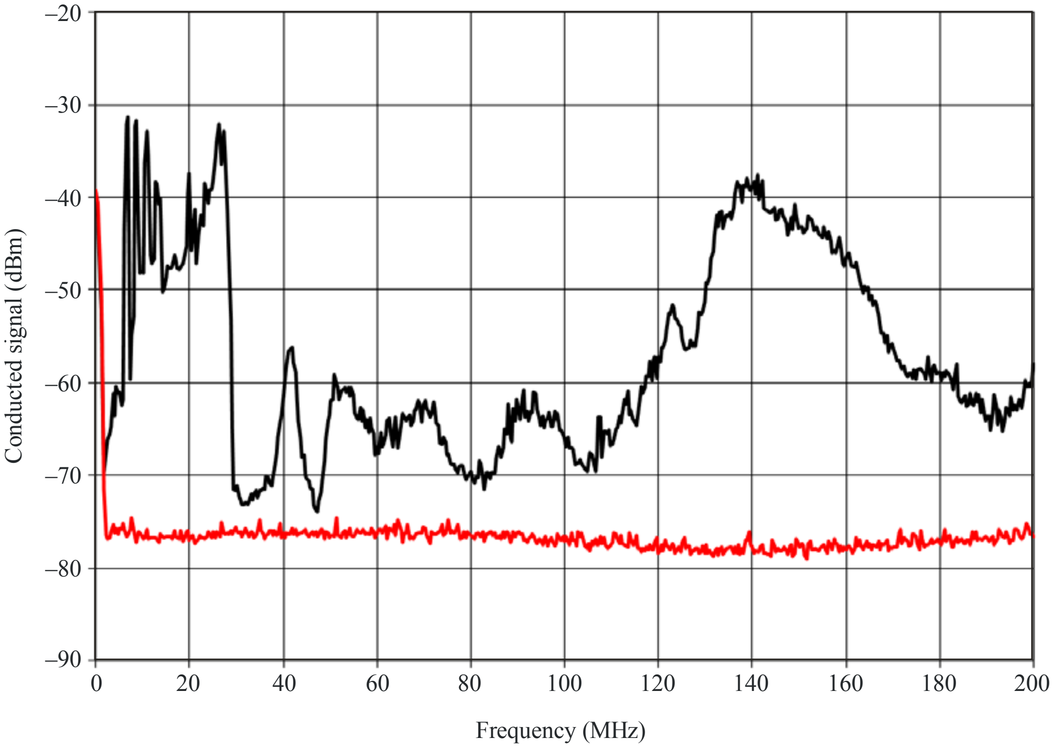


Report SM.2212-35

Figure 36 illustrates the conducted emissions from a pair of Belkin "Gigabit power line" PLT modems (Model: F5D4076-S v2) up to 200 MHz with the PLT modems in the active state (data being transferred). The upper trace (black) is compared to the noise floor (lower trace in red) of the shielded test box. Note that the PLT modems have additional emissions between 27 MHz and 70 MHz.

FIGURE 36

Conducted emissions from a pair of Belkin "Gigabit power line" PLT modems (Model: F5D4076-S v2) over a frequency range up to 200 MHz. The upper trace (black) represents the emission of modems while active (data transfer); the lower trace (red) illustrates the noise floor of the shielded test box



Report SM.2212-36

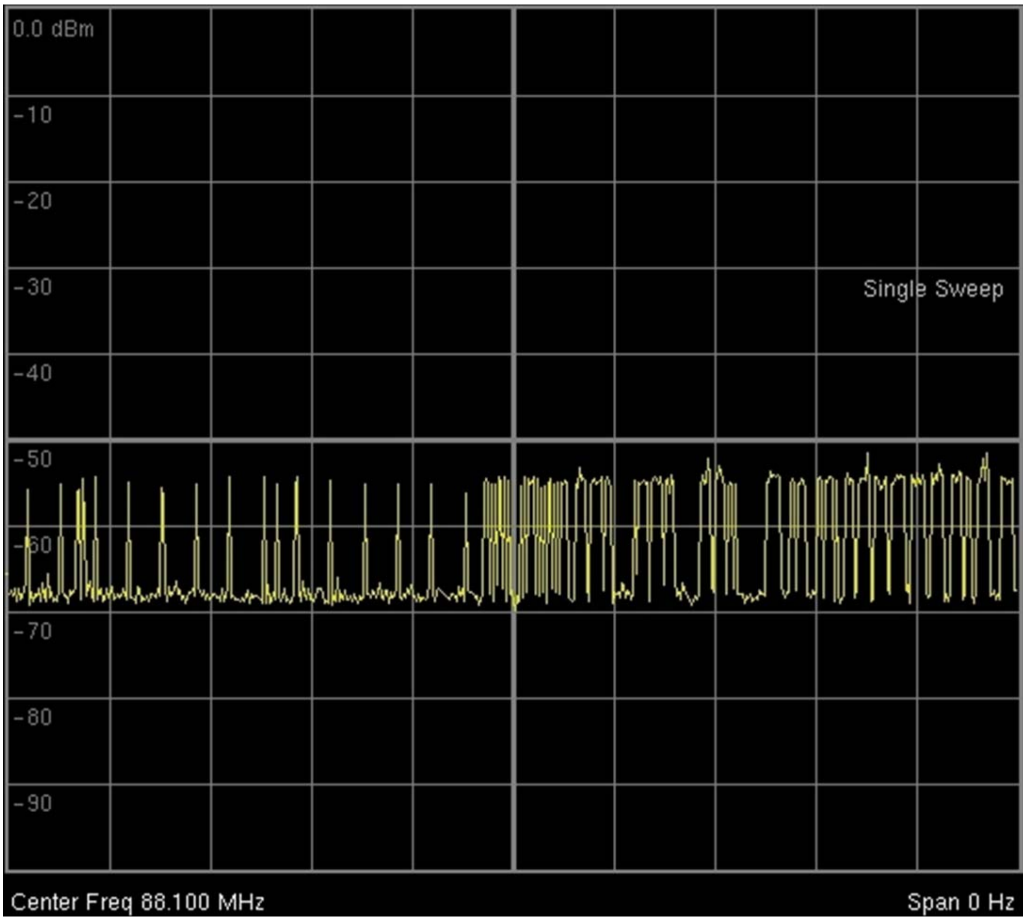
A3.3.3 FM receiver interference from the Belkin "Gigabit power line HD" F5D4076-S v2 PLT modem

Since it has been clearly shown that the PLT modems will radiate at frequencies well above 27 MHz, a test was performed using a Sony "boombox" FM broadcast receiver in the vicinity of the PLT devices. Figure 37 illustrates the conducted emissions from a pair of Belkin "Gigabit power line" PLT modems (Model: F5D4076-S v2) at a single frequency of 88.1 MHz. The spectrum analyzer shows a single sweep as the modems transition from an idle state to an active state.

The impact of the PLT interference on the FM broadcast receiver is an annoying and unacceptable "motor-boating" in the audio output. The impulse rate at idle, shown on the left half of the sweep, was approximately 40 per second, which increased during data transfer as shown in the right half.

FIGURE 37

Conducted emission over a one second interval from a pair of Belkin "Gigabit power line" PLT modems (Model: F5D4076-S v2) at a single frequency of 88.1 MHz in the FM broadcast band. The interference is exhibited as a "motor boating" effect in the audio output



Report SM.2212-37

A3.3.4 Conclusions from the CBS/NPR measurements

The CBS Broadcasting and National Public Radio (NPR) series of measurements at the NPR Labs confirm the results obtained by IRT. The Belkin "Gigabit power line HD" F5D4076-S v2 PLT modem clearly has emission throughout the radio-frequency spectrum below 1 000 MHz. Furthermore, it is the view of NABA that ITU-T Recommendation G.9960 provides no interference protection to radiocommunication services from these emissions.

A3.4 BBC measurements of radiation from PLT networks

A3.4.1 Introduction

The BBC made measurements of radiation from PLT networks in a screened room and two houses[10], with further analysis on broadcast coverage implications from BBC Distribution involving field-strength predictions and measurements. Measurements for this study took place in

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[10] BBC Research White Paper WHP 195 - VHF emissions from PLT devices: First investigation of potential interference to broadcast reception. Authors: Mark Waddell (BBC R&D) & Jonathan Stott (Jonathan Stott Consulting).

two homes, backed up by proof of procedure and calibration tests in a laboratory environment. Details on the test procedure and additional results can be found in the white paper.

With only two domestic receiving locations visited, it is difficult to extrapolate with precision from these results. However, since interference was shown to occur in conditions that were *not* equivalent to edge of coverage (indeed, there was a substantial margin above that), the number of homes whose reception of FM and DAB broadcasts would be affected if such PLT modems were widely used would clearly be appreciable. An initial assessment of the implications on service coverage and planning is given in §§ 7 and 8 of the BBC White Paper[10].

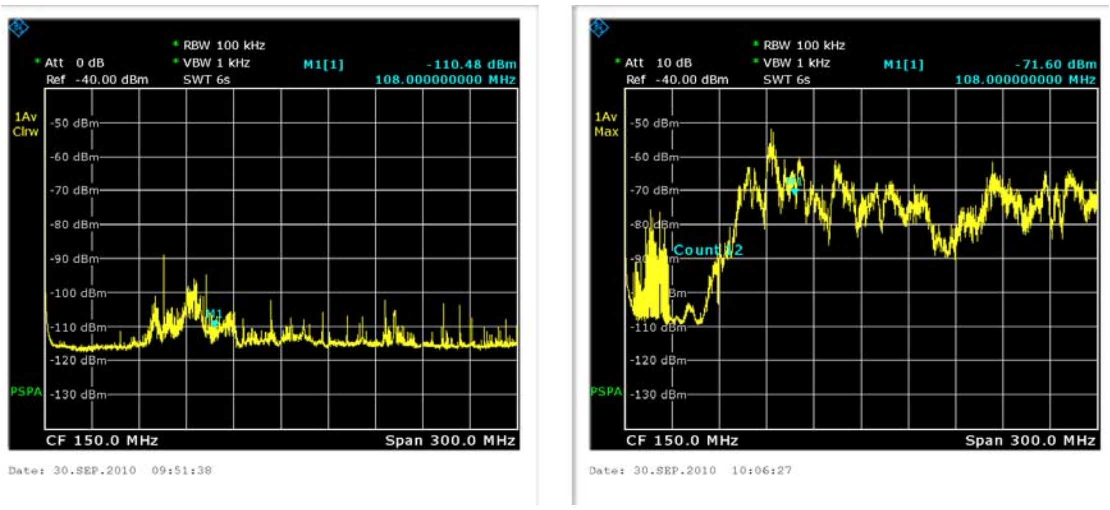
The observations and measurements contained here and in the BBC White Paper demonstrate the adverse impact of PLT on VHF broadcast reception likely to be encountered in a typical domestic environment. However, the impact of interference experience was found to vary widely with receiver location around the houses and field strength of the various transmissions available for study, as well as other factors. Instances were found in which no significant interference was noted, so it is also the case that not all homes would be so affected with the particular combination of receiver, room and transmitter commonly used by the listener. Further work should be undertaken in order to establish the degree of variability with more precision and hence achieve a better estimate of the impact of PLT on overall broadcasting coverage at VHF.

A3.4.2 Measurements in the screened room

Figure 38 shows measurements of the radiation in the screened room from 0 to 300 MHz, without (left) and with (right) the PLT network established and carrying data.

FIGURE 38

Radiation from a test PLT network as measured in a screened room



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The trace on the left of Fig. 38 shows the spectrum of the antenna signal with the PLT devices disabled, and the trace on the right shows the effect of enabling the PLT network and passing data traffic over the network. Note that the noise floor *without* the PLT network powered was not completely flat, with some radiation visible, particularly in the range 60 to 120 MHz; these signals are believed to be radiated from the spectrum analyzer itself[11] as all other equipment in the screened room was switched off for this measurement. However, the trace on the right shows that the PLT radiation were sufficiently greater in level that no confusion results. Indeed the radiation from the PLT network are some 30-40 dB higher than the noise floor of the left trace, and it was necessary to add 10 dB of attenuation at the spectrum analyzer for the trace on the right to avoid overloading; as a result it is just possible to see that the analyzer noise floor has risen correspondingly, e.g. at around 45 MHz.

Of particular interest are the strong radiation in the VHF range, from 50 to 300 MHz, which result from the network carrying data – in this case performing an FTP file transfer at about 12 Mbit/s. By way of example, once the correction factor for antenna calibration is applied, the level of radiation at 90 MHz is about 47 dB(µV/m) in a 100 kHz bandwidth. In the absence of PLT radiation, we see an analyzer noise floor of –115 dBm in the 100 kHz resolution bandwidth of the analyzer filter; this corresponds to a noise density of –165 dBm/Hz which would correspond to an analyzer noise figure of 9 dB. With the PLT network enabled and carrying traffic, the noise density increases by some 35 dB.

Although the PLT network is using VHF for the data transfer, radiation can also be seen in the HF range, below 30 MHz[12].

Interfering field strengths of the order indicated in Fig. 38 are comparable with wanted-signal strengths for VHF sound broadcasting and significant effects on reception are therefore to be expected.

Figure 39 clearly shows the significant impairment caused by PLT operation unless the wanted-signal field strength is very high. There is a range of field strengths (roughly 35 to 50 dB(µV/m)) where the audio SNR more or less tracks field strength in the absence of PLT; in this range an increase of wanted-signal field strength of roughly 20 dB is needed to restore the SNR when PLT is busy.

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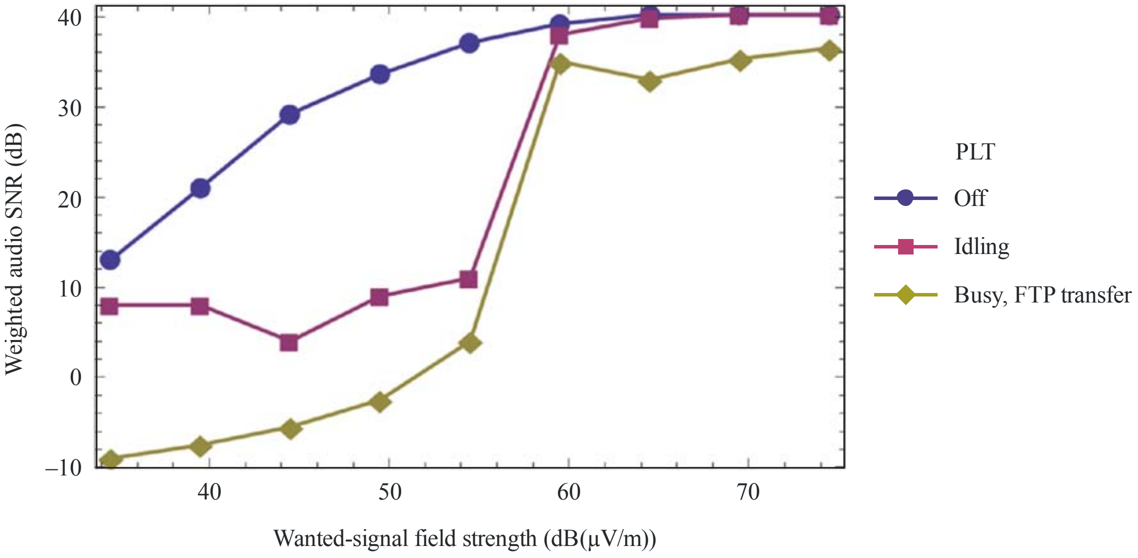
[11] Normally the measurement signal would be routed out of the screened room, with measurement apparatus like the spectrum analyzer situated outside so that any emissions from it would not reach the measurement antenna. However, on this occasion it was more convenient to make progress with the equipment and its single operator within the room.

[12] Beware of drawing too many conclusions about relative levels at HF and VHF since the measurement antenna used is not designed for HF and the calibration factor (see Appendix) alters markedly with frequency. Note also that “max-hold” mode has been used in an attempt to capture the spectrum regardless of PLT duty cycle. It appears that the PLT devices under examination will use either VHF or HF for the actual carriage of data, depending on whether the connection is adequate to provide useful capacity at VHF, but, whichever band is in use, the other band remains in an “idle mode” so that the channel behaviour can still be assessed in readiness. Thus emissions are always present to some degree in both bands.

FIGURE 39

Variation of audio SNR with wanted-signal field strength, for portable receiver in screened room with different PLT-network conditions



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A3.4.3 Measurements in Home A

Home A is a semi-detached house, well served with FM and DAB signals. National network FM signals meeting planning coverage standards are available from two transmitting stations. Home A therefore provides the opportunity to compare two scenarios of national-network FM reception at the one location. Without the test PLT network in operation, both transmitter locations readily provided satisfactory portable reception indoors.

Figure 40 shows a zero-span time-domain plot showing the pulse-like nature of the interference when the PLT network is idling.

FIGURE 40

Zero-span time-domain plot with PLT network idling

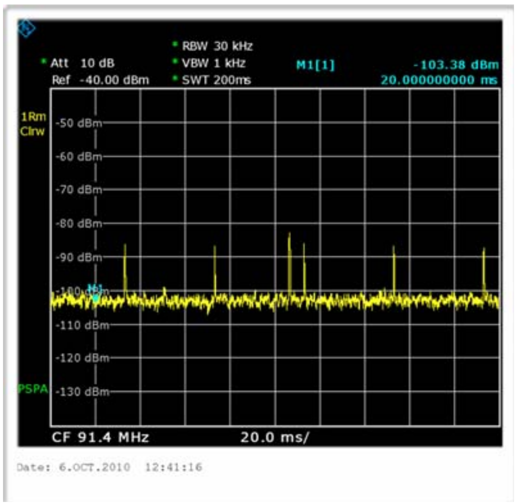
Att 10 dB
Ref -40.00 dBm
RBW 30 kHz
VBW 1 kHz
SWT 200ms
M1[1] -103.38 dBm
20.000000000 ms
CF 91.4 MHz
20.0 ms/
Date: 6.OCT.2010 12:41:16

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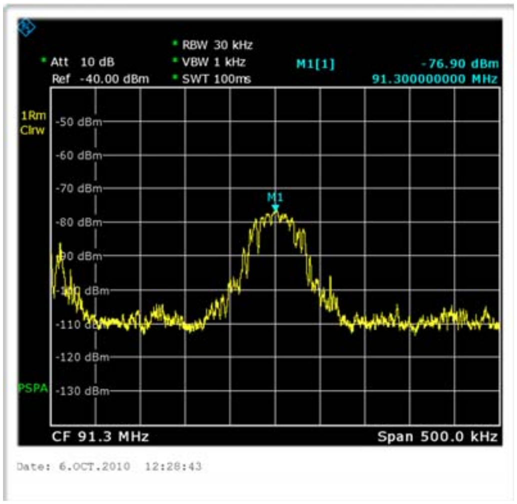
Figure 41 shows indoor reception of the wanted BBC Radio 3 FM signal from the Wrotham transmitter in the absence of PLT interference. The field strength corresponds to about 40 dB(μV/m).

FIGURE 41

BBC Radio 3 FM signal from the Wrotham transmitter in the absence of PLT interference

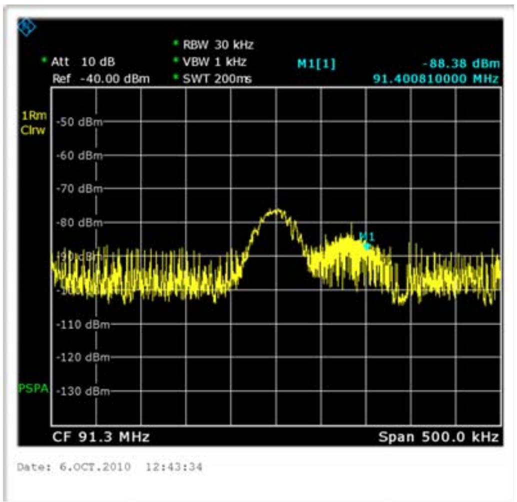


Report SM.2212-41

Figure 42 shows the spectrum when the PLT network is executing a transfer. It is clear that the (noise + interference) floor is very appreciably raised.

FIGURE 42

BBC Radio 3 FM signal from the Wrotham transmitter with PLT network executing a file transfer



Report SM.2212-42

No real impact on indoor DAB reception from the operation of the PLT network was observed at this location.

A3.4.4 Measurements in Home B

Home B is well served with national-network FM services from the Wrotham transmitter, again with signal levels available meeting planning coverage standards.

Figure 43 shows indoor FM reception, with and without the PLT network carrying data traffic. In comparison with the Home A scenario shown in Figs 41 and 42, the wanted-signal strength is about 11 dB greater while the interference is only a few dB higher, so the SIR is improved. The audible disturbance was therefore less marked, but still quite objectionable. However, reception of BBC London 94.9 MHz signal at the same location was more drastically disrupted. Its indoor field strength was measured at around 3 dB lower than the BBC Radio 3 FM signal.

Home B is also well served with national-network DAB and variously served with “local” multiplexes. The national networks give solidly reliable DAB reception with a battery-powered portable receiver throughout the property. This is not just a subjective assertion, since DAB receivers are able to give an objective measure by monitoring the operation of the internal error-correction/detection processes. The multiplexes London 1 and 3 are in practice perfectly usable, while London 2 is unreliable.

Figure 43 shows examples of spectra recorded with a few combinations of PLT network configuration and DAB receiver location. Because both PLT and DAB are broadband in comparison with the bandwidth of the spectrum analyzer in use it is possible to estimate SIR directly by visual inspection. In particular, the top left plot of Fig. 8 shows that the signals of the London 3 and both national multiplexes are clearly distinguished, while the other local multiplexes are rather weaker. There is appreciable variation with indoor location, and the bottom-right plot of Fig. 43 shows increased signal levels for all multiplexes, slightly favouring the higher-frequency multiplexes and also showing that the London local multiplexes have gained slightly relative to the national ones[13].

The top left and top right plots of Fig. 43 show reception with and without the PLT network operating for one receiver location. It is clear that the interference in this case exceeds the level of even the strongest multiplexes (e.g. the national ones) and it is no surprise that in this scenario their reception was not possible.

The bottom left plot of Fig. 43 is for the same receiver location but using a different power socket outlets for the PLT network. In this case, the SIR was slightly improved but reception of even the national networks was still significantly impaired. The bottom right plot of Fig. 43 shows reception at a different location but keeping the same PLT network route as the bottom left plot. In this case; the SIR is slightly further improved and some reception was now possible for the stronger multiplexes.

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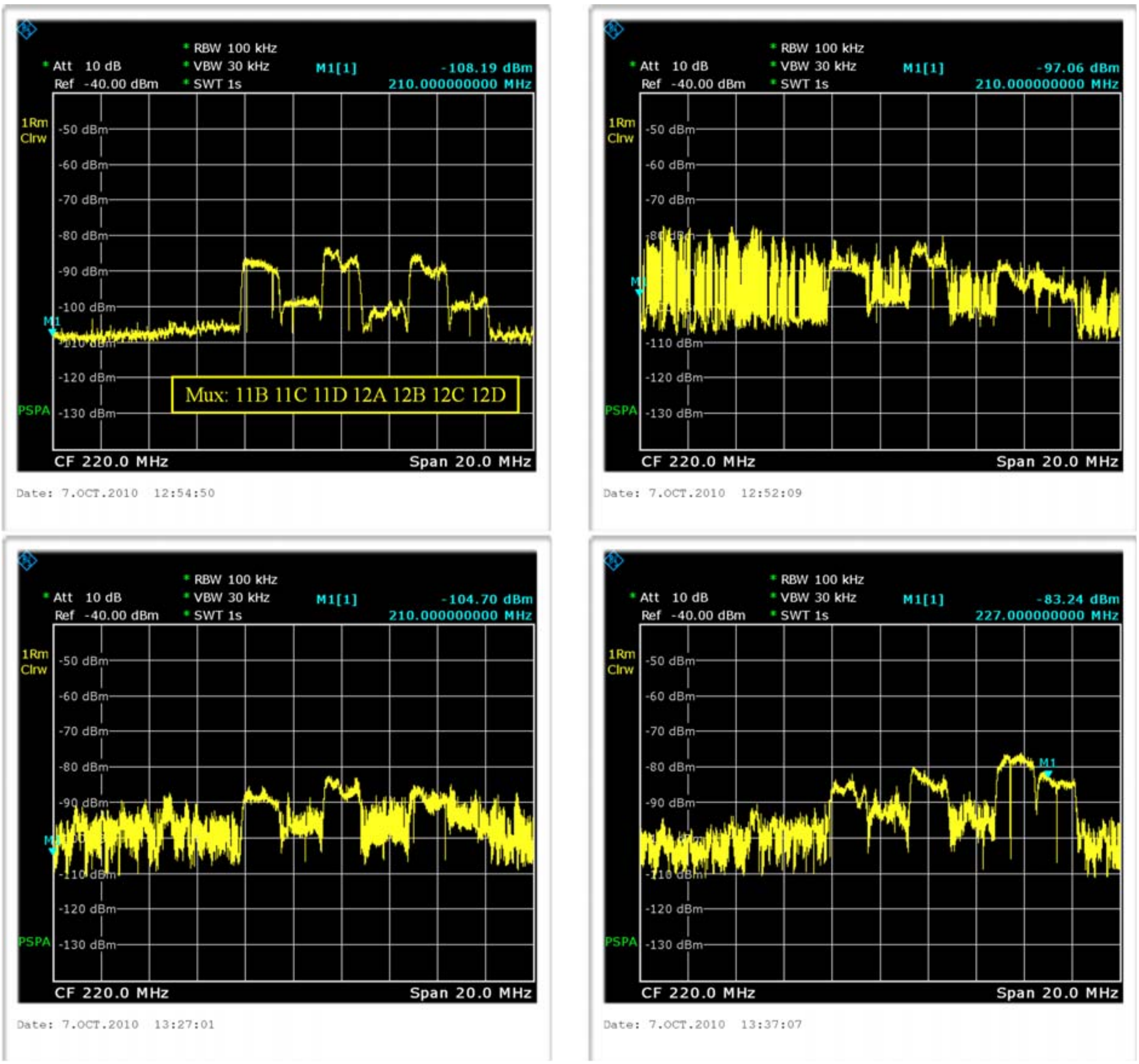
[13] The London local multiplexes use a different set of transmitter locations from the national networks; the nearest from each (Crystal Palace and Reigate respectively) is loosely north of Home B (the direction in which the sitting-room patio doors face) but not with exactly the same bearing.

FIGURE 43

DAB multiplex spectra for different combinations of indoor receiving location and PLT network configuration



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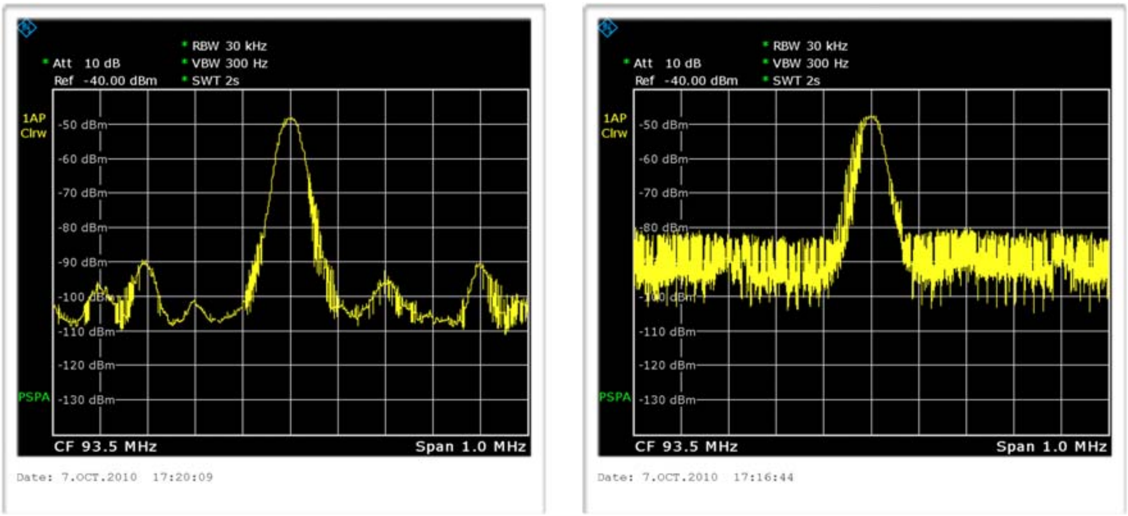
Home B is also equipped with an external antenna for Band II FM radio with a distribution amplifier in the loft so that several rooms can be fed with off-air signals.

Figure 44 shows spectra for reception of the national-network BBC Radio 4 FM 93.5 MHz (Wrotham transmitter). The left hand plot is with the PLT network tuned off and the right-hand plot is with the PLT network carrying data traffic. The noise-floor degradation from the PLT interference is clear.

FIGURE 44

Spectra of BBC Radio 4 FM (93.5 MHz, Wrotham transmitter) reception using the external antenna installation at Home B, with PLT off (left) and carrying data traffic (right)



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Care should, however, be taken in inferring SNR and SIR from these results. The spectrum analyzer used a bandwidth of 30 kHz, whereas the FM-receiver bandwidth will be appreciably greater. The receiver's RF SIR in the presence of PLT traffic will therefore be worse than the right trace suggests. Interpretation of receiver SNR from the left trace is doubly affected by the bandwidth issue and the fact that the spectrum analyzer has an attenuator in circuit in order to prevent overload.

A3.4.5 Conclusions

This study provides spectral measurements of the radiation from high-speed PLT modems in comparison with the wanted signals from Band II FM transmitters and Band III DAB transmitters. These measurements were carried out in two representative home locations together with proof of procedure and calibration tests under laboratory conditions.

The results show that the radiation from PLT are comparable to the wanted field-strengths for reception used in the established planning methods. In effect, PLT raises noise floor to a level that means that a previous good coverage areas now become borderline coverage. In effect the SNR is reduced to near to the acceptable threshold and audio quality can quickly degrade from noisy to unintelligible with only a small variation in factors such as receiver location and tropospheric propagation conditions.