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International Telecommunication Union
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Recommendation

ITU-T G.9964 (12/2023)

SERIES G: Transmission systems and media, digital systems and networks

Access networks – In premises networks

Unified high-speed wireline-based home networking transceivers – Power spectral density specification

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Recommendation ITU-T G.9964

Unified high-speed wireline-based home networking transceivers – Power spectral density specification

Summary

Recommendation ITU-T G.9964 specifies the control parameters that determine spectral content, power spectral density (PSD) mask requirements, a set of tools to support reduction of the transmit PSD, means to measure this PSD for transmission over telephone wiring, power line wiring and coaxial cable, as well as the allowable total transmit power into a specified termination impedance. It complements the system architecture and physical layer (PHY) specification in Recommendation ITU-T G.9960, the data link layer (DLL) specification in Recommendation ITU-T G.9961, as well as the modifications and additions to these Recommendations specifying the multiple input/multiple output (MIMO) home networking transceiver in Recommendation ITU-T G.9963.

This revision comprises ITU-T G.9964 (2011) plus its Amendments 1, 2 and 3, along with the addition of a narrower subcarrier spacing (12.20703125 kHz) for scenarios where the channel is very narrow (e.g., power line communication for smart grid applications).

History *

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1.1	ITU-T G.9964 (2011) Amd. 1	2016-02-26	15	11.1002/1000/12579
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Keywords

Coax, G.hn, home networking transceiver, PLC, power spectral density, powerline communication, PSD, twisted pair.

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Recommendation ITU-T G.9964

Unified high-speed wireline-based home networking transceivers – Power spectral density specification

1 Scope

This Recommendation specifies the control parameters that determine spectral content, power spectral density (PSD) mask requirements, a set of tools to support reduction of the transmit PSD, means to measure this PSD for transmission over telephone wiring, power line wiring and coaxial cable, as well as the allowable total transmit power into a specified termination impedance. It complements the system architecture and physical layer (PHY) specification in [ITU-T G.9960], and the data link layer (DLL) specification in [ITU-T G.9961] as well as the modifications and additions to these Recommendations specifying the multiple input/multiple output (MIMO) home networking transceiver in [ITU-T G.9963].

This includes support for:

– A profile for 200 MHz baseband coaxial;

– Spectral content for 200 MHz operational frequency band (OFB) for telephone lines;

– Extended bandwidth over coaxial and phoneline mediums;

– An additional subcarrier spacing of 12.20703125 kHz for narrow-band channels.

For the Profile 2 limit PSD mask (LPM) on telephone lines, in a case where transmission is not limited to networks with increased shielding, such as those with shielded cables or where cables are buried underground, conformance of equipment with this Recommendation may not ensure compliance with specific national or regional regulation on electromagnetic compatibility when installations are taken into service.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.9960] Recommendation ITU-T G.9960 (2023), *Unified high-speed wireline-based home networking transceivers – System architecture and physical layer specification.*

[ITU-T G.9961] Recommendation ITU-T G.9961 (2023), *Unified high-speed wireline-based home networking transceivers – Data link layer specification*.

[ITU-T G.9963] Recommendation ITU-T G.9963 (2023), *Unified high-speed wireline-based home networking transceivers – Multiple input/multiple output specification*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 baseband [ITU-T G.9960]: A frequency band defined by an up-convert frequency $F_{UC} = 0$ and an up-shift frequency $F_{US} = F_{SC} \times N/2$ (see Table 7-67 of [ITU-T G.9960]).

3.1.2 domain [ITU-T G.9960]: A part of an ITU-T G.9960 home network comprising the domain master and all those nodes that are registered with the same domain master. In the context of this Recommendation, use of the term "domain" without a qualifier means "ITU-T G.9960 domain", and use of the term "alien domain" means "non-ITU-T G.9960 domain". Additional qualifiers (e.g., "powerline") may be added to either "domain" or "alien domain".

3.1.3 domain master (DM) [ITU-T G.9960]: A node supporting the domain master functionality that manages (coordinates) all other nodes of the same domain (i.e., assigns bandwidth resources and manages priorities). Only one active domain master is allowed in a domain, and all nodes within a domain are managed (coordinated) by a single domain master. If a domain master fails, another node of the same domain, capable of operating as a domain master, should pick up the function of the domain master.

3.1.4 home network [ITU-T G.9960]: Two or more nodes that can communicate with each other either directly or through a relay node at the physical layer, or through an inter-domain bridge above the physical layer. A home network consists of one or more domains. In the context of this Recommendation, use of the term "home network" means "ITU-T G.9960 home network". Use of the term "alien home network" means "non-ITU-T G.9960 home network". Use of the term "network" without a qualifier means any combination of "ITU-T G.9960 home network", "non-ITU-T G.9960 home network" and "access network". Use of the term "alien network" means any combination of "non-ITU-T G.9960 home network" and "access network".

3.1.5 medium [ITU-T G.9960]: A wireline facility, of a single wire class, allowing physical connection between nodes. Nodes connected to the same medium may communicate on the physical layer, and may interfere with each other unless they use orthogonal signals (e.g., different frequency bands, different time periods).

3.1.6 node [ITU-T G.9960]: Any network device that contains an ITU-T G.9960 transceiver. In the context of this Recommendation, use of the term "node" without a qualifier means "ITU-T G.9960 node", and use of the term "alien node" means "non-ITU-T G.9960 node". Additional qualifiers (e.g., "relay") may be added to either "node" or "alien node".

3.1.7 operational frequency band (OFB) profile [ITU-T G.9960]: Categorization of OFBs depending on the PHY frame format they use. Profile 1 OFBs use a normal PHY frame format for transmission of frames; Profile 2 OFBs use a high capacity header (HCH) PHY frame format for transmission of frames.

3.1.8 operational frequency band (OFB) [ITU-T G.9960]: Range of frequencies that is allowed to be used by a node to communicate with another node of the domain.

3.1.9 radio frequency (RF) [ITU-T G.9960]: A frequency band defined by an up-convert frequency $F_{UC} > 0$ and a centre frequency $F_C = F_{UC} + F_{US} >> F_{SC} \times N/2$ (see Tables 7-67 and 7-68 of [ITU-T G.9960]).

3.1.10 subcarrier (OFDM subcarrier) [ITU-T G.9960]: The centre frequency of each orthogonal frequency division multiplexing (OFDM) sub-channel onto which bits may be modulated for transmission over the sub-channel.

3.1.11 subchannel (OFDM subchannel) [ITU-T G.9960]: A fundamental element of orthogonal frequency division multiplexing (OFDM) modulation technology. The OFDM modulator partitions the channel bandwidth into a set of parallel sub channels.

3.1.12 wire class [ITU-T G.9960]: One of the classes of wire, which has the same general characteristics: coaxial cable, home electrical-power wire, phone-line wire and Category 5 cable.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CB Coax Baseband

CRF Coax Radio Frequency

DM Domain Master

EMC Electromagnetic Compatibility

LPM Limit PSD Mask

OFB Operational Frequency Band

OFDM Orthogonal Frequency Division Multiplexing

PB Powerline Baseband

PHY Physical Layer

PSD Power Spectral Density

PSDC PSD Ceiling

PSM PSD Shaping Mask

QoS Quality of Service

RF Radio Frequency

RMS Root Mean Square

RPM Regional PSDM Mask

SM Subcarrier Mask

5 Transmit PSD mask

Transmit PSD mask (TxPSD) is determined by a subcarrier mask (SM), a PSD shaping mask (PSM), a notching of international amateur radio bands defined in this clause, the limit PSD mask (LPM) defined for each particular medium and a regional PSD mask (RPM) if specified in a regional annex (see [ITU-T G.9960]). The same TxPSD shall be applied to all nodes in the domain.

For an ITU-T G.9960 transceiver, the PSD of the transmit signal at any frequency shall never exceed the transmit PSD mask. For an ITU-T G.9963 transceiver, the sum of PSDs of the two transmit signals transmitted from the two Tx ports at any frequency shall never exceed the TxPSD. The PSD of the transmit signal may be further limited by a PSD ceiling (PSDC) that is applied to nodes involved in a particular connection (clause 5.4).

The LPM (see clauses 6.1.2, 6.2.2 and 6.3.2) specifies the absolute limit of the transmit PSD. However, if an RPM is specified for a particular region, the absolute limit shall be the minimum level between the LPM and RPM at any given frequency. The SM, PSDC and PSM provide further reduction and shaping of the transmit PSD using three mechanisms: subcarrier masking (notching), PSD ceiling (limit on PSD level) and PSD shaping.

ITU-T G.9960 and ITU-T G.9963 transceivers shall support subcarrier masking, notching of international amateur radio bands, and PSDC. Support of PSD shaping is optional.

The transmit PSD mask shall comply with national and regional regulatory requirements.

The LPM is defined based on the assumption that measurements are made using equipment conforming to [b-IEC CISPR 16-1] specifications using a root mean square (RMS) detector with a "maximum hold" function and using a resolution bandwidth of 9 kHz for frequencies below 30 MHz and 120 kHz for frequencies above 30 MHz. In order to conform to [b-IEC CISPR 22] and make reliable measurements, ITU-T G.9960 transceivers shall be active at least 10% of the time and sustain the transmit power level for a minimum of 250 ms.

NOTE – In addition to the mechanisms described in this clause that provide absolute limits to the transmit PSD (both in-band and out-of-band), this Recommendation defines a mechanism of PSDC that allows dynamic reduction of the transmit power for each particular connection to the minimum value that is sufficient to achieve the given quality of service (QoS) targets.

5.1 Subcarrier masking

Subcarrier masking shall be used to eliminate transmission on one or more subcarriers. Subcarrier masking is defined by a SM. The transmit power of subcarriers specified in SM shall be set to zero (linear scale). The SM shall override all other instructions related to the transmit power of the subcarrier.

The SM is defined as a number of masked frequency bands. Each band is specified by a start sub carrier index (x_L) and a stop subcarrier index (x_H), as $\{x_L, x_H\}$. An SM including S bands can be represented in the following format:

$$SM(S) = [\{x_{L1}, x_{H1}\}, \{x_{L2}, x_{H2}\}, \ldots \{x_{LS}, x_{HS}\}]$$

All subcarriers within the band, i.e., with indices higher than or equal to x_L and lower than or equal to x_H, shall be switched off (transmitted with zero power).

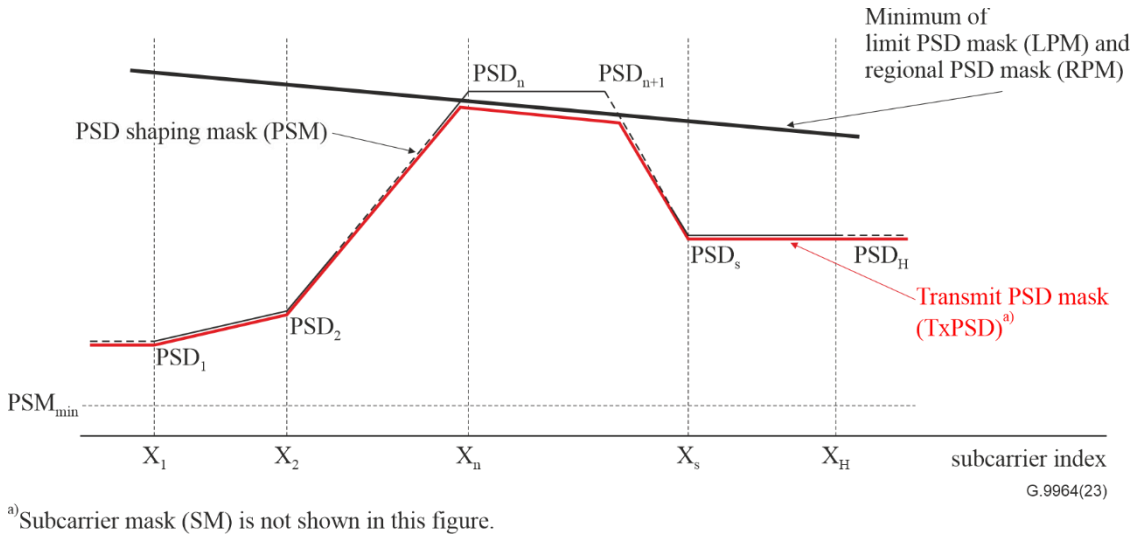
International amateur radio bands (see Annex D) are not a part of the SM. The node shall be capable of turning off one or more amateur radio bands.

NOTE – The SM is intended to incorporate masked subcarriers that are defined by the regional annex to comply with local regulations, and masked subcarriers that are defined by the user or service provider to facilitate local deployment practices.

5.2 Power spectral density shaping

PSD shaping allows transmit reduction of PSD in some parts of the spectrum, mainly for spectrum compatibility and coexistence with alien home network technologies. PSD shaping is specified by a PSM.

PSM is defined on the frequency range between the lowest subcarrier x_1 and the highest subcarrier x_H, and consists of one or more frequency segments. The boundaries of the segments are defined by set breakpoints. Inside each segment, the PSD may either be constant or form a linear slope between the given PSD points (in dBm/Hz) with the frequency expressed in a linear scale, Figure 5-1.



a)Subcarrier mask (SM) is not shown in this figure.

Figure 5-1 – Construction of transmit PSD mask

Each breakpoint of PSM is specified by a subcarrier index x_n and a value of PSD_n at that sub carrier expressed in dBm/Hz, $\{x_n, PSD_n\}$. PSD_1 shall also apply to subcarriers below x_1 and PSD_H shall also apply to subcarriers above x_H. A PSM including S segments can be represented by $(S + 1)$ breakpoints in the following format:

$$\text{PSM(S)} = [\{x_1, PSD_1\}, \{x_2, PSD_2\} \ \ldots \ \{x_S, PSD_S\}, \{x_H, PSD_H\}]$$

A node supporting PSD shaping shall support up to 32 PSM breakpoints.

The maximum steepness of PSM slopes is for further study.

If one or more PSM breakpoints are set above the LPM or regional PSD mask (RPM), the transmit PSD mask shall be set to: TxPSD = min(PSM, LPM, RPM). All values of PSD_n of PSM breakpoints shall be set above PSM_{min}. The value of PSM_{min} shall not be more than 30 dB below the peak of the PSD shaping mask.

NOTE – PSM breakpoints do not have any relation with SM breakpoints; SM and notched international amateur radio bands always override the PSM if defined over the same indices.

5.3 Notching of international amateur radio bands

If an amateur radio band is masked, the subcarriers with frequencies $(F_{AL} - F_{SC}) \leq f \leq (F_{HL} + F_{SC})$, where F_{AL} and F_{HL} are the low and the high frequency of the amateur radio band, as defined in Annex D, shall be turned off (zero power transmitted). In addition, for any node operating over a telephone line or power line, the PSD of the transmitted signal in all international amateur radio bands that are masked in the particular domain shall be at −85 dBm/Hz or lower.

The PSD slopes forming a notch are vendor discretionary.

5.4 Power spectral density ceiling

The PSDC specifies the PSD level that is used to impose a limit (i.e., a ceiling function) on the transmit signal. The PSDC is independent of frequency and indicated by a single value in dBm/Hz. The valid range of PSDC values is from −50 dBm/Hz to −100 dBm/Hz in steps of 2 dB.

The PSDC shall be supported by all ITU-T G.9960 transceivers.

5.5 Notching of VDSL2 bands

Any node operating over a telephone line, coax or power line, shall be able to reduce the PSD of the transmitted signal in one or more VDSL2 frequency bands to the levels appropriate for reliable transmission of VDSL2 signals, as defined in Annex E.

6 Medium-dependent specification of spectral content

6.1 Specification of spectral content for telephone lines

6.1.1 Control parameters

Table 6-1 shows the valid OFDM control parameters for various OFBs defined in telephone lines. The parameters are defined in [ITU-T G.9960].

Table 6-1 – OFDM control parameters for telephone lines

Domain type	**Telephone line** (Note 5)			
OFB name	**Profile 1**			**Profile 2** (Note 6)
	50 MHz-TB (Note 2)	**100 MHz-TB** (Note 3)	**200 MHz-TB** (Note 4)	
Minimum operational frequency	0 MHz	0 MHz	0 MHz	OF_{MIN}
Maximum operational frequency	50 MHz	100 MHz	200 MHz	OF_{MAX}
N	1024	2048	4096	$(OF_{MAX} - OF_{MIN})/F_{SC}$
F_{SC}	48.828125 kHz	48.828125kHz	48.828125 kHz	48.828125 kHz
S (Sampling frequency)	$N \times F_{SC}$	$N \times F_{SC}$	$N \times F_{SC}$	$N \times F_{SC}$
N_{GI}	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s
$N_{GI\text{-}HD}$	$N/4$ = 256 samples @ S Msamples/s	$N/4$ = 512 samples @ S Msamples/s	$N/4$ = 1024 samples @ S Msamples/s	$N/4$ samples @ S Msamples/s
$N_{GI\text{-}DF}$	$N/4$ = 256 samples @ S Msamples/s	$N/4$ = 512 samples @ S Msamples/s	$N/4$ = 1024 samples @ S Msamples/s	$N/4$ samples @ S Msamples/s
β	$N/32$ = 32 samples @ S Msamples/s	$N/32$ = 64 samples @ S Msamples/s	$N/32$ = 128 samples @ S Msamples/s	$N/32$ samples @ S Msamples/s
F_{US}	25 MHz	50 MHz	100 MHz	$(OF_{MAX} - OF_{MIN})/2$
F_{UC}	0 MHz	0 MHz	0 MHz	OF_{MIN}
Subcarrier indexing rule (Note 1)	Rule #1	Rule #1	Rule #1	Rule #1
NOTE 1 – See clause 7.1.4.1 of [ITU-T G.9960] for more details on subcarrier indexing rules. NOTE 2 – The range of subcarrier frequencies is between 0 and 50 MHz. NOTE 3 – The range of subcarrier frequencies is between 0 and 100 MHz. NOTE 4 – The range of subcarrier frequencies is between 0 and 200 MHz.				

Table 6-1 – OFDM control parameters for telephone lines

Domain type	**Telephone line** (Note 5)			
OFB name	**Profile 1**			**Profile 2** (Note 6)
	50 MHz-TB (Note 2)	**100 MHz-TB** (Note 3)	**200 MHz-TB** (Note 4)	
NOTE 5 – Telephone-line baseband profile is also applicable to any other pair-based copper cable (e.g., Cat5) NOTE 6 – OF_{MAX} and OF_{MIN} correspond to the maximum and minimum frequency that may be used during a Profile 2 OFB transmission. $OF_{MAX} – OF_{MIN}$ shall be a multiple of 50 MHz.				

6.1.2 PSD mask specifications over telephone lines

The LPM for operation over telephone lines (50 MHz-TB, 100 MHz-TB and 200 MHz-TB OFBs) shall be as presented in Figure 6-1 for 50 MHz-TB and 100 MHz-TB OFBs, as in Figure 6-1.1 for 200 MHz-TB OFB and as in Figure 6-1.2 for Profile 2 OFBs, with the values of frequencies f_L–f_H as presented in Tables 6-2 and 6-3.

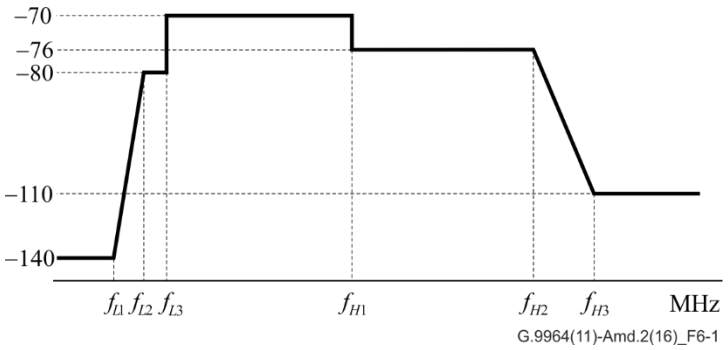


Figure 6-1 – LPM for transmission over telephone lines (amateur radio-band notches are not shown)

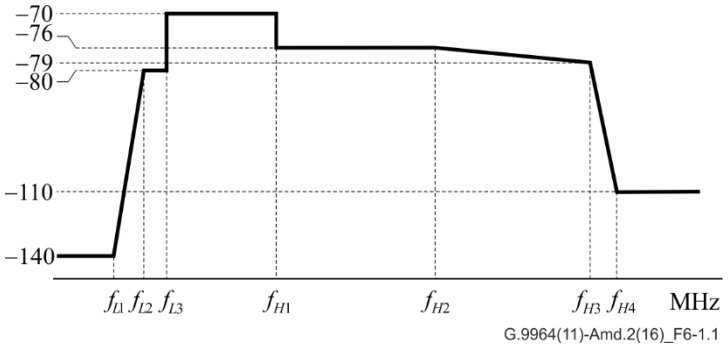


Figure 6-1.1 – LPM for transmission over telephone lines (amateur radio-band notches are not shown)

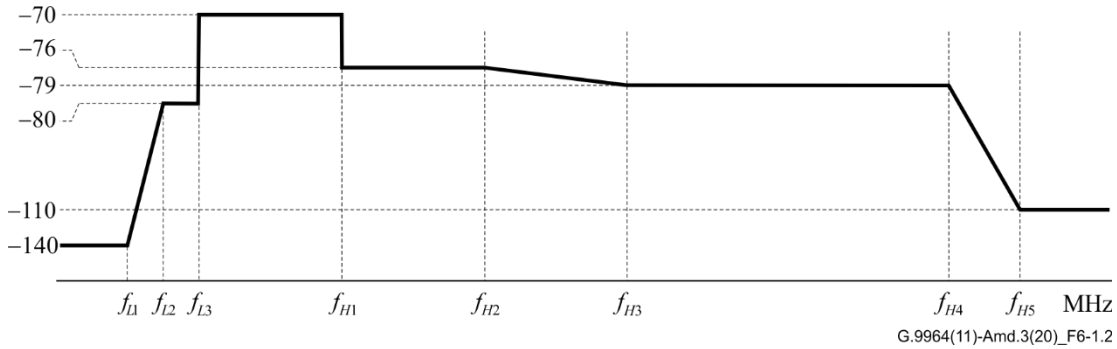


Figure 6-1.2 – LPM for transmission over telephone lines (amateur radio-band notches are not shown)

The values of frequency spectrum parameters for 50 MHz-TB, 100 MHz-TB, 200 MHz-TB and Profile 2 OFBs are presented in Tables 6-2, 6-3, 6-3.1 and 6-3.2 respectively. Intermediate points between those defined in Figures 6-1, 6-1.1 and 6-1.2 shall be obtained by linear interpolation (in dB over linear frequency scale).

Table 6-2 – Parameters of LPM for the 50 MHz-TB OFB

Parameters	Frequency, MHz	PSD, dBm/Hz	Note/Description
f_{L1}	1.7	−140	Provides protection of splitterless ADSL
f_{L2}	3.5	−80	Coincides with the amateur radio band
f_{L3}	4.0		
$f_{L3} + \Delta F$	$4.0 + \Delta F$	−70	ΔF is an arbitrary small positive value
$f_{H1} - \Delta F$	$30 - \Delta F$	−70	ΔF is an arbitrary small positive value
f_{H1}	30	−76	
f_{H2}	50		
f_{H3}	60	−110	
NOTE – Subcarriers above $f_{H2} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

Table 6-3 – Parameters of LPM for the 100 MHz-TB OFB

Parameters	Frequency, MHz	PSD, dBm/Hz	Note/Description
f_{L1}	1.7	−140	Provides protection of splitterless ADSL
f_{L2}	3.5	−80	Coincides with the amateur radio band
f_{L3}	4.0		
$f_{L3} + \Delta F$	$4.0 + \Delta F$	−70	ΔF is an arbitrary small positive value
$f_{H1} - \Delta F$	$30 - \Delta F$	−70	ΔF is an arbitrary small positive value
f_{H1}	30	−76	
f_{H2}	100		
f_{H3}	120	−110	
NOTE – Subcarriers above $f_{H2} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

Table 6-3.1 – Parameters of LPM for the 200 MHz-TB OFB

Parameters	Frequency, MHz	PSD, dBm/Hz	Note/Description
f_{L1}	1.7	−140	Provides protection of splitterless ADSL
f_{L2}	3.5	−80	Coincides with the amateur radio band
f_{L3}	4.0		
$f_{L3} + \Delta F$	$4.0 + \Delta F$	−70	ΔF is an arbitrary small positive value
$f_{H1} - \Delta F$	$30 - \Delta F$	−70	ΔF is an arbitrary small positive value
f_{H1}	30	−76	
f_{H2}	100		
f_{H3}	200	−79	
f_{H4}	240	−110	
NOTE – Subcarriers above $f_{H2} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

Table 6-3.2 – Parameters of LPM for Profile 2 OFBs

Parameters	Frequency, MHz	PSD, dBm/Hz	Note/Description
f_{L1}	1.7	−140	Provides protection of splitterless ADSL
f_{L2}	3.5	−80	Coincides with the amateur radio band
f_{L3}	4.0		
$f_{L3} + \Delta F$	$4.0 + \Delta F$	−70	ΔF is an arbitrary small positive value
$f_{H1} - \Delta F$	$30 - \Delta F$	−70	ΔF is an arbitrary small positive value
f_{H1}	30	−76	
f_{H2}	100		
f_{H3}	200	−79	
f_{H4}	400	−79	
f_{H5}	480	−110	
NOTE – Subcarriers above $f_{H2} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

NOTE 1 – When additional spectrum shaping is used as described in clause 5.2 (e.g., to provide spectrum compatibility, comply with wideband power limit, or other), various parts of this PSD mask could be reduced by switching subcarriers off or reducing their transmit power. Additional frequency notches may be applied if required.

NOTE 2 – VDSL2 is usually deployed using a service splitter ([b-ITU-T G.993.2] does not encourage splitterless VDSL2 installations). This allows the use of the ITU-T G.9960 spectrum down to f_{L3}. If splitterless VDSL2 is used, the low frequency of the ITU-T G.9960 spectrum shall be moved up and set above the upper downstream subcarrier of VDSL2.

See clause 7.2.1 of [ITU-T G.9960] for further physical layer specification of operation over telephone lines.

6.1.3 Permanently masked subcarriers

Subcarriers 0–72 (inclusive) shall be permanently masked over telephone lines. They shall not be used for transmission (neither data nor any auxiliary information).

6.2 Specification of spectral content for power lines

6.2.1 Control parameters

Table 6-4 shows the valid OFDM control parameters for various OFBs defined in power lines. The parameters are defined in [ITU-T G.9960].

Table 6-4 – OFDM control parameters for power lines

Domain type	**Powerline baseband**		
OFB name	**Profile 1**		
	25 MHz – PB (Note 3)	50 MHz – PB (Note 3)	100 MHz – PB (Note 3)
N	1024	2048	4096
k_{SS}	0.5 or 1 (Note 4)	0.5 or 1 (Note 4)	0.5 or 1 (Note 4)
F_{SC}	k_{SS} *24.4140625 kHz	k_{SS} *24.4140625 kHz	k_{SS} *24.4140625 kHz
N_{GI}	$N/32 \times k$ for k = 1,…,8 samples @ 25 Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ 50 Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ 100 Msamples/s
$N_{GI\text{-}HD}$	$N/4$ = 256 samples @ 25 Msamples/s	$N/4$ = 512 samples @ 50 Msamples/s	$N/4$ = 1024 samples @ 100 Msamples/s
$N_{GI\text{-}DF}$	$N/4$ = 256 samples @ 25 Msamples/s	$N/4$ = 512 samples @ 50 Msamples/s	$N/4$ = 1024 samples @ 100 Msamples/s
β	$N/8$ = 128 samples @ 25 Msamples/s	$N/8$ = 256 samples @ 50 Msamples/s	$N/8$ = 512 samples @ 100 Msamples/s
F_{US}	k_{SS} *12.5 MHz	k_{SS} *25 MHz	k_{SS} *50 MHz
F_{UC}	0 MHz	0 MHz	0 MHz
Subcarrier indexing rule (Note 1)	Rule #1	Rule #1	Rule #1
NOTE 1 – See clause 7.1.4.1 of [ITU-T G.9960] for more details on subcarrier indexing rules. NOTE 2 – The 25 MHz, 50 MHz and 100 MHz OFBs may be used by nodes operating in the same powerline baseband domain. NOTE 3 – The range of subcarrier frequencies is between 0 and $2\times F_{US}$ MHz. NOTE 4 – A subcarrier spacing factor of k_{SS} = 0.5 is defined for scenarios where the channel is very narrow (e.g., power line communication for smart grid applications).			

6.2.2 PSD mask specifications over power lines

The baseband LPMs for operation over power lines shall be as presented in Figure 6-2 for the 25 MHz-PB, 50 MHz-PB and 100 MHz-PB with the values of frequencies F_L – f_H as presented in Table 6-5.

NOTE 1 – PSD levels may be further limited by electromagnetic compatibility (EMC) regulatory requirements.

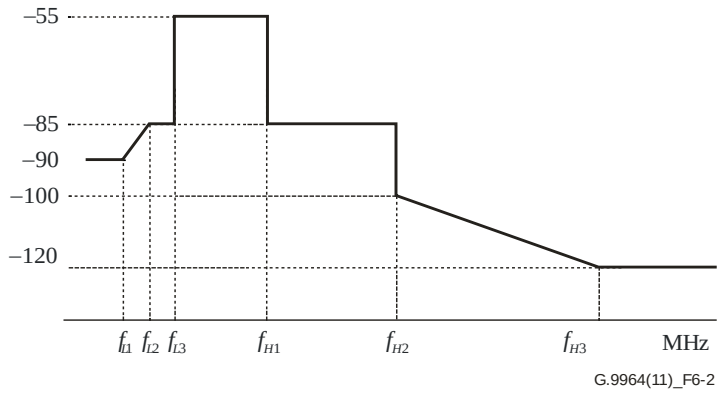


Figure 6-2 – LPM for baseband transmission over power lines for 25 MHz-PB, 50 MHz-PB and 100 MHz-PB OFBs (amateur radio-band notches are not shown)

The values of frequency spectrum parameters for 25 MHz-PB, 50 MHz-PB and 100 MHz-PB are presented in Table 6-5. Intermediate points between those defined in Figure 6-2 are obtained by linear interpolation (in dB over linear frequency scale).

Table 6-5 – Parameters of LPM for the 25 MHz-PB, 50 MHz-PB, and 100 MHz-PB OFBs

Parameters	Frequency (MHz)	PSD (dBm/Hz)	Note/Description
f_{L1}	1.1	−90	Additional reduction below 1.1 MHz is to reduce crosstalk into ADSL
f_{L2}	1.8	−85	Coincides with the amateur radio band
f_{L3}	2.0		
$f_{L3} + \Delta F$	$2.0 + \Delta F$	−55	ΔF is an arbitrary small positive value
$f_{H1} - \Delta F$	$30 - \Delta F$	−55	ΔF is an arbitrary small positive value
f_{H1}	30	−85	ΔF is an arbitrary small positive value
$f_{H2} - \Delta F$	$100 - \Delta F$		
f_{H2}	100	−100	
f_{H3}	250	−120	
NOTE – Subcarriers above $f_{H2} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

NOTE 2 – If additional spectrum shaping is used, as described in clause 5.2 (e.g., to provide spectrum compatibility with VDSL2, or to comply with the wideband power limit), various parts of this PSD mask could be reduced by switching subcarriers off or reducing their transmit power. Additional frequency notches may be applied if required.

Subcarriers with frequencies (80 MHz – F_{SC}) ≤ f ≤ (100 MHz + F_{SC}) shall be masked (zero power transmitted) via SM unless the usage of this band is allowed by the regional regulation.

See clause 7.2.2 of [ITU-T G.9960] for further physical layer specification of operation over power lines.

6.2.3 Permanently masked subcarriers

For baseband transmissions, subcarriers 0-74 (inclusive) shall be permanently masked over power lines. They shall not be used for transmission (neither data nor any auxiliary information).

6.3 Specification of spectral content for coax

6.3.1 Control parameters

Table 6-6 shows the valid OFDM control parameters for various OFBs defined in coax cable. The parameters are defined in [ITU-T G.9960].

Table 6-6 – OFDM control parameters for coax cables

Domain type	**Coax baseband** (Note 2)			**Coax**	**Coax RF** (Note 2)	
OFB name	**Profile 1 OFBs**			**Profile 2 OFB** (Note 10)	**Profile 1 OFBs**	
	50 MHz-CB (Note 4)	**100 MHz-CB** (Note 5)	**200 MHz-CB** (Note 9)		**50 MHz-CRF** (Note 6)	**100 MHz-CRF** (Note 7)
Minimum operational frequency	0 MHz	0 MHz	0 MHz	OF_{MIN}	0 MHz	0 MHz
Maximum operational frequency	50 MHz	100 MHz	200 MHz	OF_{MAX}	50 MHz	100 MHz
F_{SC}	195.3125 kHz	195.3125 kHz	195.3125 kHz	48.828125 kHz	195.3125 kHz	195.3125 kHz
S (Sampling frequency)	$N \times F_{SC}$	$N \times F_{SC}$	$N \times F_{SC}$	$N \times F_{SC}$	$N \times F_{SC}$	$N \times F_{SC}$
N_{GI}	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s	$N/32 \times k$ for k = 1,…,8 samples @ S Msamples/s
$N_{GI\text{-}HD}$	$N/4$ = 64 samples @ S Msamples/s	$N/4$ = 128 samples @ S Msamples/s	*$N/4$ = 256 samples @ S Msamples/s*	$N/4$ samples @ S Msamples/s	$N/4$ = 64 samples @ S Msamples/s	$N/4$ = 128 samples @ S Msamples/s
$N_{GI\text{-}DF}$	$N/4$ = 64 samples @ S Msamples/s	$N/4$ = 128 samples @ S Msamples/s	*$N/4$ = 256 samples @ S Msamples/s*	$N/4$ samples @ S Msamples/s	$N/4$ = 64 samples @ S Msamples/s	$N/4$ = 128 samples @ S Msamples/s
β	$N/32$ = 8 samples @ S Msamples/s	$N/32$ = 16 samples @ S Msamples/s	$N/32$ = 32 samples @ S Msamples/s	$N/32$ samples @ S Msamples/s	$N/32$ = 8 samples @ S Msamples/s	$N/32$ = 16 samples @ S Msamples/s
F_{US}	25 MHz	50 MHz	100 MHz	$(OF_{MAX} - OF_{MIN})/2$	25 MHz	50 MHz
F_{UC}	0 MHz	0 MHz	0 MHz	OF_{MIN}	*X* (Note 3)	*Y* (Note 3)
Subcarrier indexing rule (Note 1)	Rule #1	Rule #1	Rule #1	Rule #1	Rule #1 if *X* = *Y*, or rule #2 if *X* + 25 MHz = *Y* + 50 MHz (Note 8)	Rule #1 if *X* = *Y*, or rule #2 if *X* + 25 MHz = *Y* + 50 MHz (Note 8)

NOTE 1 – See clause 7.1.4.1 of [ITU-T G.9960] for more details on subcarrier indexing rules.

NOTE 2 – The 50 MHz, 100 MHz and 200 MHz OFBs may be used by nodes operating in the same coax baseband domain. The same principle applies to 50 MHz and 100 MHz OFBs defined for coax RF domain.

NOTE 3 – The values of F_{UC} shall be selected from the valid set defined in Table 7-67 of [ITU-T G.9960] and may be subject to regional spectrum management rules (see regional annexes).

Table 6-6 – OFDM control parameters for coax cables

Domain type	**Coax baseband** (Note 2)			**Coax**	**Coax RF** (Note 2)	
OFB name	**Profile 1 OFBs**			**Profile 2 OFB** (Note 10)	**Profile 1 OFBs**	
	50 MHz-CB (Note 4)	**100 MHz-CB** (Note 5)	**200 MHz-CB** (Note 9)		**50 MHz-CRF** (Note 6)	**100 MHz-CRF** (Note 7)
NOTE 4 – The range of subcarrier frequencies is between 0 and 50 MHz.						
NOTE 5 – The range of subcarrier frequencies is between 0 and 100 MHz.						
NOTE 6 – The range of subcarrier frequencies is between *X* MHz and (*X* + 50) MHz.						
NOTE 7 – The range of subcarrier frequencies is between *Y* MHz and (*Y* + 100) MHz.						
NOTE 8 – The specific indexing rule is specified in each regional annex.						
NOTE 9 – The range of subcarrier frequencies is between 0 and 200 MHz.						
NOTE 10 – $OF_{MAX} - OF_{MIN}$ shall be a multiple of 50 MHz						

6.3.2 PSD mask specifications over coax

The LPM for operation over coax RF is presented in Figure 6-3 with the frequencies as presented in Table 6-7 (50 MHz-CRF OFB) and Table 6-8 (100 MHz-CRF OFB) where the bandwidth $BW = f_{H1} - f_{L3}$.

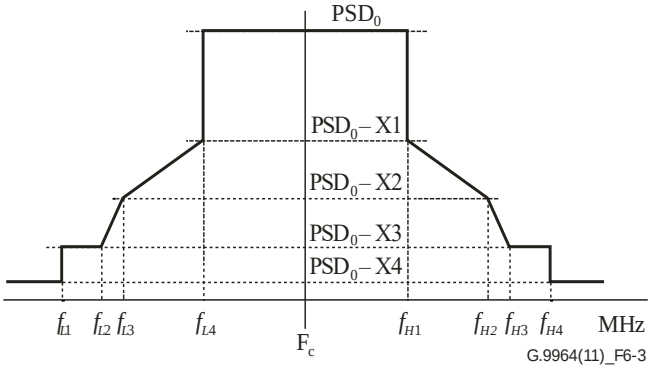


Figure 6-3 – LPM of a single channel for RF transmission over coax

The proposed values of frequency spectrum parameters for coax are presented in Tables 6-7 and 6-8. It is assumed that intermediate points between those defined in Figure 6-3 are obtained by linear interpolation (dB over linear frequency scale).

Table 6-7 – Parameters of LPM over coax RF for the 50 MHz-CRF OFB

Parameters	**Frequency (MHz)**	**PSD (dBm/Hz)** (Note 1)	**Note/Description**
$F_C - f_{L1}$	75	$PSD_0 - 50$	
$F_C - f_{L2}$	50	$PSD_0 - 45$	
$F_C - f_{L3}$	35	$PSD_0 - 40$	
$F_C - f_{L4}$	25	$PSD_0 - 20$	
	$f_{L4} + \Delta F$	PSD_0	ΔF is an arbitrary small positive value
F_C	$M \times 25$ MHz	PSD_0	
	$f_{H1} - \Delta F$	PSD_0	ΔF is an arbitrary small positive value

Table 6-7 – Parameters of LPM over coax RF for the 50 MHz-CRF OFB

Parameters	Frequency (MHz)	PSD (dBm/Hz) (Note 1)	Note/Description
$f_{H1} - F_C$	25	$PSD_0 - 20$	
$f_{H2} - F_C$	35	$PSD_0 - 40$	
$f_{H3} - F_C$	50	$PSD_0 - 45$	
$f_{H4} - F_C$	75	$PSD_0 - 50$	
NOTE 1 – $PSD_0 = -68$ dBm/Hz NOTE 2 – Subcarriers below $f_{L4} + \Delta F$, and above $f_{H1} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

Table 6-8 – Parameters of LPM over coax RF for the 100 MHz-CRF OFB

Parameters	Frequency (MHz)	PSD (dBm/Hz) (Note 1)	Note/Description
$F_C - f_{L1}$	150	$PSD_0 - 50$	
$F_C - f_{L2}$	100	$PSD_0 - 45$	
$F_C - f_{L3}$	70	$PSD_0 - 40$	
$F_C - f_{L4}$	50	$PSD_0 - 20$	
	$f_{L4} + \Delta F$	PSD_0	ΔF is an arbitrary small positive value
F_C	$M \times 25$ MHz	PSD_0	
	$f_{H1} - \Delta F$	PSD_0	ΔF is an arbitrary small positive value
$f_{H1} - F_C$	50	$PSD_0 - 20$	
$f_{H2} - F_C$	70	$PSD_0 - 40$	
$f_{H3} - F_C$	100	$PSD_0 - 45$	
$f_{H4} - F_C$	150	$PSD_0 - 50$	
NOTE 1 – $PSD_0 = -68$ dBm/Hz NOTE 2 – Subcarriers below $f_{L4} + \Delta F$, and above $f_{H1} - \Delta F$ shall not be used for transmission (neither data nor any auxiliary information).			

NOTE 1 – If additional spectrum shaping is used, as described in clause 5.2, the transmit PSD mask can be reduced in the relevant parts of this spectrum by switching subcarriers off or reducing their transmit power.

NOTE 2 – In cases where more than one channel is established over the same coax cable, appropriate gaps between centre frequencies of the channels should be set to account values of the out-of-band PSD presented in Tables 6-7 and 6-8.

NOTE 3 – Out-of-band spurious signals at the output of a node operating over coax in RF mode are supposed to meet the LPM defined in Tables 6-7 and 6-8. The limit for total power of out-of-band spurious signals is for further study. The requirements for in-band spurious signals are for further study.

NOTE 4 – Specification of guard bands are for further study.

The LPM for operation over Profile 1 coax OFBs (50 MHz-CB, 100 MHz-CB, 200 MHz-CB OFBs) is presented in Figure 6-4 with the frequencies and PSD levels presented in Table 6-9 (50 MHz-CB OFB), Table 6-10 (100 MHz-CB OFB), and Table 6-10.1 (200 MHz-CB OFB) where the bandwidth $BW = f_{H1} - f_{L2}$.

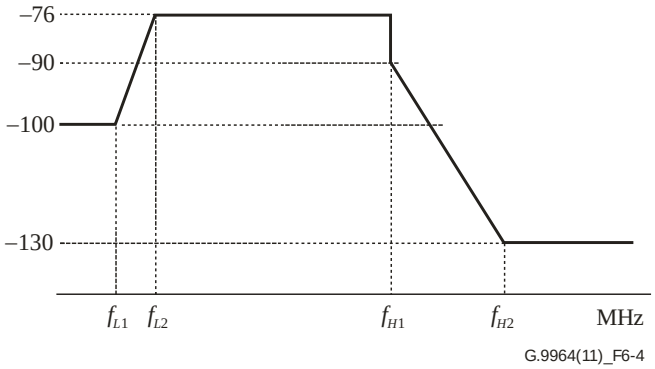


Figure 6-4 – LPM of baseband coax (Profile 1 OFBs)

The intermediate points between those defined in Figure 6-4 are obtained by linear interpolation (dB over a linear frequency scale).

Table 6-9 – Parameters of LPM over coax for the 50 MHz-CB OFB

Parameters	Frequency (MHz)	PSD (dBm/Hz)	Note/Description
f_{L1}	1	−100	
f_{L2}	5	−76	
$f_{H1} - \Delta F$	50 – ΔF	−76	ΔF is an arbitrary small positive value
f_{H1}	50	−90	
f_{H2}	70	−130	
NOTE – Subcarriers above $f_{H1} - \Delta F$ shall not be used for transmission (neither of data nor of any auxiliary information).			

Table 6-10 – Parameters of LPM over coax for the 100 MHz-CB OFB

Parameters	Frequency (MHz)	PSD (dBm/Hz)	Note/Description
f_{L1}	1	−100	
f_{L2}	5	−76	
$f_{H1} - \Delta F$	100 – ΔF	−76	ΔF is an arbitrary small positive value
f_{H1}	100	−90	
f_{H2}	140	−130	
NOTE – Subcarriers above $f_{H1} - \Delta F$ shall not be used for transmission (neither of data nor of any auxiliary information).			

Table 6-10.1 – Parameters of LPM over coax for the 200 MHz-CB OFB

Parameters	Frequency (MHz)	PSD (dBm/Hz)	Note/Description
f_{L1}	1	−100	
f_{L2}	5	−76	
$f_{H1} - \Delta F$	200 – ΔF	−76	ΔF is an arbitrary small positive value
f_{H1}	200	−90	
f_{H2}	280	−130	
NOTE – Subcarriers above $f_{H1} - \Delta F$ shall not be used for transmission (neither of data nor of any auxiliary information).			

NOTE 5 – If additional spectrum shaping is used, as described in clause 5.2, the transmit PSD mask can be reduced in the relevant parts of this spectrum by switching subcarriers off or reducing their transmit power.

See clause 7.2.3 of [ITU-T G.9960] for further physical layer specification of operation over coax.

The LPM for operation over Profile 2 coax OFBs is presented in Figure 6-4.1 with the frequencies and PSD levels presented in Table 6-10.2 where the bandwidth $BW = f_{H1} - f_{L2}$.

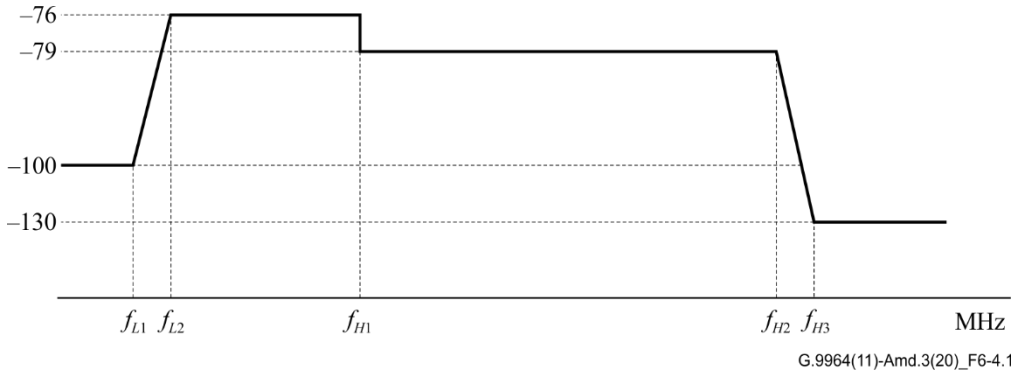


Figure 6-4.1 – LPM of coax (Profile 2 OFBs)

The intermediate points between those defined in Figure 6-4.1 are obtained by linear interpolation (dB over a linear frequency scale).

Table 6-10.2 – Parameters of limit PSD mask over coax for Profile 2 OFBs

Parameters	Frequency (MHz)	PSD (dBm/Hz)	Note/Description
f_{L1}	1	−100	
f_{L2}	5	−76	
$f_{H1} - \Delta F$	200 – ΔF	−76	ΔF is an arbitrary small positive value
f_{H1}	200	−79	
f_{H2}	2000	−79	
f_{H3}	2200	−130	

NOTE 6 – If additional spectrum shaping is used, as described in clause 5.2, the transmit PSD mask can be reduced in the relevant parts of this spectrum by switching subcarriers off or reducing their transmit power.

See clause 7.2.3 of [ITU-T G.9960] for further physical layer specification of operation over coax.

6.3.3 Permanently masked subcarriers

For baseband transmissions, subcarriers 0-10 (inclusive) shall be permanently masked over coax. They shall not be used for transmission (neither data nor any auxiliary information).

6.3.4 Coexistence on coax

Nodes on coax shall use specified detection and frequency agility capabilities and procedures to avoid interfering with alien home networks and other services (e.g., communication and broadcast services) operating on the same coax plant. Details of these capabilities and procedures will be specified in a future version of this Recommendation.

6.4 Termination impedance

The nominal values of termination (load) impedance for different types of media are defined in Table 6-11. The standard termination impedance shall be used for PSD and total transmit power measurement.

Table 6-11 – Standard termination impedance

Medium	Termination impedance (Ω)
Baseband power line	100
Telephone line	100
Baseband coax	75
RF coax	75

6.5 Total transmit power

The total transmit power of the transceiver terminated with a standard termination impedance (see clause 6.4) shall not exceed the values presented in Table 6-12.

Table 6-12 – Total transmit power limit

Medium	OFB	TX power limit (dBm)	Frequency range of measurement (MHz)
Baseband power line	50 MHz-PB	+20	0.005-100
	100 MHz-PB	+20	0.005-150
Telephone line	50 MHz-TB	+3	0.005-100
	100 MHz-TB	+4.5	0.005-150
	200 MHz-TB	+6	0.005-250
	Profile 2	$3 + 1.5 \times \text{Log}_2(F/50)$	$OF_{MAX} - OF_{MIN}$
Baseband coax	50 MHz-CB	−1	0.005-100
	100 MHz-CB	+2	0.005-150
	200 MHz-CB	+5	0.005-300
	Profile 2	$-1 + 3 \times \text{Log}_2(F/50)$	$OF_{MAX} - OF_{MIN}$
RF coax	50 MHz-RF	+5	$(F_{UC} - 100)$-$(F_{UC} + 100)$
	100 MHz-RF	+8	$(F_{UC} - 150)$-$(F_{UC} + 150)$
NOTE – $F = (OF_{MAX} - OF_{MIN})$ (see Tables 6-1, 6-4 and 6-6).			

6.6 Receiver input impedance

When operating on powerline medium and not transmitting, an implementing device shall present a minimum impedance of 40 Ω in the band from 1.8 MHz to 50 MHz measured between line (phase) and neutral terminals. It shall present a minimum impedance of 20 Ω in the ranges from 100 kHz to 1.8 MHz and from 50 MHz to 100 MHz.

Annex A

(This annex has been intentionally left blank.)

Annex B

(This annex has been intentionally left blank.)

Annex C

(This annex has been intentionally left blank.)

Annex D

International amateur radio bands

(This annex forms an integral part of this Recommendation.)

Table D.1 – International amateur radio bands in the frequency range 0–100 MHz

Band start (kHz)	**Band stop (kHz)**	**SC_{START}** (Note 1)	**SC_{END}** (Note 1)	**SC_{START}** (Note 2)	**SC_{END}** (Note 2)
1 800	2 000	73	82	36	41
3 500	4 000	143	164	71	82
7 000	7 300	286	300	143	150
10 100	10 150	413	416	206	208
14 000	14 350	573	588	286	294
18 068	18 168	740	745	370	373
21 000	21 450	860	879	430	440
24 890	24 990	1 019	1 024	509	512
28 000	29 700	1 146	1 217	573	609
50 000	54 000	2 047	2 212	1 023	1 106
69 900	70 500	2 863	2 888	1 431	1 444
14 4000	148 000	N/A	N/A	2 949	3 032
21 9000	22 5000	N/A	N/A	4 485	4 619
42 0000	450 000	N/A	N/A	8 601	9 217

NOTE 1 – Subcarrier index is in terms of 24.4140625 kHz spacing (all powerline OFBs)

NOTE 2 – Subcarrier index is in terms of 48.828125 kHz spacing (all telephone-line OFBs) where SC_{START} and SC_{END} refer to the start and stop indices of the masked subcarriers, respectively, if the corresponding bands are masked.

Annex E

Impact of ITU-T G.9960 on VDSL2 service

(This annex forms an integral part of this Recommendation.)

This annex defines the means to reduce the impact of [ITU-T G.9960] on the VDSL2 service. The means vary depending on the type of medium and if the service shares the same wires with VDSL2 or is routed nearby. The actual VDSL2 frequency bands in which impact of ITU-T G.9960 transmission occurs, and the corresponding PSD reductions are also regionally specific and may be configured via the remote or local domain management system using the configuration parameters defined in this annex. Details are for further study.

Appendix I

Additional radio frequency bands

(This appendix does not form an integral part of this Recommendation.)

This appendix lists additional radio frequency bands where PSD reduction may be required by national regulations.

Table I.1 – International broadcast bands

Band start (kHz)	Band stop (kHz)
2 300	2 498
3 200	3 400
3 900	4 000
4 750	5 060
5 900	6 200
7 200	7 450
9 400	9 900
11 600	12 100
13 570	13 870
15 100	15 800
17 480	17 900
18 900	19 020
21 450	21 850
25 670	26 100

Table I.2 – Aeronautical mobile bands

Band start (kHz)	Band stop (kHz)
2 850	3 150
3 400	3 500
3 800	3 950
4 650	4 850
5 450	5 730
6 525	6 765
8 815	9 040
10 005	10 100
11 175	11 400
13 200	13 360

Table I.2 – Aeronautical mobile bands

Band start (kHz)	Band stop (kHz)
15 010	15 100
17 900	18 030
21 924	22 000
23 200	23 350

Table I.3 – Radio astronomy bands

Band start (kHz)	Band stop (kHz)
13 360	13 410
25 550	25 670

Bibliography

[b-ITU-T G.993.2] Recommendation ITU-T G.993.2 (2006), *Very high speed digital subscriber line transceivers 2 (VDSL2)*.

[b-IEC CISPR 16-1] IEC CISPR 16-1:2010, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*.

[b-IEC CISPR 22] IEC CISPR 22:2008, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*.

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