International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.9700

(07/2019)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Access networks – Metallic access networks

Fast access to subscriber terminals (G.fast) – Power spectral density specification

Recommendation ITU-T G.9700

International Telecommunication Union

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999
Metallic access networks	**G.9700–G.9799**
Optical line systems for local and access networks	G.9800–G.9899
In premises networks	G.9900–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.9700

Fast access to subscriber terminals (G.fast) – Power spectral density specification

Summary

Recommendation ITU-T G.9700 specifies power spectral density (PSD) mask requirements for fast access to subscriber terminals (G.fast), a set of tools to support reduction of the transmit PSD mask, profile control parameters that determine spectral content, including the allowable maximum aggregate transmit power into a specified termination impedance, and a methodology for transmit PSD verification. It complements the physical layer (PHY) specification in Recommendation ITU-T G.9701.

Amendment 1 provided support for a new 106 MHz profile with +8 dBm maximum aggregate transmit power.

Amendment 2 aligns the text of clause 6.5 on notching of specific frequency bands with ITU-T G.9701 (2014) and its latest amendments, completes the specification of 212 MHz profiles, adds Annex X "Adaptation to the coax medium" in support of Annex X "Operation without multi-line coordination intended for a crosstalk free environment" that has been specified in Amendment 3 to ITU-T G.9701, and updates the table of International amateur radio frequencies in Appendix I.

The 2019 version of ITU-T G.9700 integrates the previous version and its amendments, and adds a new 106 MHz limit PSD mask intended to be used for transmission over networks with increased shielding, such as those with shielded cables or where cables are buried underground.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.9700	2014-04-04	15	11.1002/1000/12010
1.1	ITU-T G.9700 (2014) Amd. 1	2016-09-30	15	11.1002/1000/12842
1.2	ITU-T G.9700 (2014) Amd. 2	2017-06-30	15	11.1002/1000/13170
2.0	ITU-T G.9700	2019-07-12	15	11.1002/1000/13832

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

Table of Contents

Recommendation ITU-T G.9700

Fast access to subscriber terminals (G.fast) – Power spectral density specification

1 Scope

This Recommendation complements the physical layer (PHY) specification in [ITU-T G.9701].

It specifies:

- power spectral density (PSD) limit mask requirements;
- a set of tools to support reduction of the transmit PSD mask;
- profile control parameters that determine spectral content, including the allowable maximum aggregate transmit power into a specified termination impedance; and
- a methodology for transmit PSD verification.

This ensures that the technology can address:

- regional requirements;
- operator deployment requirements, for example, compatibility with other digital subscriber line (DSL) technologies;
- applicable electromagnetic compatibility (EMC) regulations or standards; and
- local EMC issues.

For in-band limit PSD mask LPM_106high, in the 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 brought 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.993.2] Recommendation ITU-T G.993.2 (2019), *Very high speed digital subscriber line transceivers 2 (VDSL2)*.

[ITU-T G.9701] Recommendation ITU-T G.9701 (2019), *Fast access to subscriber terminals (G.fast) – Physical layer specification*.

3 Definitions

This Recommendation defines the following terms:

3.1 **ceiling(*x*)**: The smallest integer which is not less than *x*.

3.2 **floor(*x*)**: The largest integer which is not greater than *x*.

3.3 f_{SC}: A parameter representing the frequency of subcarrier spacing.

3.4 subcarrier: A fundamental element of a discrete multitone (DMT) modulator. The modulator partitions the channel bandwidth into a set of parallel subchannels. The centre frequency of each subchannel is a subcarrier onto which bits may be modulated for transmission over a channel.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

DAB	Digital Audio Broadcasting
DMT	Discrete Multitone
DP	Distribution Point
DSL	Digital Subscriber Line
EMC	Electromagnetic Compatibility
FAST (G.fast)	Fast Access to Subscriber Terminals
FM	Frequency Modulation
FTU	FAST Transceiver Unit
FTU-O	FTU at the Optical network unit
FTU-R	FTU at the Remote site (i.e., subscriber end of the loop)
LESM	Low-frequency Edge Stop-band Mask
LPM	Limit PSD Mask
MBW	Measurement Bandwidth
MIB	Management Information Base
NM	Notching Mask
PSD	Power Spectral Density
PSM	PSD Shaping Mask
QoS	Quality of Service
SM	Subcarrier Mask
TDD	Time-Division Duplexing
TxPSDM	Transmit PSD Mask

5 Conventions

None.

6 Transmit PSD mask

6.1 Overview

The transmit PSD mask (TxPSDM) is constructed from the combination of the following masks:

− limit PSD mask (LPM);
− subcarrier mask (SM);
− PSD shaping mask (PSM);
− notching mask (NM); and
− low-frequency edge stop-band mask (LESM).

The TxPSDM applied to the FAST transceiver unit (FTU) at the optical network unit (FTU-O) or at the FTU remote site (i.e., subscriber end of the loop) (FTU-R) may be different.

For an FTU, the PSD of the transmit signal at any frequency shall never exceed the TxPSDM.

The LPM (see clause 7.2.1) specifies the absolute maximum limit of the TxPSDM. The subcarrier mask (SM), PSD shaping mask (PSM), notching mask (NM) and low-frequency edge stop-band mask (LESM) provide reduction and shaping of the TxPSDM using four mechanisms:

- subcarrier masking;
- notching of specific frequency bands;
- PSD shaping; and
- low-frequency edge stop-band masking.

Support of these four mechanisms is mandatory in both the FTU-O and the FTU-R.

The TxPSDM shall comply with applicable national and regional regulatory requirements.

NOTE 1 – When determining the correct PSD to use in a particular jurisdiction, operators should use tools provided to ensure compliance with national and regional electromagnetic compatibility (EMC) regulations giving special consideration to protecting receivers for the safety of life services which may not be immediately adjacent to the drop wires carrying ITU-T G.9701 signals. Examples include various VHF aeronautical radio navigation channels in the band 108-117.975 MHz, and aeronautical emergency communications channels (e.g., 121.5 MHz) and maritime emergency communications channels in the HF and VHF bands.

NOTE 2 – In addition to the masks defined in this Recommendation that provide absolute limits to the TxPSDM (both in-band and out-of-band), [ITU-T G.9701] defines two mechanisms: a mechanism of discontinuous operation that allows the FTU to dynamically switch off the transmit power in each particular connection when no data is present for transmission and a mechanism of low power mode (L2). Both mechanisms allow the system to further reduce the transmit power to a value that is sufficient to achieve the given bit rate and quality of service (QoS) targets.

NOTE 3 – TXPSDM is defined in various averaging bandwidths according to frequency as defined in Table 8-1, except in sub-bands at the low frequency band edge and in the region of MIB defined notches, where TXPSDM_W (1 MHz wideband) and TXPSDM_N (10 kHz narrowband) masks apply as described in clauses 6.5 and 6.6.

6.2 Limit PSD mask (LPM)

The limit PSD mask (LPM) defines the absolute maximum PSD limit of the TxPSDM that shall never be exceeded. All the other mask definitions and mechanisms used to construct the TxPSDM can only result in a reduction of the mask from the limits established by the LPM.

6.3 Subcarrier masking

Subcarrier masking shall be used to eliminate transmission on one or more subcarriers. The subcarrier mask (SM) is configured in the distribution point management information base (DP-MIB) by use of the ITU-T G.997.1 parameter CARMASK. The transmit power of subcarriers specified in the 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 subcarrier 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).

NOTE – The SM is intended to incorporate both masked subcarriers that are defined by an annex defining regional requirements so as to comply with local regulations and masked subcarriers that are defined by the

user or service provider to facilitate local deployment practices. Protection of radio services is not intended to be addressed by subcarrier masking; it is addressed by notching (see clause 6.5).

6.4 Power spectral density shaping

Power spectral density (PSD) shaping allows reduction of the TxPSDM in some parts of the spectrum, mainly for spectrum compatibility and coexistence with other access and home network technologies. The PSD shaping mask (PSM) is configured in the DP-MIB by use of the ITU-T G.997.1 parameter PSDMASK.

The PSM is defined on the frequency range between the lowest subcarrier x_1 (with x_1=ceiling(f_{tr1}/f_{SC})) and the highest subcarrier x_H (with x_H=floor(f_{tr2}/ f_{SC})), and consists of one or more frequency segments. The boundaries of the segments are defined by set breakpoints. Within each segment, the PSM may either be constant or form a linear slope between the given breakpoints (in dBm/Hz) with the frequency expressed in a linear scale.

Each breakpoint of the PSM is specified by a subcarrier index x_n and a value of PSD_n at that subcarrier 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:

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

An FTU shall support configuration of at least 32 PSM breakpoints.

If one or more PSM breakpoints are set above the LPM; the transmit PSD mask shall be set to: TxPSDM = min(PSM, LPM). All values of PSD_n of PSM breakpoints shall be set above –90 dBm/Hz.

6.5 Notching of specific frequency bands

The FTU shall be capable of being configured to notch one or more specific frequency bands in order to protect radio services; for example, amateur radio bands or broadcast radio bands. The international amateur radio bands to be notched are referred to as IAR bands, whilst the rest of the bands to be notched are referred to as RFI bands (see clause 7.3.1.2 of [ITU-T G.9701]).

For RFI bands, each notch in the notching mask (NM) shall be defined in terms of subcarrier indices SC_{start} and SC_{stop}.

The valid range of notch start tone index, SC_{start}, is all valid tone indices that are less than or equal to the minimum frequency of the protected radio band minus $f_{SC}/2$. The valid range of notch stop tone index, SC_{stop}, is all valid tone indices that are higher than or equal to the maximum frequency of the protected radio band plus $f_{SC}/2$.

An FTU shall support notching of 32 RFI bands simultaneously.

In addition, an FTU shall support notching of 13 IAR bands. The frequency of these IAR bands is detailed in Appendix I. FTUs should be capable of being configured to notch amateur radio bands individually based on the needed protection.

Within a notch, all subcarriers shall be turned off and the notching mask (NM) shall be equal to LPM −20 dB.

NOTE 1 – Subcarriers at either side of the masked subcarriers may also need to be turned off in order to meet the requirement on TxPSDM notch depth.

For a notch, two PSD masks are defined:

− Narrowband transmit PSD mask (TXPSDM_N)

  This mask is defined to verify the PSD using an MBW=10 kHz centred on the frequency in question.

The TXPSDM_N is defined as the maximum of the NM and a lower limit of −100 dBm/Hz:

$$\text{TxPSDM\_N} = \max[\text{NM}, -100\ \text{dBm/Hz}].$$

− Wideband transmit PSD mask (TXPSDM_W)

This mask is defined to verify a mathematically calculated wideband average PSD (PSD_W), obtained by averaging the narrowband measurements (PSD_N) (measured in an MBW=10 kHz) over a 1 MHz window centred on the frequency in question:

$$PSD\_W(f) = 10 \times \log 10\left(\left(\frac{1}{100}\right) \times \sum_{i=(-49)}^{50} 10^{\left(\frac{PSD\_N(f+i\times 10kHz)}{10}\right)}\right)$$

with:

PSD_N(f) the narrowband measurement at frequency f, expressed in dBm/Hz

PSD_W(f) the mathematically calculated wideband average PSD at frequency f, expressed in dBm/Hz.

The TXPSDM_W is defined as the maximum of the notch mask (NM) and a lower limit as defined in Table 6-1 frequency in question:

$$\text{TxPSDM\_W}(f) = \max[\text{NM}(f), \text{lower limit}(f)].$$

Table 6-1 – TXPSDM_W lower limit requirements

Frequency MHz	**TXPSDM_W lower limit [dBm/Hz]**
2.0-4.0	–100
4.0-5.0	–110
> 5.0	–112

For notches that are narrower than 1 MHz:

− the transmit PSD is only required to satisfy the narrowband transmit PSD mask TxPSDM_N, and this for frequencies ($SC_{start} \times f_{SC}$ + ½×MBW) < f < ($SC_{stop} \times f_{SC}$ − ½×MBW).

For notches that are 1 MHz or wider:

− the transmit PSD is required to satisfy the narrowband transmit PSD mask TxPSDM_N for frequencies ($SC_{start} \times f_{SC}$ + ½×MBW) < f < ($SC_{stop} \times f_{SC}$ − ½×MBW), and

− the wideband average transmit PSD (PSD_W(f)) is required to satisfy the wideband transmit PSD mask TxPSDM_W for frequencies (SCstart×f_{SC} + ½×MBW + 0.5MHz) < f < ($SC_{stop} \times f_{SC}$ − ½×MBW − 0.5MHz). The mask value to be compared against shall be the maximum value the mask takes within the 1 MHz window [f – 0.5 MHz, f + 0.5 MHz].

Appendix II details the frequencies for the broadcast radio services (frequency modulation (FM) and digital audio broadcasting (DAB)).

FM, DAB and other radio services will require different notch configurations depending on the characteristics of the specific radio service.

NOTE 2 – NM may be used to notch individual broadcast stations depending on spectrum utilization.

6.6 Low frequency edge stop-band masking

For the low frequency edge stop-band mask (LESM), two PSD masks are defined:

− Narrowband transmit PSD mask (TXPSDM_N)

This mask is defined to verify the PSD using an MBW=10 kHz centred on the frequency in question.

The TXPSDM_N is defined as shown in Figure 6-1, where PSD_{tr3} is the value of the in-band LPM at frequency f_{tr3}. The mask values in the transition band are obtained using linear interpolation in dB over a linear frequency scale.

The transmit PSD is required to satisfy the narrowband transmit PSD mask TxPSDM_N, for frequencies (0.5 MHz + ½×MBW) < f < (f_{tr3} − ½×MBW), where $f_{tr1} \leq f_{tr3} \leq 30$ MHz. The PSD values above the transition frequency f_{tr3} are considered as in-band and defined in clause 7.2.1.1.

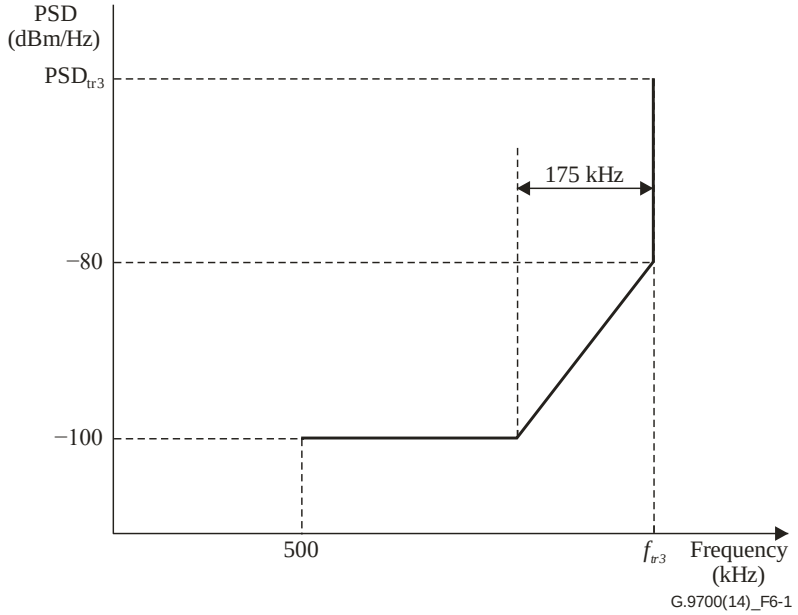

Figure 6-1 – Low-frequency edge stop-band mask

− Wideband transmit PSD mask (TXPSDM_W)

This mask is defined to verify a mathematically calculated wideband average PSD over a 1 MHz window (PSD_W(f)) as defined in clause 6.5.

The TXPSDM_W(f) is defined in Table 6-2 for the frequency in question.

The wideband average transmit PSD (PSD_W(f)) is required to satisfy the wideband transmit PSD mask TxPSDM_W for frequencies (2.0 MHz + ½×MBW + 0.5MHz) < f < (f_{tr3} − 175kHz − ½×MBW − 0.5MHz). The mask value to be compared against shall be the maximum value the mask takes within the 1 MHz window [f – 0.5 MHz, f + 0.5 MHz].

Table 6-2 – LESM TXPSDM_W requirements

Frequency (MHz)	LESM TXPSDM_W (dBm/Hz)
2.0 to 4.0	−100
4.0 to 5.0	−110
> 5.0	−112

7 Specification of spectral content

7.1 Profile control parameters

Each profile specifies normative values for the following parameters:

− the number of subcarriers (N);

− the subcarrier spacing (f_{SC});

− the cyclic extension parameters L_{CP} and β; and

− the maximum aggregate transmit power (applies to both downstream and upstream directions).

Table 7-1 shows the valid control parameters for each profile. The parameters are defined in [ITU-T G.9701].

Table 7-1 – Profile control parameters

Parameter	Profile (Note 1)		
	106 MHz (106a)	106 MHz (106b)	212 MHz (212a)
N	2048 (Note 2)	2048 (Note 2)	4096 (Note 3)
f_{SC}	51.75 kHz	51.75 kHz	51.75 kHz
L_{CP}	$N/64 \times m$ for m = 4, 8, 10, 12, 14, 16, 20, 24, 30 and 33 samples @ $2\times N\times f_{SC}$ samples/s	$N/64 \times m$ for m = 4, 8, 10, 12, 14, 16, 20, 24, 30 and 33 samples @ $2\times N\times f_{SC}$ samples/s	$N/64 \times m$ for m = 4, 8, 10, 12, 14, 16, 20, 24, 30 and 33 samples @ $2\times N\times f_{SC}$ samples/s
β	64 and 128 samples @ $2\times N\times f_{SC}$ samples/s	64 and 128 samples @ $2\times N\times f_{SC}$ samples/s	128 and 256 samples @ $2\times N\times f_{SC}$ samples/s
Maximum aggregate transmit power	+4 dBm (See clauses 7.3 and 7.4)	+8 dBm (See clauses 7.3 and 7.4)	+4 dBm (See clauses 7.3 and 7.4)
NOTE 1 – Future profiles may be defined with higher maximum aggregate transmit powers provided that they are within the bounds of their associated limit PSD masks specified in this Recommendation. NOTE 2 – The range of valid subcarrier indices corresponds to frequencies between 2 and 106 MHz. NOTE 3 – The range of valid subcarrier indices corresponds to frequencies between 2 and 212 MHz.			

7.2 PSD mask specifications

7.2.1 Limit PSD mask (LPM)

The limit PSD mask (LPM) represents the absolute maximum that the TxPSDM shall never exceed. The in-band LPMs are specified in clause 7.2.1.1. The out-of-band LPMs are specified in clause 7.2.1.2.

Specific LPMs are associated with specific profiles and directions of transmission as specified in [ITU-T G.9701].

7.2.1.1 In-band LPM

Three in-band LPMs are specified, namely, the 106 MHz LPM (LPM_106), the 212 MHz LPM (LPM_212), and the 106 MHz high LPM (LPM_106high) as shown in Figures 7-1, 7-2 and 7-3, respectively. The parameters for these LPMs are presented in Tables 7-2, 7-3 and 7-4, respectively. LPM_106high shall only be used by the FTU-O, for transmission in the downstream direction.

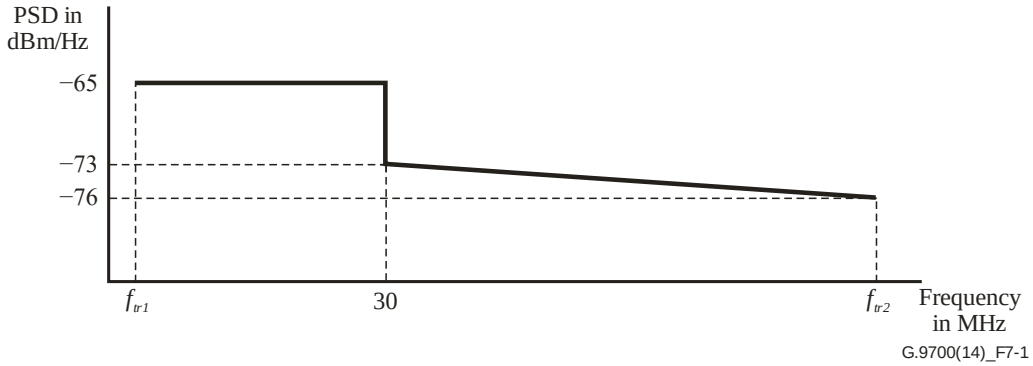

Figure 7-1 – In-band limit PSD mask LPM_106

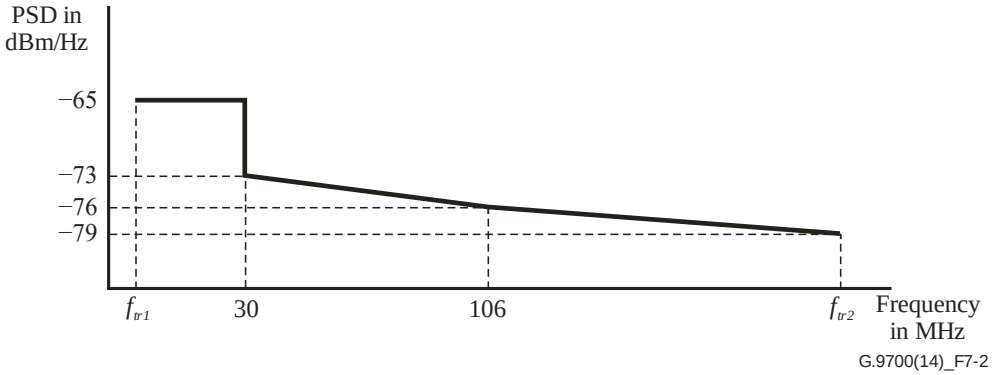

Figure 7-2 – In-band limit PSD mask LPM_212

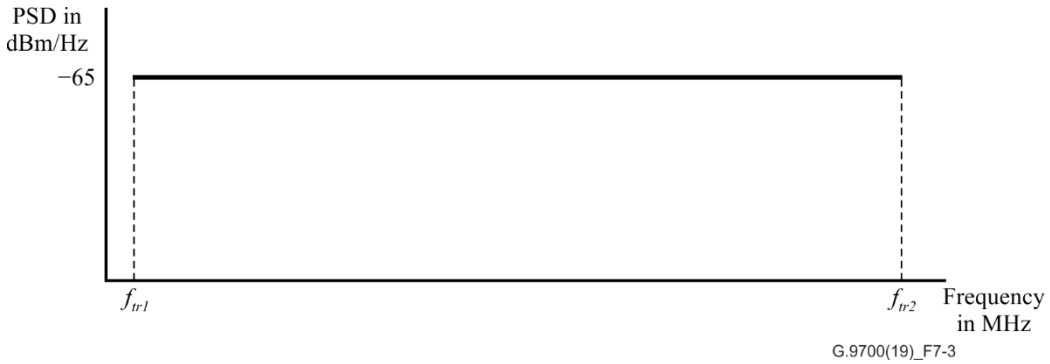

Figure 7-3 – In-band limit PSD mask LPM_106high

Table 7-2 – Parameters of LPM_106

Parameter	Frequency (MHz)	PSD (dBm/Hz)	Description
f_{tr1}	2	–65	The LPM below f_{tr1} is defined in clause 7.2.1.2.
	30	–65	
	30	–73	The PSD limit values between the points listed shall be obtained by linear interpolation in dB over linear frequency scale. The LPM above f_{tr2} is defined in clause 7.2.1.2
f_{tr2}	106	–76	

Table 7-3 – Parameters of LPM_212

Parameter	Frequency (MHz)	PSD (dBm/Hz)	Description
f_{tr1}	2	–65	The LPM below f_{tr1} is defined in clause 7.2.1.2.
	30	–65	
	30	–73	The PSD limit values between the points listed shall be obtained by linear interpolation in dB over linear frequency scale. The LPM above f_{tr2} is defined in clause 7.2.1.2
	106	–76	
f_{tr2}	212	–79	

Table 7-4 – Parameters of LPM_106high

Parameter	Frequency (MHz)	PSD (dBm/Hz)	Description
f_{tr1}	2	–65	The LPM below f_{tr1} is defined in clause 7.2.1.2.
f_{tr2}	106	–65	The LPM above f_{tr2} is defined in clause 7.2.1.2
NOTE 1 – The high PSD specified in this table might only comply with national and regional electromagnetic compatibility (EMC) regulations where transmission is over networks with increased shielding, such as those with shielded cables or where cables are buried underground. NOTE 2 – Use of high PSD values specified in this table might lead to increased power consumption at the transmitter or the receiver or both, relative to the PSD values specified in Table 7-2. This can occur especially if high PSD values are used at high frequencies, notwithstanding a constant maximum aggregate transmit power.			

NOTE – When additional spectrum shaping is used as described in clause 6 (for example, to provide spectrum compatibility or to comply with wideband power limit), various parts of the TxPSDM could be reduced by switching subcarriers off or reducing their transmit power. Additional frequency notches may also be applied if required.

7.2.1.2 Out-of-band LPM

The out-of-band LPM for the low frequency edge shall be as shown in Figure 7-4, where PSD_{tr1} is the value of the in-band LPM at frequency f_{tr1}. The parameters of this out-of-band LPM are presented in Table 7-5.

The out-of-band LPM for the high frequency edge depends on the in-band LPM. If the in-band LPM is LPM_106 or LPM_212, the out-of-band LPM for high frequency shall be as shown in Figure 7-5, where PSD_{tr2} is the value of the in-band LPM at frequency f_{tr2}. If the in-band LPM is LPM_106high, the out-of-band LPM for high frequency shall be as shown in Figure 7-6. The parameters for these LPMs are presented in Tables 7-6 and 7-7 respectively.

The out-of-band LPM applies for frequencies below the low-edge transition frequency f_{tr1} and for frequencies above the high-edge transition frequency f_{tr2}. The PSD values between the transition frequencies f_{tr1} and f_{tr2} are considered as in-band and defined in clause 7.2.1.1.

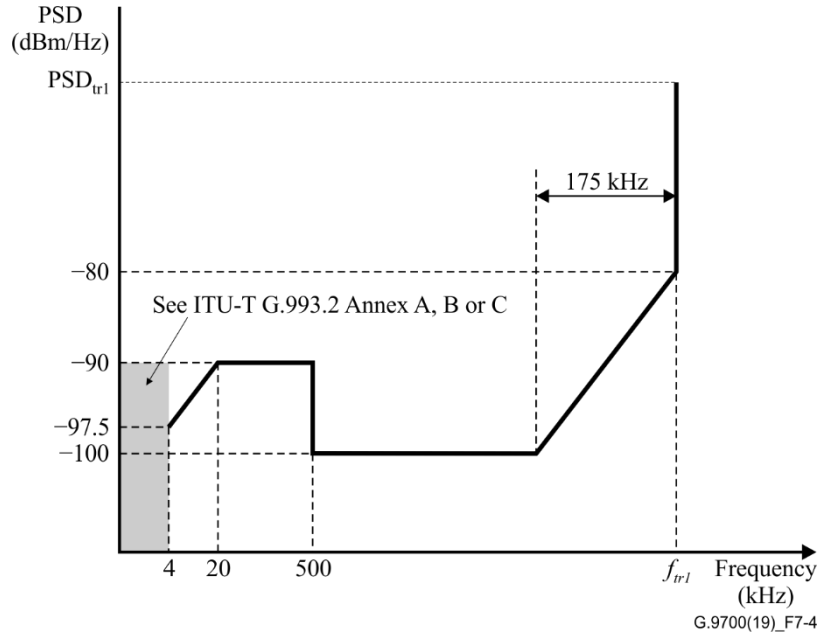

Figure 7-4 – Low-frequency edge out-of-band LPM

Requirements for frequencies below 4 kHz are specified in Annexes A, B, C and N of [ITU-T G.993.2] for the regions of North America, Europe, Japan and China, respectively.

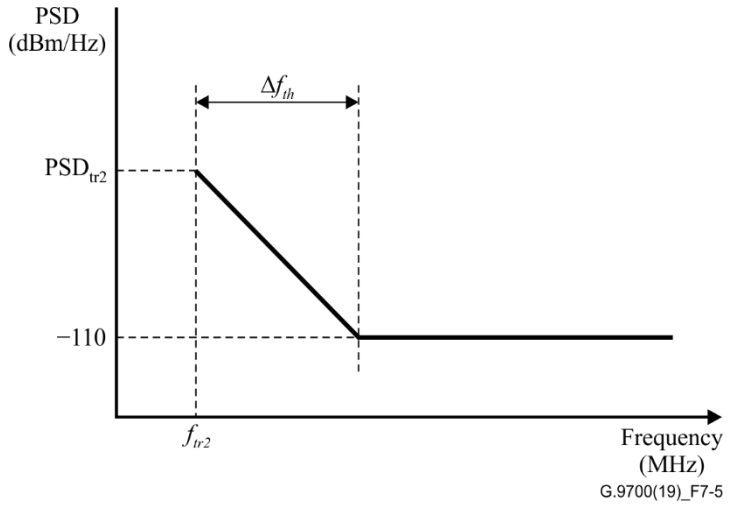

Figure 7-5 – High-frequency edge out-of-band LPM to be used in combination with LPM_106 and LPM_212

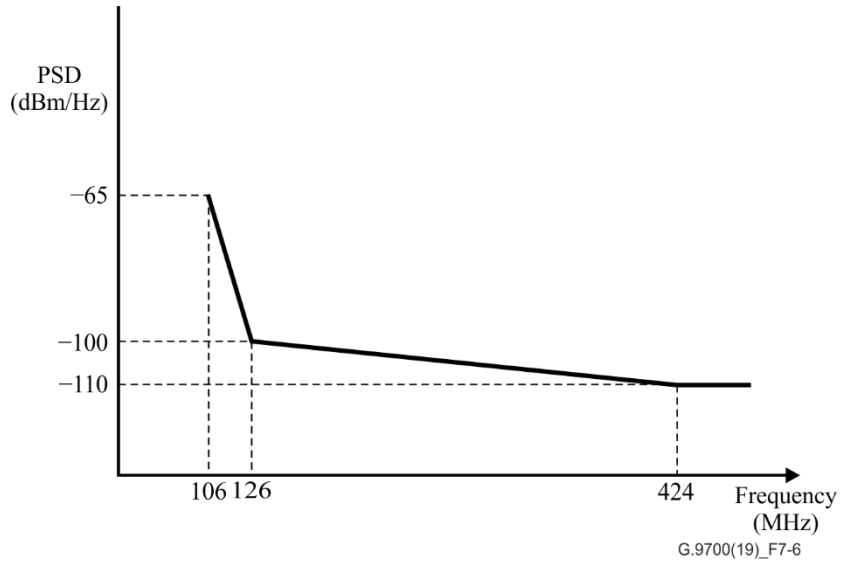

Figure 7-6 – High-frequency edge out-of-band LPM to be used in combination with LPM_106high

Table 7-5 – Parameters of low-frequency edge out-of-band LPM

f_{tr1} (MHz)	PSD_{tr1} (dBm/Hz)	Description
2	–65	The PSD limit at transition frequency f_{tr1} drops from PSD_{tr1} to –80 dBm/Hz. The PSD limit in the transition band shall be obtained by linear interpolation in dB over linear frequency scale. The PSD limit between 4 and 20 kHz shall be obtained by linear interpolation in dB over a log(f) scale. Subcarriers below f_{tr1} shall not be used for transmission (neither data nor any auxiliary information).

Table 7-6 – Parameters of high-frequency edge out-of-band LPM to be used in combination with LPM_106 and LPM_212

f_{tr2} (MHz)	PSD_{tr2} (dBm/Hz)	Transition band, Δf_{th} (MHz)	Description
106	–76	20	The PSD limit in the transition band (Δf_{th}) shall be obtained by linear interpolation in dB over linear frequency scale. Subcarriers above f_{tr2} shall not be used for transmission (neither data nor any auxiliary information).
212	–79	40	

Table 7-7 – Parameters of high-frequency edge out-of-band LPM to be used in combination with LPM_106high

Frequency (MHz)	PSD (dBm/Hz)	Description
f_{tr2}=106	–65	The PSD limit in the transition band shall be obtained by linear interpolation in dB over linear frequency scale. Subcarriers above f_{tr2} shall not be used for transmission (neither data nor any auxiliary information).
126	–100	
424	–110	

7.2.2 Permanently masked subcarriers

For all profiles, subcarriers with indices from 0 to 39 (inclusive) shall be permanently masked. They shall not be used for transmission (neither for data nor for any auxiliary information).

7.3 Termination impedance

A termination impedance of R_V = 100 Ohm, purely resistive, at the U interface, shall be used for both the FTU-O and the FTU-R. In particular, R_V = 100 Ohm shall be used as a termination for the transmit PSD and aggregate transmit power definition and verification.

7.4 Maximum aggregate transmit power

The values of the maximum aggregate transmit power are defined in this Recommendation under an assumption that the transmissions were continuous. In systems using time-division duplexing (TDD), such as [ITU-T G.9701], transmission in a particular direction is not continuous, but occurs only during designated time periods. This shall be taken in account by the applied measurement procedure.

The maximum aggregate transmit power of both the FTU-O (in the downstream direction) and the FTU-R (in the upstream direction) shall not exceed the level specified in Table 7-1 for any given profile when measured using the termination impedance defined in clause 7.3.

Further limitations are the subject for annexes defining different regional requirements (for further study).

8 Transmit PSD verification

The values of the transmit PSD mask are defined in this Recommendation under the assumption that transmission is continuous. In systems using time division duplexing (TDD), such as described in [ITU-T G.9701], transmission in a particular direction is not continuous but occurs only during designated time periods. This shall be taken into account by the applied measurement procedure.

The measurement bandwidth (MBW) for evaluation of the PSD shall be as defined in Table 8-1. The measurement bandwidth shall be centred on the frequency in question.

The mask value to be compared against shall be the maximum value the mask takes within a window $[f - ½\times\text{MBW}, f + ½\times\text{MBW}]$.

NOTE – If in a certain frequency range both a narrowband transmit PSD mask (TXPSDM_N) and a wideband transmit PSD mask (TXPSDM_W) are defined, the MBW values defined in this clause relate to the narrowband PSD measurements PSD_N.

PSD masks are specified with respect to a reference termination impedance, as defined in clause 7.3.

Table 8-1 – Measurement bandwidth settings for transmit PSD verification

Frequency band	Measurement bandwidth (MBW)
4 kHz < f < 20 kHz	1 kHz
20 kHz < f < f_{tr1}	10 kHz
(f_{tr1} + ½×MBW) to (30 MHz – ½×MBW)	1 MHz
(30 MHz + ½×MBW) to (f_{tr2} – ½×MBW)	1 MHz
> f_{tr2} to 300 MHz	100 kHz
Any notched frequency band	10 kHz

Annex A to Annex W

Annex A to Annex W have been intentionally left blank.

Annex X

Adaptation to the coax medium

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

X.1 Profile control parameters

Each profile specifies normative values for the following parameters:

− the number of subcarriers (N);

− the subcarrier spacing (f_{SC});

− the cyclic extension parameters L_{CP} and β; and

− the maximum aggregate transmit power (applies to both downstream and upstream directions).

Table X.1 shows the valid control parameters for each of the coax profiles. The parameters are defined in Annex X of [ITU-T G.9701].

Table X.1 – Profile control parameters for operation over coaxial cables

Parameter	Profiles for operation over coaxial cables (Note 1)	
	106 MHz (106c)	**212 MHz (212c)**
N	2048 (Note 2)	4096 (Note 3)
f_{SC}	51.75 kHz	51.75 kHz
L_{CP}	$N/64 \times m$ for m = 4, 8, 10, 12, 14, 16, 20, 24, 30 and 33 samples @ $2\times N\times f_{SC}$ samples/s	$N/64 \times m$ for m = 4, 8, 10, 12, 14, 16, 20, 24, 30 and 33 samples @ $2\times N\times f_{SC}$ samples/s
β	64 and 128 samples @ $2\times N\times f_{SC}$ samples/s	128 and 256 samples @ $2\times N\times f_{SC}$ samples/s
Maximum aggregate transmit power	+2 dBm (See clauses 7.3 and 7.4)	+2 dBm (see clauses 7.3 and 7.4)
NOTE 1 – Future profiles may be defined with higher maximum aggregate transmit powers provided that they are within the bounds of the limit PSD mask specified in this Recommendation. NOTE 2 – The range of valid subcarrier indices corresponds to frequencies between 2 and 106 MHz. NOTE 3 – The range of valid subcarrier indices corresponds to frequencies between 2 and 212 MHz.		

X.2 Termination impedance

For a transceiver operating over coaxial cables, a termination impedance of R_V = 75 Ohm, purely resistive, at the U interface, shall be used for both the FTU-O and the FTU-R. In particular, R_V = 75 Ohm shall be used as a termination for the transmit PSD and aggregate transmit power definition and verification.

X.3 Maximum aggregate transmit power

The values of the maximum aggregate transmit power are defined in this Recommendation under an assumption that the transmissions were continuous. In systems using TDD, such as [ITU-T G.9701], transmission in a particular direction is not continuous, but occurs only during designated time periods. This shall be taken in account by the applied measurement procedure.

The maximum aggregate transmit power of both the FTU-O (in the downstream direction) and the FTU-R (in the upstream direction) shall not exceed the level specified in Table X.1 for any given profile when measured using the termination impedance defined in clause X.2.

Appendix I

International amateur radio bands

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

Table I.1 – International amateur radio bands in the frequency range 1.8-212 MHz

Band start (kHz)	Band stop (kHz)
1 800	2 000
3 500	4 000
5 351.5	5 366.5
7 000	7 300
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 700
50 000	54 000
69 900	70 500
144 000	148 000

Appendix II

Broadcast radio bands

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

This appendix includes bands related to receivers likely to be in close proximity to the installation, omitting allocations for obsolete technologies such as analogue TV. Generally the services concerned are radio broadcasts.

Table II.1 – Broadcast radio bands in the frequency range up to 212 MHz

Band start (kHz)	Band stop (kHz)	Service
87 500	108 000	FM
174 000	216 000	Digital terrestrial television (Region 2)
174 000	230 000	Digital terrestrial television/Digital audio broadcasting (Regions 1 and 3)

Appendix III

Definition of transmitter PSD (TXPSD) for non-continuous transmissions

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

This appendix provides a formal definition for transmitter power spectral density (TXPSD) for signals comprising a stream of symbols including quiet periods, such as those produced by time division duplexed DMT systems.

This appendix defines TXPSD that is applicable to a stream of transmitted symbols, a punctured stream of symbols, or a continuous stream of symbols. Transmitted symbols are all symbols transmitted in the transmission period for the transmission direction. The quiet symbol positions in the transmission period are excluded. It does not define a measurement technique.

This appendix defines TXPSD in terms of an intermediate variable, "Transmitter Symbol PSD" (TXSPSD). TXSPSD is defined in relation to the Expectation of the energy spectral density (ESD) of symbols transmitted in a particular direction.

The ESD of a symbol voltage waveform $V_s(t)$ is derived into a reference impedance of 100 Ω.

$$ESD(V_s, f) = \frac{1}{R_0}\left|\int_{-\infty}^{\infty} V_s(t).\, e^{-i2\pi ft} dt\right|^2 (in\ unit\ of\ Joule/Hz)$$

$$R_0 = 100\ \Omega$$

TXSPSD is derived from the Expectation of the ESD over a set of transmitted symbols.

$$TXSPSD(f) = f_{DMT}.\,\mathrm{E}[ESD(V(t), f);\ V \in S] \text{ (in unit of W/Hz)}$$

$$S = \{S_0, S_1 \ldots S_N\}$$

$S_0, S_1 \ldots S_N$ is a valid sequence of transmitted symbols

$E[x]$ is the statistical expectation of x.

This normalization by the period of the symbol ensures that in the limit an infinite sequence of symbols has TXSPSD that converges to the classical PSD derived from the Fourier transform of the autocorrelation function.

The verifiable TXPSD is defined in a particular bandwidth *bw* as follows:

$$TXPSD(bw, f) = 30 + 10 \times log_{10}\left(\frac{1}{bw}\int_{f-\frac{bw}{2}}^{f+\frac{bw}{2}} TXSPSD(f_b) df_b\right) \text{ (in unit of dBm/Hz)}$$

TXPSDM(*f*) is the maximum permitted level for *TXPSD*(*bw*,*f*) of a long symbol sequence.

Methods for compliance verification are out of the scope of this Recommendation.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	Tariff and accounting principles and international telecommunication/ICT economic and policy issues
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Environment and ICTs, climate change, e-waste, energy efficiency; construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Telephone transmission quality, telephone installations, local line networks
Series Q	Switching and signalling, and associated measurements and tests
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2019