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DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Access networks

Asymmetric digital subscriber line transceivers 2 (ADSL2) – Extended bandwidth (ADSL2plus)

Recommendation ITU-T G.992.5



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Recommendation ITU-T G.992.5

Asymmetric digital subscriber line transceivers 2 (ADSL2) – Extended bandwidth (ADSL2plus)

Summary

Recommendation ITU-T G.992.5 describes asymmetrical digital subscriber line (ADSL) transceivers on a metallic twisted pair that allows high-speed data transmission between the network operator end (ATU-C) and the customer end (ATU-R), using extended bandwidth. This Recommendation defines a variety of frame bearers in conjunction with one of two other services, or without underlying service, dependent on the environment:

- 1) ADSL transmission simultaneously on the same pair with voiceband service.
- 2) ADSL transmission simultaneously on the same pair with integrated services digital network (ISDN) (see Appendix I or II or Recommendation ITU-T G.961) services.
- 3) ADSL transmission without underlying service, optimized for deployment with ADSL over voiceband service in the same binder cable.
- 4) ADSL transmission without underlying service, optimized for deployment with ADSL over ISDN service in the same binder cable.
- 5) ADSL transmission with extended upstream bandwidth, simultaneously on the same pair with voice band service.

ADSL transmission on the same pair with voiceband services and operating in an environment with TCM-ISDN (see Appendix III of Recommendation ITU-T G.961) services in an adjacent pair is for further study.

This Recommendation specifies the physical layer characteristics of the extended bandwidth asymmetric digital subscriber line (ADSL) interface to metallic loops. As compared to the ADSL2 transceiver defined in Recommendation ITU-T G.992.3, the operating modes use double the downstream bandwidth. When operating on the same pair with voiceband services, an additional operating mode is defined, using the double upstream bandwidth.

This Recommendation has been written to help ensure the proper interfacing and interworking of ADSL transmission units at the customer end (ATU-R) and at the network operator end (ATU-C) and also to define the transport capability of the units. Proper operation shall be ensured when these two units are manufactured and provided independently. A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g., crosstalk and noise).

An extended bandwidth ADSL transmission unit (ADSL2plus transceiver) can simultaneously convey all of the following: a number of downstream frame bearers; a number of upstream frame bearers; a baseband plain old telephone service (POTS)/ISDN duplex channel; and ADSL line overhead for framing, error control, operations and maintenance. Systems support a net data rate ranging up to a minimum of 16 Mbit/s downstream and 800 kbit/s upstream. Support of net data rates above 16 Mbit/s downstream and support of net data rates above 800 kbit/s upstream are optional.

This Recommendation includes mandatory requirements, recommendations and options; these are designated by the words "shall", "should" and "may", respectively. The word "will" is used only to designate events that take place under some defined set of circumstances. This Recommendation is written as a delta Recommendation relative to Recommendation ITU-T Rec. G.992.3. For the clauses which have been changed, this Recommendation contains complete replacement text (unless explicitly indicated). For the clauses which have not been changed, this Recommendation contains only the clause heading, with reference to Recommendation ITU-T G.992.3.

This Recommendation defines several optional capabilities and features:

- transport of STM and/or ATM and/or Packets;
- transport of a network timing reference;
- multiple latency paths;

- multiple frame bearers;
- short initialization procedure;
- dynamic rate repartitioning;
- seamless rate adaptation;
- extended impulse noise protection;
- erasure decoding;
- virtual noise;
- impulse noise monitor.

It is the intention of this Recommendation to provide, by negotiation during initialization, for U-interface compatibility and interoperability between transceivers complying with this Recommendation, and between transceivers that include different combinations of options.

Annex C to this Recommendation has been published independently due to its size and its specific structure.

History

This Recommendation describes extended bandwidth ADSL2 (ADSL2plus) transceivers, as a delta to the second generation ADSL (ADSL2 – Recommendation ITU-T G.992.3).

This Recommendation has been written to provide additional features relative to Recommendation ITU-T G.992.3, which was approved on 22 April 2009. Several potential improvements have been identified to better address higher data rates for shorter loops and longer reach for high data rates. This Recommendation provides a new ADSL U-interface specification, including the identified improvements, which ITU-T believes will be most helpful to the ADSL industry.

Relative to Recommendation ITU-T G.992.3, the following application-related feature has been added:

- Improved support for services requiring high downstream data rates (e.g., broadband entertainment services).

Relative to Recommendation ITU-T G.992.3, the following PMS-TC-related feature has been added:

- Support of up to 16 Reed-Solomon codewords per symbol;

Relative to Recommendation ITU-T G.992.3, the following PMD-related features have been added:

- Extended downstream bandwidth to 2.208 MHz (512 subcarriers) for all operation modes (POTS/ISDN/all-digital mode);
- Downstream spectrum control with individual maximum transmit PSD at U-C reference point per subcarrier, under operator control through CO-MIB, allows configuration per the regional requirements (e.g., North America, Europe or Japan) and deployment scenarios (e.g., central office or remote).
- Downstream spectrum shaping during showtime (shaped transmit PSD in the passband, i.e., non-flat) for improved downstream transmit PSD flexibility.

Through negotiation during initialization, the capability of equipment to support this and other ITU-T G.992.x-series ADSL Recommendations is identified. For reasons of interoperability, equipment may choose to support multiple Recommendations, such that it is able to adapt to the operating mode supported by the far-end equipment.

Source

Recommendation ITU-T G.992.5 was approved on 13 January 2009 by ITU-T Study Group 15 (2009-2012) under Recommendation ITU-T A.8 procedures.

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.

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As of the date of approval of this Recommendation, ITU [had/had not] 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/>.

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Recommendation ITU-T G.992.5

Asymmetric digital subscriber line transceivers 2 (ADSL2) – Extended bandwidth (ADSL2plus)

1 Scope

For the interrelationships of this Recommendation with other ITU-T G.99x-series Recommendations, see [b-ITU-T G.995.1].

This Recommendation describes the interface between the telecommunication network and the customer installation in terms of their interaction and electrical characteristics. The requirements of this Recommendation apply to a single asymmetric digital subscriber line (ADSL).

ADSL provides a variety of frame bearers in conjunction with other services:

- ADSL service on the same pair with voiceband services (including plain old telephone service (POTS) and voiceband data services). The ADSL service occupies a frequency band above the voiceband service, and is separated from it by filtering.
- ADSL service on the same pair as integrated services digital network (ISDN) service, as defined in Appendices I and II of [ITU-T G.961]. The ADSL service occupies a frequency band above the ISDN service, and is separated from it by filtering.
- ADSL service on the same pair with voiceband services (e.g., POTS and voiceband data services), and with TCM-ISDN services as defined in Appendix III of [ITU-T G.961] on an adjacent pair. The ADSL service occupies a frequency band above the voiceband service, and is separated from it by filtering.
- ADSL service with extended upstream bandwidth on the same pair with voiceband services (including POTS and voiceband data services). The ADSL service occupies a frequency band above the voiceband service, and is separated from it by filtering.

ADSL also provides a variety of frame bearers without baseband services (i.e., POTS or ISDN) being present on the same pair.

- ADSL service on a pair, with improved spectral compatibility with ADSL over POTS present on an adjacent pair.
- ADSL service on a pair, with improved spectral compatibility with ADSL over ISDN present on an adjacent pair.

In the direction from the network operator to the customer premises (i.e., the downstream direction), the frame bearers provided may include low-speed frame bearers and high-speed frame bearers; in the other direction from the customer premises to the central office (i.e., the upstream direction), only low-speed frame bearers are provided.

The transmission system is designed to operate on two-wire twisted metallic copper pairs with mixed gauges. This Recommendation is based on the use of copper pairs without loading coils, but bridged taps are acceptable in all but a few unusual situations.

An overview of digital subscriber line transceivers can be found in [b-ITU-T G.995.1].

Specifically, this Recommendation:

- defines the transmission protocol specific transmission convergence sub-layer for ATM, STM and Packet transport through the frame bearers provided;
- defines the combined options and ranges of the frame bearers provided;
- defines the line code and the spectral composition of the signals transmitted by both ATU-C and ATU-R;

- defines the initialization procedure for both the ATU-C and the ATU-R;
- specifies the transmit signals at both the ATU-C and ATU-R;
- describes the organization of transmitted and received data into frames;
- defines the functions of the operations, administration and management (OAM) channel.

In separate annexes, it also:

- Describes the transmission technique used to support the simultaneous transport of voiceband services and frame bearers (ADSL over POTS, Annex A) on a single twisted-pair.
- Describes the transmission technique used to support the simultaneous transport of ISDN services as defined in Appendices I and II of [ITU-T G.961], and frame bearers (ADSL over ISDN, Annex B) on a single twisted-pair.
- Describes the transmission technique used to support the transport of only frame bearers on a pair, with improved spectral compatibility with ADSL over POTS present on an adjacent pair (all-digital mode, Annex I).
- Describes the transmission technique used to support the transport of only frame bearers on a pair, with improved spectral compatibility with ADSL over ISDN present on adjacent pair (all-digital mode, Annex J).
- Describes the transmission technique used to support the simultaneous transport of voiceband services and frame bearers for extended upstream bandwidth operation (EUADSL2plus over POTS, Annex M) on a single twisted-pair.

This Recommendation defines the minimal set of requirements to provide satisfactory simultaneous transmission between the network and the customer interface of a variety of frame bearers and other services such as POTS or ISDN. This Recommendation permits network providers an expanded use of existing copper facilities. All required physical layer aspects to ensure compatibility between equipment in the network and equipment at a remote location are specified. Equipment may be implemented with additional functions and procedures.

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.961]	Recommendation ITU-T G.961 (1993), <i>Digital transmission system on metallic local lines for ISDN basic rate access</i> .
[ITU-T G.992.3]	Recommendation ITU-T G.992.3 (2009), <i>Asymmetric digital subscriber line transceivers 2 (ADSL2)</i> .
[ITU-T G.994.1]	Recommendation ITU-T G.994.1 (2003), <i>Handshake procedures for digital subscriber line (DSL) transceivers</i> .
[ITU-T G.996.1]	Recommendation ITU-T G.996.1 (2001), <i>Test procedures for digital subscriber line (DSL) transceivers</i> .

3 Definitions

See clause 3 of ITU-T G.992.3, modified as follows:

~~**3.31 power cutback (PCB):** Reduction of the transmit PSD level (expressed in dB) in any one direction, relative to the nominal transmit PSD level. The same transmit PSD level reduction is applied over the whole frequency band (i.e., flat cutback).~~

3.31 power cutback (PCB): Scalar valued parameter controlling the difference (expressed in dB), between the nominal transmit PSD level and the reference transmit PSD level (REFPSD), in any one direction. In case of non-unity tss_i , a frequency dependent transmit PSD level reduction could result (i.e., ceiled cutback).

~~**3.33 reference transmit power spectral density level (REFPSD):** The nominal transmit PSD level, lowered by the power cutback, in any one direction.~~

3.33 reference transmit power spectral density level (REFPSD): The nominal transmit PSD level, lowered by the power cutback (PCB), in any one direction.

4 Abbreviations and acronyms

See clause 4 of ITU-T G.992.3.

5 Reference models

See clause 5 of ITU-T G.992.3, adding the following text immediately before clause 5.1.

ITU-T G.992.5 provides tools for the operator of the access network to control the ADSL transmit PSD and aggregate power in the downstream and upstream directions. Depending on regional spectrum management guidelines, these tools may be needed to enable remote ADSL deployment. In this case, the ATU-C is located in a remote cabinet located between the central office and the customer premises, rather than the access node.

6 Transport protocol-specific transmission convergence (TPS-TC) function

6.1 Transport capabilities

See clause 6 of ITU-T G.992.3.

7 Physical media-specific transmission convergence (PMS-TC) function

7.1 Transport capabilities

See clause 7.1 of ITU-T G.992.3.

7.2 Additional functions

See clause 7.2 of ITU-T G.992.3.

7.3 Block interface signals and primitives

See clause 7.3 of ITU-T G.992.3.

7.4 Block diagram and internal reference point signals

See clause 7.4 of ITU-T G.992.3.

7.5 Control parameters

See clause 7.5 of ITU-T G.992.3.

7.6 Frame structure

See clause 7.6 of ITU-T G.992.3.

7.6.1 Derived definitions

See clause 7.6.1 of ITU-T G.992.3.

7.6.2 Valid framing configurations

See clause 7.6.2 of ITU-T G.992.3, modified as follows

Table 7-8 displays the allowable range of each PMS-TC control parameter. Additionally, the control parameters shall satisfy some relationships to one another for the set of control parameter values to be valid as displayed in Table 7-8. Some ranges of the valid control parameter values are expressed in terms of NSC, which is the number of subcarriers as defined in clause 8.8.1.

...

Table 7-8 – Valid framing configurations

Parameter	Capability
...	...
Relationship of N_{FEC0} and D_0	For the downstream latency path #0, configurations that satisfy the following relationship are valid: $(N_{FEC0} - 1) \times (D_0 - 1) \leq \text{254} \times \text{63} = \text{16002} \text{24000}$ For the upstream latency path #0, configurations that satisfy the following relationship are valid: $(N_{FEC0} - 1) \times (D_0 - 1) \leq 254 \times 7 = 1778$
...	...
Relation of S_p and M_p	Configurations that satisfy the following relationship are valid: $M_p / \text{23} \leq S_p \leq 32 \times M_p$ (see Note 1). For the downstream latency path #0, additional valid configurations are: $M_0 / 16 \leq S_0 \leq M_0 / \text{23}$
...	...
Delay constraints	Configurations that satisfy the following relationship are valid: $\text{1/21/3} \leq S_p \leq 64$ (see Note 3) For the downstream latency path #0, additional valid S_0 values are: $1/16 \leq S_0 < \text{1/21/3}$
...	...
NOTE 1 – This condition is a bound on the number of mux data frames per symbol. NOTE 2 – The 0.1 kbit/s overhead rate lower bound corresponds to an $SEQ_p = 2$ (see Table 7-14) and an overhead channel period of 160 ms. NOTE 3 – This condition puts bounds on the number of FEC codewords per symbol. ~~NOTE 4 – Setting MSG_{min} higher than 28 kbit/s may cause configuration errors and reduce the maximal achievable net data rate.~~	

NOTE – The ITU-T G.992.5 PMS-TC function differs from the ITU-T G.992.3 PMS-TC function only in the relationship of N_{FEC0} and D_0 , the number of Mux Data Frames per symbol and the number of FEC codewords per symbol.

7.6.3 Mandatory configurations

See clause 7.6.3 of ITU-T G.992.3, modifying Table 7-9 as follows:

Table 7-9 – Mandatory downstream control parameter support for latency path #0

Parameter	Capability
...	...
S_0	$\frac{1}{2} \leq S_0 < 64$ Support of additional optional S_0 values is indicated during initialization, through $S_{0\ min}$, with $1/16 \leq S_{0\ min} \leq \frac{1}{3}$. All values of S_0 , with $S_{0\ min} \leq S_0 < \frac{1}{3}$, shall be supported.
...	...
<u>Relationship of N_{FEC0} and D_0</u>	<u>Configurations that satisfy the following relationship shall be supported:</u> <u>$(N_{FEC0} - 1) \times (D_0 - 1) \leq 254 \times 63 = 16002$.</u>

7.7 Data plane procedures

See clause 7.7 of ITU-T G.992.3.

7.8 Control plane procedures

See clause 7.8 of ITU-T G.992.3.

7.9 Management plane procedures

See clause 7.9 of ITU-T G.992.3.

7.10 Initialization procedures

See clause 7.10 of ITU-T G.992.3, modified as follows:

Table 7-18 – Format for PMS-TC capability list information

...	...
Spar(2) bit	Definition of related Npar(3) octets
...	...
Downstream PMS-TC latency path #0 supported (always set to 1)	Parameter block of 6 octets that describes the maximum net_max downstream rate, downstream $S_{0\ min}$ ~~and~~ downstream D_0 <u>and the downstream relationship of N_{FEC0} and D_0</u> . values supported in the latency path #0. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. The net_max downstream rate shall be greater than or equal to the maximum required downstream data rate for each TPS-TC type that is supported by the ATU. The supported range of S_0 values shall be indicated by its lower bound $S_{0\ min}$. $S_{0\ min}$ shall equal $1/(n+1)$, with n coded as an unsigned 4-bit value in the 1 to 15 range. The D_0 values supported shall be individually indicated with 1 bit per value. <u>The "24000 bytes interleaver size" bit indicates the support of different relationships of N_{FEC0} and D_0. If set to ZERO, the ATU shall support all configurations of supported N_{FEC0} and D_0 such that $(N_{FEC0} - 1) \times (D_0 - 1) \leq 16'002$. If set to ONE, the ATU shall support all configurations of supported N_{FEC0} and D_0 such that $(N_{FEC0} - 1) \times (D_0 - 1) \leq 24'000$.</u>

Table 7-18 – Format for PMS-TC capability list information

Upstream PMS-TC latency path #0 supported (always set to 1)	Parameter block of 3 octets that describes the maximum net_max upstream rate and downstream D_0 values supported in the latency path #0. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. The net_max upstream rate shall be greater than or equal to the maximum required upstream data rate for each TPS-TC type that is supported by the ATU. The D_0 values supported shall be individually indicated with 1 bit per value.
Downstream PMS-TC latency path #1 supported	Parameter block of 4 octets that describes the maximum net_max downstream rate, downstream $R_{1\ max}$, and downstream $D_{1\ max}$ supported in the latency path #1. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. $R_{1\ max}$ is an unsigned 4-bit value and shall be one of the valid R_p values divided by 2. $D_{1\ max}$ is an unsigned 3-bit value and shall be the logarithm base 2 of one of the valid D_p values.
Upstream PMS-TC latency path #1 supported	Parameter block of 4 octets that describes the maximum net_max upstream rate, upstream $R_{1\ max}$, and upstream $D_{1\ max}$ supported in the latency path #1. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. $R_{1\ max}$ is an unsigned 4-bit value and shall be one of the valid R_p values divided by 2. $D_{1\ max}$ is an unsigned 3-bit value and shall be the logarithm base 2 of one of the valid D_p values.
Downstream PMS-TC latency path #2 supported	Parameter block of 4 octets that describes the maximum net_max downstream rate, downstream $R_{2\ max}$, and downstream $D_{2\ max}$ supported in the latency path #2. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. $R_{2\ max}$ is an unsigned 4-bit value and shall be one of the valid R_p values divided by 2. $D_{2\ max}$ is an unsigned 3-bit value and shall be the logarithm base 2 of one of the valid D_p values.
Upstream PMS-TC latency path #2 supported	Parameter block of 4 octets that describes the maximum net_max upstream rate, upstream $R_{2\ max}$, and upstream $D_{2\ max}$ supported in the latency path #2. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. $R_{2\ max}$ is an unsigned 4-bit value and shall be one of the valid R_p values divided by 2. $D_{2\ max}$ is an unsigned 3-bit value and shall be the logarithm base 2 of one of the valid D_p values.
Downstream PMS-TC latency path #3 supported	Parameter block of 4 octets that describes the maximum net_max downstream rate, downstream $R_{3\ max}$, and downstream $D_{3\ max}$ supported in the latency path #3. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. $R_{3\ max}$ is an unsigned 4-bit value and shall be one of the valid R_p values divided by 2. $D_{3\ max}$ is an unsigned 3-bit value and shall be the logarithm base 2 of one of the valid D_p values.
Upstream PMS-TC latency path #3 supported	Parameter block of 4 octets that describes the maximum net_max upstream rate, upstream $R_{3\ max}$, and upstream $D_{3\ max}$ supported in the latency path #3. The unsigned 12-bit net_max value is the data rate divided by ~~4000~~ 8000. $R_{3\ max}$ is an unsigned 4-bit value and shall be one of the value R_p values divided by 2. $D_{3\ max}$ is an unsigned 3-bit value and shall be the logarithm base 2 of one of the valid D_p values.
NOTE – By construction of the ADSL2plus framing, the message-based overhead data rate is strictly smaller than 64 kbit/s. Hence, the ITU-T G.994.1 phase of initialization should not request a minimum value of 64 kbit/s.	

...

The $S_0\ min$ value shall be less than or equal to ~~1/2~~1/3 (i.e., $n \geq \frac{1}{2}$). If the $S_0\ min$ octet (see Table 7-18c) is not included in the CL or CLR message, the $S_0\ min$ value shall be set equal to ~~1/2~~1/3 (implicit indication). The S_0 value selected during the exchange phase (see Table 7-7 and clause 7.10.3) shall be equal to or higher than the highest of the $S_0\ min$ values indicated in the CL and CLR message.

...

7.11 On-line reconfiguration

See clause 7.11 of ITU-T G.992.3.

7.12 Power management mode

See clause 7.11 of ITU-T G.992.3.

8 Physical media-dependent function

8.1 Transport capabilities

See clause 8.1 of ITU-T G.992.3.

8.2 Additional functions

See clause 8.2 of ITU-T G.992.3.

8.3 Block interface signals and primitives

See clause 8.3 of ITU-T G.992.3.

8.4 Block diagram and internal reference point signals

See clause 8.4 of ITU-T G.992.3.

8.5 Control parameters

8.5.1 Definition of control parameters

See clause 8.5.1 of ITU-T G.992.3, adding the following text immediately after Table 8-6:

The tss_i values depend on CO-MIB settings (see [ITU-T G.997.1]) and on local capabilities and are exchanged in the ITU-T G.994.1 phase. The tss_i values are determined by the ATU transmit function:

- For the upstream direction, the CO-MIB settings consist of a per-upstream subcarrier indication of which subcarriers may be in the upstream SUPPORTEDset and which subcarriers shall not be in the upstream SUPPORTEDset. This information is conveyed from ATU-C to ATU-R in the ITU-T G.994.1 CL upstream spectrum shaping parameter block and is used by the ATU-R (in combination with local restrictions) to determine which subcarriers to include in the upstream SUPPORTEDset (see clause 8.13.2.4).
- For the downstream direction, the CO-MIB settings consist of a per-downstream subcarrier indication of which subcarriers may be in the downstream SUPPORTEDset and which subcarriers shall not be in the downstream SUPPORTEDset. This information is used by the ATU-C (in combination with local restrictions) to determine which subcarriers to include in the downstream SUPPORTEDset (see clause 8.13.2.4).
- For the downstream direction, the CO-MIB settings also include the downstream PSD mask applicable at the U-C2 reference point (see clause 5). This MIB PSD mask may impose PSD restrictions in addition to the Limit PSD mask defined in the relevant Annex, as relevant for the chosen application option. This information is used by the ATU-C (in combination with local restrictions) to determine which subcarriers to include in the downstream SUPPORTEDset (see clause 8.13.2.4) and to determine the level of spectrum shaping (i.e., tss_i value) to be applied to these subcarriers. The downstream PSD mask specified through the CO-MIB shall satisfy the requirements defined in the remainder of this clause.

The downstream PSD mask in the CO-MIB (exchanged between NMS and access node over the Q reference point, see Figure 5-1 of [ITU-T G.997.1]) shall be specified through the downstream power back-off-shaped (DPBOSHAPED, see clause 7.3.1.2.13 of [ITU-T G.997.1]) or through a set of breakpoints (PSDMASKds, see 7.3.1.2.9 of [ITU-T G.997.1]).

- When specified through a set of breakpoints, the access node shall pass these breakpoints (PSDMASKds) to the ATU-C over the gamma reference point.
- When specified through the DPBO (i.e., DPBOESEL > 0, see clause 7.3.1.2.13 of [ITU-T G.997.1]), the access node shall pass the set of breakpoints of the modified downstream PSD mask (see clause 7.3.1.2.13 of [ITU-T G.997.1]) to the ATU-C over the gamma reference point.

At the Q and gamma reference points, each breakpoint shall consist of a subcarrier index t and a MIB PSD mask level (expressed in dBm/Hz) at that subcarrier. The set of breakpoints can then be represented as $[(t_1, PSD_1), (t_2, PSD_2), \dots, (t_N, PSD_N)]$. The subcarrier index shall be coded as an unsigned integer in the range from $\text{roundup}(f_{pb_start}/\Delta f)$ to $\text{rounddown}(f_{pb_stop}/\Delta f)$, where f_{pb_start} and f_{pb_stop} are the lower and higher edge, of the passband respectively and Δf is the subcarrier spacing defined in clause 8.8.1. The passband is defined in Annexes A, B or I, as relevant to the selected application option. The MIB PSD mask level shall be coded as an unsigned integer representing the PSD mask levels 0 dBm/Hz (coded as 0) to -127.5 dBm/Hz (coded as 255), in steps of 0.5 dBm/Hz, with valid range 0 to -95 dBm/Hz. The maximum number of breakpoints is 32. The corresponding MIB PSD mask for each frequency f shall be defined as follows:

- f_{lm_start} = frequency at which the flat extension below f_1 intersects the limit mask (0 Hz if no intersect).
- f_{lm_stop} = frequency at which the flat extension above f_N intersects the limit mask.
- At frequencies below f_1 and at frequencies above f_N , the MIB PSD mask shall be obtained as follows:

$$MIB\ PSD\ mask(f) = \begin{cases} Limit\ mask(f) & f < f_{lm_start} \\ PSD_1 & f_{lm_start} \leq f \leq f_1 \\ PSD_N & f_N < f \leq f_{lm_stop} \\ Limit\ mask(f) & f > f_{lm_stop} \end{cases}$$

NOTE 1 – In defining the set of breakpoints of the modified downstream PSD mask (see clause 7.3.1.2.13 of [ITU-T G.997.1]), the access node may take into account whether the transceiver supports windowing or not (see clause 8.8.4).

NOTE 2 – The actual transmit PSD (at the U-C reference point), while conforming to the MIB PSD mask (received through a set of breakpoints over the gamma reference point), may significantly undershoot the MIB PSD mask in some frequency regions if the MIB PSD mask shape requires faster roll-off than is supported by the available windowing capability. Appendix IV defines the PSD template to be used in capacity calculations with in band transmit spectrum shaping, except where the transceiver supports windowing and windowing is enabled, in which case the shape of the windowing should be taken into account.

In case the downstream PSD mask in the CO-MIB is expressed as a set of breakpoints (exchanged between NMS and AN over the Q reference point, see clause 7.3.1.2.9 [ITU-T G.997.1]), the set of breakpoints shall comply to the following restrictions, and the corresponding MIB PSD mask for each frequency f shall be defined as following:

1) General:

- $t_n < t_{n+1}$ for $n = 1$ to $N - 1$.
- $f_n = t_n \times \Delta f$.

2) Low-frequency end and high-frequency end of MIB PSD mask (f):

- $t_1 = \text{roundup}(f_{pb_start}/\Delta f)$ or $(73 \leq t_1 \leq 271)$.
- $t_N = \text{rounddown}(f_{pb_stop}/\Delta f)$.

3) MIB PSD stopband in lower frequency part:

if $(73 \leq t_1 \leq 271)$ then:

– $PSD_1 = -95$ dBm/Hz.

– Set of valid t_2 values is every tenth tone starting from tone 100 up until tone 280.

– The value t_1 shall be:

$$t_1 = \text{rounddown} \left(t_2 - \left(\frac{PSD_2 - PSD_1}{2.2 \text{ dB/tone}} \right) \right)$$

– At frequencies between f_1 and f_2 , the MIB PSD mask is obtained by interpolation in dB on a logarithmic frequency scale as follows:

$$MIB \text{ PSD mask}(f) = \begin{cases} PSD_1 + (PSD_2 - PSD_1) \times \frac{\log((f/\Delta f)/t_1)}{\log(t_2/t_1)} & f_1 < f \leq f_2 \end{cases}$$

4) MIB PSD inband shaping:

if $t_1 = \text{roundup}(f_{pb_start}/\Delta f)$ then, for $n = 1$ to $N - 1$:

if $(73 \leq t_1 \leq 271)$ then, for $n = 2$ to $N - 1$:

– The inband slope shall comply to:

$$\left| \frac{PSD_{n+1} - PSD_n}{t_{n+1} - t_n} \right| \leq 0.75 \text{ dB/tone}$$

– $\text{MAX}(PSD_n) - \text{MIN}(PSD_n) \leq 20$ dB.

– $\text{MAX PSD of the limit mask} - 20 \text{ dB} \leq \text{MAX}(PSD_n) \leq \text{MAX PSD of the limit mask}$.

– The MIB PSD mask is obtained by interpolation in dB on a linear frequency scale as follows:

$$MIB \text{ PSD mask}(f) = \begin{cases} PSD_n + (PSD_{n+1} - PSD_n) \times \frac{(f/\Delta f) - t_n}{t_{n+1} - t_n} & f_n < f \leq f_{n+1} \end{cases}$$

NOTE 3 – If the first breakpoint has subcarrier index $73 \leq t_1 \leq 271$, then a stopband is created in the lower frequency part of the passband, with spectrum shaping applied to the remainder of the passband. If $t_1 = \text{roundup}(f_{pb_start}/\Delta f)$, then only spectrum shaping is applied over the whole passband.

5) RFI band specification:

– An RFI band is specified in the CO-MIB PSD mask through a set of 4 breakpoints $(t(i+1), PSD(i+1))$ to $(t(i+4), PSD(i+4))$, as shown in Figure 8.5.1-1. In addition, the CO-MIB also contains an explicit indication that the pair $(t(i+2), t(i+3))$ represents an RFI band (see [ITU-T G.997.1]).

– The restrictions on the breakpoints specifying an RFI band are:

$$\frac{PSD_{i+1} - PSD_{i+2}}{t_{i+1} - t_{i+2}} \leq 1.5 \text{ dB/tone}$$

$$PSD_{i+2} \geq PSD_Limitmask(f_{i+2}) - 33.5 \text{ dB}$$

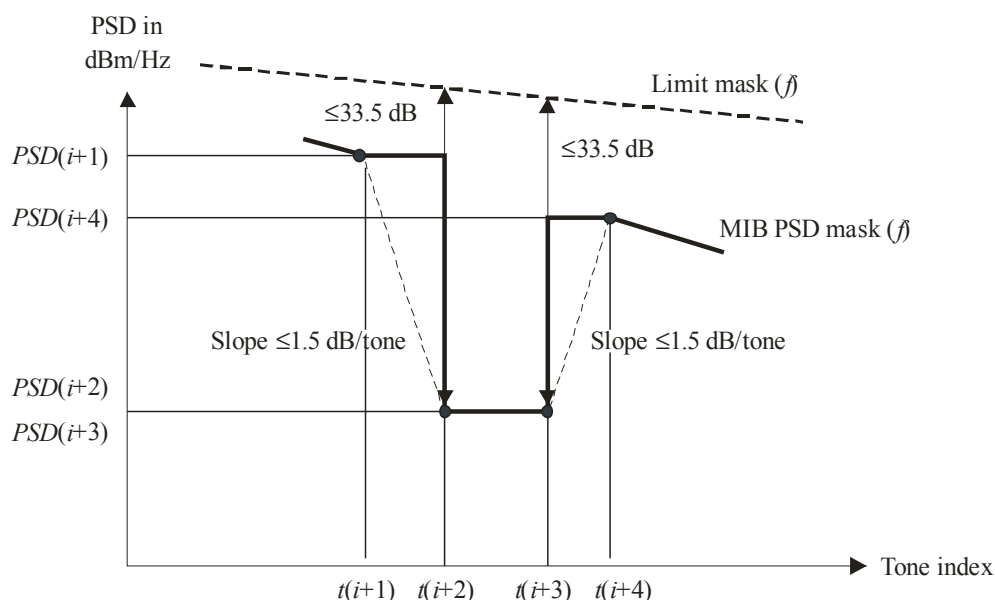
$$PSD_{i+2} = PSD_{i+3}$$

$$PSD_{i+3} \geq PSD_Limitmask(f_{i+3}) - 33.5 \text{ dB}$$

$$\frac{PSD_{i+4} - PSD_{i+3}}{t_{i+4} - t_{i+3}} \leq 1.5 \text{ dB/tone}$$

– In the RFI band, the MIB PSD mask is given by the following equations:

$$MIB \text{ PSD mask}(f) = \begin{cases} PSD_{i+1} & f_{i+1} \leq f \leq f_{i+2} \\ PSD_{i+2} = PSD_{i+3} & f_{i+2} \leq f \leq f_{i+3} \\ PSD_{i+4} & f_{i+3} \leq f \leq f_{i+4} \end{cases}$$



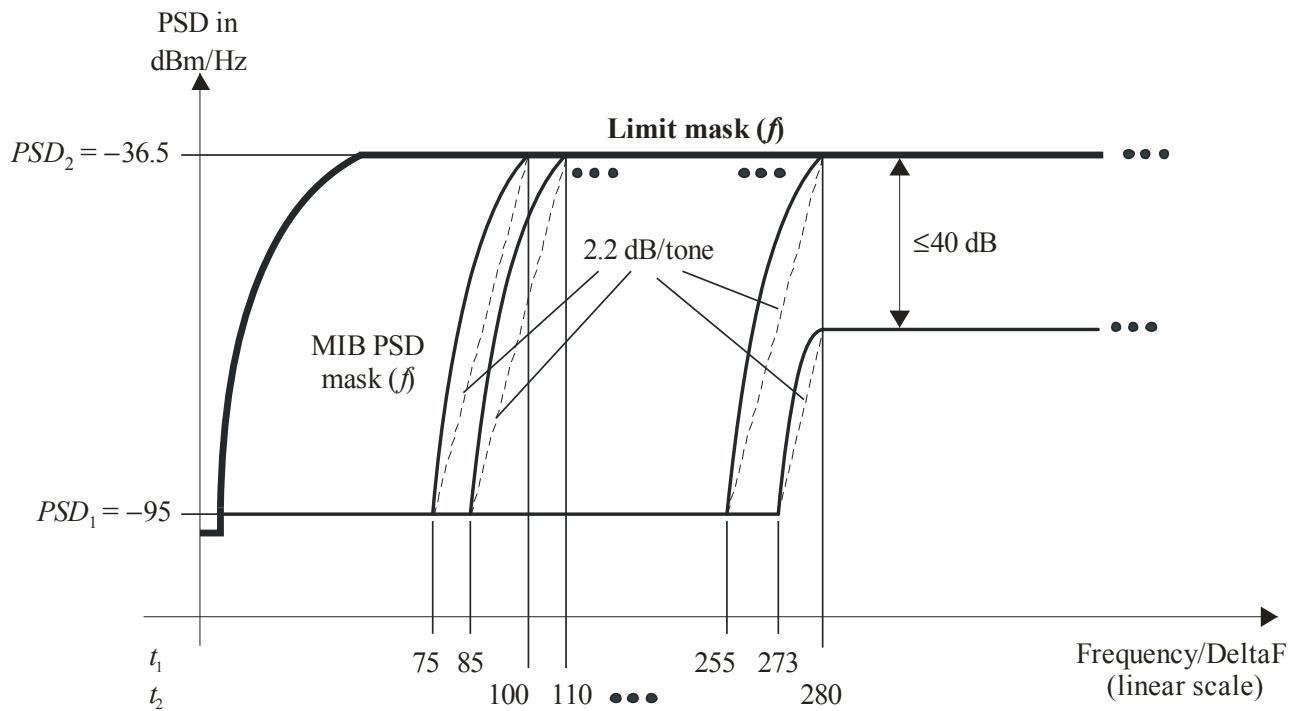
G.992.5(01_05)_F8.5.1-1

Figure 8.5.1-1 – Restrictions on breakpoints and MIB PSD mask (f)

The (informative) MIB PSD template is defined as the CO-MIB PSD mask -3.5 dB, for $f_{lm_start} \leq f \leq f_{lm_stop}$, except for the MIB PSD stopband in the lower frequency part, which remains at -95 dBm/Hz, and the stopband of the RFI bands which remains at $PSD(i+2)$.

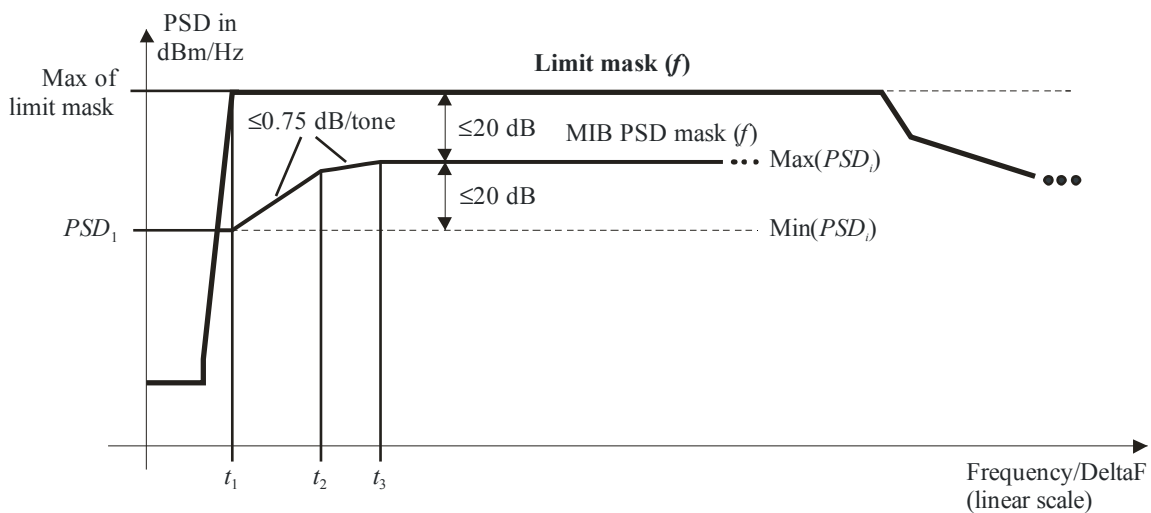
The PSD mask to which the ATU-C transmitter shall comply at the U-C2 reference point shall be the minimum (at each frequency) of the limit PSD mask (specified in Annexes A, B or I) and the CO-MIB PSD mask specified through the CO-MIB.

The following figures give a number of examples of MIB PSD masks which can be constructed within the above restrictions. Figure 8.5.1-2 illustrates a number of PSD masks which introduce a stopband in the first part of the frequency band. Figure 8.5.1-3 illustrates the restrictions on the MIB PSD in band shaping. The PSD toolbox techniques shown in these figures may be combined in practice.



G.992.5(01_05)_F8.5.1-2

Figure 8.5.1-2 – Illustration of a stopband in the first part of the frequency band



G.992.5(01_05)_F8.5.1-3

Figure 8.5.1-3 – Illustration of the restrictions on the MIB PSD in-band shaping

8.5.2 Mandatory and optional settings of control parameters

See clause 8.5.2 of ITU-T G.992.3.

8.5.3 Setting control parameters during initialization

See clause 8.5.3 of ITU-T G.992.3, modified as follows:

Table 8-11 – Format of PMD function control parameters included in MSG1

Parameter	Format
...	...
<i>CA-MEDLEY</i>	Unsigned 6-bit integer, 0 to 63 (times 512 symbols).
<i>WINDOW SAMPLES</i>	Window samples are represented by <i>NSCs</i>/64 entries. Each entry is a 16-bit unsigned integer, in multiples of 2^{-16} (see clause 8.8.4).

The value *CA-MEDLEY* represents the minimum duration (in multiples of 512 symbols) of the MEDLEY state during the initialization channel analysis phase. It can be different for the ATU-C (*CA-MEDLEY_{us}* indicates the minimum length of the R-MEDLEY state) and the ATU-R (*CA-MEDLEY_{ds}* indicates the minimum length of the C-MEDLEY state). See clauses 8.13.5.1.4 and 8.13.5.2.4.

The PMD function control parameters exchanged in the C-MSG1 message are listed in Table 8-12. [Window samples shall be included only if windowing is applied \(which is indicated in C-MSG-FMT, see clause 8.13.3.1.10\).](#)

Table 8-12 – PMD function control parameters included in C-MSG1

Octet Nr [i]	Parameter	PMD format bits [$8 \times i + 7$ to $8 \times i + 0$]
...	...	...
19	Reserved	[0000 0000]
20	w(0) (LSB)	[xxxx xxxx], bit 7 to 0
21	w(0) (MSB)	[xxxx xxxx], bit 15 to 8
...	...	...
18 + <i>NSCs</i>/32	w(<i>NSCs</i>/64 – 1) (LSB)	[xxxx xxxx], bit 7 to 0
19 + <i>NSCs</i>/32	w(<i>NSCs</i>/64 – 1) (MSB)	[xxxx xxxx], bit 15 to 8

...

NOTE – An extended range for g_i values can only be used if the transmit PSD function chooses to use a nominal transmit PSD level that is below the maximum transmit PSD level allowed by the CO-MIB ([see clause 8.5.1](#)) and can only be used within the transmit PSD mask limitations set by the CO-MIB.

8.5.3.3 During the exchange phase

See clause 8.5.3.3 of ITU-T G.992.3, modified as follows:

The format of the PMD function control and test parameters involved in the PARAMS messages shall be as shown in Table 8-14.

Table 8-14 – Format of PMD function control parameters included in PARAMS

Parameter	Format
...	...
Tone ordering table	Tone ordering is represented by <i>NSC</i> – 1 entries. Each entry is an 811 -bit unsigned integer, representing a subcarrier index in the 1 to <i>NSC</i> – 1 range .

The test parameters are mapped into messages using an integer number of octets per parameter value. In case the parameter value, as defined in clause 8.12.3, is represented with a number of bits that is not an integer number of octets, the parameter value shall be mapped into the least significant bits of the message octets. Unused more significant bits shall be set to 0 for unsigned parameter values and shall be set to the sign bit for signed parameter values.

The PMD function control parameters and test parameters exchanged in the C-PARAMS message are listed in Table 8-15.

Table 8-15 – PMD function control parameters included in C-PARAMS

Octet Nr [i]	Parameter	PMD format bits $[8 \times i + 7 \text{ to } 8 \times i + 0]$
...	...	...
5	<i>SNRM_{us}</i> (MSB)	[ssss ~~ssxx~~ sxxx], bit ~~9~~ and <u>10</u> to 8
...	...	...
$13 + 2 \times NSC_{us}$	~~Upstream tone ordering first subcarrier to map~~ Reserved	~~[xxxx xxxx], bit 7 to 0~~ [0000 0000]
<u>$14 + 2 \times NSC_{us}$</u>	<u>Upstream tone ordering first subcarrier to map (LSB)</u>	[xxxx xxxx], bits 7 to 0
<u>$15 + 2 \times NSC_{us}$</u>	<u>Upstream tone ordering first subcarrier to map (MSB)</u>	[0000 0xxx], bits 10 to 8
.....		
<u>$10 + 4 \times NSC_{us}$</u>	<u>Upstream tone ordering last subcarrier to map (LSB)</u>	[xxxx xxxx], bits 7 to 0
$11 + \textcolor{red}{34} \times NSC_{us}$	Upstream tone ordering last subcarrier to map (<u>MSB</u>)	[xxxx xxxx], bits ~~7~~ to ~~0~~ <u>10</u> to 8

The PMD function control parameters exchanged in the R-PARAMS message are listed in Table 8-16.

Table 8-16 – PMD function control parameters included in R-PARAMS

Octet Nr [i]	Parameter	PMD format bits $[8 \times i + 7 \text{ to } 8 \times i + 0]$
...	...	...
5	<i>SNRM_{ds}</i> (MSB)	[ssss ~~ssxx~~ sxxx], bit ~~9~~ and <u>10</u> to 8
...	...	...
$13 + 2 \times NSC_{ds}$	~~Downstream tone ordering first subcarrier to map~~ Reserved	~~[xxxx xxxx], bit 7 to 0~~ [0000 0000]
<u>$14 + 2 \times NSC_{ds}$</u>	<u>Downstream tone ordering first subcarrier to map (LSB)</u>	[xxxx xxxx], bits 7 to 0
<u>$15 + 2 \times NSC_{ds}$</u>	<u>Downstream tone ordering first subcarrier to map (MSB)</u>	[0000 0xxx], bits 10 to 8
.....		
~~$11 + 3$~~ <u>$10 + 4$</u> $\times NSC_{ds}$	Downstream tone ordering last subcarrier to map (<u>LSB</u>)	[xxxx xxxx], bit 7 to 0

Table 8-16 – PMD function control parameters included in R-PARAMS

Octet Nr [i]	Parameter	PMD format bits $[8 \times i + 7 \text{ to } 8 \times i + 0]$
11 + 4 × NSCds	Downstream tone ordering last subcarrier to map (MSB)	[0000 0xxx], bits 10 to 8

8.6 Constellation encoder for data symbols

See clause 8.6 of ITU-T G.992.3.

8.7 Constellation encoder for synchronization and L2 exit symbols

See clause 8.7 of ITU-T G.992.3.

8.8 Modulation

See clause 8.8 of ITU-T G.992.3.

8.8.1 Subcarriers

See clause 8.8.1 of ITU-T G.992.3.

8.8.2 Inverse discrete fourier transform (IDFT)

See clause 8.8.2 of ITU-T G.992.3.

8.8.3 Cyclic prefix

See clause 8.8.3 of ITU-T G.992.3, modified as follows.

With a data symbol rate of 4 kHz, a DMT subcarriers spacing of $\Delta f = 4.3125$ kHz and an IDFT size of $2 \times NSC$, a cyclic prefix of $(2 \times NSC \times 5/64)$ samples could be used. That is,

$$(2 \times NSC + 2 \times NSC \times 5/64) \times 4.0 \text{ kHz} = (2 \times NSC) \times 4.3125 \text{ kHz} = f_s \text{ (the sample frequency)}$$

The cyclic prefix shall, however, be shortened to $(2 \times NSC \times 4/64 = NSC/8)$ samples, and a synchronization symbol (with a length of $2 \times NSC \times 68/64$ samples) is inserted after every 68 data symbols. That is,

$$(2 \times NSC \times 4/64 + 2 \times NSC) \times 69 = (2 \times NSC \times 5/64 + 2 \times NSC) \times 68$$

For symbols with cyclic prefix, the last $NSC/8$ samples of output of the IDFT (x_n for $n = 2 \times NSC - NSC/8$ to $2 \times NSC - 1$) shall be prepended to the block of $2 \times NSC$ samples, to form a block of $(2 \times NSC \times 17/16)$ samples. Symbols with cyclic prefix are transmitted at a symbol rate of $4.3125 \times 16/17 \approx 4.059$ kHz.

In the downstream direction, the ATU-C transmitter may apply windowing. If windowing is applied, symbols with cyclic prefix shall also have a cyclic suffix. If windowing is not applied, symbols with cyclic prefix shall not have a cyclic suffix. For symbols with a cyclic suffix, the first $NSCds/32$ samples of output of the IDFT (x_n for $n = 0$ to $NSCds/32 - 1$) shall be appended to the block of $(2 \times NSC \times 17/16)$ samples, to form a block of $(2 \times NSC \times 69/64)$ samples. Symbols with cyclic suffix are transmitted at a symbol rate of $4.3125 \times 16/17 \approx 4.059$ kHz.

The cyclic prefix (and suffix if windowing is applied) shall be used for all symbols transmitted starting from the channel analysis phase of the initialization sequence (see clause 8.13.5). Before the channel analysis phase, all symbols shall be transmitted without cyclic prefix and without cyclic suffix. Symbols transmitted without cyclic prefix and without cyclic suffix are transmitted at a symbol rate of 4.3125 kHz.

If an oversampled IDFT is used (i.e., $N > NSC$, see clause 8.8.2), the number of cyclic prefix and cyclic suffix samples shall be adapted accordingly. For symbols with cyclic prefix, the last $N/8$ samples of output of the IDFT (x_n for $n = 2 \times N - N/8$ to $2 \times N - 1$) shall be prepended to the block of $2 \times N$ samples, to form a block of $(2 \times N \times 17/16)$ samples. For symbols with cyclic suffix, the first $N/32$ samples of output of the IDFT (x_n for $n = 0$ to $N/32 - 1$) shall be appended to the block of $(2 \times N \times 17/16)$ samples, to form a block of $(2 \times N \times 69/64)$ samples.

8.8.4 Parallel/serial convertor

See clause 8.8.4 of ITU-T G.992.3, modified as follows.

The block of x_n samples ($n = 0$ to $2 \times NSC - 1$) shall be read out to the digital-to-analogue convertor (DAC) in sequence.

If no cyclic prefix is used, the DAC samples y_n in sequence are:

$$y_n = x_n \text{ for } n = 0 \text{ to } 2 \times NSC - 1$$

If a cyclic prefix is used, the DAC samples y_n in sequence are (see Figure 8-5):

$$\begin{aligned} y_n &= x_n + (2 \times NSC - NSC/8) & \text{for } n = 0 \text{ to } NSC/8 - 1 \\ y_n &= x_n - (NSC/8) & \text{for } n = NSC/8 \text{ to } (17/16) \times 2 \times NSC - 1 \end{aligned}$$

If, for the downstream direction, a cyclic prefix is used and a cyclic suffix is used (windowing), then the DAC samples in sequence shall be:

$$\begin{aligned} & [1 - w(i)] \times prev_x(i) + w(i) \times x\left(2 \times NSC - \frac{NSC}{8} + i\right) & \text{for } i = 0 \text{ to } \frac{NSC}{32} - 1 \\ & x\left(2 \times NSC - \frac{NSC}{8} + i\right) & \text{for } i = \frac{NSC}{32} \text{ to } \frac{NSC}{8} - 1 \\ & x(i) & \text{for } i = 0 \text{ to } 2 \times NSC - 1 \end{aligned}$$

where the $prev_x(i)$ corresponds to the cyclic suffix of the previous symbol (see clause 8.8.3). The $NSC/32$ samples in the cyclic suffix of the previous symbol and the first $NSC/32$ samples of the cyclic prefix of the current symbol are transmitted as overlapping in time, i.e., a weighted sum is transmitted. The above defined DAC sample sequence corresponds to applying a $(2 \times NSC \times 69/64)$ samples window. The window in discrete time representation (set of w_i) shall defined as follows:

$$\begin{aligned} w_i & \text{ is vendor discretionary} & \text{for } i = 0 \text{ to } \frac{NSC}{64} - 1 \\ w_i & = 1 - w\left(\frac{NSC}{32} - 1 - i\right) & \text{for } i = \frac{NSC}{64} \text{ to } \frac{NSC}{32} - 1 \\ w_i & = 1 & \text{for } i = \frac{NSC}{32} \text{ to } 2 \times NSC \times \frac{17}{16} - 1 \\ w_i & = w\left(2 \times NSC \times \frac{69}{64} - 1 - i\right) & \text{for } i = 2 \times NSC \times \frac{17}{16} \text{ to } 2 \times NSC \times \frac{69}{64} - 1 \end{aligned}$$

Each of the time discrete window samples shall be represented in a 16-bit unsigned integer as a multiple of 65536, in the 0 to $1 - 2^{-16}$ range.

The window in continuous time representation ($w(t)$) shall be defined as follows:

$$w(t) = \sum_{i=0}^{2 \times NSC \times \frac{69}{64} - 1} \sin c(t \times f_s - i) \cdot w_i$$

The ATU-C shall indicate in the C-MSG-FMT message whether or not windowing is applied. In case windowing is applied, the C-MSG1 shall contain the window samples $w(i)$ for $i = 0$ to $NSC/64 - 1$ (see clause 8.5.3.2). These $NSC/64$ samples define the complete window of $2 \times NSC \times 69/64$ samples as defined above.

NOTE – The C-MSG1 message is transmitted in the Initialization procedures (see clause 8.13) and Short initialization procedures (see clause 8.14). It is not transmitted in the Loop diagnostics mode procedures (see clause 8.15).

If an oversampled IDFT is used (i.e., $N > NSC$, see clause 8.8.2), the number of window samples shall be adapted accordingly from the window in continuous time representation $w(t)$ to a window of $2 \times N \times 69/64$ samples. The ATU-C shall truncate in time and round samples to the same precision as the (non-oversampled) window samples communicated to the ATU-R in the C-MSG1 message. The ATU-R receiver shall take into account the error that the ATU-C transmitter may introduce through this time truncation and value rounding process.

Filtering may be applied to the sample sequence going into the DAC.

8.8.5 DAC and AFE

See clause 8.8.5 of ITU-T G.992.3, modified as follows.

The DAC produces an analogue signal that is passed through the analogue front end (AFE) and transmitted across the digital subscriber line (DSL). The analogue front end may include filtering.

If the transmit PMD function is configured in the L3 idle state, then a zero output voltage shall be transmitted at the U-C2 (for ATU-C) and the U-R2 (for ATU-R) reference point (see reference model in clause 5.4). The analogue front end may include filtering.

8.9 Transmitter dynamic range

See clause 8.9 of ITU-T G.992.3, adding the following text immediately before clause 8.9.1:

Due to the non-flat PSD used for the downstream transmitted signals, the MTPR requirements at the ATU-C are for further study.

8.10 Transmitter spectral masks

See clause 8.10 of ITU-T G.992.3, modified as follows:

In this Recommendation, Annex L is not defined.

~~Annex L: Specific requirements for a Reach Extended ADSL2 (READSL2) system operating in the frequency band above POTS:~~

- ~~• L.1.2 ATU-C transmit spectral mask for overlapped spectrum reach extended operation;~~
- ~~• L.1.3 ATU-C transmit spectral mask for non-overlapped spectrum reach extended operation;~~
- ~~• L.2.2 ATU-R transmit spectral mask 1 for reach extended operation.~~
- ~~• L.2.3 ATU-R transmit spectral mask 2 for reach extended operation.~~

8.11 Control plane procedures

See clause 8.11 of ITU-T G.992.3.

8.12 Management plane procedures

See clause 8.12 of ITU-T G.992.3.

8.12.1 ADSL line-related primitives

See clause 8.12.1 of ITU-T G.992.3.

8.12.2 Other primitives

See clause 8.12.2 of ITU-T G.992.3.

8.12.3 Test parameters

See clause 8.12.3 of ITU-T G.992.3.

8.12.4 Diagnostics mode

See clause 8.12.4 of ITU-T G.992.3.

8.12.5 Accuracy of test parameters

See clause 8.12.5 of ITU-T G.992.3.

8.12.5.1 Channel characteristics function per subcarrier (CCFps)

8.12.5.1.1 Channel attenuation in logarithmic format (HLOGps)

See clause 8.12.5.1.1 of ITU-T G.992.3, modified as follows:

The downstream HLOGps reference value shall be defined for each subcarrier as follows:

$$\text{HLOGps_reference_ds}(i) = \text{PSDps_UR2}(i) - (\text{REFPSDds} + \text{ceiled_log_tss}_i(i))$$

...

The accuracy requirements for the downstream HLOGps (HLOGps_ds) shall apply only to the following subcarriers (with the corresponding frequency ranges being a part of the passband), and only if not within the downstream BLACKOUTset (see clause 8.13.2.4):

- Annexes A and I: Subcarriers 46 to ~~208~~463.
- ~~Annex L: Subcarriers 46 to 104.~~
- Annexes B, J and M: Subcarriers 92 to ~~208~~463.

The accuracy requirements for upstream HLOGps (HLOGps_us) shall apply to the subcarriers within the following frequency ranges (defined as a part of the passband), and not within the upstream BLACKOUTset (see clause 8.13.2.4):

- Annexes A and I: Subcarriers 11 to 23.
- ~~Annex L (mask 1): Subcarriers 11 to 17.~~
- Annex B: Subcarriers 36 to 53.
- Annexes J and M: Subcarriers 11 to 53.

...

8.13 Initialization procedures

8.13.1 Overview

See clause 8.13.1 of ITU-T G.992.3.

8.13.2 ITU-T G.994.1 phase

See clause 8.13.2 of ITU-T G.992.3, adding the following text immediately before clause 8.13.2.1:

The ITU-T G.992.5 handshake codepoints are defined in [ITU-T G.994.1].

8.13.2.1 Handshake – ATU-C

See clause 8.13.2.1 of ITU-T G.992.3.

8.13.2.1.1 CL messages

See clause 8.13.2.1.1 of ITU-T G.992.3, adding the following immediately after Table 8-20:

For operation in Annex A mode, the following additional Npar(2) codepoint is defined:

<u>Npar(2)</u>	<u>Definition for CL message</u>
<u>Downstream spectrum shaping using time domain filtering only</u>	<u>When set to 1, the ATU-C indicates that only time domain filtering is used to shape the downstream inband spectrum.</u>

If the ATU-C sets the "downstream spectrum shaping using time domain filtering only" bit to ONE in the CL message, the downstream tss_i values shall all be set to ONE and the ATU-C shall shape the inband transmit PSD only in the time domain, with a shape identical to the shape of the downstream Annex A PSD mask. If the ATU-C sets this bit to ZERO in the CL message, it indicates that the ATU-R shall use the downstream tss_i values as indicated in the CL message for all calculations.

The ATU-C shall set the "downstream spectrum shaping using time domain filtering only" bit to ONE in the MS message if, and only if, both the previous CL and CLR messages have this bit set to ONE.

8.13.2.2 Handshake – ATU-R

See clause 8.13.2.2 of ITU-T G.992.3.

8.13.2.2.1 CLR messages

See clause 8.13.2.2.1 of ITU-T G.992.3, adding the following text immediately after Table 8-22:

For operation in Annex A mode, the following additional Npar(2) codepoint is defined:

<u>Npar(2)</u>	<u>Definition for CLR message</u>
<u>Downstream spectrum shaping using time domain filtering only</u>	<u>When set to 1, the ATU-R indicates that it can support processing of received signals generated with time domain only filtering of the downstream inband spectrum.</u>

The ATU-R shall set the "downstream spectrum shaping using time domain filtering only" bit to ONE in the MS message if, and only if, both the previous CL and CLR messages have this bit set to ONE.

If the "downstream spectrum shaping using time domain filtering only" bit is set to ONE in the MS message, the ATU-R shall assume that the downstream tss_i values are all set to ONE and the ATU-R shall compute the NOMATP using a set of downstream tss_i values derived from the Annex A downstream PSD mask. If the bit is set to ZERO in the MS message, the ATU-R shall use the downstream tss_i values as indicated in the previous CL message for all calculations.

8.13.2.3 ITU-T G.994.1 transmit PSD levels

See clause 8.13.2.3 of ITU-T G.992.3.

8.13.2.4 Spectral bounds and shaping parameters

See clause 8.13.2.4 of ITU-T G.992.3, modified as follows immediately after Note 4.

- If windowing is applied in the downstream direction, the $W^2(f)$ used in Equation 8-1 is the Fourier transform of the autocorrelation function of the window $w(t)$ (see clause 8.8.4), normalized such that the integral of $W^2(f)$ is equal to unity.
- The downstream tss_i values as indicated in the ITU-T G.994.1 CL message shall be used in the channel discovery phase.

- Starting from the transceiver training phase, tss_i values for subcarriers included in the downstream SUPPORTEDset shall be ceiled according to the following relationship, before being applied relative to the REFPSDds level:

$$\text{ceiled_log_}tss_i = \text{MIN}(\text{log_}tss_i + PCBds, 0 \text{ dB})$$

The $\text{ceiled_log_}tss_i$ shall only be computed at the beginning of the transceiver training phase and shall not be adapted when $PCBds$ changes during showtime (e.g., with entry into the L2 power management state or with L2 trim, see clause 9.4.1.7).

- Starting from the transceiver training phase, tss_i values for subcarriers not included in the downstream SUPPORTEDset shall be applied as indicated in the ITU-T G.994.1 CL message, relative to the REFPSDds level.

NOTE 5 – This corresponds to a ceiling of the transmit PSD to the REFPSDds level over the subcarriers included in the SUPPORTEDset, and a lowering of the transmit PSD by $PCBds$ dB over the subcarriers not included in the SUPPORTEDset. Depending on the spectrum shaping applied through the tss_i values as indicated in the ITU-T G.994.1 CL message, this may reduce the transmit PSD level only in a part or in the whole passband.

NOTE 6 – Because the ATU-C applies the downstream power cutback through a ceiling of the downstream tss_i values before being applied relative to the REFPSDds level. This implies that the ATU-R receiver will have to take into account the downstream tss_i values indicated in the ITU-T G.994.1 CL message when determining the downstream power cutback to be requested through the R-MSG-PCB message.

Figure 8-25 shows an example of the downstream tss_i values as a function of the subcarrier index i , for the case that the SUPPORTEDset contains the subcarriers with index ~~$i=40$ to 200 and $N=2 \times NSC=512$~~ $i=100$ to 399 and $i=484$ to 500 and for $N=2 \times NSC=1024$ (oversampled IDFT). At frequencies $i \times \Delta f$, with ~~$40 \leq i \leq 200$~~ $100 \leq i \leq 399$ and $484 \leq i \leq 500$ and $\Delta f=4.3125$ kHz, the tss_i value ~~equals -1 (0 dB)~~ is chosen such that for ideal filters, ideal DAC and ideal AFE, the spectrum on the U-interface corresponds with the transmit spectrum given in Annex A. At frequencies $i \times \Delta f$, with $400 \leq i \leq 483$ the carriers are not in the SUPPORTEDset to avoid the HAM-band [1.81, 2.0] MHz, taking into account a 20-tone transition band. In this case, no windowing is assumed and therefore some extra notch-filter needs to be applied to reach a stopband of -80 dBm/Hz.

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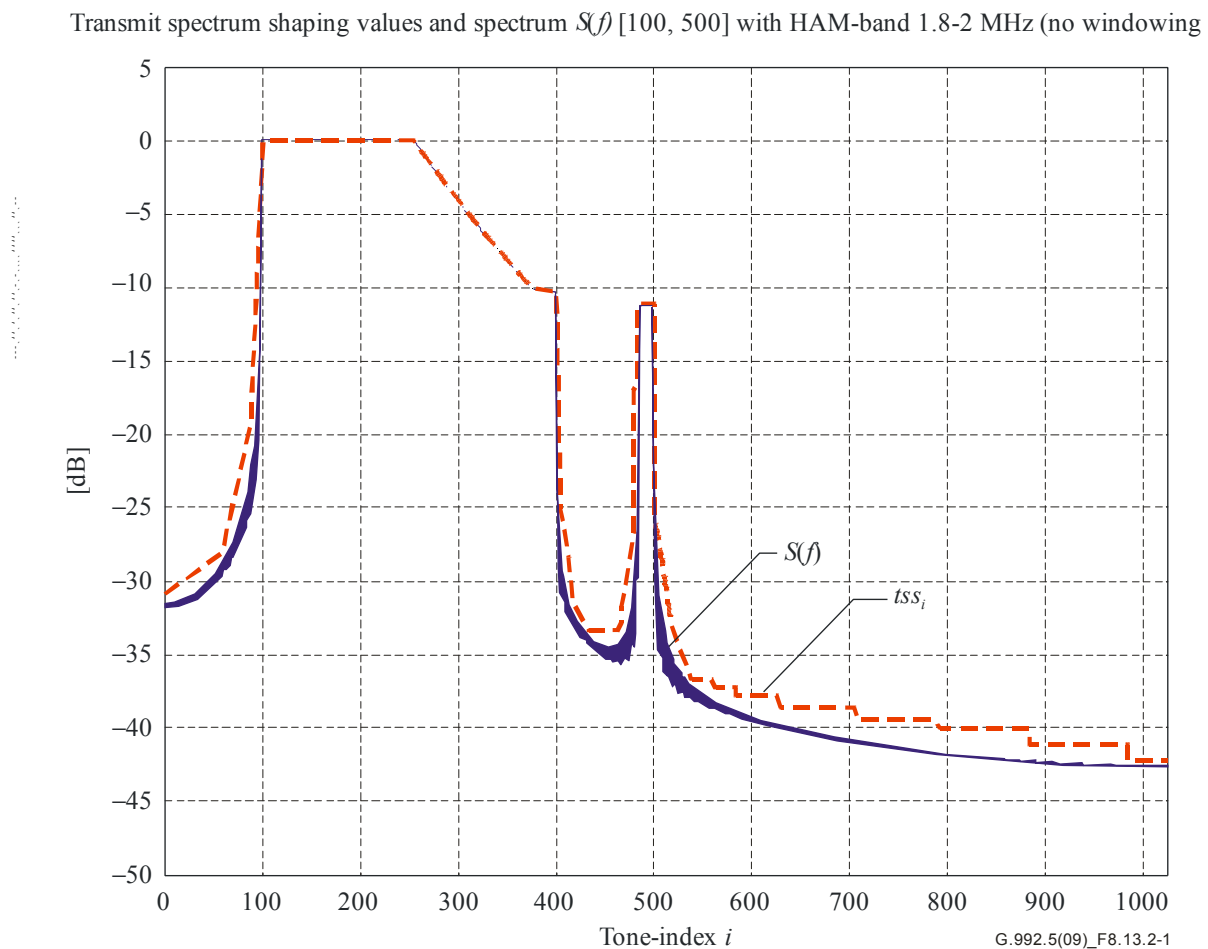
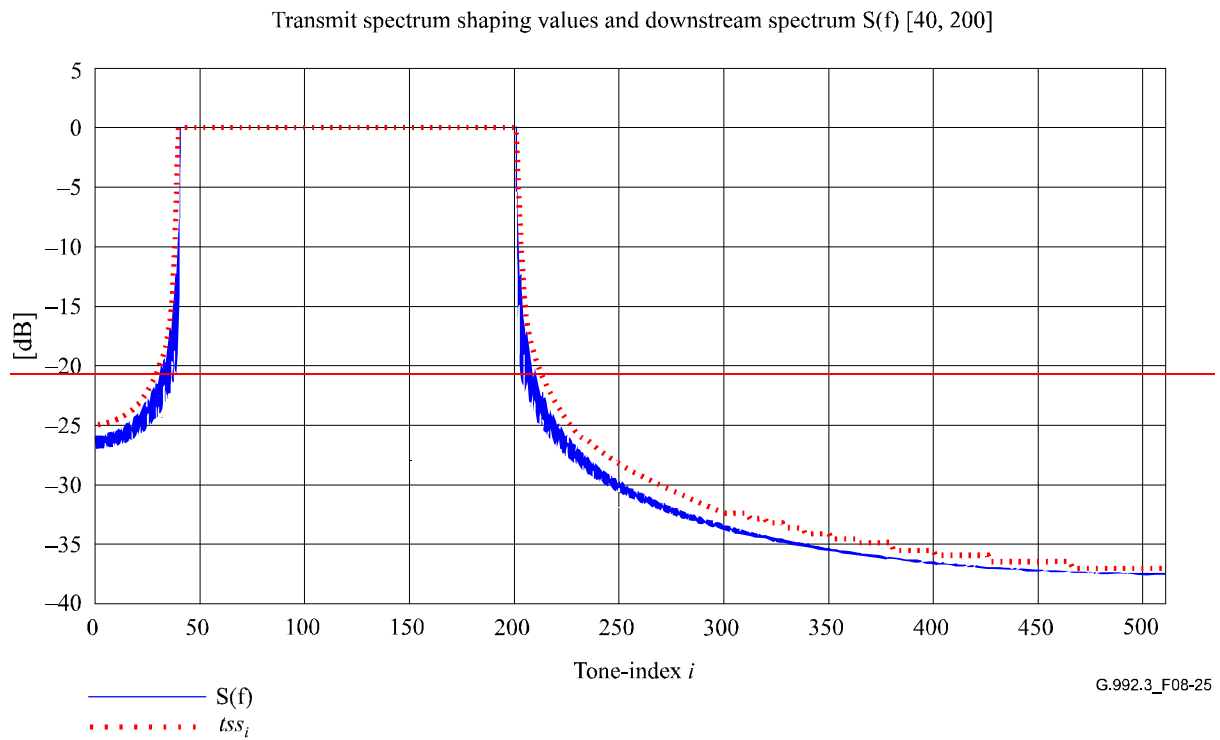


Figure 8-25 – Example of the downstream $\log_{tss_i}$ values (in dB) as a function of the subcarrier index

...

NOTE ~~5~~ 7 – For the downstream direction, the CO-MIB contains a per-subcarrier indication of the maximum transmit PSD level at the U-C reference point, to apply at all times, except during the ITU-T G.994.1 phase. The CO-MIB also contains a per-subcarrier indication whether or not the subcarrier is allowed to be sent starting from the initialization channel analysis phase. From this information, and taking into account its own capabilities, the ATU-C selects the downstream SUPPORTEDset of subcarriers and computes the CL downstream spectrum shaping parameter block information.

NOTE ~~6~~ 8 – For the upstream direction, the CO-MIB contains a per-subcarrier indication whether or not the subcarrier is allowed to be sent starting from the initialization channel analysis phase. This information is conveyed to the ATU-R in the CL upstream spectrum shaping parameter block (through SUPPORTEDset indications and only using tss_i values 0 and 1 in linear scale). From this information, and taking into account its own capabilities, the ATU-R selects the upstream SUPPORTEDset of subcarriers and computes the CLR upstream spectrum shaping parameter block information.

NOTE ~~7~~ 9 – With the tss_i values contained in the different spectrum shaping blocks, the ATU indicates which subcarriers the ATU intends to transmit (subcarriers in the SUPPORTEDset) and which ones the ATU does not intend to transmit (subcarriers not in the SUPPORTEDset) during channel analysis for both the upstream and downstream directions. This is needed to make sure the ATU-R can select a C-TREF pilot tone which will be transmitted starting from the channel analysis phase. This also facilitates the selection by the PMD receive function of unused subcarriers for SNR monitoring and the selection of subcarriers to modulate the PARAMS messages.

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8.13.3 Channel discovery phase

See clause 8.13.3 of ITU-T G.992.3.

8.13.3.1 ATU-C channel discovery

See clause 8.13.3.1 of ITU-T G.992.3.

8.13.3.1.1 C-QUIET1

See clause 8.13.3.1.1 of ITU-T G.992.3.

8.13.3.1.2 C-COMB1

See clause 8.13.3.1.2 of ITU-T G.992.3, modified as follows.

The duration of the C-COMB1 state is of fixed length. In the C-COMB1 state, the ATU-C shall transmit 128 C-COMB symbols.

During this state, the ATU-R performs timing recovery and measures some characteristics of the downstream channel for C-TREF pilot tone selection and for the estimation of the required ATU-R minimum upstream power cutback and ATU-R minimum downstream power cutback. These functions can be continued during C-COMB2.

The C-COMB symbol shall be defined as a wideband multi-tone symbol containing the 16 subcarriers with index 11, 23, 35, 47, 59, 64, 71, 83, 95, 107, 119, 143, 179, 203, 227 and 251 and all subsequent subcarriers with index $251 + k \times 24$ (with k integer such that the subcarrier index is in the 256 to $NSCds - 1$ range). The subcarrier spacing has been selected to minimize audible interference into the POTS band prior to applying cutbacks that may be required in the presence of an off-hook POTS terminal and to limit aggregate transmit power to 8.4 dBm (i.e., the 12 dB power cutback level).

The subcarriers contained in the C-COMB symbol shall modulate the same data bits that are used for the C-REVERB symbols, in such a way that same subcarrier indices modulate the same data bits with the same 4-QAM constellation, as defined in clause 8.13.4.1.1. The subcarriers not contained

in the C-COMB symbol shall be transmitted at no power (i.e., $X_i = Y_i = 0$).

The C-COMB1 state shall be followed by the C-QUIET2 state.

8.13.3.1.3 C-QUIET2

See clause 8.13.3.1.3 of ITU-T G.992.3.

8.13.3.1.4 C-COMB2

See clause 8.13.3.1.4 of ITU-T G.992.3.

8.13.3.1.5 C-ICOMB1

See clause 8.13.3.1.5 of ITU-T G.992.3.

8.13.3.1.6 C-LINEPROBE

See clause 8.13.3.1.6 of ITU-T G.992.3.

8.13.3.1.7 C-QUIET3

See clause 8.13.3.1.7 of ITU-T G.992.3.

8.13.3.1.8 C-COMB3

See clause 8.13.3.1.8 of ITU-T G.992.3.

8.13.3.1.9 C-ICOMB2

See clause 8.13.3.1.9 of ITU-T G.992.3.

8.13.3.1.10 C-MSG-FMT

See clause 8.13.3.1.10 of ITU-T G.992.3, modifying Table 8-26 as follows:

Table 8-26 – Bit definition for the C-MSG-FMT message

Bit index	Parameter	Definition
0	<i>FMT_R-REVERB1</i> (value 0 or 1)	Set to 1 indicates that the ATU-C requests an extended duration of the R-REVERB1 state. Set to 0 indicates it does not.
1		Reserved, set to 0.
2	<i>FMT_C-REVERB4</i> (value 0 or 1)	Set to 1 indicates that the ATU-C requests an extended duration of the C-REVERB4 state. Set to 0 indicates it does not.
7..3	<i>FMT_R-QUIET4</i> (value 0 to 31)	The (0 to 31) value mapped in these bits indicates the duration of the R-QUIET4 state. The MSB shall be mapped on the higher message bit index.
8	<i>FMT_C-MSG-PCB</i>	Set to 1 indicates that the C-MSG-PCB message shall include the C-BLACKOUT bits. Set to 0 indicates it shall not.
<u>9</u>	<u><i>FMT_C-MSG1</i></u>	<u>Set to 1 indicates that windowing is applied with window samples included in the C-MSG1 message.</u> <u>Set to 0 indicates no windowing is applied and no window samples are included in C-MSG1 message.</u>
<u>10</u>	<u><i>FMT-C-MEDLEYPRBS</i></u>	<u>Set to 1 indicates that the ATU-C requests to use the higher order PRBS for the C-MEDLEY data pattern (see clause 8.13.5.1.4).</u>
15.. <u>9</u> <u>11</u>		Reserved, set to 0.

8.13.3.2 ATU-R channel discovery

See clause 8.13.3.2 of ITU-T G.992.3, modifying Tables 8-31 and 8-32 as follows:

Table 8-31 – Bit definition for the R-MSG-FMT message

Bit index	Parameter	Definition
0	<i>FMT-R-REVERB1</i> (value 0 or 1)	Set to 1 indicates that the ATU-R requests an extended duration of the R-REVERB1 state. Set to 0 indicates it does not.
1		Reserved, set to 0.
2	<i>FMT-C-REVERB4</i> (value 0 or 1)	Set to 1 indicates that the ATU-R requests an extended duration of the C-REVERB4 state. Set to 0 indicates it does not.
6..3	<i>FMT-C-TREF1</i> (value 1 to 15)	The value mapped in these bits indicates the minimum duration of the C-TREF1 state. The MSB shall be mapped on the higher message bit index.
7	<i>FMT-R-MSG-PCB</i> (value 0 or 1)	Set to 1 indicates that the R-MSG-PCB message shall include the R-BLACKOUT bits. Set to 0 indicates it shall not.
8	<i>FMT-C-TREF2</i> (value 0 or 1)	Indicates that the ATU-R requests the ATU-C to transmit C-TREF symbols (if set to 1) or C-QUIET symbols (if set to 0) during R-ECT.
9	<i>FMT-C-PILOT</i> (value 0 or 1)	Set to 1 indicates that the ATU-R requests the ATU-C to transmit a fixed 4-QAM constellation point on the C-TREF pilot tone. Set to 0 indicates it does not.
<u>10</u>	<u><i>FMT-C-MEDLEYPRBS</i></u>	<u>Set to 1 indicates that the ATU-R requests to use the higher order PRBS for the C-MEDLEY data pattern (see clause 8.13.5.1.4).</u>
15.. ~~10~~ <u>11</u>		Reserved, set to 0.

Table 8-32 – Bit definition for the R-MSG-PCB message

Bit index	Parameter	Definition
5..0	<i>R-MIN_PCB_DS</i>	ATU-R minimum downstream power cutback (6-bit value with MSB in bit 5 and LSB in bit 0)
11..6	<i>R-MIN_PCB_US</i>	ATU-R minimum upstream power cutback (6-bit value with MSB in bit 11 and LSB in bit 6)
13..12	<i>HOOK_STATUS</i>	Hook status (2-bit value with MSB in bit 13 and LSB in bit 12)
15..14		Reserved, set to 0
~~23~~ <u>26</u> ..16	<i>C-PILOT</i>	Subcarrier index of downstream pilot tone (~~8~~ <u>11</u> -bit value with MSB in bit ~~23~~ <u>26</u> and LSB in bit 16)
31.. ~~24~~ <u>27</u>		Reserved, set to 0
31 + <i>NSCds</i> ..32	<i>R-BLACKOUT</i>	Blackout indication per subcarrier (subcarrier <i>NSCds</i> – 1 in bit 31 + <i>NSCds</i> , subcarrier 0 in bit 32). Bit 32 shall be set to 0 (i.e., no blackout of DC subcarrier).

8.13.4 Transceiver training phase

See clause 8.13.4 of ITU-T G.992.3.

8.13.5 Channel analysis phase

See clause 8.13.5 of ITU-T G.992.3.

8.13.5.1 ATU-C channel analysis

See clause 8.13.5.1 of ITU-T G.992.3.

8.13.5.1.1 C-MSG1

See clause 8.13.5.1.1 of ITU-T G.992.3, modifying Table 8-37 as follows:

Table 8-37 – C-MSG1 prefix, message and CRC length

Part of message	Length (bits or symbols)
Prefix	32
N_{pmd} (see Note)	160 or 160 + NSCds/4
N_{pms}	32
N_{tps}	0
N_{msg}	192 or 192 + NSCds/4
CRC	16
$LEN_C\text{-}MSG1$ (symbols)	240 or 240 + NSCds/4
NOTE – Length depends on whether or not windowing is applied (see clause 8.5.3.2).	

8.13.5.1.2 C-REVERB5

See clause 8.13.5.1.2 of ITU-T G.992.3.

8.13.5.1.3 C-SEGUE2

See clause 8.13.5.1.3 of ITU-T G.992.3.

8.13.5.1.4 C-MEDLEY

See clause 8.13.5.1.4 of ITU-T G.992.3, modified as follows.

The C-MEDLEY state is of fixed length. In this state, the ATU-C shall transmit LEN_MEDLEY symbols. The value LEN_MEDLEY shall be the maximum of the $CA_MEDLEYus$ and $CA_MEDLEYds$ values indicated by the ATU-C and the ATU-R in the C-MSG1 and R-MSG1 messages respectively. The value LEN_MEDLEY shall be a multiple of 512 and shall be less than or equal to 32256. The number of symbols transmitted in the C-MEDLEY state shall be equal to the number of symbols transmitted by the ATU-R in the R-MEDLEY state.

A C-MEDLEY symbol shall be defined depending on its symbolcount within the C-MEDLEY state. The first symbol transmitted in the C-MEDLEY state shall have symbolcount equal to zero. For each symbol transmitted in the C-MEDLEY state, the symbolcount shall be incremented.

The data pattern modulated onto each C-MEDLEY symbol shall be taken from the pseudo-random binary sequence (PRBS) defined by:

$$d_n = 1 \text{ for } n = 1 \text{ to } 9 \text{ and } d_n = d_{n-4} \oplus d_{n-9} \text{ for } n > 9$$

or:

$$d_n = 1 \text{ for } n = 1 \text{ to } 14 \text{ and } d_n = d_{n-5} \oplus d_{n-11} \oplus d_{n-12} \oplus d_{n-14} \text{ for } n > 14$$

[Support of the fourteenth order PRBS is optional for the ATU-C and ATU-R. The 14th order PRBS shall be used if, and only if, the FMT-C-MEDLEYPRBS bit is set to 1 in both the C-MSG-FMT and R-MSG-FMT message, respectively. The ninth order polynomial shall be used otherwise.](#)

The C-MEDLEY symbol with symbolcount i shall modulate the ~~512 bits $d_{512 \times i + 1}$ to $d_{512 \times (i+1)}$~~ $2 \times NSCds$ bits $d_{2 \times NSCds \times i + 1}$ to $d_{2 \times NSCds \times (i+1)}$.

Bits shall be extracted from the PRBS in pairs. For each symbol transmitted in the C-MEDLEY state, ~~256~~ $NSCds$ pairs (~~512~~ $2 \times NSCds$ bits) shall be extracted from the PRBS generator. The first extracted pair shall be modulated onto subcarrier 0 (so the bits are effectively ignored). The subsequent pairs are used to define the X_i and Y_i components for the subcarriers $i = 1$

to $NSCds - 1$, as defined in Table 8-36 for C-REVERB symbols. For the subcarriers $i = NSCds$ to $2 \times NSCds - 1$, the $X_i = Y_i = 0$.

~~NOTE 256 bit pairs per symbol are extracted from the PRBS. If $NSCds$ is less than 256 (as in [b-ITU-T G.992.4]), then the last $(256 - NSCds)$ bit pairs are effectively ignored.~~

While the ATU-C is in the C-MEDLEY state, the ATU-C and ATU-R may perform further training and SNR estimation.

The C-MEDLEY state shall be followed by the C-EXCHMARKER state.

8.13.6 Exchange phase

8.13.6.1 ATU-C exchange phase

See clause 8.13.6.1 of ITU-T G.992.3.

8.13.6.1.1 C-MSG2

See clause 8.13.6.1.1 of ITU-T G.992.3.

8.13.6.1.2 C-REVERB6

See clause 8.13.6.1.2 of ITU-T G.992.3, modifying the first paragraph as follows:

The C-REVERB6 state is of variable length. In this state, the ATU-C shall transmit a minimum of ~~(246 - $NSCus$)~~ $\text{MAX}(NSCds - NSCus - 10, 80)$ and a maximum of ~~(2246 - $NSCus$)~~ $\text{MAX}(NSCds - NSCus + 1990, 2000)$ C-REVERB symbols.

8.13.6.1.3 C-SEGUE3

See clause 8.13.6.1.3 of ITU-T G.992.3.

8.13.6.1.4 C-PARAMS

See clause 8.13.6.1.4 of ITU-T G.992.3, modifying Table 8-39 as follows:

Table 8-39 – C-PARAMS message and CRC length

Part of message	Length (bits or symbols)
N_{pmd}	$96 + 24 \times NSCus$
N_{pms}	224
N_{tps}	0
N_{msg}	$320 + \textcolor{red}{2432} \times NSCus$
CRC	16
$LEN_C-PARAMS$ (state length in symbols)	$\left\lceil \frac{336 + 24 \times NSCus}{2 \times NSC_C-PARAMS} \right\rceil$ $\left\lceil \frac{336 + 32 \times NSCus}{2 \times NSC_C-PARAMS} \right\rceil$
NOTE – $\lceil x \rceil$ denotes rounding to the higher integer.	

8.13.6.2 ATU-R exchange phase

See clause 8.13.6.2 of ITU-T G.992.3.

8.13.6.2.1 R-MSG2

See clause 8.13.6.2.1 of ITU-T G.992.3, modified as follows.