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**Amendment 4**
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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Metallic access networks

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# Improved impulse noise protection for DSL transceivers

## Amendment 4

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***PREPUBLISHED RECOMMENDATION***

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# Amendment 4 to Recommendation ITU-T G.998.4 (2010)

## Improved impulse noise protection for DSL transceivers: Amendment 4

**Summary**

Amendment 4 to Recommendation ITU-T G.998.4 (2010) covers the following functionality:

1. New annex on Low Power Mode operation with ITU-T G.993.2 and ITU-T G.993.5 (new functionality).
2. Changes to Annex C to support Annex E (new functionality).

# Amendment 4 to Recommendation ITU-T G.998.4 (2010)

## Improved impulse noise protection for DSL transceivers: Amendment 4

### 1. New Annex E on "Low Power Mode operation with ITU-T G.993.2 and G.993.5" (new functionality).

*Add new Annex E (next in Annex numbering alphabet) as follows:*

## ANNEX E

## VDSL2 Low Power Mode operation

### E.1 Scope

This Annex defines the optional Low Power Mode (LPMode) operation with ITU-T G.993.2 and G.993.5. When both VTUs are operating according to this Annex, the link is in the L2 link state. Two link sub-states related to LPMode operation are defined, referred to as L2.1 and L2.2, each with different Quality-of-Service (QoS) levels. The LPMode operation does not prohibit the use of G.993.5 and does not require the use of G.993.5.

### E.2 Functionality

To facilitate LPMode, this Annex defines a set of power management states for the VDSL2 link and the use of eoc messages to coordinate power management between the VTUs. Power reduction can be achieved by minimizing the energy transmitted by the VTU onto the U reference point as well as by reducing the power consumed by the VTUs (e.g., reducing clock speed, number of used subcarriers, turning off line drivers). Recommendation G.993.2 defines a set of VDSL2 link states (i.e., the L0 and L3 link states) between the VTU-R and VTU-O by specifying the signals that are active on the link in each state, the link transition events and associated procedures. LPMode in a particular link is achieved by transitioning the link from the L0 link state into the LPMode link state (referred to as the L2 link state), with two link sub-states L2.1 (defined in clause E.2.1) and L2.2 (defined in clause E.2.2), each with different levels of power saving, different QoS levels, and procedures to enter and exit these link sub-states.

The details of the VTU coordination with system power management functions are outside the scope of this Recommendation.

For a particular direction of transmission, the transmitting VTU determines the need for transitions into the L2.1 and L2.2 link sub-states through primitives sent by the near-end VME. The higher layer function at the transmitting VTU determines the need for transition out of the L2.1 and L2.2 link sub-states. The VTU is instructed to transition out of the L2.1 and L2.2 link sub-states through primitives sent by the higher layer function to the near-end VME. The receiving VTU receives the primitives through eoc messages from the far-end VME. Transitions into and out of the L2.1 and L2.2 link sub-states are controlled by the near-end VME setting control variables for the near-end TPS-TC, PMS-TC and PMD functions as well as sending eoc messages to the far-end VME.

The LPMode functionality defined in this Annex is an optional capability for both the VTU-O and the VTU-R. If a VTU supports LPMode operation according to this Annex, the VTU shall support downstream LPMode operation as defined for the L2.1 link sub-state in clause E.3.1 and the L2.2 link sub-state in clause E.3.2. Upstream LPMode operation is for further study.

During the initialization phase (see messages O-MSG 1 in Table C.2, R-MSG 2 in Table C.5, and O-TPS in Table C.3), it is determined based on the VTU-O capabilities, the VTU-R capabilities and the CO-MIB configuration parameters (see Table E.1), whether the particular LPMode operation is enabled or disabled. LPMode operation can be enabled or disabled, separately for upstream and downstream, and separately for the L2.1 and L2.2 link sub-states. If the L2.1 link sub-state is disabled in a particular direction, then the L2.2 link sub-state shall also be disabled.

If a VTU supports LPMode operation according to this Annex, the VTU shall support SNRM_MODE = 5 (see clause 11.4.1.1.6.1.5/G.993.2). The VTU-O may send the SAVN-Update command during L0 link state, between the L2.1 entry steps, and during L2.1 steady-state operation (i.e., after the last step of the L2.1 entry procedure is completed). The VTU-O shall not send the SAVN-Update command during the L2.1 entry step, during the exit from L2.1 link sub-state into L0 link state, and during OLR procedures associated with change of the bit loading or framing parameters in the downstream direction in either L0 or L2.1 steady-state operation.

## E.3 Link states and link state diagram

This clause amends clause 12.1.1/G.993.2 with the L2 link state and L2.1 and L2.2 link sub-states.

The VDSL2 link states and activation/deactivation procedures diagram is illustrated in Figure E.1.

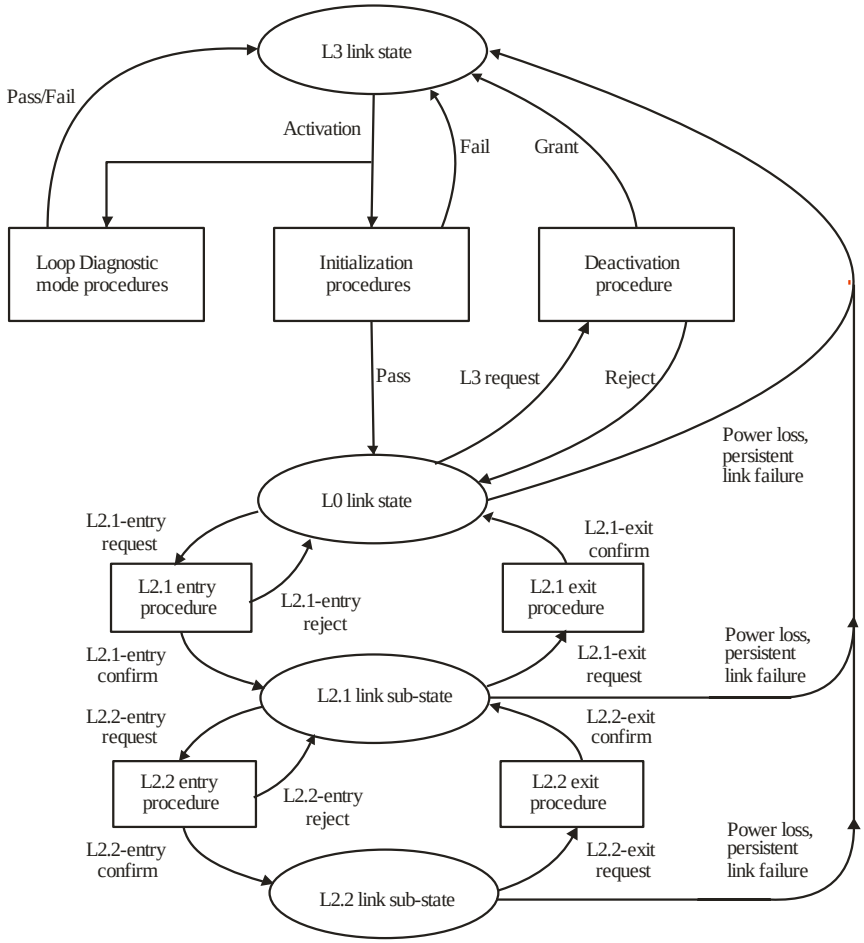


**Figure E.1 – VDSL2 link states and link state diagram**

Figure E.1 shows three link states (L0, L2 and L3), with the L2 link state consisting of the two link sub-states L2.1 and L2.2, and also shows the procedures that facilitate transitions from one link state to another. The link states are shown in rounded boxes, whilst the procedures are shown as rectangular boxes.

The L3 link state is the link state where the VTU is provisioned through a management interface for the service defined by the operator. In this link state, both the VTU-O and VTU-R do not transmit any signal.

The L0 link state is the link state achieved after the initialization procedure has completed successfully by both VTUs. In the L0 link state, the link transports user information with performance characteristics according to the CO-MIB configuration. When the link is in the L0 link state, both the VTU-O and VTU-R are in the Showtime transceiver state.

The L2 link state is represented by two link sub-states, L2.1 and L2.2. Link sub-state L2.1 is defined in clause E.3.1 and link sub-state L2.2 is defined in clause E.3.2. When the link is in either of the L2 link sub-states, both the VTU-O and VTU-R are in the Showtime transceiver state.

A procedure for a direct exit from L2.2 to L0 is not defined. An exit from L2.2 to L0 shall consist of an L2.2 exit to L2.1 (i.e., L2.2 exit procedure) followed by an L2.1 exit to L0 (i.e., L2.1 exit procedure). Similarly, a procedure for a direct entry from L0 to L2.2 is not defined. An entry from L0 to L2.2 shall consist of an entry from L0 to L2.1 (i.e., L2.1 entry procedure) followed by an entry from L2.1 to L2.2 (i.e., L2.2 entry procedure).

The VTU may apply a vendor discretionary flow control during the L2.1 and L2.2 link sub-states and during transition periods into and out of the L2.1 and L2.2 link sub-states. The applied flow control towards the upper layers shall ensure that the data rate at the gamma reference point is not higher than the data rate that can be carried over the U reference point.

Figure E.2 shows an example of PSD level trims in L2 link state transitions. The L2.1 entry procedure (see clause E.3.1.1) may consist of one or more steps, with each step executing one PSD level trim down. The L2.1 exit procedure (see clause E.3.1.2) may consist of one or more steps, with each step executing one PSD level trim up. The transition from L2.1 into L2.2 and back is a one-step transition (for each case).

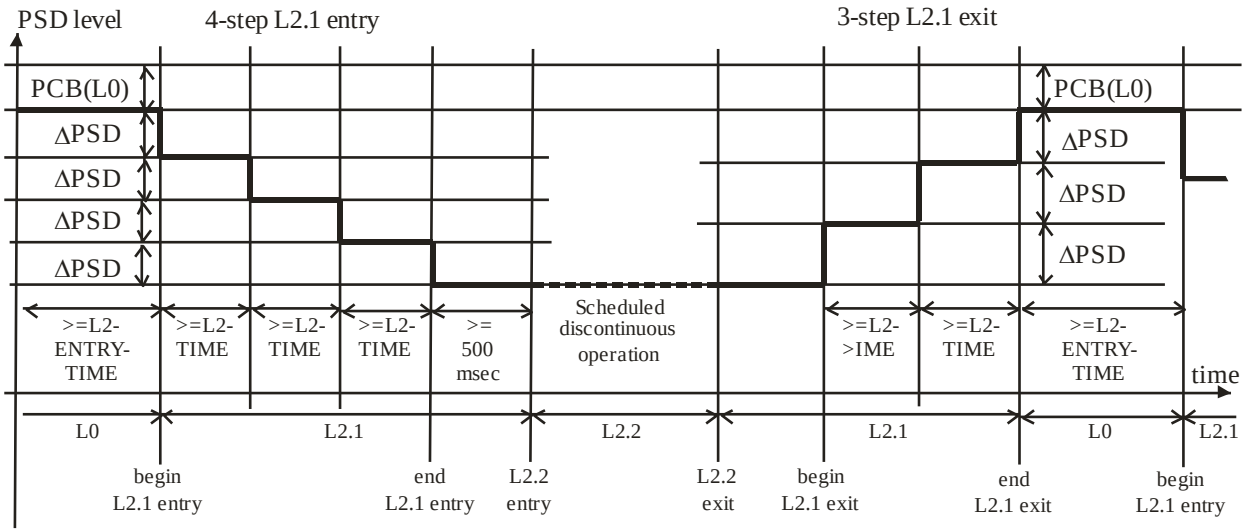


**Figure E.2 – Example of PSD level trims in L2 link state transitions**

### E.3.1 Link sub-state L2.1

The main applications for the LPMode operation in the L2.1 link sub-state are the transport of VoIP (POTS level) and keep-alive data. For LPMode operation in the L2.1 link sub-state, the power scaling technique is based on reduction of the transmit power on all or on a subset of the sub-carriers, keeping continuous transmission of symbols. The transmit power may be reduced by reducing the number of active sub-carriers, or by reducing the transmit power per sub-carrier (PSD reduction), or both.

With the link in the L2.1 link sub-state, the VTUs shall track channel changes (e.g., noise variations) through on-line reconfiguration (OLR, see clause E.3.1.3).

With the link in the L2.1 link sub-state, the TPS-TC (see clause 7), the retransmission functions (see clause 8), the PMS-TC (see clause 9), and the PMD (see clause 10) characteristics and the management functions (see clause 13) shall apply with the following differences:

- the *ETR_min* and *ETR_max* (see clause 7.1.1) do not apply. The L2.1 specific ETR bounds are configured through the CO-MIB (see clause E.4);
- the *INP_act_SHINE* (see clause 11.2.3) may be less than *INP_min* (see clause 7.1.1) and may be as low as 0, while INP_act_REIN (see clause 11.2.4) shall be no less than *INP_min_rein* (see clause 7.1.1);

- the *delay_act_RTX* (see clause 11.2.5):
  - shall be less than max(6 ms, *delay_max*);
- the *msg* (see clause 9.5.4/G.993.2) shall be set to at least 64 kbit/s in both directions. The *msg* shall be configured through the CO-MIB parameter MSGmin.
- the *TARSNRM, MAXSNRM, and SNRMOFFSET-ROC* (Note) do not apply. L2 specific SNRM bounds are configured through the CO-MIB (see clause E.4).

NOTE – Implementers should set sufficient SNR margin for ROC sub-carriers so that during L2.1 the robustness of the ROC is not compromised.

#### E.3.1.1 L2.1 entry from L0

With the link in the L0 link state, the transmitting VTU shall measure the incoming throughput (*THRP)* in bits/s as received from higher layers over the γ reference point. The *THRP* shall be measured by counting the number of bytes received over the γ-interface during each complete second.

The L2.1 entry criterion shall be defined as the *THRP* being less than the throughput threshold for entry into L2 (L2.1-ENTRY-THRP = 0.75 × L2.1-MIN-ETR, for L2.1-MIN-ETR see clause E.4) for a continuous time period that is longer than the time threshold for entry into L2 (L2.1-ENTRY-TIME, see clause E.4). The transmitting VTU shall start counting this continuous time period after the first second the *THRP* is below L2.1-ENTRY-THRP, and shall end counting it and reset the count at any second the *THRP* is equal to or above L2.1-ENTRY-THRP.

The transition from L0 into L2.1 (L2.1 entry procedure) is shown in Figure E.3. When the L2.1 entry criterion is met, then the transmitting VTU shall initiate a transition of the link from the L0 link state to the L2.1 link sub-state (see L2.1-entry-request primitive in Figure E.1 and Figure E.3). The transition may occur in a single step (using a single-step entry procedure defined in clause E.3.1.1.1) or in multiple steps (using a multi-step entry procedure defined in clause E.3.1.1.2). A multi-step entry procedure consists of executing a single-step entry procedure multiple times, once for each step in a multi-step entry procedure.

When a single-step entry procedure (for transition in a single step) or at least one step of a multi-step entry procedure (for transition in multiple steps) is completed, the link shall be considered to be in L2.1 link sub-state until the L2.1 exit to L0 procedure is executed, or the link transitions to the L3 link state.

If the L2.1 exit criterion is met prior to completion of the L2.1 entry procedure, the transmitting VTU shall abort the L2.1 entry procedure (as defined in clauses E.3.1.1.1 and E.3.1.1.2) and initiate a transition of the link back to the L0 link state, using the L2.1 exit procedure defined in clause E.3.1.2.

The L2.1 entry procedure shall use the following L2 configuration parameters provided by the CO-MIB (see clause E.4):

- Maximum ATP (dB) reduction per step (L2.1-ATPD);
- Maximum total ATP (dB) reduction (L2.1-ATPRT);
- Minimum time between steps (L2-TIME);
- Minimum ETR in L2.1 (L2.1-ETR-MIN);
- Maximum ETR in L2.1 (L2.1-ETR-MAX);
- Target SNR margin in L2.1 (L2-TARSNRM);
- Maximum SNR margin in L2.1 (L2-MAXSNRM);

- Frequency bands in which disabling of subcarriers in L2.1 link sub-state is not allowed (L2-BANDS).

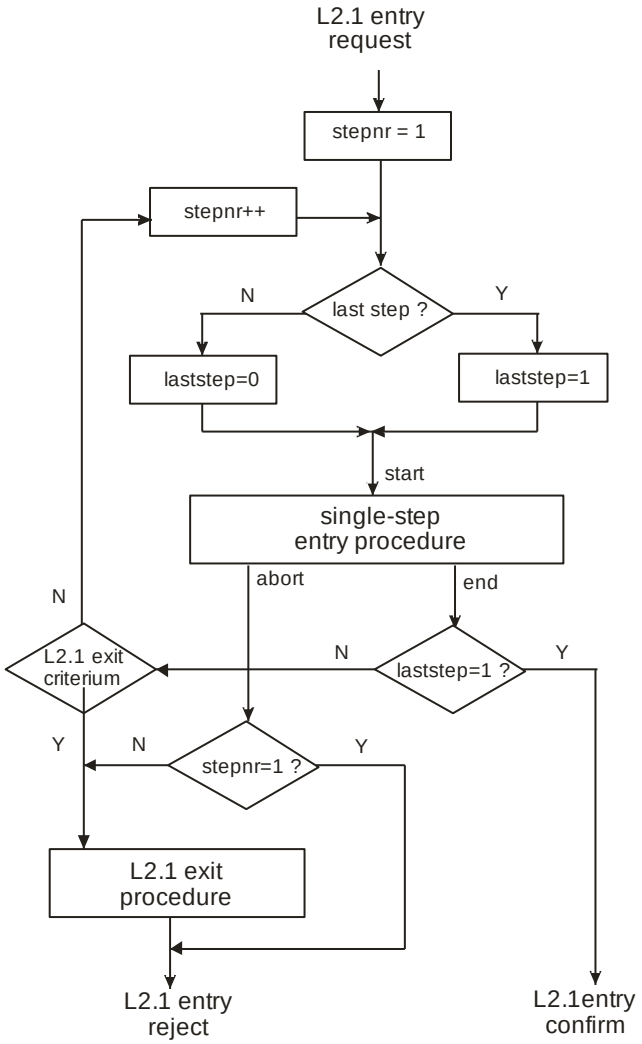


**Figure E.3 –L2.1 entry procedure**

#### E.3.1.1.1 Single-step entry procedure

The single-step entry procedure implements first a change of bit loading and framer parameters, followed by a change of transmit PSD and set of active sub-carriers.

- The modification of the bit-loading table (BLT) and framing parameters, and the modification (reduction) of the transmit PSD level and the set of active sub-carriers shall be performed separately, in different super-frames. Fine gains (i.e., the $g_i$ values) shall not be modified.
- If operation according to G.993.5 is disabled then an L2-SYNCHRO pattern is defined as consisting of one inverted sync symbol (transmitted at the end of the superframe, at the sync frame position, see Figure 10-2/G.993.2) followed by a pattern of 9 sync symbols. If operation according to G.993.5 is enabled then an L2-SYNCHRO pattern is defined as consisting of one sync symbol with inverted flag tones (transmitted at the end of the superframe, at the sync symbol position, see Figure 10-2/G.993.2) followed by a pattern of 9 sync symbols.

- To trigger the modification of bit-loading table and framing parameters, and the modification (reduction) of the transmit PSD level and the set of active sub-carriers, the transmitting VTU shall transmit an L2-SYNCHRO pattern. The modification shall apply starting from the first symbol after the last symbol of the L2-SYNCHRO pattern, i.e., from the 9-th symbol count (starting count from 0) of the corresponding super-frame.
- The single-step entry procedure shall implement a change of bit loading and framing parameters after the first L2-SYNCHRO pattern followed by a change of transmit PSD level and set of active sub-carriers after the second L2-SYNCHRO pattern. The change in the PSD level and the time between the first and the second L2-SYNCHRO pattern are determined by the transmitting VTU. The bit loading, the set of active sub-carriers and the framing parameters are determined by the receiving VTU. Changes of parameters shall be within boundary conditions and a policy defined in this clause.

#### E.3.1.1.1.1 Exchange between VTUs

The exchange between VTUs in the single-step entry procedure (see L2.1 entry procedure in Figure E.1 and VTU exchange in Figure E.4) is defined as follows:

1. The transmitting VTU shall initiate a single-step entry procedure by sending an L2.1-Entry-Step-Request command (see clause E.5.1) and wait for acknowledgement. This L2.1-Entry-Step-Request command may be repeated until acknowledgement is received. The L2.1-Entry-Step-Request command contains the sequence number of the step and whether or not this step is the last step in the L2.1 entry procedure. The L2.1-Entry-Step-Request command indicates the target PSD trim ($\Delta PSD_{TAR}$) to be applied in the step and whether a flat or ceiled PSD trim shall be applied. After sending the L2.1-Entry-Step-Request command, the transmitting VTU shall ignore any incoming OLR commands from the receiving VTU (see clause E.3.1.3).
2. Upon reception of an L2.1-Entry-Step-Request command, within 128 ms the receiving VTU shall either acknowledge the L2.1-Entry-Step-Request command by sending an L2-SRA-Request command or reject it by sending an L2.1-Entry-Step-Reject response (see clause E.5.3). After receiving the L2.1-Entry-Step-Request command, the receiving VTU shall discard any pending OLR commands (see clause E.3.1.3). The L2-SRA-Request command indicates the actual PSD trim ($\Delta PSD_{ACT}$, determined by the receiver) to be applied in the step, the bit loading, the set of active sub-carriers and the framing parameters that fit the $\Delta PSD_{ACT}$. The receiving VTU shall compute the transmission parameters indicated in L2-SRA-Request command (including $\Delta PSD_{ACT}$) to meet all the boundary conditions and policy defined in this clause.
3. After sending the L2-SRA-Request command, during the following 128 ms the receiving VTU shall expect receiving the first L2-SYNCHRO pattern or an L2-SRA-Reject response or an L2.1-Exit-Step-Request command. After sending an L2.1-Entry-Step-Reject response, the receiving VTU shall expect a new L2.1-Entry-Step-Request command (with the same or a different value of $\Delta PSD_{TAR}$), or an L2.1-Exit-Step-Request command.
4. Upon reception of the L2-SRA-Request command, within 128 ms the transmitting VTU shall either acknowledge the L2-SRA-Request command by sending the first L2-SYNCHRO pattern, or reject it by sending an L2-SRA-Reject response with a corresponding reason code, or send an L2.1-Exit-Step-Request command (if the transmitting VTU received an L2.1-exit-request primitive over the near-end γ_MGMT reference point and thus proceeding with the L2.1 entry procedure is not possible, or the transmitting VTU chooses to abort the L2.1 entry procedure). Upon reception of an L2.1-Entry-Step-Reject response, within 128 ms

the transmitting VTU shall acknowledge the L2.1-Entry-Step-Reject response with either a new L2.1-Entry-Step-Request command (with the same or a different value of $\Delta PSD_{TAR}$), or send an L2.1-Exit-Step-Request command.

5. Starting from the first symbol following the first L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the bit loading and the framing parameters indicated in the L2-SRA-Request command. The transmitting VTU shall not change the set of active sub-carriers and the transmit PSD.

6. Upon reception of the first L2-SYNCHRO pattern, within 64 ms the receiving VTU shall acknowledge the first L2-SYNCHRO pattern by sending the L2-ΔPSD-Request command (see clause E.5.3). The L2-ΔPSD-Request command indicates that the receiving VTU is ready to apply the actual PSD trim ($\Delta PSD_{ACT}$) indicated in the L2-SRA-Request command. After sending the L2-ΔPSD-Request command, during the following 128 ms the receiving VTU shall expect receiving the second L2-SYNCHRO pattern or an L2.1-Exit-Step-Request command or an L2-ΔPSD-Reject response. If the receiving VTU does not receive the second L2-SYNCHRO pattern or an L2.1-Exit-Step-Request command or an L2-ΔPSD-Reject response within this time, it shall retransmit the L2-ΔPSD-Request command. Upon reception of an L2-ΔPSD-Reject response, the receiving VTU shall not acknowledge the L2-ΔPSD-Reject response and within 128 ms expect receiving a new L2.1-Entry-Step-Request command (with the same step number as the previous L2.1-Entry-Step-Request command and the same or a different value of $\Delta PSD_{TAR}$) or an L2.1-Exit-Step-Request command.

7. Upon receiving the L2-ΔPSD-Request command, within 128 ms the transmitting VTU shall either acknowledge the L2-ΔPSD-Request command by sending the second L2-SYNCHRO pattern or reject it by sending an L2.1-Exit-Step-Request command or an L2-ΔPSD-Reject response.

8. Starting from the first symbol following the second L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the actual PSD trim ($\Delta PSD_{ACT}$) indicated in the L2-SRA-Request command, according to the procedure defined in clause E.3.1.1.1.3.

If during a single-step entry procedure the receiving VTU receives an L2.1-Exit-Step-Request command, it shall abandon the L2.1 single-step entry procedure and acknowledge the L2.1-Exit-Step-Request command as defined for the L2.1 single-step exit procedure in clause E.3.1.2.

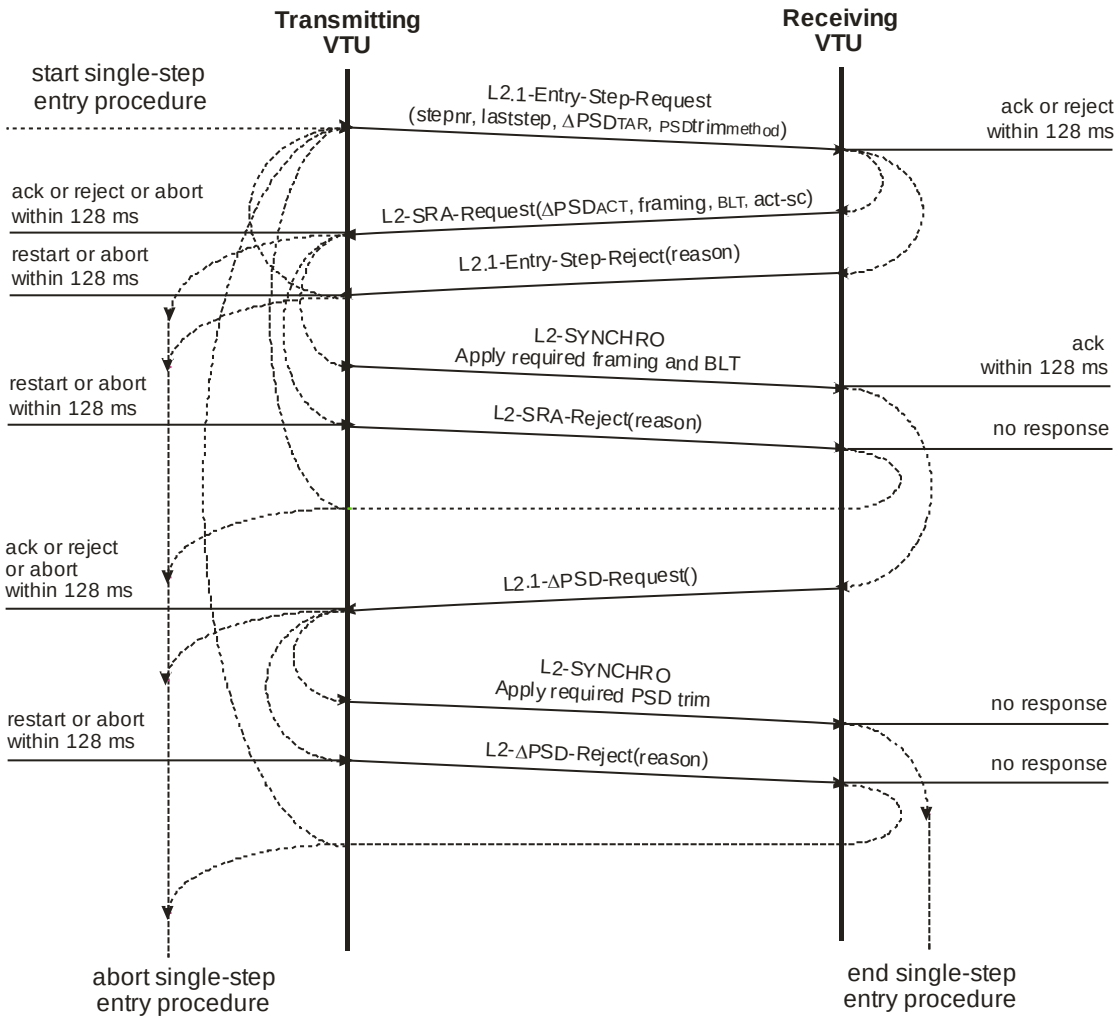


**Figure E.4 – VTU exchange in the single-step L2.1 entry procedure**

#### E.3.1.1.1.2 Boundary conditions and policy

The transmitting VTU shall select the parameters indicated in the L2.1-Entry-Step-Request command to meet the following boundary condition:

- The target PSD trim ($\Delta PSD_{TAR}$) value shall not exceed L2.1-ATPD;
- The set of subcarriers for which disabling in L2.1 is not allowed shall be equal to or a superset of the set of subcarriers indicated in L2-BANDS.

The receiving VTU shall select the parameters indicated in L2-SRA-Request command to meet the following boundary conditions:

- $\Delta PSD_{ACT} \leq \Delta PSD_{TAR}$ ;
- All subcarriers that are inactive at the instant the L2.1-Entry-Step-Request command is sent, shall remain inactive. All active subcarriers that are in the frequency bands indicated in the L2-BANDS, shall remain active (turning into a monitored subcarrier when $b_i$ is lowered to $b_i$=0 in the L2.1 link sub-state). Other active subcarriers may become inactive. The fine gains (i.e., the $g_i$ values) and tssi values of the inactive subcarriers shall be stored during the L2 link state in order to be used during the first single-step exit procedure. In the L0 link

state, the set of active sub-carriers is defined as the set of sub-carriers in the MEDLEY set with $g_i$>0 on linear scale;

- The NOMATP reduction after each entry step (relative to the instant the L2.1-Entry-Step-Request command was sent) resulting from the transmitting VTU applying the actual PSD trim ($\Delta PSD_{ACT}$) according to the procedure defined in clause E.3.1.2.1.3, shall not exceed L2.1-ATPD;
- The total NOMATP reduction (relative to the instant the entry into L2.1 was triggered) resulting from the transmitting VTU applying the actual PSD trim ($\Delta PSD_{ACT}$) according to the procedure defined in clause E.3.1.2.1.3, shall not exceed L2.1-ATPRT;
- The SNRM shall be equal to or higher than L2-TARSNRM and shall be equal to or less than the L2-MAXSNRM;
- If the single-step entry procedure is not the last step of the L2.1 entry procedure, then the primary framing parameter values shall result in a derived $ETR \geq$ L2.1-ETR-MAX, and not to exceed $ETR_{max}$;
- If the single-step entry procedure is the last step of the L2.1 entry procedure, then the primary framing parameter values shall result in a derived $ETR \geq$ L2.1-ETR-MIN, and not to exceed L2-ETR-MAX;

  NOTE – A first L2.1 exit step is required to have primary framing parameters that result in a derived ETR that is equal to or higher than L2.1-ETR-MAX (see clause E.3.1.2). The above ETR boundary conditions imply this requirement will be satisfied (assuming channel conditions at the time of the first step in the L2.1 exit procedure are the same as at the time of the last step in the L2.1 entry procedure). This requirement is also monitored during the L2.1 steady-state (see clause E.3.1.3).

Within these boundary conditions, the transmitting VTU and the receiving VTU shall determine the modification of the bit loading and framing parameters and the modification (reduction) of the transmit PSD and the set of active sub-carriers according to the following L2.1 entry policy:

- Maximize the target PSD trim ($\Delta PSD_{TAR}$) up to a value that will result in NOMATP reduction that does not exceed L2.1–ATPD.
- Maximize the actual PSD trim ($\Delta PSD_{ACT}$) up to the target PSD trim ($\Delta PSD_{TAR}$) determined by the transmitting VTU for the step;
- If the single-step entry procedure is not the last step of the L2.1 entry procedure:
  - Maximize the *ETR*;

    NOTE - This policy guarantees a smooth exit back to L0 during or after each intermediate step since the ETR is maximized and also exceeds L2.1-ETR-MAX.
- If the single-step entry procedure is the last step of the L2.1 entry procedure:
  - Maximize the *SNRM*;
  - Minimize the nominal aggregate transmit power in L2.1 (*L2.1-NOMATP*).

    NOTE – This policy implies that after the L2.1 entry from L0 (see L2.1 entry procedure in Figure E.1) is completed, the line reaches the target ATPT reduction (or as close as possible to it) and provides the required minimum bit rate while the SNRM is maximized. The latter requires the receiver to minimize the number of turned off subcarriers and increases its capability to reach L2.1-ETR-MAX after the first exit step.

#### E.3.1.1.1.3 Applying the actual PSD trim

The transmitting VTU shall apply the actual PSD trim ($\Delta PSD_{ACT}$) as follows:

- If the single-step entry procedure is the first step of the L2.1 entry procedure, then set the total PSD reduction variabe, $\Delta PSD_{TOT} = \Delta PSD_{ACT}$; otherwise increment the current value of $\Delta PSD_{TOT}$ by $\Delta PSD_{ACT}$ ;
- If a flat PSD trim is applied, then the transmit PSD (in dBm/Hz) shall be reduced on all active sub-carriers such that:

  $L2.1\text{-}MREFPSD(f) = MREFPSD(f) - \Delta PSD_{TOT}$

- If a ceiled PSD trim is applied, then the transmit PSD (in dBm/Hz) shall be reduced on all active sub-carriers such that:

  $L2.1\text{-}MREFPSD(f) = \text{MIN}\ (\ MREFPSD(f)\ ;\ MAXMREFPSD - \Delta PSD_{TOT}\ )$,

  where *L2.1-MREFPSD* applies in the L2.1 link sub-state in the same way as *MREFPSD* applies in the L0 link state, and,

  where *MAXMREFPSD* is the highest PSD level in the PSD descriptor used to convey *MREFPSD* in the O-PRM message or R-PRM message during initialization (see clause 12.3.3.2.1.3/G.993.2 or 12.3.3.2.2.3/G.993.2 respectively).

- Calculate the *L2.1-NOMATP* as follows:

  $$L2.1\text{-}NOMATP = 10\log_{10}\Delta f + 10\log_{10}\left(\sum_{i\in ACTIVE\ \text{set}}\left(10^{\frac{\text{L2.1-MREFPSD}[i]}{10}} g_i^2\right)\right),$$

  with *ACTIVEset* representing the set of active subcarriers indicated in the L2-SRA-Request;

- Sub-carriers in the MEDLEY set that became inactive during the L2.1 link sub-state shall have Zi=0;

  NOTE 1 - In case of non-vectored G.993.2, this results in no power at the U reference point.

  NOTE 2 - In case of vectored G.993.2, there may be power at the U reference point due to pre-compensation signals (i.e., Zi' different from 0).

- If downstream vectoring is applied, the downstream PSD reduction shall not cause any change to the values of pre-compensation signals at the U-O reference point;
- Sub-carriers in the *MEDLEY set* shall be transmitted at the same PSD level during sync symbols and data symbols.
- ROC and RRC sub-carriers shall not be set to inactive.

NOTE - For transceivers operating per G.993.5 or per G.993.2 Annex X or Y, implementers should avoid changes of the transceiver impedance on any of the subcarriers in the MEDLEY set.

### E.3.1.1.2 Multi-step entry procedure

For a multi-step entry procedure, the single-step entry procedure shall be executed multiple times, once for each step in the multi-step entry procedure. Each execution of the single-step entry procedure shall be according to the requirements defined in clause E.3.1.1.1. All steps in a multi-step L2.1 entry procedure shall use the same PSD trim method (i.e., either all flat PSD trims or all ceiled PSD trims).

In a multi-step entry procedure, the subsequent single-step procedure of L2.1 entry shall be initiated only if:

- the L2.1 entry criterion is still met during the entire time after the previous single-step entry procedure is completed;
- this time exceeds L2-TIME; and
- the L2.1 exit criterion (see clause E.3.1.2) is not met during this time.

If the L2.1 exit criterion is met during a multi-step L2.1 entry procedure after one or more steps and prior to completion of the last step, the transmitting VTU shall abort the multi-step entry procedure by initiating a transition of the link back to the L0 link state using the L2.1 exit procedure defined in clause E.3.1.2.

### E.3.1.2 L2.1 exit to L0

The L2.1 exit criterion shall be defined as the transmitting VTU receiving a primitive from the higher layer function indicating the need for the link to transition out of the L2.1 link sub-state.

The transition from L2.1 into L0 (L2.1 exit procedure) is shown in Figure E.5. When the link is in the L2.1 link sub-state and the L2.1 exit criterion is met, then the transmitting VTU shall initiate a transition of the link from link sub-state L2.1 to link state L0 (see L2.1-exit-request primitive in Figure E.1 and Figure E.5). The transition may occur in a single step (using a single-step exit procedure defined in clause E.3.1.2.1) or in multiple steps (using a multi-step exit procedure defined in clause E.3.1.2.2). A multi-step exit procedure consists of executing single-step exit procedure multiple times, once for each step in the multi-step exit procedure.

Once the L2.1 exit procedure has been initiated, transmitting VTU shall complete the L2.1 exit procedure to bring the link back to L0 link state, regardless whether or not the L2.1 exit criterion (see clause E.3.1.2) is still met during the execution of the L2.1 exit procedure.

When the single-step exit procedure (for transition in a single step) or all steps of the multi-step exit procedure (for transition in multiple steps) are completed, the link shall be considered to be back in L0 link state. Until then the link shall be considered to be in the L2.1 link sub-state.

The L2.1 exit procedure shall use the following L2 configuration parameters determined from the CO-MIB (see clause E.4):

- Maximum ATP (dB) increase per step (L2.1-ATPD);
- Minimum time between steps (L2-TIME);
- Maximum ETR in L2.1 (L2-ETR-MAX);
- Minimum SNR margin in L2 (L2-MINSNRM, only for a multi-step exit procedure);
- Target SNR margin in L2.1 (L2-TARSNRM);
- Maximum SNR margin in L2.1 (L2-MAXSNRM).

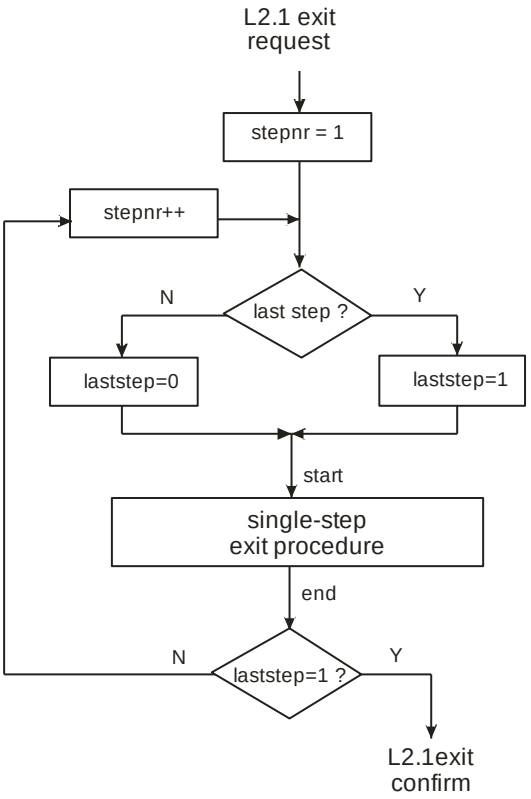


**Figure E.5 –L2.1 exit procedure**

#### E.3.1.2.1 Single-step exit procedure

The single-step exit procedure implements first a change of transmit PSD and set of active sub-carriers, followed by a change of bit loading and framer parameters.

- The modification of the bit loading table (BLT) and framing parameters, and the modification (increase) of the transmit PSD and the set of active sub-carriers shall be performed separately, in different super-frames. Fine gains (i.e., the $g_i$ values) shall not be modified.
- To trigger the modification of bit loading and framing parameters, and the modification (increase) of the transmit PSD and the set of active sub-carriers, the transmitting VTU shall transmit an L2-SYNCHRO pattern. The L2-SYNCHRO pattern for the single-step exit procedure is defined as identical to the L2-SYNCHRO pattern for the single-step entry procedure defined in clause E.3.1.1.1. The modification shall apply starting from the first symbol after the last symbol of the L2-SYNCHRO pattern, i.e., from the 9-th symbol count (starting count from 0) of the corresponding super-frame.
- The single-step exit procedure shall implement a change of transmit PSD level and set of active sub-carriers after the first L2-SYNCHRO pattern followed by a change of bit loading and framing parameters after the second L2-SYNCHRO pattern. The change in the PSD level and the time between the first and the second L2-SYNCHRO pattern is controlled by the transmitting VTU. The bit loading, the set of active sub-carriers and the framing parameters are determined by the receiving VTU.

#### E.3.1.2.1.1 Exchange between VTUs

The exchange between VTUs in the single-step exit procedure (see L2.1 exit procedure in Figure E.1 and VTU exchange in Figure E.6) is defined as follows:

1. The transmitting VTU shall initiate a single-step procedure by sending an L2.1-Exit-Step-Request command (see clause E.5.2) and wait for acknowledgement. This L2.1-Exit-Step-Request command may be repeated until acknowledgement is received. The L2.1-Exit-Step-Request command contains the sequence number of the step and whether or not this step is the last step in the L2.1 exit procedure. The L2.1-Exit-Step-Request command indicates the actual PSD trim ($\Delta PSD_{ACT}$) to be applied in the step. After sending the first L2.1-Exit-Step-Request command, the transmitting VTU shall ignore any incoming OLR commands from the receiving VTU (see clause E.3.1.3).
2. Upon reception of an L2.1-Exit-Step-Request command, the receiving VTU shall acknowledge the L2.1-Exit-Step-Request command by sending an L2-ΔPSD-Request command (see clause E.5.4) within 128 ms. After receiving the L2.1-Exit-Step-Request command, the receiving VTU shall discard any pending OLR commands (see clause E.3.1.3). The L2-ΔPSD-Request command indicates that the receiving VTU is ready to apply the actual PSD trim ($\Delta PSD_{ACT}$) indicated in the L2.1-Exit-Step-Request command
3. After sending the exit L2-ΔPSD-Request command, the receiving VTU shall expect receiving the first L2-SYNCHRO pattern during the following 128ms. If the L2.1-Exit-Step-Request command is received more than once prior the reception of the first L2-SYNCHRO pattern, the receiving VTU shall acknowledge each L2.1-Exit-Step-Request command with an identical L2-ΔPSD-Request command.
4. Upon reception of the L2-ΔPSD-Request command, the transmitting VTU shall acknowledge the L2-ΔPSD-Request command by sending the first L2-SYNCHRO pattern within 128 ms.
5. Starting from the first symbol following the first L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the actual PSD trim ($\Delta PSD_{ACT}$) indicated in the L2.1-Exit-Step-Request command, according to the procedure defined in clause E.3.1.2.1.3. The transmitting VTU shall not change the bit loading and the framing parameters.
6. Upon reception of the first L2-SYNCHRO pattern, the receiving VTU shall estimate the SNR and acknowledge the first L2-SYNCHRO pattern by sending the L2-SRA-Request command (see clause E.5.3) within 128 ms. The L2-SRA-Request command indicates the actual PSD rim ($\Delta PSD_{ACT}$) already applied in the step, the bit loading, and the framing parameters that fit the actual PSD trim ($\Delta PSD_{ACT}$) indicated in the L2.1-Exit-Step-Request command. After sending the L2-SRA-Request command, the receiving VTU shall expect receiving the second L2-SYNCHRO pattern during the following 128ms. If the receiving VTU does not receive the second L2-SYNCHRO pattern within this time, it shall retransmit the L2-SRA-Request command.
7. Upon receiving the L2-SRA-Request command, the transmitting VTU shall acknowledge the L2-SRA-Request command by sending the second L2-SYNCHRO pattern within 128ms.
8. Starting from the first symbol following the second L2-SYNCHRO pattern, both the transmitting VTU and the receiving VTU shall apply the bit loading and the framing parameters indicated in the L2-SRA-Request command.

The execution time from sending the L2.1-Exit-Step-Request command to sending the second L2-SYNCHRO pattern should not exceed 1 second.

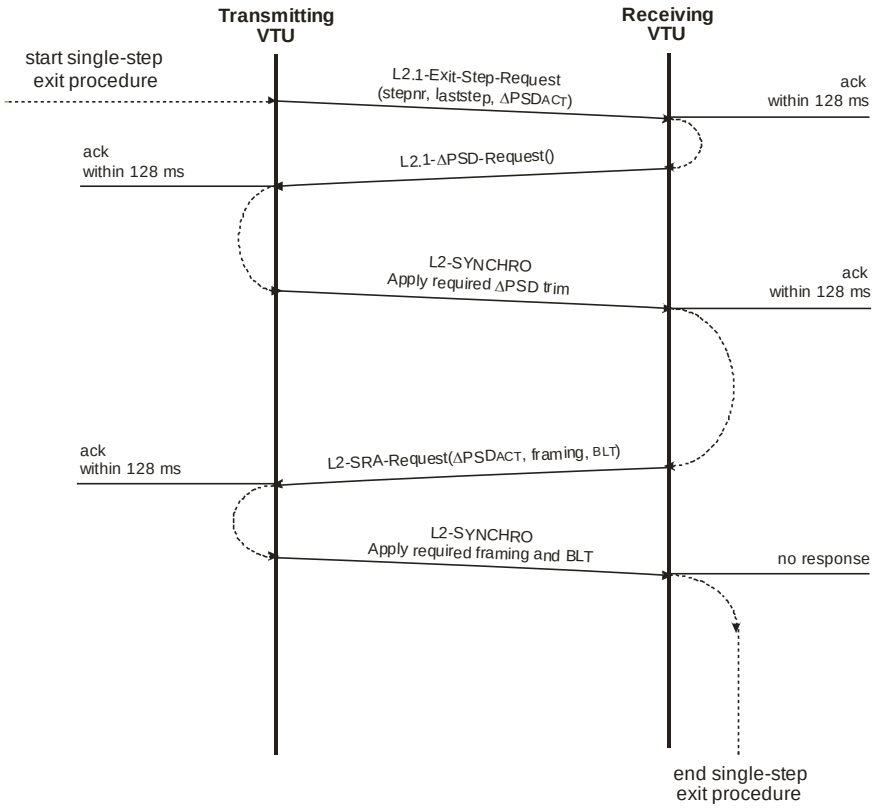


**Figure E.6 – VTU Exchange in the single-step L2.1 exit procedure**

#### E.3.1.2.1.2 Boundary conditions and policy

The transmitting VTU shall select the parameters indicated in the L2.1-Exit-Step-Request command to meet the following boundary conditions:

- The actual PSD trim ($\Delta PSD_{ACT}$) value shall not exceed L2.1-ATPD;
- The actual PSD trim ($\Delta PSD_{ACT}$ ) for the first exit step shall be equal to a value that will result in NOMATP increase that is equal to L2.1-ATPD, relative to the value of NOMATP after all sub-carriers that were turned inactive during L2.1 are re-activated.
- If the single-step exit procedure is the last step of the L2.1 exit procedure:
  - $\Delta PSD_{ACT} = \Delta PSD_{TOT}$ ;

    NOTE – This $\Delta PSD_{ACT}$ value brings the transmit PSD back to the transmit PSD that was in use at the instant the last previous L2.1 entry from the L0 link state was initiated.

The receiving VTU shall select the transmission parameters indicated in L2-SRA-Request command to meet the following boundary conditions:

- The set of active sub-carriers after the first single-step exit procedure shall be equal to the set of active sub-carriers in the L0 link state. The fine gains and tssi values of the inactive sub-carriers shall be restored to the values that were in use at the instant the last previous L2.1 entry from the L0 link state was initiated. In the L0 link state, the set of active sub-carriers is defined as the set of sub-carriers in the MEDLEY set with $g_i$>0 on linear scale;

NOTE – Because all sub-carriers that became inactive in the L2 link state are re-activated during the first single-step exit procedure, the increase in L2.1-NOMATP (defined in clause E.3.1.1.1) resulting from the first single-step exit procedure may be higher than L2.1-ATPD.

- If the single-step exit procedure is the first step and not the last step of the L2.1 exit procedure:
  - The primary framing parameters shall result in a derived ETR that is equal to or higher than L2.1-ETR-MAX, and not to exceed $ETR_{max}$;
  - The SNRM shall be equal to or higher than L2-MINSNRM;
- If the single-step exit procedure is not the first step of the L2.1 exit procedure:
  - The SNRM shall be equal to or higher than L2-TARSNRM and shall be equal to or less than the L2-MAXSNRM;
- If the single-step exit procedure is the last step of the L2.1 exit procedure:
  - The SNRM shall be in the range between MINSNRM and MAXSNRM;
  - The primary framing parameter values shall, if possible according to channel conditions, have a derived framing parameter *NDR* that is equal to or higher than the *NDR* that was in use at the instant the last previous L2.1 entry from the L0 link state was initiated;
  - If channel conditions do not allow for the *NDR* that was in use at the instant the last previous L2.1 entry from the L0 link state was initiated, , then the L2-SRA-Request command may require different primary framing parameter values (resulting in a lower derived framing parameter *NDR* than upon L2.1 entry), while still complying with the CO-MIB configuration.

Within these boundary conditions, the transmitting VTU and receiving VTU shall determine the modification (increase) of the transmit PSD and the modification of the bit loading and framing parameters, according to the following L2 exit policy:

- Maximize the actual PSD trim ($\Delta PSD_{ACT}$) up to a value that will result in NOMATP increase that does not exceed L2.1-ATPD.
- Select the primary framing parameters that maximize the derived ETR.

NOTE – This policy implies that after the first L2.1 exit step (after which the line reaches the bit rate of L2.1-ETR-MAX or more under the given circumstances), each of the following steps will provide the maximum possible increase of the ETR. The policy provides the fastest return to L0 (minimum number of exit steps under given PSD increase constraint).

#### E.3.1.2.1.3 Applying the actual PSD trim

The transmitting VTU shall apply the actual PSD trim ($\Delta PSD_{ACT}$) as follows:

- Decrement $\Delta PSD_{TOT}$ by $\Delta PSD_{ACT}$ ;
- If a flat PSD trim was applied during the L2.1 entry, then the transmit PSD (in dBm/Hz) shall be increased on all active sub-carriers and set on all re-activated subcarriers such that:

  $$L2.1\text{-}MREFPSD(f) = MREFPSD(f) - \Delta PSD_{TOT}$$

- If a ceiled PSD trim was applied during the L2.1 entry, then the transmit PSD (in dB) shall be applied on all active sub-carriers and set on all re-activated subcarriers such that:

  $$L2.1\text{-}MREFPSD(f) = \text{MIN}\ (\ MREFPSD(f)\ ;\ MAXMREFPSD - \Delta PSD_{TOT}\ ),$$

where *L2.1-MREFPSD* applies in the L2.1 link sub-state in the same way as *MREFPSD* applies in the L0 link state, and,

where *MAXMREFPSD* is the highest PSD level in the PSD descriptor used to convey *MREFPSD* during initialization (see clause 12.3.3.2.1.3/G.993.2 or 12.3.3.2.2.3/G.993.2 respectively).

- If downstream vectoring is applied, the downstream PSD increase shall not cause any change to the values of pre-compensation signals at the U-O reference point;

NOTE - For transceivers operating per G.993.5 or per G.993.2 Annex X or Y, implementers should avoid changes of the transceiver impedance on any of the subcarriers in the MEDLEY set.

#### E.3.1.2.2 Multi-step exit procedure

For a multi-step exit procedure, the single-step exit procedure shall be executed multiple times, once for each step in the multi-step exit procedure. Each execution of the single-step exit procedure shall be according to the requirements defined in clause E.3.1.2.1. All sub-carriers that became inactive in the L2.1 link sub-state shall be re-activated during the first single-step exit procedure.

### E.3.1.3 On-line reconfiguration in L2.1

While in L2.1 link sub-state (except when executing the L2.1 entry procedure or the L2.1 exit procedure), the following boundary conditions shall be met:

- The SNRM shall be equal to or higher than MINSNRM;
- A first L2.1 exit step (assuming current channel conditions) shall allow framing parameters with a derived ETR that is equal to or higher than L2.1-ETR-MAX.

  NOTE – A first L2.1 exit step is required to have framing parameters with a derived ETR that is equal to or higher than L2.1-ETR-MAX (see clause E.3.1.2). In the L2.1 link sub-state, the above ETR boundary condition assures that this requirement can be met in a first L2.1 exit step.

While in L2.1 link sub-state (except when executing the L2.1 entry procedure or the L2.1 exit procedure), VTUs shall be capable to use the bit swapping procedure as defined in clause 11.2.2.3/G.993.2 (OLR Request Type 1) in the aim to maintain the SNRM equal to or higher than L2-TARSNRM.

SRA (OLR Request Type 5) shall be a mandatory capability during L2.1 entry and L2.1 steady-state. SOS (OLR Request Type 6) shall not be used while executing the L2.1 entry procedure or the L2.1 exit procedure or while the link is in L2.1 link sub-state. The enable/disable of SRA functionality through the downstream rate adaptation mode (RA-MODE) parameter in the CO-MIB only applies to the L0 link state.

NOTE 1 - After the L2.1 exit procedure is completed, the receiving VTU may initiate the OLR requests enabled in the L0 link state (Request Type 1, Request Type 5, Request Type 6) to optimize the performance of the line.

NOTE 2 – Modification of the fine gains of active subcarriers during OLR procedures may impact the ATP of the L0 link state after exiting L2.1 due to the fact that when re-entering L0 the fine gains of the inactive subcarriers will be restored to the values of the previous L0 link state.

### E.3.2 Link sub-state L2.2

The main application for the LPMode operation in the L2.2 link sub-state is the transport of "keep alive" data at times when there is no user activity. Besides power reduction techniques applied in L2.1, for LPMode operation in the L2.2 link sub-state, the additional power scaling technique referred to as scheduled discontinuous operation (SDO) shall be used.

With SDO, symbols are transmitted only in a predefined subset of the available 256 data symbol positions per super-frame. The 256 symbol positions within each super-frame shall be divided into four groups of 64 contiguous symbol positions. Each group shall start with contiguous symbol periods where data symbols shall be transmitted, followed by contiguous symbol positions where quiet symbols (i.e., $Z_i$=0 for all sub-carriers) shall be transmitted. The symbol positions where data symbols and the symbol positions where quiet symbols are transmitted shall be the same in all super-frames during the time the link is in link sub-state L2.2.

The SDO during L2.2 is shown in Figure E.7. There are four groups, each of 64 symbol positions. Data symbols are transmitted in the first 9 symbol positions and quiet symbols are transmitted in the last 55 symbol positions of each group.

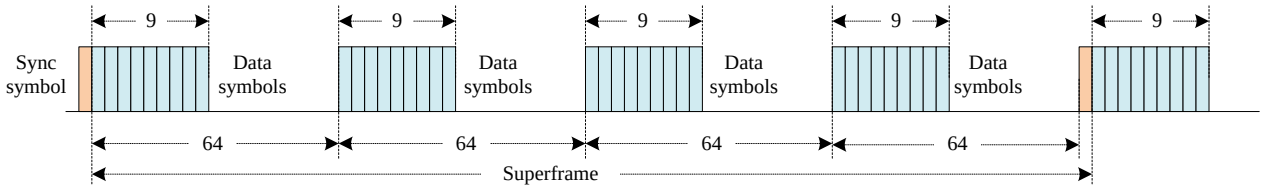


**Figure E.7 – Example of link sub-state L2.2**

The L2-SYNCHRO pattern defined for synchronization of L2.2 entry and exit (see clause E.3.2.1 and E.3.2.2) shall be transmitted at the sync symbol position followed by the first nine symbol positions of the first group of 64 symbol positions, instead of transmitting 9 data symbols.

NOTE 1 - During transmission of quiet data symbols, a backpressure should be applied towards the PMS-TC that prevents eoc to be sent.

NOTE 2 - For transceivers operating per G.993.5 or per G.993.2 Annex X or Y, implementers should avoid changes of the transceiver impedance on any of the subcarriers in the MEDLEY set, including during transmission of QUIET symbols.

While the link is in the L2.2 link sub-state, the TPS-TC functions (see clause 7), the retransmission functions (see clause 8), the PMS-TC function (see clause 9), the PMD functions (see clause 10), and the retransmission management functions (see clause 11) shall apply with the following differences:

- The retransmission functions shall be disabled in both downstream and upstream directions. The transmittingVTU shall not retransmit DTUs, regardless what was received over RRC (the content of the RRC shall be ignored by the transmitting VTU). However, data is mapped into DTUs with the same valid range of framing parameters and DTU sizes as in link sub-state L2.1.
- The *ETR_min* and *ETR_max* (see clause 7.1.1) do not apply in both upstream and downstream directions. Since retransmission is disabled, no specific *ETR* bounds are defined for link sub-state L2.2 through the CO-MIB.
- The *TARSNRM*, *MAXSNRM*, and *SNRMOFFSET-ROC* (Note) do not apply. The L2 specific SNRM bounds are configured through the CO-MIB (see clause E.4).
- The test parameters shall not be updated in the CO-MIB, and *ETR*, *EFTR*, and *delay_act_RTX* shall not be defined (see clause 11.2), the *fec* and *crc* anomalies and *leftr*

and *seftr* defects shall not occur (see clause 11.3), and the number of error-free bits passed over the β1-reference point shall be counted as zero (see clause 11.4);
- The *INP_act_SHINE* (see clause 11.2.3) may be less than *INP_min* (see clause 7.1.1) and may be as low as 0;
- The *INP_act_REIN* (see clause 11.2.4) may be less than *INP_min_rein* (see clause 7.1.1) and may be as low as 0.

NOTE - If vectoring is enabled during the L2.1 link sub-state, it may be necessary to continue supporting of FEXT cancellation also during the L2.2 link sub-state in the aim to use the same bit loading as per the L2.1 link sub-state.

The transmitting VTU shall assess the stability of the received channel, knowing that retransmission will be disabled in both directions, before triggering an entry into the L2.2 link sub-state.

#### E.3.2.1 L2.2 entry from L2.1

The L2.2 entry criterion shall be defined as no data having been received from higher layers over the γ reference point for a time period longer than 500 ms, while sufficient stability of the received channel has been assessed.

When the link is in the L2.1 link sub-state and the L2.2 entry criterion is met, then the transmitting VTU shall initiate a transition of the link from the L2.1 link sub-state to the L2.2 link sub-state (see L2.2-entry-request primitive in Figure E.1).

The bit-loading table ($b_i$), the set of active sub-carriers, and the fine gains ($g_i$) in L2.2 shall be the same as they were in L2.1 steady-state.

The entry procedure (see L2.2 entry procedure in Figure E.1) is defined as follows:

1. The transmitting VTU shall initiate an L2.2 entry procedure by sending an L2.2-Entry-Request command (see clause E.5.5) and wait for acknowledgement. This L2.2-Entry-Request command may be repeated until acknowledgement is received. After sending the L2.2-Entry-Request command, the transmitting VTU shall ignore any incoming OLR requests from the receiving VTU.
2. Upon reception of an L2.2-Entry-Request command, within 128 ms, the receiving VTU shall discard any pending OLR request and acknowledge the L2.2-Entry-Request command with an L2.2-Entry-ACK response (see clause E.5.5) or reject the L2.2-Entry-Request command with an L2.2-Entry-Reject response. After sending the L2.2-Entry-ACK response, the receiving VTU shall expect to receive an L2-SYNCHRO pattern during the following 128 ms. If the L2.2-Entry-Request command is received more than once prior to the reception of the L2-SYNCHRO pattern, the receiving VTU shall acknowledge or reject each L2.2-Entry-Request command with an L2.2-Entry-ACK response or an L2.2-Entry-Reject response, respectively.
3. Upon reception of the L2.2-Entry-ACK response, the transmitting VTU shall acknowledge the L2.2-Entry-ACK response by sending an L2-SYNCHRO pattern within 128 ms. Upon reception of the L2.2-Entry-Reject response, the transmitting VTU may repeat the L2.2-Entry-Request command.
4. Starting from the first symbol following the L2-SYNCHRO pattern, the transmitting VTU shall transmit and the receiving VTU shall receive data symbols at the data symbol positions defined by the SDO (see clause E.3.2).

When the L2.2 entry procedure is completed, the link shall be considered to be in the L2.2 link sub-state until the L2.2 exit procedure is executed, or the link transitions to the L3 link state.

While the link is in the L2.2 link sub-state, the receiving VTU shall track channel changes (e.g., noise variations) through OLR. If the receiving VTU detects that the *SNRM* during the L2.2 link sub-state is less than L2-MINSNRM, it shall send an L2.2-RX-Exit-Request command with reason code "OLR" (see clause E.5.6) to the transmitting VTU. While the link is in the L2.1 link sub-state, the *SNRM* shall be adjusted using the standard OLR procedure, as defined in clause E.3.1.3. After this OLR procedure is complete, the transmitting VTU shall initiate a transition of the link from the L2.1 link sub-state to the L2.2 link sub-state if the L2.2 entry criterion is still met (see L2.2-entry-request primitive in Figure E.1).

If the transmitting VTU detects errors due to the presence of REIN while the link in the L2.1 link sub-state, the transmitting VTU should not initiate a transition of the link from the L2.1 link sub-state to the L2.2 link sub-state. If the receiving VTU detects the presence of REIN while the link is in the L2.2 link sub-state, it shall send an L2.2-RX-Exit-Request command with reason code "REIN" (see clause E.5.6) to the transmitting VTU.

### E.3.2.2 L2.2 exit to L2.1

The L2.2 exit criterion shall be defined as the transmitting VTU receiving a primitive from the higher layer management function indicating the need for the link to transition out of the L2.2 link sub-state, or the transmitting VTU detecting a condition that upon persistency may trigger a retrain, or the transmitting VTU receiving an L2.2-RX-Exit-Request command from the receiving VTU.

When the link is in the L2.2 link sub-state and the L2.2 exit criterion is met, then the transmitting VTU shall initiate a transition of the link from the L2.2 link sub-state to the L2.1 link sub-state (see L2.2-exit-request primitive in Figure E.1).

The exit procedure (see L2.2 exit procedure in Figure E.1) is defined as follows:

1. The transmitting VTU shall initiate an L2.2 exit procedure by sending an L2.2-Exit-Request command (see clause E.5.6) and wait for acknowledgement. This L2.2-Exit-Request command may be repeated until acknowledgement is received.
2. Upon reception of an L2.2-Exit-Request command, the receiving VTU shall acknowledge the L2.2-Exit-Request command with an L2.2-Exit-ACK response (see clause E.5.6) within 128 ms. After sending the L2.2-Exit-ACK response, the receiving VTU shall expect receiving an L2-SYNCHRO pattern during the following 128 ms. If the L2.2-Exit-Request command is received more than once prior to the reception of the L2-SYNCHRO pattern, the receiving VTU shall acknowledge each L2.2-Exit-Request command with an L2.2-Entry-ACK response.
3. Upon reception of the L2.2-Exit-ACK response, the transmitting VTU shall acknowledge the L2.2-Exit-ACK response by sending an L2-SYNCHRO pattern within 128 ms.
4. Starting from the first symbol following the L2-SYNCHRO pattern, the transmitting VTU shall transmit and the receiving VTU shall receive data symbols at all the data symbol positions with parameters defined for L2.1 operation.

When the L2.2 exit procedure is completed, the link shall be considered to be back in the L2.1 link sub-state. Until then the link shall be considered to be in the L2.2 link sub-state.

## E.4 CO-MIB configuration and status reporting

The CO-MIB configuration parameters related to LPMode are defined in Table E.1. The CO-MIB reporting parameters related to LPMode are defined in Table E.2.

NOTE – A data rate of 5 Mbit/s is recommended by the Broadband Forum as the data rate to be present after the first exit step in an L2.1 exit procedure (see clause E.3.1.2). Such data rate allows an L2.1 exit to L0 without additional exit steps causing excessive delay or interruption of service. This data rate can be an appropriate setting for L2.1-ETR-MAX.

**Table E.1 – CO-MIB configuration parameters related to LPMode**

| Configuration parameter | G.997.1 reference | Definition |
|---|---|---|
| Power management state forced (PMSF) | 7.3.1.1.3 | The Power Management State Force indicates the PM state that the VTU is forced to enter via the CO-MIB. |
| Power management state enabling (PMMode) | 7.3.1.1.4 | The power management mode indicates the allowed link states. This parameter communicated to the VTU-R during initialization. Bit 0: indicates whether the L3 link state is allowed (1) or not allowed (0).<br>Bit 1: indicates whether the L2.1 link sub-state is allowed (1) or not allowed (0) in the downstream direction.<br>Bit 2: indicates whether the L2.2 link sub-state is allowed (1) or not allowed (0) in the downstream direction. |
| Minimum time interval between consecutive L2 ΔPSD trims during an L2.1 entry or L2.1 exit procedure (L2-TIME) | 7.3.1.1.6 | The minimum time (in seconds) the same transmit PSD is applied between consecutive L2 ΔPSD trims during an L2.1 entry or L2.1 exit procedure. It ranges from 0 to 255 seconds in steps of 1 second. |
| Maximum delta in aggregate transmit power (reduction or increase) per L2 ΔPSD trim during L2.1 entry or exit procedure respectively (L2.1-ATPD) | 7.3.1.1.7 | Maximum delta in aggregate transmit power (in dB) per L2 ΔPSD trim during an L2.1 entry or L2.1 exit procedure. It ranges from 0 dB to 31 dB in steps of 1 dB. |
| Total maximum aggregate transmit power reduction in L2.1 (L2.1-ATPRT) | 7.3.1.1.9 | Total maximum aggregate transmit power reduction (in dB) that can be performed in the L2.1 link sub-state. This is the sum of the ATP reductions provided by all L2 ΔPSD trims during an L2.1 entry or exit procedure. It ranges from 0 dB to 31 dB in steps of 1 dB. |
| Time threshold for entry into L2 (L2.1-ENTRY-TIME) | | Time period (in seconds) for triggering a transition from L0 link state to L2.1 link sub-state. It ranges from 1 to 255 seconds in steps of 1 second. |
| L2.1-ETR-MIN | | The minimum ETR (in kbit/s) that shall be maintained in L2.1 link sub-state. The valid range is from 256 kbits/s to 8192 kbits/sec in 8 kbit/s steps. |

| | | |
|---|---|---|
| L2.1-ETR-MAX | | The maximum ETR (in kbit/s) that shall be allowed in L2.1 link sub-state (Note). The valid range is from 4096 kbits/s to 32768 bits/sec in 8 kbit/s steps. |
| L2-MINSNRM | | Minimum SNR margin (in dB) allowed after the first L2.1 exit step of a multi-step L2.1 exit procedure. It ranges from 0 to 31 dB, with 0.1 dB steps. |
| L2-TARSNRM | | The target SNR margin (in dB) to be maintained in L2.1 link sub-state. It ranges from 0 to 31 dB, with 0.1 dB steps. |
| L2-MAXSNRM | | Maximum SNR margin (in dB) in L2.1 link sub-state, including entry to L2.1 link sub-state and exit from L2.1 link sub-state. It ranges from 0 to 31 dB, with 0.1 dB steps. |
| L2-BANDS | | Frequency bands where disabling of subcarriers in L2.1 link sub-state is not allowed. |

**Table E.2 – CO-MIB reporting parameters related to LPMode**

| **Reporting parameter** | **G.997.1 reference** | **Definition** |
|---|---|---|
| Power management state (PM-STATE) | 7.5.1.5 | The Power Management State the link is in (i.e., L0, L2.1, L2.2 or L3). Its value is configured by the near-end VTU Control Function, possibly based on configuration forced through the CO-MIB and/or by the far-end Control Function. It is defined separately for downstream and upstream. |
| PSD trim method | | The type of PSD trim applied at the last entry into L2.1 link sub-state. Valid values for the PSD trim method are "flat PSD trim" and "ceiled PSD trim". |

The CO-MIB configuration parameters communicated to the VTU-R are included in the G.998.4 LPMode parameter field shown in Table E.3. A G.998.4 LPMode parameter field shall be included in the G.998.4 parameter field in initialization message O-TPS (see Table C.3).

**Table E.3 – ITU-T G.998.4 LPMode parameter field for O-TPS**

| Field nr | Field name | Format | Description |
|---|---|---|---|
| 1 | Parameter field length | 1 byte | Total number of data bytes in ITU-T G.998.4 LPMode parameter field (Note 1). |
| 2 | L2.1-ATPDds | 1 byte | See Table E.1. |
| 3 | L2.1-ATPRTds | 1 byte | See Table E.1. |
| 4 | L2-MINSNRMds | 2 bytes | See Table E.1. |
| 5 | L2-TARSNRMds | 2 bytes | See Table E.1. |
| 6 | L2-MAXSNRMds | 2 bytes | See Table E.1. |
| 7 | L2.1-ETR-MINds | 2 bytes | See Table E.1. |
| 8 | L2.1-ETR-MAXds | 2 bytes | See Table E.1. |
| 9 | L2-BANDSds | variable | See Table E.1. |
| NOTE 1 – If operation according to this Annex is disabled, the number of data bytes may be zero. | | | |

Field #1 "Parameter field length" indicates the number of data bytes in the ITU-T G.998.4 LPMode parameter field. The data bytes are the bytes following this length indicator byte (i.e., all bytes in the ITU-T G.998.4 LPMode parameter field counting from the penultimate byte). This byte is included to allow VTU-Rs that do not support ITU-T G.998.4 LPMode to still correctly parse O-TPS.

Field #2 "L2.1-ATPDds" is a 1-byte field representing an unsigned integer in the 0..31 range (0 dB to 31 dB in steps of 1 dB).

Field #3 "L2.1-ATPRTds" is a 1-byte field representing an unsigned integer in the 0..31 range (0 dB to 31 dB in steps of 1 dB).

Field #4 "L2-MINSNRMds" is a 2-byte field representing an unsigned integer in the 0..310 range (0 dB to 31 dB in steps of 0.1 dB).

Field #5 "L2-TARSNRMds" is a 2-byte field representing an unsigned integer in the 0..310 range (0 dB to 31 dB in steps of 0.1 dB).

Field #6 "L2-MAXSNRMds" is a 2-byte field representing an unsigned integer in the 0..310 range (0 dB to 31 dB in steps of 0.1 dB).

Field #7 "L2.1-ETR-MINds" is a 2-byte field representing an ETR as a multiple of 8 kbit/s.

Field #8 "L2.1-ETR-MAXds" is a 2-byte field representing an ETR as a multiple of 8 kbit/s.

Field #9 "L2-BANDSds" is a bands descriptor as defined in Table 12-22/G.993.2.

## E.5 Coordination of link state transitions between VTU-O and VTU-R

This clause amends clause 11.2.3.9/G.993.2 with power management eoc messages for the L2 link state and its link sub-states L2.1 and L2.2.

This clause defines the following eoc messages:

- L2.1-Entry-Step-Request command and responses (see clause E.5.1);
- L2.1-Exit-Step-Request command and responses (see clause E.5.2);
- L2-SRA-Request command and responses (see clause E.5.3);
- L2-ΔPSD-Request command and responses (see clause E.5.4);
- L2.2-Entry-Request command and responses (see clause E.5.5);
- L2.2-Exit-Request command and responses (see clause E.5.6);

### E.5.1 L2.1-Entry-Step-Request command and responses

The L2.1-Entry-Step-Request command is defined in Table E.4. The L2.1-Entry-Step-Request responses are defined in Table E.5. The L2.1-Entry-Step-Request command shall be initiated by the transmitting VTU for execution of the single-step L2.1 entry procedure. The L2-Entry-Step command contains the sequence number of the step and whether or not this step is the last step in the L2.1 entry procedure. The L2.1-Entry-Step-Request command indicates the target PSD trim ($\Delta PSD_{TAR}$) and whether a flat or ceiled PSD trim shall be applied. The receiver shall either acknowledge the command by sending an L2-SRA-Request command or reject the command by sending L2.1-Entry-Step-Reject response with a corresponding reason code defined in Table E.5.

The first octet of the command and response is defined in Table 11-4/G.993.2 (normal priority). The other octets are defined in Table E.4 and Table E.5, respectively.

**Table E.4 – L2.1-Entry-Step-Request command sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.1-Entry-Step-Request | 5 | 2 | $01_{16}$ (Note 1) |
| | | 3 | One octet containing:<br>Bit 7 (MSB): set to 1 indicates that this step is the last step of the L2.1 entry procedure;<br>Bits 6-0 (LSBs): the count of the step number represented as unsigned integer (Note 2). |
| | | 4 | One octet containing the $\Delta PSD_{TAR}$ value in the range from 0 to 25.5 dB in units of 0.1 dB, represented as an unsigned integer. |
| | | 5 | PSD trim method:<br>$00_{16}$: flat PSD trim<br>$01_{16}$: ceiled PSD trim<br>(Note 1) |
| NOTE 1 – All other values are reserved by ITU-T.<br>NOTE 2 – The count of the step number shall be set to "1" for the first step of an L2.1 entry procedure, and shall increment by 1 at each subsequent step in a multi-step entry procedure. | | | |

**Table E.5 – L2.1-Entry-Step-Request responses sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2-SRA-Request | See clause E.5.3. | | See clause E.5.3. |
| L2.1-Entry-Step-Reject | 3 | 2 | $81_{16}$ (Note) |
| | | 3 | 1 octet for reason code with the following valid values:<br>$01_{16}$ – busy<br>$02_{16}$ – invalid parameters<br>$03_{16}$ – excessive PSD reduction<br>(Note) |
| NOTE – All other values are reserved by ITU-T. | | | |

### E.5.2 L2.1-Exit-Step command and responses

The L2.1-Exit-Step-Request command is defined in Table E.6. The L2.1-Exit-Step-Request responses are defined in Table E.7. The L2.1-Exit-Step-Request command initiates the execution of the single-step exit procedure with the indicated actual PSD trim that will be applied starting from the first data symbol position following the first L2-SYNCHRO pattern (see clause E.3.1.2).

The first octet of the command and response is defined in Table 11-2/G.993.2 (high priority). The other octets are defined in Table E.6 and Table E.7, respectively.

**Table E.6 – L2.1-Exit-Step-Request command sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.1-Exit-Step-Request | 4 | 2 | $02_{16}$ (Note 1) |
| | | 3 | One octet containing:<br>Bit 7 (MSB): set to 1 indicates that this step is the last step of the L2.1 exit procedure;<br>Bits 6-0 (LSBs): the count of the step number represented as unsigned integer (Note 2). |
| | | 4 | One octet containing the $\Delta PSD_{ACT}$ value in the range from 0 to 25.5 dB in units of 0.1 dB, represented as an unsigned integer (Note 3). |
| NOTE 1 – All other values are reserved by ITU-T.<br>NOTE 2 – The count of the step number shall be "1" at the first exit step, and shall increment by 1 at each subsequent step in a multi-step exit procedure.<br>NOTE 3 – The same type of PSD trim (either flat or ceiled) as requested in associated L2.1-Entry-Step-Request command shall be used. | | | |

**Table E.7 – L2.1-Exit-Step-Request responses sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2-ΔPSD-Request | See clause E.5.4. | | See clause E.5.4. |

### E.5.3 L2-SRA-Request command and responses

The L2-SRA-Request command is defined in Table E.8. The L2-SRA-Request command is initiated by the receiving VTU and shall either be acknowledged by an L2-SYNCHRO pattern or rejected by a response defined in Table E.9. The L2-SRA-Request message indicates the actual PSD trim, the bit loading (bits only, with no gains and no tone indices, overall 4 bits per subcarrier), the set of active sub-carriers, and the framing parameters that will be applied starting from the first data symbol position following the subsequent L2-SYNCHRO pattern (see clause E.3.1.1 and E.3.1.2).

The sub-carrier grouping (with a sub-carrier grouping value (G) of 1, 2 or 4) shall reduce the length of the command down to a length not requiring segmentation.

The timing of changes for the parameters indicated in the L2-SRA-Request command shall be as specified in clause Q.3.1.1.1 (single-step procedure).

The first octet of the command and response is defined in Table 11-2/G.993.2 (high priority). The other octets are defined in Table E.8 and Table E.9, respectively.

**Table E.8 – L2-SRA-Request command sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2-SRA-Request | Variable | 2 | $03_{16}$ (Note 1) |
| | | 3 | One octet containing the $\Delta PSD_{ACT}$ value in the range from 0 to 25.5 dB in units of 0.1 dB, represented as an unsigned integer. |
| | | 4-5 | two octets containing the new value for $L_1$ |
| | | 6 | one octet containing the new value for $B_{10}$ |
| | | 7 | one octet containing the new value for $M_1$ |
| | | 8 | one octet containing the new value for $R_1$ |
| | | 9 | one octet containing the new value for $Q$ |
| | | 10 | one octet containing the new value for $V$ |
| | | 11 | one octet containing the new value for $Q_{tx}$ |
| | | 12 | one octet containing the new value for $lb$ |
| | | 13 | Sub-carrier grouping value (G) for the bit-loading (G=1, 2, or 4). |
| | | Variable | Bit-loading of 1st band of MEDLEY set using the sub-carrier grouping (Note 2, Note 3). |
| | | Variable | Bit-loading of 2nd band of MEDLEY set using the sub-carrier grouping (Note 2, Note 3). |
| | | ... | ... |
| | | Variable | Bit-loading of last band of MEDLEY set using the sub-carrier grouping (Note 2, Note 3). |

NOTE 1 – All other values for octet numbers 2 are reserved by ITU-T.

NOTE 2 – The bands of the MEDLEY set are defined in O-PRM (Table 12-30/G.993.2) for downstream and in R-PRM (Table 12-36/G.993.2) for upstream, with the bands descriptor format defined in Table 12-22/G.993.2. The bit-loading for a band is $\lceil$(index of last sub-carrier – index of first sub-carrier + 1)/(2×G)$\rceil$ octets in length (4 bits per sub-carrier group with LSBs of the last octet set to 0 if the number of sub-carrier groups in the band is odd).

NOTE 3 – If the command is sent in response to the L2.1-Entry-Step-Request command, then the 4-bits per subcarrier coding $F_{16}$ is a special value and indicates that the sub-carrier shall be inactive and remain inactive until the L2.1-Exit-Step-Request command is received.

**Table E.9 – L2-SRA-Request responses sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2-SRA-Reject | 3 | 2 | $83_{16}$ (Note 1) |
| | | 3 | 1 octet for reason code with the following valid values (Note 1):<br>$01_{16}$ – busy<br>$02_{16}$ – invalid parameters |
| L2.1-Exit-Step-Request (Note 2) | See clause E.5.2 | | See clause E.5.2. |
| NOTE 1 – All other values are reserved by ITU-T.<br>NOTE 2 – The transmitting VTU shall use this command only if it received an L2.1-exit-request primitive over the near-end γ_MGMT reference point and thus proceeding with the L2.1 entry procedure is not possible, or if it chooses to abort the L2.1 entry procedure. | | | |

### E.5.4 L2-ΔPSD-Request command and responses

The L2-ΔPSD-Request command is defined in Table E.10. The L2-ΔPSD-Request command is initiated by the receiving VTU and shall either be acknowledged by an L2-SYNCHRO pattern or rejected by a response defined in Table E.11. The L2-ΔPSD-Request command indicates that the receiving VTU is ready for the ΔPSD trim (indicated in the L2.1-Exit-Step-Request command) to be applied by the transmitting VTU starting from the first data symbol position after the subsequent L2-SYNCHRO pattern (see clause E.3.1.1 and E.3.1.2).

The first octet of the command and response is defined in Table 11-2/G.993.2 (high priority). The other octets are defined in Table E.10 and Table E.11, respectively.

**Table E.10 – L2-ΔPSD-Request command sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2-ΔPSD-Request | 2 | 2 | $04_{16}$ (Note) |
| NOTE – All other values are reserved by ITU-T. | | | |

**Table E.11 – L2-ΔPSD-Request responses sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2-ΔPSD-Reject (Note 2, Note 3) | 3 | 2 | $84_{16}$ (Note 1) |
| | | 3 | 1 octet for reason code with the following valid values (Note 1): $01_{16}$ – busy |
| NOTE 1 – All other values are reserved by ITU-T.<br>NOTE 2 – The transmitting VTU may use this command during L2.1 entry procedure only. During L2.1 exit procedure, the transmitting VTU shall be prepared to implement the L2-ΔPSD-Request.<br>NOTE 3 –The transmitting VTU shall use this command only if it received an L2.1-exit-request primitive over the near-end γ_MGMT reference point and thus proceeding with the L2.1 entry procedure is not possible, or if it chooses to abort the L2.1 entry procedure. | | | |

### E.5.5 L2.2-Entry-Request command and responses

The L2.2-Entry-Request command is defined in Table E.12. The L2.2-Entry-Request responses are defined in Table E.13. The L2.2-Entry-Request command initiates the entry procedure with transmission as defined for the L2.2 link sub-state to start from the first data symbol position after the subsequent L2-SYNCHRO pattern (see clause E.3.2.1).

The first octet of the command and response is defined in Table 11-4/G.993.2 (normal priority). The other octets are defined in Table E.12 and Table E.13, respectively.

**Table E.12 – L2.2-Entry-Request command sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-Entry-Request | 2 | 2 | $05_{16}$ (Note) |
| NOTE – All other values are reserved by ITU-T. | | | |

**Table E.13 – L2.2-Entry-Request responses sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-Entry-ACK | 2 | 2 | $80_{16}$ (Note) |
| L2.2-Entry-Reject | 3 | 2 | $85_{16}$ (Note) |
| | | 3 | 1 octet for reason code with the following valid values (Note):<br>$01_{16}$ – busy |
| NOTE – All other values are reserved by ITU-T. | | | |

### E.5.6 L2.2-Exit-Request command and responses

The L2.2-Exit-Request command is defined in Table E.14. The L2.2-Exit-Request responses are defined in Table E.15. The L2.2-Exit-Request command initiates the exit procedure with transmission as defined for the L2.1 link sub-state to start from the first data symbol position after the subsequent L2-SYNCHRO pattern (see clause E.3.2.1).

The first octet of the command and response is defined in Table 11-4/G.993.2 (normal priority). The other octets are defined in Table E.14 and Table E.15, respectively.

**Table E.14 – L2.2-Exit-Request command sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-Exit-Request | 2 | 2 | $06_{16}$ (Note) |
| NOTE – All other values are reserved by ITU-T. | | | |

**Table E.14 – L2.2-Exit-Request command sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-Exit-Request | 2 | 2 | $06_{16}$ (Note) |
| NOTE – All other values are reserved by ITU-T. | | | |

**Table E.15 – L2.2-Exit-Request responses sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-Exit-ACK | 2 | 2 | $80_{16}$ (Note) |
| NOTE – All other values are reserved by ITU-T. | | | |

### E.5.7 L2.2-RX-Exit-Request command and responses

The L2.2-RX-Exit-Request command is defined in Table E.16. The L2.2-RX-Exit-Request responses are defined in Table E.17. The L2.2-RX-Exit-Requst command is a request from the receiving VTU to exit from the L2.2 link sub-state in the aim to perform OLR while in the L2.1 link sub-state (reason code "OLR") or in the aim to avoid the link being in the L2.2 link sub-state in the presence of REIN (reason code "REIN").

The first octet of the command and response is defined in Table 11-4/G.993.2 (normal priority). The other octets are defined in Table E.16 and Table E.17, respectively.

**Table E.16 – L2.2-RX-Exit-Request command sent by the receiving VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-RX-Exit-Request | 3 | 2 | $07_{16}$ (Note 1) |
| | | 3 | 1 octet for reason code with the following valid values (Note 1):<br>$01_{16}$ – OLR<br>$02_{16}$ – REIN |
| NOTE – All other values are reserved by ITU-T. | | | |

**Table E.17 – L2.2-RX-Exit-Request response sent by the transmitting VTU**

| Name | Length (Octets) | Octet number | Content |
|---|---|---|---|
| L2.2-Exit-Request | See clause E.5.6 | | See clause E.5.6. |

## 2. Changes to Annex C to support Annex E (new functionality).

*Add a field to Table C.2 as follows:*

### C.2.1.1 O-MSG 1

**…**

**Table C.2 – ITU-T G.998.4 parameter field for O-MSG1**

| | Field contents | Format | Description |
|---|---|---|---|
| 9 | Support of LPMode Annex E | 1 byte [0000 00ab] | Indicates the enabling of LPMode link sub-states L2.1 and L2.2 in the downstream direction:<br>ab=00 if both L2.1 and L2.2 are disabled<br>ab=01 is reserved for use by the ITU-T<br>ab=10 if L2.1 is enabled and L2.2 is disabled<br>ab=11 if both L2.1 and L2.2 are enabled |

**…**

Field #9 "Support of LPMode Annex E" indicates whether or not the LPMode link sub-states L2.1 and L2.2 (as defined in Annex E) are enabled in the downstream direction. The value ab depends on the CO-MIB enabling and the VTU-O supporting the LPMode link sub-states L2.1 and L2.2 in the downstream direction.

**…**

*Add a field to Table C.3 as follows:*

### C.2.1.2 O-TPS

**…**

**Table C.3 – ITU-T G.998.4 parameter field for O-TPS**

| | Field contents | Format | Description |
|---|---|---|---|
| 12 | ITU-T G.998.4 LPMode parameter field | Variable length | Control parameters for the LPMode defined in Annex E. |

**…**

Field #12 is a variable length field consisting of an integer number of octets. It is formatted as shown in Table E.3. If the VTU-O indicates in O-MSG 1 the LPMode link sub-state L2.1 is enabled and the VTU-R indicates in R-MSG 2 it supports the LPMode link sub-state L2.1, then this field shall have a length of 9 bytes. Otherwise, this field may have a length of 1 byte with value $00_{16}$.

**…**

*Add a field to Table C.5 as follows:*

### C.2.2.1 R-MSG 2

**…**

**Table C.5 – ITU-T G.998.4 parameter field for R-MSG2**

| | Field contents | Format | Description |
|---|---|---|---|
| 11 | Support of LPMode Annex E | 1 byte [0000 00ab] | Indicates the support of LPMode link sub-states L2.1 and L2.2 in the downstream direction:<br>ab=00 if both L2.1 and L2.2 are not supported<br>ab=01 is reserved for use by the ITU-T<br>ab=10 is reserved for use by the ITU-T<br>ab=11 if both L2.1 and L2.2 are supported |

**…**

Field #11 "Support of LPMode Annex E" indicates whether or not the VTU R supports the Low Power Mode (LPMode) link sub-states L2.1 and L2.2 (as defined in Annex E) in the downstream direction.

**…**