Table 10-7 – ITU-T G.993.5 parameter field A in message O-SIGNATURE

Field	Content of field	Format
1	ITU-T G.993.5 parameter field A length	1 byte
2	Vectored downstream bands	Bands descriptor
3	Upstream pilot sequence length	2 bytes
4	Upstream pilot sequence	$\lceil Npilot\_us/8 \rceil$ bytes
5	Upstream sync symbol offset	1 bytes
6	Upstream R-P-VECTOR 1 PSD cutback	1 bytes
7	Downstream sync symbol counter modulo value (*N_SSC*)	2 bytes
8	VCE vendor ID and version number	10 bytes
9	VTU-R ID	4 bytes

Field #1, "ITU-T G.993.5 parameter field A length", indicates the length of the ITU-T G.993.5 parameter field A in bytes, excluding the ITU-T G.993.5 parameter field A length field. All fields shown in Table 10-7 shall be included in the ITU-T G.993.5 parameter field A in the O-SIGNATURE message. The field shall be represented as an unsigned integer.

Field #2, "Vectored downstream bands", defines frequency bands that are allocated by the VCE for vectoring in the downstream direction. This field shall be formatted as "Bands descriptor" (see Table 12-18 of [ITU-T G.993.2]). No more than eight bands shall be specified. The subcarrier indices that define band edges shall comply with the requirements in clause 7.2.2.

Field #3, "Upstream pilot sequence length", defines the length of the upstream pilot sequence (*Npilot_us*, see clause 7.3.3) in bits. If the "pilot sequence length multiple of 4" is enabled (see clause 10.2), then valid values are all multiples of 4 in the range from 8 to 512. Otherwise, valid values are powers of 2 in the range from 8 to 512. The field shall be represented as an unsigned integer representing the length of the sequence.

Field #4, "Upstream pilot sequence", defines the pilot sequence allocated by the VCE to be modulated on the sync symbols contained in the R-P-VECTOR signals. The format is a binary string of length *Npilot_us* bits (see clause 7.3.3), with the first bit of the pilot sequence (bit index 0) mapped to the LSB of the first byte in this field and the last bit of the pilot sequence (bit index Npilot_us – 1) mapped on the MSB of the last byte of the field. The length of the field shall be derived from field #3 as $\lceil \text{Npilot\_us}/8 \rceil$. If *Npilot_us* is not a multiple of 8 then the last octet of this field shall have the 4 MSBs set to 0.

Field #5, "Upstream sync symbol offset", defines the time offset set by the VCE (expressed as a number of symbols) between the downstream sync symbol and the upstream sync symbol. The field shall be represented as an integer in 2's complement representation with valid range from –127 to +127, except 0, where negative offset indicates that the upstream sync symbols are delayed relatively to the downstream sync symbols.

NOTE – The value of 0 is excluded from the valid range of offsets between sync symbols in upstream and downstream directions on the U-interface because it may influence vendor specific processing done on the sync symbols due to reduced randomness of the echo signal.

Field #6, "Upstream R-P-VECTOR 1 PSD cutback", defines a flat attenuation set by the VCE for the upstream transmit PSD of R-P-VECTOR 1 in addition to the upstream power back-off. It is coded in steps of 0.1 dB in a 0 dB to 25.5 dB range. The field shall be represented as an unsigned integer in the 0 (0 dB) to 255 (25.5 dB) range.

Field #7 "Downstream sync symbol counter modulo value (N_SSC)", defines the modulo value to be used for maintaining the downstream sync symbols counter during Showtime. If the "pilot sequence length multiple of 4" is enabled (see clause 10.2), then this field is coded as an unsigned integer representing the value of *N_SSC*, with a single valid value being the lowest $(2n \times Npilot\_ds) \geq 1024$, where n is an integer. Otherwise, it is coded as an unsigned integer with a single valid value if N_SSC equal to 1024.

NOTE – If *N_SSC* is an integer multiple of the downstream pilot sequence length, then the pilot sequence bit index may be derived from the downstream sync symbol counter through a modulo operation.

Field #8 "VCE vendor ID and version number" defines the VCE vendor ID and version number. It consists of 10 bytes, with definition and format as depicted in Table 10-8.

Field #9 "VTU-R ID", contains the 30-bit transceiver ID of the VTU-R (with the two MSBs of this field set to 00_2). If the VTU-O has received the VTU-R ID during the last previous ITU-T G.994.1 session, then this field shall contain that VTU-R ID, otherwise this field shall be set to 00000000_{16}.

Table 10-8 – VCE Vendor ID information block (10 bytes)

ITU-T T.35 country code (2 bytes – Note 1)
Provider code (vendor identification) (4 bytes – Note 2)
Vendor specific version number (4 bytes)
NOTE 1 – If the bits in the first octet are not all set to binary ONE, the bits in the second octet shall be set to binary ZERO by the transmitter and ignored by the receiver. The only purpose of the country code is to identify the country of registry of the provider code. NOTE 2 – Specification of the coding and order of transmission of this field is the responsibility of the regional standards body allocating the provider code. See Appendix II of [ITU-T G.994.1] for provider code contact information.

Table 10-9 – ITU-T G.993.5 parameter field B in message O-SIGNATURE

Field	Content of field	Format
1	ITU-T G.993.5 parameter field B length	2 bytes
2	Upstream FDPS	Upstream FDPS descriptor

Field #1, "ITU-T G.993.5 parameter field B length", indicates the length of the ITU-T G.993.5 parameter field B in bytes, excluding the ITU-T G.993.5 parameter field B length field. If none of the fields following field #1 is included in the ITU-T G.993.5 parameter field B, then the ITU-T G.993.5 parameter field B shall be two bytes long with value 0000_{16}. The field shall be represented as an unsigned integer.

Field #2, "Upstream FDPS", defines the additional independent pilot sequences allocated by the VCE and how the upstream pilot sequences to be modulated on the sync symbols contained in the R-P-VECTOR signals are derived. This field shall be formatted as "upstream FDPS descriptor" (see Table 10-10). If upstream FDPS is disabled through ITU-T G.994.1, then the upstream FDPS descriptor shall not be included in the ITU-T G.993.5 parameter field B.

Table 10-10 – Upstream FDPS descriptor

Field	Content of field	Format
1	Index of the associated independent pilot sequence	3 bytes
2	Sign of the sequence relatively to the associated independent sequence	1 byte
3	Cyclical shift of the sequence relative to the associated independent sequence	3 bytes
4	Number of additional independent pilot sequences (*Naips*)	1 byte
5	Bits of independent pilot sequence #1	$\lceil Npilot\_us/8 \rceil$ bytes
	…	…
	Bits of independent pilot sequence #*Naips*	$\lceil Npilot\_us/8 \rceil$ bytes

Field #1, "Index of the associated independent pilot sequence", is a 24-bit field divided into eight 3-bit subfields. The first subfield (in the 3 LSB) represents the index of the independent pilot sequence to be the pilot sequence #0, the eighth subfield (in the 3 MSB) represents the index of the independent pilot sequence to be the pilot sequence #7. The index shall be represented as a 3-bit unsigned integer.

Field #2, "Sign of the sequence relatively to the associated independent pilot sequence", is an 8-bit bitmap, where a 0 indicates that the pilot sequence with the given index has the same sign as the associated independent pilot sequence and a 1 indicates that it has an inverted sign relative to the associated independent pilot sequence. The LSB indicates whether the sign inversion shall be applied to pilot sequence #0, the MSB indicates whether the sign inversion shall be applied to pilot sequence #7.

Field #3, "Cyclical shift of the sequence relative to the associated independent pilot sequence", is a 24-bit field divided into eight 3-bit subfields. The first subfield (in the 3 LSB) represents the cyclic shift of pilot sequence #0 relative to the associated independent pilot sequence, the eighth subfield (in the 3 MSB) represents the cyclic shift of pilot sequence #7 relative to the associated independent pilot sequence. The value of the subfield is the actual cyclic shift (*CyS*) represented as unsigned integer with values 0 to 7, where:

Pilot sequence bit [i] =

Associated independent pilot sequence bit [(i + $CyS \times Npilot\_us$ / 8) MOD $Npilot\_us$].

If *Npilot_us* is an odd multiple of 4, then the value of *CyS* shall be even.

Field #4, "Number of additional independent pilot sequences (*Naips*)" is a 1-byte field field representing the number of additional independent pilot sequences included in the Upstream FDPS descriptor. Valid *Naips* values are 0 to 7.

Field #5, "Bits of additional independent pilot sequences", defines the bits of the *Naips* additional independent pilot sequences (i.e., independent pilot sequence #1 to independent pilot sequence #*Naips*) allocated by the VCE to be modulated on the upstream sync symbols. Each sequence is *Npilot_us* bits long (see clause 7.3.3). Each sequence is mapped into $\lceil Npilot\_us/8 \rceil$ bytes as defined for field #4 in Table 10-7 (the last byte can be incomplete). The total length of the field shall be$Naips \times \lceil Npilot_us/8 \rceil$ bytes. Bits of the independent pilot sequence #0 are communicated in the "Upstream pilot sequence" field #4 of the ITU-T G.993.5 parameter field A.

10.3.2.2 R-MSG1

The R-MSG1 message (defined in Table 12-24 of [ITU-T G.993.2]), which is transmitted during R-P-CHANNEL DISCOVERY 1, contains an ITU-T G.993.5 parameter field. The ITU-T G.993.5

parameter field contains several parameters needed for FEXT cancellation operation, as shown in Table 10-11.

Table 10-11 – ITU-T G.993.5 parameter field in message R-MSG1

Field	Field name	Format
1	ITU-T G.993.5 parameter field length	1 byte
2	Maximum number of FEXT estimation symbols per superframe	1 byte
3	Support of optional backchannel control parameters	Parameters descriptor

Field #1, "ITU-T G.993.5 parameter field length", indicates the length of the vectoring descriptor field in bytes, excluding the ITU-T G.993.5 parameter field length field. All fields shown in Table 10-11 shall be included in the R-MSG1 message. The field shall be represented as an unsigned integer.

Field #2, "Maximum number of FEXT estimation symbols per superframe", defines the maximum number (*Kmax*) of symbols in the superframe for which the VTU-R supports error sample reporting (see clause 10.4.2.1). The field shall be formatted as an unsigned integer with valid *Kmax* values = 1, 2, 4, 6, and 8. The VTU-R shall support the value *Kmax* = 1. Other values of *Kmax* are optional.

Field #3, "Support of optional backchannel control parameters", indicate the optional values of control parameters supported by the VTU-R, as described in Table 10-12.

Table 10-12 – Optional backchannel control parameters descriptor

Bit	Description
0	Set to 1 if *F_block* = 32 with *padding* = 0 is supported and 0 otherwise.
1	Set to 1 if *F_block* = 32 with *padding* = 1 is supported and 0 otherwise.
2	Set to 1 if *F_sub* = 1 is supported and 0 otherwise.
3	Set to 1 if *L_w* = 9 is supported and 0 otherwise.
4	Set to 1 if *L_w* = 10 is supported and 0 otherwise.
5	Set to 1 if *L_w* = 11 is supported and 0 otherwise.
6	Set to 1 if *L_w* = 12 is supported and 0 otherwise.
7	Reserved by ITU-T and shall be set to 0.

10.3.3 Vectoring-specific VTU-O signals transmitted during the Channel Discovery phase

10.3.3.1 O-P-VECTOR 1

The O-P-QUIET 1 signal shall be followed by the O-P-VECTOR 1 signal.

The O-P-VECTOR 1 signal shall consist of sync symbols and quiet symbols only. sync symbols shall be transmitted at each downstream sync symbol position (as defined in clause 6.2.3). Quiet symbols shall be transmitted at all other symbol positions (see Figure 10-2).

The O-P-VECTOR 1 sync symbols shall be generated as described in clause 10.5 of [ITU-T G.993.2]. These sync symbols shall modulate a pilot sequence. The pilot sequence is a repetitive sequence, as defined in clause 6.2.3, assigned to the initializing line by the VCE. Each probe tone of a sync symbol from the SUPPORTEDCARRIERSds set with a pilot sequence bit equal to ZERO shall modulate a 00 constellation point, and with a pilot sequence bit equal to ONE shall modulate a 11 constellation point. The 00 and 11 constellation points shall be per the 4-QAM constellation defined in clause 10.3.3.2.1 of [ITU-T G.993.2]. The constellation points on subcarriers shall then be rotated by the quadrant scrambler defined in clause 12.3.6.2 of [ITU-T G.993.2].

If the bit "8192 superframes duration for O-P-VECTOR 1" is disabled in the ITU-T G.994.1 phase (see clause 10.2), then for sync symbols, the transmit PSD of all subcarriers shall be equal to CDPSDds.

If the bit "8192 superframes duration for O-P-VECTOR 1" is enabled and the bit "Use of O-P-VECTOR 1 flag tones only" is disabled in the ITU-T G.994.1 phase (see clause 10.2), then for sync symbols, the transmit PSD of all subcarriers shall be equal to CDPSDds.

If both the bit "8192 superframes duration for O-P-VECTOR 1" and the bit "Use of O-P-VECTOR 1 flag tones only" are enabled in the ITU-T G.994.1 phase (see clause 10.2), then for sync symbols, the transmit PSD of all subcarriers shall be equal to CDPSDds, except that for the first N sync symbols, the transmit power of all probe tones shall be 0 (with N a value determined by the VCE, in the range from 0 to 2048 sync symbols).

NOTE 1 – A way to identify the value of N is described in Appendix II.

The duration of O-P-VECTOR 1 is vendor discretionary, but shall be minimum 4 × 257 symbols and maximum $M \times 1024 \times 257$ symbols. Valid values for M are 1 and 8. Support of $M = 1$ is mandatory for the VTU-O and the VTU-R. Support of $M = 8$ is optional for both the VTU-O and the VTU-R. If the bit "8192 superframes duration for O-P-VECTOR 1" is enabled in the [ITU-T G.994.1] phase (see clause 10.2), then $M = 8$. Otherwise, $M = 1$.

NOTE 2 – The O-P-VECTOR 1 signal should be shortened by the VCE to accelerate full system start-up.

NOTE 3 – Appendix II provides examples of VCE control of the initialization process in the activation of multiple lines in the vectored group. Clause II.2 describes such VCE control using the "8192 superframes duration for O-P-VECTOR 1" capability in handling two groups of lines. Clause II.3 describes such VCE control using handshake capabilities.

During transmission of the O-P-VECTOR 1 signal, the SOC is in its inactive state.

During transmission of the O-P-VECTOR 1 signal, the VCE estimates the downstream FEXT channels from the initializing lines into the vectored lines based on the reported clipped error samples from the VTU-Rs of the vectored lines. From this point on, FEXT cancellation matrices are established in the VTU-Os for all vectored lines in the downstream direction and FEXT from the initializing line into vectored lines is cancelled.

The O-P-VECTOR 1 signal shall be followed by the O-P-CHANNEL DISCOVERY V1 signal, which determines the actual duration of O-P-VECTOR 1. The start time of O-P-CHANNEL DISCOVERY V1 transmission is determined by the VCE.

10.3.3.2 O-P-CHANNEL DISCOVERY V1

The O-P-CHANNEL DISCOVERY V1 signal shall be identical to the O-P-CHANNEL DISCOVERY 1 signal defined in clause 12.3.3.3.1 of [ITU-T G.993.2], with the addition of markers to indicate the downstream sync symbol positions and upstream pilot sequence positions (as defined in clause 10.3.3.5).

The addition of markers consists of modulating on all symbols the subcarriers with index $10n+9$ with constellation point 00 or 11, as defined in clause 10.3.3.5.

During transmission of O-P-CHANNEL DISCOVERY V1, the SOC is in its active state, sending O-IDLE for a period of at least 1500 symbols and no more than 2000 symbols and followed by the O-SIGNATURE message, as defined in clause 12.3.3.2.1 of [ITU-T G.992.3] and clause 10.3.2.1. The O-SIGNATURE shall be sent in auto-repeat mode, the same as O-SIGNATURE in [ITU-T G.993.2].

The O-P-CHANNEL DISCOVERY V1 signal shall be followed by the O-P-SYNCHRO V1 signal, which determines the actual duration of the O-P-CHANNEL DISCOVERY V1. The start time of O-P-SYNCHRO V1 transmission is determined by the VCE.

10.3.3.3 O-P-SYNCHRO V1

The O-P-SYNCHRO V1 signal shall be identical to the O-P-SYNCHRO 1 signal defined in clause 12.3.3.3.1 of [ITU-T G.993.2].

During transmission of O-P-SYNCHRO V1, the SOC is in its inactive state.

With the VTU-O transmitting the O-P-SYNCHRO V1 signal, the VCE notifies the VTU-R that the upstream FEXT channel estimation is completed, and that the VTU-R shall end the transmission of R-P-VECTOR 1. The VTU-O shall transmit O-P-SYNCHRO V1 only after VCE detects that R-P-VECTOR 1 is transmitted during at least 4 x 257 symbols.

The O-P-SYNCHRO V1 signal shall be followed by the O-P-CHANNEL DISCOVERY 1 signal.

10.3.3.4 O-P-CHANNEL DISCOVERY 1 and O-P-CHANNEL DISCOVERY 2

These signals shall be identical to the O-P-CHANNEL DISCOVERY 1 and O-P-CHANNEL DISCOVERY 2 signals defined in clause 12.3.3.3.1 of [ITU-T G.993.2], respectively, with the addition of markers to indicate the downstream sync symbol positions and upstream pilot sequence position (as defined in clause 10.3.3.5). The pattern of markers shall be continued taking into account all downstream sync symbol positions from the beginning of O-P-CHANNEL DISCOVERY V1.

NOTE – It is beneficial if O-P-SYNCHRO 1 and O-P-SYNCHRO 3 signals are not transmitted at downstream sync symbol positions.

During the O-P-CHANNEL DISCOVERY 1, the VTU-O shall transmit O-IDLE; the transmission shall start after the last symbol of O-P-SYNCHRO V1.

10.3.3.5 Downstream sync symbol and upstream pilot sequence markers

To indicate the time position of the downstream sync symbols and the required by VCE time position of the upstream sync symbols and upstream pilot sequence, the VTU-O shall modulate the subset of subcarriers with indices $10n+9$ with either the constellation point (00) or the constellation point (11) of the 4-QAM constellation, before the quadrant scrambler. All those subcarriers shall be modulated with the same information per symbol, i.e., either 00 or 11. Symbols whose subcarriers are modulated with either 00 or 11 are further noted in this clause as either ZERO or ONE symbols, respectively. A sequence of ZERO and ONE symbols forms a pattern that is used to indicate time positions of the sync symbol and pilot sequence.

Figure 10-6 shows the symbol modulation pattern. The time position of a downstream sync symbol shall be indicated by eight consecutive ONE symbols, starting at the time position of the downstream sync symbol of the vectored lines. The VTU-R shall derive the time position of the upstream sync symbol from the indicated time position of the downstream sync symbol by applying the offset between upstream and downstream sync symbols, which is communicated to the VTU-R in O-SIGNATURE.

The time position of the upstream pilot sequence shall be indicated by a 20-symbol pattern following the eight consecutive ONEs pattern, see Figure 10-6. This pattern of ONE and ZERO symbols shall represent the bit index of the upstream pilot sequence that modulates subcarriers of the upstream sync symbol associated (through the value of the offset) with this downstream sync symbol that precedes the mentioned 20-symbol pattern (as shown in Figure 10-6).

The bit index of the upstream pilot sequence shall be represented as an unsigned integer, and each bit of this integer is represented by two consecutive symbols of the pattern, with symbols 7 and 8 in Figure 10-6 representing the LSB. A bit value 0 shall be represented by a ZERO symbol followed by a ONE symbol. A bit value 1 shall be represented by a ONE symbol followed by a ZERO symbol. All the symbols after the 20-symbol pattern shall be ZERO symbols until the time position of the next downstream sync symbol.

NOTE – With this technique, the upstream sync symbol time position can be detected by looking for the pattern of eight consecutive ONEs and the bit index in the pilot sequence by decoding the 20 following symbols. This allows a quick detection of the time position of the upstream pilot sequence. The 10-bit pattern decoded from the 20 following symbols indicates the bit index in the upstream pilot sequence associated with the detected upstream sync symbol.

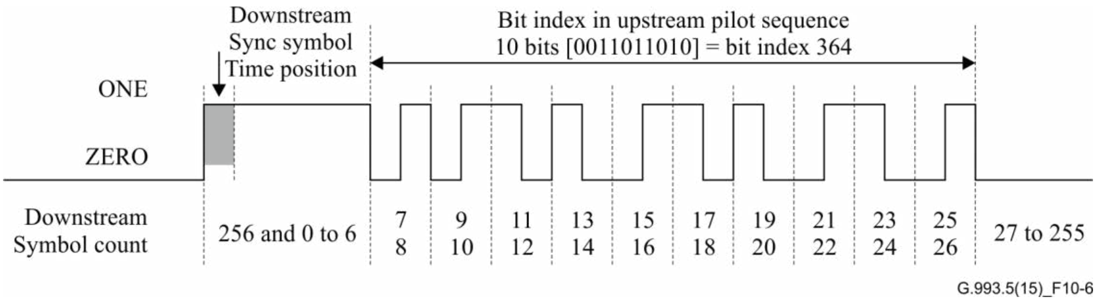

Figure 10-6 – Pattern modulated on subcarriers 10*n*+9 following the sync symbol position of the vectored lines

10.3.3.6 Initialization of multiple initializing lines

When the VCE initializes multiple lines:

– The downstream crosstalk channels from the initializing lines into the active lines of the vector group should be estimated simultaneously by insuring that O-P-VECTOR 1 signals are sent on all initialization lines during the estimation. This can be done by controlling the end and the start of O-P-VECTOR 1 in each line.

– The upstream crosstalk channels between the initializing lines and the active lines of the vector group should be estimated simultaneously by insuring that R-P-VECTOR 1 signals are sent on all initialization lines during the estimation. This can be done by controlling the end of R-P-VECTOR 1 with the O-P-SYNCHRO V1 signal in each line.

10.3.4 Vectoring specific VTU-R signals transmitted during Channel Discovery phase

10.3.4.1 R-P-VECTOR 1

The VTU-R shall transmit R-P-QUIET signal until it correctly receives the O-SIGNATURE message.

Upon receiving the O-SIGNATURE message, the VTU-R shall transmit R-P-VECTOR 1.

The VTU-R shall identify the downstream Sync symbols positions and derive the upstream sync symbol positions, by detecting the sync symbol markers on the O-P-CHANNEL DISCOVERY V1 signal.

The R-P-VECTOR 1 shall consist of sync symbols and quiet symbols only. Sync symbols shall be transmitted at each upstream sync symbol position (as defined in clause 7.3.2). Upstream sync symbol positions shall be the downstream sync symbol positions (as indicated by the markers on the O-P-CHANNEL DISCOVERY V1 signal), advanced or delayed by the upstream sync symbol offset (contained in the O-SIGNATURE message). Quiet symbols shall be transmitted at all other time positions (see Figure 10-2).

The R-P-VECTOR 1 sync symbols shall be generated as described in clause 10.4.4 of [ITU-T G.993.2]. These sync symbols shall modulate a pilot sequence. The transmission of sync symbols shall start from the sync symbol that carries the first identified reference point of the upstream pilot sequence. The timing of reference points of the pilot sequence is indicated by the markers in the O-P-CHANNEL DISCOVERY V1 signal, as described in clause 10.3.3.5.

The pilot sequence is a repetitive sequence, as defined in clause 6.2.3, assigned to the initializing line by the VCE and communicated to the VTU-R in the O-SIGNATURE message. Each probe tone of a sync symbol from the SUPPORTEDCARRIERSus set with a pilot sequence bit equal to ZERO shall modulate a 00 constellation point, and with a pilot sequence bit equal to ONE shall modulate a 11 constellation point (the SUPPORTEDCARRIERSus set is also indicated in the O-SIGNATURE message). The 00 and 11 constellation points shall be per the 4-QAM constellation defined in clause 10.3.3.2.1 of [ITU-T G.993.2]. The constellation points on subcarriers shall then be rotated by the quadrant scrambler defined in clause 12.3.6.2 of [ITU-T G.993.2].

The transmit PSD of all subcarriers shall be equal to CDPSDus and shall follow the upstream PSD limit imposed by the VTU-O as indicated in the O-SIGNATURE message.

During transmission of R-P-VECTOR 1, the SOC is in its inactive state.

During R-P-VECTOR 1, the VCE estimates the upstream FEXT channels from the initializing lines into the vectored lines. From this point on, FEXT cancellation matrices are established in the VTU-Os for all vectored lines in the upstream direction and FEXT from the initializing lines into vectored lines is cancelled.

The duration of R-P-VECTOR 1 is determined by the VTU-O. The VTU-R shall end the transmission of the R-P-VECTOR 1 signal within 64 symbols after the last symbol of the O-P-SYNCHRO V1 signal. The duration of the R-P-VECTOR 1 shall not exceed 1024 × 257 symbols.

The R-P-VECTOR 1 signal shall be followed by the R-P-CHANNEL DISCOVERY 1 signal.

10.4 Training phase

10.4.1 Overview

The Channel Discovery phase is followed by the Training phase. If both downstream and upstream vectoring are disabled after the ITU-T G.994.1 Phase, then all vectoring-related parts shall be skipped and the Training phase shall be as defined in [ITU-T G.993.2].

If downstream vectoring or upstream vectoring is enabled, then the Training phase shall be modified relative to the ITU-T G.993.2 Training phase as defined in this clause.

Figure 10-7 and Figure 10-8 highlight the signals added and the signals/messages modified in the ITU-T G.993.2 Training phase for ITU-T G.993.5 transceivers. Non-highlighted signals and messages shall be as defined in [ITU-T G.993.2].

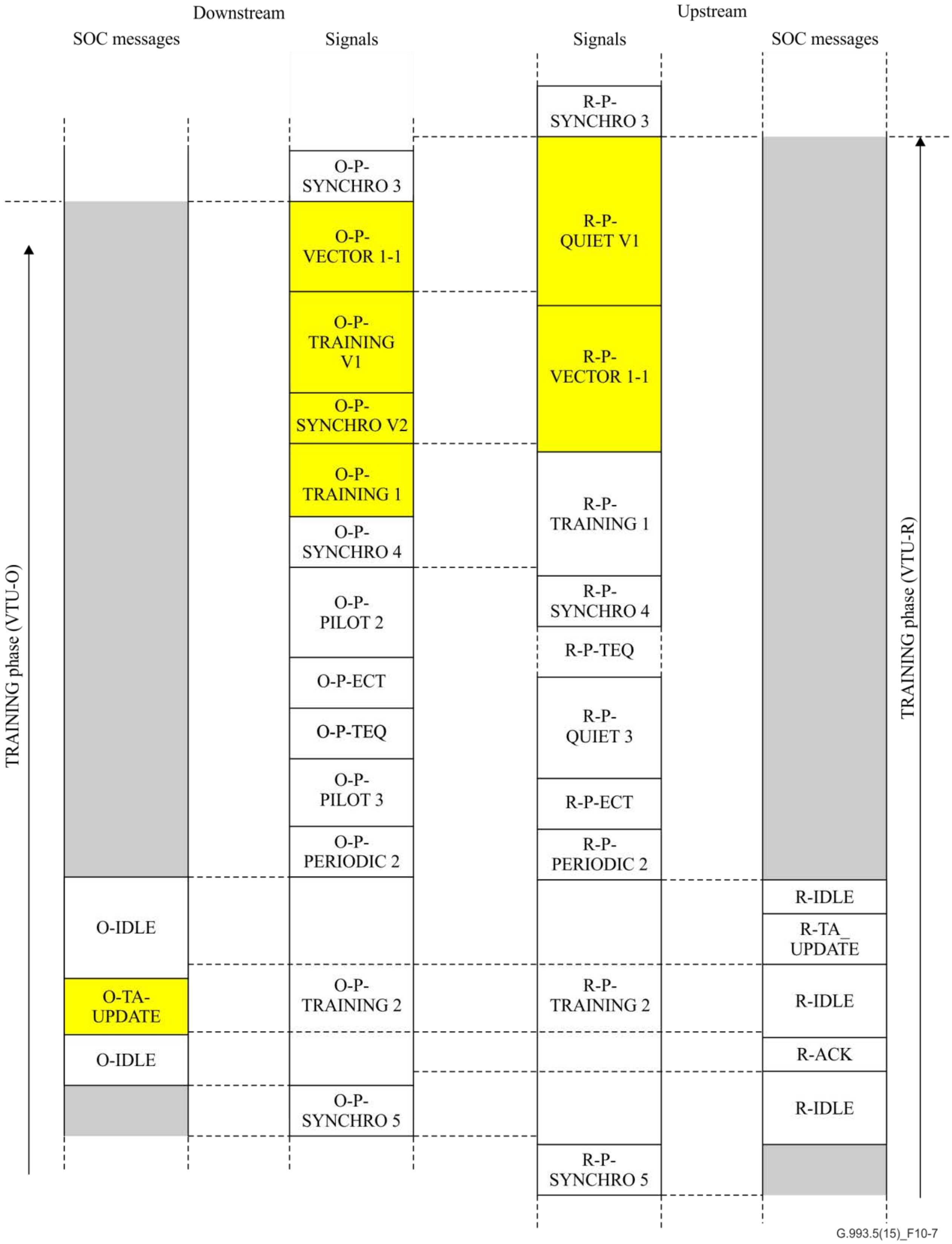

Figure 10-7 – Early stages of the Training phase

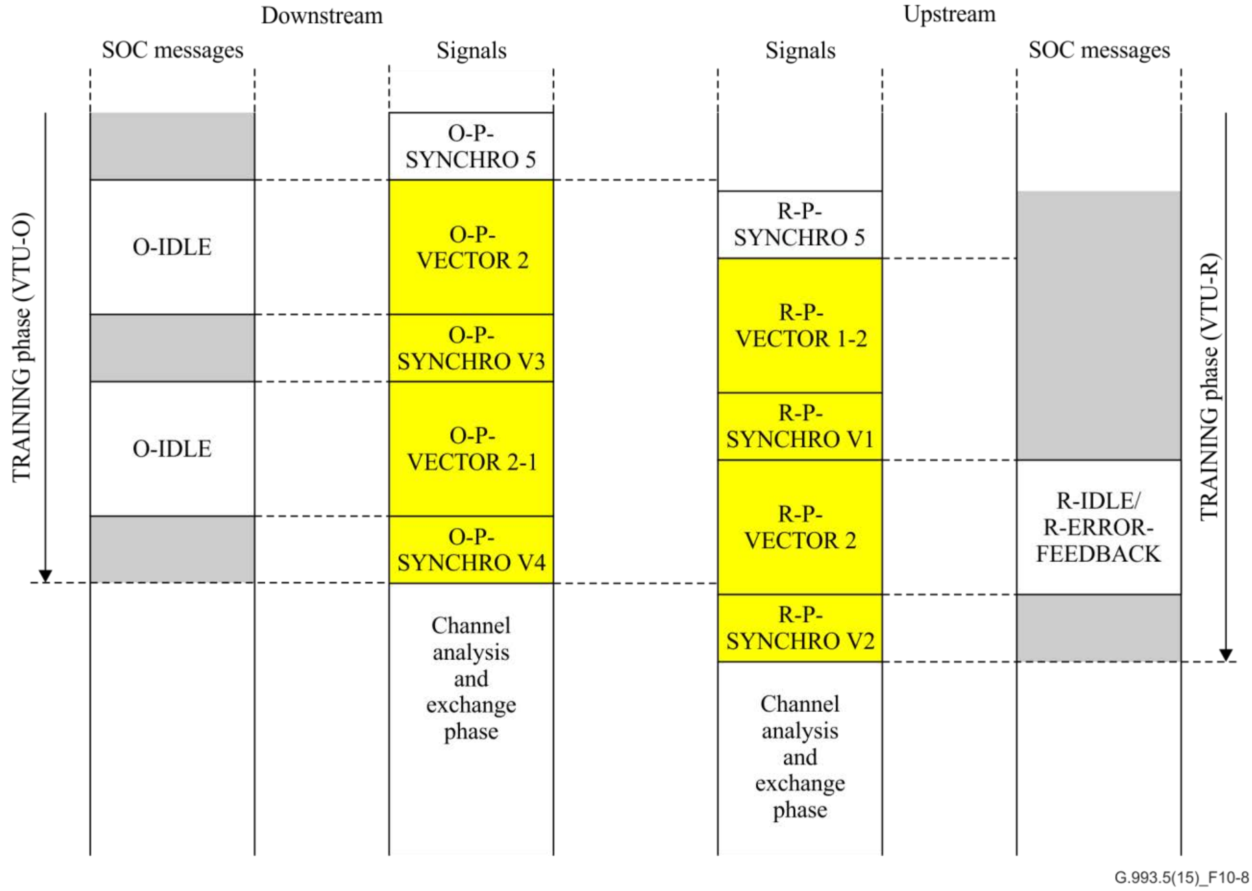

Figure 10-8 – Last stages of the Training phase

10.4.2 Modified SOC messages sent during the Training phase

10.4.2.1 O-TA_UPDATE

The O-TA_UPDATE message (defined in Table 12-32 of [ITU-T G.993.2]) which is transmitted during O-P-TRAINING 2 contains an ITU-T G.993.5 parameter field. The ITU-T G.993.5 parameter field contains several parameters needed for FEXT cancellation operation, as shown in Table 10-13.

Table 10-13 – Parameter field in message O-TA_UPDATE

Field	Field name	Format
1	ITU-T G.993.5 parameter field length	1 byte
2	Error report control parameters	Error report configuration descriptor
3	SOC repetition factor (1/R)	1 byte
4	FEXT estimation symbols per superframe	1 byte

Field #1, "ITU-T G.993.5 parameter field length", indicates the length of the ITU-T G.993.5 parameter field in bytes, excluding the ITU-T G.993.5 parameter field length field. All fields shown in Table 10-13 shall be included in the O-TA_UPDATE message. The field shall be represented as an unsigned integer.

Field #2, "error report control parameters", defines the control parameters for each of the vectored bands indicated in O-SIGNATURE. The control parameters are defined in Table 7-1 and valid values are defined in Table 7-2. The values defined in this field may include optional values indicated by the VTU-R in R-MSG1. Table 8-4 defines the mapping of the control parameters into the Error Report configuration descriptor. The VTU-O shall select control parameters so that in conjunction with the selected SOC repetition rate, the expected duration of the ERROR_FEEDBACK message will not exceed the limits defined in clause 10.4.2.2.

Field #3, "SOC Repetition Factor", defines the SOC repetition factor, 1/R, as set by the VCE. The valid 1/R values are all multiples of 10 in the [10, 120] range. This corresponds to the number of bits per symbol (*N_bits_per_symbol*) of the SOC being a multiple of 16 in the [16, 192] range. The field shall be represented as an unsigned integer.

Field #4, "FEXT estimation symbols per superframe", defines the number of symbols (K) in the superframe for which a clipped error sample shall be reported. The clipped error samples shall be reported in a format defined by Field #2. The field shall be formatted as an unsigned integer with valid values K=1, 2, 4, 6, and 8. The value of K shall not exceed the VTU-R capability (*Kmax*) indicated in the R-MSG1 message. Clause 10.4.2.2 defines the symbol positions for which clipped error samples shall be reported for different values of K.

The O-TA_UPDATE message may indicate a correction to the timing advance (TA) value. If the TA value contained in the O-TA_UPDATE message is different from the TA value previously used by the VTU-R, then the TA value shall be updated starting with the first symbol following R-P-SYNCHRO 5.

NOTE – This requirement is different from the way the TA value is updated in [ITU-T G.993.2].

10.4.2.2 R-ERROR-FEEDBACK

During transmission of R-P-VECTOR 2, the VTU-R shall report back to the VTU-O the clipped error samples through the SOC using R-ERROR-FEEDBACK messages (see Figure 10-8). The SOC message code for this message shall be $8B_{16}$. The VTU-O shall not acknowledge any of R-ERROR-FEEDBACK messages and the VTU-R shall not re-transmit any of them.

The R-ERROR-FEEDBACK messages shall be alternated with R-IDLE. Figure 10-9 shows the timeline of R-IDLE and the R-ERROR-FEEDBACK message for subsequent symbols on which the clipped error samples are reported. The sequence shall start from R-IDLE. Both R-IDLE and the R-ERROR-FEEDBACK message shall use the extended SOC channel with settings as described in clause 10.4.4.4. The rest of R-IDLE parameters shall be the same as for R-IDLE defined in clause 12.2.4 of [ITU-T G.993.2]: it shall consist of HDLC flag $7E_{16}$ sent repeatedly.

The first R-IDLE transmission (after completion of R-P-VECTOR 1-2) allows the receiver in the VTU-O to adjust to the extended SOC channel and shall be at least 16 symbols long. The duration of the other R-IDLE transmissions (denoted as t_{IDLE} in Figure 10-9) shall be set by the VTU-R so that the VTU-R can complete the R-ERROR-FEEDBACK message during the time which is less than the time period between two adjacent symbols on which the clipped error samples have to be reported. Each time period t_{IDLE} shall be at least two symbols long. Transmission of R-ERROR-FEEDBACK message shall start at the time t_{START} that shall be inside the transmission window (see Figure 10-9). The transmission window starts three symbol periods (i.e., $3 / f_{DMT}$) after the start of the symbol on which the clipped error samples are reported. The transmission window ends *W_max* symbol periods (i.e., W_max / f_{DMT}) after the start of the symbol on which the clipped error samples are reported. The maximum value of t_{IDLE} depends on the length of the R-ERROR-FEEDBACK message. The total of the value of t_{IDLE} and the duration of the transmission of the R-ERROR-FEEDBACK message shall not exceed the time-limit that will prevent the VTU-R to start transmission of the next R-ERROR-FEEDBACK message inside the next transmission window.

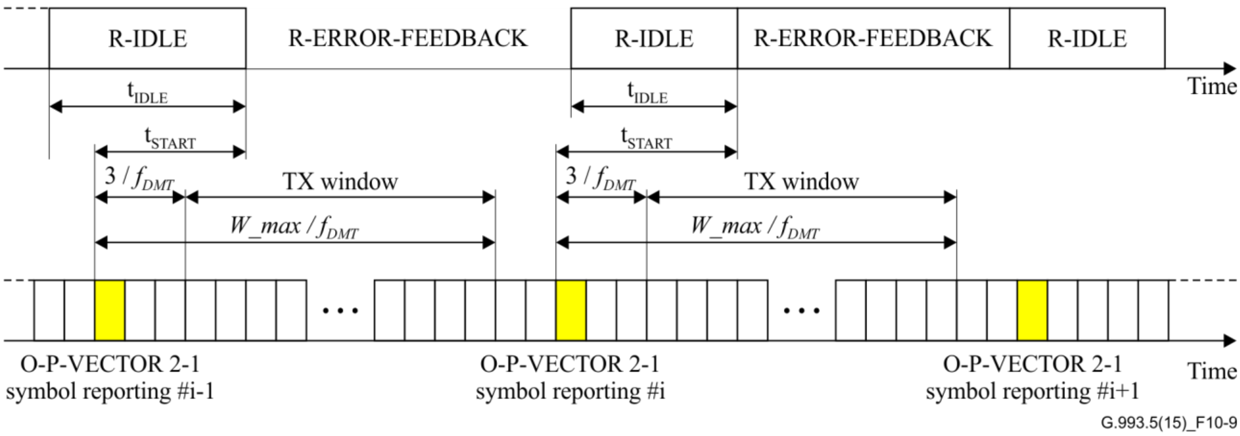

Figure 10-9 – Timeline of R-ERROR-FEEDBACK messages

Through the O-TA_UPDATE message, the VCE indicates how many FEXT estimation symbols per superframe (i.e., the value of K determined by the O-TA_UPDATE message) the clipped error samples shall be reported. For the given value of K (assigned by O-TA_UPDATE), the VTU-R shall report clipped error samples for all the O-P-VECTOR 2-1 symbols of each downstream superframe with symbol count $i(k) = (k+1) \times \lfloor 256/K \rfloor$, where $k = 0,1, 2, \ldots, K\!-\!1$. The value of W_max for the given value of K shall be computed as $W\_max = \lfloor 257/K \rfloor - 2$.

NOTE 1 – If K=1, the VTU-R reports clipped error samples on the O-P-VECTOR 2-1 downstream sync symbols only.

The number of bytes used to report the clipped error samples in a single R-ERROR-FEEDBACK message depends on the backchannel control parameters indicated in the O-TA_UPDATE message. The total number of bytes to be transmitted is equal to the number of bytes in the ERB, *N_ERB*, plus 3 (see Table 10-14).

If the size of the R-ERROR_FEEDBACK message is larger than the maximum allowed segment size, the message shall be segmented as defined in clause 12.2.6 of [ITU-T G.993.2] for AR mode, with the number of segments not to exceed 15. All segments except the last one shall be set to be of the maximum allowed segment size.

NOTE 2 – Minimum gaps between segments reduce the overhead of error feedback transmission and thus save bandwidth of the backchannel.

The number of symbols required to communicate this number of bytes can be calculated as:

$$N\_symbol = \left\lceil \frac{8 \times (N\_ERB + 3 + N\_OH)}{N\_bits\_per\_symbol} \right\rceil = \left\lceil 5 \times \frac{N\_ERB + 3 + N\_OH}{1/R} \right\rceil$$

where *N_OH* is the SOC encapsulation overhead, equal to 6 octets plus the statistical overhead due to byte stuffing, as specified in [ITU-T G.997.1]. If the R-ERROR-FEEDBACK message is segmented, the *N_OH* (per segment) shall be multiplied by the number of segments.

NOTE 3 – The 0.1% worst case statistical overhead due to byte stuffing for a message with randomized content that is longer than 512 bytes is not expected to be more than 3% and goes down for longer messages.

NOTE 4 – When padding is not used, *N_ERB* will depend on the actual values of the error samples. In that case, the number of bytes per symbol should be calculated based on the worst-case assumption of the resolution needed for the error samples.

The VCE shall configure the SOC bit rate, such that the value of *N_symbol* (including the statistical overhead due to byte stuffing) does not exceed ($\lfloor 257/K \rfloor - 2$) symbols (with K the number of symbols per superframe on which clipped error samples are reported, as indicated in the O-TA_UPDATE message). The VTU-R shall terminate transmission of the R-ERROR-

FEEDBACK message if its duration (due to unexpectedly high SOC overhead) will prevent the VTU-R to start transmission of the next R-ERROR-FEEDBACK message inside the next transmission window.

The message R-ERROR_FEEDBACK shall have the structure shown in Table 10-14.

Table 10-14 – Description of message R-ERROR_FEEDBACK

	Field name	Format
1	Message descriptor	Message code
2	Sync symbol count	2 bytes
3	Error report block	N_ERB bytes

Field #1, "Message descriptor", is a unique one-byte code that identifies the message. It shall be coded $8B_{16}$.

Field #2, "Sync symbol count", contains the sync symbol count modulo 1024 of the last received downstream sync symbol and the sequence number $k = 0, \ldots, K - 1$ of the report in the superframe. The VTU-R shall count sync symbols starting from the first downstream sync symbol after it receives O-P-SYNCHRO V3 (this sync symbol shall have count 0) through transmission of O-P-VECTOR 2-1.

The four MSBs of the 2-byte field shall represent the sequence number k of the report as an unsigned integer in the range from 0 to K–1. The ten LSBs shall represent the sync symbol count as an unsigned integer in the range from 0 to 1023. The bits 10 and 11 are reserved by ITU-T and shall be set to 0.

NOTE 5 – If the ERB is reported for a sync symbol, the "sync symbol count" field has the four MSBs set to $K - 1$ and the ten LSBs set to the count of the sync symbol for which the ERB is reported.

Field #3, "Error report block", contains the real and imaginary parts of the clipped error samples associated with the subcarriers of the indicated vectored band(s). If only a single band is reported in the R-ERROR-FEEDBACK message, then the N_{ERB} shall be calculated (see clause 7.2.3.3) as if L_w=0 for the other bands. The format is defined in clause 7.2.3.

10.4.3 Vectoring specific VTU-O signals transmitted during the Training phase

10.4.3.1 O-P-VECTOR 1-1

The O-P-SYNCHRO 3 signal shall be followed by the O-P-VECTOR 1-1 signal.

The O-P-VECTOR 1-1 signal shall be identical to the O-P-VECTOR 1 signal, except that the PSD shall be equal to MREFPSDds.

The duration of O-P-VECTOR 1-1 is vendor discretionary, but shall be minimum 4 × 257 symbols and maximum 1024 × 257 symbols.

During transmission of O-P-VECTOR 1-1, the SOC is in its inactive state.

The O-P-VECTOR 1-1 signal allows the downstream FEXT channel re-estimation from the initializing line into the vectored lines. This re-estimation is to capture changes in the FEXT channels caused by possible modifications of the VTU-O AFE configurations during the Channel Discovery phase.

The O-P-VECTOR 1-1 signal shall be followed by the O-P-TRAINING V1 signal, which determines the actual duration of O-P-VECTOR 1-1.

10.4.3.2 O-P-TRAINING V1

The O-P-TRAINING V1 signal shall be identical to the O-P-TRAINING 1 signal defined in clause 12.3.4.3.1.1 of [ITU-T G.993.2], with the addition of markers to indicate the downstream sync symbol positions and upstream pilot sequence position. Markers shall be added as defined in clause 10.3.3.5. The pattern of markers shall be continued taking into account all downstream sync symbol positions from the beginning of the O-P-CHANNEL DISCOVERY V1 signal.

During the transmission of O-P-TRAINING V1, the SOC is in its inactive state.

The O-P-TRAINING V1 signal shall be followed by the O-P-SYNCHRO-V2 signal, which determines the actual duration of the O-P-TRAINING V1.

10.4.3.3 O-P-SYNCHRO V2

The O-P-SYNCHRO V2 signal shall be identical to the O-P-SYNCHRO 4 signal described in clause 12.3.4.3.1 of [ITU-T G.993.2].

During transmission of O-P-SYNCHRO V2, the SOC is in its inactive state.

With the VTU-O transmitting the O-P-SYNCHRO V2 signal, the VCE notifies the VTU-R that the upstream FEXT channel re-estimation from the initializing lines into other vectored lines is completed, and that the VTU-R shall stop transmission of the R-P-VECTOR 1-1 signal.

The VTU-O shall transmit O-P-SYNCHRO V2 only after the VCE detects the R-P-VECTOR 1-1 signal transmitted during at least 4×257 symbols.

The O-P-SYNCHRO V2 signal shall be followed by the O-P-TRAINING 1 signal.

10.4.3.4 O-P-TRAINING 1 and O-P-TRAINING 2

These signals shall be identical to the O-P-TRAINING 1 and O-P-TRAINING 2 signals defined in clause 12.3.4.3.1 of [ITU-T G.993.2], respectively, with the addition of markers to indicate the downstream sync symbol positions and upstream pilot sequence positions (as defined in clause 10.3.3.5). The pattern of markers shall be continued taking into account all downstream sync symbol positions from the beginning of O-P-CHANNEL DISCOVERY V1.

NOTE – It is beneficial if O-P-SYNCHRO 4 and O-P-SYNCHRO 5 signals are not transmitted at downstream sync symbol positions.

10.4.3.5 O-P-VECTOR 2

The O-P-VECTOR 2 signal shall follow the O-P-SYNCHRO 5 signal.

At sync symbol positions, the O-P-VECTOR 2 signal shall contain sync symbols, modulated as defined for the O-P-VECTOR 1 signal. At other symbol positions, the SOC channel shall be modulated using one byte per symbol mapping, as defined for the O-P-TRAINING 2 signal in [ITU-T G.993.2].

During the sync symbols, the SOC is in the inactive state. During the other symbols, the SOC is in the active state, and the VTU-O shall transmit O-IDLE.

The minimum duration of O-P-VECTOR 2 is 128 symbols.

The O-P-VECTOR 2 signal shall be followed by the O-P-SYNCHRO V3 signal, which determines the actual duration of O-P-VECTOR 2.

The VTU-O shall transmit O-P-SYNCHRO V3 at least 70 symbols prior to transmission of the sync symbol (to avoid ambiguity in sync symbol count at the VTU-R).

10.4.3.6 O-P-SYNCHRO V3

The O-P-SYNCHRO V3 signal shall be identical to the O-P-SYNCHRO 5 signal, as defined in clause 12.3.4.3.1.9 of [ITU T G.993.2].

During transmission of O-P-SYNCHRO V3, the SOC is in its inactive state.

With the VTU-O transmitting the O-P-SYNCHRO-V3 signal, the VCE notifies the VTU-R that the upstream FEXT channel re-estimation from the initializing line into other vectored lines is completed, and that the VTU-R shall stop transmission of the R-P-VECTOR 1-2 signal. The VTU-O shall transmit O-P-SYNCHRO V3 only after the VCE detects the R-P-VECTOR 1-2 signal transmitted during at least 4 × 257 symbols.

The O-P-SYNCHRO V3 signal shall be followed by the O-P-VECTOR 2-1 signal.

10.4.3.7 O-P-VECTOR 2-1

The O-P-VECTOR 2-1 signal shall be identical to the O-P-VECTOR 2 signal.

During the sync symbols, the SOC is in the inactive state. During the other symbols, the SOC is in the active state, and the VTU-O shall transmit O-IDLE.

Transmission of O-P-VECTOR 2-1 enables the VCE to estimate the downstream FEXT channels from the vectored lines into the initializing line, and to update the estimates of the downstream FEXT channels from the initializing lines into the vectored lines.

The duration of O-P-VECTOR 2-1 is vendor discretionary, but shall be minimum 257 symbols and maximum 1024 × 257 symbols.

The O-P-VECTOR 2-1 signal shall be followed by the O-P-SYNCHRO V4 signal, which determines the actual duration of the O-P-VECTOR 2-1.

10.4.3.8 O-P-SYNCHRO V4

The O-P-SYNCHRO V4 signal shall be identical to the O-P-SYNCHRO V3 signal, as defined in clause 10.4.3.6.

During transmission of the O-P-SYNCHRO V4 signal, the SOC is in its inactive state.

With the VTU-O transmitting the O-P-SYNCHRO-V4 signal, the VCE notifies the VTU-R that the downstream FEXT channel estimation from the other vectored lines into the initializing lines is completed, and that the VTU-R shall stop transmission of the R-P-VECTOR 2 signal.

The Training phase is completed at this point, and the VTU-O shall transition into the Channel Analysis and Exchange phase, see Figure 10-8.

10.4.3.9 Initialization of multiple initializing lines

When the VCE initializes multiple lines:

– The downstream crosstalk channel from the initializing lines into the active lines of the vector group should be estimated simultaneously by insuring that O-P-VECTOR 1-1 signals are sent on all initialization lines during the estimation. This can be done by controlling the start and the end of O-P-VECTOR 1-1 in each line.

– The upstream crosstalk channel between the initializing lines and the active lines of the vector group should be estimated simultaneously by insuring that R-P-VECTOR 1-1 signals are sent on all initialization lines during the estimation. This can be done by controlling the end of R-P-VECTOR 1-1 with the O-P-SYNCHRO V2 signal in each line.

– The upstream crosstalk channels between the initializing lines and the active lines of the vector group should be estimated simultaneously by insuring that R-P-VECTOR 1-2 signals are sent on all initialization lines during the estimation. This can be done by controlling the end of R-P-VECTOR 1-2 with the O-P-SYNCHRO V3 signal in each line.

– The downstream crosstalk channel from the active lines into the initializing lines of the vector group should be estimated simultaneously by insuring that O-P-VECTOR 2-1 signals are sent on all initialization lines during the estimation. This can be done by controlling the end of O-P-VECTOR 2-1 with the O-P-SYNCHRO V4 signal in each line.

10.4.4 Vectoring specific VTU-R signals transmitted during the Training phase

10.4.4.1 R-P-QUIET V1

The R-P-SYNCHRO 3 signal shall be followed by the R-P-QUIET V1 signal.

The R-P-QUIET V1 signal shall be identical to the R-P-QUIET 2 signal.

During the R-P-QUIET V1 signal, the SOC is in its inactive state.

The duration of R-P-QUIET V1 signal is controlled by the VTU-O. The VTU-R shall end the transmission of R-P-QUIET V1 upon detection of the O-P-TRAINING V1 signal, and start transmission of R-P-VECTOR 1-1 signal.

10.4.4.2 R-P-VECTOR 1-1

The R-P-VECTOR 1-1 signal shall be identical to the R-P-VECTOR 1 signal, except its PSD shall be equal to MREFPSDus.

During transmission of R-P-VECTOR 1-1, the SOC is in its inactive state.

The VTU-R should use the timing advance value calculated in the Channel Discovery phase to ensure that the sync symbols of the initializing line are aligned at the VTU-O with the sync symbols of vectored lines.

The R-P-VECTOR 1-1 signal allows the upstream FEXT channel re-estimation between the initializing line and the vectored lines. This re-estimation is to capture changes in the FEXT channels caused by possible modifications of the VTU-O AFE configurations during the Channel Discovery phase.

The duration of R-P-VECTOR 1-1 signal is controlled by the VTU-O. Within 64 symbols after the last symbol of the O-P-SYNCHRO V2 signal, the VTU-R shall end the transmission of the R-P-VECTOR 1-1. The duration of R-P-VECTOR 1-1 shall not exceed 1024×257 symbols.

The R-P-VECTOR 1-1 signal shall be followed by the R-P-TRAINING 1 signal.

10.4.4.3 R-P-VECTOR 1-2

The R-P-VECTOR 1-2 signal shall follow the R-P-SYNCHRO 5 signal. The R-P-VECTOR 1-2 signal shall be identical to the R-P-VECTOR 1-1 signal.

During transmission of R-P-VECTOR 1-2, the SOC is in its inactive state.

The R-P-VECTOR 1-2 signal allows the upstream FEXT channel re-estimation between the initializing line and the vectored lines. This re-estimation is to capture changes in the FEXT channels caused by possible modifications of the timing advance during the Training phase.

The duration of R-P-VECTOR 1-2 signal is controlled by the VTU-O. Within 64 symbols after the last symbol of the O-P-SYNCHRO V3 signal, the VTU-R shall end the transmission of the R-P-VECTOR 1-2 signal. The duration of R-P-VECTOR 1-2 shall not exceed 1024×257 symbols.

The R-P-VECTOR 1-2 signal shall be followed by the R-P-SYNCHRO V1 signal.

10.4.4.4 R-P-SYNCHRO V1

The R-P-SYNCHRO V1 signal shall be identical to the R-P-SYNCHRO 5 signal, as defined in clause 12.3.4.3.2.9 of [ITU T G.993.2].

During transmission of the R-P-SYNCHRO V1 signal, the SOC is in its inactive state.

The R-P-SYNCHRO V1 signal shall be followed by R-P-VECTOR 2 signal.

10.4.4.5 R-P-VECTOR 2

At sync symbol positions, the R-P-VECTOR 2 signal shall contain sync symbols, modulated as defined for the R-P-VECTOR 1 signal. At other symbol positions, the symbols shall be modulated as for the R-P-TRAINING 2 signal, with the extended SOC channel being established.

Transmission of R-P-VECTOR 2 enables the VCE to estimate upstream FEXT channels from the vectored lines into the initializing line, and update the estimates of the upstream FEXT from the initializing lines into the vectored lines.

During the sync symbols, the SOC is in the inactive state. During the other symbols, the SOC is in the active state, and the VTU-R shall transmit R-IDLE or the R-ERROR-FEEDBACK message.

The duration of R-P-VECTOR 2 signal is controlled by the VTU-O. Within 64 symbols after the last symbol of the O-P-SYNCHRO V4 signal, the VTU-R shall end the transmission of the R-P-VECTOR 2 signal.

The R-P-VECTOR 2 signal shall be followed by the R-P-SYNCHRO V2 signal.

To establish the extended SOC, the R-P-VECTOR 2 symbols with active SOC shall be modulated with bit mapping as defined in Table 10-15, with the number of bits per symbol calculated as:

$$N_{bitspersymbol} = \frac{16}{10 \cdot R}$$

with 1/*R* an integer multiple of 10 in the [10, 120] range, as indicated in the O-TA_UPDATE message.

Table 10-15 – Bit mapping for R-P-VECTOR 2

Subcarrier index	Constellation point
5, 10, 15,..., 5*n*, ...	00
1, 1/*R*+1, 2/*R*+1, ..., *n*/*R* + 1, ...	SOC message bits 0 and 1
2, 1/*R*+2, 2/*R*+2, ..., *n*/*R* + 2, ...	SOC message bits 2 and 3
...	...
10*k*+*m*, 1/*R*+10*k*+*m*, 2/*R*+10*k*+*m*, ..., *n*/*R*+10*k*+*m*, ... with *k* = 0, 1, 2, ... , $\frac{1}{10 \cdot R}-1$ and *m* = 1, 2, 3, 4, 6, 7, 8, 9	SOC message bits 16*k*+*f*(*m*) and 16*k*+*f*(*m*)+1 with $f(m)=\begin{cases} 2m-2 & \text{if } m=1,2,3,4 \\ 2m-4 & \text{if } m=6,7,8,9 \end{cases}$
...	...
1/*R*–1, 2/*R*–1, 3/*R*–1, ..., *n* + 1/*R*–1, ...	SOC message bits $\frac{16}{10 \cdot R}-2$ and $\frac{16}{10 \cdot R}-1$

NOTE – In [ITU-T G.993.2], the SOC bit mapping allows 16 bits per symbol. For faster reporting of clipped error samples, the VCE may increase the SOC bit mapping in steps of 16 bits per symbol, from 16 bits up to 192 bits per symbol, by reducing the number of repetitions of these bits within each symbol. For operation at 4000 symbols/s, this increases the SOC bit rate in steps of 64 kbit/s, from 64 kbit/s (as in [ITU-T G.993.2]) up to 768 kbit/s. For operation at 8000 symbols/s, this increases the SOC bit rate in steps of 128 kbit/s, from 128 kbit/s (as in [ITU-T G.993.2]) up to 1536 kbit/s.

10.4.4.6 R-P-SYNCHRO V2

The R-P-SYNCHRO V2 signal shall be identical to the R-P-SYNCHRO V1 signal.

During transmission of the R-P-SYNCHRO V2 signal, the SOC is in its inactive state.

The Training phase is completed at this point, and VTU-R shall transition into the Channel Analysis and Exchange phase, see Figure 10-8.

10.5 Channel Analysis and Exchange phase

10.5.1 Overview

The Channel Analysis and Exchange phase does not require any changes with respect to [ITU-T G.993.2], other than the ITU-T G.993.5 parameter field defined for the O-PMS message.

10.5.2 Modified SOC messages sent during Channel Analysis and Exchange phase

10.5.2.1 O-PMS

The O-PMS message (defined in Table 12-46 of [ITU T G.993.2]) which is transmitted during O-P-MEDLEY contains an ITU-T G.993.5 parameter field. The ITU-T G.993.5 parameter field contains several parameters needed for FEXT cancellation operation as shown in Table 10-16.

Table 10-16 – ITU-T G.993.5 parameter field in message O-PMS

Field	Field name	Format
1	ITU-T G.993.5 parameter field length	1 byte
2	Showtime backchannel encapsulation	1 byte
3	Layer 2 VCE MAC address	6 bytes
4	Layer 2 Line_ID	2 bytes

Field #1, "ITU-T G.993.5 parameter field length", indicates the length of the ITU-T G.993.5 parameter field in bytes, excluding the ITU-T G.993.5 parameter field length field. All fields shown in Table 10-16 shall be included in the O-PMS message. The field shall be represented as an unsigned integer.

Field #2, "Showtime backchannel encapsulation", defines whether the Showtime backchannel is encapsulated into eoc messages or into Layer 2 Ethernet packets. The field shall be set to 00_{16} for eoc encapsulation and shall be set to 01_{16} for Layer 2 Ethernet encapsulation. Other values are reserved for ITU-T.

Field #3, "Layer 2 VCE MAC Address", defines the VCE MAC Address to be used by the NT as MAC destination address in case Layer 2 Ethernet encapsulation is used. The field shall be set to all 00_{16} bytes in case eoc encapsulation is used.

Field #4, "Layer 2 Line_ID", defines the Line_ID to be used by the NT in case Layer 2 Ethernet encapsulation is used. The Line_ID shall be inserted as the first two bytes of the Ethernet packet payload (see Figure 7-9). The field shall be set to 0000_{16} in case eoc encapsulation is used.

10.6 Transition from initialization to Showtime

The last symbol of O-P-SYNCHRO 6 shall be transmitted at a downstream sync symbol position, such that the first symbol of Showtime is a data symbol transmitted at downstream symbol count 0.

The first DMT symbol following O-P-SYNCHRO 6 of the Channel Analysis and Exchange phase shall be the first downstream symbol of Showtime. The PMD, PMS-TC and TPS-TC parameter settings negotiated during the Channel Analysis and Exchange phase shall be applied starting from the first symbol of Showtime.

The last symbol of R-P-SYNCHRO 6 shall be transmitted at an upstream sync symbol position, such that the first symbol of Showtime is a data symbol transmitted at upstream symbol count 0.

The first DMT symbol following R-P-SYNCHRO 6 shall be the first upstream symbol of Showtime. The PMD, PMS-TC and TPS-TC parameter settings negotiated during the Channel Analysis and Exchange phase shall be applied starting from the first symbol of Showtime.

The last symbol of R-P-SYNCHRO 6 shall be transmitted at least 15 and no more than 15+64+257 symbols after transmission of the last symbol of O-P-SYNCHRO 6.

The downstream sync symbol positions and the downstream pilot sequence shall be continued from initialization into Showtime. Each downstream sync symbol in Showtime shall be modulated by the downstream pilot sequence (see clause 6.2.3).

The upstream sync symbol positions and the upstream pilot sequence shall be continued from initialization into Showtime. Each upstream sync symbol in Showtime shall be modulated by the upstream pilot sequence (see clause 7.3.3).

10.7 Loop diagnostic mode procedures

10.7.1 Overview

The loop diagnostic mode procedure described in this clause is based on the initialization as described in clause 10.1 through 10.6, with addition of steps specific for loop diagnostic mode, and without sending R-ERROR-FEEDBACK messages.

If the loop diagnostic mode codepoint in the MS message is set (see clauses 12.3.2.1.2 and 12.3.2.2.2 of [ITU-T G.993.2]), then the loop diagnostic mode shall be entered after completion of the ITU-T G.994.1 Handshake phase. Loop diagnostic mode shall be entered upon request by either VTU. Both VTUs shall support the loop diagnostic mode.

The sequence of stages in the loop diagnostic mode shall be the same as for initialization (defined in clauses 10.1 through 10.6) up to the Channel Analysis and Exchange phase, where the test parameters listed in Table 12-64 of [ITU-T G.993.2] and defined in clause 11.4.1 of [ITU-T G.993.2] are exchanged. However, the test parameters for the quiet line noise (QLN) and the channel characteristics function (Hlog) shall be measured and exchanged during the Channel Discovery phase, as described in clause 12.4.3 of [ITU-T G.993.2].

The time-outs specified in clause 12.3.1 of [ITU-T G.993.2] do not apply to loop diagnostic mode. Time-out values are for further study.

10.7.1.1 SOC message mapping during loop diagnostic mode

See clause 12.4.1.1of [ITU-T G.993.2].

10.7.2 Channel discovery and training phases of loop diagnostic mode

10.7.2.1 SOC messages exchanged during the channel discovery and training phases of loop diagnostic mode

The SOC messages for the Channel Discovery phase and the Training phase of the loop diagnostic mode shall be the same as for the initialization procedure described in clauses 10.3 and 10.4, respectively, except for O-PRM, R-PRM, R-MSG1 and O-TA_UPDATE.

10.7.2.1.1 O-PRM & R-PRM

The test parameters for the QLN and the channel characteristics function, Hlog, shall be measured and exchanged during the Channel Discovery phase in the O-PRM-LD and R-PRM-LD messages described in clause 12.4.2.1 of [ITU-T G.993.2], which replace O-PRM and R-PRM.

NOTE – Field #13 and field #14 in O-PRM and R-PRM contain the ITU-T G.998.4 parameter field and the ITU-T G.993.5 parameter field. While field #13 and field #14 in O-PRM-LD and R-PRM-LD contain QLN and Hlog.

10.7.2.1.2 R-MSG1 (supplements clause 10.3.2.2)

Field #2, "maximum number of FEXT estimation symbols per superframe", defines the maximum number (*Kmax*) of symbols in the superframe for which the VTU-R supports error sample reporting. The field shall be formatted as an unsigned integer with value *Kmax* = 0.

Field #3, "support of optional backchannel control parameters", indicate the optional values of control parameters supported by the VTU-R. The field shall be formatted as an unsigned integer with value 00_{16}.

NOTE – This text is identical to Annex Y, clause Y.10.3.2.2 of [ITU-T G.993.2].

10.7.2.1.3 O-TA_UPDATE (supplements clause 10.4.2.1)

Field #2, "error report control parameters", defines the control parameters for each of the vectored bands indicated in O-SIGNATURE. The VTU-R shall ignore the error report control parameters.

Field #3, "SOC Repetition Factor", defines the SOC repetition factor, 1/R, as set by the VCE. The VTU R shall ignore this field.

Field #4, "FEXT estimation symbols per superframe", defines the number of symbols (*K*) in the superframe for which a clipped error sample shall be reported. The field shall be formatted as an unsigned integer with value *K* = 0.

NOTE – This text is identical to clause Y.10.4.2.1, Annex Y of [ITU-T G.993.2], except for field #3.

10.7.2.2 Signals transmitted during the channel discovery and training phases

The signals transmitted during the channel discovery and training phases are the same as defined in clauses 10.3 and 10.4 for initialization, with the following exceptions:

– the SOC message mapping shall be as defined in clause 12.4.1.1 of [ITU-T G.993.2];
– the duration of O-P-QUIET 1 shall be at least 8192 symbols but not longer than 16384 symbols;
– R-P-VECTOR 2 definition.

10.7.2.2.1 R-P-VECTOR 2 (replaces clause 10.4.4.5)

At sync symbol positions, the R-P-VECTOR 2 signal shall contain sync symbols, modulated as defined for the R-P-VECTOR 1 signal. At other symbol positions, the symbols shall be modulated as for the R-P-TRAINING 2 signal, with the SOC message mapping as defined in clause 12.4.1.1 of [ITU-T G.993.2].

Transmission of R-P-VECTOR 2 enables the VCE to estimate upstream FEXT channels from the vectored lines into the initializing line, and update the estimates of the upstream FEXT from the initializing lines into the vectored lines.

During the sync symbols, the SOC is in the inactive state. During the other symbols, the SOC is in the active state, and the VTU-R shall transmit the R-IDLE message.

The duration of R-P-VECTOR 2 signal is controlled by the VTU-O. Within 64 symbols after the last symbol of the O-P-SYNCHRO V4 signal, the VTU-R shall end the transmission of the R-P-VECTOR 2 signal.

The R-P-VECTOR 2 signal shall be followed by the R-P-SYNCHRO V2 signal.

NOTE 1 – The R-P-VECTOR 2 signal in loop diagnostic mode is identical to the R-P-VECTOR 2 signal defined in clause 10.4.4.5 for initialization, without extended SOC and with the VTU-R transmitting R-IDLE messages instead of R-ERROR-FEEDBACK messages.

NOTE 2 – This text is identical to clause Y.10.4.4.5, Annex Y of [ITU-T G.993.2], except for the SOC message mapping.

10.7.3 Channel Analysis and Exchange phase of loop diagnostic mode

The Channel Analysis and Exchange phase of loop diagnostic mode in ITU-T G.993.5 does not require any changes in comparison to loop diagnostic mode in [ITU-T G.993.2].

11 Configuration and test parameters

This Recommendation defines configuration parameters and test parameters that shall be accessible through the central office-management information base (CO-MIB). The configuration parameters are defined in clause 11.1. The test parameters are defined in clause 11.2. Configuration parameters and test parameters are defined in [ITU-T G.997.1] as management objects accessible over the Q-interface.

11.1 Configuration parameters

11.1.1 FEXT cancellation enable/disable

This configuration parameter shall be defined for each line in a group of vectored lines. It enables or disables FEXT cancellation from all the other vectored lines into a line in the vectored group. If FEXT cancellation is disabled for a line, then no FEXT cancellation shall occur from any other line in the vectored group into that line.

This configuration parameter shall be defined independently for the upstream and downstream directions.

11.1.2 FEXT cancellation not required frequency bands

This configuration parameter shall be an array of pairs of subcarrier indices. Each pair represents the start and stop subcarrier index of a frequency band in which FEXT cancellation is not required. Up to eight frequency bands may be configured.

The same configuration shall be applied for all lines in the vectored group.

This configuration parameter shall be defined independently for the upstream and downstream directions.

11.1.3 Target NDR/target ETR

Both the target net data rate (target NDR) configuration parameter and the target expected throughput (target ETR) configuration parameter shall be defined for each line in a group of vectored lines. These configuration parameters assist a VCE to decide on allocating vectored AN resources among the lines in a vectored group for FEXT cancellation. Because of limited resources, the vectored AN may be unable to mitigate all the FEXT sources into every single line in the vectored group. Therefore, The VCE may choose to limit the number of crosstalk sources to cancel for each vectored line.

11.1.3.1 Target NDR

For each line, the target NDR configuration parameter should be set to the expected NDR achievable for the line when all lines in the vectored group are active and operating without ITU-T G.998.4 retransmission, or alternatively, it may be set to a special value indicating that no target NDR is configured by the operator.

If the target NDR is configured by the operator and ITU-T G.998.4 retransmission is not selected during initialization for the applicable direction, the VCE should allocate sufficient resources in such a way that the NDR is higher than or equal to the target NDR. If at initialization time, the NDR is below the target NDR but above the minimum NDR (*net_min*, see Annex K of [ITU-T G.993.2]), the VTU shall still transition to Showtime.

This configuration parameter shall be defined independently for the upstream and downstream directions.

This configuration parameter corresponds with the ITU-T G.997.1 parameter TARGET_NDR (see clause 7.3.2.20.2 of [ITU-T G.997.1]) in the CO-MIB.

11.1.3.2 Target ETR

For each line, the target ETR configuration parameter should be set to the expected ETR achievable for the line when all lines in the vectored group are active and operating with ITU-T G.998.4 retransmission, or alternatively, it may be set to a special value indicating that no target ETR is configured by the operator.

If the target ETR is configured by the operator and ITU-T G.998.4 retransmission is selected during initialization for the applicable direction, the VCE should allocate sufficient resources in such a way that the ETR is higher than or equal to the target ETR. If at initialization time, the ETR is below the target ETR but above minimum ETR (*ETR_min*, see clause 7 of [ITU-T G.998.4]), the VTU shall still transition to Showtime.

This configuration parameter shall be defined independently for the upstream and downstream directions.

This configuration parameter corresponds with the ITU-T G.997.1 parameter TARGET_ETR (see clause 7.3.2.20.1 of [ITU-T G.997.1]) in the CO-MIB.

11.1.4 Line priorities

This configuration parameter assists a VCE to decide on allocating vectored AN resources among the lines in a vectored group for FEXT cancellation. Because of limited resources, the vectored AN may be unable to mitigate all the FEXT sources into every single line in the vectored group. Therefore, the VCE may choose to limit the number of crosstalk sources to cancel for each vectored line.

Compliance with line priorities configuration parameter is optional. If supported, this configuration parameter shall be defined for each line in a group of vectored lines. For compliance, a VCE should initially allocate sufficient resources in such a way that the target NDR (if ITU-T G.998.4 retransmission is not selected for the applicable direction) or target ETR (if ITU-T G.998.4 retransmission is selected for the applicable direction) is met for all the lines in a vectored group. Subsequently, the VCE should exploit the configured line priority levels to allocate the remaining resources among the lines to further improve the NDRs/ETRs.

For each line in the vectored group, the line priority is configured as either LOW or HIGH, or alternatively, it may be set to a special value indicating that no line priority is configured by the operator. The VCE should allocate more resources to a line with a line priority HIGH in order to further increase the NDR/ETR above the target NDR/target ETR (e.g., by further mitigating FEXT). The VCE should not allocate additional resources to a line with line priority HIGH if the maximum NDR (*net_max*, see Annex K of [ITU T G.993.2]) is already met on that line. If the maximum NDR condition is met for all the vectored lines with line priority HIGH, then the VCE may allocate its remaining resources to vectored lines with line priority LOW to improve the NDR/ETR above the target NDR/target ETR.

NOTE – A VCE with sufficient resources may not need to use the configured line priorities for allocating its resources and in such cases, the VCE may ignore the configured line priorities.

This configuration parameter shall be defined independently for the upstream and downstream directions.

11.1.5 Requested Xlin subcarrier group size (XLINGREQ)

This parameter represents the requested value of *XLING* (see clauses 11.2.1.2 and 11.2.2.2). The reported *XLING* value shall be the smallest supported value that is equal or greater than *XLINGREQ*.

This configuration parameter shall be defined independently for the upstream and downstream directions.

11.2 Test parameters

11.2.1 FEXT downstream coupling coefficients (Xlinpsds)

11.2.1.1 Definition of downstream FEXT coupling coefficients (Xlinpsds)

The FEXT insertion gain from line L_2 into line L_1 in the downstream direction over frequency *f*, $FEXT\_IG\_DS_{L1,L2}(f)$, is defined as the ratio of the received FEXT voltage into a 100-ohm load on line L_1 to the transmit voltage (into a 100-ohm load) on line L_2. If the transmit voltage on line L_2 into a 100-ohm load is $V\_REFERENCE\_O(f)$ and the received FEXT voltage on line L_1, while both ends are terminated with a 100-ohm load as shown in Figure 11-1, is $V\_FEXT\_R(f)$, then the downstream FEXT insertion gain from line L_2 into line L_1 in linear scale is given by the equation below:

$$FEXT\_IG\_DS_{L1,L2}(f) = \frac{V\_FEXT\_R(f)}{V\_REFERENCE\_O(f)}$$

The downstream FEXT coupling coefficient from line L_2 into line L_1 over the frequency f is defined as the ratio of the FEXT insertion gain from line L_2 into line L_1 to the direct channel insertion gain of line L_1 (or the channel characteristic function, *H*, of line L_1) as follows:

$$Xlinds_{L1,L2}(f) = \frac{FEXT\_IG\_DS_{L1,L2}(f)}{H_{L1}(f)}$$

The downstream FEXT coupling coefficient can also be represented in terms of the direct channel $V\_DIRECT\_R(f)$ received on line L_1, and the FEXT channel received voltage on line L_1 as:

$$Xlinds_{L1,L2}(f) = \frac{V\_FEXT\_R(f)}{V\_DIRECT\_R(f)}$$

where, as shown in Figure 11-2, $V\_DIRECT\_R(f)$ is the received voltage into a 100-ohm load on line L_1 when a transmitter with a transmit voltage equal to $V\_REFERENCE\_O(f)$ (into 100 ohms) is frozen in its transmitting state and is connected to the same line. As shown in Figure 11-1, $V\_FEXT\_R(f)$ is the received voltage on line L_1 when this line is terminated with a 100-ohm load on both sides and the transmitter with the same transmit voltage is connected to line L_2.

NOTE 1 – The definition is independent of the value of $V\_REFERENCE\_O(f)$. However, it should be of the same order as typical transmitting voltage values on the line.

NOTE 2 – The above definition is independent of any receiver filter as the receiver filter effects of line L_1 are included in both the numerator and the denominator and cancel out.

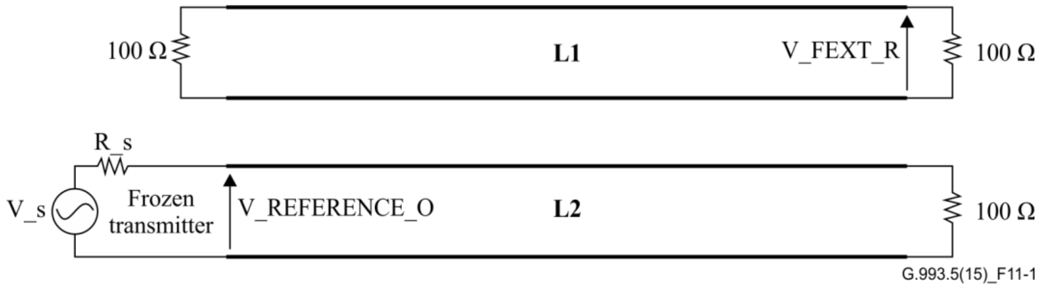

Figure 11-1 – Definition of downstream Xlin (FEXT channel received voltage)

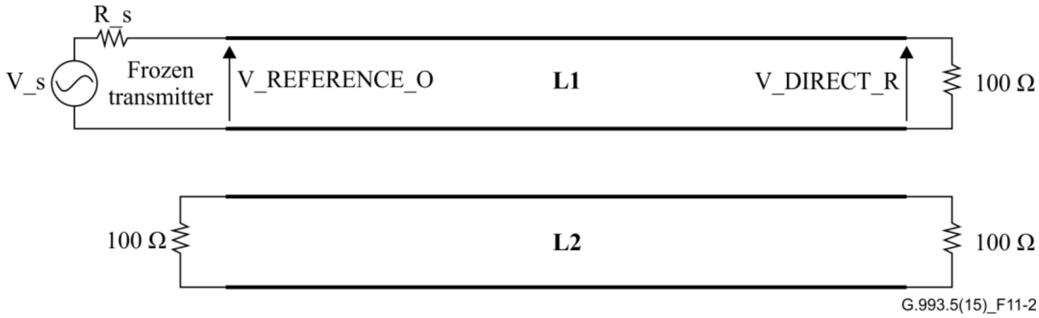

Figure 11-2 – Definition of downstream Xlin (direct channel received voltage)

11.2.1.2 Reporting of downstream FEXT coupling coefficients (Xlinpsds)

Each frequency band over which the downstream FEXT coupling coefficients $Xlinpsds_{i,k}$ $(n\times\Delta f)$ are stored and reported shall be represented by a pair of (start_subcarrier_index, stop_subcarrier_index). The reported parameter *XLINBANDSds* shall represent an array of such pairs in increasing frequency order.

NOTE – The start_subcarrier_index and stop_subcarrier_index may not coincide with the defined edges of the bandplan.

The downstream FEXT coupling coefficients $Xlinpsds_{i,k}$ $(n \times \Delta f)$, shall be stored and reported to the management entity upon request at least for all pairs of line indices (i, k) in the vectored group and subcarrier indices n for which FEXT from line k into line i is estimated or cancelled in the downstream direction over a frequency band containing the subcarrier index n and

$$n \in \bigcup_{bands} \left\{ start\_subcarrier\_index + m \times XLINGds : m = 0 \ldots \left\lfloor (stop\_subcarrier\_index - start\_subcarrier\_index) / XLINGds \right\rfloor \right\}$$

where $\lfloor x \rfloor$ denotes rounding to the lower integer.

In this description, *XLINGds* is the subcarrier group size for reporting the FEXT coupling and is restricted to powers of two, and shall be the smallest supported value that is equal to or greater than the *XLINGREQds* value (see clause 11.1.5) and less than or equal to 64, and shall be restricted to a maximum number of 511 subcarriers being reported.

The channel characteristics function $Xlinpsds_{i,k}$ $(n\times\Delta f)$, shall be represented in linear format by a scale factor and a normalized complex number $a(n) + j \times b(n)$, where n is the subcarrier index. The scale factor *XLINSCds* shall be coded as a 16-bit unsigned integer. Both $a(n)$ and $b(n)$ shall be coded as a 16-bit 2's-complement signed integers. The value of $Xlinpsus_{i,j}$ $(n\times\Delta f)$ shall be defined as $Xlinpsus_{i,j}$ $(n\times\Delta f) = (XLINSCds/2^{15}) \times (a(n) + j \times b(n))/2^{15}$. In order to maximize precision, the *scale* factor *XLINSCds* shall be chosen such that $max(|a(n)|, |b(n)|)$ over all n is equal to $2^{15} – 1$.

This data format supports an *Xlin(f)* granularity of $2^{–15}$ and an *Xlin(f)* dynamic range of approximately +6 dB to –90 dB.

An $Xlinpsds_{i,j}$ $(n\times\Delta f)$ value indicated as $a(n) = b(n) = –2^{15}$ is a special value. It indicates that no measurement could be done for done from line k into line i for subcarrier n.

An $Xlinpsds_{i,j}$ (n×Δf) value indicated with $a(n) \geq 0$ and $b(n) = 0$ for all reported n is another special value meaning that there is no phase information and the magnitude of $Xlinpsus_{i,j}$ (n×Δf) is ($XLINSCds/2^{15}$) × ($a(n)$)/2^{15}.

The magnitude of $Xlinpsds_{i,k}$ (n×Δf) in dB is $Xlogpsds_{i,k}$ (n×Δf):

$$Xlogpsus_{i,k}(n\times\Delta f) = 20\log_{10}(\,|Xlinpsus_{i,k}(n\times\Delta f)|\,)$$

All accuracy requirements for *Xlinpsus* will be formulated in terms of magnitude only (*Xlogpsds*).

Accuracy requirements for *Xlogpsds* shall allow for *Xlogpsds* to be the logarithm of the magnitude of the elements of the Taylor first-order approximation of the inverse of the pre-coder matrix (see Figure 6-1). Other accuracy requirements for *Xlogpsds* are for further study.

11.2.2 FEXT upstream coupling coefficients (Xlinpsus)

11.2.2.1 Definition of upstream FEXT coupling coefficients (Xlinpsus)

The FEXT insertion gain from line L_2 into line L_1 in the upstream direction over the frequency f, $FEXT\_IG\_US_{L1,L2}(f)$, is defined as the ratio of the received FEXT voltage into a 100 ohm load on line L_1 to the transmit voltage (into a 100 ohm load) on line L_2. If the transmit voltage on line L_2 into a 100 ohm load is $V\_REFERENCE\_R(f)$ and the received FEXT voltage on line L_1, while both ends are terminated with 100 ohm load as is shown in Figure 11-3 is $V\_FEXT\_O(f)$ then the upstream FEXT insertion gain from line L_2 into line L_1 in linear scale is given by the equation below:

$$FEXT\_IG\_US_{L1,L2}(f) = \frac{V\_FEXT\_O(f)}{V\_REFERENCE\_R(f)}$$

The upstream FEXT coupling coefficient from line L_2 into line L_1 over the frequency f is defined as the ratio of the FEXT insertion gain from line L_2 into line L_1 to the direct channel insertion gain of line L_2 (or the channel characteristic function, *H*, of line L_2) as in the following:

$$Xlinus_{L1,L2}(f) = \frac{FEXT\_IG\_US_{L1,L2}(f)}{H_{L2}(f)}$$

The upstream FEXT coupling coefficient can also be represented in terms of the direct channel, $V\_DIRECT\_O(f)$ received on line L_2 and the FEXT channel received voltage on line L_1 as:

$$Xlinus_{L1,L2}(f) = \frac{V\_FEXT\_O(f)}{V\_DIRECT\_O(f)}$$

where, as shown in Figure 11-4, $V\_DIRECT\_O(f)$ is the received voltage into a 100 ohm load on line L_2 when a transmitter with a transmit voltage equal to $V\_REFERENCE\_R(f)$ (into 100 ohm) is frozen in its transmitting state and is connected to the same line. As shown in Figure 11-3, $V\_FEXT\_O(f)$ is the received voltage on line L_1 when this line is terminated with 100 ohm loads on both sides and the transmitter with the same transmit voltage is connected to line L_2.

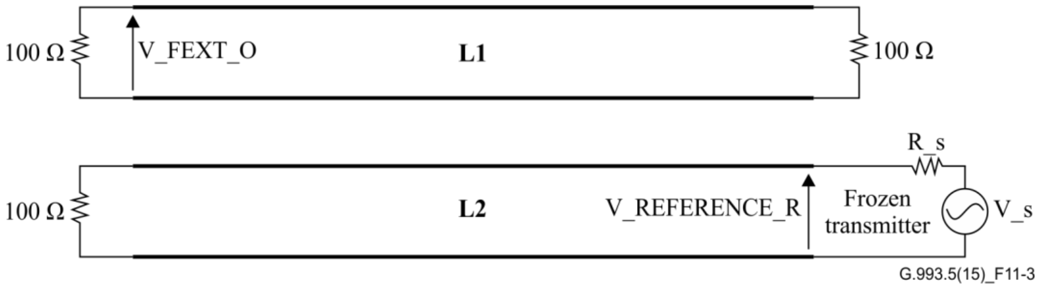

Figure 11-3 – Definition of upstream Xlin (FEXT channel received voltage)

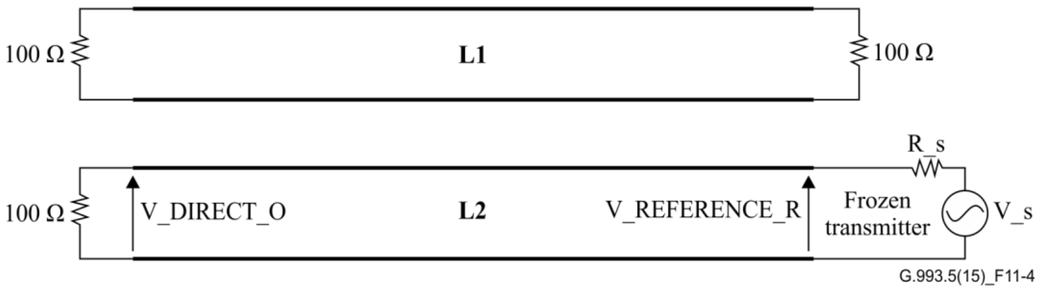

Figure 11-4 – Definition of upstream Xlin (direct channel received voltage)

11.2.2.2 Reporting of upstream FEXT coupling coefficients (Xlinpsus)

Each frequency band over which the upstream FEXT coupling coefficients $Xlinpsus_{i,k}$ ($n \times \Delta f$) are stored and reported shall be represented by a pair of (start_subcarrier_index, stop_subcarrier_index). The reported parameter *XLINBANDSus* shall represent an array of such pairs in increasing frequency order.

NOTE – The start_subcarrier_index and stop_subcarrier_index may not coincide with the defined edges of the bandplan.

The upstream FEXT coupling coefficients, $Xlinpsus_{i,k}$ ($n \times \Delta f$), shall be stored and reported to the management entity upon request at least for all pairs of line indices (i, k)in the vectored group and subcarrier indices n for which FEXT from line k into line i is estimated or cancelled in the upstream direction over a frequency band containing the subcarrier index n and

$$n \in \bigcup_{bands} \{start\_subcarrier\_index + m \times XLINGus : m = 0 \ldots \lfloor (stop\_subcarrier\_index - start\_subcarrier\_index)/XLINGus \rfloor\}$$

where $\lfloor x \rfloor$ denotes rounding to the lower integer.

In this description, *XLINGus* is the subcarrier group size for reporting the FEXT coupling and is restricted to powers of two, equal to or greater than the *XLINGREQus* value (see clause 11.1.5) and less than or equal to 64, and restricted to a maximum number of 511 subcarriers being reported.

The channel characteristics function $Xlinpsus_{i,k}$ $(n \times \Delta f)$, shall be represented in linear format by a scale factor and a normalized complex number $a(n) + j \times b(n)$, where n is the subcarrier index. The scale factor *XLINSCus* shall be coded as a 16-bit unsigned integer. Both $a(n)$ and $b(n)$ shall be coded as a 16-bit 2's-complement signed integers. The value of $Xlinpsus_{i,j}$ $(n \times \Delta f)$ shall be defined as $Xlinpsus_{i,j}$ $(n \times \Delta f) = (XLINSCus/2^{15}) \times (a(n) + j \times b(n))/2^{15}$. In order to maximize precision, the scale factor *XLINSCus* shall be chosen such that $max(|a(n)|, |b(n)|)$ over all reported n is equal to $2^{15} - 1$.

This data format supports an *Xlin(f)* granularity of 2^{-15} and an *Xlin(f)* dynamic range of approximately +6 dB to −90 dB.

An $Xlinpsus_{i,j}$ ($n \times \Delta f$) value indicated as $a(n) = b(n) = -2^{15}$ is a special value. It indicates that no measurement could be done for done from line k into line i for subcarrier n.

An $Xlinpsus_{i,j}$ ($n \times \Delta f$) value indicated with $a(n) \geq 0$ and $b(n) = 0$for all reported n is another special value meaning that there is no phase information and the magnitude of $Xlinpsus_{i,j}$ ($n \times \Delta f$) is the magnitude of $a(n)$.

The magnitude of $Xlinpsus_{i,k}$ $(n \times \Delta f)$ in dB is $Xlogpsus_{i,k}$ $(n \times \Delta f)$:

$$Xlogpsus_{i,k}\ (n \times \Delta f) = 20\log_{10}(\ |Xlinpsus_{i,k}\ (n \times \Delta f)|\ )$$

All accuracy requirements for *Xlinpsus* shall be formulated in terms of magnitude only (*Xlogpsus*) and are for further study.

Annex A

Mitigating strong FEXT

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

A.1 Introduction

This annex defines a method for mitigating strong FEXT.

This annex is an optional functionality, only applicable if the VTU is operating according to Annex Q of [ITU-T G.993.2].

The functionality defined in this annex includes:

- transmitter initiated gain adjustment for VDSL2 transceiver (TIGAV) procedure;
- use of extended error clipping threshold.

A.2 Control parameters for the minimum message overhead data rate (amends clause 9.5.4 of [ITU-T G.993.2])

For operation according to this annex, the downstream msg_{min} and the upstream msg_{min} control parameters shall be derived from the MSGMINds and MSGMINus configuration parameters (defined in the CO-MIB, see clause 7.3.1.5 of [ITU-T G.997.1]) respectively, as follows:

- for profile 35b:
  - downstream: max(MSGMINds, 200 kbit/s) ≤ msg_{min} ≤ 236 kbit/s;
  - upstream: max(MSGMINus, 64 kbit/s) ≤ msg_{min} ≤ 236 kbit/s;
- for profile 17a:
  - downstream: max(MSGMINds, 64 kbit/s) ≤ msg_{min} ≤ 236 kbit/s;
  - upstream: max(MSGMINus, 64 kbit/s) ≤ msg_{min} ≤ 236 kbit/s;

A.3 Clipped error samples

A.3.1 Definition of clipped error sample (replaces clause 3.2.4)

clipped error sample: Is a normalized error sample that is further clipped by the VTU-R with control from the VCE (see clause A.3.3).

A.3.2 Control parameters for clipped error sample reporting (amends clause 7.2.2.1)

For operation according to this annex, Table A.1 defines an additional mandatory value for the clipped error samples control parameters, in addition to the values in Table 7-2. This value is defined for the VCE to configure and for the VTU-O and VTU-R to support.

Table A.1 – Additional values of backchannel control parameters

Parameter	Additional valid value for VCE	Additional mandatory value for VTU-O and VTU-R
B_max	13	13

A.3.3 Definition of normalized error sample (amends clause 7.2.1)

For all values of *B_max*, the normalized error sample shall be as defined in clause 7.2.1.

The real and imaginary components of each normalized error sample E shall be clipped and quantized to integer values for the clipped error sample components q_x and q_y respectively, as follows:

$$\text{for } B\_max \leq 11: \begin{array}{l} q\_x = \max\left(-2^{B\_\max}, \min\left(\left\lfloor e\_x \times 2^{N\_\max-1}\right\rfloor, 2^{B\_\max}-1\right)\right) \\ q\_y = \max\left(-2^{B\_\max}, \min\left(\left\lfloor e\_y \times 2^{N\_\max-1}\right\rfloor, 2^{B\_\max}-1\right)\right) \end{array},$$

$$\text{for } B\_max = 13: \begin{array}{l} q\_x = \max\left(-CT, \min\left(\left\lfloor e\_x \times 2^{N\_\max-1}\right\rfloor, CT-1\right)\right) \\ q\_y = \max\left(-CT, \min\left(\left\lfloor e\_y \times 2^{N\_\max-1}\right\rfloor, CT-1\right)\right) \end{array},$$

where $Q = q\_x + j \times q\_y$ represents the clipped error sample and *N_max* represents the VTU-R's maximum quantization depth of normalized error samples and shall be set to 12, and *B_max* represents the upper bound of the bit index for reporting clipped error sample components q_x and q_y (*B_max* < *N_max*, with *B_max* configured by the VCE, see Tables 7-1 and 7-2).

For the case *B_max* = 13, the parameter *CT* represents the clipping threshold, which is a vendor discretionary value that shall be within the interval $[2^{B\_max} - 2^{(N\_max-1)}, 2^{B\_max}]$. The value of *CT* shall be determined by the VTU-R during initialization before sending the R-ERROR-FEEDBACK message, and shall remain identical for the remainder of initialization and the subsequent showtime (see Notes 1 and 2).

NOTE 1 – Referring to the scaling shown in Figure 7-3, the equivalent clipping intervals for *e_x* and *e_y* are:

for *B_max* ≤ 11: $\left[-\left(\frac{2^{B\_\max}}{2^{(N\_\max-1)}}\right), \left(\frac{2^{B\_\max}-1}{2^{(N\_\max-1)}}\right)\right]$, which approximately equals [−1,1) for *B_max* = 11;

for *B_max* = 13: $\left[-\frac{CT}{2^{(N\_\max-1)}}, \frac{CT-1}{2^{(N\_\max-1)}}\right]$, with $\frac{CT}{2^{(N\_\max-1)}}$ in the interval [3,4], which approximately equals [−3,3) for $CT = (2^{B\_max} - 2^{(N\_max-1)})$.

NOTE 2 – For *B_max* =13, no vendor discretionary clipping is allowed for error samples within the range of $[-(2^{B\_max} - 2^{(N\_max-1)}), (2^{B\_max} - 2^{(N\_max-1)})-1]$.

For all values of *B_max*, the values of both clipped error sample components q_x and q_y shall be represented using the two's-complement representation of *B_max*+1 bits. The format of the clipped error sample for reporting over the backchannel is defined in clause 7.2.2. The particular subcarriers on which clipped error samples shall be reported during initialization and Showtime shall be configured as described in clauses 10.4.2.1, and in clause 8.1, respectively.

A.4 OLR commands

The VTU shall support OLR commands to facilitate operation of vectored lines according to this annex, (see Table A.2).

Table A.2 – OLR commands and responses

Command type	Direction of command	Command content	Response content
OLR request type 7 (TIGAV)	From VTU-O to VTU-R	The relative gain compensation factor (r_i) and the proposed bit loading (b_i) to be applied to a set of downstream subcarriers.	TIGAV-ACK response or TIGAV-Reject response
OLR request type 8 (TIGAVRESP)	From VTU-R to VTU-O	The bit loading (b_i) to be applied to the relevant set of downstream subcarriers and framing parameters.	TIGAVRESP-ACK response or TIGAVRESP-Reject response

A.5 ITU-T G.994.1 Handshake phase (amends clause 10.2)

The functionality defined in this annex shall be negotiated during the ITU-T G.994.1 Handshake phase of initialization, using the NPar(3) codepoint defined in Table 11.68.10.1 of [ITU-T G.994.1]. The use of this codepoint in the ITU-T G.994.1 CL, CLR and MS messages is defined in Tables A.3 to A.6.

Table A.3 – VTU-O CL message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Support of strong FEXT mitigation	If set to ONE, this bit indicates that the VTU-O supports the functionality defined in this annex. If set to ZERO, this bit indicates that the VTU-O does not support the functionality defined in this annex.

Table A.4 – VTU-O MS message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Support of strong FEXT mitigation	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message, and a profile is selected to which this annex applies. If set to ONE, this bit indicates that the functionality defined in this annex is enabled. If set to ZERO, this bit indicates that the functionality defined in this annex is disabled.

Table A.5 – VTU-R CLR message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Suport of strong FEXT mitigation	If set to ONE, this bit indicates that the VTU-R supports the functionality defined in this Annex. If set to ZERO, this bit indicates that the VTU-R does not support the functionality defined in this annex.

Table A.6 – VTU-R MS message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Support of strong FEXT mitigation	This bit shall be set to ONE if, and only if, it was set to ONE in both the last previous CL message and the last previous CLR message, and a profile is selected to which this annex applies. If set to ONE, this bit indicates that the functionality defined in this annex is enabled. If set to ZERO, this bit indicates that the functionality defined in this annex is disabled.

If the ITU-T G.994.1 CLR message has the "Support of strong FEXT mitigation" Npar(3) bit set to ONE, then it shall indicate support for profile 35b and may indicate support for any other profile.

If the ITU-T G.994.1 CL message has the "Support of strong FEXT mitigation" Npar(3) bit set to ONE and the profile 35b is enabled in the CO-MIB, then it shall indicate support for profile 35b and may indicate support for any other profile.

If the ITU-T G.994.1 MS message has the "Support of strong FEXT mitigation" Npar(3) bit set to ONE, then it shall operate according to Annex Q of [ITU-T G.993.2] and select operation according to either profile 17a or profile 35b.

A.6 TIGAV functionality

The functionality associated with TIGAV procedure shall be supported by both the VTU-O and the VTU-R.

The goal of the procedure is fast accommodation of precoder changes in high crosstalk environment by indicating to the VTU-R the associated changes of compensation gain and expected changes of bit loading on relevant downstream subcarriers.

The VTU-O starts the procedure by sending a TIGAV command to the VTU-R that indicates the relative gain compensation factor (r_i) and the proposed bit loading (b_i) to be applied to the indicated set of downstream subcarriers. In response, based on the received r_i values, the VTU-R computes the actual downstream bit loading and sends it back to the VTU-O in TIGAVRESP command. Further, the VTU-O sends to the VTU-R a time marker indicating the symbol position at which the new values of r_i are applied by the VTU-R and the actual b_i values requested by the VTU-R are applied by both VTUs. The details of the message exchange are in clause A.6.2.

The VTU-R may either accept the actual bit loading to be as proposed in the TIGAV command, or request the actual bit loading to be different. In the latter case, the actual bit loading requested by the VTU-R in the TIGAVRESP shall follow the rules defined in clause A.6.1.2.

A.6.1 TIGAV and TIGAVRESP commands

The TIGAV and TIGAVRESP are OLR commands and shall be used to facilitate the TIGAV procedure. Both commands are high priority; the first octets of commands and associated responses shall be an OLR commands type defined in Table 11-2 of [ITU-T G.993.2]. The subsequent octets of the commands shall be as defined in Table A.7. The subsequent octets of the responses shall be as defined in Table A.8. The octets of all commands and responses shall be sent using the format described in clause 11.2.3.1 of [ITU-T G.993.2]. Message segmentation shall be applied as defined in clause 11.2.3.3 of [ITU-T G.993.2].

The TIGAV command shall be sent by the VTU-O only.

The TIGAVRESP command shall be sent by the VTU-R only.

The 4-bit TIGAV identification number (TID) is used to identify the particular TIGAV command. The TID shall be incremented whenever a TIGAV containing a new set of parameters is initiated by the VTU-O and wrap around at count 1111_2, i.e., incrementing from 1111_2 to 0000_2.

The VTU-R shall indicate in the TIGAVRESP command the same TID value as indicated by the VTU-O in the corresponding TIGAV command.

Table A.7 – TIGAV and TIGAVRESP commands

Name	Length (bytes)	Octet number	Content	Support
Request Type 7 (TIGAV)	Variable	2	10_{16} (Note 1)	Mandatory
		3	The four MSBs represent the TID (with valid range 0 to 15, represented as unsigned integer). The four LSBs represent the number of subcarrier band parameter subfields ($1 \le N_{scbt} \le 15$, represented as unsigned integer).	
		Variable	Subcarrier bands parameter field, includes N_{scbt} subcarrier band parameter subfields, see Table A.10.	
		Variable	1 octet for Segment Code (SC)	
Request Type 8 (TIGAVRESP) (Note 2)	Variable	2	11_{16} (Note 1)	Mandatory
		3-4	two octets containing the new value for L_1	
		5	one octet containing the new value for B_{10}	
		6	one octet containing the new value for M_1	
		7	one octet containing the new value for R_1	
		8	one octet containing the new value for Q	
		9	one octet containing the new value for V	
		10	one octet containing the new value for Q_{tx}	
		11	one octet containing the new value for *lb*	
		12	The four MSBs represent the TID (with valid range 0 to 15, represented as unsigned integer). The four LSBs represent the number of subcarrier band parameter subfields ($0 \le N_{scbr} \le 15$, represented as unsigned integer). $N_{scbr} = 0$: Accept the TIGAV proposed bit loading. $N_{scbr} > 0$: Response with the bit loading values requested by the VTU-R, indicated in the subcarrier bands parameter field.	
		Variable	Subcarrier bands parameter field, includes N_{scbr} subcarrier band parameter subfields, (see Table A.14). If N_{scbr}=0, the length of this field shall be 0 bytes.	
		Variable	1 octet for Segment Code (SC)	
NOTE 1 – All other values are reserved by ITU-T. NOTE 2 – The framing parameters in octets 3 to 11 shall be represented as defined for request type 5 in clause C.3.2 of [ITU-T G.998.4].				

The TIGAV-Reject and TIGAV-ACK, and TIGAVRESP-Reject and TIGAVRESP-ACK, are responses on TIGAV and TIGAVRESP commands, respectively (see Table A.8). The reason codes for the reject responses are defined in Table A.9.

The TIGAV-Reject and TIGAV-ACK responses shall be sent by the VTU-R only.

The TIGAVRESP-Reject and TIGAVRESP-ACK responses shall be sent by VTU-O only.

Table A.8 – TIGAV and TIGAVRESP responses

Name	Length (octets)	Octet number	Content	Support
Reject Type 7 request (TIGAV-Reject)	3	2	87_{16} (Note)	Mandatory
		3	1 octet for reason code	
ACK Type 7 request (TIGAV-ACK)	2	2	89_{16} (Note)	Mandatory
Reject Type 8 request (TIGAVRESP-Reject)	3	2	88_{16} (Note)	Mandatory
		3	1 octet for reason code	
ACK Type 8 request (TIGAVRESP-ACK)	2	2	$8A_{16}$ (Note)	Mandatory
NOTE – All other values are reserved by ITU-T.				

Table A.9 – Reason codes for TIGAV and TIGAVRESP responses

Reason	Octet value	Applicable to Reject Type 7	Applicable to Reject Type 8
Busy	01_{16} (Note)	No	Yes
Invalid parameters	02_{16} (Note)	Yes	Yes
NOTE – All other values are reserved by ITU-T.			

A.6.1.1 Parameters of the TIGAV command

The subcarrier bands parameter field in the TIGAV command includes N_{scbt} subcarrier band parameter subfields. The format of each subcarrier band parameter subfield is defined in Table A.10.

Each of the subcarrier band parameter subfields identifies one TIGAV band. A TIGAV band is delimited by its *i_start* and *i_stop* subcarrier indices:

- The *i_start* may fall on an active or on an inactive subcarrier (i.e., g_i=0). The *i_stop* may fall on an active or on an inactive subcarrier (i.e., g_i=0). There may also be inactive subcarriers within a TIGAV band.
- The *i_start* and *i_stop* determine the grid of control subcarrier indices for the "r_i" interpolation (see clause A.6.1.3) as:

  $i = i\_start + k \times F\_sub\_TIGAV$, where $k = 0, 1, 2, \ldots (N_r - 1)$,

  with a constraint: $i\_stop = i\_start + (N_r - 1) \times F\_sub\_TIGAV$, where N_r is an integer larger than 1, and *F_sub_TIGAV* is the applied *ri* sub-sampling, as defined in Table A.10.
- The *i_start* and *i_stop* indices shall satisfy:

  i_start > i_start_DSx – F_sub_TIGAV,
  i_stop < i_stop_DSx + F_sub_TIGAV,

  where *i_start_DSx* and *i_stop_DSx* are respectively the minimum and the maximum subcarrier index that belong to the particular downstream passband (see clause 7.1 of [ITU-T G.993.2]).

  NOTE – This allows freedom in choosing the location of TIGAV control point grid.
- The *i_start* and *i_stop* are independent from the MEDLEYds set, i.e., *i_start* can be smaller than, equal to, or larger than the minimum subcarrier index of MEDLEYds set and *i_stop* can be smaller than, equal to, or larger than the maximum subcarrier index of MEDLEYds set, respectively.

- The *i_start* and *i_stop* are independent from the vectored bands (as exchanged in the *vectored bands* field of the Error Feedback Command defined in Table 8-3).

For each particular TIGAV band *n*, followed by TIGAV band *n*+1 ($n = 1$ to $N_{scbt} - 1$):

- The *i_stop*(*n*) shall be less than or equal to *i_start*(*n+1*), i.e., no or one common index;
- If *i_stop*(*n*) = *i_start*(*n+1*) (i.e., one common index), the r_i and b_i values shall satisfy following constraints: *r*(*i_stop*(*n*)) = *r*(*i_start*(*n+1*)) and *b*(*i_stop*(*n*)) = *b*(*i_start*(*n+1*)).

Both inactive and active subcarriers may exist outside the TIGAV bands. On these active subcarriers, the VTU-R shall assume an $r_i = 1$ (i.e., FEQ will not be affected by TIGAV) and shall assume no change in b_i.

TIGAV bands shall be transmitted in the ascending order of their intervals of subcarrier indices.

Table A.10 – Subcarrier band parameter subfield of the TIGAV command

Parameter	Length (byte)	Definition
Control byte	1	[c000 ffff] Control bit c = 0 indicates that this subfield contains real r_i parameters (see Note 2). Control bit c = 1 indicates that this subfield contains complex r_i parameters (see Note 2). Control bits ffff = *F_sub_TIGAV* for this subfield, represented as unsigned integer.
i_start	2	TIGAV band start subcarrier index (*i_start*), represented as a 16-bit unsigned integer.
i_stop	2	TIGAV band stop subcarrier index (*i_stop*), represented as a 16-bit unsigned integer.
b_i	ceil(N_b / 2) (Note 1)	This field contains N_b TIGAV b_i parameters (see Table A.11) for subcarriers with indices *i_start* to *i_stop*, in ascending order of subcarrier indices.
real r_i	$2 \times N_r$	This field is present if and only if the control bit c = 0. This field contains N_r TIGAV real r_i parameters (see Table A.13) for subcarriers with index *i_start* + k × *F_sub_TIGAV*, with $k = 0$ to $N_r - 1$, in ascending order of subcarrier indices.
complex r_i	$3 \times N_r$	This field is present if and only if the control bit c = 1. This field contains N_r TIGAV complex r_i parameters (see Table A.12) for subcarriers with index *i_start* + k × *F_sub_TIGAV*, with $k = 0$ to $N_r - 1$, in ascending order of subcarrier indices.
NOTE 1 – N_b = *i_stop* – *i_start* + *1*. NOTE 2 – The bit c shall be set to the same value in all subcarrier band parameter subfields.		

The valid values for *F_sub_TIGAV* are 1, 4, and 8 (i.e., the r_i values may be subsampled).

Both VTU-O and VTU-R shall support all valid values for *i_start*, *i_stop*, and *F_sub_TIGAV*.

Table A.11 – The b_i parameter format in a TIGAV command

Bit	Length (bits)	Parameter (see Notes 1 and 2)	Format
3-0	4	b_i (of subcarrier k)	Unsigned integer in the [0:15] range
7-4	4	b_i (of subcarrier k+1)	Unsigned integer in the [0:15] range
NOTE 1 – The values of b_i for subcarriers that are in the specified range (i.e., from *i_start* to *i_stop*) but not part of the MEDLEYds set shall be included. They shall be set to zero by the transmitter and ignored by the receiver. NOTE 2 – If the N_b is odd, the bits 7-4 of the b_i parameter associated with the highest subcarrier index shall be set to 0000_2.			

Table A.12 – The complex r_i parameter format of the TIGAV command

Bit	Length (bits)	Content (see Notes 1 and 2)	Format
2-0	3	Exponent of r_i	E3/4
12-3	10	Mantissa of real part of r_i	M10(1Q9) signed
22-13	10	Mantissa of imaginary part of r_i	M10(1Q9) signed
23	1	Reserved by ITU-T	Bit shall be set to 0
NOTE 1 – The values of r_i for subcarriers that are in the specified range (i.e., from *i_start* to *i_stop*), but not part of the MEDLEYds set are set to a vendor discretionary non-zero value. NOTE 2 – The byte transmitted first shall contain bits 23(MSB) to 16(LSB). The byte transmitted second shall contain bits 15(MSB) to 8(LSB). The byte transmitted third shall contain bits 7(MSB) to 0(LSB).			

The format descriptor L **M** ML(i**Q**f) **E** LE/B designates a floating point format with total wordlength L. It has mantissa wordlength of ML bits, with the binary point just to the right of the i-th most significant bit (including the sign bit if signed integer), and f bits are allocated behind the binary point (i.e., ML=i+f). The exponent is always unsigned and has wordlength LE. The exponent has unity gain when its value equals B. Letters M, Q and E are syntax-separators.

The real and imaginary part of the complex gain r_i value shall both be formatted as 13M10(1Q9) E3/4 with a signed mantissa, and a common exponent.

A non-zero complex r_i value shall be within the valid range expressed in dB as:

$$-18 \text{ dB} < 20 \times \log10(\text{abs}(r_i)) < +18 \text{ dB},$$

where abs(x) is the modulus of a complex value x.

A special value of complex r_i is $r_i = 0$, which shall be coded with a mantissa=0 and exponent=0, for both real and imaginary part, and shall be accompanied with $b_i = 0$.

Table A.13 – The real r_i parameter format of the TIGAV command

Bit	Length (bits)	Content (see Notes 1 and 2)	Format
2-0	3	Exponent of r_i	E3/4
12-3	9	Mantissa of r_i	M9(0Q9) unsigned (see Note 3)
15-12	4	Reserved by ITU-T	Bits shall be set to 0
NOTE 1 – The values of r_i for subcarriers that are in the specified range (i.e., from *i_start* to *i_stop*), but not part of the MEDLEYds set are set to a vendor discretionary non-zero value. NOTE 2 – The byte transmitted first shall contain bits 15(MSB) to 8(LSB). The byte transmitted second shall contain bits 7(MSB) to 0(LSB). NOTE 3 – Real r_i values shall be positive values only.			

A real r_i value shall be formatted as floating point 12M9(0Q9) E3/4 unsigned.

A non-zero real r_i value shall be within the valid range expressed in dB as:

$$-18 \text{ dB} < 20 \times \log_{10} (r_i) < +18 \text{ dB}.$$

A special value of real r_i is $r_i = 0$, which shall be coded with a mantissa=0 and exponent=0, and shall be accompanied with $b_i = 0$.

NOTE – The TIGAV procedure does not change the downstream g_i-values. The changes in the transmit power of the downstream subcarriers associated with TIGAV is achieved by corresponding modification of the precoder.

A.6.1.2 Parameters controlled by the TIGAVRESP command

The subcarrier bands parameter field in TIGAVRESP command includes N_{scbr} subcarrier band parameter subfields. The format of each subcarrier band parameter subfield is defined in Table A.14.

Each of the subcarrier band parameter subfields identifies one TIGAVRESP band. The TIGAVRESP bands in the TIGAVRESP command shall follow the same requirements as defined for the TIGAV bands in the TIGAV command in clause A.6.1.1, and the following additional requirements:

1) The N_{scbt} is replaced with N_{scbr}.
2) If N_{scbr} is set to a non-zero value in TIGAVRESP command, the TIGAVRESP bands in TIGAVRESP command shall include at least all MEDLEY subcarriers addressed by the corresponding TIGAV command.
3) The b_i values requested by TIGAVRESP command for all MEDLEY subcarriers addressed by corresponding TIGAV command shall not exceed the b_i values proposed by the TIGAV command. In addition to this mandatory upper limit, the actual bit loading in the TIGAVRESP should be upper limited by the bit loading that is based on the change in the SNR expected from the new values of r_i, and might be upper limited by other factors.
4) If TIGAVRESP bands in TIGAVRESP command include more MEDLEY subcarriers than the corresponding TIGAV command, the b_i values on these additional MEDLEY subcarriers are determined solely by the VTU-R.

Table A.14 – Subcarrier band parameter subfield in a TIGAVRESP command

Parameter	Length (byte)	Definition
i_start	2	TIGAVRESP band start subcarrier index (*i_start*), represented as a 16-bit unsigned integer.
i_stop	2	TIGAVRESP band stop subcarrier index (*i_stop*), represented as a 16-bit unsigned integer.
b_i	ceil(N_b / 2) (Note)	This field contains N_b TIGAVRESP b_i parameters (see Table A.15) for subcarriers with indices *i_start* to *i_stop*, in ascending order of subcarrier indices.
NOTE – $N_b = i\_stop - i\_start + 1$.		

Table A.15 – The b_i parameter format in a TIGAVRESP command

Bit	Length (bits)	Parameter (see Notes 1, 2 and 3)	Format
3-0	4	b_i (of subcarrier k)	Unsigned integer in the [0:15] range
7-4	4	b_i (of subcarrier k+1)	Unsigned integer in the [0:15] range
NOTE 1 – The values of b_i for subcarriers that are in the specified range (i.e., from *i_start* to *i_stop*), but not part of the MEDLEY set, shall be included. They shall be set to zero by the transmitter and ignored by the receiver. NOTE 2 – The values of b_i shall be transmitted in ascending order of the subcarrier indices. NOTE 3 – If the N_b is odd, the bits 7-4 of the b_i parameter associated with the highest subcarrier index shall be set to 0000_2.			

A.6.1.3 Interpolation of the ri values

For each particular TIGAV band *n* (*n*=1 to N_{scbt}), the VTU-R should derive the r_i values on all active subcarriers between *i_start*(*n*) and *i_stop*(*n*) (both inclusive), by linear interpolation in between the r_i values at the control subcarrier indices communicated in the TIGAV message. Linear interpolation shall be on a linear scale over the r_i axis and a linear scale over the index axis.

NOTE 1 – The VCE should choose the r_i values in a TIGAV command such that the linear interpolation at the VTU-R produces the desired output values on intermediate active subcarriers. The method to define these r_i values (control points) is VCE vendor discretionary.

NOTE 2 – The *i_start* and *i_stop* are allowed to fall on an inactive subcarrier. The VCE should choose the r_i values on *i_start* and *i_stop* in a TIGAV command such that the linear interpolation at the VTU-R produces the desired output values on intermediate active subcarriers.

NOTE 3 – The inactive subcarriers included in a TIGAV are known by the VTU-R. The VTU-R does not need to calculate the interpolation on these carriers.

A.6.2 TIGAV procedure

The VTU-O shall not initiate a TIGAV if either an upstream or a downstream save our showtime (SOS) type 4 or 6 procedure is ongoing.

The exchange between VTUs in the TIGAV procedure is illustrated in Figure A.1 and defined as follows:

1) Upon the instruction of the VCE over the ε_m interface, the VTU-O shall initiate a TIGAV procedure by sending an OLR request type 7 command. A TIGAV command may be segmented. After sending the last segment of the TIGAV command, during the following 100 ms the VTU-O shall expect to receive the TIGAV-ACK response or a TIGAV-Reject response. The last segment of the TIGAV command may be repeated if the response times out.
   a) If the VTU-O receives an OLR request type 1, 3 and 5 during or after transmission of an OLR request type 7 and prior to receiving a response, it shall reject the OLR request type 1, 3 and 5 (see Note 1).
   b) If the VTU-O receives an SOS OLR request type 4 or 6 during the TIGAV procedure, it shall abort the TIGAV procedure immediately and respond to the OLR SOS request.
   c) The VTU-O is allowed to initiate an SOS OLR request type 4 or 6 procedure at any time after the TIGAV is initiated but not completed. The initiated SOS request shall abort the TIGAV procedure (see Notes 2 and 3).

NOTE 1 – It is expected that in the aim to speed up starting TIGAV, the VTU-O may discard any pending SRA request because the modification of transmission parameters implied by this request will anyway be overridden by TIGAV.

NOTE 2 – Termination of the TIGAV procedure due to SOS OLR request is only for the line in which the SOS request takes place; other lines in the vectored group can continue their TIGAV procedures.

NOTE 3 – Clause 11.2.2 of [ITU-T G.993.2] describes the possibility of a high priority message aborting a low priority message. This TIGAV abort by an SOS is a case when a high priority message is aborted by another high priority message, and is therefore an extension to clause 11.2.2 of [ITU-T G.993.2].

2) After reception of the last segment of a TIGAV command, the VTU-R shall either acknowledge the TIGAV command by sending the TIGAV-ACK response (see Table A.7) or reject the TIGAV command by sending a TIGAV-Reject response with a corresponding reason code.

   a) Upon receiving the first segment of a TIGAV command, the VTU-R shall reject any pending OLR command of type 1, 3 and 5 and shall not initiate any OLR request type 1, 3 and 5 procedure until the TIGAV procedure is complete.

   b) Upon receiving an SOS OLR request type 4 or 6 from the VTU-O at any time during the TIGAV procedure, it shall abort the TIGAV procedure immediately and respond to the OLR SOS request.

   c) The VTU-R is allowed to initiate an SOS OLR request type 4 or 6 procedure at any time after the TIGAV is initiated but before the start of sending the last segment of TIGAVRESP. The changes in bit loading contained in the SOS request shall be applied to the current active bit loading table (i.e., ignoring the bit loading sent in TIGAV). This initiated SOS request shall abort the TIGAV procedure. The VTU-O shall respond to the SOS OLR request with a SYNC FLAG.

   d) The VTU-R shall not initiate an SOS OLR request type 4 or 6 procedure after the start of sending the last segment of TIGAVRESP up until the end of the TIGAV procedure.

3) Within 300 ms after sending the TIGAV-ACK response, the VTU-R shall send a TIGAVRESP command. A TIGAVRESP command may be segmented. After sending the last segment of the TIGAVRESP command, during the following 100 ms the VTU-R shall expect receiving a TIGAVRESP-ACK response or a TIGAVRESP-Reject response. If the last segment of the TIGAVRESP command times out, the VTU-R shall repeat the last segment of the TIGAVRESP command. After sending the TIGAV-Reject response, the VTU-R shall exit the TIGAV procedure.

4) Upon reception of the TIGAV-ACK response, the VTU-O shall expect receiving the first segment of a TIGAVRESP command. The VTU-O shall either acknowledge the last segment of the TIGAVRESP command by sending a TIGAVRESP-ACK response, or reject the TIGAVRESP command by sending a TIGAVRESP-Reject response with a corresponding reason code. After sending the TIGAVRESP-ACK response, at the time determined by the VCE, the VTU-O shall send the TIGAV-SYNCHRO pattern. After sending the TIGAVRESP-Reject response, the VTU-O shall exit the TIGAV procedure.

NOTE 4 – The TIGAV-SYNCHRO pattern has to be sent simultaneously over all relevant lines of the vectored group. For this the VCE needs to receive the TIGAVRESP command from all lines in the vectored group prior to sending TIGAV-SYNCHRO pattern. This should be within the global TIGAV timeout.

5) Upon reception of a TIGAV-Reject response, the VTU-O shall exit the TIGAV procedure. The VTU-O may immediately start a new TIGAV procedure by sending a new TIGAV command.

6) Upon reception of a TIGAVRESP-Reject response, the VTU-R shall send a TIGAVRESP command again. If rejection persists, the VTU-R shall exit the TIGAV procedure.

7) Starting from the first symbol following the TIGAV-SYNCHRO pattern, both the VTU-O and the VTU-R shall synchronously apply the relative gain compensation factor indicated in the TIGAV command and the bit loading indicated in the TIGAVRESP command.

Timing of changes in framing parameters shall be as specified in clause C.4 of [ITU-T G.998.4].

8) The procedure times out if TIGAV-SYNCHRO is not received within 4 seconds after the VTU-R sends TIGAV ACK. Upon this timeout, the VTU-R shall exit the TIGAV procedure.

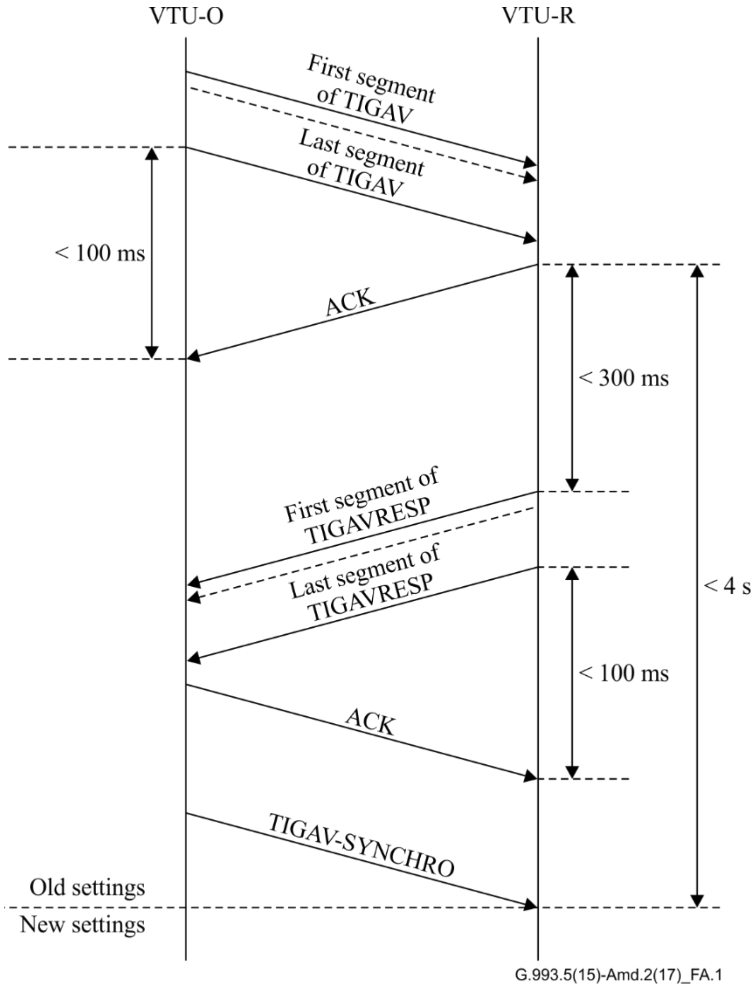

Figure A.1 – Timing diagram of TIGAV procedure

NOTE 5 – Figure A.1 does not show the case of rejecting the TIGAV command and does not show the case of rejecting the TIGAVRESP command.

A.6.2.1 Definition of TIGAV-SYNCHRO pattern

The TIGAV-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 of [ITU-T G.993.2]), followed by a pattern of 9 sync symbols with non-inverted flag tones (transmitted at the first 9 symbol positions in the next superframe).

The sync symbol is defined in clause 10.2 of [ITU-T G.993.2].

A.6.2.2 Implementing the TIGAV gain modification by the VTU-R

To implement the relative gain compensation factor (r_i) indicated in the TIGAV, the following rules shall apply:

- For subcarriers with $r_i \neq 0$, the VTU-R shall multiply its current settings of the gain stage in the receiver, for any subcarrier i with g_i >0, by the value (r_i):

  $new\_gainstage_i = current\_gainstage_i \times r_i$

NOTE – This scaling is to help the VTU-R to keep its receiver gain adjusted after a precoder update.

- For subcarriers with $r_i = 0$, the VTU-R shall set its receiver gain to a vendor discretionary non-zero value.

A.6.2.3 Relation TIGAV and subsequent autonomous SRA in downstream

An autonomous SRA requested by the VTU-R, subsequent to a TIGAV command, shall have bit loading values b_i that are less than or equal to the b_i values requested in the last TIGAV message preceding this SRA.

A.7 Main body amendments related to MREFPSD

A.7.1 Definitions (replaces clauses 3.31 and 3.32 of [ITU-T G.993.2])

3.31 MEDLEY reference PSD: The MEDLEY reference PSDs in the downstream and upstream directions are denoted as MREFPSDds and MREFPSDus, respectively. The MREFPSDus is the PSD of signals transmitted by a VTU-R at every frequency (i.e., in both the passband and the stopbands) during the training phase and the channel analysis and exchange phase of initialization. The MREFPSDds is the power spectral density (PSD) of signals transmitted by a VTU-O at every frequency (i.e., in both the passband and the stopbands) during the training phase only.

NOTE – In this Recommendation, including in this Annex, the MREFPSDds refers to the VTU-O TXPSD of the direct signal only, without pre-compensation signals. In [b-ITU-T G.9701], the MREFPSDds refers to the FTU-O TXPSD of the total signal at the U-interface, including pre-compensation signals.

3.32 MEDLEY reference PSD mask: The MEDLEY reference PSD mask is the transmit PSD mask limited at every frequency (i.e., in both the passband and the stopbands) by the PSD ceiling and limited to −80 dBm/Hz at frequencies corresponding to the designated RFI bands. In the upstream direction, the MEDLEY reference PSD mask is further reduced in accordance with the upstream power back off (UPBO) requirements. The MEDLEY reference PSD masks in the downstream and upstream directions are denoted as MREFMASKds and MREFMASKus, respectively.

A.7.2 Nominal aggregate transmit power (NOMATP) (replaces clause 10.3.4.2.1 of [ITU-T G.993.2])

NOTE – Unless otherwise specified, references in this clause refer to [ITU-T G.993.2].

The nominal aggregate transmit power in upstream (NOMATPus) shall be calculated at both the VTU-R and the VTU-O side as defined in clause 10.3.4.2.1 of [ITU-T G.993.2].

At the VTU-R side, the nominal aggregate transmit power in downstream (NOMATPds) shall be calculated as defined in clause 10.3.4.2.1 of [ITU-T G.993.2]. The g_i settings determined by the VTU-R shall be such that the value of this NOMATPds (as defined for the VTU-R) does not exceed, the CO-MIB parameter MAXNOMATPds. At the VTU-O side, the nominal aggregate transmit power in downstream (NOMATPds) is an estimate of the total amount of output power delivered by the transmit PMD function to the U-O2 reference point (defined in Figure 5-4 of [ITU-T G.993.2]) in dBm into a 100 Ohm termination impedance.

The nominal aggregate transmit power in downstream (NOMATPds) shall be computed by VTU-O, in cooperation with the VCE, according to the following equation:

$$NOMATPds = 10log_{10}(\sum_{i \epsilon MEDLEYds} P\_Zi')$$

where P_Z_i' is the power of the total transmitted signal at the output of the precoder for subcarrier i, referred to the U-O interface, in milliWatts assuming the network input impedance is 100 Ohms resistive (see Note 1).

NOTE 1 – In actual deployments, the network/loop input impedance may deviate from 100 Ohms resistive.

NOTE 2 – NOMATPds includes the direct signal as well as the precoder compensation signals.

The VTU-O, in cooperation with the VCE, shall ensure that the value of NOMATPds does not exceed, the CO-MIB parameter MAXNOMATPds.

NOTE 3 – The definition of NOMATPds is different at the VTU-R and VTU-O side. At the VTU-R side, the definition of NOMATPds is unchanged compared to [ITU-T G.993.2], and therefore the VTU-R g_i calculation is unchanged. At the VTU-O side, the definition of NOMATPds is changed compared to [ITU-T G.993.2].

The total amount of output power delivered by the transmit PMD function to the U-O2 reference point in dBm into a 100 Ohm termination impedance shall not deviate from the NOMATPds by more than 1 dB.

A.7.3 Frequency-domain transmit spectrum shaping (tssi) (replaces clause 10.3.4.3 of [ITU-T G.993.2])

NOTE – Unless otherwise specified, references in this clause refer to [ITU-T G.993.2].

The tss_i are intended for frequency-domain spectrum shaping, both upstream and downstream. The tss_i values are vendor discretionary and shall be in the range between 0 and 1 (linear) in steps of $\frac{1}{1024}$. The tss_i values shall be set such that the highest tss_i value across all subcarriers is 1. Smaller values of tss_i provide attenuation, and the value $tss_i = 0$ corresponds to no power transmitted on the particular subcarrier. If no frequency-domain spectrum shaping is applied, the tss_i values shall be equal to 1 for all subcarriers.

The tss_i values in dB (log_tss_i) are defined as $20 \times \log_{10}(tss_i)$ and shall be converted to linear values of tss_i using the equation:

$$tss_i = \frac{\text{Round}\left(1024 \times 10^{\frac{log\_tss_i}{20}}\right)}{1024}$$

The values of tss_i for the given direction of transmission shall be determined by the transmitting VTU, and shall be defined as a set of breakpoints $\{(i_1, log\_tss_{i1}) ..., (i_n, log\_tss_{in})\}$, where i is the subcarrier index. This set shall be communicated to the receiving VTU during the channel discovery phase of the initialization using O-PRM and R-PRM messages, as described in clause 12.3.3.2. Both transmitting and receiving VTUs shall derive the tss_i values for subcarriers between the breakpoints using linear interpolation of the defined log_tss_i values over the linear scale of subcarrier indexes. The receiving VTU shall assign tss_i values equal to tss_{i_n} for $i > i_n$, and equal to tss_{i1} for $i < i_1$.

The obtained values of tss_i are relevant only for subcarriers that are actually transmitted. The receiver shall ignore the tss_i values that are either received or obtained by interpolation for the subcarriers that are not used for transmission (Z_i=0, see Table 10-4).

The combined accuracy of the linear interpolation of log_tss_i values and of the conversion to linear tss_i values shall be less than one half LSB for the 10-bit representation format of the linear tss_i values. No error shall be introduced when log_tss_i equals 0 dB or is interpolated between log_tss_i values that equal 0 dB.

The transmitter of the VTU-O shall set the tss_i values such that the PSD of the transmit signal as measured in the reference impedance at the U-O2 reference point, during the training phase, shall not deviate from the values of MREFPSDds, communicated in O-PRM, by more than 1 dB (parameter "MEDLEY reference PSD", see clause 12.3.3.2).

The transmitter of the VTU-R shall set the tss_i values such that, prior to the gain adjustment (i.e., assuming g_i =1), the PSD of the transmit signal as measured in the reference impedance at the

U interface, from the start of the training phase and for the remainder of initialization, shall not deviate from the values of MREFPSDus, communicated in R-PRM, respectively, by more than 1 dB (parameter "MEDLEY reference PSD", see clause 12.3.3.2).

Thus, tss_i settings shall take into consideration any additional spectrum shaping caused by time-domain filters and analog filters included in the transmission path between the output of the modulator and U interface.

A.7.4 General (amends clause 6.1 of ITU-T G.993.5)

…

As a part of the channel matrix or separately, the VCE shall set the precoder such that the precoder output signals (Z' values shown in Figure 6-1) shall not lead at the U-O2 reference point to violation of the MREFMASK, even with highest valid g_i values (i.e., g_i = +2.5 dB) for all lines in the vectored group.

A.7.5 PSD and PSD mask summary (amends clause 7.2.3 of [ITU-T G.993.2])

NOTE – Unless otherwise specified, references in this clause refer to [ITU-T G.993.2].

…

Table 7-5 – Summary: Determination and use of PSDs and PSD masks

Parameter	When determined	When communicated between VTUs (Note)	When used
MEDLEY reference PSD mask (MREFMASK)	At the end of channel discovery phase; VTU-O determines MREFMASKds, VTU-R determines MREFMASKus	Not communicated	From the beginning of training phase and thereafter during initialization and showtime
MEDLEY reference PSD downstream (MREFPSDds)	At the end of channel discovery phase; VTU-O determines MREFPSDds	MREFPSDds is sent by VTU-O to VTU-R in O-PRM	During the training phase
MEDLEY reference PSD upstream (MREFPSDus)	At the end of channel discovery phase, VTU-R determines MREFPSDus	MREFPSDus is sent by VTU-R to VTU-O in R-PRM	During the training phase and channel analysis and exchange phase
Showtime PSD	At the end of the channel analysis and exchange phase	Determined by the PSD of the channel analysis and exchange phase and the gain values (g_i) communicated during the channel analysis and exchange phase (O-PMD and R-PMD messages). Shall not exceed MREFMASK.	During showtime
NOTE – Only the minimum set of relevant parameters characterizing PSDs and PSD masks is communicated during initialization. The communication protocols and formats are described in clause 12.			

A.7.6 Channel characteristics function per subcarrier group (CCF-ps) (amends clause 11.4.1.1.1 of [ITU-T G.993.2])

NOTE – Unless otherwise specified, references in this clause refer to [ITU-T G.993.2].

…

The measurement of a channel characteristics function is the result of the cascade of three functions:

- the transmitter filter characteristics function;
- the channel characteristics function; and
- the receiver filter characteristics function.

NOTE 1 – The channel characteristics function corresponds to the Hchannel(*f*) function used in the definition of the far-end crosstalk (see clause 7.4.1 of [ITU-T G.996.1]).

The objective is to provide means by which the channel characteristics can be accurately identified. Therefore, it is necessary for the receive PMD function to report an estimate of the channel characteristics. This task may prove to be a difficult one given the fact that the receive PMD function only observes the cascade of all three elements of the channel. The passband part of the reported H(*f*), which is most essential to debug possible issues with the physical loop, is not expected to significantly depend upon the receiver filter characteristics (not including receiver AGC). The receive PMD function shall therefore invert the gain (AGC) it has applied to the received signal and do a best effort attempt to remove the impact of the near-end receiver filter characteristics. The result is then a best estimate of how the receiver views the passband channel characteristics plus the transmitter filter characteristics. As the in-band portion of the spectrum is also expected not to significantly depend upon the transmitter filter characteristics, this result is considered a sufficient estimate of the channel characteristics for desired loop conditioning applications.

Two formats are defined for the channel characteristics as follows:

- Hlin(*f*): a format providing complex values on a linear scale; and
- Hlog(*f*): a format providing magnitude values on a base 10 logarithmic scale.

For Hlog(*f*), the receive PMD function shall also use the value of the PSD at the U interface of the transmit PMD function (as conveyed in messages during initialization) to remove the impact of the far-end transmit filter characteristics.

NOTE 2 – The Hlog includes the effect of the precompensation signals related to that line sent on the other lines of the vectored group which are in the L0 link state.

For Hlin(*f*), if the channel characteristics are reported over the VTU-O OAM interface (see Figure 5-3), the VTU-O shall do a best effort attempt to remove the impact of the near-end transmit filter characteristics from the channel characteristics measured at the VTU-R. If the channel characteristics are reported over the VTU-R OAM interface, the VTU-R shall do a best effort attempt to remove the impact of the near-end transmit filter characteristics from the channel characteristics measured at the VTU-O.

NOTE 3 – The Hlin includes the effect of the precompensation signals related to that line sent on the other lines of the vectored group which are in the L0 link state.

Hlin(*f*) shall be sent to the far-end VME during the loop diagnostic mode and shall be sent on request to the near-end VME during the loop diagnostic mode.

…

A.7.7 PMD Test Parameter Read commands and responses (replaces clause 11.2.3.11 of [ITU-T G.993.2])

NOTE – Revision marks in this clause show the changes relative to clause 11.2.3.11 of [ITU-T G.993.2].

Unless otherwise specified, references in this clause refer to [ITU-T G.993.2].

The PMD Test Parameter Read commands shall be used to retrieve the values of the PMD test parameters that are specified in clause 11.4.1 and maintained by the far-end VTU. The PMD Test Parameter Read commands are shown in Table 11-26, and may be initiated by either VTU. The responses shall be as shown in Table 11-27. The first octet of all PMD Test Parameter Read commands and responses shall be the assigned value for the PMD Test Parameter Read command type, as shown in Table 11-5. The subsequent octets of the commands shall be as shown in Table 11-26. The subsequent octets of the responses shall be as shown in Table 11-27. The octets shall be sent using the format described in clause 11.2.3.1.

Table 11-26 – PMD test parameter read commands sent by the requesting VTU

Name	Length (octets)	Octet number	Content	Support
Single Read	2	2	01_{16} (Note 1)	Mandatory
Next Multiple Read	2	2	03_{16} (Note 1)	Mandatory
Multiple Read	4	2	04_{16} (Note 1)	Mandatory
		3 to 4	2 octets describing the subcarrier group index	
Block Read	6	2	05_{16} (Note 1)	Mandatory
		3 to 4	2 octets describing the start subcarrier group index	
		5 to 6	2 octets describing the stop subcarrier group index	
Vector Block Read	7	2	06_{16} (Note 1)	Optional
		3	1 octet describing the type of test parameter to read (Note 2) 01_{16}: Channel transfer function Hlog(*f*) per subcarrier group 03_{16}: Quiet Line Noise PSD QLN(*f*) per subcarrier group 04_{16}: Signal to noise ratio SNR(*f*) per subcarrier group.	
		4 to 5	2 octets describing the start subcarrier group index	
		6 to 7	2 octets describing the stop subcarrier group index	
Scalar Read	3	2	07_{16} (Note 1)	Optional
		3	1 octet describing the type of scalar test parameters to be read (Note 2) 21_{16} to 28_{16}: the parameter index to read according to the ID of Table 11-28.	
SATN for G.993.5 Annex A	12	2	08_{16} (Note 1)	Mandatory
		3 to 12	Five 2-octet values of TXpower_dBm_D(m) for 5 potentially available downstream bands.	
NOTE 1 – All other values for octet number 2 are reserved by the ITU-T. NOTE 2 – All other values for octet number 3 are reserved by the ITU-T.				

Table 11-27 – PMD test parameter read responses sent by the responding VTU

Name	Length (octets)	Octet number	Content	Support
Single Read	42	2	81_{16} (Note 2)	Mandatory

Table 11-27 – PMD test parameter read responses sent by the responding VTU

Name	Length (octets)	Octet number	Content	Support
ACK	(Note 1)	3 to 42	Octets for the test parameters arranged for the single read format	
Multiple Read ACK	12 (Note 1)	2	82_{16} (Note 2)	Mandatory
		3 to 12	Octets for the test parameters arranged for the multiple read format	
NACK	2	2	80_{16} (Note 2)	Mandatory
Block Read ACK	Parameter-dependent (Note 1)	2	84_{16} (Note 2)	Mandatory
		3 +	Octets for the test parameters arranged for the block read format	
Vector Block Read ACK	Parameter-dependent (Note 1)	2	86_{16} (Note 2)	Optional
		3 +	Octets for the test parameters arranged for the block read format	
Scalar Read ACK	Parameter-dependent (Note 1)	2	87_{16} (Note 2)	Optional
		3 +	Octets for the test parameters arranged for the scalar read format	
SATN for G.993.5 Annex A ACK	12 (Note 1)	2	88_{16} (Note 2)	Mandatory
		3 to 12	Octets for SATN arranged for the scalar read format	

NOTE 1 – Message length equals 2 octets plus the length shown in Table 11-28.
NOTE 2 – All other values for octet number 2 are reserved by the ITU-T.

Table 11-28 – PMD test parameter ID values and length of responses

Test parameter ID (Note 1)	Test parameter name	Length for Single Read (octets)	Length for Multiple Read (octets)	Length for Block Read or Vector Block Read (octets)	Length for Scalar Read (octets)	Support
01_{16}	Channel transfer function Hlog(f) per subcarrier group	N/A	4	2 + (stop subcarrier group index – start subcarrier group index + 1) × 2 (Note 2)	N/A	Mandatory
03_{16}	Quiet line noise PSD QLN(f) per subcarrier group	N/A	3	2 + (stop subcarrier group index − start subcarrier group index + 1) (Note 2)	N/A	Mandatory
04_{16}	Signal-to-noise ratio SNR(f) per subcarrier group	N/A	3	2 + (stop subcarrier group index − start subcarrier group index + 1) (Note 2)	N/A	Mandatory

Table 11-28 – PMD test parameter ID values and length of responses

Test parameter ID (Note 1)	Test parameter name	Length for Single Read (octets)	Length for Multiple Read (octets)	Length for Block Read or Vector Block Read (octets)	Length for Scalar Read (octets)	Support
21_{16}	Loop attenuation LATN	2 × 5	N/A	N/A	2 × 5	Mandatory
22_{16}	Signal attenuation SATN	2 × 5	N/A	N/A	2 × 5	Mandatory
23_{16}	Signal-to-noise ratio margin SNRM and SNRM-pb	2 × 6	N/A	N/A	2 × 6	Mandatory
24_{16}	Attainable net data rate ATTNDR (basic method)	4	N/A	N/A	4	Mandatory
24_{16}	Attainable net data rate ATTNDR (improved method)	8	N/A	N/A	8	Optional
25_{16}	Near-end actual aggregate transmit power ACTATP	2	N/A	N/A	2	Mandatory
26_{16}	Far-end actual aggregate transmit power ACTATP	2	N/A	N/A	2	Mandatory
27_{16}	Far-end actual impulse noise protection INP_act	N/A	N/A	N/A	2	Optional
28_{16}	Far-end actual signal-to-noise ratio margin for the robust overhead channel SNRM-ROC	N/A	N/A	N/A	2	Optional

NOTE 1 – All other Test parameter ID values are reserved by the ITU-T.

NOTE 2 – Since the number of subcarriers, *G,* in the subcarrier group (see clause 11.4.1) may be different for QLN, Hlog, and SNR, the values of QLN, Hlog and SNR communicated by Multiple Read, Block Read, or Vector Block Read for the same subcarrier group index may correspond to different subcarrier indices. The subcarrier index for each parameter equals G × subcarrier group_index, where the value of G is as defined in Table 11-42 of clause 11.4.1 (for showtime) and subcarrier group index = 0 to 511.

Upon reception of a PMD Test Parameter Read command, the responding VTU shall send the corresponding response. If the format of the Test Parameter Read command is incorrect, the VTU shall respond with the negative acknowledge (NACK). Any function of either the requesting or the responding VTU shall not be affected.

The Single Read command shall be used to retrieve all test parameters with ID values from 21_{16} to 26_{16} inclusive. In response to a Single Read command, the values for the test parameters (one value per parameter) shall be transferred in numerically increasing order of the parameter ID shown in Table 11-28. The format of the octets for each parameter shall be as specified in clause 11.4.1. Values formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet. The LATN, SATN and SNRM format shall include five 2-octet values intended for 5 potentially available frequency bands for each transmission direction. The 2-octet values shall be sent in the order shown in Table 11-29. The value 00_{16} shall be used to indicate the disabled bands. Octets indicated as reserved shall be set to ZERO in the transmitter and ignored by the receiver. The SNRM test parameter shall, in addition to all SNRM-pb values (clause 11.4.1.1.6.3), include the overall SNRM value (clause 11.4.1.1.6.2). The first 2-octet value is the overall SNRM, followed by the five 2-octet values of the SNRM-pb as specified in Table 11-29. For the ATTNDR, the use of either the basic or the improved method is configured during initialization (see clause 11.4.1.1.7). The ATTNDR test parameter is specified in Table 11-30.

If operating according to Annex A of [ITU-T G.993.5], the VTU-R response to a scalar read command for SATN and to a single read command shall have SATN values equal to the special value 1023. The VTU-O shall ignore this value (i.e., the VME shall not communicate this value to the EIA for storing in the CO-MIB SATNds object).

Table 11-29 – Order for sending LATN, SATN and SNRM-pb parameters

Octet number	Upstream direction	Downstream direction
1	US0	DS1
2		
3	US1	DS2
4		
5	US2	DS3
6		
7	US3	DS4
8		
9	US4	Reserved
10		

Table 11-30 – ATTNDR test parameter

Octet number	Basic method	Improved method
1-4	*ATTNDR*	*ATTNDR*
5	N/A	Reserved and set to 00_{16}
6	N/A	$\mathit{ATTNDR\_INP\_act}_0$
7	N/A	Reserved and set to 00_{16}
8	N/A	$\mathit{ATTNDR\_delay\_act}_0$
NOTE – The format of the fields is defined in clause 11.4.1.1.7.		

A Scalar Read command shall be used to retrieve a single test parameter. Support of this read command is optional. The ID of the test parameter to retrieve shall be indicated in the third octet of the read command as specified in Table 11-26. In response to a Scalar Read command, the VTU shall send the value of the test parameter if this command and the test parameter are supported by the VTU; otherwise the VTU shall send a NACK. The format of the octets for each parameter value shall be as described in clause 11.4.1. Values formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet. The format of the LATN, SATN, SNRM and ATTNDR shall be identical to the format used in Single Read Command. The Far-end actual impulse noise protection (ID=27_{16}) shall include two 1-octet values and be sent in the order shown in Table 11-31. The value FF_{16} shall be used to indicate the disabled bearers.

Table 11-31 – Order for sending far-end actual impulse noise protection parameters

Octet number	Parameter
1	INP_act for bearer channel 0
2	INP_act for bearer channel 1

The "SATN for G.993.5 Annex A" command shall be used to retrieve SATN in case of operation according to Annex A of [ITU-T G.993.5]. It shall include five 2-octet values of TXpower_dBm_D(m) for 5 potentially available downstream bands. The format of the octets for each parameter shall be as specified for the actual aggregate transmit power (ACTATP) in clause 11.4.1.1.8. Values formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet. The 2-octet values shall be sent in the order shown in Table 11-29. The value 00_{16} shall be used to indicate the disabled bands. Octets indicated as reserved shall be set to ZERO in the transmitter and ignored by the receiver.

In response to a "SATN for G.993.5 Annex A" command, the VTU shall send the value of SATN. The format of the octets for each parameter value shall be as described in clause 11.4.1. Values formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet. The format of the SATN shall be identical to the format used in Scalar Read Command. The VTU-O shall convey this value for storing in the CO-MIB SATNds object.

In case the VTU-R detects a TIGAV or other OLR procedure after the SATN command and before the response, the VTU-R shall respond with SATN values equal to the special value 1023. The VTU-O shall convey this value for storing in the CO-MIB SATNds object and further reinitiate the SATN command. ~~The VME-O shall communicate this value to the EIA for storing in the CO-MIB SATNds object. The VME-O shall reinitiate the SATN command~~. Timing for this reinitiation is vendor discretionary.

Multiple Read and Next Multiple Read commands shall be used to retrieve test parameters of one subcarrier group. In response to a Multiple Read or Next Multiple Read command, the VTU shall send information for test parameters with ID 01_{16}, 03_{16}, and 04_{16} associated with the indicated subcarrier group. The Multiple Read command contains the index of the requested subcarrier group (see Table 11-26). If a Next Multiple Read command is to be sent, it shall only be sent after a Multiple Read command. In response to each subsequent Next Multiple Read command, the subcarrier group index shall be incremented by one. If the subcarrier group index exceeds 511 (see clause 11.4.1), the response shall be a NACK. The values of the PMD parameters per subcarrier group shall be inserted into the message in numerical order of the parameter ID shown in Table 11-28. The format of the octets for each parameter shall be as described in clause 11.4.1. Values that are formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet.

A Block Read command shall be used to retrieve test parameters over a range of subcarrier groups. In response to a Block Read command, the VTU shall send information for test parameters with ID 01_{16}, 03_{16}, and 04_{16} associated with the specified block of subcarrier groups. For test parameters specified per subcarrier group, all values for subcarrier groups with indices from #start to #stop are transferred in a single response. If the subcarrier group index exceeds 511, the response shall be a NACK. The values of the PMD parameters per subcarrier group shall be inserted into the message in increasing order of the parameter ID shown in Table 11-28. The format of the octets for each parameter value shall be as described in clause 11.4.1. Values formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet. The number of octets in a Block Read command shall not exceed the maximum length P of the eoc message specified in clause 11.2.3.1.

A Vector Block Read command shall be used to retrieve a single test parameter over a range of subcarrier groups. Support of this read command is optional. The ID of the test parameter to retrieve shall be indicated in the third octet of the read command as specified in Table 11-26. In response to a Vector Block Read command, the VTU shall send information for the test parameter associated with the specified block of subcarrier groups if this command is supported by the VTU; otherwise the VTU shall send a NACK. All values for subcarrier groups with indices from #start to #stop are transferred in a single response. If the subcarrier group index exceeds 511, the response shall be a NACK. The format of the octets for each parameter value shall be as described in clause 11.4.1. Values formatted as multiple octets shall be mapped to the response in order of most significant to least significant octet.

When transferring values of the channel transfer function Hlog(f), the quiet line noise QLN(f), and the signal-to-noise ratio SNR(f), the measurement time shall be included in the response for each test parameter. The ACK (see Table 11-27) is followed by the HLOG(f) measurement time and the value m (see clause 11.4.1.1.1), followed by the QLN(f) measurement time and value n (see clause 11.4.1.1.2), followed by the SNR(f) measurement time and value SNR (see clause 11.4.1.1.3), respectively. The measurement time shall be included only once in a response to a Block Read or Vector Block Read command, and shall be included for each test parameter in each response to a Multiple Read or Next Multiple Read command.

The values of some test parameters are represented using fewer bits than contained in the corresponding field defined for the response in Table 11-28. In the case that the field has more than one octet, the bits shall be mapped to the LSBs of the multi-octet field in the response. Unused MSBs in the multi-octet field shall be set to ZERO for unsigned quantities and to the value of the sign bit for signed quantities.

A.7.8 Signal attenuation per band (SATN-pb) (replaces clause 11.4.1.1.5 of [ITU-T G.993.2])

The signal attenuation in the m^{th} downstream band is denoted as SATN_D(m), and the signal attenuation in the m^{th} upstream band is denoted as SATN_U(m).

When operating in ITU-T G.993.5 Annex A, the signal attenuation of the m^{th} upstream band, SATN_U(m) shall be calculated as specified in the main body of clause 11.4.1.1.5 of [ITU-T G.993.5].

When operating in accordance with Annex A of [ITU-T G.993.5], the signal attenuation of the m^{th} downstream band, SATN_D(m), is defined as the difference in dB between the power received at the near end and that transmitted from the far end in the m^{th} downstream band.

Mathematically, this corresponds to:

$$\text{SATN\_D}(m) = \text{TXpower\_dBm\_D}(m) - \text{RXpower\_dBm\_D}(m)$$

During initialization and loop diagnostic mode, the received signal power in dBm, RXpower_dBm_D(m), shall be computed as the received subcarrier power, summed over those subcarriers of this band that are in the MEDLEYds set. The VTU-R shall assume that during transmission of O-P-MEDLEY, the transmit PSD for subcarriers in the MEDLEYds set is at the MREFPSDds level. Therefore, the received signal power shall be fine-tuned with the g_i values for each subcarrier in the MEDLEYds set to estimate the signal power that will be received during showtime.

Mathematically, this corresponds to:

$$\text{RXpower\_dBm\_D(m)} = 10 \times \log_{10}\left(\sum_{i \in (MEDLEYds \cap DS(m))} \left(\text{Received\_subcarrier\_power\_mW}(i) \times g_i^2 \right) \right)$$

During showtime, the received signal power in dBm, Rxpower_dBm_D(m), shall be computed as the received subcarrier power in showtime, summed over those subcarriers of this band that are in the MEDLEYds set.

Mathematically, this corresponds to:

$$\text{RXpower\_dBm\_D(m)} = 10 \times \log_{10}\left(\sum_{i \in (MEDLEYds \cap DS(m))} \left(\text{Received\_subcarrier\_power\_mW}(i) \right) \right)$$

In both equations, MEDLEYds $\cap$ DS(m) denotes all subcarriers of the MEDLEYds set that fall into the m^{th} downstream band, Received_subcarrier_power_mW is the received power on subcarrier i expressed in milli-Watts, and g_i is the gain (linear scale) for subcarrier i.

For the SATN value determined during initialization, the received signal power for each subcarrier i in the MEDLEYds set shall be fine-tuned with the g_i value conveyed in the O-PMD (for the upstream direction) and R-PMD (for the downstream direction) messages to estimate the signal power that will be received during showtime. During loop diagnostic mode, the fine tuning shall be restricted to using g_i values 0 (for subcarriers to which no bits can be allocated) and 1 (for subcarriers to which at least one bit can be allocated). For the SATN value determined during Showtime, the received signal subcarrier power shall be taken as measured.

For the SATN value determined during initialization and loop diagnostic mode, TXpower_dBm_D(m) shall be computed by the VTU-R as the aggregate transmit power, summed over the subcarriers of this band that are in the MEDLEYds set. The VTU-R shall assume that during transmission of O-P-MEDLEY, the transmit PSD for subcarriers in the MEDLEYds set is at the MREFPSDds level. Therefore, the transmitted signal power shall be fine-tuned with the g_i values for each subcarrier in the MEDLEYds set to estimate the signal power that will be transmitted during showtime.

Mathematically, this corresponds to:

$$\text{TXpower\_dBm\_D}(m) = 10 \times \log_{10} \Delta f + 10 \times \log_{10}\left(\sum_{i \in \text{MEDLEYds} \cap \text{DS}(m))} \left(10^{\frac{\text{MREFPSD}[i]}{10}} \times g_i^2 \right) \right)$$

where MEDLEYds ∩ DS(m) denotes all subcarriers of the MEDLEYds set that fall into the m^{th} downstream band, *MREFPSD[i]* is the value of MREFPSDds for subcarrier *i* in dBm/Hz as conveyed by the O-PRM message, g_i is the gain (linear scale) for subcarrier *i*, and Δf is the subcarrier spacing in Hz.

The VTU-O, in cooperation with the VCE, shall update the downstream SATN value reported by the VTU-R during initialization using the correct TXpower_dBm_D(m) values. These shall be computed by the VTU-O, in cooperation with the VCE, as an estimate of the aggregate transmit power, summed over the subcarriers of this band that are in the MEDLEYds set, fine-tuned with the g_i values for each subcarrier in the MEDLEYds set to estimate the signal power that will be transmitted during showtime.

Mathematically, this corresponds to:

$$\text{TXpower\_dBm\_D}(m) = 10log_{10}\left(\sum_{i\epsilon(MEDLEYds\cap DS(m))} Pdirect\_Zi' \times g_i^2\right)$$

where MEDLEYds ∩ DS(m) denotes all subcarriers of the MEDLEYds set that fall into the m^{th} downstream band, and *Pdirect_*Z_i*'* is the power of the direct signal at the output of the precoder for subcarrier *i*, during O-P-MEDLEY, referred to the U-O interface, in milliWatts assuming the network input impedance is 100 Ohms resistive.

NOTE 1 – In actual deployments, the network/loop input impedance may deviate from 100 Ohms resistive.

NOTE 2 – In implementations using a precoder matrix P_i for subcarrier *i*, the *Pdirect_*Z_i*'* may be computed using the diagonal coefficient of matrix P_i, "diag(P_i)", using the following equation:

$$Pdirect_{Zi}{}' = |diag(P_i)|^2 \times P_{Zi} = \Delta f \times 10^{\frac{MREFPSD(i)}{10}} \times (|diag(P_i)|)^2 .$$

For the downstream SATN value determined during initialization, the transmit signal power for each subcarrier *i* in the MEDLEYds set shall be fine-tuned with the g_i value conveyed in the R-PMD (for the downstream direction) messages to estimate the transmit signal power during showtime. During loop diagnostic mode, the fine tuning shall be restricted to using g_i values 0 (for subcarriers to which no bits can be allocated) and 1 (for subcarriers to which at least one bit can be allocated).

For the downstream SATN value determined during showtime, the VTU-R shall use the TXpower_dBm_D(*m*) values as communicated by the VTU-O in the SATN test parameter request command. These shall be computed by the VTU-O, in cooperation with the VCE, as an estimate of the aggregate transmit power, summed over the subcarriers of this band that are in the MEDLEYds set. In showtime this power already incorporates the effect of the g_i values.

Mathematically, this corresponds to:

$$\text{TXpower\_dBm\_D}(m) = 10log_{10}\left(\sum_{i\epsilon(MEDLEYds\cap DS(m))} Pdirect\_Zi'\right)$$

where MEDLEYds ∩ DS(m) denotes all subcarriers of the MEDLEYds set that fall into the m^{th} downstream band, and *Pdirect_*Z_i*'* is the power of the direct signal at the output of the precoder for subcarrier *i*, during showtime, referred to the U-O interface, in milliWatts assuming the network input impedance is 100 Ohms resistive.

NOTE 3 – In actual deployments, the network/loop input impedance may deviate from 100 Ohms resistive.

NOTE 4 – In implementations using a precoder matrix P_i for subcarrier *i*, the *Pdirect_*Z_i*'* may be computed using the diagonal coefficient of matrix P_i, "diag(P_i)", using the following equation:

$$Pdirect_{Zi}{}' = |diag(P_i)|^2 \times P_{Zi} = \Delta f \times 10^{\frac{MREFPSD(i)}{10}} \times (|diag(P_i)| \times g_i)^2 .$$

The signal attenuation shall be measured by the receive PMD function during loop diagnostic mode and initialization (i.e., estimate the signal attenuation at the start of showtime). The measurement shall be updated on request from the far-end during showtime. The signal attenuation shall be sent to the far-end on request during showtime.

The signal attenuation per downstream band, SATN_D(m), shall be represented as a 10-bit unsigned integer *satn*, with the value of SATN_D(m) defined as SATN_D(m) = *satn*/10 dB. This data format supports an SATN_D(m) granularity of 0.1 dB and an SATN_D(m) dynamic range of 102.2 dB (0 to 102.2 dB).

An SATN_D(m) value indicated as *satn* = 1023 is a special value. It indicates that the signal attenuation is out of range to be represented or "undetermined".

A.7.9 Status parameter GAINSpsds

The status parameter *GAINSpsds* is defined as:

$$GAINSpsds_i = g_i \times 10^{\frac{\left(TXPSDdirect_{Zi}{}' - MREFPSDds(i)\right)}{20}}$$

where:

TXPSDdirect_Zi' is the PSD of the direct signal at the output of the precoder for subcarrier *i*, referred to the U-O interface, in dBm/Hz assuming the network input impedance is 100 Ohms resistive;

MREFPSDds is the *MREFPSDds* value as communicated in O-PRM in dBm/Hz.

The $GAINSpsds_i$ shall be updated by the VTU-O, in cooperation with the VCE, upon OLR that change the g_i value, and upon TIGAV that change the *TXPSDdirectZi'* value.

NOTE 1 – The *GAINSpsds* is therefore only updated during the L0 link state.

The valid values for *GAINSpsds* are from 0 to approximately 1.33 (i.e., maximum valid value of g_i).

The *GAINSpsds* shall be represented as a 16-bit unsigned integer expressing the value of *GAINSpsds* in multiples of 1/512, with valid values from 0 to 682. All other values are reserved by ITU-T.

NOTE 2 – If the VTU-O does not operate according to this annex, the $GAINSpsds_i$ are the actual g_i values.

NOTE 3 – In implementations using a precoder matrix P_i for subcarrier *i*, the *GAINSpsds* may be computed using the diagonal coefficient of matrix P_i , "diag(P_i)", using the following equation (see Figure 6-1):

$$GAINSpsds_i = g_i \times diag(P_i)$$

A.8 Management

This clause defines the CO-MIB configuration, status, and inventory parameters specific to Annex A operation. These parameters shall be supported if the VTU-O supports Annex A.

A.8.1 Configuration parameters

A.8.1.1 STRONGFEXT mode (STRONGFEXT_MODE)

The configuration parameter STRONGFEXT_MODE (see clause 7.3.1.17.1 of [ITU-T G.997.1]) is a configuration parameter used to control activation of ITU-T G.993.5 Annex A during initialization.

This parameter has 4 valid values:

0: DISABLED: ITU-T G.993.5 Annex A not allowed. The "Support of strong FEXT mitigation" Npar(3) bit in the ITU-T G.994.1 CL message shall be set to ZERO.

1: PREFERRED: ITU-T G.993.5 Annex A is preferred by the operator. The "Support of strong FEXT mitigation" Npar(3) bit in the ITU-T G.994.1 CL message shall indicate whether the VTU-O supports this annex.

2: FORCED: Force the use of the ITU-T G.993.5 Annex A. The "Support of strong FEXT mitigation" Npar(3) bit in the ITU-T G.994.1 CL message shall indicate whether the VTU-O supports this annex. If the "Support of strong FEXT mitigation" Npar(3) bit is not set to ONE in the ITU-T G.994.1 MS message or the "ITU-T G.993.5" Spar(2) bit is not set to ONE in the ITU-T G.994.1 MS message, then the "ITU-T G.993.2" Spar(1) bit shall be set to ZERO in the MS.

3: FORCED_ABOVE_17MHZ:

- If the ITU-T G.994.1 MS message has the "ITU-T G.993.2" Spar(1) bit set to ONE and the "ITU-T G.993.5" Spar(2) bit set to ONE and the "Support of strong FEXT mitigation" Npar(3) bit set to ZERO, then the ITU-T G.994.1 MS message shall either
  – select operation according to a profile other than 30a and 35b, or,
  – select operation according to profile 35b, with a downstream and upstream SUPPORTEDCARRIERS set in O-SIGNATURE limited to subcarrier index 4095.
- If the ITU-T G.994.1 MS message has the "ITU-T G.993.2" Spar(1) bit is set to ONE and the "ITU-T G.993.5" Spar(2) bit set to ZERO, then the ITU-T G.994.1 MS message shall select operation according to any profile, with a downstream and upstream SUPPORTEDCARRIERS set in O-SIGNATURE limited to a vendor discretionary subcarrier index smaller than or equal to 4095.

  NOTE – The vendor discretionary highest subcarrier index should be chosen such that crosstalk generated to the other lines in the vectored group is sufficiently low, e.g., subcarrier 511 (which may correspond to ITU-T G.992.5 operation).

If the STRONGFEXT_MODE is set to PREFERRED, FORCED or FORCED_ABOVE_17MHz, then

- the RA-MODEds shall be set to Mode 3 (DYNAMIC) or 4 (DYNAMIC with SOS);
- the RTX_MODE_ds shall be set to RTX_FORCED, RTX_PREFERRED or RTX_TESTMODE.

NOTE – This annex is only applicable if the VTU is operating according to Annex Q of [ITU-T G.993.2], which requires mandatory support of SRA and downstream retransmission. This annex assumes that SRA and downstream retransmission are enabled in the CO-MIB.

If the STRONGFEXT_MODE is set to FORCED or to FORCED_ABOVE_17MHz for one line in vectored group, it shall be set to the same mode for all lines in the vectored group (i.e., all or none).

A.8.2 Status parameters

A.8.2.1 Actual STRONGFEXT mode (STRONGFEXT_MODE_ACTUAL)

The STRONGFEXT_MODE_ACTUAL (see clause 7.5.1.45.1 of [ITU-T G.997.1]) status parameter reports for the line whether or not operation in accordance with Annex A of [ITU-T G.993.5] is selected in the ITU-T G.994.1 MS message (regardless whether this selection is autonomous by the VTUs or forced through the CO-MIB).

The valid values are:

- NOT-SELECTED: ITU-T G.993.5 Annex A operation *is not* selected.
- SELECTED: ITU-T G.993.5 Annex A operation *is* selected.

A.8.3 Inventory parameters

A.8.3.1 STRONGFEXT mode support (STRONGFEXT_MODE_SUPPORT_O/R)

The STRONGFEXT_MODE_SUPPORT_O (see clause 7.4.15.1 of [ITU-T G.997.1) and STRONGFEXT_MODE_SUPPORT_R (see clause 7.4.15.2 of [ITU-T G.997.1]) inventory parameters report, for the VTU-O and the VTU-R respectively, whether ITU-T G.993.5 Annex A operation is not supported (set to 0) or supported (set to 1).

Annex B

Vectored long reach VDSL2

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

B.1 Introduction

This annex defines the long reach mode for vectored VDSL2 (VDSL2-LR).

The VDSL2-LR mode is an optional functionality for both the VTU-O and VTU-R. This mode provides different behaviours for short loop, medium loop and long loop operation on different pairs in the same vectored group. The selection of short, medium, or long loop operation is autonomous, taking account of loop loss; unless the selection is overridden by network management.

The behaviours include that:

1) A deployment may host both VDSL2 and VDSL2-LR lines. The VDSL2-LR lines and the VDSL2 lines may be in the same vectored group.
2) If both VTU-O and VTU-R support VDSL2-LR mode, then operation according to this annex is selected during the ITU-T G.994.1 Handshake phase for both VTU-O and VTU-R.
3) Both VDSL2 lines and VDSL2-LR lines are configured to use a particular VDSL2 profile (e.g., 8a/b or 17a), depending on the desired service on VDSL2 lines. Both VDSL2 and VDSL2-LR lines start initialization according to the ITU-T G.993.5 procedure and the selected profile.
4) No overlapped spectrum is allowed in US0 – the frequency band from 25 to 138/276 kHz is used for US0 only and a regular VDSL2 bandplan is used above 138/276 kHz.
5) In VDSL2-LR mode, for the long loop operation, the spectrum is limited to US0 and DS1 up to subcarrier 511 (2.208 MHz).
6) Only the mandatory cyclic extension is supported in VDSL2-LR mode.
7) Unless explicitly stated otherwise in this annex, the VDSL2-LR mode supports all functionalities applicable to the main body of this Recommendation (e.g., DPBO).
8) Upstream crosstalk cancellation is not supported on lines where VDSL2-LR long loop operation is selected (since only the US0 band is used).

B.2 Overview of the initialization procedure

The VDSL2-LR initialization procedure includes two parts:

1) Regular ITU-T G.993.5 procedure (including ITU-T G.993.5 channel estimation) with minor modifications, and
2) Additional stages:
   - PROBING: During this stage, the VTU-R determines the length of the line and indicates to the VTU-O whether to continue the VDSL2-LR initialization in short-medium loop operation or in long loop operation. Following the indication from the VTU-R, both the VTU-O and the VTU-R continue the initialization of the line either in short-medium loop operation or in long loop operation;
   - TRAINING: This stage is present if the VTU-R selected to continue the initialization of the line in long loop operation. During this stage, the VTU-O and VTU-R train the line for long loop operation.

The framework of the initialization procedure is presented in Figure B.1. It illustrates VDSL2-LR initialization (compared to regular ITU-T G.993.5 initialization), using the following notations for the exchanged signals:

- G.993.5 signals – used if the line is a regular ITU-T G.993.5 line, i.e., not operating according to this annex (a regular ITU-T G.993.5 line);
- LR signals, short-medium – used if the line is selected during the PROBING stage to continue the VDSL2-LR initialization in short-medium loop operation (to become a short or medium VDSL2-LR line);
- LR signals, long – used if the line is selected during the PROBING stage to continue the VDSL2-LR initialization in long loop operation (for a long VDSL2-LR line).