International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.993.5

Amendment 1

(12/2011)

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

Digital sections and digital line system – Access networks

Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

Amendment 1

Recommendation ITU-T G.993.5 (2010) – Amendment 1

ITU-T

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Recommendation ITU-T G.993.5

Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

Amendment 1

Summary

Amendment 1 to Recommendation ITU-T G.993.5 (2010) covers:

- Pilot sequence length of multiple of 4 (new functionality).
- Frequency dependent pilot sequence in the downstream direction (new functionality).
- Definition of upstream FEXT coupling coefficients (Xlinpsus) (new functionality).
- Improvement of clarity and consistency of wording (corrigendum).

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.993.5	2010-04-22	15
1.1	ITU-T G.993.5 (2010) Cor. 1	2011-06-22	15
1.2	ITU-T G.993.5 (2010) Amd. 1	2011-12-16	15

FOREWORD

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

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

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

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

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

Recommendation ITU-T G.993.5

Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers

Amendment 1

6.2.2 Sync symbol position

Revise the last sentence of the second paragraph:

The counter value of the first downstream sync symbol transmitted after entering Showtime shall be set by the VCE and transmitted to VTU-R in the field First SSC of the Error Feedback command (see ~~Table 8-6 and Table 8-7~~Table 8-3).

6.2.3 Modulation of a pilot sequence

Revise this clause as follows:

The VTU-O shall have the capability to modulate a VCE specified downstream pilot sequence on all probe tones of the downstream sync symbols during Initialization (see e.g., clause 10.3.3.1) and on all probe tones (see clause 3.3) of the downstream sync symbols during Showtime. The downstream pilot sequence is vendor discretionary, determined by the VCE, and is a binary string of length *Npilot_ds* (with bits indexed from 0 to *Npilot_ds – 1*, and the bit with index 0 transmitted first). If the "pilot sequence length multiple of 4" is enabled (see clause 10.2), then valid values of *Npilot_ds* are all multiples of 4 in the range from 8 to 512. Otherwise, ~~T~~the valid values of *Npilot_ds* shall be all powers of 2 in the range from 8 to 512. The pilot sequence shall be cyclically repeated after *Npilot_ds* bits, except the case where the downstream pilot sequence is changed by the VCE. The downstream pilot sequence bits may be changed by the VCE at any time without notification to the VTU-R, while maintaining the length of the pilot sequence. During initialization, the VTU-O may modulate on all flag tones of the downstream sync symbols either the downstream pilot sequence (the same as modulated on the probe tones), or an all ONEs sequence.

In Showtime, the first downstream sync symbol position shall be as defined in clause 10.6. Each sync symbol shall modulate a pilot sequence, which may be frequency independent or frequency dependent.

The modulation of a frequency independent pilot sequence on the probe tones of sync symbols is defined as whether the sync frame bits modulated onto the probe tones are set to all ZEROS (if the pilot sequence bit is ZERO) or set to all ONES (if the pilot sequence bit is ONE) (i.e., a 1-bit control per sync symbol).

The modulation of a frequency dependent pilot sequence on a probe tone of sync symbols is defined as whether the sync frame bits modulated onto the probe tone shall be set to either 00 (if the pilot sequence bit for that probe tone is ZERO) or set to 11 (if the pilot sequence bit for that probe tone is ONE). Over the tones of a particular sync symbol, the pilot sequence bit shall have a periodicity of 20 tones (considering both probe and flag tones).

The sync frame bits modulated on the flag tones (see clause 3.6) shall be used for the transmission of a Syncflag as defined in clause 10.5.3 of [ITU-T G.993.2]. The sync frame shall be modulated onto a sync symbol as defined in clause 10.5 of [ITU-T G.993.2] (including the quadrant scrambling of all MEDLEY sub-carriers, regardless of being a flag or probe tone).

7.2 Downstream vectoring requirements for the VTU-R

Revise this clause as follows:

The VTU-R shall comply with [ITU-T G.993.2], with exceptions and additional requirements contained in this Recommendation.

This Recommendation defines that all probe tones of a sync symbol, both during initialization and during Showtime, may have the same sign (i.e., if a frequency independent pilot sequence is modulated~~all probe tones modulate the same 4-QAM constellation point, either 00 or 11~~, see clause 6.2.3) or may not have the same sign (i.e., if frequency dependent pilot sequence is modulated, see clause 6.2.3). ~~However, t~~The VTU-R shall support reception and all related functionalities required for computing error signals also in case when not all probe tones of the sync symbol have the same sign, but the sign pattern over the tones of the sync symbol has a periodicity of 20 tones (considering both probe and flag tones).

7.3.2 Sync symbol position

Revise the second sentence of the fourth paragraph as follows:

The counter value of the first downstream sync symbol transmitted in Showtime shall be set by the VTU-R to the value of the field First SSC of the first received Error Feedback command (see ~~Tables 8-6 and 8-7~~Table 8-3).

7.3.3 Modulation of pilot sequence

Revise the first paragraph as follows:

The VTU-R shall have the capability to modulate a VCE-specified upstream pilot sequence on all sub-carriers of the upstream sync symbols during Initialization (see clause 10.3.4.1) and on the probe tones (see clause 3.10) of the upstream sync symbols during Showtime. The upstream pilot sequence is vendor discretionary, determined by the VCE, with length *Npilot_us* and sent to the VTU-R at initialization in the O-SIGNATURE message. Pilot sequence bits are indexed from 0 to *Npilot_us* – 1. The bit with index 0 shall be transmitted first, followed by the bit with index 1, up to bit with index *Npilot_us* – 1. If the "pilot sequence length multiple of 4" is enabled (see clause 10.2), then valid values of *Npilot_us* are all multiples of 4 in the range from 8 to 512. Otherwise, the valid values of *Npilot_us* shall be all powers of 2 in the range from 8 to 512. The pilot sequence shall be cyclically repeated after *Npilot_us* bits, except for the case where the upstream pilot sequence is changed by the VCE through the procedure defined in clause 8.2.

8.2 Pilot sequence update command and response

Change text of fourth paragraph and following as follows:

• • •

The command message length depends on the length of the upstream pilot sequence (*Npilot_us* bits, see clause 7.3.3~~with *Npilot_us* a power of 2 in the range from 8 to 512~~). Only the upstream pilot sequence bits may be changed during Showtime. The newly assigned upstream pilot sequence length shall be the same as the length of the upstream pilot sequence that was set at Initialization.

The command message bytes shall be defined as shown in Table 8-9.

Table 8-9 – Pilot sequence update command transmitted by the VTU-O

Name	Length (Octets)	Octet number	Content
Pilot sequence configuration	$3+\lceil Npilot\_us/8 \rceil$	2	01_{16} for change of upstream pilot sequence (see Note)
		3	01_{16} if interruption of current upstream pilot sequence is not allowed; 02_{16} if interruption of current upstream pilot sequence is allowed (see Note)
		4 to $3+\lceil Npilot\_us/8 \rceil$	Upstream pilot sequence bits, coded as defined for field #4 in Table 10-1.
NOTE – All other values for this octet are reserved by ITU-T.			

10.2 ITU-T G.994.1 Handshake phase

Revise this clause as follows:

The initialization procedure starts with the ITU-T G.994.1 handshake phase. During this phase, the VTU-O and the VTU-R shall exchange their vectoring capabilities in addition to the parameters communicated in a regular handshake phase as defined in [ITU-T G.993.2]. The VTU-O shall support downstream vectoring and may support upstream vectoring. The VTU-R shall support downstream vectoring and shall support upstream vectoring. Based on these capabilities, the final mode of vectored operation (i.e., downstream and upstream vectoring, or downstream-only vectoring) is determined during the ITU-T G.994.1 phase of initialization (see Tables 11.68.0.1 and 11.68.10 of [ITU-T G.994.1 + Amd.5] and Tables 7-a/b/c/d).

~~The capabilities list (CL), capabilities list request (CLR) and mode select (MS) messages shall enable downstream vectoring.~~

~~The CLR message shall enable upstream vectoring. The CL message may enable upstream vectoring. The MS message shall enable upstream vectoring if and only if the last previous CL message indicated support by the VTU-O.~~

The VCE shall force the VTU-O to set the sub-carrier spacing and symbol rate in the initializing line to the same value as used in the other vectored lines.

NOTE 1 – The same symbol rate between all lines of the vectored group is achieved by setting the same ratio between the IDFT size and CE length in samples for upstream and downstream.

NOTE 2 – During the Handshake phase, the VTU-O selects the value of CE based on the supported values indicated by the VTU-O and the VTU-R. Only the value CE=5×N/32 (where 2×N is the IDFT size) is mandatory. In the absence of other information about the CE capabilities of the VTU-R, this will be the only value that is guaranteed to be supported by a new initializing line.

Table 7-a – VTU-O CL message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Downstream vectoring	This bit shall be set to ONE, indicating the VTU-O supports downstream vectoring.
Upstream vectoring	If set to ONE, this bit indicates the VTU-O supports upstream vectoring. If set to ZERO, this bit indicates the VTU-O does not support upstream vectoring.
Pilot sequence length multiple of 4	If set to ONE, this bit indicates the VTU-O supports pilot sequence lengths that are a multiple of 4. If set to ZERO, this bit indicates the VTU-O only supports pilot sequence lengths that are a power of 2.

Table 7-b – VTU-O MS message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Downstream vectoring	This bit shall be set to ONE, indicating downstream vectoring.
Upstream vectoring	This bit shall be set to ONE if and only if set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates upstream vectoring is enabled. If set to ZERO, this bit indicates upstream vectoring is disabled.
Pilot sequence length multiple of 4	This bit shall be set to ONE if and only if set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "pilot sequence length multiple of 4" is enabled. If set to ZERO, this bit indicates only pilot sequence lengths that are a power of 2 are enabled.

Table 7-c – VTU-R CLR message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Downstream vectoring	This bit shall be set to ONE, indicating the VTU-R supports downstream vectoring.
Upstream vectoring	This bit shall be set to ONE, indicating the VTU-R supports upstream vectoring.
Pilot sequence length multiple of 4	If set to ONE, this bit indicates the VTU-R supports pilot sequence lengths that are a multiple of 4. If set to ZERO, this bit indicates the VTU-R only supports pilot sequence lengths that are a power of 2.

Table 7-d – VTU-R MS message NPar(3) bit definitions

ITU-T G.994.1 NPar(3) Bit	Definition of NPar(3) bits
Downstream vectoring	This bit shall be set to ONE, indicating downstream vectoring.
Upstream vectoring	This bit shall be set to ONE if and only if set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates upstream vectoring is enabled. If set to ZERO, this bit indicates upstream vectoring is disabled.
Pilot sequence length multiple of 4	This bit shall be set to ONE if and only if set to ONE in both the last previous CL message and the last previous CLR message. If set to ONE, this bit indicates that "pilot sequence length multiple of 4" is enabled. If set to ZERO, this bit indicates only pilot sequence lengths that are a power of 2 are enabled.

10.3.2.1 O-SIGNATURE

Change text in Field #3 as follows:

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, ~~V~~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.

Change text in Field #4 as follows:

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 $\lceil Npilot\_us/8 \rceil$. If *Npilot_us* is not a multiple of 8 then the last octet of this field shall have the 4 MSBs set to 0.

Change text in Field #7 as follows:

Field #7 "Downstream sync symbol counter modulo value (*N_SSC*)", defines the modulo value used for maintaining the downstream sync counter. 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* $(2^n \times Npilot\_ds) \geq 1024$, *with n integer*. Otherwise, ~~I~~it is coded as an unsigned integer with a single valid value of *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.

11.1 Configuration parameters

Add new clause 11.1.5 as follows:

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

Replace clause 11.2 with the following:

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.

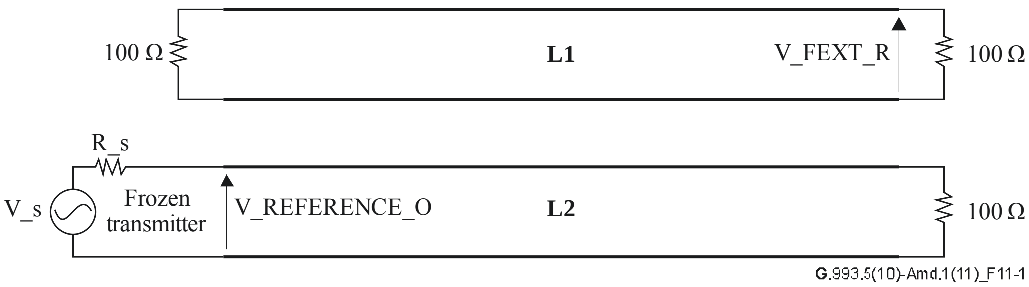

Figure 11-1 – Definition of downstream Xlin (FEXT channel received voltage)

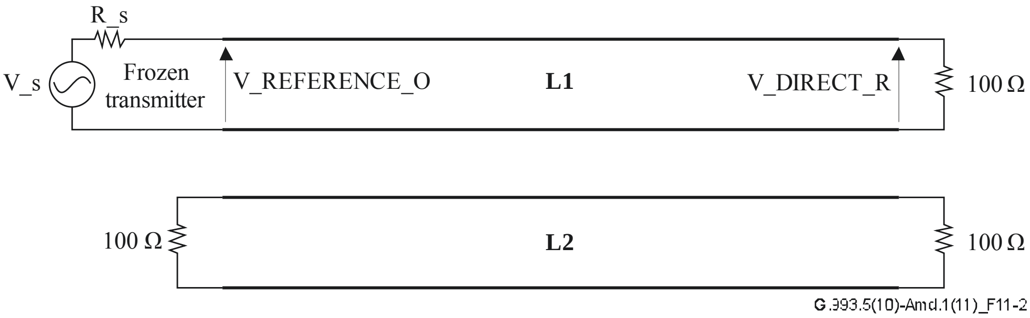

Figure 11-2 – Definition of downstream Xlin (direct channel received voltage)

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

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

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

In this description, *XLINGds* is the sub-carrier 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 $Xlinpsds_{i,j}$ ($n \times \Delta f$) value indicated with $a(n) \geq 0$ and $b(n)$ = 0for 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 ($XLINSCds/2^{15}$) × ($a(n))/2^{15}$.

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

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

All accuracy requirements for *Xlinpsus* 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.

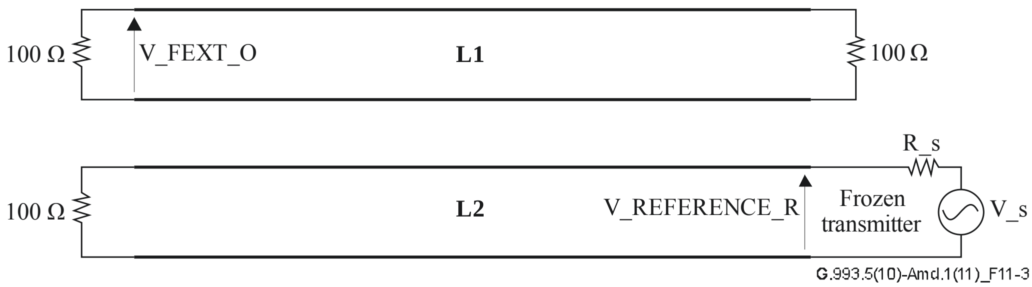

Figure 11-3 – Definition of upstream Xlin (FEXT channel received voltage)

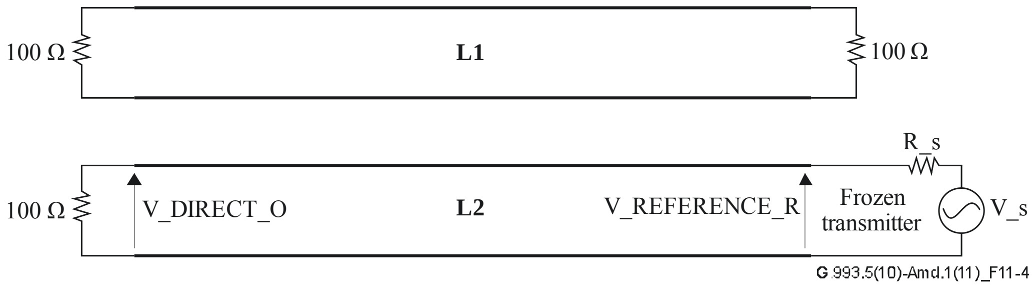

Figure 11-4 – Definition of upstream Xlin (direct channel received voltage)

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 sub-carrier 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.

I.3 MIMO crosstalk channel model A

Change the reference as follows:

A model for the crosstalk channel for North America and Europe can be found in [b-ATIS-~~pp-~~0600024]. This model is based on data gathered from measurements of actual loop plant deployed in North America and Europe and the Technical Report defines a MIMO crosstalk channel model based on these measurements and includes justification for the model.

Bibliography

Change the reference to ATIS as follows:

[b-ATIS~~-pp~~-0600024] ATIS ~~pre-published~~ Technical Report ATIS~~-PP~~-0600024 (2009), *Multiple-Input Multiple-Output Crosstalk Channel Model*.

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Printed in Switzerland
Geneva, 2012