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Technical Specification

Transmission and Multiplexing (TM); Access transmission system on metallic access cables; Symmetrical single pair high bit rate Digital Subscriber Line (SDSL); Part 2: Transceiver requirements

Reference

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

The present document is part 2 of a multi-part TS covering Access transmission system on metallic access cables; Symmetrical single pair high bit rate Digital Subscriber Line (SDSL), as identified below:

Part 1: "Functional requirements";

Part 2: "Transceiver Requirements".

1 Scope

This multi-part TS specifies requirements for transceivers providing bi-directional symmetrical high bit rate transmission on a single metallic wire pair using the echo cancellation method. The technology is referred to as Symmetrical single-pair high bit rate Digital Subscriber Line (SDSL), and is applicable to metallic access transmission systems designed to provide digital access over existing, unshielded wire pairs.

The present document is part 2 of the Technical Specification for SDSL and defines implementation requirements for transceivers which enable the functional requirements of part 1 to be met.

The requirements addressed imply interoperability of SDSL systems. Such interoperability will be achieved when SDSL transceivers provided by different manufacturers are used in one SDSL link.

NOTE: It is planned to merge the parts 1 and 2 into a common specification in the coming revision.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.
- A non-specific reference to an ETS shall also be taken to refer to later versions published as an EN with the same number.

[1] ITU-T Recommendation G.994.1: "Handshake procedures for digital subscriber line (DSL) transceivers".

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BER	Bit Error Ratio
BERTS	Bit Error Rate Test Set
BT	Bridged Tap, an unterminated twisted pair section bridged across the line
CRC	Cyclic Redundancy Check
DLL	Digital Local Line
eoc	embedded operations channel
EMC	Electromagnetic Compatibility
FCS	Frame Check Sequence
FEXT	Far End Crosstalk
HDLC	High level Data Link Control
HDSL	High bit rate Digital Subscriber Line
ISDN BA	Integrated Services Digital Network Basic rate Access
IUT	Item Under Test
LCL	Longitudinal Conversion Loss
lsb	least significant bit
LTU	Line Termination Unit
msb	most significant bit
NEXT	Near End Crosstalk
NTU	Network Termination Unit
OH	Overhead
O&M	Operation and Maintenance

PACC	Pre-activation Communication Channel
PAM	Pulse Amplitude Modulation
PLL	Phase Locked Loop
PMD	Physical Medium Dependent
PMS	Physical Medium Specific
PRBS	Pseudo-Random Bit Sequence
PSD	Power Spectral Density
PSL	Power Sum Loss
REG	Regenerator
REG-C	NTU side of the regenerator
REG-R	LTU side of the regenerator
RF	Radio Frequency
rms	root mean square
SDH	Synchronous Digital Hierarchy
SDSL	Symmetric single pair high bit rate Digital Subscriber Line
SNR	Signal to Noise Ratio
TC	Transmission Convergence
TC-PAM	Trellis Coded Pulse Amplitude Modulation
TPS	Transmission Protocol Specific
TMN	Telecommunication Management Network
TU-12	Tributary Unit-12
UC-PAM	Ungerboeck Coded Pulse Amplitude Modulation
UTC	Unable to comply
VC-12	Virtual Container-12
2B1Q	two binary one quaternary line code

4 PMD Layer Functional Characteristics

4.1 Activation

This subclause describes waveforms at the loop interface and associated procedures during activation mode. The direct specification of the performance of individual receiver elements is avoided when possible. Instead, the transmitter characteristics are specified on an individual basis and the receiver performance is specified on a general basis as the aggregate performance of all receiver elements. Exceptions are made for cases where the performance of an individual receiver element is crucial to interoperability.

In subclause 4.1.2 "convergence" refers to the state where all adaptive elements have reached steady-state. The declaration of convergence by a transceiver is therefore vendor dependent. Nevertheless, actions based on the state of convergence are specified to improve interoperability.

4.1.1 Activation PMD reference model

The block diagram of the activation mode PMD layer of an LTU or NTU transmitter is shown in figure 1.

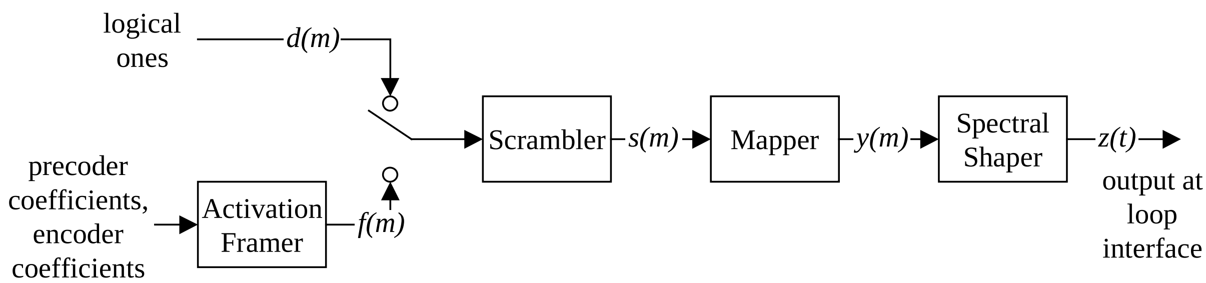

Figure 1: Activation PMD reference model

The time index *m* represents the symbol time, and *t* represents analogue time. Since activation uses 2-PAM modulation, the bit time is equivalent to the symbol time. The output of the framer are the framed information bits *f(m)*. The output of the scrambler is *s(m)*. The output of the mapper is *y(m)*, and the output of the spectral shaper at the loop interface is *z(t)*. *d(m)* is an initialization signal that shall be logical ones for all *m*. The modulation format shall be uncoded 2-PAM, with the full symbol rate selected for data mode operation. During activation the timing reference for the activation signals have a tolerance of ±32 ppm at the LTU and ±100 ppm at the NTU.

4.1.2 Activation sequence

The timing diagram for the activation sequence is given in figure 2. The state transition diagram for the activation sequence is given in figure 3. Each activation signal in the activation sequence shall satisfy the tolerance values listed in table 1.

NOTE: A warm-start procedure is under study for use in systems that can go into a deactivated state, when no communication is going on.

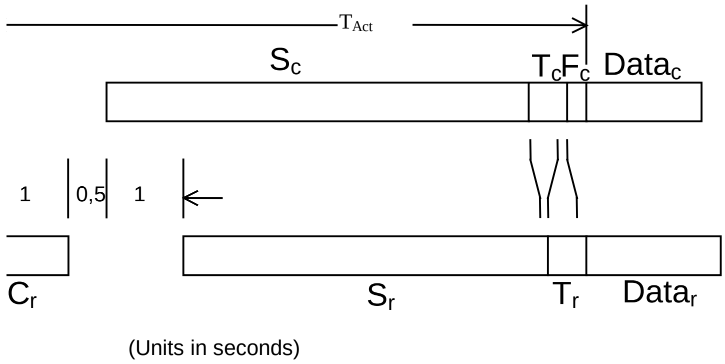

Figure 2: Timing Diagram for activation sequence

Table 1: Tolerance values for activation signals

Signal	Parameter	Reference	Nominal Value	Tolerance
C_r	duration	subclause 4.1.2.1	1 s	±20 ms
S_c	time after end of C_r	subclause 4.1.2.2	500 ms	±20 ms
S_r	time after end of C_r	subclause 4.1.2.3	1,5 s	±20 ms

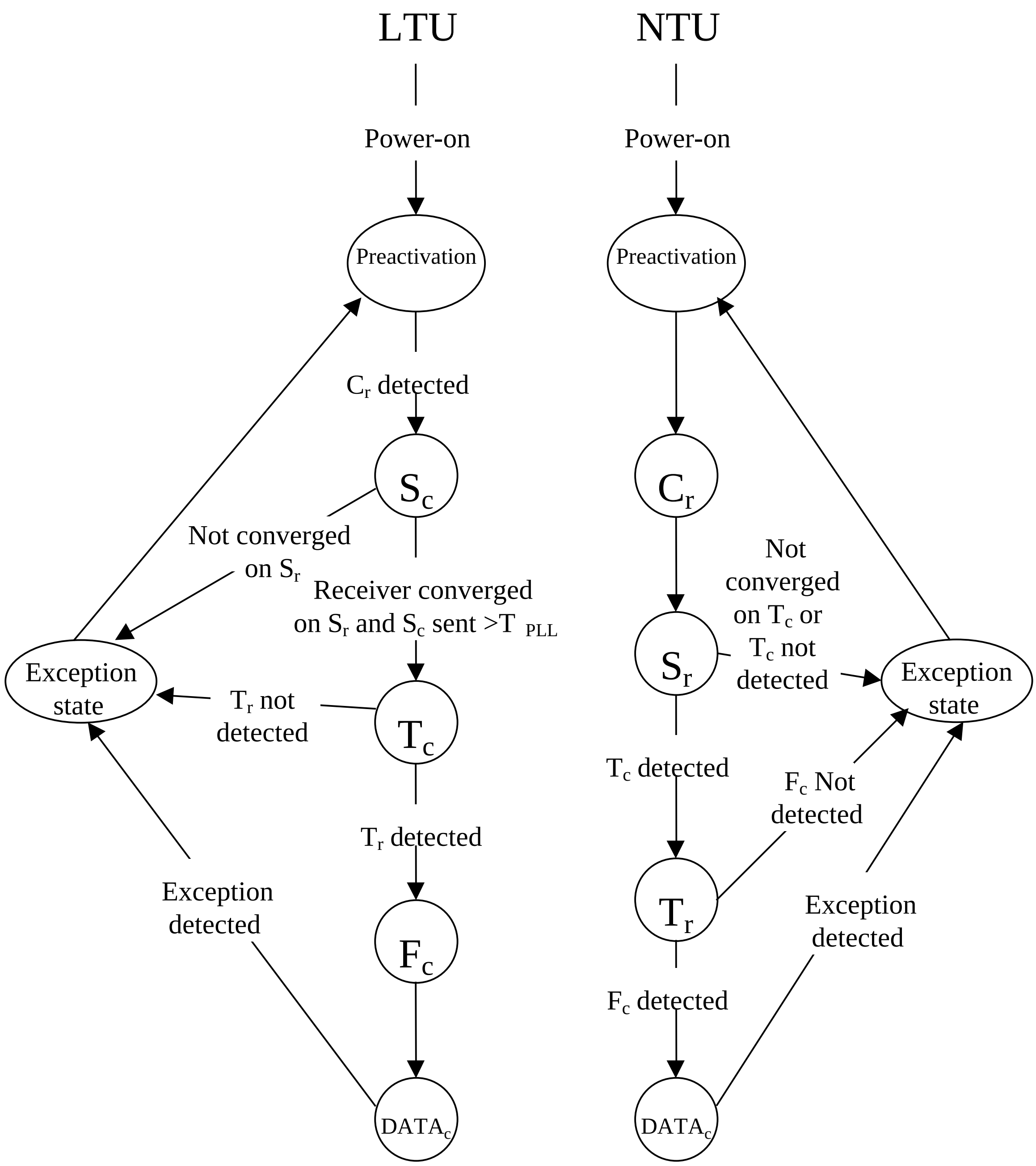

Figure 3: LTU and NTU Transmitter State Transition Diagram

4.1.2.1 Signal C_r

After exiting the pre-activation sequence (see subclause 4.1.4), the NTU shall send C_r. Waveform C_r shall be generated by connecting the signal *d(m)* to the input of the NTU scrambler as shown in figure 1. The PSD mask for C_r shall be the upstream PSD mask, as negotiated during pre-activation sequence. C_r shall have a duration of 1 s and shall be sent 0,3 s after the end of pre-activation.

4.1.2.2 Signal S_c

After detecting C_r, the LTU shall send S_c. Waveform S_c shall be generated by connecting the signal *d(m)* to the input of the LTU scrambler as shown in figure 1. The PSD mask for S_c shall be the downstream PSD mask, as negotiated during pre-activation sequence. S_c shall be sent 0,5 s after the end of C_r. If the LTU does not converge while S_c is transmitted, it shall enter the exception state (subclause 4.1.2.8).

4.1.2.3 Signal S_r

The NTU shall send S_r, beginning 1,5 s after the end of C_r. Waveform S_r shall be generated by connecting the signal *d(m)* to the input of the NTU scrambler as shown in figure 1. The PSD mask for S_r shall be the same as for C_r. If the NTU does not converge and detect T_c while S_r is transmitted, it shall enter the exception state (subclause 4.1.2.8). The method used to detect T_c is vendor dependent. In timing modes supporting loop timing, waveform S_r and all subsequent signals transmitted from the NTU shall be loop timed, i.e., the NTU symbol clock shall be locked to the LTU symbol clock.

4.1.2.4 Signal T_c

Once the LTU has converged and has been sending S_c for at least T_{PLL} seconds (see table 4), it shall send T_c. Waveform T_c contains the precoder coefficients and other system information. T_c shall be generated by connecting the signal *f(m)* to the input of the LTU scrambler as shown in figure 1. The PSD mask for T_c shall be the same as for S_c. The signal *f(m)* is the activation frame information as described in subclause 4.1.3. If the LTU does not detect T_r while sending T_c, it shall enter the exception state (subclause 4.1.2.8). The method used to detect T_r is vendor dependent.

4.1.2.5 Signal T_r

Once the NTU has converged and has detected the T_c signal, it shall send T_r. Waveform T_r contains the precoder coefficients and other system information. T_r shall be generated by connecting the signal *f(m)* to the input of the NTU scrambler as shown in figure 1. The PSD mask for T_r shall be the same as for C_r. The signal *f(m)* is the activation frame information as described in subclause 4.1.3. If the NTU does not detect F_c while sending T_r, it shall enter the exception state (subclause 4.1.2.8). The method used to detect F_c is vendor dependent.

4.1.2.6 Signal F_c

Once the LTU has detected T_r, it shall send F_c. Signal F_c shall be generated by connecting the signal *f(m)* to the input of the LTU scrambler as shown in figure 1. The PSD mask for F_c shall be the same as for S_c. The signal *f(m)* is the activation frame information as described in subclause 4.1.3 with the following exceptions: the frame sync word shall be reversed in time and the payload information bits shall be set to arbitrary values. The payload information bits correspond to the following fields in table 2: Precoder Coefficients, Encoder Coefficients and Reserved. The CRC shall be calculated on this arbitrary-valued payload. The signal F_c shall be transmitted for exactly two activation frames. As soon as the first bit of F_c is transmitted, the payload data in the T_r signal shall be ignored.

4.1.2.7 $Data_c$ and $Data_r$

Within 200 symbols after the end of the second frame of F_c, the LTU shall send $Data_c$, and the NTU shall send $Data_r$. These signals are described in subclause 4.2. The PSD mask for $Data_r$ shall be the same as for C_r, and the PSD mask for $Data_c$ shall be the same as for S_c. There is no required relationship between the end of the activation frame and any bit within the SDSL data-mode frame. $T_{PayloadValid}$ seconds (see table 4) after the end of F_c, the SDSL payload data shall be valid.

4.1.2.8 Exception state

An exception condition shall be declared during activation if any of the timeouts given in table 4 expire or if any vendor-defined abnormal event occurs. An exception condition shall be declared during data mode if the vendor-defined abnormal event occurs. A vendor-defined abnormal event shall be defined as any event that requires loop restart for recovery.

4.1.2.9 Exception condition

Exception conditions are vendor-defined. Broadly, they indicate abnormal operation that requires termination and a loop restart. An example would be a vendor-defined timeout for the transmission of signal C_r.

4.1.3 Activation framer

The format of the activation frame is shown in table 2. A T_c or T_r signal shall be generated by repetitively applying the activation frame information shown in table 2 to the scrambler shown in figure 1. The activation frame contents shall be constant during the transmission of T_c and T_r . The activation frame sync bits are not scrambled, so they shall be applied directly to the uncoded 2-PAM constellation. The total number of bits in the activation frame is 4227. The activation frame shall be sent starting with bit 1 and ending with bit 4227.

Table 2: Activation frame format

Activation frame bit lsb:msb	Definition
1:14	Frame sync for T_c and T_r: 11111001101011, where the left-most bit is sent first in time
	Frame Sync for F_c : 11010110011111, where the left-most bit is sent first in time
15:36	Precoder Coefficient 1: 22 bit signed two's complement format with 17 bits after the binary point, where the LSB is sent first in time
37:58	Precoder Coefficient 2
59:3952	Precoder Coefficients 3 - 179
3953:3974	Precoder Coefficient 180
3975:3995	Encoder Coefficient A: 21 bits where the LSB is sent first in time
3996:4016	Encoder Coefficient B: 21 bits where the LSB is sent first in time
4017:4144	Vendor Data: 128 bits of proprietary information
4145:4211	Reserved: 67 bits set to logical zeros
4212:4227	CRC: C_1 sent first in time, C_{16} sent last in time

4.1.3.1 Frame sync

The frame sync for T_c and T_r is a 14 bit Barker code. In binary, the code shall be 11111001101011, and shall be sent from left to right. For F_c and F_r, the frame sync shall be 11010110011111, or the reverse of the frame sync for T_c and T_r.

4.1.3.2 Precoder coefficients

The precoder coefficients are represented as 22-bit two's complement numbers, with the 5 most significant bits representing integer numbers from -16 (10000) to +15 (01111), and the remaining 17 bits are the fractional bits. The coefficients are sent sequentially, starting with coefficient C_1 and ending with coefficient C_N (from figure 9), and the least significant bit of each coefficient is sent first in time. The minimum number of precoder coefficients shall be 128 and the maximum number shall be 180. If fewer than 180 precoder coefficients are used, the remaining bits in the field shall be set to zero.

4.1.3.3 Encoder coefficients

Referring to figure 8, the coefficients for the programmable encoder are sent in the following order: a_0 is sent first in time, followed by a_1, a_2, …, and b_{20} is sent last in time.

4.1.3.4 Vendor ID

These 128 bits are reserved for vendor-specific data.

4.1.3.5 Reserved

These 67 bits are reserved for future use and shall be set to logical zeros.

4.1.3.6 CRC

The sixteen CRC bits (c_1 to c_{16}) shall be the coefficients of the remainder polynomial after the message polynomial, multiplied by D^{16}, is divided by the generating polynomial. The message polynomial shall be composed of the bits of the activation frame, where m_0 is bit 15 and m_{4196} is bit 4211 of the activation frame, such that:

$$CRC(D) = m_1(D)\, D^{16} \bmod g(D)$$

where:

$$m(D) = m0D4196 \oplus m1\, D4195 \oplus ... \oplus m4195\, D \oplus m4196$$

is the message polynomial,

$$g(D) = D16 \oplus D12 \oplus D5 \oplus 1$$

is the generating polynomial,

$$CRC(D) = c1D15 \oplus c2D14 \oplus ... \oplus c15D \oplus c16$$

is the CRC check polynomial, $\oplus$ indicates modulo-2 addition (exclusive OR), and D is the delay operator.

4.1.4 Pre-activation Communication Channel (PACC)

The pre-activation communication channel shall use the modulation and message structure as described in ITU-T Recommendation G.994.1 [1].

4.1.5 Scrambler

The scrambler in the LTU and the NTU transmitters shall operate as shown in figure 7.5 of part 1. The frame sync bits in the activation frame shall not be scrambled. While the frame sync bits are present at *f(n)*, the scrambler shall not be clocked, and *f(n)* shall be directly connected to *s(n).*

4.1.6 Mapper

The output bits from the scrambler *s(m)* shall be mapped to the an output level *y(m)* as follows:

Table 3: Bit-to-level mapping

Scrambler output ***s(m)***	Mapper output level ***y(m)***	Data mode index
0	-9/16	0011
1	+9/16	1000

These levels corresponding in the scrambler outputs 0 and 1 shall be identical to the levels in the 16-TC-PAM constellation (table 6) corresponding to indexes 0011 and 1000 respectively.

4.1.7 Spectral shaper

The same spectral shaper shall be used for data mode and activation mode as described in subclause 4.3.5.

4.1.8 Timeouts

Table 4 shows the system timeouts and their values. T_{act} shall be the maximum time from the start of C_r to the start of $Data_r$. It controls the overall time of the train. $T_{PayloadValid}$ shall be the time between the start of data mode and when the SDSL payload data is valid (this accounts for settling time, data flushing, frame synchronization, etc). $T_{Silence}$ shall be the minimum time in the exception state where the LTU or NTU are silent before returning to pre-activation. T_{PLL} shall be the time allocated for the NTU to pull in the LTU timing. The LTU shall transmit S_c for at least T_{PLL} seconds.

Table 4: Timeout values

Parameter	Name	Value
Maximum time from start of C_r to $Data_r$	T_{act}	15 s
Time from start of $Data_c$ or $Data_r$ to valid SDSL payload data	$T_{PayloadValid}$	1 s
Minimum silence time from exception condition to start of train	$T_{Silence}$	2 s
Time from start of S_c to NTU PLL lock	T_{PLL}	5 s

4.2 PMD pre-activation sequence

This subclause describes waveforms at the loop interface and associated procedures during pre-activation mode. The direct specification of the performance of individual receiver elements is avoided when possible. Instead, the transmitter characteristics are specified on an individual basis and the receiver performance is specified on a general basis as the aggregate performance of all receiver elements. Exceptions are made for cases where the performance of an individual receiver element is crucial to interoperability.

4.2.1 PMD pre-activation reference model

The reference model of the pre-activation mode of an LTU or NTU transmitter is shown in figure 4.

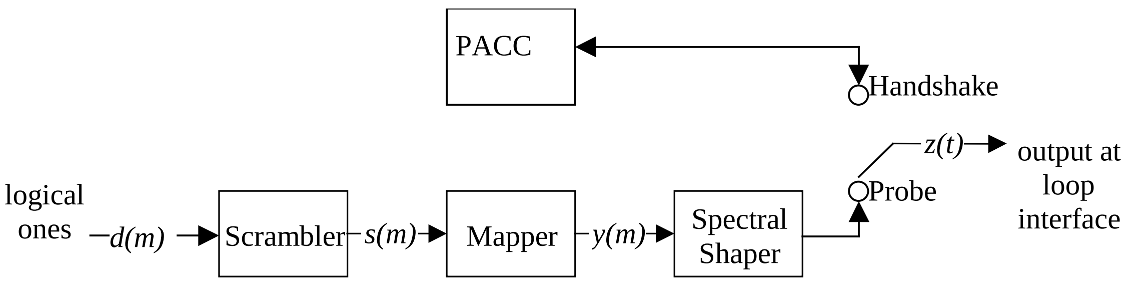

Figure 4: Pre-activation reference model

The time index *m* represents the symbol time, and *t* represents analogue time. Since the probe signal uses 2-PAM modulation, the bit time is equivalent to the symbol time. The output of the scrambler is *s(m)*. The output of the mapper is *y(m)* and the output of the spectral shaper at the loop interface is *z(t)*. *d(m)* is an initialization signal that shall be logical ones for all *m*. The probe modulation format shall be uncoded 2-PAM, with the symbol rate, spectral shape, duration, and power back-off selected by PACC. Probe results shall be exchanged by PACC.

4.2.2 PMD pre-activation sequence description

A typical timing diagram for the pre-activation sequence is given in figure 5. Each signal in the pre-activation sequence shall satisfy the tolerance values listed in table 5.

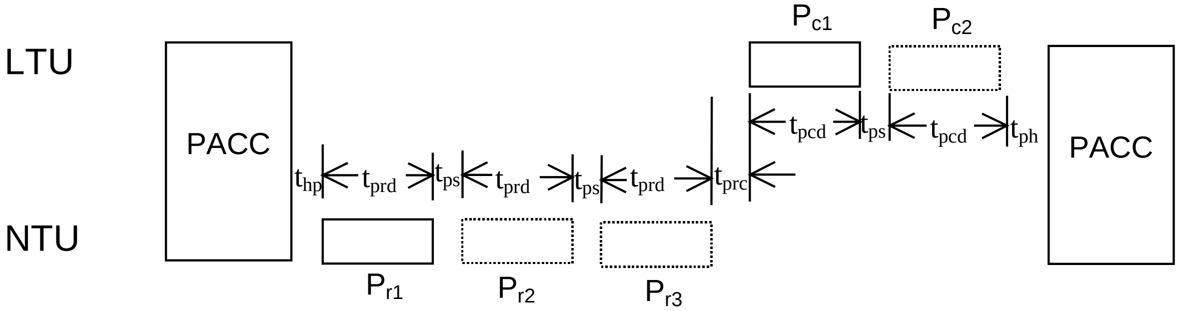

Figure 5: Typical timing diagram for pre-activation sequence

Table 5: Timing for pre-activation signals

Time	Parameter	Nominal value	Tolerance
t_{hp}	Time from end of handshake to start of remote probe	0,2 s	±10 ms
t_{prd}	Duration of remote probe	Selectable ≤ 3,1 s	
t_{ps}	Time separating two probe sequences	0,2 s	±10 ms
t_{prc}	Time separating last remote and first central probe sequences	0,2 s	±10 ms
t_{pcd}	Duration of central probe	Selectable ≤ 3,1 s	
t_{ph}	Time from end of central probe to start of handshake	0,2 s	±10 ms

NOTE: Tolerances are relative to the nominal or ideal value. They are not cumulative across the pre-activation sequence.

4.2.2.1 Signal P_{ri}

If the optional line probe is selected during the PACC session (see subclause 4.1.4), the NTU shall send the remote probe signal. The symbol rate for the remote probe signal shall be negotiated during the PACC session, and shall correspond to the symbol rate used during activation for the specified data rate. If multiple remote probe symbol rates are negotiated during the PACC session, then multiple probe signals will be generated, starting with lowest symbol rate negotiated and ending with the highest symbol rate negotiated. P_{ri} is the i^{th} probe signal (corresponding to the i^{th} symbol rate negotiated). Waveform P_{ri} shall be generated by connecting the signal *d(m)* to the input of the NTU scrambler as shown in figure 4. The PSD mask for P_{ri} shall be the upstream PSD mask used for signal C_r at the same symbol rate, and shall be selectable between the PSDs for activating at data rates of 192 kbit/s to 2 304 kbit/s in steps of 64 kbit/s. The duration (t_{prd}) and power back-off shall be the same for all P_{ri}, and shall be negotiated during the PACC session. The duration shall be selectable between 50 ms and 3,1 s in steps of 50 ms, and the power back-off shall be selectable between 0 dB and 15 dB in steps of 1 dB. The probe signal power back-off can be selected using either the received PACC signal power or *a priori* knowledge. If no information is available, implementers are encouraged to select a probe power back-off of at least 6 dB. The first remote probe signal shall begin t_{hp} seconds after the end of the PACC session. There shall be a t_{ps} second silent interval between successive remote probe signals.

4.2.2.2 Signal P_{ci}

The LTU shall send the central probe signal t_{prc} seconds after the end of the last remote probe signal. The symbol rate for the central probe signal shall be negotiated during the PACC session, and shall correspond to the symbol rate used during activation for the specified data rate. If multiple central probe symbol rates are negotiated during the PACC session, then multiple probe signals will be generated, starting with lowest symbol rate negotiated and ending with the highest symbol rate negotiated. Waveform P_{ci} is the i^{th} probe signal (corresponding to the i^{th} symbol rate negotiated). Waveform P_{ci} shall be generated by connecting the signal *d(m)* to the input of the LTU scrambler as shown in figure 4. The PSD mask for P_{ci} shall be the downstream PSD mask used for signal S_c at the same symbol rate, and shall be selectable between the PSDs for activating at data rates of 192 kbit/s to 2 304 kbit/s in steps of 64 kbit/s. The duration (t_{pcd}) and power back-off shall be the same for all P_{ci}, and shall be negotiated during the PACC session. The duration shall be selectable between 50 ms and 3,1 s in steps of 50 ms, and the power back-off shall be selectable between 0 dB and 15 dB in steps of 1 dB. The probe signal power back-off can be selected using either the received PACC signal power or a priori knowledge. If no information is available, implementers are encouraged to select a probe power back-off of at least 6 dB. There shall be a t_{ps} silent interval between successive central probe signals, and there shall be a t_{ph} second silent interval between the last central probe signal and the start of the following PACC session.

4.2.3 Scrambler

The scrambler used in the PMD pre-activation has the same basic structure as the data mode scrambler, but can have different scrambler polynomial. During PACC session the scrambler polynomial for each probe sequence is selected by the receiver from the set of allowed scrambler polynomials listed in table 6. The transmitter shall support all the polynomials in table 6. During PMD pre-activation the transmit scrambler shall use the scrambler polynomial selected by the receiver during the PACC session. The scrambler shall be initialized to all zero.

Table 6: Pre-activation scrambler polynomials

Index	LTU polynomial	NTU polynomial
0	$s(n) = s(n-5) \oplus s(n-23) \oplus d(n)$	$s(n) = s(n-18) \oplus s(n-23) \oplus d(n)$
1	$s(n) = s(n-1) \oplus d(n)$	$s(n) = s(n-1) \oplus d(n)$
2	$s(n) = s(n-2) \oplus s(n-5) \oplus d(n)$	$s(n) = s(n-3) \oplus s(n-5) \oplus d(n)$
3	$s(n) = s(n-1) \oplus s(n-6) \oplus d(n)$	$s(n) = s(n-5) \oplus s(n-6) \oplus d(n)$
4	$s(n) = s(n-3) \oplus s(n-7) \oplus d(n)$	$s(n) = s(n-4) \oplus s(n-7) \oplus d(n)$
5	$s(n) = s(n-2) \oplus s(n-3) \oplus s(n-4) \oplus s(n-8) \oplus d(n)$	$s(n) = s(n-4) \oplus s(n-5) \oplus s(n-6) \oplus s(n-8) \oplus d(n)$

4.2.4 Mapper

The output bits from the scrambler *s(m)*, shall be mapped to the output level *y(m)*, as described in subclause 4.1.6.

4.2.5 Spectral shaper

The same spectral shaper shall be used for data mode and activation mode as described in subclause 4.3.5.

4.3 Data mode

This subclause describes the waveform at the line interface during data mode given the input bit stream from the TC layer.

4.3.1 Data mode PMD reference model

The block diagram of the data mode PMD layer of an LTU or NTU transmitter is shown in figure 6.

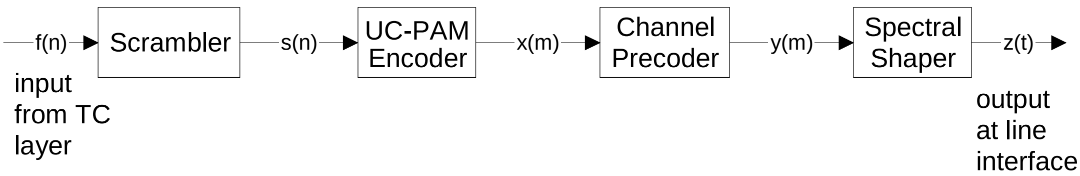

Figure 6: Data mode PMD reference model

The time index n represents the bit time, the time index m represents the symbol time, and t represents analogue time. The input from the TC layer is f(n), s(n) is the output of the scrambler, x(m) is the output of the UC-PAM (Ungerboeck Coded Pulse Amplitude Modulation) encoder, y(m) is the output of the channel precoder, and z(t) is the analogue output of the spectral shaper at the line interface. When transferring K information bits per one-dimensional PAM symbol, the symbol duration is K times the bit duration, so the K values of n for a given value of m are {mK, mK+1, …, mK+K-1}.

4.3.1.1 PMD rates

The transmission is 16 UC-PAM. There are 3 data bits and 1 redundant bit transmitted each symbol. The TU shall support a line rate of (n*64 + i*8 + 8) kbit/s, where n is an integer value from 3 to 36 and i is an integer value from 0 to 7. The tolerance on the symbol rate shall be ±32 ppm.

4.3.2 Scrambler

The scrambler in the LTU and the NTU transmitters are described in subclause 7.8 of part 1. While the frame sync bits and stuff bits are present at f(n), the scrambler shall not be clocked and f(n) shall be directly connected to s(n).

4.3.3 UC-PAM encoder

The block diagram of the UC-PAM encoder is shown in figure 7. The serial bit stream from the scrambler s(n) shall be converted to a K-bit parallel word at the m^{th} symbol time, then processed by the convolutional encoder. The resulting K+1-bit word shall be mapped to one of 2^{K+1} pre-determined levels forming x(m).

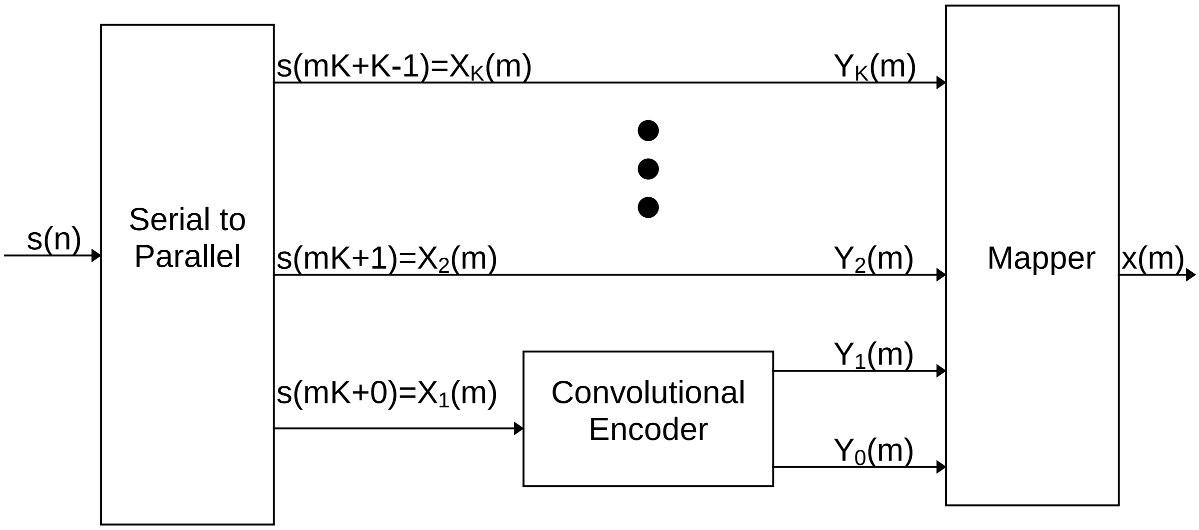

Figure 7: Block diagram of the UC-PAM encoder

4.3.3.1 Serial-to-parallel converter

The serial bit stream from the scrambler, s(n), shall be converted to a K-bit parallel word $\{X_1(m)=s(mK), X_2(m)=s(mK+1), \ldots, X_K(m)=s(mK+K-1)\}$ at the m^{th} symbol time, where $X_1(m)$ is the first in time.

4.3.3.2 Convolutional encoder

Figure 8 shows the feedforward non-systematic convolutional encoder, where T_s is a delay of one symbol time, '⊕' is binary exclusive-OR, and '⊗' is binary AND. $X_1(m)$ shall be applied to the convolutional encoder, $Y_1(m)$ and $Y_0(m)$ shall be computed, then $X_1(m)$ shall be shifted into the shift register.

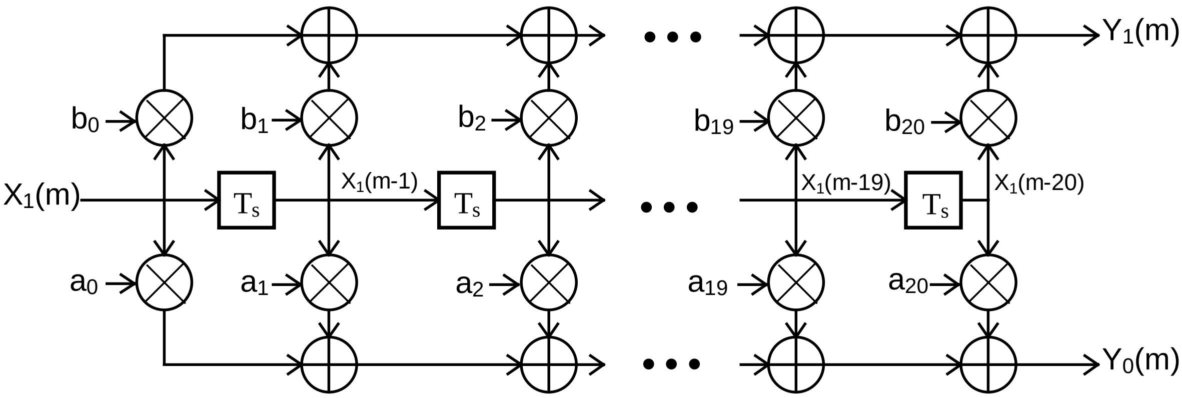

Figure 8: Block diagram of the convolutional encoder

The binary coefficients a_i and b_i shall be passed to the encoder from the receiver during the activation phase specified in subclause 4.1. A numerical representation of these coefficients is A and B, where:

$$A = a_{20}\bullet 2^{20}+a_{19}\bullet 2^{19}+a_{18}\bullet 2^{18}+...+a_0\bullet 2^0$$

and

$$B = b_{20}\bullet 2^{20}+b_{19}\bullet 2^{19}+b_{18}\bullet 2^{18}+...+b_0\bullet 2^0$$

The specific choice of Ungerboeck code is vendor specific. The Ungerboeck code shall be chosen such that the system performance requirements are satisfied.

4.3.3.3 Mapper

For K=3, the bits $Y_3(m)$, $Y_2(m)$, $Y_1(m)$, and $Y_0(m)$ shall be mapped to a level x(m) as specified in table 7.

Table 7: Data mode bit-to-level mapping

Trellis encoder output, $Y_3(m)$ $Y_2(m)$ $Y_1(m)$ $Y_0(m)$	**Level x(m) (note)**
0000	-15/16
0001	-13/16
0010	-11/16
0011	-9/16
0100	-7/16
0101	-5/16
0110	-3/16
0111	-1/16
1100	1/16
1101	3/16
1110	5/16
1111	7/16
1000	9/16
1001	11/16
1010	13/16
1011	15/16
NOTE: The values are fractions of the value 1 as defined in subclause 4.3.4.	

4.3.4 Channel precoder

The block diagram of channel precoder is shown in figure 9, where T_s is a delay of one symbol time.

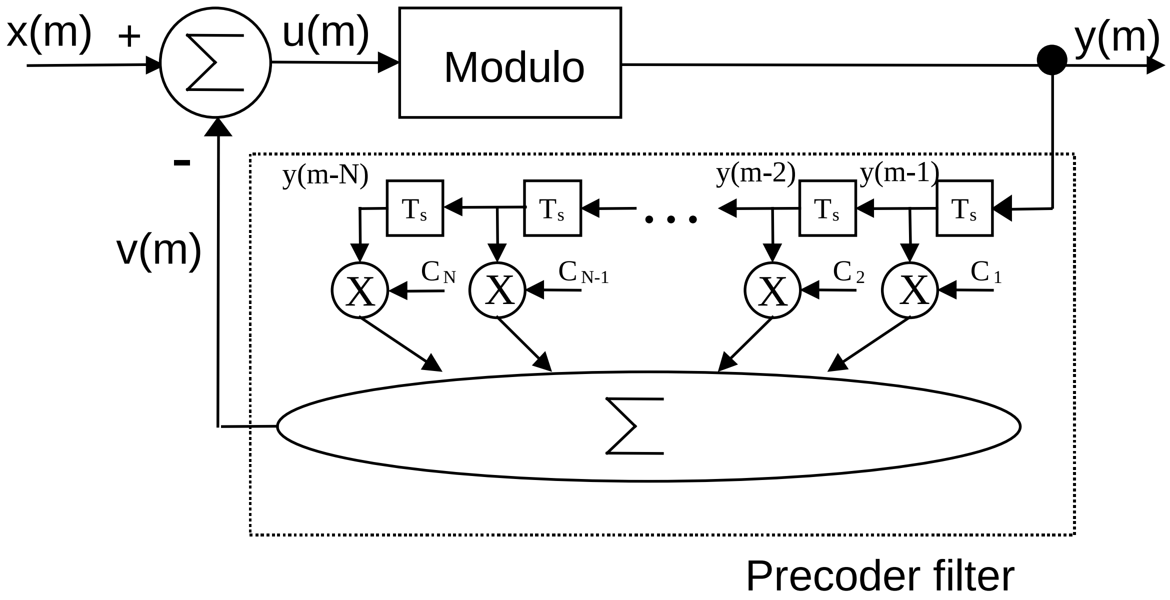

Figure 9: Block diagram of the channel precoder

The coefficients C_k of the precoder filter shall be transferred to the channel precoder as described in subclause 4.1.3.2. The output of the precoder filter v(m) shall be computed as follows:

$$v(m) = \sum_{k=1}^{N} C_k y(m-k)$$

The function of the modulo block shall be to determine y(m) as follows: for each value of u(m), find an integer d(m) such that:

$$-1 \le u(m)+2d(m) < 1$$

and then:

$$y(m) = u(m)+2d(m)$$

4.3.5 Spectral shaper

The spectral shaper for the LTU and the NTU transmitters shall operate on the output of the respective precoders (data mode) or mappers (activation and pre-activation mode). The analogue output z(t) of the spectral shaper is coupled to the loop, and shall have a power spectral density which is limited by masks and have a limited total power. Power and power spectral density is measured into a load impedance of 135 Ω. The power spectral density for all modes, including pre-activation probing signals, shall be measured using a 3 kHz wide sliding window. The test procedure for transmit power compliance is specified in TBD.

4.4 PSD masks

For all data rates, the measured transmit PSD of each LTU OR NTU shall not exceed the PSD masks specified in this subclause ($PSDMASK_{SDSL}(f)$), and the measured total power measured into a load impedance of 135 Ω shall fall within the range specified in this subclause ($P_{SDSL} \pm 0,5$ dB). The symmetric PSD masks shall be mandatory, and the asymmetric PSD masks shall be optional. Table 8 lists the supported PSDs and the associated constellation sizes.

Table 8: PSD and constellation size

Symmetric PSDs		Asymmetric PSDs			
DS	US	DS	US	DS	US
Coded 16-PAM	Coded 16-PAM	Coded 16-PAM	Coded 16-PAM	Coded 8-PAM	Coded 16-PAM
Mandatory		Optional		For further study	

4.4.1 Symmetric PSD masks

For all values of framed data rate available in the LTU OR NTU, the following set of PSD masks ($PSDMASK_{SDSL}(f)$) shall be selectable:

$$PSDMASK_{SDSL}(f) = \begin{cases} PBO \times \dfrac{K_{SDSL}}{135} \times \dfrac{1}{f_{sym}} \times \dfrac{\left[\sin\left(\dfrac{\pi f}{f_{sym}}\right)\right]^2}{\left(\dfrac{\pi f}{f_{sym}}\right)^2} \times \dfrac{1}{1+\left(\dfrac{f}{f_{3dB}}\right)^{2\times Order}} \times 10^{\frac{MaskOffsetdB(f)}{10}} & , \quad f < f_{int} \\ 0{,}5683 \times 10^{-4} \times f^{-1{,}5} & , \quad f_{int} \le f < 1{,}5 MHz \end{cases}$$

see table 10, 1,5 MHz ≤ f ≤ 11,040 MHz

The inband PSD for 0 < f < 1,5 MHz shall be measured with a 10 kHz resolution bandwidth.

Where MaskOffsetdB(f) is defined as:

$$MaskOffsetdB(f) = \begin{cases} 1 + 0{,}4 \times \dfrac{f_{3dB} - f}{f_{3dB}} & , \quad f < f_{3dB} \\ 1 & , \quad f \ge f_{3dB} \end{cases}$$

f_{int} is the frequency where the two equations governing $PSDMASK_{SDSL}(f)$ intersect. PBO is the linear power back-off scale value. K_{SDSL}, Order, N, f_{sym}, f_{3dB}, and P_{SDSL} are defined in table 9. P_{SDSL} is the range of power in the transmit PSD with 0 dB power back-off. R is the payload data rate.

Table 9: Symmetric PSD parameters

Payload Data Rate, R	K_{SDSL}	Order	f_{sym}	f_{3dB}	P_{SDSL}
R < 2 048 kbit/s	7,86	6	(R+8 kbit/s)/3	1,0xf_{sym}/2	P1(R) ≤ P_{SDSL} ≤ 13,5 dBm
R ≥ 2 048 kbit/s	9,90	6	(R+8 kbit/s)/3	1,0xf_{sym}/2	14,5 dBm

P1(R) -with R given in Hz- is defined as follows:

$$P1(R) = 0{,}3486 \log 2 (R + 8\,000) + 6{,}06$$

For 0 dB power back-off, the measured transmit power measured into a load impedance of 135 Ω shall fall within the range PSDSL ± 0,5 dB. For power back-off values other than 0 dB, the measured transmit power measured into a load impedance of 135 Ω shall fall within the range PSDSL ± 0,5 dB minus the power back-off value in dB. The measured transmit PSD measured into a load impedance of 135 Ω shall remain below PSDMASKSDSL(f).

Table 10: Out of band limitation

Frequency band	PSD constraint (note)
1,5 MHz ≤ f ≤ 11,04 MHz	-90 dBm/Hz peak with maximum power in a [f, f+1 MHz] window of –50 dBm
NOTE: This value is under study and may change to reflect a common value for all DSL systems.	

Figure 10 shows the PSD masks with 0 dB power back-off for framed data rates of 256 kbit/s, 512 kbit/s, 768 kbit/s, 1 536 kbit/s, 2 048 kbit/s and 2 304 kbit/s plus 8 kbit/s.

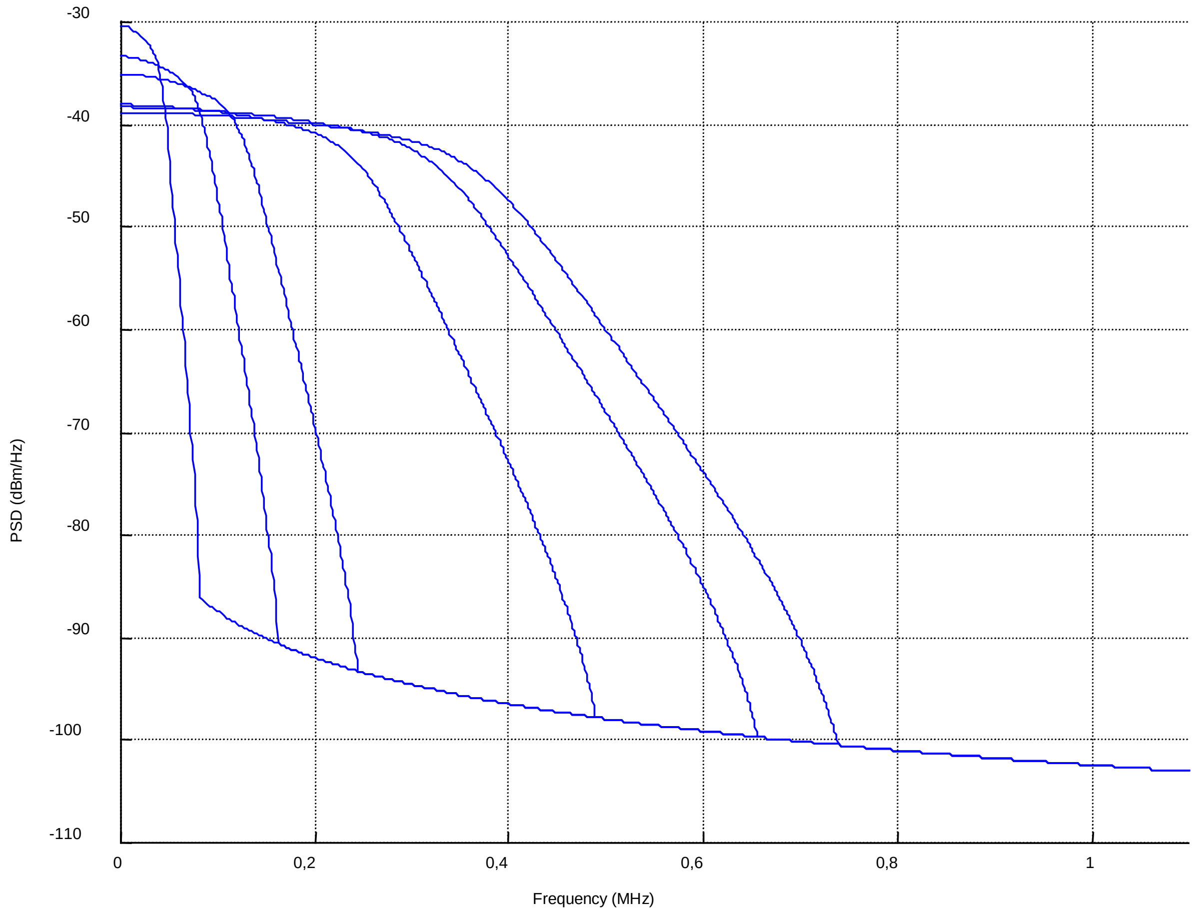

Figure 10: Symmetric PSD masks for 0 dB power back-off

The equation for the nominal PSD measured at the terminals is:

$$\mathrm{NominalPSD}(f) = \begin{cases} PBO \times \dfrac{K_{SDSL}}{135} \times \dfrac{1}{f_{sym}} \times \dfrac{\left[\sin\left(\dfrac{\pi f}{f_{sym}}\right)\right]^2}{\left(\dfrac{\pi f}{f_{sym}}\right)^2} \times \dfrac{1}{1+\left(\dfrac{f}{f_{3dB}}\right)^{2\times Order}} \times \dfrac{f^2}{f^2+f_c^2} & , \quad f < f_{int} \\ \mathrm{FloorPSD}(f) & , \quad f_{int} \le f < 1{,}5\mathrm{MHz} \end{cases}$$

see table 10, 1,5 MHz ≤ f ≤ 11,040 MHz

The inband PSD for 0 < f < 1,5 MHz shall be measured with a 10 kHz resolution bandwidth.

Where fc is the transformer cutoff frequency, assumed to be 5 kHz. Figure 11 shows the nominal transmit PSDs with 13,5 dBm power for framed data rates of 256 kbit/s, 512 kbit/s, 768 kbit/s, 1 536 kbit/s, 2 048 kbit/s and 2 304 kbit/s plus 8 kbit/s.

NOTE: The nominal PSD is given for information only.

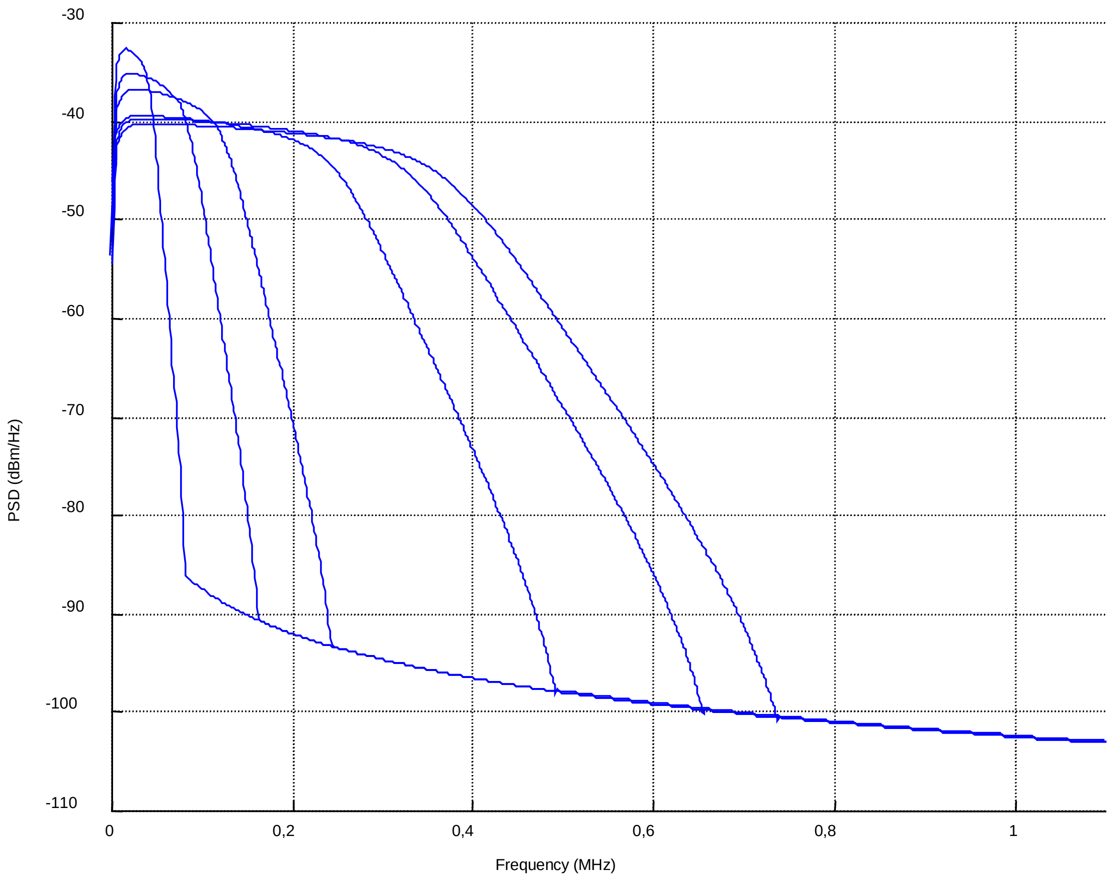

Figure 11: Nominal symmetric PSDs for 0 dB power back-off

4.4.2 Asymmetric 2 048 kbit/s and 2 304 kbit/s PSD masks

The asymmetric PSD mask set specified in this subclause shall optionally be supported for the 2 048 kbit/s and the 2 304 kbit/s payload data rate (note). Power and power spectral density is measured into a load impedance of 135 Ω.

NOTE: Other optional asymmetric PSD masks are for further study.

For the 2 048 kbit/s and the 2 304 kbit/s payload data rates available in the LTU OR NTU, the following set of PSD masks ($PSDMASK_{SDSL}(f)$) shall be selectable:

$$PSDMASK_{SDSL}(f) = \begin{cases} PBO \times \dfrac{K_{SDSL}}{135} \times \dfrac{1}{f_x} \times \dfrac{\left[\sin\left(\dfrac{\pi f}{f_x}\right)\right]^2}{\left(\dfrac{\pi f}{f_x}\right)^2} \times \dfrac{1}{1+\left(\dfrac{f}{f_{3dB}}\right)^{2\times Order}} \times 10^{\frac{MaskOffsetdB(f)}{10}} & , \quad f < f_{int} \\ 0{,}5683 \times 10^{-4} \times f^{-1{,}5} & , \quad f_{int} \le f < 1{,}5MHz \end{cases}$$

see table 10, $1{,}5\ MHz \le f \le 11{,}040\ MHz$

The inband PSD for 0 < f < 1,5 MHz shall be measured with a 10 kHz resolution bandwidth.

Where MaskOffsetdB(f) is defined as:

$$MaskOffsetdB(f) = \begin{cases} 1 + 0{,}4 \times \dfrac{f_{3dB} - f}{f_{3dB}} & , \quad f < f_{3dB} \\ 1 & , \quad f \ge f_{3dB} \end{cases}$$

f_{int} is the frequency where the two equations governing $PSDMASK_{SDSL}(f)$ intersect. PBO is the linear power back-off scale value. K_{SDSL}, Order, f_x, f_{3dB} and P_{SDSL} are defined in table 11. P_{SDSL} is the range of power in the transmit PSD with 0 dB power back-off. R is the payload data rate.

Table 11: Asymmetric PSD parameters

Payload data rate	Transmitter	K_{SDSL}	Order	f_x	f_{3dB}	P_{SDSL}
2 048 kbit/s	LTU	16,86	7	1 370 667 Hz	548 267 Hz	16,25 dBm
2 048 kbit/s	NTU	15,66	7	685 333 Hz	342 667 Hz	16,50 dBm
2 304 kbit/s	LTU	12,48	7	1 541 333 Hz	578 000 Hz	14,75 dBm
2 304 kbit/s	NTU	11,74	7	770 667 Hz	385 333 Hz	15,25 dBm

For 0 dB power back-off, the measured transmit power measured into a load impedance of 135 Ω shall fall within the range PSDSL ± 0,5 dB. For power back-off values other than 0 dB, the measured transmit power measured into a load impedance of 135 Ω shall fall within the range PSDSL ± 0,5 dB minus the power back-off value in dB. The measured transmit PSD measured into a load impedance of 135 Ω shall remain below PSDMASKSDSL(f).

Figure 2 shows the asymmetric PSD masks with 0 dB power back-off for payload data rates of 2 048 kbit/s and 2 304 kbit/s.

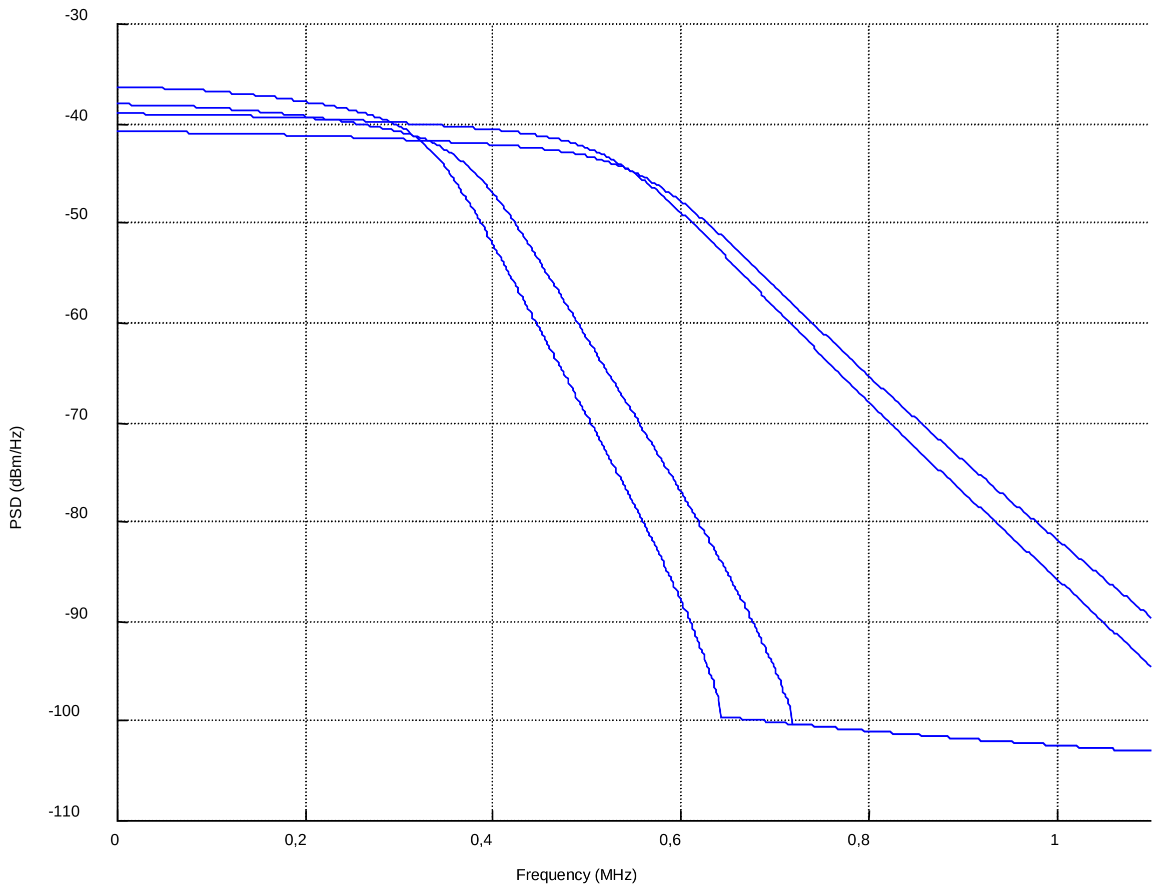

Figure 12: Asymmetric PSD masks for 0 dB power back-off

The equation for the nominal PSD measured at the terminals is:

$$\text{NominalPSD}(f) = \begin{cases} PBO \times \dfrac{K_{SDSL}}{135} \times \dfrac{1}{f_x} \times \dfrac{\left[\sin\left(\dfrac{\pi f}{f_x}\right)\right]^2}{\left(\dfrac{\pi f}{f_x}\right)^2} \times \dfrac{1}{1+\left(\dfrac{f}{f_{3dB}}\right)^{2\times Order}} \times \dfrac{f^2}{f^2+f_c^2}, & f < f_{int} \\ \text{FloorPSD}(f), & f_{int} \le f < 1{,}5\,\text{MHz} \end{cases}$$

see table 10, $1{,}5 \text{ MHz} \le f \le 11{,}040 \text{ MHz}$

The inband PSD for $0 < f < 1{,}5$ MHz shall be measured with a 10 kHz resolution bandwidth.

Where f_c is the transformer cutoff frequency, assumed to be 5 kHz. Figure 13 shows the nominal transmit PSDs with 0 dB power back-off for payload data rates of 2 048 kbit/s and 2 304 kbit/s.

NOTE: The nominal PSD is given for information only.

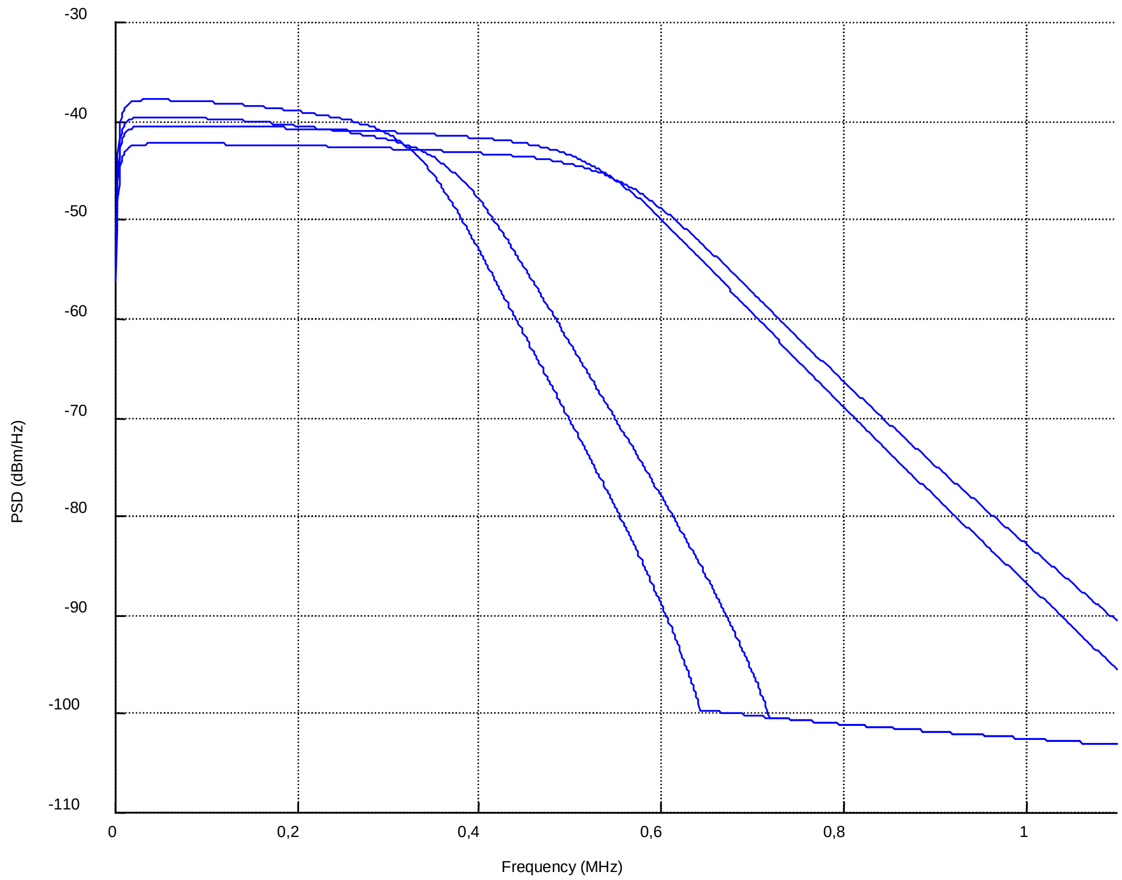

Figure 13: Nominal asymmetric PSDs for 0 dB power back-off

History

Document history		
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