American National Standard

ANSI T1.413-1998

for Telecommunications –
Network and Customer Installation Interfaces – Asymmetric Digital Subscriber Line (ADSL) Metallic Interface

DEVELOPED BY
STANDARDS COMMITTEE T1 - TELECOMMUNICATIONS

Committee T1 - Telecommunications

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American National Standard
for Telecommunications –

Network and Customer Installation Interfaces – Asymmetric Digital Subscriber Line (ADSL) Metallic Interface

Secretariat

Alliance for Telecommunications Industry Solutions

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American National Standards Institute, Inc.

Abstract

This standard presents the electrical characteristics of the Asymmetric Digital Subscriber Line (ADSL) signals appearing at the network interface. The physical interface between the network and the customer installation is also described. The transport medium for the signals is a single twisted-wire pair that supports Plain Old Tephone Service (POTS) or voiceband data services and high-speed duplex (simultaneous two-way) and simplex (from the network to the customer installation) digital services.

This interface standard provides the minimal set of requirements for satisfactory transmission between the network and the customer installation. Equipment may be implemented with additional functions and procedures.

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Foreword (This foreword is not part of American National Standard T1.413-1998.)

This standard specifies the physical layer characteristics of the Asymmetrical Digital Subscriber Line (ADSL) interface to metallic loops that was initiated under the auspices of the Accredited Standards Committee on Telecommunications, T1.

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

The ADSL transmission unit can simultaneously convey all of the following: downstream simplex bearer channels, duplex bearer channels, a baseband analog duplex channel, and ADSL line overhead for framing, error control, operations, and maintenance. Systems support a minimum net data rate of 6.144 Mbit/s downstream and 640 kbit/s upstream. Higher net data rates are optional.

This document includes requirements, recommendations and options; these are designated by the words “shall”, “should” and “may”, respectively. The word “will” is used only to designate events that will take place under some defined set of circumstances.

Two categories of performance are specified. Category I performance is required for compliance with this standard; performance enhancement options are not required for category I equipment. Category II is a higher level of performance (i.e., longer lines and greater impairments). Category II performance and characteristics are not required for compliance with this standard.

Issue 1 of this standard defined several optional capabilities and features, which included:

- echo cancelation;
- trellis code modulation;
- loop timing at either the ATU-C or the ATU-R.

This is Issue 2, which defines the following additional options:

- transport of a network timing reference;
- transport of STM and/or ATM;
- a reduced overhead framing mode.

Substantive changes from Issue 1 to Issue 2 are summarized in Annex N.

It is the intention of this standard to provide, by negotiation during initialization, for U-interface compatibility and interoperability between transceivers complying with Issue 1 and Issue 2, and between transceivers that include different combinations of options. Potential Issue 1 to Issue 2 interoperability problems are identified in Annex N.

There are fifteen annexes to this standard; five are normative (Annexes A through E) and considered part of the standard; ten are informative (Annexes F through O) and provided for information only.

Suggestions for improvements of this standard would be welcomed. They should be sent to the Alliance for Telecommunications Industry Solutions, 1200 G Street, NW, Suite 500, Washington, DC 20005.

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American National Standard for Telecommunications -

Network and Customer Installation Interfaces – Asymmetric Digital Subscriber Line (ADSL) Metallic Interface

1 Scope and purpose

1.1 Scope

This standard describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. The requirements of this standard apply to a single asymmetric digital subscriber line (ADSL). ADSL allows the provision of voiceband services (including POTS and data services up to 56 kbit/s) and a variety of digital channels. In the direction from the network to the customer premises the digital bearer channels may consist of full-duplex low-speed bearer channels and simplex high-speed bearer channels; in the other direction only low-speed bearer channels are provided.

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

Specifically, this standard:

- describes the transmission technique used to support the simultaneous transport of voiceband services and both simplex and duplex digital channels on a single twisted-pair ;
- defines the combined options and ranges of the digital simplex and full-duplex channels provided;
- defines the line code and the spectral composition of the signals transmitted by both ATU-C and ATU-R;
- specifies the transmit signals at both the ATU-C and ATU-R;
- describes the electrical and mechanical specifications of the network interface;
- describes the organization of transmitted and received data into frames;
- defines the functions of the operations channel;
- defines the ATU-R to service module(s) interface functions;
- defines the Transmission Convergence Sub-layer for ATM transport.

1.2 Purpose

This interface standard defines the minimal set of requirements to provide satisfactory simultaneous transmission between the network and the customer interface of POTS and a variety of high-speed simplex and low-speed duplex channels. The standard permits network providers an expanded use of existing copper facilities. All Layer 1 aspects required to ensure compatibility between equipment in the network and equipment at a remote location are specified. Equipment may be implemented with additional functions and procedures.

2 Referenced standards

The following standards contain provisions that, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

ANSI T1.231-1997, *Telecommunications - Digital Hierarchy - Layer 1 In-service Digital Transmission Performance Monitoring*

ANSI T1.413-1995, *Telecommunications - Network and Customer Installation Interfaces - Asymmetrical Digital Subscriber Line (ADSL) Metallic Interfac* (referred to as “issue 1” within this standard)

ANSI/IEEE 455-1985 (R1993), *Test Procedure for Measuring Longitudinal Balance of Telephone Equipment Operating in the Voiceband,* 1985 or later

ANSI/IEEE 743-1995, *Equipment Requirements and Measurement Techniques for Analog Transmission Parameters for Telecommunications*

ITU-T Recommendation I.432.1, *B-ISDN User-Network Interface - Physical Layer Specification: General Characteristics,* August 1996[1)]

[1)] Available from the American National Standards Institute, 11 West 42nd Street, New York, NY 10036.

3 Definitions, abbreviations, acronyms and symbols

NOTE - The numbers in parentheses indicate the (sub)clause(s) in which the term is used.

3.1 Definitions

3.1.1. ADSL system overhead: all overhead needed for system control, including crc, eoc, aoc, synchronization bytes, indicator bits for OAM and Reed-Solomon FEC; that is, the difference between total data rate and net data rate (5.3).

3.1.2. aggregate data rate: data rate transmitted by an ADSL system in any one direction; it includes both net data rate and overhead used by the system for eoc, aoc, crc check bytes, fixed indicator bits for OAM, synchronization control bytes and capacity for bearer channel synchronization control (i.e., $K_F + K_I$ times 32 kbit/s); it does not include Reed-Solomon FEC redundancy (6.4.1.2).

3.1.3. aggregate transmit power: the integrated transmit power over a particular frequency interval (in mWatts or dBm).

3.1.4. bearer channel: a user data stream of a specified data rate that is transported transparently by an ADSL system in ASx or LSx, and carries a bearer service.

3.1.5. bearer service: the transport of data at a certain rate without regard to its content, structure or protocol.

3.1.6. bridged taps: sections of unterminated twisted-pair cables connected in parallel across the cable under consideration.

3.1.7. category 1: basic category of transceivers with no performance-enhancing options, which meet a basic set of performance requirements (11.1).

3.1.8. category 2: category of transceivers with performance-enhancing options, which meet an expanded set of performance requirements (11.1).

3.1.9. channelization: allocation of the net data rate to bearer channels.

3.1.10. Crest factor: peak-to-rms voltage ratio.

3.1.11. cyclic prefix: periodic extention of the time domain representation of a symbol, inserted at the transmitter, to avoid symbol distortion at the receicer, due to the line impulse response.

3.1.12. data symbol rate: the average symbol rate (after allowing for the overhead of the sync symbol) at which symbols carrying data are transmitted (i.e., 4000 symbols/sec).

3.1.13. downstream: ATU-C to ATU-R direction.

3.1.14. dual latency: simultaneous transport of multiple bearer channels through the fast and the interleaved path; that is, $B_F > 0$ and $B_I > 0$. An ADSL system may operate in dual latency mode in one direction only or in both.

3.1.15. indicator bits: bits used for OAM purposes; embedded in the sync bytes (6.4.1.1).

3.1.16. line rate: total data rate plus trellis coding overhead (i.e., Σb_i times 4 kbit/s).

3.1.17. loading coils: inductors placed in series with the cable at regular intervals in order to improve the voiceband response; removed for DSL use.

3.1.18. net data rate: data rate that is available for user data in any one direction; for the downstream direction this is the sum of the simplex and duplex bearer channel data rates (i.e., $B_F + B_I$ times 32 kbit/s), with addition of 16 kbit/s if a 16 kbit/s “C”-channel is used.

3.1.19. showtime: the state of either ATU-C or ATU-R, reached after all initialization and training is completed, in which data is transmitted (see clause 9 and Annex A).

3.1.20. single latency: simultaneous transport of one or more bearer channels through either the fast or the interleaved path; that is, $B_F = 0$ or $B_I = 0$. An ADSL system may operate in single latency mode in one direction only or in both.

3.1.21. splitter: filters that separate the high-frequency signals (ADSL) from the voiceband signals; (frequently called POTS splitters even though the voiceband signals may comprise more than POTS) (4.1 and 12.2).

3.1.22. sub-carrier: one of the complex inputs Z_i to the IDFT (6.11.2).

3.1.23. symbol: the collection of complex values Z_i forming the frequency domain input for the IDFT or alternatively the collection of real values x_n forming the time domain output of the IDFT (6.11.2 and 7.11.2). Symbols may be sent with or without cyclic prefix (6.12).

3.1.24. symbol rate: the rate at which all symbols, including the sync symbol, are transmitted (i.e., $(69/68) \times 4000 = 4058.8$ symbols/sec); contrasted with the data symbol rate.

3.1.25. total data rate: aggregate data rate (q.v.) plus Reed-Solomon FEC overhead (i.e., $N_F + N_I$ times 32 kbit/s).

3.1.26. upstream: ATU-R to ATU-C direction.

3.1.27. voiceband: the 0- to 4-kHz frequency band.

3.1.28. voiceband services: POTS and all data services that use the 0- to 4-kHz band or some part of it.

3.2 Abbreviations, acronyms and symbols

ADC	analog to digital converter
ADSL	asymmetric digital subscriber line
AEX	A(S) EXtension byte: byte inserted in the transmitted ADSL frame structure to provide synchronization capacity that is shared among ASx channels (6.4, 7.4)
AGC	automatic gain control (9.4.4, 9.5.2)
aoc	ADSL overhead control channel (10.1)
ASx	any one of the simplex bearer channels AS0, AS1, AS2 or AS3 (4.2, 4.3)
ATM	asynchronous transfer mode (5.2)
ATU-C	ADSL Transceiver Unit, Central office end
ATU-R	ADSL Transceiver Unit, Remote terminal end
AWG	American Wire Gauge
B_F	the number of bearer channel bytes per data frame allocated to the fast data buffer, summed over all bearer channels (6.4.1.2.1)
B_I	the number of bearer channel bytes per data frame allocated to the interleaved buffer, summed over all bearer channels (6.4.1.2.2)
b_i	the number of bits (i.e., constellation size) modulated on sub-carrier *i*
CI	customer installation
CO	central office
CSA	carrier serving area (11.1)
crc	cyclic redundancy check: using CRC-16 code during initialization and CRC-8 code during showtime (6.4.1.3, 7.4.1.3)
DAC	digital to analog converter (4.2, 4.3)
DMT	discrete multitone
DSL	digital subscriber line (11)
EC	echo canceling (11.1)

eoc	embedded operations channel (8.1)
ERL	echo return loss
ES	errored second (11.3.1, 8.2)
FDM	frequency-division multiplexing
febe-F	binary indication of far-end block error anomaly - fast data (8.2)
febe-I	binary indication of far-end block error anomaly - interleaved data (8.2)
fecc-F	binary indication of forward error correction anomaly - fast data (8.2)
fecc-I	binary indication of forward error correction anomaly - interleaved data (8.2)
FEC	forward error correction (6.4, 7.4)
FEXT	far-end cross talk (11.1)
g_i	the fine gain scaling factor for sub-carrier *i* (6.10, 7.10)
HDSL	high-bit-rate digital subscriber line (11.1)
HEC	header error check (6.2.3.5)
HPF	high-pass filter
ib0-23	indicator bits (6.4.1.1)
ID code	vendor identification code (9.6.4)
IDFT	inverse discrete fourier transform (4.2, 4.3)
ISDN	Integrated Services Digital Network
kbit/s	kilobits per second
K_F	number of bytes in a downstream (or upstream) mux data frame for the fast data buffer; (6.4.1.2.1)
K_I	number of bytes in a downstream (or upstream) mux data frame for the interleaved data buffer; (6.4.1.2.2)
lcd	loss of cell delineation defect
LCD	loss of cell delineation failure
LEX	L(S) EXtension byte: byte inserted in the transmitted ADSL frame structure to provide synchronization capacity that is shared among LSx and ASx channels (6.4, 7.4)
lof	loss of frame defect (8.2)
LOF	loss of frame failure (8.2)
los	loss of signal defect (8.2)
LOS	loss of signal failure (8.2)
LPF	low-pass filter
lpr	loss of power primitive (8.2)
LPR	loss of power failure (8.2)
LSx	any one of the duplex bearer channels LS0, LS1 or LS2 (4.2, 4.3).
lsb	least significant bit
LTR	Local Timing Reference: 8 kHz derived from modem sampling clock (6.3)
Mbit/s	megabits per second
msb	most significant bit

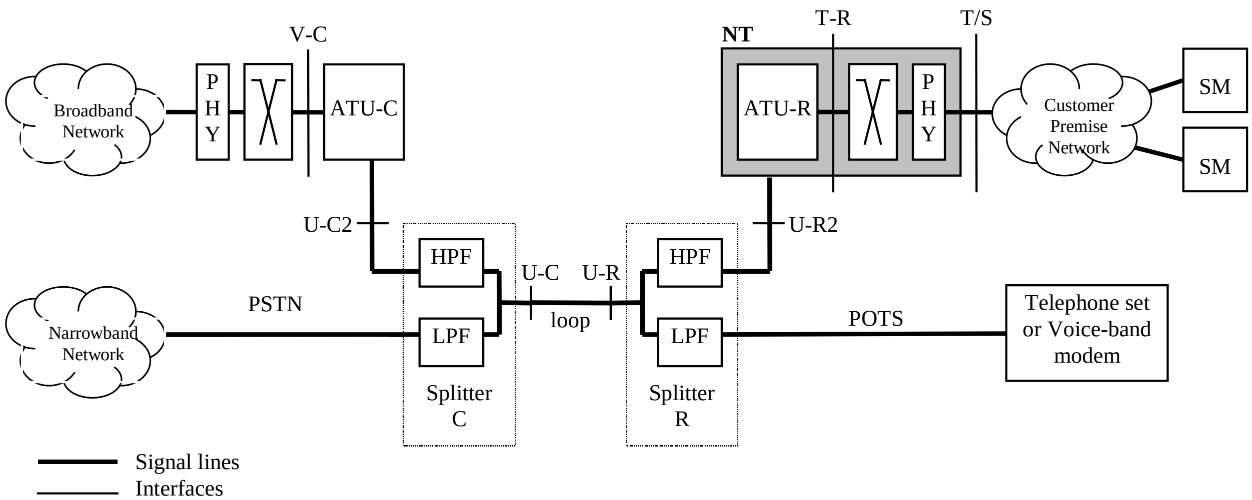
MTPR	MultiTone Power Ratio (6.13, 7.13)
N_F	number of bytes in a downstream (or upstream) FEC output data frame for the fast buffer; (6.4.1.2.1)
N_I	number of bytes in a downstream (or upstream) FEC output data frame for the interleaved buffer; (6.4.1.2.2)
ncd	no cell delineation anomaly (8.2)
NCD	no cell delineation failure
NEXT	near-end cross talk (11.1)
NI	network interface
NID	network interface device (E.5)
NMS	Network Management System (8.2)
NT	network termination (4.1)
NTR	Network Timing Reference: 8 kHz reference transmitted downstream (6.3)
OAM	operations, administration and maintenance (8)
ocd	out of cell delineation anomaly (8.2)
OSI	open systems interconnection (7 layer model)
OSS	Operations Support System (8.2)
POTS	Plain Old Telephone Service; one of the services using the voiceband; sometimes used as a descriptor for all voiceband services
PRD	pseudo-random downstream (9.4.6)
PRU	pseudo-random upstream (9.5.2)
PSD	power spectral density (6.13, 7.13)
PSTN	public switched telephone network (4.1)
PRBS	pseudo-random bit sequence
QAM	quadrature amplitude modulation (9.6, 9.7)
R_F	number of downstream (or upstream) FEC redundancy bytes per RS codeword for the fast buffer; (6.4.1.2.1)
R_I	number of downstream (or upstream) FEC redundancy bytes per codeword for the interleaved buffer; (6.4.1.2.2)
RA	rate adaptation
rdi	remote defect indication (8.2)
RRD	Revised Resistance Design
RFI	remote failure indication (8.2) or radio frequency interferer (11.3.1.3)
rms	root-mean-square
RT	remote terminal
sc0-7	synchronization control bit(s) (6.4.1.1)
sef	severely errored frame defect (8.2)
SM	service module (4.1)
SONET	Synchronous Optical NETwork (4.1)
SRL	singing return loss (13.2)

STM	synchronous transfer mode (5.1)
TPS	transport protocol specific (6.1, 6.2)
TC	transmission convergence (layer) (6.1, 6.2)
T-R	interface(s) between ATU-R and switching layer (ATM or STM)
T/S	interface(s) between NT and CI or home network (4.1)
U-C	loop interface - central office end (4.1)
U-R	loop interface - remote terminal end (4.1)
V-C	logical interface between ATU-C and a digital network element such as one or more switching systems (4.1)
XT	crosstalk
4-QAM	4-point QAM (i.e., two bits per symbol) (9.6, 9.7)
$\oplus$	exclusive-or; modulo-2 addition

4 Reference models

4.1 System reference model

The system reference model shown in Figure 1 illustrates the functional blocks required to provide ADSL service.



NOTES

1 The U-C and U-R interfaces are fully defined in this specification. The V-C and T-R interfaces are defined only in terms of logical functions; not physical. The T/S interface is not defined here.

2 The V-C interface may consist of interface(s) to one or more (STM or ATM) switching systems.

3 Implementation of the V-C and T-R interfaces is optional when interfacing elements are integrated into a common element.

4 One or other of the high-pass filters, which are part of the splitters, may be integrated into the ATU; if so, then the U-C 2 and U-R 2 interfaces become the same as the U-C and U-R interfaces, respectively.

5 A digital carrier facility (e.g., SONET extension) may be interposed at the V-C interface.

6 Due to the asymmetry of the signals on the line, the transmitted signals shall be distinctly specified at the U-R and U-C reference points.

7 The nature of the CI distribution and customer premise network (e.g., bus or star, type of media) is for further study.

8 More than one type of T-R interface may be defined, and more than one type of T/S interface may be provided from an ADSL NT (e.g., NT1 or NT2 types of functionalities).

9 A future issue of this standard may deal with CI distribution and home network requirements.

10 A more detailed definition of the splitters is given in Annex E.

Figure 1 - ADSL system reference model

ATM and STM are application options. ATU-C and ATU-R may be configured for either STM bit sync transport or ATM cell transport. Hybrid configurations (i.e., some applications run over ATM, some do not, simultaneously) are outside the scope of this standard.

If the U-C interface is STM bit sync based (i.e., no ATM cells on U-C interface), the ATU-C is configured for STM transport and shall comply with 4.2.1, 5.1 and 6.1. If the U-C interface is ATM cell based (i.e., only ATM cells on U-C interface), the ATU-C is configured for ATM transport and shall comply with 4.2.2, 5.2 and 6.2.

If the U-R interface is STM bit sync based (i.e., no ATM cells on U-R interface), the ATU-R is configured for STM transport and shall comply with 4.3.1, 5.1 and 7.1. If the U-R interface is ATM cell based (i.e., only ATM cells on U-R interface), the ATU-R is configured for ATM transport and shall comply with 4.3.2, 5.2 and 7.2.

4.2 ATU-C transmitter reference models

4.2.1 ATU-C transmitter reference model for STM transport

Figure 2 is a block diagram of an ADSL Transceiver Unit-Central office (ATU-C) transmitter showing the functional blocks and interfaces that are referenced in this standard for the downstream transport of STM data.

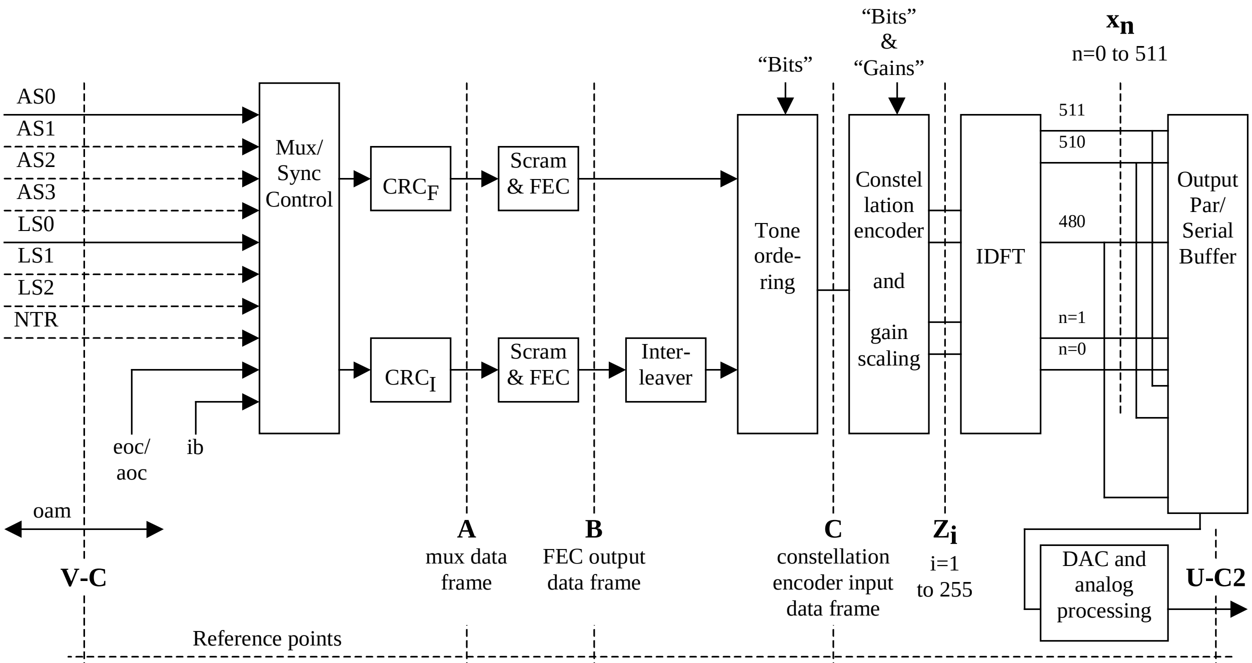


Figure 2 - ATU-C transmitter reference model for STM transport

Support of STM is optional; if it is provided, however, the following requirements shall be met:

a) The basic STM transport mode is bit serial with no byte frames defined externally; this is the mode that was assumed in Issue 1. Preservation of V-C interface byte boundaries in the ADSL data frame is optional;

b) Outside the ASx/LSx serial interfaces data bytes are transmitted msb first in accordance with ITU-T Recommendations G.703 and G.707. All serial processing in the ADSL frame (e.g., crc, scrambling, etc.) shall, however, be performed lsb first, with the outside world msb considered by the ADSL as lsb. As a result, the first incoming bit (outside world msb) shall be the first processed bit inside the ADSL (ADSL lsb);

c) ADSL equipment shall support at least bearer channels AS0 and LS0 downstream (shown as solid lines) as defined in 5.1. Support of other bearer channels (shown dotted) is optional;

d) Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the V-C interface to these paths is defined in 5.1 and 5.3. An ADSL system supporting STM transport shall support operation in a single latency mode, in which all user data are allocated to one path (fast or interleaved), and operation in a dual latency mode downstream, in which user data are allocated to both paths. Support of operation in dual latency mode upstream is optional.

4.2.2 ATU-C transmitter reference model for ATM transport

Figure 3 is a block diagram of an ADSL Transceiver Unit-Central office (ATU-C) transmitter showing the functional blocks and interfaces that are referenced in this standard for the downstream transport of ATM data.

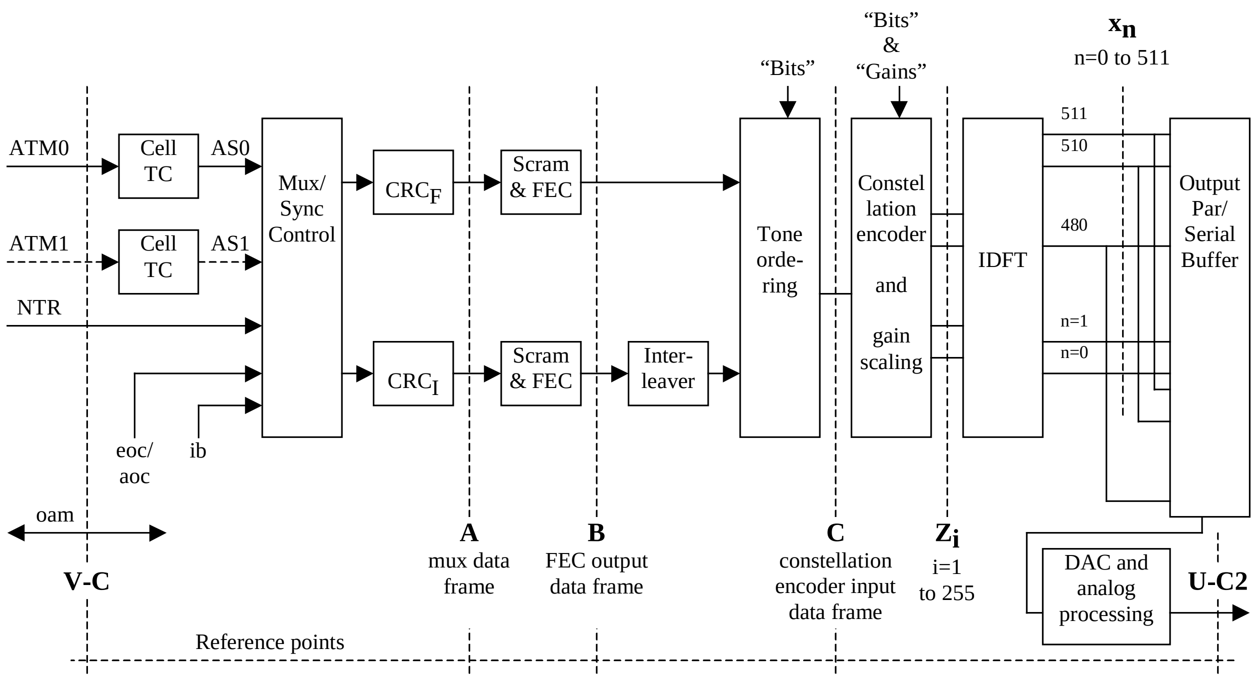


Figure 3 - ATU-C transmitter reference model for ATM transport

Support of ATM is optional; if it is provided, however, the following requirements shall be met:

a) Byte boundaries at the V-C interface shall be preserved in the ADSL data frame;

b) Outside the ASx/LSx serial interfaces data bytes are transmitted msb first in accordance with ITU-T Recommendations I.361 and I.432. All serial processing in the ADSL frame (e.g., crc, scrambling, etc.) shall, however, be performed lsb first, with the outside world msb considered by the ADSL as lsb. As a result, the first incoming bit (outside world msb) will be the first processed bit inside the ADSL (ADSL lsb), and the CLP bit of the ATM cell header will be carried in the msb of the ADSL frame byte (i.e., processed last);

c) ADSL equipment shall support at least bearer channel AS0 (shown as a solid line) as defined in 5.2. Support of other bearer channels (shown dotted) is optional;

d) Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the V-C interface to these paths is defined in 5.1 and 5.3. An ADSL system supporting ATM transport shall support operation in a single latency mode, in which all user data are allocated to one path (fast or interleaved). Support of operation in dual latency mode, in which user data are allocated to both paths, is optional;

e) The Cell TC Sublayer has an interface towards the ATM Layer (V-C interface) and an interface towards the ADSL (Mux/Sync Control block interface). Informative details on the relationship between these Cell TC Sublayer interfaces are provided in Annex J.

4.3 ATU-R transmitter reference models

4.3.1 ATU-R transmitter reference model for STM transport

Figure 4 is a block diagram of an ATU-R transmitter showing the functional blocks and interfaces that are referenced in this standard for the upstream transport of STM data.

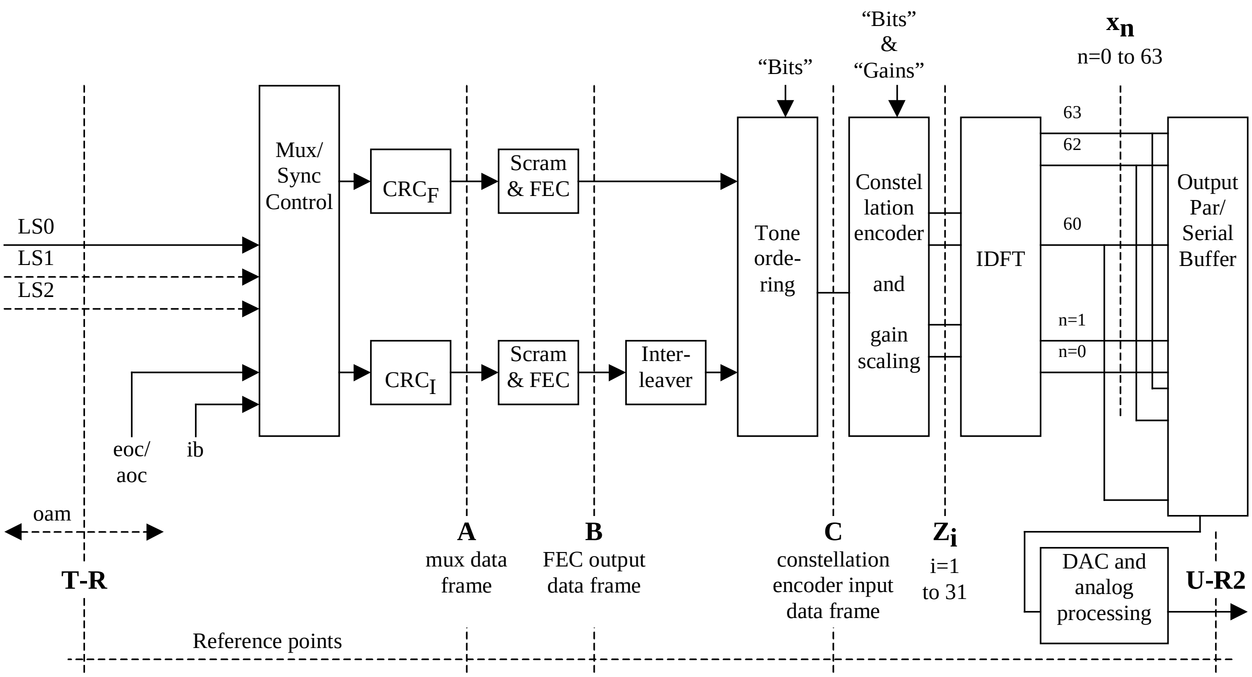


Figure 4 - ATU-R transmitter reference model for STM transport

Support of STM is optional; if it is provided, however, the following requirements shall be met:

a) The basic STM transport mode is bit serial with no byte frames defined externally; this is the mode that was assumed in Issue 1. Preservation of the T-R interface byte boundaries in the ADSL data frame is optional;

b) Outside the LSx serial interfaces data bytes are transmitted msb first in accordance with ITU-T Recommendations G.703 and G.707. All serial processing in the ADSL frame (e.g., crc, scrambling, etc.) shall, however, be performed lsb first, with the outside world msb considered by the ADSL as lsb. As a result, the first incoming bit (outside world msb) will be the first processed bit inside the ADSL (ADSL lsb);

c) ADSL equipment shall support at least bearer channel LS0 upstream (shown as a solid line) as defined in 5.1. Support of other bearer channels (shown dotted) is optional;

d) Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the T-R interface to these paths is defined in 5.1 and 5.3. An ADSL system supporting STM transport shall support operation in a single latency mode, in which all user data are allocated to one path (fast or interleaved), and operation in a dual latency mode downstream, in which user data are allocated to both paths. Support of operation in a dual latency mode upstream is optional.

4.3.2 ATU-R transmitter reference model for ATM transport

Figure 5 is a block diagram of an ATU-R transmitter showing the functional blocks and interfaces that are referenced in this standard for the upstream transport of ATM data.

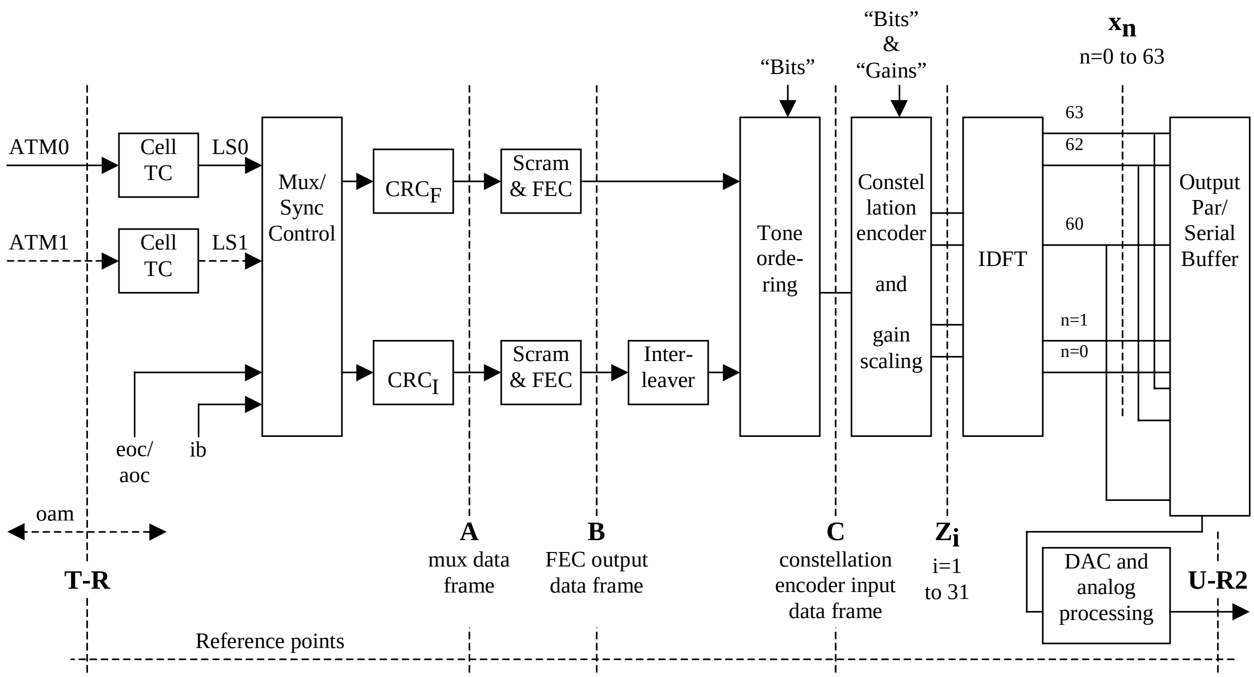


Figure 5 - ATU-R transmitter reference model for ATM transport

Support of ATM is optional; if it is provided, however, the following requirements shall be met:

a) Byte boundaries at the T-R interface shall be preserved in the ADSL data frame;

b) Outside the LSx serial interfaces data bytes are transmitted msb first in accordance with ITU-T Recommendations I.361 and I.432. All serial processing in the ADSL frame (e.g., crc, scrambling, etc.) shall, however, be performed lsb first, with the outside world msb considered by the ADSL as lsb. As a result, the first incoming bit (outside world msb) will be the first processed bit inside the ADSL (ADSL lsb), and the CLP bit of the ATM cell header will be carried in the msb of the ADSL frame byte (i.e., processed last);

c) ADSL equipment shall support at least bearer channel LS0 upstream (shown as a solid line) as defined in 5.2. Support of other bearer channels (shown dotted) is optional;

d) Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the T-R interface to these paths is defined in 5.1 and 5.3. An ADSL system supporting ATM transport shall support operation in a single latency mode, in which all user data are allocated to one path (fast or interleaved). Operation in a dual latency mode, in which user data are allocated to both paths, is optional;

e) The Cell TC Sublayer has an interface towards the ATM Layer (T-R interface) and an interface towards the ADSL (Mux/Sync Control block interface). Informative details on the relationship between these Cell TC Sublayer interfaces are provided in Annex J.

5 Transport capacity

An ADSL system may transport up to seven bearer channels simultaneously, including:

– up to four independent downstream simplex bearer channels (unidirectional from the network to the CI);

– up to three duplex bearer channels (bi-directional between the network and the CI).

The three duplex bearer channels may alternatively be configured as independent unidirectional simplex bearer channels, and the rates of the bearer channels in the two directions (network toward CI and vice versa) do not need to match.

All bearer channel data rates shall be programmable in any combination of multiples of 32 kbit/s. The ADSL data multiplexing format is flexible enough to allow other transport data rates, such as channelizations based on existing 1.544 Mbit/s, but the support of these data rates (non-integer multiples of 32 kbit/s) will be limited by the ADSL system's available capacity for synchronization (see notes 1 and 2).

The maximum net data rate transport capacity of an ADSL system will depend on the characteristics of the loop on which the system is deployed, and on certain configurable options that affect overhead (see note 3). The ADSL bearer channel rate shall be configured during the initialization and training procedure to match the user data rate.

The transport capacity of an ADSL system per se is defined only as that of the high-speed bearer channels. When, however, an ADSL system is installed on a line that also carries POTS signals the overall capacity is that of POTS plus ADSL.

NOTES

1 Part of the ADSL system overhead is shared among the bearer channels for synchronization. The remainder of each channel's data rate that exceeds a multiple of 32 kbit/s shall be transported in this shared overhead. Only framing structure 0 supports non-integer multiples of 32 kbit/s.

2 The rates for all bearer channels are based on multiples of 32 kbit/s. ADSL deployments may, however, need to interwork with DS1 (1.544 Mbit/s) data. The ADSL system overhead and data synchronization (see 6.4.2) provides enough capacity to support the framed DS1 data streams transparently (i.e., the entire DS1 signal is passed through the ADSL transmission path without interpretation or removal of the framing bits and other overhead).

3 One part of the ADSL initialization and training sequence estimates the loop characteristics to determine whether the number of bytes per data frame required for the requested configuration's total data rate can be transmitted across the given loop. The net data rate is then the total data rate minus ADSL system overhead. Part of the ADSL system overhead is dependent on the configurable options, such as allocation of user data streams to the fast or interleaved data buffer (discussed in 6.4 and 7.4), and part of it is fixed (see 5.3).

A distinction is made between the transport of synchronous (STM) and asynchronous (ATM) data. Bearer channels configured to transport STM data can also be configured to carry ATM data. ADSL equipment may be capable of simultaneously supporting both ATM and STM transport; this mode is outside the scope of this standard.

NOTES

1. If an ATU supports a particular bearer channel it shall support it through both the fast and interleaved paths.
2. The latency mode of an ADSL system may be different for downstream and upstream transmission.

5.1 Transport of STM data

ADSL systems transporting STM shall support the simplex bearer channel AS0 and the duplex bearer channel LS0 downstream; support of AS1, AS2, AS3, LS1, and LS2 is optional. Bearer channels AS0, LS0, and any other bearer channels supported shall be independently allocatable to a particular latency path as selected by the ATU-C at initialization. The ADSL system shall support dual-latency downstream.

ADSL systems transporting STM shall also support the duplex bearer channel LS0 upstream using a single latency path; support of LS1 and LS2 and dual latency is optional. Bearer channel AS0 shall support the transport of data at all multiples of 32 kbit/s from 32 kbit/s to 6144 kbit/s. Bearer channel LS0 shall support 16 kbit/s (i.e., the “C”-channel) and all multiples of 32 kbit/s from 32 kbit/s to 640 kbit/s.

When bearer channels AS1, AS2, AS3, LS1 and LS2 are supported, they shall support multiples of 32 kbit/s. The required ranges of multiples for the various ASx/LSx channels are given in Table 1. Support for multiples beyond those required and indicated in Table 1 is optional. Further, support for data rates at non-multiples of 32 kbit/s is also optional.

In addition to transporting user data, an ATU-C may optionally support the transport of a Network Timing Reference (NTR). The ATU-R may optionally reconstruct the NTR. This operation shall be independent of any clocking that is internal to the ADSL system. The means for doing this are specified in 6.3.

Table 1 - Required 32 kbit/s multiples for transport of STM

Bearer channels	Lowest Required Multiple	Largest Required Multiple	Corresponding Highest Required Data Rate
AS0	1	n_0=192	6144 kbit/s
AS1	1	n_1=144	4608 kbit/s
AS2	1	n_2=96	3072 kbit/s
AS3	1	n_3=48	1536 kbit/s
LS0	1	m_0=20	640 kbit/s
LS1	1	m_1=20	640 kbit/s
LS2	1	m_2=20	640 kbit/s

5.2 Transport of ATM data

An ADSL system transporting ATM shall support the single latency mode at all multiples of 32 kbit/s up to 6.144 Mbit/s downstream and up to 640 kbit/s upstream. For a single latency, ATM data shall be mapped to bearer channel AS0 in the downstream direction and to bearer channel LS0 in the upstream direction.

In addition to transporting ATM data, an ATU-C shall support the transport a Network Timing Reference (NTR). The ATU-R may optionally reconstruct the NTR. This operation shall be independent of any clocking that is internal to the ADSL system. The means for doing this are specified in 6.3.

The need for dual latency for ATM services depends, however, on the service/application profile, and is under study. One of three different “latency classes” may be used; viz:

- Single latency, not necessarily the same for each direction of transmission;
- Dual latency downstream, single latency upstream;
- Dual latency both upstream and downstream.

ADSL systems transporting ATM shall support bearer channel AS0 downstream and bearer channel LS0 upstream, with each of these bearer channels independently allocatable to a particular latency path as selected by the ATU-C at initialization. Therefore, support of dual latency is optional for both downsteam and upstream.

If downstream ATM data are transmitted through a single latency path (i.e., 'fast' only or 'interleaved' only), only bearer channel AS0 shall be used, and it shall be allocated to the appropriate latency path. If downstream ATM data are transmitted through both latency paths (i.e., 'fast' and 'interleaved'), only bearer channels AS0 and AS1 shall be used, and they shall be allocated to different latency paths.

Similarly, if upstream ATM data are transmitted through a single latency path (i.e., 'fast' only or 'interleaved' only), only bearer channel LS0 shall be used and it shall be allocated to the appropriate latency path. The choice of the fast or interleaved path may be made independently of the choice for the downstream data. If upstream ATM data are transmitted through both latency paths (i.e., 'fast' and 'interleaved'), only bearer channels LS0 and LS1 shall be used and they shall be allocated to different latency paths.

Bearer channel AS0 shall support the transport of data at all multiples of 32 kbit/s from 32 kbit/s to 6144 kbit/s. Bearer channel LS0 shall support all multiples of 32 kbit/s from 32 kbit/s to 640 kbit/s.

When bearer channels AS1 and LS1 are supported, they shall support multiples of 32 kbit/s. The required ranges of multiples for the various ASx/LSx channels are given in Table 1. Support for multiples beyond those required and indicated in Table 1, is optional.

NOTES

1. For ATM systems, the channelization of different payloads is embedded within the ATM data stream using different Virtual Paths and/or Virtual Channels. Therefore the basic requirements for ATM are for only one ADSL bearer channel downstream and only one ADSL bearer channel upstream.

2. Informative details of the ATU/ATM interface are given in Annex J.

5.3 ADSL system overheads and total data rates

The total data rate transmitted by the ADSL system when operating in an optional reduced overhead mode, shall include capacity for:

- the net data rate transmitted in the ADSL bearer channels;
- ADSL system overhead, which includes:
  - an ADSL embedded operations channel, eoc;
  - an ADSL overhead control channel, aoc;
  - crc check bytes;
  - fixed indicator bits for OAM;
  - Reed-Solomon FEC redundancy bytes.

When operating in the full-overhead mode the total data rate shall also include capacity for the synchronization control bytes and capacity for bearer channel synchronization control.

The above data streams shall be organized into ADSL frames and superframes as defined in 6.4 and 7.4 for the downstream and upstream data, respectively.

The ADSL system overhead (excluding RS FEC redundancy) is shown in Table 2 for downstream and in Table 3 for upstream.

Table 2 - ADSL downstream system overhead (excluding RS FEC redundancy)

	Full overhead		**Reduced overhead**	
	Fast/Sync byte (crc, ib, eoc, aoc, sync control)	**Sync capacity** (shared over all bearer channels)	**Fast/Sync byte** (crc, ib, eoc, aoc, sync control)	**Sync capacity** (shared over all bearer channels)
Fast data buffer bearer channel allocation (overhead in kbit/s)				
#ASx=0, #LSx=0	32	0	0 or 32	0
#ASx=0, #LSx≥1	32	32	32	0
#ASx≥1, #LSx=0	32	64	32	0
#ASx≥1, #LSx≥1	32	64	32	0
Interleaved data buffer bearer channel allocation (overhead in kbit/s)				
#ASx=0, #LSx=0	32	0	0 or 32	0
#ASx=0, #LSx≥1	32	32	32	0
#ASx≥1, #LSx=0	32	64	32	0
#ASx≥1, #LSx≥1	32	64	32	0
ADSL system overhead in kbit/s (excluding RS FEC redundancy)				
	64	32, 64, 96 or 128	32 or 64	0
Total	96, 128, 160 or 192		32 or 64	

Table 3 - ADSL upstream system overhead (excluding RS FEC redundancy)

	Full overhead		**Reduced overhead**	
	Fast/Sync byte (crc, ib, eoc, aoc, sync control)	**Sync capacity** (shared over all bearer channels)	**Fast/Sync byte** (crc, ib, eoc, aoc, sync control)	**Sync capacity** (shared over all bearer channels)
Fast data buffer bearer channel allocation (overhead in kbit/s)				
#LSx=0	32	0	0 or 32	0
#LSx≥1	32	32	32	0
Interleaved data buffer bearer channel allocation (overhead in kbit/s)				
#LSx=0	32	0	0 or 32	0
#LSx≥1	32	32	32	0
ADSL system overhead in kbit/s (excluding RS FEC redundancy)				
	64	32 or 64	32 or 64	0
Total	96 or 128		32 or 64	

With reduced overhead framing, a 32 kbit/s ADSL system overhead is present in each buffer type. However, when all ASx and LSx are allocated to one buffer type, synchronization control, crc, eoc, aoc and indicator bits may be carried in a single 32 kbit/s ADSL system overhead present in the buffer type used. With full overhead framing, a 32 kbit/s ADSL system overhead is always present in each buffer type.

The shared synchronization capacity includes 32 kbit/s shared among LSx within the interleaved data buffer and 32 kbit/s shared among LSx within the fast buffer for downstream and upstream. For downstream, an additional 32 kbit/s is shared among ASx within the interleave buffer and 32 kbit/s is shared among ASx within the fast buffer. The maximum overhead occurs when at least one ASx is allocated to each buffer type; the minimum overhead occurs when only and all LSx are allocated to one buffer type.

5.4 Classification by ATU options

Subclause 11.1 describes a classification, which ties together transport payload and loop range based upon whether or not certain options available for the ATU transceivers are used. Category I describes loop ranges and transport payloads using a basic transceiver with no options required. Category II describes loop ranges and transport payloads using options for trellis coding and echo cancellation.

6 ATU-C functional characteristics

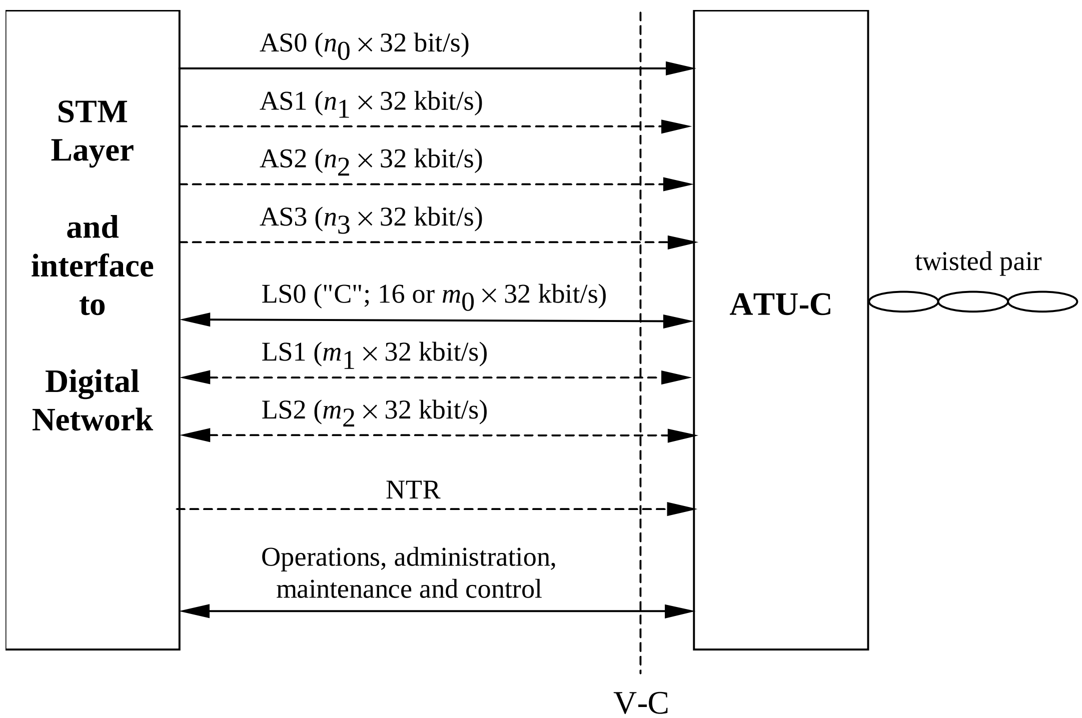
An ATU-C may support STM transport or ATM transport or both. If STM is supported, it shall be as defined in 6.1. If ATM is supported, it shall be as defined in 6.2.

6.1 STM Transmission Protocol Specific functionalities

6.1.1 ATU-C input and output V-C interfaces for STM transport

The functional data interfaces at the ATU-C for STM transport are shown in Figure 6. Input interfaces for the high-speed downstream simplex bearer channels are designated AS0 through AS3; input/output interfaces for the duplex bearer channels are designated LS0 through LS2. There shall also be a duplex interface for operations, administration, maintenance (OAM) and control of the ADSL system.

The data rates of the input and output data interfaces (i.e., n_x and m_x) at the ATU-C are specified in 5.1. The data rate at a given interface shall match the rate of the bearer channel configured to that interface.



NOTE - Interface elements that are shown by solid lines shall be supported; interface elements that are shown with dotted lines are optional.

Figure 6 - ATU-C functional interfaces to the STM layer at the V-C reference point

6.1.2 Downstream simplex bearer channels - bit rates

Four data input interfaces are defined at the ATU-C for the high-speed downstream simplex bearer channels: AS0, AS1, AS2 and AS3 (ASx in general). The required data rate configurations are specified in 5.1.

6.1.3 Downstream/upstream duplex bearer channels - bit rates

Three input and output data interfaces are defined at the ATU-C for the duplex bearer channels supported by the ADSL system: LS0, LS1, and LS2 (LSx in general). The required data rate configurations are specified in 5.1.

LS0 is also known as the "C" or control channel. It carries the signaling associated with the ASx bearer channels and it may also carry some or all of the signaling associated with the other duplex bearer channels.

6.1.4 Payload transfer delay

The one-way transfer delay for payload bits in all bearer channels (simplex and duplex) from the V reference point at central office end (V-C) to the T reference point at remote end (T-R) for bearer channels assigned to the fast buffer shall be no more than 2 ms, and for bearer channels assigned to the interleave buffer it shall be no more than $(4 + (S - 1) / 4 + S \times D / 4)$ ms, where S and D are defined in 6.6. The same requirement applies in the opposite direction, from the T-R reference point to the V-C reference point.

6.1.5 Framing structure for STM transport

An ATU-C configured for STM transport shall support the full overhead framing structure 0 as specified in 6.4. The support of full overhead framing structure 1 and the reduced overhead framing structures 2 and 3 is optional.

Preservation of V-C interface byte boundaries (if present) at the U-C interface may be supported for any of the U-C interface framing structures.

An ATU-C configured for STM transport may support insertion of a Network Timing Reference (NTR). If inserted, the NTR shall be inserted in the U-C framing structure as described in 6.3.2. Note that NTR insertion is not supported by an ATU-C complying with ANSI T1.413 Issue 1.

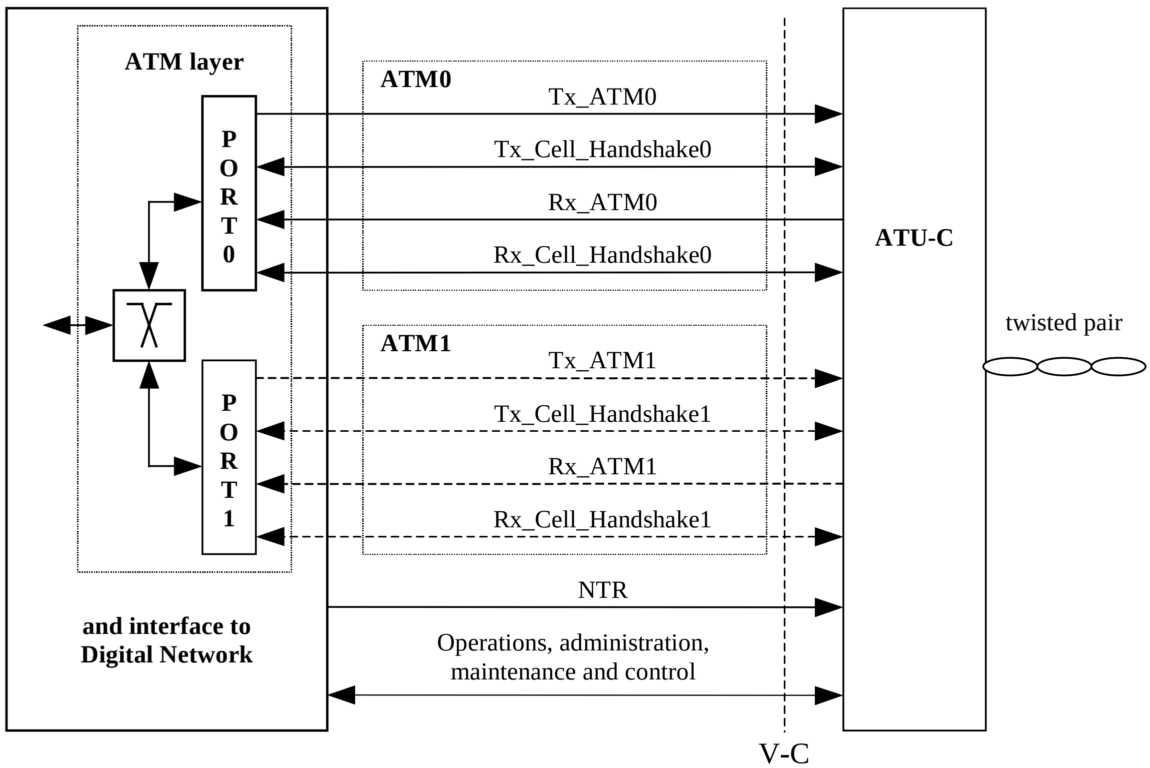
6.2 ATM Transport Protocol Specific functionalities

6.2.1 ATU-C input and output V-C interface for ATM transport

The functional data interfaces at the ATU-C for ATM transport are shown in Figure 7. The ATM channel ATM0 shall always be provided, the ATM channel ATM1 is optional and may be provided for support of dual latency mode. Each ATM channel operates as an interface to a physical layer pipe. When operating in dual latency mode, no fixed allocation between the ATM channels 0 and 1 on one hand and transport of ’fast’ and ’interleaved’ data on the other hand is assumed. This relationship is configured inside the ATU-C.

Flow control functionality shall be available on the V-C reference point to allow the ATU-C (i.e. the physical layer) to control the cell flow to and from the ATM layer. This functionality is represented by Tx_Cell_Handshake and Rx_Cell_ Handshake. A cell may be transferred from ATM to PHY layer only after the ATU-C has completed the Tx_Cell_Handshake. Similarly, a cell may be transferred from the PHY layer to the ATM layer only after the ATU-C has completed the Rx_Cell_Handshake. This functionality is important to avoid cell overflow or underflow in the ATU-C and ATM layer.

There shall also be a duplex interface for operations, administration, maintenance (OAM) and control of the ADSL system.



NOTE - Interface elements that are shown by solid lines shall be supported; interface elements that are shown with dotted lines are optional.

Figure 7 - ATU-C functional interfaces to the ATM layer at the V-C reference point

6.2.2 Payload transfer delay

The one-way transfer delay (excluding cell specific functionalities) for payload bits in all bearer channels (simplex and duplex) from the V reference point at central office end (V-C) to the T reference point at remote end (T-R) for bearer channels assigned to the fast buffer shall be no more than 2 ms, and for bearer channels assigned to the interleave buffer it shall be no more than $(4 + (S - 1) / 4 + S \times D / 4)$ ms, where S and D are defined in 6.6. The same requirement applies in the opposite direction, from the T-R reference point to the V-C reference point.

NOTE - The additional delay introduced by the cell specific functionalities is implementation specific.

6.2.3 ATM Cell specific functionalities

6.2.3.1 Idle Cell Insertion

Idle cells shall be inserted in the transmit direction for cell rate decoupling. Idle cells are identified by the standardized pattern for the cell header given in ITU-T Recommendation I.432.

NOTE - This standard is written on the assumption that idle cells will be discarded by an ATU-R receiver.

6.2.3.2 Header Error Control Generation.

The HEC byte shall be generated in the transmit direction as described in ITU-T Recommendation I.432, including the recommended modulo 2 addition (XOR) of the pattern 01010101 to the HEC bits.

The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with ITU-T Recommendation I.432.

6.2.3.3 Cell payload scrambling

Scrambling of the cell payload field shall be used in the transmit direction to improve the security and robustness of the HEC cell delineation mechanism. In addition, it randomizes the data in the information field, for possible improvement of the transmission performance. The self-synchronizing scrambler polynomial $X^{43}+1$ and procedures defined in ITU-T Recommendation I.432 shall be implemented.

NOTE - This standard is written on the assumption that the cell payload will be descrambled by an ATU-R receiver.

6.2.3.4 Bit timing and ordering

When interfacing ATM data bytes to the AS0 or AS1 bearer channel, the most significant bit (msb) shall be sent first. The AS0 or AS1 bearer channel data rate shall be an integer multiple of 32 kbit/s, with bit timing synchronous with the ADSL downstream modem timing base (see Note 3 to Table 6 and Table 7).

6.2.3.5 Cell Delineation.

The cell delineation function permits the identification of cell boundaries in the payload. It uses the Header Error Control (HEC) field in the cell header.

Cell delineation shall be performed using a coding law checking the header error control (HEC) field in the cell header according to the algorithm described in ITU-T Recommendation I.432. The ATM cell delineation state machine is shown in Figure 8. Details of the state diagram are described below:

a) In the HUNT state, the delineation process is performed by checking bit by bit for the correct HEC. Once such an agreement is found, it is assumed that one header has been found, and the method enters the PRESYNC state. When byte boundaries are available within the receiving physical layer prior to cell delineation as with the framing modes 1, 2 and 3 (see 6.4), the cell delineation process may be performed byte by byte;

b) In the PRESYNC state, the delineation process is performed by checking cell by cell for the correct HEC. The process repeats until the correct HEC has been confirmed DELTA (see note) times consecutively. If an incorrect HEC is found, the process returns to the HUNT state;

c) In the SYNCH state the cell delineation process will be assumed to be lost if an incorrect HEC is obtained ALPHA times consecutively.

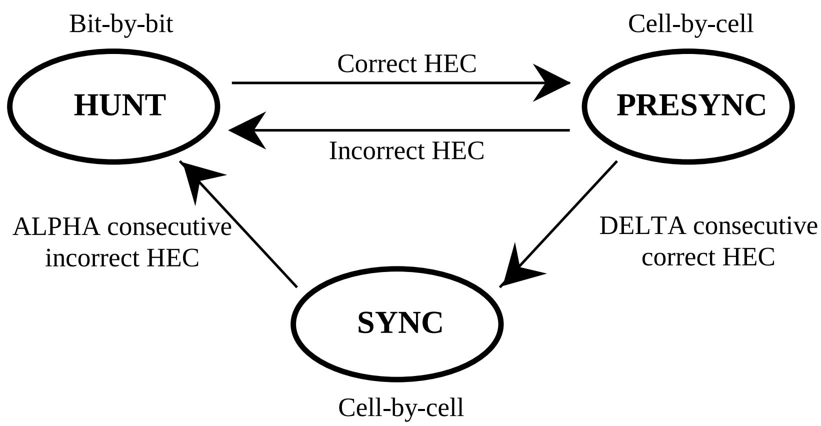


Figure 8 - ATM cell delineation state machine

NOTE - With reference to ITU-T Recommendation I.432, no recommendation is made for the values of ALPHA and DELTA as the choice of these values is not considered to effect interoperability. However, it should be noted that the use of the values recommended for an SDH based physical layer in ITU-Recommendation I.432 (ALPHA=7, DELTA=6) may be inappropriate due to the particular transmission characteristics of ADSL.

6.2.3.6 Header Error Control Verification

The Header Error Control (HEC) covers the entire cell header. The code used for this function is capable of either:

- single bit error correction;
- multiple bit error detection.

Error detection shall be implemented as defined in ITU-T Recommendation I.432 with the exception that any HEC error shall be considered as a multiple bit error, and therefore, HEC error correction shall not be performed.

6.2.4 Framing structure for ATM transport

An ATU-C configured for ATM transport shall support the full overhead framing structures 0 and 1 as specified in 6.4. The support of reduced overhead framing structures 2 and 3 is optional.

The ATU-C transmitter shall preserve V-C interface byte boundaries (explicitly present or implied by ATM cell boundaries) at the U-C interface, independent of the U-C interface framing structure.

To ensure framing structure 0 interoperability between an ATM ATU-C and an ATM cell TC plus an STM ATU-R (i.e., ATM over STM), the following shall apply:

- an STM ATU-R transporting ATM cells and not preserving T-R byte boundaries at the U-R interface shall indicate during initialization that frame structure 0 is the highest frame structure supported;
- an STM ATU-R transporting ATM cells and preserving T-R byte boundaries at the U-R interface shall indicate during initialization that frame structure 0, 1, 2 or 3 is the highest frame structure supported, as applicable to the implementation;
- an ATM ATU-C receiver operating in framing structure 0 can not assume that the ATU-R transmitter will preserve T-R interface byte boundaries at the U-R interface and shall therefore perform the cell delineation bit-by-bit (see 6.2.3.5).

An ATU-C configured for ATM transport shall support insertion of a Network Timing Reference (NTR). The network operator may choose not to insert the NTR. If inserted, the NTR shall be inserted in the U-C framing structure as described in 6.3.2. Note that NTR insertion is not supported by an ATU-C complying to ANSI T1.413 Issue 1.

6.3 Network timing reference

6.3.1 Need for NTR

Some services require that a reference clock be available in the higher layers of the protocol stack (i.e., above the physical layer); this is used to guarantee end-to-end synchronization of transmit and receive sides. Examples are Voice and Telephony Over ATM (VTOA) and Desktop Video Conferencing (DVC).

To support the distribution of a timing reference over the network, the ADSL system allows to transport an 8 kHz timing marker as network timing reference (NTR). This 8 kHz timing marker may be used for voice/video playback at the decoder (D/A converter) in DVC and VTOA applications.

The ATU-C may have access to a source NTR, if provided by the network at the V-C reference point, which may be derived from a Primary Reference Source (PRS) clock in the ATM broadband network.

6.3.2 Transport of the NTR

The intention of the NTR transport mechanism is that the ATU-C should provide timing information at the U-C reference point to enable the ATU-R to deliver to the T-R reference point timing information that has a timing accuracy corresponding to the accuracy of the clock provided to the V-C reference point.

If transport of the NTR is provided, an ADSL system shall transport the NTR in the ADSL framing structure as follows:

- The ATU-C shall generate an 8 kHz local timing reference (LTR) by dividing its sampling clock by the appropriate integer (276 if 2.208 MHz is used);

– It shall transmit the change in phase offset between the input NTR and LTR (measured in cycles of the 2.208 MHz clock, that is, units of approximately 452 ns) from the previous superframe to the present one; this shall be encoded into four bits ntr3-ntr0 (with ntr3 the msb), representing a signed integer in the -8 to +7 range in 2's-complement notation. The bits ntr3-ntr0 shall be carried in the indicator bits 23 (ntr3) to 20 (ntr0) as shown in Table 5.

NOTES

1. A positive value of the change of phase offset, $\Delta^2\phi$, shall indicate that the LTR is higher in frequency than the NTR.

2. Alternatively, the ATU-C may choose to lock its downstream sampling clock (2.208 MHz) to 276 times the NTR frequency; in that case it shall encode $\Delta^2\phi$ to zero.

3. The NTR, as specified in ANSI T1.101, has a maximum frequency variation of ±32 ppm. The LTR, as specified in 6.11.1, has a maximum frequency variation of ±50 ppm. The maximum mismatch is therefore ±82 ppm. This would result in an average change of phase offset of approximately ±3.5 clock cycles over one 17 ms superframe, which can be mapped into 4 overhead bits.

4. One method that the ATU-C may use to measure this change of phase offset is shown in Figure 9.

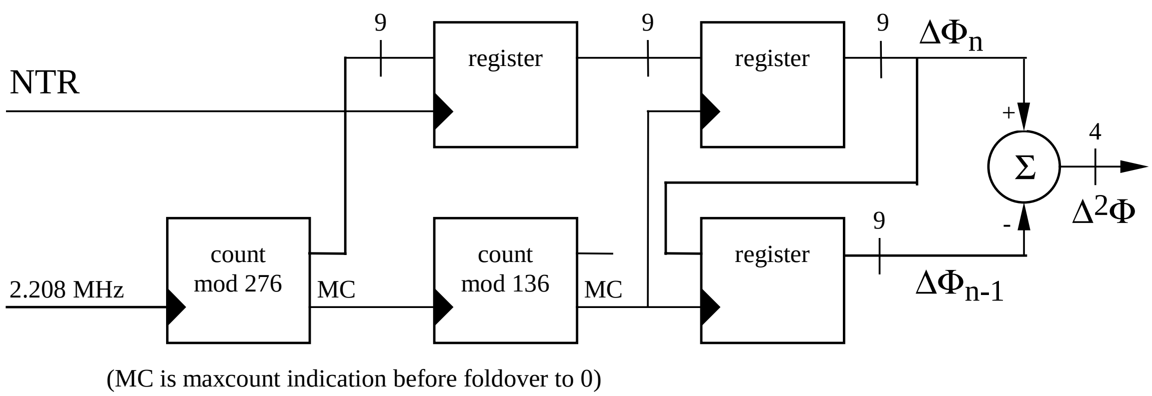


Figure 9 - Example implementation of the $\Delta^2\phi$ measurement

6.3.3 Accuracy requirements

The accuracy requirements are for further study.

6.4 Framing

This subclause specifies framing of the downstream signal (ATU-C transmitter). The upstream framing (ATU-R transmitter) is specified in 7.4.

Two types of framing are defined: full overhead and reduced overhead. Furthermore, two versions of full overhead and two versions of reduced overhead are defined. The four resulting framing structures are defined in Table 4 and referred to as framing structures 0, 1, 2, and 3.

Table 4 - Definition of framing structures

Framing structure	Definition
0	Full overhead framing with asynchronous bit-to-modem timing (enabled synchronization control mechanism)
1	Full overhead framing with synchronous bit-to-modem timing (disabled synchronization control mechanism)
2	Reduced overhead framing with separate fast and sync bytes in fast and interleaved latency buffer respectively (64 kbit/s framing overhead)
3	Reduced overhead framing with merged fast and sync byte, using either the fast or interleaved latency buffer (32 kbit/s framing overhead)

Requirements for framing structures to be supported, depend upon the ATU-C being configured for either STM or ATM transport, and are defined in 6.1.5 and 6.2.4 respectively.

The ATU-C shall indicate during initialization the highest framing structure number it supports. If the ATU-C indicates it supports framing structure *k*, it shall also support all framing structures *k*-1 to 0. If the ATU-R indicates a lower framing structure number during initialization, the ATU-C shall fall back to the framing structure number indicated by the ATU-R.

As specified in Clause 4, outside the ASx/LSx serial interfaces data bytes are transmitted msb first in accordance with ITU-T Recommendations G.703, G.707, I.361 and I.432. All serial processing in the ADSL frame (e.g., crc, scrambling, etc.) shall, however, be performed lsb first, with the outside world msb considered by the ADSL as lsb. As a result, the first incoming bit (outside world msb) will be the first processed bit inside the ADSL (ADSL lsb)

6.4.1 Data symbols

Figure 2 and Figure 3 show functional block diagrams of the ATU-C transmitter with reference points for data framing.

Up to four downstream simplex bearer channels and up to three duplex bearer channels shall be synchronized to the 4 kHz ADSL data frame rate, and multiplexed into two separate data buffers (fast and interleaved). A cyclic redundancy check (crc), scrambling, and forward error correction (FEC) coding shall be applied to the contents of each data buffer separately, and the data from the interleaved buffer shall then be passed through an interleaving function. Data from the two data buffers shall then be tone ordered as defined in 6.7, and combined into a data frame that is input to the constellation encoder. After constellation encoding, the data frame shall be modulated onto a DMT data symbol to produce an analog signal for transmission across the customer loop.

A bit-level framing pattern shall not be inserted into the data frame or superframe structure. Data frame boundaries are delineated by the cyclic prefix inserted in the DMT symbol by the modulator (see 6.12). Superframe boundaries are determined by the synchronization symbol, which shall also be inserted by the modulator, and which carries no user data (see 6.11.3).

Because of the addition of FEC redundancy bytes and data interleaving, the data frames (i.e., bit-level data prior to constellation encoding) have different structural appearance at the three reference points through the transmitter. As shown in Figure 2 and Figure 3, the reference points for which data framing is described in the following subclauses are:

- A (Mux data frame): the multiplexed, synchronized data after the crc has been inserted (synchronization is described in 6.4.2, crc is specified in 6.4.1.3). Mux data frames shall be generated at an average rate of 4.0 kHz (i.e., a mux data frame is carried in 68 out of 69 DMT symbols, at a DMT symbol rate of $4000\times69/68$ Hz);

– B (FEC output data frame): the data frame generated at the output of the FEC encoder at the DMT symbol rate, where an FEC block may span more than one DMT symbol period;

– C (Constellation encoder input data frame): the data frame presented to the constellation encoder.

6.4.1.1 Superframe structure

ADSL uses the superframe structure shown in Figure 10. Each superframe is composed of 68 ADSL data frames, numbered from 0 to 67, which are encoded and modulated into 68 DMT data symbols, followed by a DMT synchronization symbol, which carries no user or overhead bit-level data and is inserted by the modulator (see 6.11.3) to establish superframe boundaries. From the bit-level and user data perspective, the DMT symbol rate is 4000 symbols/sec (period = 250 µs), but in order to allow for the insertion of the synchronization symbol, the transmitted DMT symbol rate is 69/68 × 4000 symbols/sec. Each data frame within the superframe contains data from the fast buffer and the interleaved buffer. The size of each buffer depends on the assignment of bearer channels made during initialization (see 6.4.1.2 and 9.8.4).

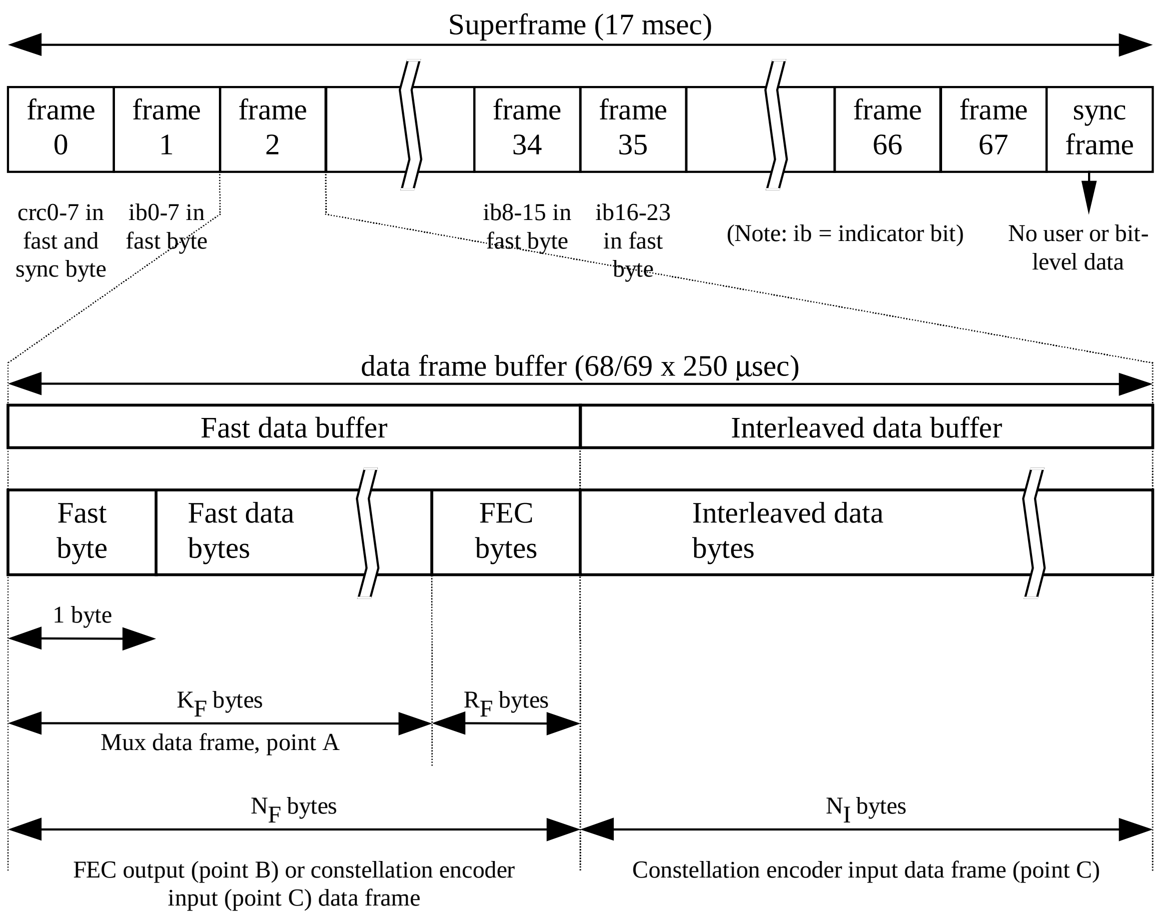


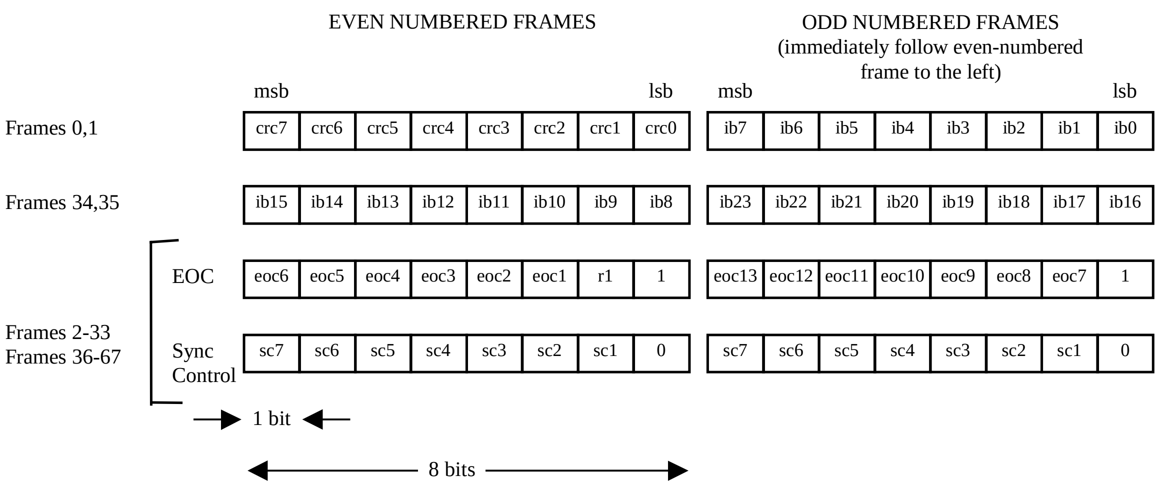
Figure 10 - ADSL superframe structure - ATU-C transmitter

Eight bits per ADSL superframe shall be used for the crc on the fast data buffer (crc0-crc7), and 24 indicator bits (ib0-ib23) shall be assigned for OAM functions. As shown in Figure 10 and Figure 11 , the synchronization byte of the fast data buffer ("fast byte") carries the crc check bits in frame 0 and the fixed overhead bit assignments in frames 1, 34, and 35. The fast byte in other frames is assigned in even-frame/odd-frame pairs to either the eoc or to synchronization control of the bearer channels assigned to the fast buffer.

Bit 0 of the fast byte in an even-numbered frame (other than frames 0 and 34) and bit 0 of the fast byte of the odd-numbered frame immediately following shall be set to "0" to indicate these frames carry synchronization control information.

When they are not required for synchronization control, crc, or indicator bits, the fast bytes of two successive ADSL frames, beginning with an even-numbered frame, may contain indications of "no synchronization action" (see 6.4.2 and 7.4.2), or alternatively, they may be used to transmit one eoc message, consisting of 13 bits.

Bit 0 of the fast byte in an even-numbered frame (other than frames 0 and 34) and bit 0 of the fast byte of the odd-numbered frame immediately following shall be set to "1" to indicate these frames carry a 13-bit eoc message, which is defined in Table 20, and one additional bit, r1. The r1 bit is reserved for future use and shall be set to 1.



NOTE - In all frames bit 7 = msb and bit 0 = lsb.

Figure 11 - Fast sync byte (“fast” byte) format - ATU-C transmitter

The ATU-C shall support the indicator bits defined in Table 5.

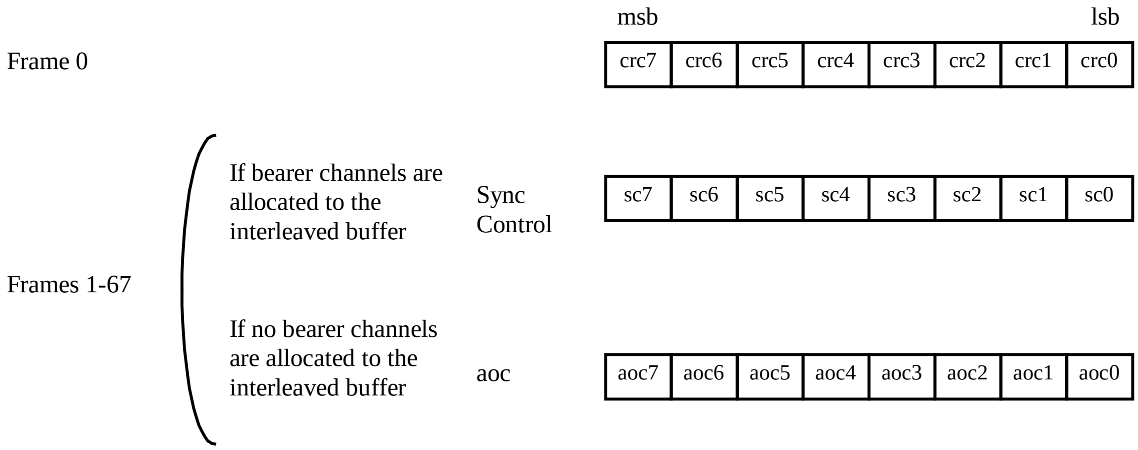
Table 5 - Definition of indicator bits, ATU-C transmitter (fast data buffer, downstream direction)

Indicator bit (see note 1)	Definition
ib0-ib7	Reserved for future use and set to 1 (see note 2)
ib8	febe-I
ib9	fecc-I
ib10	febe-F
ib11	fecc-F
ib12	los
ib13	rdi
ib14	ncd-I (see note 3)
ib15	ncd-F (see note 3)
ib16	hec-I (see note 3)
ib17	hec-F (see note 3)
ib18-19	Reserved for future use and set to 1 (see note 2)
ib20-23	NTR0-3 (see note 4)

NOTES

1. See 8.2 for definitions of the bits and their use.
2. Reserved bits are set to 1 because all indicator bits are defined as active low.
3. The ncd and hec indicators are used for ATM transport only; they shall be set to 1 for STM transport.
4. If the NTR is not transported, ib20-23 shall be set to 1.

Eight bits per ADSL superframe shall be used for the crc on the interleaved data buffer (crc0-crc7). As shown in Figure 11 and Figure 12, the synchronization byte of the interleaved data buffer ("sync byte") carries the crc check bits for the previous superframe in frame 0. In all other frames (1 through 67), the sync byte shall be used for synchronization control of the bearer channels assigned to the interleaved data buffer or used to carry an ADSL overhead control (aoc) channel. In the full overhead mode (see 6.4.1.2), when any bearer channel appears in the interleave buffer, then the aoc data shall be carried in the LEX byte, and the sync byte shall designate when the LEX byte contains aoc data and when it contains a data byte from the bearer channels. When no bearer channels are allocated to the interleave data buffer (i.e., all B_I(ASx) = B_I(LSx) = 0), then the sync byte shall carry the aoc data directly (AEX and LEX bytes, described in 6.4.1.2, do not exist in the interleaved buffer in this case). The format of the sync byte is described in 6.4.2.2.



NOTE - If bearer channels are allocated to the interleaved buffer, aoc is carried in the LEX byte.

Figure 12 - Interleaved sync byte ("sync" byte) format - ATU-C transmitter

NOTE - The names "fast byte" and "sync byte" are abbreviations for, and are used interchangeably with "fast synchronization byte" and "interleaved synchronization byte", respectively.

6.4.1.2 Frame structure (with full overhead)

Each data frame shall be encoded into a DMT symbol, as described in 6.7 through 6.9. As is shown in Figure 10, each data frame is composed of data from the fast data buffer and an the interleaved data buffer, and the data frame structure has a different appearance at each of the reference points (A, B, and C). The bytes of the fast buffer shall be clocked into the constellation encoder first, followed by the bytes of the interleaved data buffer. Bytes are clocked least significant bit first.

Each bearer channel shall be assigned to either the fast or the interleaved buffer during initialization (see 9.6.2), and a pair of bytes, [B_F, B_I], transmitted for each bearer channel, where B_F and B_I designate the number of bytes allocated to the fast and interleaved buffers, respectively.

The seven [B_F, B_I] pairs to specify the downstream bearer channel rates are

- B_F(ASx), B_I(ASx) for x = 0, 1, 2 and 3, for the downstream simplex bearer channels;
- B_F(LSx), B_I(LSx) for x = 0, 1 and 2, for the (downstream transport of the) duplex bearer channels.

The rules for allocation are:

- for any bearer channel X, except the 16 kbit/s "C"-channel, either B_F(X) = the number of bytes from X per data frame of the fast buffer and B_I (X) = 0, or B_F(X) = 0 and B_I(X) = the number of bytes from X per frame of the interleaved buffer;
- for the 16 kbit/s "C"-channel, B_F(LS0) = 255 (binary 11111111) and B_I(LS0) =0, or B_F(LS0) = 0 and B_I(LS0) = 255.

6.4.1.2.1 Fast data buffer (with full overhead)

The frame structure of the fast data buffer shall be as shown in Figure 13 for reference points A and B, which are defined in Figure 2 and Figure 3.

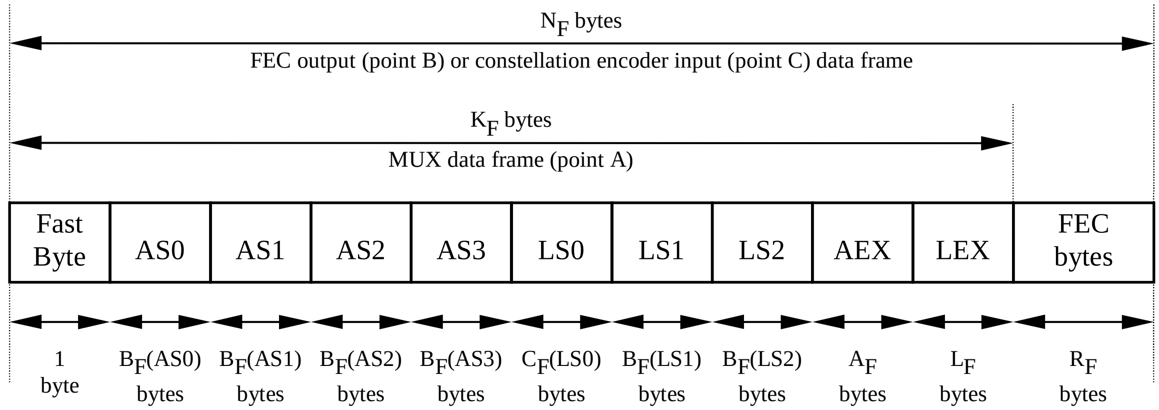


Figure 13 - Fast data buffer - ATU-C transmitter

The following shall hold for the parameters shown in Figure 13:

N_F $= K_F + R_F$

R_F = number of FEC redundancy bytes per RS codeword

K_F $= 1 + B_F + A_F + L_F$

B_F $= \sum_{x=0}^{3} B_F(\text{ASx}) + C_F(\text{LS0}) + \sum_{x=1}^{2} B_F(\text{LSx})$

C_F(LS0) = 0 if B_F(LS0) = 255 (binary 11111111)

= B_F(LS0) otherwise

A_F = 0 if B_F(ASx) = 0 for x = 0-3

= 1 otherwise

L_F = 0 if B_F(ASx) = 0 for x = 0-3 and B_F(LSx) = 0 for x = 0-2

= 1 otherwise (including B_F(LS0) = 255)

At reference point A (Mux data frame) in Figure 2 and Figure 3, the fast buffer shall always contain at least the fast byte. This is followed by B_F(AS0) bytes of bearer channel AS0, then B_F(AS1) bytes of bearer channel AS1, B_F(AS2) bytes of bearer channel AS2 and B_F(AS3) bytes of bearer channel AS3. Next come the bytes for any duplex (LSx) bearer channels allocated to the fast buffer. If any B_F(ASx) is non-zero, then both an AEX and an LEX byte follow the bytes of the last LSx bearer channel, and if any B_F(LSx)is non-zero, the LEX byte shall be included.

When B_F(LS0) = 255, no bytes are included for the LS0 bearer channel. Instead, the 16 kbit/s “C”-channel shall be transported in every other LEX byte on average, using the sync byte to denote when to add the LEX byte to the LS0 bearer channel.

R_F Reed-Solomon FEC redundancy bytes shall be added to the mux data frame (reference point A) to produce the FEC output data frame (reference point B), where R_F is given in the RATES1 options used during initialization.

Because the data from the fast buffer is not interleaved, the constellation encoder input data frame (reference point C) is identical to the FEC output data frame (reference point B).

6.4.1.2.2 Interleaved data buffer (with full overhead)

The frame structure of the interleaved data buffer is shown in Figure 14 for reference points A and B, which are defined in Figure 2 and Figure 3.

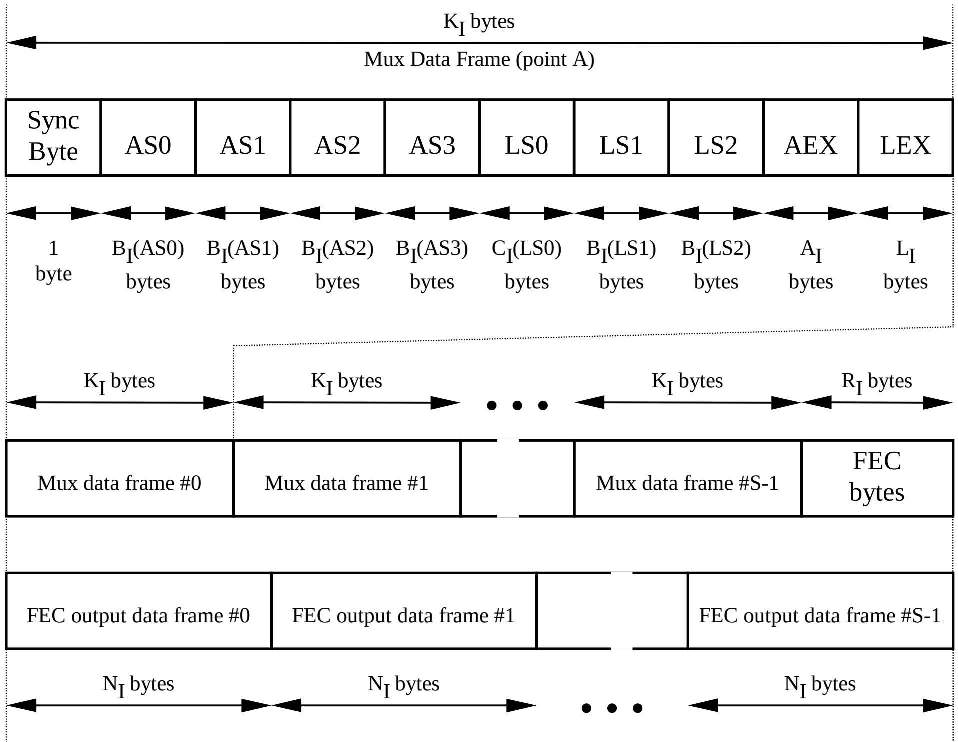


Figure 14 - Interleaved data buffer, ATU-C transmitter

The following shall hold for the parameters shown in Figure 14:

N_I	$= (S \times K_I + R_I) / S$
R_I	= number of FEC redundancy bytes per RS codeword
S	= number of DMT symbols per RS codeword
	= number of mux data frames per RS codeword
K_I	$= 1 + B_I + A_I + L_I$
B_I	$= \sum_{x=0}^{3} B_I(\text{ASx}) + C_I(\text{LS0}) + \sum_{x=1}^{2} B_I(\text{LSx})$
C_I(LS0)	= 0 if B_I(LS0) = 255 (binary 11111111)
	= B_I(LS0) otherwise
A_I	= 0 if B_I(ASx) = 0 for x = 0-3
	= 1 otherwise
L_I	= 0 if B_I(ASx) = 0 for x = 0-3, and B_I(LSx) = 0 for x = 0-2

= 1 otherwise (including B_I(LS0) = 255)

At reference point A, the Mux data frame, the interleaved data buffer shall always contain at least the sync byte. The rest of the buffer shall be built in the same manner as the fast buffer, substituting B_I in place of B_F. The length of each mux data frame is K_I bytes, as defined in Figure 14.

The FEC coder shall take in S mux data frames and append R_I FEC redundancy bytes to produce the FEC codeword of length $N\text{-}FEC_I = S \times K_I + R_I$ bytes. The FEC output data frames shall contain $N_I = N\text{-}FEC_I / S$ bytes, where N_I is an integer. When $S > 1$, then for the S frames in an FEC codeword, the FEC output data frame (reference point B) shall partially overlap two mux data frames for all except the last frame, which shall contain the R_I FEC redundancy bytes.

The FEC output data frames are interleaved to a specified interleave depth. The interleaving process (see 6.6.2) delays each byte of a given FEC output data frame a different amount, so that the constellation encoder input data frames contain bytes from many different FEC data frames. At reference point A in the transmitter, mux data frame 0 of the interleaved data buffer is aligned with the ADSL superframe and mux data frame 0 of the fast data buffer (this is not true at reference point C). At the receiver, the interleaved data buffer will be delayed by ($S \times$ interleave depth $\times$ 250) µs with respect to the fast data buffer, and data frame 0 (containing the crc bits for the interleaved data buffer) will appear a fixed number of frames after the beginning of the receiver superframe.

6.4.1.3 Cyclic redundancy check (crc)

Two cyclic redundancy checks (crc's) - one for the fast data buffer and one for the interleaved data buffer - shall be generated for each superframe and transmitted in the first frame of the following superframe. Eight bits per buffer type (fast or interleaved) per superframe allocated to the crc check bits. These bits are computed from the k message bits using the equation:

$$\text{crc}(D) = M(D)\, D^8 \text{ modulo } G(D),$$

where:

$M(D) = m_0 D^{k-1} + m_1 D^{k-2} + \ldots + m_{k-2} D + m_{k-1}$ is the message polynomial,

$G(D) = D^8 + D^4 + D^3 + D^2 + 1$ is the generating polynomial,

$\text{crc}(D) = c_0 D^7 + c_1 D^6 + \ldots + c_6 D + c_7$ is the check polynomial,

D is the delay operator.

That is, crc is the remainder when $M(D)\, D^8$ is divided by $G(D)$.

The crc check bits are transported in the sync bytes (fast and interleaved; 8 bits each) of frame 0 for each data buffer.

The bits covered by the crc include:

- fast data buffer:

  - frame 0: ASx bytes (x = 0, 1, 2, 3), LSx bytes (x = 0, 1, 2), followed by any AEX and LEX bytes;

  - all other frames : fast byte, followed by ASx bytes (x = 0, 1, 2, 3), LSx bytes (x = 0, 1, 2), and any AEX and LEX bytes.

- interleaved data buffer:

  - frame 0: ASx bytes (x = 0, 1, 2, 3), LSx bytes (x = 0, 1, 2), followed by any AEX and LEX bytes;

  - all other frames : sync byte, followed by ASx bytes (x = 0, 1, 2, 3), LSx bytes (x = 0, 1, 2), and any AEX and LEX bytes.

Each byte shall be clocked into the crc least significant bit first.

The number of bytes over which the crc is computed varies with the allocation of bytes to the fast and interleaved data buffers (the numbers of bytes in ASx and LSx vary according to the [B_F, B_I] pairs; AEX is present in a given buffer only if at least one ASx is allocated to that buffer; LEX is present in a given buffer only if at least one ASx or one LSx is allocated to that buffer).

Because of the flexibility in assignment of bearer channels to the fast and interleaved data buffers, crc field lengths over an ADSL superframe will vary from approximately 67 bytes to approximately 14875 bytes.

6.4.2 Synchronization

If the bit timing base of the input bearer channels (ASx or LSx) is not synchronous with the ADSL modem timing base, the input bearer channels shall be synchronized to the ADSL timing base using the synchronization control mechanism (consisting of synchronization control byte and the AEX and LEX bytes). Forward-error-correction coding shall always be applied to the synchronization control byte(s).

If the bit timing base of the input bearer channels (ASx or LSx) is synchronous with the ADSL modem timing base, then the synchronization control mechanism is not needed, and the synchronization control byte shall always indicate "no synchronization action" (see Table 6 and Table 7).

6.4.2.1 Synchronization for the fast data buffer

Synchronization control for the fast data buffer may occur in frames 2 through 33, and 36 through 67 of an ADSL superframe as described in 6.4.1.1, where the fast sync byte may be used as the synchronization control byte. No synchronization action shall be taken for those frames for which the fast byte is used for crc, indicator bits, or eoc.

The format of the fast sync byte when used as synchronization control for the fast data buffer shall be as given in Table 6.

Table 6 - Fast byte format (Fast data buffer)

Bits	Designation	Codes
sc7, sc6	ASx bearer channel designator	"00" : AS0 "01" : AS1 "10" : AS2 "11" : AS3
sc5, sc4	Synchronization control for the designated ASx bearer channel (see note 3)	"00" : no synchronization action "01" : add AEX byte to designated ASx bearer channel "11" : add AEX and LEX bytes to ASx bearer channel "10" : delete last byte from designated ASx bearer channel
sc3, sc2	LSx bearer channel designator (see note 3)	"00" : LS0 "01" : LS1 "10" : LS2 "11" : no synchronization action
sc1	Synchronization control for the designated LSx bearer channel	"1" : add LEX byte to designated LSx bearer channel "0" : delete last byte from designated LSx bearer channel
sc0	Synchronization/eoc designator	"0" : perform synchronization control as indicated in sc7-sc1 "1" : this byte is part of an eoc frame

NOTES

1. ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) or DS1C (3.152 Mbit/s) rates. The synchronization control option that allows adding up to two bytes to an ASx bearer channel provides sufficient overhead capacity to transport combinations of DS1 or DS1C channels transparently (without interpreting or stripping and regenerating the framing embedded within the DS1 or DS1C). The synchronization control algorithm shall, however, guarantee that the fast byte in some minimum number of frames is available to carry eoc frames, so that a minimum eoc rate (4 kbit/s) may be maintained.

2. When a 16 kbit/s “C”-channel is used, the LS0 bearer channel is transported in the LEX byte, using the "add LEX byte to designated LSx bearer channel", with LS0 as the designated bearer channel, every other frame on average.

3. If the bit timing base of the input bearer channels (ASx, LSx) is synchronous with the ADSL modem timing base then ADSL systems need not perform synchronization control by adding or deleting AEX or LEX bytes to/from the designated ASx and LSx channels, and the synchronization control byte shall indicate "no synchronization action" (i.e., sc7-0 coded “XX0011X0”, with X discretionary).

6.4.2.2 Synchronization for the interleaved data buffer

Synchronization control for the interleaved data buffer may occur in frames 1 through 67 of an ADSL superframe as described in 6.4.1.1, where the sync byte may be used as the synchronization control byte. No synchronization action shall be taken during frame 0, where the sync byte is used for crc and the LEX byte carries aoc.

The format of the sync byte when used as synchronization control for the interleaved data buffer shall be as given in Table 7. In the case where no bearer channels are allocated to the interleaved data buffer, the sync byte shall carry the aoc data directly, as shown in Figure 12 in 6.4.1.1.

Table 7 - Sync byte format (Interleaved data buffer)

Bits	Designation	Codes
sc7, sc6	ASx bearer channel designator	"00" : AS0 "01" : AS1 "10" : AS2 "11" : AS3
sc5, sc4	Synchronization control for the designated ASx bearer channel (see note 3)	"00" : no synchronization action "01" : add AEX byte to designated ASx bearer channel "11" : add AEX and LEX bytes to ASx bearer channel "10" : delete last byte from designated ASx bearer channel
sc3, sc2	LSx bearer channel designator	"00" : LS0 "01" : LS1 "10" : LS2 "11" : no synchronization action
sc1	Synchronization control for the designated LSx bearer channel	"1" : add LEX byte to designated LSx bearer channel "0" : delete last byte from designated LSx bearer channel
sc0	Synchronization/aoc designator	"0" : perform synchronization control as indicated in sc7-sc1 "1" : LEX byte carries ADSL overhead control channel data; synchronization control is allowed for "add AEX" or "delete" as indicated in sc7-sc4

NOTES

1. ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) or DS1C (3.152 Mbit/s) rates. The synchronization control option that allows adding up to two bytes to an ASx bearer channel provides sufficient overhead capacity to transport combinations of DS1 or DS1C channels transparently (without interpreting or stripping and regenerating the framing embedded within the DS1 or DS1C).

2. When a 16 kbit/s “C”-channel is used, the LS0 bearer channel is transported in the LEX byte, using the "add LEX byte to designated LSx bearer channel", with LS0 as the designated bearer channel, every other frame on average.

3. If the bit timing base of the input bearer channels (ASx, LSx) is synchronous with the ADSL modem timing base then ADSL systems need not perform synchronization control by adding or deleting AEX or LEX bytes to/from the designated ASx and LSx bearer channels, and the synchronization control byte shall indicate "no synchronization action" for any ASx or LSx bearer channel. In this case and if framing structure 1 is used, the sc7-0 shall always be coded “XX0011XX”, with X discretionary. When sc0 is set to 1, the LEX byte shall carry

aoc. When sc0 is set to 0, the LEX byte shall be coded 00h. The sc0 may be set to 0 only in between transmissions of 5 concatenated and identical aoc messages.

6.4.3 Reduced overhead framing

The format described in 6.4.1.2 for full overhead framing includes overhead to allow for the synchronization of seven ASx and LSx bearer channels. When the synchronization function described in 6.4.2 is not needed, the ADSL equipment may operate in a reduced overhead mode. This mode retains all the full overhead mode functions except synchronization control. When using the reduced overhead framing, the framing structure shall be as defined in 6.4.3.1 (when operating with separate fast and sync bytes) or 6.4.3.2 (when operating with merged fast and sync bytes).

6.4.3.1 Reduced overhead framing with separate fast and sync bytes

The AEX and LEX bytes shall be eliminated from the ADSL frame format, and both the fast and sync bytes shall carry overhead information as described in 6.4.1.2. The fast byte carries the fast buffer CRC, indicator bits, and eoc messages, and the sync byte carries the interleaved buffer CRC and apc messages. The assignment of overhead functions to fast and sync bytes when using the the full overhead framing and when using the reduced overhead framing with separate fast and sync bytes shall be as shown in Table 8.

In the reduced overhead framing with separate fast and sync bytes, the structure of the fast data buffer shall be as shown in 6.4.1.2.1 with A_F and L_F set to 0. The structure of the interleaved data buffer shall be as shown in 6.4.1.2.2 with A_I and L_I set to 0.

Table 8 - Overhead functions for full and reduced overhead mode with separate fast and sync bytes

	Full Overhead Mode		**Reduced Overhead Mode (separate fast and sync bytes)**	
Frame Number	**Fast byte**	**Sync byte**	**Fast byte**	**Sync byte**
0	fast CRC	interleaved CRC	fast CRC	interleaved CRC
1	ib0-7	sync or aoc	ib0-7	aoc
34	ib8-15	sync or aoc	ib8-15	aoc
35	ib16-23	sync or aoc	ib16-23	aoc
all other frames	sync or eoc	sync or aoc	sync or eoc (see note)	aoc
NOTE - In the reduced overhead mode only the “no synchronization action” code shall be used.				

6.4.3.2 Reduced overhead framing with merged fast and sync bytes

In the single latency mode, data is assigned to only one data buffer (fast or interleaved). If data is assigned to only the fast buffer, then only the fast byte shall be used to carry overhead information. If data is assigned to only the interleave buffer, then only the sync byte shall be used to carry overhead information. Reduced overhead framing with merged fast and sync bytes shall not be used when operating in dual latency mode.

For ADSL systems transporting data using a single data buffer (fast or interleaved), the CRC, indicator, eoc and aoc function shall be carried in a single overhead byte assigned to separate data frames within the superframe structure. The CRC remains in frame 0 and the indicator bits in frames 1, 34, and 35. The aoc and eoc bytes are assigned to alternate pairs of frames. For ADSL equipment operating in single latency mode using the reduced overhead framing with merged fast and sync bytes, the assignment of overhead functions shall be as shown in Table 9.

In the single latency mode using the reduced overhead framing with merged fast and sync bytes, only one data buffer shall be used. If the fast data buffer is used, the structure of the fast data buffer shall be as shown in 6.4.1.2.1 (with A_F and L_F set to 0) and the interleaved data buffer shall be empty (no sync byte and $K_I = 0$). If the interleaved data buffer is used, the structure of the interleaved data buffer shall be as shown in 6.4.1.2.2 (with A_I and L_I set to 0) and the fast data buffer shall be empty (no fast byte and $K_F = 0$).

Table 9 - Overhead functions for reduced overhead mode with merged fast and sync bytes

	(Fast Buffer Only)	**(Interleaved Buffer Only)**
Frame Number	**Fast Byte format**	**Sync Byte format**
0	fast CRC	Interleaved CRC
1	ib0-7	ib0-7
34	ib8-15	ib8-15
35	ib16-23	ib16-23
4n+2, 4n+3 with n = 0...16, n ≠8	sync or eoc (see note)	sync or eoc (see note)
4n, 4n+1 with n = 0...16, n ≠0	aoc	aoc
NOTE - In the reduced overhead mode only the “no synchronization action” code shall be used.		

6.5 Scramblers

The binary data streams output (lsb of each byte first) from the fast and interleaved buffers shall be scrambled separately using the following algorithm for both:

$d_n' = d_n \oplus d_{n-18}' \oplus d_{n-23}'$

where

d_n is the n-th output from the fast or interleaved buffer (i.e., input to the scrambler),

d_n' is the n-th output from the corresponding scrambler.

This is illustrated in Figure 15.

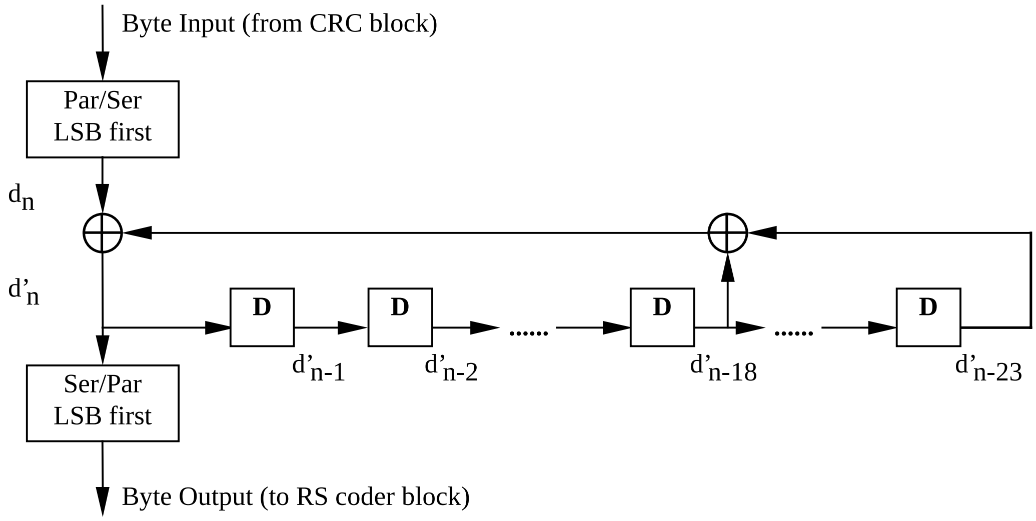


Figure 15 - Scrambler

These scramblers are applied to the serial data streams without reference to any framing or symbol synchronization. Descrambling in receivers can likewise be performed independent of symbol synchronization.

6.6 Forward error correction

The ATU-C shall support downstream transmission with at least any combination of the RS FEC coding capabilities shown in Table 10.

Table 10 - Minimum FEC coding capabilities for ATU-C

Parameter	Fast buffer	Interleaved buffer
Parity bytes per RS codeword	R_F = 0,2,4,6,8,10,12,14,16 (see note 1)	R_I = 0,2,4,6,8,10,12,14,16 (see note 1 and 2)
DMT symbols per RS codeword Mux data frames per RS codeword	S = 1	S = 1, 2, 4, 8, 16 (see note 3)
Interleave depth	not applicable	D = 1, 2, 4, 8, 16, 32, 64 (see note 3)

NOTES

1. R_F can be > 0 only if K_F > 0, and R_I can be > 0 only if K_I > 0.
2. R_I shall be an integer multiple of S.
3. Exception: support of the combination S > 1 and D = 1 is not required.
4. The ATU-C shall also support upstream transmission with at least any combination of the RS FEC coding capabilities shown in Table 19.

6.6.1 Reed-Solomon coding

R (i.e., R_F or R_I) redundant check bytes c_0, c_1, ... , c_{R-2}, c_{R-1} shall be appended to K (= K_F or $S \times K_I$) message bytes m_0, m_1, ... , m_{K-2}, m_{K-1} to form a Reed-Solomon code word of size $N = K + R$ bytes. The check bytes are computed from the message byte using the equation:

$C(\mathrm{D}) = M(\mathrm{D})\,\mathrm{D}^R$ modulo $G(\mathrm{D})$

where:

$M(\mathrm{D}) = m_0\,\mathrm{D}^{K-1} + m_1\,\mathrm{D}^{K-2} + \ldots + m_{K-2}\,\mathrm{D} + m_{K-1}$ is the message polynomial,

$C(\mathrm{D}) = c_0\,\mathrm{D}^{R-1} + c_1\,\mathrm{D}^{R-2} + \ldots + c_{R-2}\,\mathrm{D} + c_{R-1}$ is the check polynomial,

$G(\mathrm{D}) = \Pi\,(\mathrm{D} + \alpha^i)$ is the generator polynomial of the Reed-Solomon code, with the index of the product running from $i = 0$ to R-1.

That is, $C(\mathrm{D})$ is the remainder obtained from dividing $M(\mathrm{D})\,\mathrm{D}^R$ by $G(\mathrm{D})$. The arithmetic is performed in the Galois Field GF(256), where α is a primitive element that satisfies the primitive binary polynomial $x^8 + x^4 + x^3 + x^2 + 1$. A data byte ($d_7$, d_6, ... , d_1, d_0) is identified with the Galois Field element $d_7\alpha^7 + d_6\alpha^6 + \ldots + d_1\alpha + d_0$

The number of check bytes R, and the codeword size N vary, as explained in 6.4.

6.6.2 Interleaving

The Reed-Solomon codewords in the interleaved buffer shall be convolutionally interleaved. The interleaving depth varies, as explained in 6.4, but it shall always be a power of 2. Convolutional interleaving is defined by the following rule:

> Each of the N bytes B_0, B_1, ..., B_{N-1} in a Reed-Solomon codeword is delayed by an amount that varies linearly with the byte index. More precisely, byte B_i (with index i) is delayed by (D-1) $\times$ i bytes, where D is the interleave depth.

An example for $N = 5$, $D = 2$ is shown in Table 11, where B^j_i denotes the i-th byte of the j-th codeword.

Table 11 - Convolutional interleaving example for $N = 5$, $D = 2$

Inter-leaver input	B^j_0	B^j_1	B^j_2	B^j_3	B^j_4	B^{j+1}_0	B^{j+1}_1	B^{j+1}_2	B^{j+1}_3	B^{j+1}_4
Inter-Leaver output	B^j_0	B^{j-1}_3	B^j_1	B^{j-1}_4	B^j_2	B^{j+1}_0	B^j_3	B^{j+1}_1	B^j_4	B^{j+1}_2

With the above-defined rule, and the chosen interleaving depths (powers of 2), the output bytes from the interleaver always occupy distinct time slots when N is odd. When N is even, a dummy byte shall be added at the beginning of the codeword at the input to the interleaver. The resultant odd-length codeword is then convolutionally interleaved, and the dummy byte shall then be removed from the output of the interleaver.

6.6.3 Support of higher downstream bit rates with S=1/2

With a rate of 4000 data frames per second and a maximum of 255 bytes (maximum RS codeword size) per data frame, the ADSL downstream total data rate is limited to approximately 8 Mbit/s per latency path. The total data rate limit can be increased to about 16 Mbit/s for the interleaved path by mapping two RS codewords into one FEC output data frame (i.e., by using $S = 1/2$ in the interleaved path). $S = 1/2$ shall be used in the downstream direction only over bearer channel AS0. Support of $S = 1/2$ is optional.

When the K_I data bytes per interleaved Mux data frame cannot be packed into one RS codeword, i.e., K_I is such that $K_I + R_I > 255$, the K_I data bytes shall be split into two consecutive RS codewords. When K_I is even, the first and second codeword shall have the same length $N_I1 = N_I2 = (K_I / 2 + R_I)$, otherwise the first codeword shall be one byte longer than the second, i.e. first codeword has $N_I1 = (K_I + 1) / 2 + R_I$ bytes, the second codeword has $N_I2 = (K_I - 1) / 2 + R_I$ bytes. For the FEC output data frame, $N_I = N_I1 + N_I2$, with $N_I < 511$ bytes.

The convolutional interleaver requires all codewords to have the same odd length. To achieve the odd codeword length, insertion of a dummy (not transmitted) byte may be required. For $S = 1/2$, the dummy byte addition to the first and/or second codeword at the input of the interleaver shall be as in Table 12

Table 12 - Dummy byte insertion at interleaver input for $S = 1/2$

N_I1	N_I2	Dummy Byte Insertion Action
odd	odd	No action
even	even	Add one dummy byte at beginning of both codewords
odd	even	Add one dummy byte at the beginning of the second codeword
even	odd	Add one dummy byte at the beginning of the first codeword and two dummy bytes at the beginning of the second codeword (the de-interleaver shall insert one dummy byte into the de-interleaver matrix on the first byte and the (D+1)-th byte of the corresponding codeword to make the addressing work properly.)

6.7 Tone ordering

A DMT time-domain signal has a high peak-to-average ratio (its amplitude distribution is almost Gaussian), and large values may be clipped by the digital-to-analog converter. The error signal caused by clipping can be considered as an additive negative impulse for the time sample that was clipped. The clipping error power is almost equally distributed across all tones in the symbol in which clipping occurs. Clipping is therefore most likely to cause errors on those tones that, in anticipation of a higher received SNR, have been assigned the largest number of bits (and therefore have the densest constellations). These occasional errors can be reliably corrected by the FEC coding if the tones with the largest number of bits have been assigned to the interleave buffer.

The numbers of bits and the relative gains to be used for every tone shall be calculated in the ATU-R receiver, and sent back to the ATU-C according to a defined protocol (see 9.9.13) The pairs of numbers are typically stored, in ascending order of frequency or tone number *i*, in a bit and gain table.

The "tone-ordered" encoding shall first assign all the bits from the fast buffer (i.e., $8 \times N_F$ bits) to the tones with the smallest number of bits assigned to them, and then assign all the bits from the interleaved buffer (i.e., $8 \times N_I$ bits) to the remaining tones. All tones shall be encoded with the number of bits assigned to them; one tone may therefore have a mixture of bits from the fast and interleaved buffers.

The ordered bit table b'_i shall be based on the original bit table b_i (i=0 to 255) as follows:

For k = 0 to 15 {

From the bit table, find the set of all i with the number of bits per tone $b_i = k$;

Assign b_i to the ordered bit allocation table in ascending order of i ;

}

A complementary de-ordering procedure should be performed in the ATU-R receiver. It is not necessary, however, to send the results of the ordering process to the receiver because the bit table was originally generated in the ATU-R, and therefore that table has all the information necessary to perform the de-ordering.

Figure 16 and Figure 17 show an example of tone ordering and bit extraction (without and with trellis coding respectively) for a 6-tone DMT case, with N_F = 1 and N_I = 1 for simplicity.

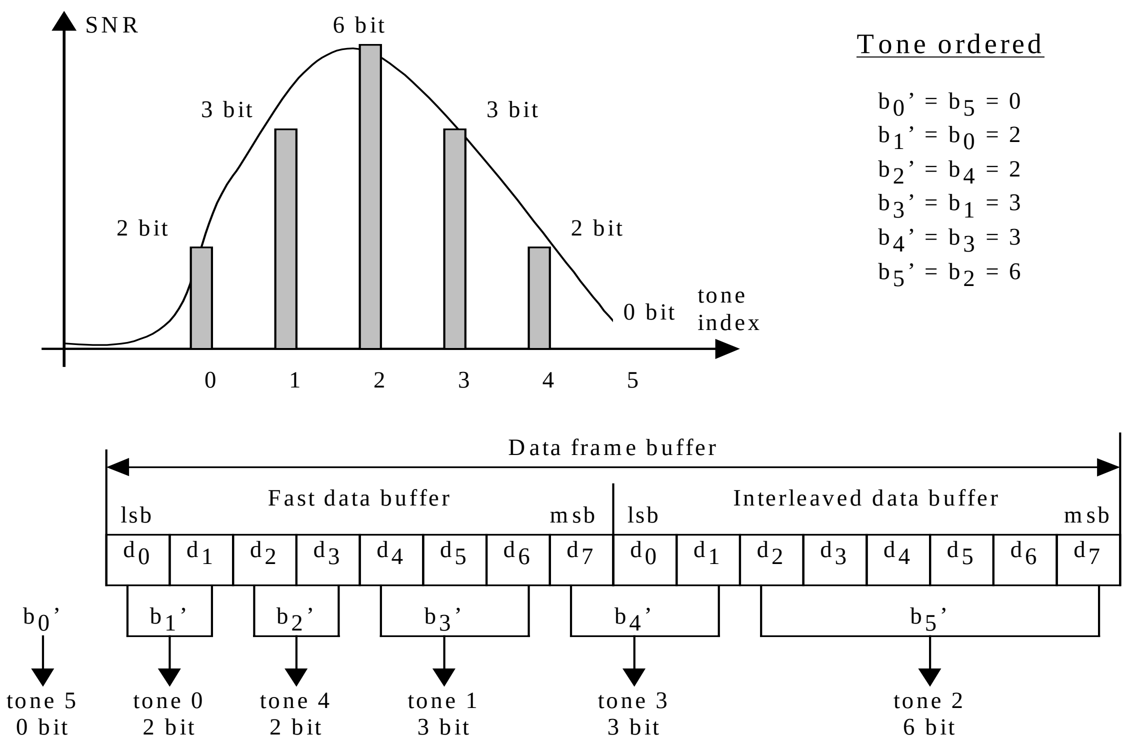


Figure 16 - Tone ordering and bit extraction example (without trellis coding)

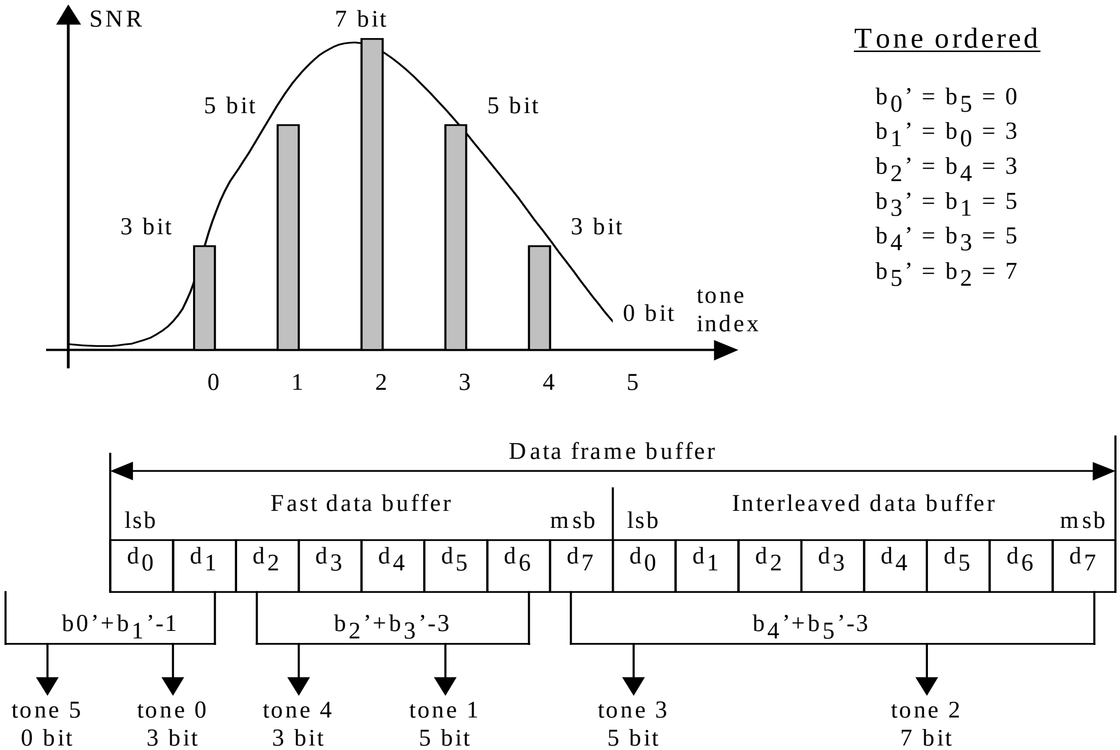


Figure 17 - Tone ordering and bit extraction example (with trellis coding)

6.8 Constellation encoder (with trellis coding)

Block processing of Wei’s 16-state 4-dimensional trellis code is optional to improve system performance. An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to $N_{downmax}$, with $8 \le N_{downmax} \le 15$.

6.8.1 Bit extraction

Data bytes from the data frame buffer shall be extracted according to a re-ordered bit allocation table b'_i, least significant bit first. Because of the 4-dimensional nature of the code, the extraction is based on pairs of consecutive b'_i, rather than on individual ones, as in the non-trellis-coded case. Furthermore, due to the constellation expansion associated with coding, the bit allocation table specifies b'_i , the number of coded bits per tone, which can be any integer from 2 to 15. Given a pair (x,y) of consecutive b'_i, $x+y$-1 bits (reflecting a constellation expansion of 1 bit per 4 dimensions, or one half bit per tone) are extracted from the data frame buffer. These $z = x+y-1$ bits (t_z , t_{z-1} , ... , t_1) are used to form the binary word u as shown in Table 13. The tone ordering procedure ensures $x \le y$. Single-bit constellations are not allowed because they can be replaced by 2-bit constellations with the same average energy. Refer to 6.8.2 for the reason behind the special form of the word u for the case $x = 0$, $y > 1$.

Table 13 - Forming the binary word *u*

Condition	Binary word / comment
$x > 1$, $y > 1$	$u = (t_z, t_{z-1}, ..., t_1)$
$x = 1$, $y \geq 1$	Condition not allowed
$x = 0$, $y > 1$	$u = (t_z, t_{z-1} , ..., t_2, 0, t_1, 0)$
$x = 0$, $y = 1$	Condition not allowed
$x = 0$, $y = 0$	Bit extraction not necessary, no message bits being sent
NOTE - t1 is the first bit extracted from the data frame buffer.	

The last two 4-dimensional cosets in the data frame shall be chosen to force the convolutional encoder state to the zero state. For each of these cosets, the 2 lsb's of *u* are pre-determined, and only (x+y -3) bits shall be extracted from the data frame buffer and shall be allocated to $t_3, t_4, \ldots, t_z$.

6.8.2 Bit conversion

The binary word $u = (u_{z'} , u_{z'-1} , ..., u_1)$ determines two binary words $v = (v_{z'-y} ,...,v_0)$ and $w = (w_{y-1},...,w_0)$, which are used to look up two constellation points in the encoder constellation table. For the usual case of x >1 and y >1, $z' = z = x+y-1$, and v and w contain x and y bits respectively. For the special case of $x = 0$ and $y > 1$, $z' = z+2 = y+1$, $v = (v_1,v_0) = 0$ and $w = (w_{y-1},...,w_0)$. The bits (u_3,u_2,u_1) determine (v_1,v_0) and (w_1,w_0) according to Figure 18.

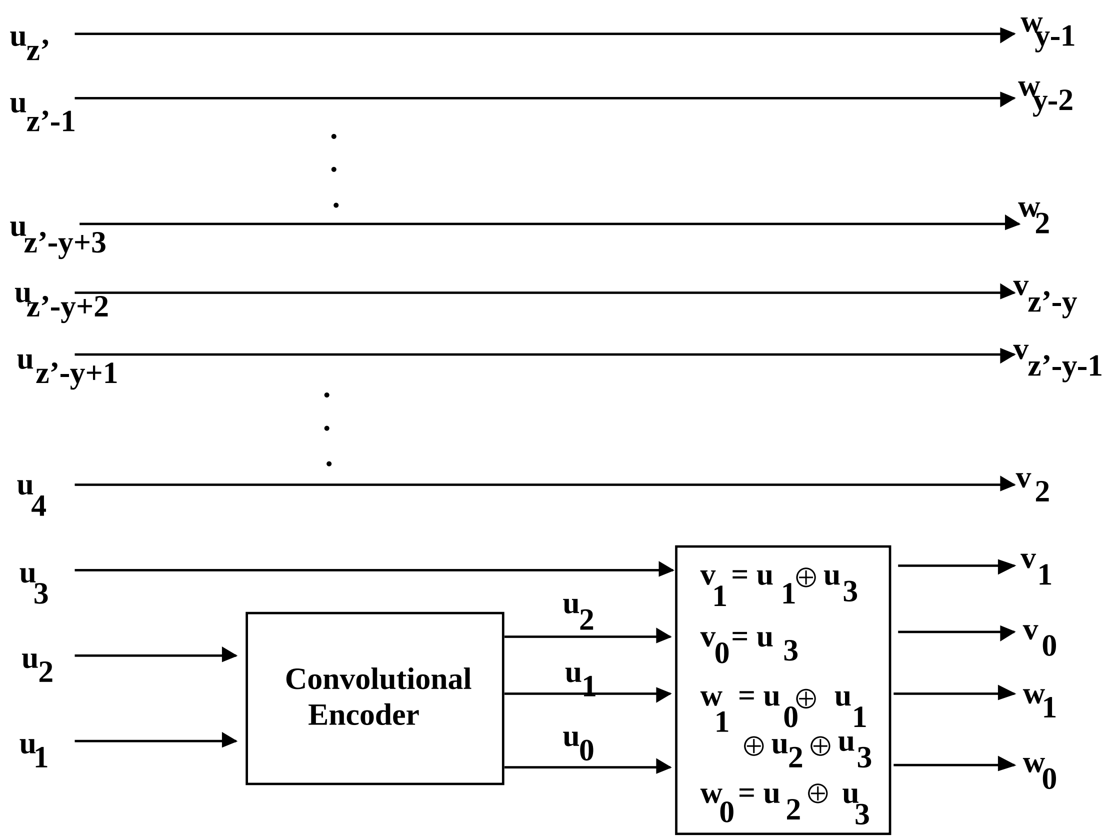


Figure 18 - Conversion of *u* to *v* and *w*

The convolutional encoder shown in Figure 18 is a systematic encoder (i.e. u_1 and u_2 are passed through unchanged) as shown in Figure 19. The state variables (S_3, S_2, S_1, S_0) are used to label the states of the trellis shown in Figure 21. At the beginning of the encoding of a data frame, the convolutional encoder state is initialized to (0, 0, 0, 0).

The remaining bits of v and w are obtained from the less significant and more significant parts of ($u_{z'}$, $u_{z'-1}$, ... ,u_4), respectively. When x >1 and y > 1, $v = (u_{z'-y+2}, u_{z'-y+1}, ..., u_4, v_1, v_0)$ and w = ($u_{z'}$, $u_{z'-1}$, ..., $u_{z'-y+3}$, w_1, w_0). When $x = 0$, the bit extraction and conversion algorithms have been judiciously designed so that $v_1 = v_0 = 0$. The binary word v is input first to the constellation encoder, and the binary word w last.

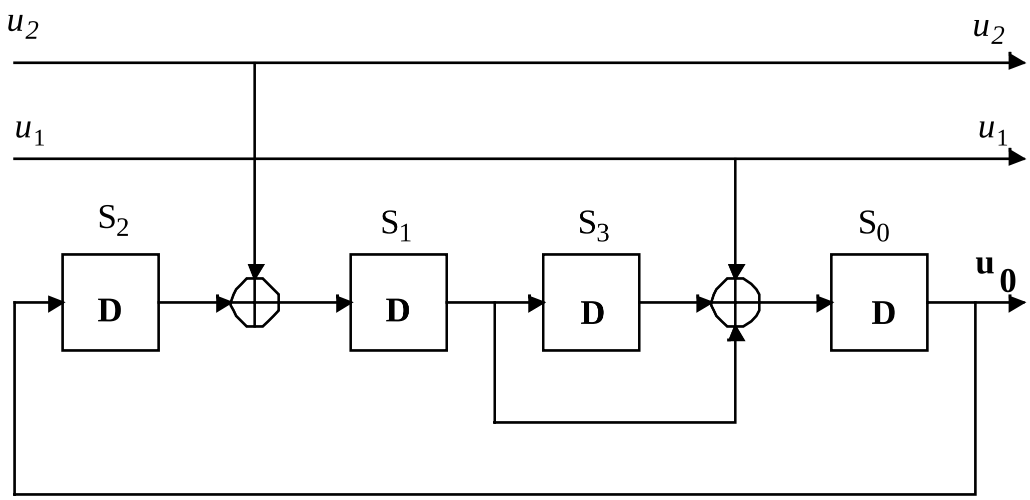


Figure 19 - Convolutional encoder.

In order to force the final state to the zero state (0,0,0,0), the 2 lsb's u_1 and u_2 of the final two 4-dimensional coset in the data frame are constrained to $u_1 = S_1 \oplus S_3$, and $u_2 = S_2$.

6.8.3 Coset partition and trellis diagram

In a trellis code modulation system, the expanded constellation is labeled and partitioned into subsets ("cosets") using a technique called mapping by set-partitioning. The four-dimensional cosets in Wei's code can each be written as the union of two Cartesian products of two 2-dimensional cosets. For example, $C_4^0 = (C_2^0 \times C_2^1) \cup (C_2^2 \times C_2^3)$. The four constituent 2-dimensional cosets, denoted by C_2^0, C_2^1, C_2^2, C_2^3, are shown in Figure 20.

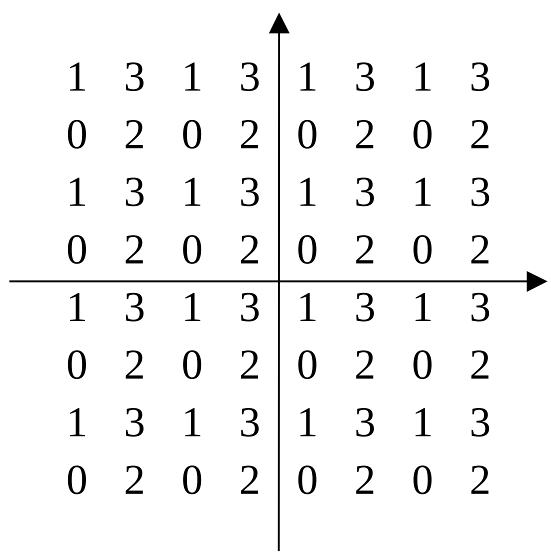


Figure 20 - Constituent 2-dimensional cosets for Wei's code

The encoding algorithm ensures that the 2 least significant bits of a constellation point comprise the index *i* of the 2-dimensional coset C_2^i in which the constellation point lies. The bits (v_1, v_0) and (w_1, w_0) are in fact the binary representations of this index.

The three bits (u_2,u_1,u_0) are used to select one of the 8 possible four-dimensional cosets. The 8 cosets are labeled C_4^i where *i* is the integer with binary representation (u_2,u_1,u_0). The additional bit u_3 (see Figure 18) determines which one of the two Cartesian products of 2-dimensional cosets in the 4-dimensional coset is chosen. The relationship is shown in Table 14. The bits (v_1,v_0) and (w_1,w_0) are computed from (u_3,u_2,u_1,u_0) using the linear equations given in Figure 18.

Table 14 - Relation between 4-dimensional and 2-dimensional cosets

4-D Coset	u_3 u_2 u_1 u_0	v_1 v_0	w_1 w_0	2-D Cosets
C_4^0	0 0 0 0	0 0	0 0	$C_2^0 \times C_2^0$
	1 0 0 0	1 1	1 1	$C_2^3 \times C_2^3$
C_4^4	0 1 0 0	0 0	1 1	$C_2^0 \times C_2^3$
	1 1 0 0	1 1	0 0	$C_2^3 \times C_2^0$
C_4^2	0 0 1 0	1 0	1 0	$C_2^2 \times C_2^2$
	1 0 1 0	0 1	0 1	$C_2^1 \times C_2^1$
C_4^6	0 1 1 0	1 0	0 1	$C_2^2 \times C_2^1$
	1 1 1 0	0 1	1 0	$C_2^1 \times C_2^2$
C_4^1	0 0 0 1	0 0	1 0	$C_2^0 \times C_2^2$
	1 0 0 1	1 1	0 1	$C_2^3 \times C_2^1$
C_4^5	0 1 0 1	0 0	0 1	$C_2^0 \times C_2^1$
	1 1 0 1	1 1	1 0	$C_2^3 \times C_2^2$
C_4^3	0 0 1 1	1 0	0 0	$C_2^2 \times C_2^0$
	1 0 1 1	0 1	1 1	$C_2^1 \times C_2^3$
C_4^7	0 1 1 1	1 0	1 1	$C_2^2 \times C_2^3$
	1 1 1 1	0 1	0 0	$C_2^1 \times C_2^0$

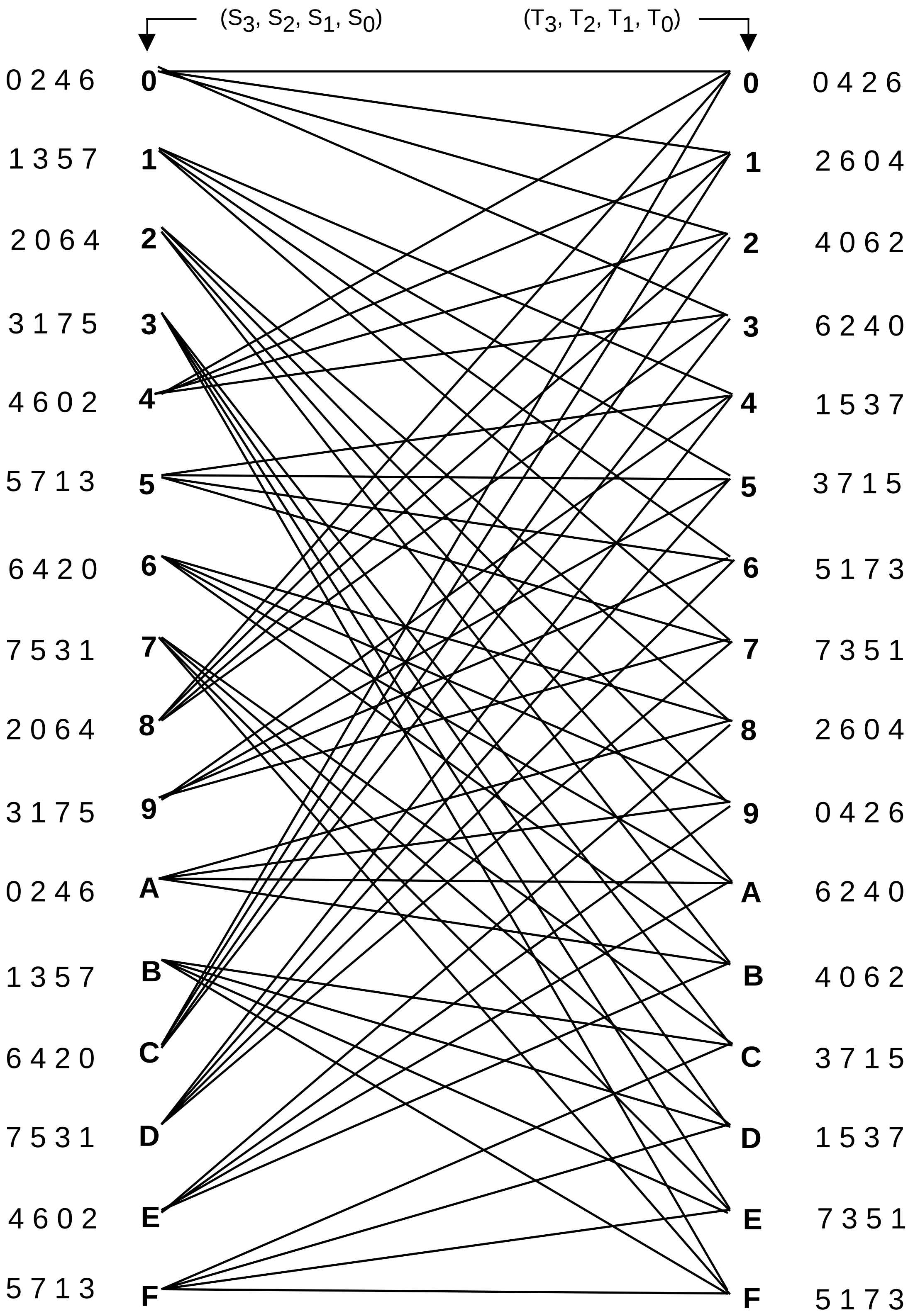


Figure 21- Trellis diagram

Figure 21 shows the trellis diagram based on the finite state machine in Figure 19, and the one-to-one correspondence between (u_2,u_1,u_0) and the 4-dimensional cosets. In Figure 21, $S = (S_3,S_2,S_1,S_0)$, represents the current state, while $T = (T_3,T_2,T_1,T_0)$ represents the next state in the finite state machine.

Each state S , represented by its hex value in bold, is connected to four states T , similarly represented, by four branches determined by the values of u_2 and u_1. Each branch is labeled with the 4-dimensional coset specified by the values of u_2, u_1 (and $u_0 = S_0$, see Figure 20).

To make the constellation diagram more readable the indices of the 4-dimensional coset labels are listed next to the starting and end points of the branches, rather than on the branches themselves. The leftmost label corresponds to the uppermost branch for each state. The constellation diagram is used when decoding the trellis code by the Viterbi algorithm.

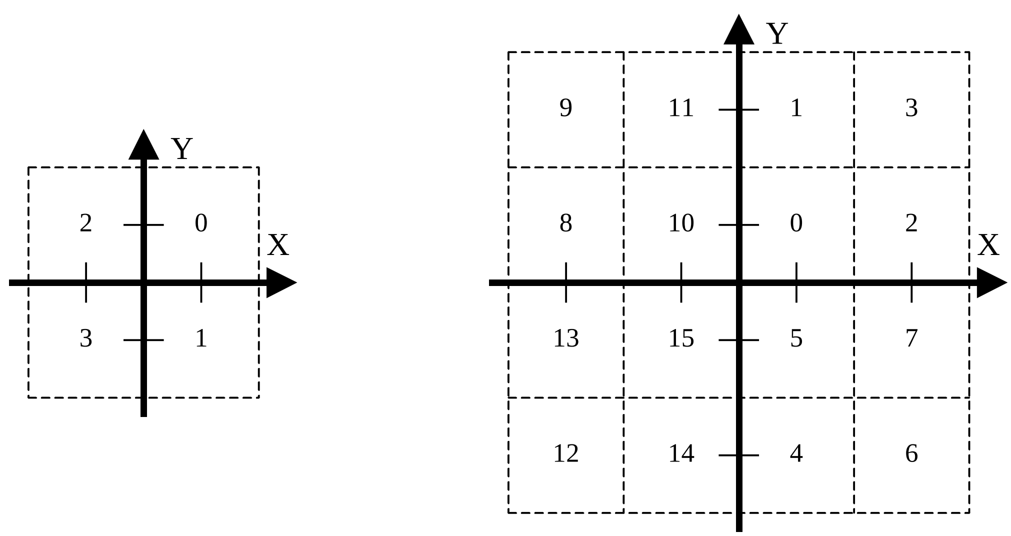
6.8.4 Constellation encoder

For a given sub-carrier, the encoder shall select an odd-integer point (X,Y) from the square-grid constellation based on the b bits of either $\{v_{b-1},v_{b-2}, ...,v_1,v_0\}$ or $\{w_{b-1},w_{b-2}, ...,w_1,w_0\}$. For convenience of description, these b bits are identified with an integer label whose binary representation is ($v_{b-1},v_{b-2}, ...,v_1,v_0$), but the same encoding rules apply also to the w vector. For example, for b=2, the four constellation points are labeled 0,1,2,3 corresponding to (v_1,v_0) = (0,0), (0,1), (1,0), (1,1), respectively.

NOTE - v_0 is the first bit extracted from the buffer.

6.8.4.1 Even values of b

For even values of b, the integer values X and Y of the constellation point (X,Y) shall be determined from the b bits $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$ as follows. X and Y are the odd integers with 2's-complement binary representations ($v_{b-1}, v_{b-3}, ..., v_1$, 1) and ($v_{b-2}, v_{b-4},..., v_0$, 1), respectively. The most significant bits (msb's), v_{b-1} and v_{b-2}, are the sign bits for X and Y, respectively. Figure 22 shows example constellations for b = 2 and b= 4.



NOTE - The values of X and Y shown are spaced 2 units apart with coordinates (±1, ±3 grid) and represent the output of the constellation encoder. These values require appropriate scaling 1) such that all constellations regardless of size represent the same rms energy and 2) by the fine gain scaling (6.10) before modulation by the IDFT (6.11.2).

Figure 22 - Constellation labels for b = 2 and b = 4

The 4-bit constellation can be obtained from the 2-bit constellation by replacing each label *n* by a 2 × 2 block of labels as shown in Figure 23.

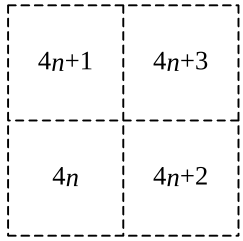


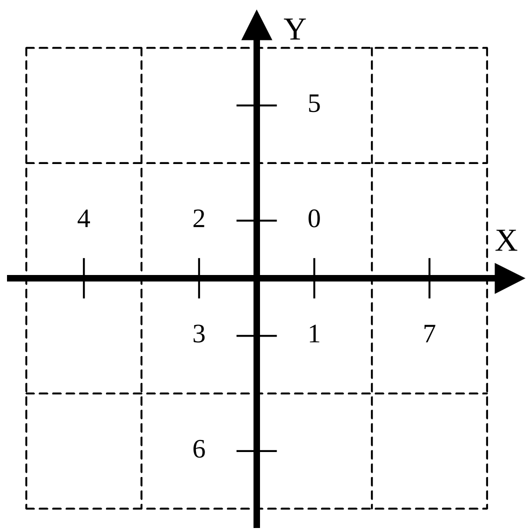
Figure 23 - Expansion of point *n* into the next larger square constellation

The same procedure can be used to construct the larger even-bit constellations recursively.

The constellations obtained for even values of *b* are square in shape. The least significant bits $\{v_1,v_0\}$ represent the coset labeling of the constituent 2-dimensional cosets used in the 4-dimensional Wei trellis code.

6.8.4.2 Odd values of b, b = 3

Figure 24 shows the constellation for the case b = 3.



NOTE - The values of X and Y shown are spaced 2 units apart with coordinates (±1, ±3 grid) and represent the output of the constellation encoder. These values require appropriate scaling 1) such that all constellations regardless of size represent the same rms energy and 2) by the fine gain scaling (6.10) before modulation by the IDFT (6.11.2).

Figure 24 - Constellation labels for *b* = 3

6.8.4.3 Odd values of b, b>3

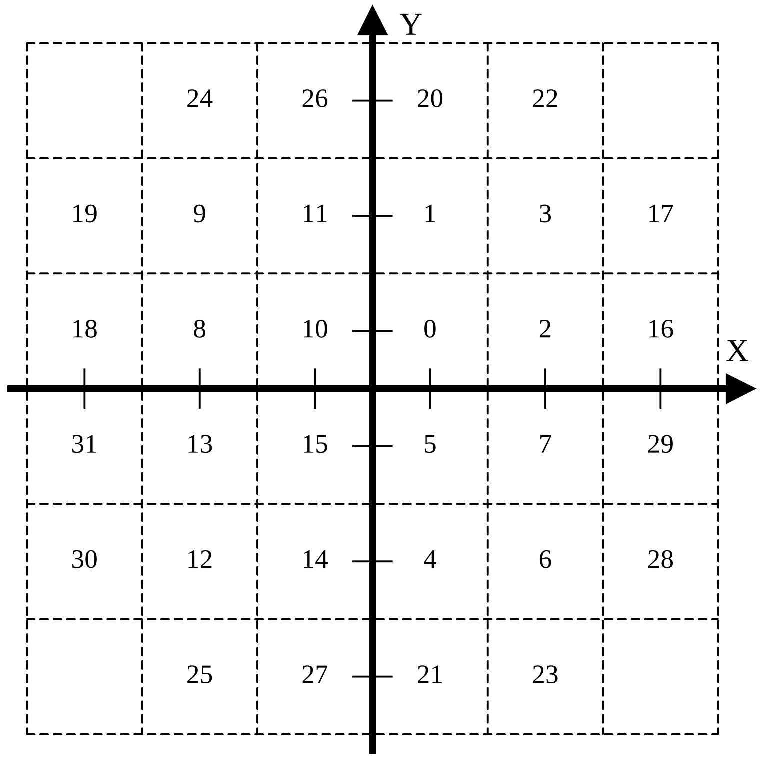
If *b* is odd and greater than 3, the 2 msb's of *X* and the 2 msb's of *Y* are determined by the 5 msb's of the *b* bits. Let $c = (b+1)/2$, then *X* and *Y* have the 2's-complement binary representations $(X_c,X_{c-1},v_{b-4},$

$v_{b\text{-}6}$,...,v_3,v_1,1) and (Y_c,$Y_{c\text{-}1}$,$v_{b\text{-}5}$,$v_{b\text{-}7}$,$v_{b\text{-}9}$,...,v_2,v_0,1), where X_c and Y_c are the sign bits of X and Y respectively. The relationship between X_c, $X_{c\text{-}1}$, Y_c, $Y_{c\text{-}1}$ and $v_{b\text{-}1}$, $v_{b\text{-}2}$, ..., $v_{b\text{-}5}$ is shown in the Table 15.

Table 15 - Determining the top 2 bits of *X* and *Y*

$v_{b-1}, v_{b-2}, \ldots, v_{b-5}$	X_c, X_{c-1}	Y_c, Y_{c-1}
0 0 0 0 0	0 0	0 0
0 0 0 0 1	0 0	0 0
0 0 0 1 0	0 0	0 0
0 0 0 1 1	0 0	0 0
0 0 1 0 0	0 0	1 1
0 0 1 0 1	0 0	1 1
0 0 1 1 0	0 0	1 1
0 0 1 1 1	0 0	1 1
0 1 0 0 0	1 1	0 0
0 1 0 0 1	1 1	0 0
0 1 0 1 0	1 1	0 0
0 1 0 1 1	1 1	0 0
0 1 1 0 0	1 1	1 1
0 1 1 0 1	1 1	1 1
0 1 1 1 0	1 1	1 1
0 1 1 1 1	1 1	1 1
1 0 0 0 0	0 1	0 0
1 0 0 0 1	0 1	0 0
1 0 0 1 0	1 0	0 0
1 0 0 1 1	1 0	0 0
1 0 1 0 0	0 0	0 1
1 0 1 0 1	0 0	1 0
1 0 1 1 0	0 0	0 1
1 0 1 1 1	0 0	1 0
1 1 0 0 0	1 1	0 1
1 1 0 0 1	1 1	1 0
1 1 0 1 0	1 1	0 1
1 1 0 1 1	1 1	1 0
1 1 1 0 0	0 1	1 1
1 1 1 0 1	0 1	1 1
1 1 1 1 0	1 0	1 1
1 1 1 1 1	1 0	1 1

Figure 25 shows the constellation for the case b = 5.



NOTE - The values of X and Y shown are spaced 2 units apart with coordinates (±1, ±3, ±5 grid) and represent the output of the constellation encoder. These values require appropriate scaling 1) such that all constellations regardless of size represent the same rms energy and 2) by the fine gain scaling (6.10) before modulation by the IDFT (6.11.2).

Figure 25 - Constellation labels for *b* = 5

The 7-bit constellation shall be obtained from the 5-bit constellation by replacing each label *n* by the 2 × 2 block of labels as shown in Figure 23:

Again, the same procedure shall be used to construct the larger odd-bit constellations recursively. Note also that the least significant bits $\{v_1,v_0\}$ represent the coset labeling of the constituent 2-dimensional cosets used in the 4-dimensional Wei trellis code.

6.9 Constellation encoder (without trellis coding)

An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to $N_{downmax}$, with $8 \leq N_{downmax} \leq 15$). The constellation encoder shall not use trellis coding with this option.

6.9.1 Bit extraction

Data bits from the data frame buffer shall be extracted according to a re-ordered bit allocation table b'_i, least significant bit first. The number of bits per sub-carrier, b'_i, can take any non-negative integer values not exceeding $N_{downmax}$, with the exception of $b'_i = 1$. For a given tone $b'_i = b$ bits are extracted from the data frame buffer, and these bits form a binary word $\{v_{b-1},v_{b-2}, ...,v_1,v_0\}$. The first bit extracted shall be v_0, the lsb.

6.9.2 Constellation encoder

The constellation encoder requirements shall be as specified in 6.8.4.

6.10 Gain scaling

For the transmission of data symbols, gain scaling, g_i, shall be applied to all data-carrying sub-carriers as requested by the ATU-R (see 6.15.3 and 9.9.13) and possibly updated during showtime via the bit swap procedure. Only values of g_i within a range of approximately 0.75 to 1.33 (i.e., -2.5 to +2.5 dB) may be used to equalize the expected error rates for all data-carrying sub-carriers.

For the transmission of synchronization symbols, no gain scaling shall be applied to any sub-carrier.

Each point, (X_i, Y_i), or complex number $X_i + jY_i$, output from the encoder is multiplied by g_i:

$Z_i = g_i \times (X_i + j\,Y_i)$

NOTE - The g_i define a scaling of the root mean square (rms) sub-carrier levels relative to those used in C-MEDLEY (see 9.6.6). They are independent of any methods that manufacturers may use to simplify implementation (e.g., constellation nesting).

6.11 Modulation

6.11.1 Sub-carriers

The frequency spacing, Δf, between sub-carriers is 4.3125 kHz, with a tolerance of ±50 ppm.

6.11.1.1 Data sub-carriers

The channel analysis signal defined in 9.6.6 allows for a maximum of 255 sub-carriers (at frequencies $i \times \Delta f$ with i = 1 to 255) to be used. If echo cancelling (EC) is used to separate downstream and upstream signals, then the lower limit on i is determined by the POTS splitting filters; if frequency division multiplexing (FDM) is used the lower limit on i is set by the downstream-upstream separation filters. The cut-off frequencies of these filters are completely at the discretion of the manufacturer because, in either case, the range of usable i is determined during the channel analysis (9.6 and 9.7).

6.11.1.2 Pilot

Sub-carrier 64 (f = 276 kHz) shall be reserved for a pilot; that is $b_{64} = 0$ and $g_{64} = 1$. The data modulated onto the pilot sub-carrier shall be a constant {0,0}, generating the {+,+} constellation point. Use of this pilot allows resolution of sample timing in a receiver modulo-8 samples (assuming a downstream sampling rate of 2.208 MHz). Therefore a gross timing error that is an integer multiple of 8 samples could still persist after a micro-interruption (e.g., a temporary short-circuit, open circuit or severe line hit); correction of such timing errors is made possible by the use of the synchronization symbol defined in 6.11.3.

6.11.1.3 Nyquist frequency

The sub-carrier at the Nyquist frequency (sub-carrier 256) shall not be used for data; other possible uses are for further study.

6.11.1.4 DC

The sub-carrier at DC (sub-carrier 0) shall not be used (i.e., Z_0=0).

6.11.2 Modulation by the inverse discrete Fourier transform (IDFT)

The modulating transform defines the relationship between the 512 real values x_n and the Z_i

$$x_n = \sum_{i=0}^{511} \exp\left(\frac{j\pi n i}{256}\right) \times Z_i \qquad for\ n = 0\ to\ 511$$

The constellation encoder and gain scaling generate only 255 complex values of Z_i (plus zero at dc, and one real value if the Nyquist frequency is used). In order to generate real values of x_n these values of Z_i shall be augmented so that the vector Z has Hermitian symmetry. That is,

$Z_i = \mathrm{conj}\,(Z_{512-i})$ for i = 257 to 511

6.11.3 Synchronization symbol

The synchronization symbol permits recovery of the superframe boundary after micro-interruptions that might otherwise force retraining.

The data symbol rate, f_{symb} = 4 kHz, the carrier separation, Δf = 4.3125 kHz, and the IDFT size, N = 512, are such that a cyclic prefix of 40 samples could be used. That is,

$(512 + 40) \times 4.0 = 512 \times 4.3125 = 2208$

The cyclic prefix shall, however, be shortened to 32 samples, and a synchronization symbol (with a nominal length of 544 samples) is inserted after every 68 data symbols. That is,

$(512 + 32) \times 69 = (512 + 40) \times 68$

The data pattern used in the synchronization symbol shall be the pseudo-random downstream sequence PRD, (d_n, for n = 1 to 512) defined by

$d_n = 1$ for n = 1 to 9

$d_n = d_{n-4} \oplus d_{n-9}$ for n =10 to 512

NOTES

1. The period of the PRD is only 511 bits, so $d_{512} = d_1$.
2. The d_1 - d_9 shall be re-initialized for each sync symbol, so each symbol uses the same data.

The first pair of bits (d_1 and d_2) shall be used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); the first and second bits of subsequent pairs are then used to define the X_i and Y_i. for i = 1 to 255 as shown in Table 16. No gain scaling shall be applied to any sub-carrier.

Table 16 - Mapping of two data bits into a 4-QAM constellation point

d_{2i+1}, d_{2i+2}	Decimal label (see note)	X_i, Y_i.
0 0	0	+ +
0 1	1	+ -
1 0	2	- +
1 1	3	- -
NOTE - This labeling is different from the mapping in 6.8.4.1, where d_{2i+1} would be considered the first and least significant bit.		

Bits 129 and 130, which modulate the pilot sub-carrier (sub-carrier 64), shall be overwritten by the data {0,0}: generating the {+,+} constellation point.

The data modulated onto each sub-carrier shall be as defined above; it shall not depend on which sub-carriers are used. The transmit PSD for each of the sub-carriers is defined in 6.15.4.

6.12 Cyclic prefix

The last 32 samples of the output of the IDFT (x_n for n = 480 to 511) shall be prepended to the block of 512 samples and read out to the digital-to-analog converter (DAC) in sequence. That is, the subscripts, n, of the DAC samples in sequence shall be 480.....511, 0......511.

The cyclic prefix shall be used for all symbols beginning with the C-RATES1 segment of the initialization sequence, as defined in 9.6.2.

6.13 Transmitter dynamic range

The transmitter includes all analog transmitter functions: the digital-to-analog converter (DAC), the anti-aliasing filter, the hybrid circuitry, and the high-pass part of the POTS splitter. The transmitted signal shall conform to the frequency requirements as described in 6.11.1 for frequency spacing.

6.13.1 Maximum clipping rate

The maximum output signal of the transmitter shall be such that the output signal shall be clipped no more than 0.00001% of the time.

6.13.2 Noise/Distortion floor

The signal to noise plus distortion ratio of the transmitted signal in a given sub-carrier is specified as the ratio of the rms value of the full-amplitude tone in that sub-carrier to the rms sum of all the non-tone signals in the 4.3125 kHz frequency band centered on the sub-carrier frequency. This ratio is measured for each sub-carrier used for transmission using a MultiTone Power Ratio (MTPR) test as shown in Figure 26.

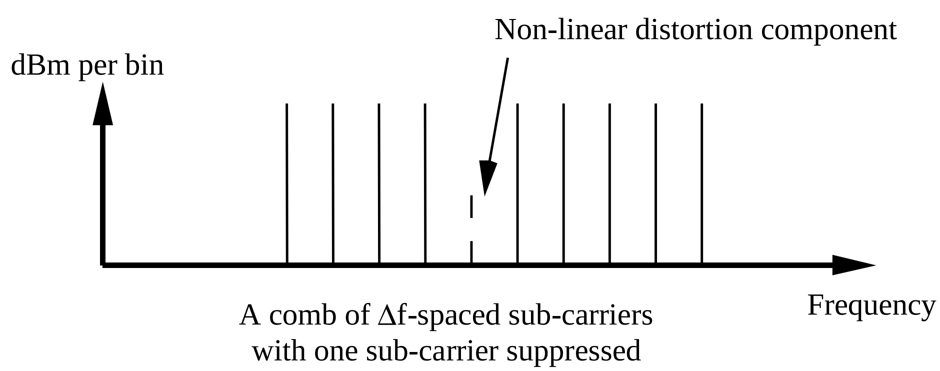


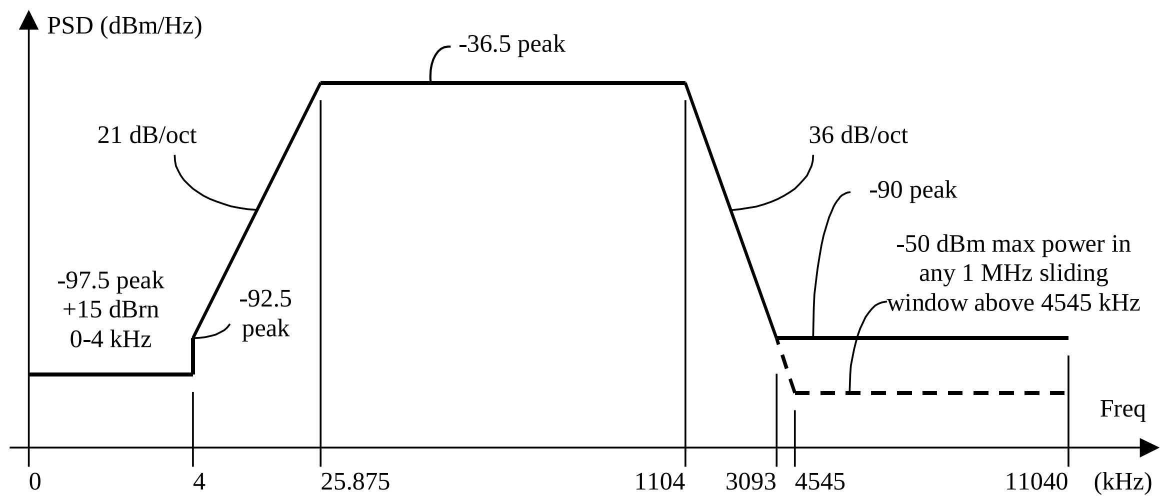
Figure 26 - MTPR test

Over the transmission frequency band, the MTPR of the transmitter in any sub-carrier shall be no less than $(3N_{downi} + 20)$ dB, where N_{downi} is defined as the size of the constellation (in bits) to be used on sub-carrier i. The minimum transmitter MTPR shall be at least 38dB (corresponding to an N_{downi} of 6) for any sub-carrier.

NOTE - Signals transmitted during normal initialization and data transmission cannot be used for this test because the DMT symbols have a cyclic prefix appended, and the PSD of a repetitive signal does not have nulls at any sub-carrier frequencies. A gated FFT-based analyser could be used, but this would measure both the non-linear distortion and the linear distortion introduced by the transmit filter. Therefore this test will imply that the transmitter be programmed with special software—probably to be used during development only. The subject of an MTPR test that can be applied to a production modem is for further study.

6.14 Transmitter spectrum

Figure 27 shows the power spectral density (PSD) mask for the transmitted signal. The low frequency stop band is defined as the voiceband; the high frequency stop band is defined as frequencies greater than 1.104 MHz.



FREQUENCY BAND (kHz)	EQUATION FOR LINE (dBm/Hz)
$0 < f < 4$	-97.5, with max power in the in 0-4 kHz band of +15 dBrn
$4 < f < 25.875$	$-92.5 + 21 \times \log_2 (f/4)$
$25.875 < f < 1104$	-36.5
$1104 < f < 3093$	$-36.5 - 36 \times \log_2(f/1104)$
$3093 < f < 4545$	-90 peak, with max power in the $[f, f + 1$ MHz] window of ($-36.5 -36 \times \log_2(f/1104) + 60$) dBm
$4545 < f < 11040$	-90 peak, with max power in the $[f, f+1$MHz] window of -50 dBm

NOTES

1. All PSD measurements are in 100 ohms; the POTS band aggregate power measurement is in 600 ohms.

2. All PSD and power measurements shall be made at the U-C interface (see Figure 1); the signals delivered to the PSTN are specified in Annex E.

3. The breakpoint frequencies and PSD values are exact; the indicated slopes are approximate.

4. Above 25.875 kHz, the peak PSD shall be measured with a 10 kHz resolution bandwidth.

5. The power in a 1 MHz sliding window is measured in 1 MHz bandwidth, starting at the measurement frequency.

Figure 27 - ATU-C transmitter PSD mask

6.14.1 Passband PSD and response

The transmit PSD within the 25.875 kHz to 1104 kHz passband shall be no greater than -36.5 dBm/Hz reduced by power cut-back in multiples of 2 dB; the lower end of the passband actually used by the transmitter depends on whether echo cancelling or FDM is used, and is manufacturer discretionary; the upper end depends on whether the signal is for initialization (see 6.15.1) or steady state (see 6.15.3).

The passband ripple during steady-state shall be no greater than +3.5 dB; the maximum PSD of (-40 - 2n + 3.5) dBm/Hz applies across the whole passband from 25 kHz to 1104 kHz.

The group delay variation over the pass band shall not exceed 50µs.

6.14.2 Low frequency stop band rejection

In the transition band from 4 kHz to 25.875 kHz, the transmit PSD shall not exceed a mask that decreases at approximately 21 dB/octave from (-40 dBm/Hz + 3.5 dB) at the passband-edge (25.875 kHz) to -92.5 dBm/Hz at 4.0 kHz,

In the band from 0 to 4 kHz, the transmit PSD shall be no greater than -97.5 dBm/Hz. Furthermore, the aggregate power in the 0 to 4 kHz band, measured in 600 ohms, shall not exceed + 15 dBrn (see Annex E for the method of measurement).

NOTE - A continuation of the transition band rolloff to lower frequencies would intersect the -97.5 dBm/Hz noise floor at 3400 Hz. However, to limit interference with voiceband services, the noise floor is extended to 4000 Hz.

6.14.3 High frequency stop band rejection

The transmit PSD shall not exceed a mask that decreases at 36 dB/octave from (-40 dBm/Hz + 3.5 dB) at the passband-edge (1.104 MHz) to a floor of -90 dBm/Hz at 3.093 MHz.

In addition, at all frequencies f from 3.093 to 4.545 MHz, the transmit power in the [f, f + 1 MHz] window shall not exceed $(-36.5 - 36 \times \log_2(f/1104) + 60)$ dBm. At all frequencies f from 4.545 to 11.040 MHz, the transmit power in the [f, f + 1 MHz] window shall not exceed -50 dBm.

6.15 Transmit power spectral density and aggregate power level

There are three different PSD masks for the ATU-C transmit signal, depending on the type of signal sent. In all cases the power in the voiceband measured at the U-C interface and that is delivered to the Public Switched Telephone Network (PSTN) interface shall conform to the specification in 6.14.2.

NOTE - The power emitted by the ATU-C is limited by the requirements in this subclause. Notwithstanding these requirements, it is assumed that the ADSL will comply with applicable FCC requirements on emission of electromagnetic energy. These requirements may be found in FCC Title 47 and other FCC documents.

6.15.1 All initialization signals (except C-ECT) starting with C-REVERB1

The nominal PSD in the band from 25.875 to 1104 kHz shall be set at -40 dBm/Hz for an aggregate transmit power not greater than 20.4 dBm. If measurement of the upstream power indicates that power cut-back is necessary, then the nominal PSD shall be set at -42, -44, -46, -48, -50, or -52 dBm/Hz (i.e., nominal PSD = $-40-2n$ dBm/Hz with n = 0 to 6, see 9.4.6).

During the C-REVERB and C-SEGUE signals, all sub-carriers from index i to *255* shall be transmitted, with i vendor discretionary (see 6.14.1). However, at the vendor's discretion, one or more of these sub-carriers may not be transmitted during the C-MEDLEY signal.

To allow for non-ideal transmit filter effects (e.g., passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the nominal PSD level. The maximum transmit PSD shall therefore be no higher than $-39-2n$ dBm/Hz.

6.15.2 C-ECT

Because C-ECT is a vendor defined signal (see 9.4.9), the PSD specification shall be interpreted only as a maximum. This maximum level is $-39-2n$ dBm/Hz (with n indicating the power cut back, n=0 to 6) for the band from 25.875 to 1104 kHz. Sub-carriers 1 to 5 may be used, but the power in the voiceband that is delivered to the PSTN interface shall conform to the specification given in 6.14.2.

6.15.3 Steady-state data signal

The nominal PSD in the band from 25.875 to 1104 kHz shall be set at -40 dBm/Hz. The nominal aggregate power shall be set at -3.65+10log(*ncdown*) dBm, where *ncdown* is the number of sub-carriers used (i.e., with b_i>0) (20.4 dBm if all sub-carriers are used). The transmit PSD and aggregate power may, however, be changed from their nominal values in either of the following circumstances:

– A power cut back may have been applied, reducing the nominal PSD level to -40-2*n* dBm/Hz, with *n* = 0 to 6 (see 9.4.6).

– The bits & gains table (received from the ATU-R during initialization and possibly updated through bit swaps, see 9.9.14 and 11.2) may not allocate bits to some sub-carriers and may finely adjust (i.e., within a ±2.5 dB range) the transmit PSD level of others in order to equalize expected error rates on each of those sub-carriers.

– Vendor discretionary transmit PSD levels for unused sub-carriers (i.e., with b_i=0). The maximum transmit PSD for these sub-carriers is specified in b) and c) below.

To allow for non-ideal transmit filter effects (e.g., passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the finely adjusted nominal PSD level. The maximum transmit PSD shall therefore be no higher than -36.5-2*n* dBm/Hz.

The transmit PSD of each sub-carrier is defined as follows:

a) For the sub-carriers with (b_i > 0), the ATU-C transmitter shall transmit at PSD levels equal to that specified by the g_i (e.g., g_i = 1, then transmit at C-MEDLEY transmit PSD level). Over these sub-carriers, the sum of the 10log(g_i^2) (fine gains in dB) shall not exceed 0 dB, with 10log(g_i^2) in the -2.5 to +2.5 dB range.

b) For the sub-carriers with (b_i = 0 & g_i > 0), the ATU-C transmitter should and is recommended to transmit at PSD levels equal to that specified by the g_i (e.g., g_i = 1, then transmit at C-MEDLEY level), with a 4-QAM constellation point (which may change from symbol to symbol). The ATU-R receiver cannot assume any particular PSD levels on those sub-carriers. The transmit PSD levels of those sub-carriers shall be no higher than the C-REVERB1 transmit PSD level + 10log(g_i^2) dB. Over these sub-carriers, the sum of the 10log(g_i^2) (fine gains in dB) shall not exceed 0 dB, with 10log(g_i^2) in the -2.5 to +2.5 dB range.

c) For the sub-carriers with (b_i = 0 & g_i = 0), the ATU-C transmitter should and is recommended to transmit no power on those sub-carriers. The ATU-R receiver cannot assume any particular PSD levels on those sub-carriers. The transmit PSD levels of those sub-carriers shall be at least 10 dB below the C-REVERB1 transmit PSD level.

The aggregate transmit power over the 25.875 to 1104 kHz band shall be no higher than 20.4-2*n* dBm, which is equivalent to an average transmit PSD of no higher than -40-2*n* dBm/Hz (with *n* indicating power cutback, *n* = 0 to 6).

6.15.4 Synchronization symbol

The transmit PSD level for for those sub-carriers with g_i > 0 shall be the same as for the initialization signal C-REVERB1 (i.e., nominally -40-2*n* dBm/Hz). The transmit PSD level for those sub-carriers with g_i = 0 shall be at least 10 dB below the C-REVERB1 transmit PSD level.

Since the g_i are applied only to the data symbols, the transmit PSD of a synchronization symbol differs from the transmit PSD of a data symbol. These g_i are calculated for the multipoint constellations in order to equalize the expected error rate on all sub-carriers, and are therefore irrelevant for most of the 4-QAM modulated sub-carriers of the synchronization symbol.

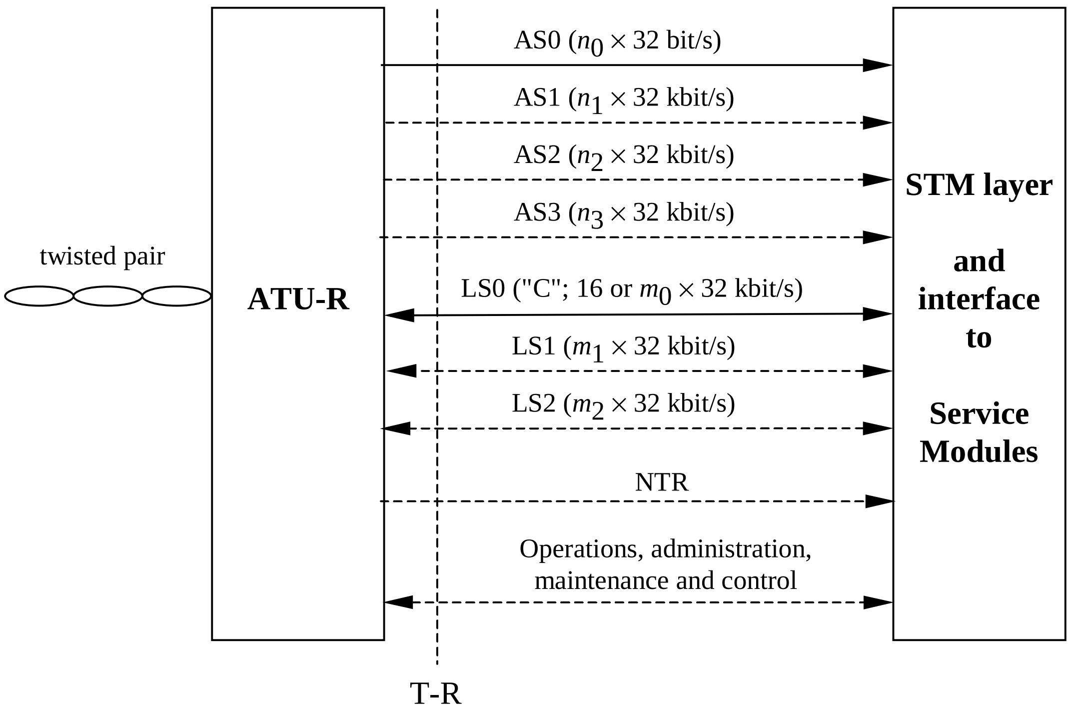
7 ATU-R functional characteristics

7.1 STM Transmission Protocol Specific functionalities

7.1.1 ATU-R input and output T-R interfaces for STM transport

The functional data interfaces at the ATU-R are shown in Figure 28. Output interfaces for the high-speed downstream simplex bearer channels are designated AS0 through AS3; input-output interfaces for the duplex bearer channels are designated LS0 through LS2. There may also be a functional interface to transport operations, administration and maintenance (OAM) indicators from the SMs (service modules) to the ATU-R; this interface may physically be combined with the LS0 upstream interface.

The data rates of the input and output data interfaces (i.e., n_x and m_x) at the ATU-R are specified in 5.1. The data rate at a given interface shall match the rate of the bearer channel configured to that interface.



NOTE - Interface Elements that are shown by solid lines shall be supported; interface elements that are shown with dotted lines are optional.

Figure 28 - ATU-R functional interfaces to the STM layer at the T-R reference point

7.1.2 Downstream simplex bearer channels - Transceiver bit rates

The simplex bearer channels are transported in the downstream direction only; therefore their data interfaces at the ATU-R operate only as outputs. The data rates are the same as those for the ATU-C transmitter, as specified in 6.1.2.

7.1.3 Duplex bearer channels - Transceiver bit rates

The duplex bearer channels are transported in both directions, so the ATU-R shall provide both input and output data interfaces. The data rates are the same as for the ATU-C, as specified in 6.1.3.

7.1.4 Framing structure for STM transport

An ATU-R configured for STM transport shall support the full overhead framing structure 0 as specified in 7.4. The support of full overhead framing structure 1 and reduced overhead framing structures 2 and 3 is optional.

Preservation of T-R interface byte boundaries (if present) at the U-R interface may be supported for any of the U-R interface framing structures.

An ATU-R configured for STM transport may support reconstruction of a Network Timing Reference (NTR). Note that the NTR reconstruction is not supported by an ATU-R complying with ANSI T1.413 Issue 1.

7.2 ATM Transport Protocol Specific functionalities

7.2.1 ATU-R input and output T-R interfaces for ATM transport

The ATU-R input and output T-R interfaces are identical to the ATU-C input and output interfaces, as described in 6.2, except for the NTR, which is optional at the T-R reference point (see Figure 29).

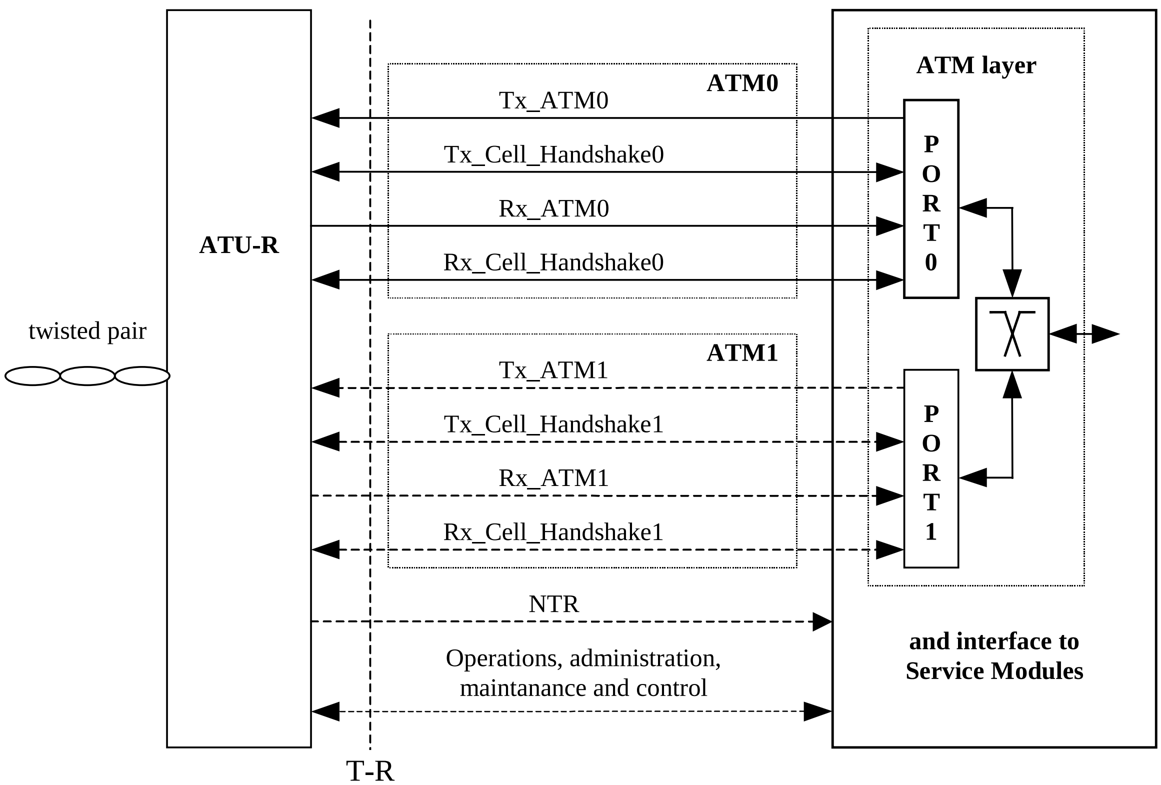


Figure 29 - ATU-R functional interfaces to the ATM layer at the T-R reference point

7.2.2 ATM Cell specific functionalities

The ATM cell specific functionalities performed at the ATU-R shall be identical to the ATM cell specific functionalities performed at the ATU-C, as described in 6.2.3.

7.2.3 Framing structure for ATM transport

An ATU-R configured for ATM transport shall support the full overhead framing structures 0 and 1 as specified in 7.4. The support of reduced overhead framing structures 2 and 3 is optional.

The ATU-R transmitter shall preserve T-R interface byte boundaries (explicitly present or implied by ATM cell boundaries) and the U-R interface, independent of the U-R interface framing structure.

To ensure framing structure 0 interoperability between an ATM ATU-R and an ATM cell TC plus an STM ATU-C (i.e., ATM over STM), the following shall apply:

- an STM ATU-C transporting ATM cells and not preserving V-C byte boundaries at the U-C interface shall indicate during initialization that frame structure 0 is the highest frame structure supported;
- an STM ATU-C transporting ATM cells and preserving V-C byte boundaries at the U-C interface shall indicate during initialization that frame structure 0, 1, 2 or 3 is the highest frame structure supported, as applicable to the implementation;
- an ATM ATU-R receiver operating in framing structure 0 can not assume that the ATU-C transmitter will preserve V-C interface byte boundaries at the U-C interface and shall therefore perform the cell delineation bit-by-bit (see 6.2.3.5).

An ATU-R configured for ATM transport may support reconstruction of a Network Timing Reference (NTR). Note that the NTR reconstruction is not supported by an ATU-R complying with ANSI T1.413 Issue 1.

7.3 Network timing reference

If the ATU-C has indicated that it will use indicator bits 20 to 23 (see 6.3.2) to transmit the change of phase offset, the ATU-R may deliver the 8 kHz signal to the T-R interface

The mechanism to transport the NTR over the U-interface is described in 6.2. Delivery of the NTR at the T-R interface shall be independent of the method of loop timing that is agreed upon by ATU-C and ATU-R during initialization (see 9.2 and 9.3).

7.4 Framing

Framing of the upstream signal (ATU-R transmitter) closely follows the downstream framing (ATU-C transmitter), which is specified in 6.4, but with the following exceptions:

- there are no ASx bearer channels and no AEX byte;
- a maximum of three bearer channels exist, so that only three [B_F, B_I] pairs are specified;
- the minimum RS FEC coding parameters and interleave depth differ (see Table 19);
- four bits of the fast and sync bytes are unused (corresponding to the bit positions used by the ATU-C transmitter to specify synchronization control for the ASx channels) (see Table 17 and Table 18);
- the four indicator bits for NTR transport are not used in upstream direction.

Two types of framing are defined: full overhead and reduced overhead. Furthermore, two versions of full overhead and two versions of reduced overhead are defined. The four resulting framing structures are defined as for the ATU-C in 6.4 and are referred to as framing structures 0, 1, 2 and 3.

Requirements for framing structures to be supported, depend upon the ATU-R being configured for either STM or ATM transport, and are defined in 7.1.4 and 7.2.3 respectively.

The ATU-R shall indicate during initialization the highest framing structure number it supports. If the ATU-R indicates it supports framing structure *k*, it shall also support all framing structures *k*-1 to 0. If the ATU-C indicates a lower framing structure number during initialization, the ATU-R shall fall back to the framing structure number indicated by the ATU-C.

As noted in clause 4, outside the ASx/LSx serial interfaces data bytes are transmitted msb first in accordance with ITU-T Recommendations G.703, G.707, I.361, and I.432. All serial processing in the ADSL frame (e.g., crc, scrambling, etc.) shall, however, be performed lsb first, with the outside world msb considered by the ADSL as lsb. As a result, the first incoming bit (outside world msb) will be the first processed bit inside the ADSL (ADSL lsb).

7.4.1 Data symbols

The ATU-R transmitter is functionally similar to the ATU-C transmitter, as specified in 6.2.1, except that up to three duplex bearer channels are synchronized to the 4 kHz ADSL data frame rate (instead of up to four simplex and three duplex bearer channels as is the case for the ATU-C) and multiplexed into the two separate buffers (fast and interleaved buffer). The ATU-R transmitter and its associated reference points for data framing are shown in Figure 4 and Figure 5.

7.4.1.1 Superframe structure

The superframe structure of the ATU-R transmitter is identical to that of the ATU-C transmitter, as specified in 6.4.1.1 and shown in Figure 10.

The ATU-R shall support the indicator bits defined in Table 5. The NTR indicator bits (ib20-23) shall not transport the network timing reference in upstream direction and shall be set to 1

7.4.1.2 Frame structure (with full overhead)

Each data frame shall be encoded into a DMT data symbol, as described in 7.5 through 7.12. As specified for the ATU-C and shown in Figure 10, the data frame buffer is composed of a fast data buffer and an interleaved data buffer, and the data frame structure has a different appearance at each of the reference points (A, B, and C). The bytes of the fast buffer shall be clocked into the constellation encoder first, followed by the bytes of the interleaved data buffer. Bytes are clocked least significant bit first.

The assignment of bearer channels to the fast and interleaved buffers shall be configured during initialization (see 9.6) with the exchange of a [B_F, B_I] pair for each bearer channel, where B_F designates the number of bytes of a given bearer channel to allocate to the fast buffer, and B_I designates the number of bytes allocated to the interleaved data buffer.

The three possible [B_F, B_I] pairs are B_F(LSx), B_I(LSx) for x = 0, 1 and 2, for the duplex bearer channels; they are specified as for the ATU-C in 6.4.1.2.

7.4.1.2.1 Fast data buffer

The frame structure of the fast data buffer is shown in Figure 30 for the three reference points that are defined in Figure 4 and Figure 5. This structure is the same as that specified for the ATU-C with the following exceptions:

- ASx bytes do not appear;
- the AEX byte does not appear.

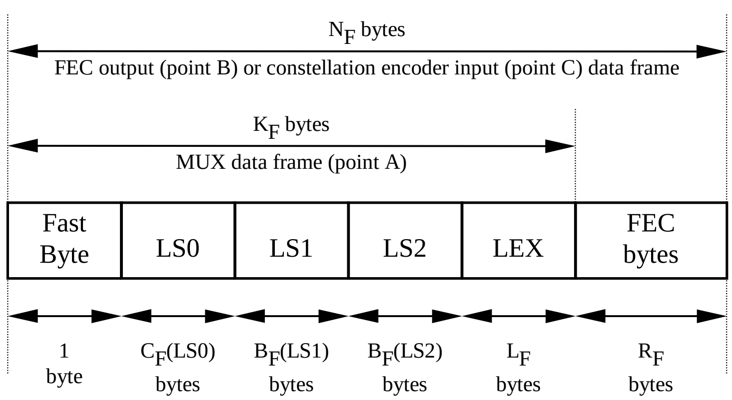


Figure 30 - Fast data buffer - ATU-R transmitter

The following shall hold for the parameters shown in Figure 30:

N_F	$= K_F + R_F$	
R_F	= number of upstream RS FEC redundancy bytes per codeword.	
K_F	$= 1 + B_F + L_F$	
B_F	$= C_F(\text{LS0}) + B_F(\text{LS1}) + B_F(\text{LS2})$	
$C_F(\text{LS0})$	= 0	if $B_F(\text{LS0}) = 255$ (binary 11111111)
	$= B_F(\text{LS0})$	otherwise
L_F	= 0	if $B_F(\text{LS0}) = B_F(\text{LS1}) = B_F(\text{LS2}) = 0$
	= 1	otherwise

At reference point A (the mux data frame) in Figure 4 and Figure 5, the fast buffer always contains at least the fast byte. This is followed by B_F(LS0) bytes of bearer channel LS0, then B_F(LS1) bytes of bearer channel LS1, and B_F(LS2) bytes of bearer channel LS2, and if any B_F(LSx) is non-zero, a LEX byte.

When B_F(LS0) = 255 (Binary 11111111), no separate bytes are included for the LS0 bearer channel. Instead, the 16 kbit/s “C”-channel shall be transported in every other LEX byte on average, using the syncchronization byte to denote when to add the LEX byte to the LS0 bearer channel.

R_F RS FEC redundancy bytes shall be added to the mux data frame (reference point A) to produce the FEC output data frame (reference point B), where R_F is given in the C-RATES1 signal options received from the ATU-C during initialization (see clause 9). Because the data from the fast data buffer is not interleaved, the constellation encoder input data frame (reference point C) is identical to the FEC output data frame (reference point B).

7.4.1.2.2 Interleaved data buffer

The frame structure of the interleaved data buffer is shown in Figure 31 for the three reference points that are defined in Figure 4 and Figure 5. This structure is the same as that specified for the ATU-C, with the following exceptions:

- ASx bytes do not appear;
- the AEX byte does not appear.

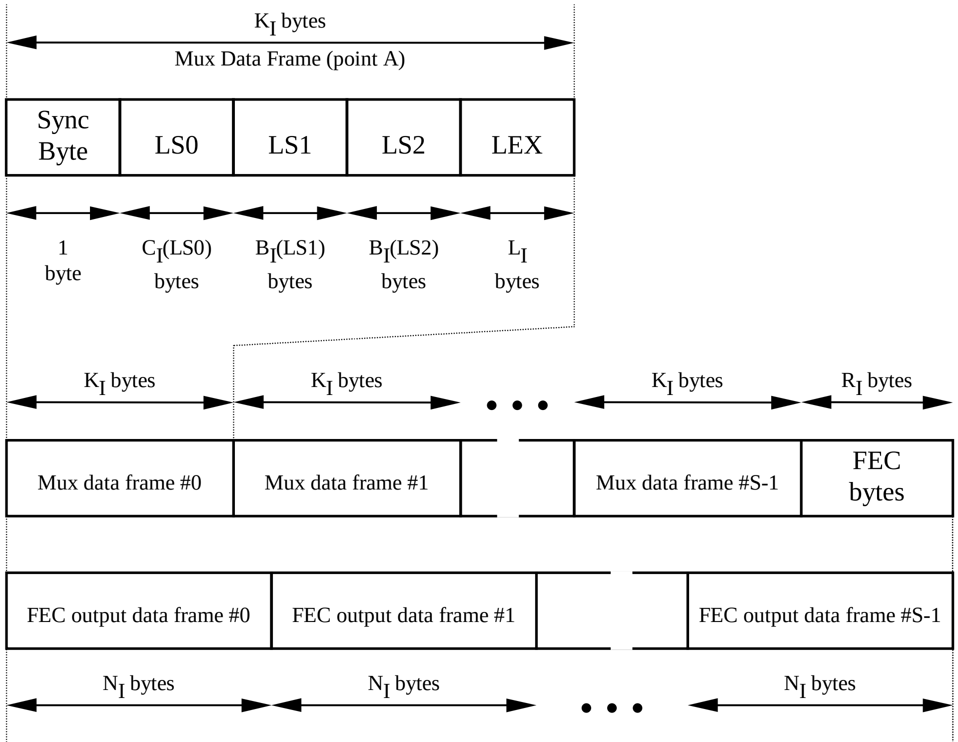


Figure 31 - Interleaved data buffer - ATU-R transmitter

The following shall hold for the parameters shown in Figure 31:

N_I	$= (S \times K_I + R_I)/ S$	
R_I	= number of upstream FEC redundancy bytes per RS codeword	
S	= number of DMT symbols per RS codeword	
	= number of mux data frames per RS codeword	
K_I	$= 1 + B_I + L_I$	
B_I	$= C_I$(LS0) + B_I(LS1) + B_I(LS2)	
C_I(LS0)	= 0	if B_I(LS0) = 255 (binary 11111111)
	= B_I(LS0)	otherwise
L_I	= 0	if B_I(LS0) = B_I(LS1) = B_I(LS2) = 0
	= 1	otherwise

7.4.1.3 Cyclic redundancy check (crc)

Two cyclic redundancy checks (crc's) - one for the fast data buffer and one for the interleaved data buffer - are generated for each superframe and transmitted in the first frame of the following superframe. Eight bits per buffer type (fast or interleaved) per superframe are allocated to the crc check bits. These bits are computed from the k message bits using the equation:

The crc bits are transported in the fast byte (8 bits) of frame 0 in the fast data buffer, and the sync byte (8 bits) of frame 0 in the interleaved data buffer.

The bits covered by the crc include;

- for the fast data buffer:
  - frame 0: LSx bytes (x = 0, 1, 2), followed by the LEX byte;
  - all other frames: fast byte, followed by LSx bytes (x = 0, 1, 2), and LEX byte.
- for the interleaved data buffer:
  - frame 0: LSx bytes (x = 0, 1, 2), followed by the LEX byte;
  - all other frames: sync byte, followed by LSx bytes (x = 0, 1, 2), and LEX byte.

Each byte shall be clocked into the crc least significant bit first.

The crc-generating polynomial, and the method of generating the crc byte are the same as for the downstream data; these are specified in 6.4.1.3.

7.4.2 Synchronization

If the bit timing base of the input bearer channels (LSx) is not synchronous with the ADSL modem timing base the input data streams shall be synchronized to the ADSL timing base using the synchronization control mechanism (consisting of synchronization control byte and the LEX byte). Forward-error-correction coding shall always be applied to the synchronization control byte(s).

If the bit timing base of the input bearer channels (LSx) is synchronous with the ADSL modem timing base then the synchronization control mechanism is not needed. The synchronization control byte shall always indicate "no synchronization action" (see Table 17 and Table 18).

7.4.2.1 Synchronization for the fast data buffer

Synchronization control for the fast data buffer can occur in frames 2 through 33 and 36 through 67 of an ADSL superframe as described in 7.4.1.1, where the fast byte may be used as the synchronization control byte. No synchronization action is to be taken for those frames in which the fast byte is used for crc, fixed indicator bits, or eoc.

The format of the fast byte when used as synchronization control for the fast data buffer shall be as given in Table 17.

In the case where no signals are allocated to the interleaved data buffer, the sync byte carries the aoc data directly as shown in Figure 30.

Table 17 - Fast byte format for synchronization (Fast data buffer)

Bit	Application	Specific usage
sc7-sc4	not used	set to "0" until specified otherwise
sc3, sc2	LSx bearer channel designator	"00" : LS0 "01" : LS1 "10" : LS2 "11" : no synchronization action
sc1	Synchronization control for the designated LSx bearer channel	"1" : add LEX byte to designated LSx bearer channel "0" : delete last byte from designated LSx bearer channel
sc0	Synch/eoc designator	"0" : perform synchronization control as indicated in sc7-sc1 "1" : this byte is part of an eoc frame

NOTE - If the bit timing base of the input bearer channels (LSx) is synchronous with the ADSL modem timing base then ADSL systems need not perform synchronization control by adding or deleting LEX bytes to/from the designated LSx channels, and the synchronization control byte shall indicate "no synchronization action" (i.e., sc7-0 coded “000011X0”, with X discretionary).

When the data rate of the “C”-channel is 16 kbit/s, the LS0 bearer channel shall be transported in the LEX byte, using the "add LEX byte to designated LSx bearer channel", with LS0 as the designated bearer channel, every other frame on average.

7.4.2.2 Synchronization for the interleaved data buffer

Synchronization control for the interleaved data buffer may occur in frames 1 through 67 of an ADSL superframe as described in 7.4.1.1, where the sync byte may be used as the synchronization control byte.

No synchronization action shall be taken during frame 0, where the sync byte is used for crc, and the LEX byte carries aoc.

The format of the sync byte when used as synchronization control for the interleaved data buffer shall be as given in Table 18. In cases where no bearer channels are allocated to the interleaved data buffer, the sync byte shall carry the aoc data directly, as shown in Figure 12 in 6.4.1.1.

Table 18 - Sync byte format for synchronization (Interleaved data buffer)

Bit	Application	Specific usage
sc7-sc4	not used	set to "0" until specified otherwise
sc3, sc2	LSx bearer channel designator	"00" : LS0 "01" : LS1 "10" : LS2 "11" : no synchronization action
sc1	Synchronization control for the designated LSx bearer channel	"1" : add LEX byte to designated LSx bearer channel "0" : delete last byte from designated LSx bearer channel
sc0	Synch/aoc designator	"0" : perform synchronization control as indicated in sc3-sc1 "1" : LEX byte carries aoc data; synchronization control is allowed for "delete" as indicated in sc3-sc1

NOTE - If the bit timing base of the input bearer channels (LSx) is synchronous with the ADSL modem timing base then ADSL systems need not perform synchronization control by adding or deleting LEX bytes to/from the designated LSx bearer channels and the synchronization control byte shall always indicate "no synchronization action" for any LSx channel. In this case and if framing structure 1 is used, the sc7-0 shall always be coded "000011XX", with X discretionary. When sc0 is set to 1, the LEX byte carries aoc. When sc0 is set to 0, the LEX byte shall be coded 00h. The sc0 may be set to 0 only inbetween transmissions of 5 concatenated and identical aoc messages.

When the data rate of the "C"-channel is 16 kbit/s, the LS0 bearer channel shall be transported in the LEX byte, using the "add LEX byte to designated LSx bearer channel", with LS0 as the designated bearer channel, every other frame on average.

7.4.3 Reduced overhead framing

The format described in 7.4.1.2 for full overhead framing includes overhead to allow for the synchronization of three LSx bearer channels. When the synchronization function described in 7.4.2 is not needed, the ADSL equipment may operate in a reduced overhead mode. This mode retains all the full overhead mode functions except synchronization control. When using the reduced overhead framing, the framing structure shall be as defined in 6.4.3.1 (when using separate fast and sync bytes) or 6.4.3.2 (when using merged fast and sync bytes)

7.5 Scramblers

The data streams output from the fast and interleaved data buffers shall be scrambled separately using the same algorithm as for the downstream data buffers, specified in 6.5

7.6 Forward error correction

The upstream data shall be Reed-Solomon coded and interleaved using the same algorithm as for the downstream data, specified in 6.6.

The RS FEC coding overhead, the number of symbols per RS codeword, and the interleave depth are given in the C-RATES1 options received from the ATU-C during initialization (see clause 9).

The ATU-R shall support upstream transmission with at least any combination of the RS FEC coding capabilities shown in Table 19.

Table 19 - Minimum FEC coding capabilities for ATU-R

Parameter	Fast buffer	Interleaved buffer
Parity bytes per R-S codeword	R_F = 0,2,4,6,8,10,12,14,16 (see note 1)	R_I = 0,2,4,6,8,10,12,14,16 (see note 1)
DMT symbols per R-S codeword Mux data frames per RS codeword	S = 1	S = 1, 2, 4, 8, 16 (see note 3)
Interleave depth	not applicable	D = 1, 2, 4, 8 (see note 3)

NOTES

1. R_F can be >0 only if K_F > 0 and R_I can be > 0 only if K_I > 0.
2. R_I shall be an integer multiple of S.
3. Exception: support of the combination S > 1 and D = 1 is not required.
4. The ATU-R shall also support upstream transmission with at least any combination of the RS FEC coding capabilities shown in Table 10.

7.7 Tone ordering

The tone ordering algorithm shall be the same as for the downstream data, specified in 6.7

7.8 Constellation encoder (with trellis coding)

Block processing of Wei's 16-state 4-dimensional trellis code to improve system performance is optional. An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to N_{upmax}, where $8 \le N_{upmax} \le 15$.

The encoding algorithm shall be the same as that used for downstream data (with the substitution of the constellation limit of N_{upmax} for $N_{downmax}$), specified in 6.8.

7.9 Constellation encoder (without trellis coding)

An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to N_{upmax} , where $8 \le N_{upmax} \le 15$. The encoding algorithm is the same as that used for downstream data (with the substitution of the constellation limit of N_{upmax} for $N_{downmax}$), which is specified in 6.9. The constellation encoder shall not use trellis coding with this option.

7.10 Gain scaling

For the transmission of data symbols, gain scaling, g_i , shall be applied to all data-carrying sub-carriers as requested by the ATU-C (see 7.15.3 and 9.8.13) and possibly updated during showtime via the bit swap procedure. Only values of g_i within a range of approximately 0.75 to 1.33 (i.e., -2.5 to +2.5 dB) may be used to equalize the expected error rates for all data-carrying sub-carriers.

For the transmission of synchronization symbols, no gain scaling shall be applied to any sub-carrier.

Each point, (X_i, Y_i), or complex number $X_i + jY_i$, output from the encoder is multiplied by g_i:

$$Z_i = g_i \times (X_i + j\,Y_i)$$

> NOTE - The g_i define a scaling of the root mean square (rms) sub-carrier levels relative to those used in R-MEDLEY (see 9.6.6). They are independent of any methods that manufacturers may use to simplify implementation (e.g., constellation nesting).

7.11 Modulation

7.11.1 Sub-carriers

The frequency spacing, Δf, between sub-carriers shall be 4.3125 kHz with a tolerance of ±50 ppm.

7.11.1.1 Data sub-carriers

The channel analysis signal, defined in 9.5.2, allows for a maximum of 31 sub-carriers (at frequencies $i \times \Delta f$, i=1 to 31) to be used. The lower limit on i is determined by the POTS splitting filters; if frequency division multiplexing (FDM) is used, the upper limit on i is set by the downstream-upstream separation filters. The cut-off frequencies of these filters are completely at the discretion of the manufacturer because in either case the range of usable i is determined during the channel analysis (9.6 and 9.7).

7.11.1.2 Pilot

Sub-carrier 16 (f = 69.0 kHz) shall be reserved for a pilot; that is b_{16} = 0 and g_{16} = 1. The data modulated onto the pilot sub-carrier shall be a constant {0,0}, generating the {+,+} constellation point. Use of this pilot allows resolution in a receiver of sample timing modulo-4 samples (assuming an upstream sampling rate of 276 kHz). Therefore a gross timing error that is an integer multiple of 4 samples, could still persist after a micro-interruption (e.g., a temporary short-circuit, open circuit or severe line hit); correction of such timing errors is made possible by the use of the synchronization symbol defined in 7.11.3.

7.11.1.3 Nyquist frequency

The sub-carrier at the Nyquist frequency (sub-carrier 32) shall not be used for data; other possible uses are for further study.

7.11.1.4 DC

The sub-carrier at DC (sub-carrier 0) shall not be used (i.e., Z_0 = 0).

7.11.2 Modulation by the inverse discrete fourier transform

The modulating transform defines the relationship between the 64 real values x_n and the Z_i

$$x_n = \sum_{i=0}^{63} \exp\left(\frac{j\pi n i}{32}\right) \times Z_i \qquad for\ n = 0\ to\ 63$$

The constellation encoder and gain scaling generate only 31 complex values of Z_i (plus zero at dc and one real value if the Nyquist frequency is used). In order to generate real values of x_n these values of Z_i shall be augmented so that the vector Z has Hermitian symmetry. That is,

Z_i = conj [Z_{64-i}]   for i = 33 to 63

7.11.3 Synchronization symbol

The synchronization symbol permits recovery of the superframe boundary after micro-interruptions that might otherwise force retraining.

The data symbol rate, f_{symb} = 4 kHz, the sub-carrier separation, Δf = 4.3125 kHz, and the IDFT size, N = 64, are such that a cyclic prefix of 5 samples could be used. That is,

$(64 + 5) \times 4.0 = 64 \times 4.3125 = 276$

The cyclic prefix shall, however, be shortened to 4 samples, and a synchronization symbol (with a nominal length of 68 samples) inserted after every 68 data symbols. That is,

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

The data pattern used in the synchronization symbol shall be the pseudo-random upstream sequence PRU (d_n, for n = 1 to 64), defined by

$d_n = 1$ for n = 1 to 6

$d_n = d_{n-5} \oplus d_{n-6}$ for n = 7 to 64

NOTES

1. The period of PRU is only 63 bits, so $d_{64} = d_1$.
2. The d_1 - d_6 shall be re-initialized for each symbol, so each symbol uses the same data.

The first pair of bits (d_1 and d_2) shall be used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs shall be used to define the X_i and Y_i. for i = 1 to 31 as shown in Table 16. No gain scaling shall be applied to any sub-carrier.

Bits 33 and 34, which modulate the pilot sub-carrier (sub-carrier 16) are overwritten by the data {0,0}, generating the {+,+} constellation point.

The data modulated onto each sub-carrier shall be as defined above; it shall not depend on which sub-carriers are used. The transmit PSD for each sub-carrier is defined in 7.15.4.

7.12 Cyclic prefix

The last 4 samples of the output of the IDFT (x_n for n = 60 to 63) shall be prepended to the block of 64 samples and read out to the digital-to-analog convertor (DAC) in sequence. That is, the subscripts, n, of the DAC samples in sequence shall be 60...63, 0...63.

The cyclic prefix shall be used for all symbols beginning with R-REVERB3 of the initialization sequence, as defined in 9.7.2

7.13 Transmitter dynamic range

The transmitter includes all analog transmitter functions: the digital-to-analog converter (DAC), the anti-aliasing filter, the hybrid circuitry, and the high-pass part of the POTS splitter. The transmitted signal shall conform to the frequency requirements described in 7.11.1 for frequency spacing.

7.13.1 Maximum clipping rate

The maximum output signal of the transmitter shall be such that the output signal shall be clipped no more than 0.00001% of the time.

7.13.2 Noise/Distortion floor

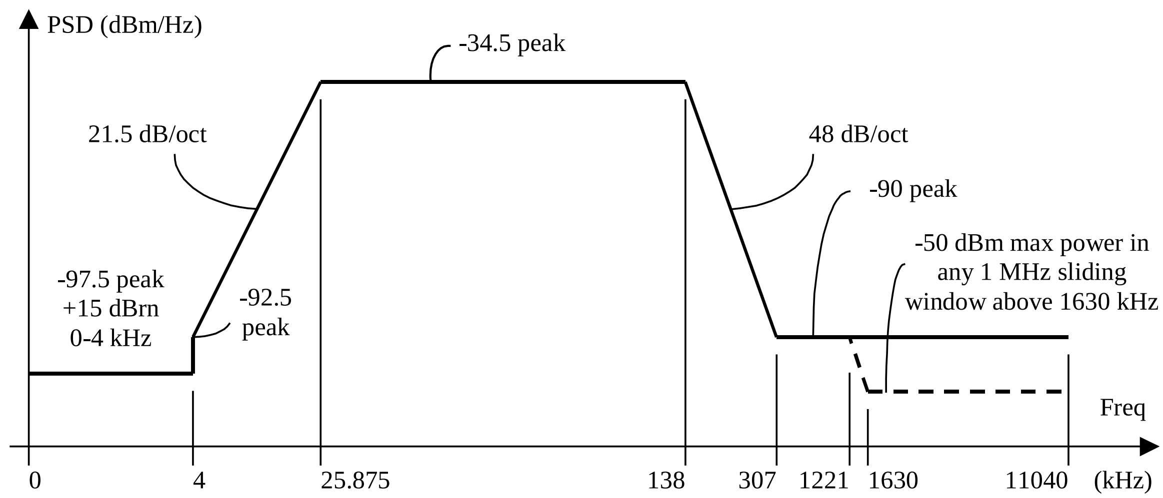
The signal-to-noise-plus-distortion ratio of the transmitted signal in a given sub-carrier is specified as the ratio of the rms value of the full-amplitude tone in that sub-carrier to the rms sum of all the non-tone signals in the 4.3125 kHz frequency band centered on the sub-carrier frequency. This ratio is measured for each sub-carrier used for transmission using a MultiTone Power Ratio (MTPR) test as shown in Figure 26.

Over the transmission frequency band, the MTPR of the transmitter in any sub-carrier shall be no less than ($3N_{upi}$ + 20) dB, where N_{upi} is defined as the size of the constellation (in bits) to be used on sub-carrier i. The minimum transmitter MTPR shall be at least 38dB (corresponding to an N_{upi} of 6) for any sub-carrier.

NOTE - Signals transmitted during normal initialization and data transmission cannot be used for this test because the DMT symbols have a cyclic prefix appended, and the PSD of a repetitive signal does not have nulls at any sub-carrier frequencies. A gated FFT-based analyser could be used, but this would measure both the non-linear distortion and the linear distortion introduced by the transmit filter. Therefore this test will imply that the transmitter be programmed with special software—probably to be used during development only. The subject of an MTPR test that can be applied to a production modem is for further study.

7.14 Transmitter spectral response

Figure 32 shows the power spectral density (PSD) mask for the transmitted signal. The low frequency stop band is defined as the voiceband; the high frequency stop band is defined as frequencies greater than 138 kHz.



FREQUENCY BAND (kHz)	EQUATION FOR LINE (dBm/Hz)
$0 < f < 4$	-97.5, with max power in the in 0-4 kHz band of +15 dBrn
$4 < f < 25.875$	$-92.5 + 21.5 \times \log_2(f/4)$
$25.875 < f < 138$	-34.5
$138 < f < 307$	$-34.5 - 48 \times \log_2(f/138)$
$307 < f < 1221$	-90
$1221 < f < 1630$	-90 peak, with max power in the $[f, f + 1$ MHz$]$ window of $(-90 - 48 \times \log_2(f/1221) + 60)$ dBm
$1630 < f < 11040$	-90 peak, with max power in the $[f, f+1$MHz$]$ window of -50 dBm

NOTES

1. All PSD measurements are in 100 ohms; the voiceband aggregate power measurement is in 600 ohms.
2. All PSD and power measurements shall be made at the U-R interface (see Figure 1); the signals delivered to the POTS are specified in Annex E.
3. The breakpoint frequencies and PSD values are exact; the indicated slopes are approximate.
4. Above 25.875 kHz, the peak PSD shall be measured with a 10 kHz resolution bandwidth.
5. The power in a 1 MHz sliding window is measured in 1 MHz bandwidth, starting at the measurement frequency.

Figure 32 - ATU-R transmitter PSD mask

7.14.1 Pass band PSD and response

The transmit PSD within the 25.875 kHz to 138 kHz passband shall be no greater than -38 dBm/Hz; the upper end of the passband actually used by the transmitter depends on whether the signal is for initialization (see 7.15.1) or steady state (see 7.15.3).

The pass band ripple during steady state shall be no greater than +3.5 dB; the maximum PSD of -34.5 dBm/Hz applies across the whole passband from 25.875 kHz to 138 kHz;

The group delay variation over the passband shall not exceed 50µs.

7.14.2 Low-frequency stop band rejection

In the transition band from 4 kHz to 25.875 kHz, the transmit PSD shall not exceed a mask that decreases at approximately 21.5 dB/octave from (-38 dBm/Hz + 3.5 dB) at the passband-edge (25.875 kHz) to -92.5 dBm/Hz at 4.0 kHz.

In the band from 0 to 4 kHz, the transmit PSD shall be no grater than -97.5 dBm/Hz. Furthermore, the aggregate power in the 0 to 4 kHz band, measured in 600 ohms, shall not exceed +15 dBrn (see Annex E for the method of measurement).

> NOTE - A continuation of the transition band rolloff to lower frequencies would intersect the -97.5 dBm/Hz noise floor at 3400 Hz. However, to limit interference with voiceband services, the noise floor is extended to 4000 Hz.

7.14.3 High-frequency stop band rejection

The transmit PSD shall not exceed a mask that decreases at 48 dB/octave from (-38 dBm/Hz + 3.5 dB) at the passband-edge (138 kHz) to a floor of -90 dBm/Hz at 307 kHz.

In addition, at all frequencies f from 1.221 to 1.630 MHz, the transmit power in the [f, f + 1 MHz] window shall not exceed ($-90 - 48 \times \log_2(f/1221) + 60$) dBm. At all frequencies f from 1.630 to 11.040 MHz, the transmit power in the [f, f + 1 MHz] window shall not exceed -50 dBm.

7.15 Transmit power spectral density and aggregate power level

There are three different PSD masks for the ATU-C transmit signal, depending on the type of signal sent. In all cases the power in the voiceband measured at the U-R interface and that is delivered to the POTS interface shall conform to the specification in 7.14.2.

> NOTE - The power emitted by the ATU-R is limited by the requirements in this subclause. Notwithstanding these requirements, it is assumed that the ADSL will comply with applicable FCC requirements on emission of electromagnetic energy. These requirements may be found in FCC Title 47 and other FCC documents.

7.15.1 All initialization signals (except R-ECT) starting with R-REVERB1

The nominal PSD in the band from 25 to 138 kHz shall be -38 dBm/Hz for an aggregate power of not greater than 12.5 dBm.

During the R-REVERB and R-SEGUE signals, all sub-carriers from index i to 31 shall be transmitted, with i vendor discretionary (see 7.14.1). However, at the vendor's discretion, one or more of these sub-carriers may not be transmitted during the R-MEDLEY signal.

To allow for non-ideal transmit filter effects (e.g., passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the nominal PSD level. The maximum transmit PSD shall therefore be no higher than -37 dBm/Hz.

7.15.2 R-ECT

Because R-ECT is a vendor defined signal (see 9.5.5), the PSD specification shall be interpreted only as a maximum. This maximum level is -38 dBm/Hz for the band from 25.875 to 138 kHz. Sub-carriers 1 to 5 may be used, but the power in the voiceband that is delivered to the POTS interface shall conform to the specification given in 7.14.2.

7.15.3 Steady-state data signal

The nominal PSD in the band from 25.875 to 138 kHz shall be set at -38 dBm/Hz. The nominal aggregate power shall be set at $-1.65+10\log(ncup)$, where *ncup* is the number of sub-carriers used (i.e., with $b_i > 0$) (12.5 dBm if all sub-carriers are used). The transmit PSD and aggregate power may, however, be changed from their nominal values in either of the following circumstances:

- The bits & gains table (received from the ATU-C during initialization and possibly updated through bit swaps, see 9.8.13 and 11.2) may not allocate bits to some sub-carriers and may finely adjust (i.e., within a ±2.5 dB range) the transmit PSD level of others in order to equalize expected error rates on each of those sub-carriers.

– Vendor discretionary transmit PSD levels for unused sub-carriers (i.e., $b_i = 0$). The maximum transmit PSD for these sub-carriers is sprcified in b) and c) below.

To allow for non-ideal transmit filter effects (e.g., passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the finely adjusted nominal PSD level. The maximum transmit PSD shall therefore be no higher than -34.5 dBm/Hz.

The transmit PSD of each sub-carrier is defined as follows:

a) For the sub-carriers with ($b_i > 0$), the ATU-R transmitter shall transmit at PSD levels equal to that specified by the g_i (e.g., $g_i = 1$, then transmit at R-MEDLEY transmit PSD level). Over these sub-carriers, the sum of the $10\log(g_i^2)$ (fine gains in dB) shall not exceed 0 dB, with $10\log(g_i^2)$ in the -2.5 to +2.5 dB range.

b) For the sub-carriers with ($b_i = 0$ & $g_i > 0$), the ATU-R transmitter should and is recommended to transmit at PSD levels equal to that specified by the g_i (e.g., $g_i = 1$, then transmit at R-MEDLEY level), with a 4-QAM constellation point (which may change from symbol to symbol). The ATU-C receiver cannot assume any particular PSD levels on those sub-carriers. The transmit PSD levels of those sub-carriers shall be no higher than the R-REVERB1 transmit PSD level + $10\log(g_i^2)$ dB. Over these sub-carriers, the sum of the $10\log(g_i^2)$ (fine gains in dB) shall not exceed 0 dB, with $10\log(g_i^2)$ in the -2.5 to +2.5 dB range.

c) For the sub-carriers with ($b_i = 0$ & $g_i = 0$), the ATU-R transmitter should and is recommended to transmit no power on those sub-carriers. The ATU-C receiver cannot assume any particular PSD levels on those sub-carriers. The transmit PSD levels of those sub-carriers shall be at least 10 dB below the R-REVERB1 transmit PSD level.

The aggregate transmit power over the 25.875 to 138 kHz band shall be no higher than 12.5 dBm, which is equivalent to an average transmit PSD of no higher than -38 dBm/Hz.

7.15.4 Synchronization symbol

The transmit PSD level for for those sub-carriers with $g_i > 0$ shall be the same as for the initialization signal R-REVERB1 (i.e., nominally -38 dBm/Hz). The transmit PSD level for those sub-carriers with $g_i = 0$ shall be at least 10 dB below the R-REVERB1 transmit PSD level.

Since the g_i are applied only to the data symbols, the transmit PSD of a synchronization symbol differs from the transmit PSD of a data symbol. These g_i are calculated for the multipoint constellations in order to equalize the expected error rate on all sub-carriers, and are therefore irrelevant for most of the 4-QAM modulated sub-carriers of the synchronization symbol.

8 Operations and maintenance

8.1 Embedded operations channel (eoc) requirements

An embedded operations channel for communication between the ATU-C and ATU-R shall be used for in-service and out-of-service maintenance and for the retrieval of a limited amount of ATU-R status information and ADSL performance monitoring parameters. The eoc may also be used in the future to extend maintenance and performance monitoring to the service module(s) at the customer premises. This clause describes the eoc functions, protocol, and commands. Insertion of eoc messages within the ADSL data frames is described in 6.4 and 7.4.

8.1.1 Eoc organization and protocol

The ADSL eoc allows the ATU-C (acting as master of the link) to invoke commands and the ATU-R (acting as slave) to respond to the commands. The ATU-C determines the eoc rate of the ADSL link; therefore only one eoc message shall be inserted in the upstream direction (by the ATU-R) for each received eoc message. One exception to this is for the “dying gasp” message, which is the only autonomous message currently allowed from the ATU-R and is inserted as soon as appropriate bytes are available.

This sub-clause defines only the content and meaning of the eoc messages; the insertion of them into the data frames is defined in 6.4.1 and 7.4.1.

8.1.2 Eoc message structure

The 13 bits of an eoc message are partitioned among five fields, which are summarized in Table 20 and defined in the following subclauses. The eoc protocol states are defined in 8.1.4.

Table 20 - eoc message fields

Field #	Bit(s)	Description	Notes
1	1-2	Address field	Can address 4 locations
2	3	Data (0) or opcode (1) field	Data used for read/write
3	4	Byte parity field Odd (1) or even (0)	Byte order indication for multibyte transmission
4	5	Message/Response field Message/Response message (1) or Autonomous message (0)	Currently no autonomous messages are defined for the ATU-C; the “dying gasp” message is the only autonomous message defined for the ATU-R
5	6-13	Information field	One out of 58 opcodes or 8 bits of data

8.1.2.1 Address field (# 1)

The two bits of the address field can address up to four locations. Only two locations are presently defined:

- 11: ATU-C address;
- 00: ATU-R address.

The adress values 10 and 01 are reseved for future use, and are presently invalid.

The ATU-C shall address messages to the ATU-R by setting the ADDRESS field equal to the ATU-R address. When responding to a message from the ATU-C, the ATU-R shall keep the ADDRESS field equal to its own ATU-R address. Only when sending an autonomous message to the ATU-C, shall the ATU-R set the ADDRESS field equal to the ATU-C address.

8.1.2.2 Data or opcode field (# 2)

A 0 in this field indicates that the information field of the current eoc message contains a data byte; a 1 that it contains an operation code for an ADSL eoc message.

8.1.2.3 Byte parity field (# 3)

For the first byte of data that is to be either read or written, this bit shall be set to 1 to indicate “odd” byte. For the next byte, it shall be set to 0 to indicate “even” byte and so on, alternately. This bit helps to speed up multi-byte reads and writes of data by eliminating the need for intermediate opcodes to indicate to the far end that the previous byte was successfully received.

The byte parity field shall always be set to 1 if the information field carries an opcode different from the Next Byte opcode; the byte parity field may be set to 0 otherwise.

8.1.2.4 Message/Response field

A 1 in this field designates that the current eoc message is an eoc protocol message (master)/response(slave) message; a 0 designates that it is an autonomous message that does not disturb the current state of the eoc protocol at either the ATU-C or the ATU-R and that does not cause an eoc response message to the other ATU. For the ATU-C, no autonomous messages are currently defined and this field shall always be set to 1. For the ATU-R, the only autonomous message currently defined is the “dying gasp” (see 8.1.5.4) message. For all other messages from the ATU-R, this field shall be set to 1.

8.1.2.5 Information field (# 5)

Up to 58 different opcodes or 8 bits of (binary or ASCII) data may be encoded in the information field.

The opcode set is restricted to codes that provide a minimum Hamming distance of 2 between all opcodes, and a minimum distance of 3 between certain critical codes and all other codes.

8.1.3 Eoc message sets

The ATU-C sends eoc (command) messages to the ATU-R to perform certain functions. Some of these functions require the ATU-R to activate changes in the circuitry (e.g., to send crc bits that are corrupt). Other functions that can be invoked are to read from and to write into data registers located at the ATU-R. The data registers are used for reading status- or performance-monitoring parameters from the ATU-R, or for limited maintenance extensions to the CI wiring distribution network or service modules.

Some of these commands are “latching”, meaning that a subsequent command shall be required to release the ATU-R from that state. Thus, multiple ADSL eoc-initiated actions can be in effect simultaneously. A separate command, “Return To Normal”, is used to unlatch all latched states. This command is also used to bring the ADSL system to a known state, the idle state, when no commands are active in the ATU-R location. To maintain the latched state, the command “Hold State” shall be sent to bring the ADSL system to a known state, the Idle State.

The ATU-C always issues the eoc messages, and the ATU-R acknowledges that it has received a message correctly by echoing it, or by sending a response message.

There are three types of eoc messages:

- bidirectional eoc messages: these may be sent by the ATU-C, and echoed by the ATU-R as an indication of correct reception;
- ATU-C to ATU-R (downstream) messages;
- ATU-R to ATU-C (upstream) messages: these may be in response to a downstream message or autonomous (i.e., unsolicited).

All the eoc messages and their opcodes are summarized in Table 21.

Table 21 - eoc message opcodes

HEX (see note 1)	**Opcode meaning**	**Direction** (note 2)	**Abbreviation** **and notes**
01	Hold state	d/u	HOLD
F0	Return all active conditions to normal	d/u	RTN
02	Perform “self test”	d/u	SLFTST
04	Unable-to-comply (UTC)	u	UTC
07	Request corrupt crc	d/u	REQCOR (latching)
08	Request end of corrupt crc	d/u	REQEND
0B	Notify corrupt crc	d/u	NOTCOR (latching)
0D	Notify end of corrupt crc	d/u	NOTEND
0E	End of data	d/u	EOD
10	Next byte	d	NEXT
13	Request test parameters update	d/u	REQTPU
(20,23,25,26) (29,2A,2C,2F) (31,32,34,37) (38,3B,3D,3E)	Write data register numbers 0-F	d/u	WRITE
(40,43,45,46) (49,4A,4C,4F) (51,52,54,57) (58,5B,5D,5E)	Read data register numbers 0-F	d/u	READ
(19,1A,1C,1F)	Vendor proprietary protocols	d/u	Four opcodes are reserved for vendor proprietary use.
E7	Dying gasp	u	DGASP
(15, 16, 80, 83, 85, 86, 89, 8A, 8C, 8F)	Undefined codes		These codes are reserved for future use and shall not be used for any purpose.

NOTES

1. The opcode values are given in hex (msb left, lsb right) with the msb mapping to bit eoc13 and the lsb to bit eoc6 (see Figure 11). The values guarantee a minimum Hamming distance of
   – 2 between all opcodes (by requiring odd parity for all but two critical codes);
   – 3 between the "Return to Normal" (or "idle") code and all other codes;
   – 3 between the "Dying Gasp" code and all other codes.
2. The three types of messages are identified thus;
   – d/u (downstream/upstream) bidirectional messages (8.3.1.1);
   – d (downstream): ATU-C to ATU-R messages (8.3.1.2);
   – u (upstream): ATU-R to ATU-C messages (8.3.1.3).

8.1.3.1 Bidirectional eoc messages

Messages that may be sent by the ATU-C, and echoed by the ATU-R as an indication of correct reception, are as follows (with their abbreviated names and hex opcodes in parentheses):

– *Hold State:* (HOLD, 01) This message tells the ATU-R to maintain the ATU-R eoc processor and any active ADSL eoc-controlled operations (such as latching commands) in their present state;

– *Return to Normal (Idle Code):* (RTN, F0) This message releases all outstanding eoc-controlled operations (latched conditions) at the ATU-R and returns the ADSL eoc processor to its initial state. This code is also the message sent during idle states;

– *Request Corrupt crc:* (REQCOR , 07) This message requests the ATU-R to send corrupt crcs to the ATU-C until canceled by the "Request End of Corrupt crc" or "Return to Normal" message. In order to allow multiple ADSL eoc-initiated actions to be in effect simultaneously, the "Request corrupt crc" command shall be latching;

– *Request End of Corrupt crc:* (REQEND, 08) This message requests the ATU-R to stop sending corrupt crcs toward the ATU-C;

– *Notify Corrupted crc:* (NOTCOR, 0B) This message notifies the ATU-R that intentionally corrupted crcs will be sent from the ATU-C until cancellation is indicated by "Notify End of Corrupted crc" or "Return to Normal";

– *Notify End of Corrupted crc:* (NOTEND, 0D) This message notifies the ATU-R that the ATU-C has stopped sending corrupted crcs;

– *Perform Self Test:* (SLFTST, 02) This message requests the ATU-R to perform a self test. The result of the self test shall be stored in a register at the ATU-R. After the ATU-R self test, the ATU-C reads the test results from the ATU-R register;

– *Receive/Write Data (Register #):* (WRITE, see Table 21) This message directs the ATU-R to enter the Data Write Protocol state, receive data, and write it in the register specified by the Opcode;

– *Read/Send Data (Register #):* (READ, see Table 21) This message directs the ATU-R to enter the Data Read Protocol state, read data from the register specified by the Opcode, and transmit it to the ATU-C;

– *End of Data:* (EOD, 0E) This message is sent by the ATU-C after it has sent all bytes of data to the ATU-R. This message has a slightly different meaning when sent by the ATU-R, as defined in 8.1.3.3;

– *Vendor Proprietary Opcodes:* (VPC, 19 ,1A ,1C ,1F) Four opcodes have been reserved for vendor proprietary use. The ATU-C shall read the Vendor ID (identification) code register of the ATU-R to ensure compatibility between ATUs before using proprietary opcodes;

– *Request Test Parameters Update:* (REQTPU, 13) This message requests the ATU-R to update the test parameters set as defined in 8.2.5. Test parameters supported by the ATU-R shall be updated within 10 seconds after the request is received. Updated test parameters may be read by the ATU-C thereafter.

8.1.3.2 ATU-C to ATU-R messages

One message that may be sent only by the ATU-C is

– *Next Byte:* (NEXT, 10) This message is sent repeatedly by the ATU-C (toggling bit four for multi-byte data until all data has been sent) while it is in Data Read Protocol state (i.e., after the ATU-R has acknowledged the previously sent *Receive*/*Write Data* command;

8.1.3.3 ATU-R to ATU-C messages

Additional messages that may be sent only by the ATU-R are:

– *Unable to Comply Acknowledgment:* (UTC, 04) The ATU-R shall send this message when it receives an ADSL eoc message that it cannot perform, either because it does not recognize or implement the command or because the command is unexpected, given the current state of the ADSL eoc interface. An example of an unexpected command is one that indicates that the information field contains data, but that was not preceded by a “Write Data” command;

– *End of Data:* (EOD, 0E) This message is sent by the ATU-R in either of the following cases:

– in response to a “Next Byte” message from the ATU-C that is received after all bytes have been read from the currently addressed ATU-R register;

– in response to a message from the ATU-C that contains a data byte after all bytes have been written to the currently addressed ATU-R register;

– *Dying gasp:* (DGASP, E7) This is the only autonomous (i.e., unsolicited) message that the ATU-R may send; see 8.1.5.4.

8.1.3.4 Autonomous data transfers

A fourth type of eoc messages may be the autonomous data transfers. Definition of this eoc message type is for further study. A possible definition is given in Annex L.

8.1.4 Data registers in the ATU-R

The ATU-R registers shall be defined as:

– *ATU-R Vendor ID code (2 bytes):* The ATU-R Vendor ID code shall be a copy of the Vendor Identification field as defined in Annex D, and included in R-MSG1 during initialization (see 9.6).

– *ATU-R Revision number:* The ATU-R Version Number register shall be at least one byte long; longer registers are vendor discretionary. The most significant byte shall be a copy of the concatenation of the ATU-R ANSI T1.413 and vendor revision number fields included in R-MSG1 during initialization (bits 25-18 as defined in 9.7.6); the other bytes are vendor discretionary.

– *ATU-R Serial number (32 bytes):* The format of the ATU-R Serial Number is vendor discretionary.

– *Self Test Results:* The most significant byte of the Self Test Results shall be 00hex if the selftest passed, and 01hex if it failed (the meaning of “failure” is vendor discretionary); other values are reserved for future use. The length and syntax of the remainder are vendor discretionary.

– *Line attenuation (1 byte):* The line attenuation is defined in 8.3.

– *SNR Margin (1 byte):* The SNR margin is defined in 8.3.

– *ATU-R configuration (30 bytes)*: The ATU-R configuration data, as defined in 6.4, 6.6, 7.4, 7.6 and in Table 27 shall be read (one byte for each variable) in the following order:

downstream B_F(AS0), B_I(AS0), B_F(AS1), B_I(AS1), B_F(AS2), B_I(AS2), B_F(AS3), B_I(AS3),

downstream B_F(LS0), B_I(LS0), B_F(LS1), B_I(LS1), B_F(LS2), B_I(LS2), reserved,

upstream B_F(LS0), B_I(LS0), B_F(LS1), B_I(LS1), B_F(LS2), B_I(LS2), reserved, downstream RS_F, RS_I, S, D ($RS_F = R_F$, $RS_I = R_I / S$)

upstream RS_F, RS_I, S, D ($RS_F = R_F$, $RS_I = R_I / S$)

Both reserved bytes shall be set to 00hex.

Table 22 summarizes the ATU-R data registers and their applications.

Table 22 - ATU-R data registers

REG # (HEX)	USE	LENGTH	DESCRIPTION
0	Read	2 bytes (see note 1)	ATU-R vendorID (see Annex D)
1	R	Vendor discretionary	ATU-R revision number
2	R	32 bytes	ATU-R serial number
3	R	Vendor discretionary	Self test results
4	Read/Write (R/W)	Vendor discretionary	Vendor discretionary
5	R/W	Vendor discretionary	Vendor discretionary
6	R	1 byte	Line attenuation
7	R	1 byte	SNR margin
8	R	30 bytes	ATU-R Configuration (see 6.4 and 7.4)
9-F	reserved	reserved	see note 2

NOTES

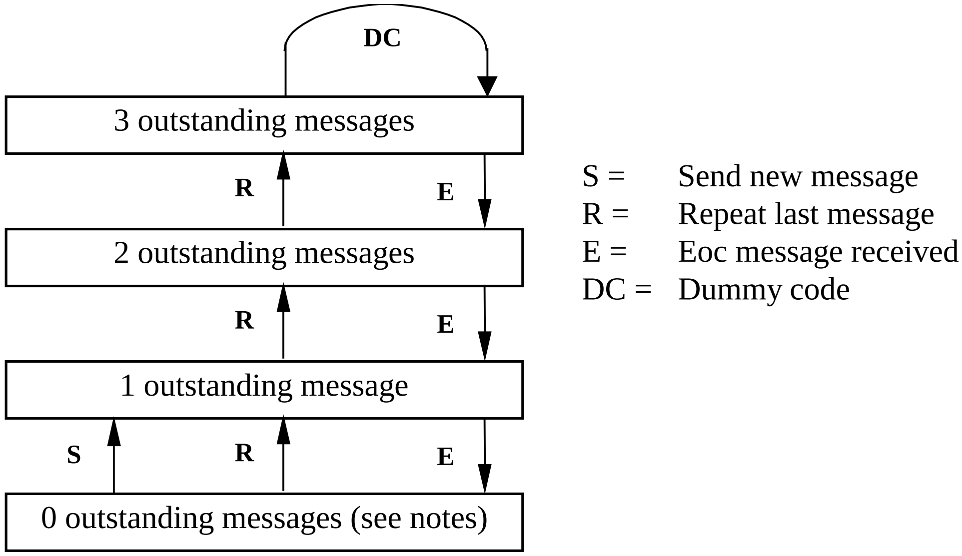
1. Registers shall be read most significant byte first.
2. Registers 9 through F are reserved for future use; ATU-R shall respond UTC (unable-to-comply) if requested to read from or write to one of these registers.

8.1.5 Eoc protocol states

The ADSL eoc protocol operates in a repetitive command and response mode. The ATU-C acts as the master and issues command messages; the ATU-R acts as slave and responds to the messagess issued by the ATU-C. Three identical properly-addressed consecutive (i.e. no other eoc messages are received in between) messages shall be received before an action is initiated (both at ATU-C and ATU-R). Only one command and only three or fewer messages, under the control of the ATU-C, shall be outstanding (i.e., unacknowledged) at any one time.

NOTE - This restriction on the number of messages guarantees that an ATU-R with fewer opportunities to insert eoc frames into the upstream path will be able to acknowledge all eoc messages from the ATU-C.

The procedure for dealing with outstanding messages at the ATU-C is shown in Figure 33. Only when it has no outstanding messages may the ATU-C send a message different from the previous message sent; this then results in one outstanding message. When one or two messages are outstanding, the ATU-C may only repeat the previous message sent; thereby ensuring that all outstanding messages will be identical.



NOTES

1. Immediately after initialization the ATU-C shall have no outstanding messages.
2. For E, R, and S all the eoc messages with bit 5 set to 1 shall be considered. Other eoc messages shall not cause a change of state in the eoc state machine.

Figure 33 - ATU-C state diagram for outstanding eoc messages

Whenever there are three outstanding messages, the ATU-C shall stop sending messages and stuff the available eoc bandwidth with dummy synchronization control bytes (see 6.4.1.2). Sending messages may be resumed after receiving one or more acknowledgements (echoes) from the ATU-R. Only one command shall be outstanding at any time. Therefore, all outstanding messages shall be indentical. To deal with messages that are not echoed by the ATU-R (e.g., those that are erased from the line due to impulse noise and will therefore remain outstanding), the ATU-C shall implement an adequate error recovery mechanism. This mechanism does not affect interoperability and is therefore outside the scope of this specification.

The eoc protocol state diagrams of the ATU-R and ATU-C shall be as shown in Figure 34 and Figure 35, respectively.

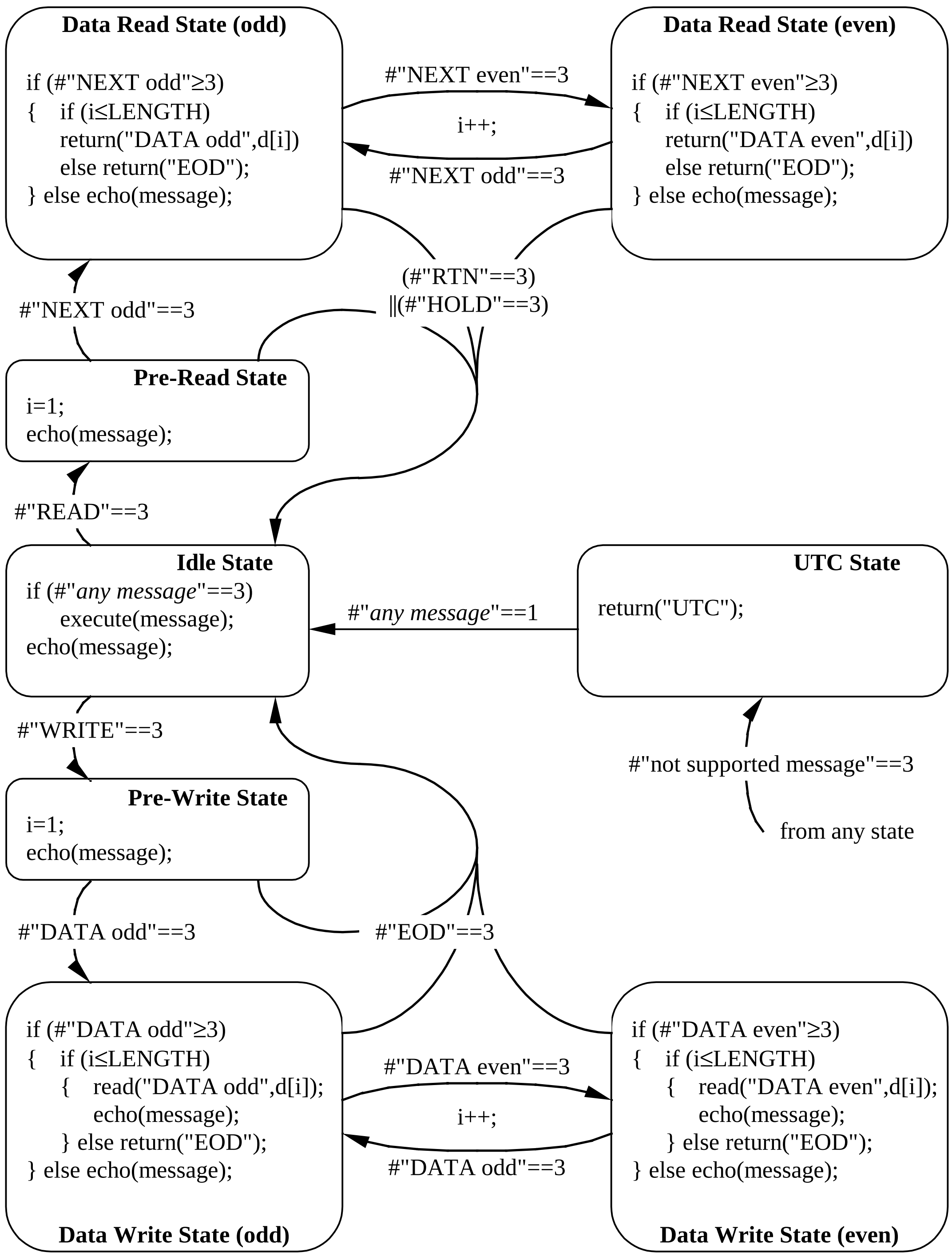


Figure 34 - EOC receiver state machine at ATU-R.

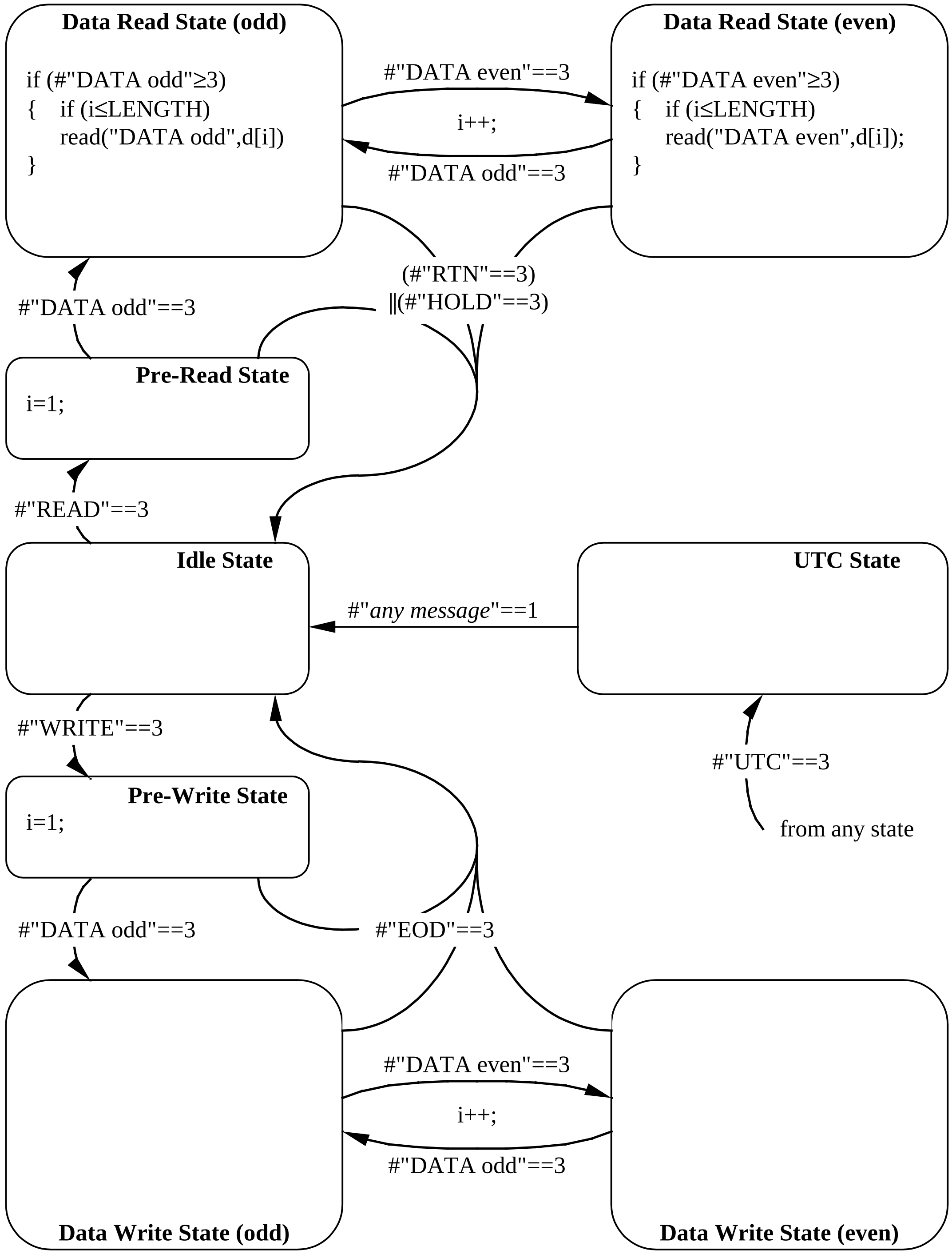


Figure 35 - EOC receiver state machine at ATU-C.

NOTES on Figure 34 and Figure 35

1. The protocol state changes are performed based on received messages. At ATU-C, received messages are responses from the ATU-R to messages sent from the ATU-C. Depending on the ATU-C receiver protocol state, the ATU-C transmitter message set may be restricted. It is left up to the ATU-C transmitter to organize and send a sequence of message such that the right response from the ATU-R is achieved based on the receiver protocol state machines.

2. *(#"message"==N)* is true if and only if the previously received N received messages are identical (i.e. all 13 bits equal) and properly addressed (i.e. having ATU-R address). *(#"message"==1)* means the most recently received message is different (in at least 1 out of 13 bits) from the immediately preceding message and is properly addressed.

3. Moving to another state (based on the message received) shall be considered first, then the (same or new) state shall be executed. At the ATU-R execution of commands in the Idle State shall be as described in 8.1.3 (invoking latching, unlatching or selftest).

4. All the eoc messages with bit 5 set to 1 shall be considered as received messages and cause an eoc response message at the ATU-R. Other eoc messages shall not cause a change of state in the eoc state machine and shall not cause an eoc response message at the ATU-R.

The responses allowed from the ATU-R fall into three categories:

- message/echo-response protocol states: Idle State and EXE State;
- message/unable-to-Comply-response protocol state: UTC State;
- message/data-response protocol states: Data Read States and Data Write States (Data Read States includes Pre-Read, Data Read odd and Data Read even States, Data Write State includes Pre-Write, Data Write odd and Data Write even States).

In addition to these states, one autonomous message shall be allowed from the ATU-R to the ATU-C to indicate "dying gasp". This message does not change the protocol state, nor does it count as a response to any ATU-C message; however, other actions (e.g., an automatic reset at the ATU-C) taken as a result of receiving this message may lead to a change of state (e.g., back to Idle State).

The eoc protocol shall enter the Message/Echo-response protocol state (Idle State) when the ATU's transition from the initialization and training sequence to steady state transmission. In order to cause the desired action in the ATU-R, the ATU-C shall repeat the message (without exceeding the limit of outstanding messages) until it receives three identical consecutive eoc message echoes from the ATU-R. This completes the command and response protocol, but the ATU-C may continue to send the same message thereafter. The command and response protocol for that message must be completed before a new message (containing a new command), which may induce a different protocol state in the ATU-R, may be issued.

At the ATU-R, depending on the state it is in, various restricted sets of eoc messages shall be acceptable. These sets shall be as shown in Table 23. Reception of other, unapplicable, messages shall result in an Unable-to-Comply (UTC) response to the ATU-C.

Table 23 - eoc messages acceptable at the ATU-R

ATU-R state	eoc messages acceptable at the ATU-R			
Idle	all messages acceptable			
UTC	all messages acceptable			
Data pre-read	Read	NEXT odd	RTN	HOLD
Data read odd, even	NEXT odd	NEXT even	RTN	HOLD
Data pre-write	WRITE	DATA odd	EOD	
Data write odd.even	DATA odd	DATA even	EOD	

8.1.5.1 Message/echo-response protocol state

This state is identical to the Idle State shown in Figure 34 and Figure 35.

To initiate an action at the ATU-R, the ATU-C shall begin sending eoc messages with the Data/opcode set to 1 and with the appropriate message opcode in the information field.

The ATU-R shall initiate action when, and only when, three identical, consecutive, and properly addressed eoc frames that contain a message recognized by the ATU-R have been received. The ATU-R shall respond to all received messages. The response shall be an echo of the received ADSL eoc message. The combination of the ATU-C sending an ADSL eoc frame and the ATU-R echoing the frame back comprises the message/echo-response protocol state.

For the ATU-C to confirm correct reception of the message by the ATU-R, the message/echo-response ADSL eoc protocol state is repeated until the master node receives three identical and consecutive echoes. This serves as an implicit acknowledgment to the ATU-C that the ATU-R has correctly received the transmitted message and is acting on it. This completes the Message/Echo-response protocol mode.

Because eoc frames are inserted into ADSL frames only when the appropriate byte is available, the amount of time it takes to complete a message under error-free conditions will depend on the vendor's synchronization control algorithm, on the number of signals allocated to the fast buffer, and on the rates of those signals.

The ATU-C continuously sends the activating message after the receipt of the three valid echoes, or alternatively, it may switch to sending the "Hold State" message. If the message was one of the latching commands, then the ATU-R shall maintain the commanded condition until the ATU-C issues the appropriate command that ends the specific latched condition or until the ATU-C issues the "Return to Normal" command (at which time all latched conditions in the ATU-R must be terminated).

8.1.5.2 Message/unable-to-comply response protocol state

When the ATU-R does not support a message that it has received three times identically and consecutively, it shall respond with the Unable-To-Comply (UTC) ADSL eoc response message with its own address in lieu of a third identical and consecutive echo. In this manner the ATU-R will switch to the message/UTC-response protocol state.

The transmission by the ATU-R and reception by the ATU-C of three identical, consecutive, properly addressed Unable-To-Comply messages constitutes notification to the ATU-C that the ATU-R does not support the requested function, at which time the ATU-C may abandon its attempt.

8.1.5.3 Message/data-response protocol state

The ATU-C may either write data into, or read data from the ATU-R memory.

8.1.5.3.1 Data read protocol

To read data from the ATU-R, the ATU-C shall send an appropriate read opcode message to the ATU-R that specifies the register to be read. After receiving at least three identical and consecutive acknowledgments, the ATU-C shall request the first byte to be sent from the ATU-R by sending "Next Byte" messages with bit four set to 1, indicating a request for an "odd" byte. The ATU-R shall respond to these "Next Byte" messages by echoing them until it has received three such messages consecutively, identically and properly addressed. Beginning with the third such reception, the ATU-R shall respond by sending the first byte of the register in the information field of an ADSL eoc frame with bit four set to 1 to indicate "odd byte" and with bit 3 set to 0 to indicate that the eoc frame is a data frame (as opposed to a frame that contains an opcode in the information field). The ATU-C continues to send the "Next Byte" message with bit four set to "odd byte", and the ATU-R continues to respond with a data frame containing the first byte of data and bit four equal to "odd byte", until the ATU-C has received at least three consecutive, identical and properly addressed data frames with bit four set to "odd byte".

If there are more data to be read, the ATU-C shall request the second byte of data by sending "Next Byte" messages with bit four set to 0 ("even byte"). The ATU-R echoes all messages received until three such "Next Byte" messages have been received, and on the third consecutive, identical and properly addressed "Next Byte" message, the ATU-R starts sending data frames containing the second byte of the register with bit four set to "even byte". The ATU-C continues to send the "Next Byte" message with bit four set to "even byte", and the ATU-R continues to respond with a data frame containing the second byte of data and bit four set to "even byte".

The process continues for the third and all subsequent bytes with the value of bit four toggling from "odd byte" to "even byte" or vice versa, on each succeeding byte. Each time bit four is toggled, the ATU-R echoes for two correct frames, and starts sending the data frame on the third reception. The process ends only when all data in the register has been read.

To continue reading data, once the ATU-R is in the Data Read odd or even State, the only message that the ATU-C is allowed to send is the “Next Byte” message with bit four toggling. To end the data read mode abnormally, the ATU-C sends either “Hold State” or “Return to Normal”, depending on whether any latched states are to be retained. If the ATU-R receives any other message three times consecutively, identically and properly addressed while it is in Data Read odd or even State, it shall go into the UTC State.

If, after all bytes have been read from the ATU-R register, the ATU-C continues to send the “Next Byte” message with bit four toggled, then the ATU-R shall send an “End of Data” message (with bit three set to 1 indicating opcode) beginning with the third such reception.

For the ATU-C, the data read mode ends either when the ATU-C has received the last requested data byte three times consecutively, identically and properly addressed, or when the ATU-C has received three consecutive, identical and properly addressed “End of Data” messages with bit three set to 1. The ATU-C shall then switch itself and the ATU-R over to the Idle State with the “Hold State” or “Return to Normal” message, and the ATU-R shall release the register and leaves the Data Read State after receiving three identical, consecutive and properly addressed “Hold State” or “Return to Normal” messages.

8.1.5.3.2 Data write protocol

To write data to the ATU-R’s memory, the ATU-C shall send a “Write Data” opcode message to the ATU-R that specifies the register to be written. When the ATU-R acknowledges with three consecutive, identical and properly addressed echo messages, the ATU-C sends the first byte of data. The ATU-R shall acknowledge the receipt of the byte with an echo of the message. After the ATU-C is satisfied with three identical, consecutive and properly addressed echo responses, it shall start sending the next byte of data. Each time the ATU-C receives at least three identical and consecutive correct data echo responses, it shall switch to sending the next byte of data. It shall also toggle the “odd/even” bit accordingly. (“Next Byte” messages are not used in the Data Write mode). The ATU-C shall end the write mode with the “End of Data” message indicating to the ATU-R to release the register and return to the Idle State.

To continue writing data, once the ATU-R is in the Data Write odd or even State, the only message that the ATU-C is allowed to send is the “DATA Byte” message with bit 3 set to 0 and with bit four toggling or, to end the Data Write State abnormally, the ATU-C may switch to the “EOD” message. If the ATU-R receives any other message three times consecutively, identically and properly addressed while it is in Data Write State, it shall go into the UTC State.

If, after all bytes have been written to the ATU-R register, the ATU-C continues to send a next byte of data, then the ATU-R shall send an “End of Data” message (with bit three set to 1 indicating opcode), beginning with the third such reception.

8.1.5.4 “dying gasp”

The ATU-R shall have the ability to detect when the electrical power has been shut off. After such detection of a near-end Loss-of-Power (lpr) condition (see 8.2.2.1), the ATU-R shall insert emergency priority eoc messages into the ADSL upstream data to implement a “dying gasp” as an lpr indicator. The “dying gasp” eoc message shall have bit 5 set to 0 to indicate autonomous message, and bit 3 set to 1 to indicate opcode, and shall contain the “dying gasp” opcode (see Table 21) in the information field.

At least six contiguous dying gasp eoc messages shall be inserted in the next (at least twelve) available ADSL upstream bytes available for eoc (see 7.4.1) beginning with an even-numbered frame, regardless of the number of eoc frames received in the downstream channel.

The ATU-C shall not send a response to a “dying gasp” message back to the ATU-R. An lpr indicator is present at the ATU-C if at least 4 “dying gasp” messages are received within the last twelve contiguous upstream bytes available for eoc, beginning with an even-numbered frame (see Loss-of-Power primitive definition in 8.2.2.2). Sending the “dying gasp” shall not cause the ATU-R to change the eoc protocol state, nor shall receiving it cause the ATU-C to immediately change state.

8.2 In-service performance monitoring and surveillance

The following terminology is used in this standard (see Figure 36):

– *Near-end:* Near-end means performance of the loop-side received signal at the input of the ATU;

– *Far-end:* Far-end means performance of the downstream loop-side received signal at the input of the ATU-R, where this performance is reported to the ATU-C in upstream indicators (see 6.4.1.1, 7.4.1.1 and 8.1.5.4), or performance of the upstream loop-side received signal at the input of the ATU-C, where this performance is reported to the ATU-R in downstream overhead indicators; this case is a mirror image of the above;

– *Primitives:* Primitives are basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicators from the far-end. Performance primitives are categorized as events, anomalies and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators;

– *Anomalies:* An anomaly is a discrepancy between the actual and desired characteristics of an item. The desired characteristic may be expressed in the form of a specification. An anomaly may or may not affect the ability of an item to perform a required function. Performance anomalies are defined in 8.2.1.3;

– *Defects:* A defect is a limited interruption in the ability of an item to perform a required function. It may or may not lead to maintenance action depending on the results of additional analysis. Successive anomalies causing a decrease in the ability of an item to perform a required function are considered as a defect.;

– *Thresholds:* All performance parameters (e.g., errored seconds) have associated thresholds, which may be set, read, or changed by the Operations Support System (OSS) to the ATU-C, or by the Network Management System (NMS) to an ATU-R that is doing performance monitoring (near-end or far-end);

– *Threshold Crossing Alert:* A threshold crossing for a performance parameter. Such an alert may be autonomously reported to the OSS by the ATU-C or to the NMS by an ATU-R (see 8.2.6.2). Note that the mechanism for setting, reading, or changing thresholds is beyond the scope of this standard (see ANSI T1.231).

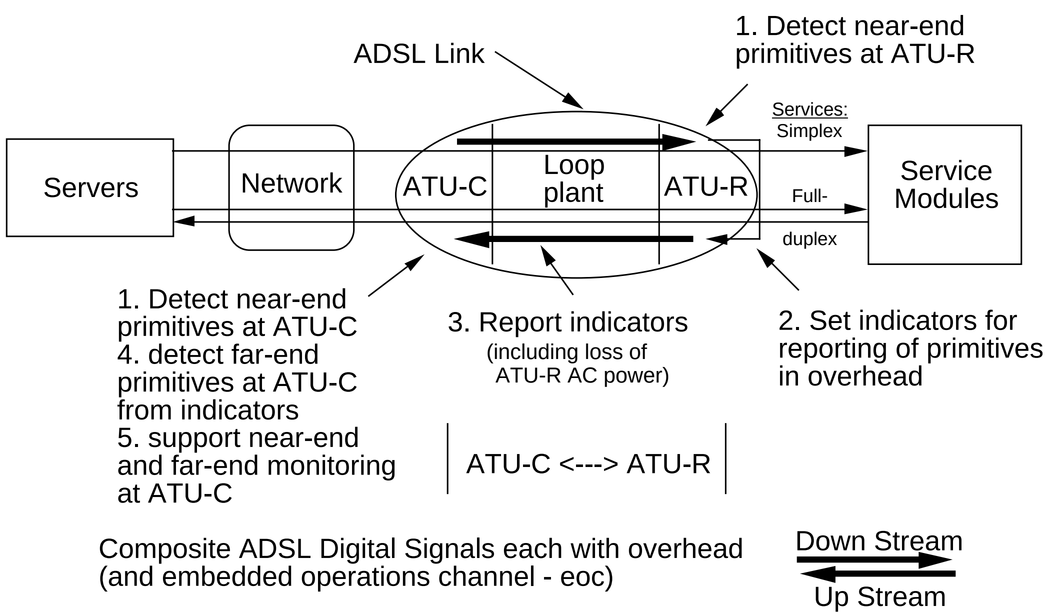
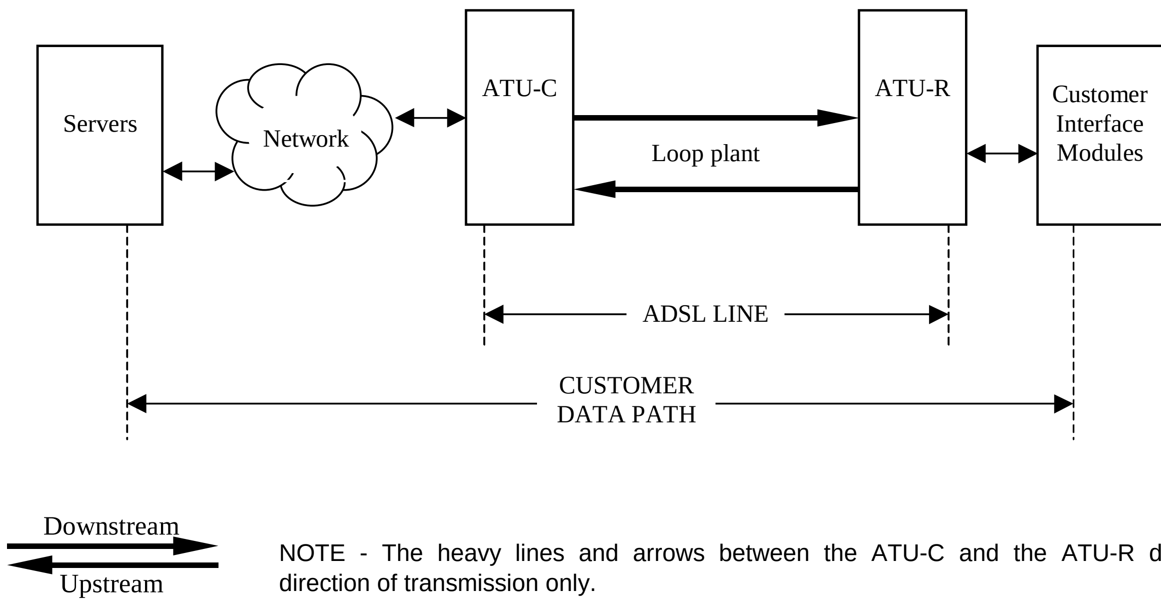


Figure 36 - In-service surveillance of the ADSL link shown from standpoint of ATU-C

ADSL lines are a physical transport vehicle that provides the means of moving digital information between two points at data rates from 32 kbit/s to at least 6.144 Mbit/s. ADSL lines are characterized by a metallic transmission medium utilizing an analog coding algorithm, which provides both analog and digital performance monitoring at the line entity. ADSL lines are delimited by their two end-points, known as *line terminations*. An ADSL line termination is the point where the analog coding algorithms end and the subsequent digital signal is monitored for integrity. Figure 37 illustrates the *lines* used within ADSL systems.

ADSL systems have been designed to deliver packet/cell based payloads. However, when ADSL systems operate in the STM mode non-cell based data paths may be transported. The performance monitoring capabilities required to maintain those data paths are imbedded within the packet/cell systems. The ADSL system shall support the data path monitoring requirements as required by the specific payload technology.



NOTE - The heavy lines and arrows between the ATU-C and the ATU-R denote direction of transmission only.

Figure 37 - Illustration of ADSL Lines

8.2.1 ADSL line related primitives

8.2.1.1 ADSL line related near-end anomalies

Four near-end anomalies are defined:

– *Forward Error Correction (fec-I) anomaly:* An fec-I anomaly occurs when a received FEC code for the interleaved data stream indicates that errors have been corrected;

– *Forward Error Correction (fec-F) anomaly:* An fec-F anomaly occurs when a received FEC code for the fast data stream indicates that errors have been corrected.

– *Cyclical Redundancy Check (crc-I) anomaly:* A crc-I anomaly occurs when a received CRC-8 code for the interleaved data stream is not identical to the corresponding locally generated code;

– *Cyclical Redundancy Check (crc-F) anomaly:* A crc-F anomaly occurs when a received CRC-8 code for the fast data stream is not identical to the corresponding locally generated code;

8.2.1.2 ADSL line related far-end anomalies

Similarly, four far-end anomalies are defined:

– *Far-end Forward Error Correction (ffec-I) anomaly:* An ffec-I anomaly is a fec-I anomaly detected at the far end and is reported once per superframe by the fecc-I indicator (see 6.4.1.1). The fecc-I indicator shall be coded 1 to indicate that no fec-I anomaly is present in the previous superframe and shall be coded 0 to indicate that at least one fec-I anomaly is present in the previous superframe. A ffec-I anomaly occurs when a received fecc-I indicator is set to 0. A ffec-I anomaly terminates when a received fecc-I indicator is set to 1;

– *Far-end Forward Error Correction (ffec-F) anomaly:* An ffec-F anomaly is an fec-F anomaly detected at the far end and is reported once per superframe by the fecc-F indicator (see 6.4.1.1). The fecc-F indicator shall be coded and reported in the same way as the fecc-I indicator. The ffec-F anomaly shall occur and terminate in the same way as the febe-I anomaly;

– *Far-end Block Error (febe-I) anomaly:* A febe-I anomaly is a crc-I anomaly detected at the far-end and is reported once per superframe by the febe-I indicator (see 6.4.1.1). The febe-I indicator shall be coded 1 to indicate that no crc-I anomaly is present in the previous superframe and shall be coded 0 to indicate that a crc-I anomaly is present in the previous superframe. A febe-I anomaly occurs when a received febe-I indicator is set to 0. A febe-I anomaly terminates when a received febe-I indicator is set to 1;

– *Far-end Block Error (febe-F) anomaly*: A febe-F anomaly is a crc-F anomaly detected at the far-end and is reported once per superframe by the febe-F indicator (see 6.4.1.1). The febe-F indicator shall be coded and reported in the same way as the febe-I indicator. The febe-F anomaly shall occur and terminate in the same way as the febe-I anomaly;

8.2.1.3 ADSL line related near-end defects

Two near-end defects are defined:

– *Loss-Of-Signal (los) defect:* A pilot tone reference power shall be established by averaging the ADSL pilot tone power for 0.1 sec. after the start of steady state data transmission (i.e., after initialization), and a threshold shall be set at 6 dB below the reference power. A los defect occurs when the level of the received ADSL pilot tone power, averaged over a 0.1 sec. period, is lower than the threshold, and terminates when this level, measured in the same way, is at or above the threshold;

– *Severely Errored Frame (sef) defect:* A sef defect occurs when the contents of two consecutively received ADSL synchronization symbols do not correlate with the expected content over a subset of the tones. A sef defect terminates when the content of two consecutively received ADSL synchronization symbols correlate with the expected contents over the same subset of the tones. The correlation method, the selected subset of the tones, and the threshold for declaring the sef defect condition are implementation discretionary;

8.2.1.4 ADSL line related far-end defects

Similarly, two far-end defects are defined:

– *Far-end Loss-Of-Signal (los) defect:* A far-end los defect is a los defect detected at the far-end and is reported by the los indicator. The los indicator (see 6.4.1.1) shall be coded 1 to indicate that no los defect is being reported and shall be coded 0 for 6 consecutive superframes to indicate that a los defect is being reported. A far-end los defect occurs when 4 or more out of 6 contiguous los indicators are received set to 0. A far-end los defect terminates when 4 or more out of 6 contiguously received los indicators are set to 1;

– *Far-end Remote Defect Indication (rdi) defect:* A rdi defect is a sef defect detected at the far-end and is reported once per superframe by the rdi indicator. The rdi indicator (see 6.4.1.1) shall be coded 1 to indicate that no sef defect is present in the previous superframe and shall be coded 0 to indicate that a sef defect is present in the previous superframe. A rdi defect occurs when a received rdi indicator is set to 0. An rdi defect terminates when a received rdi indicator is set to 1;

8.2.2 STM data path related primitives

In case STM data are transported on the U-interface, various ADSL payload types can be used. These payload types are not specified in this version of the standard and are for further study. The ADSL payload related primitives for STM transport are specific to a particular payload type and are for further study.

8.2.3 ATM data path related primitives

8.2.3.1 ATM data path related near-end anomalies

Six near-end anomalies are defined:

– *No Cell Delineation (ncd-I) anomaly:* An ncd-I anomaly occurs immediately after ATM Cell TC start-up when ATM data are allocated to the interleaved buffer and as long as the cell delineation process operating on these data is in the HUNT or PRESYNC state (see cell delineation state diagram, figure 8, in 6.2.3.5). Once cell delineation is acquired, subsequent losses of cell delineation shall be considered ocd-I anomalies;

– *No Cell Delineation (ncd-F) anomaly:* An ncd-F anomaly occurs immediately after ATM Cell TC start-up when ATM data are allocated to the fast buffer and as long as the cell delineation process operating on these data is in the HUNT or PRESYNC state (see cell delineation state diagram, figure 8, in 6.2.3.5). Once cell delineation is acquired, subsequent losses of cell delineation shall be considered ocd-F anomalies;

– *Out of Cell Delineation (ocd-I) anomaly:* An ocd-I anomaly occurs when ATM data are allocated to the interleaved buffer and the cell delineation process operating on these data transitions from SYNC to HUNT state (see cell delineation state diagram, figure 8, in 6.2.3.5). An ocd-I anomaly terminates when the cell delineation process transitions from PRESYNC to SYNC state or when the lcd-I defect maintenance state is entered;

– *Out of Cell Delineation (ocd-F) anomaly:* An ocd-F anomaly occurs when ATM data are allocated to the fast buffer and the cell delineation process operating on these data transitions from SYNC to HUNT state (see cell delineation state diagram, figure 8, in 6.2.3.5). An ocd-F anomaly terminates when the cell delineation process transitions from PRESYNC to SYNC state or when the lcd-F defect maintenance state is entered;

– *Header Error Check (hec-I) anomaly*: An hec-I anomaly occurs when an ATM cell header error check fails on the interleaved data (see header error check in 6.2.3.6);

– *Header Error Check (hec-F) anomaly*: An hec-F anomaly occurs when an ATM cell header error check fails on the fast data (see header error check in 6.2.3.6).

8.2.3.2 ATM data path related far-end anomalies

Similarly, six far-end anomalies are defined:

– *Far-end No Cell Delineation (fncd-I) anomaly:* A fncd-I anomaly is a ncd-I anomaly detected at the far-end and is reported once per superframe by the ncd-I indicator (see 6.4.1.1). The ncd-I indicator shall be coded 1 to indicate no ncd-I anomaly or ocd-I anomaly or lcd-I defect is present in the previous superframe and shall be coded 0 to indicate that at least one ncd-I anomaly or ocd-I anomaly or lcd-I defect is present in the previous superframe. An fncd-I anomaly occurs immediately after ATU start-up and terminates if a received ncd-I indicator is coded 1;

– *Far-end No Cell Delineation (fncd-F) anomaly:* A fncd-F anomaly is a ncd-F anomaly detected at the far-end and is reported once per superframe by the ncd-F indicator (see 6.4.1.1). The ncd-F indicator shall be coded and reported in the same way as the ncd-I indicator. The fncd-F anomaly shall occur and terminate in the same way as the fncd-I anomaly;

– *Far-end Out of Cell Delineation (focd-I) anomaly:* A focd-I anomaly is an ocd-I anomaly detected at the far-end and is reported once per superframe by the ncd-I indicator (see 6.4.1.1). A focd-I anomaly occurs if no fncd-I anomaly is present and a received ncd-I indicator is coded 0. A focd-I anomaly terminates if a received ncd-I indicator is coded 1.

– *Far-end Out of Cell Delineation (focd-F) anomaly:* A focd-F anomaly is an ocd-F anomaly detected at the far-end and is reported once per superframe by the ncd-F indicator (see 6.4.1.1). The focd-F anomaly shall occur and terminate in the same way as the focd-I anomaly;

– *Far-end Header Error Check (fhec-I) anomaly*: A fhec-I anomaly is an hec-I anomaly detected at the far end and is reported once per superframe by the hec-I indicator (see 6.4.1.1). The hec-I indicator shall be coded 1 to indicate that no hec-I anomaly is present in the previous superframe and shall be coded 0 to indicate that at least one hec-I anomaly is present in the previous superframe. A fhec-I anomaly occurs when a received hec-I indicator is set to 0. A fhec-I anomaly terminates when a received hec-I indicator is set to 1;

– *Far-end Header Error Check (fhec-F) anomaly*: A fhec-F anomaly is an hec-F anomaly detected at the far end and is reported once per superframe by the hec-F indicator (see 6.4.1.1). The hec-F indicator shall be coded and reported in the same way as the hec-I indicator. The fhec-F anomaly shall occur and terminate in the same way as the fhec-I anomaly;

NOTE - The fhec-I and fhec-F anomalies are reported once per superframe. This results in a low granularity of hec anomaly reporting since hundreds of ATM cells may be received over a one superframe time period.

8.2.3.3 ATM data path related near-end defects

Two near-end defects are defined:

– *Loss of Cell Delineation (lcd-I) defect*: A lcd-I defect occurs when at least one ocd-I anomaly is present in each of 4 consecutive superframes and no sef defect is present. An lcd-I defect terminates when no ocd-I anomaly is present in 4 consecutive superframes;

– *Loss of Cell Delineation (lcd-F) defect*: An lcd-F defect occurs when at least one ocd-F anomaly is present in each of 4 consecutive superframes and no sef defect is present. An lcd-F defect terminates when no ocd-I anomaly is present in 4 consecutive superframes;

8.2.3.4 ATM data path related far-end defects

Similarly, two far-end defects are defined:

– *Far-end Loss of Cell Delineation (flcd-I) defect*: An flcd-I defect is an lcd-I defect detected at the far-end and is reported by the ncd-I indicator (see 6.4.1.1). A flcd-I defect occurs when a focd-I anomaly is present and 4 consecutively received ncd-I indicators are coded 0 and no rdi defect is present. A flcd-I defect terminates if 4 consecutively received ncd-I indicators are coded 1.

– *Far-end Loss of Cell Delineation (flcd-F) defect*: An flcd-F defect is an lcd-F defect detected at the far-end and is reported by the ncd-F indicator (see 6.4.1.1). A flcd-F defect occurs and terminates in the same way as the flcd-I defect.

8.2.4 Other ADSL indicators, parameters and signals

8.2.4.1 Other near-end primitives

One other near-end primitives is defined:

– *Loss-of-power (lpr):* A lpr primitive occurs when the ATU electrical supply (mains) power drops to a level equal to or below the manufacturer-determined minimum power level required to ensure proper operation of the ATU. A lpr primitive terminates when the power level exceeds the manufacturer determined minimum power level.

8.2.4.2 Other far-end primitives

Similarly, one other far-end primitives is defined:

– *Far-end Loss-of-power (lpr):* A far-end lpr primitive is a lpr primitive detected at the far-end and is reported by the lpr indicator. The lpr indicator shall be coded with emergency priority in the next 6 available outgoing eoc messages (see the eoc protocol for “dying gasp” in 8.1.5.4). A far-end lpr primitive occurs when an lpr indicator is present. A far-end lpr primitive terminates if for a period of 0.5 s no lpr indicator is present and no near-end los defect is present. The condition for a lpr indicator being present is defined in the eoc protocol for “dying gasp” (8.1.5.4).

8.2.4.3 Failure count parameters

The ATU-C shall provide near-end and far-end failure counters for each near-end and far-end failure defined in 8.2.5, 8.2.6 and 8.2.7. The ATU-R may optionally provide near-end and far-end failure counters.

A particular failure count is the number of occurrences of a particular failure event, where a failure event occurs when the failure is declared, and ends when the failure clears.

8.2.5 ADSL line related failures

Any failure defined in this clause shall be conveyed to the OSS by the ATU-C and should be conveyed to the NMS by the ATU-R after it is detected.

8.2.5.1 ADSL line related near-end failures

The following near-end failures shall be provided at the ATU-C and the ATU-R:

– *Loss-of-signal (LOS):* An LOS failure is declared after 2.5 ± 0.5 seconds of contiguous los defect, or, if los defect is present when the criteria for LOF failure declaration have been met (see LOF definition below). An LOS failure is cleared after 10 ± 0.5 s of no los defect;

– *Loss-of-frame (LOF):* An LOF failure is declared after 2.5 ± 0.5 seconds of contiguous sef defect, except when a los defect or failure is present (see LOS definition above). A LOF failure is cleared when LOS failure is declared, or after 10 ± 0.5 seconds of no sef defect.

– *Loss-of-power (LPR):* An LPR failure is declared after the occurrence of a lpr primitive, followed by other to be determined conditions. This definition is under study.

8.2.5.2 ADSL line related far-end failures

The following far-end failures shall be provided at the ATU-C (ATU-R is at the far-end), and are optional at the ATU-R (ATU-C is at the far-end).

– *Far-end Loss-Of-Signal (LOS) failure:* A far-end LOS failure is declared after 2.5 ± 0.5 seconds of contiguous far-end los defect, or, if far-end los defect is present when the criteria for LOF failure declaration have been met (see LOF definition below). A far-end LOS failure is cleared after 10 ± 0.5 seconds of no far-end los defect;

– *Far-end Remote Failure Indication (RFI) failure:* A far-end RFI failure is declared after 2.5 ± 0.5 seconds of contiguous rdi defect, except when a far-end los defect or failure is present (see LOS definition above). A RFI failure is cleared when far-end LOS failure is declared, or after 10 ± 0.5 seconds of no rdi defect;

– *Far-end Loss-of-PoweR (LPR) failure:* A far-end LPR failure is declared after the occurrence of a far-end lpr primitive followed by 2.5 ± 0.5 seconds of contiguous near-end los defect. A LPR failure is cleared after 10 ± 0.5 seconds of no near-end los defect.

8.2.6 STM data path related failures

The ADSL payload related failures for STM transport are for further study (see 8.2.2).

8.2.7 ATM data path related failures

Any failure defined in this subclause shall be conveyed to the OSS by the ATU-C and should be conveyed to the NMS by the ATU-R after it is detected.

8.2.7.1 ATM related near-end failures

The following near-end failures shall be provided at the ATU-C and the ATU-R:

– *NCD-I failure:* An NCD-I failure is declared when a ncd-I anomaly persists for more than 2.5 ± 0.5 seconds. An NCD-I failure terminates when no ncd-I anomaly is present for more than 10 ± 0.5 seconds;

– *NCD-F failure:* An NCD-F failure is declared when a ncd-F anomaly persists for more than 2.5 ± 0.5 seconds. An NCD-F failure terminates when no ncd-F anomaly is present for more than 10 ± 0.5 seconds;

– *LCD-I failure:* An LCD-I failure is declared when a lcd-I defect persists for more than 2.5 ± 0.5 seconds. An LCD-I failure terminates when no lcd-I defect is present for more than 10 ± 0.5 seconds;

– *LCD-F failure:* An LCD-F failure is declared when a lcd-F defect persists for more than 2.5 ± 0.5 seconds. An LCD-F failure terminates when no lcd-F defect is present for more than 10 ± 0.5 seconds.

8.2.7.2 ATM related far-end failures

The following far-end failures shall be provided at the ATU-C (ATU-R is at the far-end), and are optional at the ATU-R (ATU-C is at the far-end):

- *Far-end No Cell Delineation (FNCD-I) failure:* An FNCD-I failure is declared when a fncd-I anomaly persists for more than 2.5 ± 0.5 seconds. An FNCD-I failure terminates when no fncd-I anomaly is present for more than 10 ± 0.5 seconds;
- *Far-end No Cell Delineation (FNCD-F) failure:* An FNCD-F failure is declared when a fncd-F anomaly persists for more than 2.5 ± 0.5 seconds. An FNCD-F failure terminates when no fncd-F anomaly is present for more than 10 ± 0.5 seconds;
- *Far-end Loss of Cell Delineation (FLCD-I) failure:* An FLCD-I failure is declared when a flcd-I defect persists for more than 2.5 ± 0.5 seconds. An FLCD-I failure terminates when no flcd-I defect is present for more than 10 ± 0.5 seconds;
- *Far-end Loss of Cell Delineation (FLCD-F) failure:* An FLCD-F failure is declared when a flcd-F defect persists for more than 2.5 ± 0.5 seconds. An FLCD-F failure terminates when no flcd-F defect is present for more than 10 ± 0.5 seconds.

8.2.8 ADSL line related performance parameters

The ADSL line related near-end and far-end performance parameters are defined in Annex M.

8.2.9 STM data path related performance parameters

The ADSL data path related performance parameters for STM transport are for further study (see 8.2.2).

8.2.10 ATM data path related performance parameters

The following near-end performance parameters shall be provided at the ATU-C and the ATU-R:

- *Near-end HEC_violation_count-I*: The near-end HEC_violation_count-I performance parameter is a count of the number of occurrences of a near-end hec-I anomaly (see 8.2.3.1).
- *Near-end HEC_violation_count-F*: The near-end HEC_violation_count-F performance parameter is a count of the number of occurrences of a near-end hec-F anomaly (see 8.2.3.1).
- *Near-end HEC_total_cell_count-I*: The near-end HEC_total_cell_count-I performance parameter is a count of the total number of cells passed through the cell delineation process operating on the interleaved data while in the SYNC state.
- *Near-end HEC_total_cell_count-F*: The near-end HEC_violation_count-F performance parameter is a count of the total number of cells passed though the cell delineation process operating on the fast data while the SYNC state.
- *Near-end User_total_cell_count-I*: The near-end User_total_cell_count-I performance parameter is a count of the total number of cells in the interleaved data path delivered at the V-C (for ATU-C) or T-R (for ATU-R) interface.
- *Near-end User_total_cell_count-F*: The near-end User_total_cell_count-F performance parameter is a count of the total number of cells in the fast data path delivered at the V-C (for ATU-C) or T-R (for ATU-R) interface.

The performance counters at the far-end may be accessed as described in the ATM Forum ILMI or through the clear channel eoc protocol as described in Annex L.

8.2.11 Performance monitoring functions

Near-end performance monitoring (PM) functions shall be provided at the ATU-C, and are optional at the ATU-R. Far-end performance monitoring functions shall be provided at the ATU-C (ATU-R is at the far-end), and are optional at the ATU-R (ATU-C is at the far-end).

8.2.11.1 ADSL line related performance parameters

8.2.11.1.1 Performance data storage

Performance data storage shall be done in accordance with the performance monitoring functions defined in ANSI T1.231.

8.2.11.1.2 Performance data reporting

Threshold Crossing Alerts and Failures shall be reported autonomously by the ATU-C or associated equipment. Threshold Crossing Alerts and Failures may be reported autonomously by the ATU-R or associated equipment. The ATU-C shall allow the OSS and the ATU-R shall allow the NMS to inhibit such autonomous reporting. The mechanism for inhibiting autonomous reporting is outside the scope of this standard (see ANSI T1.231).

Performance data reporting shall be done in accordance with the performance monitoring functions defined in ANSI T1.231.

8.2.11.2 ATM data path related performance parameters

The ATM data path related performance parameters shall be stored and reported as for the ADSL line related performance parameters (see 8.2.11.1).

8.3 Test parameters

The attenuation (ATN) and signal-to-noise ratio (SNR) margin test parameters apply to on-demand test requests; e.g., to check for adequate physical media performance margin at acceptance and after repair verification, or at any other time following the execution of initialization and training sequence of the ADSL system. ATN and SNR, as measured by the receivers at both the ATU-C and the ATU-R shall be externally accessible from the ATU-C, but they are not required to be continuously monitored. They are made available on-demand as defined in 8.1.3.

8.3.1 Near-end test parameters

The following near-end test parameters shall be provided at the ATU-C and the ATU-R:

– *Attenuation (ATN):* The attenuation is the difference in dB between the power received at the near-end and that transmitted from the far-end. Received signal power in dBm is the sum of all data-carrying (i.e., b_i > 0) DMT sub-carrier powers averaged over a 1 second period. Transmitted signal power is -3.65+10log(Σgi^2) dBm, summed over the data-carrying sub-carriers. The attenuation ranges from from 0 to 63.5 dB with 0.5 dB steps;

– *Signal-to-Noise Ratio (SNR) margin:* The signal-to-noise ratio margin represents the amount of increased received noise (in dB) relative to the noise power that the system is designed to tolerate and still meet the target BER of 10^{-7}, accounting for all coding (e.g., trellis coding, RS FEC) gains included in the design. The SNR margin ranges from -64.0 dB to +63.5 dB with 0.5 dB steps.

8.3.2 Far-end test parameters

The following far-end test parameters shall be provided at the ATU-C:

– *Far-end Attenuation (ATN):* The far-end attenuation is the attenuation measured at the at the far-end. It can be read from the eoc ATN register using the eoc command set (see 8.1.4). The eoc ATN register shall be coded as an unsigned integer, ranging from 0 to 127, corresponding to a 0 to 63.5 dB attenuation (0.5 dB steps);

– *Far-end Signal-to-Noise Ratio(SNR) margin:* The far-end signal-to-noise ratio margin is the signal-to-noise ratio margin measured at the at the far-end. It can be read from the eoc SNR register using the eoc command set (see 8.1.4). The eoc SNR register shall be coded as a 2's complement signed integer, ranging from -128 to +127, corresponding to a -64 to +63.5 dB signal-to-noise ratio margin (0.5 dB steps).

9 Initialization

9.1 Overview

9.1.1 Basic functions of initialization

ADSL transceiver initialization is required in order for a physically connected ATU-R and ATU-C pair to establish a communications link. Establishment may be initiated by the ATU-C or the ATU-R as follows:

– An ATU-C, after power-up or loss of signal, and an optional self-test, may transmit activation tones (9.2) and await a response from the ATU-R (9.3.3). It shall make no more than two attempts; if no response is received it shall wait for an activation request from the ATU-R (9.3.1) or an instruction from the network to retry;

– An ATU-R, after power-up and an optional self-test, may repeatedly transmit activate request (9.3.1). If, however, the ATU-R receives C-TONE it shall remain silent for approximately one minute (9.3.2), unless it detects an activation signal (9.2.2).

In order to maximize the throughput and reliability of this link, ADSL transceivers shall determine certain relevant attributes of the connecting channel and establish transmission and processing characteristics suitable to that channel. The timeline of Figure 38 provides an overview of this process. In Figure 38, each receiver can determine the relevant attributes of the channel through the transceiver training and channel analysis procedures. Certain processing and transmission characteristics can also be established at each receiver during this time. During the exchange process each receiver shares with its corresponding far-end transmitter certain transmission settings that it expects to see. Specifically, each receiver communicates to its far-end transmitter the number of bits and relative power levels to be used on each DMT sub-carrier, as well as any messages and final data rates information. For highest performance these settings should be based on the results obtained through the transceiver training and channel analysis procedures.

ATU-C

Activation and acknowledgment (9.2)	Transceiver training (9.4)	Channel analysis (9.6)	Exchange (9.8)

ATU-R

Activation and acknowledgment (9.3)	Transceiver training (9.5)	Channel analysis (9.7)	Exchange (9.9)

time →

Figure 38 - Overview of initialization

Determination of channel attribute values and establishment of transmission characteristics requires that each transceiver produce, and appropriately respond to, a specific set of precisely-timed signals. This clause describes these initialization signals, along with the rules that determine the proper starting and ending time for each signal. This description is made through the definition of initialization signaling states in which each transceiver will reside, and the definition of initialization signals that each transceiver will generate.

A state and the signal generated while in that state have the same name, which may sometimes, for clarity, be prefixed by “state”or “signal”

The sequence of generated downstream and upstream states/signals for a successful initialization procedure is shown by the time-lines of Figures 39 to 42; details of the timing of the states are shown in Figures 43 to 45. The dashed arrows indicate that the change of state in the ATU at the head of the arrow is caused by a successful reception of the last signal shown in the box at the base of the arrow. For example, in Figure 41, the ATU-R stays in state R-REVERB3 until it finishes receiving C-CRC2, at which point it moves on to R-SEGUE2 after an appropriate delay (see 9.7.2).

NOTE - The arrows show the sequence of events in a successful initialization. More detailed state diagrams, which deal with failures to detect signals, timeouts, etc., are given in Annex A.

The description of a signal consists of three parts:

– The first part is a description of the voltage waveform that the transmitter shall produce at its output when in the corresponding state.

– The output voltage waveform of a given initialization signal is described using the DMT transmitter reference model shown in Figures 2 to 5. These figures are not a requirement or suggestion for building a DMT transmitter. Rather, they are a model for facilitating accurate and concise DMT signal waveform descriptions. In the figures Z_i is DMT sub-carrier *i* (defined in the frequency domain), and x_n is the *n*-th IDFT output sample (defined in the time domain). The DAC and analog processing block of Figures 2 to 5 construct the continuous transmit voltage waveform corresponding to the discrete digital input samples. More precise specifications for this analog block arise indirectly from the analog transmit signal linearity and power spectral density specifications of 6.14 and 7.14. The use of the figures as a transmitter reference model allows all initialization signal waveforms to be described through the sub-carrier sequence Z_i , required to produce that signal. Allowable differences in the characteristics of different digital to analog and analog processing blocks will produce somewhat different continuous-time voltage waveforms for the same initialization signal. However, a compliant transmitter will produce initialization signals whose underlying DMT sub-carrier sequences match exactly those provided in the signal descriptions of 9.2 to 9.9;

– The second is a statement of the required duration, expressed in DMT symbol periods, of the signal. This signal duration may be a constant or may depend upon the detected signaling state of the far end transceiver. The duration of a single DMT symbol period depends on whether the cyclic prefix is being used; some initialization signals contain a cyclic prefix, and some do not. ATU-C signals up to and including C-SEGUE1 are transmitted without a cyclic prefix; those from C-RATES1 on are transmitted with a prefix. Similarly, ATU-R signals up to and including R-SEGUE1 do not use a prefix; those from R-REVERB3 onward do. The duration of any signal in seconds is therefore the defined number of symbol periods times the duration of the symbol being used;

– The third part of a signal’s description is a statement of the rule specifying the next state.

9.1.2 Transparency to methods of separating upstream and downstream signals.

Manufacturers may choose to implement this standard using either frequency-division-multiplexing (FDM) or echo canceling (EC) to separate upstream and downstream signals. The initialization procedure described here ensures compatibility between these different implementations by specifying all upstream and downstream control signals to be in the appropriate, but narrower, frequency bands that would be used by an FDM transceiver, and by defining a time period during which an EC transceiver can train its echo canceler.

9.1.3 Resetting during initialization and data transmission

If errors or malfunctions are detected or timeout limits are exceeded at various points in the initialization sequence, the ATU-C and ATU-R shall return to the initial states C-QUIET1 and R-ACT-REQ, respectively, for retraining. Furthermore, some errors detected during data transmission (i.e., after a successful initialization) may also require retraining. The overall state diagram is shown in Annex A.

9.2 Activation and acknowledgment - ATU-C

A host controller may be used to monitor the ATU-C activities and keep track of the state of the ATU-C if errors or malfunctions occur that require resetting to C-QUIET1, and retraining.

The sequence of states/signals for activation and acknowledgement at both ATU-C and ATU-R is shown in Figure 39.

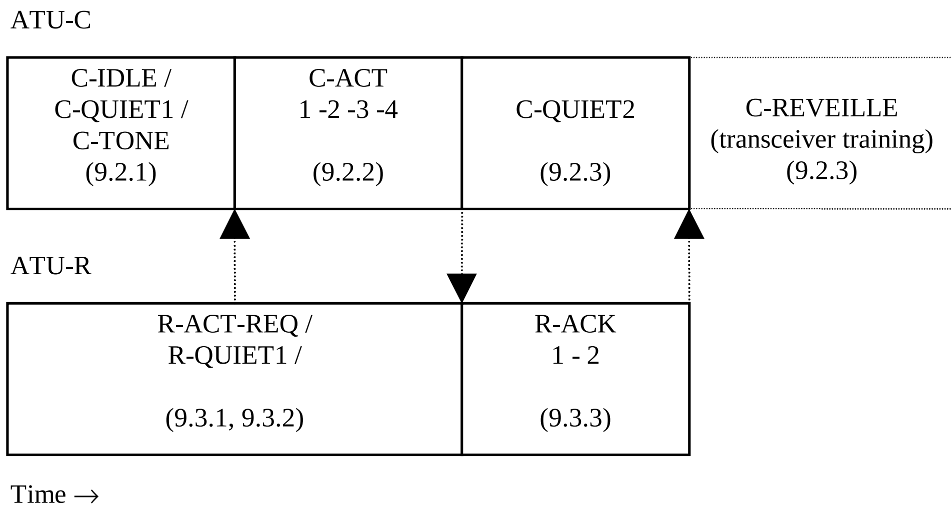


Figure 39 - Timing diagram of activation and acknowledgment (9.2-9.3)

9.2.1 Pre-activate states

Three pre-activation states shall exist at the ATU-C:

- C-QUIET1;
- C-IDLE;
- C-TONE.

The transitions between these and other vendor-optional states are shown in Figure A.1, and described in Annex A.

9.2.1.1 C-QUIET1

Upon power-up and after an optional self-test the ATU-C shall enter state C-QUIET1.

NOTE - QUIET and IDLE signals are defined as zero output voltage from the DAC of Figures 2 to 5.

When the ATU-C is in C-QUIET1, either a command from the host controller or a successful detection of R-ACT-REQ (defined as detecting 128 consecutive symbols of active R-ACT-REQ signal followed by silent symbols) shall cause it to go to state C-ACT (see 9.2.2). To ensure full compatibility between FDM and EC systems, the ATU-C transmitter shall remain in state C-QUIET1 until the ATU-C receiver no longer detects the 128 active symbols of the R-ACT-REQ signal. (i.e., detects the first silent symbol of R-ACT-REQ).

Alternatively, the host controller may command the ATU-C to enter C-IDLE.

NOTE - Depending on the loop characteristics, the ATU-R may only detect the higher or lower transmit power of R-ACT-REQ and therefore the ATU-C may respond before the end of the 128 active R-ACT-REQ symbols (see Figure 43).

9.2.1.2 C-IDLE

The ATU-C shall enter C-IDLE from C-QUIET1 in response to a host command. The difference between states C-QUIET1 and C-IDLE is that the ATU-C receiver reacts to R-ACT-REQ in C-QUIET1, but ignores it in C-IDLE.

If R-ACT-REQ is detected while in C-IDLE state, the host controller may elect to go to state C-TONE.

The ATU-C shall stay in C-IDLE indefinitely until the host controller issues the appropriate command to go to either state C-TONE, C-QUIET1, C-ACT, or C-SELFTEST (see 9.2.2).

NOTE - C-SELFTEST is not defined herein; it is a vendor-option that does not affect compatibility.

9.2.1.3 C-TONE

The ATU-C shall transmit C-TONE to instruct the ATU-R not to transmit R-ACT-REQ. C-TONE is a single frequency sinusoid at $f_{C\text{-}TONE}$ = 310.5 kHz. Referring to Figures 2 to 5, C-TONE is defined as

$$Z_i = \begin{cases} 0, \ i \neq 72, \ 0 \leq i \leq 256 \\ A_{C-TONE}, \ i = 72 \end{cases}$$

where $A_{C\text{-}TONE}$ shall be such that the transmit power level is -3.65 dBm (-40 dBm/Hz over single 4.3125 kHz tone spacing) for the first 64 symbols, and 24 dB lower for the second 64 symbols. This signal is transmitted for 128 consecutive symbols, and no cyclic prefix is used. C-IDLE immediately follows C-TONE.

9.2.2 C-Activate

The ATU-C shall transmit a C-Activate signal to initiate a communication link to the ATU-R To allow for inter-operability between FDD and EC systems, and among different vendors with different implementation of such systems, four activate signals, C-ACT1 to C-ACT4 are defined. These shall be used to distinguish different system requirements for loop timing and the use of a pilot tone. These four signals are mutually exclusive; any given ATU-C shall transmit one and only one. Throughout the remainder of this document the generic term C-ACT will refer to the appropriate state and signal.

Loop timing is defined as the combination of the slaving of an ADC clock to the received signal (i.e., to the other transceiver's DAC clock), and tying the local DAC and ADC clocks together. Only one of the two transceivers can perform loop timing. Loop timing shall always be active during any ADSL connection. All ATU-Rs shall be capable of performing loop timing. The ATU-C shall decide and inform the ATU-R (via the choice of the activation tone used) whether the ATU-C or ATU-R will perform loop timing

It is understood that an ATU-C may train its equalizer during the last 512 symbols of R-REVERB1. Such equalizer training, at the ATU-C, requires sufficient sampling clock stability at the ATU-R transmitter.

After loop timing is acquired at ATU-R, the ATU-R shall re-acquire loop timing after a period with free running timing (i.e., no C-PILOT over maximum 512 symbols) within 512 symbols after the C-PILOT re-appearing. This applies to C-QUIET4 and C-QUIET5 and may also apply to C-QUIET3 and C-ECT.

The meaning of the four C-Activate signals is summarized in Table 24.

Table 24 - Meaning of four C-Activate signals

	Loop timing at	Pilot during R-QUIET3/R-PILOT1
C-ACT1	ATU-C	No
C-ACT2	ATU-R	No
C-ACT3	ATU-C	Vendor discretionary (see 9.2.2.3)
C-ACT4	ATU-R	Vendor discretionary (see 9.2.2.4)

9.2.2.1 C-ACT1

The ATU-C shall transmit C-ACT1 when the ATU-C will perform loop timing, and it cannot accept a pilot during R-QUIET3/R-PILOT1.

C-ACT1 is a single frequency sinusoid at $f_{C\text{-}ACT1}$ = 207 kHz defined as in 9.2.1.3 but with i = 48. $A_{C\text{-}ACT1}$ shall be such that the transmit power level is -3.65 dBm (-40 dBm/Hz over a single 4.3125 kHz tone spacing) for the first 64 symbols, and 24 dB lower for the second 64 symbols. This signal shall be transmitted for 128 consecutive symbols, and no cyclic prefix shall be used.

C-QUIET2 immediately follows C-ACT1.

9.2.2.2 C-ACT2

The ATU-C shall transmit C-ACT2 to instruct ATU-R to perform loop timing, and to indicate that it cannot accept a pilot during R-QUIET3/R-PILOT1.

C-ACT2 is a single frequency sinusoid at $f_{C\text{-}ACT2}$ = 189.75 kHz defined as in 9.2.1.3 but with $i = 44$.

The level and duration of C-ACT2 shall be the same as those of C-ACT1.

C-QUIET2 immediately follows C-ACT2.

9.2.2.3 C-ACT3

The ATU-C shall transmit C-ACT3 when the ATU-C will perform loop timing, and it requests a pilot during R-QUIET3/R-PILOT1.

NOTE - The decision whether to transmit R-PILOT1 is at the discretion of the vendor of the ATU-R.

C-ACT3 is a single frequency sinusoid at $f_{C\text{-}ACT3}$ = 224.25 kHz defined as in 9.2.1.3, but with $i = 52$.

The level and duration of C-ACT3 shall be the same as those of C-ACT1.

C-QUIET2 immediately follows C-ACT3.

9.2.2.4 C-ACT4

The ATU-C shall transmit C-ACT4 to instruct ATU-R to perform loop timing, and to request a pilot during R-QUIET3/R-PILOT1.

NOTE - The decision whether to transmit R-PILOT1 is at the discretion of the vendor of the ATU-R.

C-ACT4 is a single frequency sinusoid at $f_{C\text{-}ACT4}$ = 258.75 kHz defined as in 9.2.1.3 but with $i = 60$.

The level and duration of C-ACT4 shall be the same as those of C-ACT1.

C-QUIET2 immediately follows C-ACT4.

9.2.3 C-QUIET2

The purpose of C-QUIET2 is to allow the detection of R-ACK1 or R-ACK2 without the need to train the ATU-C echo canceller. The duration of C-QUIET2 is 128 symbols.

After C-QUIET2, ATU-C enters one of three states:

- C-REVEILLE*:* If the ATU-C detects R-ACK (see 9.3.3) it shall enter the state C-REVEILLE. Even if the ATU-C detects R-ACK in fewer than 128 symbols, the full duration of C-QUIET2 shall be maintained;
- C-ACT*:* If the ATU-C fails to detect R-ACK, and the state C-ACT has not been entered more than twice the ATU-C shall enter the state C-ACT. (A counter, which is reset upon entering C-QUIET1, should keep track of how many times ATU-C goes from C-QUIET2 and back to C-ACT);
- C-QUIET1*:* If the ATU-C does not detect R-ACK after returning twice to C-ACT it shall return to C-QUIET1.

9.3 Activation and acknowledgment - ATU-R

As in the ATU-C, a host controller may be used to monitor the ATU-R activities, and keep track of the state of the ATU-R if errors or malfunctions occur that require resetting to R-ACT-REQ.

9.3.1 R-ACT-REQ

R-ACT-REQ is used when it is desirable for the ATU-R to initiate a communication link to the ATU-C. One example is when a customer at ATU-R requests a service. R-ACT-REQ is transmitted after power-up and an optional successful self-test (see Annex A).

R-ACT-REQ is a single sinusoid at $f_{R\text{-}ACT\text{-}REQ}$ = 34.5 kHz defined as in 9.2.1.3, but with i = 8.

$A_{R\text{-}ACT\text{-}REQ}$ shall be such that the transmit power level is -1.65 dBm (-38 dBm/Hz over a single 4.3125 kHz tone spacing) for the first 64 symbols and 20 dB lower for the second 64 symbols, and $A_{R\text{-}ACT\text{-}REQ}$ = 0 for the next 896 symbols. This signal shall be transmitted for 1024 consecutive symbols.

The ATU-R shall stay in R-ACT-REQ indefinitely (i.e., transmitting the single tone signal for 128 symbols, then shutting the signal off for 896 symbols, and then repeating the process) until either:

– a successful detection of C-ACT signal from the ATU-C, in which case the ATU-R shall enter R-ACK as soon as the full duration of C-ACT signal has been detected;

– a successful detection of C-TONE signal from the ATU-C, in which case the ATU-R shall enter R-QUIET1.

NOTE - Depending on the loop characteristics, the ATU-R may only detect the higher or lower transmit power of C-ACT and therefore the ATU-C may respond before the end of the 128 C-ACT symbols (see Figure 43).

9.3.2 R-QUIET1

The duration of R-QUIET1 depends upon whether the ATU-R detects C-ACT:

– if the ATU-R detects C-ACT it shall immediately enter R-ACK;

– if it does not, it shall remain quiet for 240,000 symbols (approximately 60 seconds) and then re-enter R-ACT-REQ.

9.3.3 R-Acknowledge

R-Acknowledge is transmitted by the ATU-R, as an acknowledgement of the detection of C-ACT, in order to continue initiating a communication link to the ATU-C. Three acknowledge signals are defined. The uses of R-ACK1 and R-ACK2 are defined; the use of R-ACK3 is for further study. Throughout the rest of this document the generic term R-ACK will refer to the appropriate state and signal.

The meanings of R-ACK1 and R-ACK2 are summarized in Table 25. R-ACK2 signifies that the ATU-R requires a pilot during C-QUIET3, C-QUIET4, C-QUIET5. The interpretation of R-ACK1 depends upon which modem is performing loop timing as shown in Table 25.

When loop timing is to be performed at the ATU-R, and R-ACK1 is transmitted, then the C-QUIET3 state is split into two substates. C-PILOT1A is sent during the first portion, C-QUIET3A during the latter. (see 9.4.4 and 9.4.5)

Table 25 - Meaning of R-ACK1 and R-ACK2

	With C-ACT1 or C-ACT3 (Loop timing at ATU-C)		**With C-ACT2 or C-ACT4 (Loop timing at ATU-R)**	
	R-ACK1	R-ACK2	R-ACK1	R-ACK2
C-QUIET3	Quiet	Pilot	Pilot Quiet	Pilot
C-QUIET4	Quiet	Pilot	Pilot	Pilot
C-QUIET5	Quiet	Pilot	Quiet	Pilot

9.3.3.1 R-ACK1

R-ACK1 is a single sinusoid at $f_{R\text{-}ACK1}$ = 43.125 kHz defined as in 9.2.1.3, but with i = 10.

$A_{R\text{-}ACK1}$ shall be such that the transmit power level is -1.65 dBm (-38 dBm/Hz over a single 4.3125 kHz tone spacing) for the first 64 symbols and 20 dB lower for the second 64 symbols. This signal shall be transmitted for 128 consecutive symbols. R-QUIET2 follows immediately after R-ACK1.

9.3.3.2 R-ACK2

R-ACK2 signifies that the ATU-R requires a pilot during C-QUIET3, C-QUIET4, and C-QUIET5. It is a single sinusoid at $f_{R\text{-}ACK2}$ = 51.75 kHz defined as in 9.3.1.2, but with i = 12. The level and duration of R-ACK2 shall be the same as those of R-ACK1.

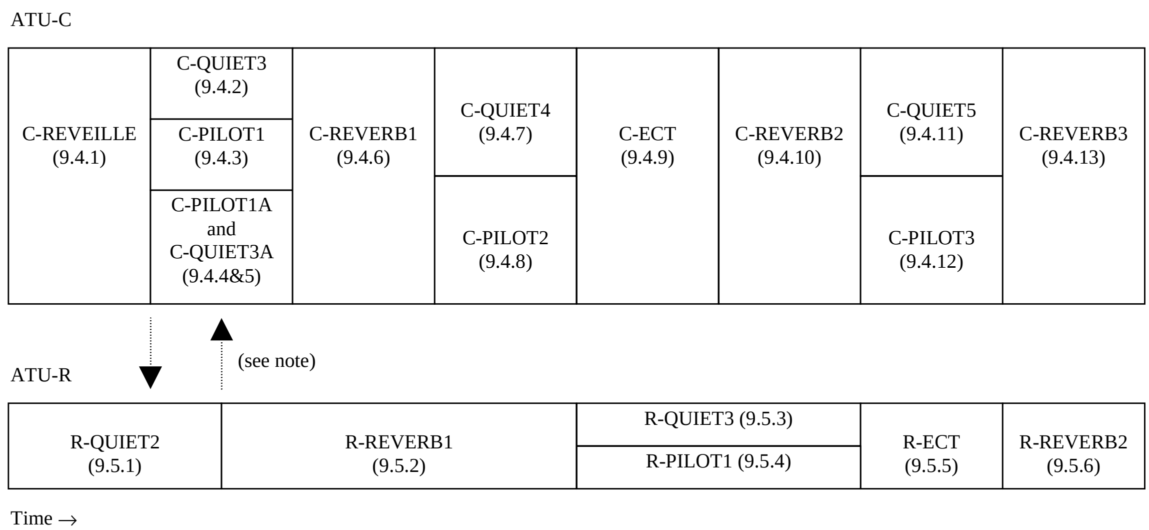
9.3.3.3 R-ACK3

R-ACK3 is reserved for future initialization options. It is a single sinusoid at $f_{R\text{-}ACK3}$ = 60.375 kHz defined as in 9.3.1.2, but with i = 14. The level and duration of R-ACK3 shall be the same as those of R-ACK1.

An Issue 2 ATU-C shall ignore R-ACK3 if present. Additionally an Issue 2 ATU-C shall still detect R-ACK1 and R-ACK2 if R-ACK3 is received at the same time (i.e. ignore $Z_i \neq 0$ for i = 14).

9.4 Transceiver training - ATU-C

This subclause and 9.5 describe the signals transmitted during transceiver training by the ATU-C and ATU-R, respectively. Synchronization of the mutual training begins with the transmission of R-REVERB1 (see 9.5.2), and is maintained throughout training by both transceivers counting the number of symbols from that point on. Thus C-REVEILLE always coincides with R-QUIET2, C-QUIET5 or C-PILOT3 coincides with R-ECT, and so on.



NOTE - Because the ATU-C and ATU-R states are synchronized from this point on, no more "cause-and-effect" arrows are shown.

Figure 40 - Timing diagram of transceiver training (9.4-9.5)

9.4.1 C-REVEILLE

C-REVEILLE is a single frequency sinusoid at $f_{C\text{-}REVEILLE}$ = 241.5 kHz, defined as in 9.2.1.3, but with i = 56. $A_{C\text{-}REVEILLE}$ shall be such that the transmit power level is -3.65 dBm for the first 64 symbols, and 24 dB lower for the second 64 symbols.

C-REVEILLE shall be used as an acknowledgment of the detection of R-ACK, and as a transition to C-QUIET3, C-PILOT1 or C-PILOT1A; it shall be transmitted for 128 consecutive symbols without cyclic prefix.

If R-ACK1 was detected earlier and the ATU-C is performing loop timing then the ATU-C shall enter C-QUIET3; If R-ACK1 was detected and the ATU-R is performing loop timing the ATU-C shall enter C-PILOT1A; if R-ACK2 was detected the ATU-C shall enter C-PILOT1.

9.4.2 C-QUIET3

During C-QUIET3, or C-PILOT1 as appropriate, the ATU-C shall measure the aggregate received upstream power on sub-carriers 7-18 of R-REVERB1, and thereby calculate a downstream PSD.

Within 16 symbols after detection of the first symbol of R-REVERB1 the ATU-C shall start a timer: this establishes synchronization of the subsequent transitions between states at ATU-C and ATU-R. After 512 symbols the ATU-C shall go to C-REVERB1. Thus the minimum duration of C-QUIET3 is 512 symbols, but it will exceed this by the round-trip propagation and signal-processing time plus the amount of time required by ATU-R to detect C-QUIET3/C-PILOT1 and respond by transmitting R-REVERB1 (see 9.5.2). The duration of C-QUIET3 shall not exceed 4436 symbols.

C-REVERB1 follows C-QUIET3.

9.4.3 C-PILOT1

C-PILOT1 is a single frequency sinusoid at f_{PILOT1} = 276 kHz defined as in 9.3.1.2, but with i = 64.

$A_{\text{C-PILOT1}}$ shall be such that the transmit power level is -3.65 dBm.

The duration of C-PILOT1 shall be defined in the same way as that of C-QUIET3. The duration of C-PILOT1 can be up to 4436 symbols - it’s exact length depends on the length of R-QUIET2.

C-REVERB1 follows C-PILOT1.

9.4.4 C-PILOT1A

Within 16 symbols of detection after the first symbol of R-REVERB1 the ATU-C shall start a timer (this establishes synchronization of the subsequent transitions between states at the ATU-C and ATU-R) and shall proceed to C-QUIET3A.

An ATU-C implementation which would like to know that an ATU-R will acquire pilot lock prior to the start of R-REVERB1 can detect the length of R-QUIET2.

C-PILOT1A is the same transmitted signal as C-PILOT1 (9.4.3). The duration of C-PILOT1A can be up to 4000 symbols - it’s exact length depends on the length of R-QUIET2.

C-QUIET3A follows C-PILOT1A

9.4.5 C-QUIET3A

Within 512 to 516 symbols after the first symbol of R-REVERB1, the ATU-C shall go to C-REVERB1. Thus the minimum duration of C-QUIET3A is 512-16 (496) symbols, the maximum is 516 symbols. The total duration of C-QUIET3A and C-PILOT1A is a minimum of 512 symbols, but it will exceed this (up to a maximum duration of 4436 symbols) by the round trip propogation and signal processing time plus the amount of time required by ATU-R to detect C-PILOT1A and respond by transmitting R-REVERB1.

C-REVERB1 follows C-QUIET3A.

9.4.6 C-REVERB1

C-REVERB1 is a signal that allows the ATU-R receiver to adjust its automatic gain control (AGC) to an appropriate level. The data pattern used in C-REVERB1 shall be the pseudo-random downstream sequence (PRD), d_n for n = 1 to 512, defined in 6.11.3 and repeated here for convenience:

$d_n = 1$ for n = 1 to 9

$d_n = d_{n-4} \oplus d_{n-9}$ for n =10 to 512

The bits shall be used as follows: the first pair of bits (d_1 and d_2) is used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs are used to define the X_i and Y_i. for i = 1 to 255 as defined in Table 16. Although data bits are defined for all the sub-carriers, the sub-carriers actually transmitted during C-REVERB1 start from a vendor discretionary sub-carrier index (see 6.15.1). No gain scaling shall be applied to any sub-carrier.

NOTES

1. The period of PRD is only 511 bits, so $d_{512} = d_1$.
2. The d_1 to d_9 shall be re-initialized for each symbol, so each symbol of C-REVERB1 uses the same data.

Bits 129 and 130, which modulate the pilot carrier (i = 64), shall be overwritten by the data {0,0}: generating the {+,+} constellation point.

The nominal transmit PSD for C-REVERB1 is -40 dBm/Hz (i.e., -3.65 dBm total transmit power in any 4.3125 kHz sliding window over the used passband). If, however, the total received upstream power on sub-carriers 7-18 is greater than 3 dBm, then the PSD for C-REVERB1 and all subsequent downstream signals shall be as shown in Table 26. The received upstream power measurement shall be performed with an accuracy of ± 1 dB or better.

Table 26 - Power cut-back: downstream PSD as a function of upstream received power

Upstream received power (dBm)	< 3	< 4	< 5	< 6	< 7	< 8	< 9
Max downstream PSD (dBm/Hz)	-40	-42	-44	-46	-48	-50	-52

This chosen level shall become the reference level for all subsequent gain calculations.

The duration of C-REVERB1 is 512 (repeating) symbols without cyclic prefix. If loop timing is performed at the ATU-C and the R-ACK1 was detected earlier the ATU-C shall then enter C-QUIET4; if loop timing is performed at the ATU-R or R-ACK2 was detected it shall enter C-PILOT2.

9.4.7 C-QUIET4

The duration of C-QUIET4 is 3072 symbols. C-ECT follows C-QUIET4.

9.4.8 C-PILOT2

The C-PILOT2 signal is the same as C-PILOT1; the duration is 3072 symbols.

9.4.9 C-ECT

C-ECT is a vendor-defined signal that is used to train the echo canceller at ATU-C for EC implementations. Vendors of FDM versions have complete freedom to define their C-ECT signal. The duration of C-ECT, however, is fixed at 512 symbols. The receiver at ATU-R should ignore this signal. C-REVERB2 follows C-ECT.

NOTE - The level of the ADSL signal in the frequency band from 0 to about 10 kHz that leaks through the POTS low-pass filter is tightly limited (see Annex E). Therefore it is recommended that sub-carriers 1-4 not be used for C-ECT, or, at least, that they be transmitted at a much lower level.

9.4.10 C-REVERB2

C-REVERB2 is a signal that allows the ATU-R receiver to perform synchronization and to train any receiver equalizer. C-REVERB2 is the same as C-REVERB1 (see 9.4.6). The duration of C-REVERB2 is 1536 (repeating) symbols without cyclic prefix. If the R-ACK1 was detected earlier the ATU-C shall enter C-QUIET5; if R-ACK2 was detected it shall enter C-PILOT3

9.4.11 C-QUIET5

The duration of C-QUIET5 is 512 symbols. C-REVERB3 follows C-QUIET5.

9.4.12 C-PILOT3

C-PILOT3 signal is the same as C-PILOT1 (9.4.3). The duration of C-PILOT3 is 512 symbols. C-REVERB3 follows C-PILOT3.

9.4.13 C-REVERB3

C-REVERB3 is a second training signal, which allows the ATU-R receiver to perform or maintain synchronization and to further train any receiver equalizer. C-REVERB3 is the same as C-REVERB2 (see 9.4.10). The duration of C-REVERB3 is 1024 (repeating) symbols without cyclic prefix. This is the last segment of transceiver training. C-SEGUE1 follows immediately.

9.5 Transceiver training - ATU-R

9.5.1 R-QUIET2

The minimum duration of R-QUIET2 is 128 DMT symbols. The ATU-R shall progress to R-REVERB1 only after it has detected all of C-REVEILLE and any part of the following C-QUIET3/3A or C-PILOT1/1A that is needed for reliable detection. If the ATU-R does not detect both signals within 4000 symbols it shall reset to R-ACT-REQ.

The ATU-R may optionally extend the duration of R-QUIET2 to a maximum duration of 4000 symbols. An ANSI T1.413 Issue 2 ATU-C shall support a maximum duration of R-QUIET2 of 4000 symbols. An ATU-R which extends R-QUIET2 and detects an ATU-C timeout shall reset to R-ACT-REQ and shall subsequently ensure R-QUIET2 has a duration less than or equal to 256 symbols.

An ATU-R that extends R-QUIET2, to at least 1024 symbols, indicates by so doing that it will perform pilot acquisition prior to sending R-REVERB1. An R-QUIET2 duration of ≤ 256 symbols indicates that it will not perform pilot acquistion prior to sending R-REVERB1.

NOTES

1. The delay in the ATU-R in going from C-QUIET2 to R-REVERB1 is to allow the possibility that the ATU-R may fully synchronize its time base before sending R-REVERB1.

2. It has been recognized that the extension of the R-QUIET2 beyond 256 symbols may create a backward compatability issue with Issue 1 ATU-C implementations. Therefore an ATU-R that extends R-QUIET2 beyond 256 symbols shall be capable of detecting a time-out of an Issue 1 ATU-C which can not accommodate an extended R-QUIET2.

9.5.2 R-REVERB1

R-REVERB1 is used to allow the ATU-C to

– measure the upstream wideband power in order to adjust the ATU-C transmit power level;

– adjust its receiver gain control;

– synchronize its receiver and train its equalizer.

The data pattern used in R-REVERB1 is the pseudo-random upstream sequence PRU defined in 7.11.3 and repeated here for convenience:

$d_n = 1$ for $n = 1$ to 6

$d_n = d_{n-5} \oplus d_{n-6}$ for $n = 7$ to 64

The bits shall be used as follows: the first pair of bits (d_1 and d_2) is used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs are used to define the X_i and Y_i. for $i = 1$ to 31 as defined for C-REVERB1 in Table 16. Although data bits are defined for all the sub-carriers, the sub-carriers actually transmitted during R-REVERB1 start from a vendor discretionary sub-carrier index (see 7.15.1). No gain scaling shall be applied to any sub-carrier.

NOTES

1. The period of PRD is only 63 bits, so $d_{64} = d_1$.

2. The d_1 to d_6 shall be re-initialized for each symbol, so each symbol of R-REVERB1 uses the same data.

Bits 33 and 34, which modulate the pilot carrier (i = 16), are overwritten by the data {0,0}: generating the {+, +} constellation point.

The nominal transmit PSD for R-REVERB1 and all subsequent upstream signals is -38 dBm/Hz (i.e., -1.65 dBm total transmit power in any 4.3125 kHz sliding window over the used passband).

R-REVERB1 is a periodic signal, without cyclic prefix, that is transmitted consecutively for 4096 symbols. The first 512 symbols coincide with C-QUIET3 or C-PILOT1 signal in time, the second 512 symbols coincide with C-REVERB1, and the last 3072 symbols coincide with C-QUIET4 or C-PILOT2.

If C-ACT1 or C-ACT2 was detected earlier the ATU-R shall enter R-QUIET3 immediately after R-REVERB1; if C-ACT3 or C-ACT4 was detected the ATU-R may enter R-PILOT1 or R-QUIET3 at the vendor's discretion.

9.5.3 R-QUIET3

The duration of R-QUIET3 is 2048 symbols, of which the first 512 symbols coincide with C-ECT in time, and the next 1536 symbols coincide with C-REVERB2. The final symbol of R-QUIET3 may be shortened by any number of samples that is an integer multiple of four to accommodate transmitter to receiver frame alignment. R-ECT immediately follows R-QUIET3.

9.5.4 R-PILOT1

R-PILOT1 is a single frequency sinusoid at $f_{R\text{-}PILOT1}$ = 69 kHz, defined as in 9.2.1.3 but with i = 16 and $A_{R\text{-}PILOT1}$ shall be such that the transmit power level is -1.65 dBm.

The nominal duration of R-PILOT1 is the same as that of R-QUIET3, but the final symbol may be shortened by any number of samples that is an integer multiple of four in order to accommodate transmitter to receiver frame alignment. R-ECT immediately follows R-PILOT1.

9.5.5 R-ECT

R-ECT, similar to C-ECT, is a vendor-defined signal that may be used to train an echo canceller at ATU-R. Vendors of FDM versions have absolute freedom to define R-ECT signal. The duration of R-ECT, however, is fixed at 512 DMT symbols. The receiver at ATU-C ignores this signal. R-REVERB2 follows R-ECT.

NOTE - The level of the ADSL signal in the frequency band from 0 to about 10 kHz that leaks through the POTS low-pass filter is tightly limited (see Annex E). Therefore it is recommended that sub-carriers 1-4 not be used for R-ECT, or, at least, that they be transmitted at a much lower level.

9.5.6 R-REVERB2

The signal R-REVERB2 is the same as R-REVERB1 (see 9.5.2); it can be used by ATU-C to perform timing recovery and receiver equalizer training. The duration of R-REVERB2 shall be between 1024 and 1056 symbols. This signal is the last segment of transceiver training. ATU-R then begins channel analysis and starts transmitting R-SEGUE1.

9.6 Channel analysis (ATU-C)

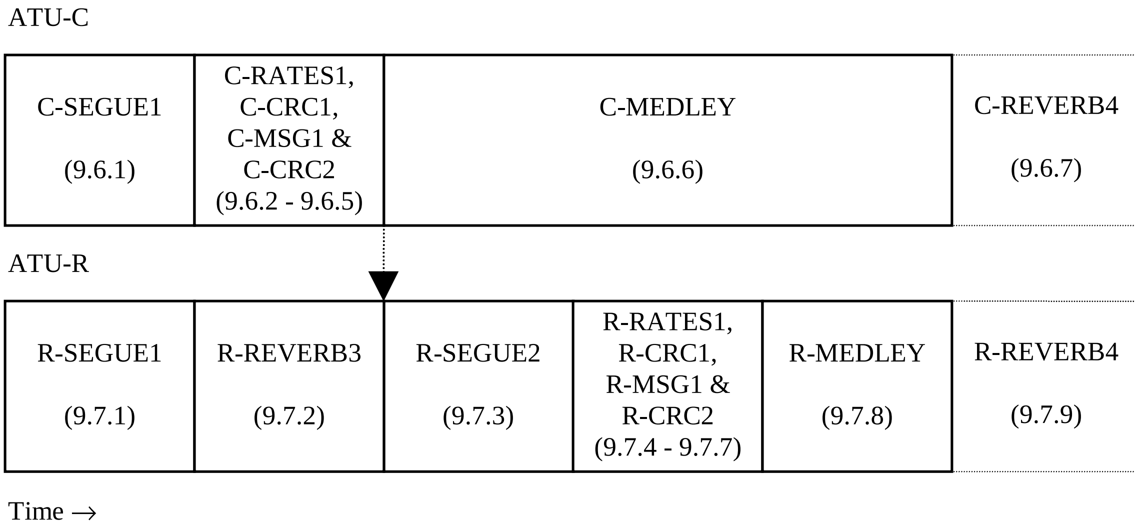


Figure 41 - Timing diagram of channel analysis (9.6-9.7)

During channel analysis the synchronization between ATU-C and ATU-R may be broken during R-REVERB3, which has an indefinite duration; this potential timeout is described in 9.7.2. Furthermore, if during channel analysis any CRC check sum indicates an error in any of the control data, this shall trigger a reset to C-QUIET1.

9.6.1 C-SEGUE1

Except for the pilot tone, C-SEGUE1 shall be generated from a tone-by-tone 180 degree phase reversal of C-REVERB1 (i.e. + maps to -, and - maps to +, for each of the 4-QAM signal constellation). The duration of C-SEGUE1 is 10 (repeating) symbol periods. Following C-SEGUE1, ATU-C enters state C-RATES1.

9.6.2 C-RATES1

C-RATES1 is the first ATU-C signal for which a cyclic prefix (defined in 6.12) is used. The purpose of C-RATES1 is to transmit four options for data rates and formats to the ATU-R. Each option consists of three fields:

– B_F lists the number of bytes in the fast buffer for each of AS0, AS1, AS2, AS3, LS0, LS1, LS2, LS0 (upstream), LS1 (upstream), LS2 (upstream) channels, in that order; B_F has a total of 80 (= 10×8) bits. The first 8 bits of B_F specify the number of bytes in AS0, the second 8 bits specify the number of bytes in AS1, and so on. Each byte of B_F is transmitted with least significant bit first;

– B_I similarly lists the number of bytes in the interleaved buffer;

– $\{RS_F, RS_I, S, D, FS(\text{LS2})\}$ is a ten-byte quantity comprising (one byte each)

– the RS_F field, containing RS_F, the number of parity bytes per symbol in the downstream fast buffer, with $0 \le RS_F \le 63$ and RS_F equal to R_F (see Figure 13);

– the RS_I field, containing the value of RS_I , the number of parity bytes per symbol in the downstream interleave buffer, with $0 \le RS_I \le 63$ and RS_I equal to R_I/ S (see Figure 14);

– the S field, containing the value of S, the number of symbols per codeword (downstream), with $0 \le S \le 63$;

– the D field, containing the downstream interleave depth in codewords, with $0 \le D \le 128$;

– the FS(LS2) field is a field of eight zeros;

– the same five quantities $\{RS_F, RS_I, S, D, FS(\text{LS2})\}$ in the upstream direction (one byte each, in that order).

The four options are transmitted in order of decreasing preference. C-RATES 1 is preceded by a 4-byte prefix of {01010101 01010101 01010101 01010101}. Table 27 summarizes C-RATES1.

Table 27 - C-RATES1

		Option 1			Option 2			Option 3			Option 4		
	Prefix	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*
Nr of bytes	4	10	10	10	10	10	10	10	10	10	10	10	10

Only one bit of information is transmitted in each symbol of C-RATES1: a zero bit is encoded to one symbol of C-REVERB1 and a one bit is encoded to one symbol of C-SEGUE1. Since there are a total of 992 bits of C-RATES1 information, the duration of C-RATES1 is 992 symbols. The 992 bits are to be transmitted in the order shown in Table 27 , with the least significant bit first. That is, the least significant bit of option 1, B_F, is to be transmitted during the 33rd symbol of C-RATES1, after the prefix. Following C-RATES1, the ATU-C shall enter state C-CRC1.

9.6.3 C-CRC1

C-CRC1 is a cyclic redundancy check for detection of errors in the reception of C-RATES1 at the ATU-R. The CRC bits are computed from the C-RATES1 bits using the equation:

$c(D) = a(D)\, D^{16}$ modulo g(D),

where

$a(D) = a_0\, D^{959} + a_1\, D^{958} \ldots + a_{959}$ is the message polynomial formed from the 960 bits of C-RATES1, with a_0 the least significant bit of the first byte of C-RATES1 (i.e., option 1 B_F);

$g(D) = D^{16} + D^{12} + D^5 + 1$ is the CRC generator polynomial, and

$c(D) = c_0 D^{15} + c_1 D^{14} \ldots.. + c_{14} D + c_{15}$ is the CRC check polynomial.

The 16 bits c_0-c_{15} are transmitted (c_0 first and c_{15} last) in 16 symbol periods using the method described in 9.6.2. Following C-CRC1, the ATU-C shall enter state C-MSGS1.

9.6.4 C-MSGS1

C-MSGS1 transmits a 48-bit message signal to the ATU-R. This message includes vendor identification, ATU-C transmit power level used, trellis coding option, echo cancelling option, etc. The message, *m*, is defined by:

$m = \{m_{47}, m_{46}, \ldots\ldots m_1, m_0\}$

with m_0 being transmitted first. The message components are defined in the following sub-clauses, and their assigned positions within the composite message, *m,* are defined in Table 28.

A total of 48 symbol periods are used to communicate the 48-bit message, using the encoding method described in 9.6.2. Following C-MSGS1, the ATU-C shall enter signaling state C-CRC2.

Table 28 - Assignment of 48 bits of C-MSGS1

Suffix(ces) of m_i	**Parameter**
47-44 (see note 1)	Minimum required SNR margin; see note 2
43-28	Vendor identification
27-26	Reserved for future use; see note 3
25-23	T1.413 revision number
22-18	Vendor revision number
17	Trellis coding option
16	Echo canceling option
15	Expanded exchange sequence
14	Reserved for future use; see note 3
13-12	Set to {00}; see note 4
11	Network timing reference
10-9	Framing structure
8-6	Transmit PSD during initialization
5-4	Reserved for future use; see note 3
3-0	Maximum numbers of bits per sub-carrier supported

NOTES

1. Within the separate fields the least significant bits have the lowest subscripts.
2. A positive number of dB; binary coded 0-15 dB.
3. All bits “reserved for future use” shall be set to 0 until defined.
4. Power boost is not allowed in Issue 2 transceivers; therefore the {00}, which indicated -40 dBm/Hz in Issue 1 transceivers, shall be used.

9.6.4.1 Minimum required SNR margin - bits 47 - 44

Binary coded 0 to 15 dB

9.6.4.2 Vendor identification - bits 43 - 28

The vendor ID is coded in binary. The currently assigned vendor ID’s are listed in Annex D. Others may be added in the future.

9.6.4.3 T1.413 revision number - bits 25 - 23

For ATU’s complying with ANSI T1.413 Issue 2, the revision number shall be coded {001}.

NOTE - This is consistent with the three most significant bits of the revision number of a ANSI T1.413 Issue 1 ATU being set to {000}.

9.6.4.4 Vendor revision number - Bits 22-18

To facilitate upgrades in the future, five bits are reserved to allow any vendor to include a revision number for each unit. When an ATU-C connects to an ATU-R with the same vendor ID, this may serve to simplify upgrades, diagnostics, maintenance, etc.

9.6.4.5 Trellis coding option - Bit 17

m_{17} = 0 indicates no trellis coding capability, m_{17} = 1 indicates trellis coding capability.

9.6.4.6 Echo cancellation option - Bit 16

m_{16} = 0 indicates no echo cancellation, m_{16} = 1 indicates echo cancellation.

9.6.4.7 Expanded exchange sequence - Bit 15

The extended exchange sequence shall be enabled (bit 15 = 1). The extended exchange sequence shall be used if and only if both ATU's indicate bit 15 = 1.

9.6.4.8 NTR - Bit 11

m_{11} = 1 indicates that the ATU-C will use indicator bits ib23 to ib 20 as defined in 6.3.2.

9.6.4.9 Framing structure - Bits 10,9

Indicates the highest framing structure supported by the ATU-C (see 6.4). The lowest framing structure indicated by the ATU-C or ATU-R shall be used.

9.6.4.10 Transmit PSD during initialization - Bits 8,7,6

The ATU-C shall report the level of C-REVERB1 chosen as a result of the calculation described in 9.4.6. The encoding rules for $m_{8,}$ $m_{7,}$ m_6 are shown in Table 29.

Table 29 - C-MSG1 encoding rules for transmit PSD during C-REVERB1

m_8	m_7	m_6	**PSD** dBm/Hz
1	1	1	-40
1	1	0	-42
1	0	1	-44
1	0	0	-46
0	1	1	-48
0	1	0	-50
0	0	1	-52

9.6.4.11 Maximum numbers of bits per sub-carrier supported - Bits 3-0

The $N_{downmax}$ (transmit) capability shall be binary encoded onto {$m_{3\ ...}$ m_0} (e.g., 1101 = 13)

The maximum number of bits for the upstream data, N_{upmax}, that the ATU-C receiver can support need not be signaled to the ATU-R; it will be implicit in the bits and gains message, C-B&G, which is transmitted after channel analysis.

9.6.5 C-CRC2

C-CRC2 is a cyclic redundancy check for detection of errors in the reception of C-MSGS1 at the ATU-R. The CRC generator polynomial is as defined in 9.6.3. The CRC message polynomial is as constructed in 9.6.3, with m_0 corresponding to a_0 and m_{47} corresponding to a_{47}. The CRC check polynomial is generated in the same way as defined in 9.6.3. These 16 bits are transmitted in 16 symbol periods using the method described in 9.6.3. Following C-CRC2, the ATU-C shall enter signaling state C-MEDLEY.

9.6.6 C-MEDLEY

C-MEDLEY is a wideband pseudo-random signal used for estimation at the ATU-R of the downstream SNR. The data to be transmitted are derived from the pseudo-random sequence, PRD, and modulated as defined in 6.11.3 and 9.4.6. In contrast to C-REVERB1, however, the cyclic prefix is used and the data sequence continues from one symbol to the next (i.e., d_1 to d_9 are not re-initialized for each symbol); since PRD is of length 511, and 512 bits are used for each symbol, the sub-carrier vector for C-MEDLEY therefore changes from one symbol period to the next. The pilot sub-carrier is over-written by the {+,+} constellation point.

Although data bits are defined for all the sub-carriers, the sub-carriers actually transmitted during C-MEDLEY shall be the same as or a subset of those transmitted during C-REVERB1 (see 6.15.1).

C-MEDLEY is transmitted for 16384 symbol periods. Following C-MEDLEY the ATU-C shall enter the state C-REVERB4.

9.6.7 C-REVERB4

C-REVERB4 is similar to C-REVERB2 (see 9.4.10), the only difference being the addition of a cyclic prefix on every symbol, and a maximum duration of 6000 symbols. C-REVERB4 continues into the exchange procedure, and its duration is not fixed. The timeout features of C-REVERB4 are defined in 9.8.1

9.7 Channel analysis (ATU-R)

During channel analysis there are two situations where the ATU-R shall reset itself to R-ACT-REQ: a timeout and a detected error in the received control data. A timeout occurs if the time in R-REVERB3 exceeds the limit of 4000 symbols. Also, if any C-CRC checksum indicates there is an error in the received control data, then it shall trigger a reset to R-ACT-REQ.

9.7.1 R-SEGUE1

Except for the pilot tone, R-SEGUE1 is generated from a tone-by-tone 180 degree phase reversal of R-REVERB1 (i.e. + maps to -, and - maps to +, for each of the 4-QAM signal constellation). The duration of R-SEGUE1 is 10 symbol periods. Following R-SEGUE1 the ATU-R shall enter state R-REVERB3.

9.7.2 R-REVERB3

R-REVERB3 is similar to R-REVERB1 (see 9.5.2); the only difference is that R-REVERB3 is the first ATU-R signal with the addition of a cyclic prefix to every symbol (defined in 7.12). The duration of R-REVERB3 is not fixed but has a maximum of 4000 symbols. If C-CRC2 is not detected within 4000 symbols the ATU-R shall timeout and reset to R-ACT-REQ. After detection of C-RATES1 - C-CRC2, the ATU-R shall continue to send R-REVERB3 for 20 additional symbols before entering R-SEGUE2.

9.7.3 R-SEGUE2

The signal R-SEGUE2 is similar to R-SEGUE1 (see 9.7.1); the only difference is the addition of the cyclic prefix. Following R-SEGUE2 the ATU-R shall enter state R-RATES1.

9.7.4 R-RATES1

Table 30 - R-RATES1

		Option 1			**Option 2**			**Option 3**			**Option 4**		
	Prefix	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*
Nr of bytes	4	3	3	5	3	3	5	3	3	5	3	3	5

The purpose of R-RATES1 for the upstream channel is the same as that of C-RATES1 for the downstream channel (see 9.6.2). Each option consists of three fields:

- B_F lists the number of bytes in the fast buffer for each of LS0, LS1, LS2, in that order; B_F has a total of 24 (= 3 $\times$ 8) bits. The first 8 bits of B_F specify the number of bytes in LS0, the second 8 bits specify the number of bytes in LS1, and so on. Each byte of B_F is transmitted with least significant bit first;
- B_I similarly lists the number of bytes in the interleaved buffer;
- {RS_F, RS_I, *S, D, FS*(LS2)} is a five-byte quantity comprising;
- RS_F, the number of parity bytes per symbol in the fast buffer (upstream);
- RS_I, the number of parity bytes per symbol in the interleave buffer (upstream);
- *S*, the number of symbols per codeword (upstream);
- *D*, the interleave depth (upstream) in codewords for the interleave buffer;
- the *FS*(LS2) is a field of eight zeros.

The four options are transmitted in order of decreasing preference. For the present system, ATU-C has control over all the data rates, so R-RATES1 is copied from the appropriate fields of C-RATES1.

Only one bit of information is transmitted during each symbol period of R-RATES1: a zero bit is encoded to one symbol of R-REVERB1 and a one bit is encoded to one symbol of R-SEGUE1 (with addition of cyclic prefix). Since there are a total of 384 bits of RATES1 information, the length of R-RATES1 is 384 symbols. The 384 bits are to be transmitted in the order shown in Table 30 , with the least significant bit first. That is, the least significant bit of option 1, B_F (see Table 30), is to be transmitted during the 33rd symbol of R-RATES1, after the prefix. Following R-RATES1, the ATU-R shall enter state R-CRC1.

9.7.5 R-CRC1

R-CRC1 is a cyclic redundancy check intended for detection of an error in the reception of R-RATES1 at the ATU-C. The CRC polynomial c(D) and generator polynomial g(D) are the same as for C-CRC1 (see 9.6.3). The 16 bits c_0 to c_{15} are transmitted (c_0 first and c_{15} last) in 16 symbol periods using the same method as R-RATES1 (see 9.7.4). Following R-CRC1, the ATU-R shall enter state R-MSGS1.

9.7.6 R-MSGS1

R-MSGS1 transmits a 48-bit message signal to the ATU-C. This message includes vendor identification, trellis coding option, echo cancelling option, etc. The message, *m*, is defined by:

$$m = \{m_{47}, m_{46}, \ldots\ldots , m_1, m_0\}$$

with m_0, the least significant bit, being transmitted first. The message components are defined in the following subclauses, and their assigned positions within the composite message, *m,* are defined in Table 31.

A total of 48 symbol periods are used to communicate the 48 bit message, using the encoding method described in 9.7.4. Following R-MSGS1, the ATU-R shall enter signaling state R-CRC2.

Table 31 - Assignment of 48 bits of R-MSGS1

Suffix(ces) of m_i	**Parameter**
47-44	Reserved for future use
43-28	Vendor identification
27-26	Reserved for future use
25-23	T1.413 revision number
22-18	Vendor revision number
17	Trellis coding option
16	Echo cancelling option
15	Expanded exchange sequence
14	Support of higher bit rates
13	Support of dual latency downstream
12	Support of dual latency upstream
11	Network timing reference
10-9	Framing structure
8-4	Reserved for future use
3-0	Maximum numbers of bits per sub-carrier supported

NOTES

1. All bits “reserved for future use” shall be set to 0 until defined.
2. Within the separate fields the least significant bits have the lowest subscripts.
3. Bits 25-18 shall be copied in the Revision Number eoc register (see 8.1.4).

9.7.6.1 Vendor identification - Bits 43 - 28

The vendor ID is coded in binary. The currently assigned vendor IDs are listed in Annex D. Others may be added in the future.

9.7.6.2 T1.413 revision number- bits 25 - 23

For ATUs complying with ANSI T1.413 Issue 2, the revision number shall be coded {001}.

NOTE - This is consistent with the three most significant bits of the version number of a ANSI T1.413 Issue 1 ATU being set to {000}.

9.7.6.3 Vendor revision number- Bits 22-18

The version number is encoded as defined in 9.6.4.4.

9.7.6.4 Trellis coding option - Bit 17

m_{17} = 0 indicates no trellis coding capability; m_{17} = 1 indicates trellis coding capability.

9.7.6.5 Echo cancellation option - Bit 16

m_{16} = 0 indicates no echo cancellation; m_{16} = 1 indicates echo cancellation.

9.7.6.6 Extended Exchange Sequence - Bit 15

The extended exchange sequence shall be enabled (bit 15 = 1). The extended exchange sequence shall be used if and only if both ATUs indicate bit 15 = 1.

9.7.6.7 Support of higher bit rates - Bit 14

m_{14} = 1 indicates the ATU-R supports higher bit rates option (i.e., S=1/2 with 2 RS codewords per DMT symbol); m_{14} = 0 indicates the ATU-R does not support this option.

9.7.6.8 Support of dual latency downstream - Bit 13

m_{13} = 1 indicates the ATU-R supports dual latency downstream; m_{13} = 0 indicates the ATU-R does not support dual latency downstream.

9.7.6.9 Support of dual latency upstream - Bit 12

m_{12} = 1 indicates the ATU-R supports dual latency upstream; m_{12} = 0 indicates the ATU-R does not support dual latency upstream.

9.7.6.10 Network timing reference - Bit 11

m_{11} = 1 indicates the ATU-R supports reconstruction of the network timing reference from the downstream indicator bits 23-20.

9.7.6.11 Framing structure - Bits 10-9

Indicates the highest framing structure supported by the ATU-R (see 7.4). The lowest framing structure indicated by the ATU-C or ATU-R shall be used.

9.7.6.12 Maximum numbers of bits per sub-carrier supported - Bits 3-0

The N_{upmax} (transmit) capability is encoded onto $\{m_3 \ldots m_0\}$ with a conventional binary representation (e.g., 1101 = 13)

NOTE - The maximum number of bits for the downstream data, $N_{downmax}$, that the ATU-R receiver can support need not be signaled to the ATU-C; it will be implicit in the bits and gains message, R-B&G, which is transmitted after channel analysis.

9.7.7 R-CRC2

R-CRC2 is a cyclic redundancy check for detection of errors in the reception of R-MSGS1 at the ATU-C. The CRC generator polynomial is as defined in 9.7.5. The CRC message polynomial is as constructed in 9.7.5, with m_0 corresponding to a_0 and m_{47} corresponding to a_{47}. The CRC check polynomial is generated in exactly the same way as described in 9.7.5. These 16 bits are transmitted in 16 symbol periods using the method described in 9.7.5. Following R-CRC2, the ATU-R shall enter state R-MEDLEY.

9.7.8 R-MEDLEY

R-MEDLEY is a wideband pseudo-random signal used for estimation of the upstream SNR at the ATU-C. The data to be transmitted are derived from the pseudo-random sequence PRU defined in 9.5.2. In contrast to R-REVERB1, however, the cyclic prefix is used and the data sequence continues from one symbol to the next (i.e., d_1-d_6 are not re-initialized for each symbol). Because the sequence is of length 63, and 64 bits are used for each symbol, the sub-carrier vector for R-MEDLEY changes from one symbol period to the next. The pilot sub-carrier is over-written by the {+,+} constellation point.

Although data bits are defined for all the sub-carriers, the sub-carriers actually transmitted during R-MEDLEY shall be the same as or a subset of those transmitted during R-REVERB1 (see 6.15.1).

R-MEDLEY is transmitted for 16384 symbol periods. Following R-MEDLEY the ATU-R enters signaling state R-REVERB4.

9.7.9 R-REVERB4

R-REVERB4 is the same as R-REVERB3 (see 9.7.2). The duration of R-REVERB4 is 128 symbols. This signal marks the end of channel analysis, and R-SEGUE3 immediately follows R-REVERB4.

9.8 Exchange - ATU-C

The timing diagram of exchange is shown in Figure 42. The full diagram shows the expanded exchange sequence (EES), which shall be used if both the ATU-C and ATU-R have set bit 15 to 1 in C-MSG1 and R-MSG1 respectively. The by-pass transitions labeled “SES” show the transitions of the short exchange sequence, which shall be used if the ATU-C or the ATU-R set bit 15 to 0 in C-MSG1 or R-MSG1 respectively. The latter occurs only if either ATU complies with ANSI T1.413 Issue 1.

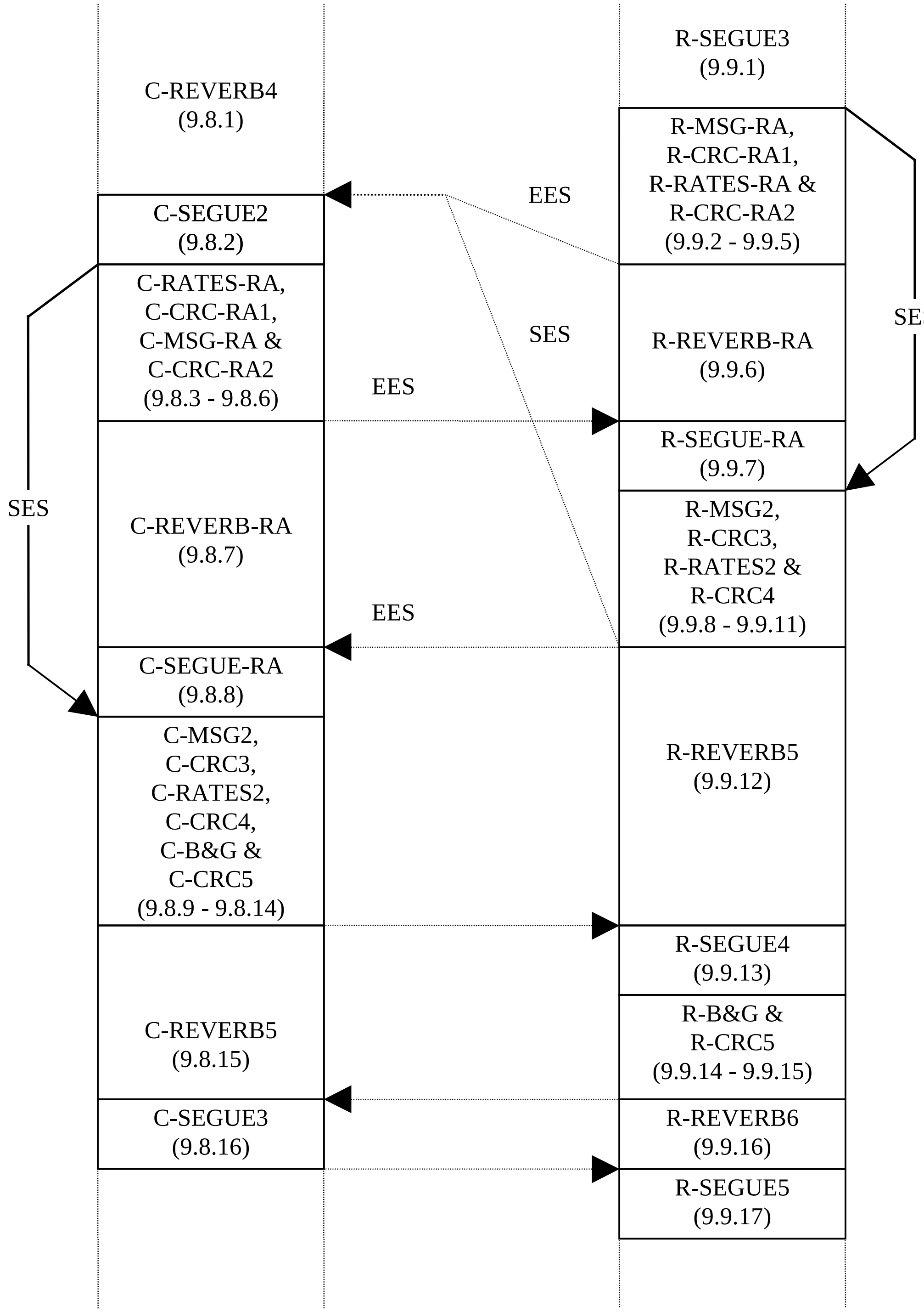


Figure 42 - Timing diagram of exchange

During exchange there are two events that shall cause the ATU-C to reset to C-QUIET1: timeouts and error detection by a CRC checksum. The exchange procedure is partly synchronized between ATU-C and ATU-R, and partly interactive. During the interactive part (C-REVERB4, C-REVERB-RA and C-REVERB5) a timeout shall occur when the time in the C-REVERB4 state exceeds 6000 symbols or when the time in C-REVERB-RA or C-REVERB5 state exceeds 4000 symbols.

9.8.1 C-REVERB4

If the ATU-C does not detect R-CRC4 (or R-CRC-RA2 if the extended exchange sequence is used) within 6000 symbols, it shall timeout and reset to C-QUIET1. After detection of R-SEGUE3 - R-CRC4 (or R-SEGUE3 - R-CRC-RA2 if the extended exchange sequence is used), the ATU-C shall continue to transmit C-REVERB4 for another 80 symbols before progressing to state C-SEGUE2.

9.8.2 C-SEGUE2

The signal C-SEGUE2 is the same as C-SEGUE1 (see 9.6.1), the only difference is the addition of the cyclic prefix. The duration of C-SEGUE2 is 10 symbol periods. Following C-SEGUE2:

– if the expanded exchange sequence is being used the ATU-C shall enter state C-RATES-RA to begin a second exchange of rates;

– if the expanded exchange sequence is not being used the ATU-C shall by-pass the “rate adaptation” sequence and enter state C-MSGS2 (see 9.8.9).

9.8.3 C-RATES-RA

C-RATES-RA is used to send four new options for transport configuration for both upstream and downstream.

NOTE - These options will, in general, be closer to the optimum bit rate for the the channel than those in C-RATES1, and should be based on the channel information received in R-MSG-RA.

The format of C-RATES-RA is the same as that of C-RATES1, except that the 4-byte prefix (55 55 55 55 hex) is not transmitted, and the signal is transmitted 8 bits per symbol, as defined for C-MSG2 (see 9.8.9) The duration of C-RATES-RA is 120 symbols.

The {RS_F, RS_I, S, D, FS(LS2)} shall have an extended syntax (compared to C-RATES1). It is a ten-byte quantity comprising (one byte each)

– the RS_F field, containing RS_F, the number of parity bytes per symbol in the downstream fast buffer in bits 5 (msb) to 0 (lsb) with $RS_F = R_F$ (see Figure 13);

– the RS_I field, containing

– the value of RS_I , the number of parity bytes per symbol in the downstream interleave buffer, in bits 5 (msb) to 0 (lsb), with $RS_I = R_I / S$ (see Figure 14); and;

– the most significant bit B_8 of B_I (AS0), the number of payload bytes in the AS0 bearer channel in the downstream interleave buffer, in bit 7 (see note 1);

– the S field, containing

– the value of S, the number of downstream symbols per codeword (downstream) in bits 5 (msb) to 0 (lsb) (see note 2);

– the two most significant bits, D_9 and D_8 , of the downstream interleave depth in codewords, D , in bits 7 and 6 (see note 3);

– the D field, containing the eight least significant bits D_7 to D_0 of the downstream interleave depth in codewords;

– the FS(LS2) field, containing eight zero bits;

– the same five quantities {RS_F, RS_I, S, D, FS(LS2)} in the upstream direction (one-byte each, in that order).

NOTES

1. In order to support data rates greater than 8 Mbit/s the B_I(AS0) field, which was only eight bits in ANSI T1.413 Issue 1, has been expanded to nine bits, with B_8 being placed in the msb position of the RS_I field as shown in Table 33.

2. The necessity to use S = 1/2 would be indicated by K_I + R_I > 255 (see 6.4.1.2.2 and 6.6.3). Nevertheless, the S field bits 5-0 shall be coded {000000} (unused code in ANSI T1.413 Issue 1) to indicate S = 1/2.

3. In order to support interleave depths greater than 128 the D field, which was eight bits in ANSI T1.413 Issue 1, has been expanded to ten bits (interleave depth D up to 512).

The four options are transmitted in order of decreasing preference. Table 32 summarizes C-RATES-RA and Table 33 summarizes the RRSD fields.

Table 32 - C-RATES-RA

	Option 1			Option 2			Option 3			Option 4		
	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*	B_F	B_I	*RRSD*
Nr of bytes	10	10	10	10	10	10	10	10	10	10	10	10

Table 33 - RRSI fields of C-RATES-RA

	Bit number							
fields	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
RS_F	0	0	msb		value of RS_F			lsb
RS_I	B_8(AS0)	0	msb		value of RS_I			lsb
S	D_9	D_8	msb		value of S			lsb
D	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
FS(LS2)	value of *FS*(LS2) set to {00000000}							

9.8.4 C-CRC-RA1

C-CRC-RA1 is a cyclic redundancy check for detection of errors in the reception of C-RATES-RA1 at the ATU-R. Its relation to C-RATES-RA1 is the same as that of C-CRC3 to C-MSG2 (see 9.8.10). Its 16 bits shall be transmitted in 2 symbols (see 9.8.3). Following C-CRC-RA1, the ATU-C shall enter state C-MSG-RA.

9.8.5 C-MSG-RA

C-MSG-RA is the same in format as C-MSG1; the bit assignment is as shown in Table 34.

Table 34 - Assignment of 48 bits of C-MSGS-RA

Suffix(ces) of m_i	**Parameter**
47-44	New minimum required SNR margin
43-0	Reserved for future use (set to 0; see note)
NOTE - Within the separate fields the least significant bits have the lowest subscripts.	

The 48 bits are transmitted in 6 symbols (see 9.8.9) Following C-MSG-RA the ATU-C shall enter state C-CRC-RA2

9.8.6 C-CRC-RA2

C-CRC-RA2 is a cyclic redundancy check for detection of errors in the reception of C-MSG-RA at the ATU-R. Its relation to C-MSG-RA is the same as that of C-CRC3 to C-MSG2 (see 9.8.10). Its 16 bits shall be transmitted in 2 symbols (see 9.8.5). Following C-CRC-RA2, the ATU-C shall enter state C-REVERB-RA.

9.8.7 C-REVERB-RA

C-REVERB-RA is the same as C-REVERB4. If, however, the ATU-C does not detect R-SEGUE-RA within 4000 symbols it shall timeout and reset to C-QUIET1. After detection of R-CRC4 the ATU-C shall continue to transmit C-REVERB-RA for at least another 80 symbols before moving to state C-SEGUE-RA.

9.8.8 C-SEGUE-RA

C-SEGUE-RA is the same as C-SEGUE2. Following C-SEGUE-RA the ATU-C shall enter state C-MSG2

9.8.9 C-MSGS2

C-MSGS2 transmits a 32-bit message signal to the ATU-R. This message includes the total number of bits per symbol supported, the estimated upstream loop attenuation, and the performance margin with the selected rate option. The message, *m*, is defined by:

$$m = \{m_{31}, m_{30}, \ldots\ldots m_1, m_0\}$$

with m_0 being transmitted first. The message components are defined in the following subclauses, and their assigned positions within the composite message, *m,* are defined in Table 35.

Table 35 - Assignment of 32 bits of C-MSGS2

Suffix(ces) of m_i	**Parameter**
31-26	Estimated average loop attenuation
25-21	Reserved for future use
20-16	Performance margin with selected rate option
15-9	Reserved for future use
8-0	Total number of bits supported

NOTES

1. All bits “reserved for future use” shall be set to 0 until defined.
2. Within the separate fields the least significant bits have the lowest subscripts.

A total of 4 symbol periods are used to communicate the 32 bit message, with 8 bits transmitted on each symbol. Two bits are encoded onto each of the nominal sub-carriers numbered 43 to 46 using the 4-QAM constellation labeling given in 6.11.3 (for the synchronization symbol) and 9.4.6 (for C-REVERB1). The same two bits are also encoded in the same way onto a set of backup carriers, namely, sub-carriers 37 through 40 if the ATU-R has indicated compliancy with ANSI T1.413 Issue 1 and sub-carriers 91 to 94 if the ATU-R has indicated compliancy with ANSI T1.413 Issue 2 (see 9.7.6.2).

The least significant byte of the message is transmitted in the first symbol of C-MSGS2, with the two least significant bits of each byte encoded onto nominal carrier 43 and backup carrier 37 or 91. In addition, the pilot, sub-carrier 64, shall be modulated with the {+,+} constellation point.

Following C-MSGS2, the ATU-C shall enter signaling state C-CRC3.

9.8.9.1 Estimated average upstream loop attenuation

During channel analysis the ATU-C receiver estimates the upstream channel gain of each sub-carrier in preparation for computing the SNR for each sub-carrier; it shall also calculate the average loop attenuation. This attenuation is defined as the difference between the total maximum transmit power (as defined in 7.15.3) and the total received power, rounded to the nearest 0.5 dB.

The attenuation, is encoded into bits 31-26 of C-MSGS2 as the integer binary representation of twice the attenuation (e.g., if the average attenuation is 21.5 dB then $\{m_{31}, \ldots m_{26}\} = 101011$).

9.8.9.2 Performance margin with selected rate option

The ATU-C receiver shall select one of the rates options sent from the ATU-C during C-RATES1 or C-RATES-RA (depending on whether the short or the expanded exchange sequence is used with a satisfactory upstream performance margin. This selected option is encoded in C-RATES2. This margin (rounded to the nearest dB) is encoded into bits 20-16 of C-MSGS2 using a conventional binary representation (e.g., if the margin is 9 dB then $\{m_{20}, \ldots m_{16}\} = 01001$).

9.8.9.3 Total number of bits per symbol supported

The ATU-C receiver shall also calculate the maximum number of bits per symbol that the upstream channel can support with the performance margin defined locally (e.g., over the oam interface) at an error rate of 10^{-7}. This number is encoded into bits 8-0 using a conventional binary representation (e.g., if the maximum number of bits that can be supported is 127 (data rate = 508 kbit/s), $\{m_8, \ldots m_0\} = 001111111$).

9.8.10 C-CRC3

C-CRC3 is a cyclic redundancy check for detection of errors in the reception of C-MSGS2 at the ATU-R. The CRC polynomial c(D) and generator polynomial g(D) are the same as for CRC1, as defined in 9.6.3. These 16 bits shall be transmitted in 2 symbol periods using the method described in 9.8.9. Following C-CRC3, the ATU-C shall enter state C-RATES2.

9.8.11 C-RATES2

C-RATES2 is the reply to R-RATES-RA if the expanded exchange sequence is being used, or to R-RATES1 if it is not. It combines the selected downstream option with the selected upstream option. It thus transmits the final decision on the rates that will be used in both directions.

NOTE - The ATU-C may change the downstream option from that selected in R-RATES2.

The length of C-RATES2 is 8 bits, and the bit pattern for C-RATES2 is shown in Table 36. Other bit patterns that are not specified in Table 36 are reserved for future use. If none of the options requested during C-RATES1 or C-RATES-RA (depending on whether the short or the expanded exchange sequence is used) can be implemented, ATU-C then returns to C-QUIET1 for retraining. One symbol period is used to transmit these 8 bits using the method described in 9.8.9. Following C-RATES2, the ATU-C shall enter signaling state C-CRC4.

Table 36 - Bit pattern for C-RATES2

(Downstream, upstream)	Bit pattern for C-RATES2 (msb first) (see note 1)
(option 1, option 1)	00010001
(option 1, option 2)	00010010
(option 1, option 3)	00010100
(option 1, option 4)	00011000
(option 2, option 1)	00100001
(option 2, option 2)	00100010
(option 2, option 3)	00100100
(option 2, option 4)	00101000
(option 3, option 1)	01000001
(option 3, option 2)	01000010
(option 3, option 3)	01000100
(option 3, option 4)	01001000
(option 4, option 1)	10000001
(option 4, option 2)	10000010
(option 4, option 3)	10000100
(option 4, option 4)	10001000
all options fail (see note 2)	00000000

NOTES

1. All other bit patterns that are not shown are reserved for future use.
2. If it is determined that none of the four options can be implemented with the connection the ATU-C shall return to C-QUIET1 for retraining.

9.8.12 C-CRC4

C-CRC4 is a cyclic redundancy check for detection of errors in the reception of C-RATES2 at the ATU-R. Its relation to C-RATES2 is the same as that of C-CRC3 to C-MSGS2. Its 16 bits shall be transmitted in 2 symbols (see 9.8.11). Following C-CRC4, the ATU-C shall enter state C-B&G.

9.8.13 C-B&G

C-B&G shall be used to transmit to the ATU-R the bits and gains information (i.e., b_1, g_1, b_2, g_2, ... b_{31}, g_{31}), that are to be used on the upstream carriers. b_i indicates the number of bits to be coded by the ATU-R transmitter onto the i-th upstream carrier; g_i indicates the scale factor, relative to the gain that was used for that carrier during the transmission of R-MEDLEY, that shall be applied to the i-th upstream carrier. Because no bits or energy shall be transmitted at dc or one-half the sampling rate, b_0, g_0, b_{32}, and g_{32} shall all be presumed to be zero and shall not be transmitted. Because sub-carrier 16 is reserved as pilot sub-carrier, b_{16} shall be set to 0 and g_{16} shall be set to 1 (see 7.11.1.2).

Each b_i shall be represented as an unsigned 4-bit integer, with a valid b_i value lying in the range of zero to N_{upmax}, the maximum number of bits that the ATU-R is prepared to modulate onto any sub-carrier, which is communicated in R-MSGS1.

Each g_i shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 001.010000000 would instruct the ATU-R to scale the constellation for carrier i, by a gain factor of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during R-MEDLEY.

For sub-carriers on which no data are to be transmitted, and the receiver will never allocate bits (e.g., out-of-band sub-carriers) both b_i and g_i shall be set to zero (0000 and 00000000 0000, respectively). For sub-carriers on which no data are to be currently transmitted, but the receiver may allocate bits later (e.g., as a result of an SNR improvement), the b_i shall be set to zero and the g_i to a value in the 0.75 to 1.33 range (000.110000000 to 001.010101011).

A total of 62 bytes of bits and gains information is to be transmitted during C-B&G, and a total of 62 symbol periods is required, using the method described in 9.8.9. Following C-B&G the ATU-C shall enter state C-CRC5.

The C-B&G information shall be mapped in a 496-bit message m defined by:

$$m = \{m_{495}, m_{494}, \ldots, m_1, m_0\} = \{ g_{31}, b_{31}, \ldots, g_1, b_1\}$$

With the msb of b_i and g_i in the higher m index and m_0 being transmitted first. The message m shall be transmitted in 62 symbols, using the transmission method as described in 9.8.9.

Following C-B&G, the ATU-C shall enter state C-CRC5.

9.8.14 C-CRC5

C-CRC5 is a cyclic redundancy check for detection of errors in the reception of C-B&G at the ATU-R. Its relation to C-B&G is the same as that of C-CRC3 to C-MSGS2. Its 16 bits shall be transmitted in 2 symbols (see 9.8.13). Following C-CRC5, the ATU-C shall enter state C-REVERB5.

9.8.15 C-REVERB5

C-REVERB5 is the same as C-REVERB4 (see 9.6.7). The only difference is the maximum duration of 4000 symbols. The duration of C-REVERB5 depends upon the state of the ATU-R and the internal processing of the ATU-C. The ATU-C shall transmit C-REVERB5 until it has received, checked the reliability of, and established in the ATU-C transmitter, the downstream bits and gains information contained in R-B&G. If bits and gains information is not received, checked and established within 4000 symbols, the ATU-C shall timeout and reset to C-QUIET1. The ATU-C shall enter state C-SEGUE3 as soon as it is prepared to transmit according to the conditions specified in R-B&G.

9.8.16 C-SEGUE3

C-SEGUE3 is used to notify the ATU-R that the ATU-C is about to enter the steady-state signaling state C-SHOWTIME. The signal C-SEGUE3 is the same as C-SEGUE2 (see 9.8.2). The duration of C-SEGUE3 is 10 symbol periods. Following C-SEGUE3 the ATU-C has completed initialization and shall enter state C-SHOWTIME.

9.9 Exchange - ATU-R

During exchange there are two cases when the ATU-R shall reset itself: timeouts and error detection by a CRC checksum. Both shall trigger a reset to R-ACT-REQ. The exchange procedure is partly synchronized between ATU-C and ATU-R, and partly interactive. During the interactive parts (R-REVERB5 and R-REVERB6) a timeout shall occur when the time in either state exceeds 4000 symbols.

9.9.1 R-SEGUE3

The signal R-SEGUE3 is the same as R-SEGUE2 (see 9.7.3). The duration of R-SEGUE3 is 10 symbol periods. Following R-SEGUE3

– if expanded exchange sequence is being used the ATU-R shall enter state R-MSGSRA-RA to begin a second exchange of rates

– if the expanded exchange sequence is not being used the ATU-C shall by-pass the “rate adaptation” sequence and enter state R-MSGS2 (see 9.9.8).

9.9.2 R-MSG-RA

R-MSG-RA is a similar to R-MSG2, but expanded by 48 bits. The bit assignments are as shown in Table 37.

Table 37 - Assignment of 80 bits of R-MSG-RA

Suffix(ces) of m_i	Parameter
79 - 56	Reserved for future use (see note 1)
55 - 49	Number of RS overhead bytes (*R*)
48 - 40	Number of RS payload bytes (*K*)
39 - 32	Number of tones carrying data (*ncloaded*)
31 - 25	Estimated average loop attenuation
24 - 21	Coding gain
20 -16	Performance margin with selected rate option
15 -14	Reserved for future use (see note 1)
13 - 12	Maximum Interleaving Depth (D_{max})
11 - 0	Total number of bits per DMT symbol (b_{max})

NOTES:

1. Reserved bits shall be coded 0 until defined otherwise.
2. Within the separate fields the least significant bits have the lowest subscripts.

9.9.2.1 Number of RS overhead bytes (R)

This is the R (R_I or R_F, as defined in 6.4.1.2) parameter used to calculate b_{max}.

This parameter shall be calculated assuming single latency operation with $S \leq 1$.

9.9.2.2 Number of RS payload bytes (K)

This is the K (K_I or K_F, as defined in 6.4.1.2) parameter used to calculate b_{max}.

This parameter shall be calculated assuming single latency operation with $S \leq 1$.

9.9.2.3 Number of tones carrying data (ncloaded)

This is the number of sub-carriers with $b_i > 0$ used to calculate b_{max}.

9.9.2.4 Estimated average loop attenuation

This parameter shall be defined as in R-MSG2, see 9.9.8.

9.9.2.5 Coding gain

The coding gain of RS FEC and trellis coding as used to calculate b_{max}.

The coding gain is expressed in steps of 0.5 dB in the 0 to 7.5 dB range.

9.9.2.6 Performance margin with selected rate option

This parameter shall be defined as in R-MSG2, see 9.9.8. If R-RATES-RA indicates "no option selected", then this parameter shall be set to 0 or reflect the performance margin in dB corresponding to b_{max} (which may be 0 to 3 dB above the minimum requested SNR margin).

9.9.2.7 Maximum Interleaving Depth

This parameter shall reflect the maximum interleaving depth supported by the ATU-R receiver as defined in Table 38.The ATU-R shall support an interleaving depth of 64. The higher values are optional.

Table 38 - Bit settings for Maximum Interleaving Depth

Bit 13	Bit 12	D_{max}
0	0	64
0	1	128
1	0	256
1	1	512

9.9.2.8 Total number of bits supported (b_{max})

This parameter shall be defined as in R-MSG2, see 9.9.8. If both ATU-C and ATU-R support trellis coding, then trellis coding shall be assumed when calculating b_{max}.

NOTE - The following relationship exists between b_{max}, *ncloaded*, *K* and *R*:

1. With trellis coding $b_{max} = 8 \times (K + R / S) + \text{roundup}(ncloaded / 2) + 4 = \Sigma\, b_i$.
2. Without trellis coding $b_{max} = 8 \times (K + R / S) = \Sigma\, b_i$.

9.9.3 R-CRC-RA1

R-CRC-RA1 is a cyclic redundancy check for detection of errors in the reception of R-MSG-RA. Its relation to R-MSG-RA is the same as that of R-CRC3 to R-MSGS2. Following R-CRC-RA1, the ATU-R shall enter state R-RATES-RA.

9.9.4 R-RATES-RA

R-RATES-RA is the reply to C-RATES1 based on the results of the downstream channel analysis and is similar to R-RATES2. Instead of listing the B_F, B_I as in C-RATES1, the ATU-R does one of the following:

– sends back only the option number of the highest data rate that can be supported based on the measured SNR of the downstream channel (not taking into account impulse noise resilience);

– indicates that no option selection was made at this time, but will be made later based on C-RATES-RA information;

– indicates none of the options requested during C-RATES1 can be implemented.

As in R-RATES2, 4 bits are used for the option number. A total of 8 bits are used for R-RATES-RA, and the bit patterns are shown in Table 39. Other bit patterns that are not specified in Table 39 are reserved for future use. One symbol period is used to transmit these 8 bits using the method described in 9.9.8. Following R-RATES2, the ATU-R shall enter state R-CRC4.

The format of R-RATES-RA is the same as R-RATES2, except for the additional bit pattern used to indicate "no option selected".

Table 39 - Bit pattern for R-RATES-RA

Downstream	Bit pattern for R-RATES-RA (msb first)
option 1	00010001
option 2	00100010
option 3	01000100
option 4	10001000
no option selected	00000001
all options fail	00000000
NOTE - All other bit patterns that are not shown are reserved for future use.	

9.9.5 R-CRC-RA2

R-CRC-RA2 is a cyclic redundancy check for detection of errors in the reception of R-RATES-RA. Its relation to R-RATES-RA is the same as that of R-CRC3 to R-MSGS2. Following R-CRC-RA2, the ATU-R shall enter state R-REVERB-RA.

9.9.6 R-REVERB-RA

R-REVERB-RA is the same as R-REVERB3 (see 9.7.2). The duration of R-REVERB-RA depends upon the signaling state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB-RA until it has received and checked the reliability of the upstream bits and gains information contained in C-RATES-RA. After the ATU-R has received C-CRC-RA2, it shall continue to transmit R-REVERB-RA for another 64 symbols. It shall then enter R-SEGUE-RA.

If it has not successfully detected all the control signals within 4000 symbols it shall timeout and reset to R-ACT-REQ.

9.9.7 R-SEGUE-RA

R-SEGUE-RA is the same as R-SEGUE4. Following R-SEGUE-RA the ATU-R shall enter state R-MSG2

9.9.8 R-MSGS2

R-MSGS2 transmits a 32-bit message signal to the ATU-C. This message includes the total number of bits per symbol supported, the estimated downstream loop attenuation, and the performance margin with the selected rate option. The message, *m*, is defined by:

$$m = \{m_{31},\ m_{30},\ \ldots\ldots\ m_1, m_0\}$$

with m_0 being transmitted first. The message components are defined in the following subclauses, and their assigned positions within the composite message, *m,* are defined in Table 40.

Table 40 - Assignment of 32 bits of R-MSGS2

Suffix(ces) of m_i	Parameter
31 - 25	Estimated average loop attenuation
24 - 21	Reserved for future use
20 -16	Performance margin with selected rate option
15 -12	Reserved for future use
11 - 0	Total number of bits supported

NOTES

1. All bits “reserved for future use” shall be set to 0 until defined.
2. Within the separate fields the least significant bits have the lowest subscripts.

A total of 4 symbol periods are used to communicate the 32 bit message, with 8 bits transmitted on each symbol. Two bits are encoded onto each of the nominal sub-carriers numbered 10 through 13 using the 4-QAM constellation labeling given in 6.11.3 (for the synchronization symbol) and 9.4.6 (for C-REVERB1). The same two bits are also encoded in the same way onto a set of backup carriers, namely, sub-carriers 6 through 9 if the ATU-C has indicated compliancy with ANSI T1.413 Issue 1 and sub-carriers 20 to 23 if the ATU-C has indicated compliancy with ANSI T1.413 Issue 2 (see 9.6.4.3).

The least significant byte of the message is transmitted in the first symbol of R-MSGS2, with the two least significant bits of each byte encoded onto nominal carrier 10 and backup carrier 6 or 20. In addition, the pilot, sub-carrier 16, shall be modulated with the {+,+} constellation point.

Following R-MSGS2, the ATU-R shall enter state R-CRC3.

9.9.8.1 Estimated average downstream loop attenuation

During channel analysis the ATU-R receiver estimates the downstream channel gain of each sub-carrier in preparation for computing the SNR for each sub-carrier; it shall also calculate the average loop attenuation. This attenuation is defined as the difference between the ATU-C maximum transmit power (as defined in 6.15.3, taking into account power cutback) and the total received power, rounded to the nearest 0.5 dB.

The attenuation is encoded into bits 31 - 25 of R-MSGS2 as the integer binary representation of twice the attenuation (e.g., if the average attenuation is 21.5 dB then $\{m_{31}, ... m_{25}\}$ = 0101011).

9.9.8.2 Performance margin with selected rate option

The ATU-R receiver shall select one of the rates options sent from the ATU-C during C-RATES1 or C-RATES-RA (depending on whether the short or extended exchange sequence is used with a satisfactory downstream margin). This selected option is encoded in R-RATES2. This margin (rounded to the nearest dB) is encoded into bits 20-16 of R-MSGS2 using a conventional binary representation (e.g., if the margin is 9 dB then $\{m_{20}, ... m_{16}\}$ = 01001).

9.9.8.3 Total number of bits per symbol supported

The ATU-R receiver shall also calculate the maximum number of bits per symbol that the downstream channel can support with the performance margin defined in C-MSGS1 or C-MSGS-RA (depending on whether the short or the expanded exchange sequence is used) at an error rate of 10^{-7}. This number is encoded into bits 11 - 0 using a conventional binary representation (e.g., if the maximum number of bits that can be supported is 1724 (data rate = 6896 kbit/s), $\{m_{11}, ... m_0\}$ = 11010111100).

9.9.9 R-CRC3

R-CRC3 is a cyclic redundancy check for detection of errors in the reception of R-MSGS2 at the ATU-C. The CRC polynomial c(D) and generator polynomial g(D) are as described in 9.6.3. These bits are transmitted in 2 symbol periods using the method described in 9.9.8. Following R-CRC3, the ATU-R shall enter state R-RATES2.

9.9.10 R-RATES2

R-RATES2 is the reply to C-RATES1 or C-RATES-RA (depending on whether the short or the expanded exchange sequence is used) based on the results of the downstream channel analysis. Instead of listing the B_F, B_I as in C-RATES1, the ATU-R sends back only the option number of the selected data rate that can be supported based on the measured SNR of the downstream channel (not taking into account impulse noise resilience). As in C-RATES2, 4 bits are used for the option number. A total of 8 bits are used for R-RATES2, and the bit patterns are shown in Table 41. Other bit patterns that are not specified in Table 41 are reserved for future use. If none of the options requested during C-RATES1 can be implemented, ATU-R then returns to R-ACT-REQ for retraining. One symbol period is used to transmit these 8 bits using the method described in 9.9.8. Following R-RATES2, the ATU-R shall enter state R-CRC4.

Table 41 - Bit pattern for R-RATES2

Downstream	**Bit pattern for R-RATES2 (msb first)** (see note 1)
option 1	00010001
option 2	00100010
option 3	01000100
option 4	10001000
all options fail (see note 2)	00000000

NOTES

1. All other bit patterns that are not shown are reserved for future use.
2. If it is determined that none of the four options can be implemented with the connection, the ATU-R shall return to R-ACT-REQ for retraining.

9.9.11 R-CRC4

R-CRC4 is a cyclic redundancy check for detection of errors in the reception of R-RATES2 at the ATU-C. Its relation to R-RATES2 is the same as that of R-CRC3 to R-MSGS2. Following R-CRC4, the ATU-R shall enter state R-REVERB5.

9.9.12 R-REVERB5

R-REVERB5 is the same as R-REVERB3 (see 9.7.2). The duration of R-REVERB5 depends upon the signaling state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB5 until it has received and checked the reliability of the upstream bits and gains information contained in C-B&G. After the ATU-R has received C-CRC5, it shall continue to transmit R-REVERB5 for another 64 symbols. It shall then enter R-SEGUE4. If it has not successfully detected all the control signals within 4000 symbols it shall timeout and reset to R-ACT-REQ.

9.9.13 R-SEGUE4

The purpose of R-SEGUE4 is to notify the ATU-C that the ATU-R is about to enter R-B&G. R-SEGUE4 is the same as R-SEGUE3 (see 9.9.1). The duration of R-SEGUE4 is 10 symbol periods. Following R-SEGUE4 the ATU-R shall enter state R-B&G.

9.9.14 R-B&G

The purpose of R-B&G is to transmit to the ATU-C the bits and gains information (i.e., b_1, g_1, b_2, g_2, ... b_{255}, g_{255}) to be used on the downstream sub-carriers. b_i indicates the number of bits to be coded by the ATU-C transmitter onto the i-th downstream sub-carrier; g_i indicates the scale factor that shall be applied to the i-th downstream sub-carrier, relative to the gain that was used for that carrier during the transmission of C-MEDLEY. Because no bits or energy shall be transmitted at DC or one-half the sampling rate, b_0, g_0, b_{256}, and g_{256} shall all be presumed to be zero, and shall not transmitted. Because sub-carrier 64 is reserved as pilot sub-carrier, b_{64} shall be set to 0 and g_{64} shall be set to 1 (see 6.11.1.2).

Each b_i is represented as an unsigned 4-bit integer, with valid b_i values lying in the range of zero to $N_{downmax,}$ the maximum number of bits that the ATU-C is prepared to modulate onto any sub-carrier, which is communicated in C-MSGS1.

Each g_i is represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 001.010000000 would instruct the ATU-C to scale the constellation for carrier i by a gain factor of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during C-MEDLEY.

For sub-carriers on which no data are to be transmitted, and the receiver will never allocate bits (e.g., out-of-band sub-carriers) both b_i and g_i shall be set to zero(0000 and 00000000 0000, respectively). For sub-carriers on which no data are to be currently transmitted, but the receiver may allocate bits later (e.g., as a result of an SNR improvement), the b_i shall be set to zero and the g_i to a value in the 0.75 to 1.33 range (000.110000000 to 001.010101011).

A total of 510 bytes of bits and gains information is to be transmitted during R-B&G, so that a total of 510 symbol periods is required. The transmission format is the same as described in 9.9.8. Following R-B&G the ATU-R shall enter state R-CRC5.

The R-B&G information shall be mapped in a 4080-bit message m defined by:

$$m = \{m_{4079}, m_{4078}, \ldots, m_1, m_0\} = \{ g_{255}, b_{255}, \ldots, g_1, b_1\}$$

With the msb of b_i and g_i in the higher m index and m_0 being transmitted first. The message m shall be transmitted in 510 symbols, using the transmission method as described in 9.9.7.

Following R-B&G, the ATU-R shall enter state R-CRC5.

9.9.15 R-CRC5

R-CRC5 is a cyclic redundancy check for detection of errors in the reception of R-B&G at the ATU-C. Its relation to R-B&G is the same as that of R-CRC3 to R-MSGS2. Following R-CRC5, the ATU-R shall enter state R-REVERB6.

9.9.16 R-REVERB6

R-REVERB6 is the same as R-REVERB3 (see 9.7.2). The duration of R-REVERB6 depends upon the signaling state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB6 until it has detected all ten symbols of C-SEGUE3; it shall then enter R-SEGUE5. If it has not successfully detected C-SEGUE3 within 4000 symbols it shall timeout and reset to R-ACT-REQ.

9.9.17 R-SEGUE5

The purpose of R-SEGUE5 is to notify the ATU-C that the ATU-R is about to enter the steady-state signaling state R-SHOWTIME. R-SEGUE5 is identical to R-SEGUE3 (see 9.9.1). The duration of R-SEGUE5 is 10 symbol periods. Following R-SEGUE5 the ATU-R has completed initialization and shall enter state R-SHOWTIME.

9.10 Details of the initialization timing

The requirements for the initialization sequence (as defined in 9.1 through 9.9) are shown in Figure 43, Figure 44 and Figure 45. Figure 43 shows the first part of the initialization sequence, up to C-MEDLEY and R-MEDLEY. Figure 44 shows the continuation in case the extended exchange sequence is not used. Figure 45 shows the continuation in case the extended exchange is used.

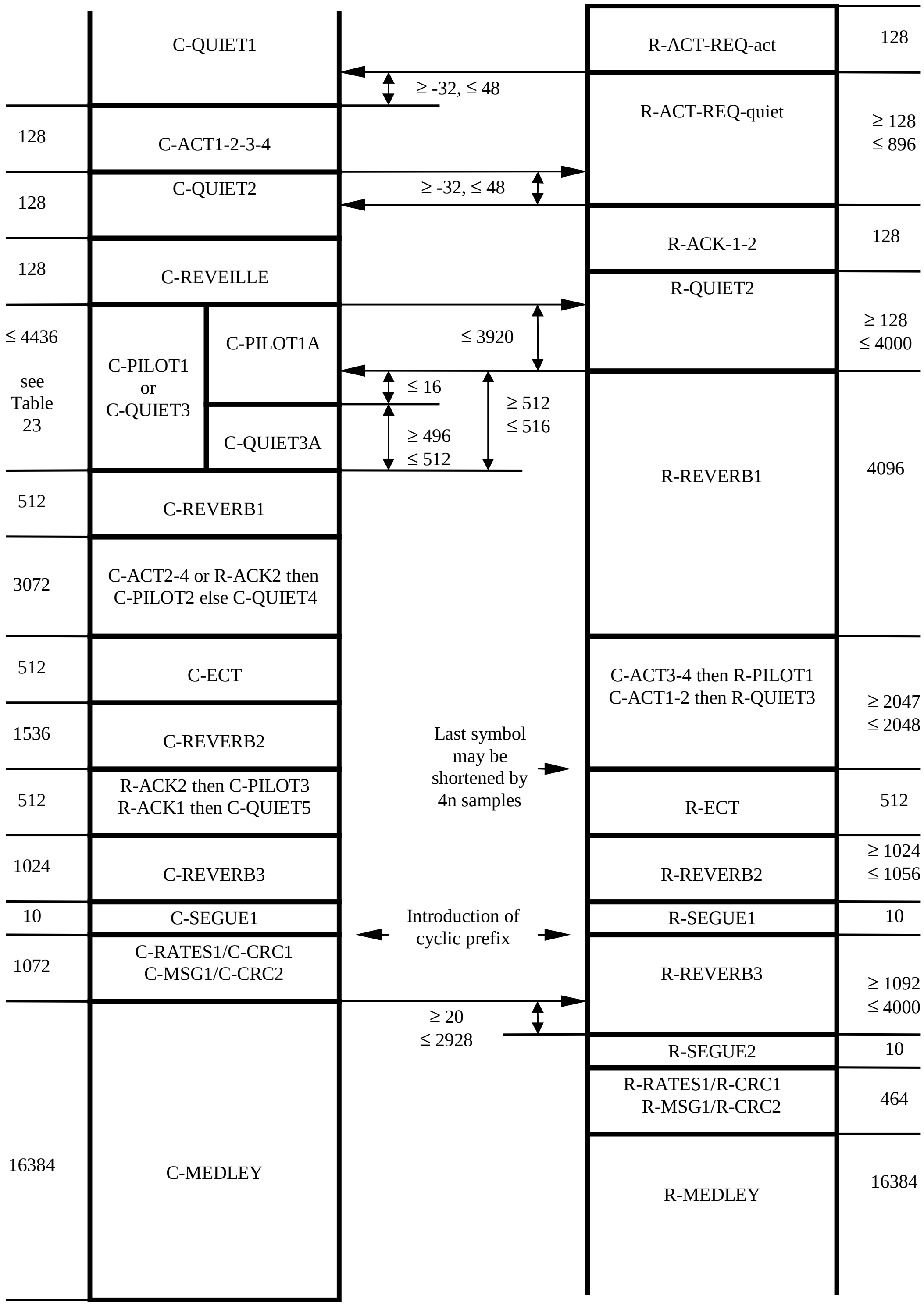


Figure 43 - Timing diagram of the initialization sequence (part 1).

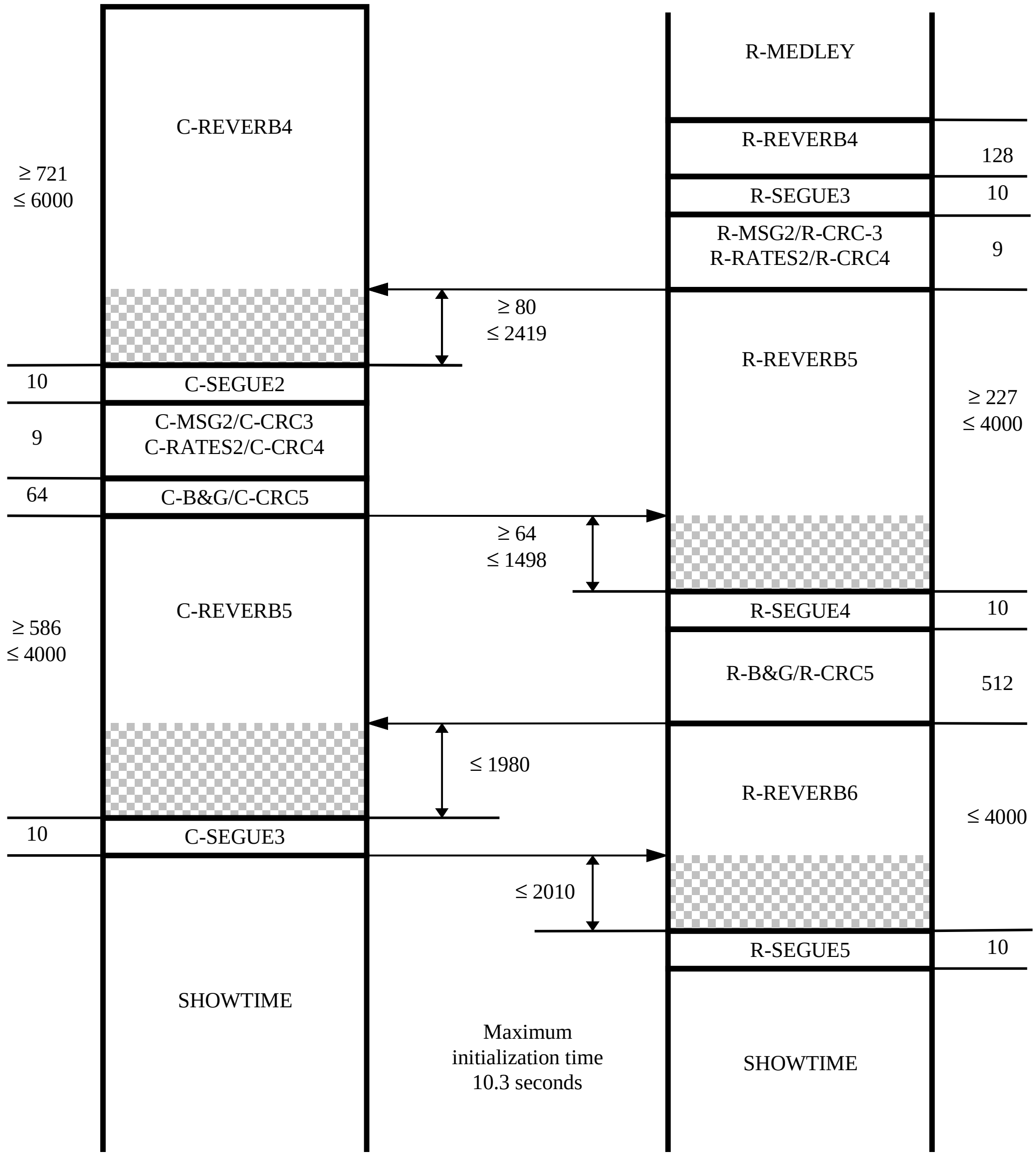


Figure 44 - Timing diagram of the initialization sequence (part 2 - without RA).

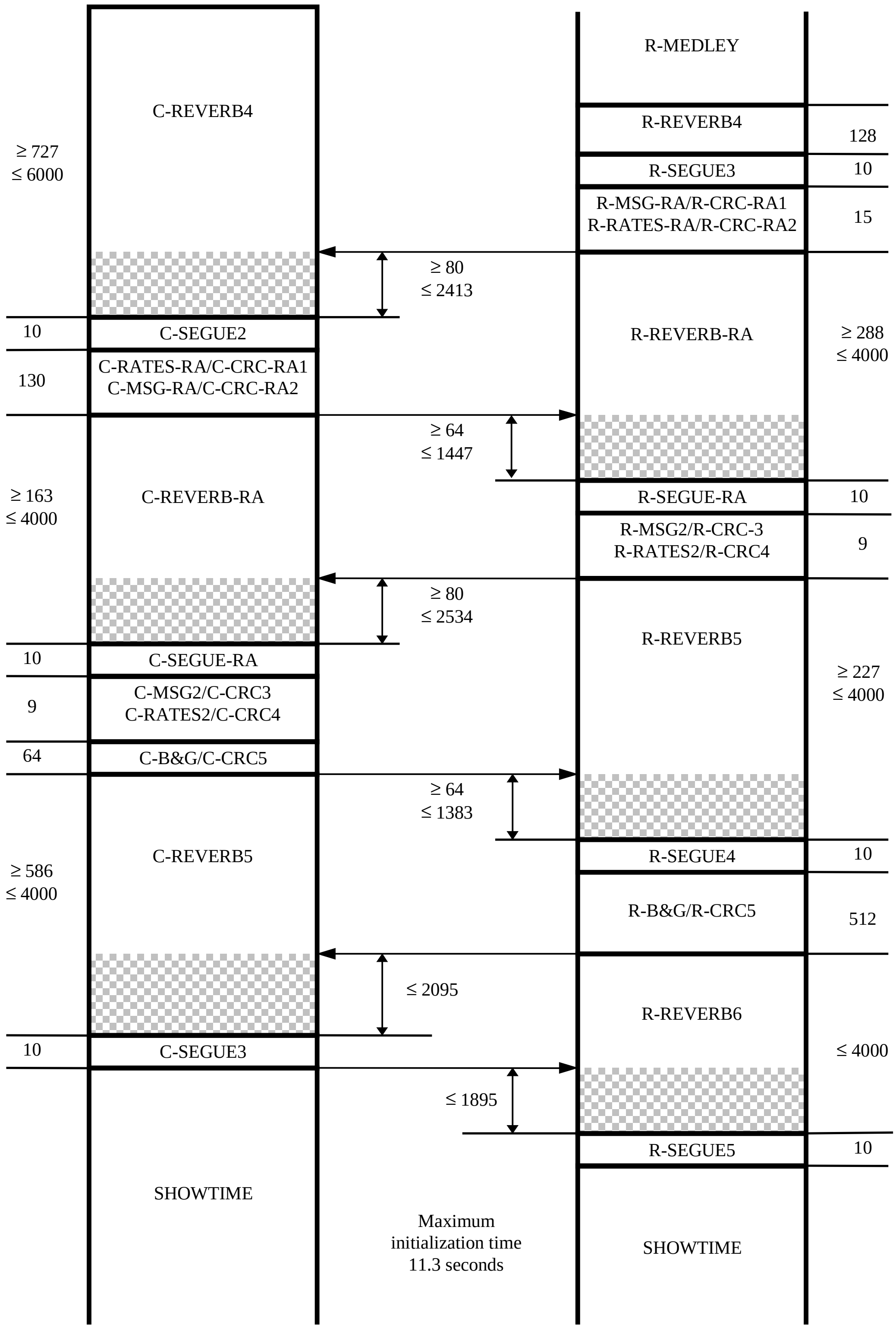


Figure 45 - Timing diagram of the initialization sequence (part 2 - with RA).

10 On-line adaptation and reconfiguration

10.1 The ADSL overhead control (aoc) channel

The aoc data are carried as overhead bytes in the ADSL framing structure. The actual multiplexing of these overhead bytes into the ADSL framing structure depends on the framing structure used (i.e., full overhead or reduced overhead) and on the allocation of any bearer channel to the fast or interleaved data buffer (see 6.4 and 7.4).

10.1.1 Aoc message header

The type and length of an aoc message (except for the acknowledge messages) are identified by a byte-length header. In particular, the aoc channel sends the all binary zeros “00000000” aoc stuffing pattern in the Idle State, and a valid aoc message always begins with a non-zero byte. Table 42 summarizes the current valid aoc message headers. For example, in the case of a bit swap, the aoc header “11111111” will be detected, and the next byte of aoc data shall determine whether the message is a bit swap request or a bit swap acknowledge. In the case when a function is requested but cannot be performed by either the ATU-C or the ATU-R for any reason (e.g., because the requested b_i value exceeds the maximum number of bits per tone supported), an unable-to-comply message (“11110000”) shall be issued. Future aoc headers can be added when new aoc messages/functions are identified. Also, a block of aoc header values (“1100xxxx”) is set aside for vendor specific aoc messages.

Table 42 - Aoc message headers.

Header	Message length (bytes)	Interpretation
00001111	undefined	Reconfiguration message
1100xxxx	undefined	Vendor specific message
11110000	1	Unable-to-comply message (see note)
11111100	13	Extended bit swap request message
11111111	9	Bit swap request message
11111111	3	Bit swap acknowledge message
NOTE - The unable-to-comply message shall consist of a single byte: the header byte.		

The header bytes values are given in binary format (msb left, lsb right) and represent aoc7-aoc0 bits (msb in bit 7, lsb in bit 0) as carried in the overhead (see 6.4 and 7.4). All other bytes in the aoc message shall be mapped according to the same convention.

10.1.2 Aoc protocol

All aoc messages shall be transmitted 5 consecutive times (i.e., 5 concatenated and identical messages without aoc stuffing patterns in between) for extra security. At least 20 aoc stuffing patterns shall be inserted between two consecutive groups of five concatenated and identical messages.

An ATU receiving an aoc message shall act on that aoc message only if it has received three identical messages in a time period spanning 5 of that particular message. When an ATU receives an unrecognizable command, it shall take no action.

10.2 On-line adaptation - Bit swapping

Bit swapping enables an ADSL system to change the number of bits assigned to a subcarrier, or change the transmit energy of a subcarrier without interrupting data flow.

Either ATU may initiate a bit swap; the swapping procedures in the upstream and downstream channels are independent, and may take place simultaneously.

For the bit swap protocol, the “receiver” is the ATU that is receiving the data; it transmits a bit swap (extended or simple) request message and receives the bit swap acknowledge message. The “transmitter” is the ATU that is transmitting the data; it receives a bit swap request (extended or simple) message and transmits the bit swap acknowledge message.

There shall be a maximum of one downstream bit swap request outstanding at any time.

There shall be a maximum of one upstream bit swap request outstanding at any time.

10.2.1 Bit swap channel

The bit swap process uses the aoc channel, described in 10.1. All bit swap messages shall be repeated five consecutive times over this channel.

10.2.2 Superframe counting

The transceivers coordinate the bit swaps as follows:

- The ATU-C and ATU-R transmitters shall start their counters immediately after transmitting C-SEGUE3 and R-SEGUE5 (see 9.8.10 and 9.12.11), respectively; this marks the transition between initialization and steady state operation;
- Superframe counting shall start with the first superframe at beginning of Showtime being superframe 0;
- Each transmitter shall increment its counter after sending each ADSL superframe (see 6.2);
- Correspondingly, each receiver shall start its counter immediately after receiving C-SEGUE3 or R-SEGUE5, respectively, and then increment it after receiving each superframe.
- Superframe counting shall be performed MOD 256.

Synchronization of the corresponding transmitter and receiver superframe counters is maintained using the synchronization symbol in the ADSL frame structure. Any form of restart that requires a transition from initialization to steady state shall reset the superframe counter.

10.2.3 Bit swap request

The receiver shall initiate a bit swap by sending a bit swap request to the transmitter via the aoc channel. This request tells the transmitter which sub-carriers are to be modified.

The format of the request is shown in Table 43.

Table 43 - Format of the bit swap request message

Message header	Message fields 1 - 4	
{11111111} (8 bits)	Command (8 bits)	Sub-carrier index (8 bits)

The request shall comprise nine bytes as follows:

- an aoc message header consisting of 8 binary ones;
- message fields 1-4, each of which each consists of an eight-bit command followed by a related eight-bit sub-carrier index. Valid eight-bit commands for the bit swap message shall be as shown in Table 44. The eight-bit sub-carrier index is counted from low to high frequencies with the lowest frequency sub-carrier having the number zero. Sub-carrier index 0 shall not be used.

Table 44 - Bit swap request commands

Value	Interpretation
00000000	Do nothing
00000001	Increase the number of allocated bits by one
00000010	Decrease the number of allocated bits by one
00000011	Increase the transmitted power by 1 dB
00000100	Increase the transmitted power by 2 dB
00000101	Increase the transmitted power by 3 dB
00000110	Reduce the transmitted power by 1 dB
00000111	Reduce the transmitted power by 2 dB
00001xxx	Reserved for vendor discretionary commands

The bit swap request message (i.e., header and message fields) shall be transmitted five consecutive times.

NOTE - With a g_i update of Δ dB, the new g_i value should be given by g_i = (1/512) $\times$ round (512 $\times$ g_i $\times$ 10exp(Δ/20) to avoid g_i divergence between ATU-C and ATU-R after several bit swaps.

10.2.4 Extended bit swap request

Any on-line adaptation may be encoded in an extended bit swap request. However, because a single-bit sub-carrier is not allowed, an extended bit swap request containing 6 fields shall be used when decreasing the number of bits on a sub-carrier from 2 to 0, or when increasing the number of bits on a sub-carrier from 0 to 2. The format of this extended bit swap request is similar to that of the bit swap request (10.2.3), but the number of message fields is increased to 6, and a different message header is used. The format of the request is shown in Table 45.

Table 45 - Format of the extended bit swap request message

Message header	Message fields 1 - 6	
{11111100} (8 bits)	Command (8 bits)	Sub-carrier index (8 bits)

The receiver shall initiate an extended bit swap by sending an extended bit swap request message to the transmitter. This request tells the transmitter which sub-carriers are to be modified. The extended bit swap request message shall comprise 13 bytes as follows:

- An eight bit extended bit swap request message header of {11111100}
- Message fields 1 to 6, each of which is defined as in 10.2.3.

The receiver shall use two identical message fields to request a 0 to 2 increase or a 2 to 0 decrease of the number of bits on a sub-carrier, according to the allowable bit-swap commands defined in Table 44.

The extended bit swap request is transmitted 5 consecutive times.

10.2.5 Bit swap acknowledge

NOTE - “Bit swap” hereafter shall refer to either a regular or an extended bit swap.

Within 400 ms after receiving the bit swap request message, the transmitter shall send a bit swap acknowledge message, which shall contain the following:

– a bit swap acknowledge message header coded “11111111”;

– one message field, which consists of an eight-bit bit swap acknowledge command followed by an eight-bit superframe counter number. The acknowledge command shall be coded “11111111”; the counter number indicates when the bit swap is to take place. This number shall be at least 47 greater than the counter number when the request was received (this corresponds to a minimum wait time of 800 ms). The new bit and/or transmit power table(s) shall then take effect starting from the first frame (frame 0) of an ADSL superframe, after the specified superframe counter number has been reached. That is, if the bit swap superframe counter number contained in the bit swap acknowledge message is *n*, then the new table(s) shall take effect starting from frame 0 of the (*n*+1)th ADSL superframe.

Table 46 - Format of the bit swap acknowledge

Message header (8 bits) 11111111	Acknowledge command (8 bits) 11111111	Bit swap superframe counter number (8 bits)

The bit swap acknowledge is transmitted five consecutive times.

10.2.6 Bit swap - Receiver

The receiver shall start a timeout of 500 ± 20 ms from the moment it sends a bit swap request message. When no acknowledgment has been detected in this timeout interval, the receiver shall resend a bit swap request message (which shall have the same parameters) and restart the timeout. Only when an acknowledgment has been detected within the timeout interval shall the receiver prepare for a bit swap at the time specified in the acknowledge message.

Upon timeout, the bit swap message shall be retransmitted. However, after a finite (implementation specific) number of unsuccessful retries, the receiver shall take recovery actions to accomplish bit swap; these recovery actions are to be determined.

The receiver shall then wait until the superframe counter equals the value specified in the bit swap acknowledge message. Then, beginning with frame 0 of the next ADSL superframe, the receiver shall

– change the bit assignment of the appropriate sub-carriers and perform tone reordering based on the new sub-carrier bit assignment;

– update applicable receiver parameters of the appropriate sub-carriers to account for a change in their transmitted energy.

NOTE - A new bit swap request shall be sent only after the previous bit swap has taken place or when the 500 ± 20 ms timeout has occurred while waiting for a bit swap acknowledge.

10.2.7 Bit swap - Transmitter

After transmitting the bit swap acknowledge, the transmitter shall wait until the superframe counter equals the value specified in the bit swap acknowledge. Then, beginning with frame 0 of the next ADSL superframe, the transmitter shall

– change the bit assignment of the appropriate sub-carriers, and perform tone re-ordering based on the new sub-carrier bit assignment ;

– change the transmit energy in the appropriate sub-carriers by the desired factor.

NOTE - If the transmitter receives a new bit swap request message while waiting, it shall immediately stop waiting and update the superfame counter for bit swap according to the new message. It shall restart the process for the newly arrived bit swap request message assuming that the new message equals the previous.

11 Loop plant, impairments, and testing

This clause addresses laboratory testing to ensure conformance to transceiver performance requirements. These laboratory methods evaluate a system's ability to minimize digital bit errors caused by interference from:

- crosstalk coupling from other systems;
- background noise;
- impulse noise;
- POTS signaling.

These potential sources of impairment are simulated in a laboratory set-up that includes test loops, test sets, and interference injection equipment, as well as the test system itself. Figure 46 and Figure 47 show the general arrangement for testing downstream and upstream respectively.

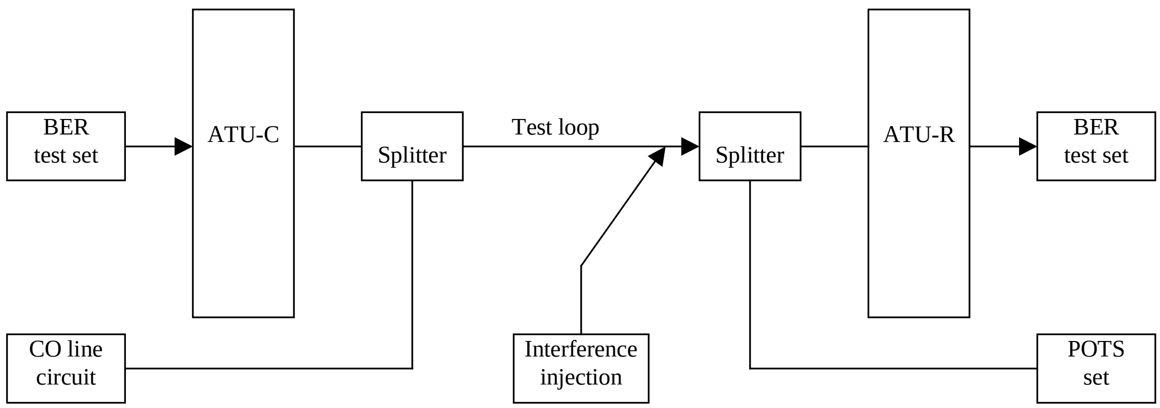


Figure 46 - Overview of test set-up for downstream testing

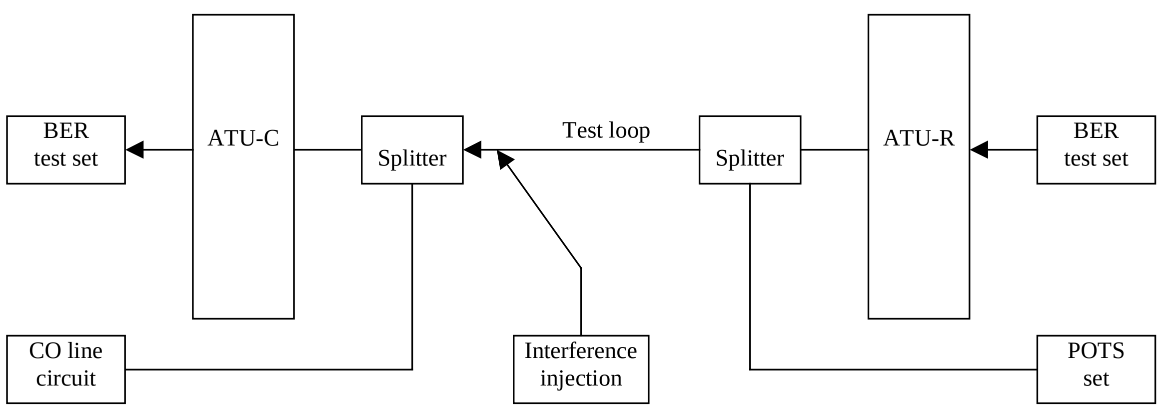


Figure 47 - Overview of test set-up for upstream testing

The crosstalk and impulse noise interfering signals are simulations that are derived from a consideration of real loop conditions and measurements. The test procedure is to inject the interference into the test loops and measure the effect on system performance by a bit error test simultaneously run on the system information channels.

For crosstalk an initial, or reference, power level for the interference represents the expected worst case. If the interference power can be increased without exceeding a specified error threshold, the system has a positive performance margin. Performance margin, expressed in dB, is the difference between the interference level at which the error threshold is reached, and the reference (or 0 dB) level.

The specified error threshold with crosstalk interference is a BER of 10^{-7}; the minimum performance margin is 6 dB.

In the case of impulse noise, an increasing interference level is similarly applied up to the error threshold, and the estimated performance is computed from this information. Because the impulse noise characteristics of the loop plant are not completely understood, the estimation method is based on measured data from several sites. The estimated number of error-causing impulses is compared to a 0.14 % errored-seconds (ES) criterion. The test procedure makes separate determinations of crosstalk margins and impulse error thresholds, although a background crosstalk interference is applied during impulse tests.

The POTS measurement uses a number of signaling and alerting activities done with real phones and CO lines, and also has crosstalk interference present. The BER test sets check for ES or a BER threshold.

11.1 Test loops

ADSL transmission at 1.536 Mbit/s is assessed in terms of performance against an objective of coverage over all copper loops without load coils conforming to Revised Resistance Design (RRD) rules.

For test purposes, the RRD loops are represented by loops 7, 9, and 13 specified in 4.5.1 and, Figure 8 of ANSI T1.601. The primary cable constants are listed in Tables 2, 3, and 4 of ANSI T1.601. An additional loop (Loop #0) with a length of less than 10 feet is added to the ANSI T1.601 test loops.

ADSL transmission at 6.144 Mbit/s is assessed in terms of performance against an objective of coverage over loops that conform to Carrier Serving Area (CSA) design rules (a subset of RRD loops in Bellcore SR-TSV-002275). For testing purposes, the CSA loops are represented by loops 4, 6, 7, and 8, shown in Figure 13 and Figure 14 of Bellcore TA-NWT-001210.

For 10 or 24 disturber NEXT interference from T1 lines in adjacent binder groups, ADSL transmission is assessed with a mid-CSA loop.

The ADSL control channel and other duplex bearer channels are evaluated with all test loops.

The configurations of the test loops are shown in Figure 48; formulas for calculating the primary parameters of 24 AWG and 26 AWG cables, and the resistance and attenuation of the loops are given in Annex G.

The ATU operating modes for performance evaluation of category I (basic) and category II (optional) are as specified in Table 47. All types of equipment shall interwork with at least category I performance and shall support the characteristics of a Category I ATU as defined in Table 47. All Category II equipment shall interwork with category II performance and shall support the characteristics of a Category II ATU as defined in Table 47.

Table 47 - ATU operating modes for performance evaluation by category

Characteristics	Category I (basic)	Category II (optional)
Trellis option	Off	On
Spectrum	Non-overlapping spectrum	Overlapping spectrum

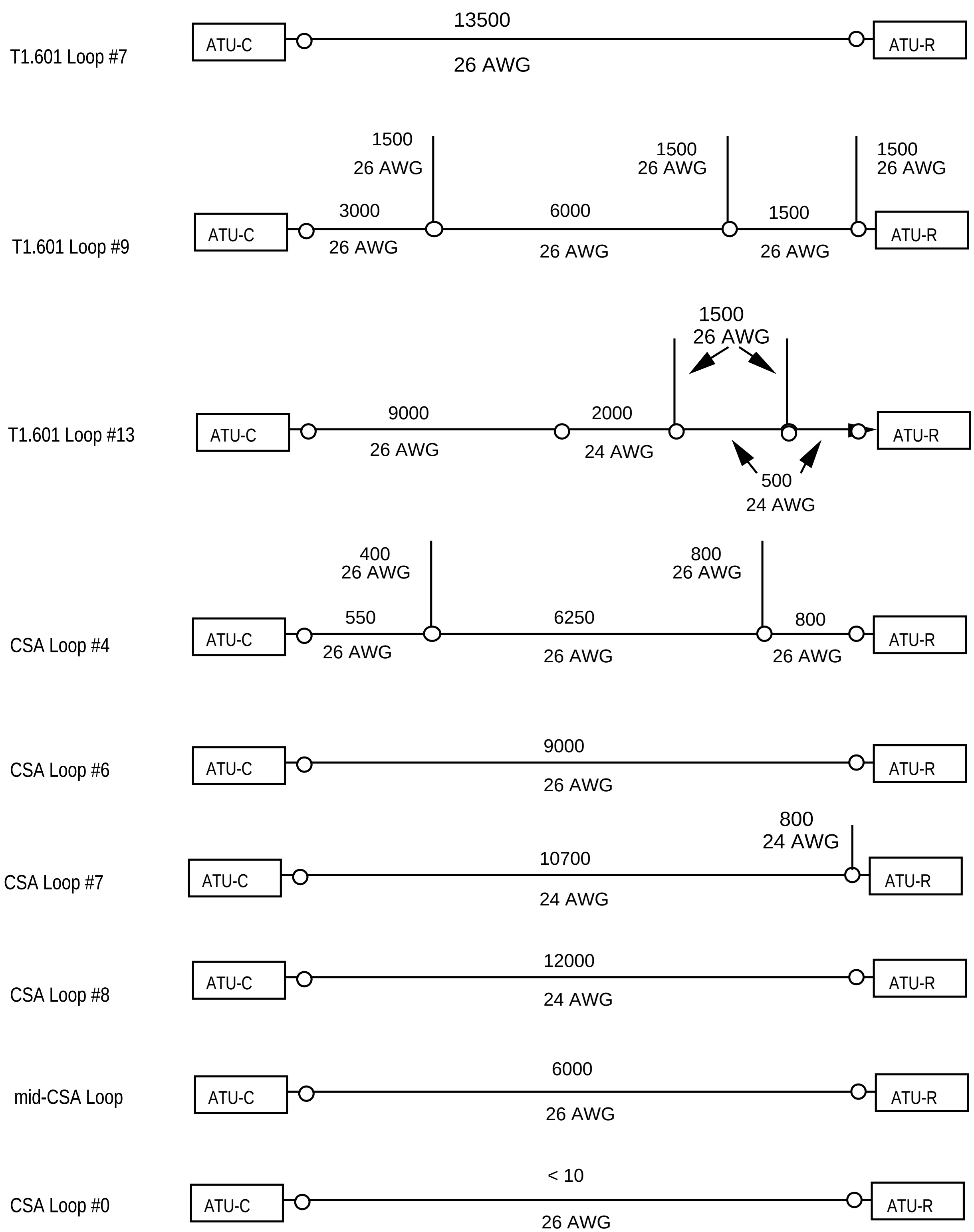
The specific combinations of loops and rates shown in Table 48 shall be tested for either category I or category II ATU's, as indicated.

Table 48 - Loop sets and maximum rates for category I and II testing

Loop sets	ATU Category	Net data rate (kbit/s)			
		STM only		ATM and STM	
		Simplex (AS0)	Duplex (LS0)	DownStream (AS0)	UpStream (LS0)
T1.601 (7,13)	I	1536	16	1696	160
		1536	160		
CSA (4,6,7), Mid-CSA	I	5920	224	6144	224
T1.601 (7,9,13)	II	1536	16	1696	160
		1536	160		
CSA (4,6,8), Mid-CSA	II	5504	640	6144	640

NOTES

1. The channelization shall be tested with full overhead framing as defined in 6.4 and 7.4.
2. The 224 kbit/s in LS0 upstream is the addition of 64 and 160 kbit/s, as allocated in ANSI T1.413 Issue 1 to LS0 and LS1 respectively.
3. The 640 kbit/s in LS0 upstream is the addition of 64 and 576 kbit/s, as allocated in ANSI T1.413 Issue 1 to LS0 and LS2 respectively.



NOTES

1. Lengths are in feet.
2. AWG = American Wire Gauge.

Figure 48 - Test loops

11.2 Impairments and simulation in testing

11.2.1 Crosstalk

Crosstalk spectral compatibility is tested using simulations of the interference caused by coupling from other transmission systems sharing the same cable. Four combinations of white noise and crosstalk from the following systems are used:

- DSL;
- HDSL;
- ADSL;
- T1 line (adjacent binder group).

For each of these the Power Spectral Density (PSD) of the transmitted signal and of the induced crosstalk is calculated for the appropriate number of disturbers and crosstalk model. The detailed analysis of the PSD and the model are provided in Annex B.

The interferers used for the tests are

- 10 or 24 disturber DSL NEXT;
- 10 or 20 disturber HDSL NEXT;
- 10 or 24 disturber ADSL NEXT and FEXT;
- 10 or 24 disturber T1 NEXT (adjacent binder group).

The resulting noise power spectra for these interferers are shown in Annex B, where the derivation of the spectrum is described for each of these sources.

11.2.2 Impulse noise

There are two impulse waveforms defined for testing. These are reconstructions of actual recorded impulses observed in field tests, and represent the single the most likely waveforms at specific sites. These wave forms are shown in Figure 49 and Figure 50 as approximations only. The two impulse wave forms for testing purposes are described in Annex C with the amplitudes specified at 160 nanosecond intervals**.**

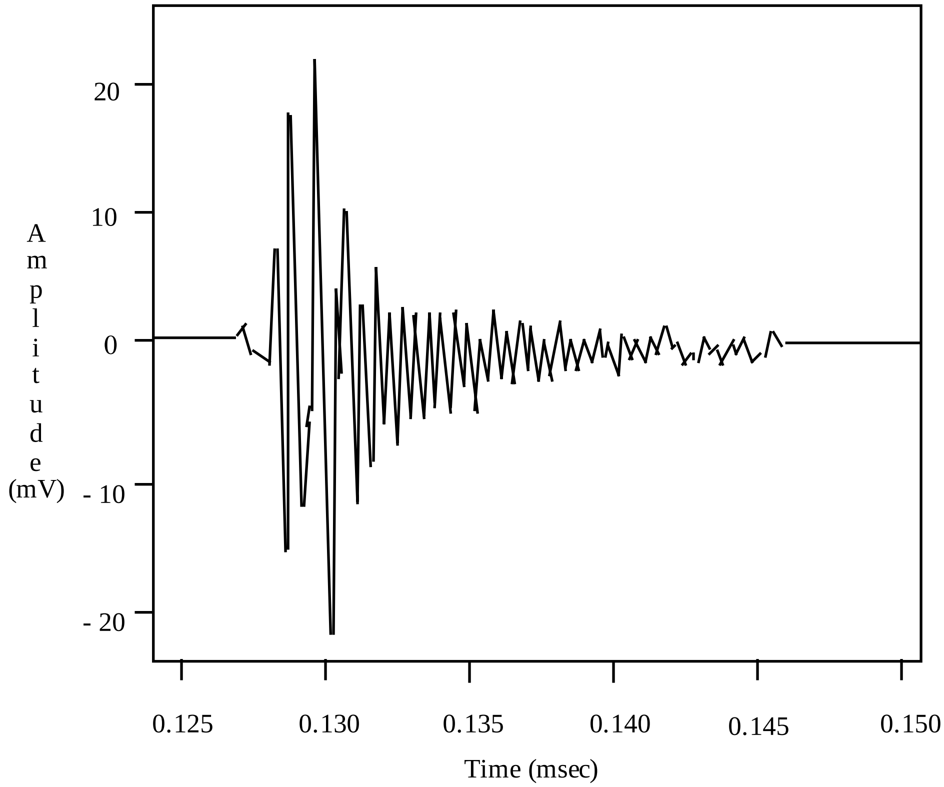


Figure 49 - Test impulse 1

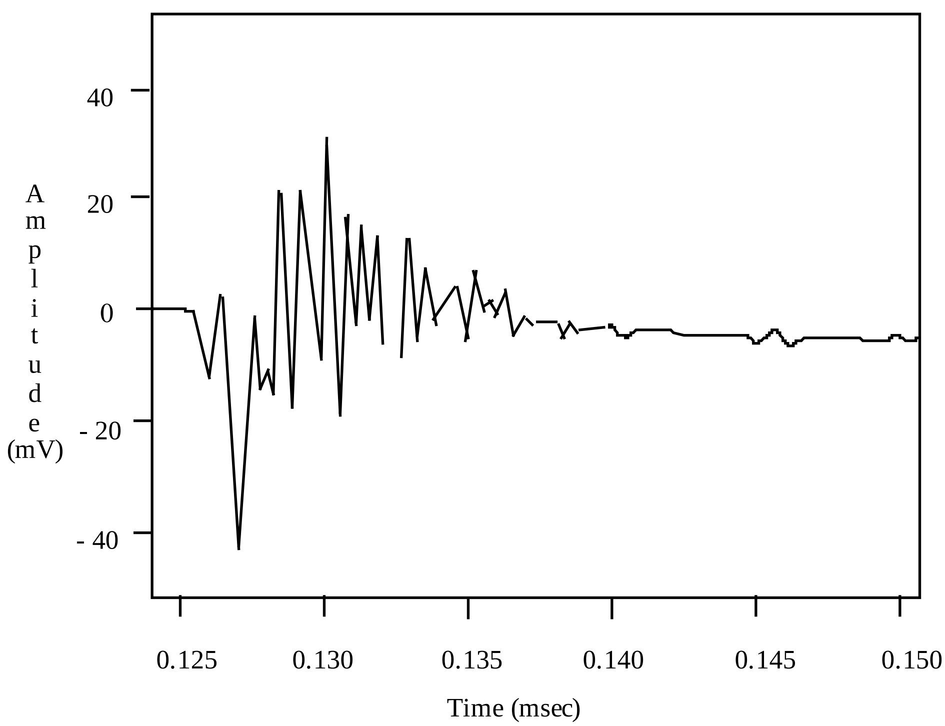


Figure 50 - Test impulse 2

11.3 Test procedures

11.3.1 Laboratory test set-up

Figure 51 and Figure 52 show the test setup for measuring performance margins on ADSL systems. The test system consists of a central office transceiver (ATU-C), a remote end transceiver (ATU-R), and associated splitters. The two transceivers are connected together by the test loop. Calibrated simulated crosstalk is injected through a high impedance network at the U-C or U-R interface (for upstream and downstream, respectively) of the receiving transceiver. Impulse noise from a waveform generator is similarly injected. Crosstalk and impulses are injected at the ATU-R for downstream tests, and at the ATU-C for upstream tests.

Pseudo-random binary data from the transmitter of the bit error rate (BER) test set is presented at the input of the ATU-C, and the output data from the ATU-R are connected to the receiver of the same or a similar BER test set. The test set measures BER or errored seconds (ES), as needed. Similar error testing is done in the upstream direction at the data rates needed for the particular system under test.

A telephone set is connected to the telephone jack of the splitter at the ATU-R end, and a working telephone line circuit is connected to the telephone jack on the splitter at the ATU-C end.

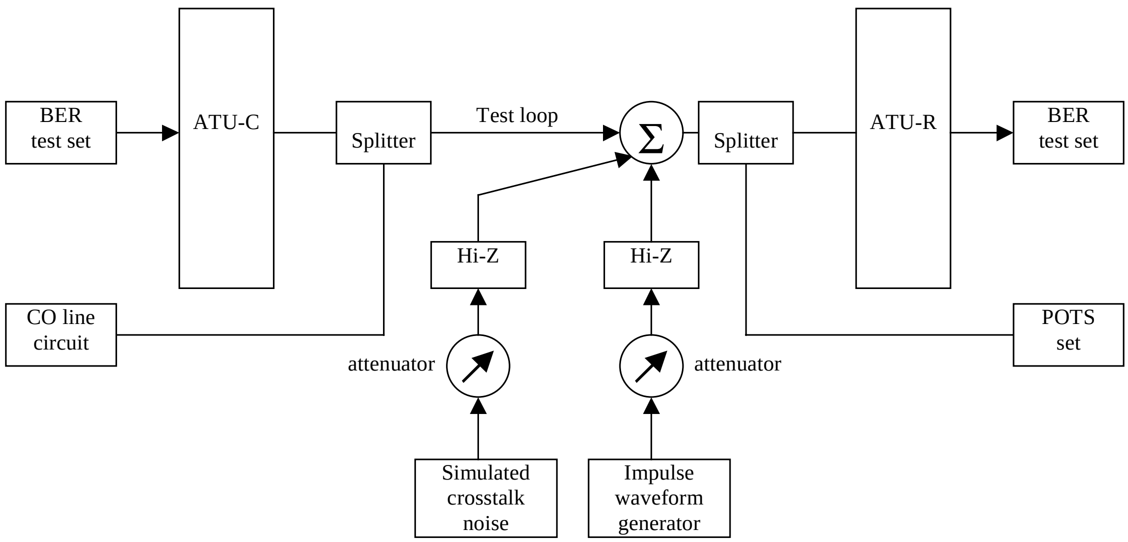


Figure 51 - Laboratory test set-up for measuring downstream performance margins

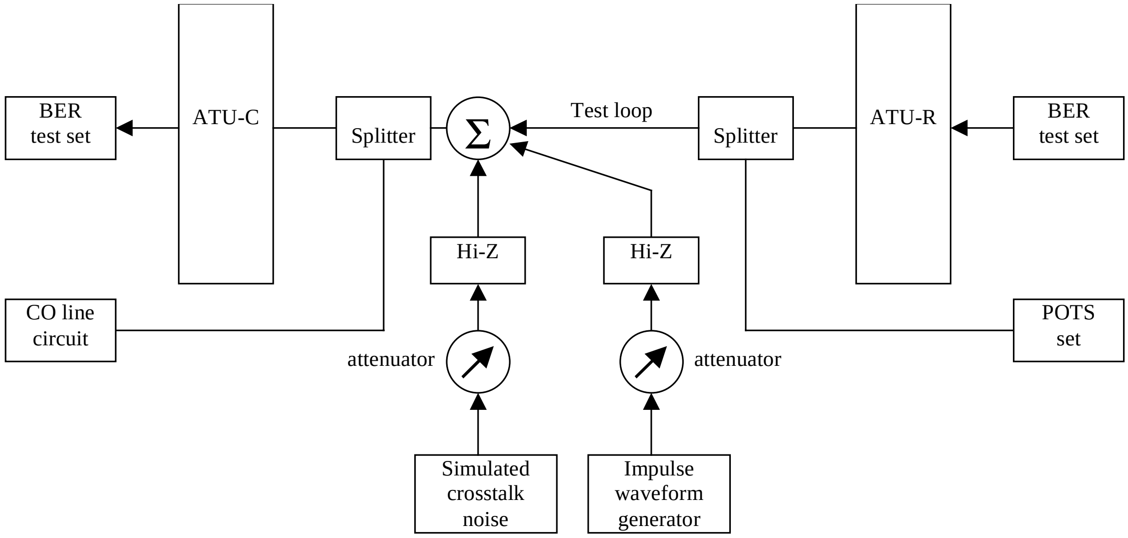


Figure 52 - Laboratory test set-up for measuring upstream performance margins

11.3.1.1 Crosstalk noise injection

Simulated crosstalk, XT (NEXT and/or FEXT) is introduced into the test loop at the receiver end so as to achieve the appropriate voltage level without disturbing the impedance of the test loop or the transceiver. This is done with a balanced series feed of high impedance. One method for both test and calibration is shown in Figure 53. The Thevenin impedance of all noise-coupling circuits connected to the test loop shall be greater than 4000 ohms.

The simulated XT should ideally have the power and spectral density defined by the equations for P_{NEXT} or P_{FEXT} in Annex B. It is acknowledged, however, that if the method of generating the simulated XT is similar to that shown in Figure 53, then its accuracy will depend on the design of the filter used to shape the white noise. Therefore a calculated XT PSD may be defined for which a tolerance on f_0 of $\pm$2% is allowed at each null. Then the accuracy of the simulated XT shall be within $\pm$1 dB of the calculated XT for all frequencies at which the calculated value is less than 45 dB below the peak value. The total power of the simulated XT shall be within $\pm$0.5 dB of the specified value using the same calibration termination.

The crest factor of the simulated XT shall be equal to or greater than 5.

The simulated XT PSD shall be verified using the calibration termination shown in Figure 53 and a selective voltmeter or true RMS meter with a resolution bandwidth of approximately 3 MHz. The crosstalk power being calibrated is the power into the resistor R_{rec}; this is half the power into the parallel combination referred to as the calibration termination. DSL and HDSL crosstalk the circuit shall be calibrated for 1.3 dB less crosstalk than specified in Annex B, in order to compensate for the use of 100 ohm terminations instead of 135 ohms.

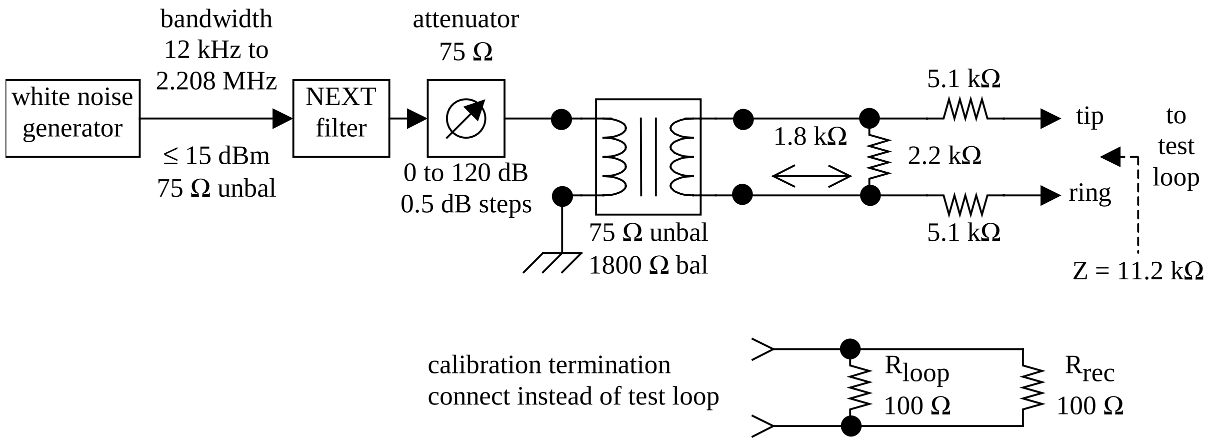


Figure 53 - High impedance crosstalk injection circuit

Care should be taken when specifying the white noise generator in Figure 53; consideration should be given to the following factors:

- *The probability distribution of the peak amplitude:* The noise shall be Gaussian within all frequency bands;
- *Crest factor:* The crest factor is an indication of the number of standard deviations to which the noise follows a Gaussian distribution. The crest factor shall be at least 5;
- *The frequency spectrum:* If the noise is generated using digital methods the sequence repetition rate will affect the correlation of the samples, and thence the frequency spectrum. The noise bandwidth shall be at least 2.208 MHz.

11.3.1.2 Impulse noise injection

The same coupling circuit as is used in 11.3.1.1 is used for impulse noise injection. The amplitude level of the impulses may be measured with an oscilloscope.

11.3.1.3 RFI injection

The questions of whether and how much RFI should be injected is for further study

11.3.1.4 Error testing

The error test set(s) shall be capable of testing at all channel rates available in the test system (see clause 5). A test pattern of length no less than 2^{20}-1 shall be used.

11.3.2 Test conditions

11.3.2.1 Crosstalk interference

Table 49 and Table 50 show the combinations of test loops and numbers of interferers to be tested for category I ATU's, downstream and upstream respectively. Table 51 and Table 52 show the combinations of test loops and numbers of interferers to be tested for category II ATU's, downstream and upstream respectively. Net data rates to be tested and the allocation to bearer channels shall be as defined in Table 48.

Table 49 - Crosstalk tests for category I (downstream)

Test loops	Margin	Crosstalk (note)			
	(dB)	ADSL upstream NEXT and ADSL downstream FEXT	HDSL NEXT	DSL NEXT	T1 NEXT adj. binder
T1.601 (7,13)	6	—	—	24	—
CSA (4)	6	24	—	24	—
CSA (6)	6	—	20	—	—
CSA (7)	6	10	—	10	—
Mid-CSA loop	3	_	—	—	10

NOTE - The indicated interferers for each test are summed together with AWGN with PSD of -140 dBm/Hz to form a composite power spectral density.

Table 50 - Crosstalk tests for category I (upstream)

Test loops	Margin	Crosstalk (note)			
	(dB)	ADSL downstream NEXT and ADSL upstream FEXT	HDSL NEXT	DSL NEXT	T1 NEXT adj. binder
T1.601 (7,13)	6	—	—	24	—
CSA (4)	6	24	—	24	—
CSA (6)	6	—	20	—	—
CSA (7)	6	10	—	10	—
Mid-CSA loop	3	_	—	—	10

NOTE - The indicated interferers for each test are summed together with AWGN with PSD of -140 dBm/Hz to form a composite power spectral density.

Table 51 - Crosstalk tests for category II (downstream)

Test loops	Margin	Crosstalk (note)			
	(dB)	ADSL upstream NEXT and ADSL downstream FEXT	HDSL NEXT	DSL NEXT	T1 NEXT from adj. binder
T1.601 (7,9,13)	6	—	—	24	—
CSA (4,6,8)	6	10	10	24	—
Mid-CSA loop	6	_	—	10	24
NOTE - The indicated interferers for each test are summed together with AWGN with PSD of -140 dBm/Hz to form a composite power spectral density.					

Table 52 - Crosstalk tests for category II (upstream)

Test loops	Margin	Crosstalk (note)			
	(dB)	ADSL downstream NEXT and ADSL upstream FEXT	HDSL NEXT	DSL NEXT	T1 NEXT from adj. binder
T1.601 (7,9,13)	6	—	—	24	—
CSA (4,6,8)	6	10	10	24	—
Mid-CSA loop	6	_	—	10	24
NOTE - The indicated interferers for each test are summed together with AWGN with PSD of -140 dBm/Hz to form a composite power spectral density.					

11.3.2.2 Impulse test

Table 53 and Table 54 show the combinations of test loops and interferers to be tested. Net data rates to be tested and the allocation to bearer channels shall be as defined in Table 48.

Table 53 - Test loops, interferers, and data rates for impulse tests for category I

Test Loops	Interferers		
	Impulse 1	Impulse 2	crosstalk (note)
T1.601 (7,13)	yes	yes	yes
CSA (4,6,7)	yes	yes	yes
Mid-CSA (6 kft)	yes	yes	yes

Table 54 - Test loops, interferers, and data rates for impulse tests for category II

Test Loops	Interferers		
	Impulse 1	Impulse 2	Crosstalk (note)
T1.601 (7,9,13)	yes	yes	yes
CSA (4,6,8)	yes	yes	yes
Mid-CSA (6 kft)	yes	yes	Yes
NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in Table 49 or Table 51. The total power of the applied interference shall be fixed at 4 dB below the reference level.			

11.3.2.3 POTS

The interference due to POTS service on the same line is generated by use of actual telephones and central office circuits connected in the normal way to the system under test. The following POTS signaling and alerting activities shall be performed:

- Call phone at ATU-R and allow to ring 25 times;
- Pick up ringing phone at ATU-R, 25 times;
- Perform off-hook and on-hook activity on phone at ATU-R, 25 times;
- Perform pulse and tone dialing.

Table 55 and Table 56 show the combinations of test loops and interferers to be tested for categories I and II. Net data rates to be tested and the allocation to bearer channels shall be as defined in Table 48.

Table 55 - Test loops, interferers, and data rates for POTS tests category I

Test loops	Interferers	
	POTS signaling	Crosstalk (note)
ANSI (7,13)	yes	yes
CSA (4,6,7)	yes	yes
Mid-CSA loop	yes	yes
NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in Table 49. The total power of the applied interference shall be fixed 4 dB below the reference or 0 dB margin level.		

Table 56 - Test loops, interferers, and data rates for POTS tests category II

Test loops	Interferers	
	POTSsignaling	Crosstalk (note)
ANSI (7,9,13)	yes	yes
CSA (4,6,8)	yes	yes
Mid-CSA loop	yes	yes

NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in Table 51. The total power of the applied interference shall be fixed level 4 dB below the reference or 0 dB margin level.

11.3.3 Test methods

For the purpose of performing the tests as described in 11.3.3.1 to 11.3.3.3, the ATU-C and ATU-R shall be configured with a specific set of RS coding parameters which are delineated in Table 10 and Table 19. The allocation of the bearer channels to the fast and/or interleaved buffer is left to the vendor's discretion.

With the test set-up as shown in Figure 51, the test combinations described in 11.3.2 shall be tested as follows:

11.3.3.1 Crosstalk

Before testing, the ADSL units are trained with the crosstalk interference specified in 11.2.1 and 11.3.2.1 present. The simulated NEXT power is injected at the appropriate reference level. The power levels given in 11.2.1 for each type of NEXT are considered the 0 dB margin for that type and number of disturbers. For example, the 0 dB margin level for 24-disturber DSL NEXT was -52.6 dBm. Margin measurements are made by changing, in whole dB steps, the power level of the crosstalk injected at the transceiver and monitoring the BER over the test loops. A tested system has positive margin of *x* dB for a given type of crosstalk on a given loop if the system was able to operate at a BER $\leq 10^{-7}$ on all ADSL bearer channels with injected crosstalk power *x* dB above the 0 dB margin level defined in 11.2.1.

The criteria for margin level determination shall include a check that the ADSL unit can train at the margin level.

The minimum testing times to determine BERs with 95% confidence are shown in Table 57.

Table 57 - Minimum test time for crosstalk

Bearer channel data rate	Minimum test time
above 6.144 Mbit/s	100 seconds
1.536 Mbit/s to 6.144 Mbit/s	500 seconds
less than 1.536 Mbit/s	20 minutes

11.3.3.2 Impulse noise

Before testing, the ADSL units are trained with the crosstalk interference specified in 11.3.2.2 present. The test procedure consists of injecting the selected impulse wave form at varying amplitude levels and random phase. At each level the impulse is applied 15 times with a spacing of at least one second while a bit error measurement is made on the ADSL bearer channels. The amplitude (u_e) in millivolts at which half the impulses cause a bit error is determined for each wave form.

Using the above amplitude determinations, the following equation gives the estimated probability that a second will contain one or more bit errors:

Probability(ES) = 0.0037 $\times$ P(u>u_e1) + 0.0208 $\times$ P(u>u_e2)

where

P(u>u_e) = $\frac{25}{u_e^2}$ for 5 mV$\leq$ u_e $\leq$ 40 mV

P(u>u_e) = $\frac{0.625}{u_e}$ for u_e> 40 mV

u_e1 refers to waveform 1

u_e2 refers to waveform 2

The resulting Probability(ES) value shall be less than 0.14%.

11.3.3.3 POTS interference

Before testing, the ADSL units are trained with the crosstalk interference specified in 11.3.2.3 present. Signaling disturbances are created through use of the CO line connected to the splitter at the ATU-C, and the telephone set connected to the telephone jack of the splitter at the ATU-R. During these activities the ADSL channels shall be monitored while noting any test conditions that cause bit errors in the ADSL bearer channels.

Bit error requirements related to the POTS interference test are for further study.

12 Electrical characteristics

This clause specifies the combination of ATU and high-pass filter, as shown in Figure 1; further information about the low-pass filter is specified in Annex E.

12.1 DC characteristics

All requirements of this standard shall be met in the presence of all POTS loop currents from 0 mA to 100 mA, and differential loop voltages as follows:

- D.C. voltages of 0 V to minus 60 V;
- ringing signals no larger than 103 V rms at any frequency from 20 to 30 Hz with a DC component in the range from 0 V to minus 60 V;
- The input DC resistance of the ATU-x at the U-x interface shall be greater than or equal to 5 Megohms.

NOTE - The most common implementation of the splitter filters is with the low-pass and high-pass connected in parallel at the U-x port. In this arrangement the high-pass filter will typically block D.C. with capacitors.

12.2 Voiceband characteristics

12.2.1 Input impedance

The imaginary part of the ATU-x input impedance, as measured at the U-x interface, at 4 kHz shall be in the range of 1.1-2.0 kΩ (approximately equivalent to a 20 - 34 nF capacitor) for the ATU-R (or the ATU-C that has an integrated splitter and high pass function) and in the range of 500 ohms to 1.0 kΩ (approximately equivalent to 40 - 68 nF) for the ATU-C designed to be used with an external splitter. In both cases the imaginary part of the impedance shall increase monotonically with decreasing frequency below 4 kHz.

See Annex E for additional information.

12.2.2 ADSL noise interference into the POTS circuit

This is the specification for the voiceband PSD of ATU-C and ATU-R (see 6.14.2 and 7.14.2, respectively).

12.3 ADSL band characteristics

12.3.1 Longitudinal balance

Longitudinal balance at the U-C and U-R interfaces shall be > 40 dB over the frequency range 30 kHz to 1104 kHz. If only the HPF part of the POTS splitter is integrated in the ATU, the measurement of the longitudinal balance in the ADSL band shall be performed as shown in Figure 54. If both the LPF and the HPF part of the POTS splitter are integrated in the ATU, the measurement of the longitudinal balance in the ADSL band shall be performed with the PSTN and POTS interfaces terminated with ZTC and ZTR respectively, as shown in Figure 55.

Longitudinal balance is given by the equation

$$LBal = 20 \times \log_{10} \left| \frac{e_l}{e_m} \right| dB$$

where

e_l = the applied longitudinal voltage (referenced to the building or green wire ground of the ATU);

e_m = the resultant metallic voltage appearing across a terminating resistor.

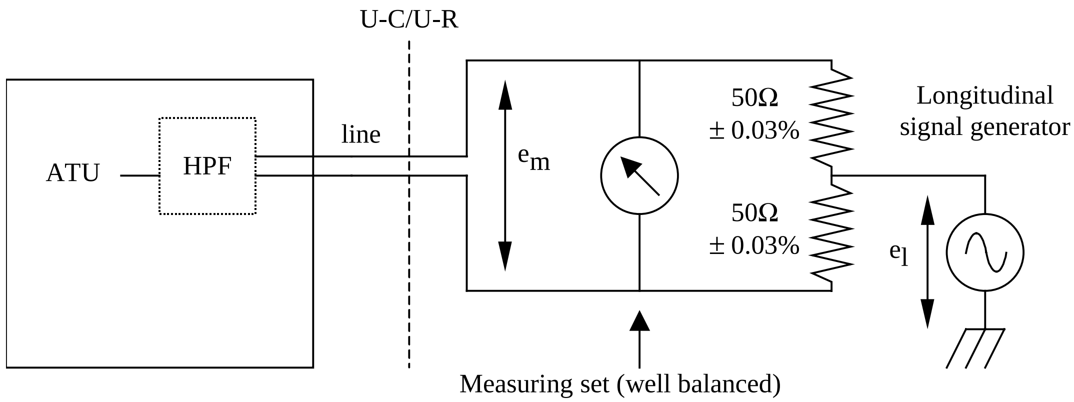


Figure 54 - Longitudinal balance above 30 kHz measurement method (only HPF integrated)

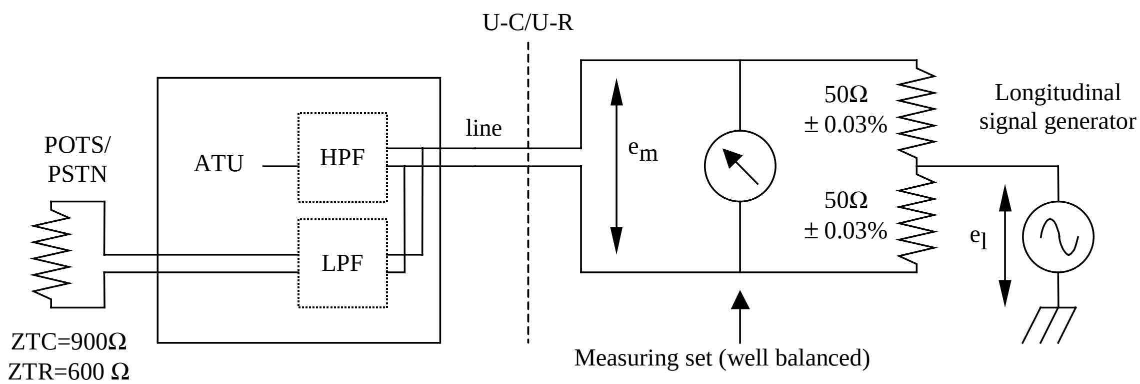


Figure 55 - Longitudinal balance above 30 kHz measurement method (HPF and LPF integrated)

13 Physical characteristics

13.1 Wiring polarity integrity

ADSL operation shall be independent of the polarity of the pair of wires connecting the ATU-C and the ATU-R

13.2 Connector

13.2.1 RJ31X for modems with internal POTS splitters

For single mountings, the connection of the POTS splitter to the existing Customer Interface wiring shall be as specified in Table 58 and shown in Figure 56 using an 8 pin plug and jack (RJ31X) equipped with shorting bars. In this configuration the cord connecting the POTS splitter and ATU-R unit shall be hard wired. The use of a separate POTS splitter physically separated from the ATU-R is not precluded by this standard. The layer 1 requirements for the ATU-R-to-splitter interface may be defined in a later issue of the standard. For multiple mountings, other connection arrangements may be appropriate.

Table 58 - Pin assignments for 8-position jack and plug at Network Interface

Pin No.	Assignment for Jack	Assignment for Plug
1	Tip or ring to POTS distribution	Tip or ring to POTS splitter (out)
2	No connection	No connection
3	No connection	No connection
4	Tip or ring from network interface	Tip or ring to POTS splitter (in)
5	Tip or ring from network interface	Tip or ring to POTS splitter (in)
6	No connection	No connection
7	No connection	No connection
8	Tip or ring to POTS distribution	Tip or ring to POTS splitter (out)

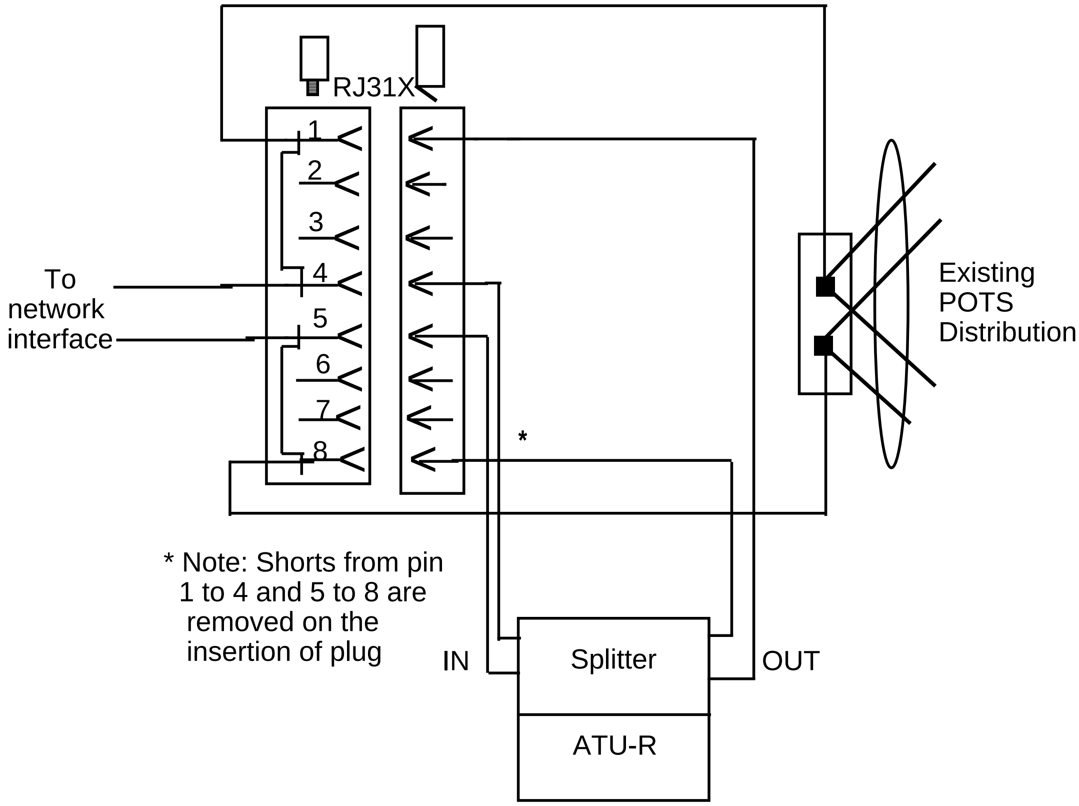
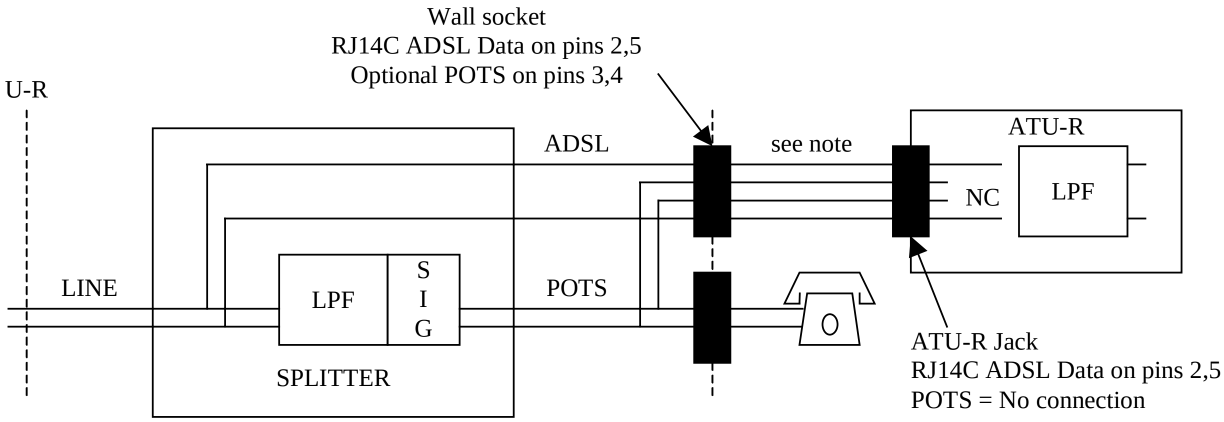


Figure 56 - Interface on the customer premises side of the U-R

13.2.2 RJ14C for Externally mounted POTS splitters

External POTS splitters are normally mounted in the NID or near the building entrance. It is expected that wires from the external POTS splitter will be run on inside premises wiring either new or old, and that the termination at the wall jack will be on a RJ14C jack. In this arrangement POTS voiceband signals may be present on the center pair of wires, pair 1 (Pins 3,4). The ADSL signal shall be supplied on pair 2 (Pins 2,5). A cord to connect the wall jack with the ATU-R would have a separation of 80 dB between pairs. See E.5 in Annex E for details.



NOTE - See E.5 in Annex E for further information on cable.

Figure 57- House Wiring for external POTS splitter

13.3 Wiring requirements for an ATU-R with integrated POTS splitter.

It is recommended for an AUT-R with integral POTS splitter that the plug and jack arrangement specified in 13.2.1 be used. The connections between plug 1 and jack 2 are as specified in Table 59, and illustrated in Figure 58. The pin connections for plug 2 shall be as specified in Table 58. In this configuration the cord connecting the POTS splitter and ATU-R unit shall be hard wired.

Table 59 - Pin assignments for 8-position jack and plug at remote location

Pin No.	Assignment for Jack 2
1	From pin 1 of plug 1 to pin 1 of jack 2
2	No connection
3	No connection
4	From pin 4 of plug 1 to pin 4 of jack 2
5	From pin 5 of plug 1 to pin 5 of jack 2
6	No connection
7	No connection
8	From pin 8 of plug 1 to pin 8 of jack 2

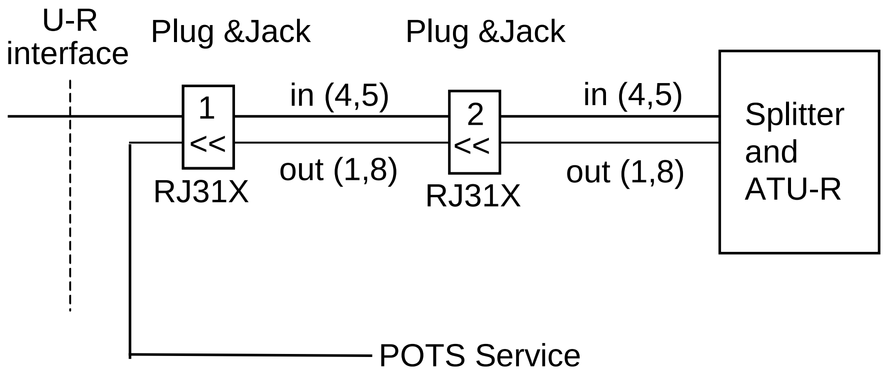


Figure 58 - Wiring for a remote ATU-R with integrated POTS splitter

13.4 Maximum distance for a remotely located unit

The distance between plug and jack 1 and the ATU-R unit with integral POTS splitter shall not exceed 300 feet when the two pairs, (4,5) and (1,8) are in a common sheath.

14 Environmental conditions

14.1 Protection

Material referring to protection may be found in Annex O of this standard.

14.2 Electromagnetic compatibility

Material referring to electromagnetic compatibility may be found in Annex O of this standard.

Annex A
(normative)

ATU-C and ATU-R state diagrams

A.1 Introduction

This annex provides state diagrams for the ATU-C and ATU-R, some portions of which shall be supported to guarantee interworking between different manufacturers' units, and some portions of which are presented here as an example only - their functions may be required or desired, but the implementation is left to the vendor.

A.2 Definitions

The following terms and abbreviations are used in this annex. Where states or events have been defined elsewhere in this standard, the definitions are referenced here for convenience.

- C-ACT : See 9.2.2;
- C-TONE : See 9.2.1.3;
- R-ACT-REQ : See 9.3.1;
- R-ACK : See 12.3.3;
- lof-rs : Loss of ADSL frame sync/resync event. This event occurs when some algorithm, which may be vendor-specific, determines that a resync attempt is required. Note that this lof-rs event is probably (but not required to be) related to the sef (severely errored frame) defect defined for operations and maintenance (8.2).
- Persistent LOF : Persistent LOF is declared after 2.5 ± 0.5 seconds of near-end LOF failure with sef defect still present. LOF failure and sef defect are defined for operations and maintanance in 8.2.
- Persistent LOS : Persistent LOS is declared after 2.5 ± 0.5 seconds of near-end LOS failure with los defect still present. LOS failure and los defect are defined for operations and maintanance in 8.2.
- high BER : High bit error rate in received data: detected by thresholding #crc errors (near-end crc-8i and crc-8f error anomalies, defined in 8.2) over some period of time.
- host control channel : An ATU-C configuration control channel from some host controller, such as an ACOT (ADSL Central Office Terminal), which controls one or more ATU-C line units. Note that this channel has no relationship or direct interworking with the "C"-channel, which is sometimes also called the control channel.
- reconfig1 : A channelization reconfiguration that can be accomplished without resetting certain key portions of the data framing, transmitter, or receiver functions (clauses 6 and 7), and thus can be performed without disrupting channels that would not change as a result of the reconfiguration. For example, if four 1.536 Mbit/s simplex channels are currently active and are all allocated to the interleave data buffer, then a reconfiguration that requires two of them to remain active, and the other two to be replaced by a 3.088 Mbit/s channel would qualify as a reconfig1.
- reconfig2: A channelization reconfiguration that requires resetting of some key portion of the data framing, transmitter, or receiver functions (clauses 6 and 7), and which thus cannot be achieved without loss of some user data. This reconfiguration request will require a fast retrain. Examples are:
  - a change of the bearer channel rates, such as a request for a reconfiguration from a single 6.144 Mbit/s simplex bearer channel to a 6.312 Mbit/s simplex bearer channel, which requires a change in aggregate transmitted bit rate, FEC codeword size, and resetting the interleave/deinterleave functions;
  - if four 1.536 Mbit/s simplex bearer channels are currently active and are all allocated to the interleave data buffer, then a reconfiguration that requires one or more of them to move to the fast

data buffer would require a fast retrain to allocate the extra AEX byte for the fast data buffer, to change the FEC codeword parameters of the interleaved data buffer, and to reset the interleave/deinterleave functions.

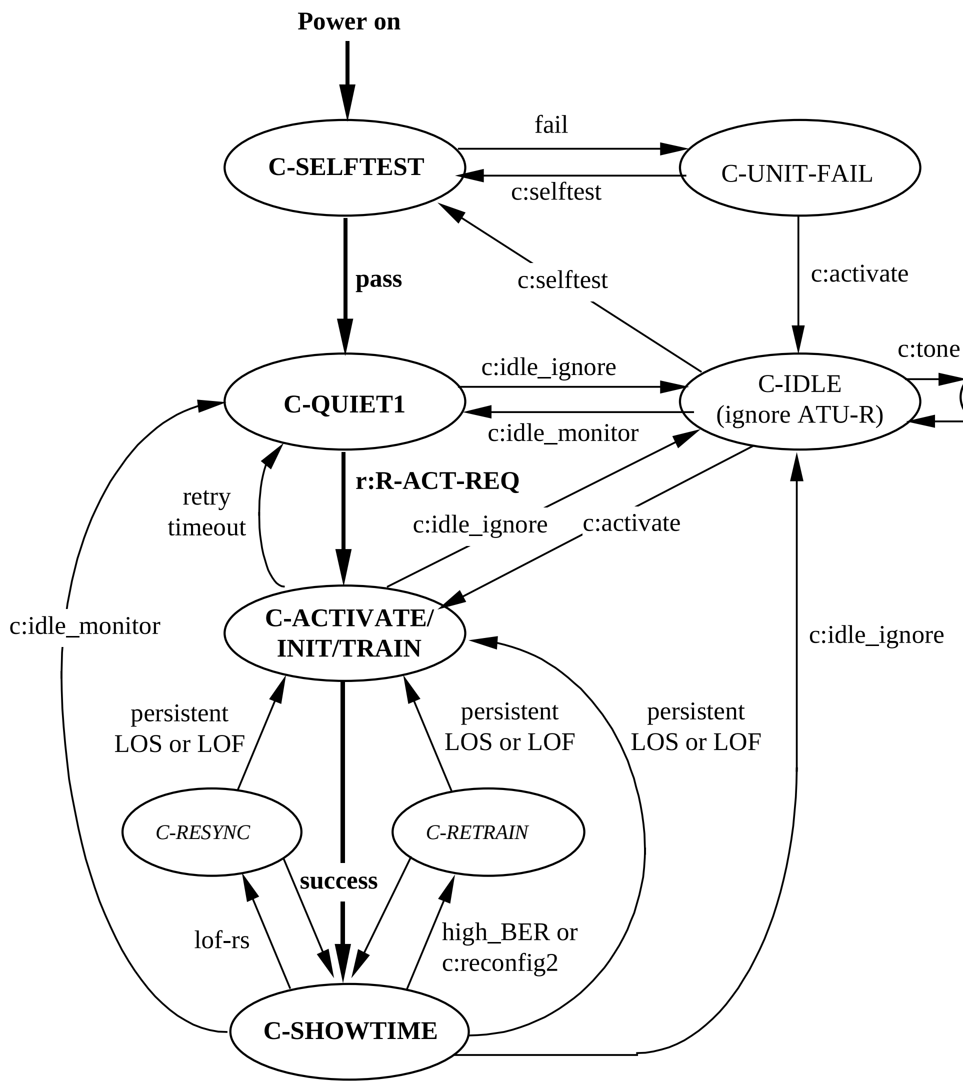
A.3 State Diagrams

State diagrams are given in Figure A.1 for the ATU-C, and in Figure A.2 for the ATU-R. States are indicated by ovals, with the name of the state given within the oval. The states are defined in Table A.1 for the ATU-C and in Table A.2 for the ATU-R. Transitions between states are indicated by arrows, with the event causing the transition listed next to the arrow. For some events, the source of the event is indicated with letter(s) and a colon preceding the event name; a key to the source events is provided at the bottom of each figure. All states shall be supported, except the optional *Retrain* and *Resync* states.

In the state diagram for the ATU-C, a C-IDLE state would be desired to guarantee a quiet mode, which may be useful prior to provisioning, to allow certain tests (e.g., MLT), or to discontinue service. A selftest function is desirable, but it may be a vendor/customer option to define when selftest occurs (e.g., always at power-up or only under CO control), and which transition to take after successfully completing selftest (e.g., enter C-IDLE, or enter C-QUIET1, or enter C-Activate/Init/Train).

A variety of "host controller" commands (events preceded by "c:") are optional in the ATU-C state diagram and shown as example events and transitions between states. The way in which these events are implemented is left to the vendor, since many options are possible (e.g., separate host controller port on the ATU-C, switches or other front-panel controls, fixed options).

An optional *Retrain* state is shown in both state diagrams (fast retrain is still under study). An optional *Resync* state is shown in both state diagrams, to be left as a vendor option that may use vendor proprietary algorithms.



NOTES

1. Event Sources:

– c:___ host controler command;

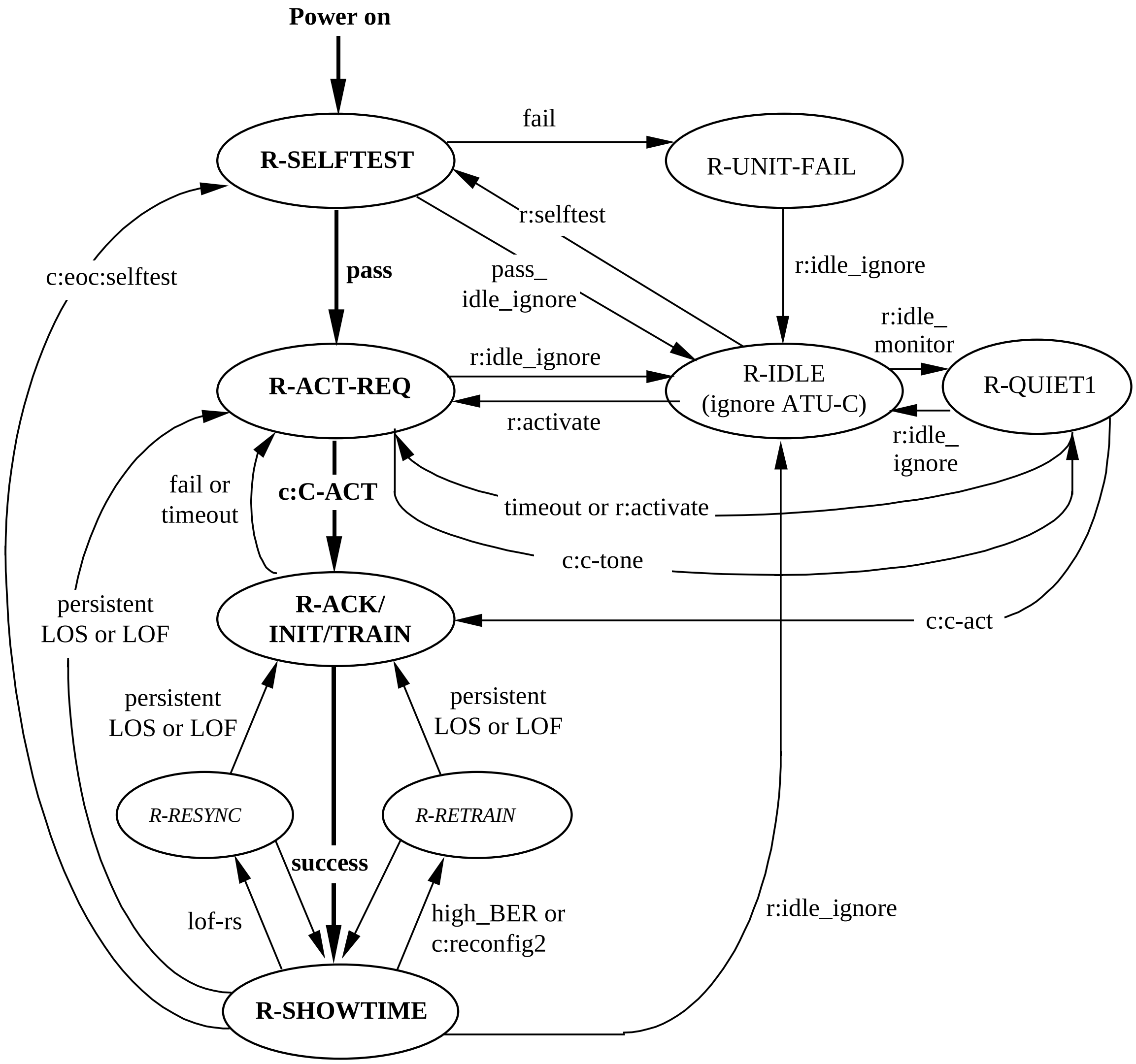
– r:___ received from ATU-R.

2. The main sequence of states is shown in bold.

3. Optional (vendor discretionary) states are shown in *italics*.

4. States are defined in Table A.1; terms in clause A.2.

Figure A.1 - State diagram for the ATU-C



NOTES

1. Event Sources:

– r:___ host controler command;

– c:___ received from ATU-C.

2. The main sequence of states is shown in bold.

3. Optional (vendor discretionary) states are shown in *italics*.

4. States are defined in A.2; terms in clause A.2.

Figure A.2 - State diagram for the ATU-R

Table A.1 - ATU-C state definitions

State Name	Description
C-SELFTEST	Unit performs selftest. Transmitter and receiver off (quiet at U-C interface); no response to host control channel (e.g., ACOT)
C-UNIT-FAIL	(selftest failed) Monitor host control channel if possible (could allow ATU host controller to retrieve selftest results)
C-IDLE (9.2.2) (Idle; ignore ATU-R)	Transmitter and receiver off (no response to R-ACT-REQ). Monitor host control channel
C-TONE	Transmit C-TONE tone and transition back to C-IDLE
C-QUIET1 (9.2.1) (Idle; monitor ATU-R)	Transmitter off Receiver on, monitor for R-ACT-REQ; if detected, transition to C-Activate/Init/Train state Monitor host control channel

C-ACTIVATE/INIT
/TRAIN
(Starts with State C-ACT of 9.2; includes 9.2, 9.4, 9.6, 9.8)
	Initialize Train_Try_Counter
	while (--Train_Try_Counter >= 0)
	{ Transmit C-ACT (9.2.2)
	Start timer
	If receive R-ACK before timer expires
	proceed with initialization/training
	If successful, transition to C-ACTIVE
	}
	Transition to C-QUIET1
	Monitor host control channel

C-SHOWTIME (Steady State Data Transmission; 6, 8.2, 8.2, 10)	Perform steady state bit pump functions (user data channels active) Allow bit swaps and non-intrusive reconfigurations (reconfig1) Monitor host control channel Monitor alarms, eoc, aoc If LOS or LOF event, transition to C-Activate/Init/Train

(continued)

Table A.1 - ATU-C state definitions *(concluded)*

C-Resync (optional; vendor proprietary)	(State is entered when some algorithm, possibly based on loss of ADSL sync framing, determines that resync is required) Declare sef (defined in 8.2) - user data transmission has been disrupted If signal present (i.e., not los) Attempt to find sync pattern and realign (vendor proprietary) If successful, remove sef and transition to C-SHOWTIME Else time-out on sef, declare LOF failure, on persistent LOF transition to C-Activate/Init/Train Else time-out on los, declare LOS failure, on persistent LOS transition to C-Activate/Init/Train
C-Retrain (fast retrain for further study)	(State can only be entered if received signal is still present and if ADSL frame sync is still maintained) Declare sef (defined in 8.2) - user data transmission has been disrupted If signal present (i.e., not los) Channel ID and bit allocation calculation Reset Data Framing and V-C interface circuits If successful, remove sef and return to C-SHOWTIME Else time-out on sef, declare LOF failure, on persistent LOF failure, transition to C-Activate/Init/Train Else time-out on los, declare LOS failure, on persistent LOS failure transition to C-Activate/Init/Train

Table A.2 - ATU-R state definitions

State Name	**Description**
R-SELFTEST	Unit performs selftest. Transmitter and receiver off (quiet at U-R interface). If selftest passes and receiver is in automatic training mode transition to R-ACT-REQ If selftest passes and receiver is under external control, transition to R-IDLE else transition to R-UNIT-FAIL
R-UNIT-FAIL	(selftest failed - no exit from this state, except to cycle power)

R-ACT-REQ
(9.3.1)
	Receiver on, monitoring for C-ACT or C-TONE
	while (C-ACT not received AND C-TONE not received)
	{ Transmit R-ACT-REQ for 128 symbols (see 9.3.1)
	No transmission for 896 symbols
	}
	If (C-ACT was received) transition to R-INIT/TRAIN
	If (C-TONE was received) transition to R-QUIET1
	Monitor host control channel (see note)

R-QUIET1 (9.3.2) (Idle; monitor ATU-C)	Transmitter off; Receiver on, monitoring for C-ACT Start timer (60 seconds, see 9.3.2) At timeout transition to R-ACT-REQ Monitor host control channel
R-INIT/TRAIN (Starts with State R-ACK of 9.3; includes 9.3, 9.5, 9.7, 9.9)	Transmit R-ACK Proceed with Initialization and Training Sequence If successful, transition to R-SHOWTIME Else transition to R-ACT-REQ
R-SHOWTIME (Steady State Data Transmission; 7, 8.2, 10)	Perform steady state bit pump functions (user data channels active) Allow bit swaps and nonintrusive reconfigurations (reconfig1) Monitor alarms, eoc, aoc, host control channel If persistent LOS or LOF failure, transition to R-ACT-REQ
R-IDLE (ignore ATU-C)	Transmitter and receiver off, monitor host control channel

(continued)

Table A.2 - ATU-R state definitions *(concluded)*

R-RESYNC (optional; vendor proprietary)	(State is entered when some algorithm, probably based on loss of ADSL sync framing, determines that resync is required) Declare sef (defined in 8.2) - user data transmission has been disrupted If signal present (i.e., not los) Attempt to find sync pattern and realign (vendor proprietary) If successful, remove sef and transition to R-SHOWTIME else time-out on sef, declare LOF failure, on persistent LOF failure transition to R-ACT-REQ else time-out on los, declare LOS failure, on persistent LOS failure transition to R-ACT-REQ
R-RETRAIN (fast retrain for further study)	(State can only be entered if received signal is still present and if ADSL frame sync is still maintained) Declare sef (defined in 8.2) - user data transmission has been disrupted Reset Data Framing and T-interface circuits If signal present (i.e., not los) Channel ID and bit allocation calculation If successful, remove sef and transition to R-SHOWTIME else time-out on sef, declare LOF failure, on persistent LOF failure transition to R-ACT-REQ else time-out on los, declare LOS failure, on persistent LOS failure transition to R-ACT-REQ

Annex B
(normative)

Power spectral density of crosstalk disturbers

Crosstalk margin measurements were made for four types of disturbers, DSLs, HDSLs, T1s and ADSL lines. DSL, HDSL, and ADSL crosstalk is from pairs in the same binder group; T1 crosstalk is from pairs in an adjacent binder group.

B.1 Simulated DSL power spectral density and induced NEXT

The power spectral density (PSD) of Basic Access DSL disturbers is expressed as:

$$PSD_{DSL\text{-}Disturber} = K_{DSL} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^4}, \qquad f_{3dB} = 80\ kHz,\ 0 \le f < \infty$$

where $f_o = 80\ kHz,\ K_{DSL} = \frac{5}{9} \times \frac{V_p^2}{R},\ V_p = 2.50$ Volts and R = 135 Ohms

This equation gives the single-sided PSD; that is, the integral of PSD, with respect to *f*, from 0 to infinity, gives the power in Watts. $PSD_{DSL\text{-}Disturber}$ is the PSD of an 80 ksymbols/sec 2B1Q signal with random equiprobable levels, with full-band square-topped pulses and with 2nd order Butterworth filtering (f_{3dB} = 80 kHz).

The PSD of the DSL NEXT can be expressed as:

$$PSD_{DSL-NEXT} = PSD_{DSL-Disturber} \times \left(x_n \times f^{3/2}\right) \qquad for\ 0 \le f < \infty, n < 50$$

where $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of $PSD_{DSL\text{-}Disturber}$ and $PSD_{DSL\text{-}NEXT}$ over various frequency ranges of interest are presented in Table B.1.

Table B.1 - DSL transmit and DSL-induced NEXT power

Frequency Range	**Transmit Power** dBm	**NEXT Power** DBm 24 disturber
0-0.16 MHz	13.60	-52.62
0-0.32 MHz	13.60	-52.62
0-1.544 MHz	13.60	-52.62
0-3 MHz	13.60	-52.62
0-10 MHz	13.60	-52.62

Figure B.1 shows the theoretical PSD of 24 Disturber DSL NEXT.

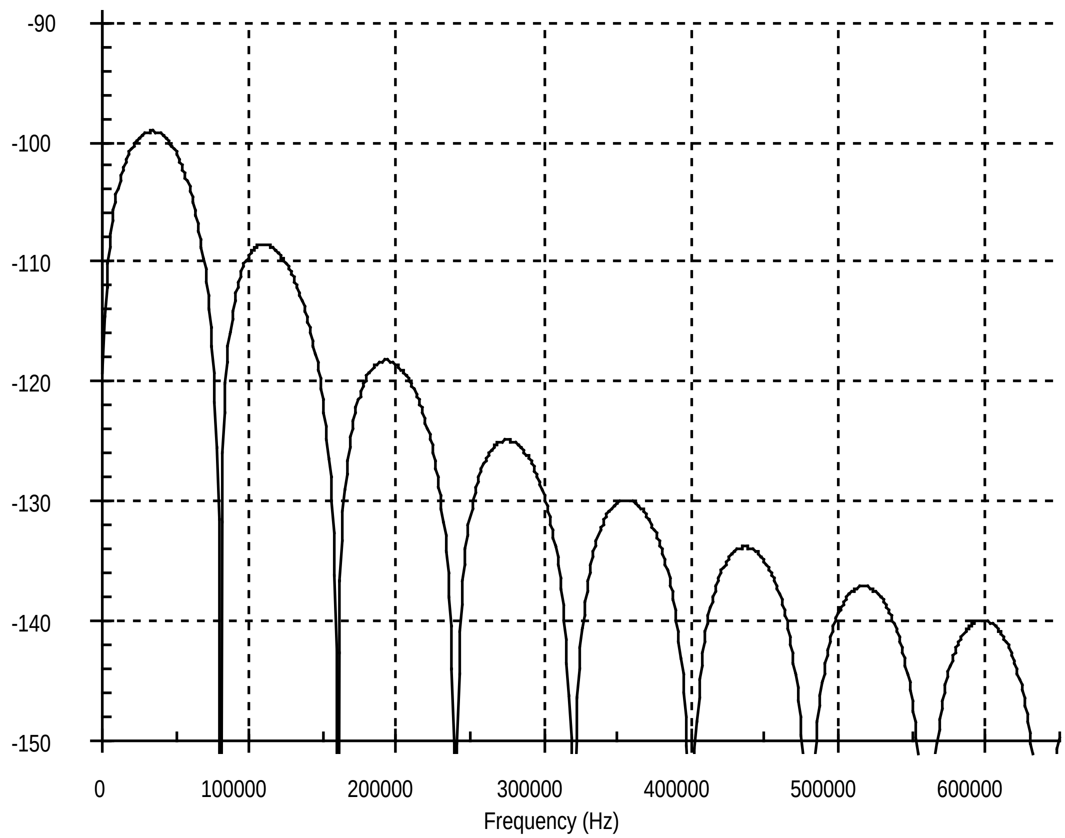


Figure B.1 - 24-disturber DSL NEXT

B.2 Simulated HDSL power spectral density and induced-NEXT

The PSD of HDSL disturbers is expressed as:

$$PSD_{HDSL\text{-}Disturber} = K_{HDSL} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^8}, \qquad f_{3dB} = 196 \text{ kHz}, \ 0 \le f < \infty$$

where $f_o = 392kHz$, $K_{HDSL} = \frac{5}{9} \times \frac{V_p^2}{R}$, $V_p = 2.70$ Volts, and R = 135 Ohms

This equation gives the single-sided PSD; that is, the integral of PSD, with respect to *f*, from 0 to infinity, gives the power in Watts. $PSD_{HDSL\text{-}Disturber}$ is the PSD of a 392 ksymbols/sec 2B1Q signal with random equiprobable levels, with full-band square-topped pulses and with 4-th order Butterworth filtering (f_{3dB} = 196 kHz).

The PSD of the HDSL NEXT can be expressed as:

$$PSD_{HDSL-NEXT} = PSD_{HDSL-Disturber} \times \left(x_n \times f^{3/2}\right) \qquad for \ 0 \le f < \infty, n < 50$$

where $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of $PSD_{HDSL\text{-}Disturber}$ over various frequency ranges of interest is presented in Table B.2 along with the induced NEXT power.

Table B.2 - HDSL transmit and induced NEXT power

Frequency Range	**Transmit Power** dBm	**NEXT Power** **10 disturbers** dBm
0-0.196 MHz	13.44	-46.9
0-0.392 MHz	13.60	-46.3
0-0.784 MHz	13.60	-46.3
0-1.544 MHz	13.60	-46.3
0-1.568 MHz	13.60	-46.3
0-3 MHz	13.60	-46.3

Figure B.2 shows the theoretical PSD of 10-Disturber HDSL NEXT.

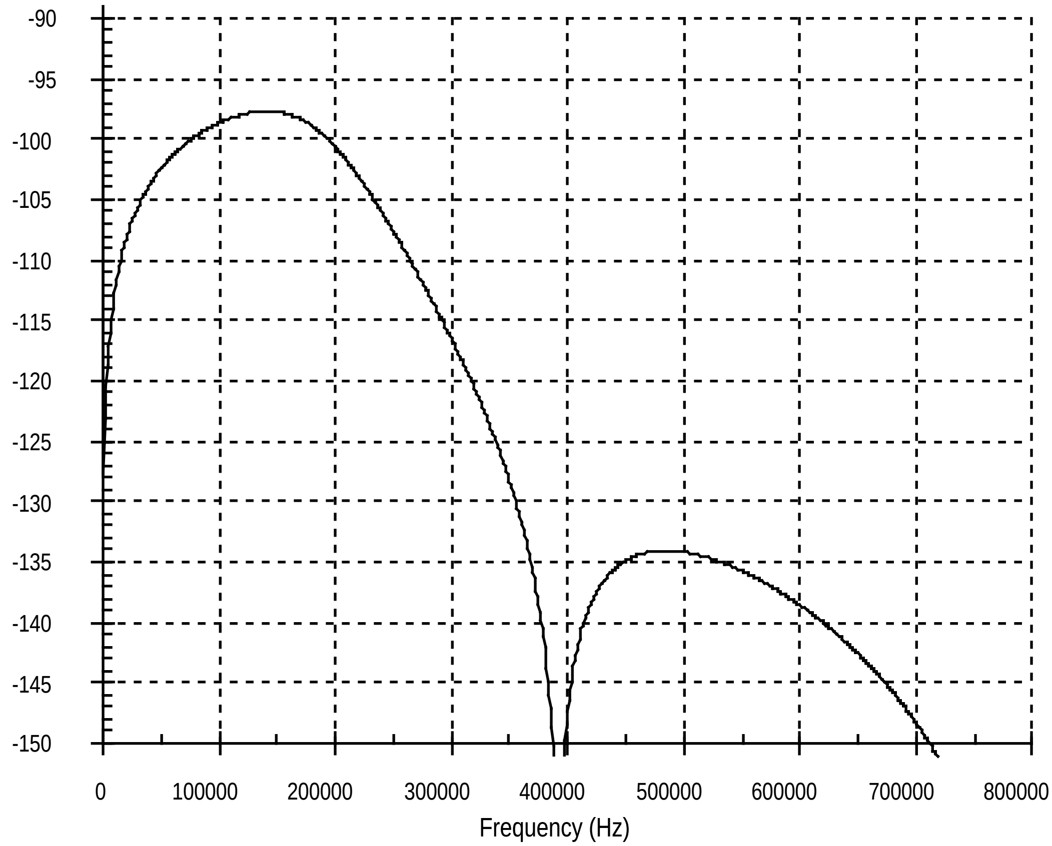


Figure B.2 - 10-disturber HDSL NEXT

B.3 Simulated T1 line power spectral density and induced - NEXT

The PSD of the T1 line disturber is assumed to be the 50% duty-cycle random Alternate Mark Inversion (AMI) code at 1.544 Mbit/s. The single-sided PSD has the following expression.

$$PSD_{T1-Disturber} = \frac{V_P^2}{R_L} \times \frac{2}{f_o} \left[\frac{\sin\left(\frac{\pi f}{f_o}\right)}{\left(\frac{\pi f}{f_o}\right)} \right]^2 \sin^2\left(\frac{\pi f}{2 f_o}\right) \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^6} \times \frac{f^2}{f^2 + f_{3dB}^2}\ , \qquad 0 \le f < \infty$$

The total power of the transmit T1 signal is computed by:

$$P_{T1-total} = \frac{1}{4} \frac{V_p^2}{R_L}$$

It is assumed that the transmitted pulse passes through a low-pass shaping filter. The shaping filter is chosen as a third order low-pass Butterworth filter with 3-dB point at 3.0 MHz. The filter magnitude squared transfer function is:

$$\left|H_{shaping}(f)\right|^2 = \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^6}$$

In addition, the coupling transformer is modeled as a high-pass filter with 3-dB point at 40 kHz as:

$$\left|H_{Transformer}(f)\right|^2 = \frac{f^2}{f^2 + f_{3dB}^2}$$

Furthermore, it is assumed that V_p = 3.6 Volts, R_L = 100 Ohms, and f_o = 1.544 MHz.

The PSD of the T1 NEXT can be expressed as:

$$PSD_{T1-NEXT} = PSD_{T1-Disturber} \times \left(x_n \times f^{3/2}\right) \qquad for\ 0 \le f < \infty,\ n < 50$$

where $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The T1 transmit and T1-induced NEXT powers using n-crosstalk models (x_n) are presented in Table B.3.

Table B.3 - T1 transmit and induced NEXT power with shaping and coupling transformer

Frequency Range	**Transmit Power** dBm	**NEXT Power** **4 disturbers** dBm	**NEXT Power** **24 disturbers** dBm
0-1.544 MHz	14.1	-34.7	-30.0
0-3 MHz	14.57	-32.8	-28.1

Figure B.3 shows the theoretical PSD of 4 and 24-Disturber T1 NEXT.

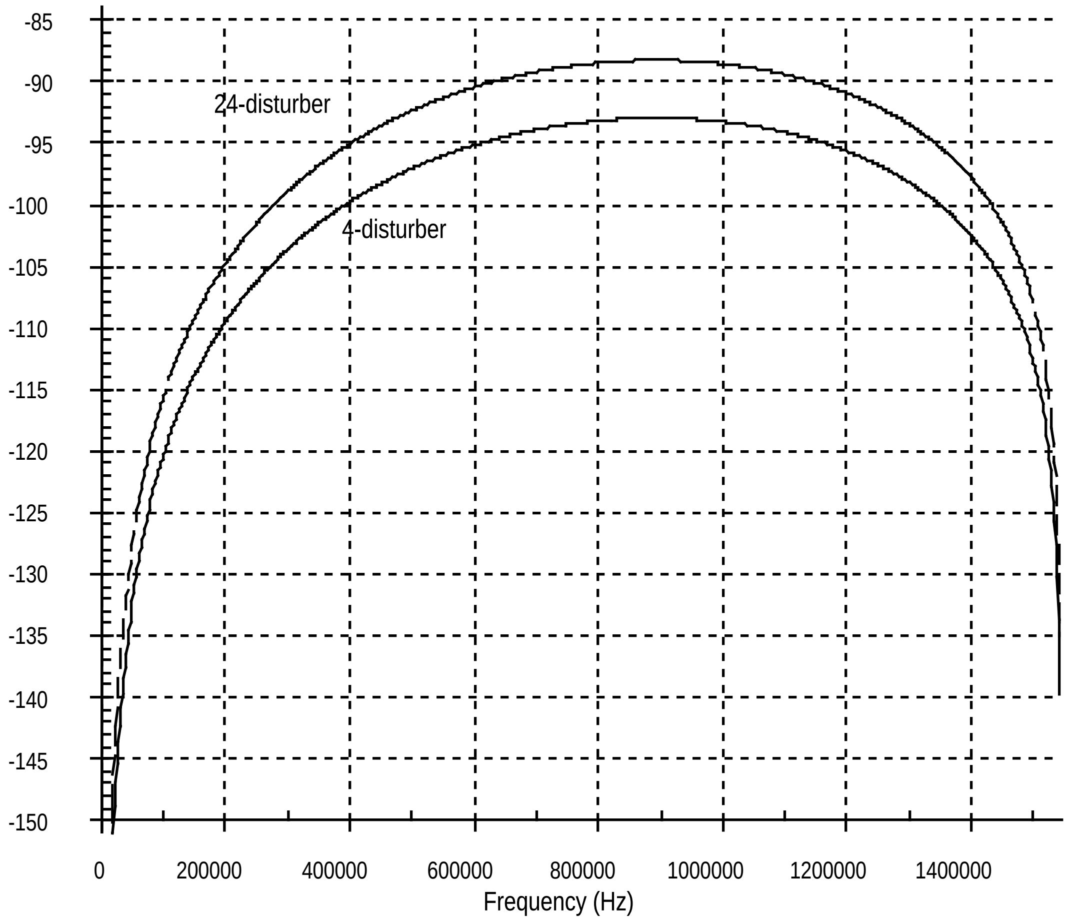


Figure B.3 - 4 and 24-disturber T1 NEXT

For testing, the T1 interferer power and the PSD curve are adjusted downward by a total of 15.5 dB to allow for the adjacent binder effect and an averaging factor which accounts for noncollocation of the T1 and ADSL terminals.

B.4 Simulated ADSL downstream PSD and induced FEXT and NEXT

The PSD of ADSL disturbers is expressed as:

$$PSD_{\text{ADSL-Disturber}} = K_{\text{ADSL}} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times |LPF(f)|^2 \times |HPF(f)|^2 , \qquad 0 \le f < \infty$$

where $f_o = 2.208 \times 10^6$ Hz, $K_{\text{ADSL}} = 0.1104$ Watts

This equation gives the single sided PSD, where K_{ADSL} is the total transmitted power in Watts for the downstream ADSL transmitter before shaping filters, and is set such that the ADSL PSD will not exceed the maximum allowed PSD. f_0 is the sampling frequency in Hz and

$$\left|LPF(f)\right|^2 = \frac{f_h^{\alpha}}{f^{\alpha} + f_h^{\alpha}} \;,\; f_h = 1.104\times10^6\,Hz,\, \alpha = \frac{36}{10\log(2)} = 11.96$$

is a low pass filter with a 3 dB point at 1104 kHz and 36 dB/oct rolloff, and

$$\left|HPF(f)\right|^2 = \frac{f^{\alpha} + f_l^{\alpha}}{f^{\alpha} + f_h^{\alpha}} \;,\; f_l = 4000\ Hz,\ f_h = 25875\ Hz,\, \alpha = \frac{57.5}{10\log\frac{f_h}{f_l}} = 7.09$$

is a high pass filter with 3 dB points at 4 and 25.875 kHz and 57.5 dB attenuation in the voiceband, separating ADSL from POTS. With this set of parameters the $PSD_{ADSL\text{-}Disturber}$ is the PSD of a downstream transmitter that uses all the sub-carriers.

B.4.1 FEXT

The FEXT loss model is:

$$\left|H_{FEXT}(f)\right|^2 = \left|H_{channel}(f)\right|^2 \times k \times l \times f^{\,2}$$

where

$H_{channel}$(f) is the channel transfer function,

k is the coupling constant and is $8 \times 10^{-20} \times (n/49)^{0.6}$ for n<50 or 3.083×10^{-20} for 10, 1% worst-case disturbers,

l is the coupling path length in feet and equals 9000 ft for CSA #6,

f is in Hz.

The FEXT noise PSD is therefore:

$$PSD_{ADSL-FEXT} = PSD_{ADSL-Disturber} \times \left|H_{FEXT}(f)\right|^2$$

The integration of $PSD_{ADSL\text{-}Disturber}$ and $PSD_{ADSL\text{-}FEXT}$ over the various frequency ranges is shown in table B.4.

Table B.4 - $PSD_{ADSL\text{-}Disturber}$ and $PSD_{ADSL\text{-}FEXT}$ power with shaping and coupling transformer

Frequency range	Transmit power ADSL-Disturber dBm	FEXT Power 10 disturbers dBm	FEXT power 24 disturbers dBm
0 - 1.104 MHz	19.0	- 69.6	- 67.3
0 - 2.204 MHz	19.2	- 69.6	- 67.3
0 - 4.416 MHz	19.2	- 69.6	- 67.3

Figure B.4 shows the theoretical PSD of 10-disturber downstream ADSL FEXT on CSA loop #6.

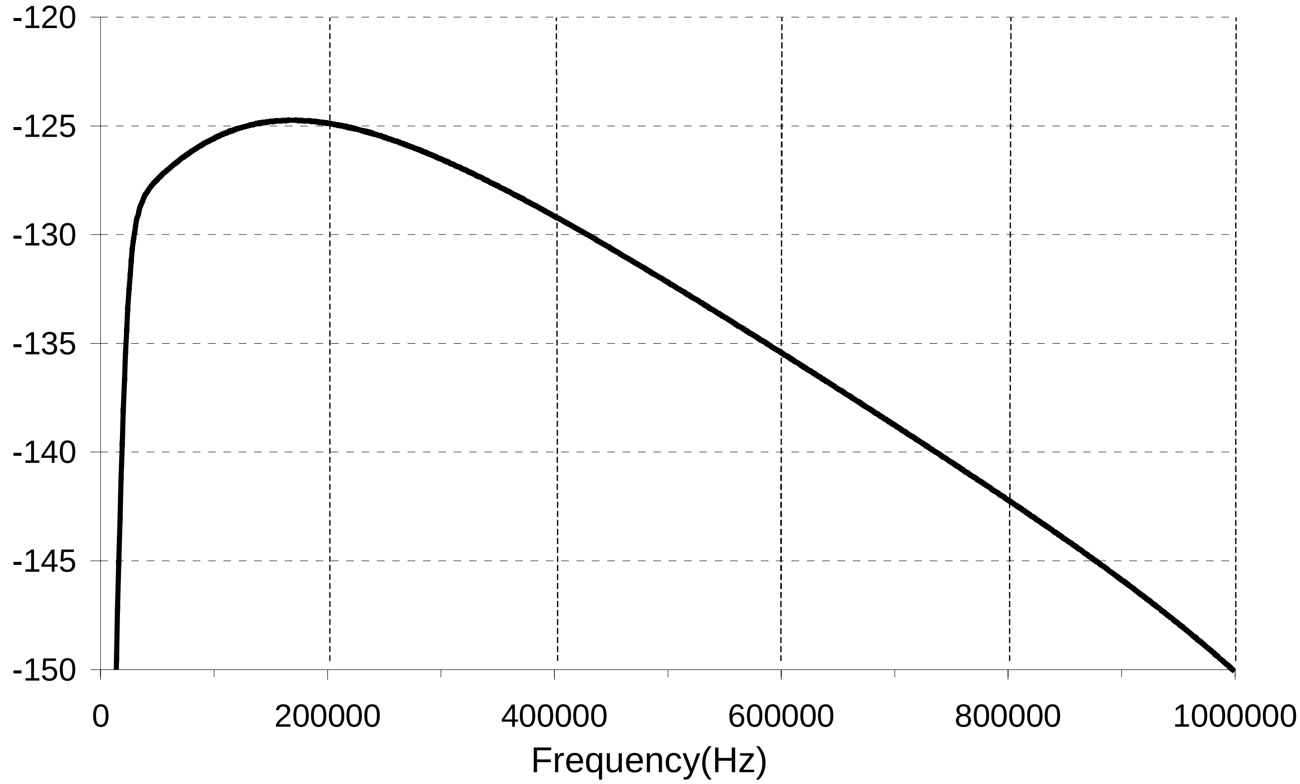


Figure B.4 - Theoretical 10-disturber downstream ADSL FEXT

B.4.2 NEXT

The PSD of the ADSL NEXT into the upstream is defined as:

$$PSD_{ADSL-NEXT} = PSD_{ADSL-Disturber} \times \left(x_n \times f^{3/2}\right) \qquad for\ 0 \le f < \infty, n < 50$$

where $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

The integration of the induced NEXT over the band from 0 to 1.104 MHz for n=49 is -25.4 dBm.

Figure B.5 shows the theoretical PSD of 10-disturber downstream ADSL NEXT into the upstream.

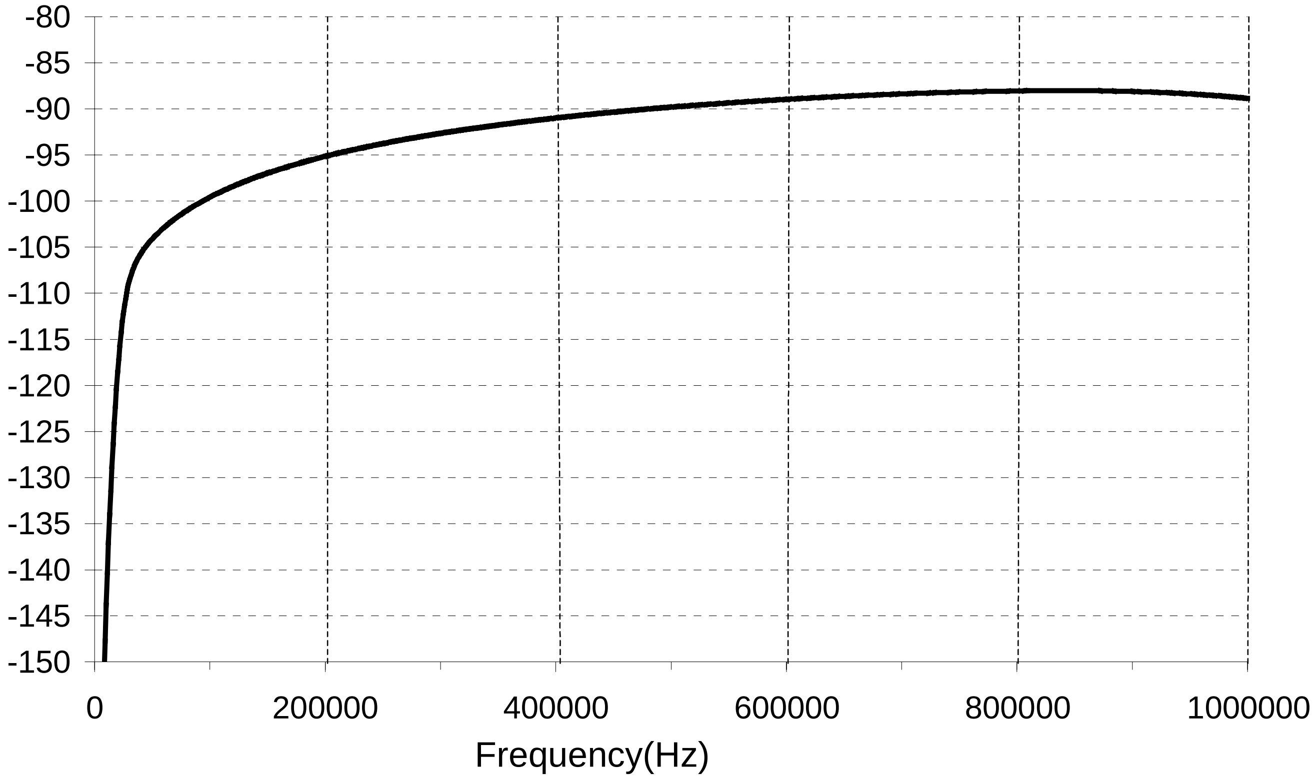


Figure B.5 - 10-disturber downstream ADSL NEXT into the upstream

B.5 Simulated ADSL-upstream PSD and induced FEXT and NEXT

The PSD of ADSL disturbers is expressed as:

$$PSD_{\text{ADSL-Disturber}} = K_{\text{ADSL}} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times |LPF(f)|^2 \times |HPF(f)|^2, \qquad 0 \le f < \infty$$

where $f_o = 276 \times 10^3 \text{ Hz}, K_{\text{ADSL}} = 0.0437\ Watts,$

This equation gives the single sided PSD, where K_{ADSL} is the total transmitted power in Watts for the upstream ADSL transmitter before shaping filters, and is set such that the ADSL PSD will not exceed the maximum allowed PSD. f_0 is the sampling frequency in Hz and

$$\left|LPF(f)\right|^2 = \frac{f_h^\alpha}{f^\alpha + f_h^\alpha}\ ,\ f_h = 138 \times 10^3\ Hz, \alpha = \frac{24}{10\log(181.125/138)} = 20.32$$

is a low pass filter with a 3 dB point at 138 kHz and 24 dB attenuation at 181.125 kHz, and

$$\left|HPF(f)\right|^2 = \frac{f^\alpha + f_l^\alpha}{f^\alpha + f_h^\alpha}\ ,\ f_l = 4000\ Hz,\ f_h = 25875\ Hz, \alpha = \frac{59.5}{10\log\frac{f_h}{f_l}} = 7.34$$

is a high pass filter with 3 dB points at 4 and 25.875 kHz and 59.5 dB attenuation in the voiceband, separating ADSL from POTS. With this set of parameters the $PSD_{\text{ADSL-Disturber}}$ is the PSD of an upstream transmitter that uses all the sub-carriers.

This ADSL-disturber PSD reflects a model for test purposes. For consistency with ANSI T1.413 Issue 1, this ADSL-disturber PSD model uses the ANSI T1.413 Issue 1 upstream PSD mask (LPF is 24 dB down at 181.125 kHz). An ADSL-disturber PSD figure derived from the ANSI T1.413 Issue 2 upstream PSD mask (see 7.14) will deviate from this model.

B.5.1 FEXT

The FEXT loss model is:

$$\left|H_{FEXT}(f)\right|^2 = \left|H_{channel}(f)\right|^2 \times k \times l \times f^2$$

where

H_{channel}(f) is the channel transfer function,

k is the coupling constant and is $8 \times 10^{-20} \times (n/49)^{0.6}$ for n<50 or 3.083×10^{-20} for 10, 1% worst-case disturbers,

l is the coupling path length in feet and equals 9000 ft for CSA #6,

f is in Hz.

The FEXT noise PSD is therefore:

$$PSD_{ADSL-FEXT} = PSD_{ADSL-Disturber} \times \left|H_{FEXT}(f)\right|^2$$

Figure B.6 shows the theoretical PSD of 10-disturber upstream ADSL FEXT on CSA loop #6.

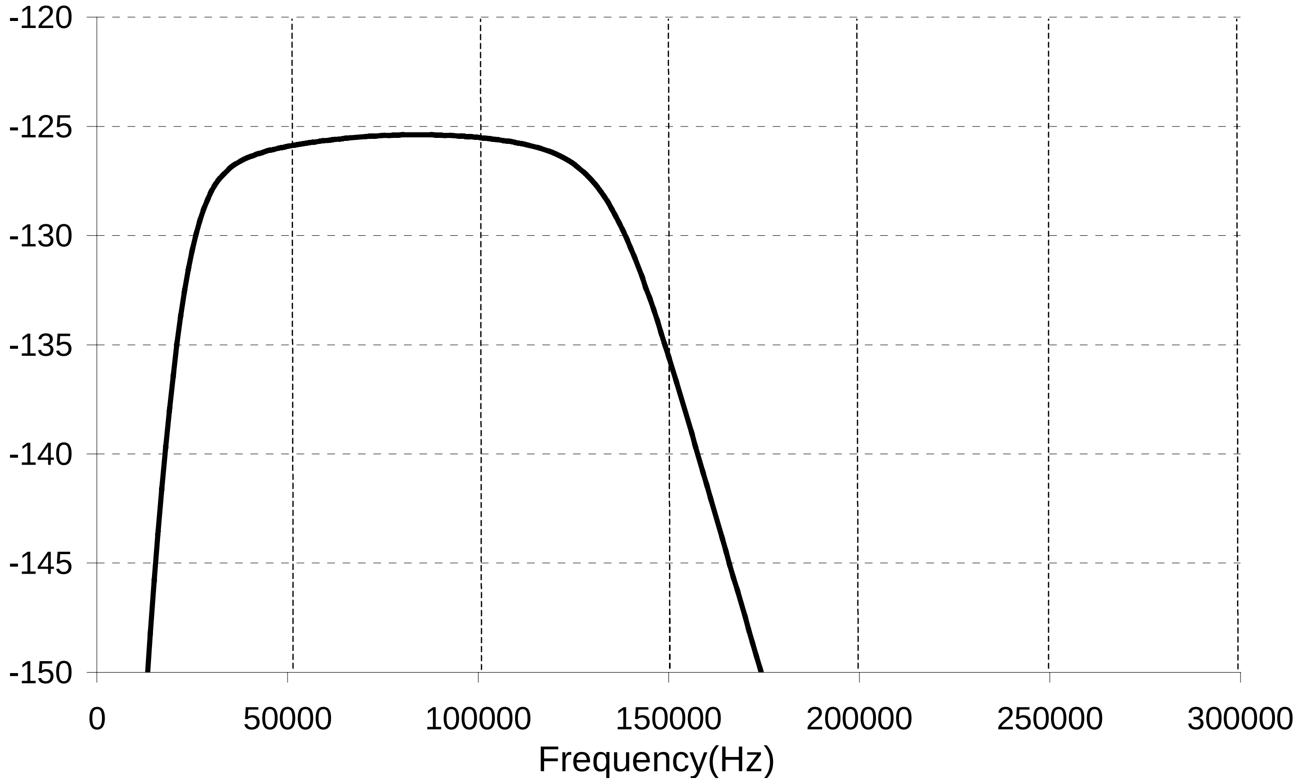


Figure B.6 - Theoretical 10-disturber upstream ADSL FEXT

B.5.2 NEXT

The upstream ADSL signal nominally occupies the band from 25 to 138 kHz, but the upper sidelobes of the pass-band signal beyond 138 kHz may also contribute to the NEXT into the downstream signal. Their effect will depend on the method of anti-aliassing used in the remote transmitter, which issue is addressed in 7.12.3. The PSD of the upstream ADSL NEXT can be expressed as:

$$PSD_{ADSL-NEXT} = PSD_{ADSL,us-Disturber} \times \left(x_n \times f^{3/2}\right) \qquad for\ 0 \le f < \infty,\ n < 50$$

where $x_n = 8.818 \times 10^{-14} \times (n/49)^{0.6}$ or equivalently, $x_n = 0.8536 \times 10^{-14} \times n^{0.6}$

Figure B.7 shows the theoretical PSD of 10-disturber upstream ADSL NEXT into the downstream.

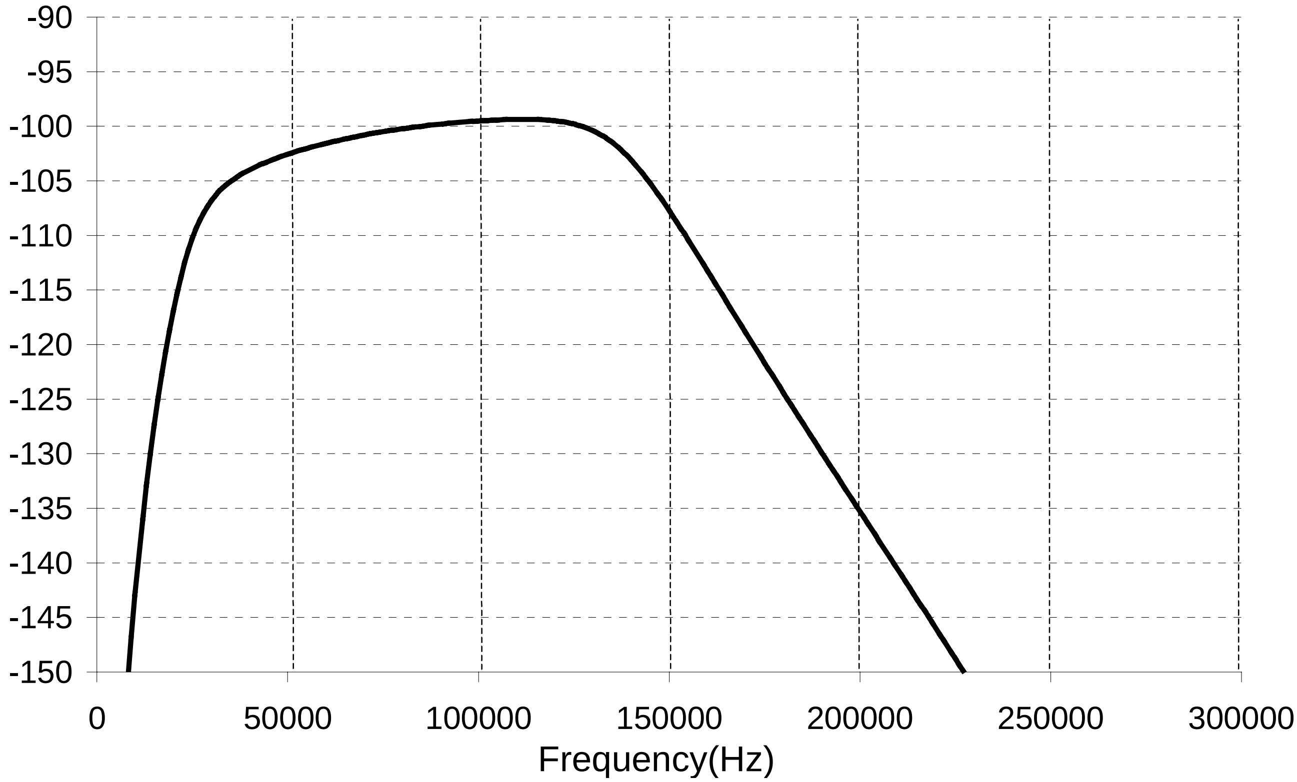


Figure B.7 - Theoretical 10-disturber upstream ADSL NEXT into the downstream

Annex C
(normative)

Characteristics of test impulse waveforms

The two test impulse waveforms specified in clause 15 of the standard are described in Table C.1 and Table C.2 with the impulse wave amplitude given in millivolts at 160 nanosecond time intervals. The specific means of generating these waveforms for test purposes is left to the implementor.

Table C.1 - Impulse number 1

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
1	0.0000	51	-6.3934	101	0.1598
2	0.0000	52	1.7582	102	-1.7582
3	0.0000	53	2.2377	103	0.1598
4	0.0000	54	-4.9549	104	0.4795
5	0.0000	55	2.2377	105	-1.2787
6	0.0000	56	1.7582	106	0.7992
7	0.0000	57	-5.5943	107	1.2787
8	0.0000	58	1.4385	108	-0.7992
9	0.0000	59	2.3975	109	0.0000
10	0.9590	60	-3.6762	110	-0.3197
11	-0.4795	61	1.4385	111	-2.2377
12	-1.2787	62	0.4795	112	-1.1188
13	-1.1188	63	-5.7541	113	-0.7992
14	-1.4385	64	-0.4795	114	-1.5984
15	-1.5984	65	0.3197	115	0.1598
16	-2.2377	66	-3.3566	116	0.4795
17	-1.4385	67	2.3975	117	-0.9590
18	7.6721	68	2.3975	118	0.0000
19	6.7131	69	-3.1967	119	-0.3197
20	-16.6229	70	0.7992	120	-1.5984
21	-12.9467	71	0.6393	121	0.0000
22	18.7008	72	-3.5164	122	0.4795
23	9.5902	73	1.1188	123	-0.7992
24	-13.5861	74	1.7582	124	0.4795
25	-5.2746	75	-2.3975	125	0.7992
26	-6.3934	76	1.2787	126	-0.9590
27	-1.9180	77	0.9590	127	-0.9590
28	23.0164	78	-3.3566	128	-0.4795
29	3.9959	79	0.0000	129	-0.6393
30	-23.4959	80	0.1598	130	0.4795
31	-3.1967	81	-3.0369	131	1.1188
32	4.3156	82	1.1188	132	0.0000
33	-3.0369	83	1.5984	133	0.0000
34	10.7090	84	-2.0779	134	0.0000
35	2.2377	85	0.1598	135	0.0000
36	-12.9467	86	0.3197	136	0.0000
37	3.1967	87	-2.5574	137	0.0000
38	1.9180	88	0.1598	138	0.0000
39	-9.9098	89	0.1598	139	0.0000
40	5.5943	90	-2.0779	140	0.0000
41	5.9139	91	0.6393		
42	-6.7131	92	0.9590		
43	2.3975	93	-1.7582		
44	1.2787	94	-0.1598		
45	-8.4713	95	-0.6393		
46	2.5574	96	-3.0369		
47	2.8771	97	-0.3197		
48	-6.0738	98	0.4795		
49	2.2377	99	-1.4385		
50	1.7582	100	0.4795		

Table C.2 - Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
1	0.0000	51	0.6404	101	0.6404
2	0.0000	52	15.5295	102	0.6404
3	0.0000	53	18.8916	103	-0.4803
4	0.0000	54	-3.8424	104	-0.3202
5	0.0000	55	-3.0419	105	-0.9606
6	0.0000	56	11.6872	106	-2.8818
7	0.0000	57	-0.3202	107	-2.5616
8	0.0000	58	-7.5246	108	-0.8005
9	0.0000	59	13.4483	109	-0.4803
10	-0.6404	60	18.4113	110	-0.8005
11	0.9606	61	-0.4803	111	-0.4803
12	0.1601	62	-3.0419	112	-0.9606
13	-5.4433	63	9.7660	113	-1.1207
14	-12.3276	64	11.2069	114	-0.6404
15	-12.1675	65	4.0025	115	-0.4803
16	0.0000	66	0.6404	116	-0.9606
17	5.2832	67	0.6404	117	-1.4409
18	0.1601	68	1.7611	118	-1.6010
19	-20.8128	69	3.3621	119	-1.2808
20	-45.3078	70	5.6034	120	-0.9606
21	-46.7487	71	7.8448	121	-0.9606
22	-28.9778	72	2.5616	122	-1.2808
23	-13.4483	73	-4.6428	123	-1.1207
24	0.6404	74	0.6404	124	-1.1207
25	0.9606	75	10.7266	125	-1.4409
26	-14.4089	76	8.3251	126	-1.4409
27	-13.7685	77	1.9212	127	-1.4409
28	-9.4458	78	3.6823	128	-2.0813
29	-17.4507	79	4.3227	129	-2.4015
30	-2.5616	80	0.3202	130	-1.9212
31	26.5763	81	2.7217	131	-1.4409
32	16.1699	82	7.2044	132	-1.1207
33	-17.7709	83	3.2020	133	-1.2808
34	-17.1305	84	-2.7217	134	-1.9212
35	13.6084	85	-1.4409	135	-2.2414
36	27.0566	86	1.2808	136	-2.2414
37	18.0911	87	1.4409	137	-2.5616
38	14.2488	88	0.8005	138	-3.0419
39	5.6034	89	0.1601	139	-3.0419
40	-8.1650	90	0.0000	140	-2.5616
41	12.4877	91	1.1207	141	-1.2808
42	37.3029	92	1.1207	142	-0.1601
43	9.6059	93	0.6404	143	-0.6404
44	-18.8916	94	1.1207	144	-2.5616
45	5.1231	95	0.6404	145	-3.2020
46	22.2537	96	-1.1207	146	-3.0419
47	1.1207	97	-0.8005	147	-2.5616
48	-0.9606	98	0.1601	148	-2.0813
49	20.4926	99	-1.2808	149	-1.4409
50	14.2488	100	-1.4409	150	-1.6010

Table C.2 *(continued)*

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
151	-1.9212	201	-0.8005	251	-1.2808
152	-1.9212	202	-0.9606	252	-1.6010
153	-2.0813	203	-1.6010	253	-1.6010
154	-2.4015	204	-2.4015	254	-1.4409
155	-2.5616	205	-2.5616	255	-0.4803
156	-2.5616	206	-2.8818	256	0.4803
157	-1.9212	207	-2.7217	257	0.4803
158	-1.6010	208	-1.9212	258	-0.4803
159	-1.6010	209	-1.1207	259	-0.9606
160	-1.9212	210	-0.9606	260	-1.1207
161	-1.9212	211	-1.1207	261	-1.4409
162	-2.0813	212	-1.4409	262	-1.2808
163	-2.2414	213	-1.7611	263	-0.1601
164	-2.5616	214	-2.4015	264	0.3202
165	-2.7217	215	-2.5616	265	0.0000
166	-2.2414	216	-2.2414	266	-0.4803
167	-1.2808	217	-1.7611	267	-0.4803
168	-1.2808	218	-1.7611	268	-0.4803
169	-2.2414	219	-1.4409	269	-0.6404
170	-3.0419	220	-0.9606	270	-0.4803
171	-2.8818	221	-0.8005	271	-0.1601
172	-2.5616	222	-0.9606	272	0.0000
173	-2.2414	223	-1.6010	273	0.0000
174	-1.9212	224	-2.2414	274	-0.1601
175	-1.9212	225	-2.4015	275	-0.1601
176	-2.2414	226	-2.2414	276	-0.4803
177	-2.5616	227	-1.9212	277	-0.6404
178	-2.7217	228	-1.4409	278	-0.3202
179	-2.5616	229	-0.4803	279	0.1601
180	-2.4015	230	0.0000	280	0.4803
181	-2.2414	231	-0.6404	281	0.3202
182	-2.0813	232	-1.6010	282	-0.1601
183	-1.7611	233	-1.7611	283	-0.3202
184	-1.6010	234	-1.6010	284	-0.4803
185	-1.7611	235	-1.9212	285	-0.6404
186	-2.2414	236	-1.9212	286	-0.4803
187	-3.0419	237	-1.4409	287	0.1601
188	-3.2020	238	-0.4803	288	0.6404
189	-2.7217	239	0.0000	289	0.6404
190	-1.9212	240	0.0000	290	0.4803
191	-1.2808	241	-0.6404	291	0.0000
192	-0.9606	242	-1.6010	292	-0.6404
193	-1.1207	243	-2.4015	293	-0.6404
194	-2.0813	244	-1.9212	294	-0.4803
195	-2.8818	245	-0.9606	295	-0.1601
196	-3.0419	246	-0.4803	296	0.4803
197	-2.7217	247	-0.1601	297	0.6404
198	-2.7217	248	-0.1601	298	0.4803
199	-2.0813	249	0.0000	299	0.6404
200	-1.4409	250	-0.8005	300	0.4803

(continued)

Table C.2 *(continued)*

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
301	-0.1601	351	0.8005	401	0.9606
302	-0.9606	352	1.4409	402	0.6404
303	-0.9606	353	1.6010	403	0.4803
304	-0.1601	354	1.2808	404	0.6404
305	0.6404	355	0.6404	405	0.6404
306	0.8005	356	0.0000	406	0.4803
307	0.8005	357	-0.4803	407	0.3202
308	0.4803	358	-0.6404	408	0.1601
309	0.1601	359	0.0000	409	0.3202
310	-0.1601	360	0.8005	410	0.4803
311	-0.3202	361	1.4409	411	0.9606
312	-0.1601	362	1.6010	412	1.2808
313	0.0000	363	1.2808	413	0.9606
314	0.1601	364	0.6404	414	0.1601
315	0.6404	365	0.0000	415	-0.1601
316	0.8005	366	-0.4803	416	0.0000
317	0.6404	367	-0.1601	417	0.4803
318	0.4803	368	0.1601	418	0.8005
319	0.0000	369	0.9606	419	0.6404
320	-0.4803	370	1.4409	420	0.4803
321	-0.4803	371	1.6010	421	0.8005
322	0.1601	372	1.1207	422	0.8005
323	0.8005	373	0.3202	423	0.4803
324	0.8005	374	-0.4803	424	0.1601
325	0.6404	375	-0.4803	425	0.0000
326	0.1601	376	0.1601	426	0.0000
327	0.4803	377	0.8005	427	0.1601
328	0.4803	378	1.1207	428	0.3202
329	0.3202	379	1.1207	429	0.6404
330	-0.3202	380	0.9606	430	0.9606
331	-0.4803	381	0.6404	431	0.8005
332	0.0000	382	0.1601	432	0.3202
333	0.6404	383	0.0000	433	0.1601
334	1.1207	384	0.1601	434	0.0000
335	1.2808	385	0.6404	435	0.1601
336	0.6404	386	1.1207	436	0.1601
337	0.1601	387	0.9606	437	0.1601
338	-0.1601	388	0.6404	438	0.1601
339	0.0000	389	0.6404	439	0.6404
340	0.0000	390	0.6404	440	1.1207
341	0.1601	391	0.3202	441	0.9606
342	0.3202	392	0.0000	442	0.4803
343	0.8005	393	0.4803	443	0.0000
344	1.2808	394	1.1207	444	-0.3202
345	1.2808	395	1.1207	445	-0.3202
346	0.9606	396	0.6404	446	0.0000
347	0.1601	397	0.1601	447	0.1601
348	-0.8005	398	0.0000	448	0.6404
349	-0.9606	399	0.1601	449	0.9606
350	-0.1601	400	0.8005	450	0.8005

(continued)

Table C.2 *(concluded)*

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
451	0.6404	461	0.0000	471	0.0000
452	0.0000	462	-0.9606	472	0.0000
453	-0.8005	463	-1.1207	473	0.0000
454	-0.8005	464	-0.4803	474	0.0000
455	0.0000	465	0.4803	475	0.0000
456	0.4803	466	1.1207	476	0.0000
457	0.6404	467	1.1207	477	0.0000
458	0.6404	468	0.6404	478	0.0000
459	0.8005	469	0.0000	479	0.0000
460	0.6404	470	0.0000	480	0.0000

Annex D
(normative)

Vendor identification numbers

Sixteen bits (hex coded from 0000 to FFFF) are reserved for vendor identification; these shall be used by the ATU-C in C-MSGS1 (see 9.6.4), and by the ATU-R in R-MSGS1 (see 9.7.6). The numbers (with 0000 and 0001 unused), are given below in both numerical and alphabetical order. Further applications for vendor ID numbers should be addressed to subcommittee T1E1.4 :

Numerical order

0000 *not allocated*

0001 *not allocated*

0002 Westell, Inc.

0003 ECI Telecom

0004 Texas Instruments

0005 Intel

0006 Amati Communcations Corp.

0007 General Data Communications, Inc.

0008 Level One Communications

0009 Crystal Semiconductor

000A Lucent Technologies

000B Aware, Inc.

000C Brooktree

000D NEC

000E Samsung

000F Northern Telecom, Inc.

0010 PairGain Technologies

0011 Paradyne

0012 Adtran

0013 INC

0014 ADC Telecommunications

0015 Motorola

0016 IBM Corp.

0017 Newbridge Network Corp.

0018 DSC

0019 Teltrend

001A Exar Corp.

001B Siemens Telecom Networks

001C	Analog Devices
001D	Nokia
001E	Ericsson Information Systems
001F	Tellabs Operations, Inc.
0020	Orckit Communications, Inc.
0021	AWA
0022	Alcatel Network Systems, Inc.
0023	National Semiconductor Corp.
0024	Italtel
0025	SAT - Société Anonyme de Télécommunications
0026	Fujitsu Network Trans. Systems
0027	MITEL
0028	Conklin Corp.
0029	Diamond Lane
002A	Cabletron Systems, Inc.
002B	Davicom Semiconductor, Inc.
002C	Metalink
002D	Pulsecom
002E	US Robotics
002F	AG Communications Systems
0030	Rockwell
0031	Harris
0032	Hayes Microcomputer Products, Inc.
0033	Co-optic
0034	Netspeed, Inc.
0035	3-Com
0036	Copper Mountain, Inc
0037	Silicon Automation Systems, Ltd
0038	Ascom
0039	Globespan Semiconductor, Inc.
003A	STMicroelectronics
003B	Coppercom
003C	Compaq Computer Corp.
003D	Integrated Technology Express
003E	Bay Networks, Inc.
003F	Next Level Communications

0040	Multi-Tech Systems, Inc.
0041	AMD
0042	Sumitomo Electric
0043	Philips M&N Systems
0044	Efficient Networks, Inc.
0045	Interspeed
0046	Cisco Systems
0047	Tollgrade Communications, Inc.
0048	Cayman Systems
0049	FlowPoint Corp.
004A	I.C.COM
004B	Matsushita
004C	Siemens Semiconductor
004D	Digital Link
004E	Digitel
004F	Alcatel Microelectronics
0050	Centillium Corp.
0051	Applied Digital Access, Inc.
0052	Smart Link, Ltd.

Alphabetical Order

0014	ADC Telecommunications
0012	Adtran
002F	AG Communications Systems
004F	Alcatel Microelectronics
0022	Alcatel Network System, Inc.
0006	Amati Communications Corp.
0041	AMD
001C	Analog Devices
0051	Applied Digital Access, Inc.
0038	Ascom
0021	AWA
000B	Aware, Inc.
003E	Bay Networks, Inc.

000C	Brooktree
002A	Cabletron Systems, Inc.
0048	Cayman Systems
0050	Centillium Corp.
0046	Cisco Systems
003C	Compaq Computer Corp.
0028	Conklin Corp.
0033	Co-optic
0036	Copper Mountain, Inc
003B	Coppercom
0009	Crystal Semiconductor
002B	Davicom Semiconductor, Inc.
0029	Diamond Lane
004D	Digital Link
004E	Digitel
0018	DSC
0003	ECI Telecom
0044	Efficient Networks, Inc.
001E	Ericsson Information Systems
001A	Exar Corp.
0049	FlowPoint Corp.
0026	Fujitsu Network Trans. Systems
0007	General Data Communications, Inc.
0039	Globespan Semiconductor, Inc.
0031	Harris
0032	Hayes Microcomputer Products, Inc.
0016	IBM Corp.
004A	I.C.COM
0013	INC
003D	Integrated Technology Express
0005	Intel
0045	Interspeed
0024	Italtel
0008	Level One Communications
000A	Lucent Technologies
004B	Matsushita
002C	Metalink
0027	MITEL

0040	Multi-Tech Systems, Inc.
0015	Motorola
0023	National Semiconductor Corp.
000D	NEC
0034	Netspeed, Inc.
0017	Newbridge Network Corp.
003F	Next Level Communications
001D	Nokia
000F	Northern Telecom, Inc.
0020	Orckit Communications, Inc.
0010	PairGain Technologies
0011	Paradyne
0043	Philips M&N Systems
002D	Pulsecom
0030	Rockwell
000E	Samsung
004C	Siemens Semiconductor
001B	Siemens Telecom Networks
0037	Silicon Automation Systems, Ltd
0052	Smart Link, Ltd.
0025	SAT - Société Anonyme de Télécommunications
003A	STMicroelectronics
0042	Sumitomo Electric
001F	Tellabs Operations, Inc.
0019	Teltrend
0004	Texas Instruments
0047	Tollgrade Communications, Inc.
002E	US Robotics
0002	Westell, Inc.
0035	3-Com

NOTE - The next issue of the ADSL standard is intended to provide a new vendor ID mechanism, which will be aligned with the applicable ITU-T Recommendation and American National Standards (e.g., T.35 and ANSI T1.220).

Annex E
(normative)

POTS splitter requirements

E.1 Introduction

The purpose of the low-pass filters is twofold. For ADSL signals, protection from the high-frequency transients and impedance effects that occur during POTS operation - ringing transients, ring trip transients, and off-hook transients and impedance changes - is provided. For POTS voiceband service, the low-pass filters provide protection from ADSL signals which may impact through nonlinear or other effects remote devices (handset, fax, voiceband modem, etc.) and central office operation. This filtering should be performed while maintaining the quality of the end-to-end - that is, between the POTS and PSTN interfaces of Figure 1 - voiceband connection.

E.1.1 POTS Splitter Function Location

Two POTS Splitter functions are defined. One for the Remote (R) end and one for the Central Office (CO) end. The function can be implemented either internally to the ATU modem or externally. In either case, all functions in this annex are required (exception is Maintenance Test Signatures, see note in E.1.7).

In the diagrams of the external CO POTS Splitters the capacitors are shown as 0.12 uF. These capacitors are for DC blocking. They work in concert with the input to the modem’s HPF function and are to be included in the input impedance calculation of the modem. This point is not available for inspection when the CO Splitter function is provided internally to the modem and therefore the capacitors do not appear explicitly. The DC blocking function is however provided in the normal HPF function. This difference is taken into account in the test setups in this document.

In a case where some or all of the HPF function is incorporated in the external CO POTS splitter the 0.12 uF capacitors do not appear since the DC blocking will be included in the HPF function. Incorporating some or all of the HPF in the CO POTS splitter is for further study.

E.1.2 Frequencies Used in Testing

Two bands of frequencies are used for testing. Testing is not performed between 4 - 30 kHz but it is expected that the LPF will be well behaved in this area (i.e., the amplitude response is monotonically decreasing from 4 to 16 kHz).

- Voiceband frequencies are from 0 - 4 kHz.
- ADSL Band frequencies are from 30 - 1104 kHz.

All external POTS splitters with LPF or LPF/HPF included shall meet specifications between 30 and 1104 kHz.

Not all integral modem designs are intended to occupy the full spectrum between 30 and 1104 kHz. In each implementation, testing may be performed only on the utilized frequency band. The band of frequencies used in testing each modem shall be explicitly stated by the vendor in literature and in each test report.

E.1.3 Balanced Terminations

All testing is done in a BALANCED (i.e. metallic) method. One end of some setups may contain an unbalanced connection to facilitate testing methodology if the resultant measurement maintains balance.

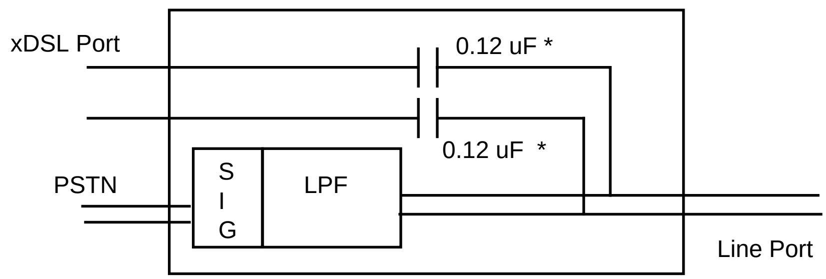
E.1.4 Single Ended Testing

Single ended testing is performed on each POTS Splitter function. Specifications contained in this annex are written for single Splitter functions, not end to end. End-to-End testing is listed in clause 11. Splitters that meet the requirements of this annex will not adversely effect the requirements of clause 11 testing.

Alternately, compliance with this annex does NOT guarantee clause 11 performance since the modems are not included in this annex testing.

E.1.5 POTS Splitter Functions

The external Central Office POTS Splitter may be mounted some distance from the ATU-C modem. To protect from DC faults, DC blocking capacitors are included on the xDSL port of the POTS Splitter. These capacitors form part of the input to the xDSL HPF function and need to be included in calculations of that input impedance (approximately 20 - 34 nF). If the POTS Splitter function is included entirely within the modem, the capacitors are included as part of the HPF function.



NOTE - (*) These capacitors are for the external POTS Splitter without the HPF function only. Internal Splitter function or external splitters with a complete HPF function may incorporate this capacitance in the input to the HPF function. The D.C. blocking capacitors are optional on splitters integrated within the equipment closely associated with the ATU-C.

Figure E.1 - External POTS Central Office Splitter without HPF Function

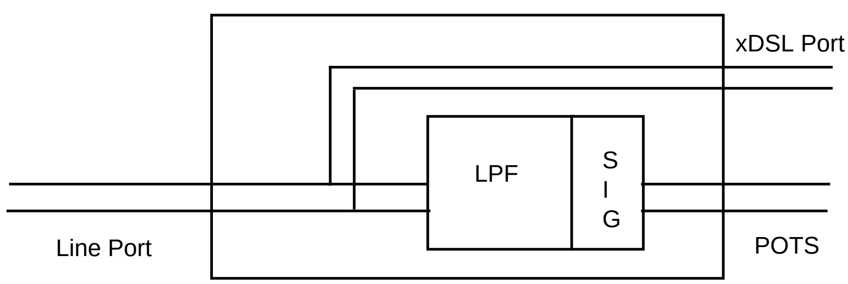
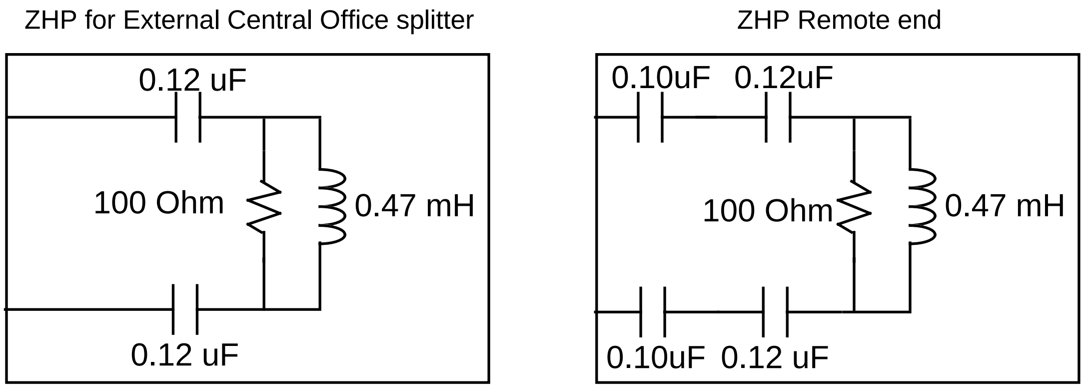


Figure E.2 - External POTS Remote Splitter

E.1.6 ZHP Defined

To facilitate testing of the POTS Splitter independently of the actual modem or specific vendor, two ZHP's are defined to allow proper termination of the xDSL port during voiceband testing (see Figure E.3). The ZHP is valid only for voiceband frequencies. The combination of capacitors in the ZHP-r is only representative. The input shall be 27 nF, however derived.



NOTE - Component Tolerances: Capacitors = 2.5%, Resistors = 1%, Coils = 5%.

Figure E.3 - ZHP Definitions

E.1.7 Maintenance Test Signatures

For this standard (ANSI T1.413 Issue 2), if the Maintenance Test Signatures are provided, they will be as shown in this document. It is intended that in Issue 3 of this document the signatures will be required. Some service providers may require these signatures sooner than Issue 3.

In order to allow the POTS Splitter to be managed by the network operational support systems and to be identified by metallic loop test systems, the POTS Splitter function shall contain signatures that are activated only by the metallic test systems. The signatures are unique for ADSL and are different for each end of the loop. All Central Office end POTS Splitters will have the same signature and all Remote end POTS Splitters will have the same signature. The signatures are designed to be active only during the maintenance test mode and will not interfere with normal operation of the circuit. The signatures are located on the POTS/PSTN side of the LPF function protecting the ADSL Band frequencies from the non-linear effects of the diodes. The signatures are defined below in Figure E.4.

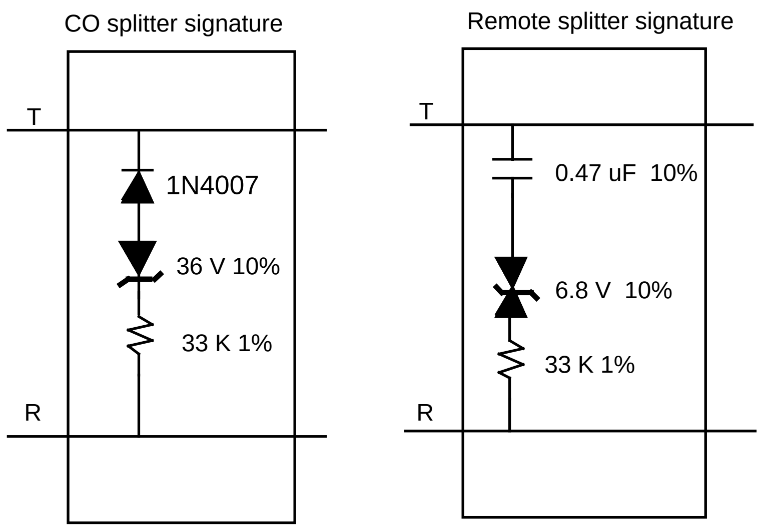


Figure E.4 - Maintenance Test Signatures

E.2 DC Characteristics

All requirements of this standard shall be met in the presence of all POTS loop currents from 0 mA to 100 mA. The low-pass filter shall pass POTS tip-to-ring DC voltages of 0 V to minus 60 V DC and ringing signals no larger than 103 V rms superimposed on the DC signal at any frequency from 20 to 30 Hz.

The DC resistance from tip-to-ring at the PSTN interface with the U-C interface shorted, or at the POTS interface with the U-R interface shorted, shall be less than or equal to 25 ohms. The DC resistance from tip to ground and from ring to ground at the PSTN interface with the U-C interface open, or at the POTS interface with the U-R interface open shall be greater than or equal to 5 Megohms.

E.3 Voiceband Characteristics

E.3.1 Metallic Balanced (differential mode)

E.3.1.1 Test Loops

Loops to be used for testing in this annex are divided into two groups. This is done to obtain more specific requirements under the widely varying conditions of short and long loops and to account for the effect of the opposite Splitter impedances being seen through the loop and effecting performance.

- Short Loops: 0, 0.5 Kft, 2.0 Kft, 5 Kft pairs of 26 AWG cables;
- Long Loops: ANSI T1.601 resistance design loops 7, 9, 13 and T1 TR28 CSA loops 4, 6, 7, 8.

E.3.1.2 Insertion Loss at 1004 Hz.

For each of the test loops specified in E.3.1.1 above, and using the test set-up shown in Figure E.5 or Figure E.6, the insertion loss from the source to the termination shall be measured with and without the Splitter/ZHP combination inserted.

The increase in insertion loss at 1004 Hz on any of the test loops, due to the addition of the Splitter/ZHP shall be less than specified below.

Short loop	ZTc = 900	ZTr = 600	Loss less than 1.0 dB CO end
Long loop	ZTc = 900	ZTr = 600	Loss less than 0.75 dB CO end
Short loop	ZTc = 900	ZTr = 600	Loss less than 1.0 dB RT end
Long loop	ZTc = 900	ZTr = 600	Loss less than 0.75 dB RT end

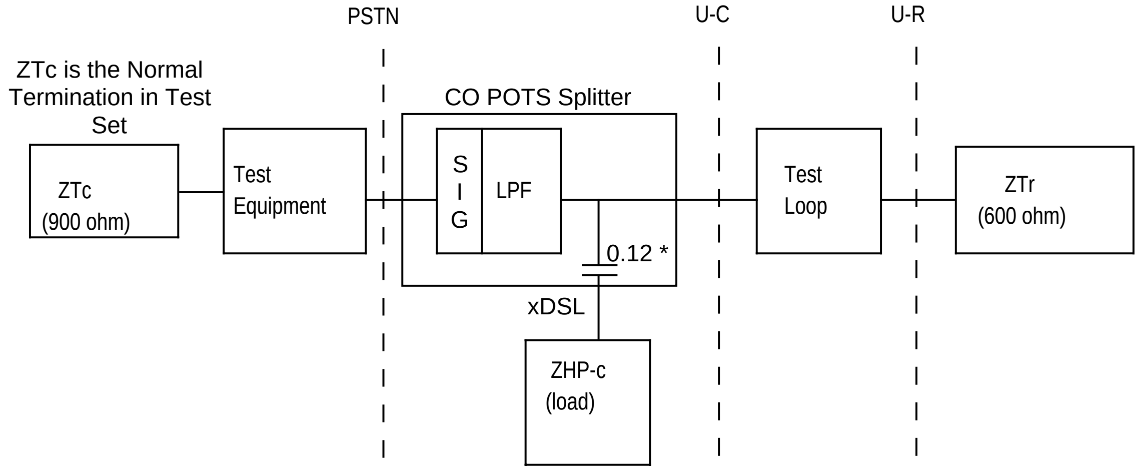
E.3.1.3 Attenuation Distortion in the Voiceband

The variation of insertion loss with frequency shall be measured using the test set up in Figure E.5 or Figure E.6. The defined ZHP will be attached to the xDSL port of the Splitter. (If the Splitter is an internal part of the ATU, then the modem remains attached as the xDSL load). The increase in Attenuation Distortion, relative to the 1004 Hz insertion loss, caused by the POTS Splitter, including the ZHP (or modem) load attached, using each of the test loops identified above shall be within the following margins:

NOTE - Attenuation is a positive value, gain is negative value.

				0.2 - 3.4 kHz		3.4 - 4.0 kHz	
Short loop	CO Splitter	ZTc = 900	ZTr = 600	+1.5	-1.5	+2.0	-2.0
Long loop	CO Splitter	ZTc = 900	ZTr = 600	+0.5	-1.5	+1.0	-1.5
Short loop	R Splitter	ZTc = 900	ZTr = 600	+1.5	-1.5	+2.0	-2.0
Long Loop	R Splitter	ZTc = 900	ZTr = 600	+0.5	-1.5	+1.0	-1.5

Figure E.5 defines the test configuration and the value of the test components that shall be used for transmission measurements in the voiceband for the Central Office POTS Splitter.



NOTES

1. ZTc = 900 ohm.

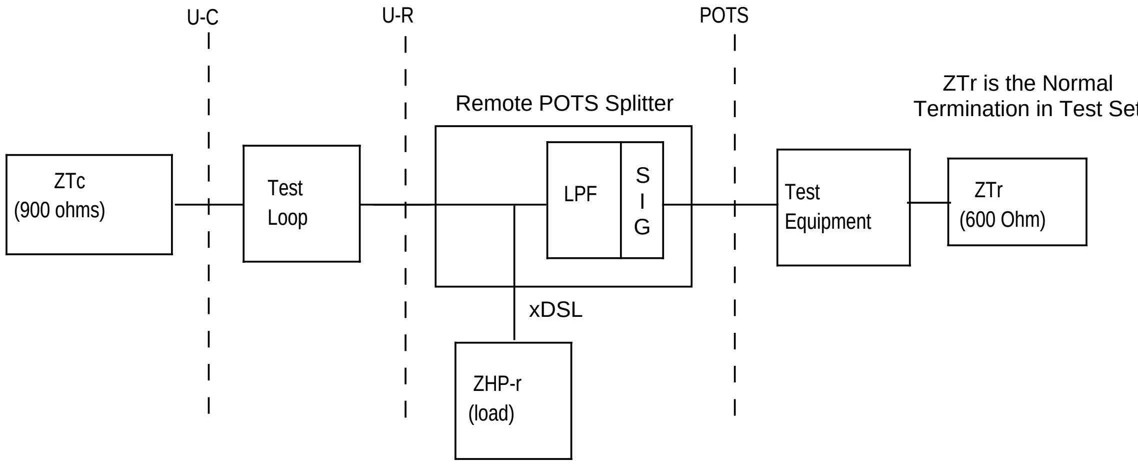
2. ZTr = 600 ohm.

3. ZHP-c is the impedance presented to the POTS connection by an ATU-C through the capacitance of the POTS splitter DC blocking capacitors.

4. (*) These capacitors are only for the external POTS Splitter without the HPF function. Internal Splitter function or external splitters with a complete HPF function may incorporate this capacitance in the input to the HPF function.

Figure E.5 - Transmission measurements in voiceband for the Central Office Splitter

Figure E.6 defines the test configuration and the value of the test components that shall be used for transmission measurements in the voiceband for the Remote POTS Splitter



NOTES

1. ZTc = 900 ohm.
2. ZTr = 600 ohm.
3. ZHP-r is the impedance presented to the POTS connection by an ATU-R.

Figure E.6 - Transmission measurements in voiceband on the Remote POTS Splitter

E.3.1.4 Delay Distortion

The delay distortion of the POTS Splitter shall be measured using Figure E.5 or Figure E.6. The increase in delay distortion caused by the POTS Splitter in each of the test loops shall be less than:

				0.6 - 3.2 kHz	3.2 - 4.0 kHz
Short loop	CO Splitter	ZTc = 900	ZTr = 600	200 uS	250 uS
Long loop	CO Splitter	ZTc = 900	ZTr = 600	200 uS	250 uS
Short loop	R Splitter	ZTc = 900	ZTr = 600	200 uS	250 uS
Long Loop	R Splitter	ZTc = 900	ZTr = 600	200 uS	250 uS

E.3.1.5 Return Loss

Figure E.7 or Figure E.8 define the test configuration and the value of the test components that shall be used for impedance measurements in the voiceband for both the Central Office and Remote POTS Splitter units.

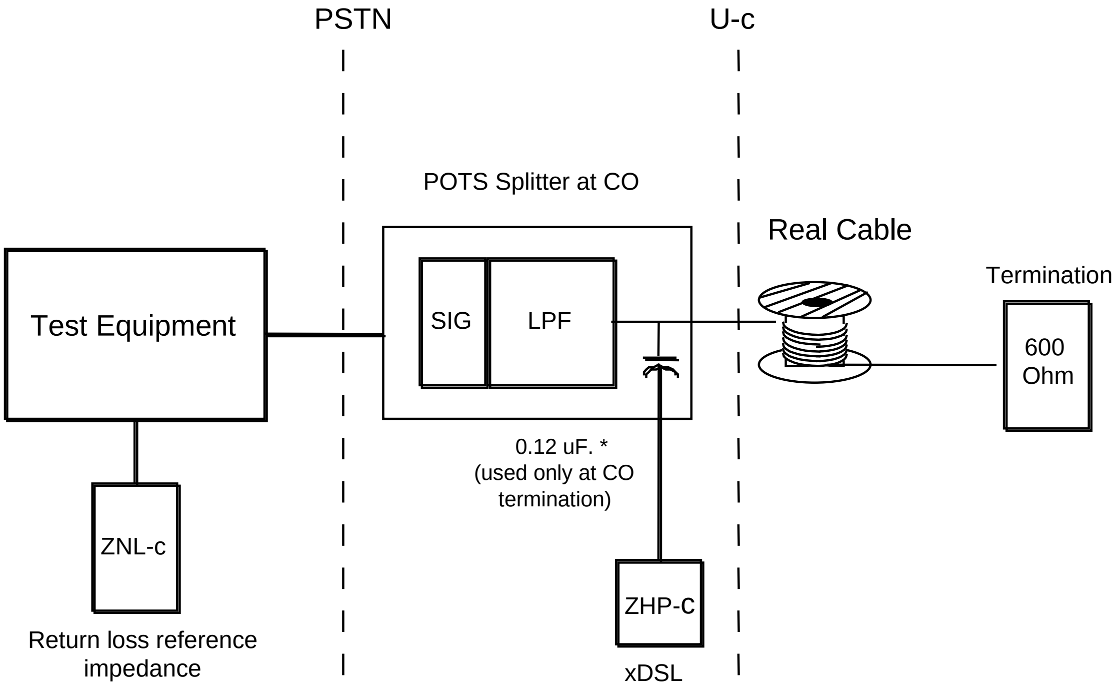


Figure E.7 - CO POTS Splitter Return Loss Set-Up

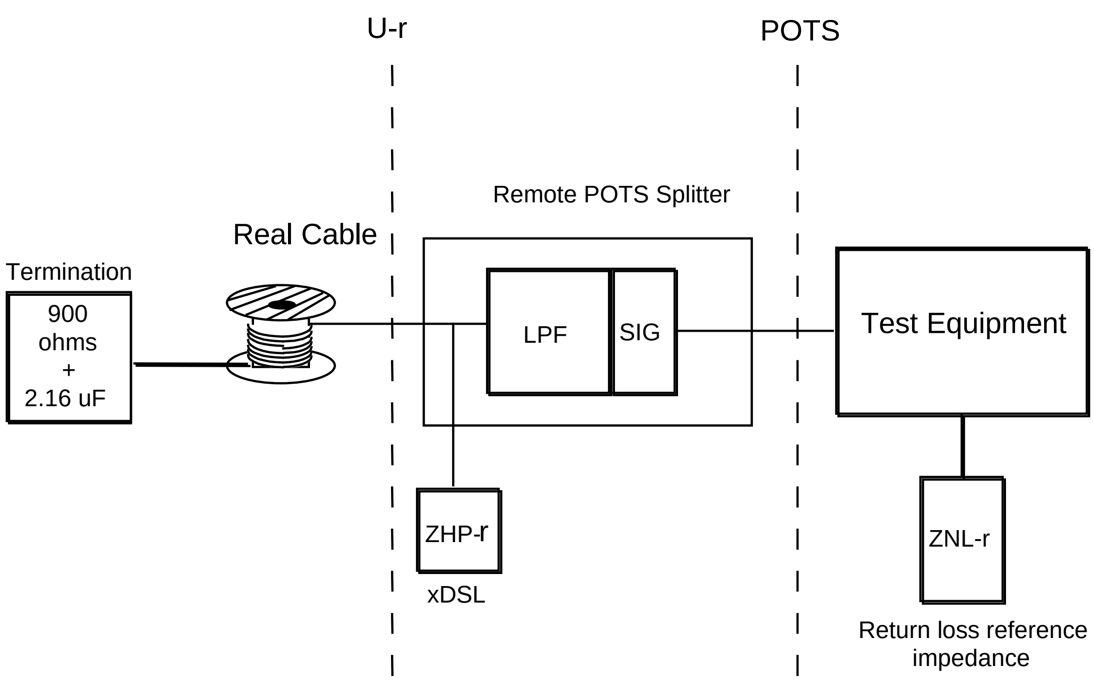


Figure E.8 - Remote POTS Splitter Return Loss Set-Up

NOTES to Figure E.7 and Figure E.8

1. ZNL-c = 800 ohm in parallel with the series connection of a 100 ohm resistor and a 50 nF capacitor (non-loaded loop model seen from CO).

This value comes from the Bellcore LSSGR as a reference compromise impedance for nonloaded cable.

2. ZNL-r = 1330 ohm in parallel with the series connection of a 348 ohm resistor and a 100 nF capacitor (non-loaded loop model seen from RT).

3. ZHP-c is the impedance presented to the POTS connection by an ATU-C through the capacitance of the POTS splitter DC blocking capacitors.

4. ZHP-r is the impedance presented to the POTS connection by an ATU-R.

5. (*) These capacitors are for the external POTS Splitter without the HPF function only. Internal Splitter function or external splitters with a complete HPF function may incorporate this capacitance in the input to the HPF function.

The return loss of each splitter under the specified conditions, either with or without the ZHP attached, for short and long loops, shall be greater than (dB):

	Zref	Zterm	ERL (dB)	SRL-L (dB)	SRL-H (dB)	Comments
CO splitter	ZNL-c	600 ohm	8	5	5	
CO splitter	ZNL-c	600 ohm	N/A	N/A	2	single frequency
RT splitter	ZNL-r	900 ohm+2.16 μF	6	5	3	
RT splitter	ZNL-r	900 ohm+2.16 μF	N/A	N/A	2	single frequency

Individual frequencies start at 2200 Hz and sweep to 3400 Hz.

E.3.1.6 Distortion

The distortion contributed by the low pass filter shall be measured using the test configuration of Figure E.5 or Figure E.6 and the Null Loop.

With an applied tone set in accordance with ANSI/IEEE 743, at a level of -9 dBm, the second and third order intermodulation distortion products shall be at least 57 dB and 60 dB, respectively, below the received signal level.

E.3.2 Longitudinal Balance of POTS Splitter

The longitudinal balance of the POTS Splitter can be measured using two different techniques. One technique would be to treat the POTS splitter as a separate entity which would require using the 2 PORT testing technique. The other technique that can be used to test the CO splitter would be to treat the POTS splitter, ATU-C and CO line card combination as a one port network. This one port network would require using the 1 PORT testing technique.

E.3.2.1 Longitudinal Balance of POTS Splitter using 2 PORT Testing Technique

This method shall be used to test a POTS splitter when it is treated as a separate entity.

The longitudinal balance of the POTS Splitter (without loops), measured in either direction between the POTS/PSTN and line port, as a two port device, shall be measured in accordance with ANSI/IEEE 455. In the case where DC blocking capacitors are included as part of the Splitter function on the xDSL port, the xDSL port will be shorted. Otherwise the xDSL port shall be open. Because of the maintenance signatures, the applied longitudinal voltage shall be maximum 3.0 V p-p. The balance shall be greater than 58 dB for frequencies between 200 Hz - 1 kHz with a straight line level decreasing to 53 dB at 3 kHz. A DC bias current of 25 mA will be applied.

The termination of the test set is set for series-balance measurement in accordance with ANSI/IEEE 455. Prior to testing, a test circuit balance (calibration) of 77 dB (58 + 19 dB) will be achieved to ensure 1 dB accuracy.

Figure E.9 shows the test set-up for the external CO POTS splitter. The xDSL port is shorted. If testing longitudinal balance on an integrated CO modem, the ATU-C shall be connected but powered down.

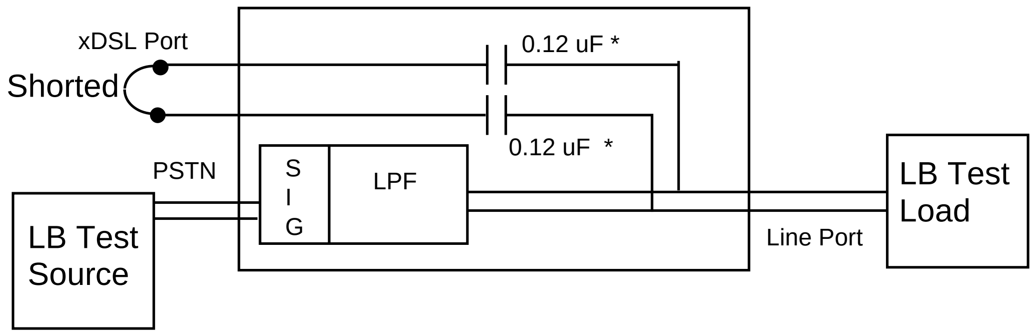


Figure E.9 - Longitudinal Balance CO Test Setup in Accordance with ANSI/IEEE 455

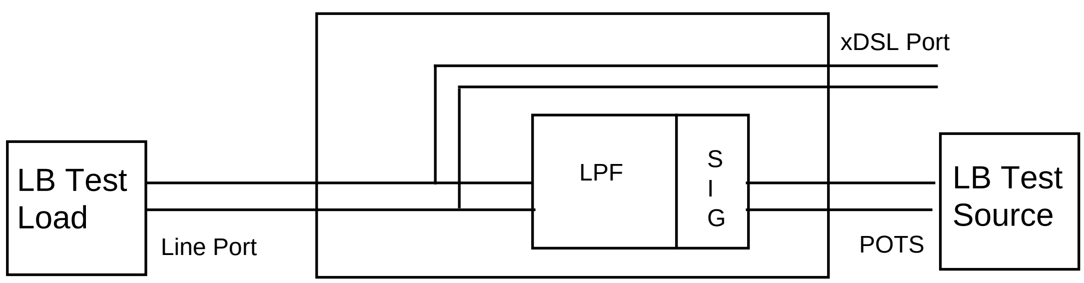


Figure E.10 - Longitudinal Balance Remote Test Setup in Accordance with ANSI/IEEE 455

E.3.2.2 Longitudinal Balance of POTS Splitter using 1 PORT Testing Technique

This method shall be used to test a CO splitter when the POTS splitter, ATU-C and CO line card combination are treated as a one port network.

The longitudinal balance of the combined POTS splitter, ATU-C and CO line card (without loops) shall be measured in accordance with ANSI/IEEE Standard 455. Because of the maintenance signatures, the applied longitudinal voltage shall be maximum 3.0 V p-p. The balance shall be greater than 52 dB for frequencies between 200 Hz - 3 kHz. A DC POTS load to generate a bias current of 25 mA will be used.

Prior to testing, a test circuit balance (calibration) of 71 dB (52+ 19 dB) will be achieved to ensure 1 dB accuracy.

Figure E.11 shows the test set-up for the combined POTS splitter, ATU-C and CO line card combination one port network.

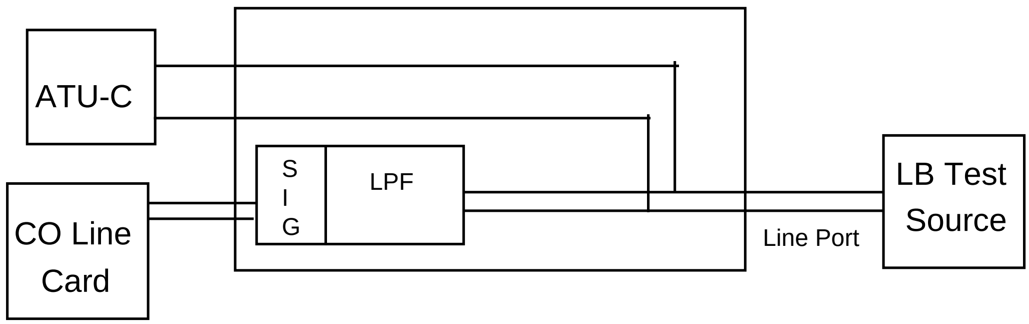


Figure E.11 - Longitudinal Balance CO Test Setup for 1 Port Networks in Accordance with ANSI/IEEE 455

E.3.3 Transparent Testing Capacitance

To allow the current metallic test systems to continue to test with current test capabilities, an input impedance is defined for a special, narrow frequency band.

E.3.3.1 Tip-to-Ring Capacitance

The intent of this requirement is to limit the maximum capacitance seen by metallic line testing systems. By setting this limit, the metallic test systems can still test POTS services with the accuracy and dependability they have today.

Overall, the admittance of the POTS or PSTN port shall be capacitive.

The capacitance present at either the POTS or PSTN interfaces in the frequency range of 20 - 30 Hz shall be a maximum of 250 nF. This amount includes the capacitance of the two POTS splitters with attached modems.

NOTE - It is expected that, in the next issue of this standard, the maximum allowed capacitance may be changed to 300 nF.

The following, per end, maximum/minimums shall be met:

POTS splitter, either CO or Remote, without the modem connected:

– 90 nF Max

– 20 nF Min

Modem input allowance, including the DC blocking capacitors at the CO end:

– 35 nF Max

– 20 nF Min

Modem with integral POTS splitter function or external POTS splitter with both HPF and LPF functions, are the sum of the above:

– 125 nF Max

– 40 nF Min

NOTES

1. It is expected that, in the next issue of this standard, the maximum allowed POTS splitter capacitance, either CO or Remote, without the modem connected, may be changed to 115 nF.

2. It is expected that, in the next issue of this standard, the maximum modem input allowance, including the DC blocking capacitors at the CO end, may be changed to 150 nF.

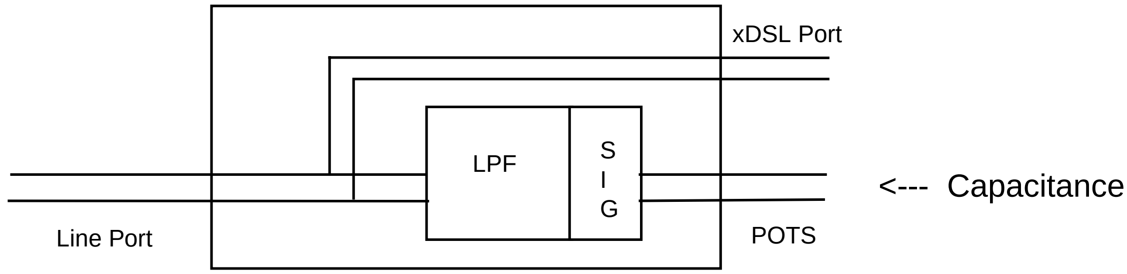


Figure E.12 - Capacitance Test

E.3.3.2 Capacitance to Ground

There should be no designed AC path to ground. In order to maintain the ability to test accurately the maximum stray capacitance to ground from either leg of the POTS Splitter shall be less than 1.0 nF.

E.4 ADSL Band Testing

E.4.1 ADSL Band Attenuation

The insertion loss of the low-pass filter and ZHP (i.e., the difference in attenuation measured with and without the filter), measured as shown in Figure E.13 or Figure E.14, shall be greater than 65 dB from 30 to 300 kHz and greater than 55 dB from 300 to 1104 kHz with an input level of 10 dBm.

NOTE - It is expected that, in the next issue of this standard, the difference in attenuation may be measured in the 32 to 300 kHz range rather than in the 30 to 300 kHz range.

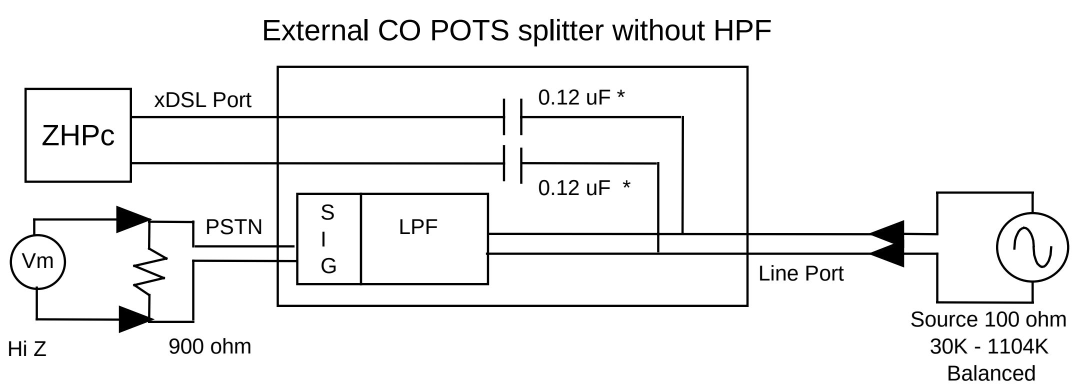


Figure E.13 - Measurement of the CO Splitter Attenuation in the ADSL Band

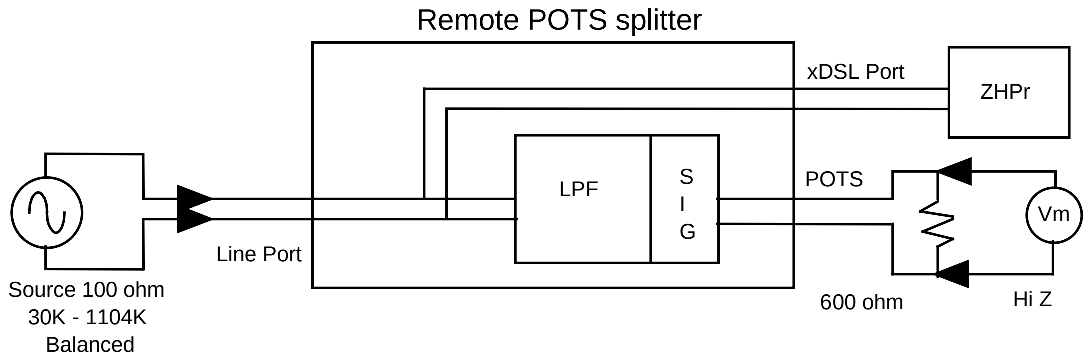


Figure E.14 - Measurement of the Remote Splitter Attenuation in the ADSL Band

E.4.2 Input impedance (loading of ADSL signal path)

The insertion loss caused by the low-pass filter in the band from 30 to 1104 kHz between nominal impedances with an input level of -10 dBm, as shown in Figure E.15 or Figure E.16 shall be no more than 0.25 dB.

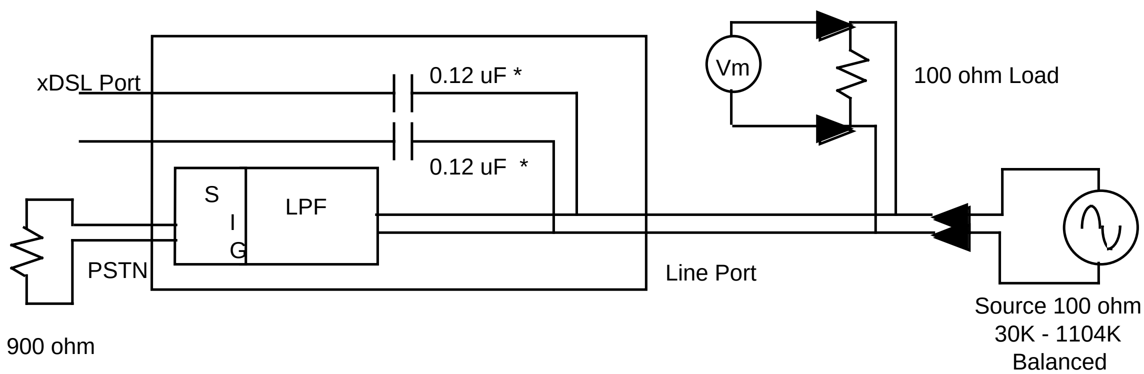


Figure E.15 - Measurement of Loading Effect of the CO Splitter in the ADSL Band

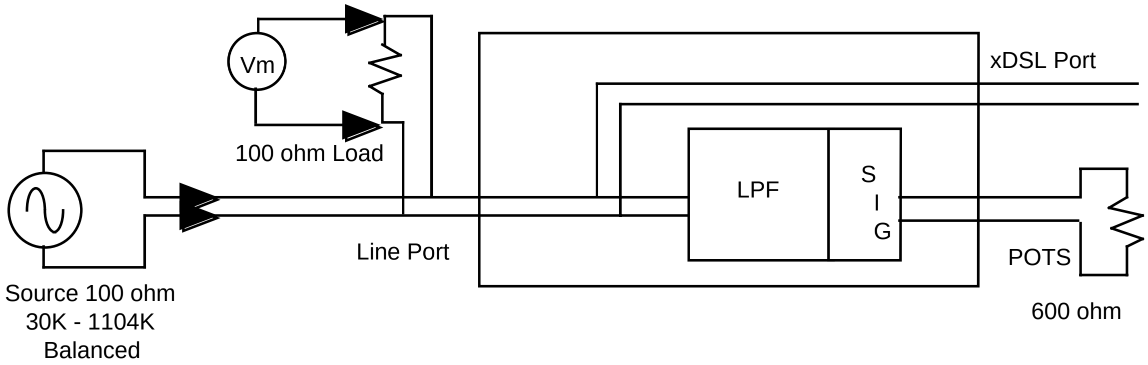


Figure E.16 - Measurement of Loading Effect of the Remote Splitter in the ADSL Band

E.5 Home Premises Physical Considerations (Informative)

The running of ADSL signals and POTS signals together within a single multiple pair cable cross-couples POTS noises into the received ADSL signals. These POTS noises are generated as the result of ringing, ringing trip, dial pulsing, and on/off hook operation. The levels of these noises are great enough that without adequate pair-to-pair isolation, errors in the received data are possible. This quality of service degradation may be mitigated by the use of interleaving or error control in any higher level data communications protocol.

The wiring configuration reference model, using separate cables, for an external POTS Splitter is shown in Figure E.17. If POTS and ADSL are to be run in the same cable, intercable isolation is assumed to be a minimum of 80 dB between pairs (i.e., CAT5 cable). It must be noted that the length of intrapremises cabling must be included in the transmission link budgets. Use of other cable types (i.e., Quad or Standard twisted pairs) with lower separation specifications may result in higher errors and lower performance.

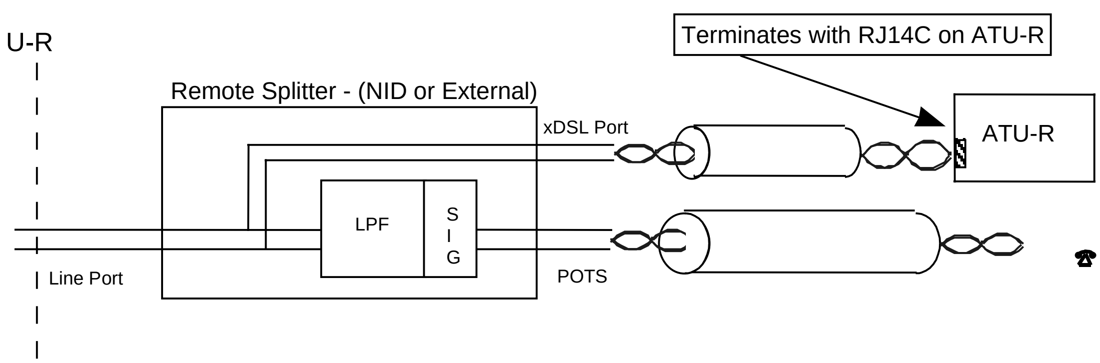
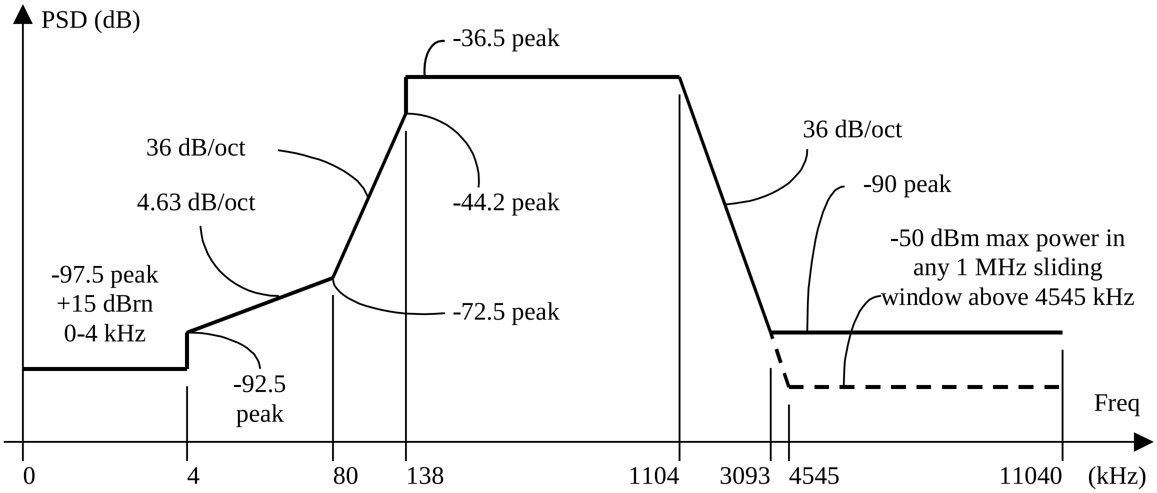


Figure E.16 - Home Premise Wiring on Separate Sheaths for ATU-R

Annex F
(informative)

ATU-C Transmitter PSD Mask for Reduced NEXT

This informative annex gives a spectral mask for the ATU-C transmitted signal, which results in reduced NEXT into the ADSL upstream band, relative to the mask in 6.14. The mask is defined in Figure F.1. Adherence to this mask will, in many cases, result in improved upstream performance of the other ADSL systems in the same or adjacent binder group, with the improvement dependent upon the other interferers. This mask differs from the mask in 6.14 only in the band from 4 kHz to 138 kHz.



NOTES

1. All PSD measurements are in 100 ohm; the POTS band aggregate power measurement is in 600 ohm. All PSD and power measurements are made at the U-C interface (see Figure 1); the signals delivered to the PSTN are specified in Annex E.
2. The breakpoint frequencies and values are exact; the indicated slopes are approximate.
3. Above 25.875 kHz, the peak PSD is measured with a 10 kHz resolution bandwidth.
4. The power in a 1 MHz sliding window is measured in 1 MHz bandwidth, starting at the measurement frequency.

Frequency band (kHz)	**Equation for line** (dBm/Hz)
$0 < f < 4$	-97.5, with max power in the in 0-4 kHz band of +15 dBrn
$4 < f < 80$	$-92.5 + 4.63 \times \log_2 (f/4)$
$80 < f < 138$	$-72.5 + 36 \times \log_2 (f/80)$
$25.875 < f < 1104$	-36.5
$1104 < f < 3093$	$-36.5 - 36 \times \log_2(f/1104)$
$3093 < f < 4545$	-90 peak, with max power in the [f, f + 1 MHz] window of $(-36.5 -36 \times \log_2(f/1104) + 60)$ dBm
$4545 < f < 11040$	-90 peak, with max power in the [f, f+1MHz] window of -50 dBm

Figure F.1 - ATU-C transmitter PSD mask for Reduced NEXT

Annex G
(informative)

Characteristics of typical telephone cables

G.1 Resistance and insertion loss

Table G.1, Table G.2 and Table G.3 provide the calculated resistance and insertion loss between 100 ohm terminations of the loops shown in Figure 48.

Table G.1 - Resistance and insertion loss values for test loops at 70°F

Loop #	**Resistance** (ohm)	**Frequency** (kHz) **Insertion loss** (dB)										
		20	**40**	**100**	**200**	**260**	**300**	**400**	**500**	**600**	**780**	**1100**
T1.601 # 7	1127	29.8	36.7	45.2	52.8	57.3	60.2	67.7	74.8	81.7	93.0	110
T1.601 # 9	877	27.6	36.4	52.5	47.5	55.7	62.0	60.3	71.5	72.2	82.7	96.2
T1.601 # 13	909	26.6	34.1	47.9	48.3	55.7	61.3	62.2	71.4	74.1	85.3	100
CSA # 4	634	17.6	22.0	29.6	39.6	40.1	42.5	49.2	50.2	53.8	55.7	70.7
CSA # 6	751	20.0	24.4	30.1	35.2	38.2	40.2	45.1	49.9	54.4	62.0	73.6
CSA # 7	562	17.3	20.9	26.8	33.6	37.8	38.6	43.1	49.9	57.9	60.2	72.7
CSA # 8	630	19.2	22.8	27.7	34.4	38.3	40.8	46.9	52.4	57.4	65.4	77.8
Mid-CSA	501	13.3	16.2	20.0	23.4	25.4	26.8	30.1	33.2	36.3	41.3	49.1

Table G.2 - Resistance and insertion loss in dB for test loops at 90°F

Loop #	**Resistance** (ohm)	**Frequency** (kHz) **Insertion loss** (dB)										
		20	**40**	**100**	**200**	**260**	**300**	**400**	**500**	**600**	**780**	**1100**
T1.601 # 7	1176	30.6	37.9	46.9	54.6	59.1	62.1	69.6	76.6	83.4	95.0	113
T1.601 # 9	915	28.4	37.5	53.4	49.1	57.2	63.1	61.9	72.8	73.6	84.2	98.1
T1.601 # 13	948	27.4	35.2	49.0	49.9	57.2	62.5	63.7	72.8	75.6	87.0	102
CSA # 4	658	18.0	22.6	30.4	40.3	41.0	43.5	50.0	50.9	54.3	56.6	71.6
CSA # 6	784	20.5	25.2	31.2	36.4	39.4	41.4	46.4	51.1	55.6	63.3	75.2
CSA # 7	586	17.9	21.6	27.7	34.0	38.7	39.5	44.1	50.9	58.8	61.4	74.0
CSA # 8	657	19.8	23.6	28.7	35.4	39.3	41.8	47.9	53.5	58.6	66.8	79.4
Mid-CSA	523	13.8	16.7	20.7	24.2	26.2	27.6	30.9	34.0	37.1	42.2	50.1

Table G.3 - Resistance and insertion loss in dB for test loops at 120°F

Loop #	**Resistance** (ohm)	**Frequency** (kHz) **Insertion loss** (dB)										
		20	**40**	**100**	**200**	**260**	**300**	**400**	**500**	**600**	**780**	**1100**
T1.601 # 7	1250	31.9	39.6	49.4	57.4	61.8	64.8	72.3	79.3	86.1	97.9	116
T1.601 # 9	972	29.5	39.1	54.7	51.5	59.5	65.0	64.1	74.4	75.7	86.4	101
T1.601 # 13	1008	28.5	36.8	50.7	52.3	59.5	64.5	66.0	74.9	77.9	89.4	105
CSA # 4	704	18.9	23.8	32.2	41.9	42.8	45.2	51.5	52.8	56.0	58.7	74.1
CSA # 6	833	21.4	26.3	32.8	38.2	41.2	43.2	48.2	52.9	57.4	65.3	77.5
CSA # 7	623	18.7	22.6	29.1	36.2	40.0	43.2	45.5	52.5	60.2	63.2	76.0
CSA #8	699	20.7	24.8	30.2	36.9	40.8	43.3	49.4	55.1	60.4	68.8	81.7
Mid-CSA	555	14.4	17.5	21.8	25.5	27.5	28.8	32.1	35.1	38.3	43.5	51.6

G.2 Primary constants

The primary constants R, L, C, and G of both polyethylene insulated cable (PIC) and pulp insulated cable, at 0°F, 70°F, and 120°F, are specified in Annex G of ANSI T1.601.

The variation of *R* and *L* with frequency can be accurately modeled as follows:

$$R(f) = \sqrt[4]{r_{0c}^4 + a_c \times f^2} \quad \text{and} \quad L(f) = \frac{l_0 + l_\infty \times (f / f_m)^b}{1 + (f / f_m)^b}$$

where

r_{0c} (kΩ/kft) is the copper DC resistance;

a_c is characterizing the rise of resistance with frequency in the "skin" effect;

l_0 (mH/kft) and l_∞ (mH/kft) are the low and high frequency inductance, respectively;

f (MHz) is the frequency at which R and L are calculated;

f_m (MHz) and *b* are characterizing the transition between low and high frequency in the measured inductance values.

The six coefficients for 24 and 26 AWG PIC cable (per kft at 70°F) are given in Table G.4.

Table G.4 - Coefficients for calculation of *R* and *L* (24 and 26 AWG PIC at 70° F)

	r_{0c} kΩ/kft	a_c	l_0 mH/kft	l_∞ mH/kft	f_m MHz	*b*
24 AWG	0.0537	0.000386	0.1873	0.1292	0.6973	0.8188
26 AWG	0.0836	0.001034	0.1867	0.1343	0.8696	0.8472

For PIC cable the C values are constant with frequency (15.72 nF/kft), and the G values are negligibly small.

Annex H
(informative)

Aspects of ADSL systems based on 2048 kbit/s

H.1 Scope

This annex provides clarification on options within the main body of the standard that relate to systems operating in a 2048 kbit/s environment (hereafter referred to as 2048 kbit/s applications).

H.2 Bearer channel allocations

The configuration of those allocations that are appropriate for 2048 kbit/s applications are shown in Table H.1. The noise models and test loops presented in this annex are for bearer channel allocations as shown in Table H.1.

Table H.1 - Bearer channel allocations for 2048 kbit/s applications

2048 kbit/s configuration	ATU Category	Net data rate (kbit/s)			
		STM only		ATM and STM	
		Simplex (AS0)	Duplex (LS0)	DownStream (AS0)	UpStream (LS0)
1	I	2048	16	2208	160
		2048	160		
2	I	2048	16	2048	32
NOTE - The channelization is tested with full overhead framing.					

H.3 Noise models

Two noise sources are described for the testing of ADSL systems. These are frequency-domain sources that model the steady-state operating environment caused by crosstalk from adjacent wire pairs due to differing transmission systems. The two models differ because of the need to cater to countries that may or may not have HDB3-based primary rate systems operating at 2048 kbit/s in their access networks. Model A is for the case where no such interferers exist, while model B includes the crosstalk coupling effects of these types of systems.

H.3.1 Injection method

Test noise is applied as described in 11.3.1.1.

H.3.2 Crosstalk noise sources

The power spectral density of the crosstalk noise sources used for performance testing is given in Figure H.1 for model A, and in Figure H.2 for model B. Model A includes discrete tones, which represent radio frequency interference that is commonly observed, especially on wire pairs routed above ground. Further details of the specification of these noise models are shown in Table H.2, Table H.3 and Table H.4.

The resulting wideband noise power over the frequency range 1 kHz to 1.5 MHz for model A is -49.4 ± 0.5 dBm and for model B is -43.0 ± 0.5 dBm.

The noise probability density function is approximately Gaussian with a crest factor 5.

The accuracy of the power spectral density is within ±1 dB over the frequency range 1 kHz to 1.5 MHz, when measured with a resolution bandwidth of 1 kHz.

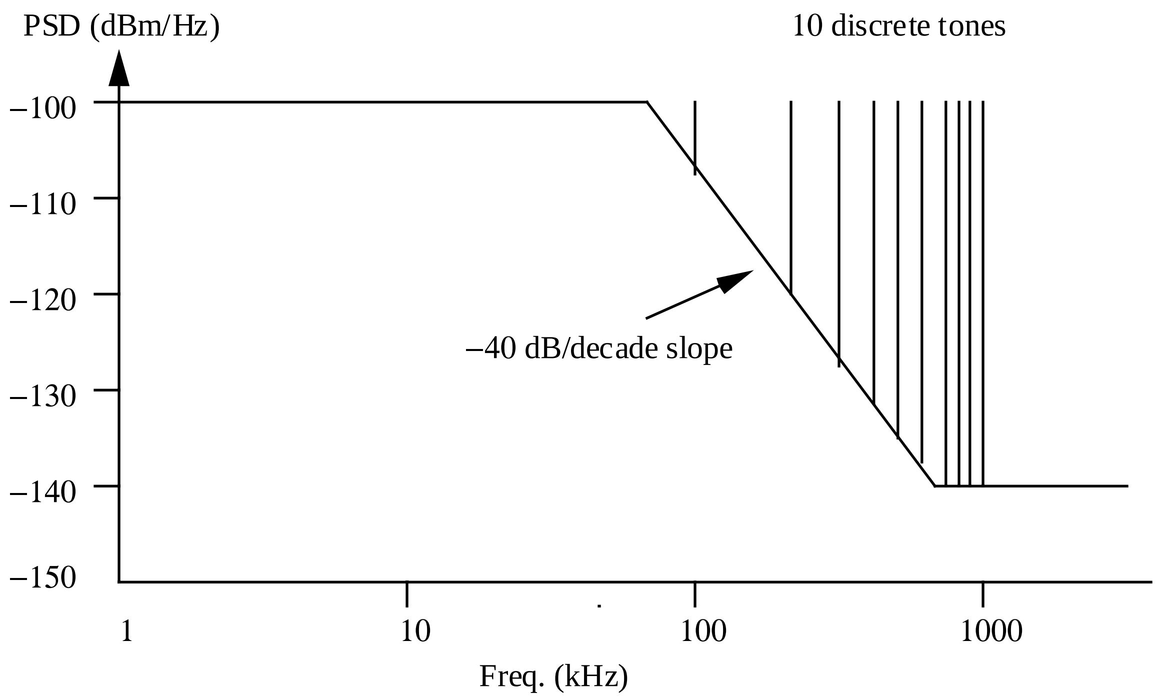


Figure H.1 - Single sided noise power spectral density into 100 Ω for model A

Table H.2 - Co-ordinates for noise model A

Freq. kHz	**PSD** dBm/Hz	**PSD** μV/√Hz
1	-100	3.16
79.5	-100	3.16
795	-140	0.03
1500	-140	0.03

Table H.3 - Tone frequencies and powers for noise model A

Freq. kHz	**Power** dBm
99	-70
207	-70
333	-70
387	-70
531	-70
603	-70
711	-70
801	-70
909	-70
981	-70

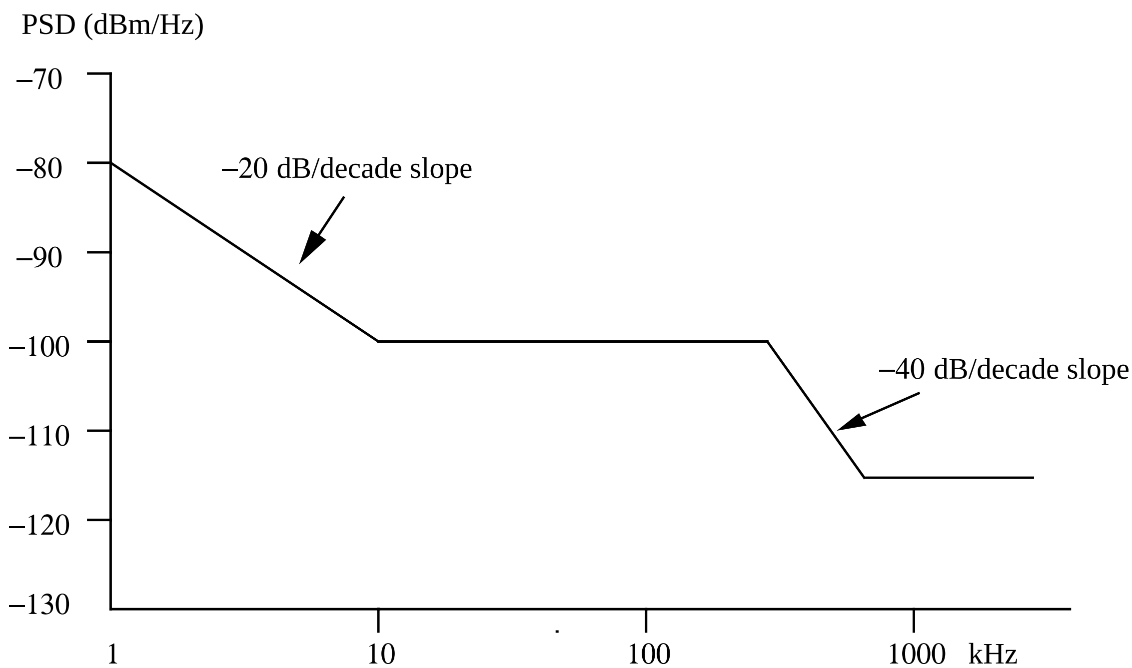


Figure H.2 - Single sided noise power spectral density into 100 Ω for model B

Table H.4 - Co-ordinates for noise model B

Freq. kHz	**PSD** dBm/Hz	**PSD** μV/√Hz
1	-80	31.62
10	-100	3.16
300	-100	3.16
711	-115	0.56
1500	-115	0.56

H.4 Test loops

To test the performance of the ADSL system incorporating the bearer channel capabilities outlined in clause H.2, the test loops specified in Figure H.3 are used. The power spectral density of the ADSL downstream transmission is as described in 6.13 of the standard.

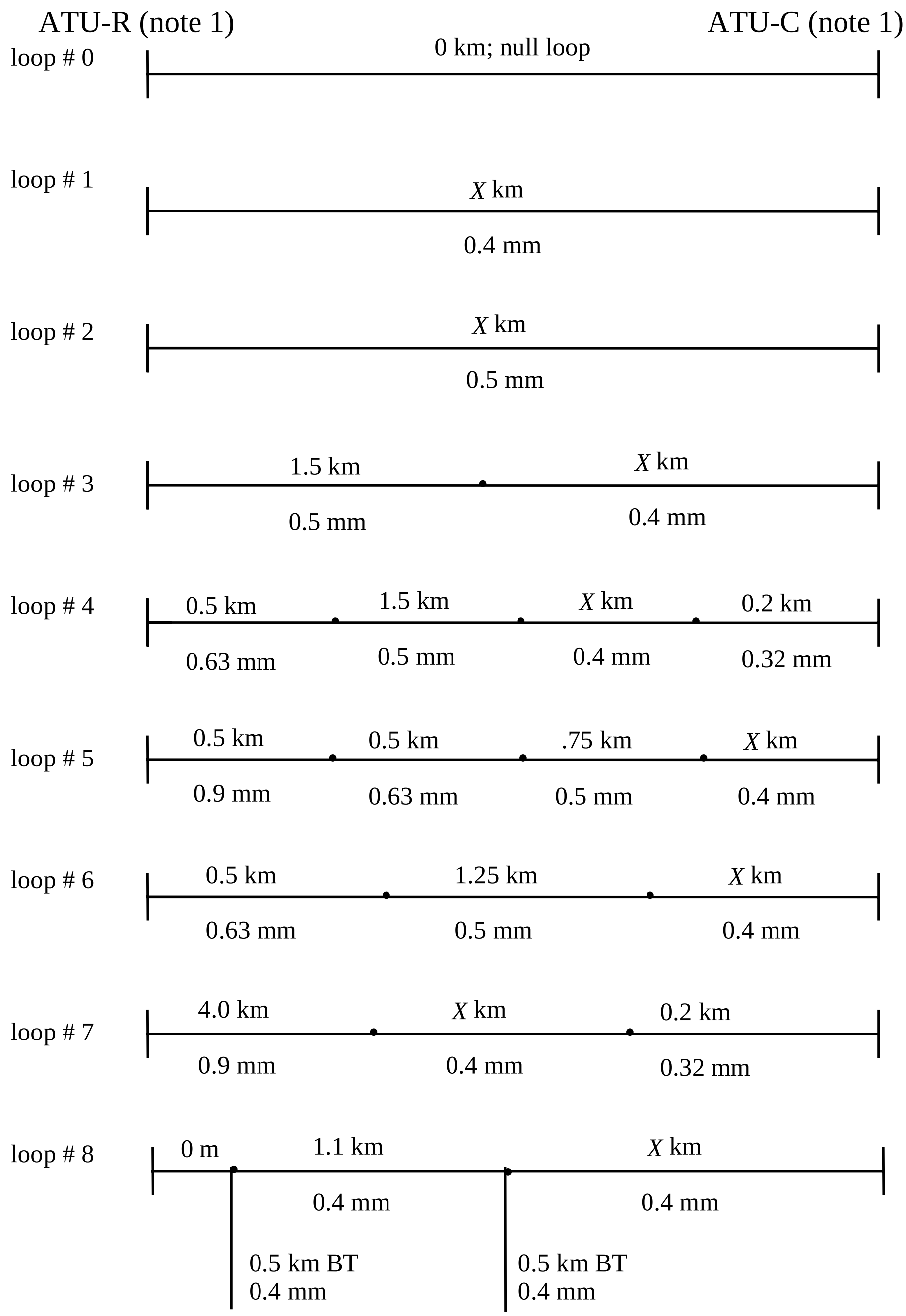
The variation of the primary line constants (R, L and C) with frequency for the different reference cable types are given in Table H.9 and Table H.10. Note that G is assumed zero. The RLC values are quoted per km at a temperature of 20°C and are measured values that have been smoothed.

The variation of R and L with frequency can be accurately modeled as follows:

$$R(f) = \sqrt[4]{r_{0c}^{4} + a_c \times f^{2}} \quad \text{and} \quad L(f) = \frac{l_0 + l_\infty \times (f / f_m)^b}{1 + (f / f_m)^b}$$

The six coefficients for the cable types referenced in Figure H.3 are given in Table H.11, where *f* and *fm* are assumed to be specified in MHz.

Note also that there are adjustable sections (marked 'X') in Figure H.3. The nominal lengths of these sections are shown in Table H.5 - Table H.8. The lengths of the sections are based on the reference RLC values for each cable type shown in Table H.11 and Table H.12. For repeatability of measurement results, however, the lengths of these sections are adjusted to give the overall insertion loss given in Table H.5 - Table H.8. Insertion loss is measured at 300 kHz with 100 Ω (balanced resistive) source and termination impedances



NOTES

1. These test loops are shown with the ATU-Rs on the left; this is the European convention, which is in contrast to Figure 48, where the ATU-Rs are on the right.

2. All cable is Polyethylene insulated.

3. 1 km = 3.28 kft.

4. BT = bridged tap (i.e., a section of unterminated cable).

Figure H.3 - Test loop set for 2048 kbit/s configuration 1 or 2 operation with noise model A or B

Table H.5 - Loop-set insertion loss and nominal lengths for 2048 kbit/s configuration 1 (noise model A)

Loop #	**Nominal value of adjustable length ’X’** km	**Loop insertion loss at 300 kHz** dB
1	3.45	49.0
2	4.55	49.0
3	2.30	49.0
4	1.80	49.0
5	2.40	49.0
6	2.25	49.0
7	1.35	49.0
8	1.50	43.0

Table H.6 - Loop-set insertion loss and nominal length for 2048 kbit/s configuration 2 (noise model A)

Loop #	**Nominal value of adjustable length ’X’** km	**Loop insertion loss at 300 kHz** dB
1	3.60	51.0
2	4.80	51.0
3	2.50	51.0
4	2.00	51.0
5	2.55	51.0
6	2.40	51.0
7	1.55	51.0
8	2.10	51.0

Table H.7 - Loop-set insertion loss and nominal lengths for 2048 kbit/s configuration 1 (noise model B)

Loop #	**Nominal value of adjustable length 'X'** km	**Loop insertion loss at 300 kHz** dB
1	2.45	35.0
2	3.20	34.0
3	1.30	35.0
4	0.80	35.0
5	1.40	35.0
6	1.25	35.0
7	0.40	35.0
8	1.00	35.0

Table H.8 - Loop-set insertion loss and nominal lengths for 2048 kbit/s configuration 2 (noise model B)

Loop #	**Nominal value of adjustable length 'X'** km	**Loop insertion loss at 300 kHz** dB
1	2.55	36.0
2	3.40	36.0
3	1.40	36.0
4	0.90	36.0
5	1.50	36.0
6	1.35	36.0
7	0.50	36.0
8	1.10	36.0

Table H.9 - RLC values for 0.32, 0.4, and 0.5 mm PE cables

	0.32 mm C=40 nf/km		**0.4 mm** C=50 nF/km		**0.5 mm** C=50 nF/km	
Freq kHz	**R** Ω/km	**L** mH/km	**R** Ω/km	**L** mH/km	**R** Ω/km	**L** mH/km
0.	409.000	607.639	280.000	587.132	179.000	673.574
2.5	409.009	607.639	280.007	587.075	179.015	673.466
10.	409.140	607.639	280.110	586.738	179.244	672.923
20.	409.557	607.639	280.440	586.099	179.970	671.980
30.	410.251	607.639	280.988	585.322	181.161	670.896
40.	411.216	607.639	281.748	584.443	182.790	669.716
50.	412.447	607.639	282.718	583.483	184.822	668.468
100.	422.302	607.631	290.433	577.878	199.608	661.677
150.	437.337	607.570	302.070	571.525	218.721	654.622
200.	456.086	607.327	316.393	564.889	239.132	647.735
250.	477.229	606.639	332.348	558.233	259.461	641.208
300.	499.757	605.074	349.167	551.714	279.173	635.119
350.	522.967	602.046	366.345	545.431	298.103	629.489
400.	546.395	596.934	383.562	539.437	316.230	624.309
450.	569.748	589.337	400.626	533.759	333.591	619.557
500.	592.843	579.376	417.427	528.409	350.243	615.202
550.	615.576	567.822	433.904	523.385	366.246	611.211
600.	637.885	555.867	450.027	518.677	381.657	607.552
650.	659.743	544.657	465.785	514.272	396.528	604.192
700.	681.138	534.942	481.180	510.153	410.907	601.104
750.	702.072	526.991	496.218	506.304	424.835	598.261
800.	722.556	520.732	510.912	502.707	438.348	595.639
850.	742.601	515.919	525.274	499.343	451.480	593.217
900.	762.224	512.264	539.320	496.197	464.258	590.975
950.	781.442	509.503	553.064	493.252	476.71	588.896
1000.	800.272	507.415	566.521	490.494	488.857	586.966
1050.	818.731	505.831	579.705	487.908	500.720	585.169
1100.	836.837	504.623	592.628	485.481	512.317	583.495

NOTE - G = 0 at all frequencies.

Table H.10 - RLC values for 0.63 and 0.9 mm PE cables

	0.63 mm C = 45 nF/km		**0.9 mm** C = 40 nF/km	
Freq kHz	**R** Ω/km	**L** mH/km	**R** Ω/km	**L** mH/km
0.	113.000	699.258	55.000	750.796
2.5	113.028	697.943	55.088	745.504
10.	113.442	693.361	56.361	731.961
20.	114.737	687.008	59.941	716.775
30.	116.803	680.714	64.777	703.875
40.	119.523	674.593	70.127	692.707
50.	122.768	668.690	75.586	682.914
100.	143.115	642.718	100.769	647.496
150.	164.938	622.050	121.866	625.140
200.	185.689	605.496	140.075	609.652
250.	204.996	592.048	156.273	598.256
300.	222.961	580.960	170.987	589.504
350.	239.764	571.691	184.556	582.563
400.	255.575	563.845	197.208	576.919
450.	270.533	557.129	209.104	572.237
500.	284.753	551.323	220.365	568.287
550.	298.330	546.260	231.081	564.910
600.	311.339	541.809	241.326	561.988
650.	323.844	537.868	251.155	559.435
700.	335.897	534.358	260.615	557.183
750.	347.542	531.212	269.745	555.183
800.	358.819	528.378	278.577	553.394
850.	369.758	525.813	287.138	551.784
900.	380.388	523.480	295.452	550.327
950.	390.734	521.352	303.538	549.002
1000.	400.816	519.402	311.416	547.793
1050.	410.654	517.609	319.099	546.683
1100.	420.264	515.956	326.602	545.663

NOTE - G = 0 at all frequencies.

Table H.11 - Coefficients for calculation of *R* and *L*

	r_{0c} kΩ/km	a_c	l_0 mH/km	l_∞ mH/km	f_m MHz	b
0.32 mm	0.4090	0.3822	0.6075	0.5000	0.6090	5.2690
0.4 mm	0.2800	0.0969	0.5873	0.4260	0.7459	1.3850
0.5 mm	0.1792	0.0561	0.6746	0.5327	0.6647	1.1950
0.63 mm	0.1130	0.0257	0.6994	0.4772	0.2658	1.0956
0.9 mm	0.0551	0.0094	0.7509	0.5205	0.1238	0.9604

H.5 ADSL/POTS splitter impedances

The design impedance for the POTS port of the splitter is application specific, and therefore outside the scope of this informative annex. Of particular importance are return loss and resultant sidetone levels. It is expected that some 2048 kbit/s applications will require that the splitter matches to a complex telephony impedance. Significant differences may exist between particular applications; examples are:

- Telephony impedances;
- Telephony return loss;
- Out of (POTS) band signalling systems (e.g., subscriber private metering 11 kHz to 50 kHz);
- Low frequency telemetry.

H.6 Testing

Performance testing is outlined in the main body of the standard (see clause 15). Note differences exist here with respect to the crosstalk noise sources (see H.3.2) and the test loops (see clause H.4), and the addition of a maximum stress linearity test (see H.6.1). Further details appropriate for testing are given in the main body of the standard.

H.6.1 Maximum stress linearity test

This test stresses the ADSL system to ensure that adequate linearity is achieved in implementations. A modified Loop #1 from the loop-set given in Figure H.3 is used for this test. The modification is detailed in Table H.12. An additive white Gaussian noise source with a power spectral density of -140 ± 1 dBm/Hz over the frequency range 1 kHz to 1.5 MHz is applied at the ATU-R in place of the crosstalk source. A resolution bandwidth of 1 kHz is used for calibration of the power spectral density.

Table H.12 - Insertion loss (and nominal length) for Loop #1

2048 kbit/s configuration	**Nominal value of adjustable length 'X' of Loop #1** km	**Loop insertion loss at 300 kHz** dB
1	4.35	62.0
2	4.70	67.0

Annex I
(informative)

Extended impulse noise tests

Figure I.1 - Figure I.4 show some measured examples of impulse noise of very long duration.

The impulse noise is measured at the customer premises telephone jack and includes continuous time. The impulse noise is superimposed on continuous tone interference from AM radio.

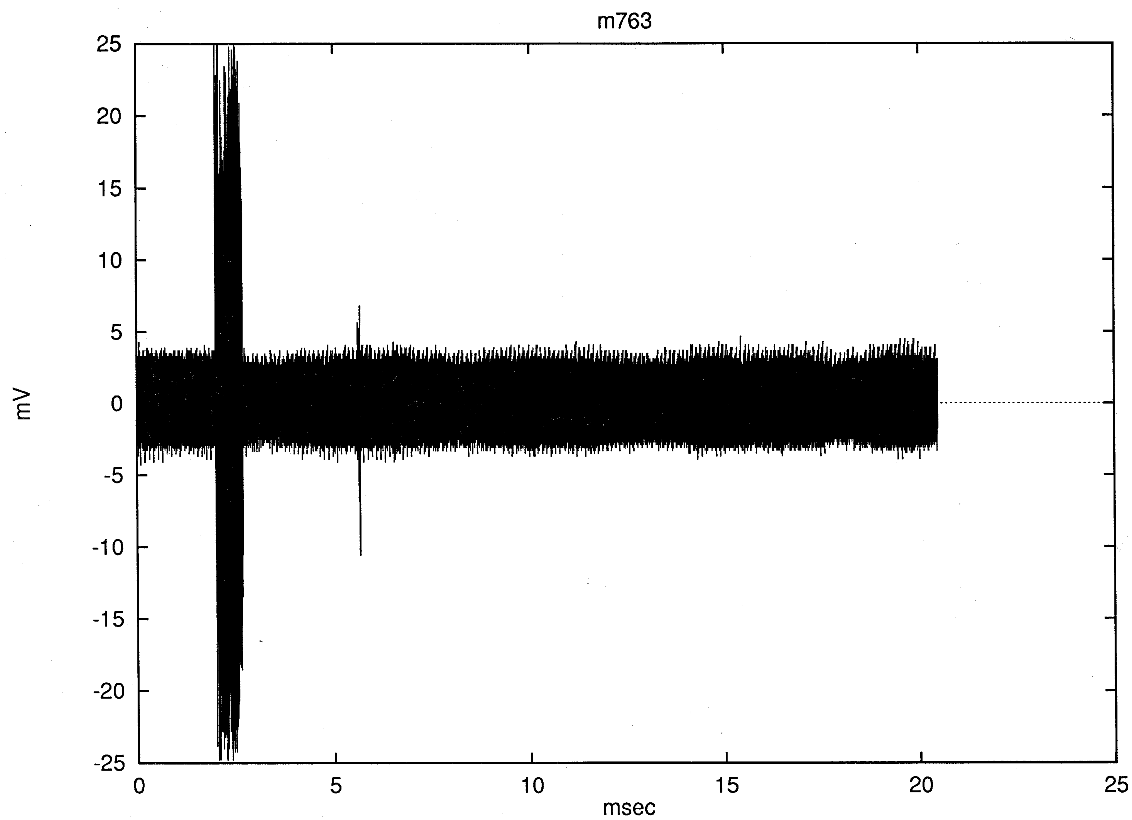


Figure I.1 - Impulse noise of very long duration (#1)

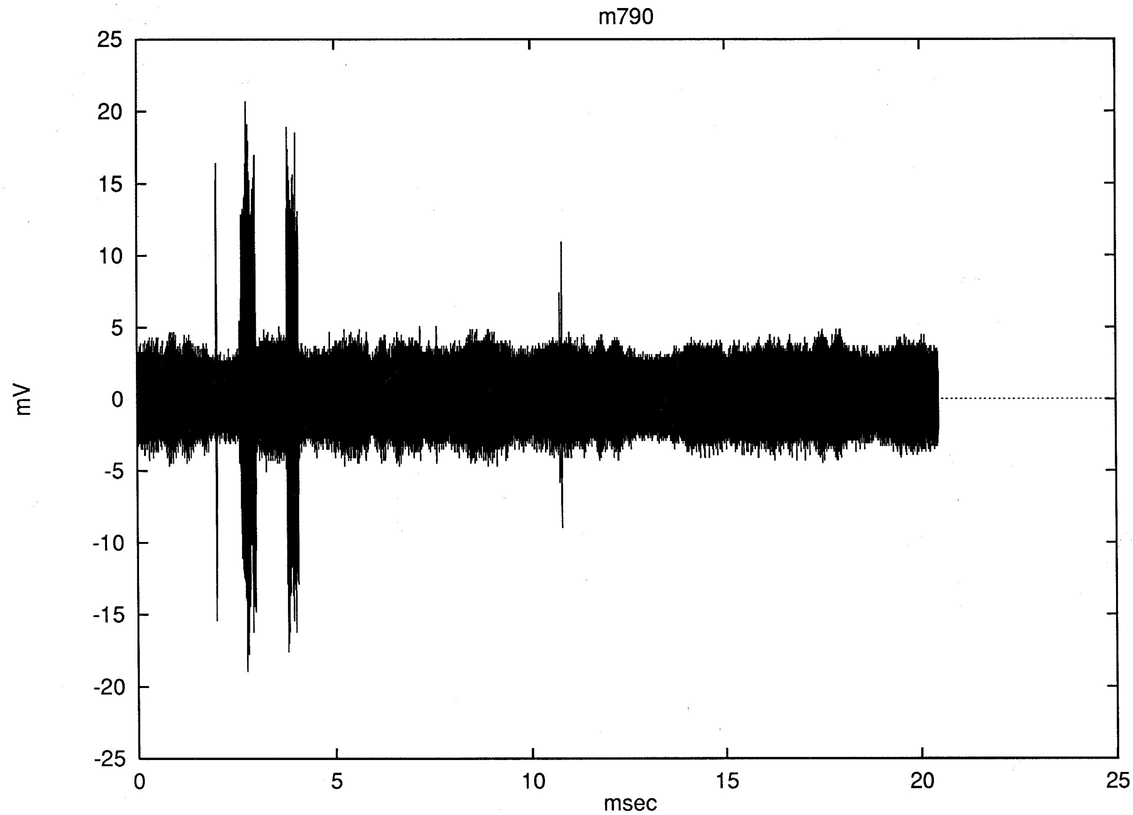


Figure I.2 - Impulse noise of very long duration (#2)

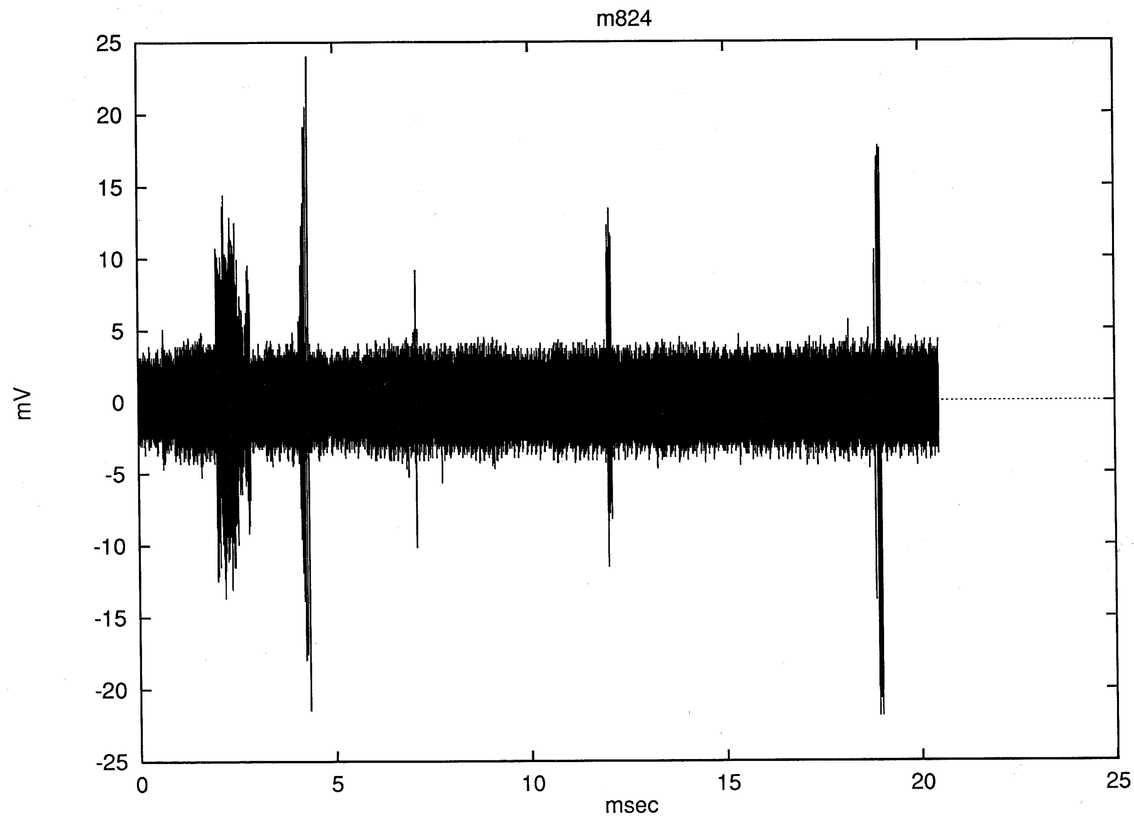


Figure I.3 - Impulse noise of very long duration (#3)

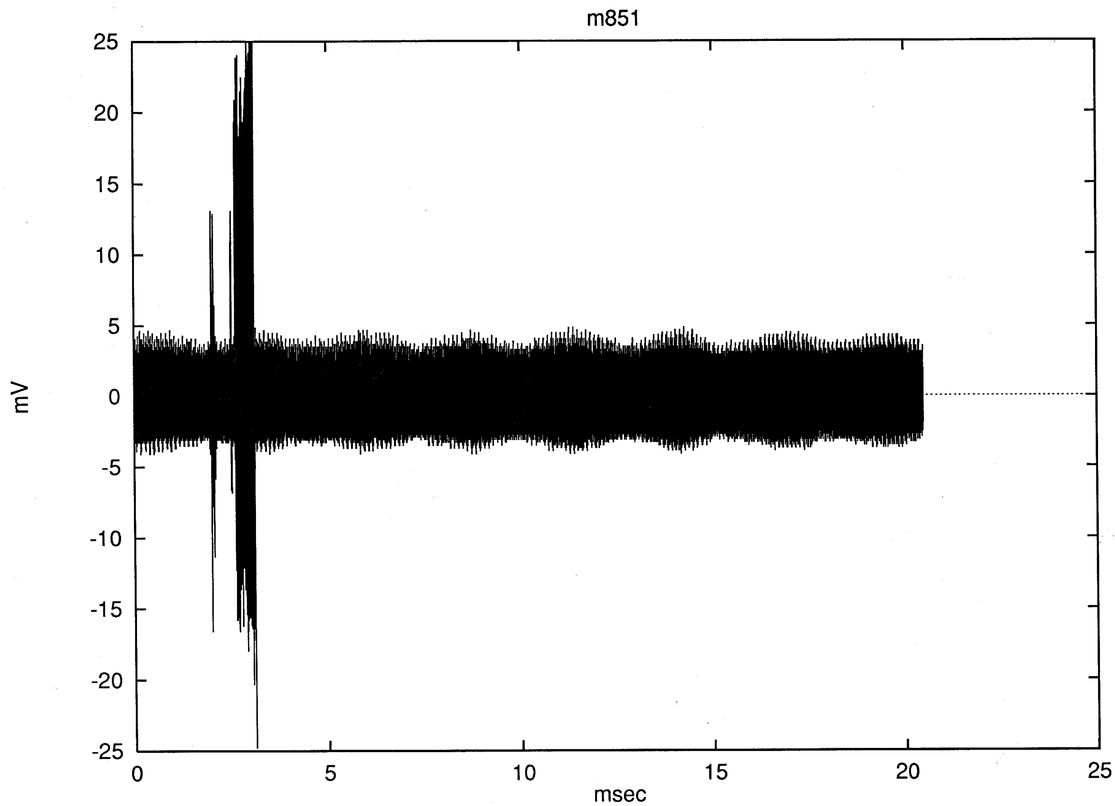


Figure I.4 - Impulse noise of very long duration (#4)

Annex J
(informative)

Cell TC Sublayer interfaces

This annex describes the interfaces of the ATM Cell TC Sublayer towards the Mux/Sync Control Block and towards the ATM Layer. The ATU consists of the Cell Specific Transmission Convergence Sublayer (Cell TC), the Mux/Sync Control block (ADSL framing) and the other physical layer functions (FEC and modulation), as shown in Figures 3 and 5.

The ATM layer to Physical Layer (i.e., ATU-C) interfaces (named V-C and T-R) and the ATM Cell TC to Mux/Sync Control Block interfaces are described in this annex and shown in Figure J.1. The interface to the Mux/Sync Control block carries data, bit timing, byte boundary information and NCD and HEC indicators for OAM (see 6.4.1.1).

Figure J.2 shows the interface of an ATM Cell TC to an STM ATU-C Mux/Sync Control block. This interface may carry data and bit timing information only, as described for an STM ATU-C in 6.1.5. Interoperability of an ATM ATU-C and an ATM cell TC plus an STM ATU-C (i.e., ATM over STM) is described in 6.2.4.

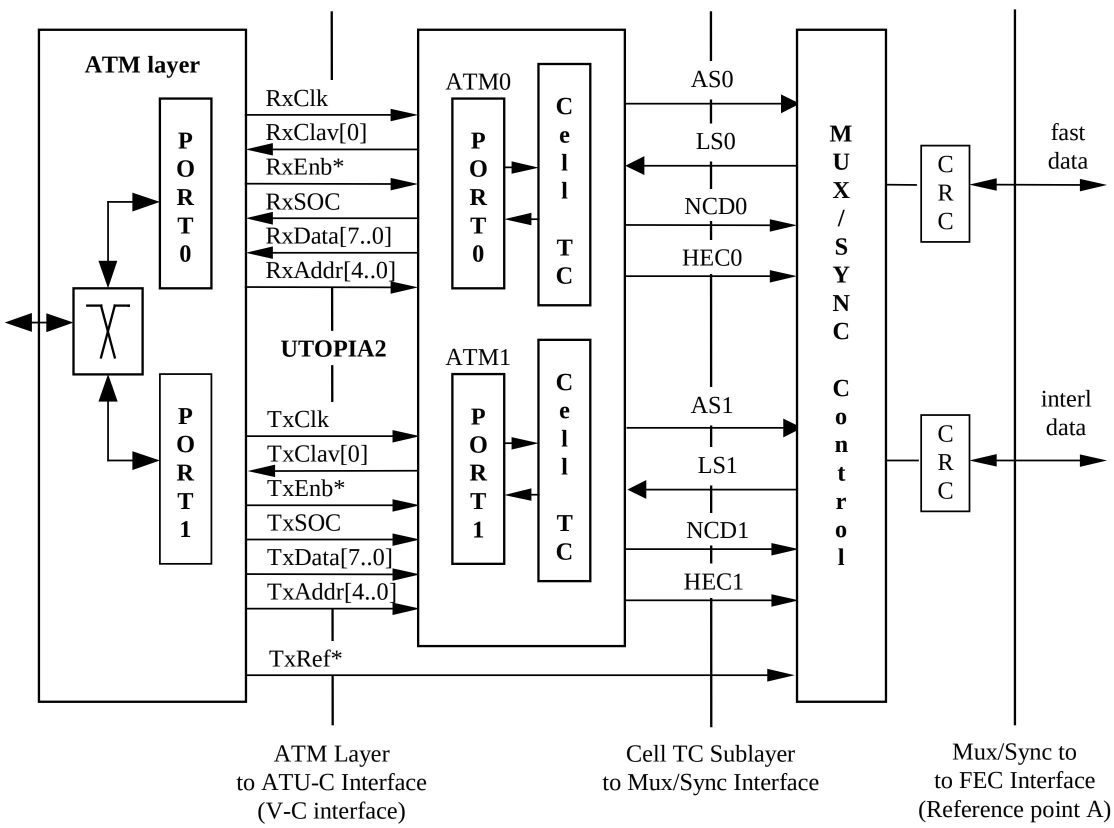


Figure J.1 - Interfaces to Cell TC Sublayer, internal to ATM ATU-C

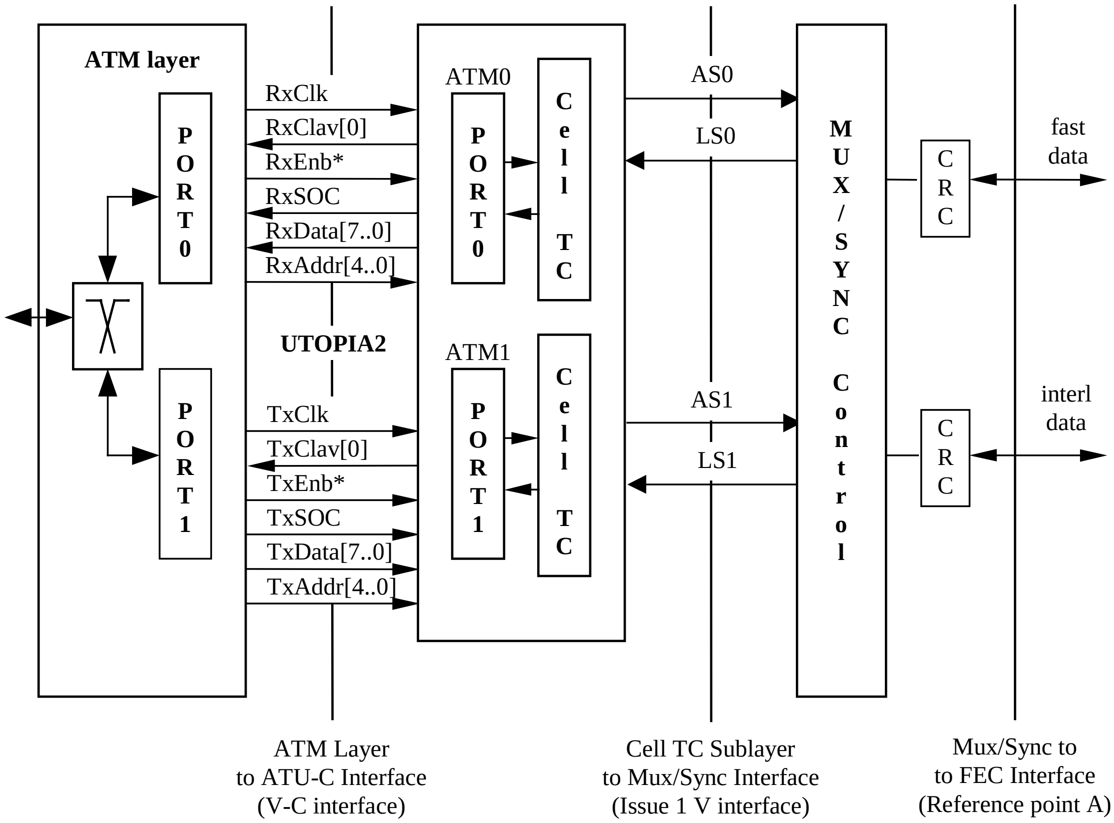


Figure J.2 - Interfaces to Cell TC Sublayer, external to STM ATU-C

The ATM Layer performs cell multiplexing from and demultiplexing to the appropriate physical port (i.e. latency path - fast or interleaved) based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header. Configuration of the cell demultiplexing process is done by ATM Layer management.

A Cell Specific Transmission Convergence Sublayer (Cell TC) is provided for each latency path separately. Cell TC functionalities are described in 6.2.3.

The logical input and output interfaces at the V-C reference point for ATM transport is based on the UTOPIA Level 2 interface with cell level handshake. The logical interface is given in Table J.1 and Table J.2 and shown in Figure J.1 and Figure J.2. When a flow control flag is activated by the ATU-C (i.e., the ATU-C wants to transmit or receive a cell), the ATM layer initiates a cell Tx or cell Rx cycle (53 byte transfer). The ATU supports transfer of a complete cell within 53 consecutive clock cycles. The UTOPIA Tx and Rx clocks are mastered from the ATM layer. The same logical input and output interfaces based on the UTOPIA Level 2 interface can be used at the Issue 2 T-R reference point in the ATU-R.

Table J.1 - UTOPIA Level 2 ATM Interface Signals for Tx

Signal Name	Direction	Description
Transmit Interface		
TxClk	ATM to PHY	Timing signal for transfer
TxClav[0]	PHY to ATM	Asserted to indicate that the PHY Layer has buffer space available to receive a cell from the ATM Layer (deasserted 4 cycles before the end of the cell transfer)
TxEnb*	ATM to PHY	Asserted to indicate that the PHY Layer must sample and accept data during the current clock cycle
TxSOC	ATM to PHY	Identifies the cell boundary on TxData
TxData[7..0]	ATM to PHY	ATM Cell Data transfer (8-bit mode)
TxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for TxClav status
TxRef*	ATM to PHY	Network Timing Reference (8 kHz timing signal) (only at V-C interface)

Table J.2 - UTOPIA Level 2 ATM Interface Signals for Rx

Signal Name	Direction	Description
Receive Interface		
RxClk	ATM to PHY	Timing signal for transfer
RxClav[0]	PHY to ATM	Asserted to indicate to the ATM Layer that the PHY Layer has a cell ready for transfer to the ATM Layer (deasserted at the end of the cell transfer)
RxEnb*	ATM to PHY	Asserted to indicate that the ATM Layer will sample and accept data during the next clock cycle
RxSOC	PHY to ATM	Identifies the cell boundary on RxData
RxData[7..0]	PHY to ATM	ATM Cell Data transfer (8-bit mode)
RxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for RxClav status
RxRef*	PHY to ATM	Network Timing Reference (8 kHz timing signal) (only at T_{SM} interface)

More details on the UTOPIA Level 2 interface can be found in the ATM Forum Specification, af-phy-0039.000.

Annex K
(informative)

Dynamic Rate Adaptation

K.1 Introduction

The Rate Adaptation at start-up procedure (see 9.8 and 9.9) optimizes the modem settings for the existing channel conditions and service requirements. Channel conditions and service requirements may, however, change over time. In order to avoid a lengthy restart to reconfigure the modem, a mechanism that allows reconfiguration of the modem during Showtime is proposed. This mechanism is referred to as Dynamic Rate Adaptation (DRA).

This annex describes an aoc-based DRA mechanism. The purpose of this DRA mechanism is not to provide “on-the-fly” Rate Adaptation, where the modem configuration would change continuously, tracking the slightest variation of the line conditions without affecting the user-traffic, but rather to allow for occasional changes, which would involve service interruption of the order of tens of milliseconds.

This DRA procedure may be augmented by a non-aoc-based fast Warm Restart procedure for the case where the aoc channel becomes unreliable. The specification of this Warm Restart procedure, however, is delayed to Issue 3.

K.1.1 General concepts

The proposed DRA mechanism is a mechanism that during Showtime, without the need to restart:

– allows rate modifications (see note) for both US and DS (up- and downgrades).

– allows rate repartitionings between the fast and the interleaved paths.

– provides a aoc-based protocol that prior to the actual swap of the modem configuration runs without interfering with the user-traffic.

– allows the ATU-C to gather information or metrics about operational conditions

– follows the same philosophy as RA during Start-up

NOTE - Rate modification implies more than just bit-rate but also FEC and Interleaving settings.

Note, however, that the DRA mechanism does not:

– provide an on-the-fly rate adaptation solution, where the modem configuration would track the slightest variation of the line conditions without affecting the user-traffic.

– specify the policy that describes - based on the gathered metrics and/or additional information- when or how to reconfigure the modem settings. Furthermore the DRA mechanism assumes that the policy resides within the network and not within customer equipment.

– require the actual reconfiguration to occur error-free. During the transition period, user-data may be lost during tens of milliseconds for both communication directions.

K.2 DRA Protocol and Messages

K.2.1 DRA Concept

The DRA protocol expands the Issue 1 aoc message set by defining new DRA aoc messages. The purpose of these new messages is to:

a) allow the ATU-C to gather detailed information about the line conditions (*monitoring*)

b) propose to the ATU-R a new rate configuration - if needed. (*configuration)*

c) exchange configuration information - if the proposal is accepted by ATU-R. (*exchange)*

d) initiate and synchronize a swap to the new rate configuration. (*swap*)

The next subclauses highlight how each of these functions is implemented through aoc messages.

The maximum length of the new aoc-messages is limited to 13 bytes, this being the maximum length of an Issue 1 aoc message.

Just like Issue 1 aoc-messages, DRA-aoc messages are transmitted 5 times for protection against transmission errors. For concatenated messages composed of multiple 13-byte messages, each 13-byte message is sent 5 times consecutively, before the next 13-byte message is sent 5 times consecutively.

K.2.2 DRA-aoc messages

Table K.1 lists the new DRA-aoc command set.

Table K.1 - DRA Command Set

Header (hex)	**Command** (hex)	**Length** (bytes)	**Message**	**Source**
DF	0x00	7	DRA_Monitor_Request	ATU-C
DF	0x20	13	DRA_Monitor_Reply	ATU-R
DF	0x40...0x42	3×13	DRA_Configuration_Request	ATU-C
DF	0x60	4	DRA_Configuration_Reply	ATU-R
DF	0x80...0x9F	4×13	DRA_Exchange_Request	ATU-C / ATU-R
DF	0xA0	4	DRA_Exchange_Reply	ATU-R / ATU-C
DF	0xC0	8	DRA_Swap_Request	ATU-C
DF	0xE0	8	DRA_Swap_Reply	ATU-R
DF	Other		*Reserved*	

NOTE - In all DRA messages, reserved bits or fields are coded 0, unless explicitly stated otherwise.

K.3 Monitoring

The ATU-C monitors the changing line conditions. Through the eoc, the SNR margin and the line attenuation from the DS can be retrieved. However, more information may be required in order to decide whether or not a new configuration is proposed, and if so, what the new proposal will be. In order to allow the ATU-C to gather more information about the DS, two new aoc messages are defined.

NOTE - The ATU-C already monitors the US, thus no US-related information needs to be exchanged.

K.3.1 DRA_Monitor_Request

DRA_Monitor_Request is generated by the ATU-C; its format is given in Table K.2.

Table K.2 - DRA Monitor Request

Message Format	Bits	Definition
DRA_Monitor_Request {		
Header	8	0xDF
Command	8	0x00
Reserved	3	
Req_SNR_Margin	5	Required SNR Margin to be used for the b_{max} that will be calculated by the ATU-R and returned within *DRA_Monitor_Reply* message. Unsigned value in dB. Allowed values ranging from 0 to 15 dB.
Reserved	32	
}		

K.3.2 DRA_Monitor_Reply

This message is sent by the ATU-R in response to DRA_Monitor_Request from the ATU-C.

The ATU-R may also send this message unsolicited, whenever considered necessary: e.g. when line conditions change significantly and endanger proper operation of the modem and in particular the aoc channel. However, in order to prevent these messages from monopolizing the aoc channel, after sending an unsolicited DRA_Monitor_Reply, the ATU-R does not send another one before having received a DRA_Monitor_Request from the ATU-C.

The format of this DRA-aoc message is shown in Table K.3.

Table K.3 - DRA-aoc message format

Message Format	Bits	Definition
DRA_Monitor_Reply {		
Header	8	0xDF
Command	8	0x20
Attenuation	6	See R-MSG-RA (*current value*)
Req_SNR_Margin	5	Requested SNR margin (used in b_{max} calculation, see below). Same format as **Req_SNR_Margin** in *DRA_Monitor_Request*.
Noise_Margin	5	See R-MSG-RA (*current value*)
Coding_Gain	4	See R-MSG-RA (*used in* b_{max} *calculation*)
$\boldsymbol{b_{max}}$	12	See R-MSG-RA (*see below*)
RS_Payload	9	See R-MSG-RA (*used in* b_{max} *calculation*)
RS_Overhead	7	See R-MSG-RA (*used in* b_{max} *calculation*)
Nr_of_Tones	8	See R-MSG-RA (*used in* b_{max} *calculation*)
Reserved	32	
}		

Attenuation and Noise Margin are updated values based on the current modem conditions.

B_{max} indicates the maximum number of bits that can be carried per DMT symbol assuming a single latency and the Coding_Gain, RS_Payload, RS_Overhead and Nr_of_tones values listed. The same definitions as during RA at Start-Up apply.

The Required SNR margin used for the derivation of b_{max} coincides:

- in the case of an autonomous *DRA_Monitor_Reply*, with the Required SNR Margin that was used during the configuration of the current, active configuration.
- in the case of a response to a *DRA_Monitor_Request*, with the Req_SNR_Margin listed in *DRA_Monitor_Request*.

K.4 Configuration

Based on the gathered metrics and/or additional information, a network entity aware of the DRA policy may detect that the conditions are met, and modify the modem configuration. Two new aoc messages are defined to allow the ATU-C to propose one new configuration to the ATU-R for the DS.

NOTE - No need for US information exchange at this stage.

K.4.1 DRA_Configuration_Request

DRA_Configuration_Request is a concatenated message sent by the ATU-C. It consists of three 13-byte messages. The format of the messages is shown in Table K.4 (HDR and COM fields are one byte long, length of other fields is indicated in bits, indexes d and u refer to downstream and upstream respectively).

Table K.4 - DRA Configuration Request format

HDR	COM	RSM	BFd	BFd	BFd	BFd	BFd	RES	BFd	BFd	BFu	BFu	BFu
0xDF	0x42	(4)	(8)	(8)	(8)	(8)	(8)	(4)	(8)	(8)	(8)	(8)	(8)

HDR	COM	BId	BId	BId	BId	BId	RES	BId	BId	BIu	BIu	BIu
0xDF	0x41	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)

HDR	COM	RES	RSFd	RSId	Sd	Dd	RES	RSFd	RSId	Sd	Dd	RES
0xDF	0x40	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)

The definition of the messages is shown in Table K.5.

Table K.5 - DRA Configuration Request messages

Message Fields	Bits	Definition
RSM	4	Required SNR Margin to be used for the evaluation of this configuration. Value in dB. The allowed values range from 0 to 15 dB.
BFd, BFu, **BId, BIu,** **RSFd, RSId,** **RSFu, RSIu,** **Sd, Su** **Dd, Du**	8	Same definitions and ordering as in C-Rates-RA apply.
RES	4 or 8 (See Table K.4)	These reserved bits are coded ‘1’.

K.4.2 DRA_Configuration_Reply

This message is sent by the ATU-R in response to *DRA_Configuration_Request* from the ATU-C. The format and definition of the message are shown in Table K.6 and Table K.7.

Table K.6 - DRA Configuration Reply format

HDR	COM	STA	DAT
0xDF	0x60		

Table K.7 - DRA Configuration Reply messages

Message Format	Bits	Definition	
DRA_Configuration_Reply {			
Header	8	0xDF	
Command	8	0x60	
Status (STA)	8	0x00 :	Reserved
		0x01 :	ACK : New configuration accepted
		0x02 :	Retransmit : resend all *DRA_Configuration_Request* messages
		0x03 :	Option Fail : proposed option rejected
		0x04-0xFF : Reserved	
Data (DAT)	8	if STA=ACK : Noise margin for this configuration as in R-MSG2	
		if STA=RETRANSMIT: 0x00	
		if STA=OPTION_FAIL:	
			0x00 : General Failure Code
			0x01-0x1F : *Reserved* for Specific Failure Codes
}			

K.5 Exchange

Once both sides agree on the new configuration, both sides must be informed about which Bi and Gi to use on each tone. This is done in this third phase.

For this purpose two additional DRA-aoc messages are defined: *DRA_Exchange_Request* and its reply *DRA_Exchange_Reply*.

Unlike the previous DRA messages, the messages are used in both the downstream and upstream direction. For the Downstream the ATU-R is generating the *DRA_Exchange_Request* and the ATU-C answers with an *DRA_Exchange_Reply*. For the upstream the ATU-C generates the *DRA_Exchange_Request* and the ATU-R answers with *DRA_Exchange_Reply*.

K.5.1 DRA_Exchange_Request

DRA_Exchange_Request is a concatenated message sent by the ATU-C. It consists of four 13-byte messages.

This message is used to communicate the modified Bi and Gi of the respective communication direction. Because one set of four 13-bytes messages may be insufficient to communicate all the modified values, a set of messages may be repeated for a new set of tones until all the new settings have been exchanged successfully.

The format and definition of *DRA_Exchange_Request* are given in Table K.8 and Table K.9. The 13-bytes message consists of 3 bytes followed by eight 10-bit fields. Each of these 10-bit fields encodes the Bi&Gi value of one tone.

Table K.8 - DRA_Exchange_Request format

HDR	COM	Ti	B&G	B&G	B&G	B&G	RES	B&G	B&G	B&G	B&G
0xDF			(8×Ti +0)	(8×Ti +1)	(8×Ti +2)	(8×Ti +3)		(8×Ti +4)	(8×Ti +5)	(8×Ti +6)	(8×Ti +7)

For the upstream only one block of four 13-bytes messages is needed. For the downstream a maximum of 8 blocks of four 13-bytes messages are needed.

The COM values of consecutive *DRA_Exhange_Request* messages are ordered as follows:

- the COM values decrease by one for each consecutive message (assuming no retransmission is needed)
- the COM value of the last *DRA_Exchange_Request* message is 0x80.

For the upstream direction, this means that the 4 COM values used are - in order - 0x83, 0x82, 0x81 and 0x80.

For the downstream direction the first COM value depends on how many blocks of four 13-byte message are needed. In the case that the maximum of 8 blocks (256 tones) are needed, the consecutive COM-values are 0x9F, 0x9E....0x83,0x82,0x81 and 0x80. If for example only 7 blocks (224 tones) are needed then the first COM value is 0x9B.

A new block of 4 *DRA_Exchange_Request* messages is allowed to be sent out only after the previous block of 4 messages has succesfully been acknowledged (cf. *DRA_Exchange_Reply*).

Table K.9 - DRA Exchange Request messages

Message Format	**Bits**	**Definition**		
DRA_Exchange_Request {				
Header	8	0xDF		
Command	8	0x9F...0x80 (Downstream) 0x83...0x80 (Upstream)		
Tone Number (Ti)	5	Tone segment (0 to 31)		
bi&gi (bits & gains)	4 x10	b_i and g_i values of 8 subsequent tones, starting from tone 8 × Ti.		
		b_i	4 bits	new b_i -value encoded as integer
		g_i	6 bits	new g_i value :
				0x00 : No Power
				0x01-0x3F : -3.875 dB to 3.875 dB in steps of 0.125 dB
				Notice that $\|gi\|$ must be ≤ 2.5 dB in order to be valid.
RES	3	These reserved bits are coded '1'		
bi&gi (bits & gains)	4 x10	b_i and g_i values of 8 subsequent tones, starting from tone 8×Ti.		
}				

K.5.2 DRA_Exchange_Reply

This message is sent in response to a *DRA_Exchange_Request* message; its format and message definition are shown in tables Table K.10 and Table K.11.

Table K.10 - DRA_Exchange_Reply format

HDR	COM	STA	DAT
0xDF	0xA0		

Table K.11 - DRA_Exchange_Reply messages

Message Format	Bits	Definition	
DRA_Exchange_Reply {			
Header	8	0xDF	
Command	8	0xA0	
Status (STA)	8	0x00 :	Reserved
		0x01 :	ACK : New bi-gi configuration accepted
		0x02 :	Retransmit : resend last set of 4 DRA_Exchange_ Request messages
		0x03 :	Option Fail : proposed option rejected
		0x04-0xFF :	Reserved
Data (DAT)	8	if STA=ACK :	COM value of the last 13-byte message of the block of 4 that is being acknowledged (notice: upstream always 0x80).
		if STA=RETRANSMIT:	COM value of the last 13-byte message of the block of 4 that must be retransmitted.
		if STA=OPTION_FAIL:	
			0x00 General Failure Code
			0x01-0x1F reserved for Specific Failure Codes
}			

K.6 Swap

Once the modems have agreed on the appropriate settings for the new configuration, the swap to the new configuration must be activated and synchronized. A swap always refers to the most recently agreed and successfully exchanged rate configuration settings.

Two new messages are defined: *DRA_Swap_Request* and *DRA_Swap_Reply*. *DRA_Swap_Request* will be sent by the ATU-C to inform the ATU-R about when to swap the rate. The ATU-R will acknowledge this request through the use of *DRA_Swap_Reply*.

During the transition from one rate configuration to another, tones may be sent with the wrong bi and gi. This also applies to sync symbols. Sync symbols may be corrupted. The pilot tone however must be maintained in order to allow frame and superframe detection. The transition time where the bi and gi may be corrupted is quantified prior to the actual rate swap through the use of two sets of parameters :

a) a SuperFrame Reference Number (*SFR*) to identify around which superframe boundary the rate swap will occur. Valid values of *SFR* are :

$SFR = 4 \times N - 1$ where N is an integer number

If the modems operate with the minimum required *S*-values (see Table 10 and Table 19), these *SFR*-references always coincide with code-word boudaries. This avoids an explicit Reset of the FEC-mechanism. However, if a different *S*-value is used, then a reset is performed.

Notice that *SFR* equals zero at the first Showtime symbol and is then increased by one (modulo 256) at each consecutive superframe. The definition of *SFR* is identical to the definition used for synchronizing a Bit-Swap operation.

By analogy with the bit-swap specification, the SFR value exceeds by at least 47 the superframe counter value that coincides with when the *DRA_Swap_Request* message is sent out.

b) a second set of parameters will indicate how many symbols before and after the reference superframe boundary

– the transmitter for the respective communication direction can send wrong constellation sizes and gains, therefore corrupting data;

– the receiver of the respective communication direction may not be able to recover the correct data. This value is not supposed to affect the speed at which the DRA swap is executed by the transmitter, but it allows it to quantify the loss of data during a DRA.

In total 8 duration values (e's) are exchanged. The e-values indicate the capability of the ATU's to adjust, fast or slow, to a change in bi/gi and FECsettings. 4 e-values are sent out by the ATU-C to the ATU-R within the *DRA_Swap_Request* message. These are:

- *Eps_DS_TX_neg*
- *Eps_DS_TX_pos*
- *Eps_US_RX_neg*
- *Eps_RX_RX_pos*

The ATU-R in *DRA_Swap_Reply* sends 4 analoguous e-parameters:

- *Eps_US_TX_neg*
- *Eps_US_TX_pos*
- *Eps_DS_RX_neg*
- *Eps_DX_RX_pos*

The syntax of these fields relies on following rules :

- "DS/US" refers to the communication direction.
- "TX/RX" refers to whether the e-value refers to the transmitting or receiving function.
- "neg/pos" refers to whether the e-parameter identifies respectively the beginning - expressed in how many frames before the SFR reference - or the end - expressed in how many symbols after the SFR reference - of the timespan in which the data may be corrupted.

Each ATU only indicates the e's that apply to its side. There is no negotiation process of e's involved.

Each e-value is positive and encoded in one byte as an unsigned value indicating a duration ranging from 0 to 255 frames.

The maximum number of corrupted symbols (CS) for the downstream direction (incl. receiver) can be quantified as:

$$CS_{DS} = \max(Eps\_DS\_TX\_neg, EPS\_DS\_RX\_neg) + \max(Eps\_DS\_TX\_pos, Eps\_DS\_RX\_pos)$$

The maximum number of corrupted symbols for the upstream direction (incl. receiver) can be quantified as:

$$CS_{US} = \max(Eps\_US\_TX\_neg, EPS\_US\_RX\_neg) + \max(Eps\_US\_TX\_pos, Eps\_US\_RX\_pos)$$

K.6.1 Example

Consider the situation shown in Figure K.1:

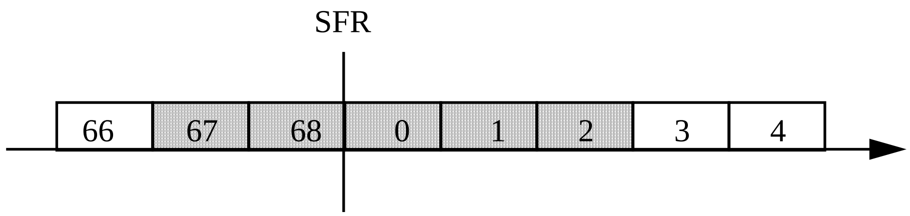


Figure K.1 - Corrupted frames transmitted by ATU-C

The grey zones represent the corrupted frames or DMT symbols that the ATU-C will transmit downstream during a DRA Swap. In this particular situation, *Eps_DS_TX_neg* is equal to 2 (two zones are gray before SFR), and *Eps_DS_TX_pos* is equal to 3 (three zones are gray after SFR).

If the ATU-R receiver capability to adapt to the new configuration is identified by an *EPS_DS_RX_neg* of 0, and an *EPS_DS_RX_pos* of 5 (see Figure K.2), then the maximum number of corrupted symbols is 7.

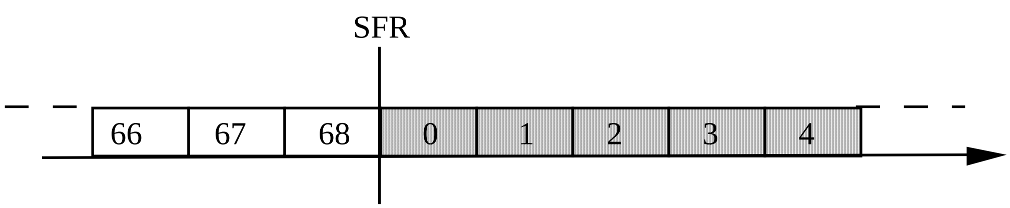


Figure K.2 - Frames corrupted by the ATU-R receiver

K.6.2 DRA_Swap_Request

This message is sent by the ATU-C; its format and message definition are shown in Table K.12 and Table K.13.

Table K.12 – DRA_Swap_Request format

HDR	COM	STA	DAT	EDTN	EDTP	EURN	EURP
0xDF	0xC0						

Table K.13 – DRA_Swap_Request messages

Message Format	Bits	Definition
DRA_Swap_Request {		
Header	8	0xDF
Command	8	0xC0
Status (STA)	8	0x00 : Reserved
		0x01 : SWAP Request
		0x02 : SWAP Information Request (*cf. below*)
		0x03-0xFF : Reserved
Data (DAT)	8	if STA=SWAP: *SFR*. Notice that the two least significant bits must be encoded as 0x3.
		if STA≠SWAP: Reserved
Eps_DS_TX_neg (EDTN)	8	*cf. above*
Eps_DS_TX_pos (EDTP)	8	*cf. above*
Eps_US_RX_neg (EURN)	8	*cf. above*
Eps_US_RX_pos (EURP)	8	*cf. above*
}		

Swap Information Request allows the ATU-C to retrieve the e's of the ATU-R and evaluate data loss without requesting a rate swap.

K.6.3 DRA_Swap_Reply

This message is sent by the ATU-R as a reply to *DRA_Swap_Request*; its format and message definition are given in Table K.14 and Table K.15.

Table K.14 – DRA_Swap_Reply format

HDR	COM	STA	DAT	EUTN	EUTP	EDRN	EDRP
0xDF	0xE0						

Table K.15 – DRA_Swap_Reply messages

Message Format	Bits	Definition	
DRA_Swap_Reply {			
Header	8	0xDF	
Command	8	0xE0	
Status (STA)	8	0x00 :	Reserved
		0x01 :	ACK SWAP
		0x02:	NACK_SWAP
		0x03:	ACK SWAP_INFO
		0x04 :	NACK SWAP_INFO
		Other :	Reserved
Data (DAT)	8	if STA=ACK: same *SFR*-value as *DRA_Swap_Request*	
		if STA≠ACK: *Reserved*	
Eps_US_TX_neg (EUTN)	8	*cf. above*	
Eps_US_TX_pos (EUTP)	8	*cf. above*	
Eps_DS_RX_neg (EDRN)	8	*cf. above*	
Eps_DS_RX_pos (EDRP)	8	*cf. above*	
}			

K.7 DRA State Diagram

K.7.1 State Machine Conventions

When being in a particular state, only the messages shown in the diagram are responded to. Any other message received is ignored.

Sharp-edged rectangles indicate states. Text covering an arrow indicates the condition for that arrow. Round-edged rectangles indicate actions to be taken along the arrows and maximum time (in ms) to perform that action.

The grey states and transitions refer to the standardized Bit Swap mechanism.

K.7.2 ATU-R State Machine

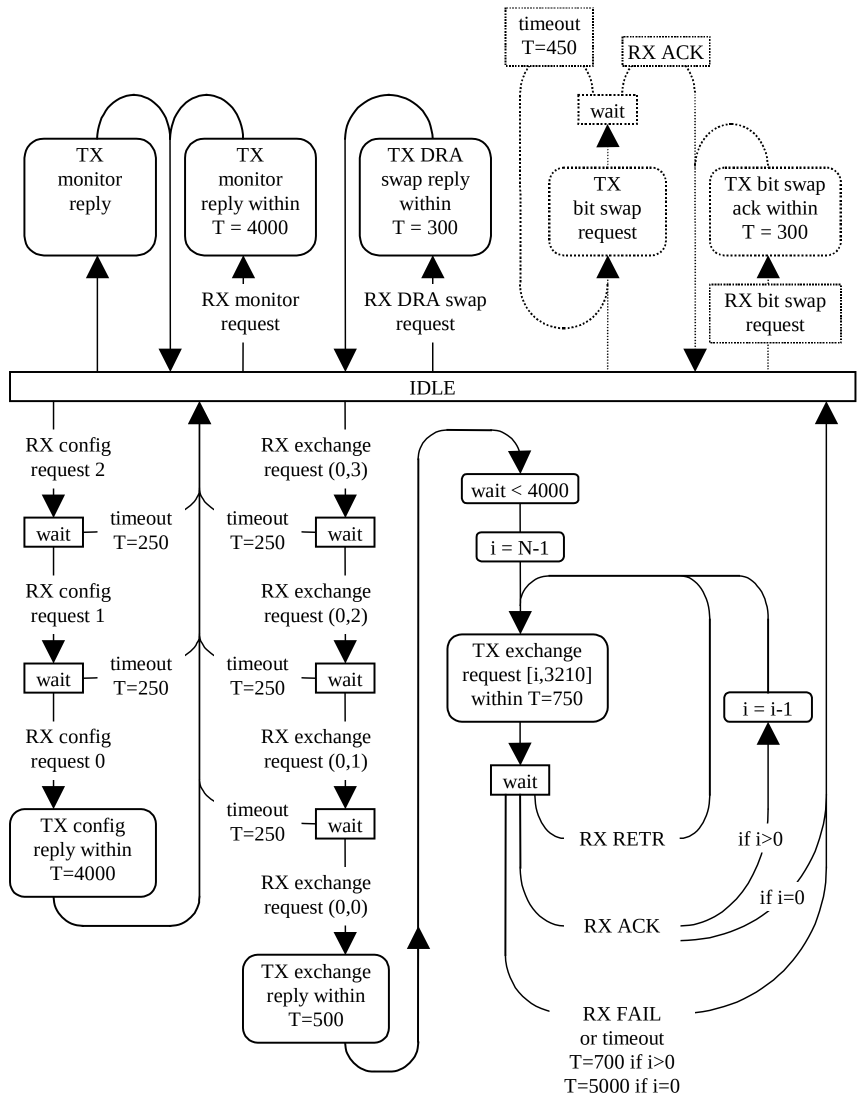


Figure K.3 - ATU-R State Diagram for aoc

K.7.3 ATU-C State Machine

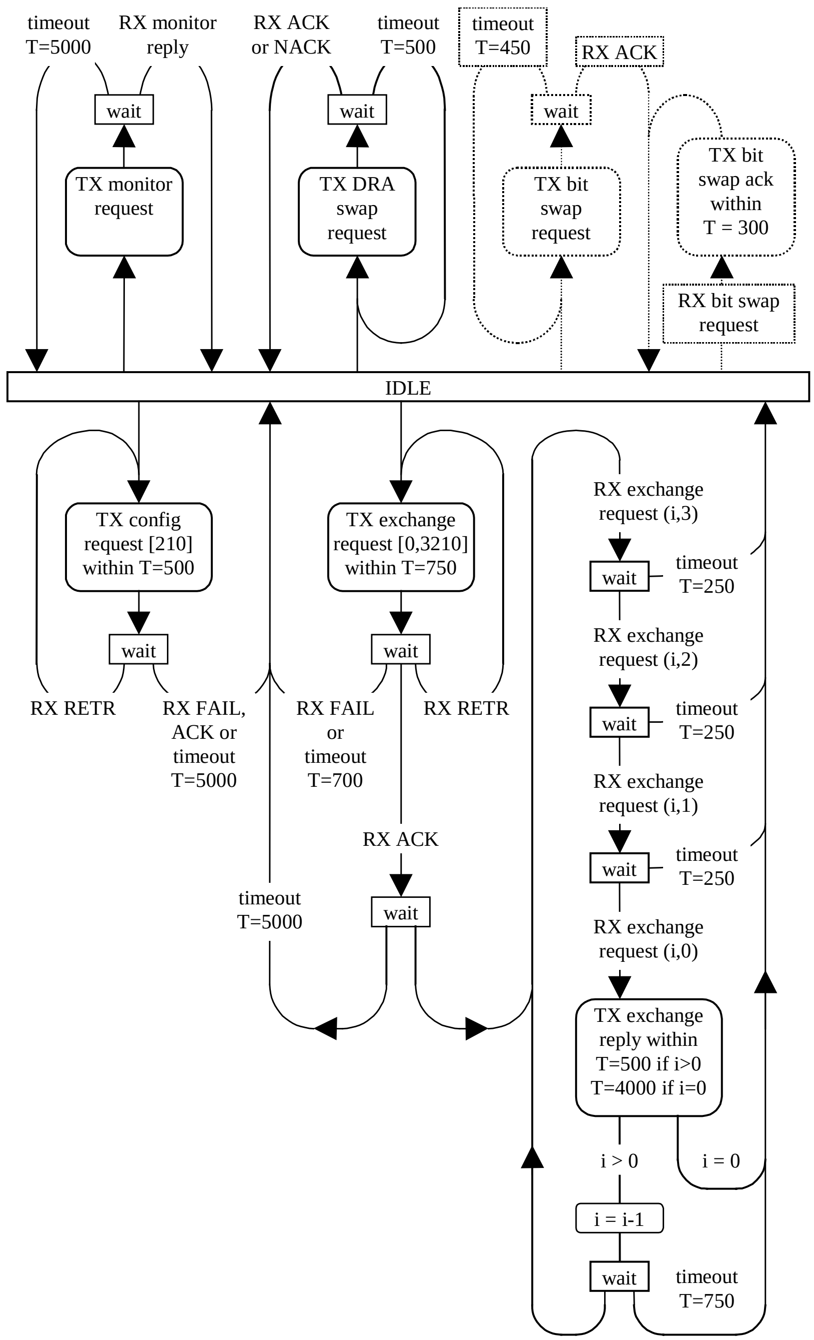


Figure K.4 - ATU-C State Diagram for aoc

Annex L
(informative)

Full Duplex Autonomous Data Transfer for the eoc

L.1 Introduction

This informative annex describes enhancements to the Embedded Operation Channel (eoc) which would allow the support of a full duplex autonomous data mode in addition to functions already described in clause 8 of this standard. These enhancements are fully compatible with both the normative text for this standard and Issue 1 of ANSI T1.413.

The autonomous mode can be defined using the existing constructs of the ANSI T1.413 eoc without interfering with the existing protocol by appropriate use of already defined eoc frame header bits to allow the use of autonomous messages that can be sent from either the ATU-C or the ATU-R. A frame containing a byte of the streaming eoc channel has the ‘data or opcode bit’ set to ‘data’ and the ‘autonomous message bit’ set to ‘autonomous message’.

It is proposed that these “autonomous data frames” can be sent “autonomously” from either the ATU-C or the ATU-R. The state machines for the eoc are unaffected by support for the autonomous “bytes” That is, these autonomous data frames can be inserted regardless of the current state of the eoc state machine. Thus, sending or receiving an “autonomous byte frame” would not affect the state machine for the eoc on either the sender or the receiver. This will allow autonomous date frames to be inserted as required in either the upstream or downstream channel. There is no requirement that streaming byte frames, if supported, be inserted contiguously. That is opcode frames may be inserted between any two streaming byte frames. There is also be no requirement for any specific rate of insertion of streaming byte frame into the eoc.

When an autonomous data frame is received, and the receiver supports this enhancement, its one-byte payload is placed in a buffer on the receiving modem to allow assembly of any higher level PDU’s supported. The receiver does not acknowledge streaming byte frames. A higher level protocol supported over this channel, might however, support retransmission of its PDU’s over the streaming byte channel.

In order to ensure compatibility with systems supporting only the normative version of the eoc, any ATU-C or ATU-R implementing this enhancement must deal reasonably with the responses from those systems in case they receive an autonomous data eoc frame. An eoc implementation limited to the normative part of eoc, does not change the protocol state when receiving an autonomous eoc frame, and will not respond to autonomous eoc data frames. Any system implementing this proposal disables at the higher layers the further sending of autonomous data frames in case a significant number of these messages be left without response from the receiver, as seen by the higher layers.

Implementing this proposal will allow definition of a transmission channel capable of full duplex messaging at rates as high as 15 kbit/s while supporting the functionality of the existing ANSI T1.413 eoc. The data path enabled by implementing this enhancement to the eoc does not itself support flow control. It is assumed that a higher level protocol implemented over this path could support a flow control method if the receiver needs protection from being over run by autonomous data being sent at the above rate.

The following text describes the implementation of this enhancement in detail. It is based on the normative text in clause 8 and, for ease of cross-reference, uses the same subclause numbering. Only subclauses that contain changes are given here.

L.2 Embedded operations channel (eoc) requirements (8.1)

An embedded operations channel for communication between the ATU-C and ATU-R is used for in-service and out-of-service maintenance, and for the retrieval of ATU-R status information and ADSL performance monitoring parameters.

L.2.1 eoc organization and protocol (8.1.1)

In general, the ATU-C, as master, determines the eoc rate of the ADSL link; therefore only one eoc response is inserted in the upstream direction (by the ATU-R) for each received eoc command. Exceptions to this are the “dying gasp” message and autonomous data transfers, which are the only autonomous messages currently allowed from the ATU-R and are inserted as soon as upstream “fast” bytes are available.

L.2.2 eoc message structure (8.1.2)

Table L.1 shows the modifications to Table 20.

Table L.1 - EOC message fields

Field #	Bit(s)	Description	Notes
1	1,2	Address Field	Can Address 4 locations
2	3	Data (0) or opcode (1) field	Data used for read/write or when an autonomous data message is sent
3	4	Byte parity field Odd (1) or even (0)	Byte order indication for multiple transmission
4	5	Message/Response field Message/Response message (1) Autonomous message (0)	Set to 0 by ATU-R to send dying gasp message or autonomous data transfers. Set to 0 by ATU-C to send autonomous data transfers.
5	6-13	Information field	One out of 58 opcodes or 8 bits of data

L.2.2.1 Message/response field (#4) (8.1.2.4)

At the ATU-C, a 1 in this field designates that the current eoc message is an eoc protocol command (master) message; a 0 designates that this is an autonomous message that does not disrupt the current eoc protocol state at either the ATU-C or ATU-R. At the ATU-R, a 1 in this field designates that the current eoc message is an eoc protocol response (slave) message; a 0 designates that it is an autonomous message that does not disturb the current eoc protocol state at either the ATU-C or the ATU-R. The only autonomous message currently defined for the ATU-C is the autonomous data transfer (see 8.1.3.4). The only autonomous messages currently defined for the ATU-R are the “dying gasp” (see 8.1.5.4) message and the upstream autonomous data transfers (see 8.1.3.4).

L.2.2.2 eoc message sets (8.1.3)

There are four types of eoc messages:

- bi-directional eoc messages: these are sent by the ATU-C, are echoed by the ATU-R as an indication of correct reception,and require an opcode;
- ATU-C to ATU-R (downstream) messages: these are sent by the ATU-C, are not echoed by the ATU-R and require an opcode;
- ATU-R to ATU-C (upstream) messages: these are sent by the ATU-R, are not echoed by the ATU-C and require an opcode; these are eoc protocol responses to downstream commands or an autonomous message such as “dying gasp” (i.e., unsolicited)
- Autonomous Data Transfers: these are autonomous data transfers sent by either the ATU-C or ATU-R; they are unsolicited, are not echoed or acknowledged at the eoc layer, do not use an opcode and do not affect the eoc protocol state.

L.2.2.3 Autonomous Data Transfers (8.1.3.4)

Autonomous Data Transfers are unsolicited data transfers that can be initiated by either the ATU-C or ATU-R. Unlike normal eoc protocol messages, autonomous data transfers require no echoing (acknowledgments) at the eoc layer nor repetition. This lightweight approach to data transfers enables high speed, unsolicited management exchanges ($32/68 \times 32 = 15$ kbit/s) between the ATU-C and ATU-R without impacting the current eoc protocol states.

Autonomous Data Transfers can be inserted regardless of the state of the eoc state machine. An Autonomous Data Transfer will not change the eoc message/echo-response protocol state nor can it count as a response to any ATU-C protocol message. An Autonomous Data Transfer allows for the transport of a single byte of data and does not require the repetitive eoc message/echo-response protocol. Consecutive Autonomous Data Transfers can be issued as soon as "fast" byte pairs are available for eoc messages. The flow of Autonomous Data Transfers can be interrupted at any time for bi-directional, ATU-C to ATU-R or ATU-R to ATU-C eoc messages. The ATU-C formats all Autonomous Data Transfers (to the ATU-R) with the Address field (#1) set to 00 (ATU-R's address); the Data field (#2) set to 0 (data); the Byte parity field (#3) set to 1; the Autonomous message field (#4) is set to 0 (autonomous); and the information field (#5) is used for 8 bits of data. The ATU-R formats all Autonomous Data Transfers (to the ATU-C) with the Address field (#1) set to 11 (ATU-C's address); the Data field (#2) set to 0 (data); the Byte parity field (#3) set to 1; the Autonomous message field (#4) is set to 0 (autonomous); and the information field (#5) is used for 8 bits of data.

Annex M
(informative)

ADSL line related performance parameters

This annex provides the user with the definitions of the ADSL line related performance parameters, prior to the publishing of this information in ANSI T1.231. When ANSI T1.231[2)] is published with these performance parameters, this annex will be superseded.

M.1 ADSL performance parameters

Specifications are given in this subclause and Table M.1. Support of the performance parameter in a network element is indicated in Table M.1 as: required (R), application specific (A), or optional (O). Table M.1 has the precedence over the following text for requirements on ADSL performance parameters.

In addition to the performance parameters defined below T1M1.3 has identified the need to develop a parameter that will record the lowest operating data rate for the reporting interval.

M.1.1 Near-end ADSL line performance parameters

M.1.1.1 Code violation-line (CVI-L)

This parameter is a count of interleaved data stream CRC-8 anomalies occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.1.2 Code violation-line (CVF-L)

This parameter is a count of fast data stream CRC-8 anomalies occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.1.3 Forward Error Correction Count Line (ECI-L)

This parameter is a count of interleaved data stream fec-I anomalies (the number of corrected codewords) occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.1.4 Forward Error Correction Count Line (ECF-L)

This parameter is a count of fast data stream fec-F anomalies (the number of corrected codewords) occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.1.5 Forward Error Correction second-line (ECS-L)

This parameter is a count of 1-second intervals with one or more fec anomalies.

M.1.1.6 Errored second-line (ES-L)

This parameter is a count of 1-second intervals with one or more CRC-8 anomalies, or one or more LOS defects, or one or more SEF defects, or one or more LPR defects.

M.1.1.7 Severely errored second-line (SES-L)

This parameter is a count of 1-second intervals with x=18 or more CRC-8 anomalies, or one or more LOS defects, or one or more SEF defects, or one or more LPR defects.

> NOTE - The ability to program the value of x may be useful in case future standards activities change the definition of SES-L and is not meant to imply that this number is variable.

M.1.1.8 LOS second (LOSS-L)

This parameter is a count of 1-second intervals containing one or more LOS defects.

M.1.1.9 Unavailable second (UAS-L)

This parameter is a count of 1-second intervals for which the ADSL line is unavailable.

The ADSL line becomes unavailable at the onset of 10 contiguous SES-Ls. The 10 SES-Ls are included in unavailable time.

[2)] Please contact the Secretariat for more information on this forthcoming revision

Once unavailable, the ADSL line becomes available at the onset of 10 contiguous seconds with no SES-Ls. The 10 seconds with no SES-Ls are excluded from unavailable time.

Some parameter counts are inhibited during unavailability - see ANSI T1.231 for inhibiting rules.

M.1.2 Far-end ADSL line performance parameters

For valid far-end monitoring, far-end parameters are derived based on the receipt of valid far-end reporting signals. The invalid data flag is raised in accordance with ANSI T1.231.

M.1.2.1 Code violation-line far-end (CVI-LFE)

This parameter is a count of interleaved data stream febe-I anomalies occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.2.2 Code violation-line far-end (CVF-LFE)

This parameter is a count of fast data stream febe-F anomalies occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.2.3 Forward Error Correction Count Line far-end (ECI-LFE)

This parameter is a count of interleaved data stream ffec-I anomalies occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.2.4 Forward Error Correction Count Line far-end (ECF-LFE)

This parameter is a count of fast data stream ffec-F anomalies occurring during the accumulation period. This parameter is subject to inhibiting - see ANSI T1.231 for inhibiting rules.

M.1.2.5 Forward Error Correction second-line far-end (ECS-LFE)

This parameter is a count of 1-second intervals with one or more ffec anomalies.

M.1.2.6 Errored second far-end (ES-LFE)

This parameter is a count of 1-second intervals with one or more febe anomalies, or one or more LOS-FE defects, or one or more RDI defects, or one or more LPR-FE defects.

M.1.2.7 Severely errored second-line far-end (SES-LFE)

This parameter is a count of 1-second intervals with x=18 or more febe, or one or more far-end LOS defects, or one or more RDI defects, or one or more LPR-FE defects.

> NOTE - The ability to program the value of x may be useful in case future standards activities change the definition of SES-L and is not meant to imply that this number is variable.

M.1.2.8 LOS second (LOSS-LFE)

This parameter is a count of 1-second intervals containing one or more far-end LOS defects.

M.1.2.9 Unavailable seconds far-end (UAS-LFE)

This parameter is a count of 1-second intervals for which the far-end ADSL line is unavailable.

The far-end ADSL line becomes unavailable at the onset of 10 contiguous SES-LFEs. The 10 SES-LFEs are included in unavailable time.

Once unavailable, the far-end ADSL line becomes available at the onset of 10 contiguous seconds with no SES-LFEs. The 10 seconds with no SES-LFEs are excluded from unavailable time.

Some parameter counts are inhibited during unavailability - see ANSI T1.231 for inhibiting rules.

M.2 ADSL performance data collection

Parameter definitions, failure definitions, and other indications, parameters, and signals are defined above and in Table M.1. Functions are indicated as required (R), application specific (A), or optional (O). Required functions are met for ADSL performance monitoring. Optional functions may be met according to the needs of the users. Some functions are identified as "performance monitoring application specific" (A). The NE provides functions identified for a given performance monitoring application in addition to the required functions if that NE provides monitoring for the performance monitoring application.

ADSL performance monitoring applications:

– ADSL application 1 (A_1): Near-end and far-end monitoring applications for interleaved data stream signals at the ATU-C:

An NE processes interleaved data stream primitives when the interleaved channel is utilized.

– ADSL application 2 (A_2): Near-end and far-end monitoring application for fast data stream signals at the ATU-C:

An NE processes fast data stream primitives when the fast channel is utilized.

– ADSL application 3 (A_3): Near-end and far-end monitoring applications for interleaved data stream signals at the ATU-R:

It is optional for the NE to provide near-end and far-end monitoring. However, if the NE provides near-end and far-end monitoring, it processes interleaved data stream primitives when the interleaved channel is utilized.

– ADSL application 4 (A_4): Near-end and far-end monitoring application for fast data stream signals at the ATU-R:

It is optional for the NE to provide near-end and far-end monitoring. However, if the NE provides near-end and far-end monitoring, it processes fast data stream primitives when the fast channel is utilized.

– ADSL application 5 (A_5): Near-end and far-end forward error correction monitoring application is provided by both the ATU-C and ATU-R when FEC is used to measure the impact of system degradation.

– ADSL application 6 (A_6): Far-end monitoring application is provided by the ATU-C and may be provided at the ATU-R.

Table M.1 - ADSL parameter definitions

Name	Text subclause	End	Use	Definition
CVI-L	M.1.1.1	Near	$A_{1,3}$	Count of interleaved data stream CRC-8 anomalies
CVI-LFE	M.1.2.1	Far	$A_{1,3,6}$	Count of interleaved data stream febe-I anomalies
CVF-L	M.1.1.2	Near	$A_{2,4}$	Count of fast data stream CRC-8 anomalies
CVF-LFE	M.1.2.2	Far	$A_{2,4,6}$	Count of fast data stream febe-F anomalies
ECI-L	M.1.1.3	Near	$A_{1,3,5}$	Count of interleaved data stream fec-I anomalies
ECI-LFE	M.1.2.3	Far	$A_{1,3,5,6}$	Count of interleaved data stream ffec-I anomalies
ECF-L	M.1.1.4	Near	$A_{2,4,5}$	Count of fast data stream fec-F anomalies
ECF-LFE	M.1.2.4	Far	$A_{2,4,5,6}$	Count of fast data stream ffec-F anomalies
ECS-L	M.1.1.5	Near	A_5	fec-I ≥ 1 **OR** fec-F ≥ 1
ECS-LFE	M.1.2.5	Far	$A_{5,6}$	ffec-I ≥ 1 **OR** ffec-F ≥ 1
ES-L	M.1.16	Near	R	interleaved CRC-8 ≥ 1 **OR** fast CRC-8 ≥ 1 **OR** los ≥ 1 **OR** sef ≥ 1 **OR** lpr ≥ 1
ES-LFE	M.1.2.6	Far	A_6	febe-I ≥ 1 **OR** febe-F ≥ 1 **OR** los-FE ≥ 1 **OR** rdi ≥ 1 **OR** lpr-FE ≥ 1

(continued)

Table M.1 - ADSL parameter definitions *(concluded)*

Name	Text subclause	End	Use	Definition
SES-L	M.1.1.7	Near	R	(interleaved CRC-8 **+** fast CRC-8) ≥ 18 **OR** los ≥ 1 **OR** sef ≥ 1 **OR** lpr ≥ 1
SES-LFE	M.1.2.7	Far	A_6	(febe-I **+** febe-F) ≥ 18 **OR** los-FE ≥ 1 **OR** rdi ≥ 1 **OR** lpr-FE ≥ 1
LOS-L	M.1.1.8	Near	O	los ≥ 1
LOS-LFE	M.1.2.8	Far	O	los-FE ≥ 1
UAS-L	M.1.1.9	Near	R	A second of unavailability
UAS-LFE	M.1.2.9	Far	A_6	A second of unavailability

NOTES

1. See M.2 for definitions for A, O, and R.

2. Note that **OR** represents a logical OR of two conditions, while **AND** represents a logical AND of two conditions. Note that “**+”** represents an arithmetic addition.

3. Unavailability begins at the onset of 10 contiguous severely errored seconds, and ends at the onset of 10 contiguous seconds with no severely errored seconds.

Annex N
(informative)

Summary of changes from Issue 1 to Issue 2

The main changes from ANSI T1.413 Issue 1 to Issue 2—in the approximate order in which they appear in the new document—are as follows:

NOTE - Only the substantive changes are shown; editorial ones have been assumed and incorporated.

– Reference models for both STM and ATM transport are included (Clause 4), and the Transmission Convergence layers for both STM and ATM are defined (6.1 and 6.2);
– Transport of a Network Timing Reference is specified (6.3);
– Reduced overhead modes are defined (6.4);
– The LS2 framing marker is removed (6.4);
– The specification of ISDN transport in LS1 is removed (6.4);
– A minimum required set of RS FEC parameters is defined (6.6, 7.6);
– Net data rates > 8 Mbit/s are provided for (6.6.3);
– The transmit PSDs of both ATU-C and ATU-R transmitters are more strictly and consistently defined (6.14 and 7.14);
– Power boost is removed (6.15);
– Clause 8 (POTS) has been moved to Annex E, and the order of the remaining clauses has been changed;
– Some eoc messages are added, and state machines for both ATU-C and -R are defined (8.1);
– The oam primitives and parameters are defined more consistently with ANSI T1.231 (8.2);
– The oam requirements for the ATU-R to SM interface are removed (8);
– The ATU-R to SM interface requirements are removed;
– Loop timing is performed, and some activation and acknowledgment signals are changed to facilitate it (9.2.2);
– An expanded initialization sequence to enable Rate Adaptive Initialization is added (9.8 and 9.9);
– The definition of cross-talking signals is expanded to include ADSL-NEXT (Annex B.4);
– Specification of the POTS low-pass filter is changed to allow single-ended testing (Annex E);
– An informative Annex F providing a downstream PSD mask for reduced NEXT is added;
– Some examples of very long noise impulses are added (Annex I);
– An informative Annex J on the ATM cell TC sublayer interface is added;
– An informative Annex K on on-line (dynamic) rate adaptation is added;
– An informative Annex L on autonomous data transfers for eoc (i.e., clear channel eoc) is added;
– All informative references are moved into a bibliography (Annex O);

In making these changes to ANSI T1.413 Issue 1, backwards compatibility has been carefully considered and has been assured, except for the following:

– In case loop timing is not performed at the ATU-C, Issue 1 allows the ATU-R to freely choose to perform loop timing itself, while Issue 2 requires the ATU-R to perform loop timing. An Issue 1 ATU-R may not be able to meet this requirement.

Annex O
(informative)

Bibliography

O.1 Informative references contained in this standard

ANSI T1.101-1994, *Telecommunications - Synchronization Interface Standard*

ANSI T1.220-1991 (R1997), *Telecommunications - Information Interchange - Coded representation of the North American Telecommunications Industry Manufacturers, Suppliers, and Related Service Companies*

ANSI T1.601-1992, *Telecommunications – Integrated Services Digital Network (ISDN) Basic Access Interface for Use on Metallic Loops for Application at the Network Side of NT (Layer 1 Specification)*

TR28, Technical Report No. 28; *High-Bit-Rate Digital Subscriber Line (HDSL)*, Committee T1-Telecommunications, February 1994[3)]

Title 47, *Code of Federal Regulations*, Part 15 and Part 68, FCC.

Bellcore SR-TSV-002275, *BOC Notes on the LEC Networks-1990*, Issue 2, 1997.

Bellcore Technical Advisory TA-NWT-001210, *Generic Requirements for High-Bit-Rate Digital Subscriber Lines.*

ATM Forum Specification, UTOPIA Level 2 v1.0, af-phy-0039.000, June 1995.

ATM Forum Specification, Integrated Layer Management Interface (ILMI) v4.0, af-ilmi-0065.000, July 1996.

ITU-T Recommendation G.703, *Physical/electrical characteristics of hierarchical digital interfaces,* April 1991.[1)]

ITU-T Recommendation G.707, *Network node interface for the synchronous digital hierarchy (SDH),* March 1996.[1)]

ITU-T Recommendation I.361, *B-ISDN ATM Layer specification,* November 1995.[1)]

ITU-T Recommendation T.35, *Terminal Equipment and Protocols for Telematic Services - Procedure for the Allocation of CCITT Defined Codes for Non-standard Facilities*, January 1991.[1)]

O.2 Additional references on overvoltage, surge protection, and EMC

This standard describes the electrical characteristics of the ADSL access signals appearing at the NI, and the physical interface between the network and the CI. Such phenomena as lightning and overvoltages due to inductive interference or power crosses lie beyond the scope of this standard. However, these and other topics are discussed in the following readily available documents:

ANSI/IEEE C62.42-1986, *Guide for the Application of Gas Tube Arrester Low-Voltage Surge-Protective Devices*

Technical reference TR-EOP-000001, *Lightning, Radio Frequency and 60-Hz Disturbances at the Bell Operating Company Network Interface*, Issue 2, Bellcore, Piscataway, N.J., June 1987

Both the above documents contain useful information on the application of surge arresters and the loop electrical environment.

[3)] Available from ATIS, 1200 G Street, NW, Suite 500, Washington DC, 20005.

ANSI/EIA/TIA-571-1991, *Environmental Considerations for Telephone Terminals*

This standard discusses the normal operating environment of the telephone terminal equipment, fire hazards, and protection.

ANSI/UL 1950-1997, *Safety of Information Technology Equipment, Including Electrical Business Equipment*

CCITT, COM V-No. 53, *Measurement of Transients at the Subscriber Termination of a Telephone Loop*(November 1983)[1)]

Batorsky, D. V.; Burke M.E., 1980 Bell system noise survey of the loop plant. *AT&T Bell Lab. Tech. J.* 63(5): 1984 May-June.

Bodle, D.W. ; Gresh, P.A. Lightning surges in paired telephone cable facilities. *Bell Syst. Tech. J*. 40: 1961 March.

Carrol, R. L.; Loop transients measurements in Cleveland, South Carolina. *Bell Syst. Tech. J.* 59(9): 1980 November.

Carrol, R. L.; Miller, P. S. Loop transients at the customer station. *Bell Syst. Tech. J.* 59(9): 1980 November.

Clarke, Gord; Coleman, Mike. Study sheds light on overvoltage protection. *Telephony*. 1986 November 24.

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Heirman, Donald N. Time variations and harmonic content of inductive interference in urban/suburban and residential/rural telephone plants. *IEEE, 1976 Annals*, No. 512C0010.

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