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SERIES I: INTEGRATED SERVICES DIGITAL NETWORK

ISDN user-network interfaces – Layer 1 Recommendations

B-ISDN user-network interface – Physical layer specification: 25 600 kbit/s operation

ITU-T Recommendation I.432.5

(Previously CCITT Recommendation)

ITU-T I-SERIES RECOMMENDATIONS

INTEGRATED SERVICES DIGITAL NETWORK

For further details, please refer to ITU-T List of Recommendations.

ITU-T RECOMMENDATION I.432.5

B-ISDN USER-NETWORK INTERFACE – PHYSICAL LAYER SPECIFICATION: 25 600 kbit/s OPERATION

Summary

This Recommendation covers physical layer characteristics for transporting Asynchronous Transfer Mode (ATM) cells at a nominal bit rate of 25 600 kbit/s over 100 ohm UTP, 120 ohm, and 150 ohm STP twisted pair cables at the S_B reference point of the B-ISDN User Network Interface (UNI). The maximum distance is approximately 100 m. This Recommendation may be used to take advantage of existing building wiring.

Functionality is presented in terms of Physical Media Dependent (PMD) and Transmission Convergence (TC) sublayers, using a cell-based format.

This Recommendation is part of the I.432-Series Recommendations, and includes references to Recommendation I.432.1 [3] on general characteristics, and Recommendation I.432.2 [4] on transmission convergence sublayer aspects.

Source

ITU-T Recommendation I.432.5 was prepared by ITU-T Study Group 13 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 20th of June 1997.

FOREWORD

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Recommendation I.432.5

B-ISDN USER-NETWORK INTERFACE – PHYSICAL LAYER SPECIFICATION: 25 600 kbit/s OPERATION

(Geneva, 1997)

1 Introduction

1.1 Scope

This Recommendation covers physical layer characteristics for transporting Asynchronous Transfer Mode (ATM) cells at a nominal bit rate of 25 600 kbit/s over 100 ohm UTP, 120 ohm, and 150 ohm STP twisted pair cables at the S_B reference point of the B-ISDN User Network Interface (UNI). The maximum distance is approximately 100 m. This Recommendation may be used to take advantage of existing building wiring.

The physical layer functionality is divided into a Physical Media Dependent (PMD) sublayer and a Transmission Convergence (TC) sublayer. The PMD sublayer provides the definitions for the transmitter, the receiver, timing recovery, media interface connector and the transmission media. The TC sublayer defines the line coding, scrambling, data framing and synchronization (see Table 1).

Table 1/I.432.5 – Functions of the TC and PMD sublayers

Transmission Convergence (TC) sublayer	HEC generation/verification Cell scrambling/descrambling Line coding/decoding Cell delineation Cell rate decoupling
Physical Media Dependent (PMD) sublayer	Bit timing Physical media Connectors

The term "bit rate" used throughout this Recommendation refers to the logical information rate, before line coding. The term "line symbol rate" will be used when referring to the rate after line coding (25 600 kbit/s bit rate results in a 32 Mbaud line symbol rate after 4B5B encoding).

1.2 Reference configuration

The reference point S_B of the B-ISDN customer access is defined in Recommendations I.413 [2], I.414 [6], and I.432.1 [3].

2 Physical media characteristics at the S_B reference point for 25 600 kbit/s physical layer interface

2.1 Transmission link requirements

2.1.1 Line and bit rates

The nominal line symbol rate is 32 Mbaud. Due to the use of the 4B5B block code, the bit rate is 25 600 kbit/s.

The transmitter at the customer side should use a free-running transmitter clock that operates at the nominal bit rate within a tolerance of ±100 ppm.

2.1.2 Bit rate symmetry

Interfaces are symmetric; i.e. the bit rates are the same in both transmit and receive directions.

2.1.3 Bit Error Ratio (BER)

The active input interface should operate at a BER not to exceed 10^{-10} when presented with a transmitter described in 2.2 and transmitting through the channel reference model described in 2.4 in the presence of the worst-case crosstalk noise given in 2.4.

Measurement of BER is normally performed out-of-service. In-service measurements based upon different parameters, e.g. block errors, background block errors, etc., are under study.

2.1.4 Transmission link timing

Figure 1 illustrates the conceptual components of the TC/PMD and the timing source.

The TC/PMD uses a local crystal oscillator or a distributed low jitter timing reference that supports a nominal transmission rate of 25 600 kbit/s.

2.1.5 Free running timing configurations

The recommended approach is to use point-to-point timing where the transmit clock on each end of a link is independent, as depicted in Figure 2. Under these conditions, the pulse waveform templates of 2.2.2 bound the acceptable pulse shapes to be found on any link.

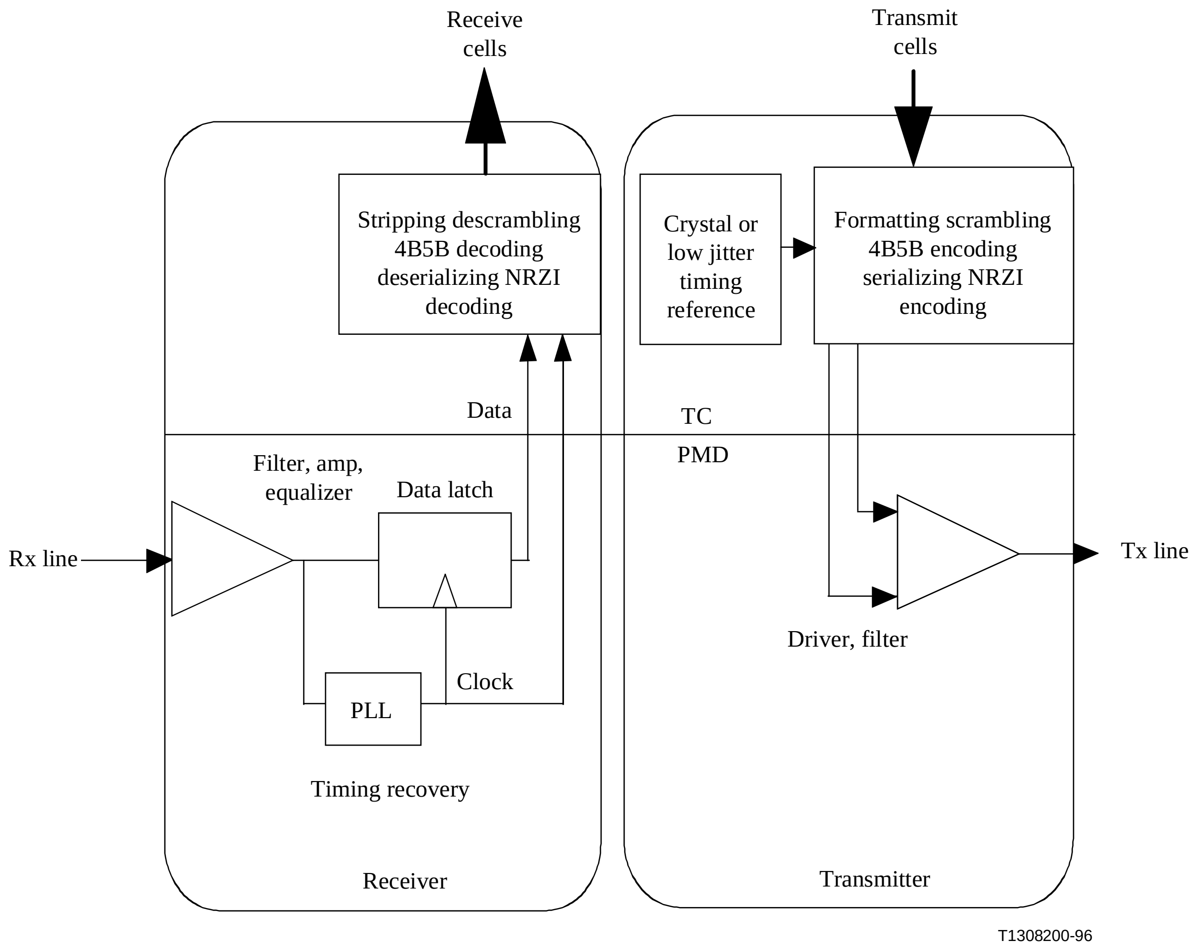

Figure 1/I.432.5 – Illustration of example TC/PMD components and transmitter timing

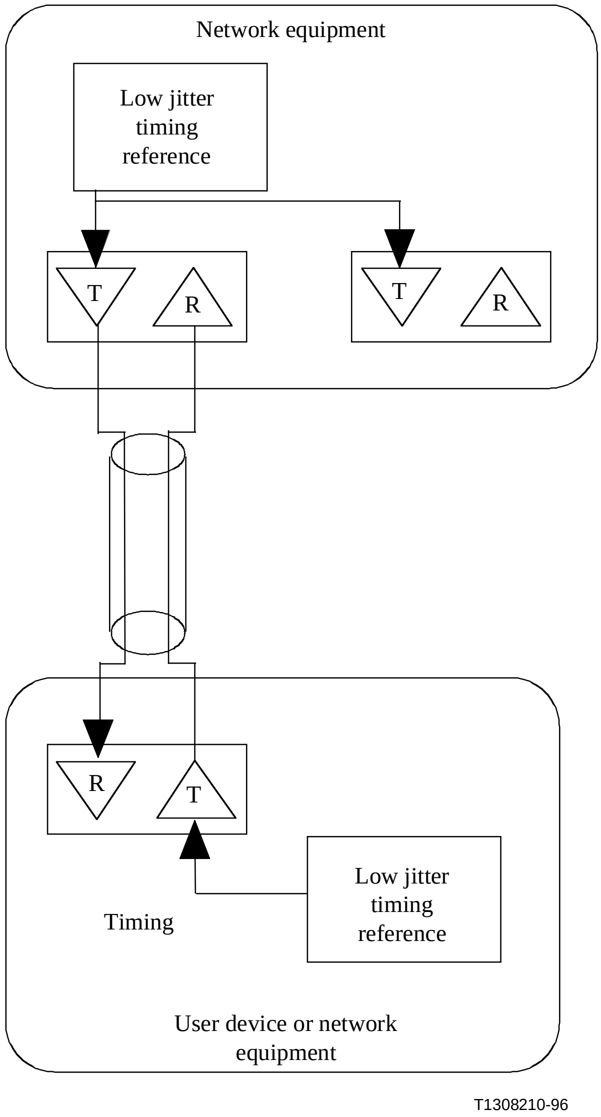

Figure 2/I.432.5 – User device - network equipment timing configurations

2.2 Transmitter requirements

These recommendations place requirements on the transmitted signal. Measurement to these parameters will require that a means exists to send unscrambled, unencoded data streams at the line symbol rate through the transmitter circuitry.

For all transmitter measurements, the transmitter should be terminated in a 100 ohm resistive load for 100 ohm UTP Recommendations.

The transmitter should be terminated in a 150 ohm resistive load for 150 ohm STP Recommendations.

The transmitter should be terminated in a 120 ohm resistive load for 120 ohm recommendations.

Unless stated separately, the parameters given below apply to all of the 100, 120, and 150 ohm measurements.

2.2.1 Transmitter zero-crossing distortion

Duty cycle distortion is intended to measure the static, non-data-dependent distortion in the data edge zero-crossings typically caused by asymmetrical propagation or rise/fall times of transmitter logic or in the conversion from a single-ended to a differential data stream. Edge jitter is intended to measure the dynamic and data dependent distortion in the data edge zero-crossings typically caused by transmit filtering and noises internal and external to the transmitter circuitry.

2.2.1.1 Duty cycle distortion

Duty cycle distortion applies to the transmitted data stream given below and is defined as one half the difference in the positive and negative pulse widths of the AC coupled transmitter waveform.

NOTE – The waveform given below is only a test waveform for the purpose of measuring the launch amplitude and should not be construed as a waveform which may be seen during normal operation of the physical layer.

The Transmitter Duty Cycle Distortion (TDCD) should be less than 1.5 ns peak when the output is clocked by a local clock source.

Two test waveforms (symbol elements at line symbol rate) are defined to be: 00110011 ..., and 01010101 .... These are test patterns only, and they may not be scrambled nor encoded.

2.2.1.2 Edge jitter

Edge jitter applies to any waveform compliant with the scrambling and encoding recommendations in clause 3. It is defined as the maximum of the peak variation of the rising edges of data relative to the transmit clock and the falling edges of data relative to the transmit clock.

The Transmitter Edge Jitter (TEJ) should be less than 4 ns peak-to-peak when the output is clocked by a local clock source.

2.2.2 Transmitter waveshapes

The transmitter wave shape should conform to the waveform templates defined in Tables 2 to 6 below. An additional constraint is that the worst case 3 dB corner frequency of the transmitter output should be less than or equal to 12 kHz.

Figures 3 to 7 and the corresponding Tables 2 to 6 below list and plot the data points that define the pulse templates.

NOTE – Amplitude is expressed as the measured pulse amplitude normalized such that the value 1 on each graph represents the amplitude of the fundamental frequency for the single symbol element. Time is expressed in percent of the measured pulse width. With a line symbol rate of 32 Mbaud, the nominal line symbol width is 31.25 nanoseconds. (Therefore, for example, the nominal duration – corresponding to the 100% mark – for the five-symbol element is 156.25 nanoseconds.)

Table 2/I.432.5 – Template for five-symbol element waveform

Point	Upper time (%)	Upper amplitude	Lower time (%)	Lower amplitude
A	–0.3	0	0.3	0
B	6.3	1.20	10.5	0.90
C	14	1.20	23.0	0.50
D	23	1.05	36.0	0.75
E	34	1.20	53.0	0.60
F	56	0.95	87.0	0.60
G	95	0.92	99.7	0
H	100.3	0	–	–

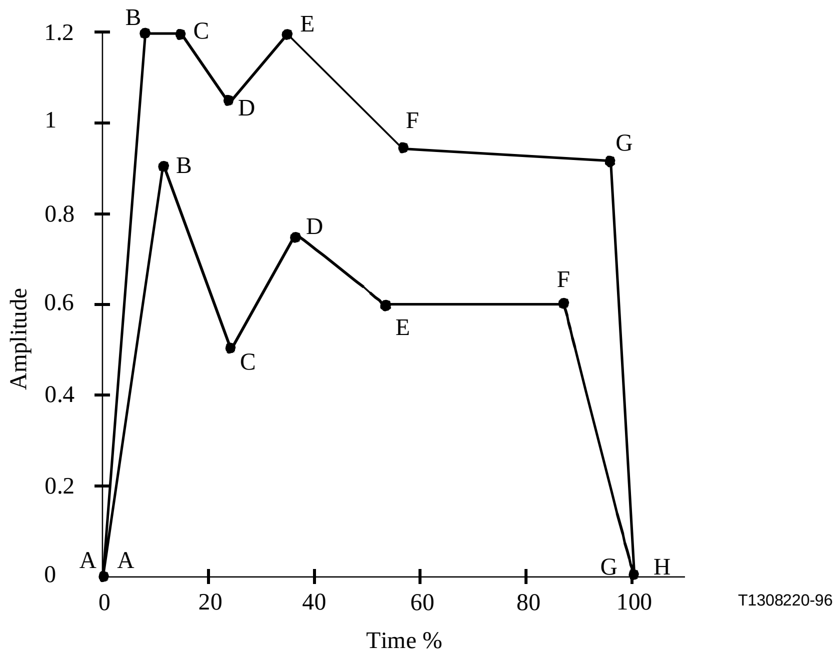

Figure 3/I.432.5 – Pulse template for Table 2 five-symbol element waveform

Table 3/I.432.5 – Template for four-symbol element waveform

Point	Upper time (%)	Upper amplitude	Lower time (%)	Lower amplitude
A	–0.4	0	0.4	0
B	7.9	1.20	13.1	0.90
C	17	1.20	28.0	0.50
D	29	1.05	45.0	0.75
E	43	1.20	66.0	0.60
F	70	0.95	84.0	0.60
G	93.5	0.92	99.6	0
H	100.4	0	–	–

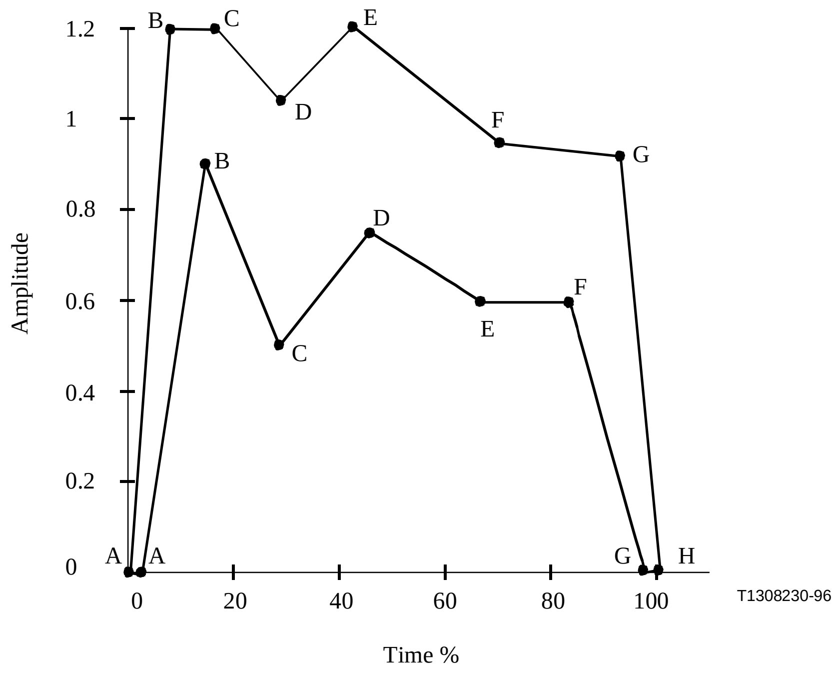

Figure 4/I.432.5 – Pulse template for Table 3 four-symbol element waveform

Table 4/I.432.5 – Template for three-symbol element waveform

Point	Upper time (%)	Upper amplitude	Lower time (%)	Lower amplitude
A	–0.5	0	0.5	0
B	10.5	1.20	17.5	0.90
C	23.0	1.20	37.5	0.50
D	38.0	1.05	59.5	0.75
E	57.0	1.20	87.5	0.6
F	93.0	0.95	99.5	0
G	100.5	0	–	–

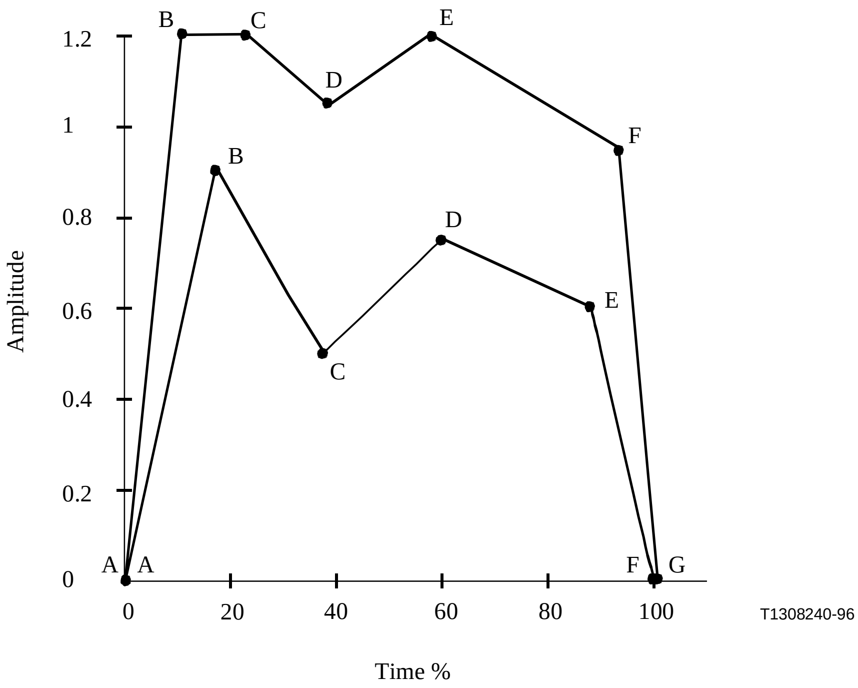

Figure 5/I.432.5 – Pulse template for Table 4 three-symbol element waveform

Table 5/I.432.5 – Template for two-symbol element waveform

Point	**Upper time (%)**	**Upper amplitude**	**Lower time (%)**	**Lower amplitude**
A	–1.0	0	1.0	0
B	15.5	1.20	26.0	0.90
C	34.5	1.20	57.0	0.50
D	56.5	1.05	81.5	0.65
E	85.0	1.20	99.0	0
F	101.0	0	–	–

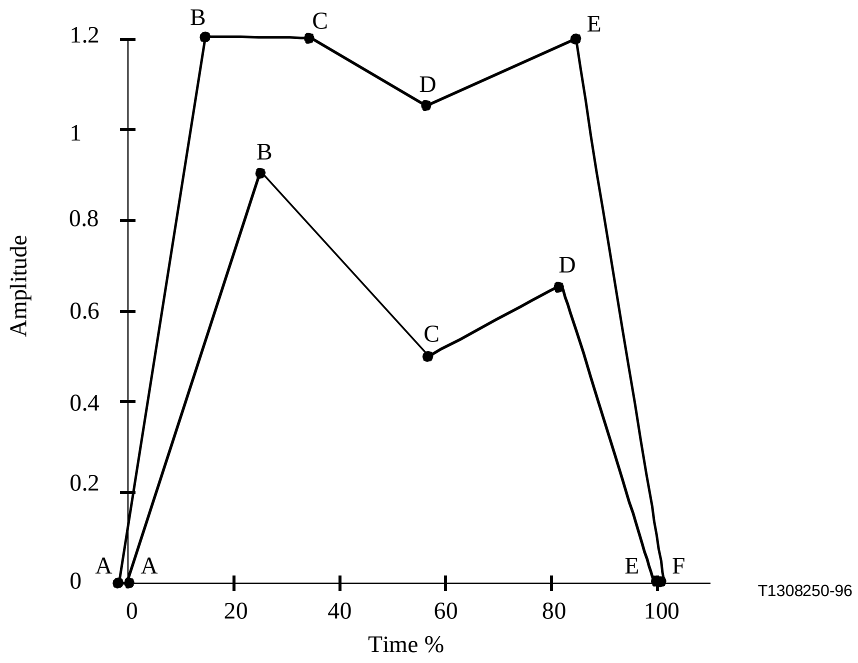

Figure 6/I.432.5 – Pulse template for Table 5 two-symbol waveform

Table 6/I.432.5 – Template for one-symbol element waveform

Point	Upper time (%)	Upper amplitude	Lower time (%)	Lower amplitude
A	–1.5	0	1.5	0
B	23.5	0.83	26.0	0.55
C	48.5	1.15	51.5	0.95
D	80.0	0.86	77.5	0.52
E	101.5	0	98.5	0

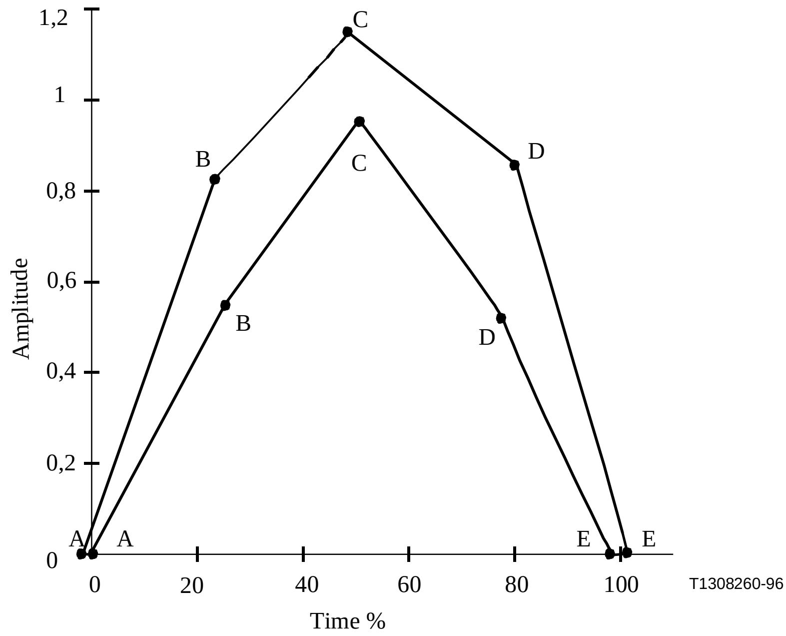

Figure 7/I.432.5 – Pulse template for Table 6 one-symbol element waveform

2.2.3 Transmitter launch amplitude

Transmitter Launch Amplitude (TLA) applies to the transmitted data stream shown below and is defined as the peak-to-peak amplitude of the transmitted waveform.

The transmitter launch amplitude should be between the values listed below. The test waveform (symbol elements at line symbol rate) is defined to be: 01010101 ....

- 100 ohm (UTP): 2.7 < TLA < 3.4 volts peak-to-peak.
- 150 ohm (STP): 3.3 < TLA < 4.2 volts peak-to-peak.
- 120 ohm: 2.95 < TLA < 3.75 volts peak-to-peak.

2.2.4 Transmitter return loss

Transmitter Return Loss (TRL) applies to a transmitter which is actively transmitting any waveform compliant with the scrambling and encoding described in clause 3.

The transmitter return loss should be greater than the values given in Table 7 across the full allowed range of characteristic impedance (according to the media type).

Table 7/I.432.5 – Transmitter return loss

Frequency range	Return loss
1-6 MHz	14 dB
6-17 MHz	12 dB
17-25 MHz	8 dB

2.3 Receiver requirements

2.3.1 Receiver acquisition timing

The receiver should acquire phase lock in the presence of a BER of less than 10^{-10} with a Receiver Acquisition Time (RAT) of less than 50 ms when provided with a valid signal.

A valid signal is defined as a signal from a transmitter compliant with 2.2 and scrambled and encoded as defined in clause 3 which has been sent through a channel that complies with 2.4.

2.3.2 Receiver return loss

The Receiver Return Loss (RRL) should be greater than the values given in Table 8 across the full allowed range of characteristic impedance (according to the media type).

Table 8/I.432.5 – Receiver return loss

Frequency range	Return loss
1-17 MHz	15 dB
17-25 MHz	8 dB

2.4 Copper link segment characteristics

The copper link segment consists of one or more sections of twisted pair copper cable media containing two or four pairs along with intermediate connectors required to connect sections together and terminated at each end in the recommended electrical data connector. The cable is interconnected to provide two continuous electrical paths which are connected to the interface port at each end. The transmitter and receiver requirements are consistent with the media defined below. The link segment is defined for 100 ohm UTP, 120 ohm, and 150 ohm STP cabling systems.

2.4.1 100 ohm link segment

This subclause defines the cabling and connector conditional requirements when a 100 ohm cable/connector system is deployed. These requirements define the minimum requisites for a compliant and functional system. Note that as long as 100 ohm components are used consistently, a specification of category 3 unshielded cable and connectors allows for the optional use of higher grade components (e.g. category 4 and category 5) and the optional use of cable and/or connector shields.

2.4.1.1 100 ohm UTP link segment

The electrical parameters important to link performance are attenuation, near-end crosstalk loss (NEXT loss), characteristics impedance and Structural Return Loss (SRL).

All components comprising a link segment should meet or exceed all of the requirements for category 3 as specified by EIA/TIA 568A 95 [7] and ISO/IEC 11801:1995 [5].

The composite channel attenuation should meet or exceed the category 3 attenuation performance limits defined in Annex E of EIA/TIA 568A 95 [7].

The composite channel NEXT loss should meet or exceed the category 3 NEXT loss performance limits defined in Annex E of EIA/TIA 568A 95 [7].

2.4.1.2 Reference model configuration for 100 ohm UTP systems

The reference model for a category 3 UTP system is defined to be a link consisting of 90 metres of category 3 UTP cable, 10 metres of category 3 flexible cords, and four (4) category 3 connectors internal to the link.

2.4.1.3 Examples of 100 ohm UTP compliant channels

Since the link segment requirements for attenuation and NEXT loss are derived from the electrical performance of the channel reference model, the channel reference model defines a compliant link. Additionally, link segments consisting of no more than 90 metres of category 3 UTP cable, no more than 10 metres of category 3 flexible cords and no more than four category 3 connectors internal to the link are examples of compliant links.

However, any installed link consisting of category 3 components and meeting the link attenuation and NEXT loss requirements of 2.4.1.1 is acceptable.

In many situations it is also possible to trade-off attenuation for NEXT loss and derive links which may differ from the topology of the channel reference model but still have acceptable performance. The number of potential trade-offs is quite large and this subject is beyond the scope of this Recommendation.

2.4.1.4 100 ohm UTP attenuation

Attenuation describes the loss in signal level as a signal propagates along a homogeneous medium such as a cable or cord.

The cable used in constructing a link should meet or exceed the horizontal category 3 UTP cable attenuation requirements of Section 10 of EIA/TIA 568A 95 [7] and Clause 8 of ISO/IEC 11801:1995 [5].

The cordage used in constructing flexible cords and patch cables should meet or exceed the attenuation requirements for category 3 flexible cordage specified in Section 10 of EIA/TIA 568A 95 [7].

In general, the per unit length attenuation limits for cordage are 20% higher than those allowed for horizontal cables.

2.4.1.5 100 ohm UTP NEXT loss

NEXT loss defines the amount of unwanted signal coupling between distinct pairs of multipair cable. It is the result of parasitic capacitive and inductive coupling between the various conductors comprising a cable.

The cable and cordage used in constructing a link should meet or exceed the horizontal category 3 UTP cable NEXT requirements of Section 10 of EIA/TIA 568A 95 [7] and Clause 8 of ISO/IEC 11801:1995 [5].

2.4.1.6 Characteristic impedance and structural return loss

Characteristic impedance is the ratio of voltage to current of a wave propagating along one direction in a uniform transmission line. When a transmission line is not completely uniform in construction, the characteristic impedance may exhibit slight variations as a function of length. This variation is measured by a quantity defined as Structural Return Loss (SRL). It is a measure of the deviation of characteristic impedance from a nominal value in a transmission line which is not perfectly homogeneous.

Both the characteristic impedance and structural return loss of cables and cords used in construction of a link should meet the requirements specified for 100 ohm category 3 in Section 10 of EIA/TIA 568A 95 [7] and Clause 8 of ISO/IEC 11801:1995 [5].

2.4.1.7 100 ohm connecting hardware

The electrical performance of connecting hardware can be critical to the overall performance of a transmission channel. In general, the electrical parameters specified for connecting hardware are attenuation, NEXT loss and return loss.

All connecting hardware used within this PMD channel (outlets, transition connectors, patch panels, and cross-connect fields) should meet or exceed the category 3 electrical requirements for attenuation, NEXT loss, and return loss specified in Section 10 of EIA/TIA 568A 95 [7] and Clause 9 of ISO/IEC 11801:1995 [5].

All measurements on connecting hardware should be conducted in accordance with the procedures described in Annex B of EIA/TIA 568A 95 [7] and Annex A.2 of ISO/IEC 11801:1995 [5]. These requirements apply to all individual UTP connectors, including patch panels, transition connectors, cross-connect fields, and telecommunication outlets.

The connector termination practices and UTP cable practices described in Section 10 of EIA/TIA 568A 95 [7] should be followed.

2.4.1.8 UTP media interface connector

Each end of the category 3 UTP link segment should be terminated with media interface connectors specified in IEC 603-7 [8] (commonly referred to as RJ-45). This connector is an 8-contact modular socket/plug, and the mated combination should meet the requirements of 2.4.1.7.

The cable assembly should connect the corresponding contacts of the plugs at either end of the link (i.e. Pin 1 to Pin 1, Pin 2 to Pin 2, etc.).

This ensures that the cable assembly is a straight through (no crossover) cable and that the polarity of the assembly is maintained.

The UTP-MIC should be an 8-contact socket as specified in IEC 603-7 [8], that is attached to the ATM user device and the ATM network equipment.

The contact assignments for the UTP-MIC socket should be as listed in Table 9.

Table 9/I.432.5 – Contact assignments for UTP-MIC socket

Contact	Signal at the ATM user device	Signal at the ATM network equipment
1	Transmit +	Receive +
2	Transmit –	Receive –
3	Unused	Unused
4	Unused	Unused
5	Unused	Unused
6	Unused	Unused
7	Receive +	Transmit +
8	Receive –	Transmit –

2.4.2 120 ohm link segment

This subclause defines the cabling and connector conditional requirements when a 120 ohm cable/connector system is deployed. These requirements define the minimum requisites for a compliant and functional system. Note that as long as 120 ohm components are used consistently, a specification of category 4 unshielded cable and connectors allows for the optional use of higher grade components (e.g. category 5) and the optional use of cable and/or connector shields.

NOTE – Therefore, systems commonly called "FTP" (foiled twisted pair) which employ 120 ohm shielded category 5 twisted pair are typically consistent with the requirements in this subclause.

The 120 ohm cable system connects the transmitter on one end of the link segment to the receiver on the other end of the link segment. The cable system consists of one or more sections of twisted pair cable containing two wire pairs, along with intermediate connectors required to connect sections together. The media interface connector is used to terminate the ends of the fixed wiring. The cable is interconnected to provide two continuous electrical paths between the transmitters and receivers at the end points.

2.4.2.1 120 ohm link segment

This subclause defines the link segment characteristics for 120 ohm link using 120 ohm category 4 cable specified in ISO/IEC 11801:1995 [5] which meets the performance requirements of this system. The channel link requirements are independent of the cable type but have been defined using the attenuation and NEXT loss requirements for category 4 cable. The maximum allowable length of the cable system will vary depending on the quality of the cable, and patch cord(s).

The composite channel attenuation for a 120 ohm link should meet the attenuation performance limits defined in Annex E of EIA/TIA 568A 95 [7] for category 4 cables.

The composite channel NEXT loss for a 120 ohm link should meet the NEXT loss performance limits defined in Annex E of EIA/TIA 568A 95 [7] for category 4 cables.

Under these conditions, both the characteristic impedance and SRL of cables and cords used in construction of a link should meet the requirements specified for 120 ohm category 4 in Section 10 of EIA/TIA 568A 95 [7] and Clause 8 of ISO/IEC 11801:1995 [5].

2.4.2.2 Reference model configuration for 120 ohm systems

A typical cable system includes fixed cable terminated in the media interface connector and attachment cables for both ends. The per unit length attenuation of an attachment cable is typically allowed to be up to 150% that of the fixed cable. Refer to ISO/IEC 11801:1995 [5], Clause 6, for more detailed information.

The reference model for a 120 ohm system is defined to be a link consisting of 90 metres of 120 ohm cable, 10 metres of 120 ohm patch cord, and 4 category 4 connectors internal to the link.

2.4.2.3 Examples of 120 ohm compliant channels

Since the link requirements for attenuation and NEXT loss are derived from the electrical performance of the channel reference model, the channel reference model defines a compliant link. Additionally, links consisting of no more than 90 metres of 120 ohm cable, no more than 10 metres of 120 ohm patch cord and no more than 4 category 4 connectors internal to the link are examples of compliant links. However, any installed link consisting of category 4 components and meeting the link attenuation and NEXT loss requirements of 2.4.2.1 is acceptable.

In many situations it is also possible to trade-off attenuation for NEXT loss and derive links which may differ from the topology of the channel reference model but still have acceptable performance.

The number of potential trade-offs is quite large and this subject is beyond the scope of this Recommendation.

2.4.2.4 120 ohm connecting hardware and media interface connector

The connecting hardware and media interface connector defined for 100 ohm link segments should also apply to 120 ohm systems except that all references to category 3 requirements should be replaced by category 4.

2.4.3 150 ohm link segment

The 150 ohm cable system connects the transmitter on one end of the link segment to the receiver on the other end of the link segment. The cable system consists of one or more sections of shielded twisted pair cable containing two wire pairs, along with intermediate connectors required to connect sections together. The media interface connector is used to terminate the ends of the fixed wiring. The cable is interconnected to provide two continuous electrical paths between the transmitters and receivers at the end points.

2.4.3.1 150 ohm STP link segment

The system can operate with a variety of STP cable types. EIA/TIA 568A 95 [7] and ISO/IEC 11801:1995 [5] define STP cables which will meet the performance requirements of this system. The channel link requirements are independent of the cable type but have been defined using the attenuation and NEXT loss requirements for category 3 UTP cable. The maximum allowable length of the cable system will vary depending on the quality of the STP cable and patch cord(s).

The composite channel attenuation for a 150 ohm STP link should meet the attenuation performance limits defined in Annex E of EIA/TIA 568A 95 [7] for category 3 UTP cables.

The composite channel NEXT loss for a 150 ohm STP link should meet the NEXT loss performance limits defined in Annex E of EIA/TIA 568A 95 [7] for category 3 UTP cables.

Under these conditions both the characteristic impedance and structural return loss of cables and cords used in construction of a link should meet the requirements specified for 150 ohm STP in Section 10 of EIA/TIA 568A 95 [7].

2.4.3.2 Reference model configuration for 150 ohm STP systems

A typical cable system includes fixed cable terminated in the media interface connector and attachment cables for both ends. The per unit length attenuation of an attachment cable is typically allowed to be up to 150% that of the fixed cable. Refer to ISO/IEC 11801:1995 [5], Clause 6, for more detailed information.

The reference model for an STP system is defined to be a link consisting of 90 metres of STP-A cable, 10 metres of STP-A patch cord, and 4 STP-A connectors internal to the link.

2.4.3.3 Examples of 150 ohm STP compliant channels

Since the link requirements for attenuation and NEXT loss are derived from the electrical performance of the channel reference model, the channel reference model defines a compliant link. A channel reference model defines a compliant link. Additionally, links consisting of no more than 90 metres STP-A cable, no more than 10 metres of STP-A patch cord and no more than 4 STP-A connectors internal to the link are examples of compliant links. However, any installed link consisting of STP components and meeting the link attenuation and NEXT loss requirements of 2.4.3.1 is acceptable.

In many situations it is also possible to trade-off attenuation for NEXT loss and derive links which may differ from the topology of the channel reference model but still have acceptable performance.

The number of potential trade-offs is quite large and this subject is beyond the scope of this Recommendation.

2.4.3.4 STP media interface connector

Each end of the fixed cable should be terminated in the STP media interface connector.

The STP media interface connector should meet all the requirements of the telecommunications connector as defined in EIA/TIA 568A 95 [7], Section 11.

The STP media interface connector contact assignments should be as listed in Table 10.

Table 10/I.432.5 – Contact assignments for STP-MIC connectors

Contact	Signal at the ATM user device	Signal at the ATM network equipment
B	Transmit +	Receive +
R	Receive +	Transmit +
G	Receive –	Transmit –
O	Transmit –	Receive –

At the physical level of the interface, at the S_B reference point, the bit rate should be 25 600 kbit/s. The maximum bit rate available for user information cells, signalling cells and ATM and higher layers OAM information cells, excluding the "start-of-cell" commands, is 25 125 kbit/s.

3 Functions provided by the transmission convergence sublayer

The functions of the TC sublayer are:

- scrambling and descrambling;
- 4B5B block encoding and decoding (including command codes) which provides the means for:
  - cell delineation and scrambler/descrambler reset;
  - support of a periodic timing signal for isochronous services;
- NRZI encoding and decoding;
- HEC generation and verification;
- cell rate decoupling.

Figure 8 is an example block diagram of the transmission convergence sublayer that identifies the above functions and their data flow relationships.

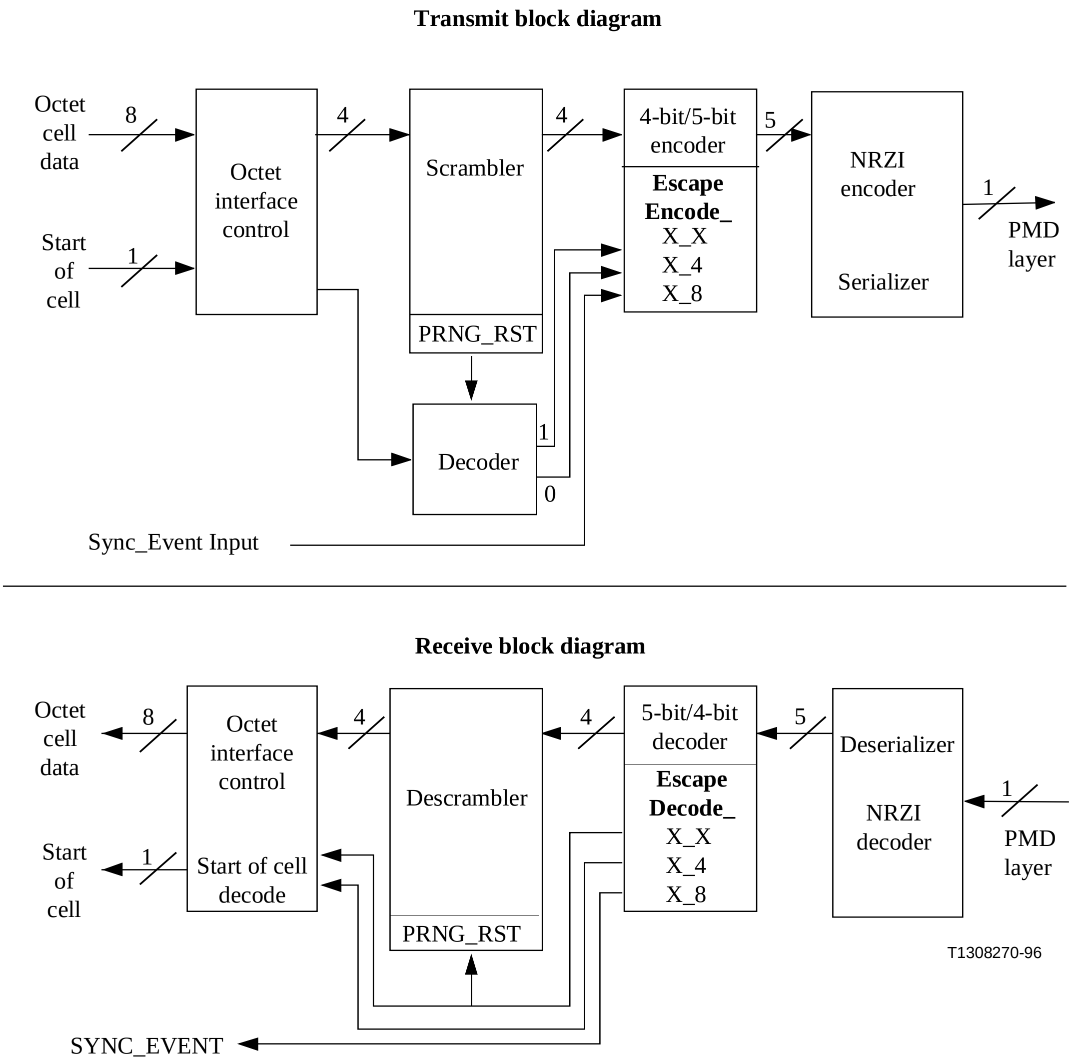

Figure 8/I.432.5 – Example block diagrams of the transmission convergence sublayer

3.1 Cell scrambling and descrambling

To provide the appropriate frequency distribution of the electrical signal across the line, the data octets should be scrambled before transmission as exemplified in Figure 9.

All 53 octets of the ATM cell should be scrambled and encoded prior to transmission.

The scrambler and the de-scrambler are each comprised of a 10-bit PRNG (pseudo-random number generator). The PRNG is based on the following polynomial:

$$x^{10} + x^7 + 1$$

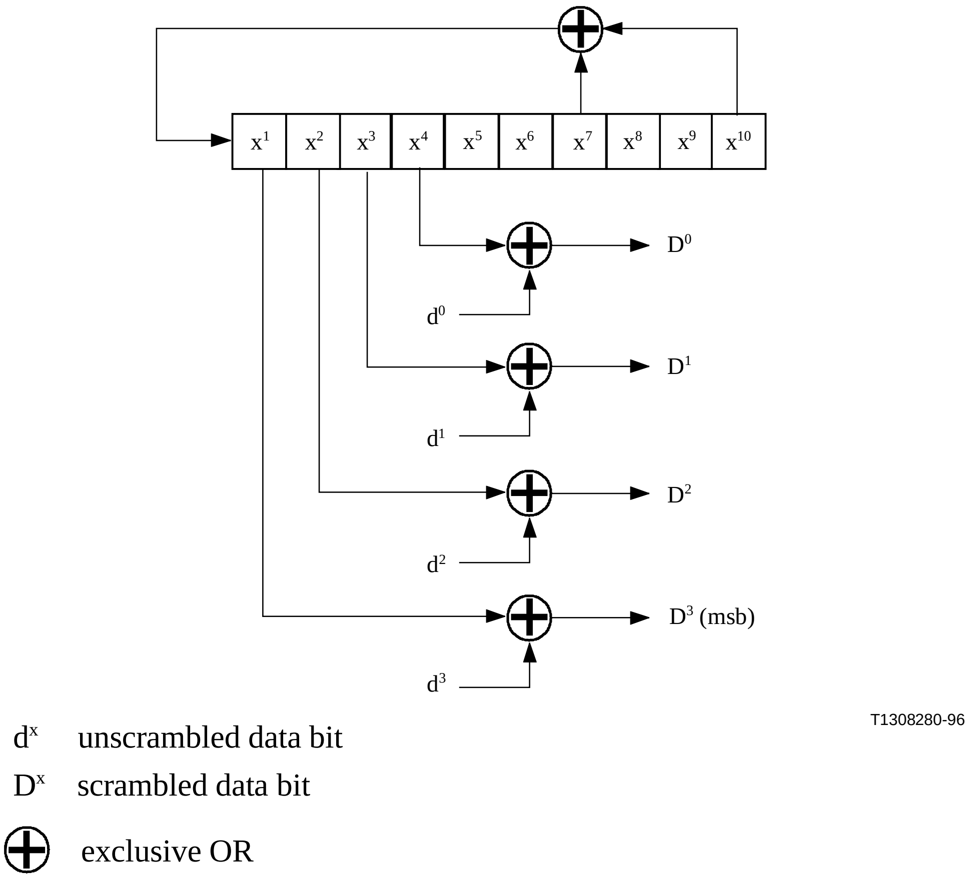

Figure 9/I.432.5 – Pseudo-random number generator example block diagram

The PRNG is clocked 4 times after each nibble regardless of whether the command octet, valid data or idle data is being transmitted. Command octets should not be scrambled.

The scrambler/descrambler is implemented such that each successive data nibble (starting with the high-order nibble and high-order bit within each nibble) is XORed with the corresponding 4 bits of the PRNG (x^1 x^2 x^3 x^4 as illustrated in the above diagram) each nibble cycle ($4 \times$ bit cycle time).

The PRNG is reset to its initial state (hex 3FF) upon every detection of two consecutive escape ("X") nibbles, whether or not these escape nibbles are octet-aligned (i.e. form a start-of-cell X_X sequence). The first nibble after the two consecutive escape nibbles should then be XORed with the initial "F" of the scrambler sequence, unless it is part of a command byte, as these are never scrambled. The PRNG should always be either reset or clocked (four new PRNG bits generated) after every nibble (including idles and commands), regardless of whether or not the nibble was scrambled.

NOTE – Figure 10 shows a case that will occur in normal operation whenever X_X is immediately followed by another command octet such as X_8. In this case, a second PRNG reset occurs as a result of the detection of a second pair of X symbols.

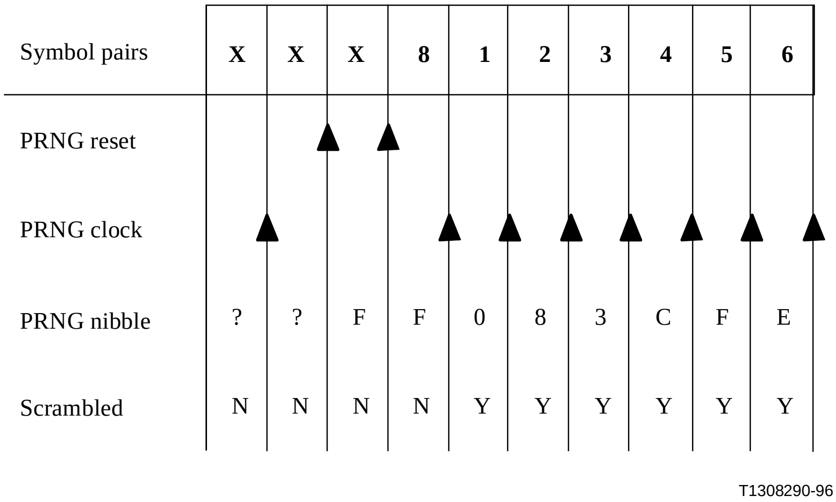

Figure 10/I.432.5 – Start-of-cell symbol pairs

For this PRNG to approximate a random source, it is recommended that the times for PRNG resets be between 100 microseconds and 500 milliseconds, PRNG reset should occur at the start of first cell or after the PRNG reset timer expires. A maximum time between resets is recommended to limit the time two end stations can be misaligned in the scrambler sequence.

3.1.1 PRNG sequence

For clarification purposes, the PRNG sequence for each nibble (starting from its reset state) is as follows:

F, 0, 8, 3, C, F, E, 8, C, 7 ,C, C, 7, D, 4, 3, 9, 4, 0, 0, 1, 8, 4, 4, 0, 3, 9, 5, 8, 4, 5, 8, 7, D, 5, B, D, 0, 0, 3, 8, D ...

3.2 4B5B block coding and decoding

A 4B5B encode/decode scheme is utilized to ensure that an adequate number of transitions occur on the line. The code provides the following features:

- provides an average of over 3 transitions per 5-bit symbol;
- run length is limited to less than or equal to 5;
- free of short-term "DC level" variations.

Each symbol of the code is composed of 5 bits. Of the 32 possible symbols, 17 are valid in this implementation. The remaining 15 symbols are invalid.

The 17 valid symbols represent 16 4-bit data nibbles (hex 0 through F) and one Escape (X) code. This escape symbol has the "comma" property of being unique among all possible valid symbol pairs. Table 11 below lists the valid 4-bit nibble to 5-bit symbol conversions.

Table 11 should be used to encode data nibbles for transmission and to decode 5-bit symbols upon reception. All symbols not listed in this table are invalid.

Table 11/I.432.5 – Conversion table – 4-bit command/data to 5-bit symbols

Data	Symbol	Data	Symbol	Data	Symbol	Data	Symbol
0000	10101	0001	01001	0010	01010	0011	01011
0100	00111	0101	01101	0110	01110	0111	01111
1000	10010	1001	11001	1010	11010	1011	11011
1100	10111	1101	11101	1110	11110	1111	11111
ESC (X)	00010						
NOTE – The binary values for 4-bit data nibbles and 5-bit encoded symbols in this table are shown most-significant bit first (i.e. at left).							

For each ATM cell processed, the data within is scrambled, encoded and NRZI-coded before it is transmitted. Likewise on the receiver, once a start-of-cell command is detected, the serial data is NRZI decoded, and the resulting 5-bit symbols decoded to form a data nibble. The nibbles are then descrambled and re-combined to form the ATM cell.

3.2.1 Symbol-pair level code structure

Five-bit encoded symbols should always be paired. Two types of symbol pair entities are defined which represent:

- commands;
- data octets.

Commands are composed of the escape symbol followed by any of the 16 data symbols or by the escape symbol. This provides 17 possible commands of which three are defined and valid. The set of 3 valid (bold) and 14 invalid (reserved for future use) commands are:

- **X_X = Start-of-cell (with scrambler reset)**
- X_0 = Invalid (reserved for future use)
- X_1 = Invalid (reserved for future use)
- X_2 = Invalid (reserved for future use)
- X_3 = Invalid (reserved for future use)
- **X_4 = Start-of-cell (with no scrambler reset)**
- X_5 = Invalid (reserved for future use)
- X_6 = Invalid (reserved for future use)
- X_7 = Invalid (reserved for future use)
- **X_8 = Sync_Event**
- X_9 = Invalid (reserved for future use)
- X_A = Invalid (reserved for future use)
- X_B = Invalid (reserved for future use)
- X_C = Invalid (reserved for future use)
- X_D = Invalid (reserved for future use)
- X_E = Invalid (reserved for future use)
- X_F = Invalid (reserved for future use)

All the above described command symbol pairs (X_X, X_4, and X_8) are transmitted in symbol pair alignment. The symbol pair alignment boundary is defined by the first occurrence of a command symbol pair. Subsequent command symbol pairs are transmitted in symbol pair alignment with the first command symbol pair.

All five-bit encoded symbols are transmitted serially with the most significant bit transmitted first.

3.2.2 Cell delineation

Cell delineation is accomplished by prefixing either of two valid commands to the each ATM cell before transmission. As defined above, the two valid start-of-cell commands are:

- **X_X = Start-of-cell (with scrambler reset); and**
- **X_4 = Start-of-cell (with no scrambler reset).**

3.2.3 Support for a timing signal

For applications requiring "network clock", this function is necessary. Transport of a timing sync pulse to support isochronous communications may be accommodated. A special Sync_Event command symbol-pair, X_8, may be inserted into the transmitted stream at any symbol-pair boundary.

It is expected that this means will be used to carry an 8 kHz timing signal although this feature could be used to carry other timing references.

The Sync_Event timing marker command is generated at the next octet boundary after the incoming synchronization event is detected. The Sync_Event command symbol-pair should have priority over all line activity (data or command symbol pairs) and should be transmitted at the next symbol-pair boundary after the incoming synchronization event is detected. When this occurs during a cell transfer, the data transfer should be temporarily interrupted on a symbol pair boundary and the X_8 command symbol pair should be inserted. This condition is the only allowable interrupt in an otherwise contiguous transfer of the 54-symbol pair stream (one command symbol pair plus 53 data symbol pairs).

As an option, when a Sync_Event command is detected by the receiver (ATM user equipment), the Sync_Event command can be "wrapped around" and transmitted onto the upstream path (to the ATM network equipment).

Figure 11 is an illustration of cell structure showing start-of-cell commands with and without scrambler reset and a Sync_Event command interrupting the flow of Cell N+1.

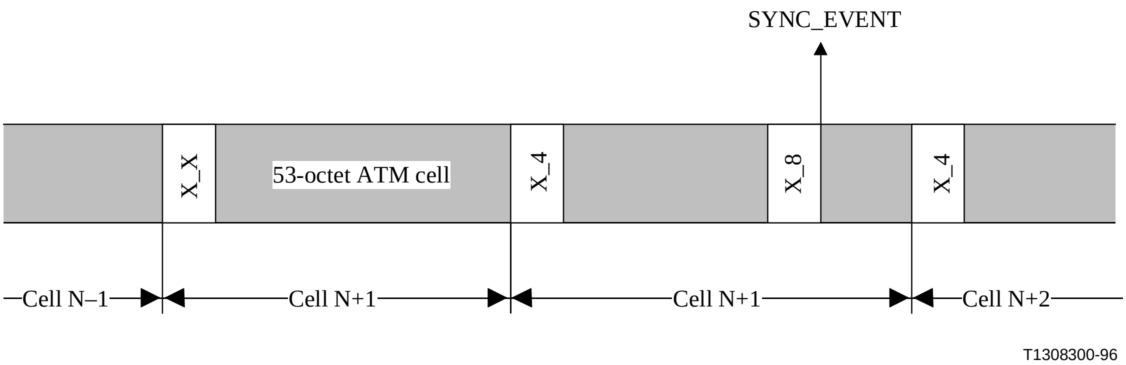

Figure 11/I.432.5 – Example of cell delineation and Sync_Event using commands

In the example in Figure 11, the Nth ATM cell is preceded by a X_X start-of-cell command. This causes both the scrambler and the descrambler to reset their pseudo-random nibble generators to the initial state. For cell N+1, the ATM cell is simply preceded by an X_4 start-of-cell command without scrambler/descrambler reset. Also in cell N+1, a timing sync pulse results in an X_8 timing marker command.

Reception of any command other than X_X, X_4 or X_8 within the 53-octet ATM cell is considered an error and the cell may be discarded. Reception of the X_X or X_4 command within the 53-octet ATM cell causes the octets of the cell that have been received to be discarded and the reception of a new cell to be initiated.

On the receiver, the decoder determines from the received symbols whether a timing marker command (X_8) or a start-of-cell command was sent (X_X or X_4). Anytime a start-of-cell command is detected, the next 53 octets received are decoded and forwarded to the descrambler.

Transmissions during idle states (where no command or data are being transmitted) will continually be sent out onto the line. This arbitrary data, excluding the escape symbol X, will continue to be encoded and scrambled to maintain synchronization of the receive PLL. Upon the beginning of a valid cell transmission, the command symbol-pair would be immediately initiated. (Note that the 4B5B code guarantees a maximum run length of five bits. This, in addition to the fact that all non-control octets are scrambled, will provide more than sufficient transitions to maintain bit sync during idle states.)

The TC sublayer transfers complete 53-octet ATM cells to and from the ATM layer.

3.3 NRZI encoding and decoding

In order to bound the run length of either binary 1s or 0s during transmission, data symbols from the encoder should be serialized and NRZI encoded before transfer to the PMD layer.

Each symbol is serialized most significant bit first, and then NRZI encoded.

Serial data received from the PMD is NRZI decoded before symbol boundaries are detected.

3.4 HEC generation and verification

The Header Error Control (HEC) covers the entire cell header. For this interface, only detection of bit errors is described. Support of bit error detection based on HEC field is used.

The transmitter calculates the HEC value for the first four octets of the cell header, and inserts the result into the HEC field (the last octet of the ATM cell header). The HEC field is an 8-bit sequence. It is the remainder of the division (modulo 2) by the generator polynomial $x^8 + x^2 + x + 1$ of the polynomial x^8 multiplied by the content of the header excluding the HEC field. The pattern 01010101 is XORed with the 8-bit remainder before being inserted into the HEC field.

Equipment supporting this UNI should implement HEC error detection as defined in Recommendation I.432.1 [3]. Equipment supporting this UNI should generate the HEC octet as defined in Recommendation I.432.1 [3]. The generator polynomial and coset used should be in accordance with Recommendation I.432.1 [3].

Figure 12 depicts the HEC verification flow at the receiver. The TC sublayer does not forward any cell to the ATM layer which has an incorrect HEC.

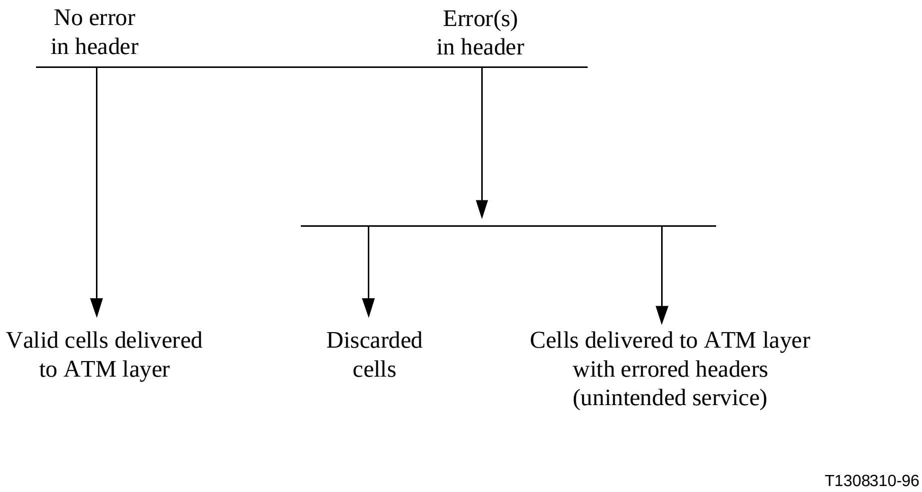

Figure 12/I.432.5 – HEC verification flow

As defined in Recommendation I.432.1 [3], the HEC method is capable of single bit error correction and multiple bit error detection. Because the 4B5B block code used in this UNI causes multiple bit errors for each corrupted bit, the HEC error correction mode is not used. HEC error detection is necessary. Upon detection of a header error in a received cell, that cell should be discarded.

4 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

[1] ITU-T Recommendation I.113 (1997), *Vocabulary of terms for broadband aspects of ISDN*.

[2] ITU-T Recommendation I.413 (1993), *B-ISDN user-network interface.*

[3] ITU-T Recommendation I.432.1 (1996), *B-ISDN user-network interface – Physical layer specifications: General characteristics*.

[4] ITU-T Recommendation I.432.2 (1996), *B-ISDN user-network interface – Physical layer specifications: 155 520 kbit/s and 622 080 kbit/s operation*.

[5] ISO/IEC 11801:1995, *Information technology – Generic cabling for customer premises.*

[6] ITU-T Recommendation I.414 (1993), *Overview of Recommendations on layer 1 for ISDN and B-ISDN customer access.*

5 Bibliography

[7] EIA/TIA 568A 95, *Commercial Building Telecommunications Cabling Standard*, 25 October 1995.

[8] IEC 603-7 (1990), *Connectors for use with printed boards*.

6 Definitions

For the purposes of this Recommendation, the definitions given in Recommendation I.113 [1] apply. In addition, the following specific term is used in this Recommendation.

6.1 channel: A copper link segment/transmission media consisting of one or more sections of twisted pair copper cable media containing two or four pairs along with intermediate connectors required to connect sections together and terminated at each end in the specified electrical data connector.

7 Abbreviations

This Recommendation uses the following abbreviations.

ATM	Asynchronous Transfer Mode
BER	Bit Error Ratio
B-ISDN	Broadband Integrated Services Digital Network
FTP	Foiled Twisted Pair
HEC	Header Error Control
MIC	Media Interface Connector
NEXT	Near-End Crosstalk
NRZI	Non-Return to Zero Invert
PLL	Phase-Lock Loop
PMD	Physical Media Dependent
PRNG	Pseudo-Random Number Generator
RAT	Receiver Acquisition Time
RRL	Receiver Return Loss
SRL	Structural Return Loss
STP	Shielded Twisted Pair
TC	Transmission Convergence
TDCD	Transmitter Duty Cycle Distortion
TEJ	Transmitter Edge Jitter
TLA	Transmitter Launch Amplitude
TRL	Transmitter Return Loss
UNI	User Network Interface
UTP	Unshielded Twisted Pair
4B5B	4 Bit/5 Bit line coding mechanism

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