Digital Communication Systems

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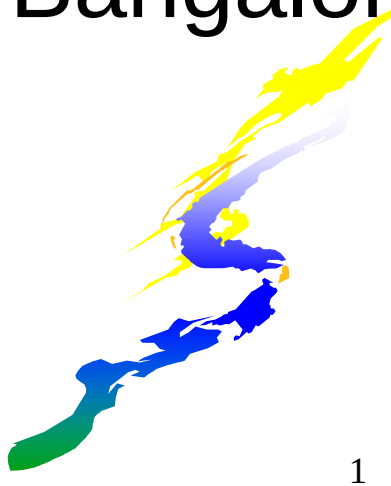


Topics in Digital Communications

- Digital communication system advantages and disadvantages
- Digital communication system classification
- Digitization of analog signals
- Digital transmission systems
- Data communication systems
- Integrated Services Digital Network and other advanced digital communication systems

Digital Communication advantages

- Reliable communication; less sensitivity to changes in environmental conditions (temperature, etc.)
- Easy multiplexing
- Easy signaling
  - Hook status, address digits, call progress information
- Voice and data integration
- Easy processing like encryption and compression
- Easy system performance monitoring
  - QOS monitoring
- Integration of transmission and switching
- Signal regeneration, operation at low SNR, superior performance
- Integration of services leading to ISDN

Digital Communication System Disadvantages

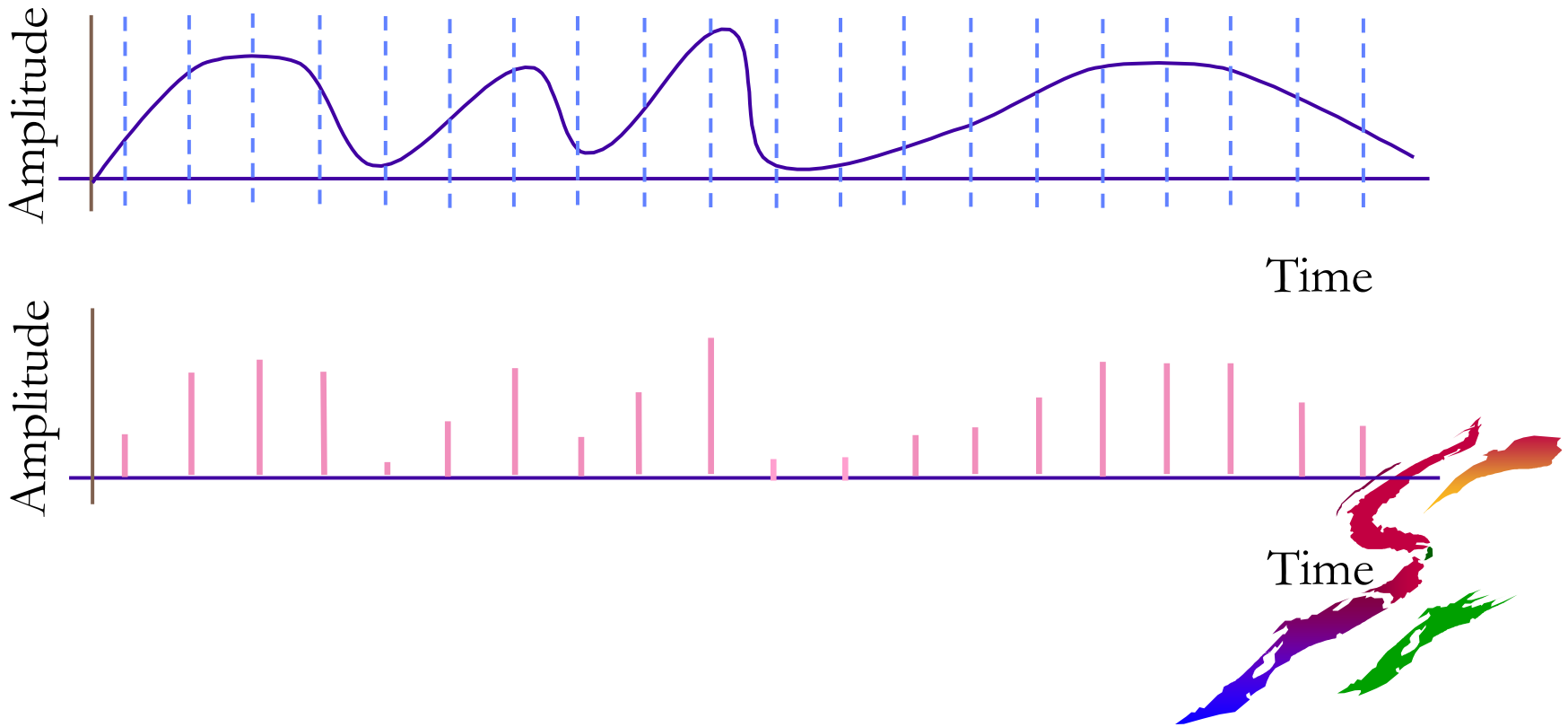
- Increased bandwidth
  - 64 KB for a 4 KHz channel, without compression (However, less with compression)
- Need for precision timing
  - Bit, character, frame synchronization needed
- Analogue to Digital and Digital to Analogue conversions
  - Very often non-linear ADC and DAC used, some performance degradation
- Higher complexity

Types of Digital Communication Systems

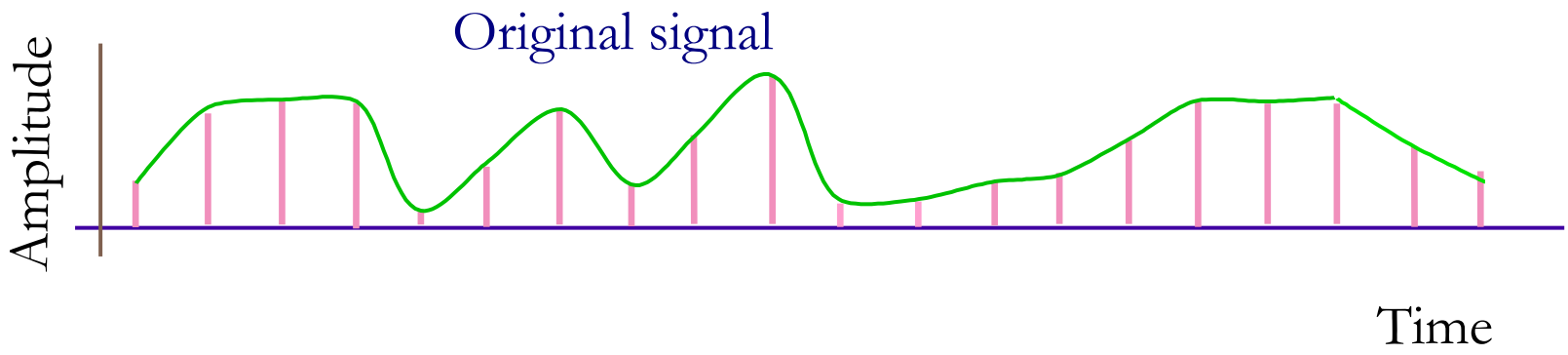
Signal Type	Transmission	Example
Analog	Analog	Classical telephony
Analog	Digital	PCM TDM
Digital	Analog	Modems
Digital	Digital	ISDN, LANs

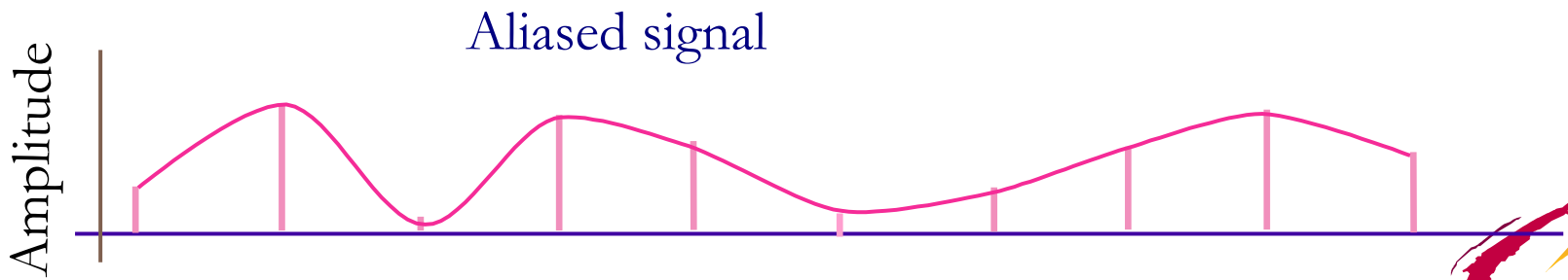
Digitization of analogue signals

- Signal sampling



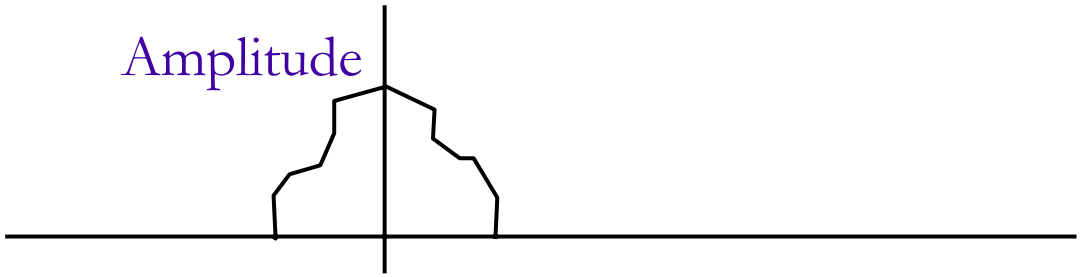
Nyquist Criterion, Aliasing



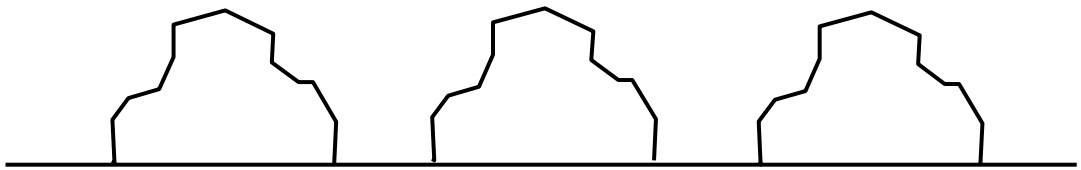


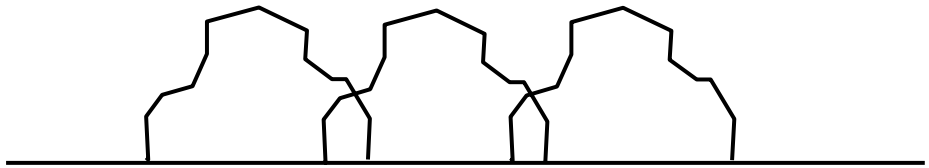
Nyquist sampling rate fs > 2. fb

Spectrum of baseband signals



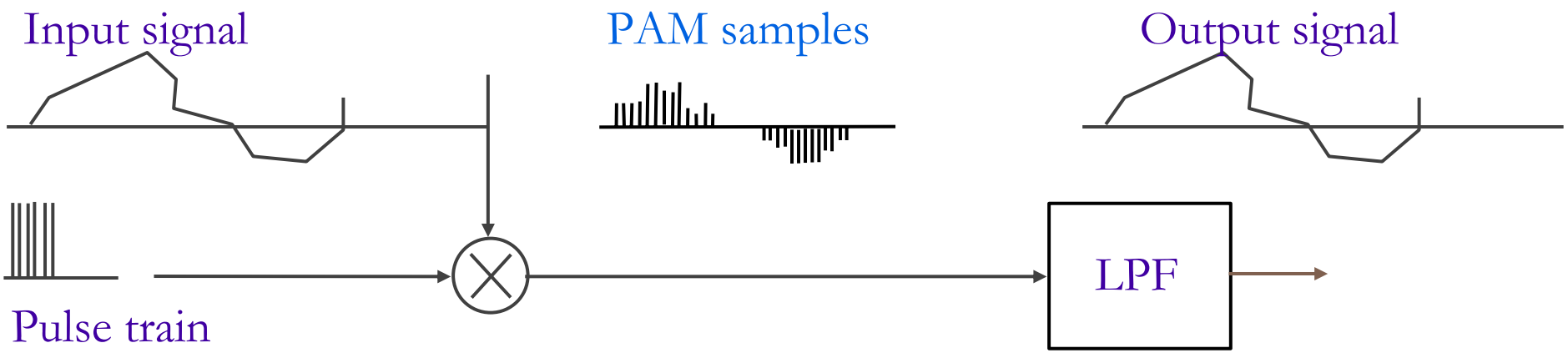
Spectrum of the properly sampled base band





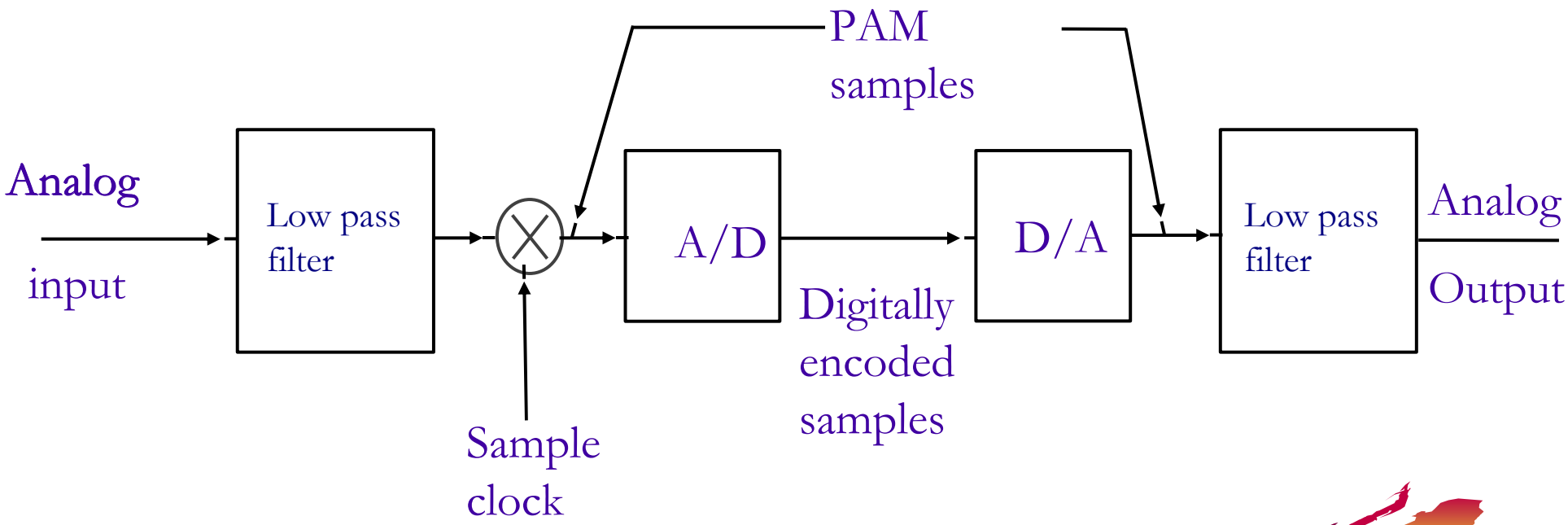
Spectrum of the under sampled base band

Speech signal digitisation

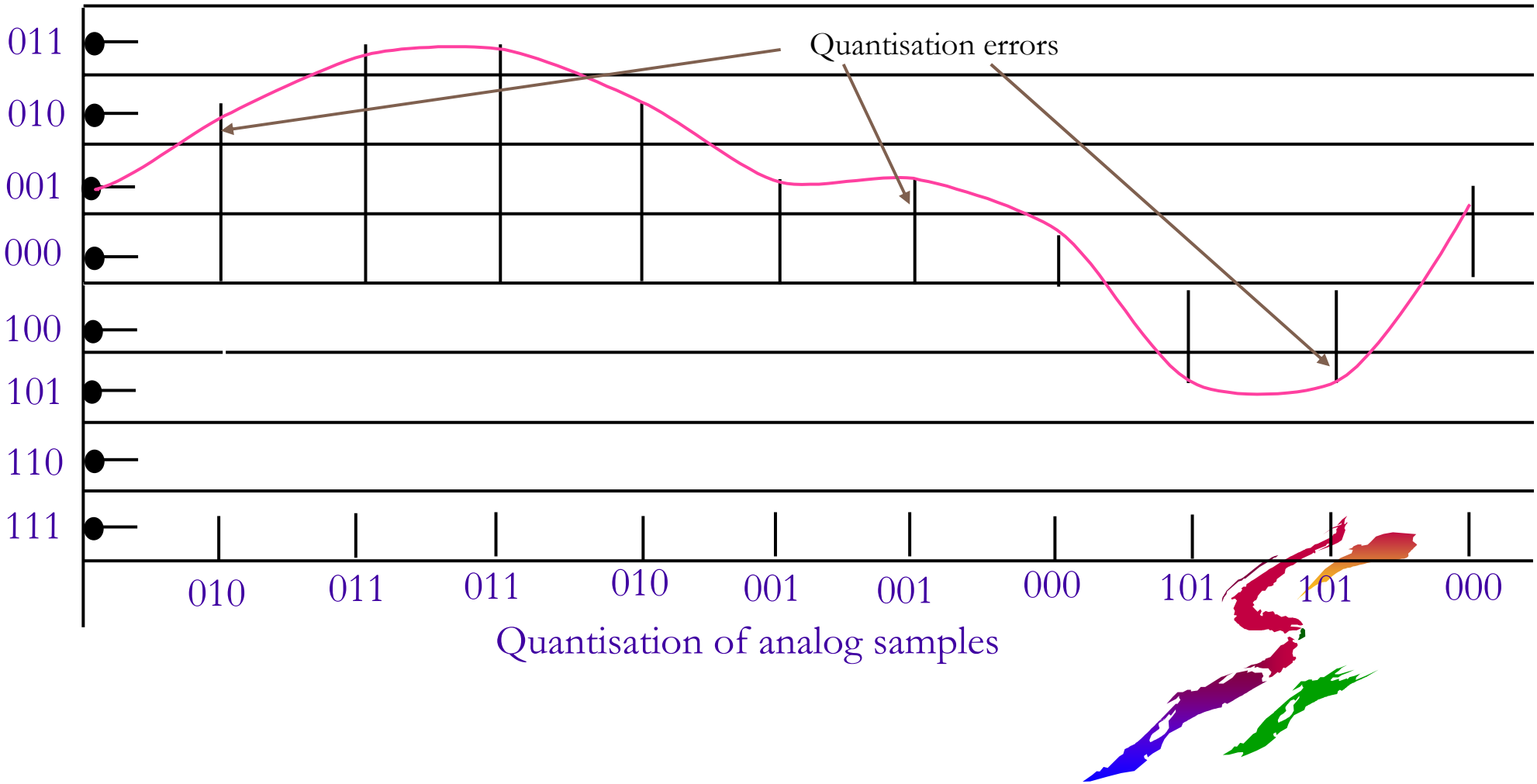


Pulse amplitude modulation

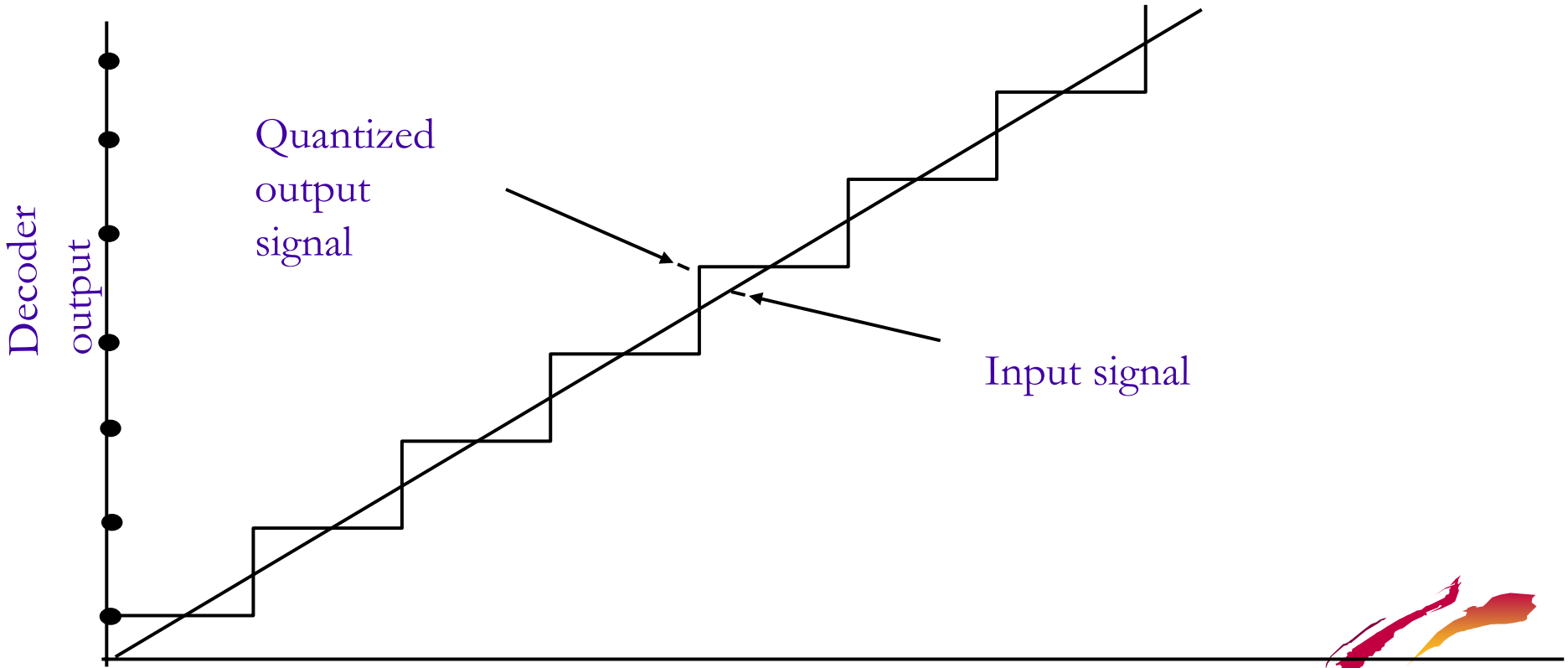
Pulse Code Modulation (PCM)

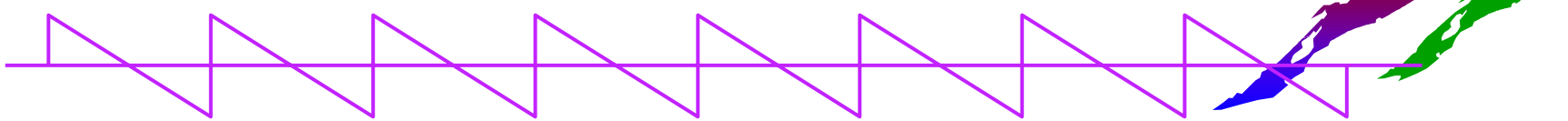


Quantisation of speech signal samples



Quantisation error in PCM





Quantisation error as a function of amplitude

PCM system - Typical parameters

4 KHz Speech signal

8 KHz Sampling

8 bits / sample digitising

per speech channel 8 x 8 bits = 64 kbps

T1 carrier: 24 channels. 8 bits in 125 μs / channel

24 x 8 = 192 bits in 125 μs / frame, 1 bit per frame for sync

193 bits in 125 μs, **Line rate 193/125 μsec = 1.544 Mbps**

ITU (EUROPEAN)

32 Channels 8 bits/ 125 μss / channel

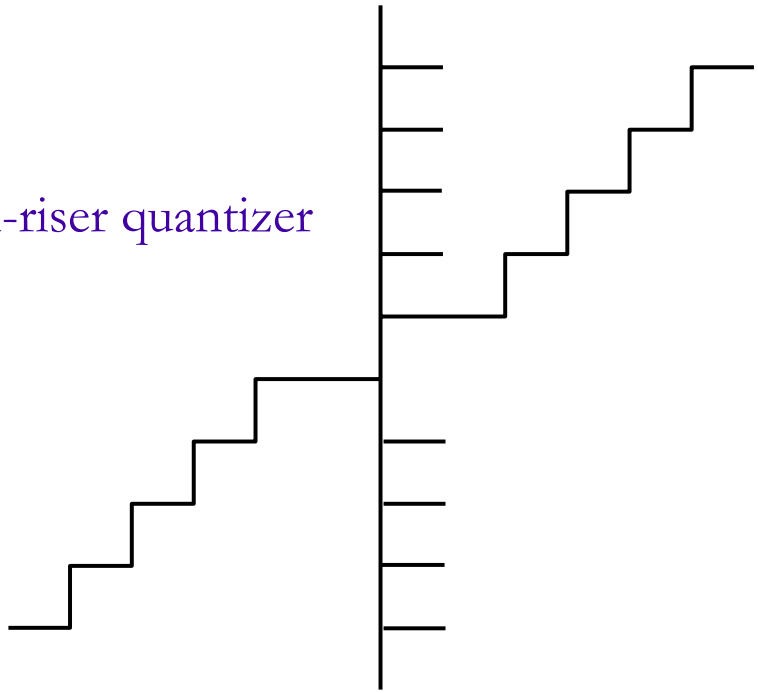
32 X 8 bits / 125 μs = 2.048 Mbps

30 channels info; 2 channels management

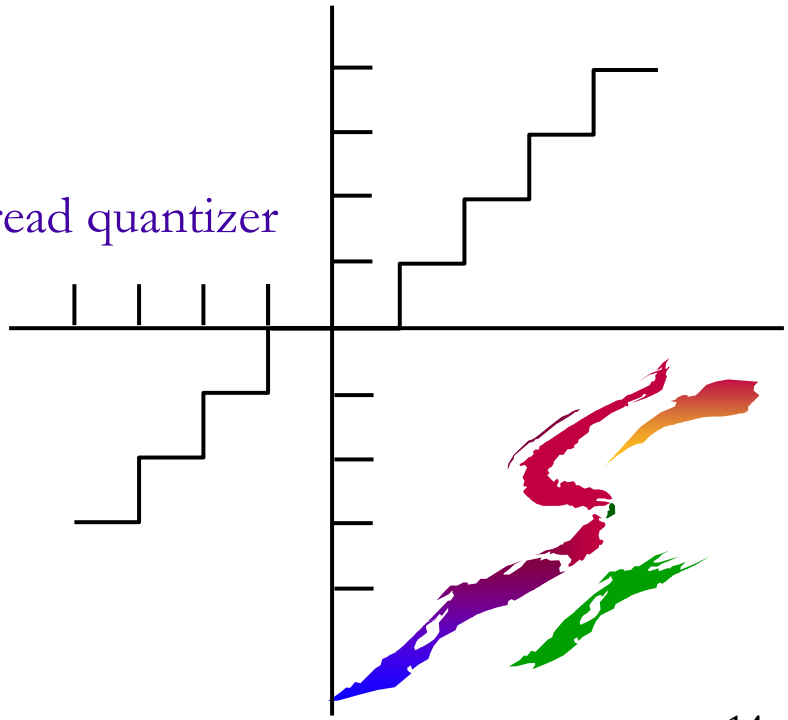
Idle channel noise minimisation

Idle channel noise: Caused by uncertainty in coding a sample near zero value

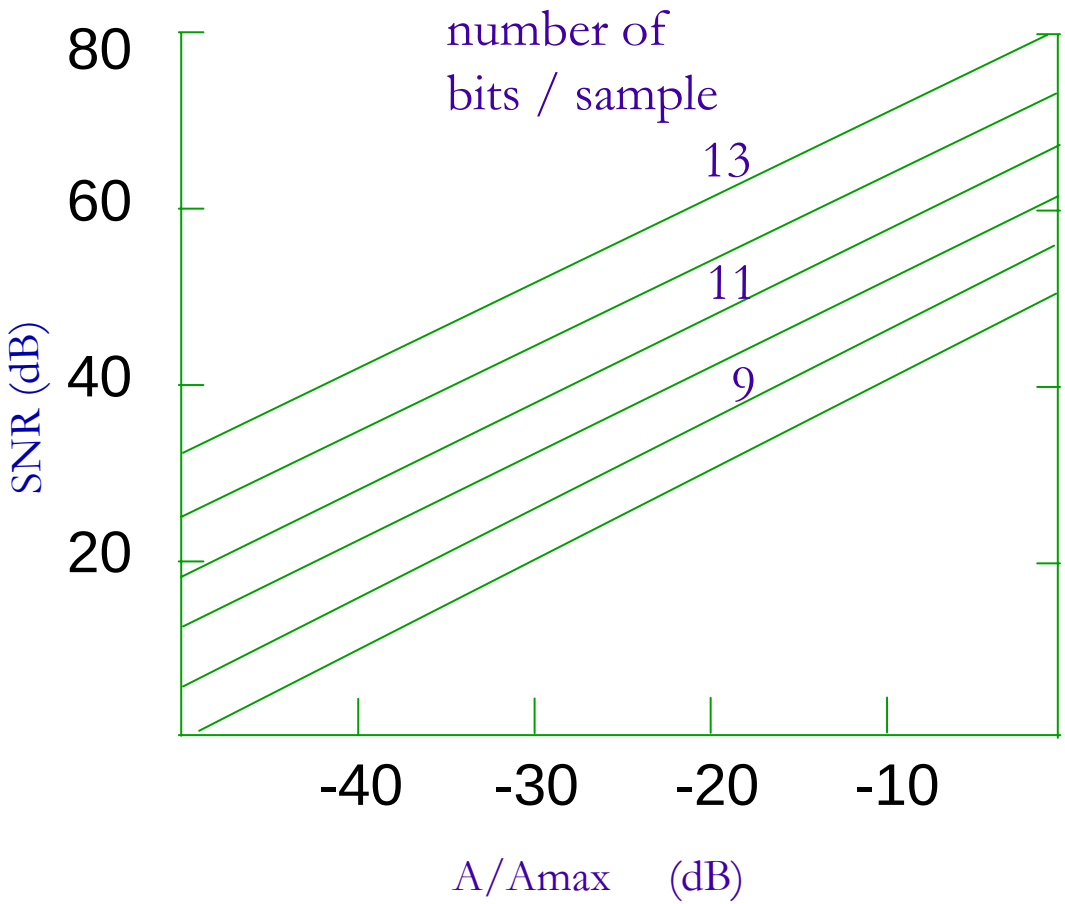
Mid-riser quantizer



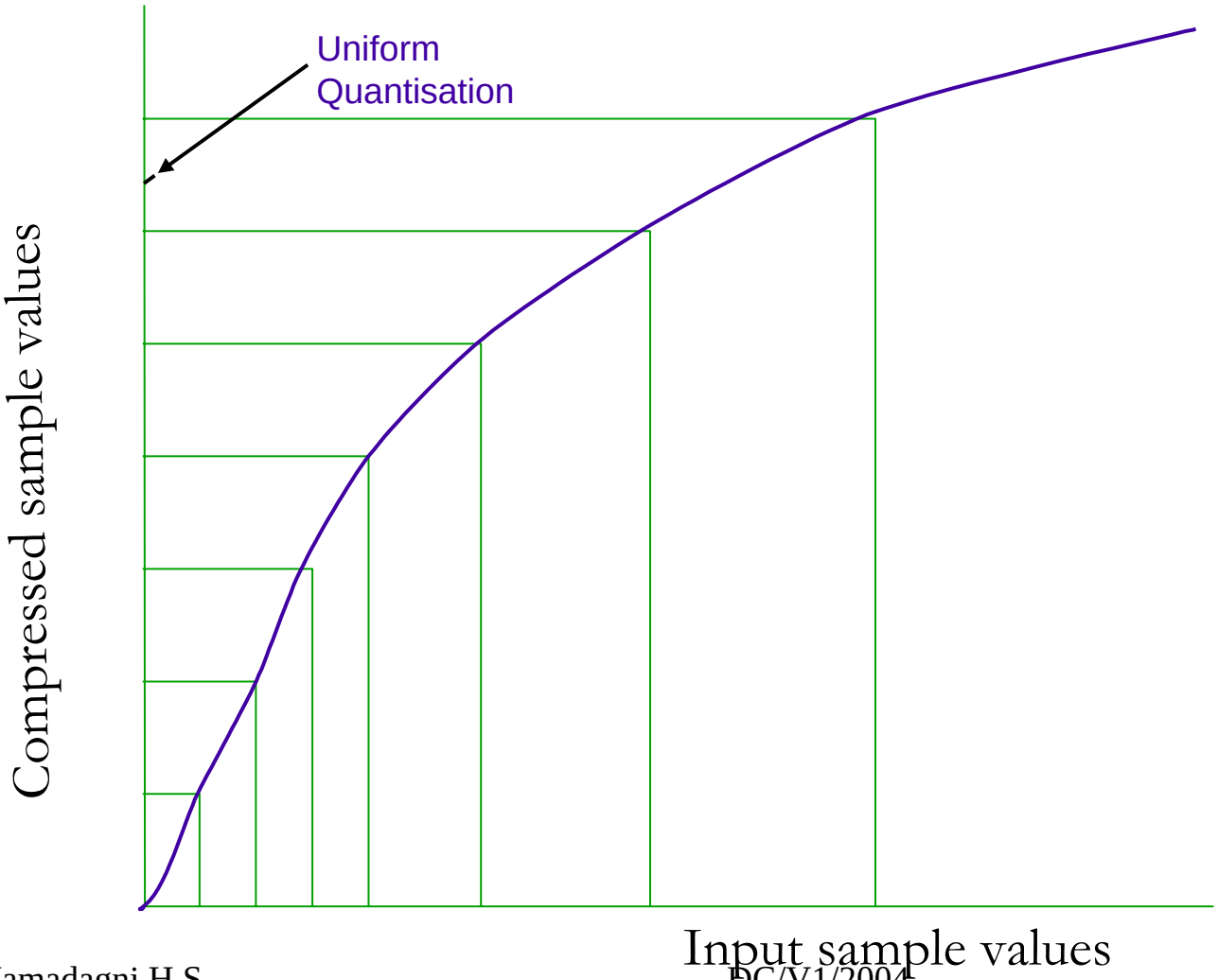
Mid-tread quantizer



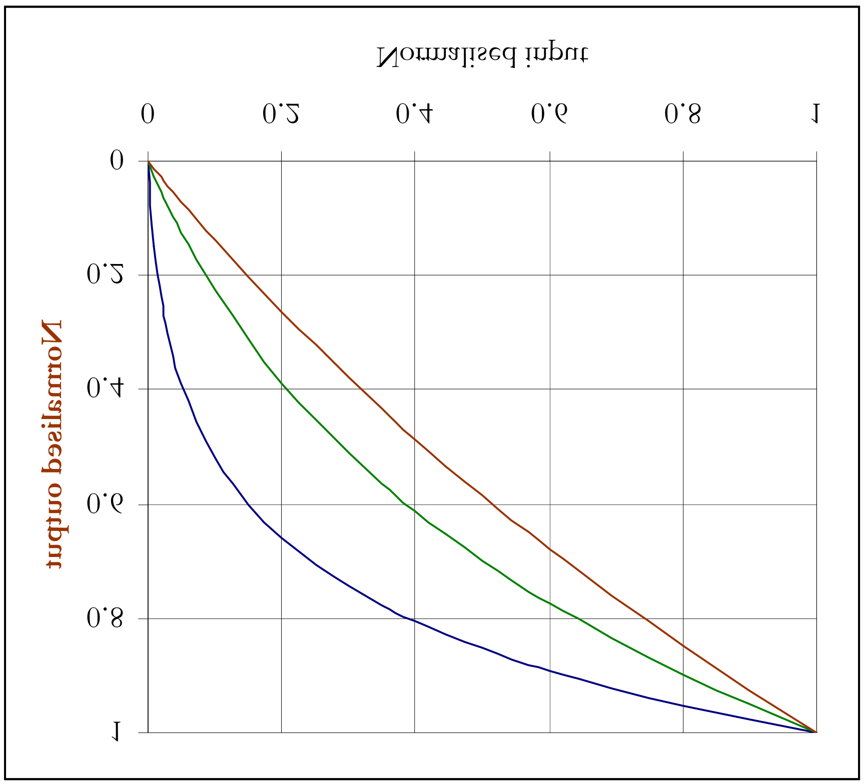
Signal to quantizing noise of uniform PCM



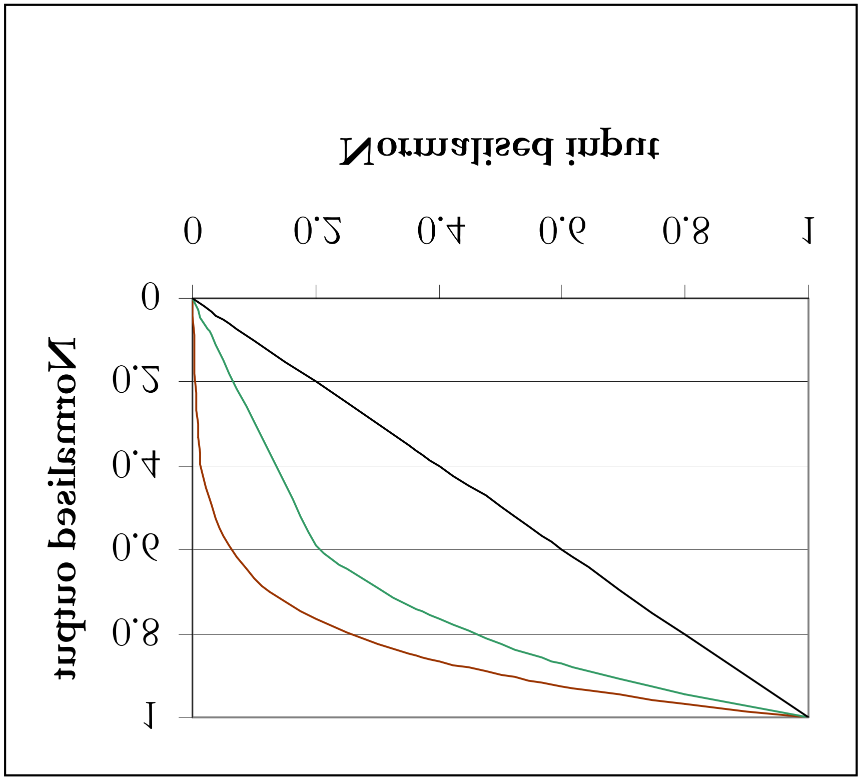
Non-linear AD conversion



Compression law - μ law



Compression law - A law



Non linear AD conversion laws used in PCM for speech

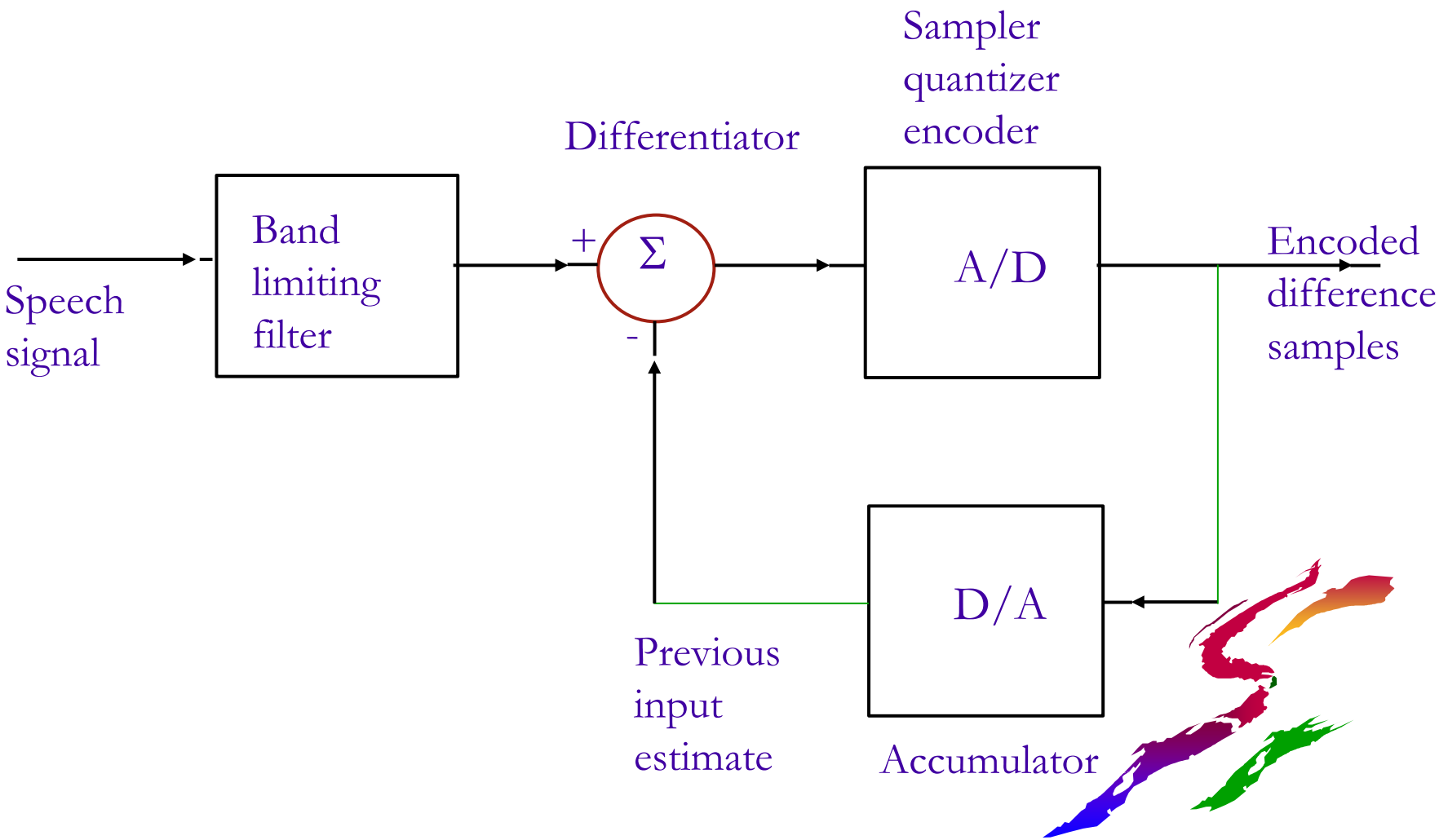
$$F_\mu(x) = sgn(x)\frac{\ln(1+\mu|x|)}{\ln(1+\mu)}$$

μ law

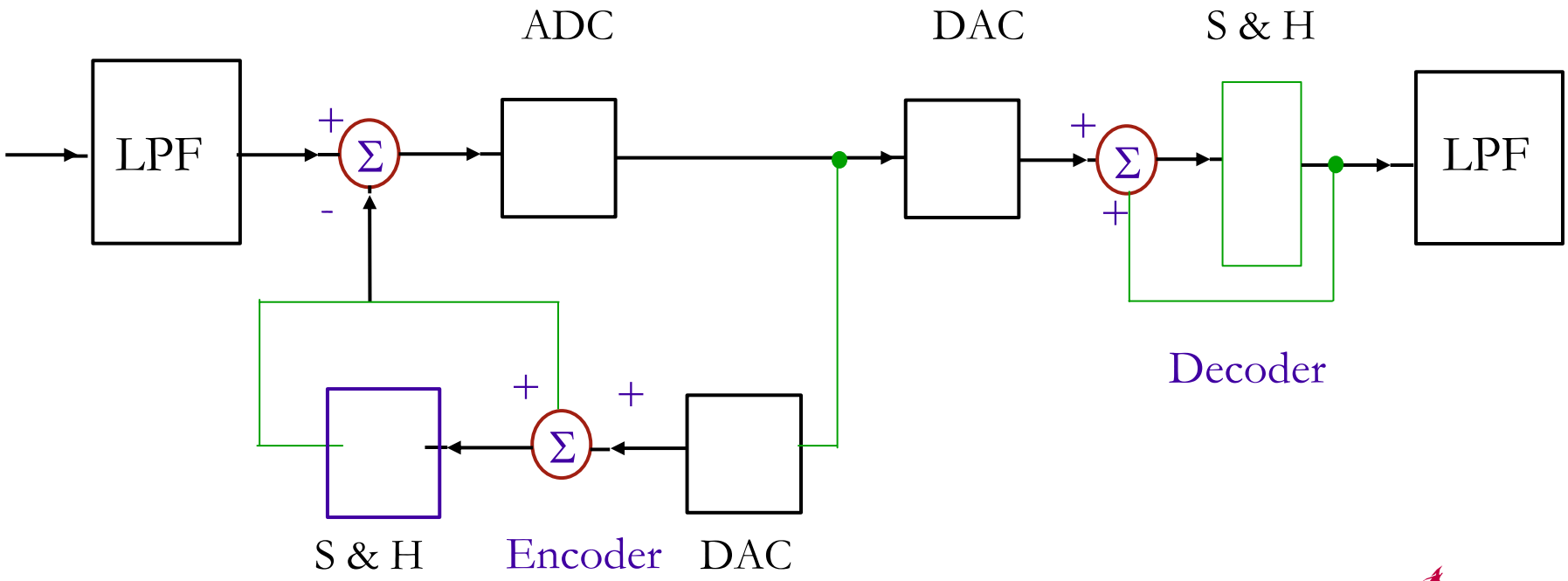
$$F_A(x) = sgn(x)\frac{A|x|}{1+\ln A}$$

A law

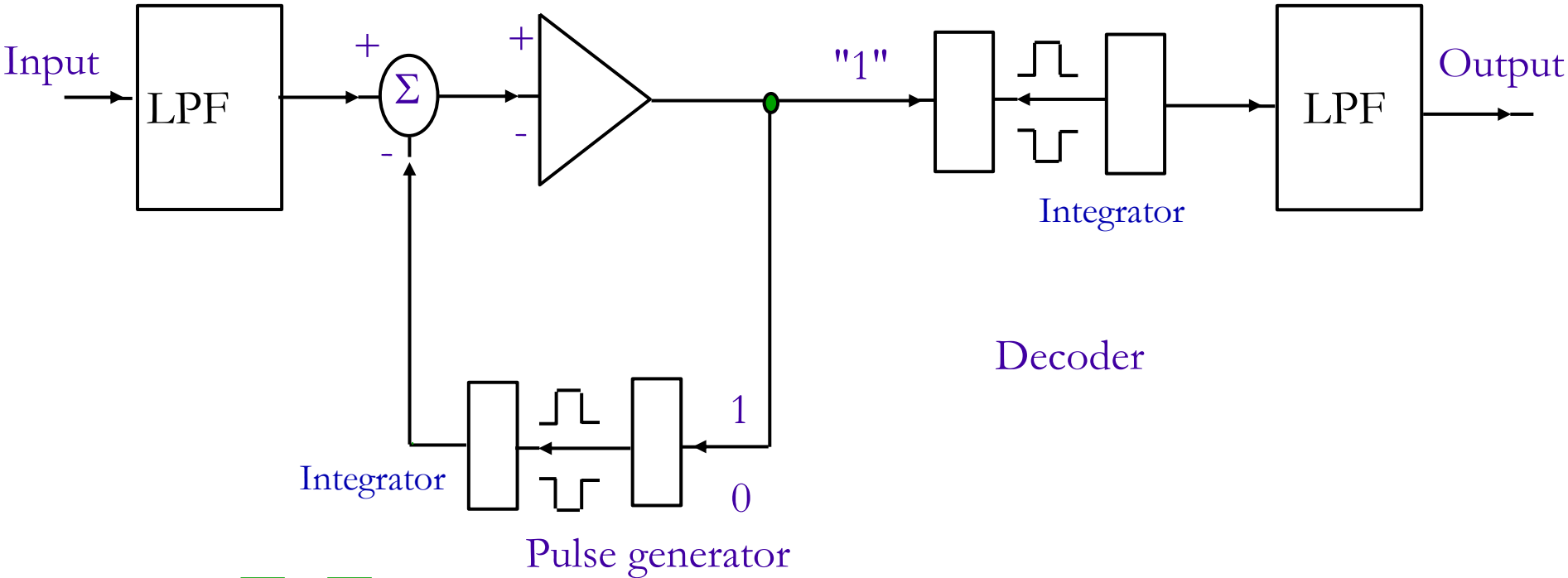
Low bit rate coding: DPCM, Differential PCM

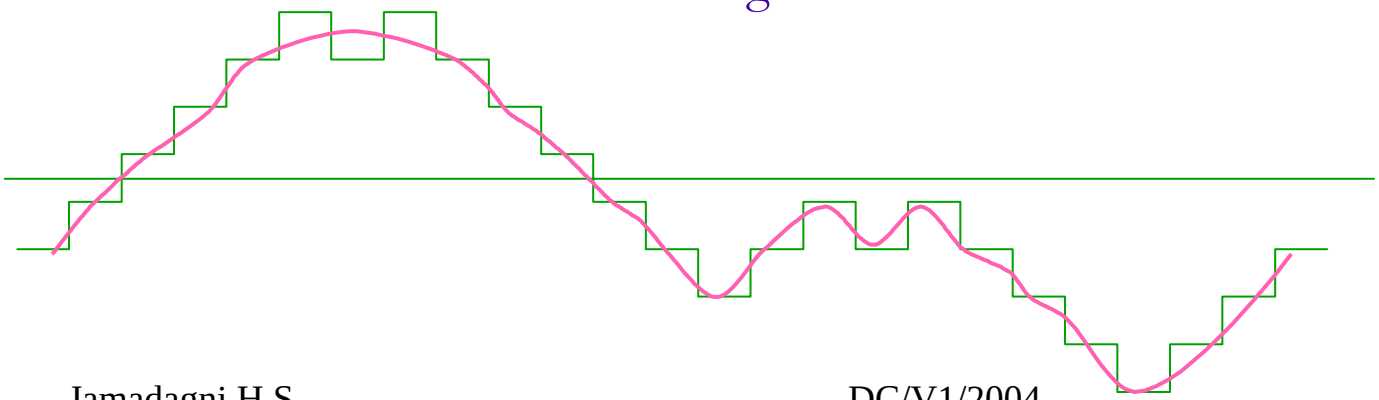


DPCM implementation

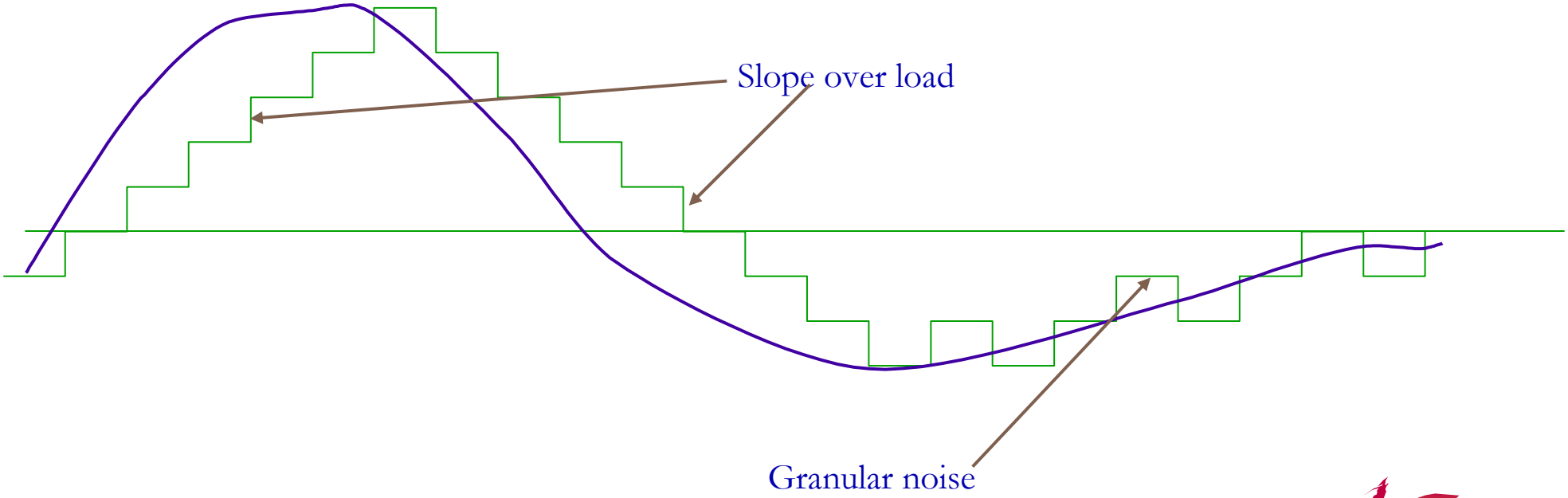


Delta modulation



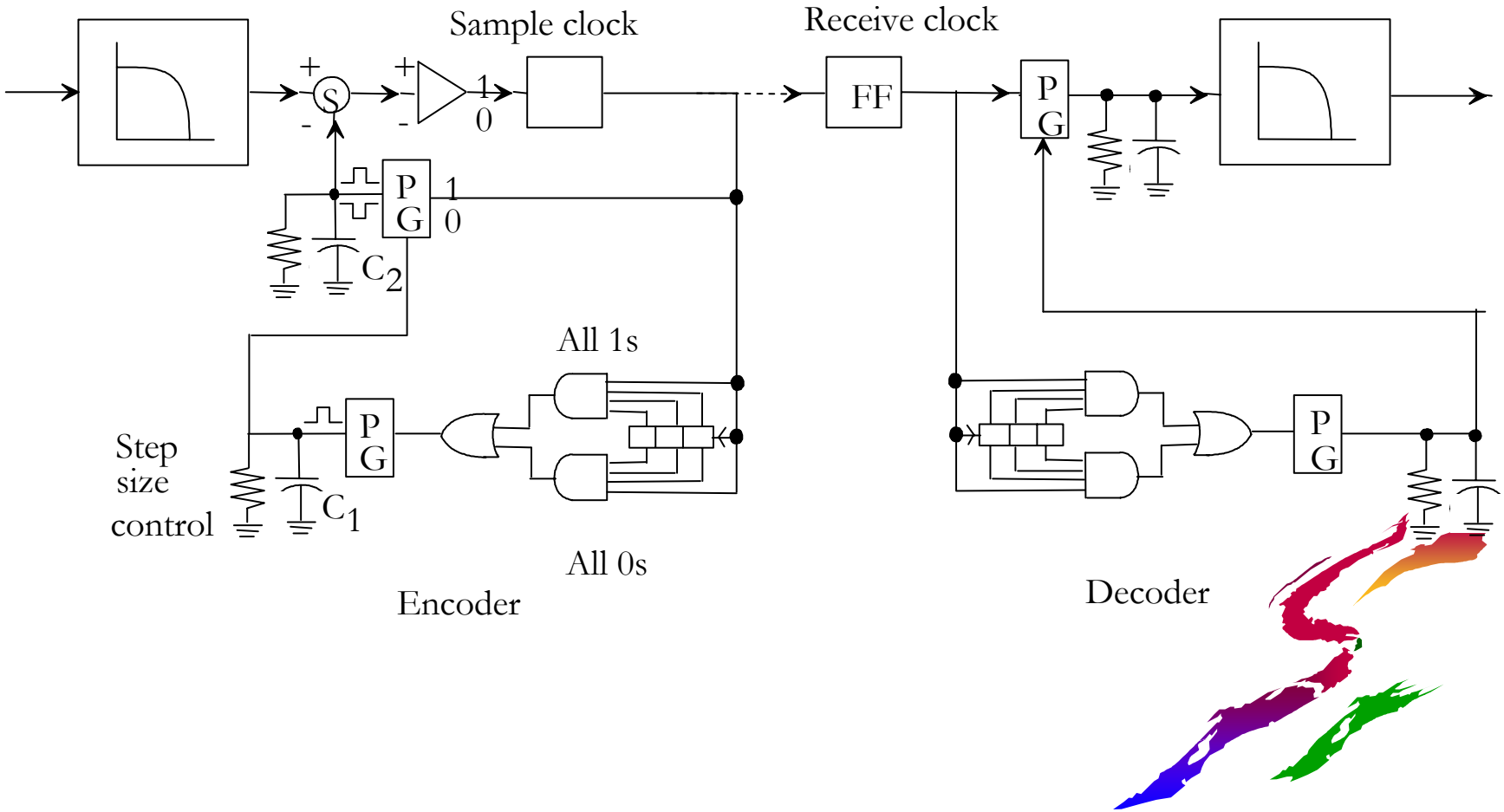


Slope overload distortion in Delta modulation

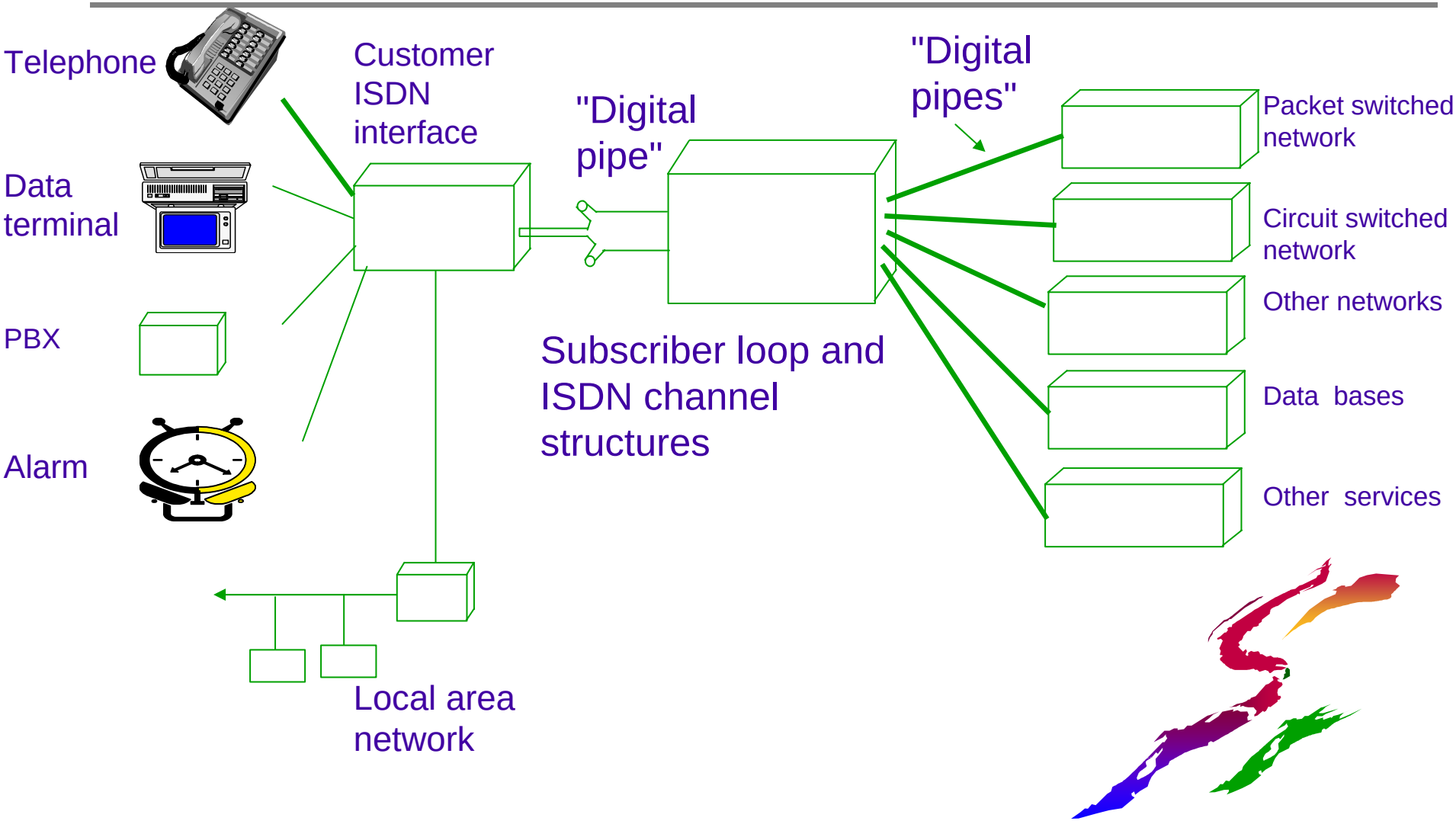


Low Data Rate Modulation

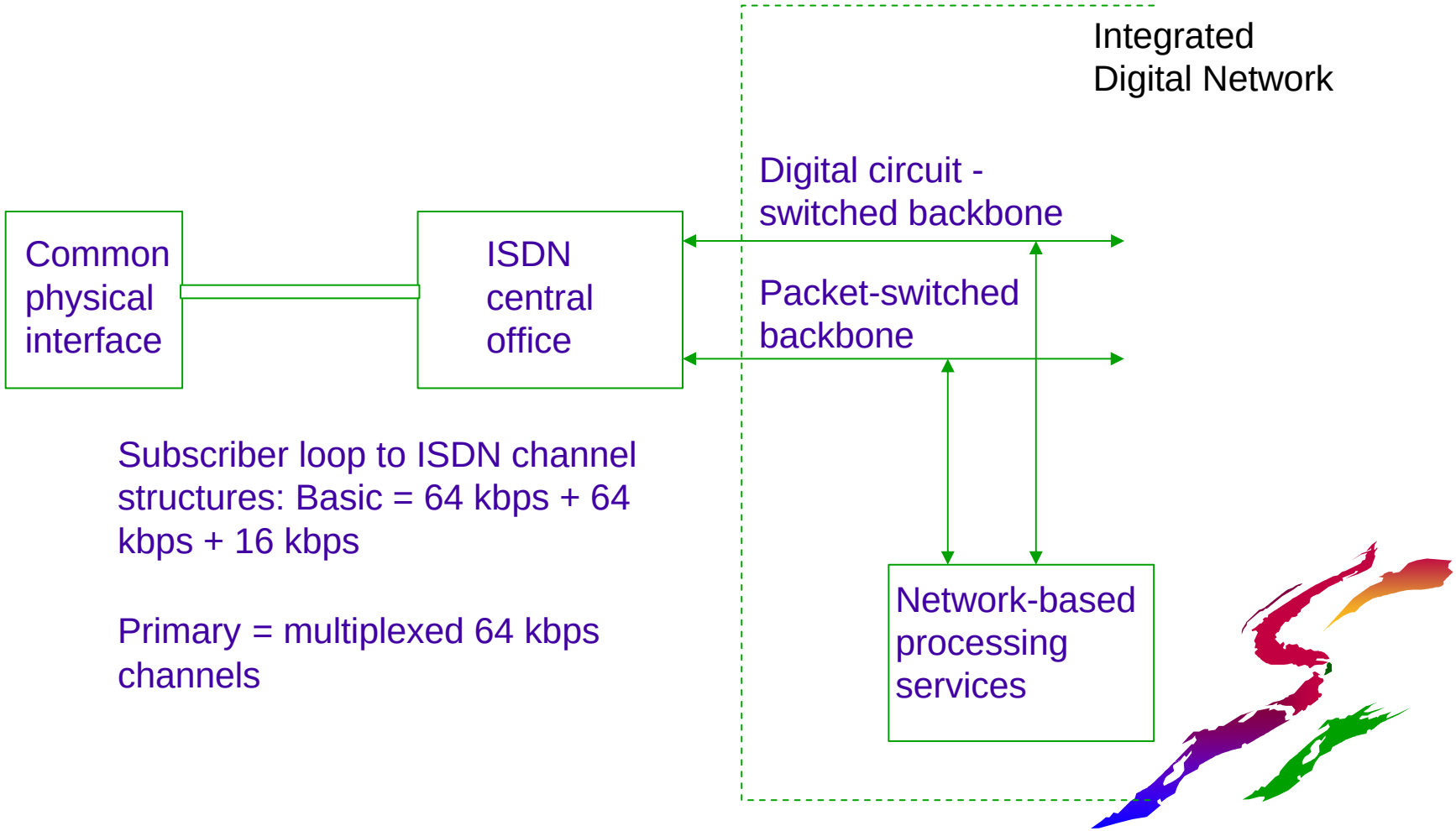
- CVSD (Continuous Variable Slope Delta Modulation)



Conceptual view of ISDN



Block diagram of ISDN functions



Subscriber loop to ISDN channel structures: Basic = 64 kbps + 64 kbps + 16 kbps

Primary = multiplexed 64 kbps channels

ISDN principles

- ISDN is based on concepts developed for telephony. Therefore, evolutionary changes
- Transition from the present network to ISDN may require about one decade.
- End-to-end digital connectivity to be obtained using digital transmission, TDM switching and or SDM switching.
- Present ITU standards part of new standards
- In early development of ISDN interim measures needed for interfacing with present networks

Principles of ISDN (Cont.)

- Supports a wide range of voice and non-voice applications
- Switched and non-switched connections Circuit switching and packet switching
- Based on 64 Kbps channels
- Intelligence for providing service features, maintenance and management integrated
- Layered protocol used
- Flexibility for implementation at specific national situations

ISDN evolution

- Digital exchanges commissioned in late 60's and 70's

Integrated digital transmission and switching established (IDN)

- Integrating services in IDN is the latest step leading to ISDN INTEGRATED SERVICES DIGITAL NETWORK

ISDN services: Definition of attributes

- All services on the ISDN network are characterised by "attributes" defined in ITU 1.130 standards
- Attributes have a definition and allowable values
- Any service has a set of valid attributes

ISDN services: Attributes

Attribute Name	Values
Info. transfer mode	Circuit, packet
Info. transfer rate	Bit rate
Info. transfer capability	Speech, 3.1 KHz audio 7 KHz audio 15 KHz audio Video Other values
Connection performance	Bit error rate

ISDN service classification

Services defined by attributes

- Bearer services
- Teleservices
- Secondary services

Bearer services provide capability to transfer information between ISDN access points and involve only low level layers (1,2 and 3)

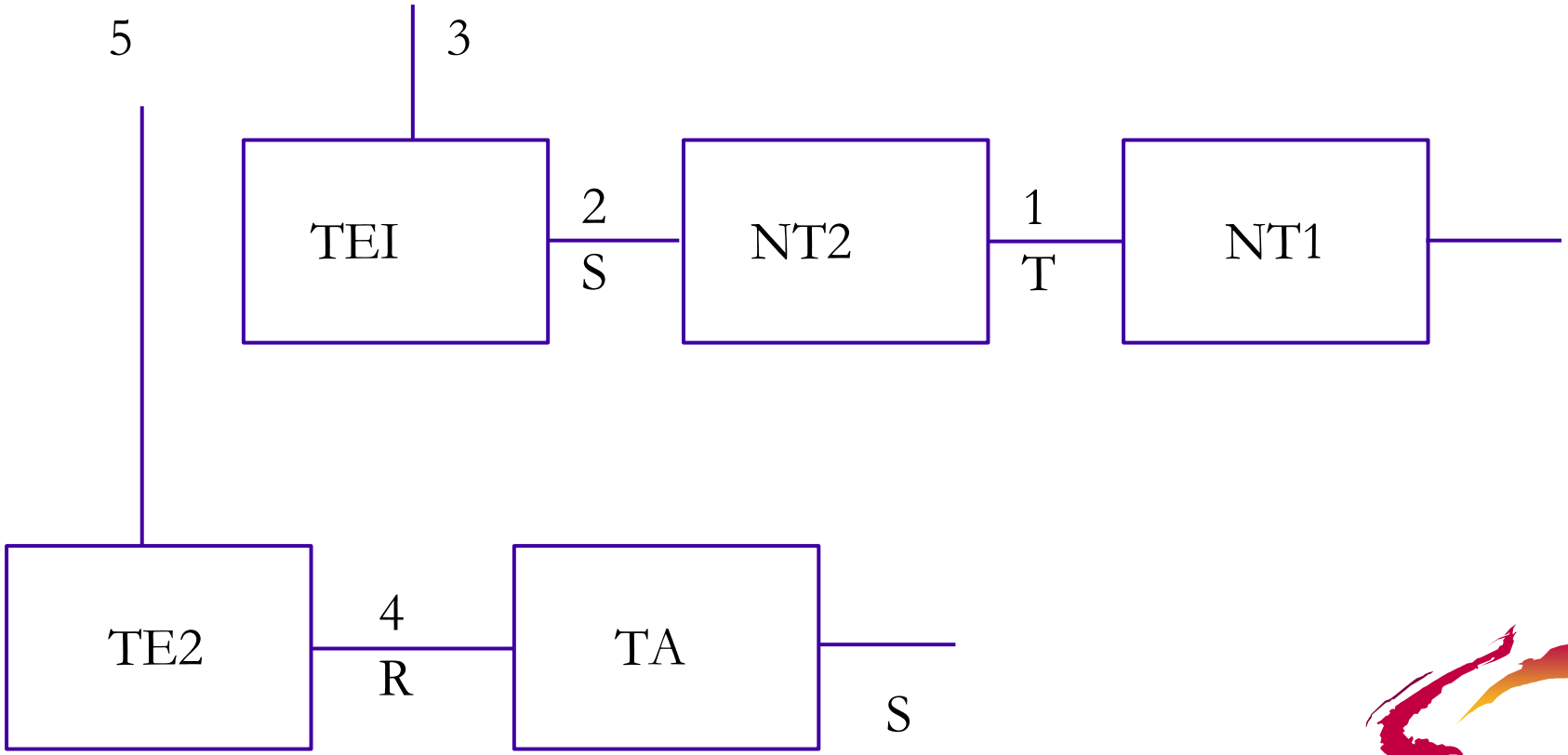
ISDN teleservices

- Low layer attributes

- High layer attributes
- Type of user information
- Layer 4 protocols
- Layer 5 protocols
- Layer 6 protocols
- Layer 7 protocols

- General attributes
- Quality of service

Customer access to services supported by ISDN



Functional grouping

- TE: Terminal equipment
  TE1: S interface terminal
  TE2: R interface terminal

- TA: Terminal adapter
  adapts TE2 to S interface

- NT: Network termination
  NT2: Optional, PBX applications
  NT1: S/T interface to U interface

- Interface structure
  2B + D 192 Kbps line rate
  23B + 4536 Kbps line rate

Network functional principles

- Services to be internationally compatible
- UNI standardised so that TE is portable
- Standardise network capability

High Layer
Low Layer
Operation & manage

Layer 1: Physical layer connection activation deactivation, bit transmission channel structure mutiplex.

Layer 2: Data link connection establishment, Data link congestion handling How control, error, sequence control, frame sync.

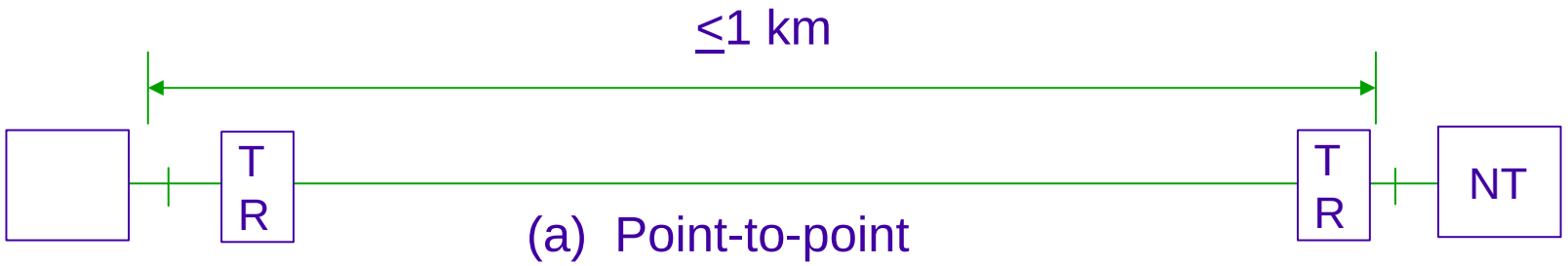
Access channel and rate

Channel name	Bit rate
D	16 Kbps 64 Kbps
B	64 Kbps
H0	384 Kbps
H1	
H11	1536 Kbps
H12	1920 Kbps

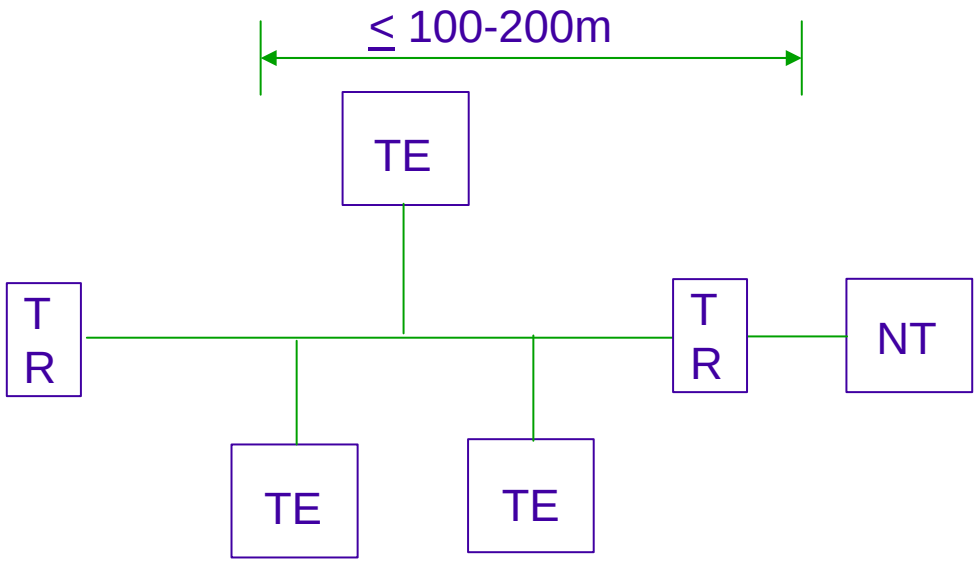
Bearer services

- 64 Kbps unrestricted, 8 KHz structured
- 64 Kbps 8 KHz structured, speech
- 64 Kbps 8 KHz structured, 3.1 KHz audio
- 384 Kbps unrestricted
- 1536 Kbps unrestricted
- 1920 Kbps unrestricted
- Packet - mode services

ISDN subscriber premises connections



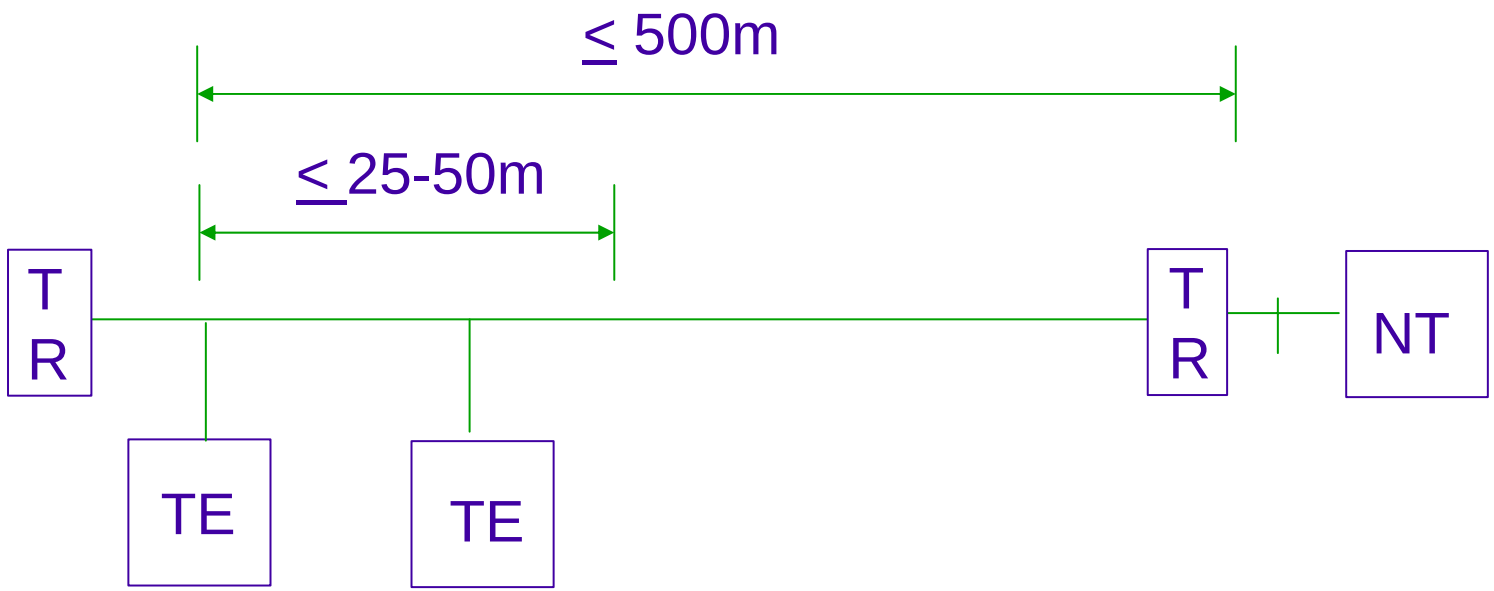
(a) Point-to-point



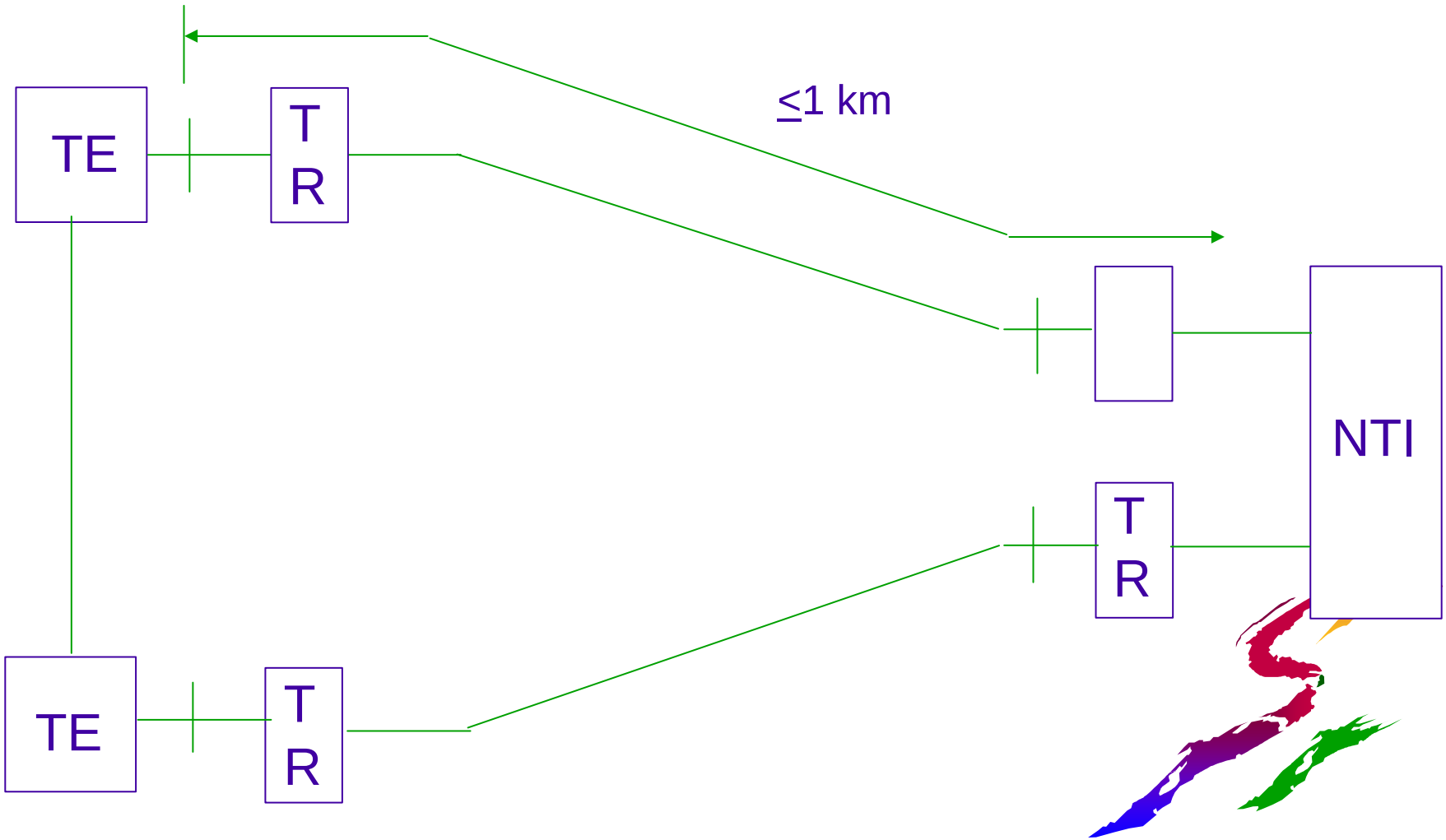
(b) Short passive bus

TR = Terminating Resistor

Extended passive bus



NT1 star



User - Network Interface: Layer 1 specifications

B channel: 64 Kbps, two channels
Bit timing and rate: 192 Kbps
- Octet timing
- Frame alignment

D channel: 16 Kbps
Power feeding : 40 V DC 1--mW max.
- Activating and deactivating
- Frame structure and organisation

Line code: Pseudo - ternary
D channel access control : Similar to HDLC

Layer 1 functions

- Encoding of digital data for transmission across the interface.
- Full-duplex transmission of B channel data
- Full-duplex transmission of D channel data.
- Multiplexing of channels to form basic or primary access transmission structure.
- Activation and deactivation of physical circuit.
- Power feeding from network termination to the terminal.
- Terminal identification.
- Faulty terminal isolation.
- D channel contention access

ISDN Layer 2

Traffic over D channel (control Info and data over D) Q 921

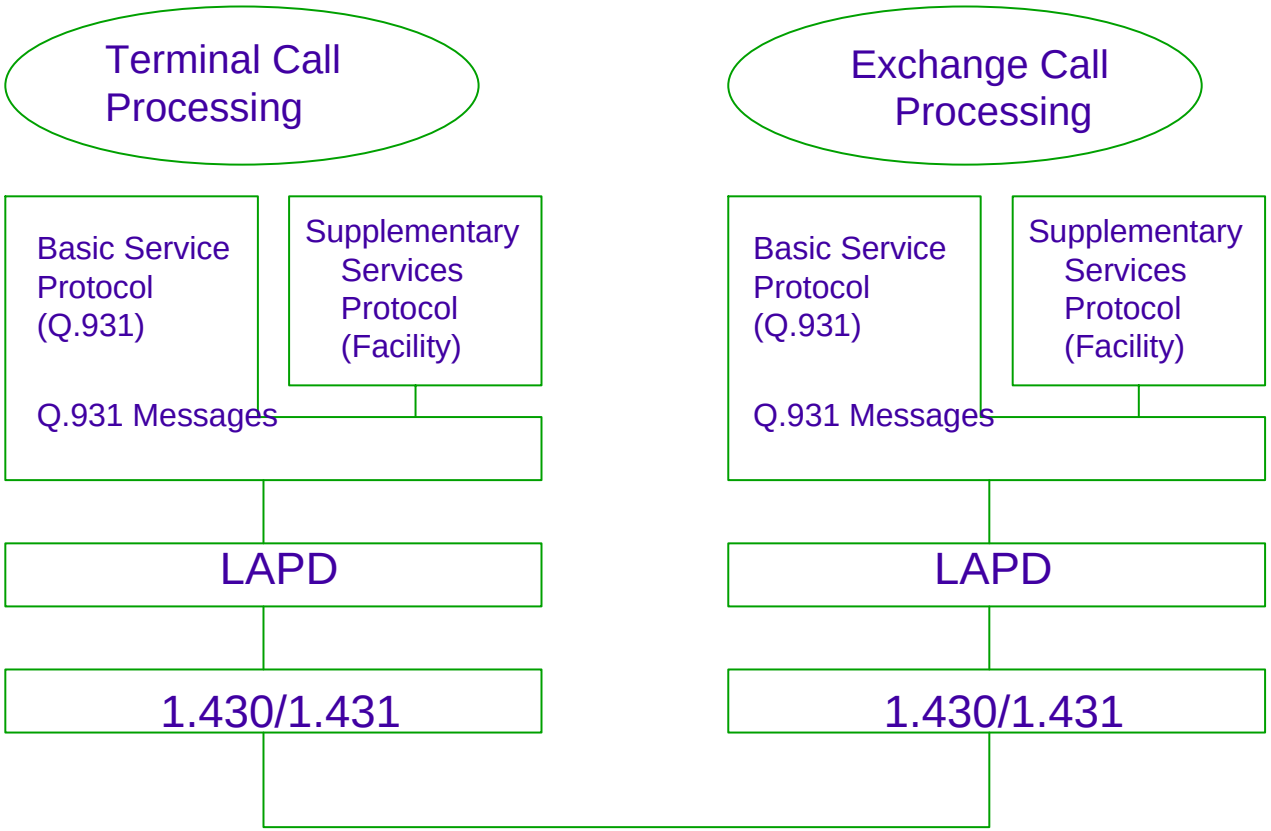
Q921 services

- Convey user Info between layers entities using D channel
- Support multiple terminals at user-NW installation
- Multiple layer 3 entity support two types of transfer
- Unacknowledged transfer (un no: frames)
- Acknowledged transfer (like X 25) HDLC

Function of other layers

layer 3 :	routing
	network connection establishment
	release
	multiplexing
	congestion control
	addressing
layer 4 :	error detection / recovery
	flow control
	layer 4 connection, release, muxing
Layer 5 :	session connection, etc.
	management
	session - transport management
layer 6 :	encryption / decryption
	compression / expansion
Layer 7 :	application related functions

Modelling of basic and supplementary services



Basic Call Control

- interact with layer 2 (LAPD) to transmit / receive messages
- generate & interpret layer 3 messages
- admin of times and logical entities (call reference) used in control
- admin of resources (like B ch1)
- check to provide proper service consistent with user requirements
- routing / relaying
- network connection control
- error detection (sequences)
- error recovery
- sequencing layer 3 information

Protocol reference model I 320

1. Protocol reference model I320

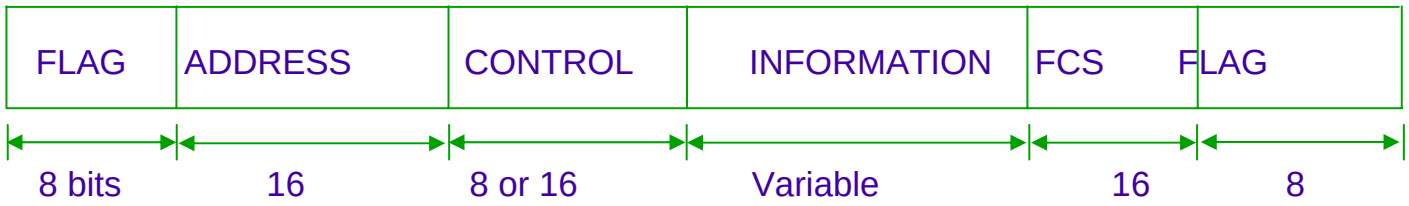
- Circuit - switched connection under common channel signalling
- Packet - switched comm over B/D/H
- Signalling between users and network based facilities (data base fores.)
- End - to - end signalling for users
- Combinations for multimedia comm.

2. Types of Info flow

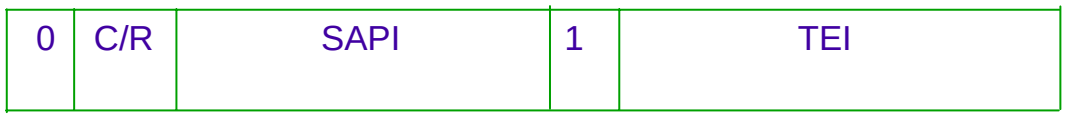
1. User Info: digitised voice, data between users. Transmitted transparently through ISDN or processed (encrypted for e.g.)

2. Control Info : acted upon this Info switching a connection / clearing change service characteristics

Frame format in ISDN layer 2

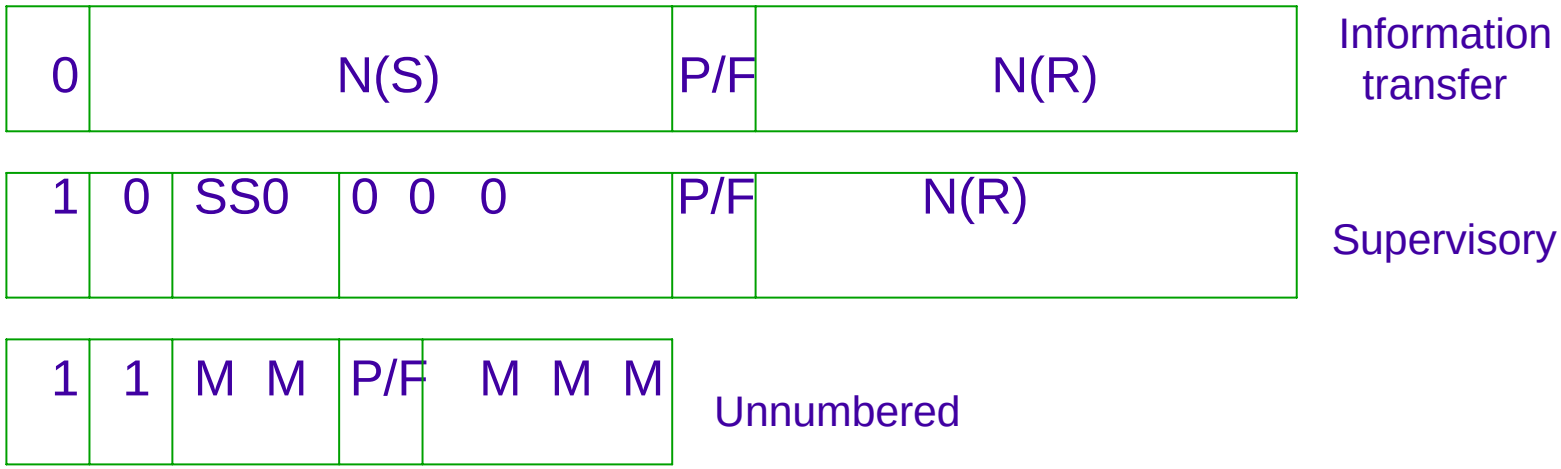


(a) Frame format



C/R is Command/response
SAPI is Service access point identifier
TEI is Terminal endpoint identifier

LAPD format



N(S) = Transmitter send sequence number
N(R) = Transmitter receive sequence number
S = Supervisory function bit
M = Modifier function bit
P/F = Poll/final bit

LAPD commands and responses

Name	Control Field	C/R	Description
	Information format		
I (Information)	0-N(S)--P-N(R)--	C	Exchange user data
	Supervisory Format		
RR (Receive Ready)	10000000*-N(R)--	C/R	Positive ack; ready to receive I-frame
RNR (Receive Not Ready)	10100000*-N(R)--	C/R	Positive ack; not ready top receive
REJ (Reject)	10010000*-N(R)--	C/R	Negative ack; go back N

Unnumbered format

SABME (Set Asyn chronous Balanced Mode)	1111P110	C	Request logical connection
DM (Disconnected Mode)	1111F000	R	Unable to establish or main maintain logical connection
UI (unnumbered Information)	1100P000	C	Used for unacknowledged information transfer service
DISC (Disconnect)	1100P010	C	Terminate logical connection
UA (Unnumbered Acknowledgement)	1100F110	R	Acknowledge SABME or DISC
FRMR (Frame Reject)	1110F001	R	Reports receipt of unaccept- able frame
XID (Exchange ID- identification)	1111*101	C/R	Exchange identification information

Q931 message types

Circuit - mode connection control functions needed for circuit-switched B channel calls

Packed - mode connection control functions needed for circuit-switched connections to ISDN packet-switched node.

User - user signalling messages with global call reference

functions are 4 types

- call establishment set up a call on B chl.
- call information user-NW Info transfer after set-up
- call clearing
- miscellaneous

Messages

Signalling exchanged between user - network, network - network.

Protocol discriminator (0001000) for Q931 call reference
message type

length (1 for BRI, 2 for PRI)
call reference call reference value
(assigned by TE for 0/9 NT for calls)
(local significance) flag: 0: originator , 1: remote end

call reference length = 0 supp.services Q932
CRF = ϕ global CRF

SAPI and TEI assignments

(a) SAPI Assignments

SAPI Value	Related Protocol or Management Entity
0	Call-control procedures
16	packet communication conforming to X.25 level 3
32-61	Frame relay communication
63	Layer 2 management procedures
All others	Reserved for future standardisation

(b) TEI Assignments

TEI Value	User Type
0-63	Nonautomatic TEI assignment user equipment
64-126	Automatic TEI assignment user equipment
127	Used during automatic TEI assignment

Q931 messages for circuit mode connections

Call Establishment Messages

Message	Significance	Direction	Function
ALERTING	global	both	Indicates that user alerting has begun
CALL PROCEEDING	local	both	Indicates that call establishment has been initiated
CONNECT	global	both	Indicates call acceptance by called TE
CONNECT ACKNOWLEDGE	local	both	Indicates that user has been awarded the call
PROGRESS	global	both	Reports progress of a call
set-up	global	both	Initiates call establishment
set-up ACKNOWLEDGE	local	both	Indicates that call establishment has been initiated but requests more information

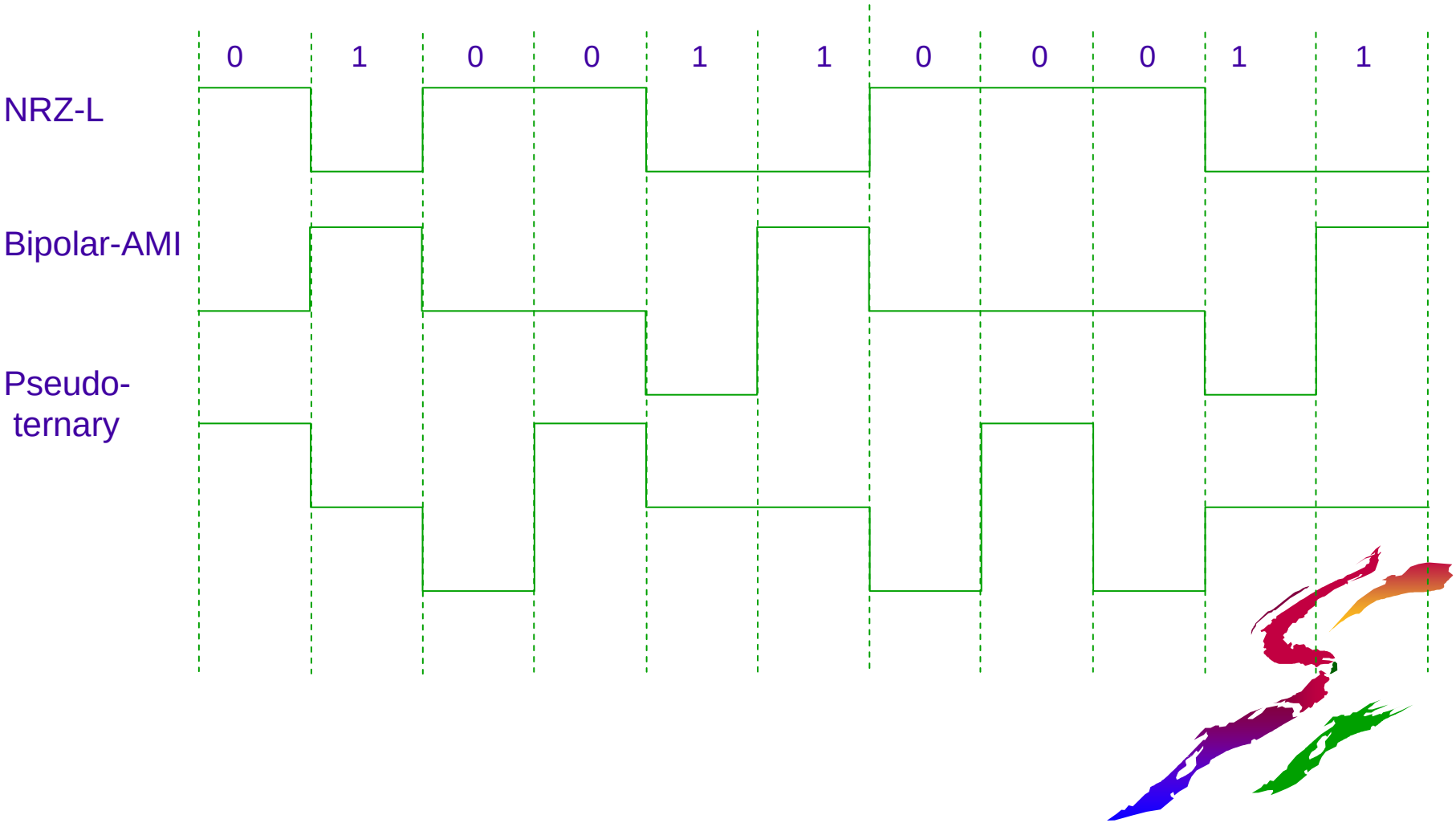
Call information phase messages

Message	Significance	Direction		Function
RESUME	local	u	n	Requests resumption of previously suspended call
RESUME ACKNOWLEDGE	local	n	u	Indicates requested call has been re-established
RESUME REJECT	local	n	u	Indicates failure to resume suspended call
SUSPEND	local	u	n	Requests suspension of a call
SUSPEND ACKNOWLEDGE	local	n	u	Indicates call has been suspended
SUSPEND REJECT	local	n	u	Indicates failure of requested call suspension

Call clearing messages

Message	Significance	Direction	Function
DISCONNECT	global	both	Sent by user to request connection clearing; sent by network to indicate connection clearing
RELEASE	local	both	Indicates intent to release channel and call reference
RELEASE COMPLETE	local	both	Indicates release of channel and call reference
INFORMATION	local	both	Provides additional information
NOTIFY	access	both	Indicates information pertaining to a call
STATUS	local	both	Sent in response to a STATUS INQUIRY or at any time to report an error
STATUS INQUIRY	local	both	Solicits STATUS message

Digital Signal Encoding Format in ISDN



Physical connector in ISDN

Contact Assignments for Plugs and Jacks of ISDN

Contact Number	TE	NT
a	Power Source 3	Power Sink 3
b	Power Source 3	Power Sink 3
c	Transmit	Receive
d	Received	Transmit
e	Received	Transmit
f	Transmit	Received
g	Power Sink 2	Power Source 2
h	Power Sink 2	Power Source 2

The U interface

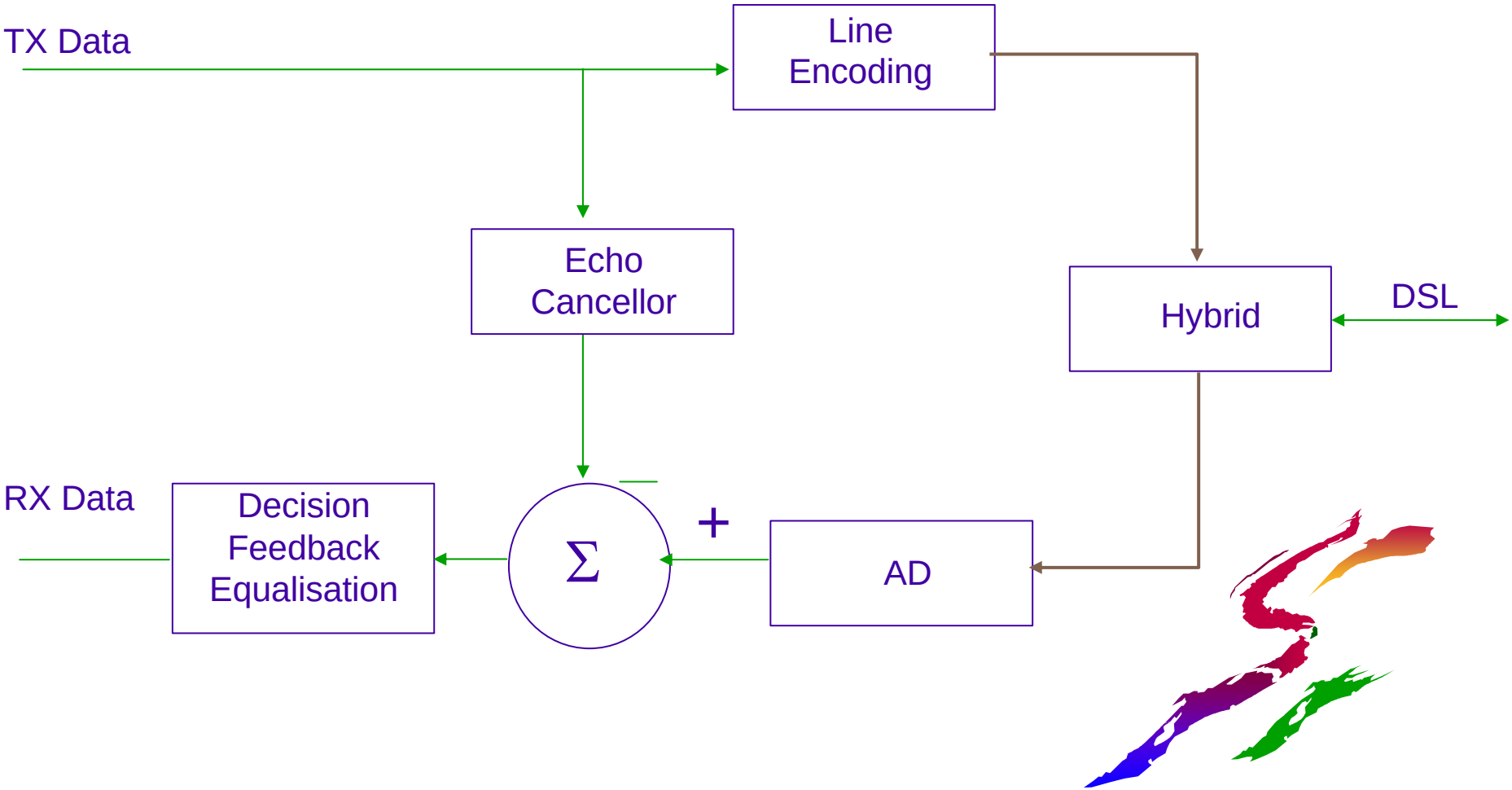
Fixed by local administration

- 4 wire interface
  no echo cancellation procedures, simple line termination

- 2 wire interface
  Ping-Pong operation, no echo cancellation, only one cable pair, simple termination, limited lengths, extra processing for comm. direction handling

- 2 wire interface
  full duplex operation, echo cancellation, only one cable pair, no limitation on length , extensive processing for echo cancellation

U interface circuit

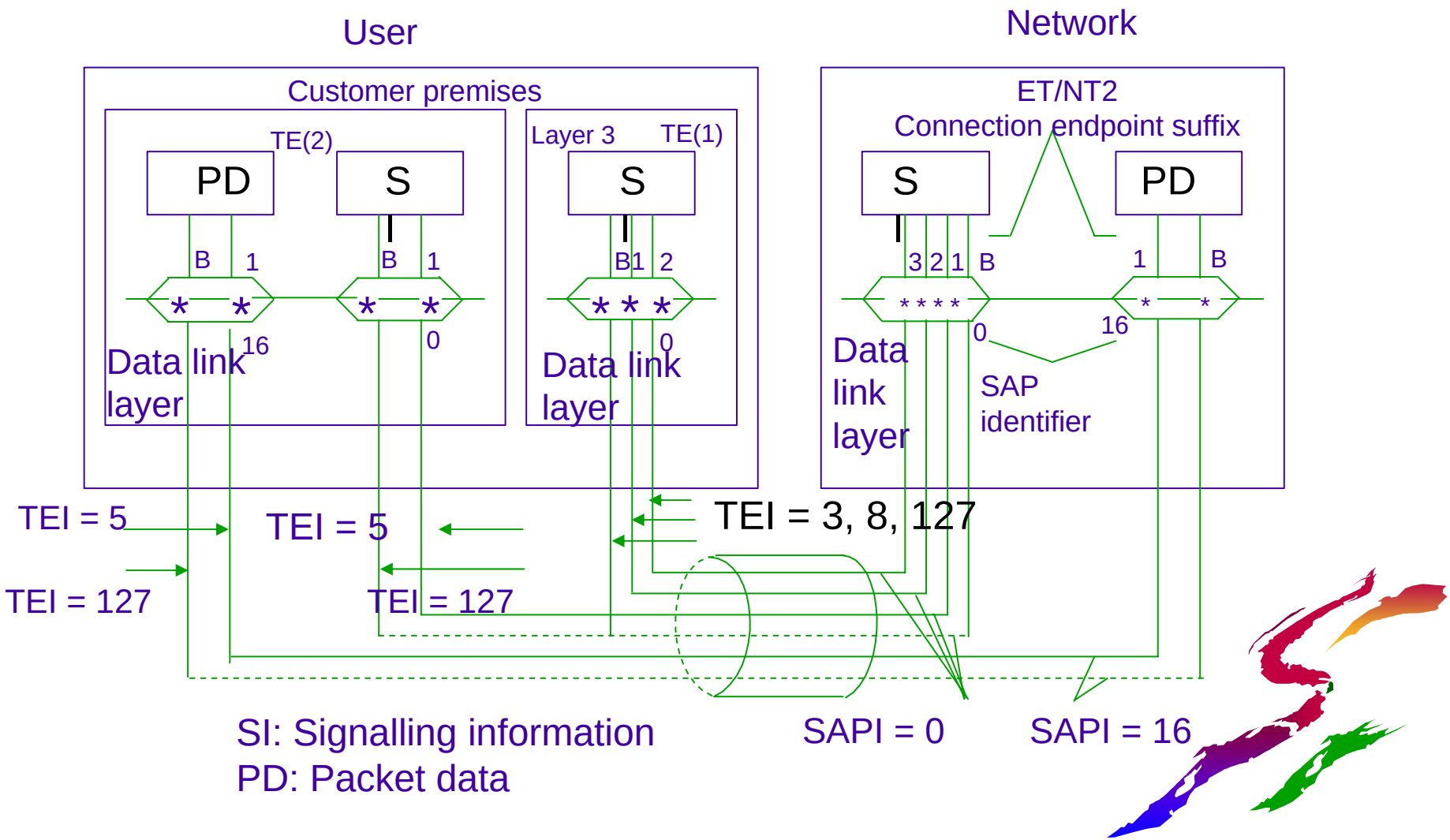


ANSI U interface frame and superframe structure

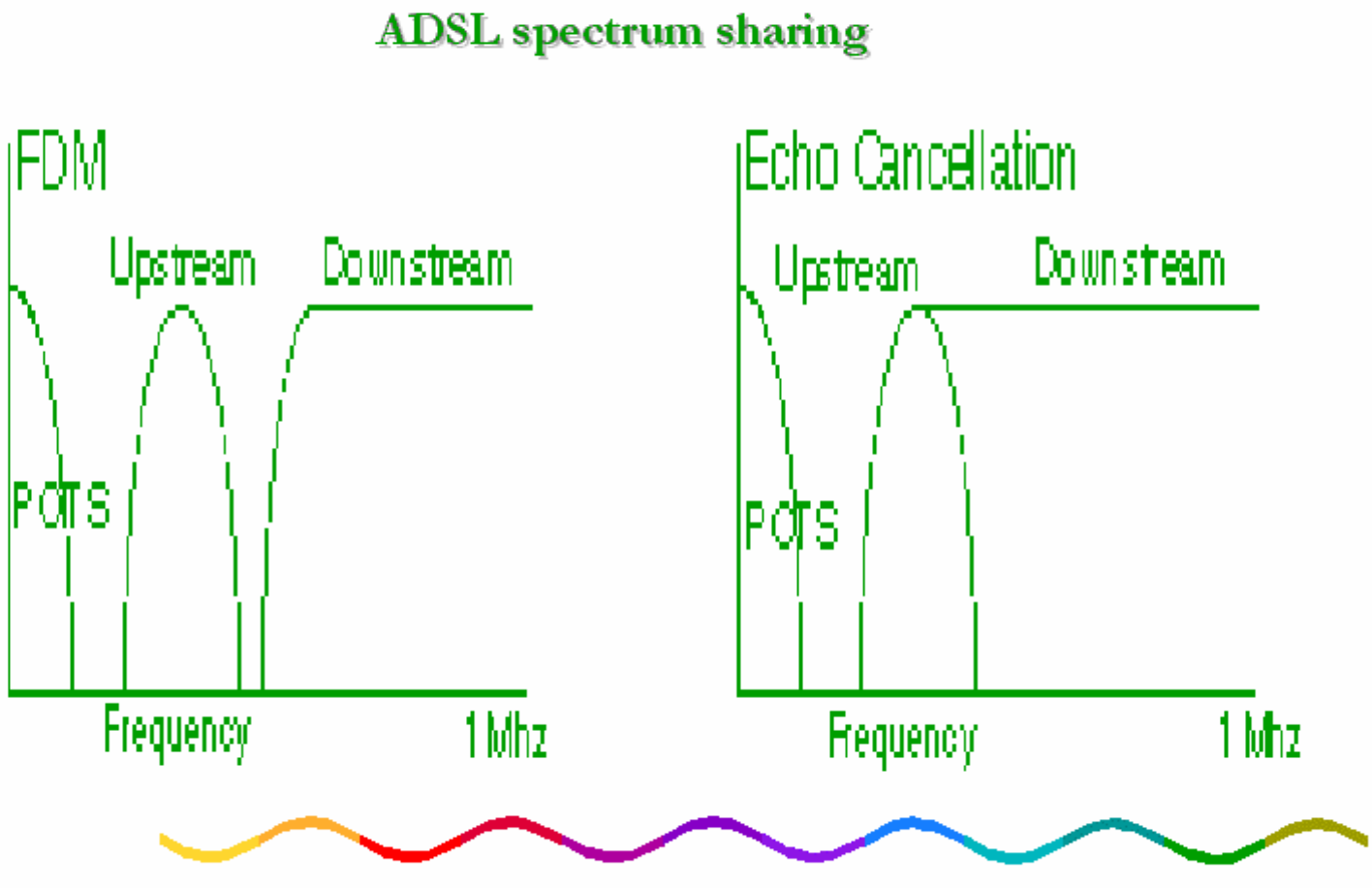
	18	18	18		18	6 total 240 bits
1	ISW	2B + D	2B + D		2B + D	M1 to M6
2	SW	2B + D	2B + D		2B + D	M1 to M6
3	SW	2B + D	2B + D		2B + D	M1 to M6
4	SW	2B + D	2B + D		2B + D	M1 to M6
5	SW	2B + D	2B + D		2B + D	M1 to M6
6	SW	2B + D	2B + D		2B + D	M1 to M6
7	SW	2B + D	2B + D		2B + D	M1 to M6
8	SW	2B + D	2B + D		2B + D	M1 to M6

SW = Sync Word = +3+3-3-3-3+3-3+3+3
ISW= Inverted SW=-3-3+3+3+3-3+3-3-3
2B+D = |B1 |B2 |D | (|8|8|2) M1 to M6 over head bits
Data are encoded as 00 = -3, 01= -1, 11=+1, 10 = +3

TEI and SAPI assignment

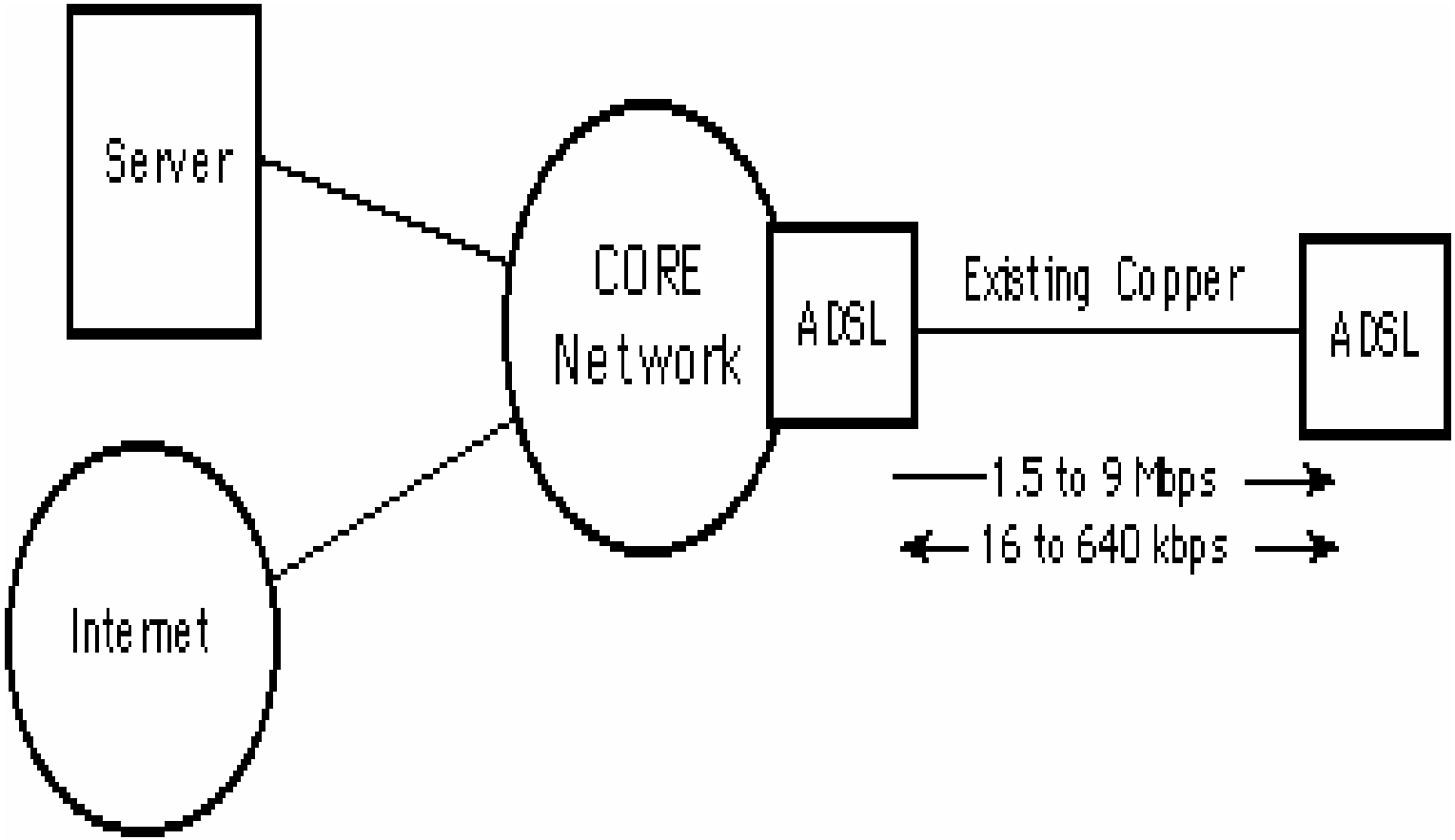


Asymetric Digital Subscriber Line



Asymmetric Digital Subscriber Line (ADSL) basics

- A new MODEM technology
- Converts existing twisted-pair telephone lines into access paths for multimedia and high speed data communications.
- ADSL transmits more than 6 Mbps (optionally up to 8 Mbps) to a subscriber, and as much as 640 kbps (optionally up to 1 Mbps) more in both directions.
- Such rates expand existing access capacity by a factor of 50 or more without new cabling.
- ADSL can transform the existing public information network (limited to voice, text and low resolution graphics) to a powerful, ubiquitous system capable of bringing multimedia, including full motion video, to everyone's home now.



ADSL Connection

ADSL basics (contd 1)

- ADSL will play a crucial role over the next ten or more years for delivering information in video and multimedia formats.
- New broadband cabling will take decades to reach all prospective subscribers.
- Success of these new services will depend upon reaching as many subscribers as possible during the first few years.
- By bringing movies, television, video catalogs, remote CD-ROMs, corporate LANs, and the Internet into homes and small businesses, ADSL will make these markets viable, and profitable, for telephone companies and application suppliers alike.

ADSL basics (contd 2)

Three information channels

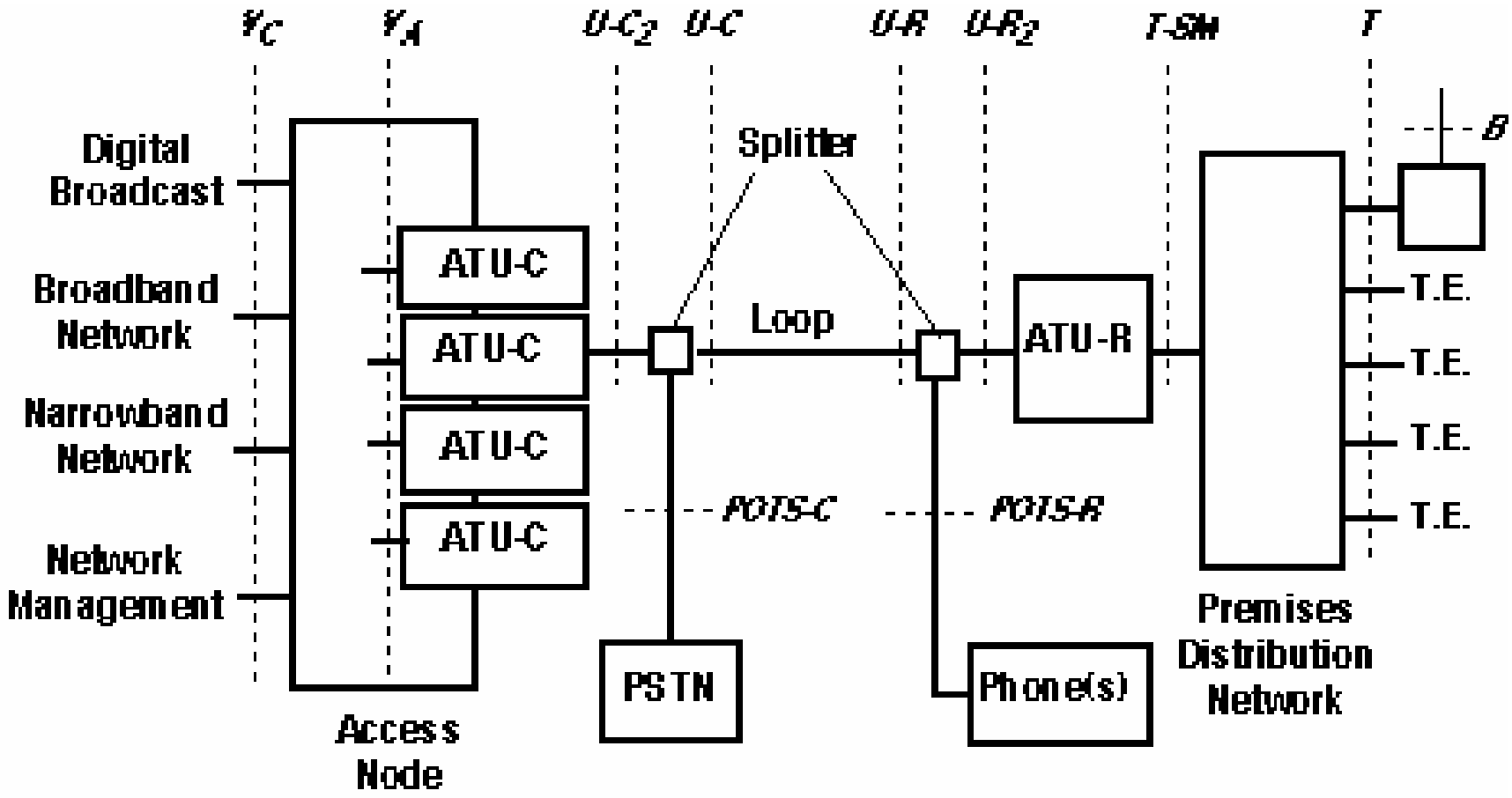
- a high speed downstream channel
  - Speed ranges from 1.5 to 6.1 Mbps
- a medium speed duplex channel
  - Speed range from 16 to 640 kbps
- a POTS (Plain Old Telephone Service) or an ISDN channel.
  - The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS/ISDN, even if ADSL fails.

Each channel can be submultiplexed to form multiple, lower rate channels, depending on the system.

Consistent with North American and European digital hierarchies

ADSL reach

Data Rate	Distance	Wire Size	Distance
1.5 or 2 Mbps	18,000 ft	0.5 mm	5.5 km
1.5 or 2 Mbps	15,000 ft	0.4 mm	4.6 km
6.1Mbps	12,000 ft	0.5 mm	3.7 km
6.1 Mbps	9,000 ft	0.4 mm	2.7 km


V_C
V_A
$U\text{-}C_2$
U-C
U-R
$U\text{-}R_2$
T-SM
T
B
Digital Broadcast
Broadband Network
Narrowband Network
Network Management
ATU-C
ATU-C
ATU-C
ATU-C
Splitter
Loop
POTS-C
POTS-R
ATU-R
T.E.
T.E.
T.E.
T.E.
PSTN
Phone(s)
Premises Distribution Network
Access Node

Communication Systems

POINT-TO-POINT	BROADCAST
↗ONE SOURCE	ONE SOURCE
↗ONE SINK	MANY SINKS
FOR INFORMATION	FOR INFORMATION
↗FEED BACK FROM SINKS, IN FACT TWO WAY COMM.	SINKS
↗PRIVACY NEEDED EAVES DROPPING TO BE AVOIDED	PRIVACY PROHIBITED NO SUCH REQUIREMENT
↗PRIVATE DATA, INFO EXCHANGE	PUBLIC INFO TRANSFER
↗REQUIRES ESTABLISHMENT OF PATH BETWEEN PARTIES	NO
↗THIS PATH ESTABLISHMENT IS CALLED "SWITCHING"	NO SWITCHING
↗REQUIRES "SIGNALLING"	NO

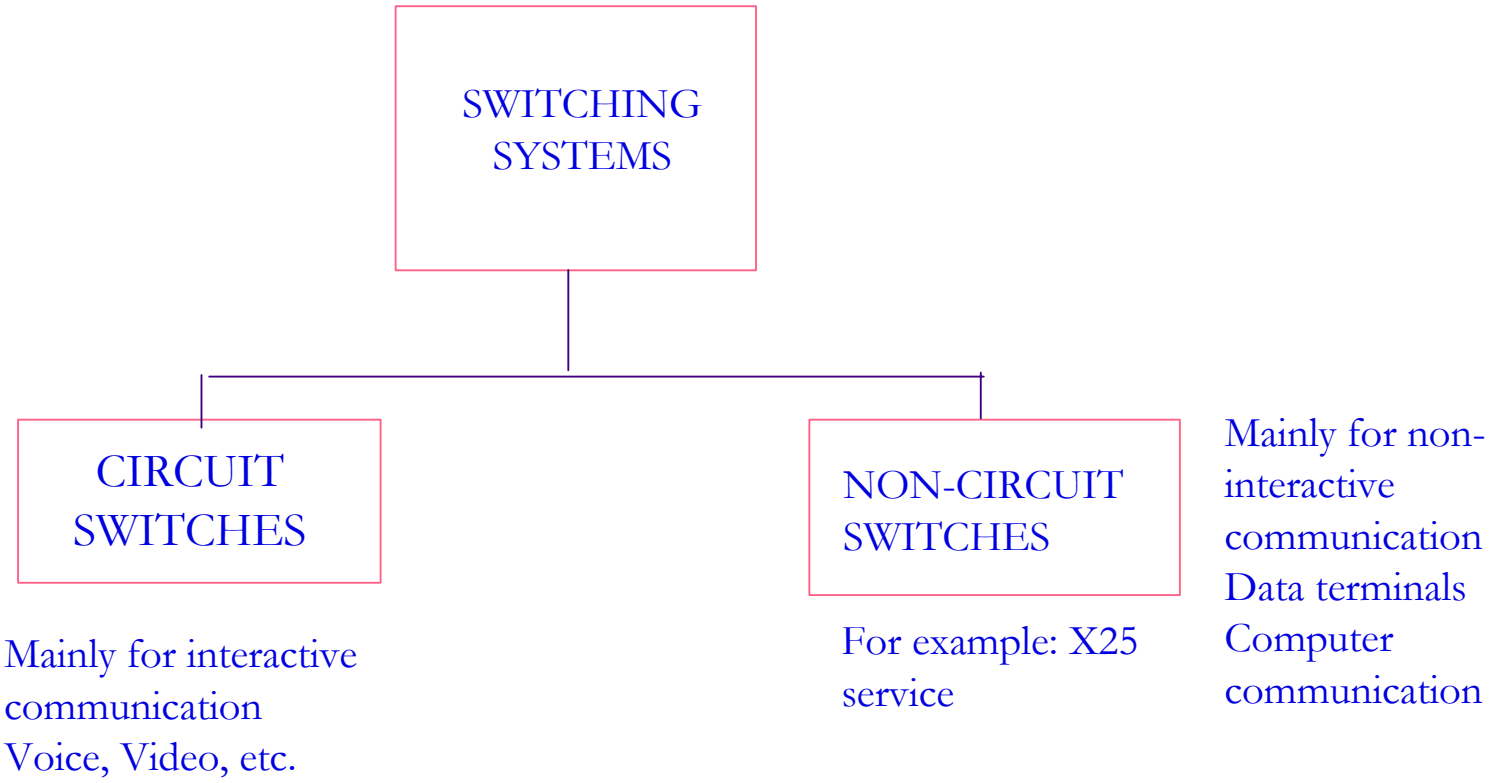
History of Switching

•Manual - through operator	1880 onwards
•Step-by-Step Strowger	~1897
•First "big" strowger exchange	1919
•# 1 Cross bar	1938
•# 5 Cross bar	1948
•# 3 Cross bar	1974
•ESS I	1965
•ESS II	1970
•ESS III	1976
•ESS ZB	1976
•ESS IA	1980 onwards

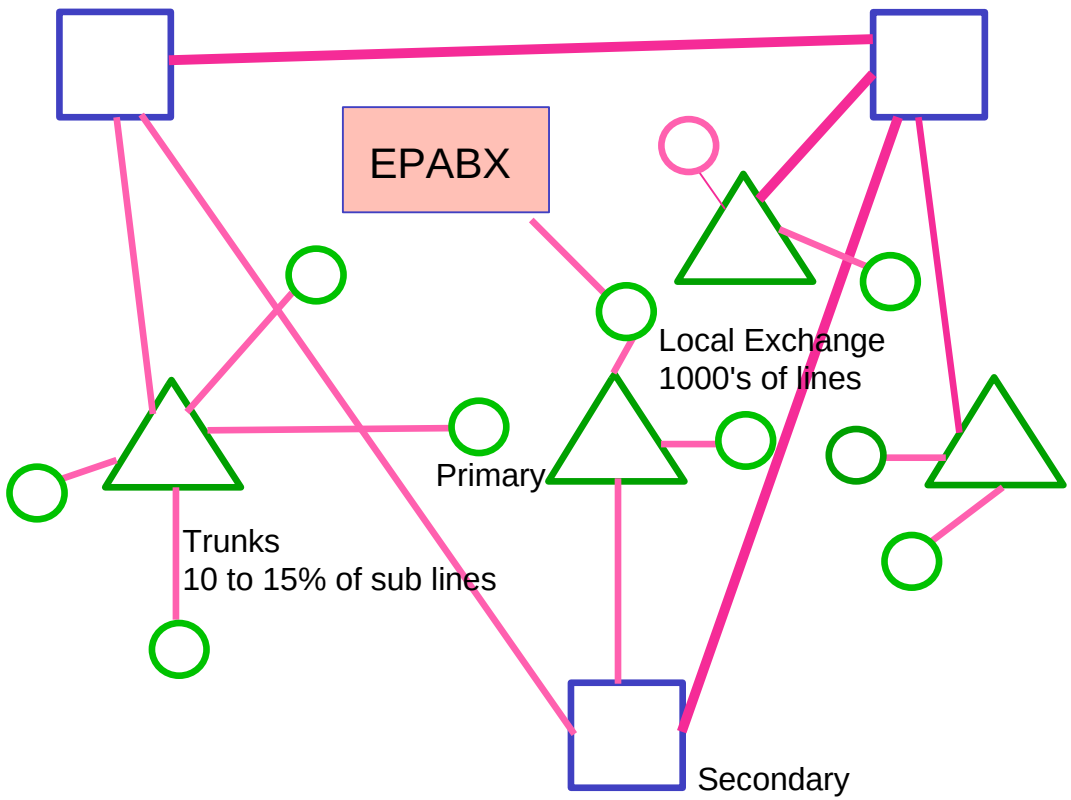
PAX : Private automatic exchange useful for local connections only

PABX: Private automatic branch Exchange useful for local and trunk connections

Types of Switching Systems



Switching system topology



Signals in Switching Systems

Switching system objective: To interconnect two circuits for information exchange

Information: Voice, Data, FAX, Still Video, moving video, etc.

Type of signal	Bandwidth	Data rate
Voice	4 KHz	64 Kbps
Data		300 bps to several mbps
Still video	1 to 4 MHz	
Moving video	4 to 10 MHz	1 to 30 Mbps
FAX		30 to 150 Mbps
		9.6 Kbps

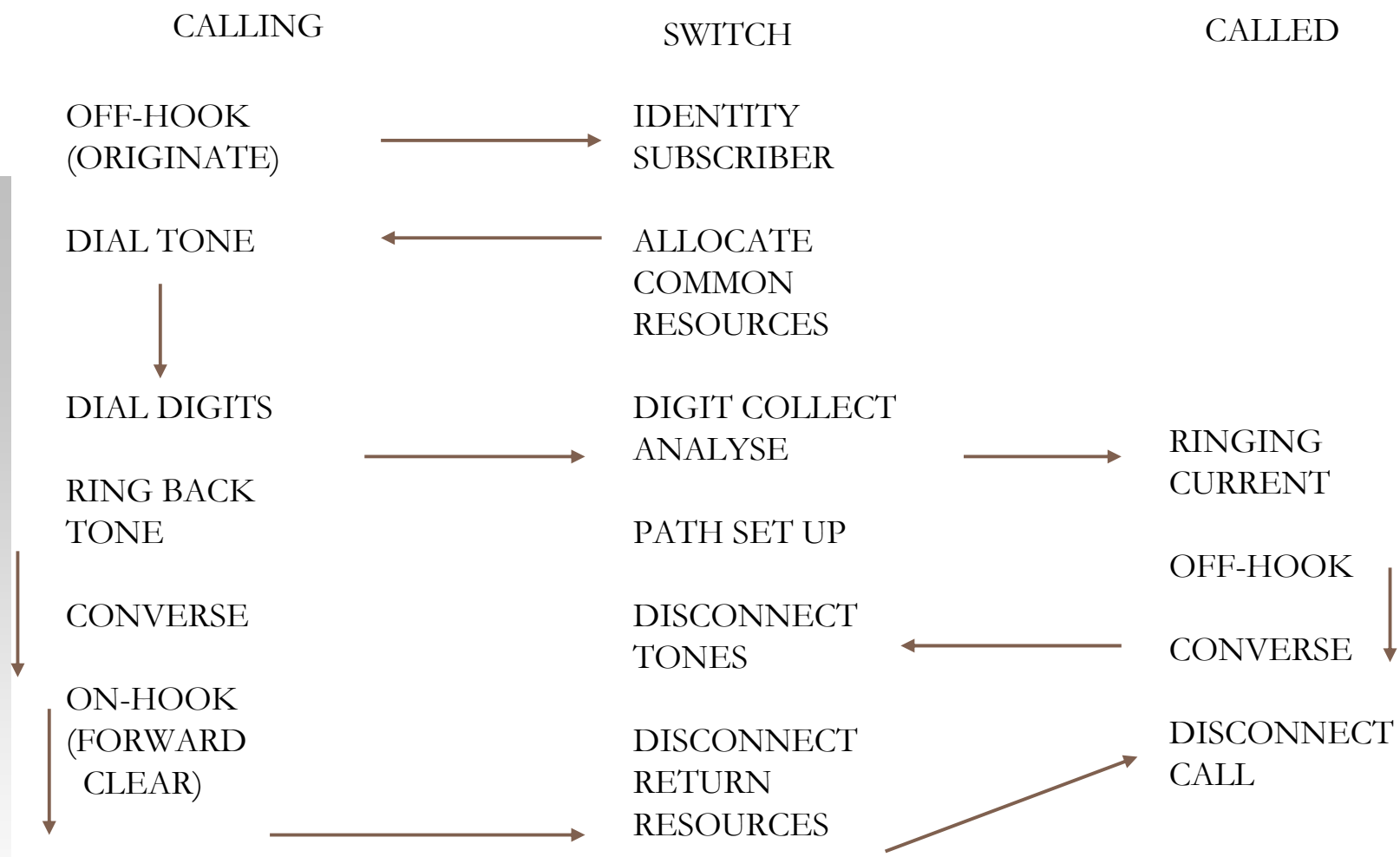
Tasks of a Switch

1. SWITCHING: ESTABLISHING CONNECTIONS BETWEEN SUBSCRIBERS

2. SIGNALLING
   - CHANNEL ASSOCIATED - COMMUNICATION
   - CHANNEL (ZW) USED FOR SIGNALLING
     - FEED TONES
     - REMOVE TONES
     - DTMF, PULSE DIALLING
   - FLASH DETECTION
   - TONE OVER CONVERSATION..-
   - LINE SIGNALLING - SIGNALS TRANSMITTED
     - BETWEEN EQUIPMENT THAT TERMINATE & CONTINUOUSLY MONITOR TRAFFIC CIRCUIT
     - OFF-HK, ON-HK ETC. ARE EXAMPLES
   - SELECTION SIGNALLING - ROUTING INFO
     - DIGITS, C-O-S INFO ETC.
   - COMMON CHANNEL SIGNALLING
   - SEPARATE CHANNEL FOR SIGNALS

3. MANAGEMENT
   - METERING , DIAGNOSTICS, CLASS OF SERVICE

Call processing in a Switch



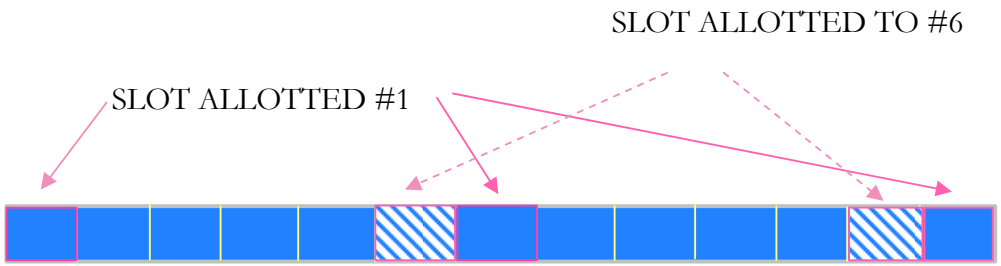
Switching System Architectures

SPACE DIVISION

- establish connection through' galvanic connections
- once established, contact remains till disconnection
- dedicated paths
- expansion requires additional "paths"
- The actual switch is called a "CROSS POINT"

TIME DIVISION

- establish connections through data exchange in a memory
- contact between two parties at specific "time-slot"
- dedicated time-slot
- Expansion requires additional "time-slots"
- The actual switch is called a "SPEECH MEMORY"



Switching System Operations

- Path establishment - using extensive signalling
- Information interchange - using error free communication
- Facilities - offering extensive facilities to subscribers
- Tariff computation - using extensive signalling
- Tearing down the path after information exchange is complete - using signalling
- Billing - using computation facilities
- Maintenance - using computation facilities and a few added equipment
- Performance measurement - using computation facilities and a few added equipment

Electronic Stored Program Control Switches

- COMMON CONTROL
- CONTROL through' COMPUTER HW + SW
- BOTH TIME DIVISION & SPACE DIVISION POSSIBLE

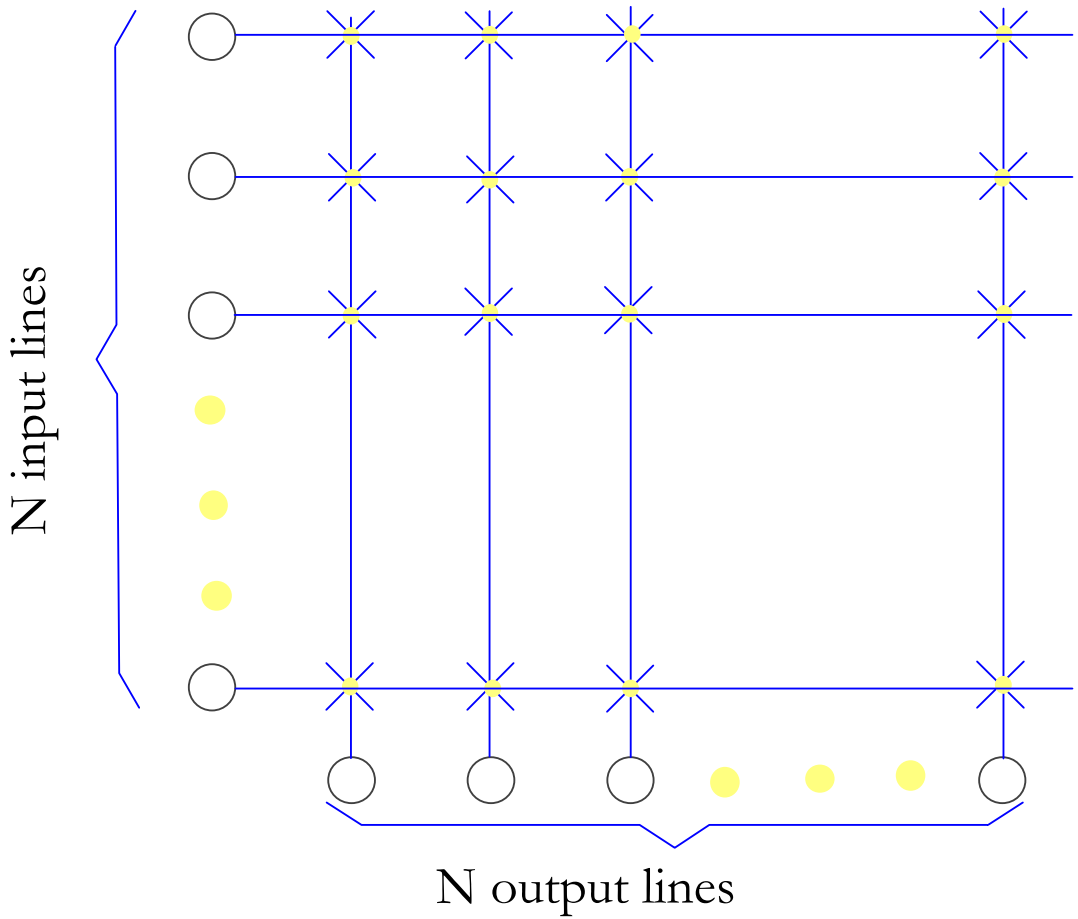
SPACE DIVISION SWITCHING

- USING REED CONTACTS FOR CROSS POINTS
- USING SOLID STATE (JFETS/MOS FETs) FOR CROSS POINTS
- USING THYRISTORS/TRIACS FOR CROSS POINTS

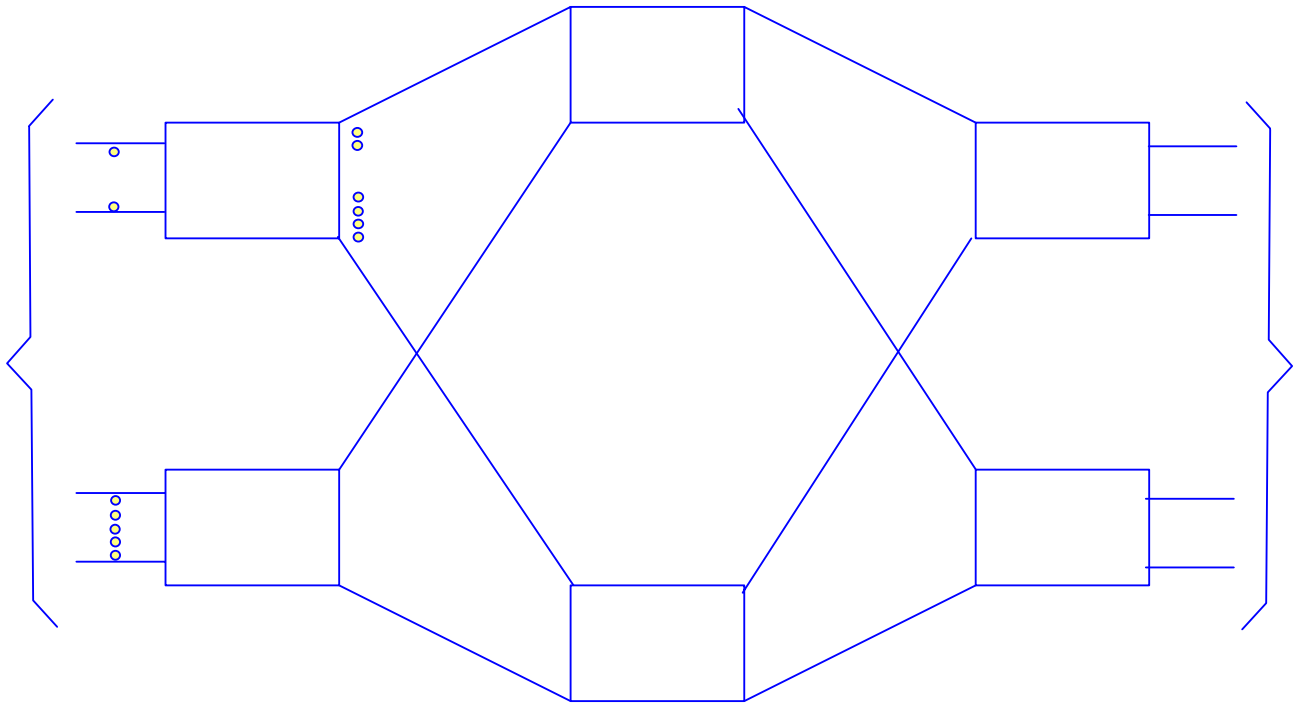
Analogue Switch Features

- Low cost for small switches (say up to 64 subscribers)
- Low distortion due to direct speech switching
- Introducing tones very easy
- Cost vs service trade-off possible
- Fairly good bandwidth
- Blocking switch, particularly for large number of subscribers
- Cost increases with number of switches
- Expansion is difficult
- Handling data difficult
- Lower reliability due to switches

A generic N by N switch



Space division switch



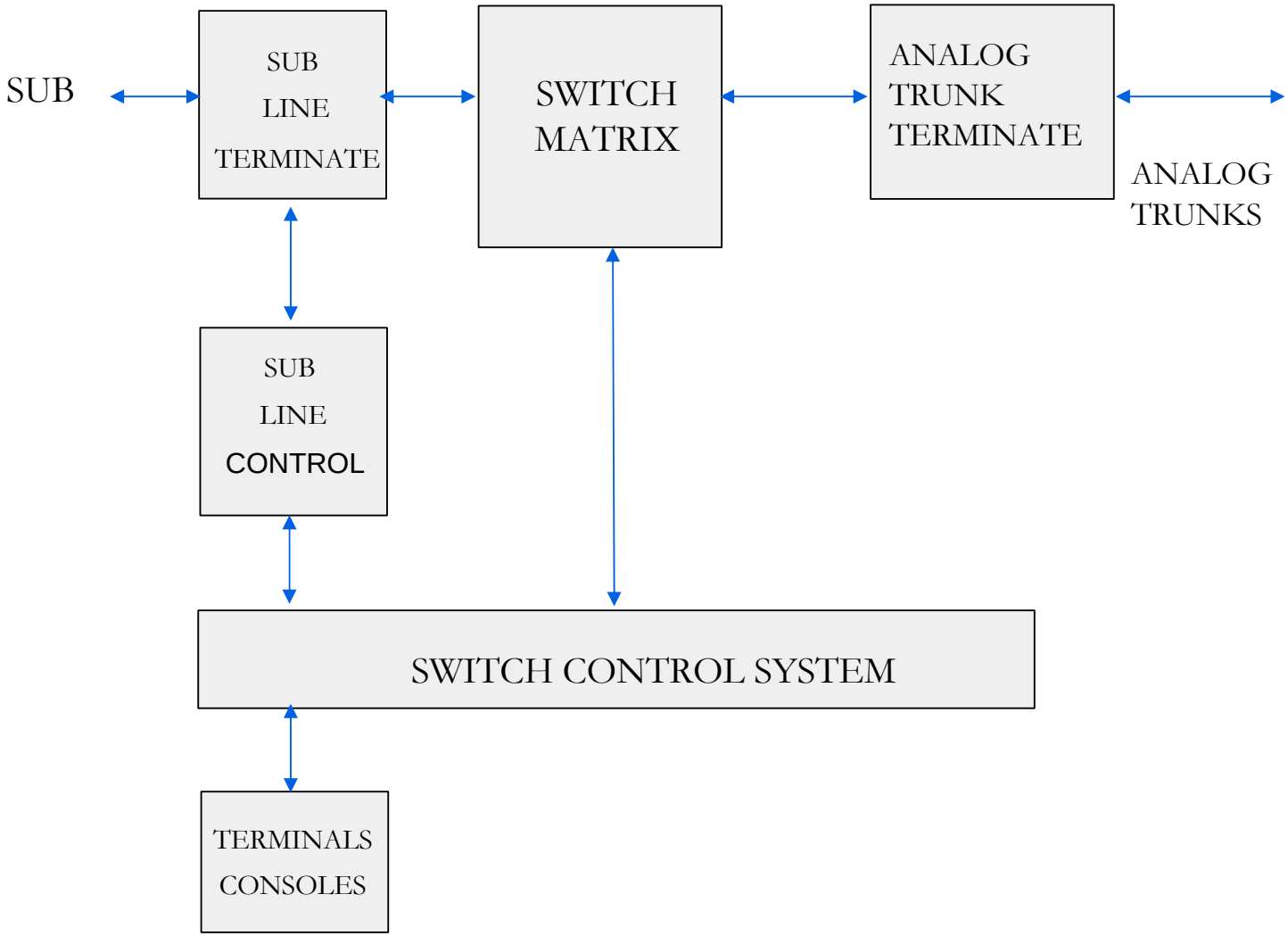
First stage Second stage Third stage

Three-stage space-division switch

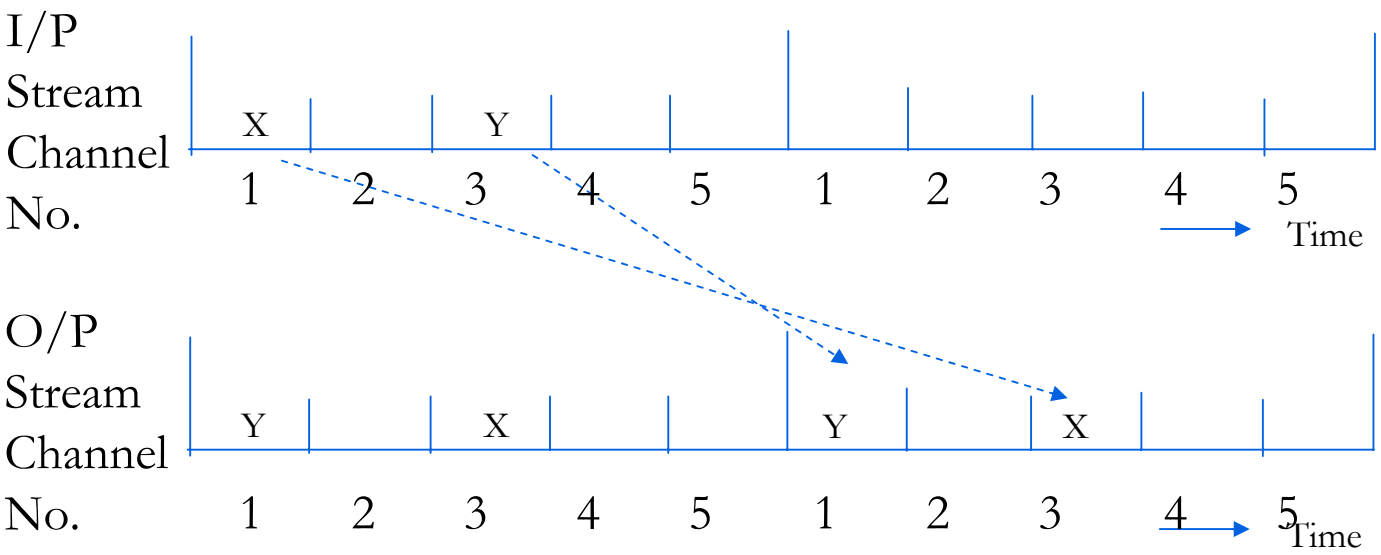
Number of cross points for a non-blocking switch

Lines	Single-Stage	Three stage
128	7,680	16,384
512	63,488	262,144
2,048	516, 096	4.2 x 10e6
8,192	4.2 x 10e6	6.7 x 10e7
32,768	3.3 x 10e7	1 x 10e9
131,072	2.6 x 10e8	1.7 x 10e10

SPC Digital Switch Block schematic

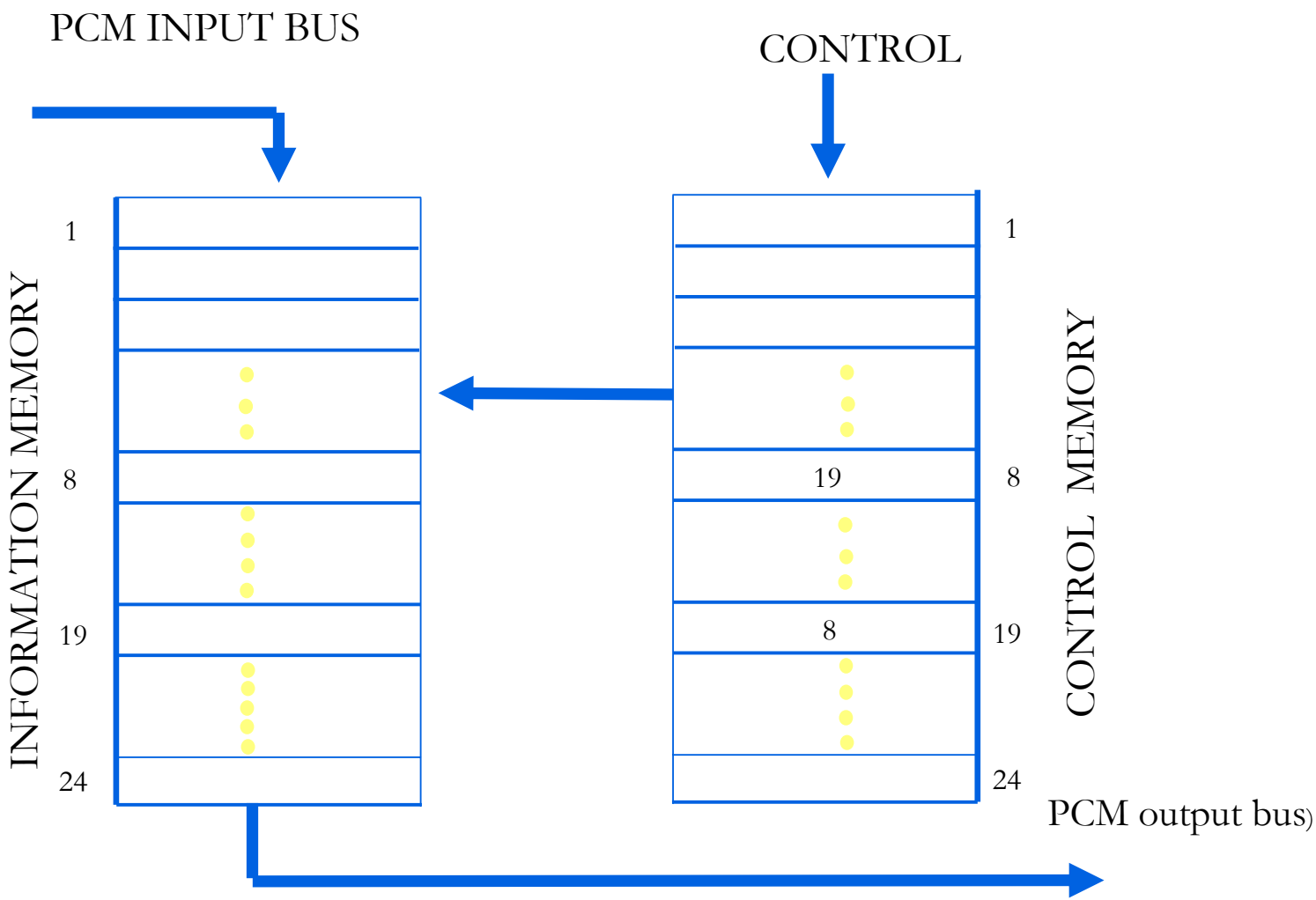


Time slot interchange

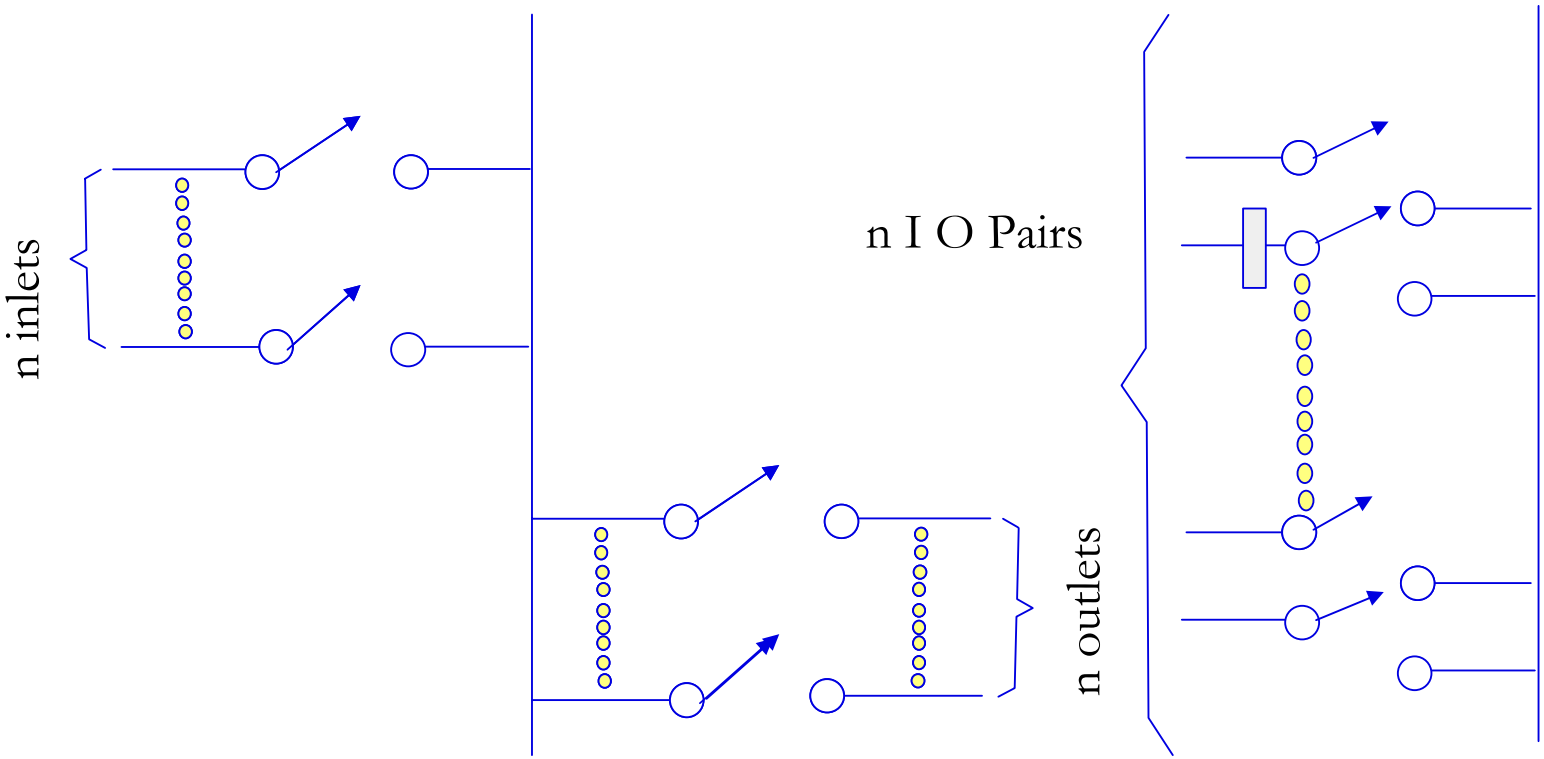


* One Frame delay

Implementation of a digital TSI switch



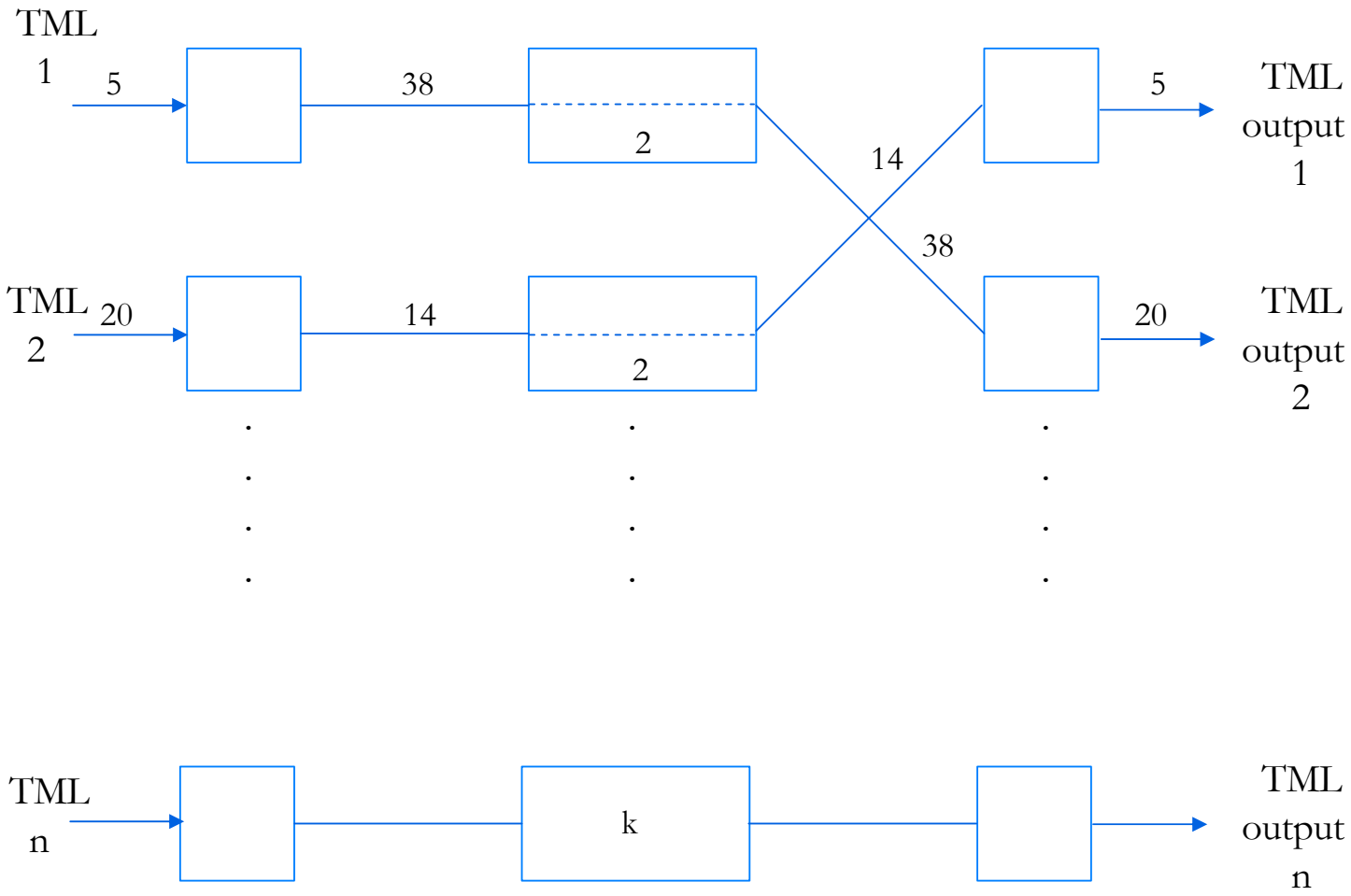
TDM Bus switch



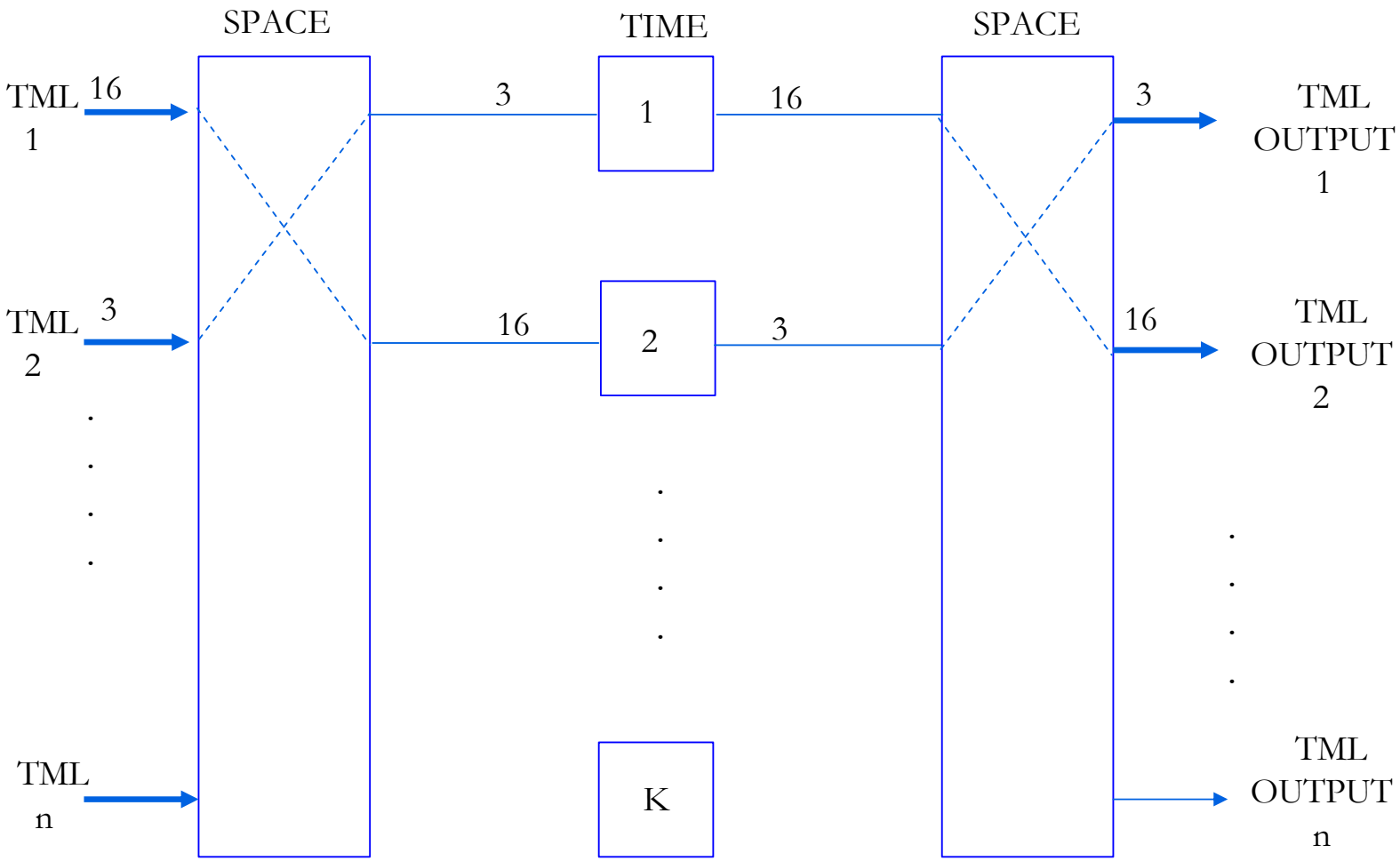
A Simple Time-Division Switch

A Simple Folded Time-Division Switch

Time-space-time Switch



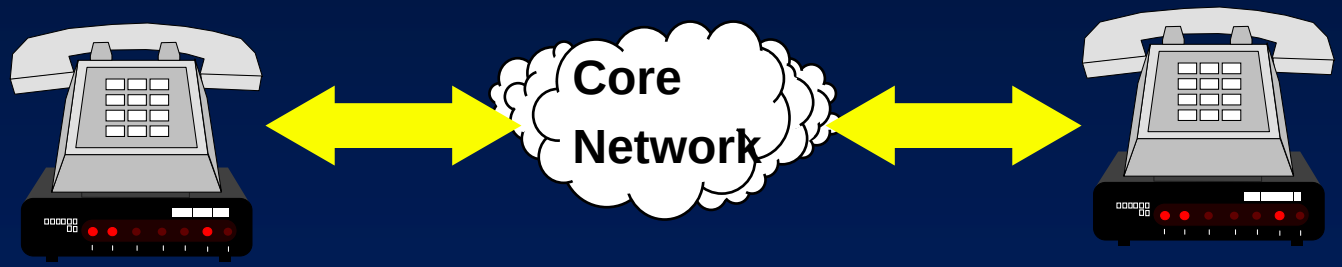
Space-time-space switch



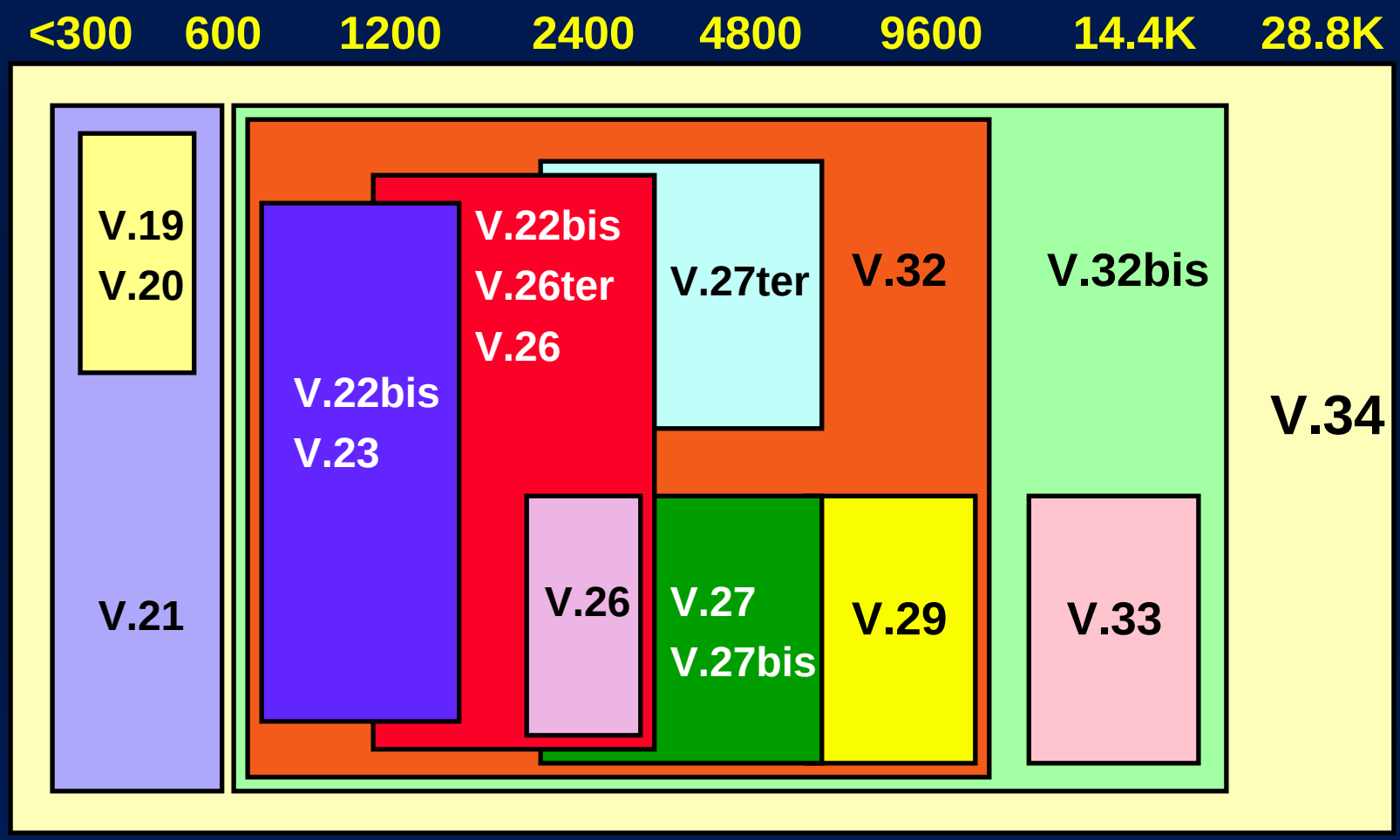
Overview

- Copper Access
- Bandwidth Requirements
- Distance vs. Rate
- ADSL
- Modulation Techniques
- Competing Technologies

- **Voice Grade Modems**
  - **V.22 // V.32 // V.34**
    - **1,200 to 28,800 bps (33,600 bps)**
    - **Full Duplex**
    - **Data communications**
    - **56kbps modems are not full duplex (asymmetric much like ADSL)**

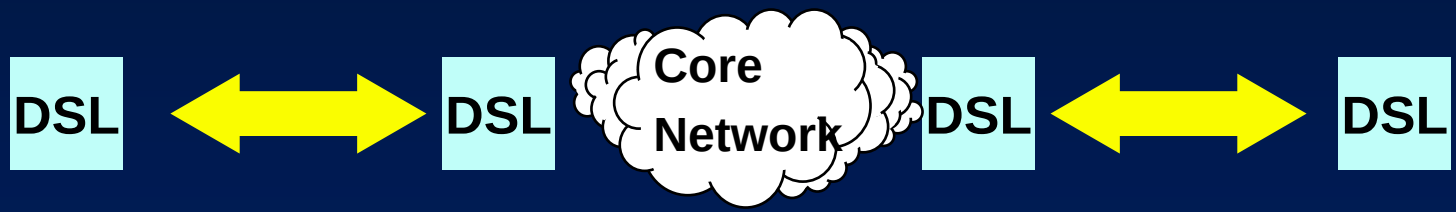


Copper Access Technologies // Voice (V-series)



SmartVideoconferencing™

- **Digital Subscriber Line**
  - **DSL (ISDN BRI)**
    - **160 kbps (two 64 kbps (B) + one 16 kbps (D) + 16 kbps operation and maintenance channel [OMC])**
    - **Full Duplex**
    - **ISDN, voice and data communications**



Copper Access Technologies // HDSL and SDSL

- **High Data Rate and Single Line (Symmetric)**
  - **HDSL and SDSL**
    - **1.544 Mbps // 2.048 Mbps**
    - **Full Duplex**
    - **T1/E1, telco feeders, WAN**
    - **SDSL (single twisted pair)**

Copper Access Technologies // ADSL and RADSL

- **Asymmetric Digital Subscriber Line (Rate Adaptive)**
  - **ADSL // RADSL**
    - **1.5 Mbps to 9 Mbps (downstream)**
    - **16 kbps to 1.5 Mbps (upstream)**
    - **Internet access, video on demand, remote LAN access, multimedia**
    - **RADSL = adapt speeds based on conditions and distances**

Bandwidth Requirements

Application Type	File Size	Modem	ISDN 128kbps	DSL 384kbps	DSL 768kbps	DSL 1.544Mbps	DSL 6.144 Mbps
E-mail	**30k**	8.3 s	1.9 s	0.63 s	0.31 s	0.16 s	0.04 s
Digitized Photo	**125k**	34.7 s	7.8 s	2.6 s	1.3 s	0.6 s	0.2 s
	250k	69.4 s	15.6 s	5.2 s	2.6 s	1.3 s	0.3 s
Documents							
Video Conferencing	**384k**	No	No	Yes	Yes	Yes	Yes
	5M	23.1 m	5.2 m	1.7 m	52.1 s	25.9 s	6.5 s
X-Ray							
Bulk File Transfer	**20M**	1.5 h	20.0 m	6.9 m	3.5 m	1.7 m	26.0 s

Distance vs. Rate (downstream)

- **ADSL (24g wire)**
  - 1.544 Mbps @ 18,000 ft
  - 2.048 Mbps @ 16,000 ft
  - 6.312 Mbps @ 12,000 ft
  - 8.448 Mbps @ 9,000 ft
- **VDSL (24g wire)**
  - 12.96 Mbps @ 4,500 ft
  - 25.82 Mbps @ 3,000 ft
  - 51.84 Mbps @ 1,000 ft

Distance is from Central Office or RT (repeater terminal) unit

ADSL

- **Asymmetric data streams**
  - **Most applications fit this model**
    - **video on demand**
    - **home shopping**
    - **Internet access**
    - **remote LAN access**

Asymmetric Digital Subscriber Line (ADSL) basics

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- Converts existing twisted-pair telephone lines into access paths for multimedia and high speed data communications.
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ADSL basics (contd 2)

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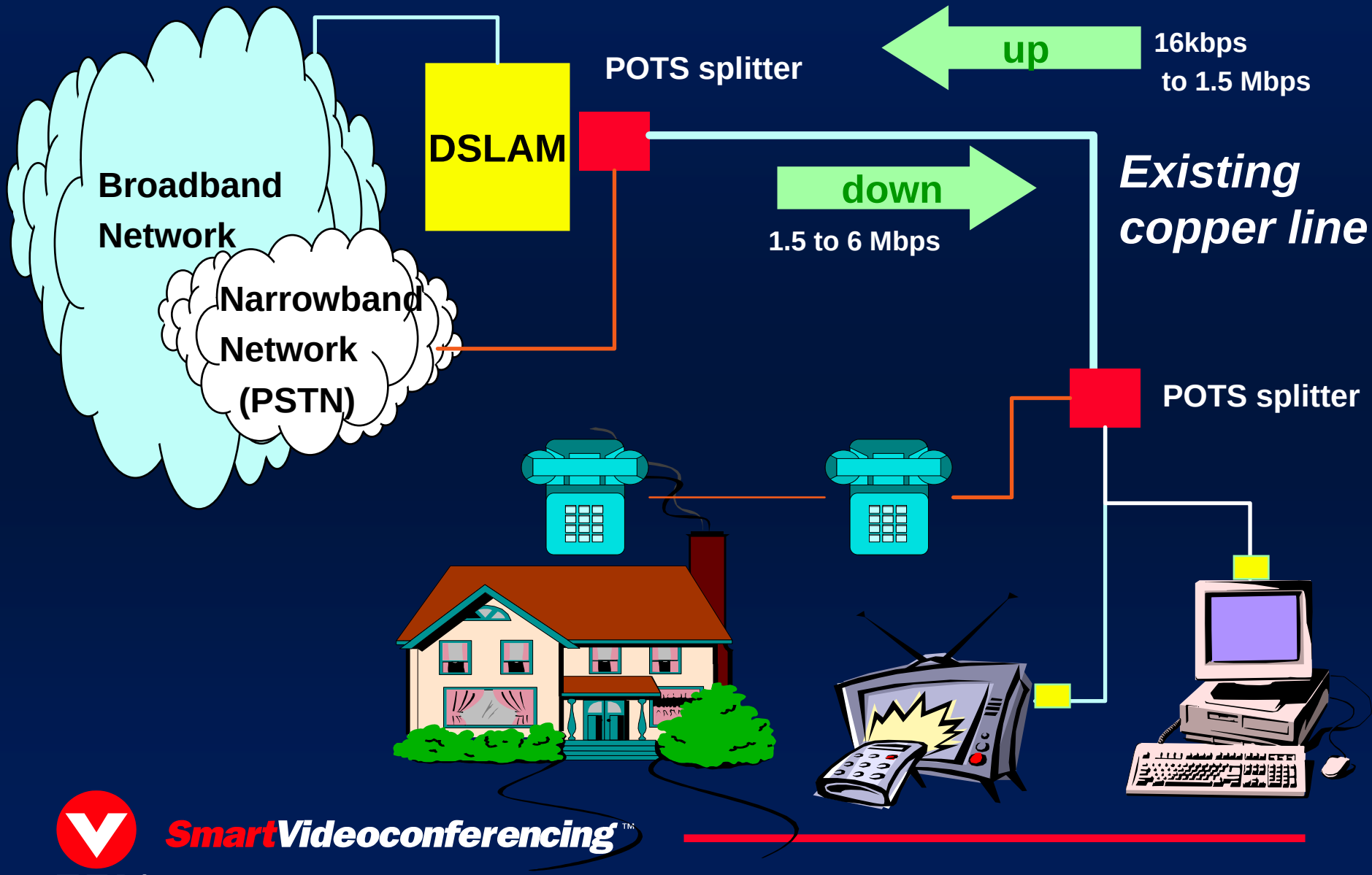
  - Speed ranges from 1.5 to 6.1 Mbps
- a medium speed duplex channel
  - Speed range from 16 to 640 kbps
- a POTS (Plain Old Telephone Service) or an ISDN channel.
  - The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS/ISDN, even if ADSL fails.

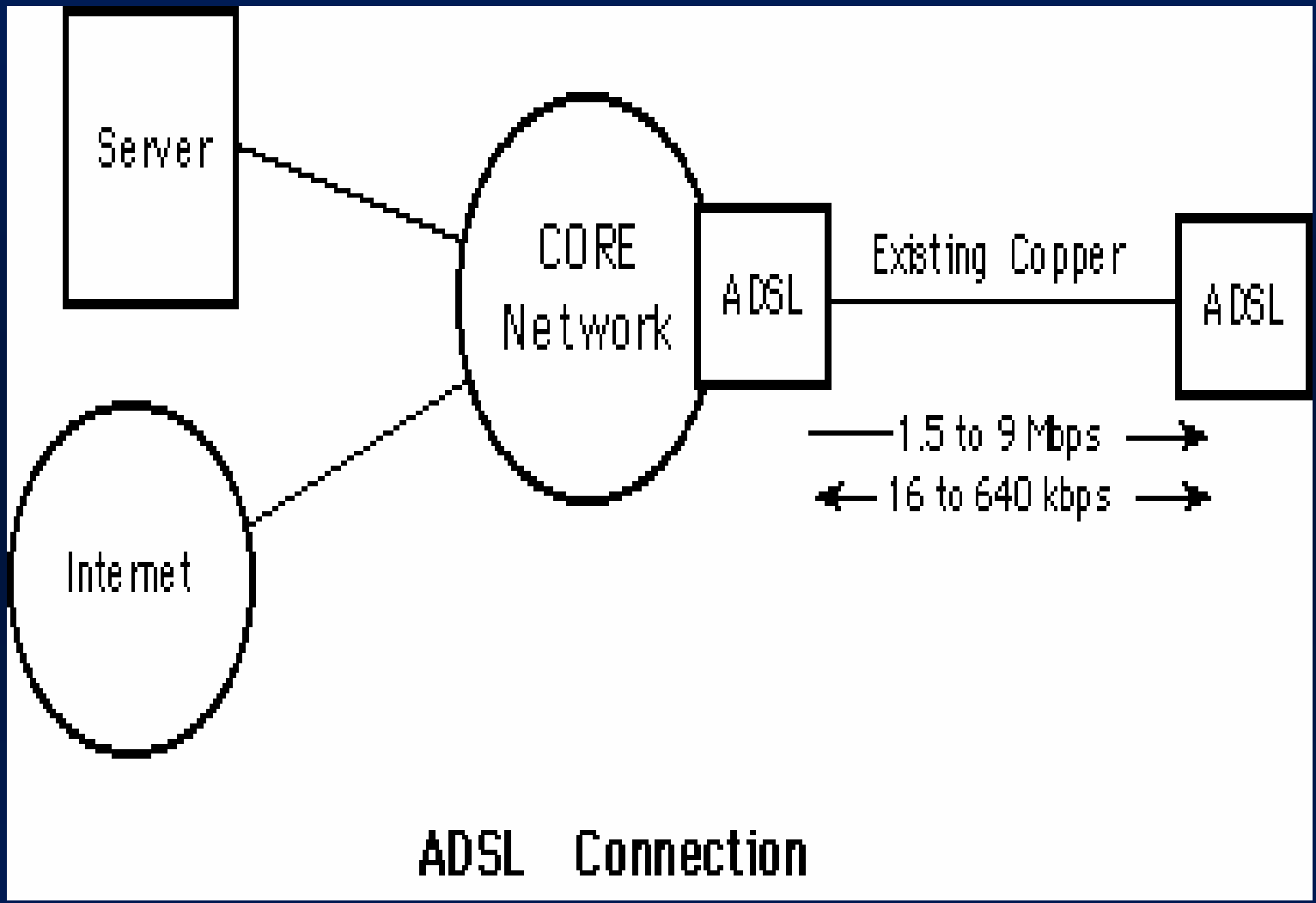
Each channel can be submultiplexed to form multiple, lower rate channels, depending on the system.

Consistent with North American and European digital hierarchies

ADSL in operation



SmartVideoconferencing™


Server
CORE
Network
ADSL
Existing Copper
ADSL
1.5 to 9 Mbps
16 to 640 kbps
Internet
ADSL Connection

ADSL reach

Data Rate	Distance	Wire Size	Distance
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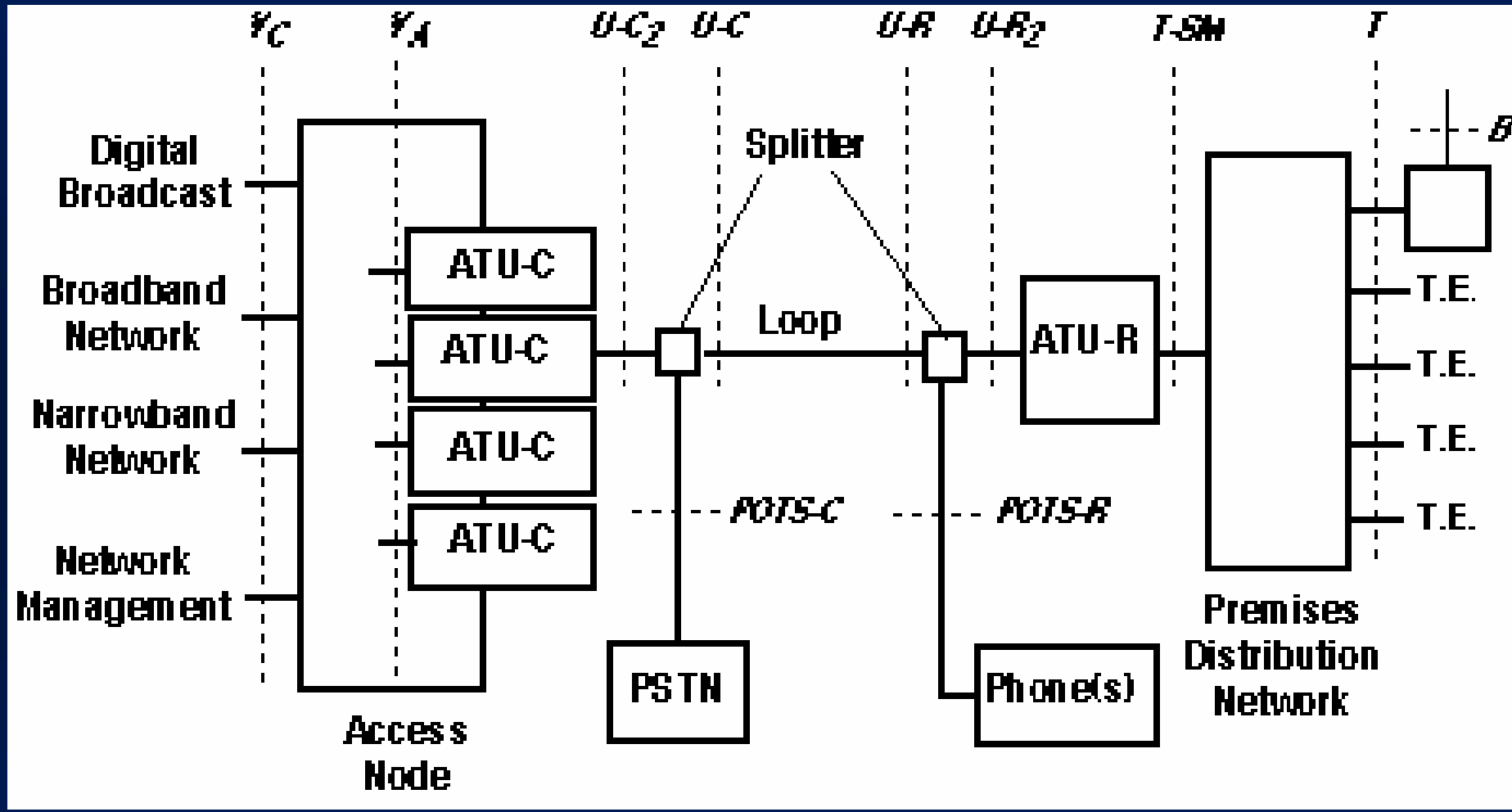
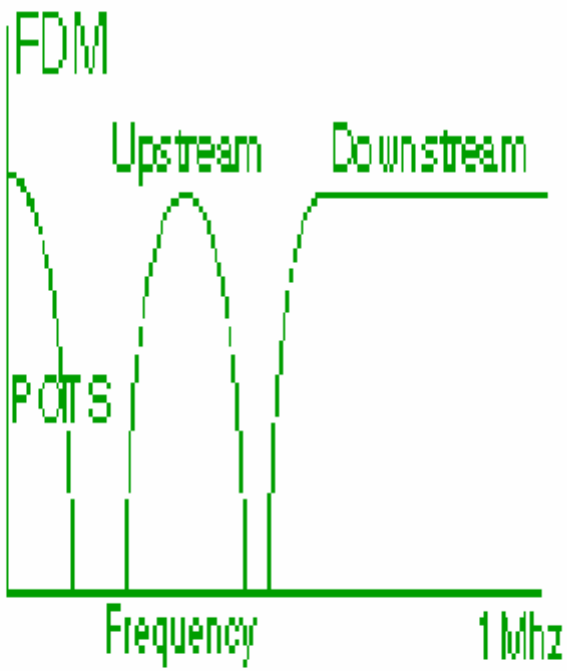
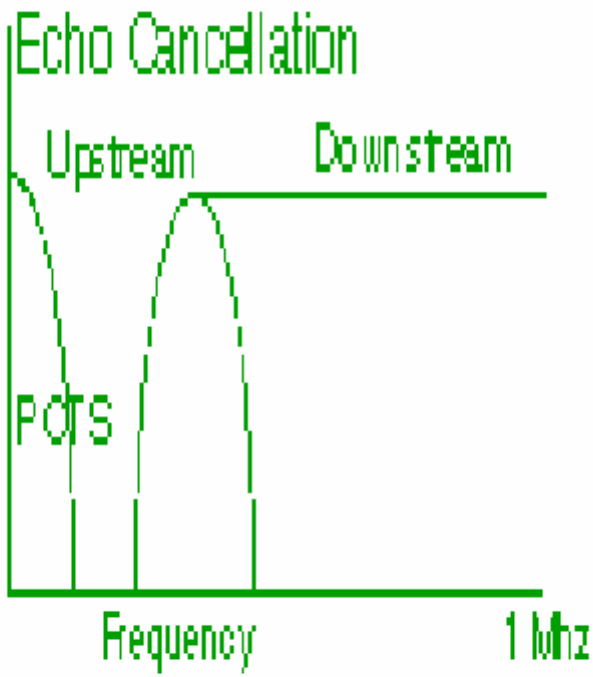

V_C
V_A
$U\text{-}C_2$
U-C
U-R
$U\text{-}R_2$
T-SM
T
B
Digital Broadcast
Broadband Network
Narrowband Network
Network Management
ATU-C
ATU-C
ATU-C
ATU-C
Splitter
Loop
POTS-C
POTS-R
ATU-R
T.E.
T.E.
T.E.
T.E.
PSTN
Phone(s)
Premises Distribution Network
Access Node

ADSL spectrum sharing

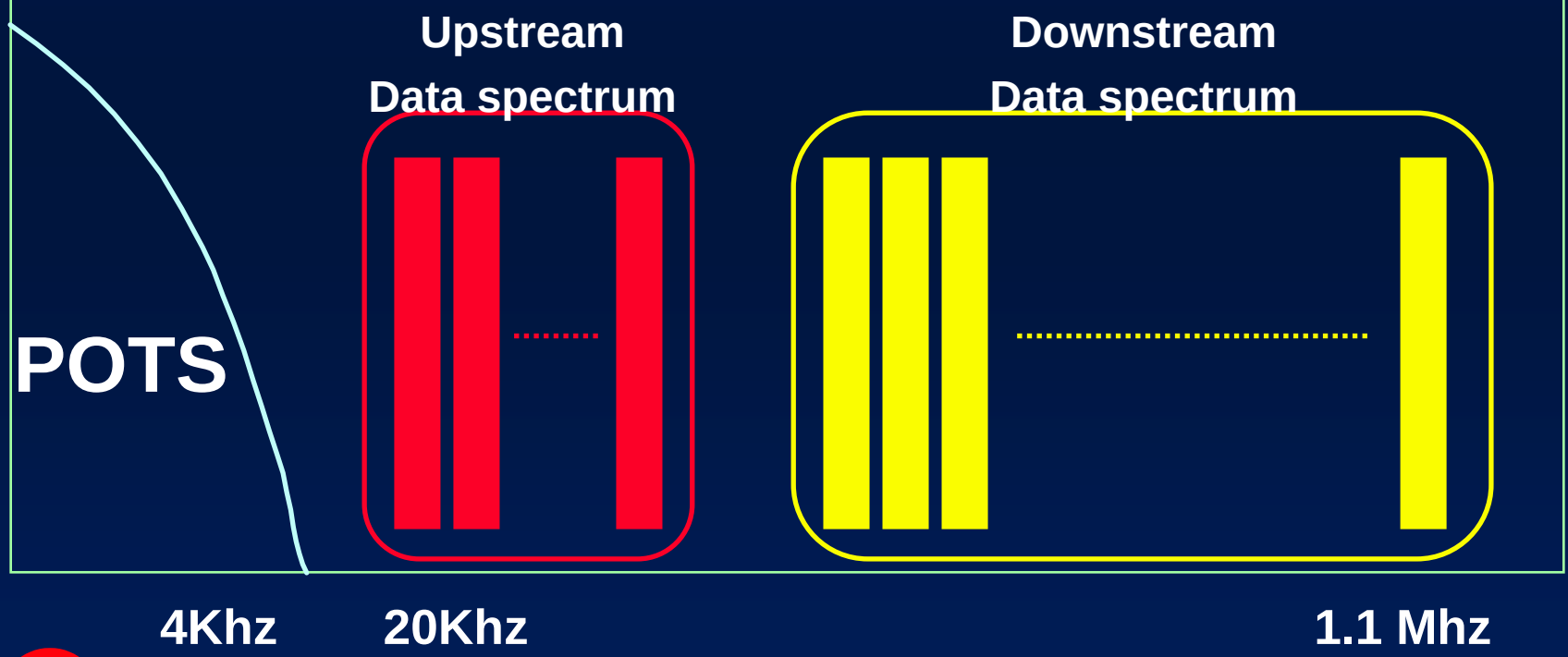




ADSL (spectrum)

Frequency Spectrum

T1/T3 circuits, Bridge Taps, load coils are disturbers when in the same or adjacent binder as ADSL twisted pair.



SmartVideoconferencing™

Modulation Techniques (ADSL)

- **Discrete Multitone modulation (DMT)**
  - **multicarrier sub-channels (256 downstream, 32 upstream) [4 Khz]**
  - **inferior quality, traffic reassigned to different channel**
    - **6 Mbps downstream**
    - **640 kbps upstream**

Modulation Techniques (ADSL)

- **Carrierless Amplitude/Phase modulation (CAP)**
  - **proprietary, mature technology**
  - **single carrier system similar to V.34**
  - **automatic bit rate adjustments for line impairments**
    - **1.5 Mbps downstream**
    - **64 kbps upstream**

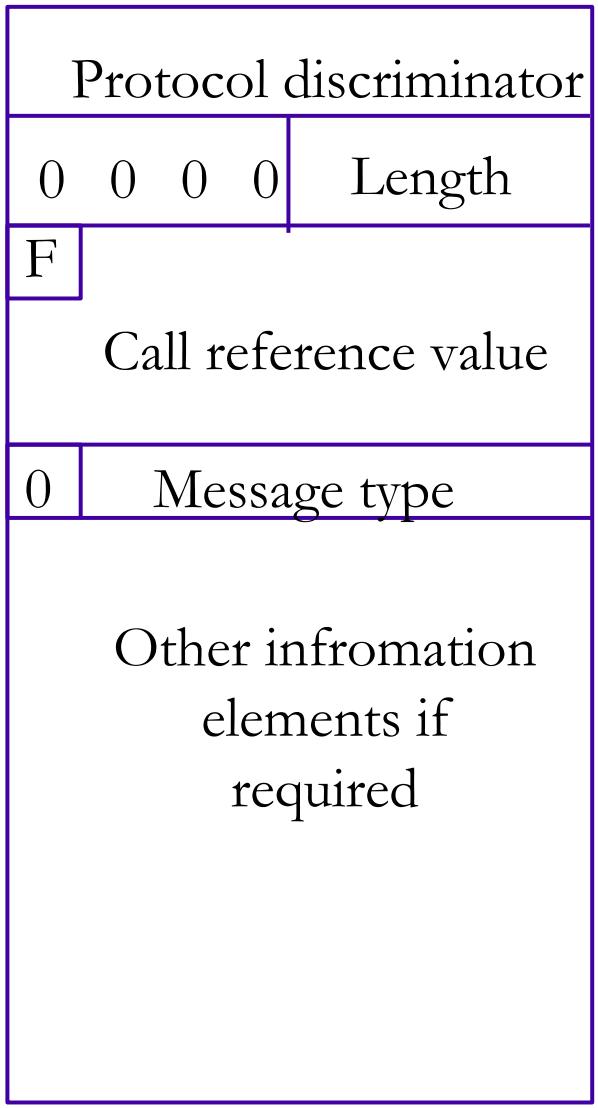
Competing Technologies

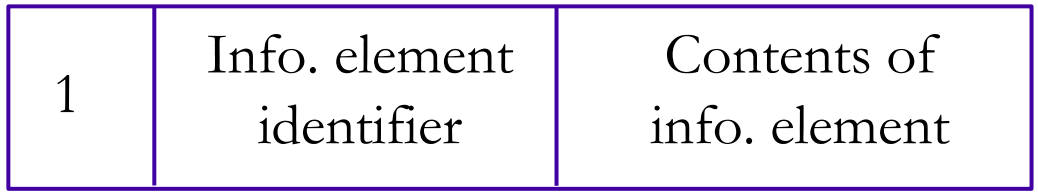
- **Cable Modems**
  - 18,000 ft limit (head-end)
  - Most cable operators need to upgrade their networks to support bi-directional service
  - 128 kbps up to 30 Mbps (shared bandwidth, up to 200 users on a loop)
  - Security
  - Reliability in question

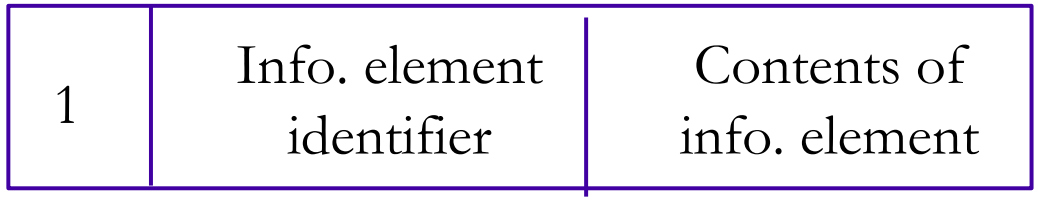
Competing Technologies

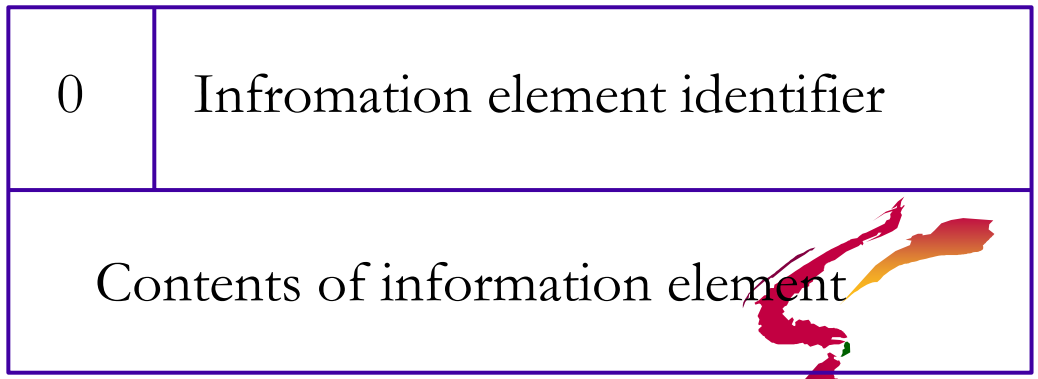
- **Digital Satellite transmission**
  - **Still need upstream data provider (usually handled through modem or ISDN)**
  - **up to 30 Mbps downstream**
  - **Also used for push-technology**

Q. 931 Message format





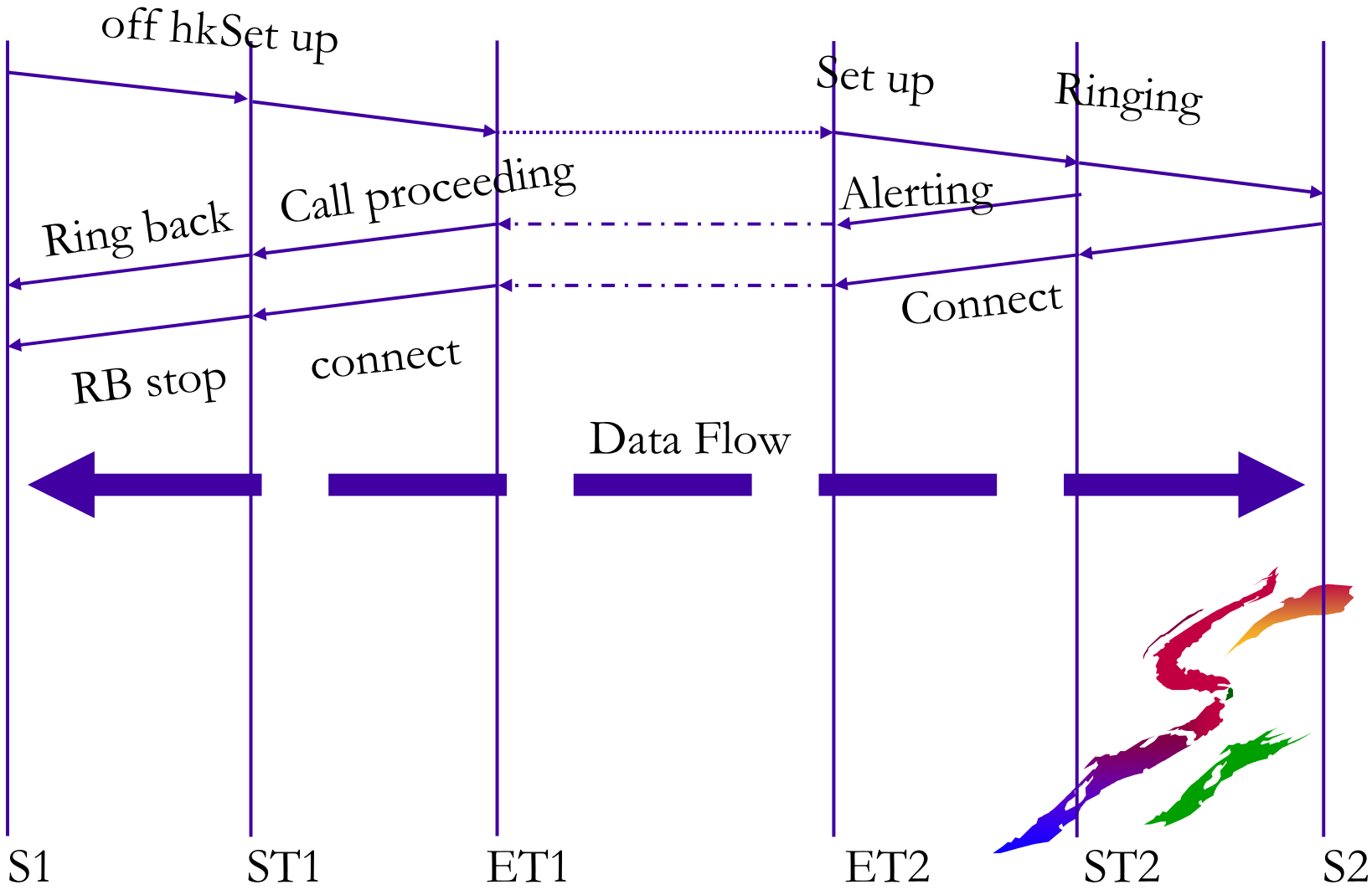




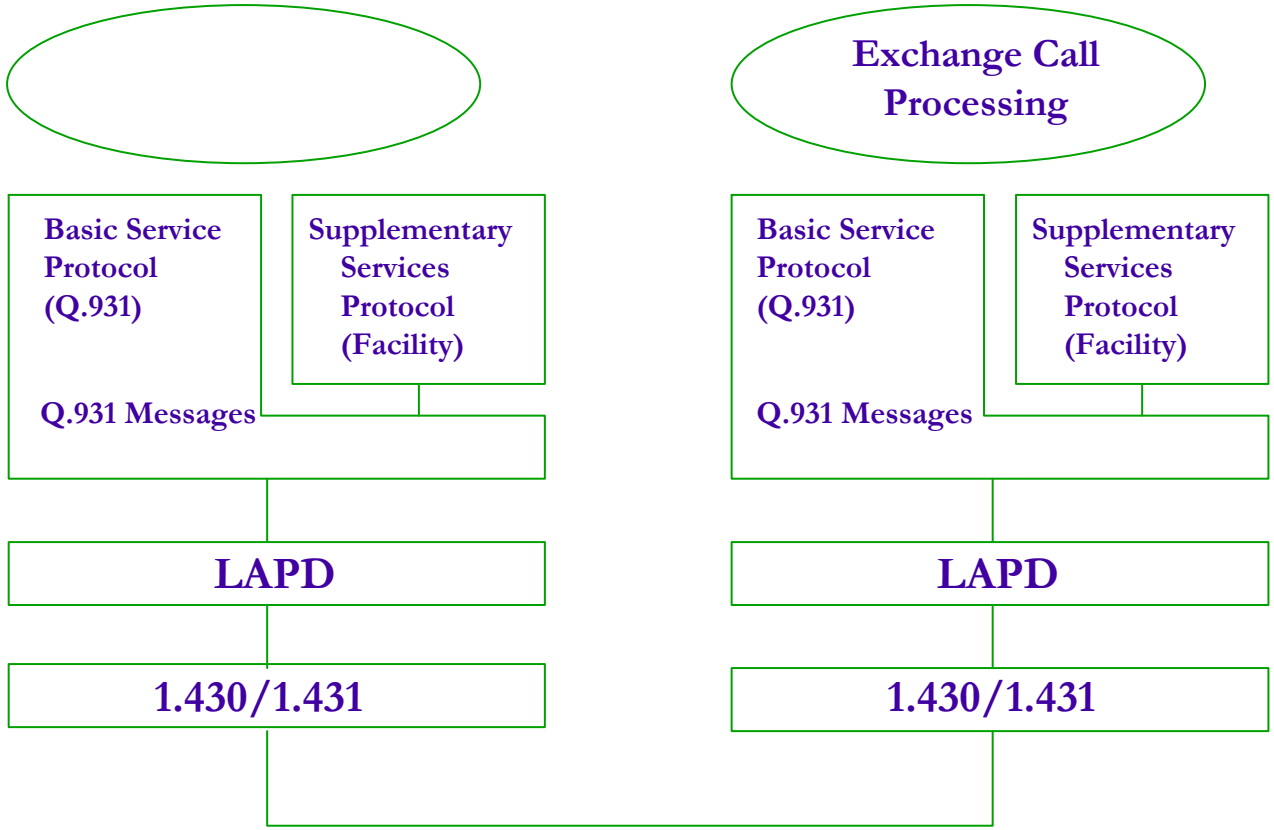
Bearer capability infromation element identifier

1	0	0	0	0	0	1	0	0	Bearer capability info.element identifier
2									Length of bearer capability contents
3	1	X	X	X	X	X	X	X	Codinbg std., info. transfer capability
4a	X	X	X	X	X	X	X	X	Transfer mode, transfer rate
4b									
5	X	X	X	X	X	X	X	X	Rate multiplier
5a	0/1		X	X	X	X	X	X	Layer 1 identity, user info. layer 1
5b									
5c									
5d									
5e									
6	1	X	X	X	X	X	X	X	Layer 2 identity, user info. layer 2
7	1	X	X	X	X	X	X	X	Layer 3 identity, user info. layer3

Procedure for a circuit-switched call



Modelling of basic and supplementary services



Layer 3 Functions

Routing
Network connection establishment
Connection release
Multiplexing
Congestion control
Addressing

Layer 2 Functions

Traffic over D channel (control Info and data over D) Q 921

Q921 services

- ***Convey user Info between layers entities using D channel***
- ***Support multiple terminals at user-NW installation***
- ***Multiple layer 3 entity: support two types of transfer***
- ***Unacknowledged transfer (unnumbered frames)***
- ***Acknowledged transfer (like X 25) HDLC***

Function of other layers

layer 4 :	*error detection / recovery*
	flow control
	layer 4 connection, release, muxing
Layer 5 :	*session connection*
	management
	session - transport management
layer 6 :	*encryption / decryption*
	compression / expansion
Layer 7 :	*application related functions*

Protocol reference model I 320

1. Protocol reference model I320

- *Circuit - switched connection under common channel signalling*
- *Packet - switched comm over B/D/H*
- *Signalling between users and network based facilities (data base fores.)*
- *End - to - end signalling for users*
- *Combinations for multimedia comm.*

2. Types of Info flow

1. User Info: digitised voice, data between users. Transmitted transparently through ISDN or processed (encrypted for e.g.)

2. Control Info : acted upon this Info switching a connection / clearing change service characteristics

Basic Call Control

- *interact with layer 2 (LAPD) to transmit / receive messages*
- *generate and interpret layer 3 messages*
- *admin of times and logical entities (call reference) used in control*
- *admin of resources (like B ch1)*
- *check to provide proper service consistent with user requirements*
- *routing / relaying*
- *network connection control*
- *error detection (sequences)*
- *error recovery*
- *sequencing layer 3 information*

Layer 1 Functions

- *Encoding of digital data for transmission across the interface*
- *Full-duplex transmission of B channel data*
- *Full-duplex transmission of D channel data.*
- *Multiplexing of channels to form basic or primary access transmission structure.*
- *Activation and deactivation of physical circuit.*
- *Power feeding from network termination to the terminal.*
- *Terminal identification.*
- *Faulty terminal isolation.*
- *D channel contention access*

Q931 message types

Circuit - mode connection control functions needed for circuit-switched B channel calls

Packed - mode connection control functions needed for circuit-switched connections to ISDN packet-switched node.

User - user signalling messages with global call reference

functions are 4 types

- call establishment set up a call on B chl.
- call information user-NW Info transfer after set-up
- call clearing
- miscellaneous

Messages

Signaling exchanged between user - network, network - network.

Protocol discriminator (0001000) for Q931 call reference
Message type: length (1 for BRI, 2 for PRI)
Call reference: call reference value (assigned by TE local significance)
Flag: 0: originator, 1: remote end
Call reference length = 0, Supplementary services Q932
CRF = 0, global CRF

Q931 messages for circuit mode connections

Call Establishment Messages

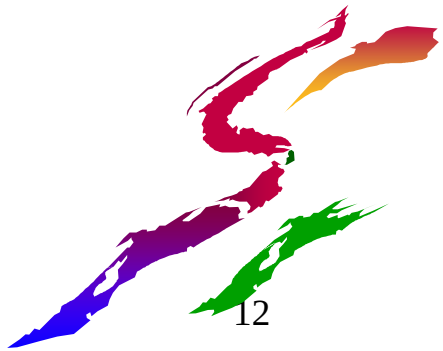
Message	Significance	Direction	Function
ALERTING	global	both	Indicates that user alerting has begun
CALL PROCEEDING	local	both	Indicates that call establishment has been initiated
CONNECT	global	both	Indicates call acceptance by called TE
CONNECT ACKNOWLEDGE	local	both	Indicates that user has been awarded the call
PROGRESS	global	both	Reports progress of a call
SETUP	global	both	Initiates call establishment
SETUP ACKNOWLEDGE	local	both	Indicates that call establishment has been initiated but requests more information

Call information phase messages

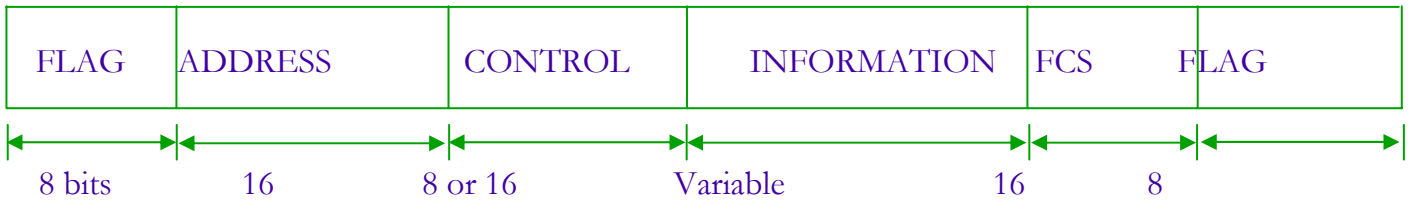
Message	Significance	Direction		Function
RESUME	local	u	n	Requests resumption of previously suspended call
RESUME ACKNOWLEDGE	local	n	u	Indicates requested call has been reestablished
RESUME REJECT	local	n	u	Indicates failure to resume suspended call
SUSPEND	local	u	n	Requests suspension of a call
SUSPEND ACKNOWLEDGE	local	n	u	Indicates call has been suspended
SUSPEND REJECT	local	n	u	Indicates failure of requested call suspension

Call clearing messages

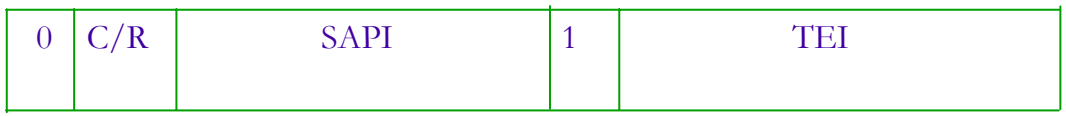
Message	Significance	Direction	Function
DISCONNECT	global	both	Sent by user to request connection clearing; sent by network to indicate connection clearing
RELEASE	local	both	Indicates intent to release channel and call reference
RELEASE COMPLETE	local	both	Indicates release of channel and call reference
INFORMATION	local	both	Provides additional information
NOTIFY		both	Indicates information pertaining to a call
STATUS	local	both	Sent in response to a STATUS INQUIRY or at any time to report an error
STATUS INQUIRY	local	both	Solicits STATUS message



Frame format in ISDN layer 2

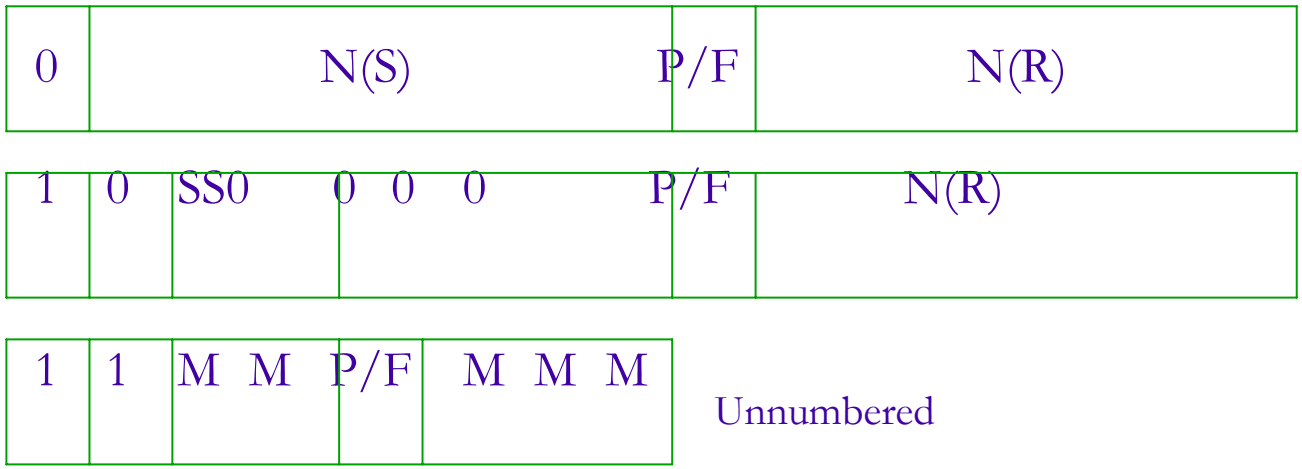


(a) Frame format



C/R is Command/response
SAPI is Service access point identifier
TEI is Terminal endpoint identifier

LAPD format



N(S) = Transmitter send sequence number
N(R) = Transmitter receive sequence number
S = Supervisory function bit
M = Modifier function bit
P/F = Poll/final bit

LAPD commands and responses

Name	Control Field	C/R	Description
	Information format		
I (Information)	0-N(S)--P-N(R)--	C	Exchange user data
	Supervisory Format		
RR (Receive Ready)	10000000*-N(R)--	C/R	Positive ack; ready to receive I-frame
RNR (Receive Not Ready)	10100000*-N(R)--	C/R	Positive ack; not ready top receive
REJ (Reject)	10010000*-N(R)--	C/R	Negative ack; go back N

Unnumbered format

SABME (Set Asyn chronous Balanced Mode)	1111P110	C	Request logical connection
DM (Disconnected Mode)	1111F000	R	Unable to establish or main maintain logical connection
UI (unnumbered Information)	1100P000	C	Used for unacknowledged information transfer service
DISC (Disconnect)	1100P010	C	Terminate logical connection
UA (Unnumbered Acknowledgement)	1100F110	R	Acknowledge SABME or DISC
FRMR (Frame Reject)	1110F001	R	Reports receipt of unaccept-able frame
XID (Exchange ID-identification)	1111*101	C/R	Exchange identification information

SAPI and TEI assignments

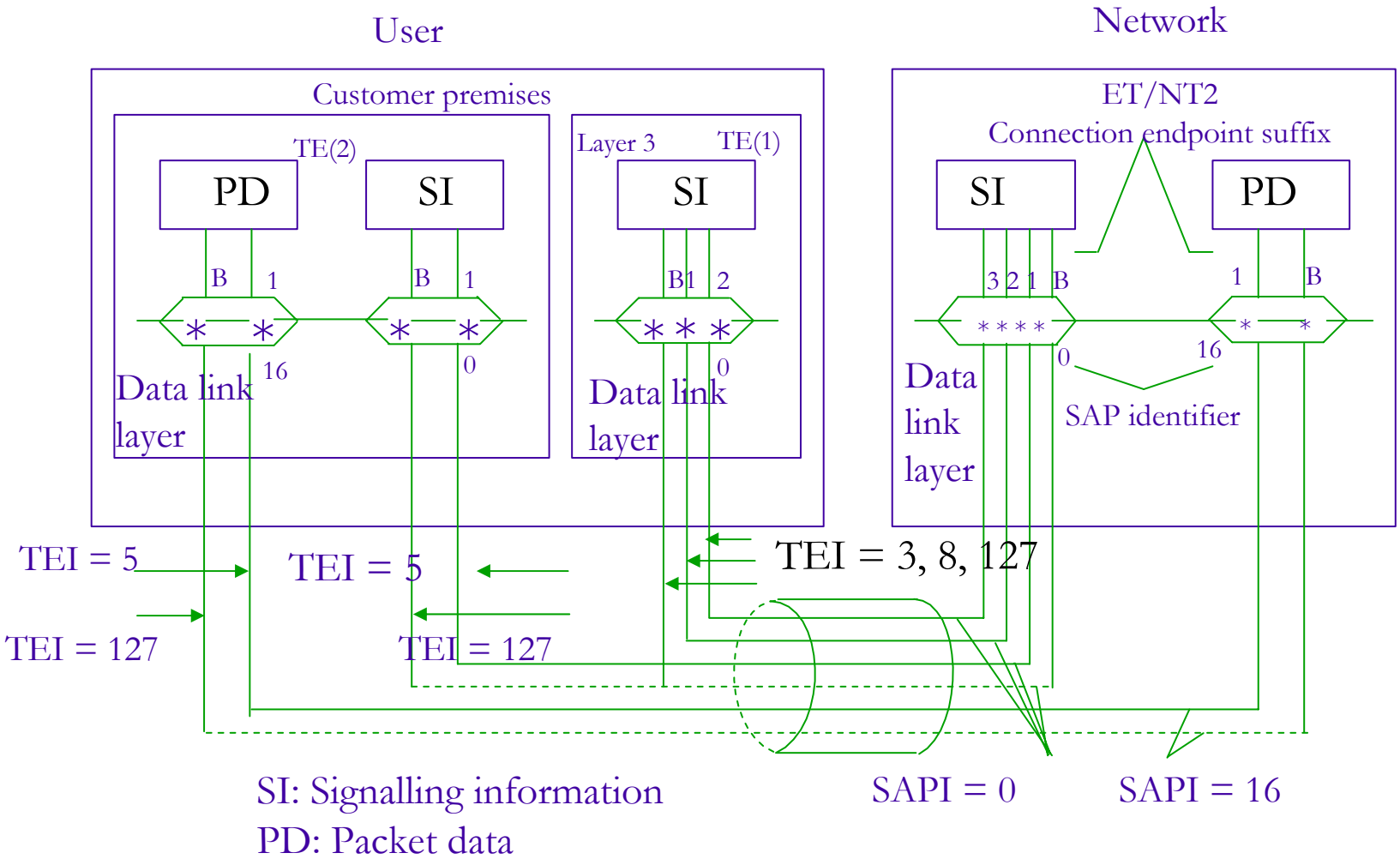
(a) SAPI Assignments

SAPI Value	Related Protocol or Management Entity
0	Call-control procedures
16	packet communication conforming to X.25 level 3
32-61	Frame relay communication
63	Layer 2 management procedures
All others	Reserved for future standardisation

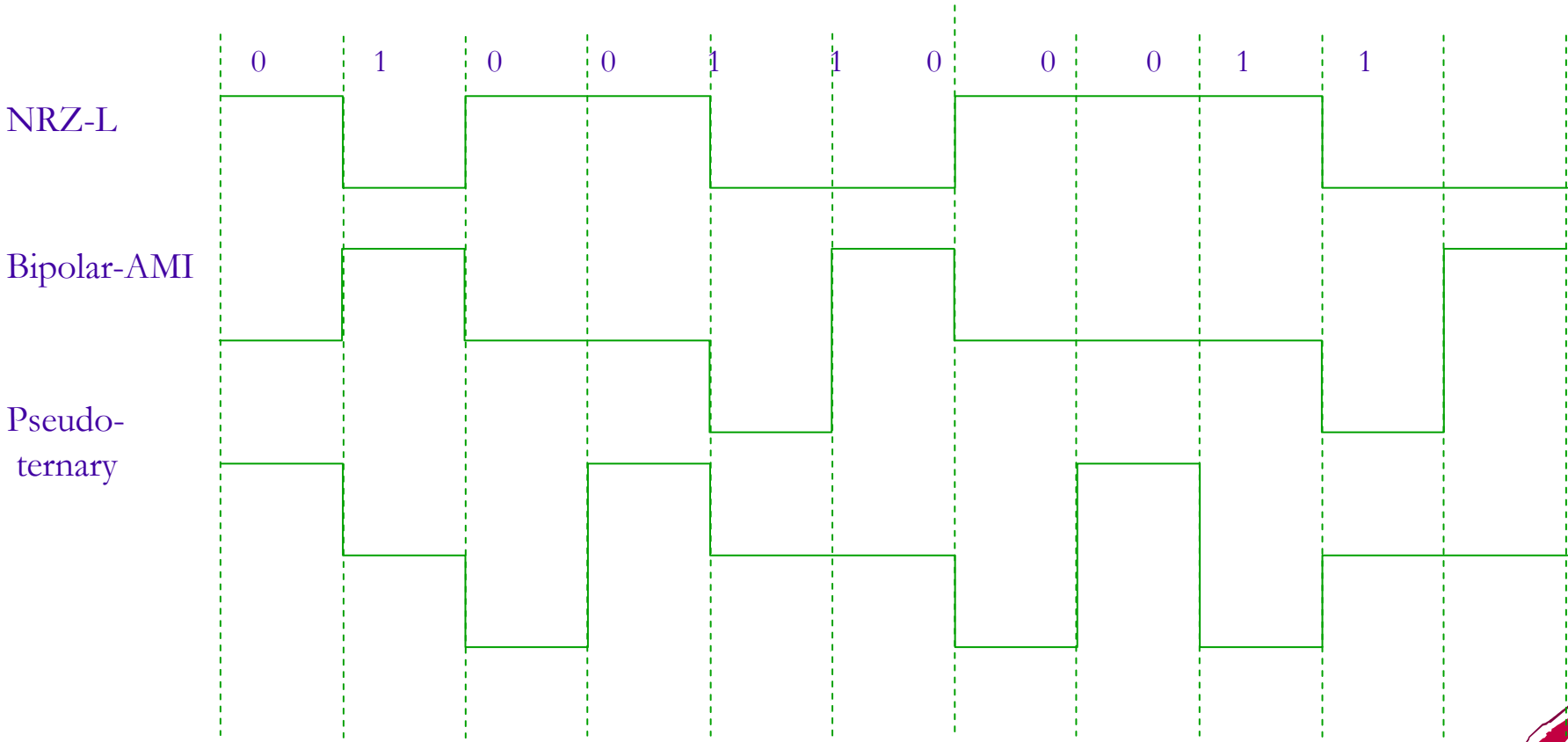
(b) TEI Assignments

TEI Value	User Type
0-63	Nonautomatic TEI assignment user equipment
64-126	Automatic TEI assignment user equipment
127	Used during automatic TEI assignment

TEI and SAPI assignment



Digital Signal Encoding Format in ISDN



Physical connector in ISDN

Contact Assignments for Plugs and Jacks of ISDN

Contact Number	TE	NT
a	Power Source 3	Power Sink 3
b	Power Source 3	Power Sink 3
c	Transmit	Receive
d	Received	Transmit
e	Received	Transmit
f	Transmit	Received
g	Power Sink 2	Power Source 2
h	Power Sink 2	Power Source 2

The U interface

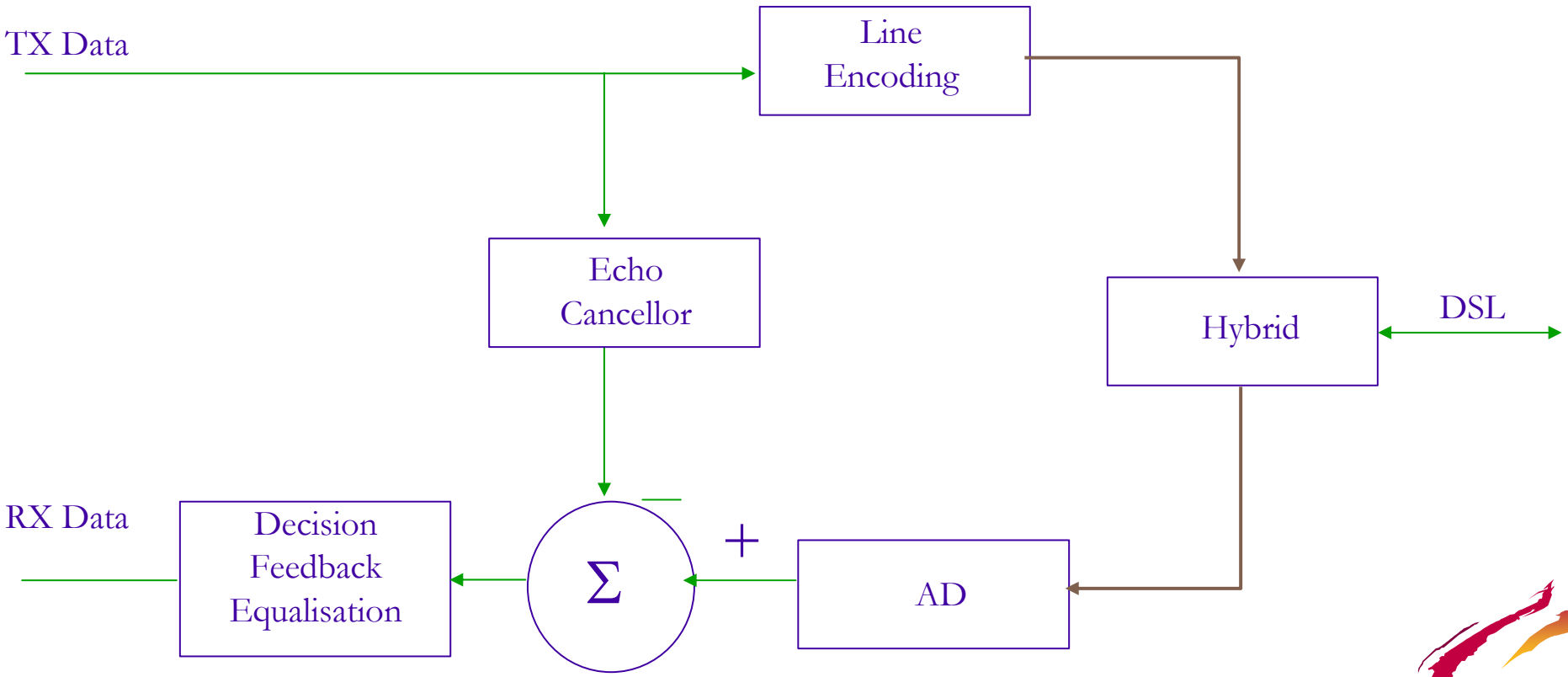
Fixed by local administration

- 4 wire interface
  no echo cancellation procedures, simple line termination

- 2 wire interface
  Ping-Pong operation, no echo cancellation, only one cable pair, simple termination, limited lengths, extra processing for comm. direction handling

- 2 wire interface
  full duplex operation, echo cancellation, only one cable pair, no limitation on length , extensive processing for echo cancellation

U interface circuit



ANSI U interface frame and superframe structure

	18	18	18		18	6 total 240 bits
1	ISW	2B + D	2B + D		2B + D	M1 to M6
2	SW	2B + D	2B + D		2B + D	M1 to M6
3	SW	2B + D	2B + D		2B + D	M1 to M6
4	SW	2B + D	2B + D		2B + D	M1 to M6
5	SW	2B + D	2B + D		2B + D	M1 to M6
6	SW	2B + D	2B + D		2B + D	M1 to M6
7	SW	2B + D	2B + D		2B + D	M1 to M6
8	SW	2B + D	2B + D		2B + D	M1 to M6

SW = Sync Word = +3+3-3-3-3+3-3+3+3

ISW= Inverted SW=-3-3+3+3+3-3+3-3-3

2B+D = |B1 |B2 |D | (|8|8|2) M1 to M6 over head bits

Data are encoded as 00 = -3, 01= -1, 11=+1, 10 = +3