



# Digital Communication Systems

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## Topics in Digital Communications

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- 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

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- 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

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- 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

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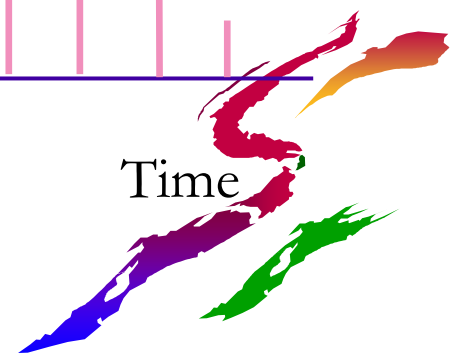
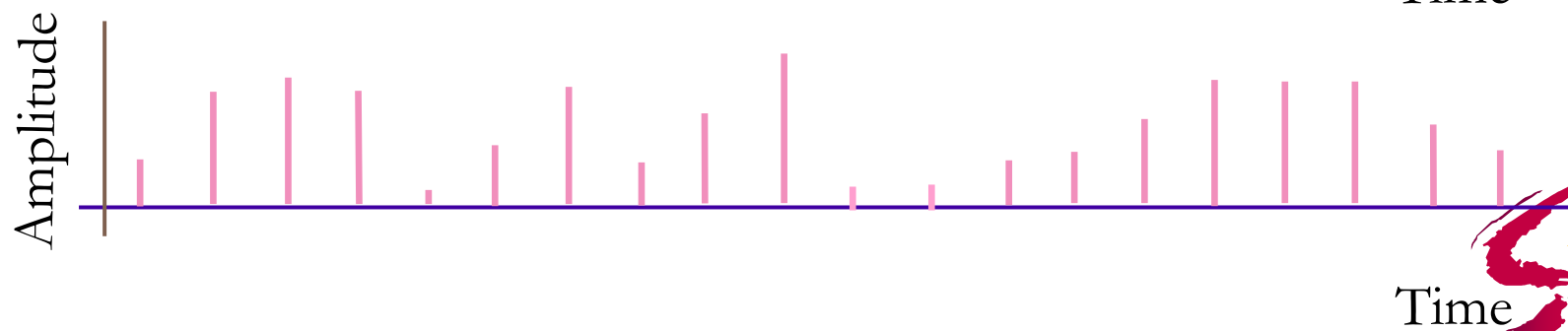
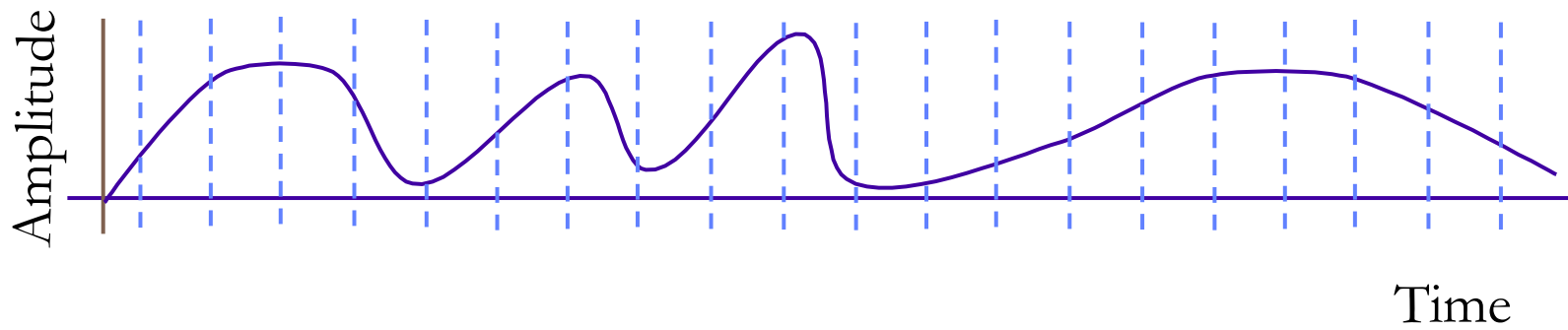
<u>Signal Type</u>	<u>Transmission</u>	<u>Example</u>
Analog	Analog	Classical telephony
Analog	Digital	PCM TDM
Digital	Analog	Modems
Digital	Digital	ISDN, LANs



## Digitization of analogue signals

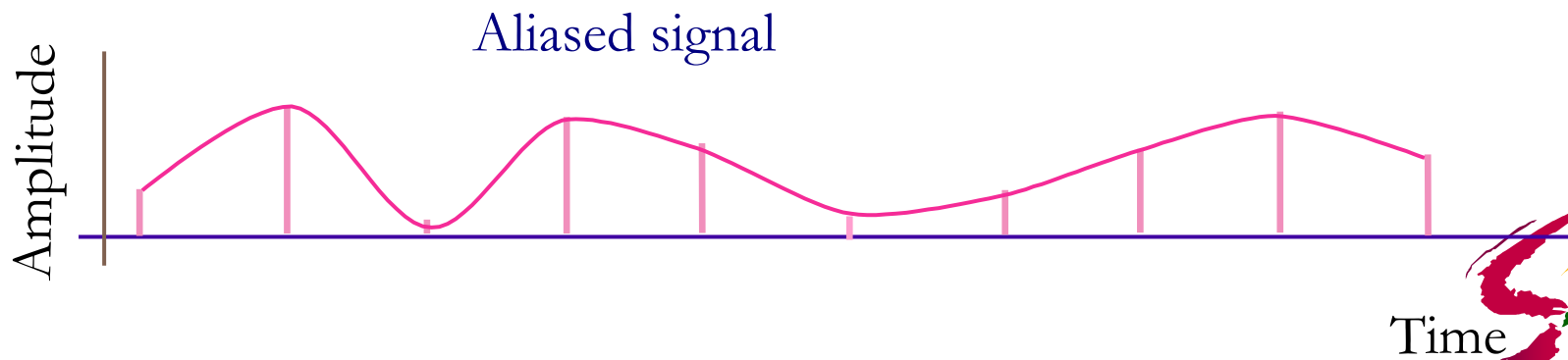
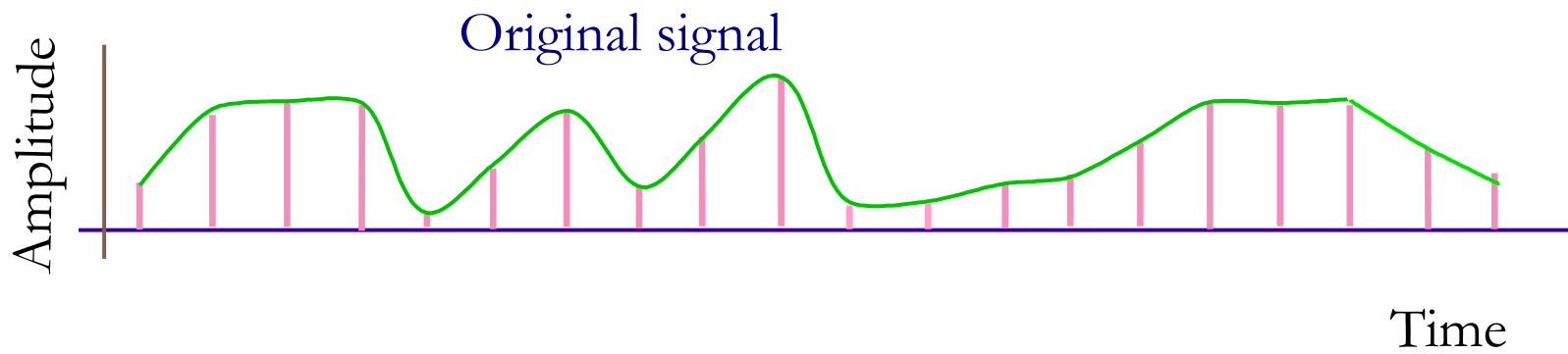
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- Signal sampling



# Nyquist Criterion, Aliasing

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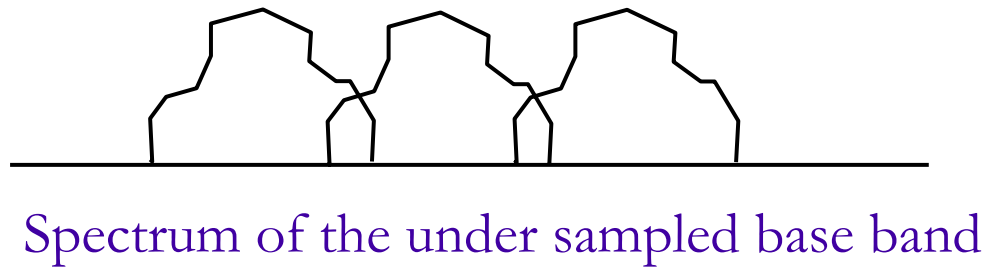
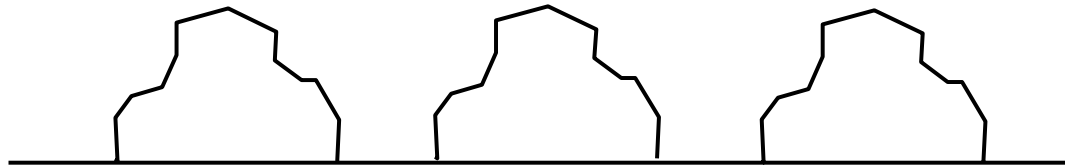
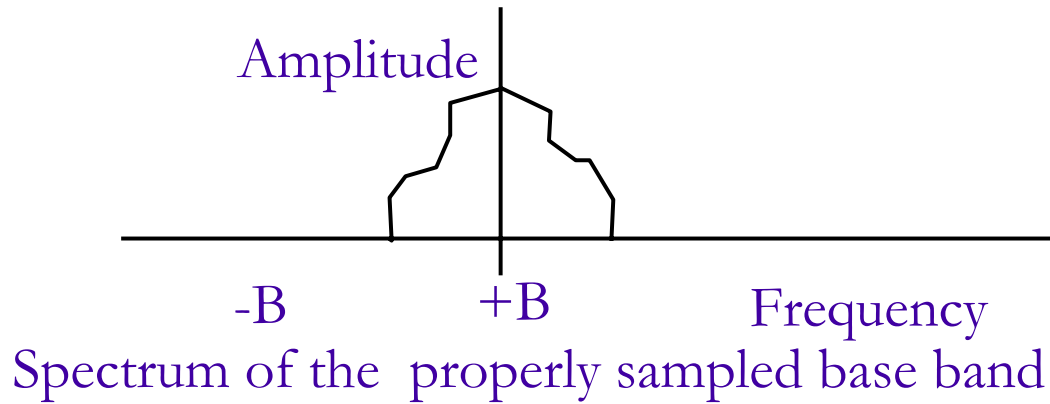


Nyquist sampling rate  $f_s > 2 \cdot f_b$



# Spectrum of baseband signals

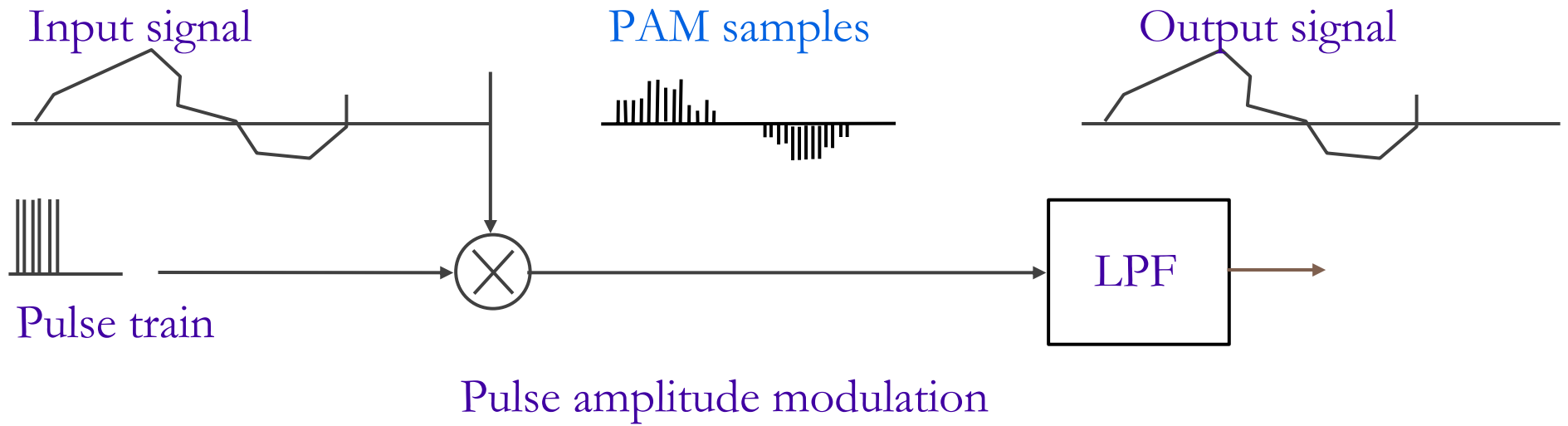
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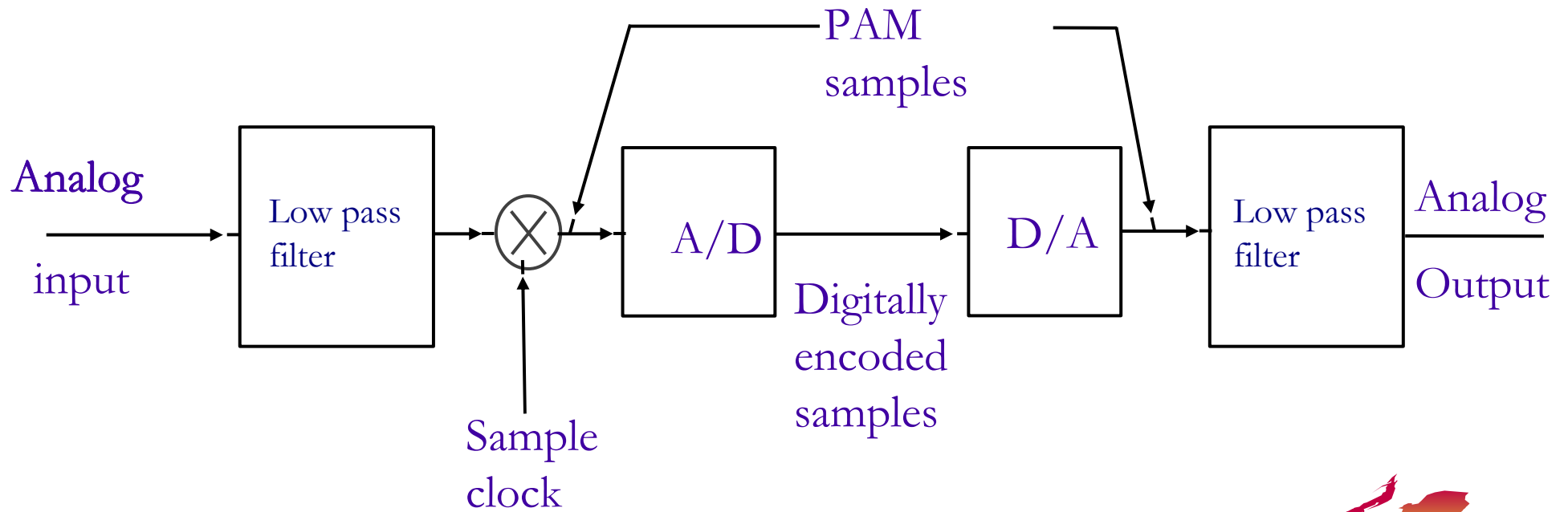
# Speech signal digitisation

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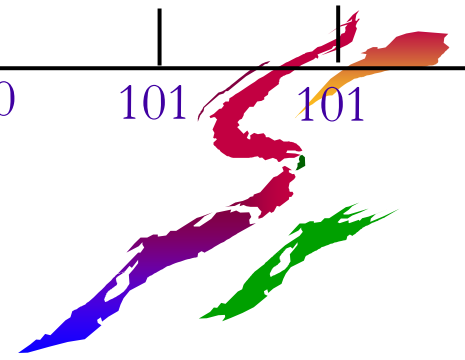
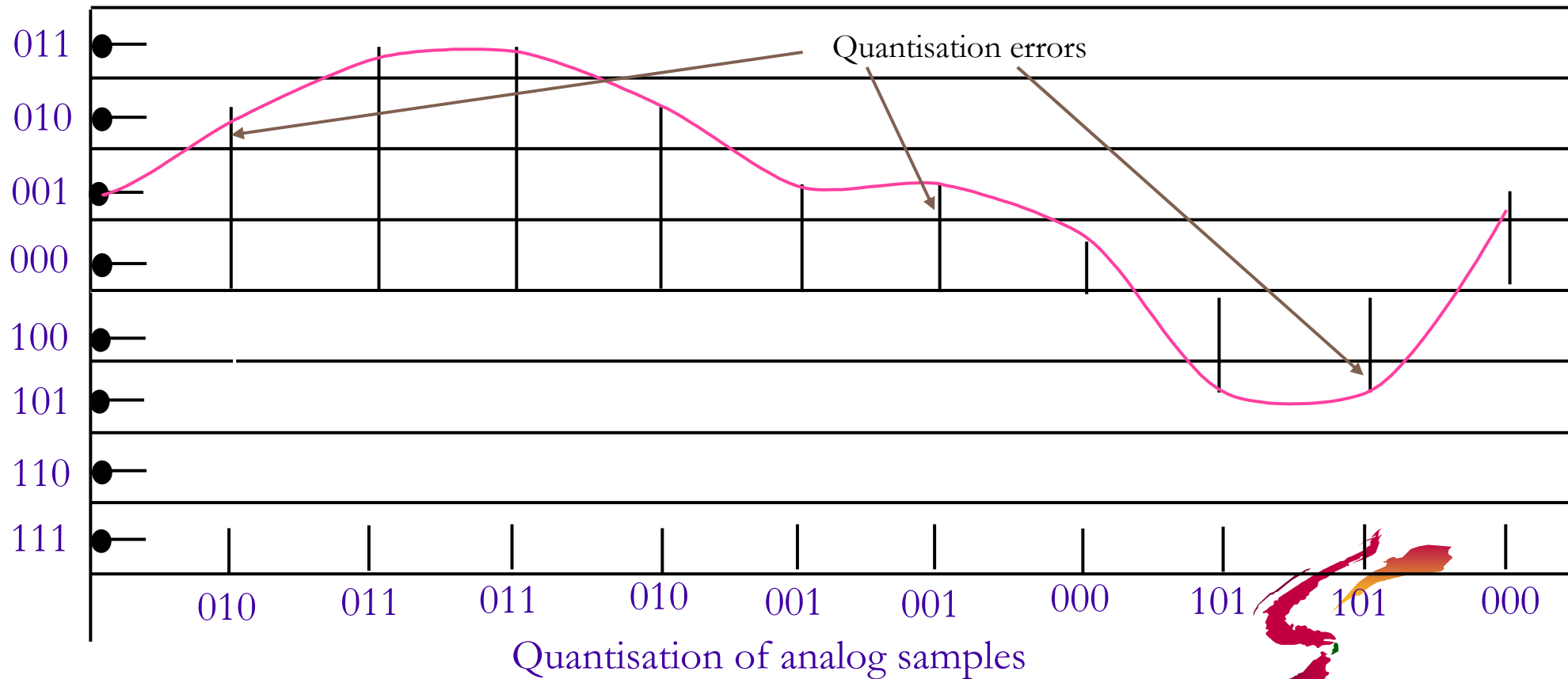


# Pulse Code Modulation (PCM)

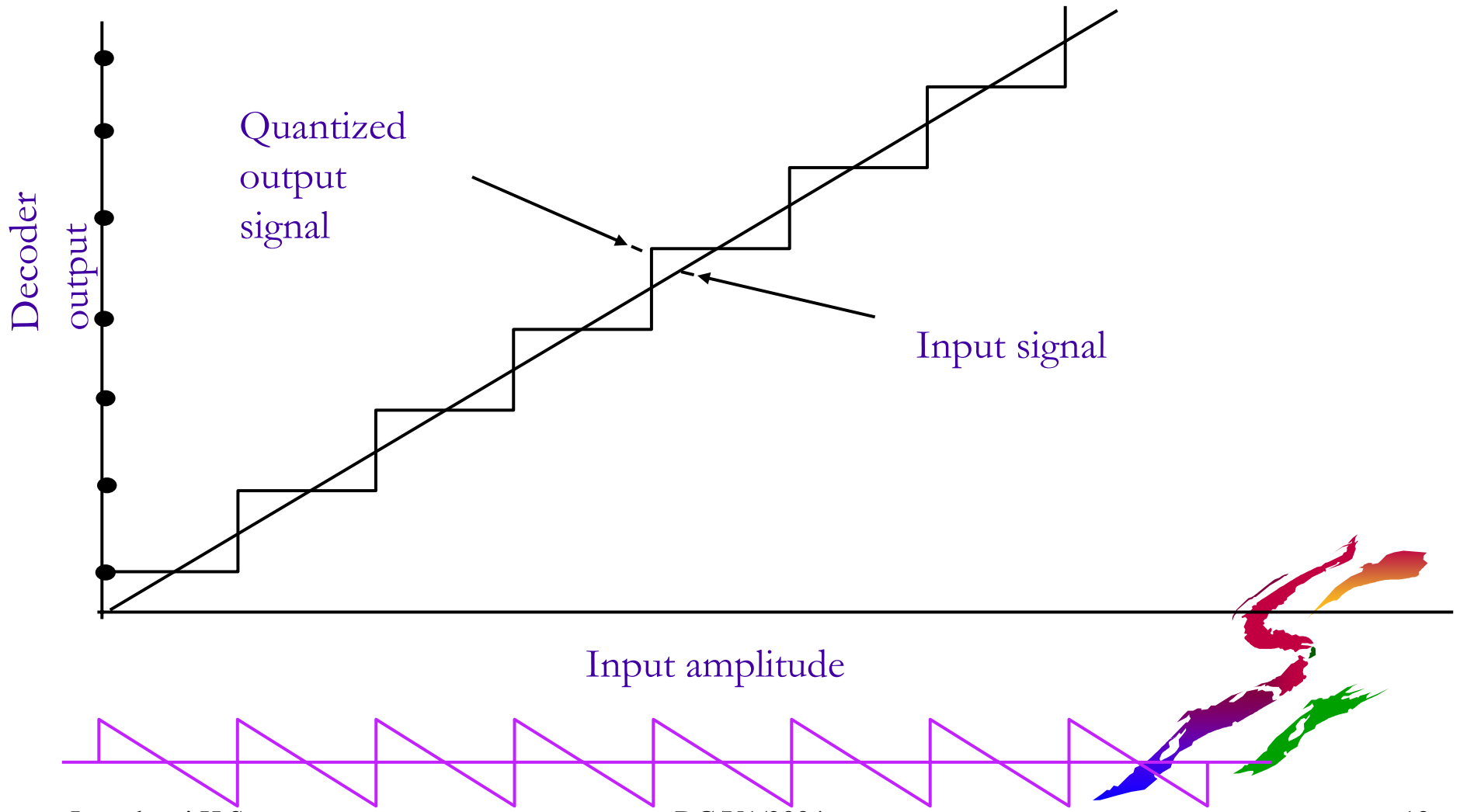
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# Quantisation of speech signal samples



# Quantisation error in PCM



## PCM system - Typical parameters

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### 4 KHz Speech signal

8 KHz Sampling

8 bits / sample digitising

per speech channel  $8 \times 8 \text{ bits} = 64 \text{ kbps}$

**T1 carrier:** 24 channels. 8 bits in  $125 \mu\text{s}$  / channel

$24 \times 8 = 192 \text{ bits}$  in  $125 \mu\text{s}$  / frame, 1 bit per frame for sync

193 bits in  $125 \mu\text{s}$ , **Line rate  $193/125 \mu\text{sec} = 1.544 \text{ Mbps}$**

### ITU (EUROPEAN)

32 Channels 8 bits/  $125 \mu\text{s}$  / channel

$32 \times 8 \text{ bits} / 125 \mu\text{s} = 2.048 \text{ Mbps}$

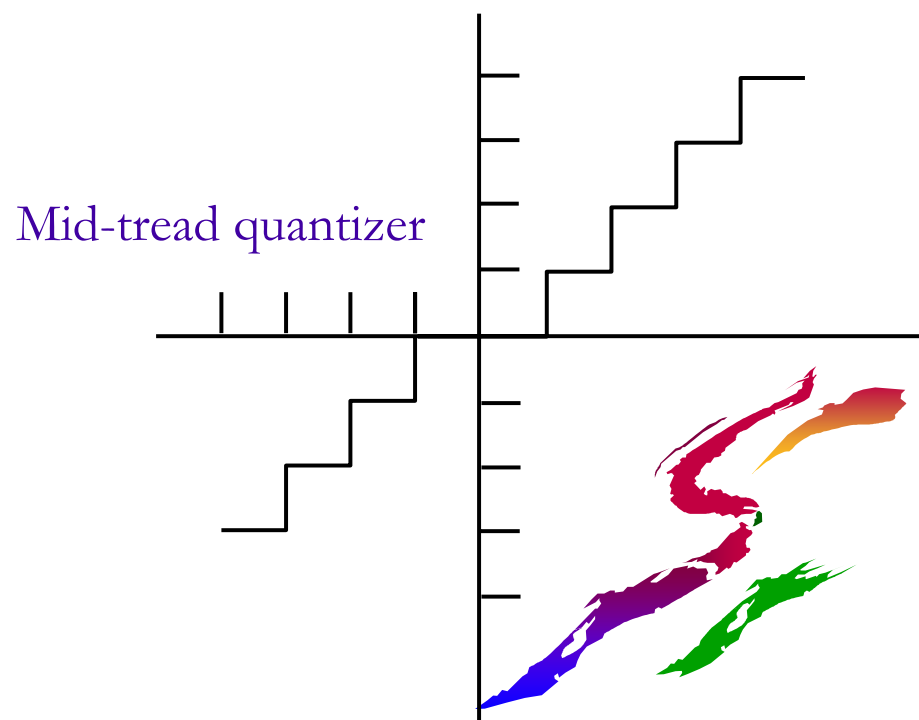
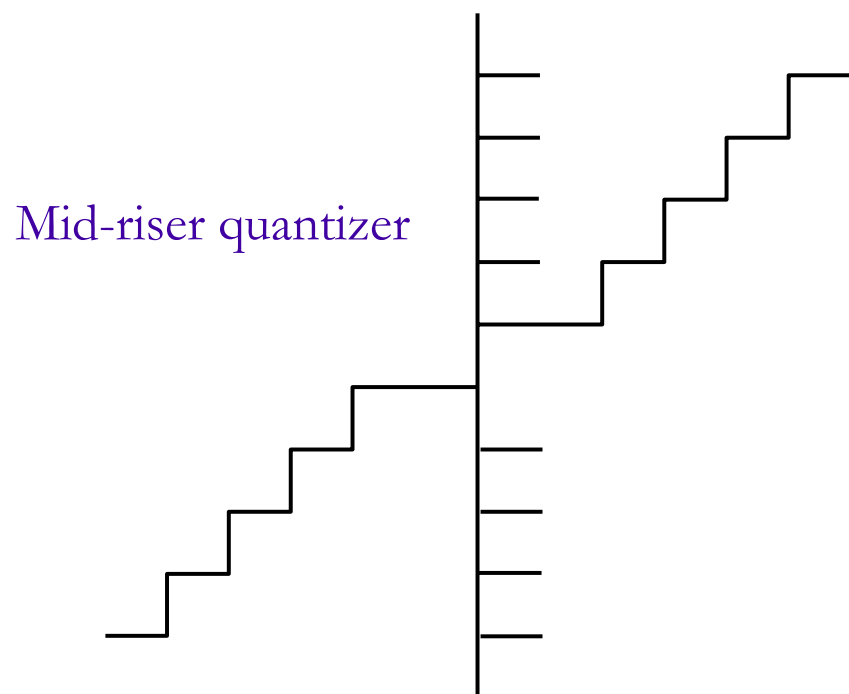
30 channels info; 2 channels management



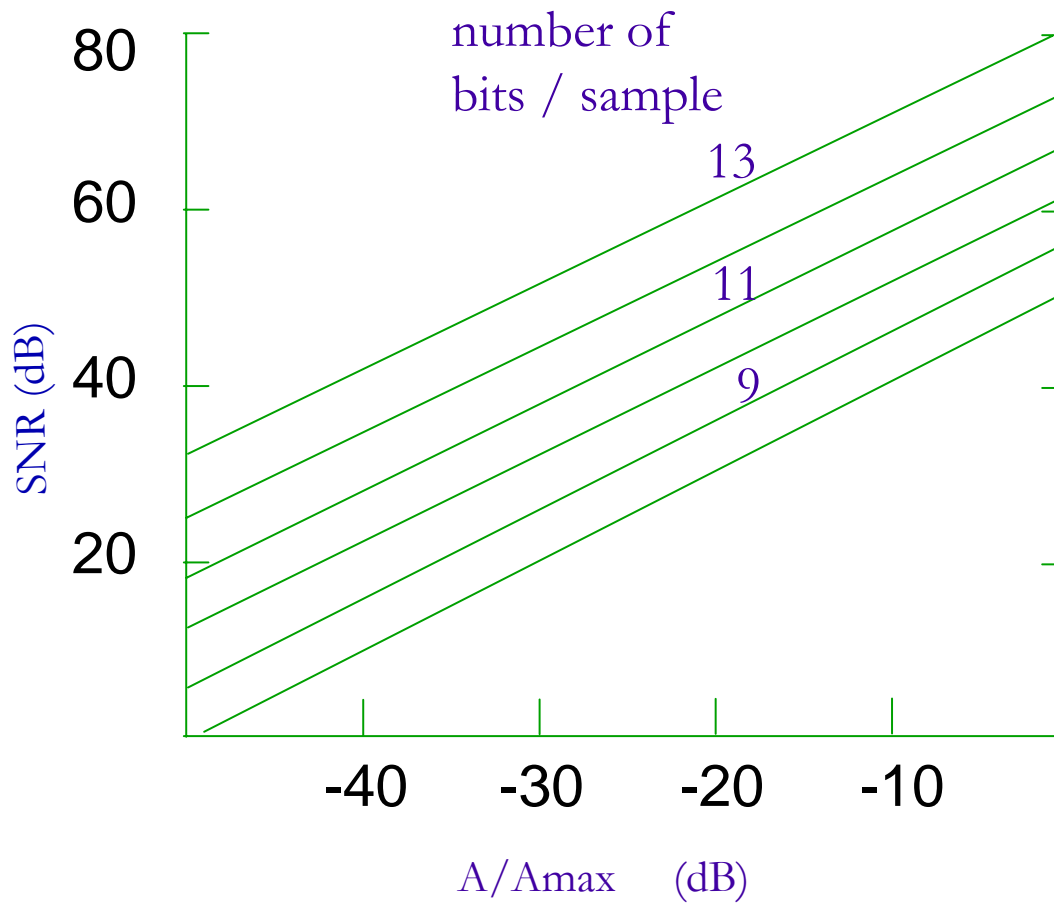
## Idle channel noise minimisation

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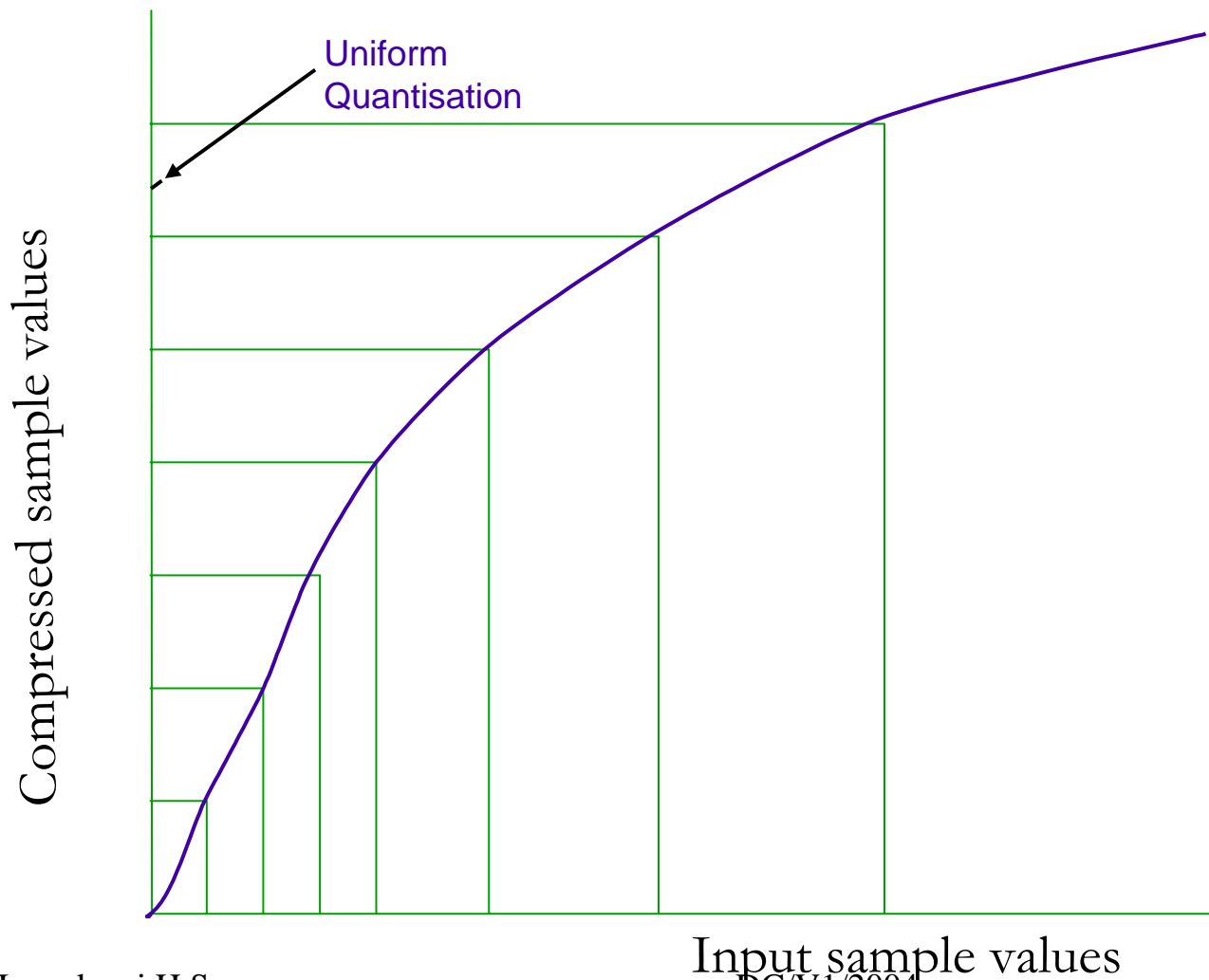
**Idle channel noise:** Caused by uncertainty in coding a sample near zero value



# Signal to quantizing noise of uniform PCM



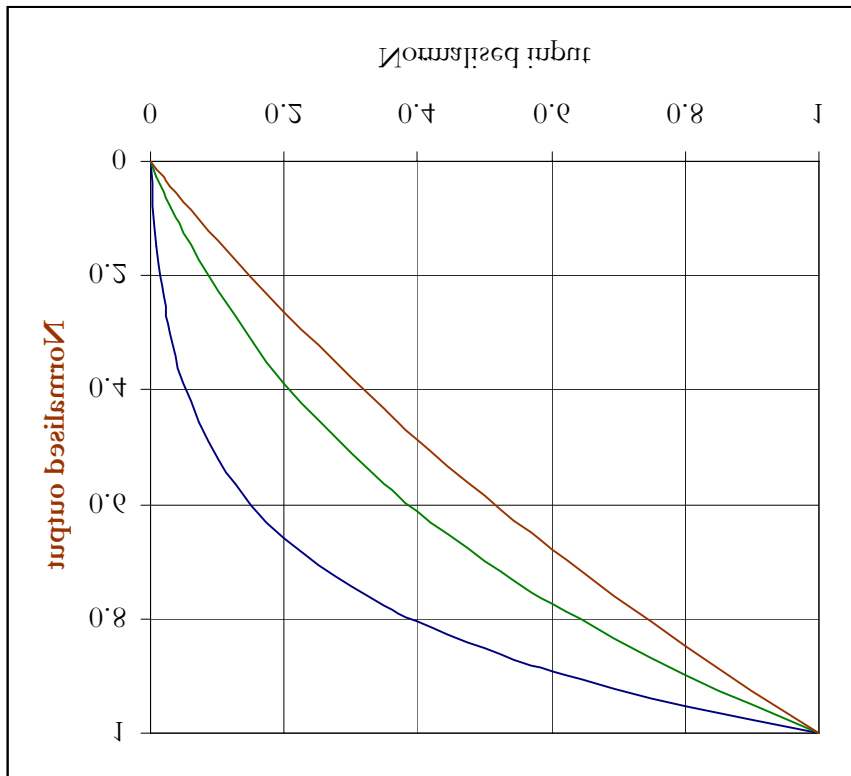
# Non-linear AD conversion





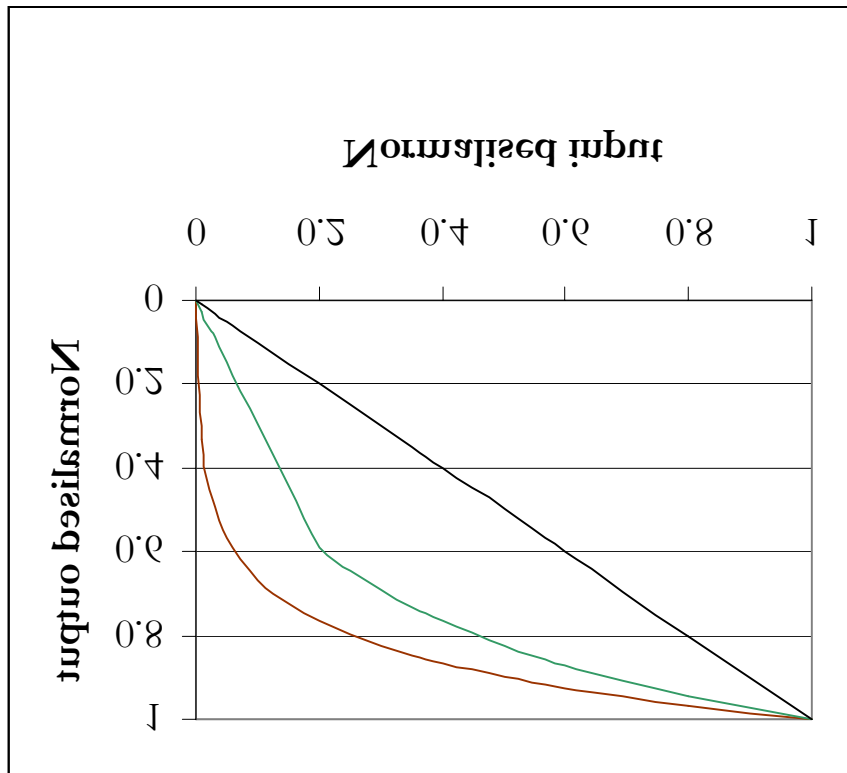
# Compression law - $\mu$ law

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# Compression law - A law

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## Non linear AD conversion laws used in PCM for speech

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$$E_{\mu}(x) = 28M(x) \frac{1^{\mu}(1 + \mu)}{1^{\mu}(1 + \mu|x|)}$$

$\mu$  law

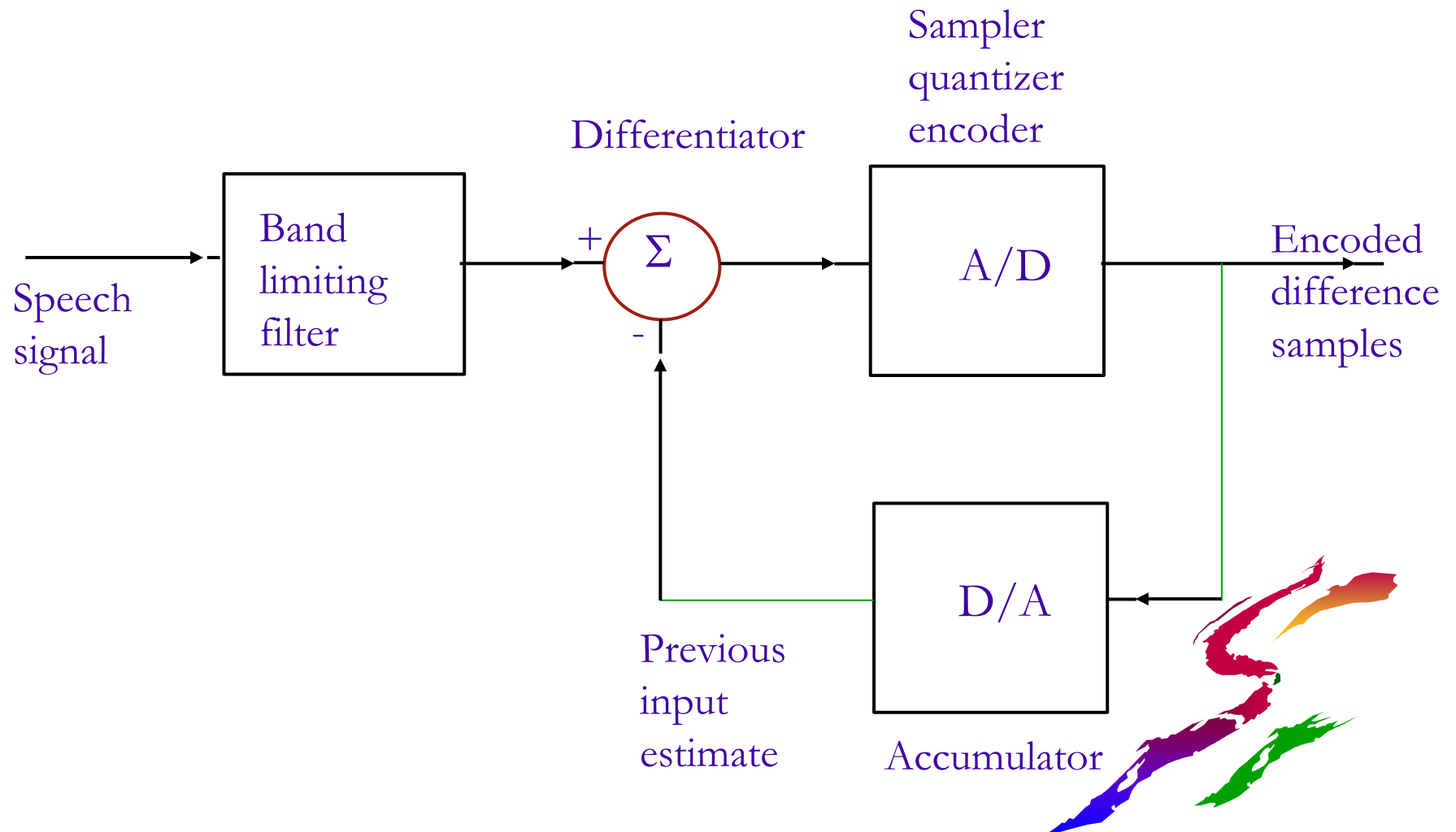
$$E_A(x) = 28M(x) \frac{1 + 1^A}{|x|^A}$$

A law

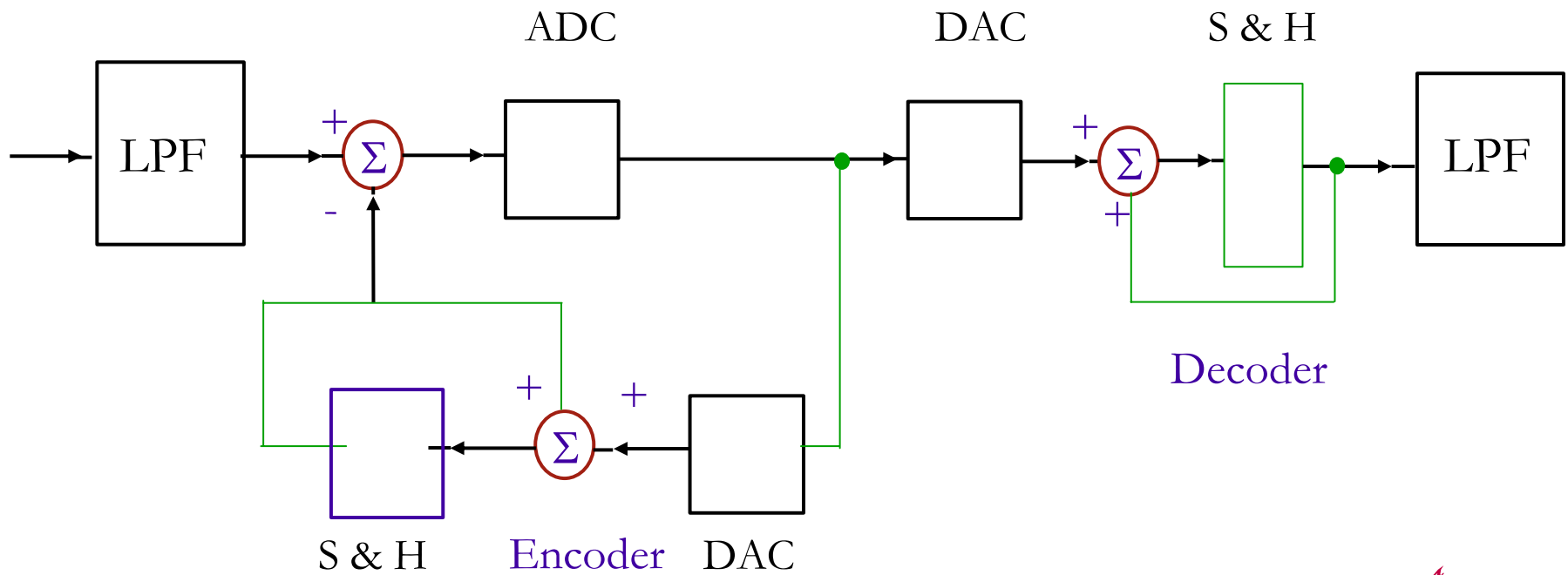


## Low bit rate coding: DPCM, Differential PCM

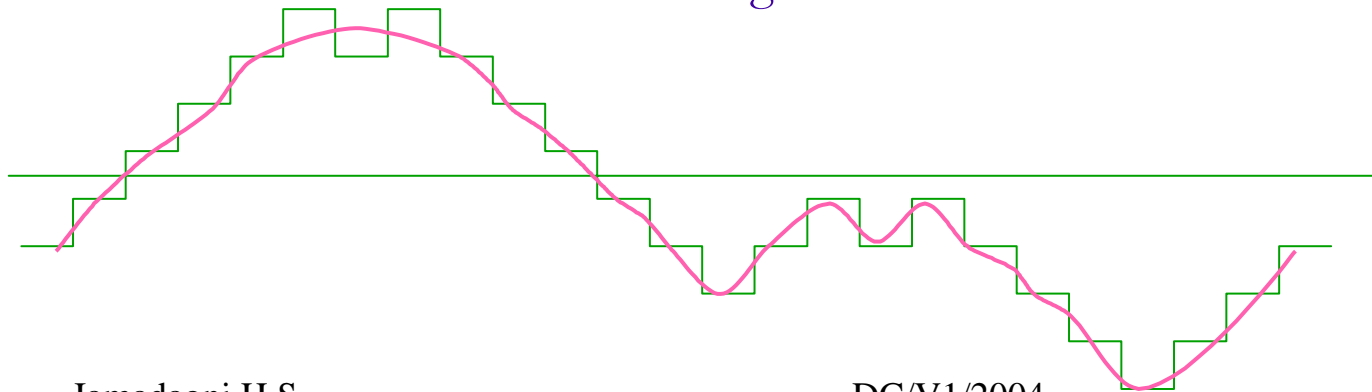
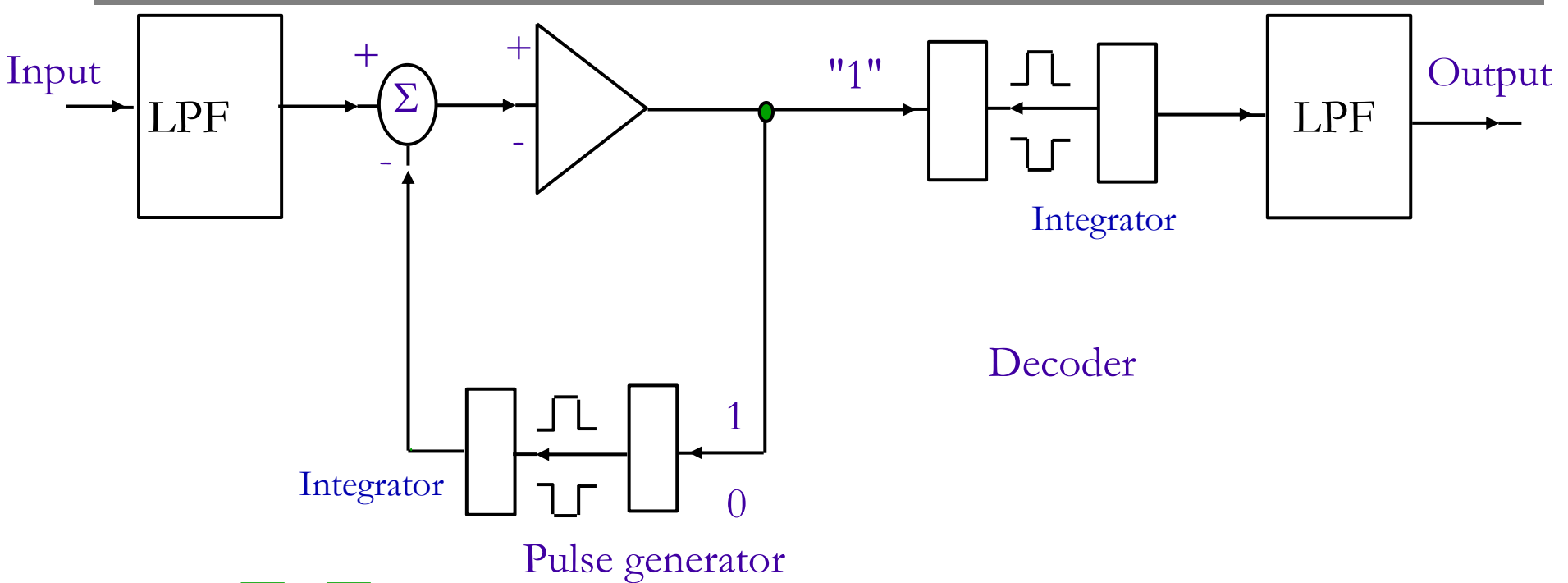
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# DPCM implementation

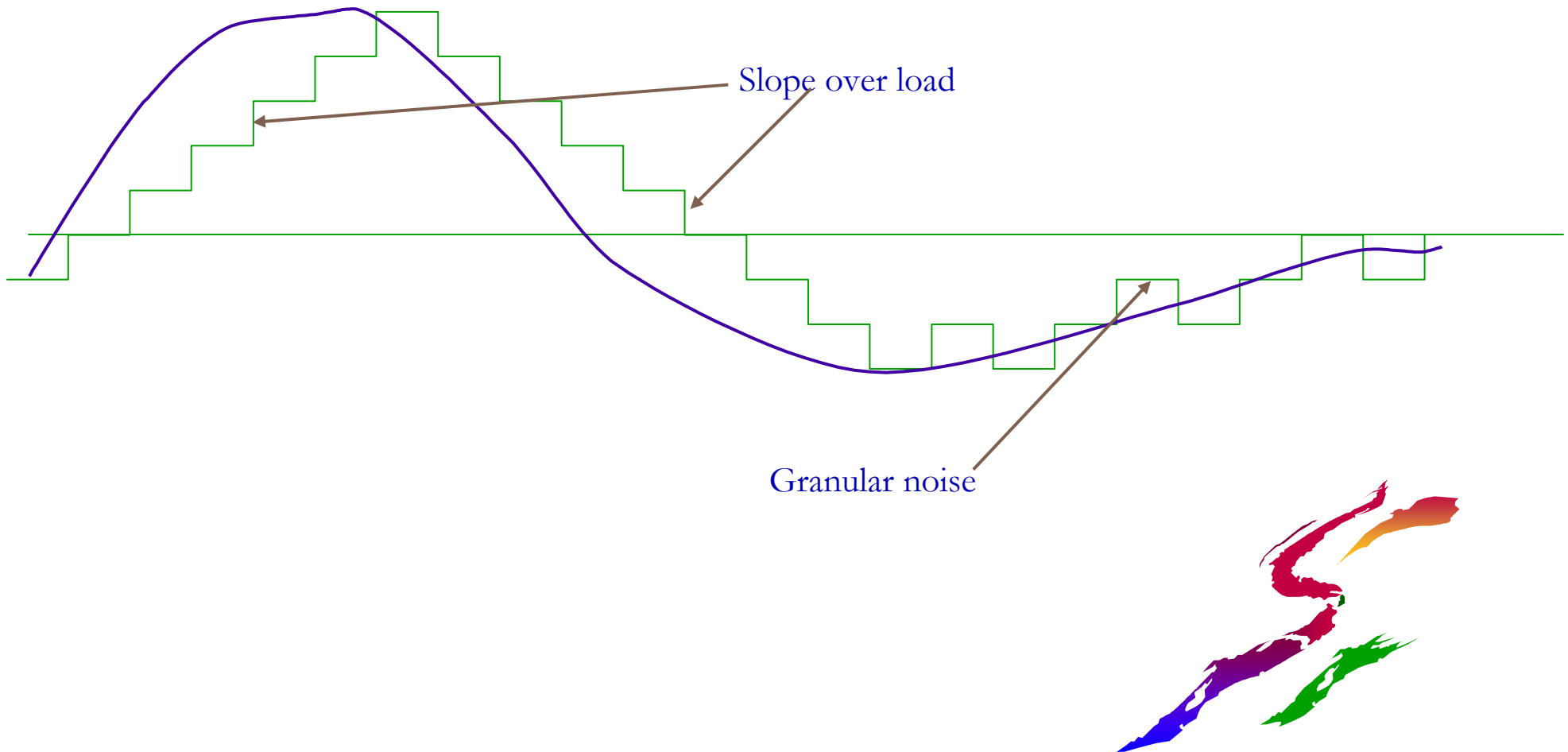


# Delta modulation



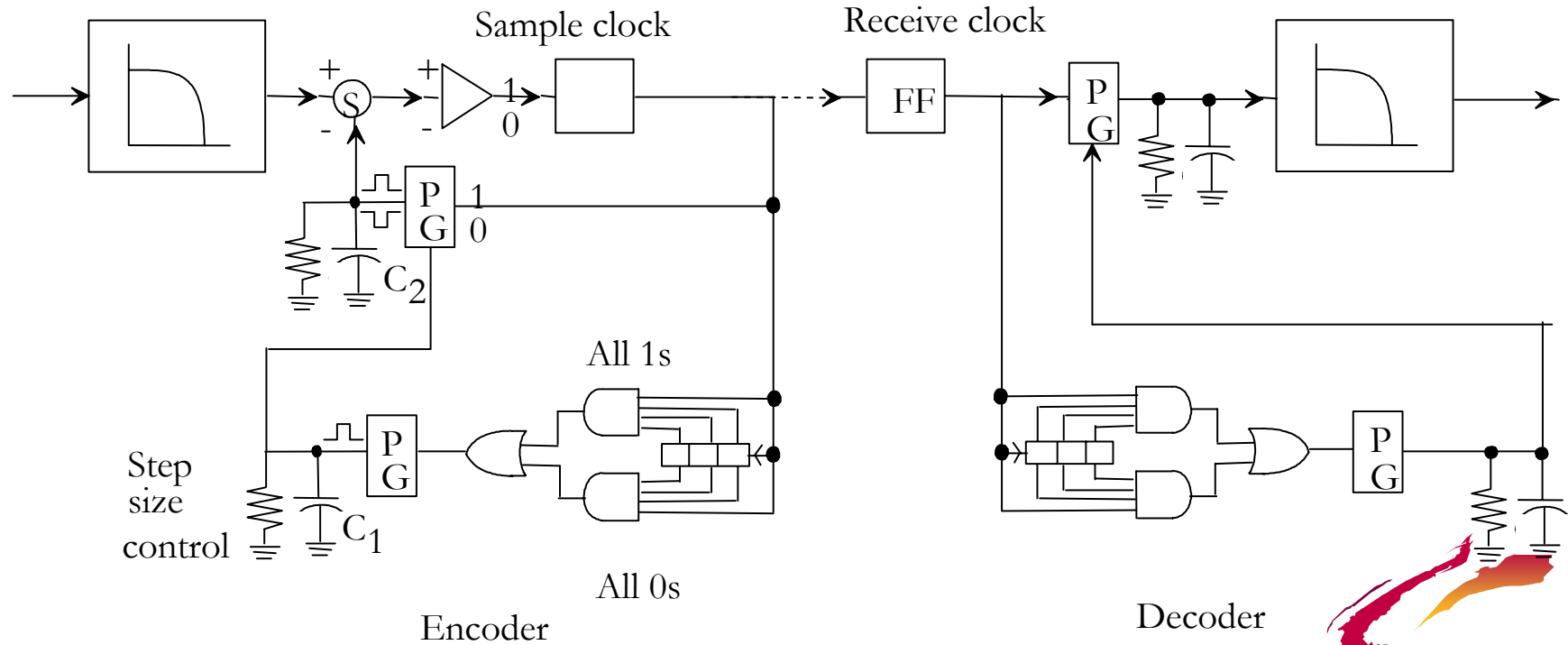
# Slope overload distortion in Delta modulation

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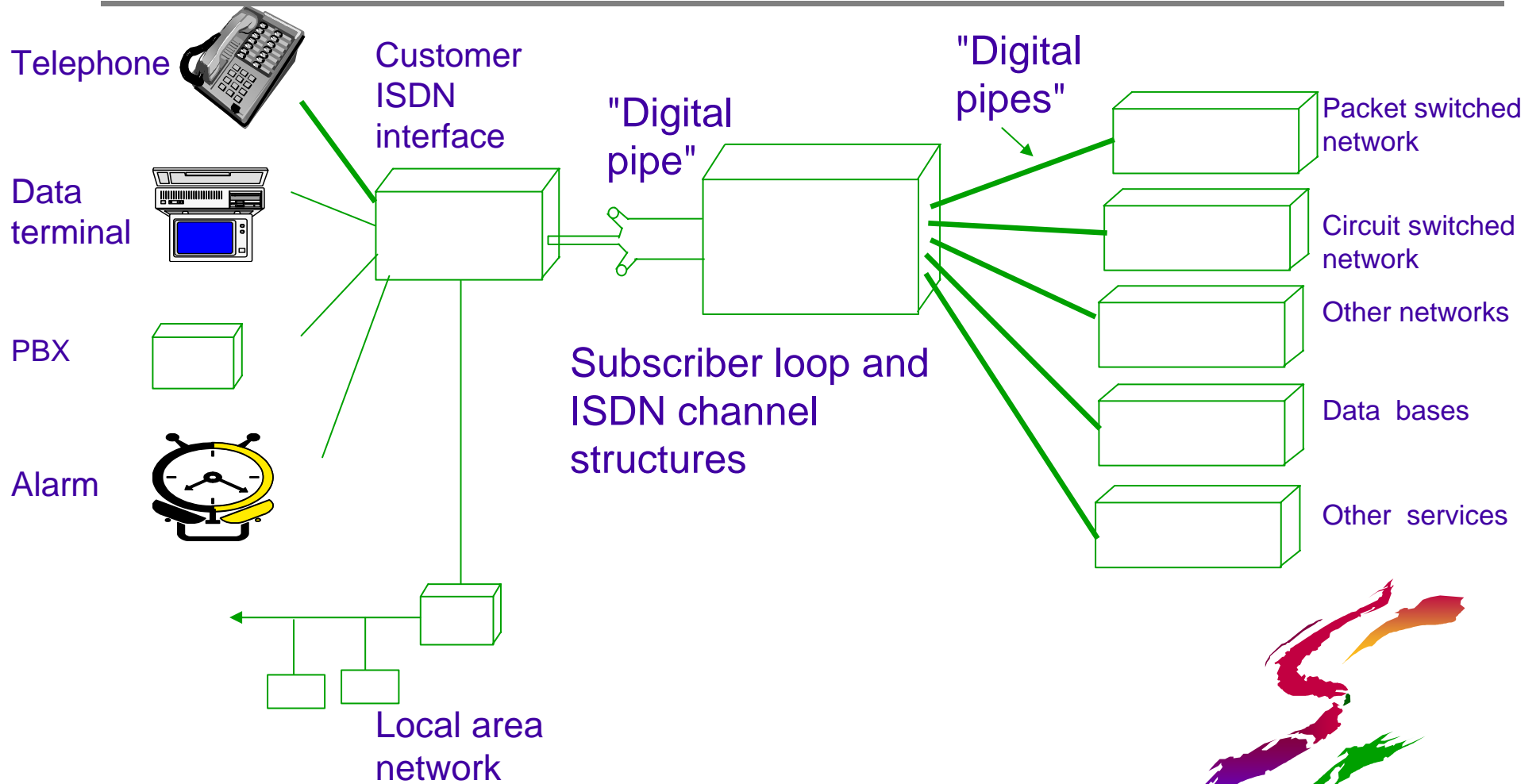
## Low Data Rate Modulation

- CVSD (Continuous Variable Slope Delta Modulation)

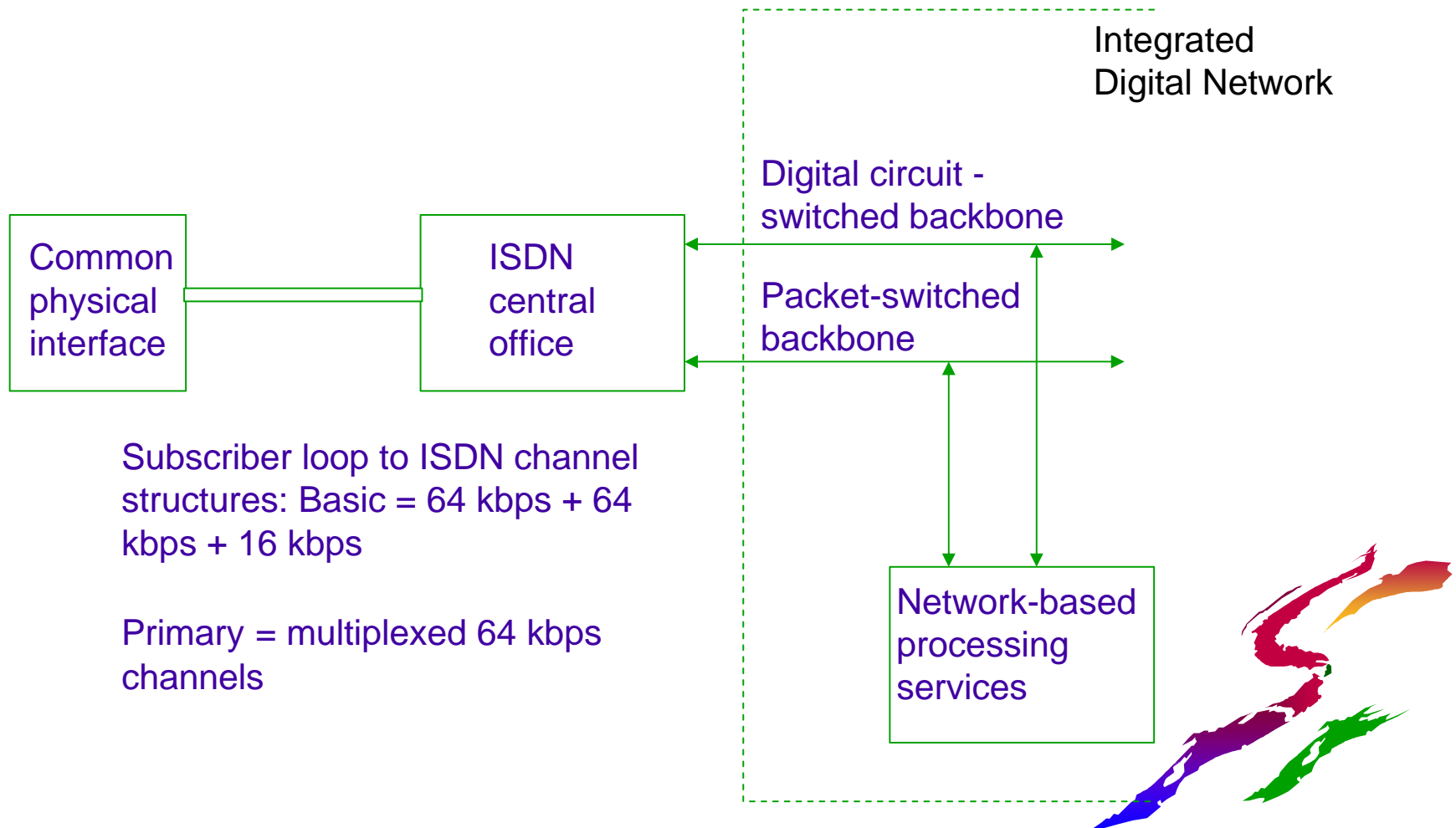




# Conceptual view of ISDN



# Block diagram of ISDN functions



## ISDN principles

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- 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.)

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- 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

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- 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

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- 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

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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

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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

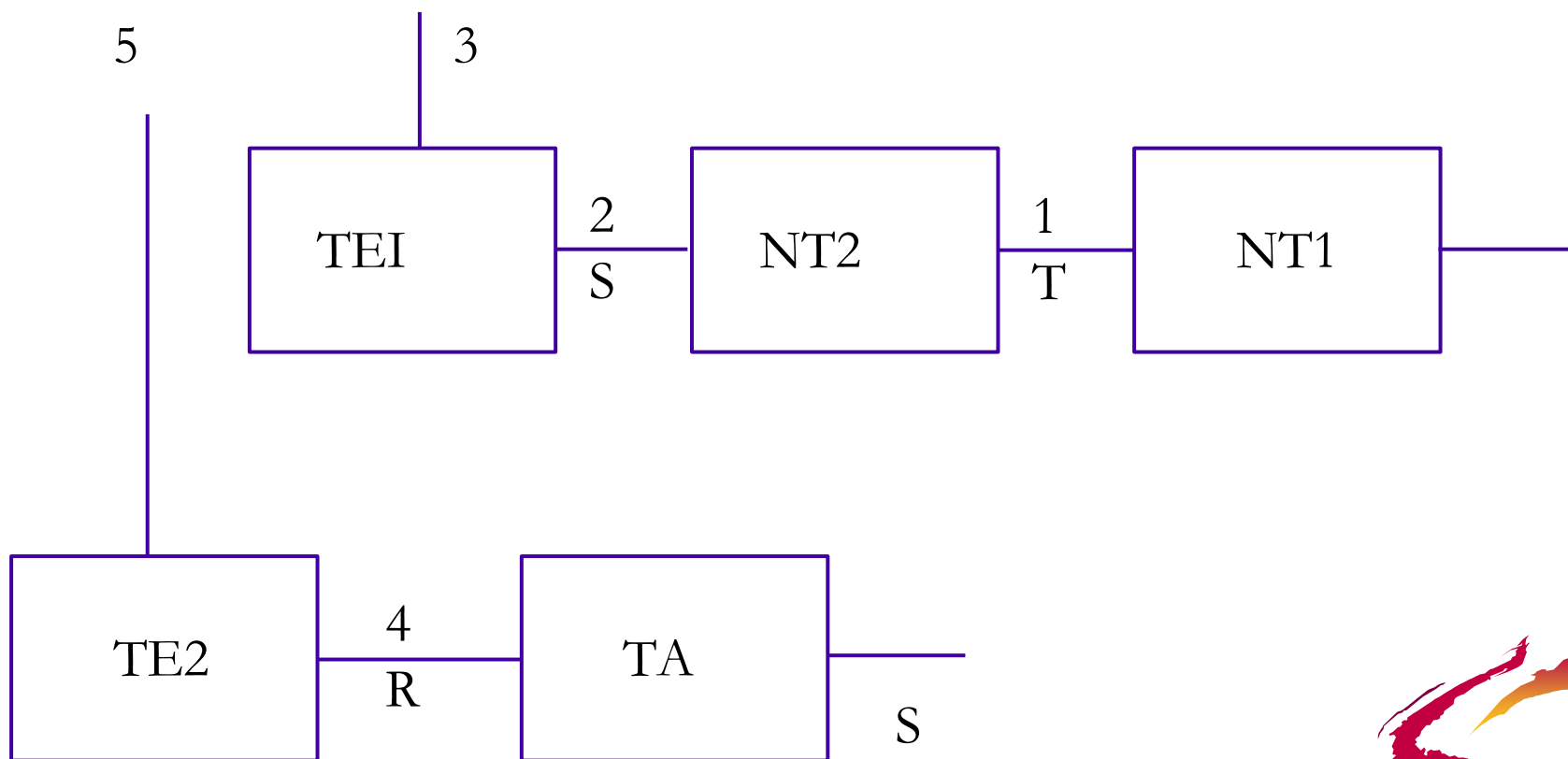
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- Low layer attributes
- High layer attributes
- Type of user information
- Layer 4 protocols
- Layer 5 protocols
- Layer 6 protocols
- Layer 7 protocols
- General attributes
- Quality of service



# Customer access to services supported by ISDN

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## Functional grouping

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- 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

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



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

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



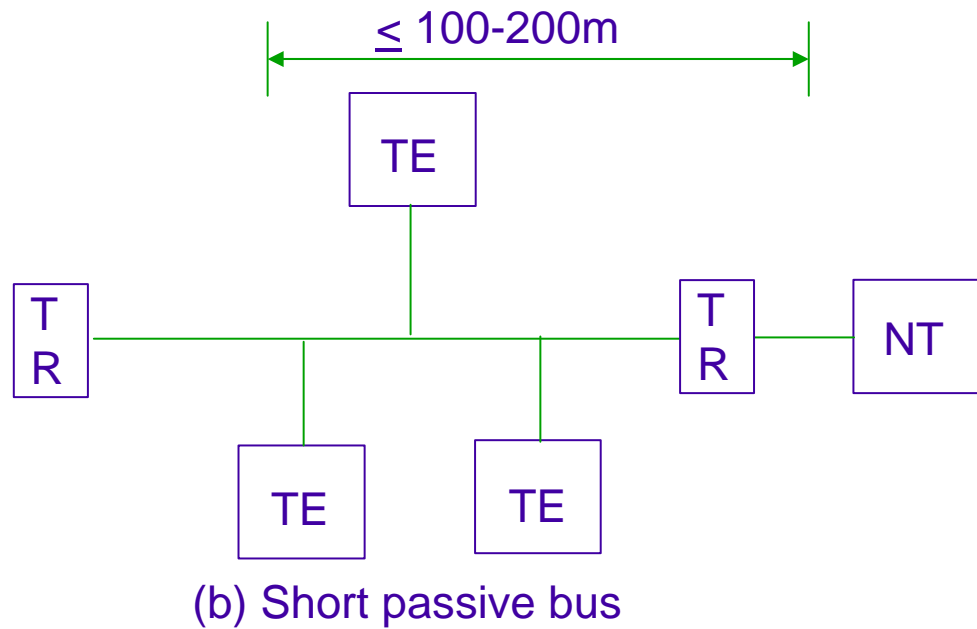
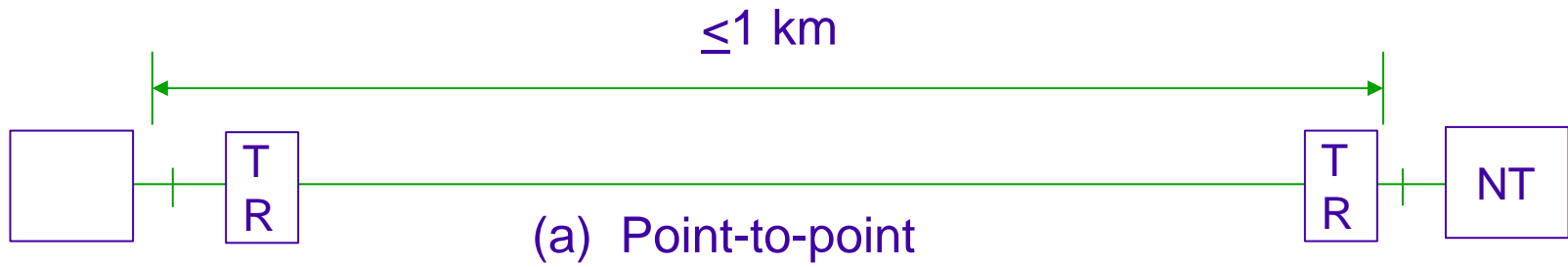
## Bearer services

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- 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

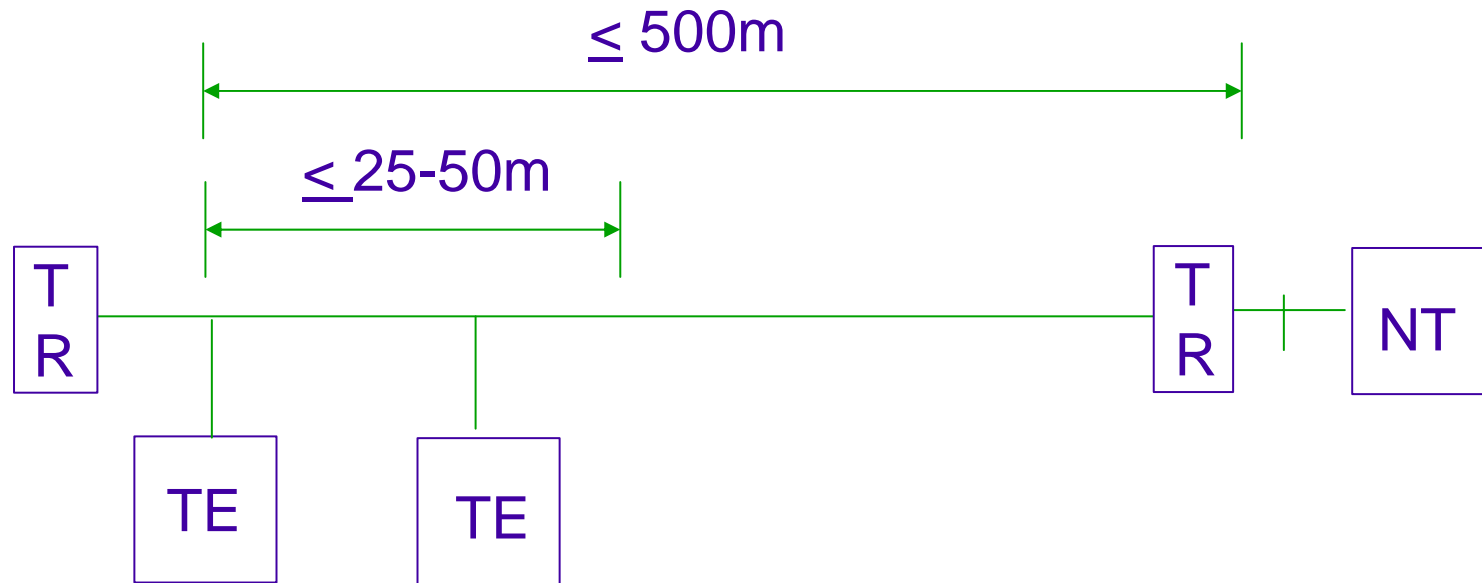


TR = Terminating Resistor



## Extended passive bus

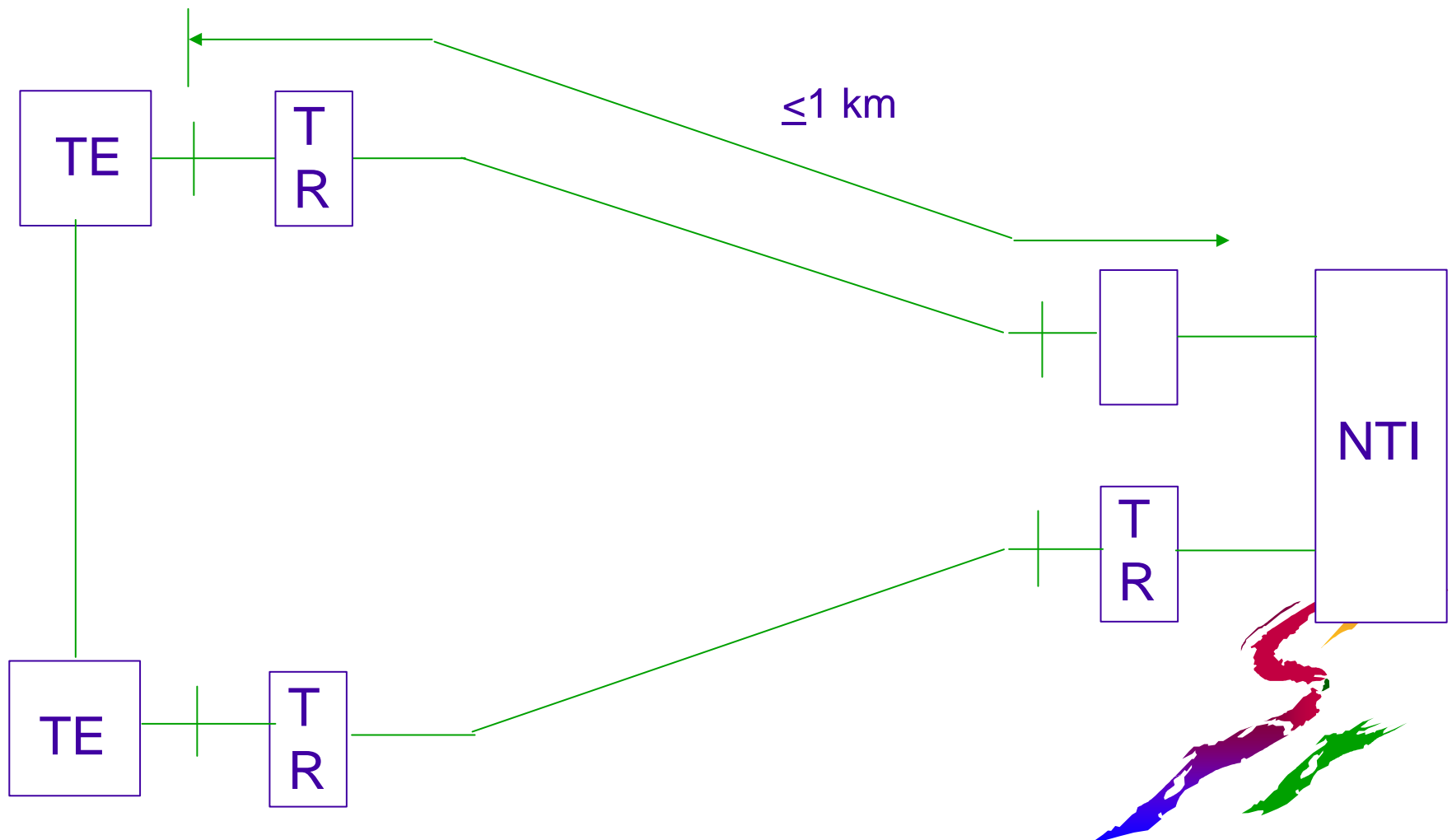
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# NT1 star

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## User - Network Interface: Layer 1 specifications

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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

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- ↗ 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

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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

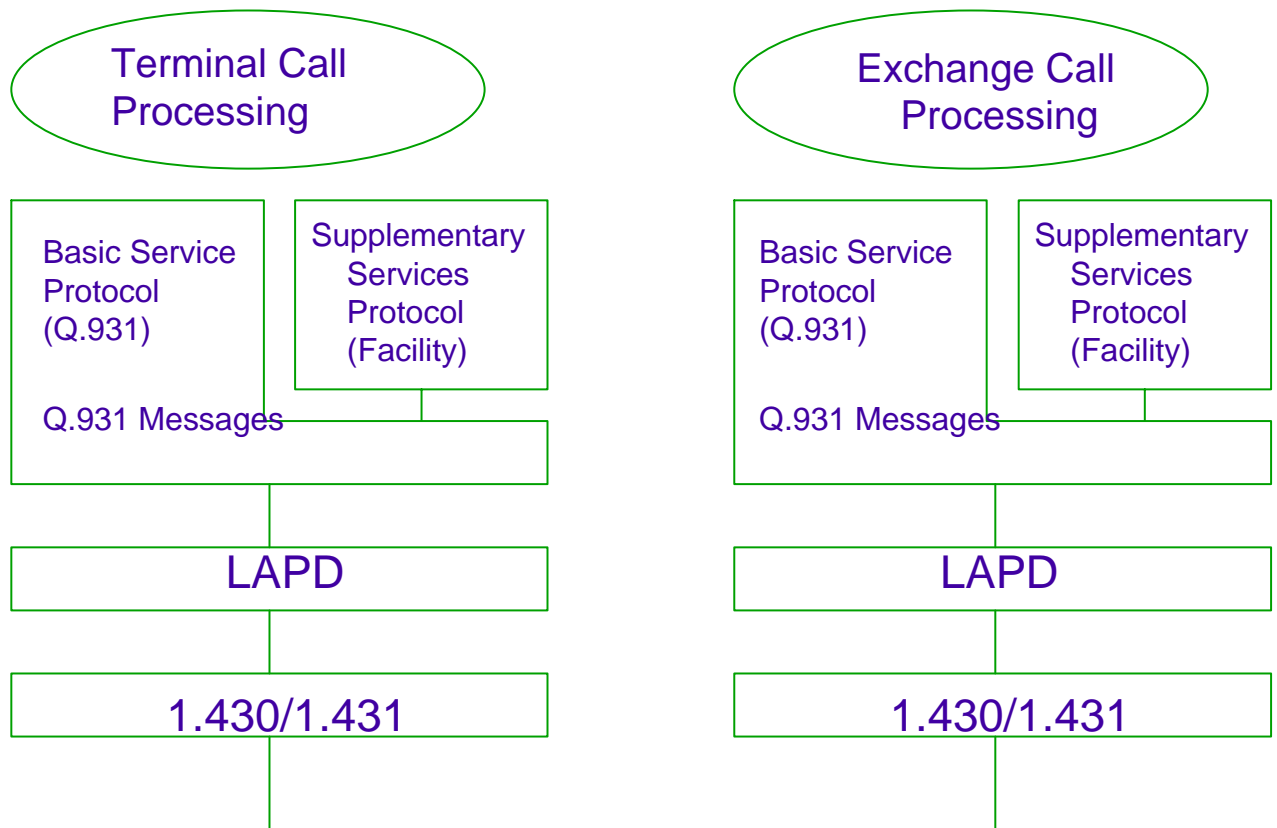
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layer 3 :	routing network connection establishment release multiplexing congestion control addressing
layer 4 :	error detection / recovery flow control layer 4 connection, release, muxing
Layer 5 :	session connection, etc. management session - transport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



# Modelling of basic and supplementary services

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## Basic Call Control

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- 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

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## 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

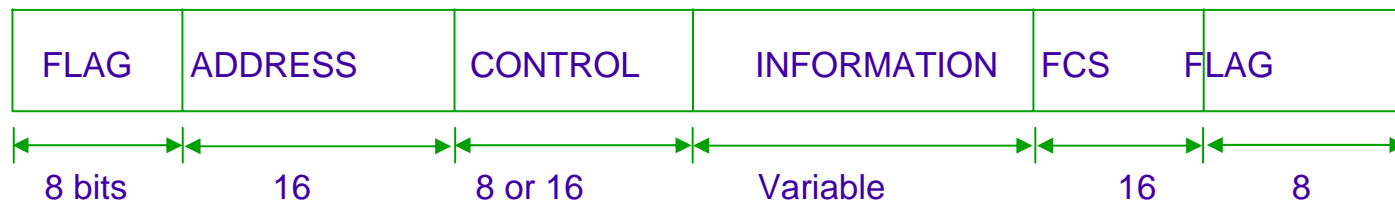
1. User Info: digitised voice, data between users. Transmitted transparently through ISDN or processed (encrypted for e.g.)
2. Control Info : acted upon this Info switching a connection / clearing change service characteristics



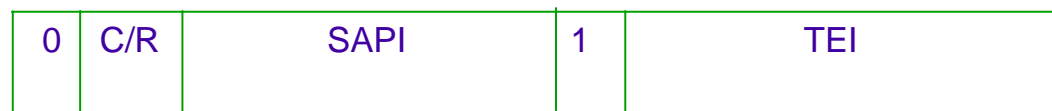


## Frame format in ISDN layer 2

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(a) Frame format

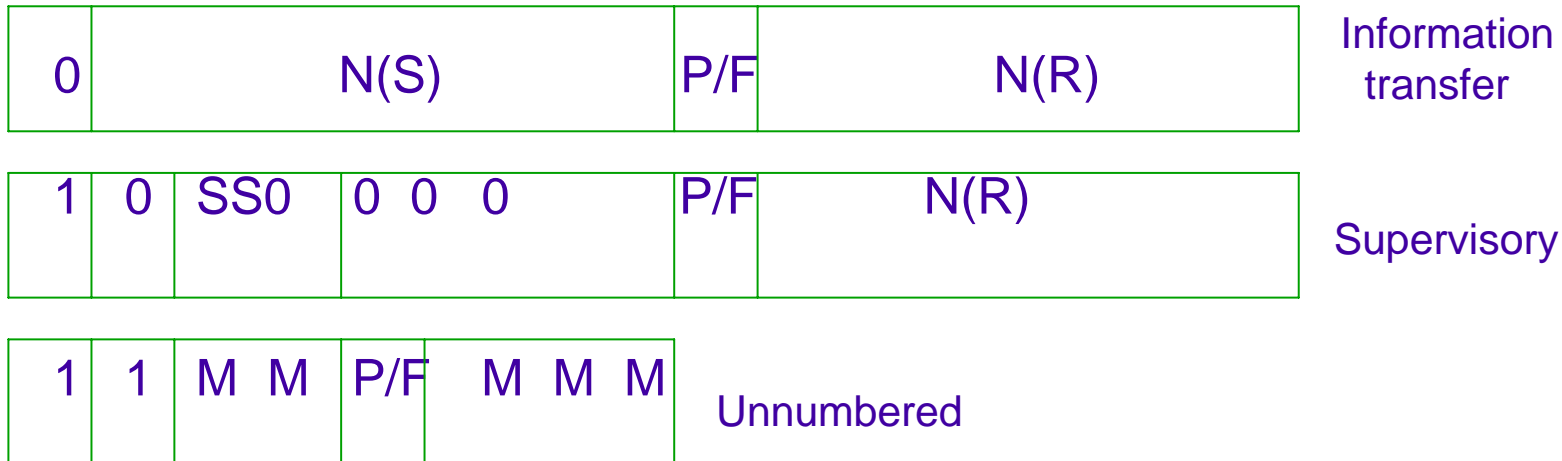


C/R is Command/response  
SAPI is Service access point identifier  
TEI is Terminal endpoint identifier



# LAPD format

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- 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

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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)	1000000*-N(R)--	C/R	Positive ack; ready to receive I-frame
RNR (Receive Not Ready)	1010000*-N(R)--	C/R	Positive ack; not ready to receive
REJ (Reject)	1001000*-N(R)--	C/R	Negative ack; go back N



## Unnumbered format

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SABME (Set Asynchronous Balanced Mode)	1111P110	C	Request logical connection
DM (Disconnected Mode)	1111F000	R	Unable to establish or 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 unacceptable frame
XID (Exchange ID-identification)	1111*101	C/R	Exchange identification information



## Q931 message types

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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

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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 =  $\phi$       global CRF



## SAPI and TEI assignments

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SAPI Value	(a) SAPI Assignments 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

TEI Value	(b) TEI Assignments 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

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### 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

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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

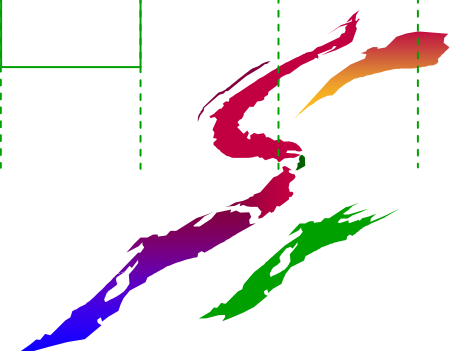
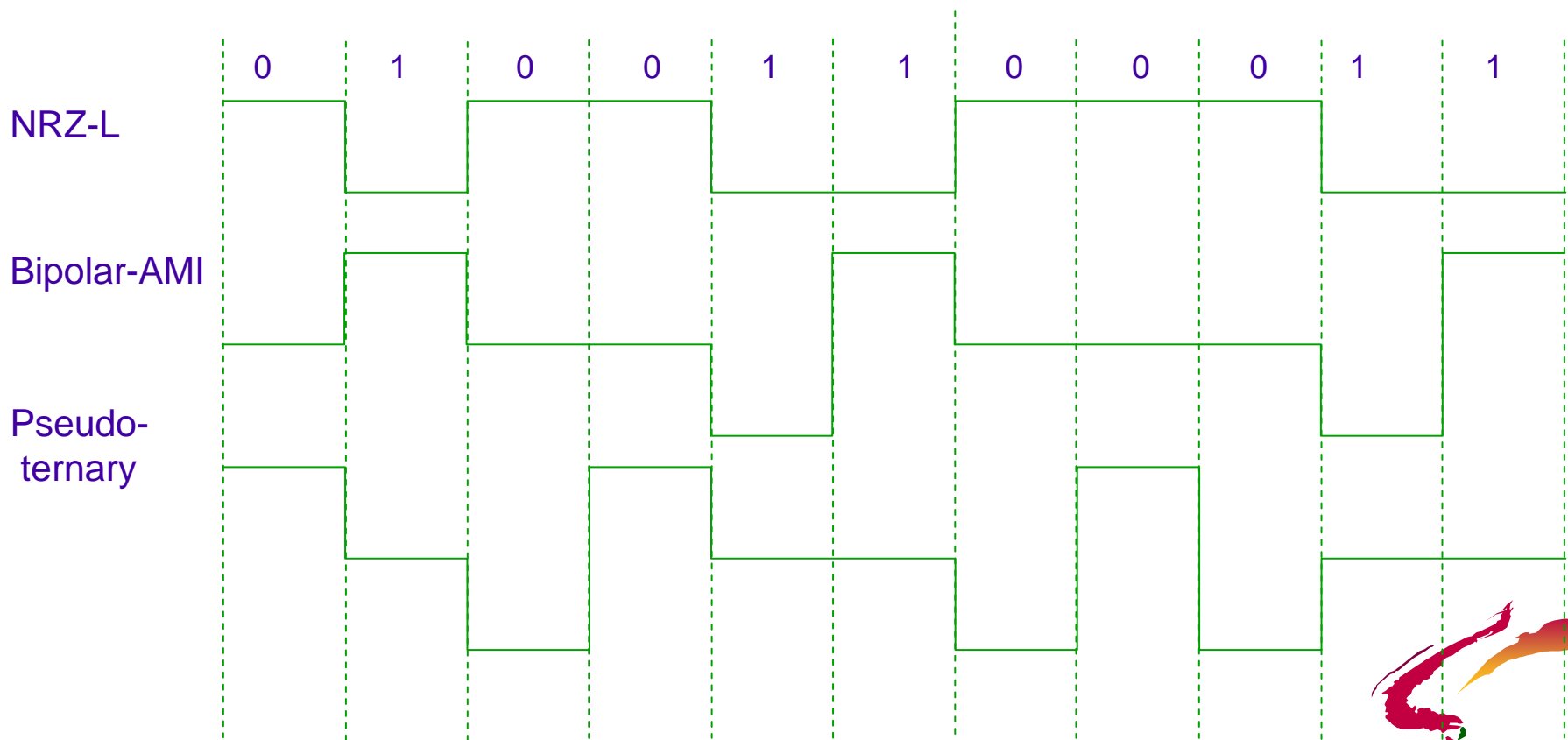
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Message	Significance	Direction	Function
DISCONNECT	global	both	Sent by user to request connection clearing; sent by network to indicate connection clearing
RELEASE	local	both	Indicates intent to release channel and call reference
RELEASE COMPLETE	local	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

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## Physical connector in ISDN

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### Contact Assignments for Plugs and Jacks of ISDN

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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

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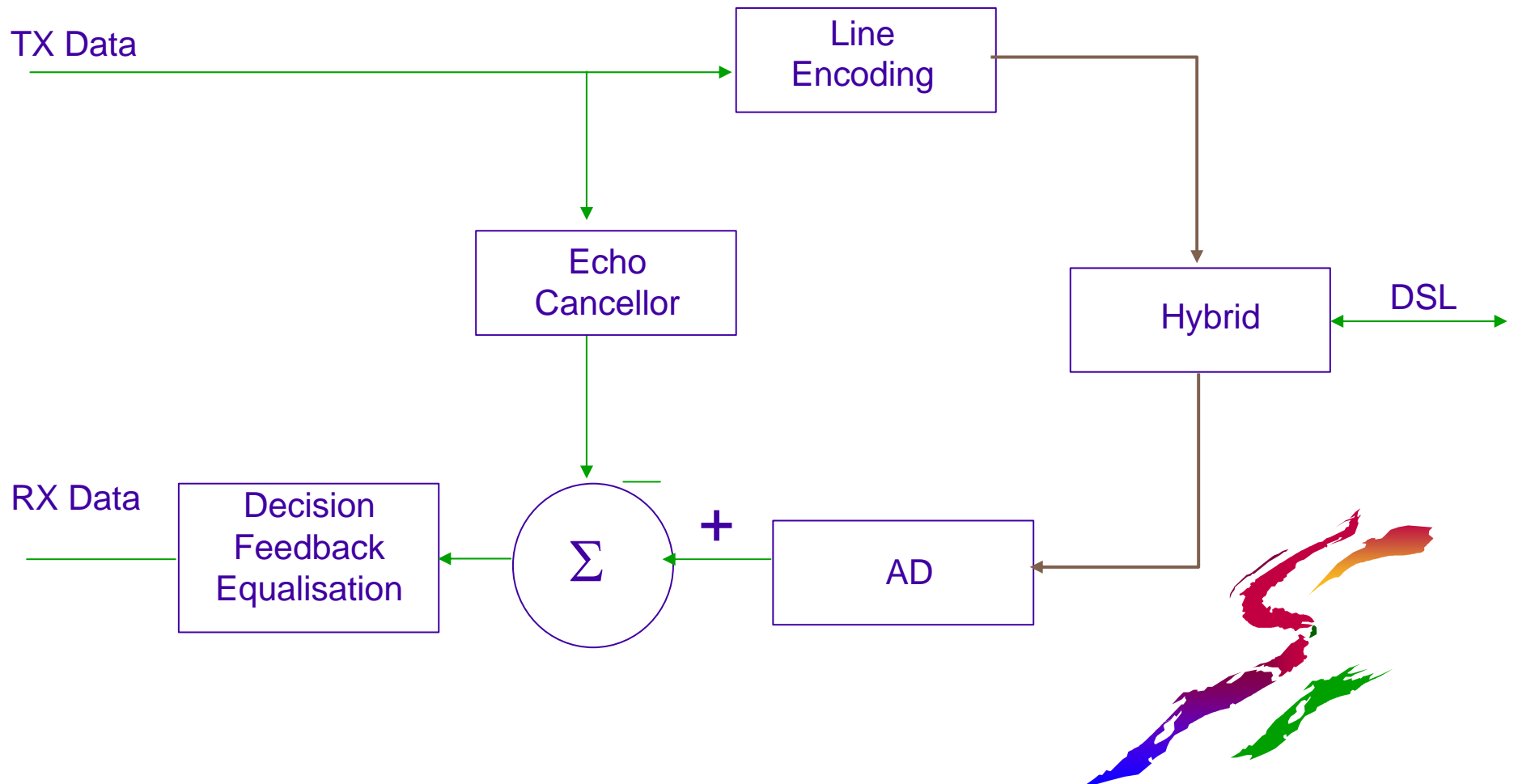
Fixed by local administration

- 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

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# ANSI U interface frame and superframe structure

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

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

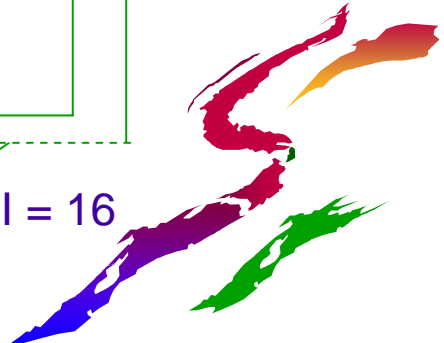
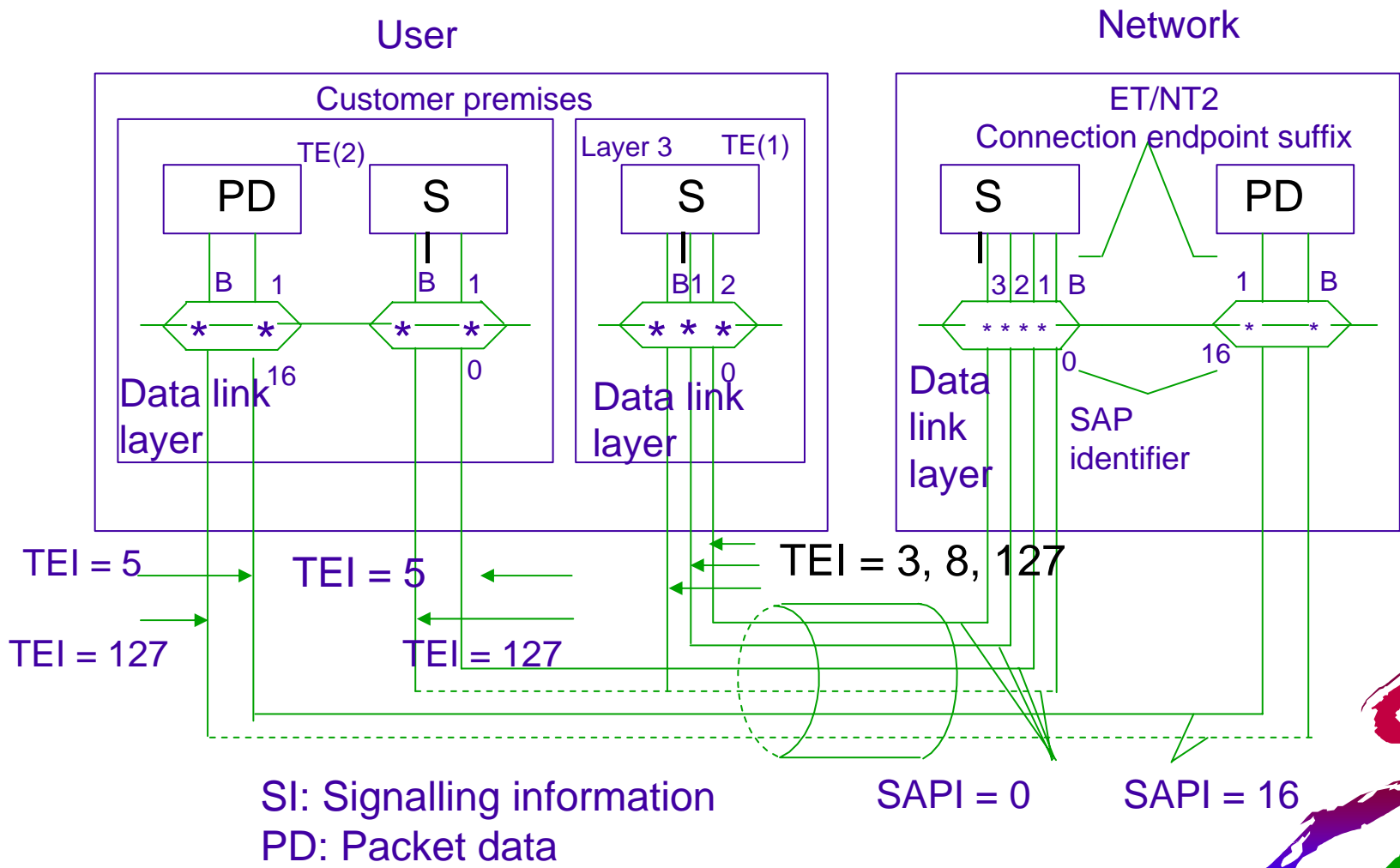
ISW= Inverted SW=-3-3+3+3+3-3+3-3-3

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



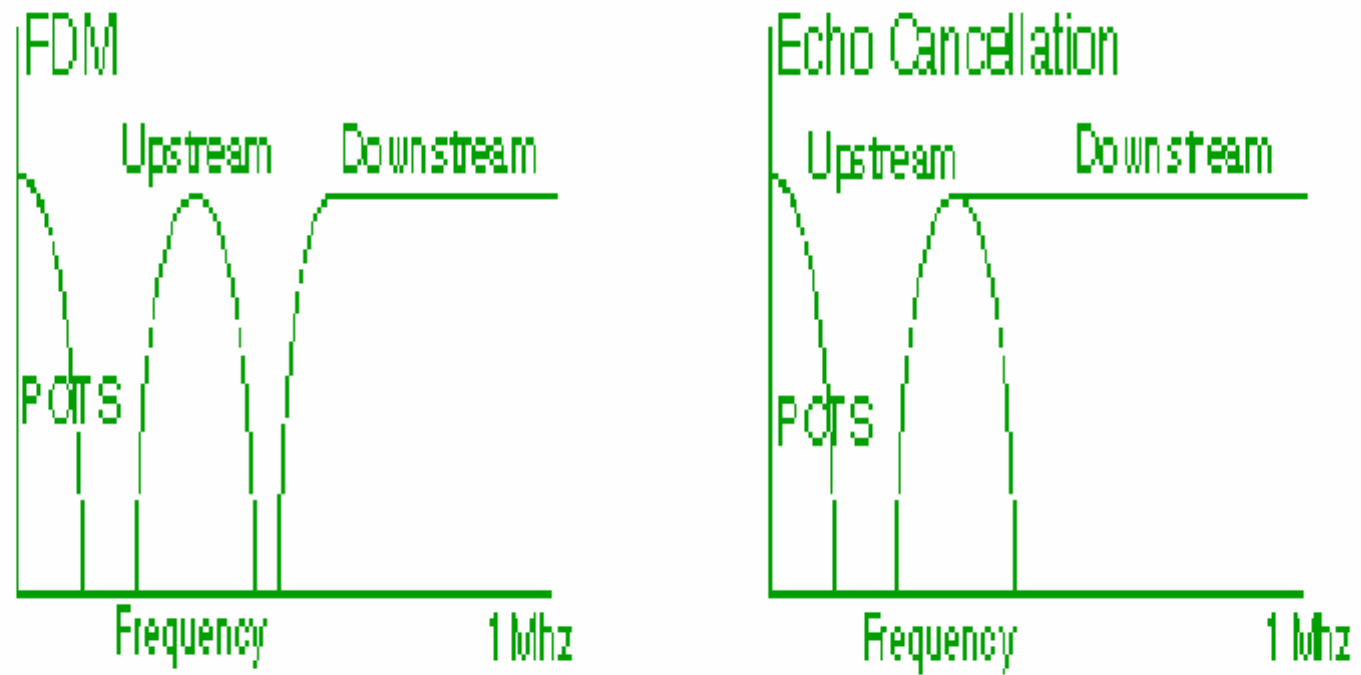
# TEI and SAPI assignment





# Asymmetric Digital Subscriber Line

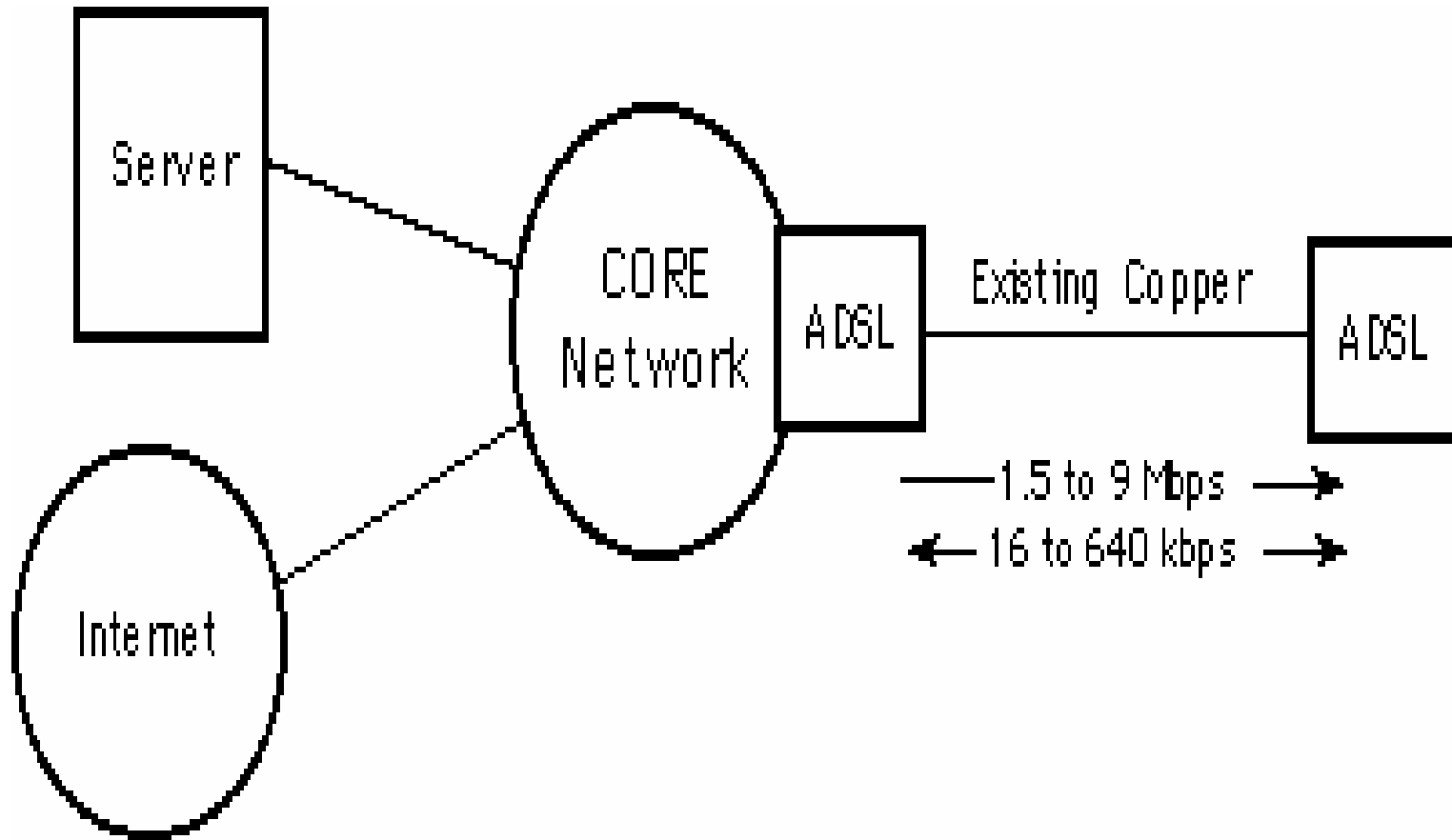
**ADSL spectrum sharing**



## 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

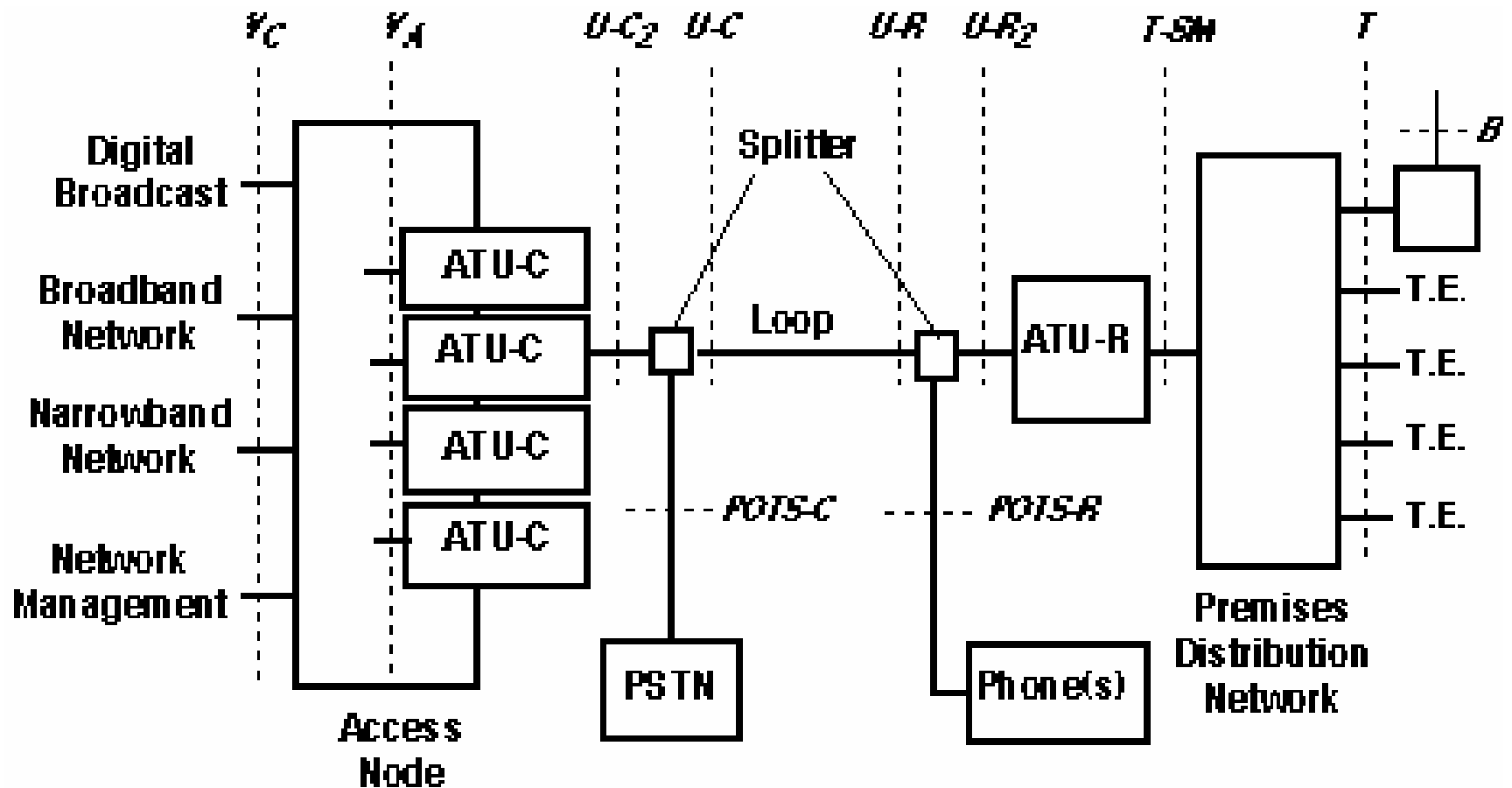
- a high speed downstream channel
  - Speed ranges from 1.5 to 6.1 Mbps
  
- a medium speed duplex channel
  - Speed range from 16 to 640 kbps
  
- a POTS (Plain Old Telephone Service) or an ISDN channel.
  - The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted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

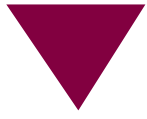
Each channel can be submultiplexed to form multiple, lower rate channels, depending on the system.

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





# Communication Systems

---

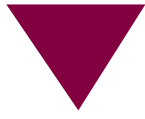
## POINT-TO-POINT

- ONE SOURCE
- ONE SINK
- FOR INFORMATION
- FEED BACK
- FROM SINKS, IN
- FACT TWO WAY COMM.
- PRIVACY NEEDED
- EAVES DROPPING TO
- BE AVOIDED
- PRIVATE DATA, INFO
- EXCHANGE
- REQUIRES ESTABLISHMENT
- OF PATH BETWEEN
- PARTIES
- THIS PATH ESTABLISHMENT
- IS CALLED "SWITCHING"
- REQUIRES "SIGNALLING"

## BROADCAST

- ONE SOURCE
- MANY SINKS
- FOR INFORMATION
- SINKS
- PRIVACY PROHIBITED
- NO SUCH REQUIREMENT
- PUBLIC INFO TRANSFER
- NO
- NO SWITCHING
- NO





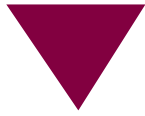
## History of Switching

---

- 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

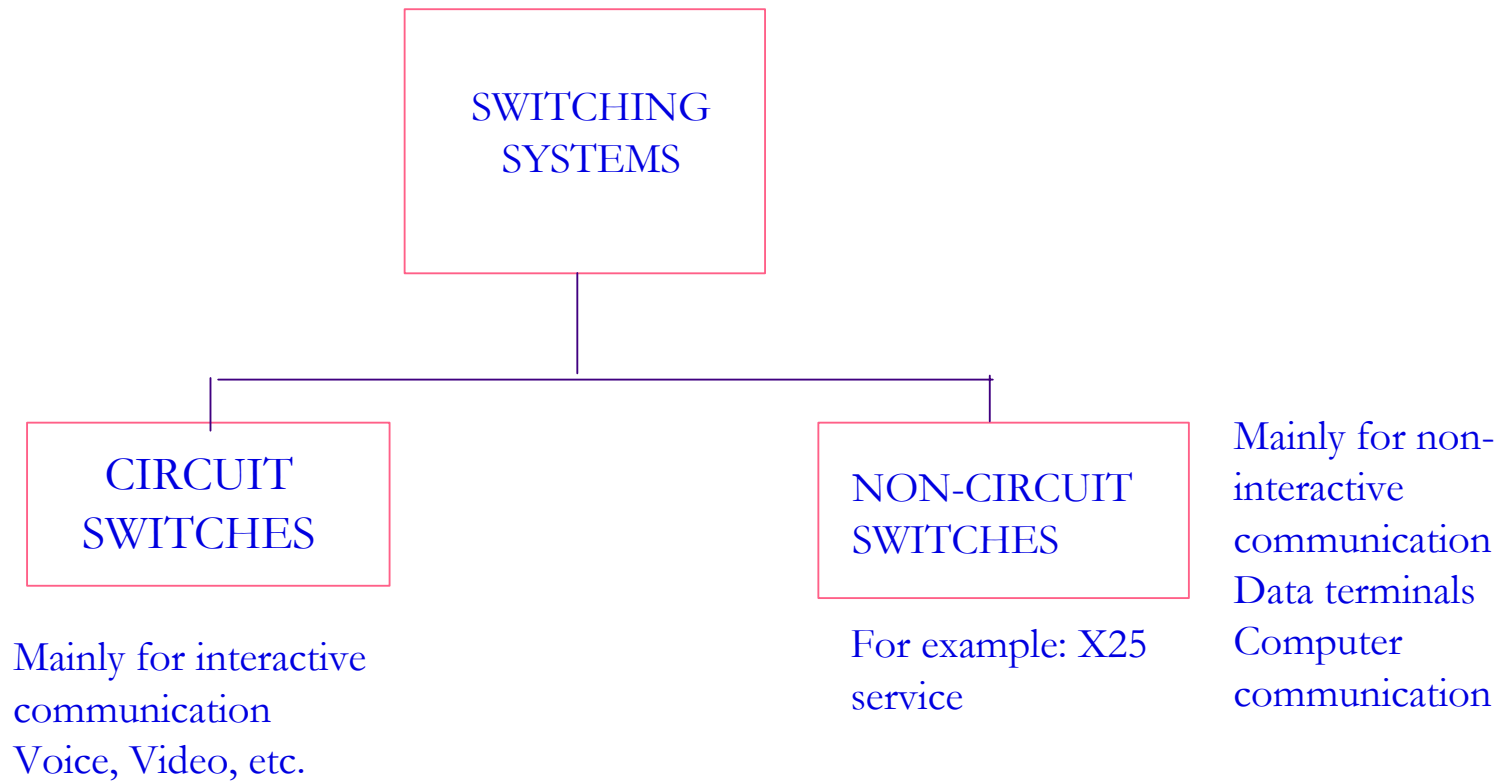
PAX : Private automatic exchange useful for local connections only

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

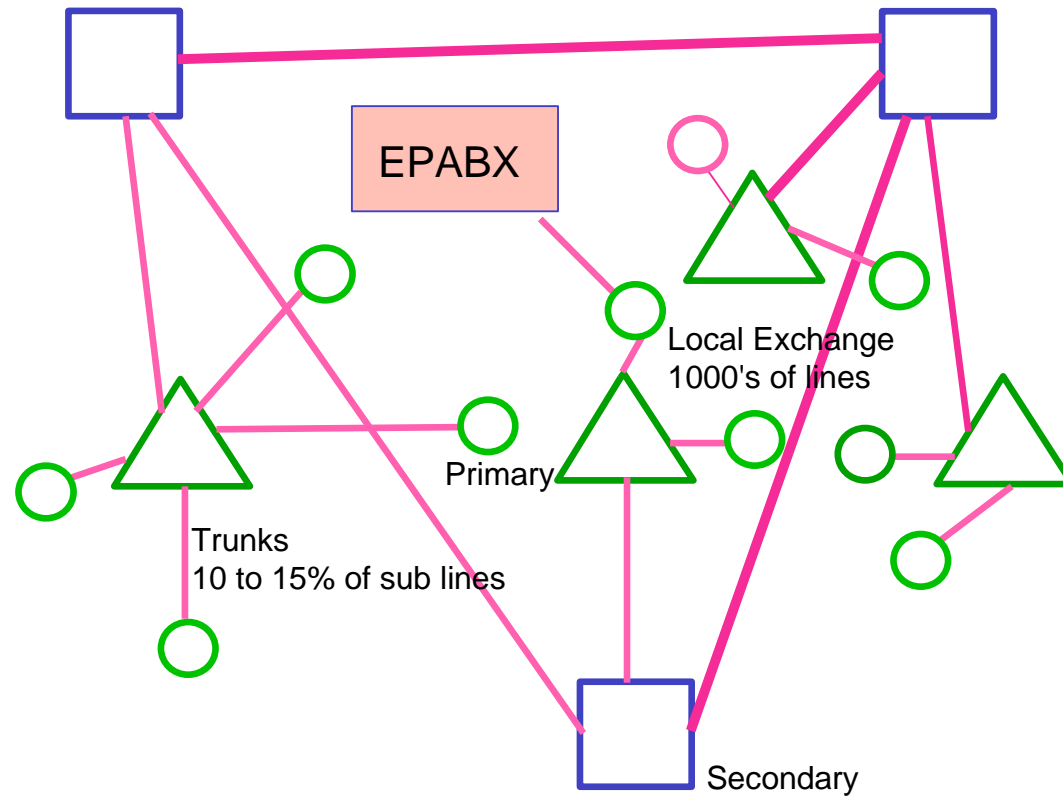


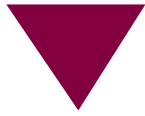
# Types of Switching Systems

---



# Switching system topology





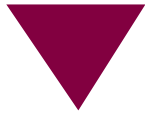
## Signals in Switching Systems

---

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

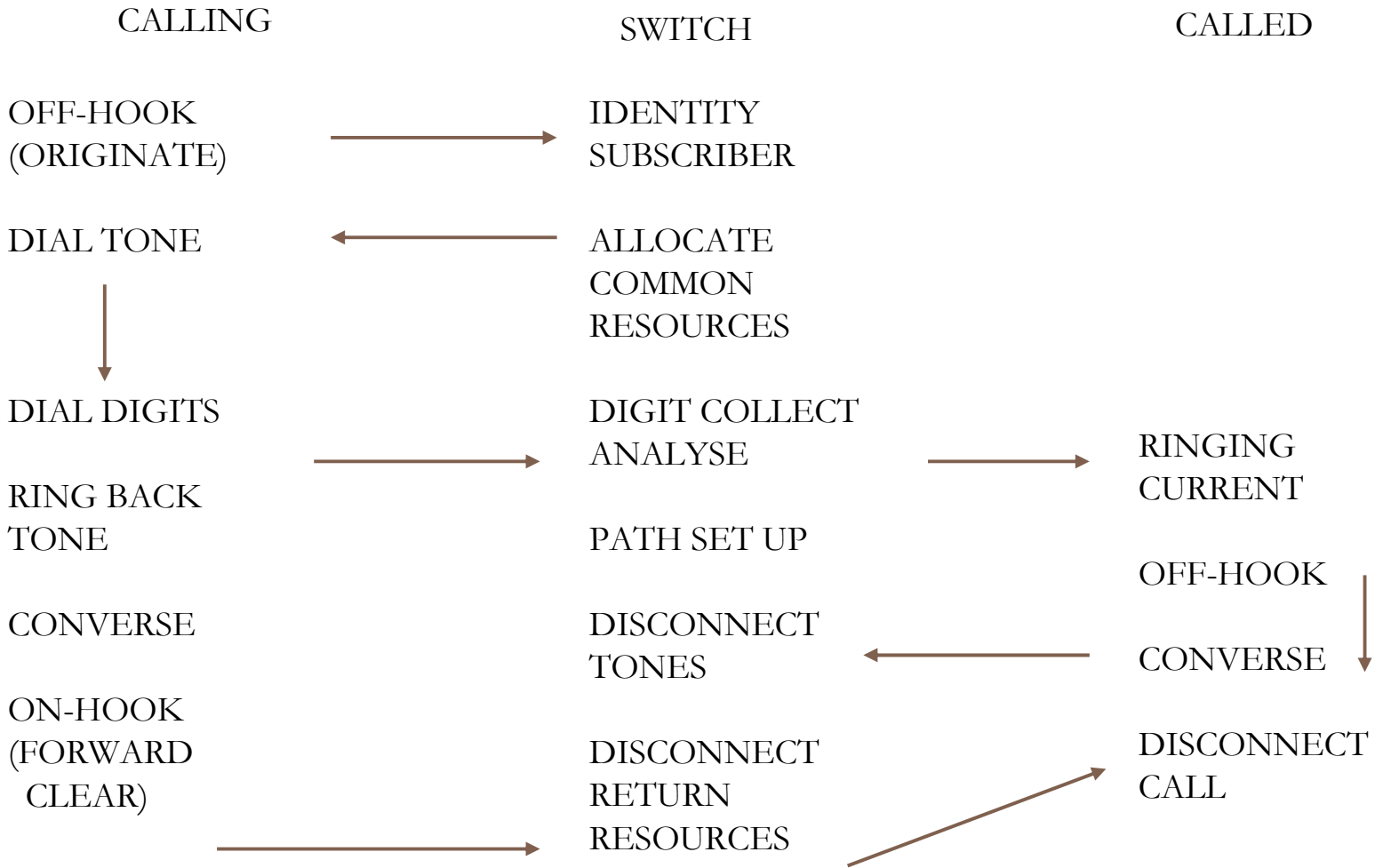
SEPARATE CHANNEL FOR SIGNALS

3. MANAGEMENT

METERING , DIAGNOSTICS, CLASS OF SERVICE



# Call processing in a Switch



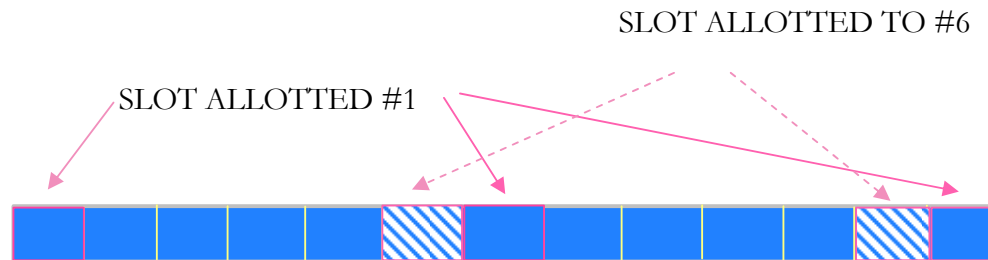
# Switching System Architectures

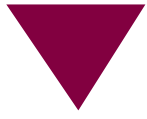
## SPACE DIVISION

- 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

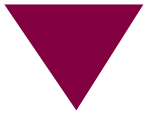
- ↗ USING REED CONTACTS FOR CROSS POINTS
- ↗ USING SOLID STATE (JFETS/MOS FETs) FOR CROSS POINTS
- ↗ USING THYRISTORS/TRIACS FOR CROSS POINTS



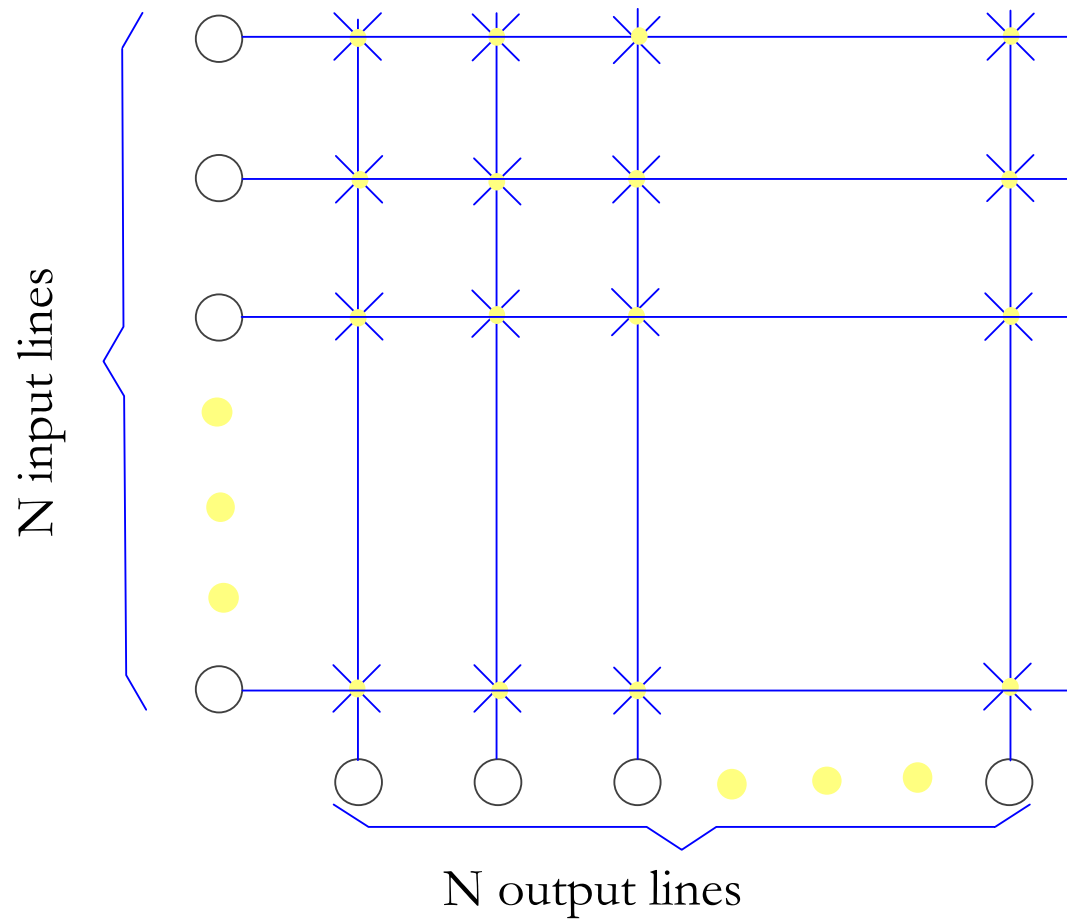
## Analogue Switch Features

---

- ↗ 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



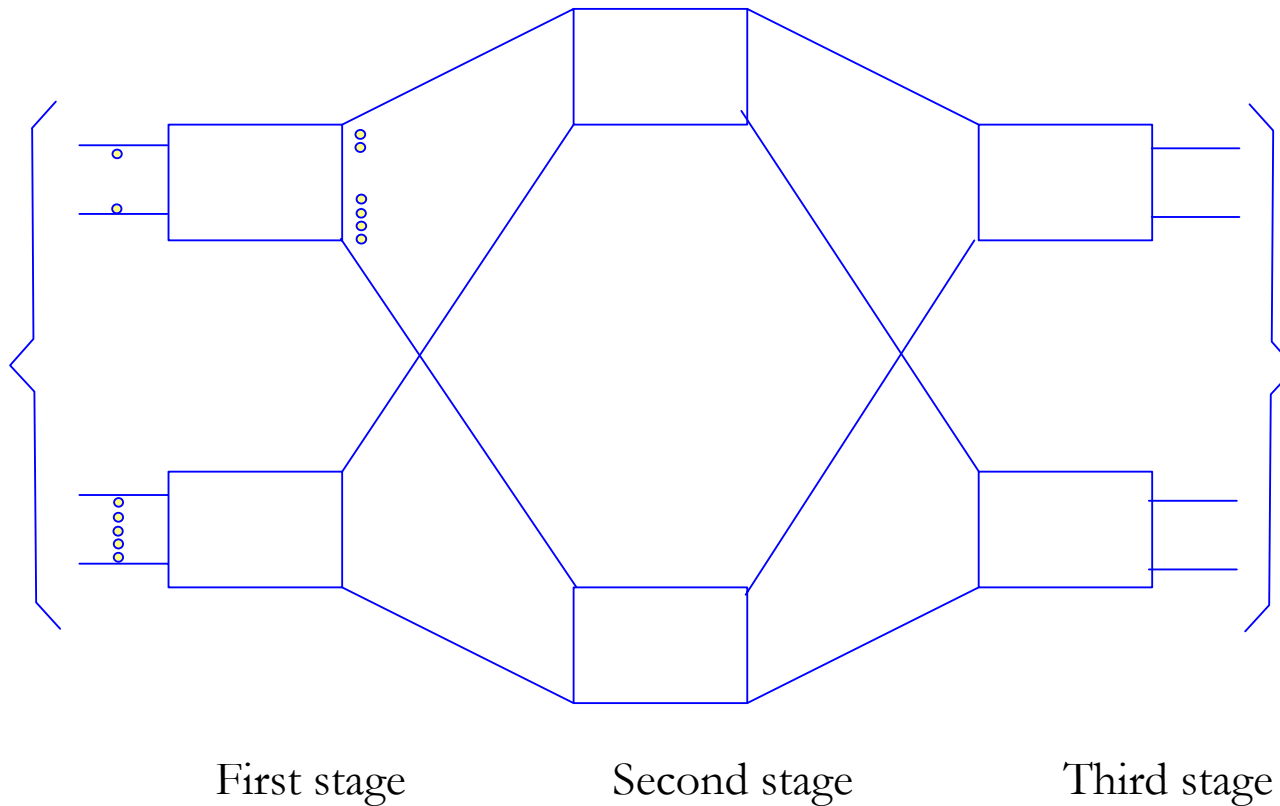
## A generic N by N switch





# Space division switch

---



Three-stage space-division switch

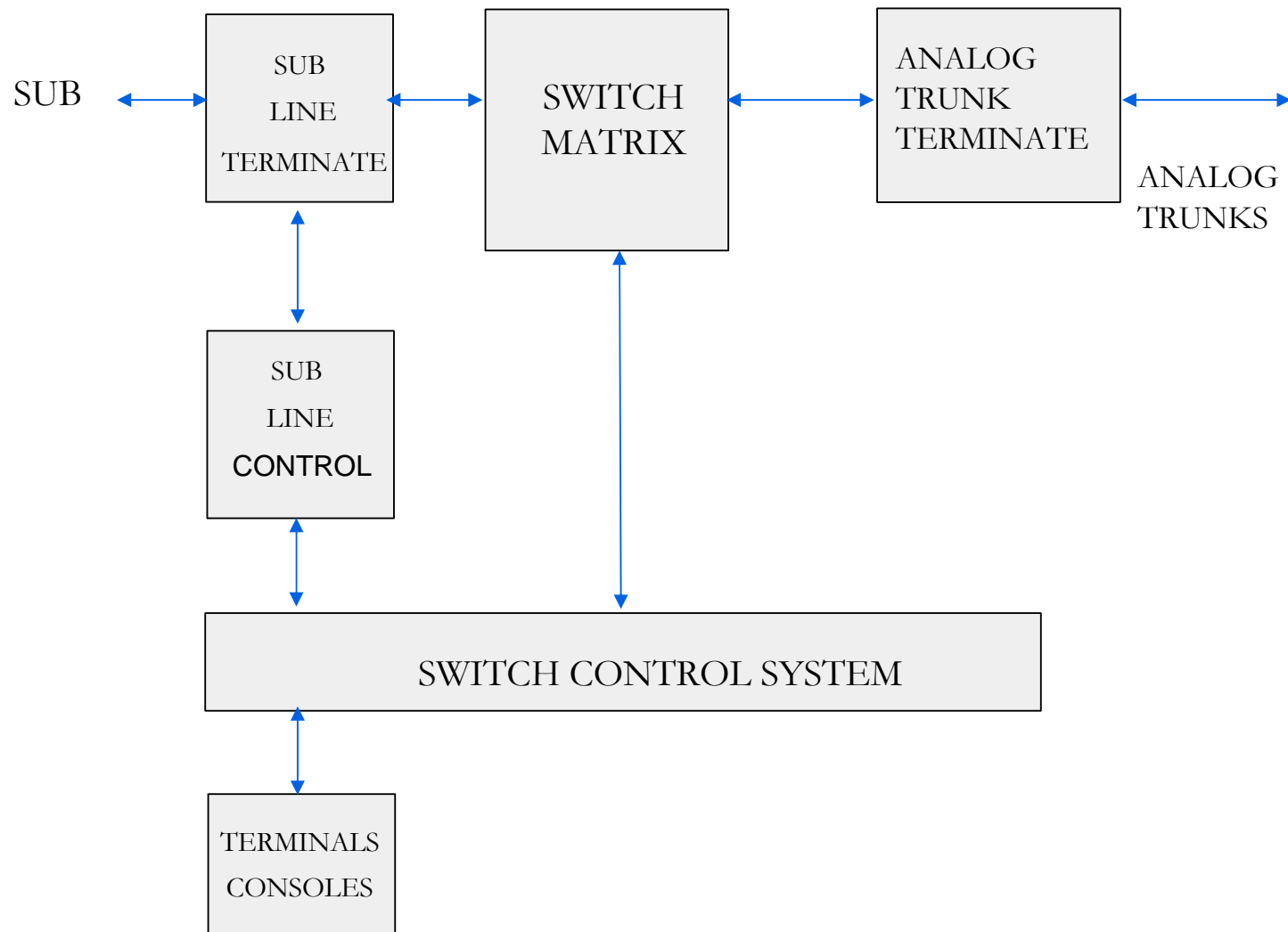


## Number of cross points for a non-blocking switch

---

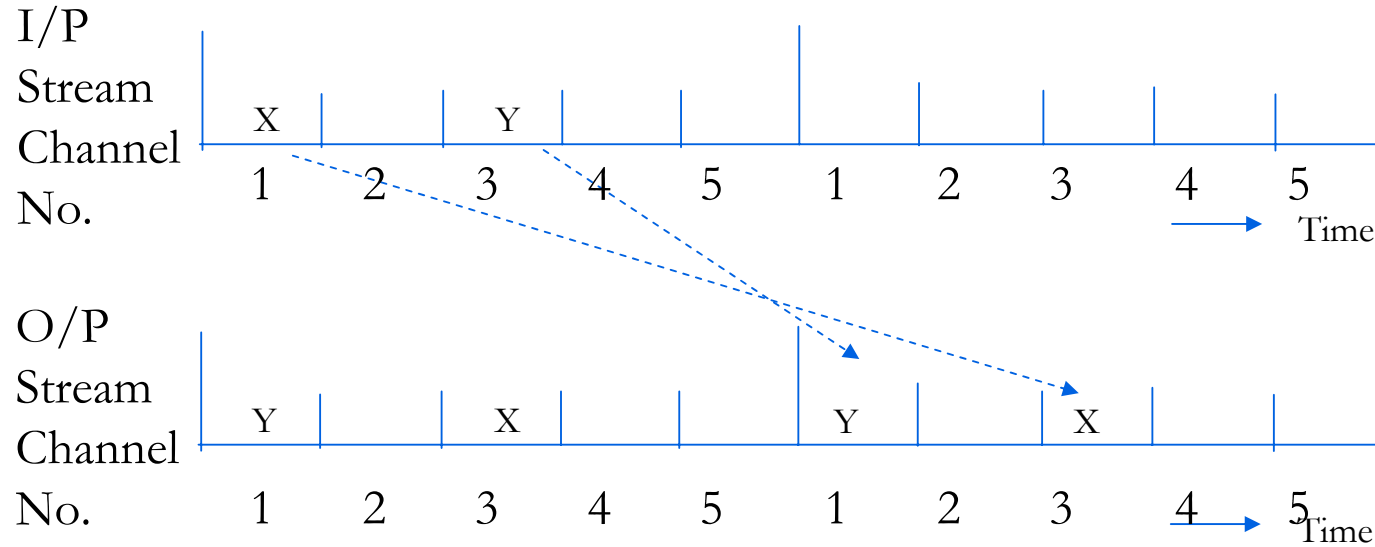
Lines	Single-Stage	Three stage
128	7,680	16,384
512	63,488	262,144
2,048	516,096	$4.2 \times 10^6$
8,192	$4.2 \times 10^6$	$6.7 \times 10^7$
32,768	$3.3 \times 10^7$	$1 \times 10^9$
131,072	$2.6 \times 10^8$	$1.7 \times 10^{10}$

## SPC Digital Switch Block schematic



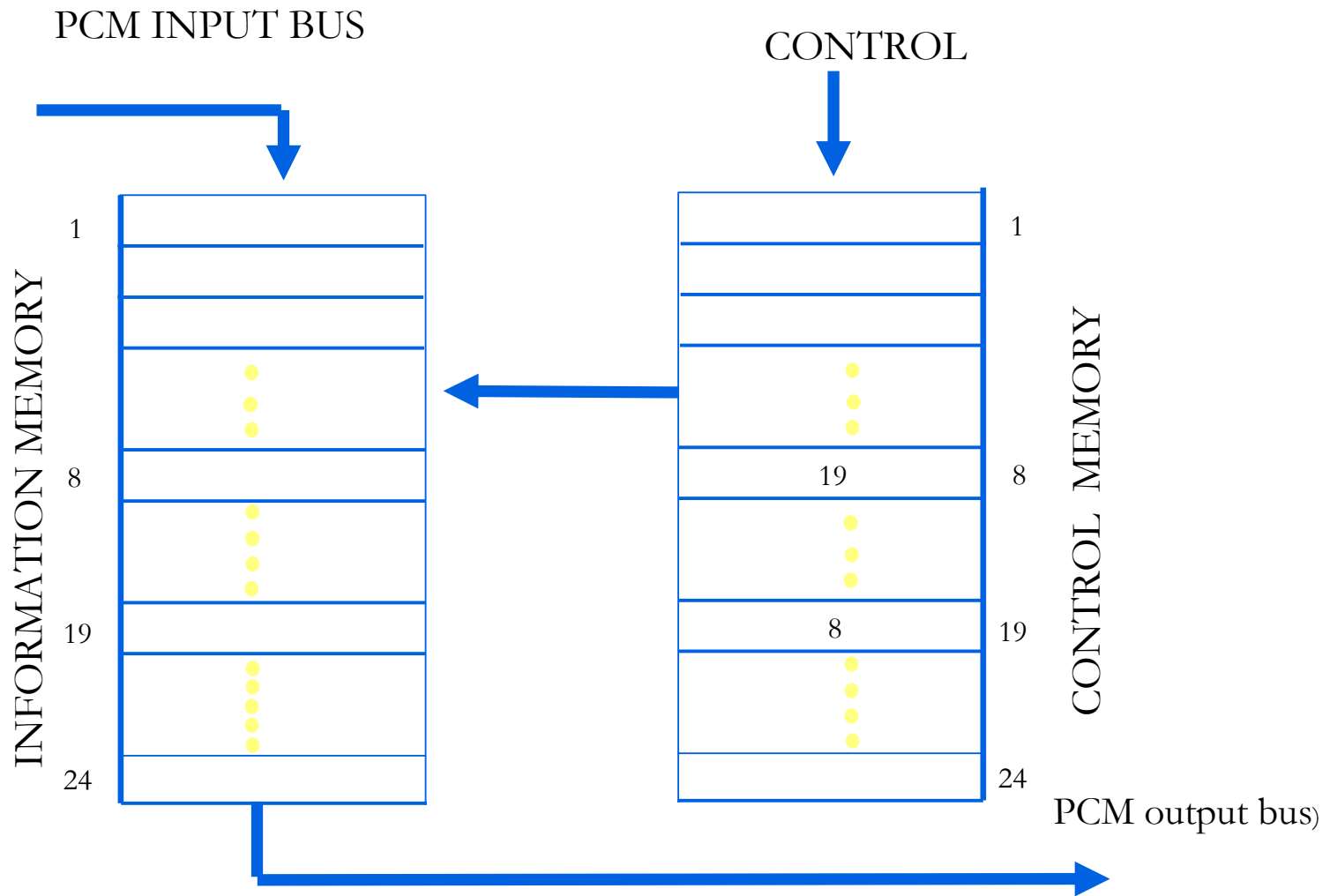


## Time slot interchange

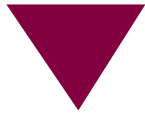


\* One Frame delay

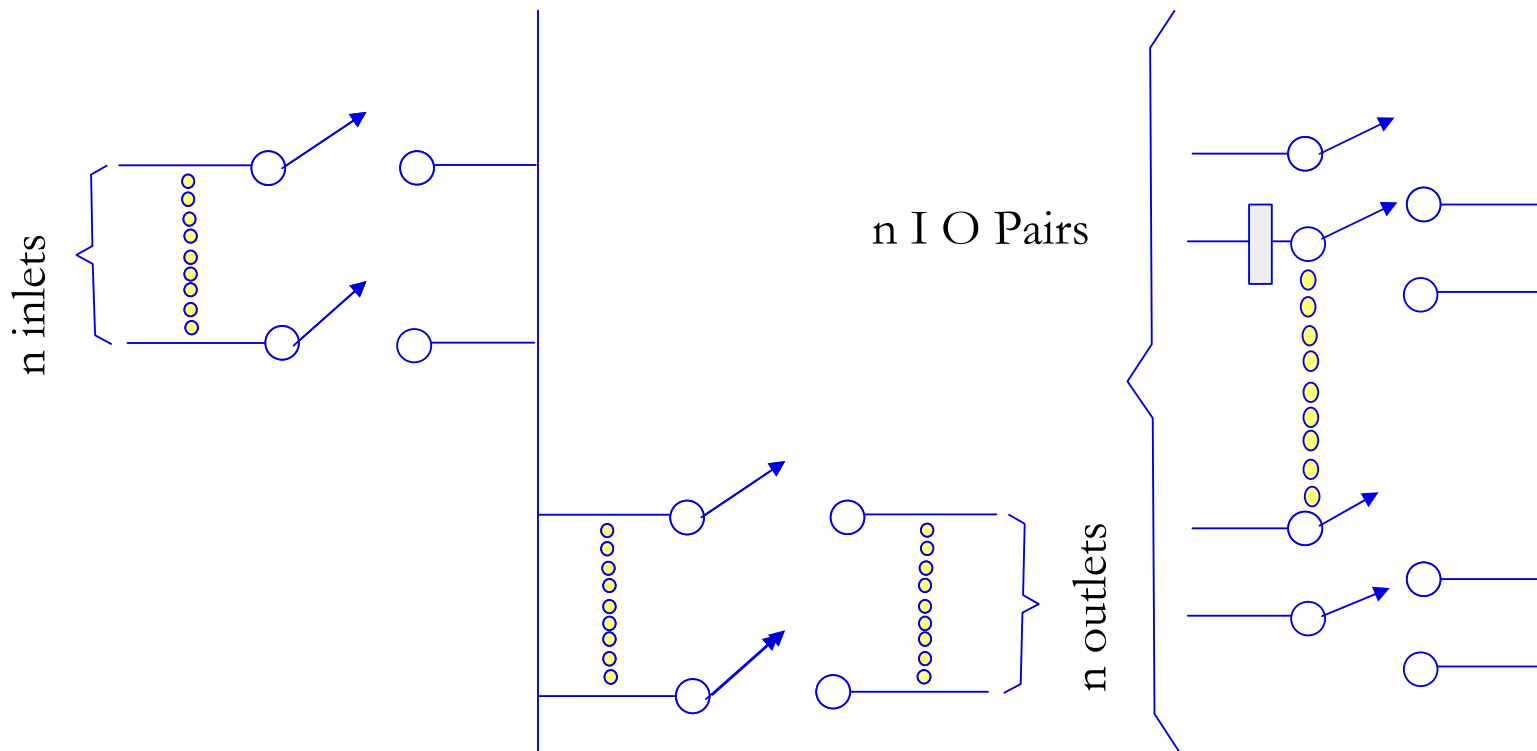
# Implementation of a digital TSI switch





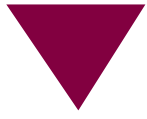


# TDM Bus switch

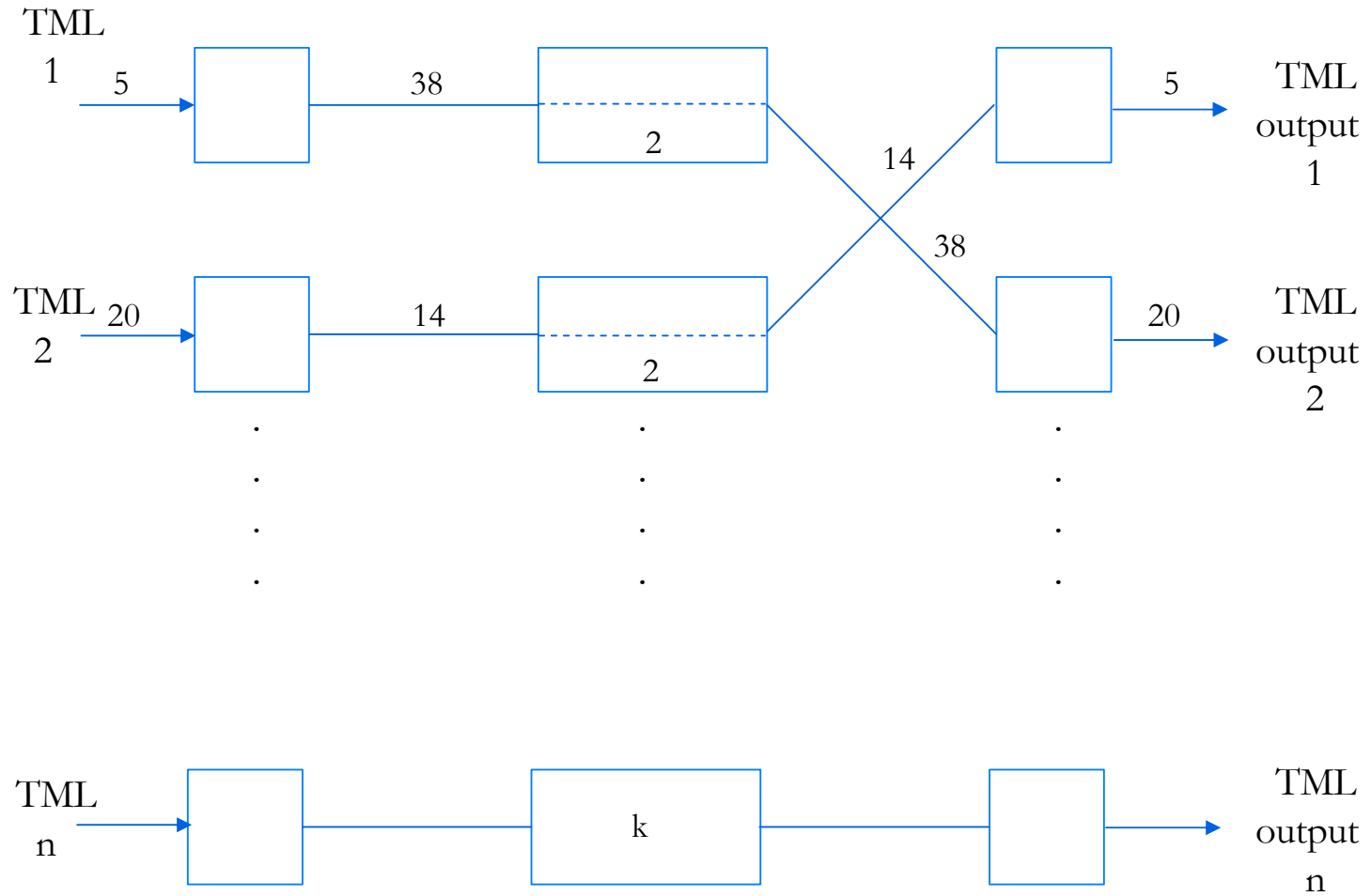


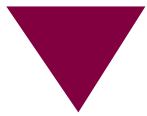
A Simple Time-Division Switch

A Simple Folded Time-Division Switch

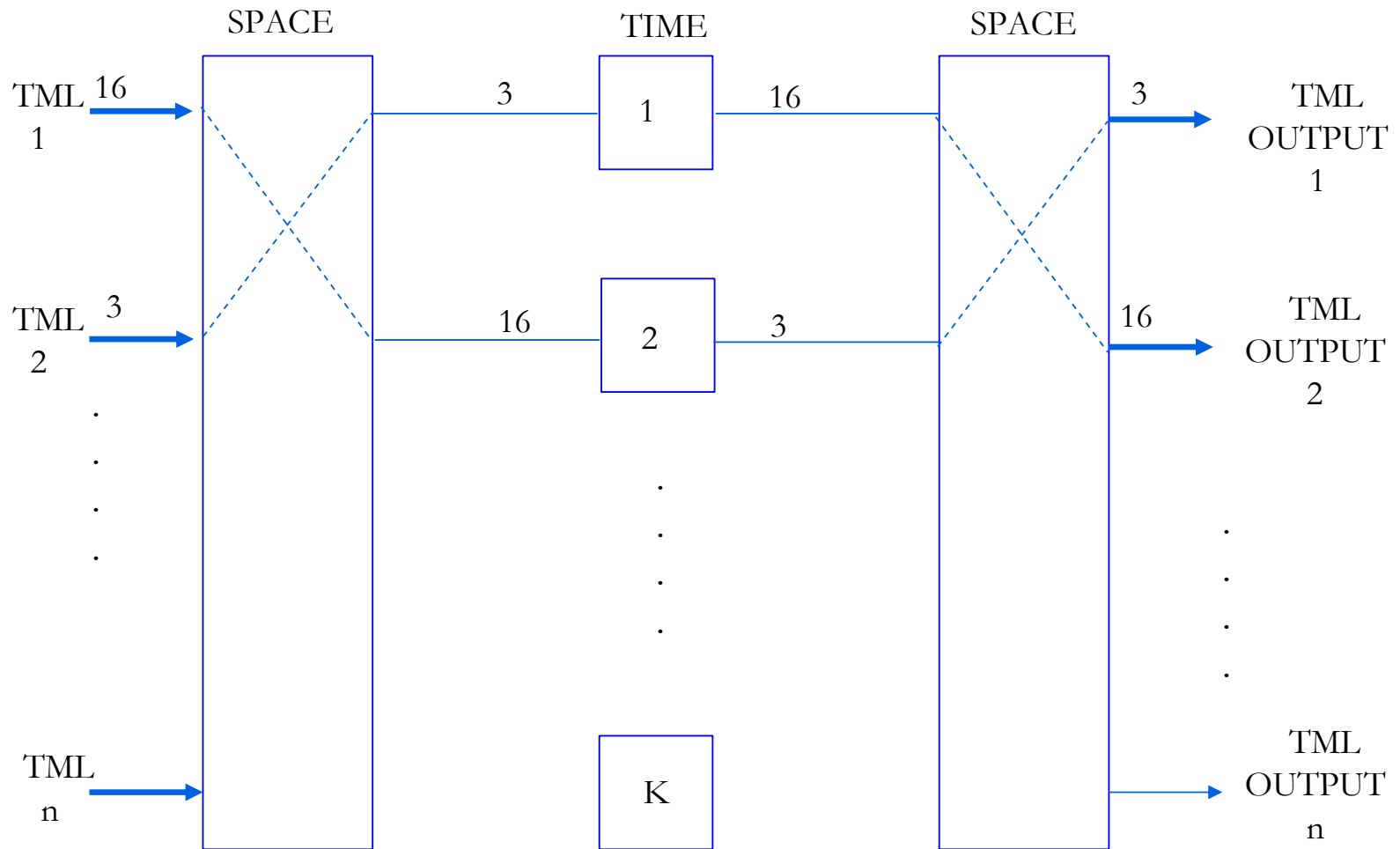


# Time-space-time Switch





# Space-time-space switch



## Overview

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



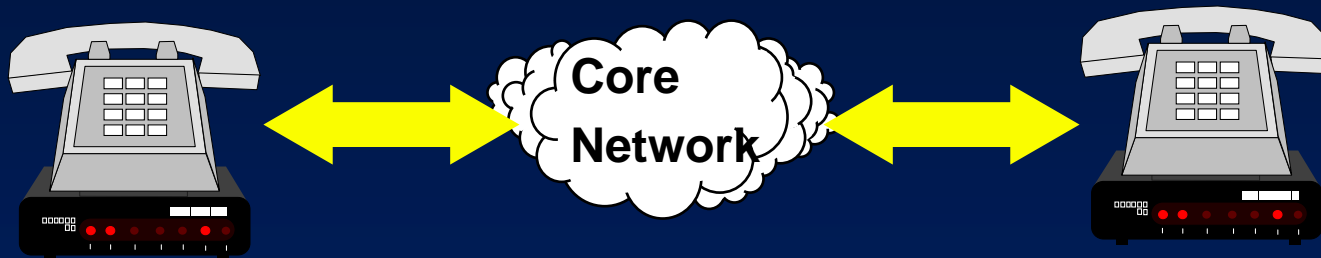
**SmartVideoconferencing**<sup>™</sup>

TEL<sup>®</sup>

Jamadagni H S

DC/V1/2004

- **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)



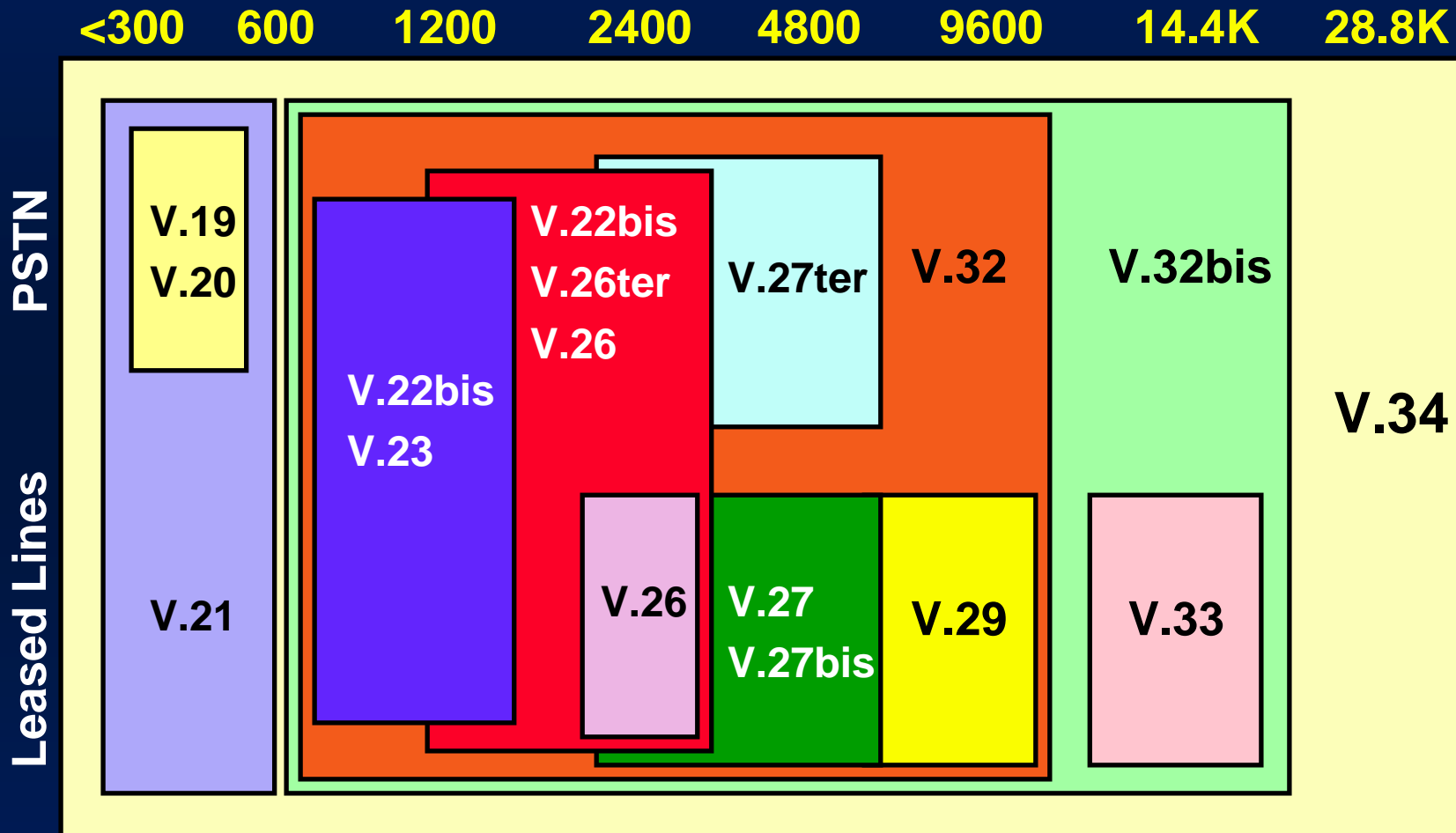
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# Copper Access Technologies // Voice (V-series)



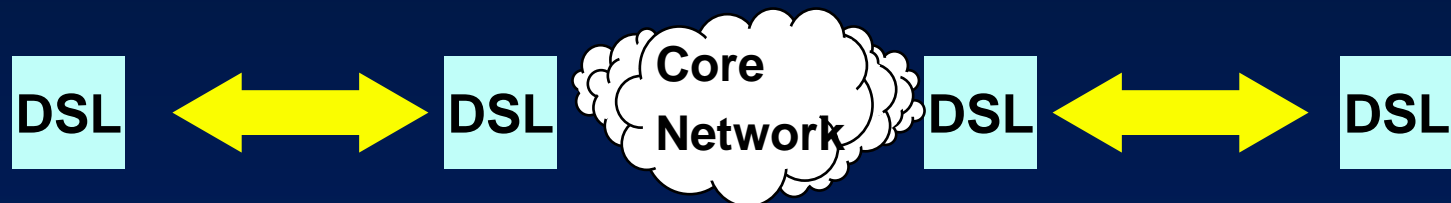
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- **Digital Subscriber Line**
  - **DSL (ISDN BRI)**
    - 160 kbps (two 64 kbps (B) + one 16 kbps (D) + 16 kbps operation and maintenance channel [OMC])
    - Full Duplex
    - ISDN, voice and data communications



- **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)**





- **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

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



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## *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**



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



## 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.



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## 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.



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## ADSL basics (contd 2)

### Three information channels

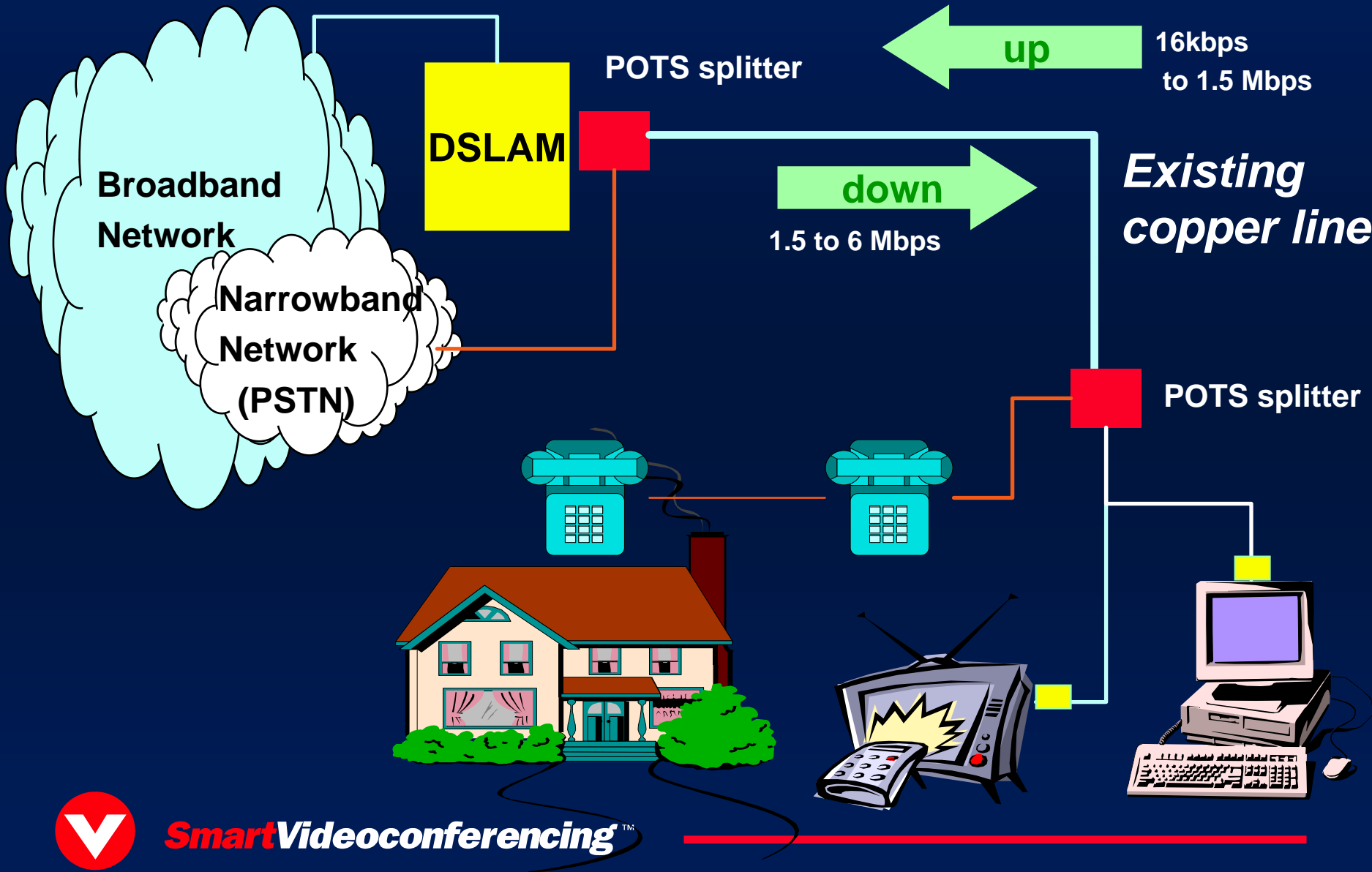
- a high speed downstream channel
  - Speed ranges from 1.5 to 6.1 Mbps
  
- a medium speed duplex channel
  - Speed range from 16 to 640 kbps
  
- a POTS (Plain Old Telephone Service) or an ISDN channel.
  - The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted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

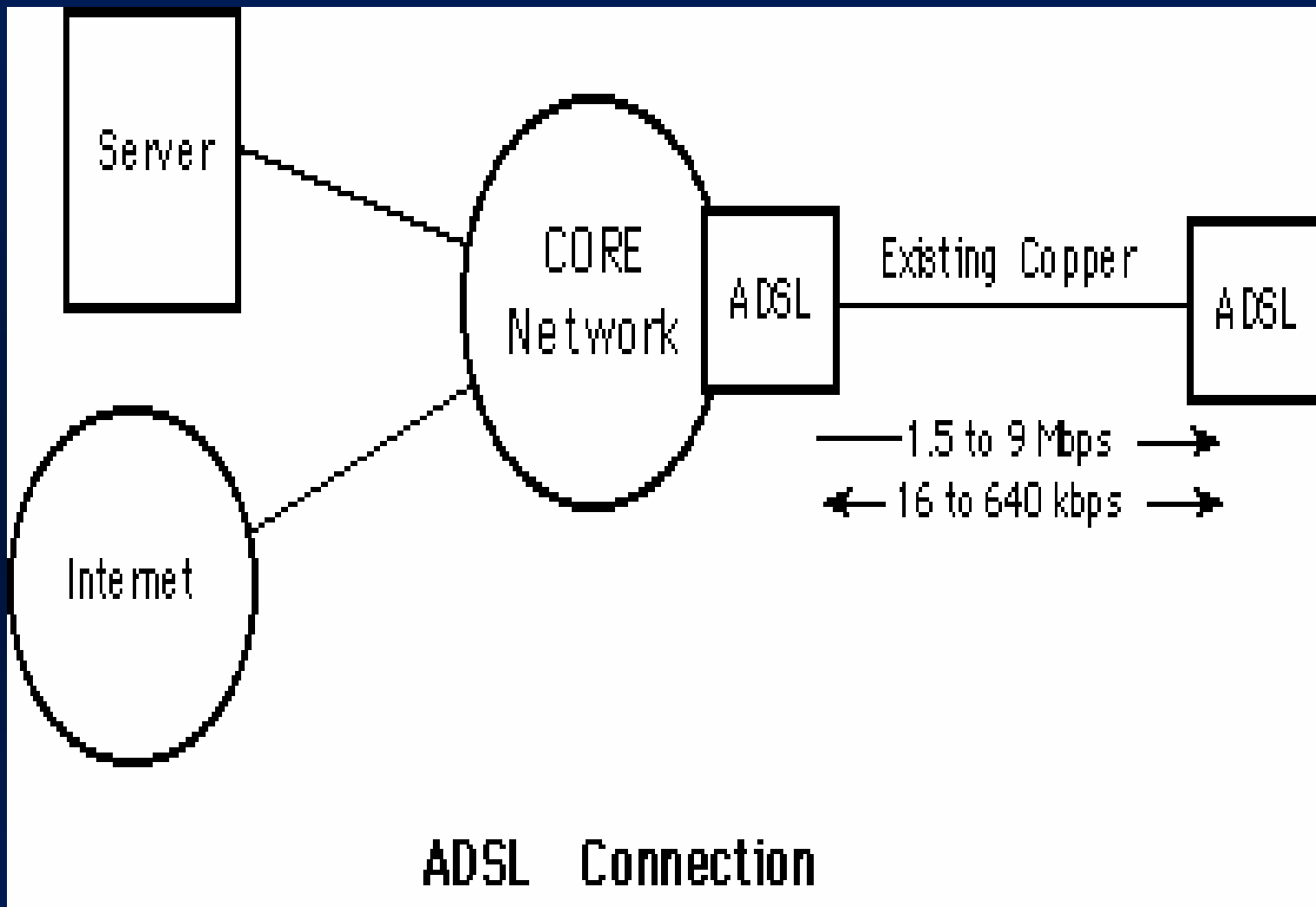


# ADSL in operation



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## 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

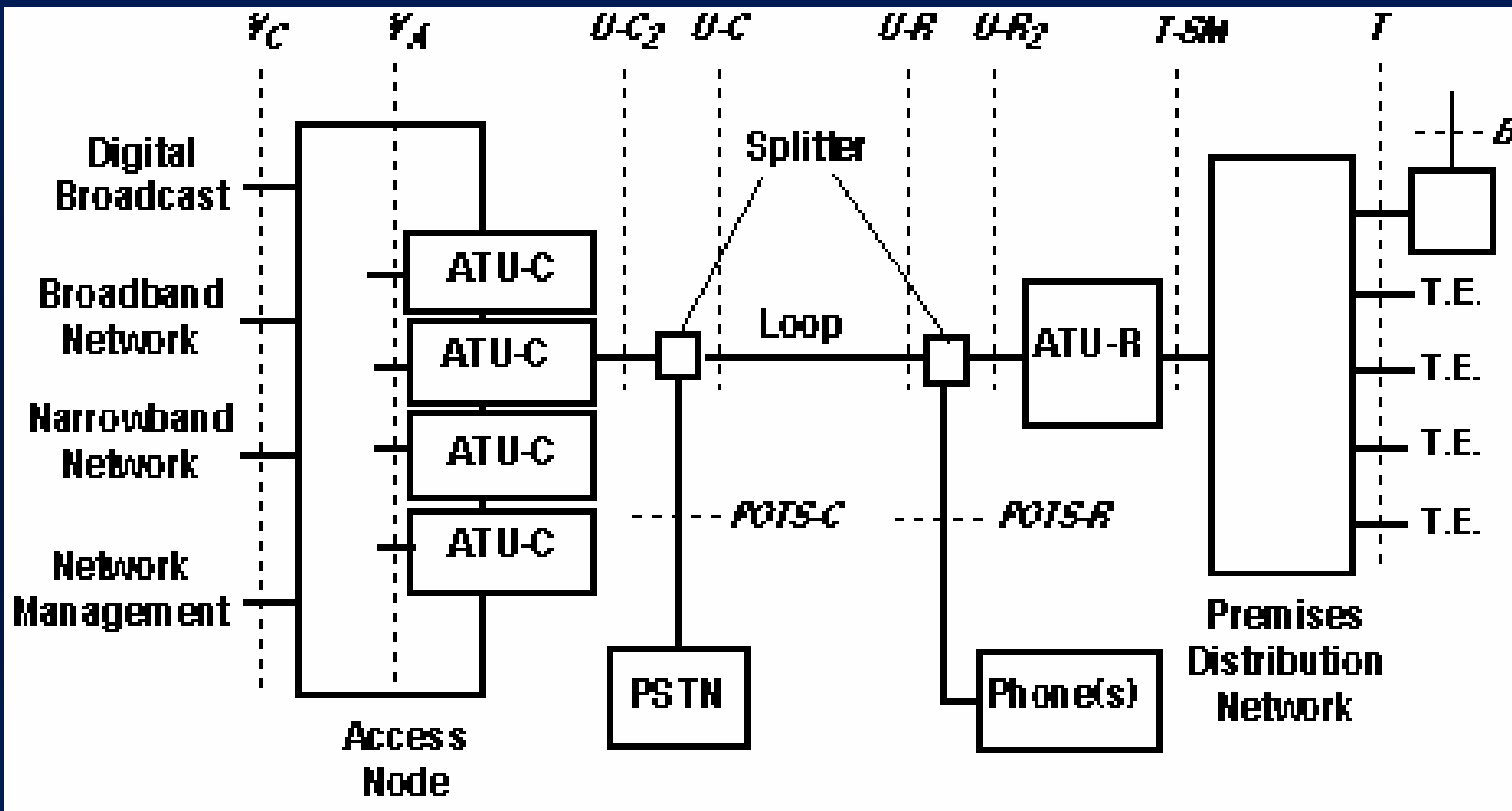


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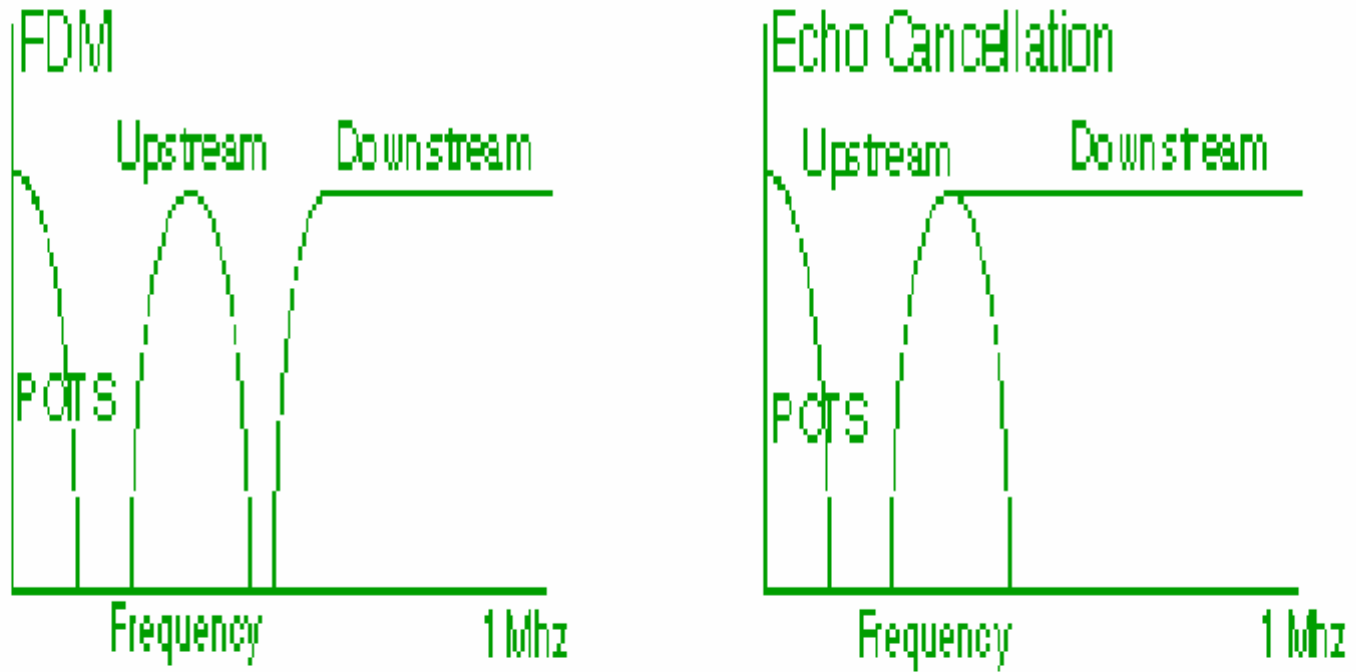
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## ADSL spectrum sharing



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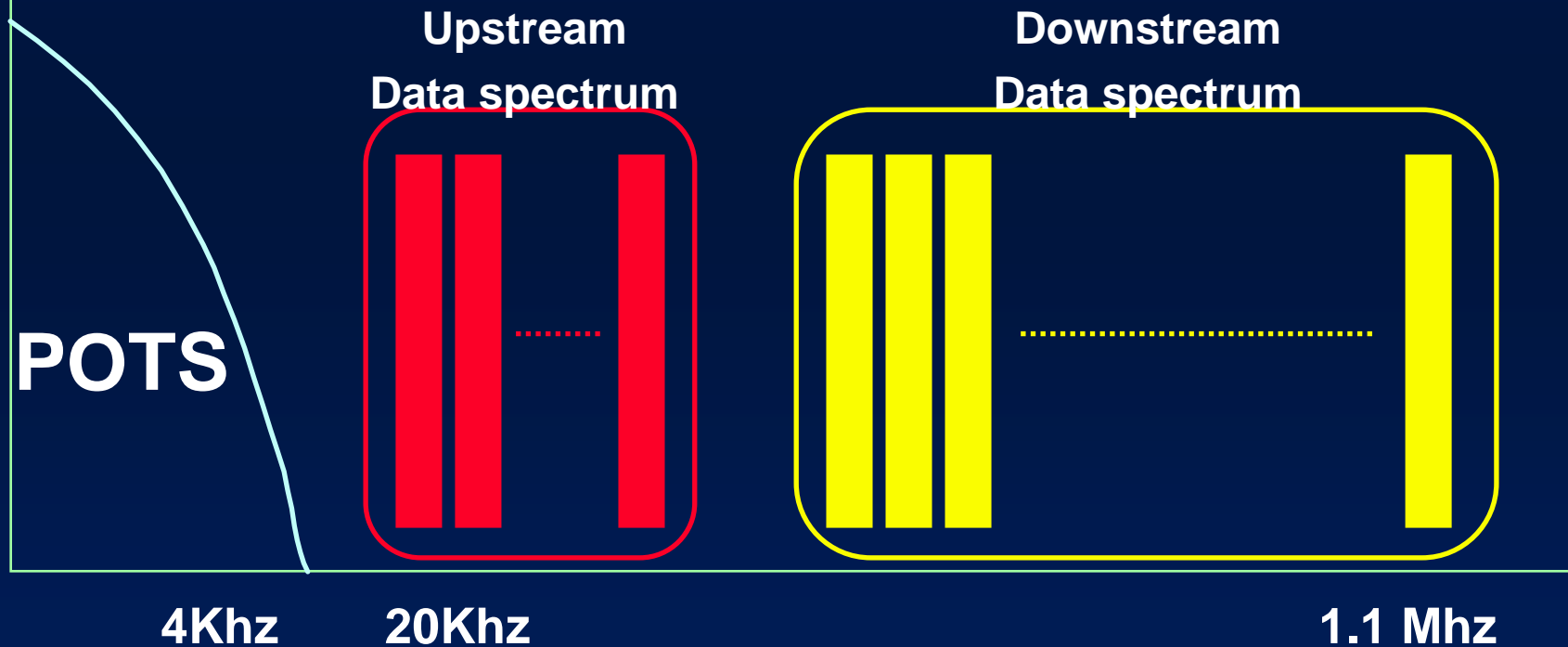
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# ADSL (spectrum)

## Frequency Spectrum

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



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- **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



- **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



### • 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





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



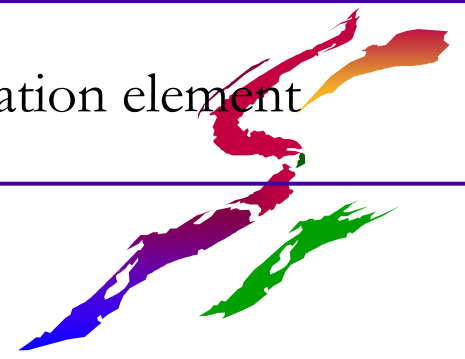
## Q. 931 Message format

Protocol discriminator				
0	0	0	0	Length
F	Call reference value			
0	Message type			
Other information elements if required				

1	Info. element identifier	Contents of info. element
---	--------------------------	---------------------------

1	Info. element identifier	Contents of info. element
---	--------------------------	---------------------------

0	Information element identifier	
Contents of information element		



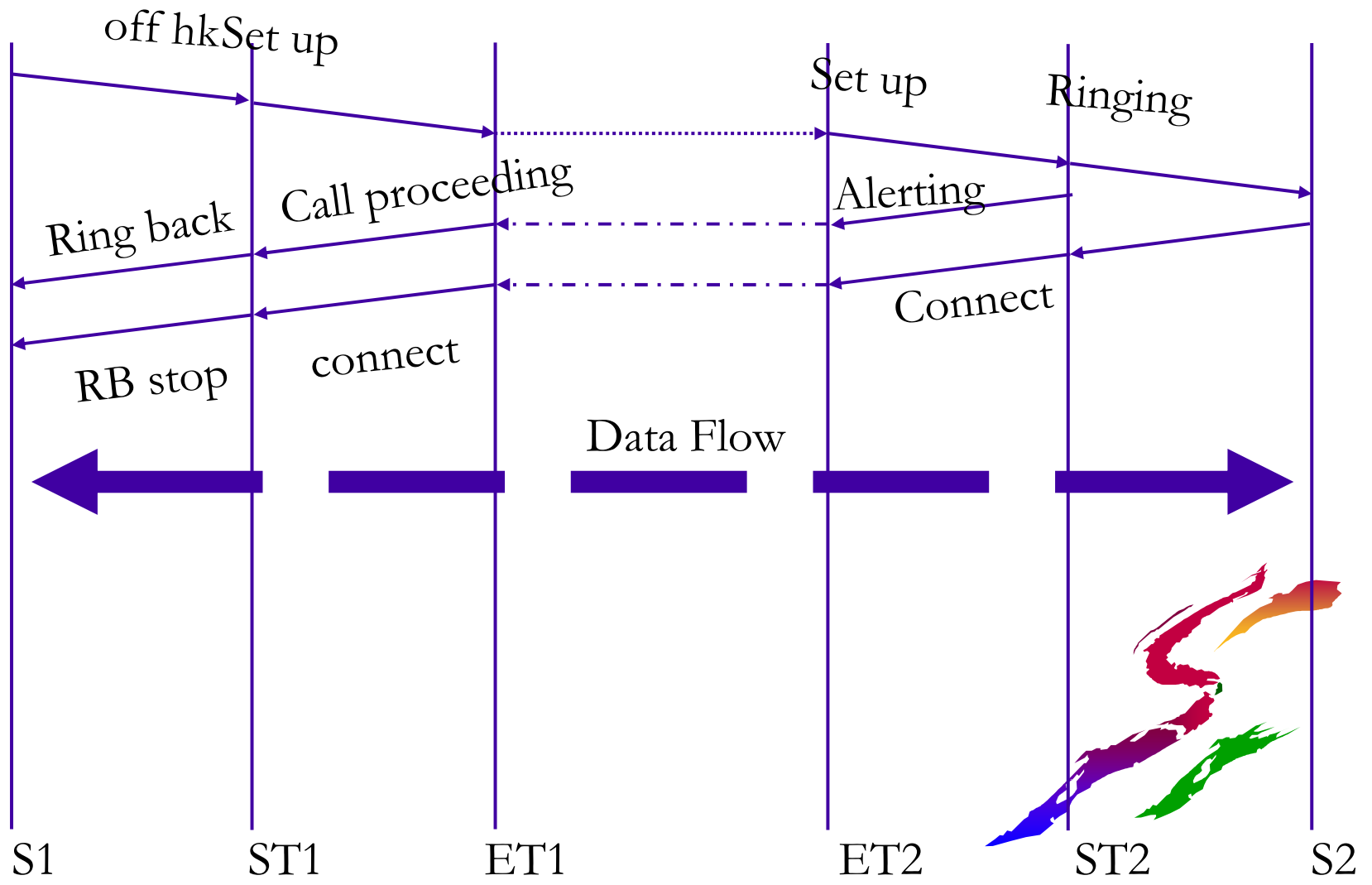
## Bearer capability information element identifier

---

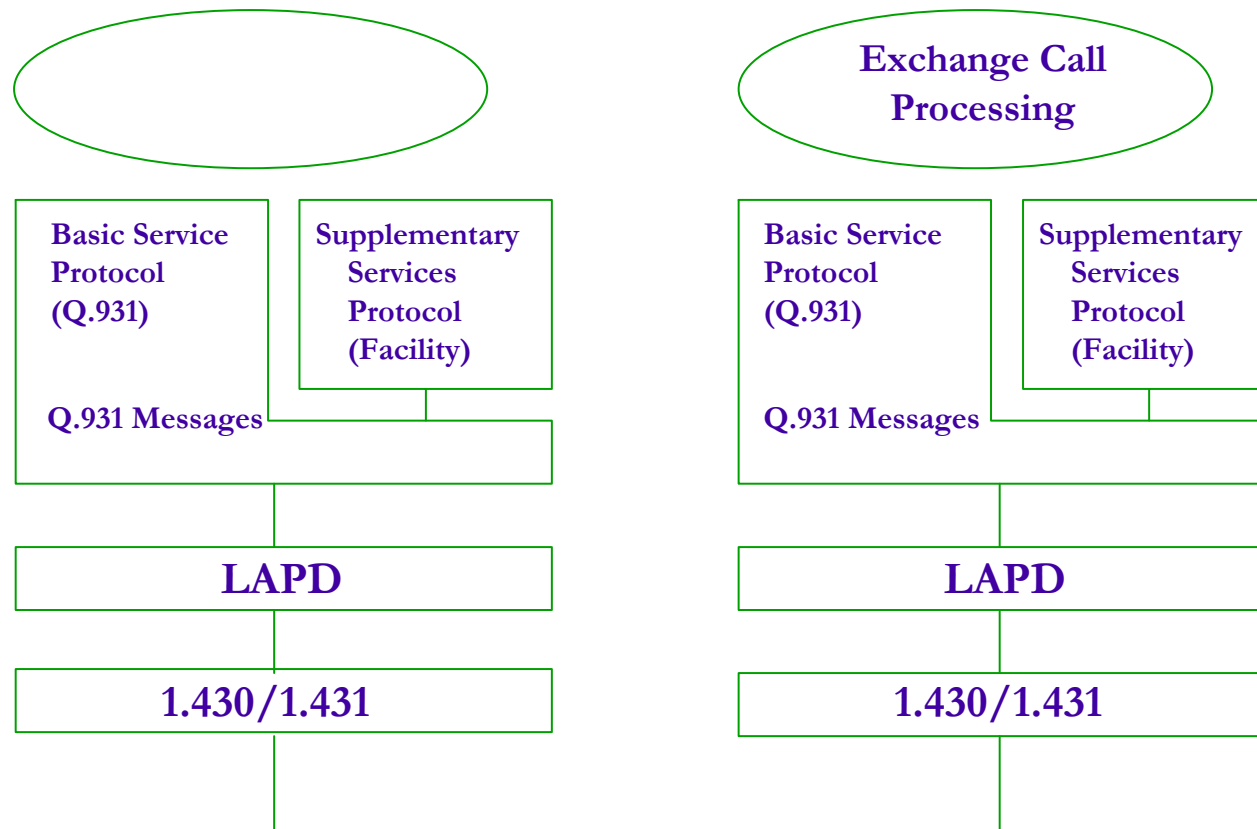
1	0 0 0 0 0 1 0 0	Bearer capability info.element identifier
2		Length of bearer capability contents
3	1 X X X X X X X	Coding std., info. transfer capability
4a	X X X X X X X X	Transfer mode, transfer rate
4b		
5	X X X X X X X X	Rate multiplier
5a	0/1 X X X X X X	Layer 1 identity, user info. layer 1
5b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



# 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*

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**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*

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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*

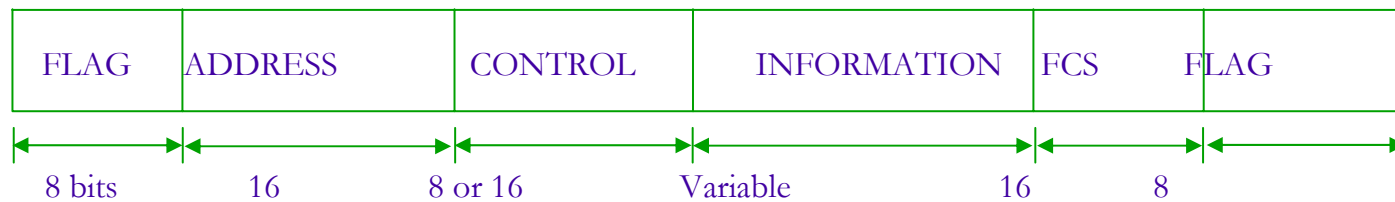
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Message	Significance	Direction	Function
DISCONNECT	global	both	Sent by user to request connection clearing; sent by network to indicate connection clearing
RELEASE	local	both	Indicates intent to release channel and call reference
RELEASE COMPLETE	local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

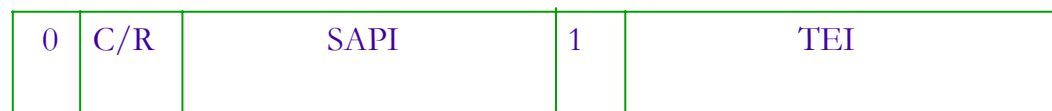




# Frame format in ISDN layer 2



(a) Frame format



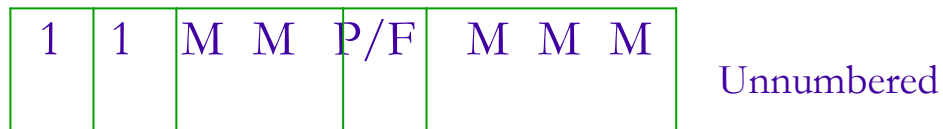
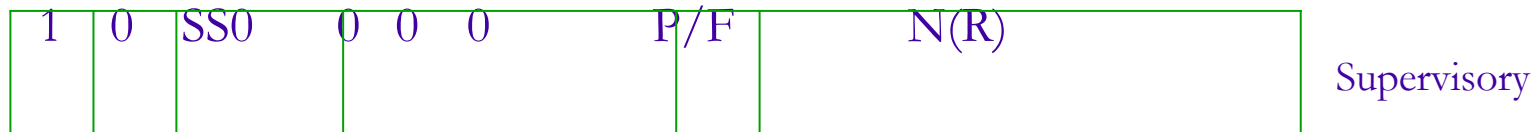
C/R is Command/response

SAPI is Service access point identifier

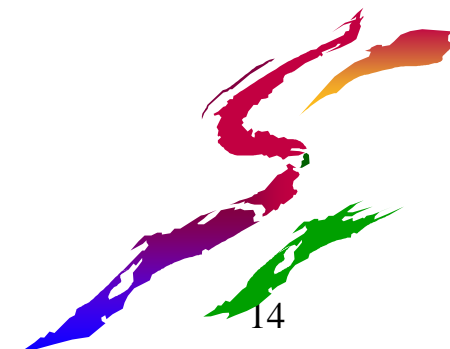
TEI is Terminal endpoint identifier



# 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*

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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)	1000000*-N(R)--	C/R	Positive ack; ready to receive I-frame
RNR (Receive Not Ready)	1010000*-N(R)--	C/R	Positive ack; not ready to receive
REJ (Reject)	10010000*-N(R)--	C/R	Negative ack; go back N

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## *Unnumbered format*

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SABME (Set Asynchronous Balanced Mode)	1111P110	C	Request logical connection
DM (Disconnected Mode)	1111F000	R	Unable to establish or 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 unacceptable frame
XID (Exchange ID-identification)	1111*101	C/R	Exchange identification information

# *SAPI and TEI assignments*

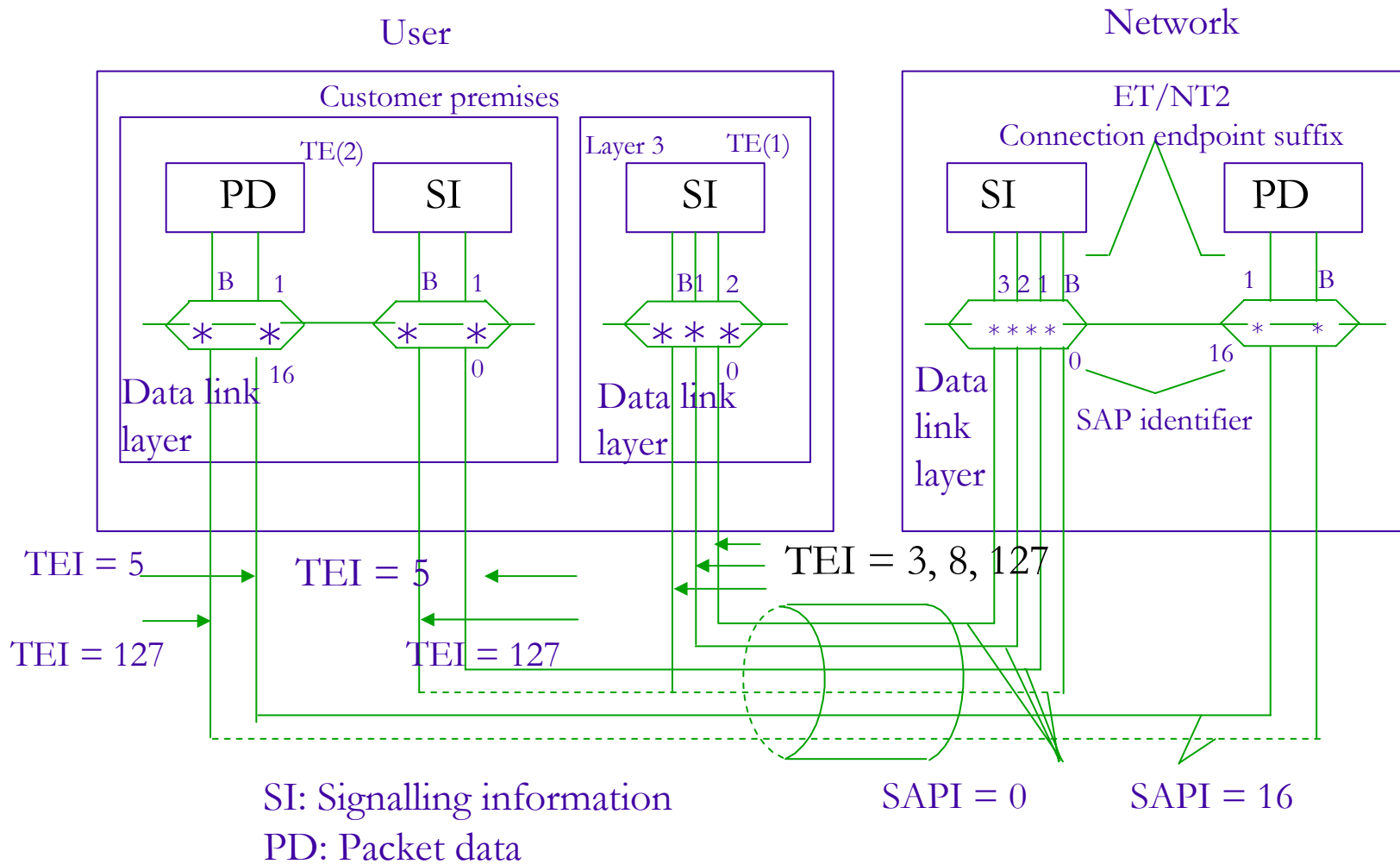
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SAPI Value	(a) SAPI Assignments Related Protocol or Management Entity
0	Call-control procedures
16	packet communication conforming to X.25 level 3
32-61	Frame relay communication
63	Layer 2 management procedures
All others	Reserved for future standardisation

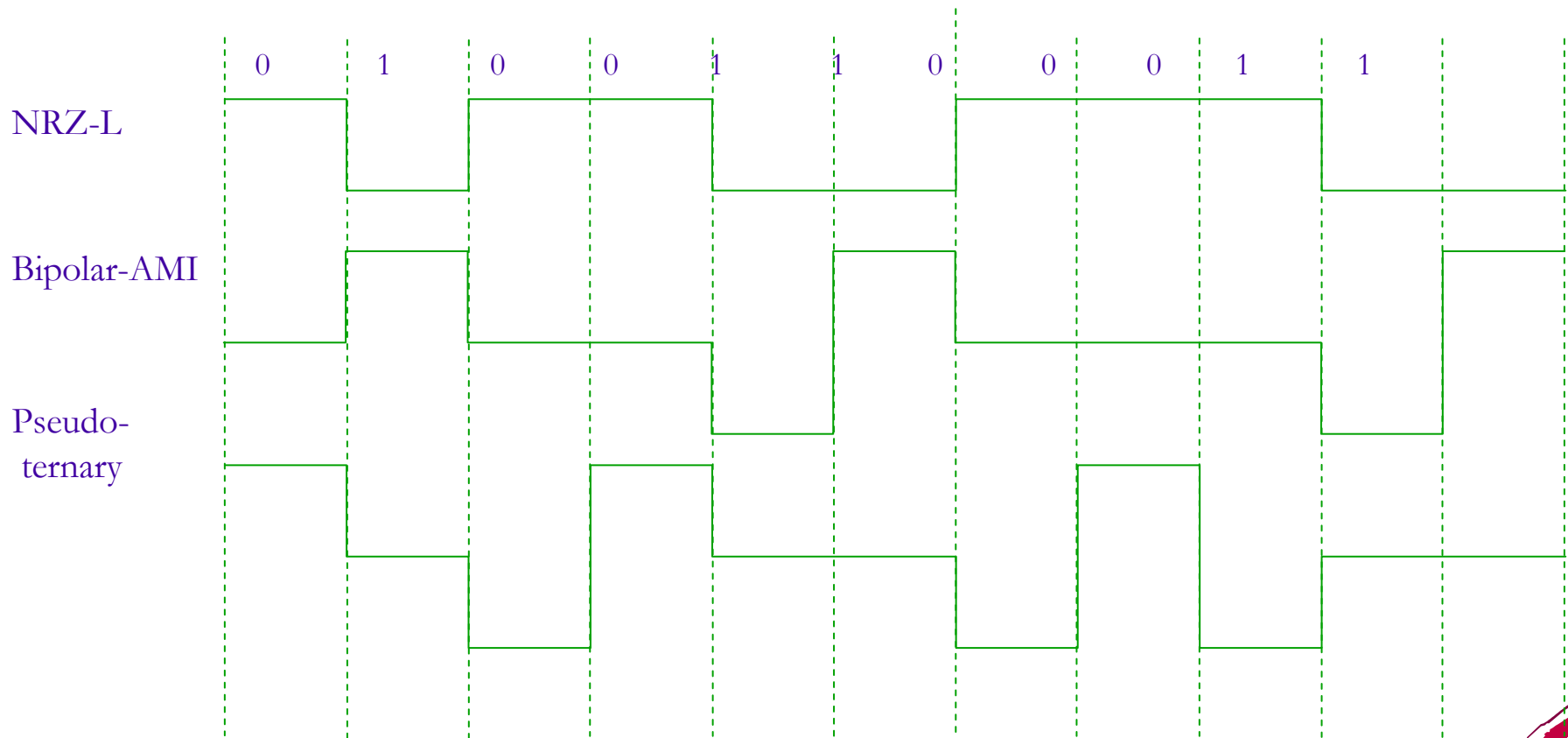
TEI Value	(b) TEI Assignments User Type
0-63	Nonautomatic TEI assignment user equipment
64-126	Automatic TEI assignment user equipment
127	Used during automatic TEI assignment



# TEI and SAPI assignment



# Digital Signal Encoding Format in ISDN



# *Physical connector in ISDN*

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## 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*

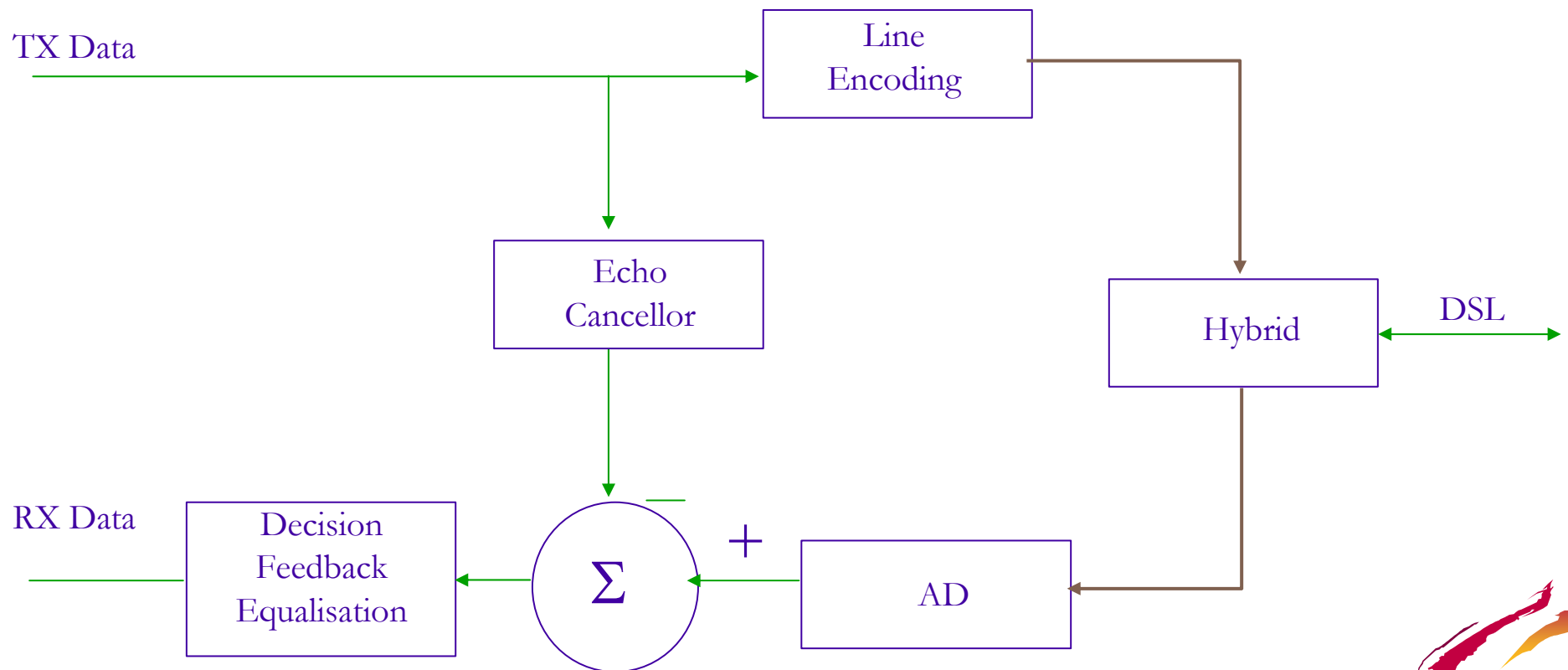
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Fixed by local administration

- 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		M1 to M6
2	SW	2B + D	2B + D		M1 to M6
3	SW	2B + D	2B + D		M1 to M6
4	SW	2B + D	2B + D		M1 to M6
5	SW	2B + D	2B + D		M1 to M6
6	SW	2B + D	2B + D		M1 to M6
7	SW	2B + D	2B + D		M1 to M6
8	SW	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

