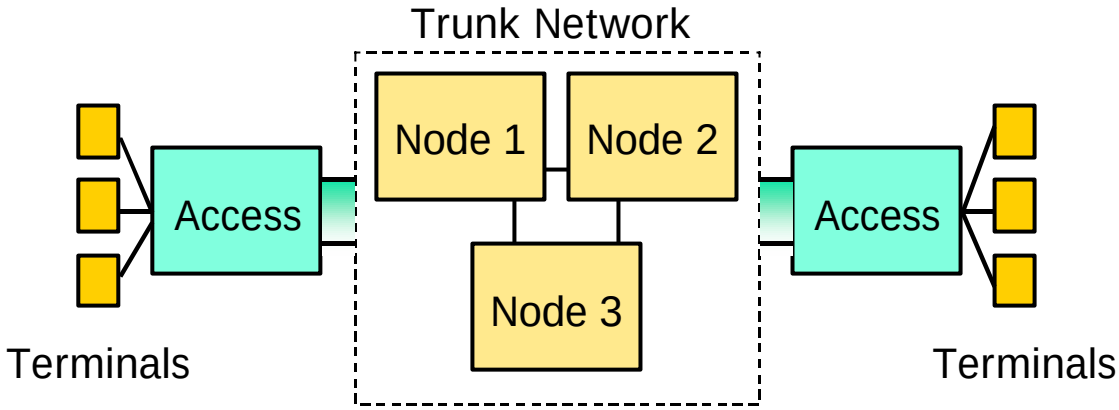
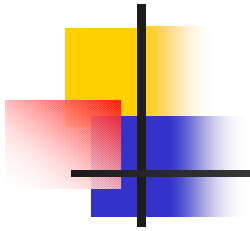
Public Switched Telephone Network (PSTN)

Topics in PSTN

- Introduction
  - review of early exchanges
  - PSTN Standards
- User services & terminals
- Modern exchange technology
  - interface standards
  - access and trunk networks
  - signaling
  - network management
  - internetworking (telecommunications between networks)





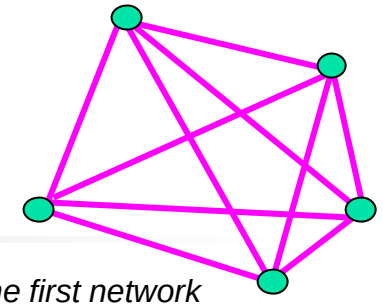
Introduction

- PSTN switching is based on circuit switching by duplex* connections
- Temporary bidirectional connections
- Originally for speech (voice) only at 300-3400 Hz
- Earlier two subscribers connected by purely physical connection (physical switch contacts)
- Nowadays by time slots ~ ISDN is integrated to PSDN
- PCM is the TDMA standard for the digital transmission
- PCM time slots consist of 8 bit samples
- For voice digital exchange sets up 64 kbit/s connections
- Data connections by (1) modems, (2) ISDN interface (3) leased lines via X.25 / Frame relay, or (4) ADSL

**What are semi-duplex and simplex?*

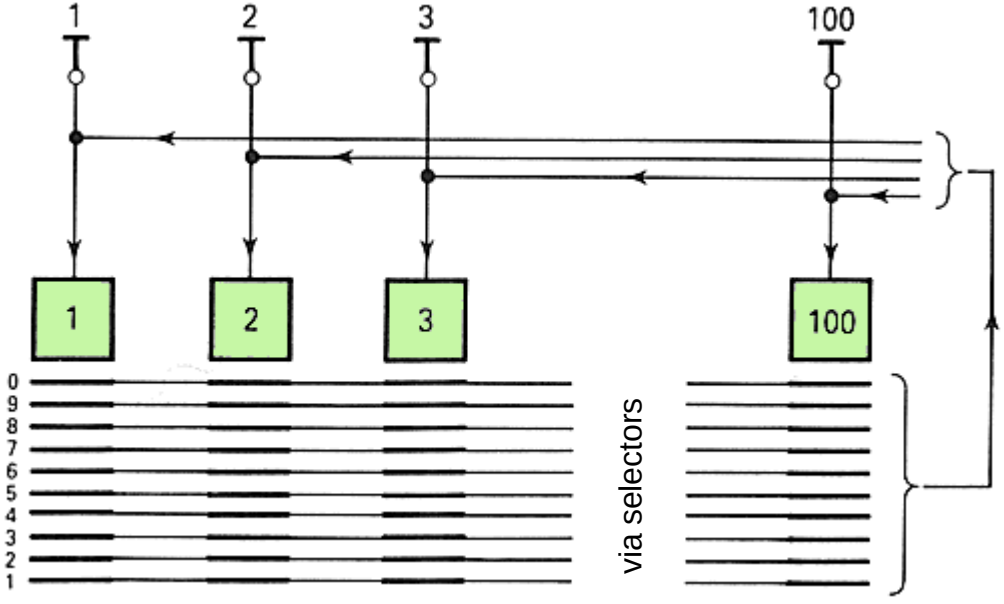
PCM: pulse coded modulation

History



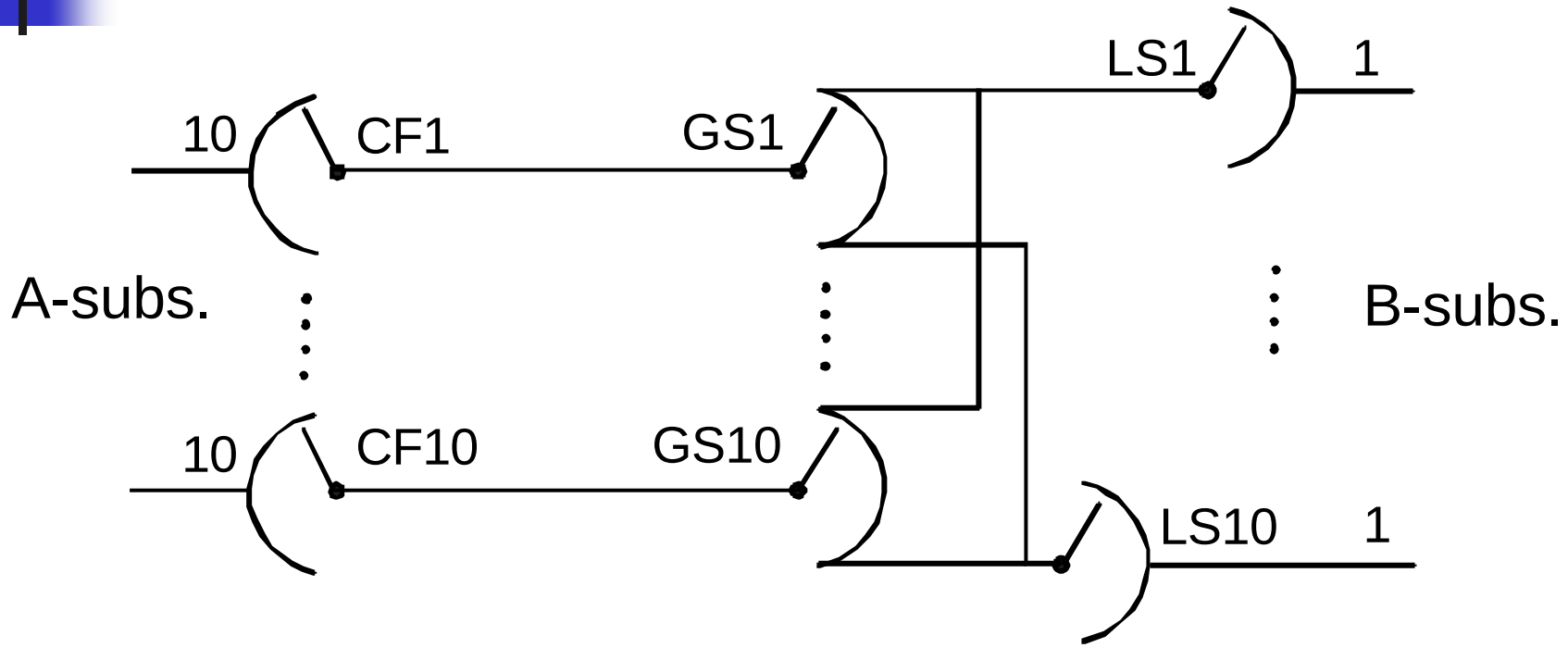
Topology of the first network using Strowger switch

- 1876 A. G. Bell telephone patent
- 1878 The first exchange constructed in La Porte, the US
  - could connect any two of the 21 subscribers
  - manual switching
- 1891 first automatic exchange: Strowger Switch by Almon B. Strowger: an undertaker in Kansas City
- A 100 line Strowger switch:
  - each user has its own selector
  - no concentrators
  - expensive



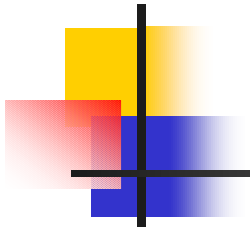
See further info also at: http://www.seg.co.uk/telecomm/

An early analog PBX: 100 subscriber exchange (Subscriber controlled call set-up)



MAIN PARTS:
- Call finders (CF)
- Group selectors (GS)
- Line selectors (LS)

Call setup:
1. A-sub. picks up handset (CF detects)
   - exchange sends line available -tone
2. A-sub. sends pulses (GS, LS activated)
   - exchange sends ringing tone



An early exchange, call setup

- One of the 100 subscribers lifts his handset -> Call finder is activated to search the line.
- After the line is located other relays connect the dial-tone generator.
- The subscriber selects two digits.
- The first digit selects the subscriber group by using the group selector.
- The second digit selects the line selector.
- Selection is done by sending pulses that move the selectors stepwise.
- When connection is established a ringing tone is sent.
- Note that only 10 subscribers of 100 can call at the same time to different numbers! (why?) (concentration is 1:10)

PSTN exchange development

Efficient use of switches

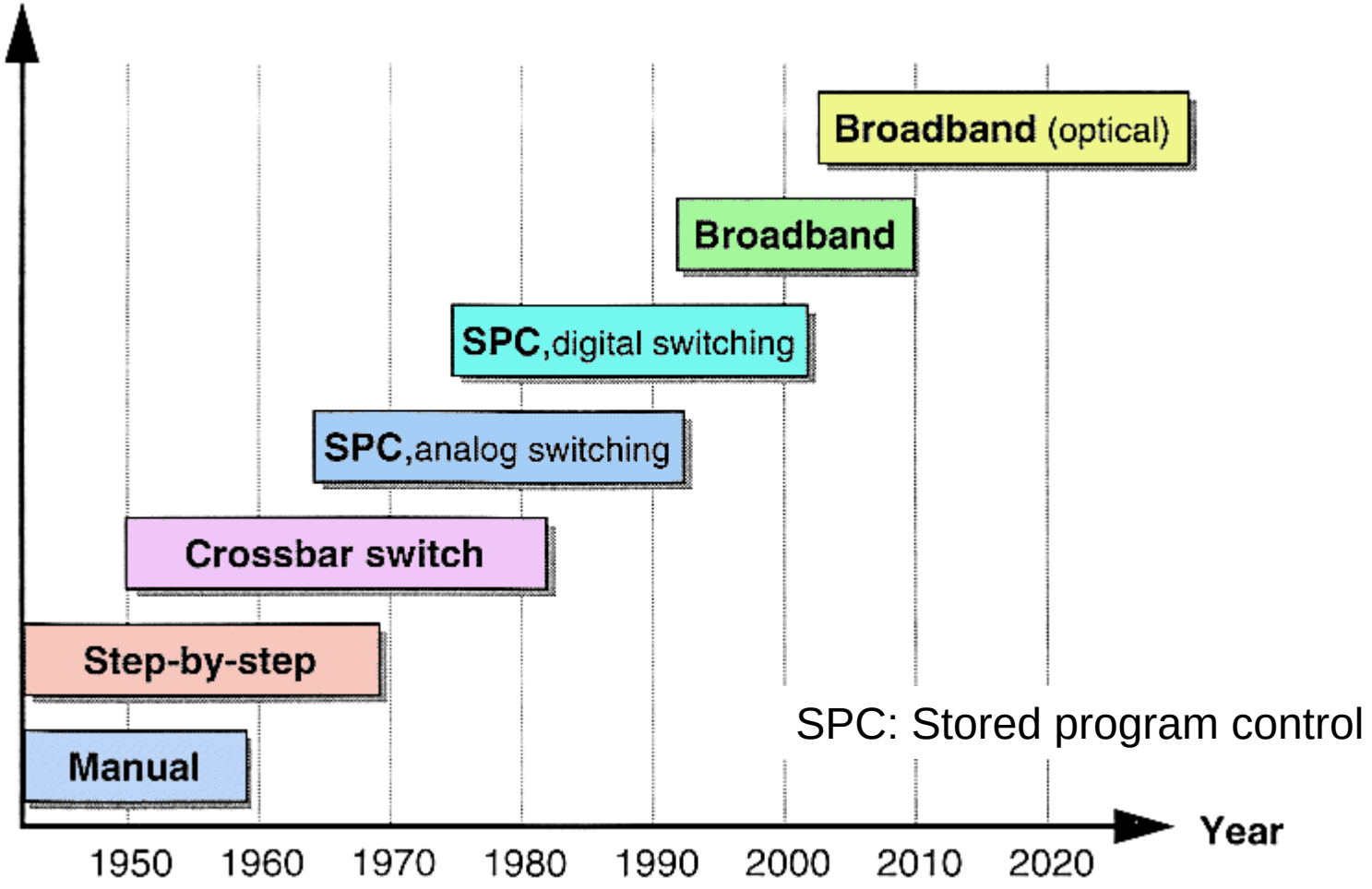
More flexibility & services

1960 and before

SPC era

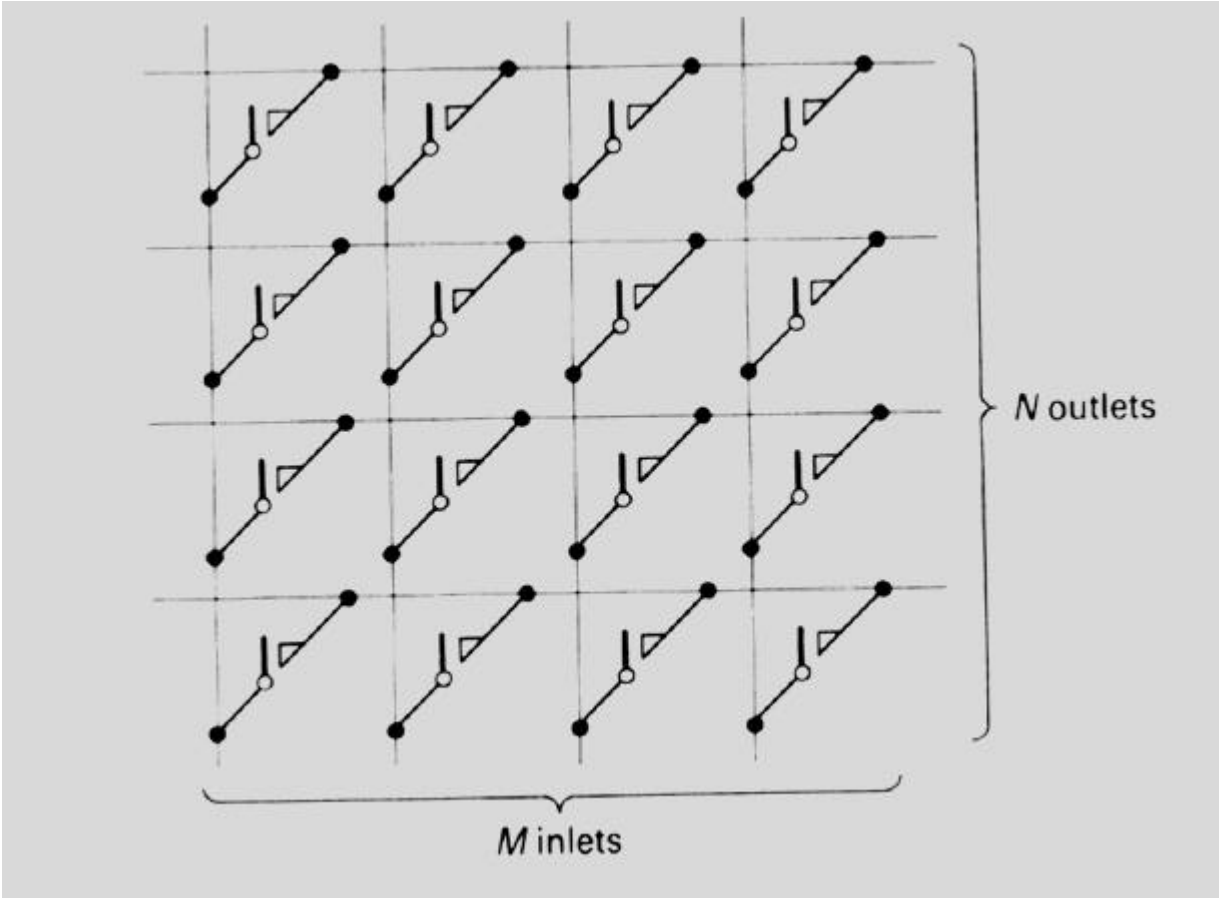
- Register-controlled setup (1920 -)
  - B-subscriber number receiver by a **register**
  - register controls all the remaining call setup stages
- Distributed control
  - **Markers** indicate idle switches
  - Thus markers control path routing
- Stored program control, 1960s and 1970s (SPC)
  - New services
    - supervision (operation & maintenance O&M)
    - integrated charging
    - gathering statistics
  - IN services
  - Easier updating and maintenance

Categorizing switching

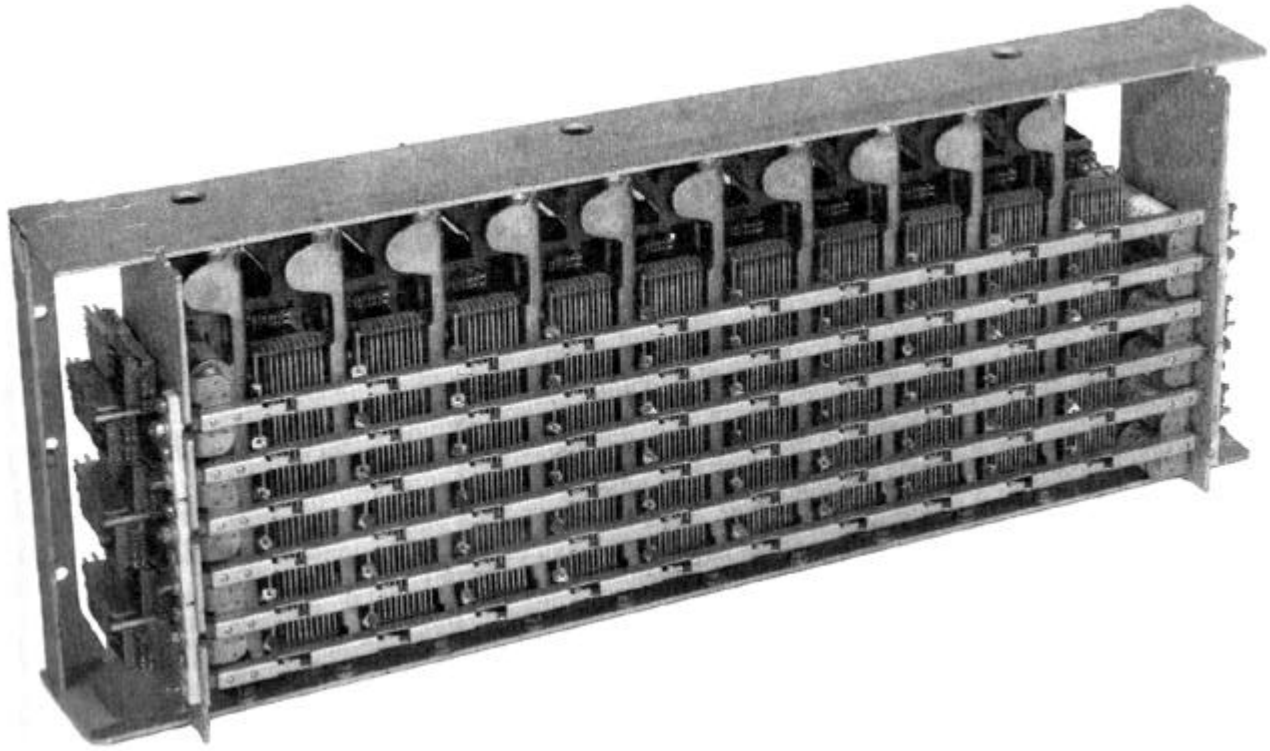


SPC: Stored program control

Crossbar switch



Crossbar switch - mechanics[1]



[1]J.E.Flood: Telecommunication Switching and Networks

Access network

- local network, local loop or subscriber network
- Copper pairs are ideally suited to
  - supplying **power** to the telephones
  - **baseband** transmission of voice
  - **no modulation** is required as in the case of fibre and radio applications
  - existing copper pair can also be used to access services of **greater bandwidth** in other networks
- attenuation of voice signals represented a problem for network planners - solution **loading coils**

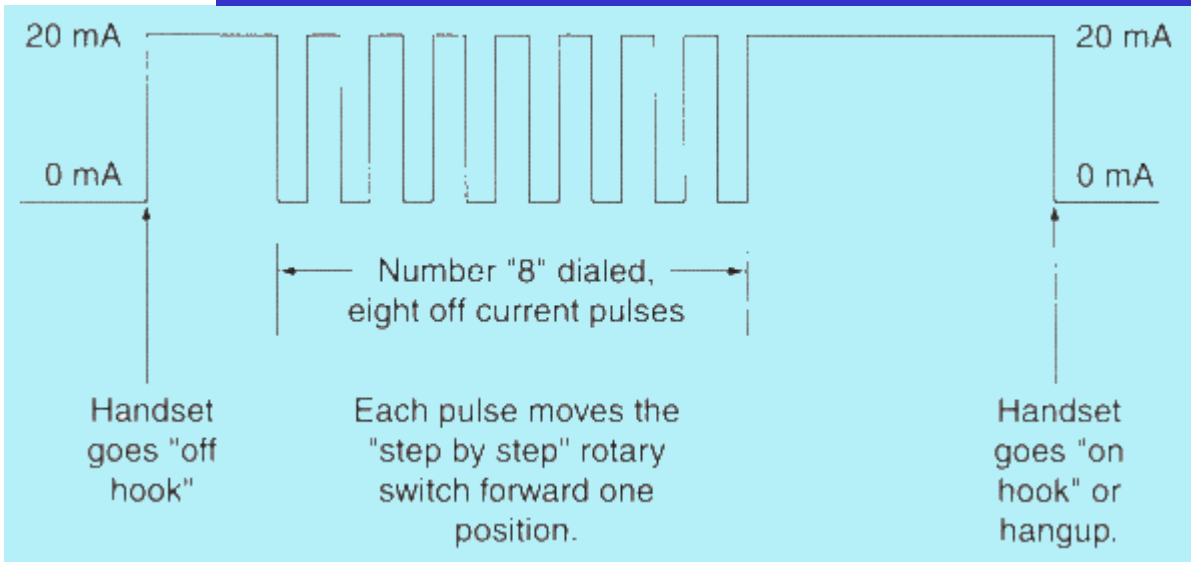
Present-day PSTN 'terminals[1]' in access network

- Fixed-line phones (analog, ISDN)
- Cordless phones (PBX-RF interface: DECT[2])
- Fax
- Pay phones
- Private Branch Exchange (PBX)
- Gateways to Public Land Mobile Networks (PLMN):
  - GSM
  - wireless local area networks (WLAN)
- Local loop data extensions
  - modems
  - ADSL technology
  - (leased lines)

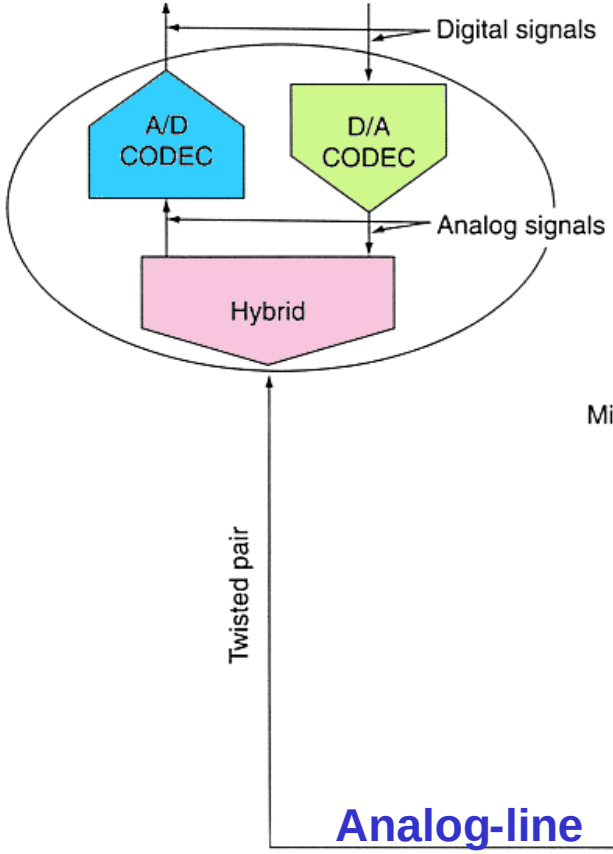
[1]also interfaces to other networks & equipment
[2]DECT: Digital Enhanced Cordless Telecommunications

Analog local loop interface

Loop current used for signaling & message



Digital-lines to ISDN central office

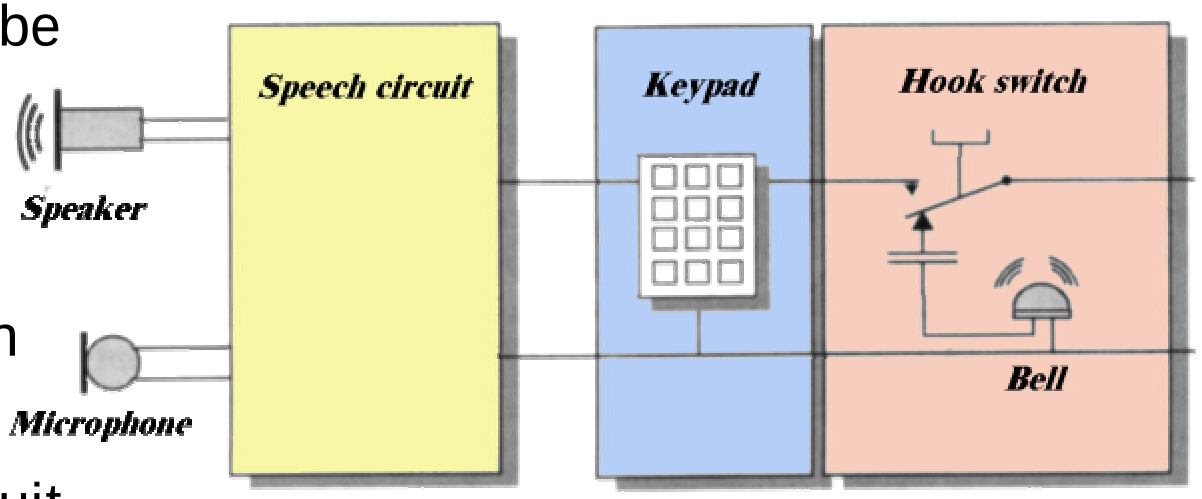


per trunk signaling in local loop:

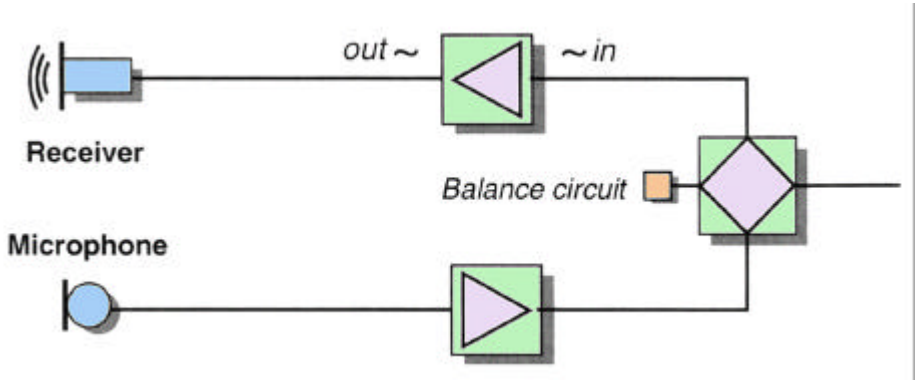
- long setup time
- hacking easy
- voice grade circuits
- interference & cross-talk sensitive
- expensive

Basic telephone terminal

- A basic phone can be made by using just four units
  - The bell
  - The hook switch
  - The keypad
  - The speech circuit

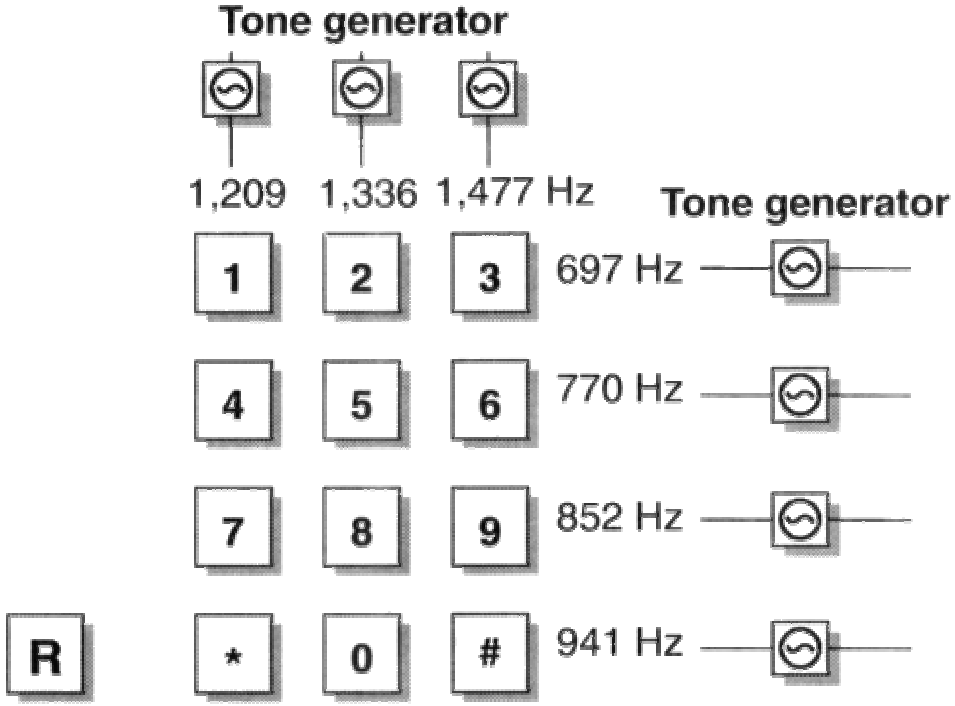


- Modern keypads use dual-tone dialing
- The speech circuit adapts voice levels and isolates mic and speaker



Dual-tone dialing

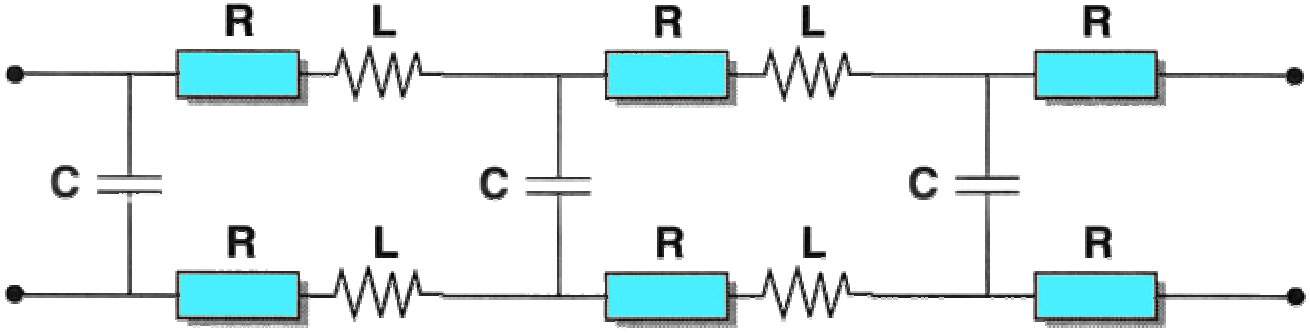
- Dual-tone dialing is used in subscriber loop to transmit the selected B-subscriber number
- Earlier pulse selection was applied (very rare nowadays)



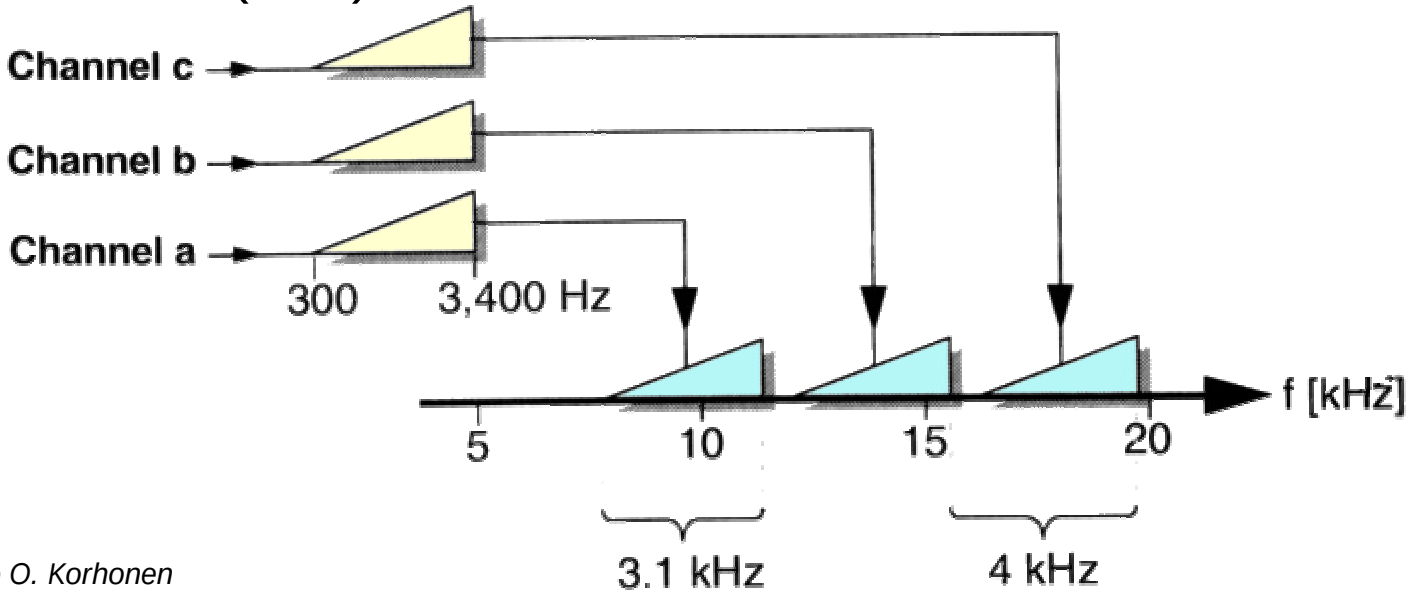
Some features in PSTN of ´60

Trunk network

- Coil loading was used to enhance higher frequency range



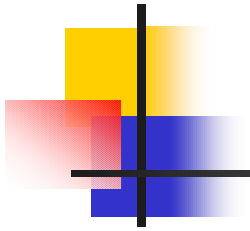
- Frequency division multiplexing (FDM) with single sideband (SSB) modulation was used in trunk networks



Trunk network

- 1960s employed both frequency division multiplexing (**FDM**) and "**baseband**" over paired cable
- FDM was anyhow the backbone of the trunk networks of the 1960s
  - ITU-T FDM recommendations specify
    - capacity and frequencies for FDM systems with 12, 60, 300, 900, 960, 2,700 and 10,800 **channels**
    - **Carrier** frequencies are between 60 kHz and just under 60 MHz
- In general, FDM can be used in symmetrical paired cable, coaxial cable, radio link and satellite
- Modern trunk networks apply optical links that may use Dense Wavelength Division Multiplexing (**DWDM**)

Some features of PSTN of ´60 (cont.)

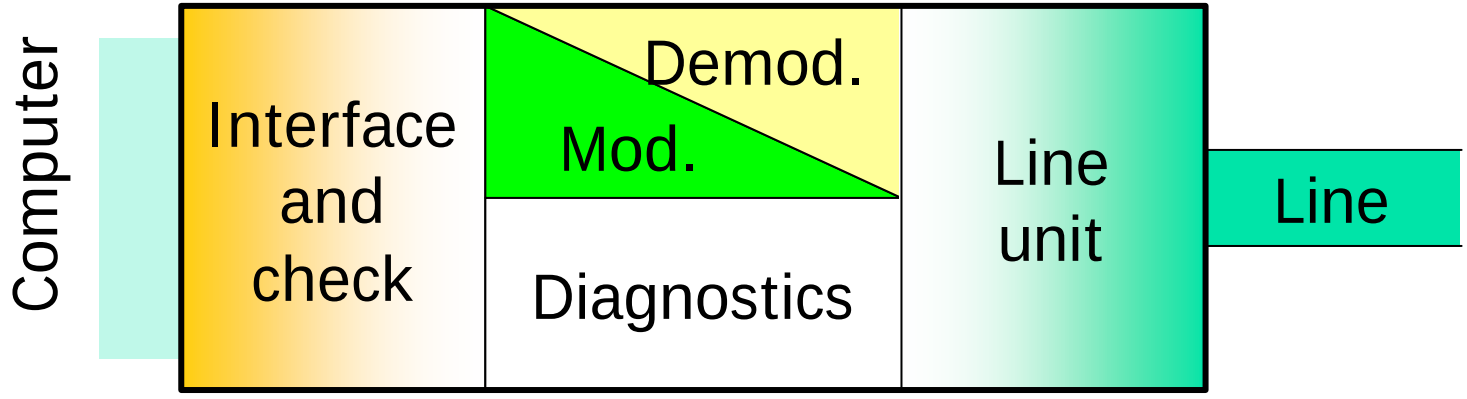


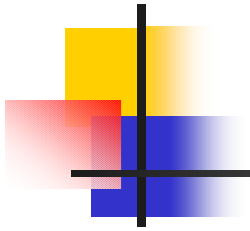
- Network **intelligence** and **value-added services**
  - not supported as such
  - operators were anyhow intelligent :)
    - value added services by tracking what happens in the area!
- Inter-exchange **signaling**
  - call setup took about 15 seconds
  - **channel-associated** signaling (CAS: No.5, R1,R2*)
  - about 10% of trunk line capacity was taken by signaling
- Operation and maintenance (O&M)
  - using local info-databases and local workforce
  - network maintenance was based on on-field check-ups

**nowadays in ISDN & PLMN: common channel signaling (CCS): SS7*

Basic modules of a modem

- Diagnostic unit
  - Checks faults and controls the modem
- Interface and line units
  - Adapt the modem and terminal
- Modem performs A/D and D/A conversion and selects rate such that transmission quality criteria (error rate) can be meet





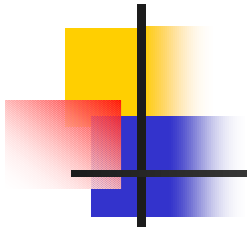
Modem specifications

- ITU-T specifies several modem standards as
  - V.26 (11/88) - 2400 bits per second modem for use on 4-wire leased lines
  - V.27 (11/88) - 4800 bits per second modem for use on leased lines
  - V.27ter (11/88) - 4800/2400 bits per second modem for use in the general switched telephone
  - V.29 (11/88) - 9600 bits per second modem for use on point-to-point 4-wire leased lines
  - V.90 (09/98) - 56 000 bit/s downstream and up to 33 600 bit/s upstream modem for use in the general switched telephone

What is specified in a modem recommendation?

- Data signaling rates, symbol rates, carrier frequencies
  pre-emphasis, scrambler, framing, encoder
- Interface circuits
- Start-up signals and sequences
- Operating procedures
- Testing conditions
- There are two kind of modems specified by ITU-T:
- Digital modems: Generates G.711 signals and receives V.34 signals passed through a G.711 encoder. Connected to a digital switched network through a digital interface
- Analog modems: Generates V.34 signals and receives G.711 signals that have been passed through a G.711 decoder in an analog PSTN local loop

G.711 (11/88) - Pulse code modulation (PCM) of voice frequencies
V.34 (02/98) - A modem operating (up to 33 600 bit/s) for use in 2-wire analog PSTN



An extract from G.711

1 General

The characteristics given below are recommended for **encoding voice-frequency signals**.

2 Sampling rate

The nominal value recommended for the sampling rate is **8000** samples per second. The tolerance on that rate should be ± 50 parts per million (ppm).

3 Encoding law

3.1 **Eight binary digits per sample** should be used for international circuits.

3.2 Two encoding laws are recommended and these are commonly referred to as the **A-law** and the **m-law**. The definition of these laws is given in Tables 1a/G.711 and 1b/G.711 and Tables 2a/G.711 and 2b/G.711 respectively.

V.34 Modem specifications

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

V.34
(02/98)

SERIES V: DATA COMMUNICATION OVER THE TELEPHONE NETWORK

Interfaces and voiceband modems

A modem operating at data signalling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits

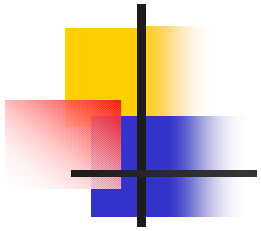
V.34 Modem specifications

ITU-T V-SERIES RECOMMENDATIONS

DATA COMMUNICATION OVER THE TELEPHONE NETWORK

General	V.1–V.9
Interfaces and voiceband modems	**V.10–V.34**
Wideband modems	V.35–V.39
Error control	V.40–V.49
Transmission quality and maintenance	V.50–V.59
Simultaneous transmission of data and other signals	V.60–V.99
Interworking with other networks	V.100–V.199
Interface layer specifications for data communication	V.200–V.249
Control procedures	V.250–V.299
Modems on digital circuits	V.300–V.399

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

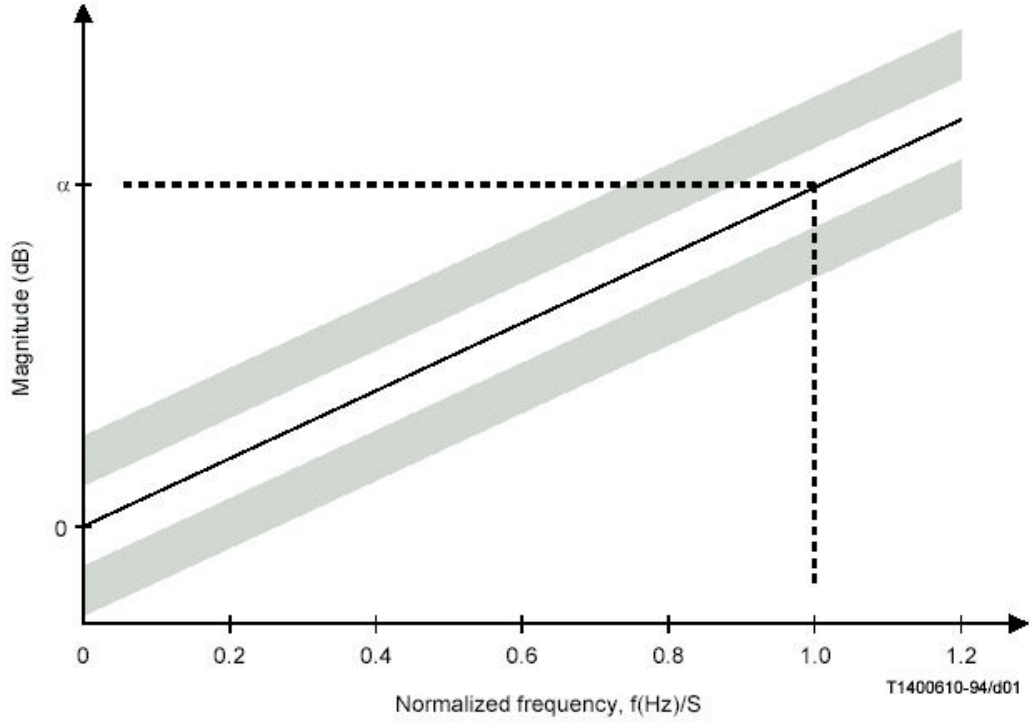


V.34 Modem specifications

5.4.1 Transmit spectrum specifications

The transmit spectrum specifications use a normalized frequency, which is defined as the ratio f/S, where f is the frequency in Hz and S is the symbol rate.

The magnitude of the transmitted spectrum shall conform to the templates shown in Figures 1 and 2 for normalized frequencies in the range from (d/e – 0.45) to (d/e + 0.45). The transmitted spectrum shall be measured using a 600 Ω pure resistive load. See also Tables 3 and 4.



NOTE – Tolerance for transmit spectrum is ± 1 dB.

Figure 1/V.34 – Transmit spectra templates for indices 0 to 5

6 DTE interfaces

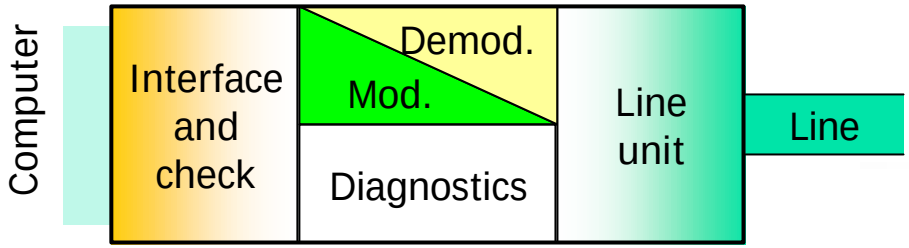


Table 5/V.34 – Interchange circuits for combined primary and secondary channel interfaces

Interchange circuit		Notes
No.	Description	
102	Signal ground or common return	
103	Transmitted data	
104	Received data	
105	Request to send	
106	Ready for sending	
107	Data set ready	
108/1 or 108/2	Connect data set to line Data terminal ready	
109	Data channel received line signal detector	
113	Transmitter signal element timing (DTE source)	1
114	Transmitter signal element timing (DCE source)	2
115	Receiver signal element timing (DCE source)	2
125	Calling indicator	
133	Ready for receiving	3
140	Loopback/maintenance	
141	Local loopback	
142	Test indicator	
118	Transmitted secondary channel data	4
119	Received secondary channel data	4
120	Transmit secondary channel line signal	4, 5
121	Secondary channel ready	4, 5
122	Secondary channel received line signal detector	4, 5, 6

V.34 Modem specifications

V.34 Modem specifications

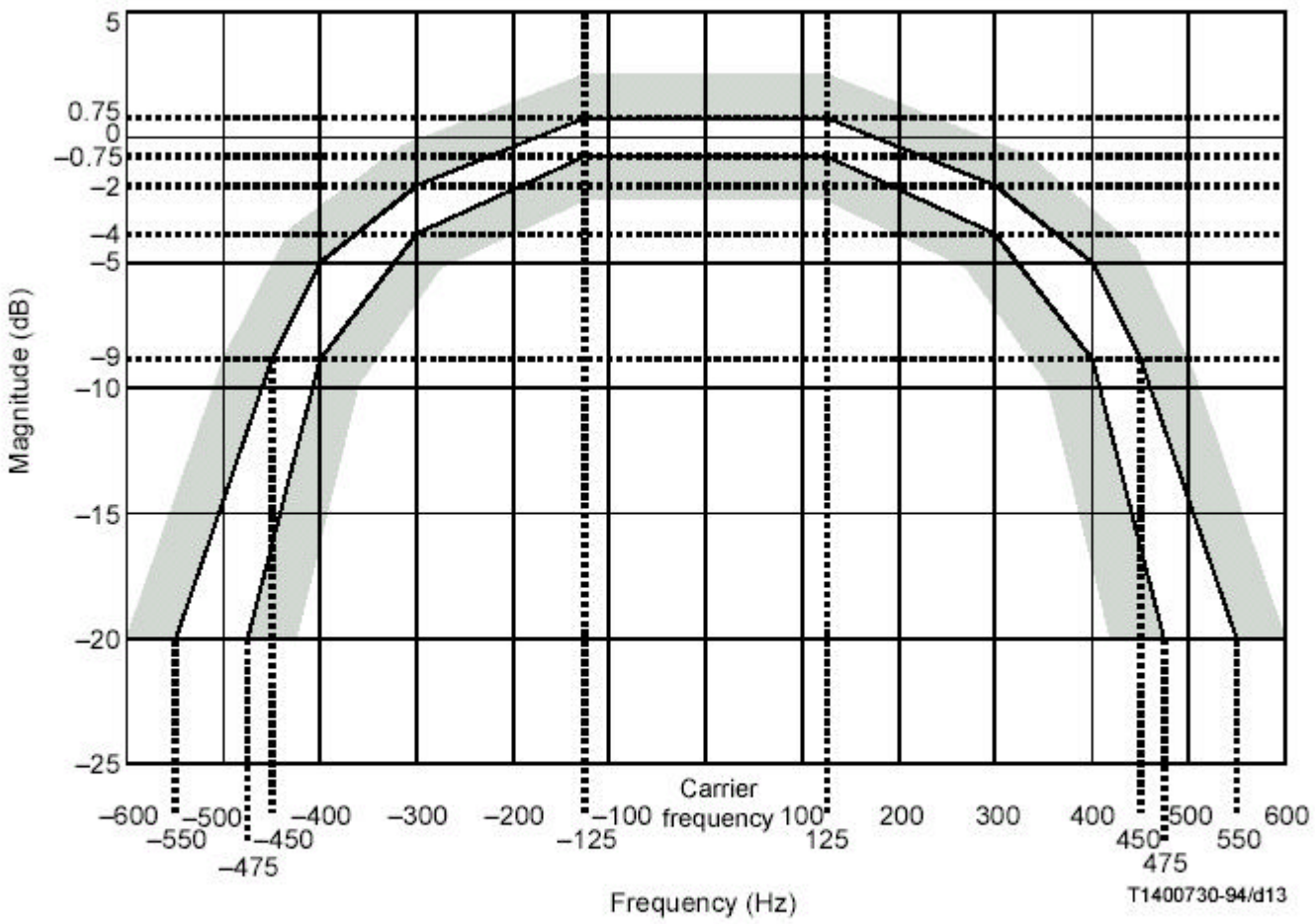
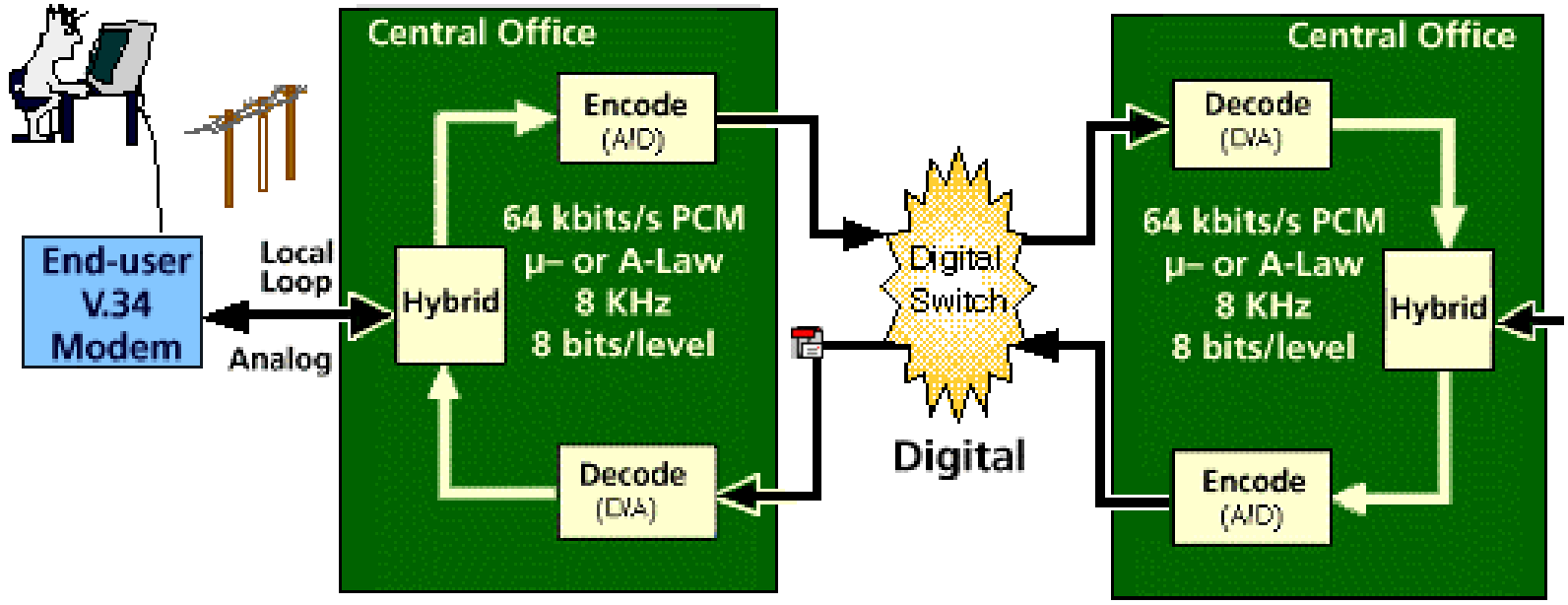


Figure 13/V.34 – Transmit spectrum template for INFO modulation

Connecting V.34 (33.6 kb/s) modem

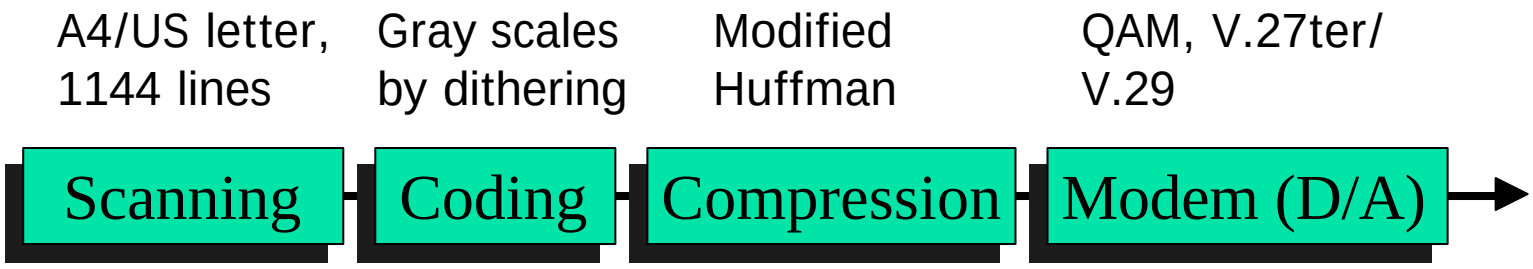


A-law: in Europe, μ-law:in the US

See also: “A brief introduction to modem technology” at http://www.physics.udel.edu/wwwusers/watson/student_projects/scen167/thosguys/

Fax communications over PSTN

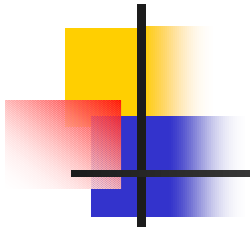
- Faxes follow standard PSTN modem communications recommendations or IEEE recommendations, as V.17 *(02/91) (- Wire modem for facsimile applications with rates up to 14 400 bit/s)*
- Faxes are divided into groups:
  - Group 1 (´68): Analog scanning, 2400 bits/s
  - Group 2 (´76): Analog scanning, 4800 bits/s
  - Group 3 (´80): Digital scanning, 14400 bits/s
  - Group 4 (´84): Digital scanning, 64 kbit/s (ISDN)
- Example of modules in group 3 transmitting fax:



PSTN in ITU-T standards *(www.itu.org)*

- Series D Recommendations - General tariff principles
- Series E Recommendations - Overall network operation, telephone service, service operation and human factors
- Series G Recommendations - Transmission systems and media, digital systems and networks
- Series I Recommendations - Integrated services digital network (ISDN)
- Series M Recommendations - Network maintenance: international transmission systems, telephone circuits, telegraphy, facsimile, and leased circuits

ITU: International Telecommunications Union

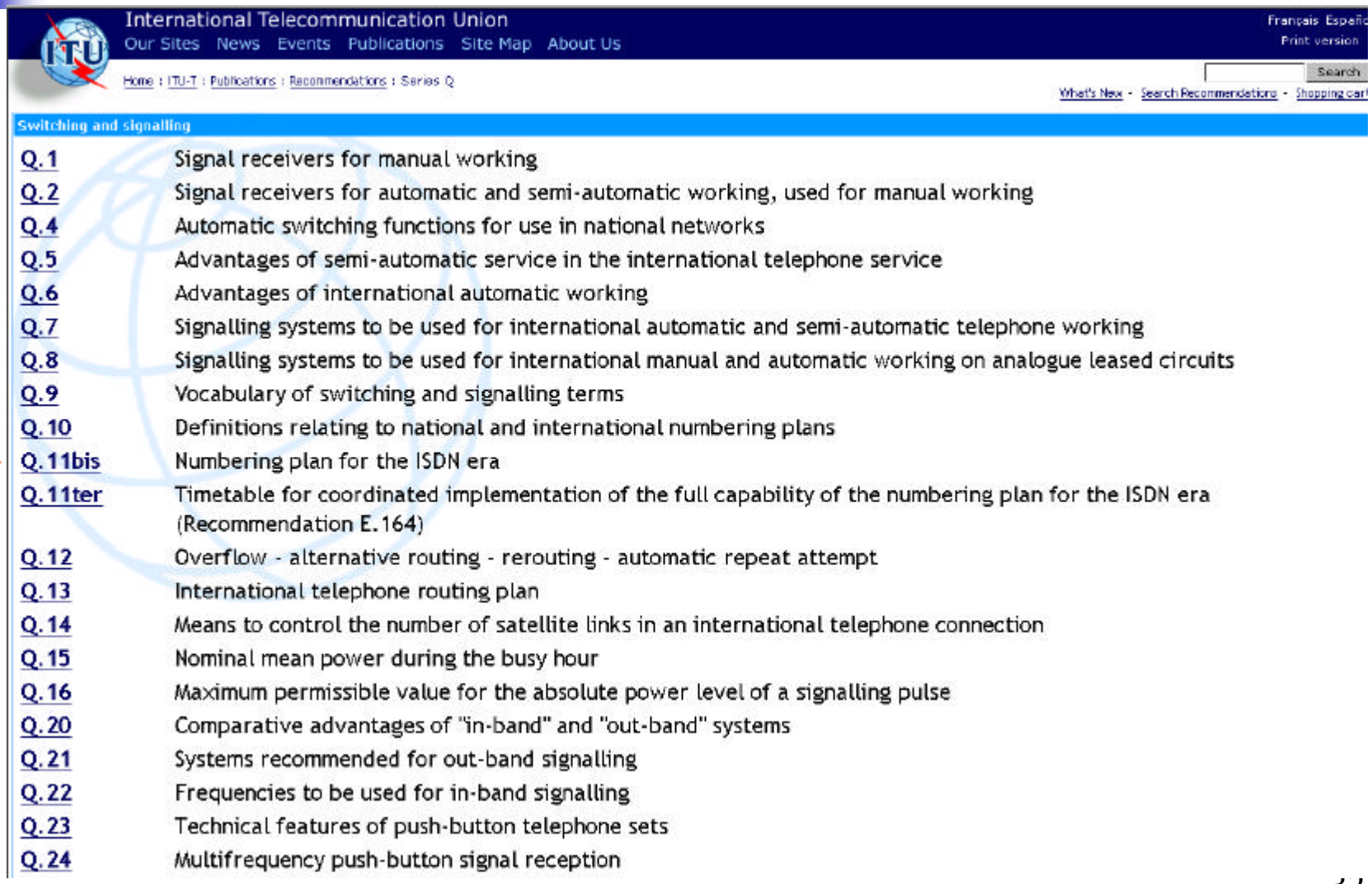


More PSTN standards *(www.itu.org)*

- Series O Recommendations - Specifications of measuring equipment
- Series P Recommendations - Telephone transmission quality, telephone installations, local line networks
- Series Q Recommendations - Switching and signaling (Signaling Systems no:4,5,6, and 7, Register Signaling no: R1, R2, IN - Service)
- Series V Recommendations - Data communication over the telephone lines

Example: Q-recommendations: Switching and signalling*

(Illustrative examples denoted by arrows)



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Switching and signalling

Q.1	Signal receivers for manual working
Q.2	Signal receivers for automatic and semi-automatic working, used for manual working
Q.4	Automatic switching functions for use in national networks
Q.5	Advantages of semi-automatic service in the international telephone service
Q.6	Advantages of international automatic working
Q.7	Signalling systems to be used for international automatic and semi-automatic telephone working
Q.8	Signalling systems to be used for international manual and automatic working on analogue leased circuits
Q.9	Vocabulary of switching and signalling terms
Q.10	Definitions relating to national and international numbering plans
Q.11bis	Numbering plan for the ISDN era
Q.11ter	Timetable for coordinated implementation of the full capability of the numbering plan for the ISDN era (Recommendation E.164)
Q.12	Overflow - alternative routing - rerouting - automatic repeat attempt
Q.13	International telephone routing plan
Q.14	Means to control the number of satellite links in an international telephone connection
Q.15	Nominal mean power during the busy hour
Q.16	Maximum permissible value for the absolute power level of a signalling pulse
Q.20	Comparative advantages of "in-band" and "out-band" systems
Q.21	Systems recommended for out-band signalling
Q.22	Frequencies to be used for in-band signalling
Q.23	Technical features of push-button telephone sets
Q.24	Multifrequency push-button signal reception

*http://www.itu.int/rec/recommendation.asp?type=products&lang=e&parent=T-REC-Q

Switching and signalling (cont.)

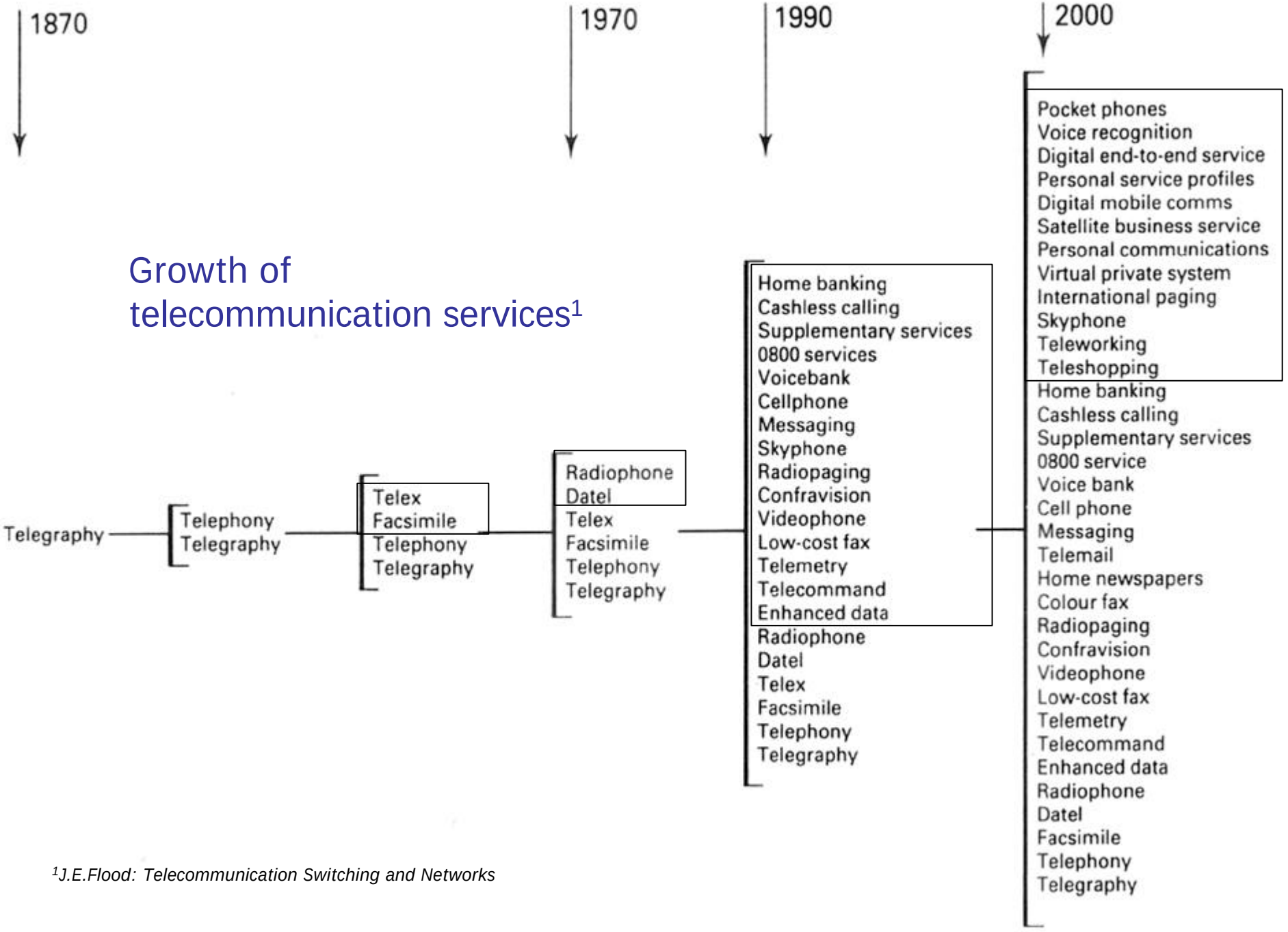
Q.52	Signaling between international switching centers and stand-alone echo control devices
Q.55	Signalling between signal processing network equipment (SPNE) and international switching centres (ISC)
Q.56	Signalling between signal processing network equipment (SPNE) and international switching centres (ISC) over an IP network
Q.65	The unified functional methodology for the characterization of services and network capabilities
Q.68	Overview of methodology for developing management services
Q.71	ISDN circuit mode switched bearer services
Q.72	Stage 2 description for packet mode services
Q.76	Service procedures for Universal Personal Telecommunication - Functional modelling and information flows
Q.80	Introduction to stage 2 service descriptions for supplementary services
Q.81.1	Direct dialling-in
Q.81.2	Multiple subscriber number
Q.81.3	Calling line identification presentation (CLIP) and calling line identification restriction (CLIR)
Q.81.5	Connected line identification, presentation and restriction (COLP) and (COLR)
Q.81.7	Malicious call identification (MCID)
Q.81.8	Sub-addressing (SUB)
Q.82.1	Call transfer
Q.82.2	Call forwarding
Q.82.3	Call deflection
Q.82.4	Line hunting
Q.82.7	Explicit call transfer
Q.83.1	Call waiting (CW)
Q.83.2	Call hold
Q.83.3	Stage 2 description for call completion supplementary services : Completion of call to busy subscriber
Q.83.4	Terminal portability
Q.84.1	Conference calling (CONF)

If you don't find it from Recommendations something is lost: How to use pay phones?

- Recommendation E.134 (03/93) - Human factors aspects of public terminals: Generic operating procedures

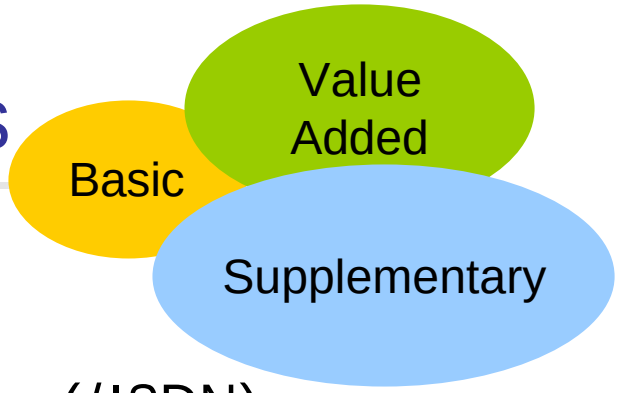
Terminal type	User action					
	Initialization	Means of payment	Identification	Communication	Next	End
Payphone	Lift handset	Insert means of payment	Input number (Address)	Transfer information	Press desig-nated button	Replace handset
Public fax (Sendmode)	Place document	Insert means of payment	Input number	Transfer information	Press desig-nated button	Automatic
Public fax (Receive mode)	Place document	Insert means of payment	Input number (of Network Node)	Transfer information	Press desig-nated button	Automatic
Public Videotex		Insert means (if required)	Select option	Transfer information	Select another option	

Growth of telecommunication services[1]

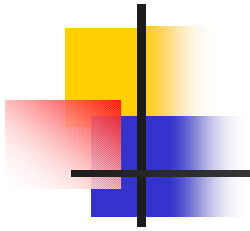


[1]*J.E.Flood: Telecommunication Switching and Networks*

Present-day PSTN services



- **Basic** service
  - bearer service (*local loop access*): analog (/ISDN)
- **Value-added** services (*telephonist-originated*) services as
  - directory inquiry (118)
  - weather, stock exchange, ticket reservation ...
- **Supplementary** services (*Intelligent Terminal (IN) implementation*)
  - distributed supplementary as ‘call forwarding unconditional’ (Q.82.2), ‘call waiting’, ‘queuing’ ...
  - centralized supplementary services (IN) use specialized routing & charging as VPN, credit card calls, free phone (receiver pays), universal access number (connected automatically to the nearest office), ...



PSTN today summarized

- ISDN very popular in switches (in Finland all-digital exchanges)
- ISDN getting popular also for **local loop access**
- **Versatile access part** (analog/digital terminals possible)
- Conventional local loop **technology develops fast**
- Remote controlled **O&M**
- IN services fully-developed - **Intelligence moves to terminals**
- Fiber-optical **DWDM** links connect exchanges
- Common channel signaling (**SS7**)
- **SDH**-based (Synchronous Digital Hierarchy) trunk-networking
- Gets still more subscribers!

Switching: Transfer modes & connections

Transfer modes

PSTN

Circuit switching

- developed for voice
- nowadays also for data
- well-specified delays
- echo problems

Packet switching

- developed for data
- nowadays also for voice
- Statistical multiplexing
- variable delays

Ethernet

Connection types

ATM

Connection oriented

- hand-shaking
- strict error requirements
- for fast data transfer

Frame-relay

X.25

Connectionless

- broadcasting
- modest error rates often accepted
- fast data in good channels

UDP*

*User Datagram Protocol