University of Manchester

Department of Computer Science

CS3282

Digital Communications’06

1. Introduction & overview

Barry Cheetham

www.cs.man.ac.uk/~barry/mydocs/cs3282

Reading list

- IA Glover & PM Grant ‘Digital Communications’, (2nd Ed)
  Prentice-Hall, 2004
- A S. Tanenbaum, ‘Computer Networks (4th Ed),
  Prentice Hall, 2003.

Supplementary books

- B. Sklar ‘Digital Comms’ (2nd Ed) Prentice-H, 2001
- T.S. Rappaport, ‘Wireless Comms’

Syllabus

1. Intro & overview
2. Revision of Fourier transform theory
3. Digitising speech & images
4. Intro to binary transmission at base-band
5. Matched filtering
6. Pulse shaping
7. Hartley- Shannon Law
8. Binary transmission by modulated carrier (& OFDM)
9. Multi-level transmission
10. Multiple access to channel

Aims

1. Up-to-date overview of wired & wireless

telephone & computer networks

2. Principles of digital transmission (i) at base-band

(ii) by single carrier modulation

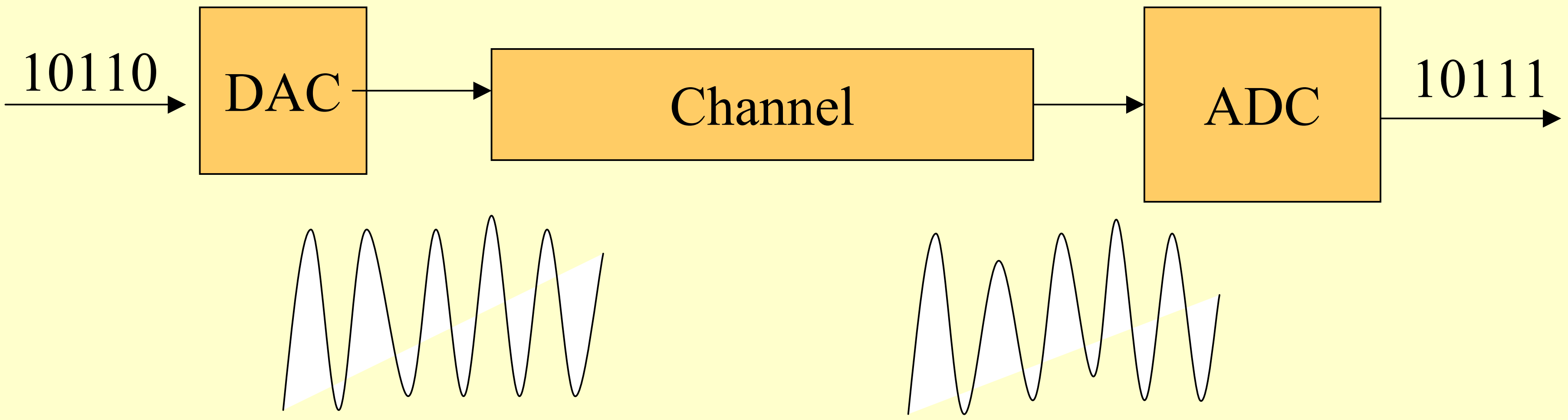
(iii) by multi-carrier modulation

3. Revise & put into context work in previous courses.

1.1. Overview of the course

- Requirements & limitations of digital transmission for
  - » fixed & mobile telephony,
  - » wired & wireless computer networks,
  - » data storage & digital broadcasting.
- Vast and rapidly advancing subject
- Fundamental ideas & detail.
- Large number of technical terms & acronyms
- Conceptualising skills.
- Must visualise signals in time & frequency domains
- Term "physical layer" explained
- Characteristics of wired & wireless channels discussed.
- Also look higher up chain of ‘protocol layers’.

- Transmitter like DAC :
  converts bit-stream to analog waveform suitable for channel
- Receiver like ADC



Time & frequency domains

- Each binary digit represented by analogue waveform segment
- Need to relate waveform shape to frequency spectrum.
- Need brief revision of Fourier transforms & spectral analysis.

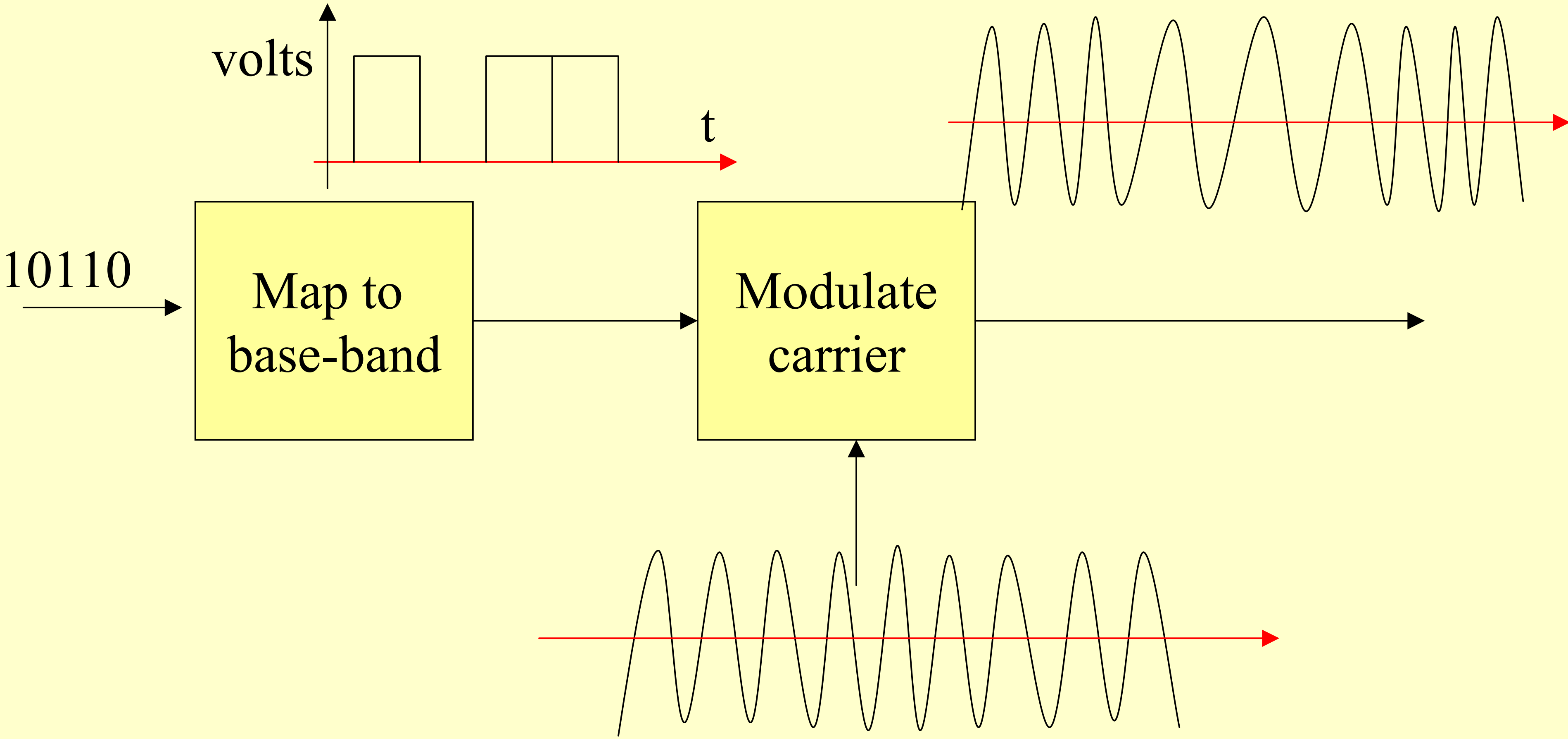
- Section 3 considers transmission of speech, music and video.
- Section 4 explains 'asynchronous' & 'synchronous' transmission,
- Also effects of noise, band-limiting & channel characteristics.
- Sections 5 & 6 revise matched filtering, pulse shaping & equalisatn.
- Base-band transmission first.

- Phenomenal advances in speed & efficiency of digital transmission:
  - » 56 kb/s computer modems over telephone lines
  - » Broad-band network access via ADSL
  - » Continuing developments of wireless telephony
  - » Emerging field of wireless computer networks.
  - » Digital broadcasting for radio & TV.
- Given bandwidth & signal-to-noise ratio,
  Shannon-Hartley Law gives bit-rate achievable (Sectn 7)

Carrier modulated transmission

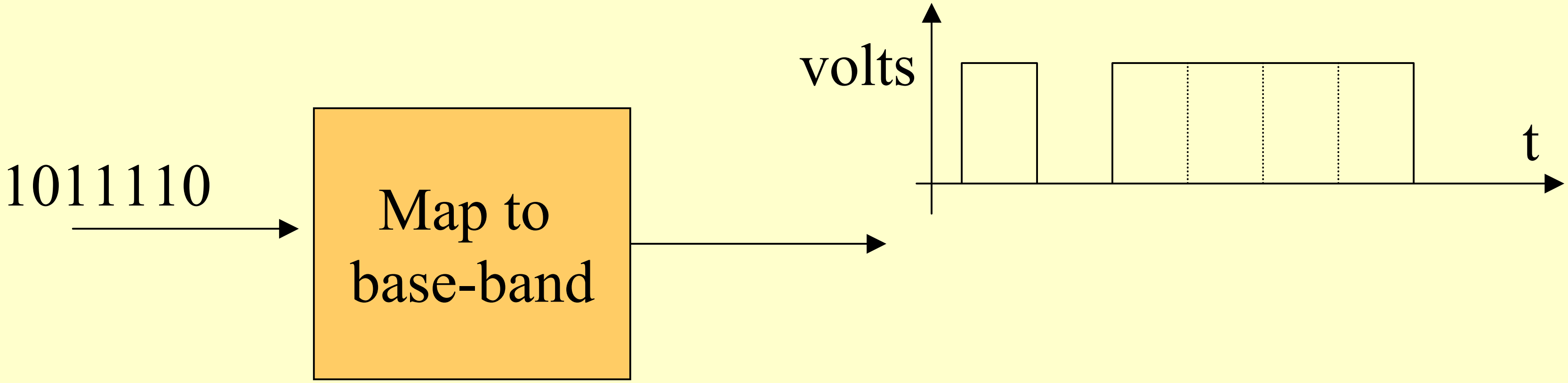
- Most digital communication systems use sinusoidal "carrier".
- Modulated by "base-band" signal which represent data.
- Modifies amplitude, frequency and/or phase of carrier.
- Changes detectable at receiver.
- Transmission placed in frequency band suitable for channel & equipment, & a voids clashing with other transmissions.

Modulation of single carrier



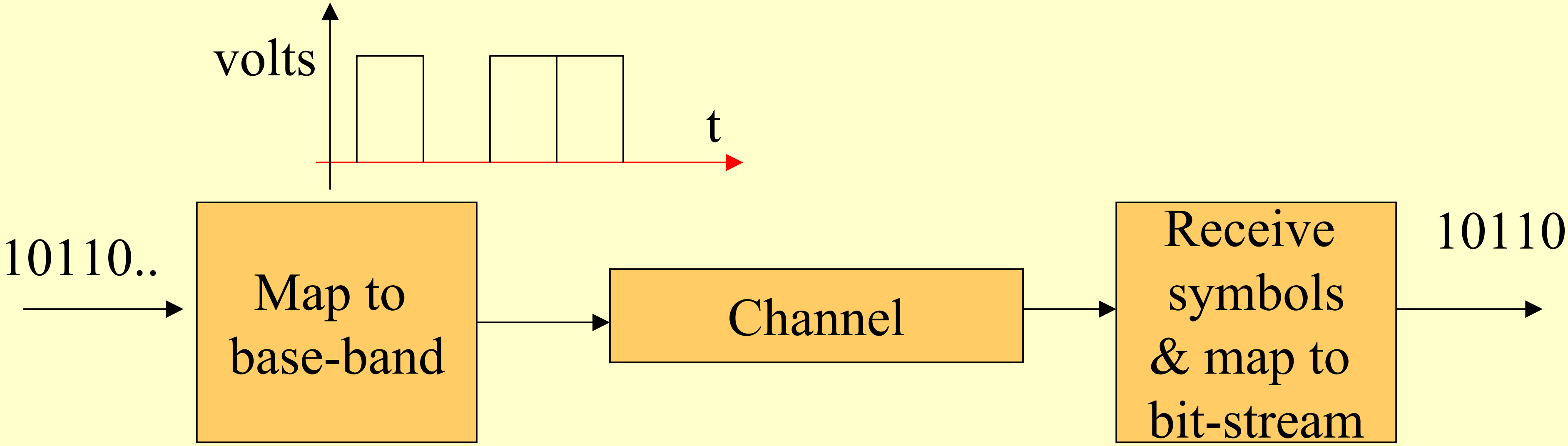
Real base-band

- Often has frequency band starting at zero Hz.
- Simplest is series of rectangular pulses : unipolar or bipolar.
- This is real base-band signal.

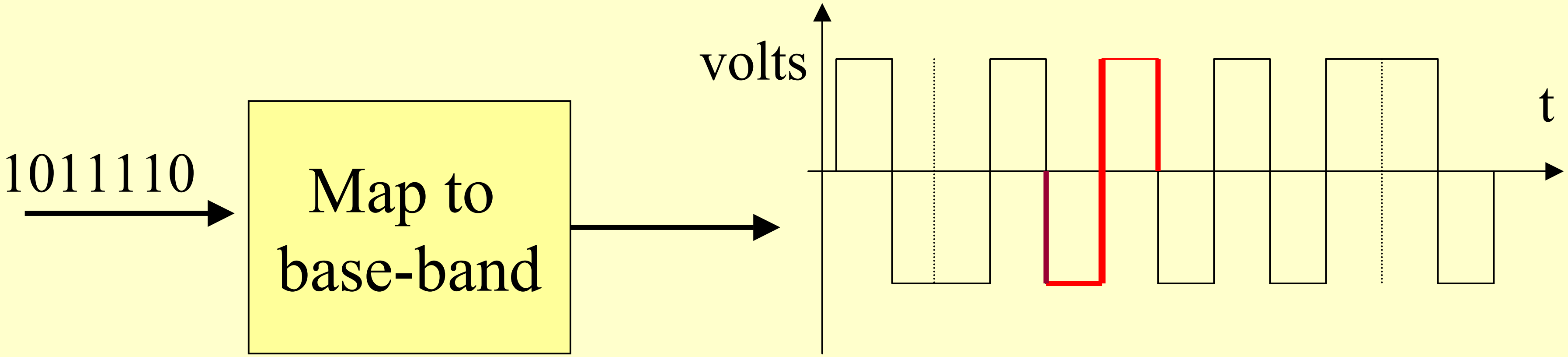


Real base-band signalling.

- Wires have large bandwidth not shared.
- Ethernet uses base-band signalling over wires
- Telephone lines often block frequencies below 300 Hz.
- Can shape pulses to not require the zero to 300 Hz bandwidth.



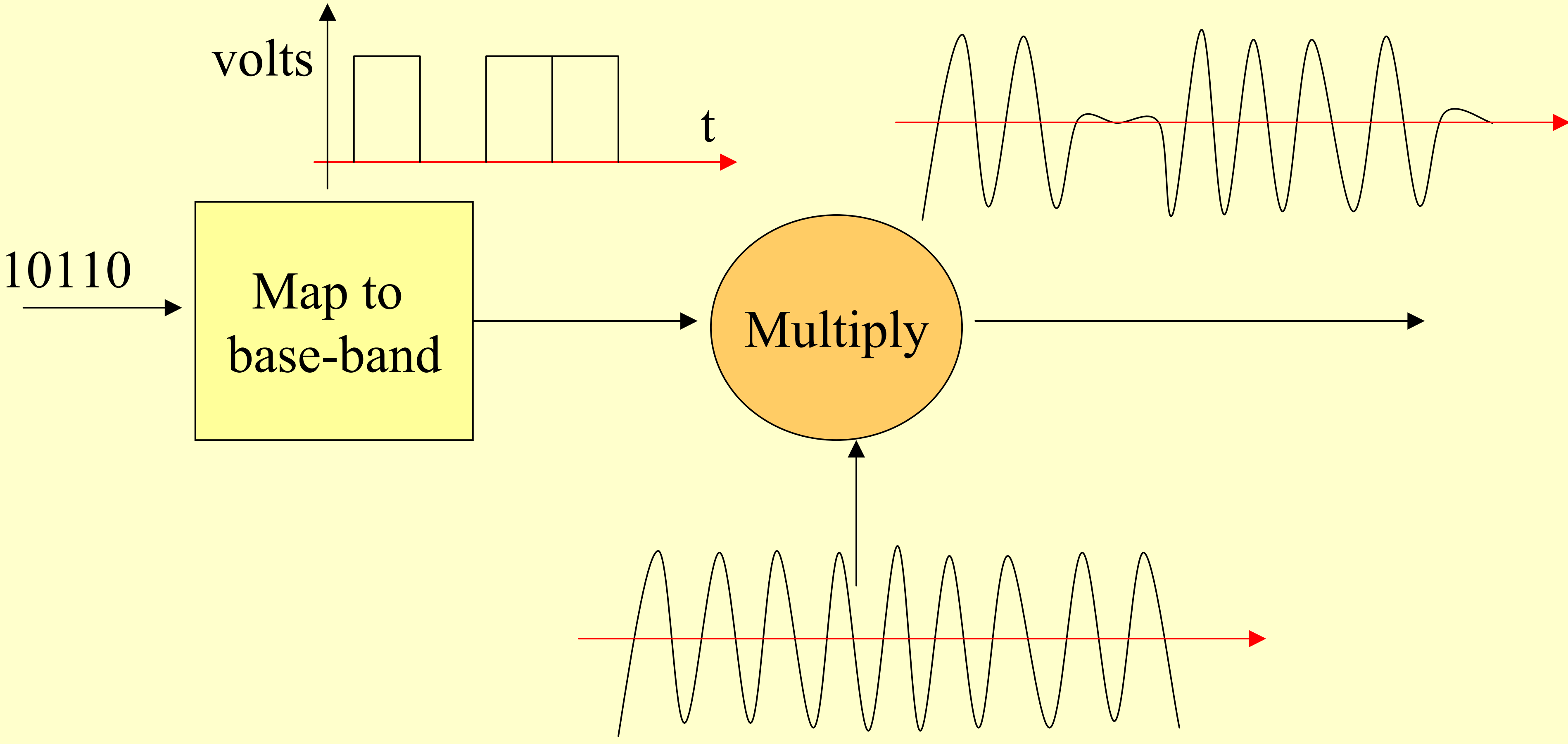
Manchester coding



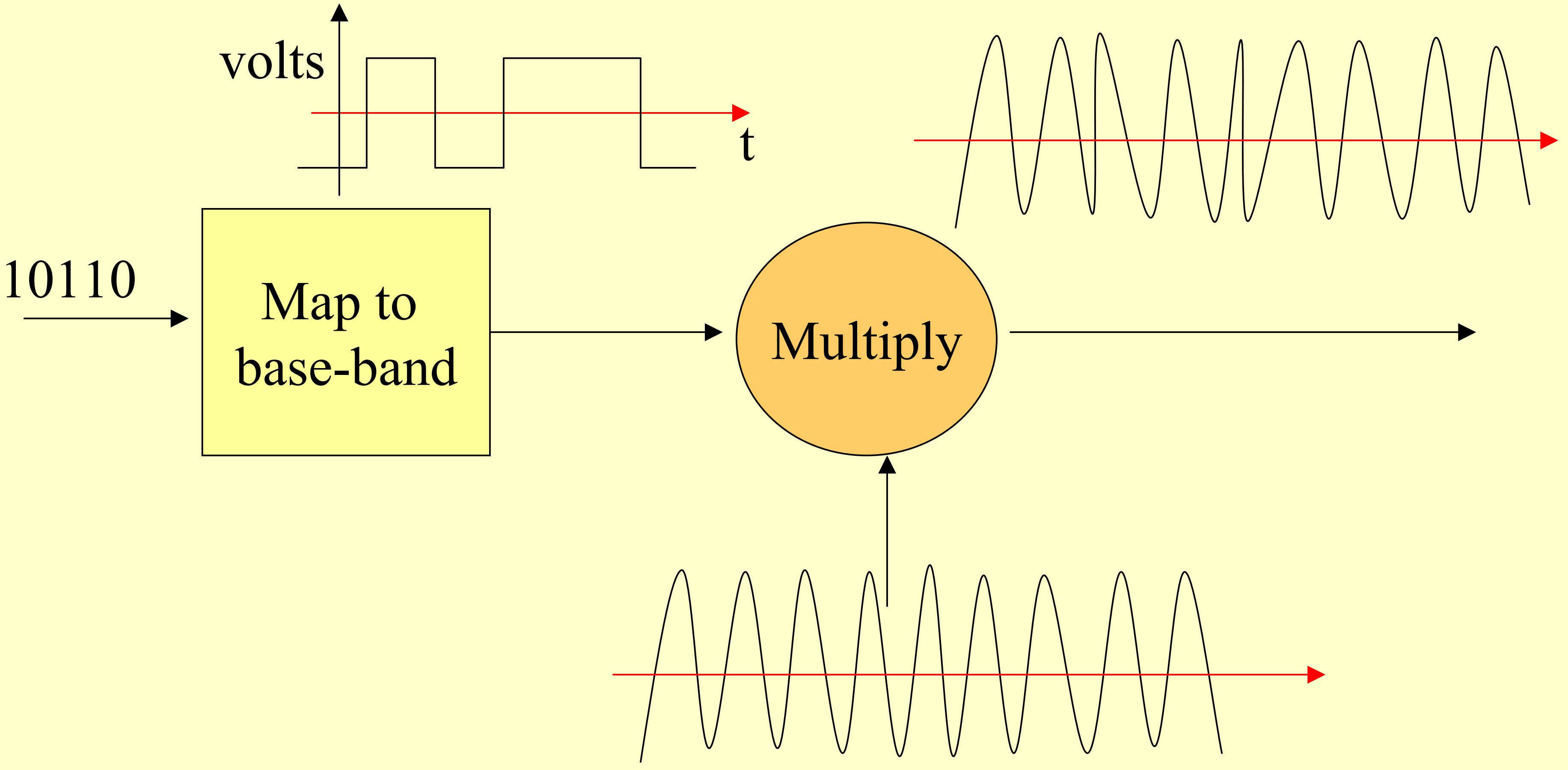
ASK, PSK & FSK

- Ideas so far can be understood in terms of real base-band signals.
- Generalised to carrier modulated signals in Section 8.
- Starts by revising ASK, FSK and PSK.
- These are 'single carrier' digital modulation schemes.

Amplitude modulation of single carrier



Phase modulation of single carrier

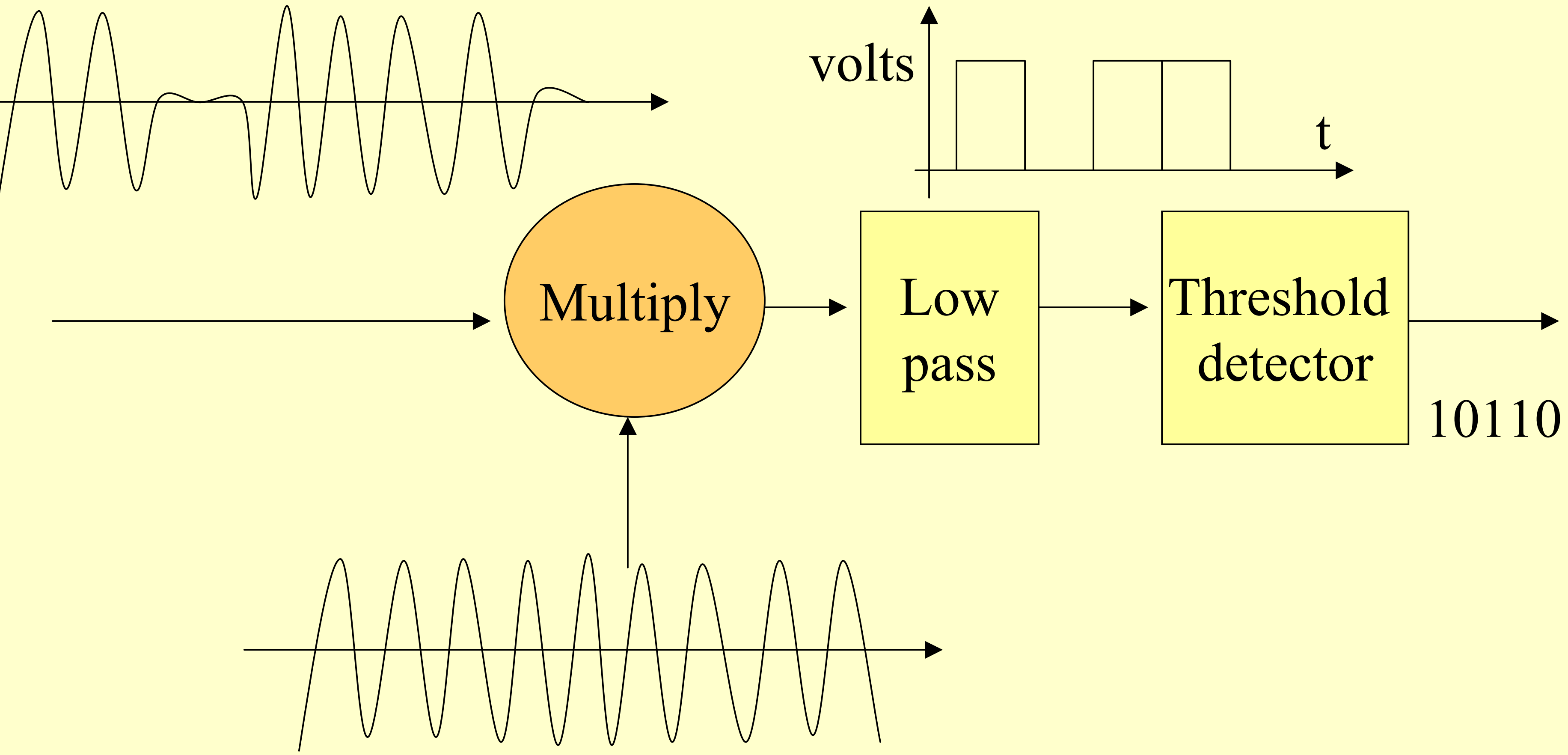


Coherent receivers

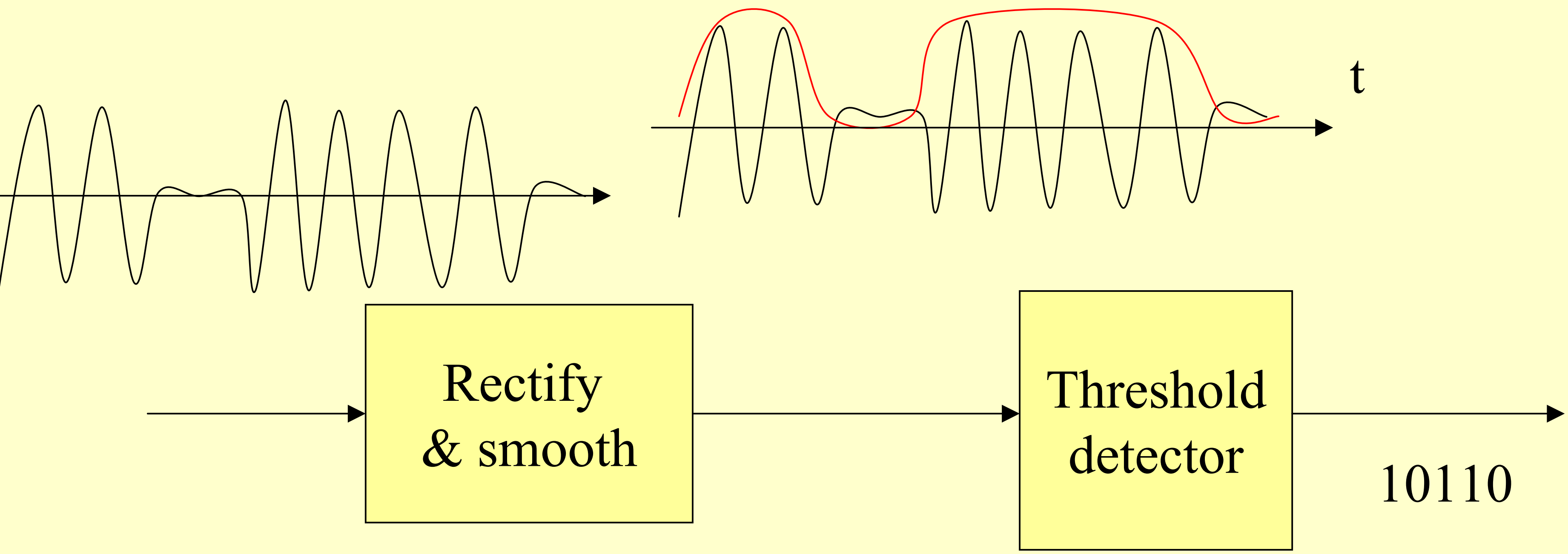
- Two types of digital receiver: non-coherent & coherent.

- Coherent receivers require local carrier generation at receiver

Coherent demodulation of ASK



Non-coherent detection of ASK

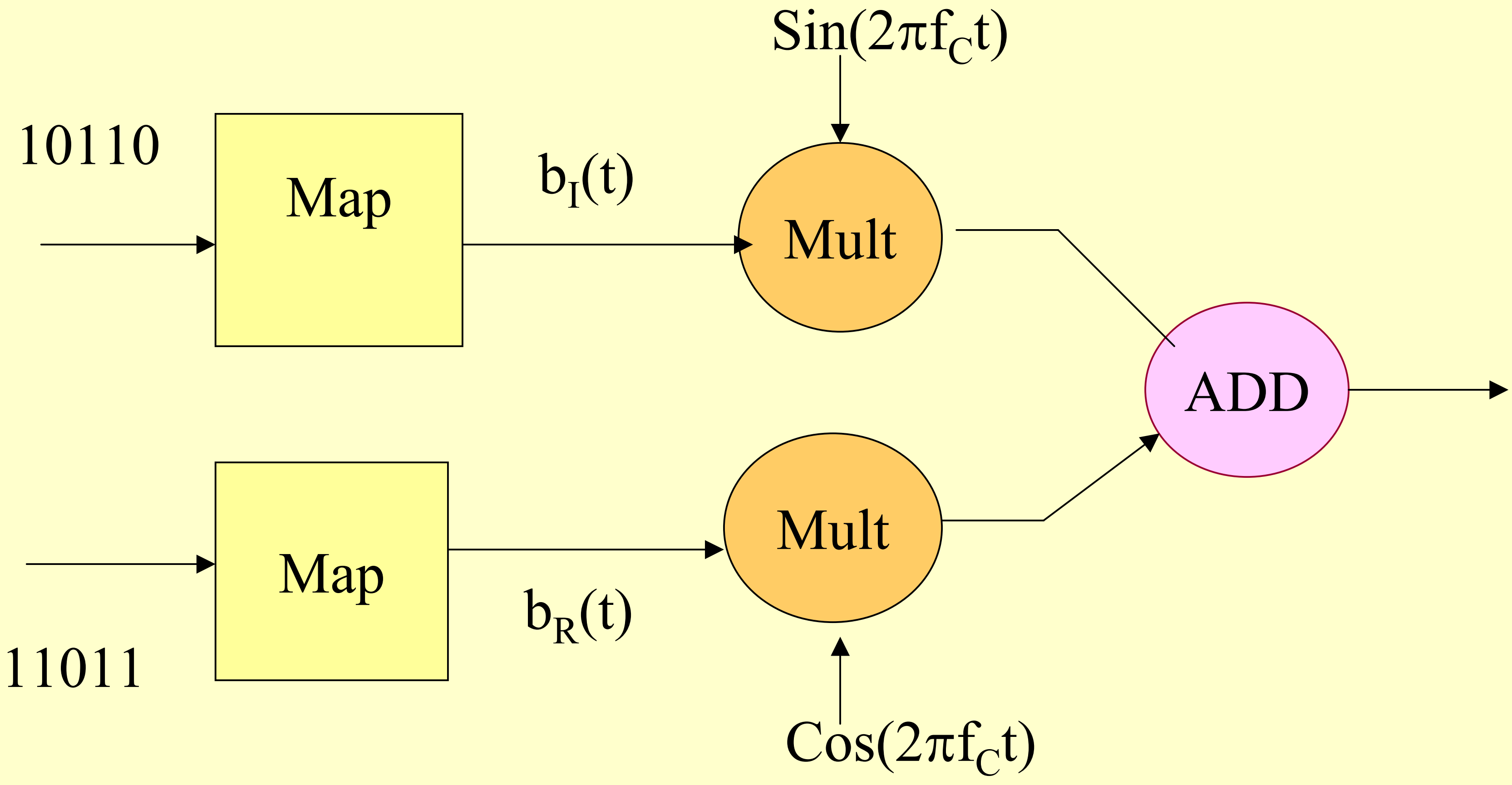


An advantage of coherent receiver

- Allows us to use a 'vector’ modulator & demodulator.

- More efficient forms of single carrier ASK, FSK and PSK.

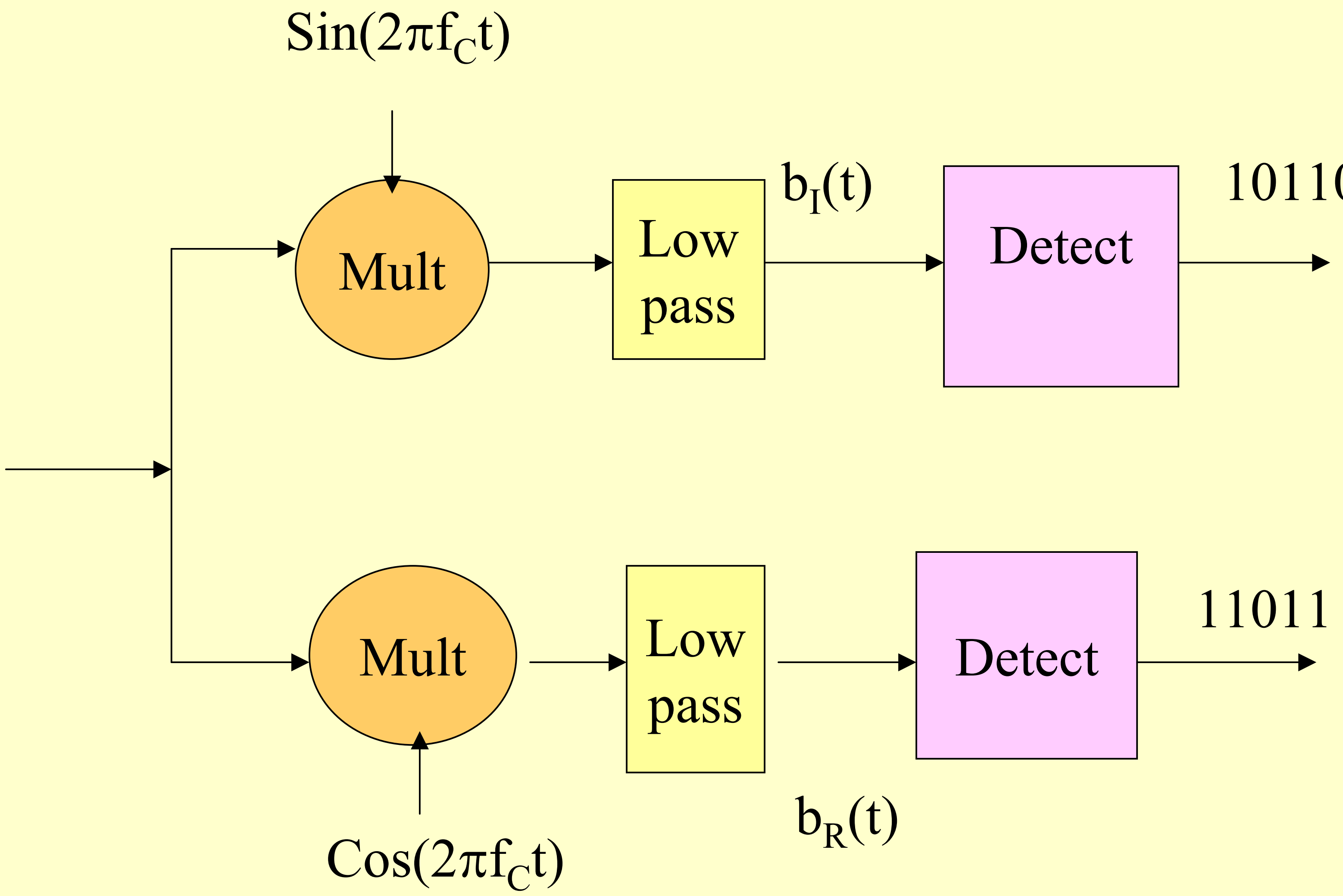
Vector modulator for single carrier



Complex base-band signal

- Base-band signal considered to have a real & imag parts.
- Simply two independent real base-band channels.

Vector de-modulator



Multi-carrier modulation

- For bandwidth-efficient fast digital transmission over radio channels subject to frequency-selective fading.
- Occurs due to reflections of radio signals from buildings & walls.
- Can cancel each other out at certain frequencies.
- Section 8 introduces OFDM for wireless LANs & digital TV.
- It is multi-carrier technique : more than one carrier frequency.
- Wireless LANs use 64 & broadcasting use 1024 or more.
- Modulation process is achieved by one FFT computation.
- With cyclic extension,

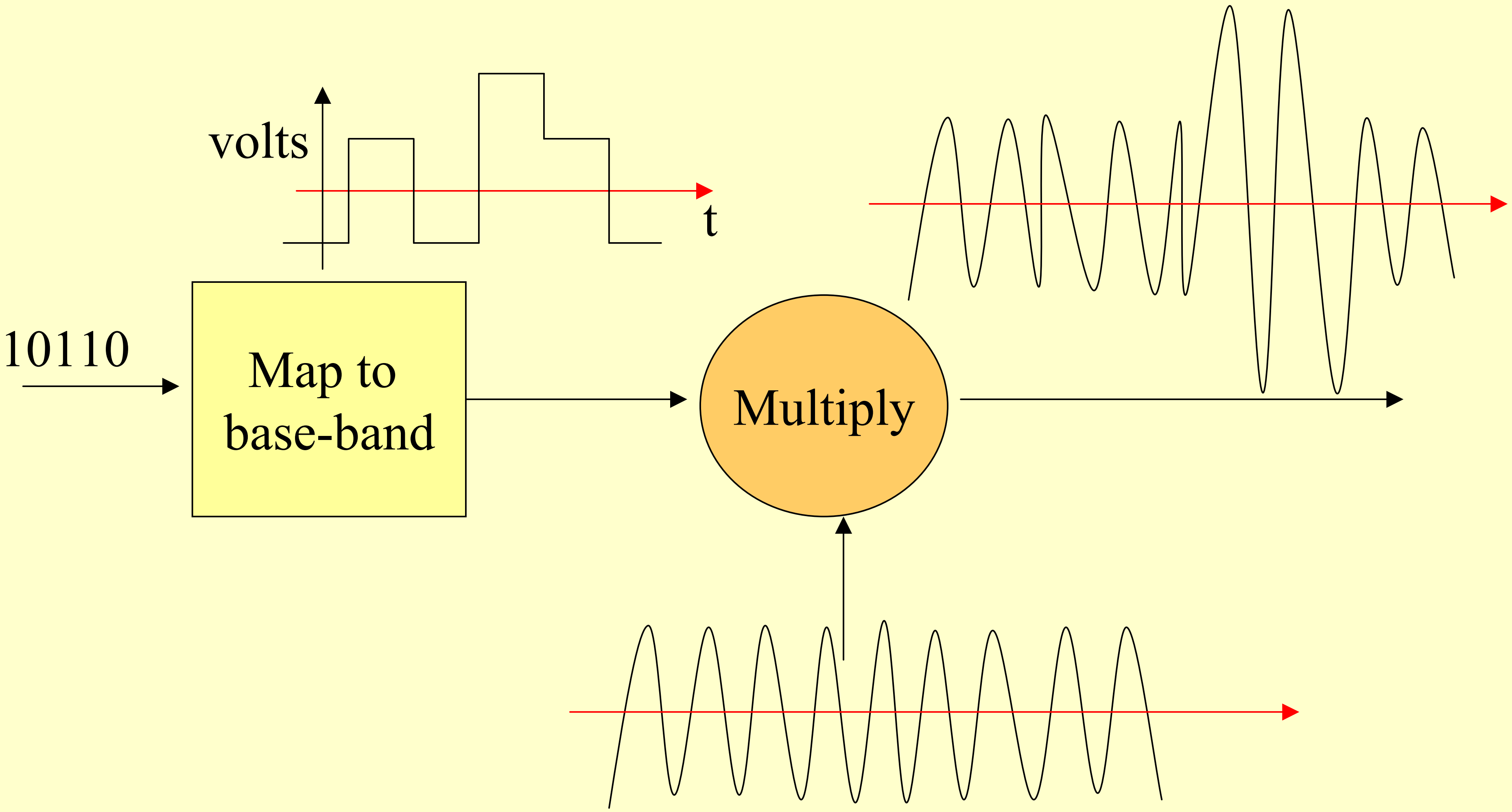
  pulse-shaping & matched filtering unnecessary

  & equalisation simplified.

Multi-level signalling

- With binary signalling, each pulse represents one bit.
- Up to 2 bits/second per Hz at base-band.
- Also for ASK etc. with vector-modulation & coherent detection.
- About 3.1 kb/s over a 300-3400 kHz domestic telephone link.
- Less than 10% of what we know to be achievable.
- Section 9 deals with multi-level modulation schemes.
- Each symbol(pulse) represents more than one bit
- Combine multi-level ASK & PSK to produce QAM & APK
- Widely used in data modems for up to abt 33kb/s.
- For 56kb/s, nature of PCM speech transmission exploited.

Amplitude & phase modulatn of single carrier



Multiple access techniques (Sectn 10)

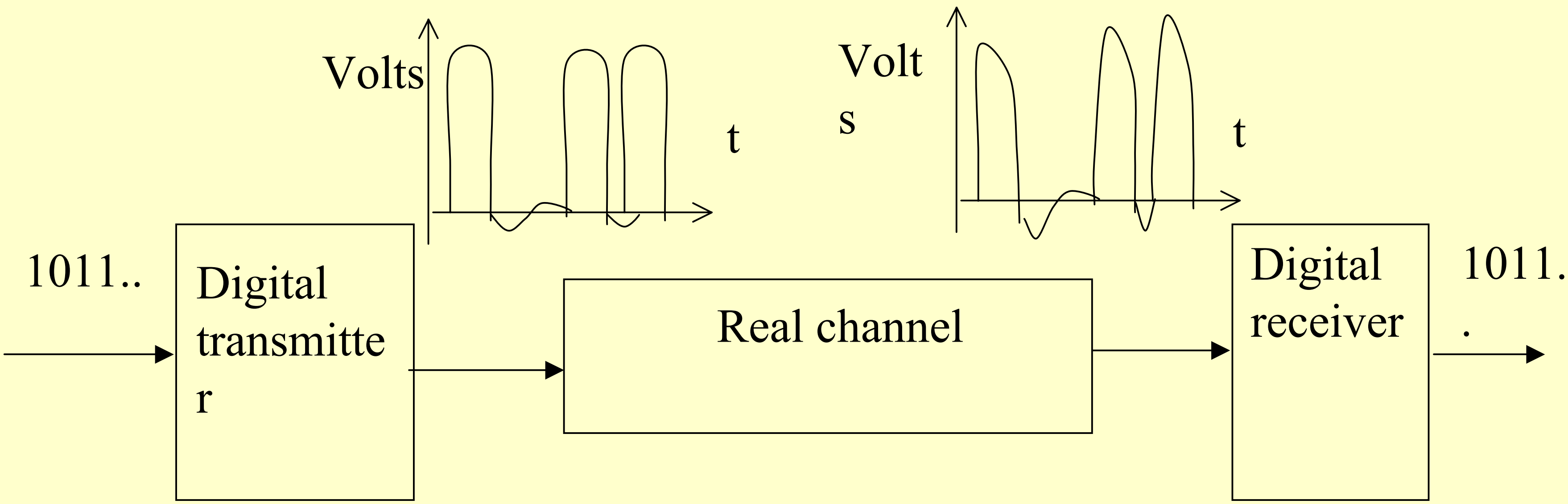
- For digital communication by radio.
- Sharing a given radio bandwidth efficiently between users,
- e.g. mobile phone users,
- Possible in many different ways, e.g. CDMA
- Used in USA currently for 2G mobile telephony
- Will be used for 3^{rd} gen mobile phones world-wide.

Related topics:

- Direct sequence spread spectrum techniques (DSSS)
- Frequency hopping (FHSS)
- Complementary code keying (CCK)

1.2. Digital transmission channels

D*igital transmitter & digital receiver* at ends of analogue *channel*.



•*Channel* may be wire or cable, optical fibre, radio, infrared etc.
•Or magnetic & optical recording devices (e.g. CDROMs, DVDs etc.).
•Similarities of storage & transmission striking.
•Bandwidth utilisation & error concealment raise similar issues.
•Overall delay & cost requirements considerably different.
•Where instantaneous transmission not needed, cost savings enormous

•Performance of digital transmission link is governed by:
    (a) usable channel bandwidth,
    (b) received noise &
    (c) channel in-band frequency characteristics.
•Factor (c) is highly variable especially for mobile.
•Mobility introduces a 4^{th} factor : 'Doppler' frequency shift.

•Discuss design of digital transmitters & receivers with ref to

bandwidth & frequency-response of channel

& received noise characteristics.

•Fundamental limitations in what can be achieved established.

•This is referred to as “physical layer” of a communication system

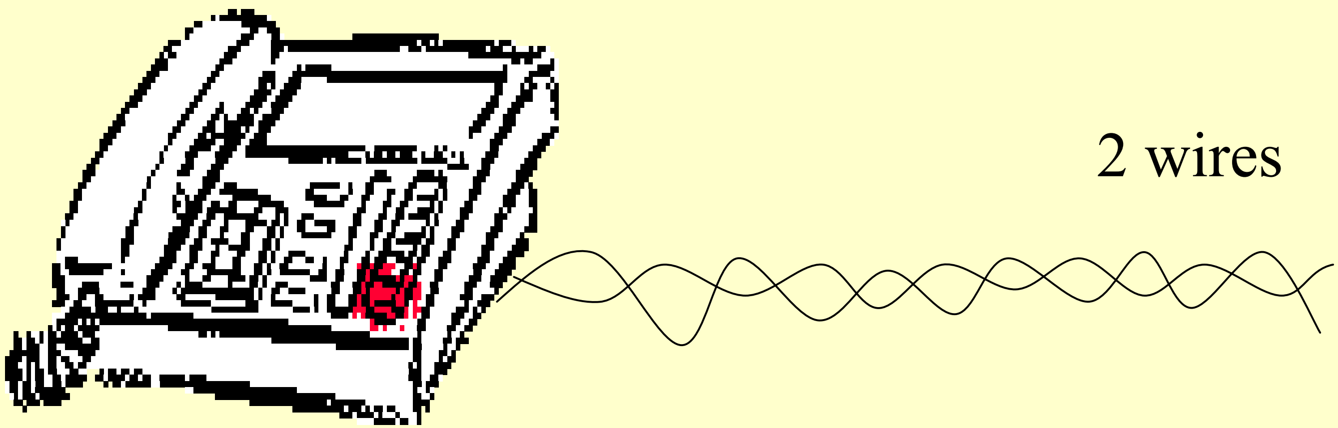
•Lowest layer of the “OSI reference model”.

1.3. Telephone networks

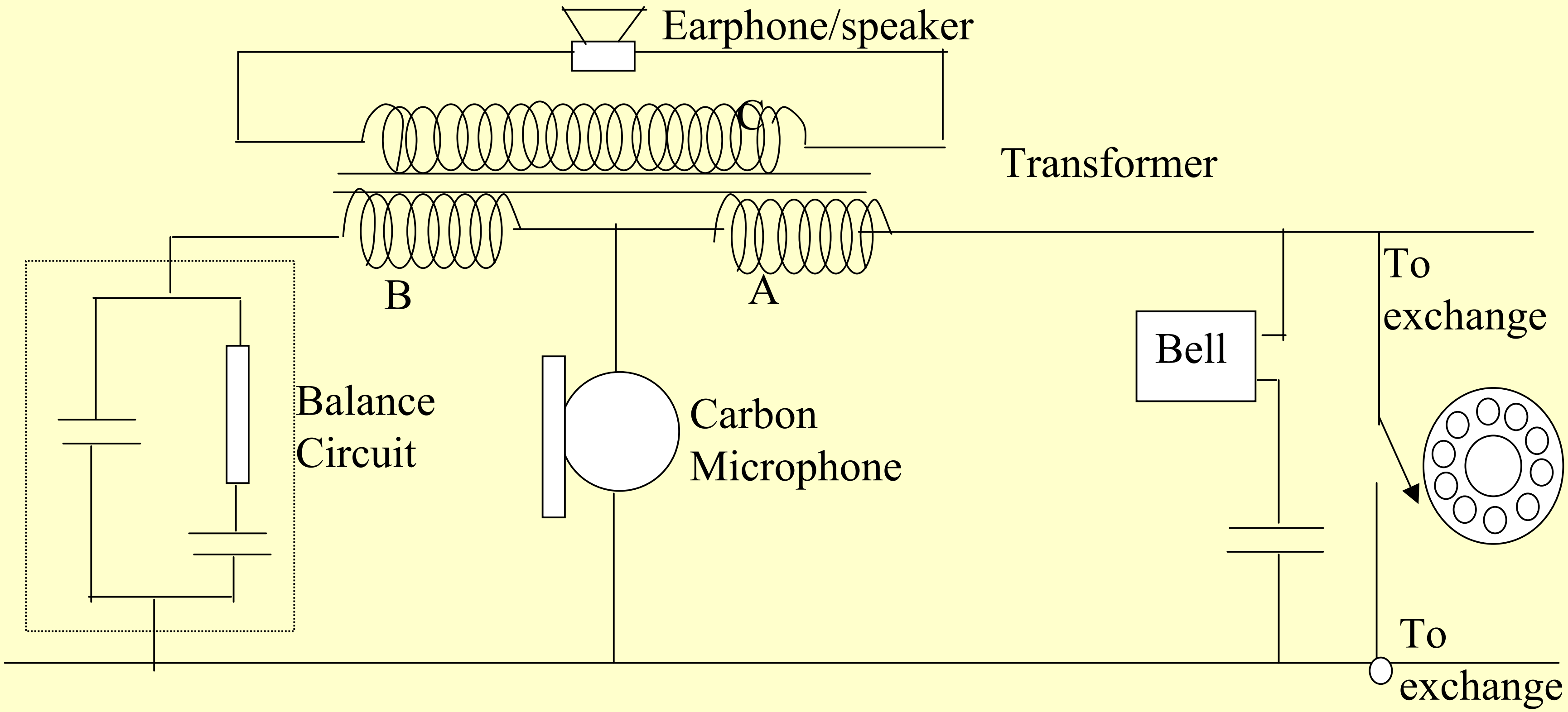
- *Wired (POTS) & wireless (mobile)*
- *POTs* : 'Plain old fashioned telephone system'
- Analogue using twisted pairs for "last mile"
- Digital exchange to exchange.

1.3.1. The terminal:

- Familiar telephone handset more complicated than it looks.
- Linked to the local exchange by just 2 wires.
- Provide signalling (dialling & ringing)
  & then carry a 2-way conversation.
- To ring bell, exchange sends low freq AC signal.



- Dialling by "loop disconnect " or multi-tone (DTMF) signalling.
- In principle, circuitry in a domestic phone is:



- Orig carbon microphone with carbon granules as variable resistor.
- Battery (in local exchange) provides current.
- Speech causes resistance & therefore current to vary.
- Electromagnetic speaker earphone.
- Transformer in handset reduces side-tone
- Detects talker's signal & generates equal & opposite signal to cancel most of it out.
- Balance circuit matches impedance of line to local exchange.
- Signals from local exchange pass thro' A & B in same direction & sum at C to provide earphone signal.

1.3.2. Bandwidth:

- Intelligibility & naturalness preserved if bandwidth 300- 3400 Hz.
- Analogue speech conveyed in 4kHz wide fdm channels,
- "trunk" wires or point-to-point radio links between exchanges.
- Margin for imperfect filtering.
- Same bandwidth adopted for digital transmission,
- Speech to be sampled at 8 kHz.
- 300 Hz limit originally because of transformers
  & electro-mechanical switches.
- POTs 'exchange to exchange' transmission now digital
- Mobile telephony digital throughout.
- Protocols for telephone communication exist.
- Physical layer is how bits are transmitted over *channel*s.

1.3.3: The Channels

- ‘Last mile’ still mostly via line-pairs carrying analogue signals.
- Single pair of wires provided for each user.
- Not ‘go’ & ‘return’ signals with ‘earth’.
- Often bare copper wires on wooden telegraph poles.
- Now "twisted pairs" in underground cables carrying many pairs.
- Twisting reduces "cross-talk".
- Local exchange will serve thousands of telephone customers
- Must be able to connect each customer
  to local exchange of a called person.
- Cannot have separate channel for each call.
- Multiplex many channels along high capacity links. :

Types of 'exchange to exchange' channels:

• Twisted pairs (Orig for analogue & adapted to digital)

• Co-axial cables (Repeaters at 1.8 km)

• Microwave radio links (Also carry TV)

•Optical fibres (Repeaters at up to 50 km)

1.3.4 Analogue transmission:

FDM groups/supergps/hypergps (960 channels)

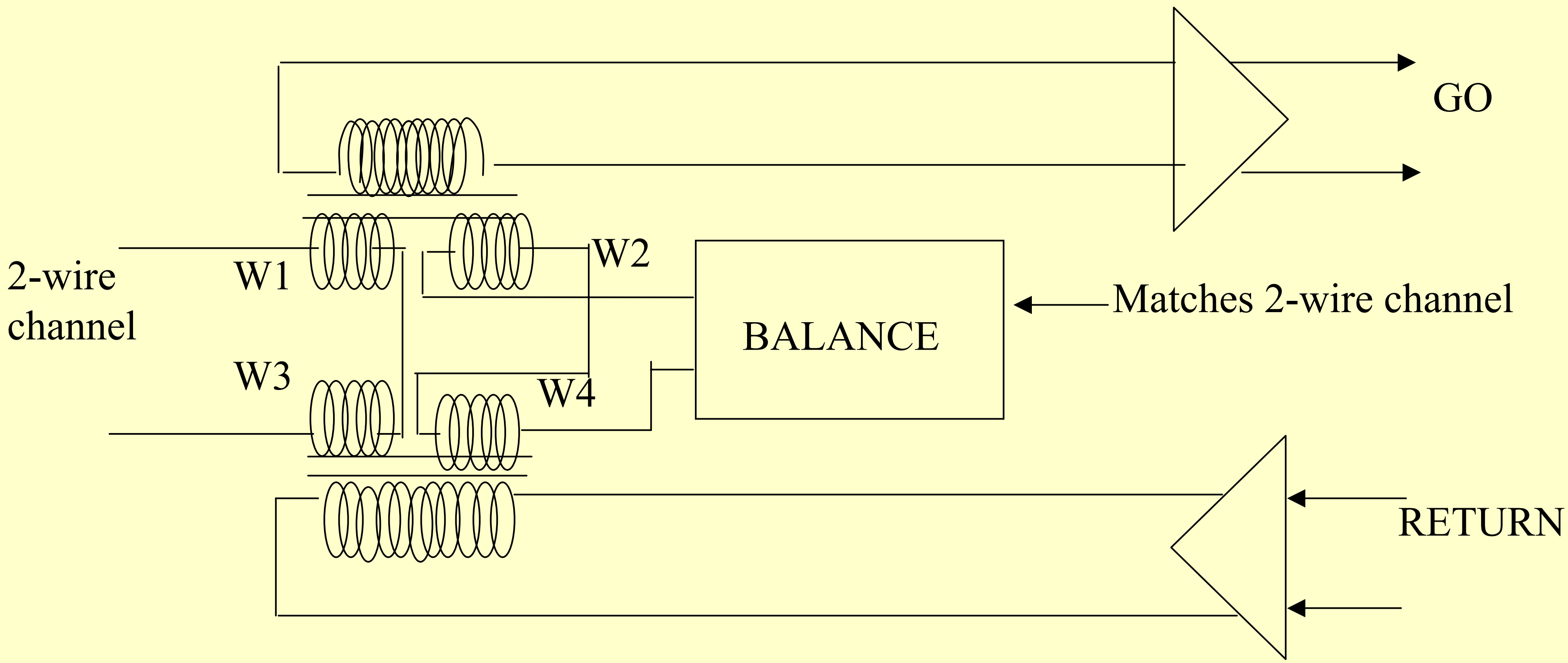
1.3.5 Digital transmission

TDM groups/supergps/hypergps (1920)

1.3.6: Two/four wire conversion:

Separate "go" & "return" links for exchange-exchange.

2-4 line & 4-2 line conversion by ‘hybrid’ at local exchange.



1.3.7 Wireless telephony

- Cordless & cellular mobile phones.
- For cellular:
  - Wireless local loop (then wired)
  - Radio medium shared
  - Cellular base-stations can “hand off”
  - Fading due to multi-path (flat or frequency selective)

Multi-path fading

- Flat : gain & phase-delay constant across band. (Equalisatn not needed)
- Frequency selective: gain & phase vary with frequency (Equalisatn needed)
- Coherence bandwidth B_C:

  largest bandwth without freq selective fading.
- In city B_C = 30 kHz
- 900 MHz GSM phone with 200 kHz bandwdth needs equaliser.

1.3.8. Advantages of digital voice networks in telephony

1. Ease of multiplexing
2. Ease of signalling
3. Use of modern technology & DSP for

   Reproducibility, *programmability*, *time-sharing*, *automatic testing*, *versatility*, etc.
4. Integration of transmission & switching
5. Operability at low signal-to-noise-ratios
6. Signal regeneration possible
7. Accommodation of other services
8. Performance monitoring
9. Ease of encryption (security).

1.3.9: Disadvantages

1. PCM transmission: - bandwidth larger
2. Analogue/digital conversion needed:
3. Need for time synchronisation
4. Topologically restricted multiplexing:
5. Incompatibility with existing analogue facilities:

Questions on telephone networks

1.As this is a course on digital transmission, why need analog FT?

2.Why is lowest 300Hz bandwidth lost on POTs telephones?

3.Why do we need a hybrid & what happens when it works badly?

4. What causes ‘fading’ in a mobile telephone channel?

4a What are the two types of fading?

5. What is meant by B_C and the ‘rms delay spread’?

6. From list, what do you consider the main advantage of digital?

6a. Why not use two wires & ground separately for go/retn?

1.4. Computer networks

1.4.1 Wired networks

- LANs use Ethernet (on twisted pairs)
- Collision Sense Multiple Access / CD or ‘switched’

1.4.2 Bridges routers & gateways

- Bridge: interconnects 2 LANs
- Router: like local telephone exchange
  (High capacity links shared with telephony)
- Gateway: Connect devices with different protocols
  (e.g. TCP/IP and telephones)

1.4.3 Protocols:

7 layer OSI & TCP/IP ref models

Layer	OSI Reference Model	TCP/IP Reference Model
7	Application Layer	Application Layer
6	Presentation Layer	
5	Session Layer	
4	Transport Layer	Transport Layer
3	Network Layer	Internet Layer
2	Data Link Layer	Host-to-Network Layer
1	Physical Layer	

Table 1.1: - Comparison between OSI Reference Model and TCP/IP Reference Model

Above TCP/IP internet layer is the ***TCP/IP transport layer***
Similar to the *OSI transport layer*, with 2 end-to-end protocols:-

i) TCP (Transmission control protocol): reliable error free protocol with acknowledgement & retransmission.

ii) UDP (User Datagram Protocol): "fire and forget" protocol .

Questions on wired computer networks

1. If IEEE802.11 is ‘wi-fi’ what is IEEE802.3 ?
2. What is the ‘mac-sub-layer’?
3. Why are there no bit-errors in emails?
4. Why is TCP/IP not ideal for VoIP?
5. What is the difference between CSMA/CD & CSMA/CA?

1.4.4 Wireless computer networks

For speech, data multi-media & Internet:

- 3G mobile: connection oriented, expensive bands

- Wireless LANs: packet switched
  no infrastructure needed (ad-hoc)
  no contracts to sign
  use FREE bands (2.4 & 5 GHz)
  free wireless access to wired network
  telephony & mm as well?

Standards for wireless LANs

- IEEE 802.11 (WI-FI): version a, b, g, e, etc.
- Hiperlan 1 & 2
- Bluetooth
- WIMAX

Physical layer for WLANs

* 2.4-2.48 GHz & 5.17-5.8 GHz (ISM) bands

* Multi-path & AWGN as with cellular phones.

* Access more like Ethernet (CSMA / **CA**)

* PCF mode and DCF mode

* RTS/CTS and ‘virtual collision sensing’ (NAV)

* MAC protocols control access to medium

CSMA with collision avoidance

- ‘Hidden node’ problem :
- ‘**A**’ hears ‘**B**’ & ‘**C**’ but **B** & **C** cannot hear each other
- **B** & **C** may transmit at same time.
- Solved by RTS/CTS and virtual carrier sensing using **NAV**
- **NAV** : ‘Network allocation vector’
- If **B** wishes to transmit, it sends short RTS (request to trans)
- ‘**A**’ hears it, tells other users to set ‘NAV’ flag for a period.
- Then ‘**A**’ sends CTS to ‘**B**’.
- **NAV** like ‘virtual’ carrier. Stops devices from transmitting.

Original IEEE 802.11

- Released in 1997   1 or 2 Mb/s
- Must use spread spectrum in 2.4 GHz band
- Two versions: FHSS & DSSS
- FHSS version hops around 80 carriers: .4 s dwell
- DSSS uses chipping sequence: {10110111000}
- Each bit => 11 chips. 1Mb/s => 11 Mb/s
- Spreads to 22 MHz.

IEEE 802.11 frame structure

Preamble	Header	Payload
80 or 144	32 or 48	variable

Modulation technique:

FHSS : 2 or 4-level Gaussian FSK at 1 Mbaud

DSSS : 2 or 4 level differental PSK at 11 Mbaud

Latest IEEE802.11 standards

IEEE 802.11a : OFDM in 5.17-5.8 GHz band

64 carriers each modulated with PSK etc.

Up to 54 Mb/s. Great for multi-path.

IEEE 802.11b : Operates in 2.4-2.48GHz band

Same as 802.11 for preamble / header

Replaces 11-chip Barker sequence by codes.

1, 2, 5.5 or 11 Mb/s for payload (CCK)

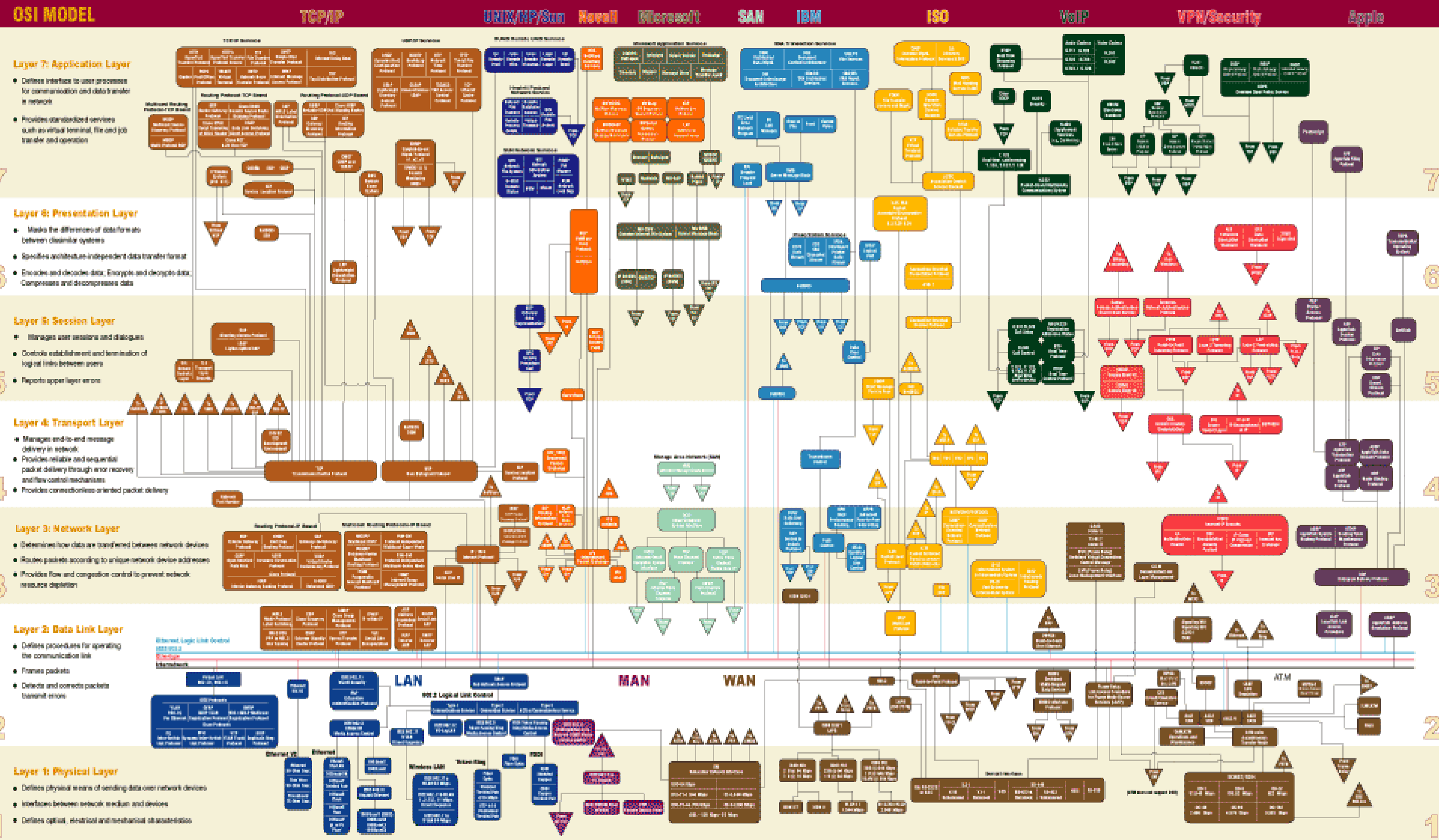
IEEE802.11g standard (Nov 2001)

* Extension to IEEE802.11b in 2.4 GHz band
* OFDM payload option at up to 54Mb/s
* Same preamble/header as IEEE802.11 orig DSSS & b
* OFDM classified as a spread spectrum technique

“Bluetooth”

- Short range “piconet” for computer peripherals etc.
- Orig not IEEE standard & not compatible.
- Operates in 2.4 GHz band over 10 metres.
- FHSS over 80 carriers: 160 hops /s
- Binary FSK at 1Mb/s.
- Wipes out IEEE 802.11b transmissions over its range??.
- IEEE 802.15.1 is standardisation of ‘Bluetooth’.

NETWORK COMMUNICATION PROTOCOLS MAP



ANSI
American National Standard Institute
11 west 42nd Street
New York NY 10036 USA
Tel: 212-642-4900
www.ansi.org

ETSI
European Telecommunications Standards Institute
Route des Lucioles
F-06921 Sophia Antipolis Cedex, France
Tel: 33 (0)4 92 94 42 00
www.etsi.org

FCC
Federal Communications Commission
1919 M Street NW
Washington DC USA
Tel: 202-418-0200
www.fcc.gov

IEEE
Institute of Electrical and Electronics Engineers, Inc.
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331 USA
Tel: 908-981-0060
www.ieee.org

ISO
International Organization for Standardization
One rue de Varembe CH-1211
Case Postale 56
Geneva 20, Switzerland
Tel: 41-22-749-0111
www.iso.ch

ITU
International Telecommunications Union
Place des Nations
CH-1211 Geneva 20, Switzerland
Tel: 41 22 99 51 11
www.itu.ch

ISOC: Internet Society
www.isoc.org
IETF: Internet Engineering Task Force
www.ietf.org
1775 Wiehle Ave. Suite 102
Reston VA 20190 USA
Tel: 703-326-9880

IEC
International Electrotechnical Commission
3, rue de Varembe
P.O. Box 131
1211 Geneva 20, Switzerland
Tel: 41-22-919-02-11
www.iec.ch

Javvin

www.javvin.com

WIMAX (IEEE802.16)

- Provides metropolitan area network (man) connectivity
- Bit-rates up to 75 Mb/s.
- ‘Last-mile’ and ‘hot-spot’ broadband connections
- Cellular base station links
- Links between buildings.
- 3-5 miles normally, but up to 30 miles
- Uses OFDM

Telephone & computer networks

- Much commonality physically & conceptually
- Connection oriented/ connectionless?
- Technologies merging: VoIP

  ATM

  PPP
- Issue is "quality of service" (QoS)

Questions on wireless computer networks

1. What is ‘wimax’? (not in notes)
2. Why is the 11-chip Barker sequence used with IEEE802.11b?
3. What does FHSS have to do with the first nude actress?
4. What are the ‘ISM’bands & what are they used for?
5. What is the ‘hidden node problem’ & how is it solved?
6. What is the difference between CSMA/CD & CSMA/CA?