INF3190 - Data Communication

Physical Layer

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Characteristics

ISO DEFINITION: the physical layer provides the following features:

- mechanical,
- electrical,
- functional and
- procedural

to initiate, maintain and terminate physical connections between

- Data Terminal Equipment (DTE) and
- Data Circuit Terminating Equipment (DCE, "postal socket")
- and/or data switching centers

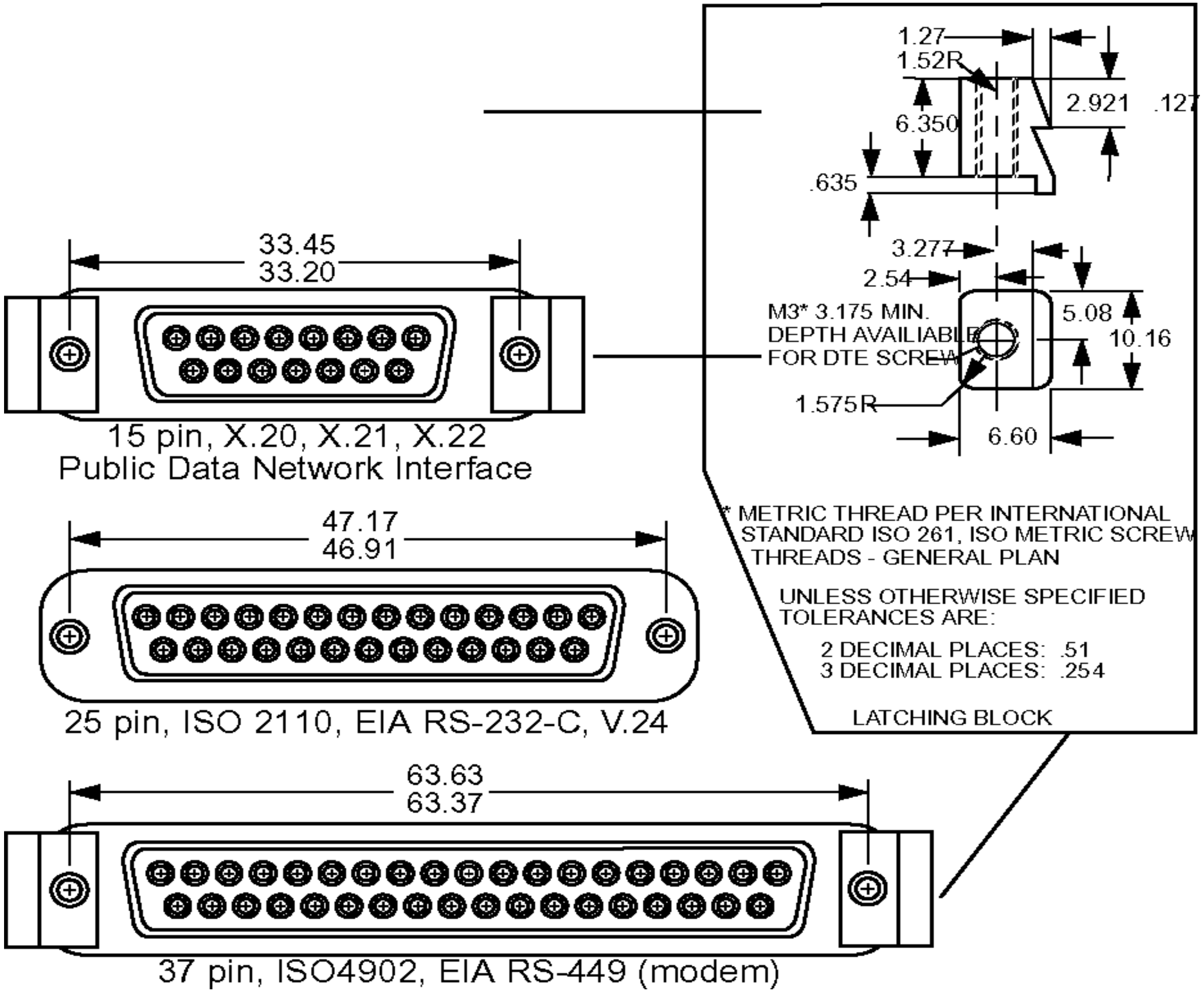
Using **physical connections**, the physical layer ensures

- the transfer of a **transparent bitstream**
- between data link layer-entities

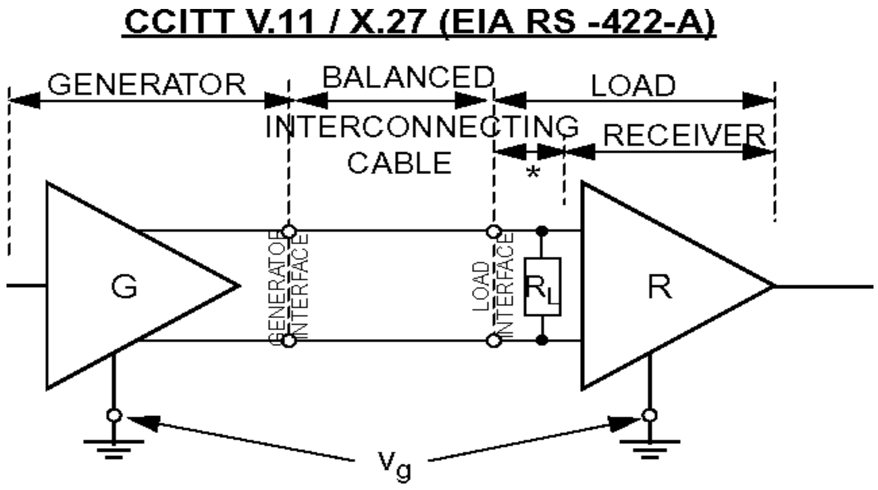
A physical connection permits transfer of a **bitstream** in the modes

- duplex or
- semi-duplex

Mechanical


33.45
33.20
15 pin, X.20, X.21, X.22
Public Data Network Interface
47.17
46.91
25 pin, ISO 2110, EIA RS-232-C, V.24
63.63
63.37
37 pin, ISO4902, EIA RS-449 (modem)
1.27
1.52R
6.350
2.921
.127
.635
3.277
2.54
M3* 3.175 MIN.
DEPTH AVAILIABLE
FOR DTE SCREW
5.08
10.16
1.575R
6.60
* METRIC THREAD PER INTERNATIONAL
STANDARD ISO 261, ISO METRIC SCREW
THREADS - GENERAL PLAN
UNLESS OTHERWISE SPECIFIED
TOLERANCES ARE:
2 DECIMAL PLACES: .51
3 DECIMAL PLACES: .254
LATCHING BLOCK

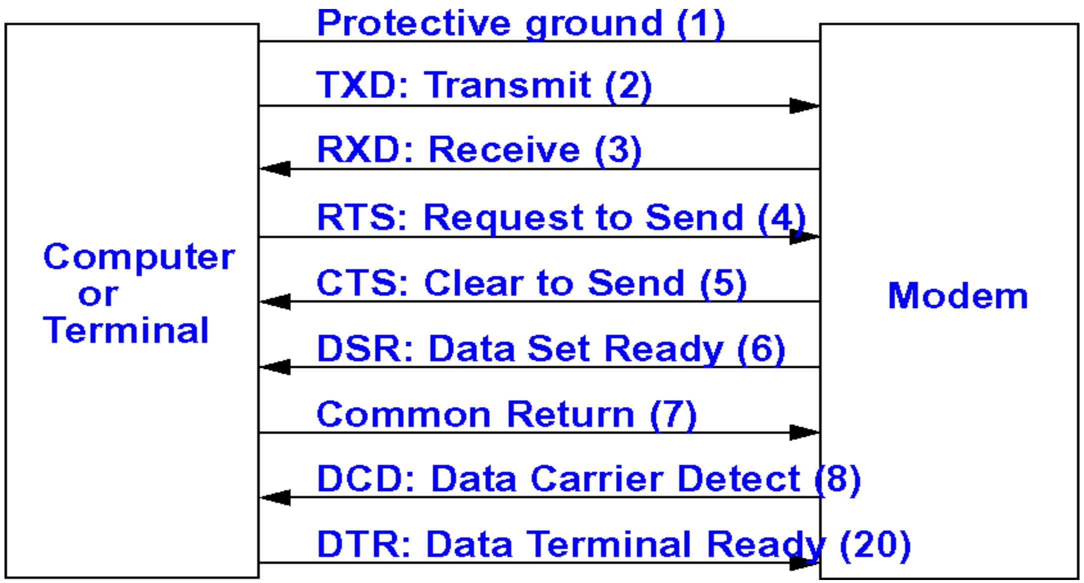
Electrical



e. g. .. "

- designed for IC Technology
- balanced generator
- differential receiver
- two conductors per circuit
- signal rate up to 10 Mbps
- distance: 1000m (at appr. 100 Kbps) to10m (at 10Mbps)
- considerably reduced crosstalk
- interoperable with V.10 / X.26 ..."

Functional, Procedural



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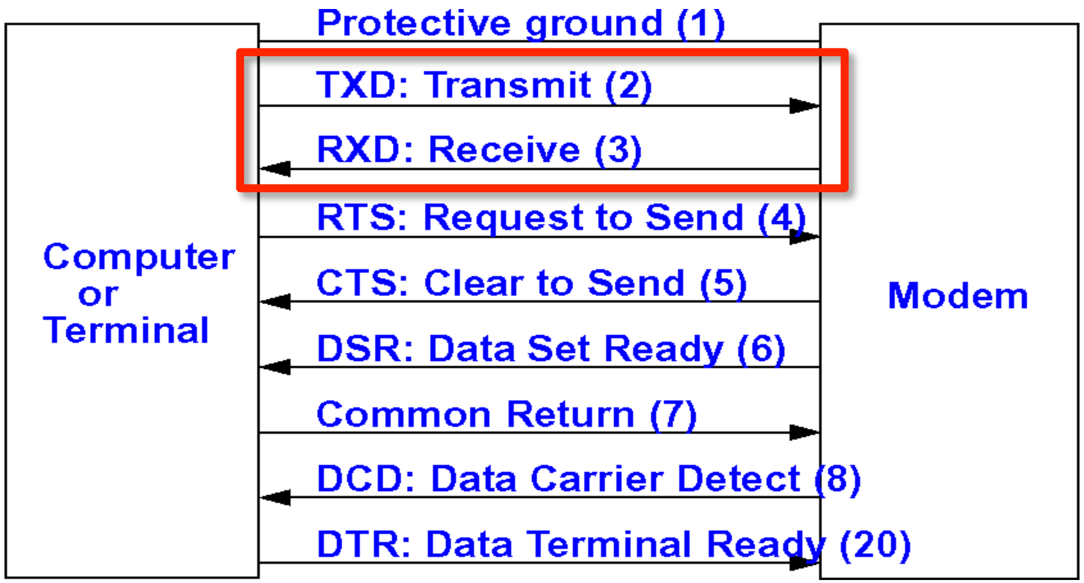
Example RS-232-C, functional specification describes

- connection between pins
  - e.g. "zero modem" computer-computer-connection (Transmit(2) - Receive(3))
- meaning of the signals on the lines
  - DTR=1, when the computer is active, DSR=1, modem is active, ...
  - Action/reaction pairs specify the permitted sequence per event
  - e. g. when the computer sends an RTS, the modem responds with a CTS when it is ready to receive data

Physical Layers



But how do we get **bits** into these cables?

Part 1: Basic terminology

- Frequency
- Period
- Amplitude
- Phase

- Wavelength
- Bandwidth

- Baseband
- Passband

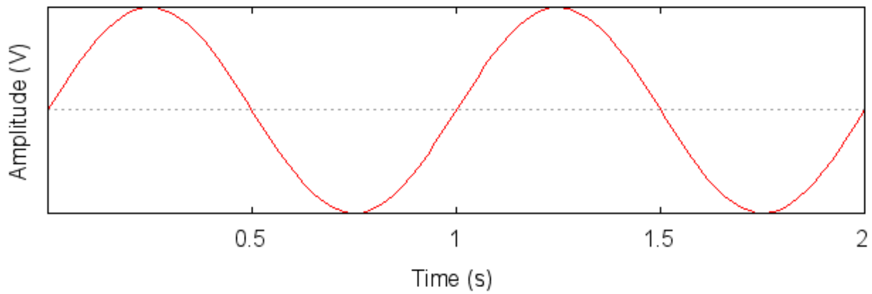
- Nyquist's bit rate
- Shannon's capacity

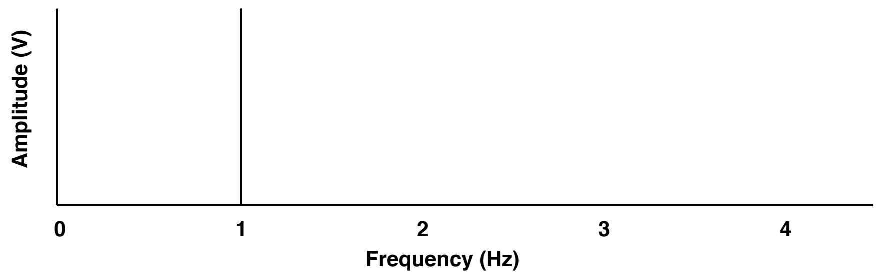
Signaling

periodic analog signal

it's Fourier transformation expresses it in terms of frequency and amplitude

(peak) **amplitude** of the signal: value of highest intensity, proportional to the energy carried: *here 1V*





period of the wave: amount of time to complete a wave: *here 1s*

⇔

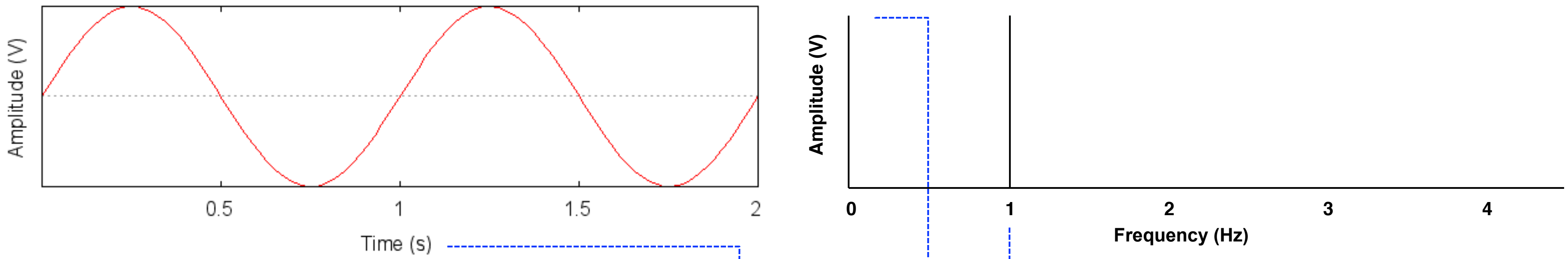
frequency: the number of waves per seconds (Hz): *here 1Hz*

Signaling

The Fourier Series approximates any signal as a sum of sine functions.
Here: only 1 sine function
=> need only 1 element of a Fourier series to describe it:

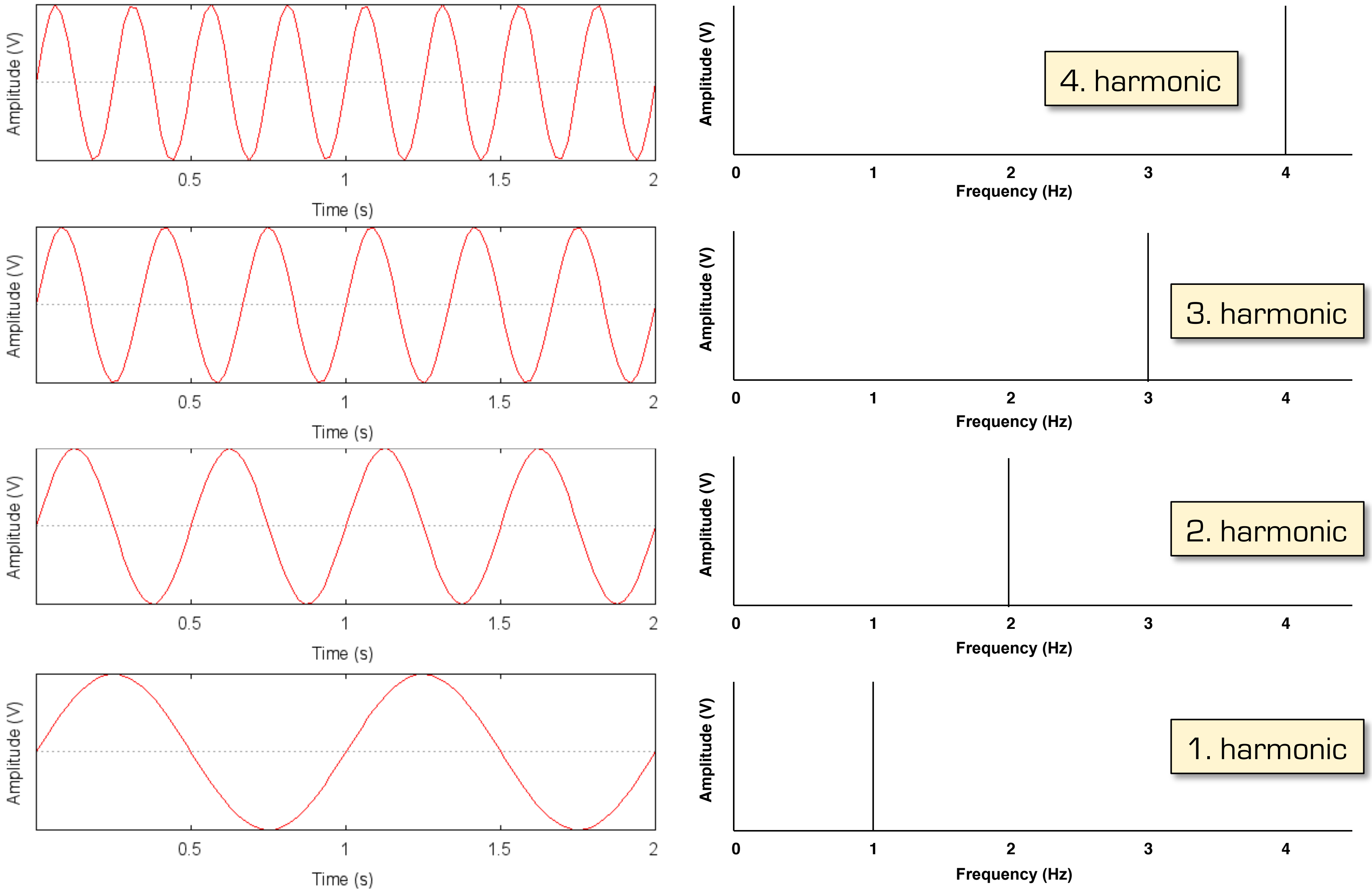
$$S_{A,f}(t) = A \times \sin(2\pi f t)$$

it's Fourier transformation expresses it in terms of frequency and amplitude

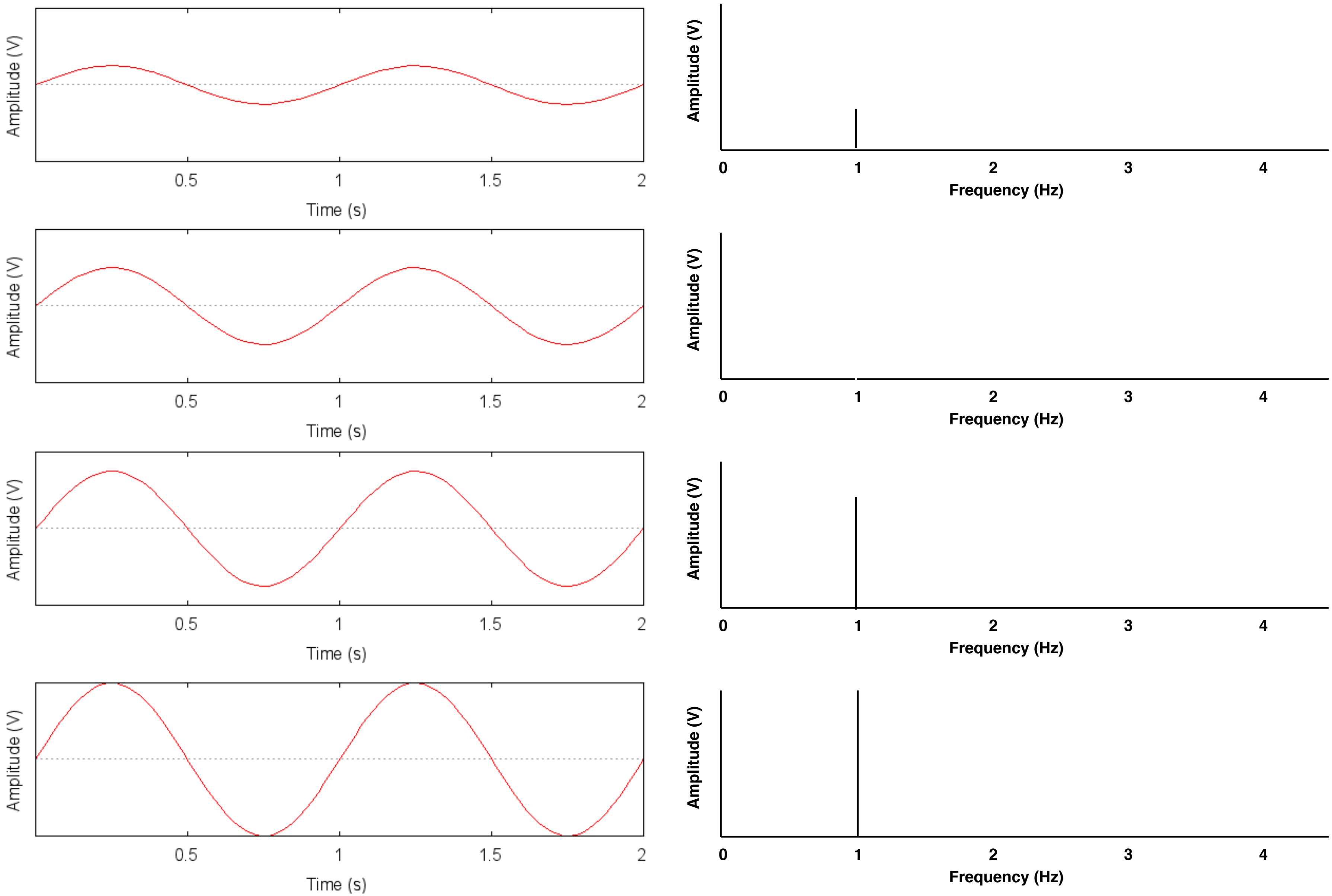


$$A \times \sin(2\pi f t) = S_{A,f}(t)$$

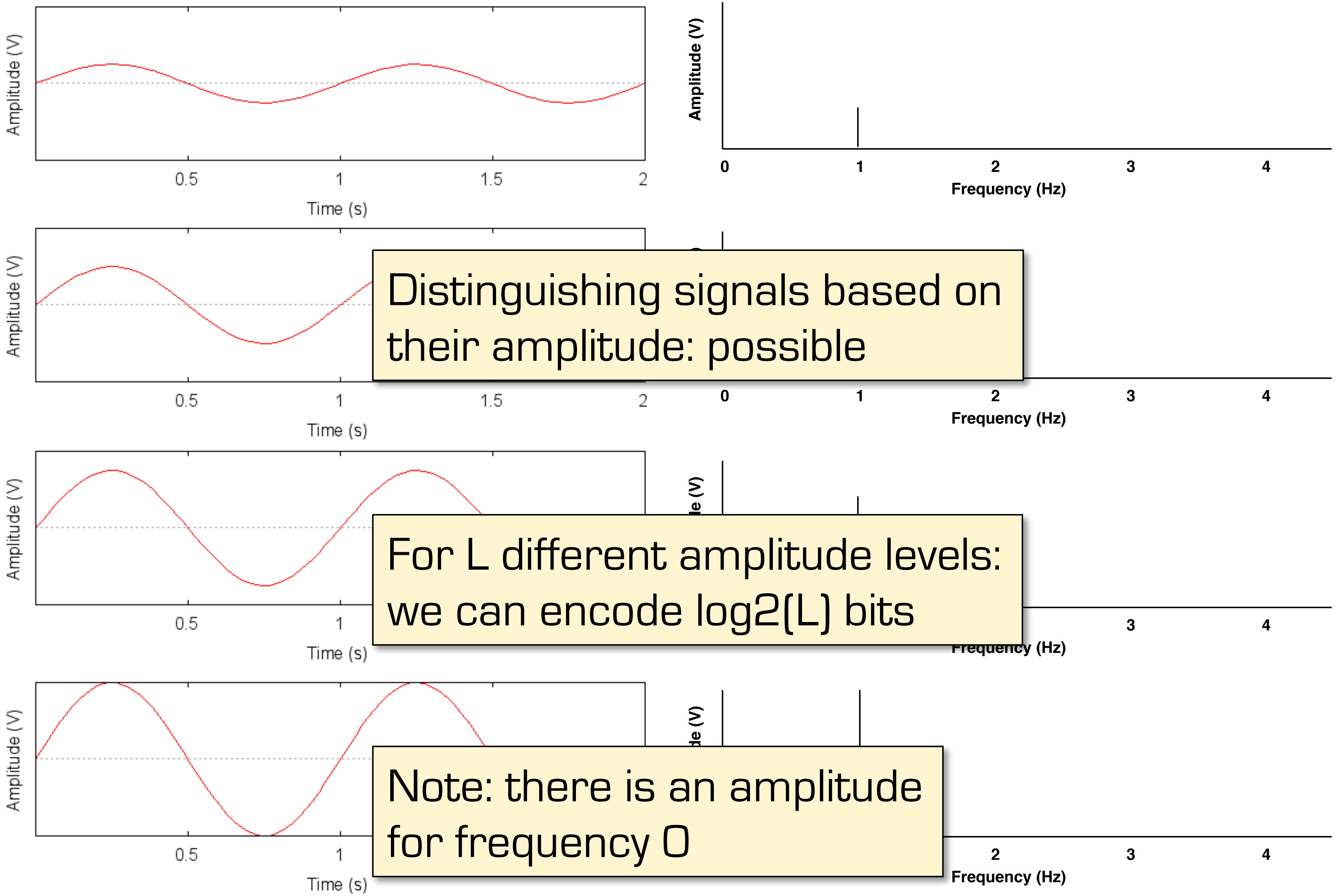
Frequency


Amplitude (V)
0.5
1
1.5
2
Time (s)
Amplitude (V)
0
1
2
3
4
Frequency (Hz)
4. harmonic
3. harmonic
2. harmonic
1. harmonic

Amplitude



Amplitude



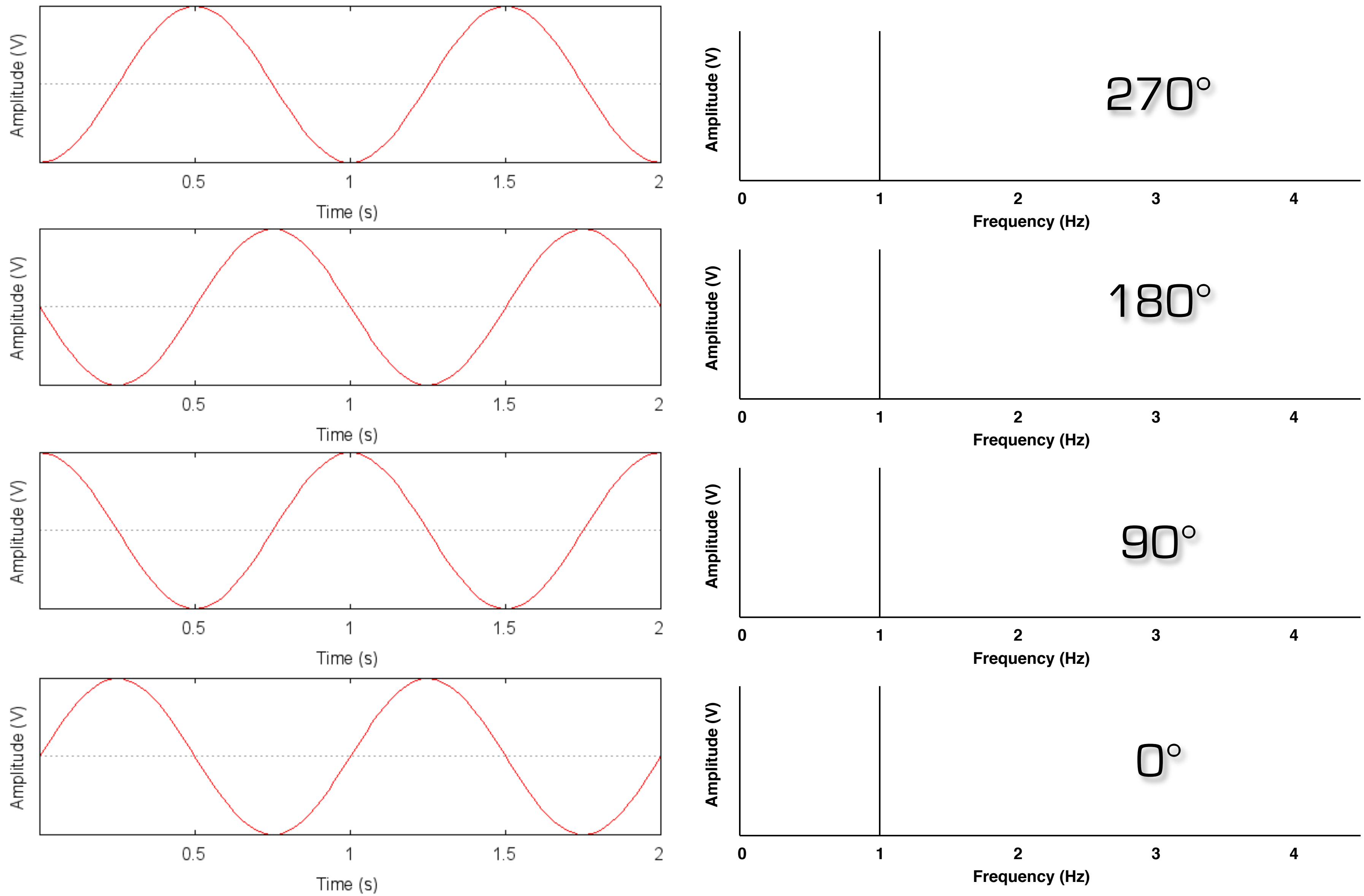
Distinguishing signals based on their amplitude: possible

For L different amplitude levels: we can encode log2(L) bits

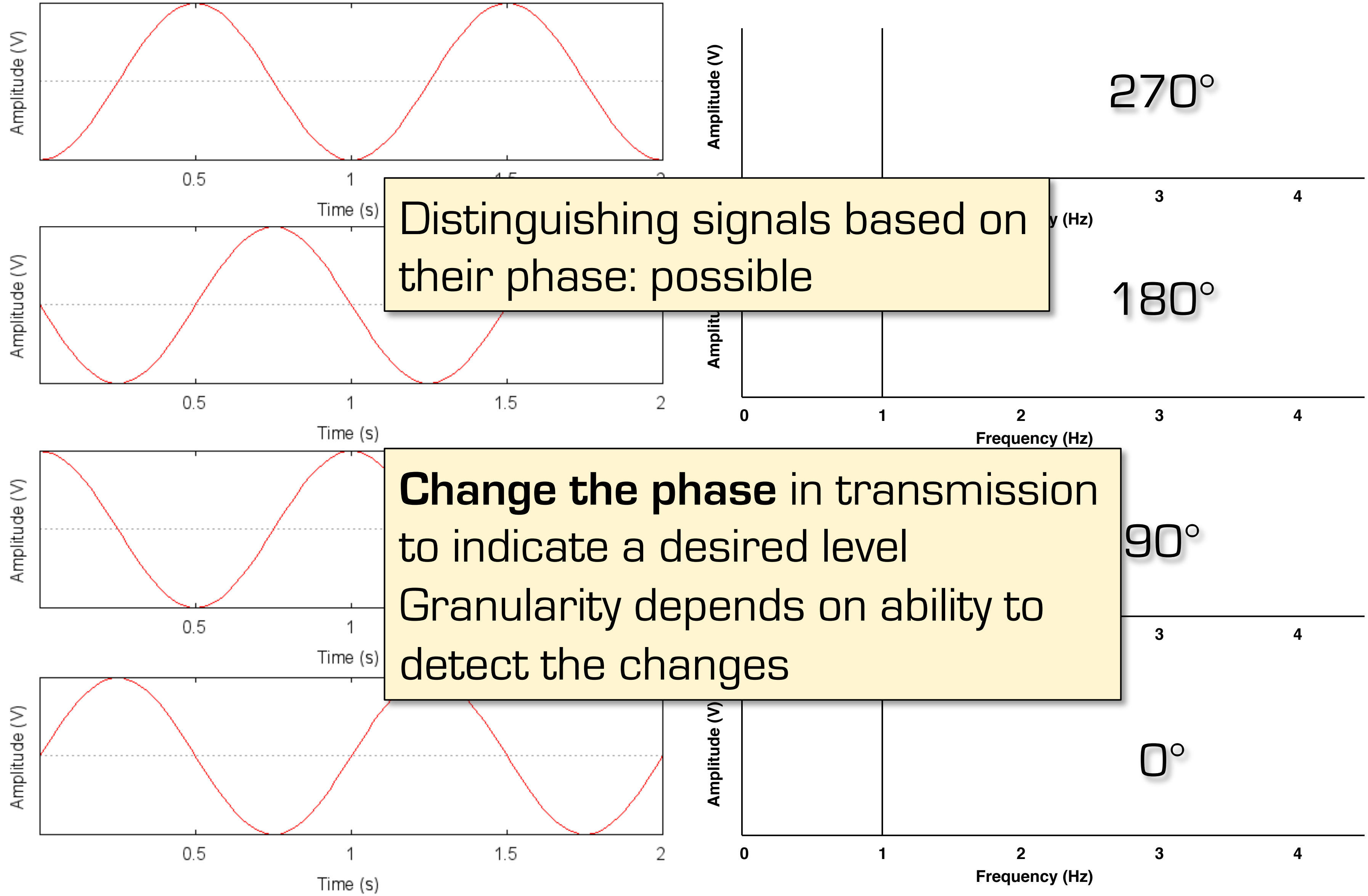
Note: there is an amplitude for frequency 0

Phases

Phase: position of the waveform relative to time 0



Phases

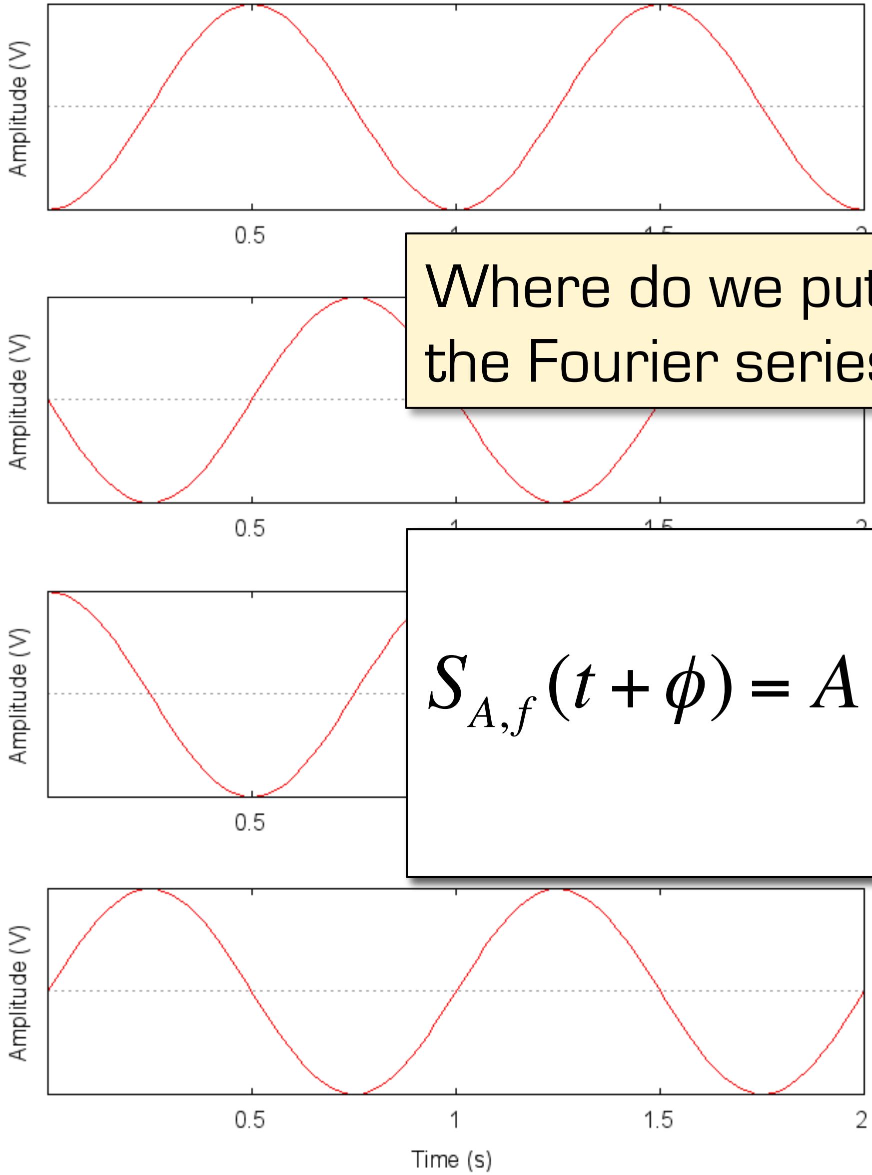


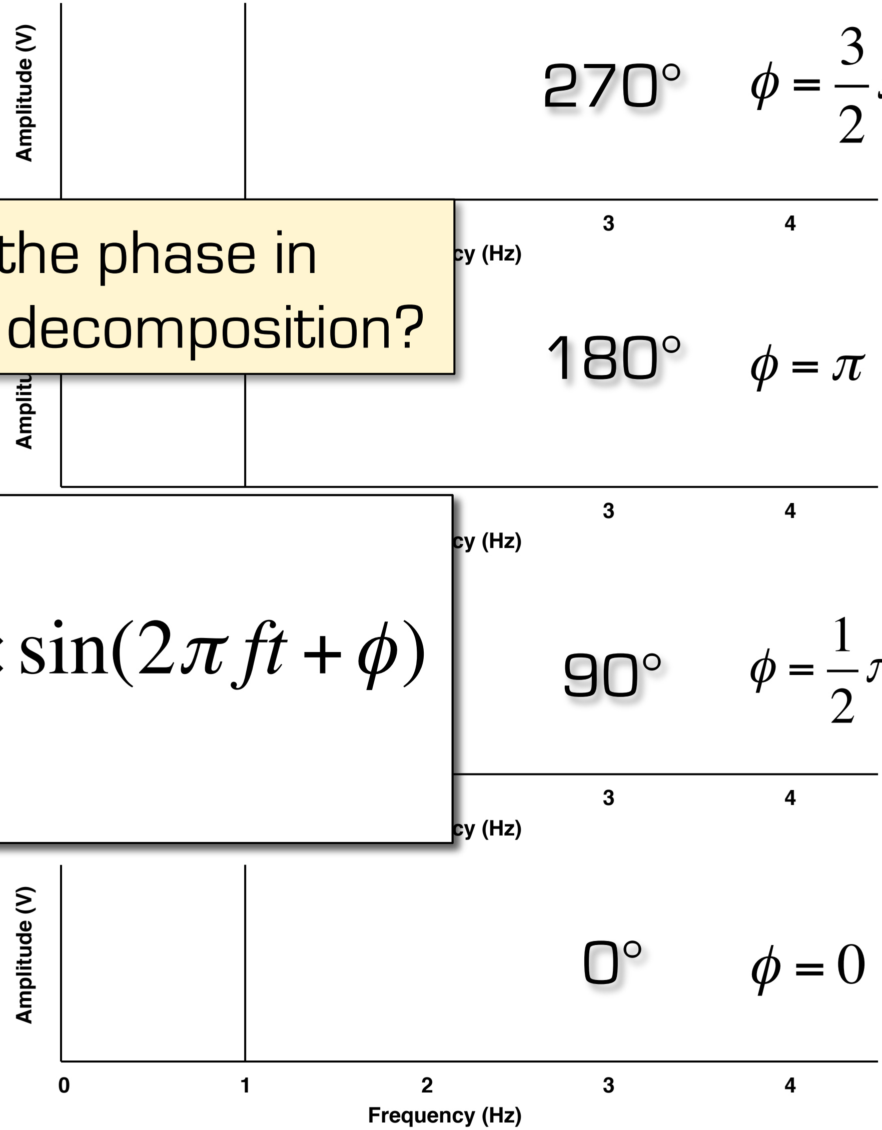
Distinguishing signals based on their phase: possible

Change the phase in transmission to indicate a desired level

Granularity depends on ability to detect the changes

Phases





270° $\phi = \frac{3}{2}\pi$

180° $\phi = \pi$

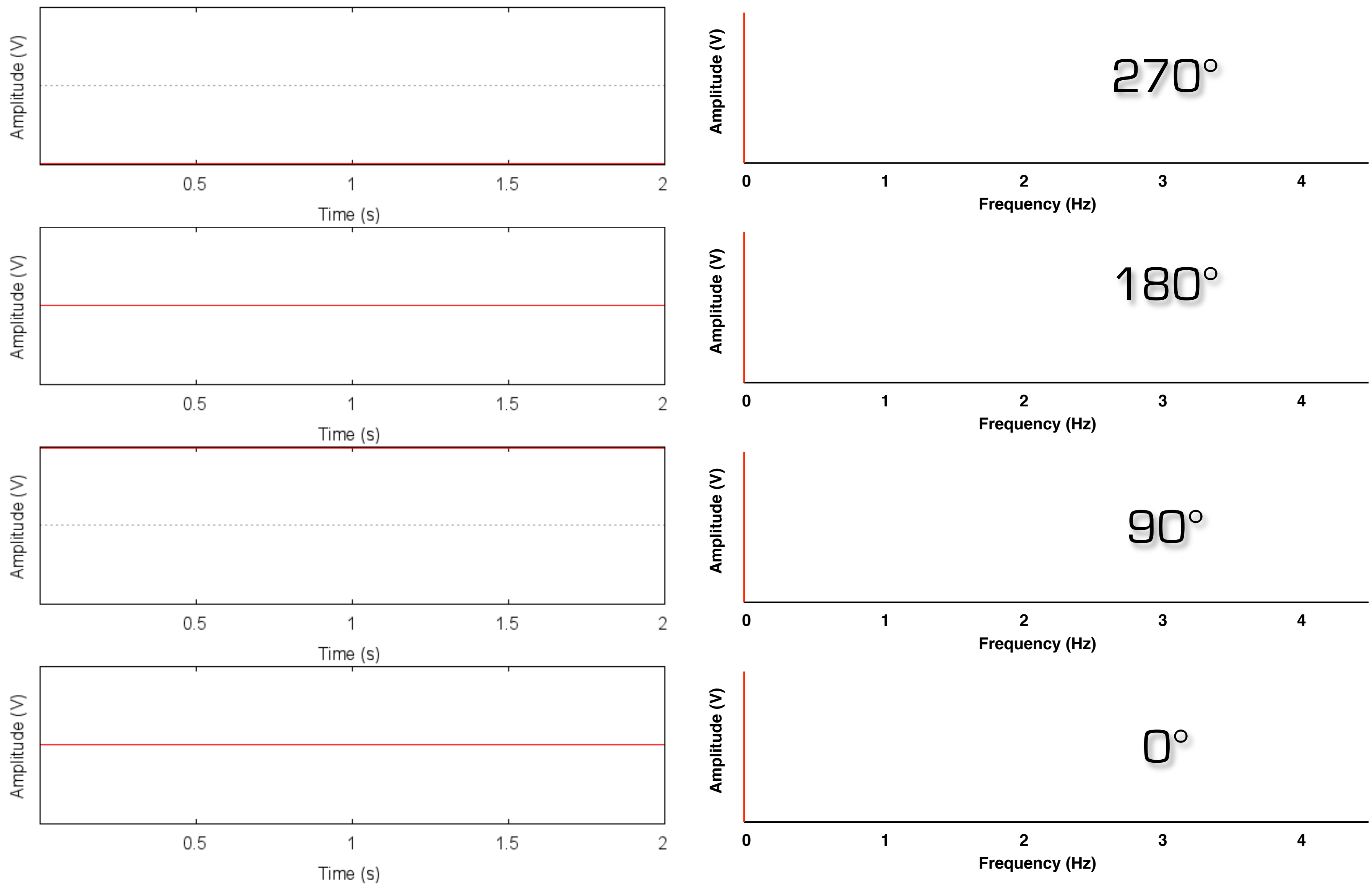
90° $\phi = \frac{1}{2}\pi$

0° $\phi = 0$

Where do we put the phase in the Fourier series decomposition?

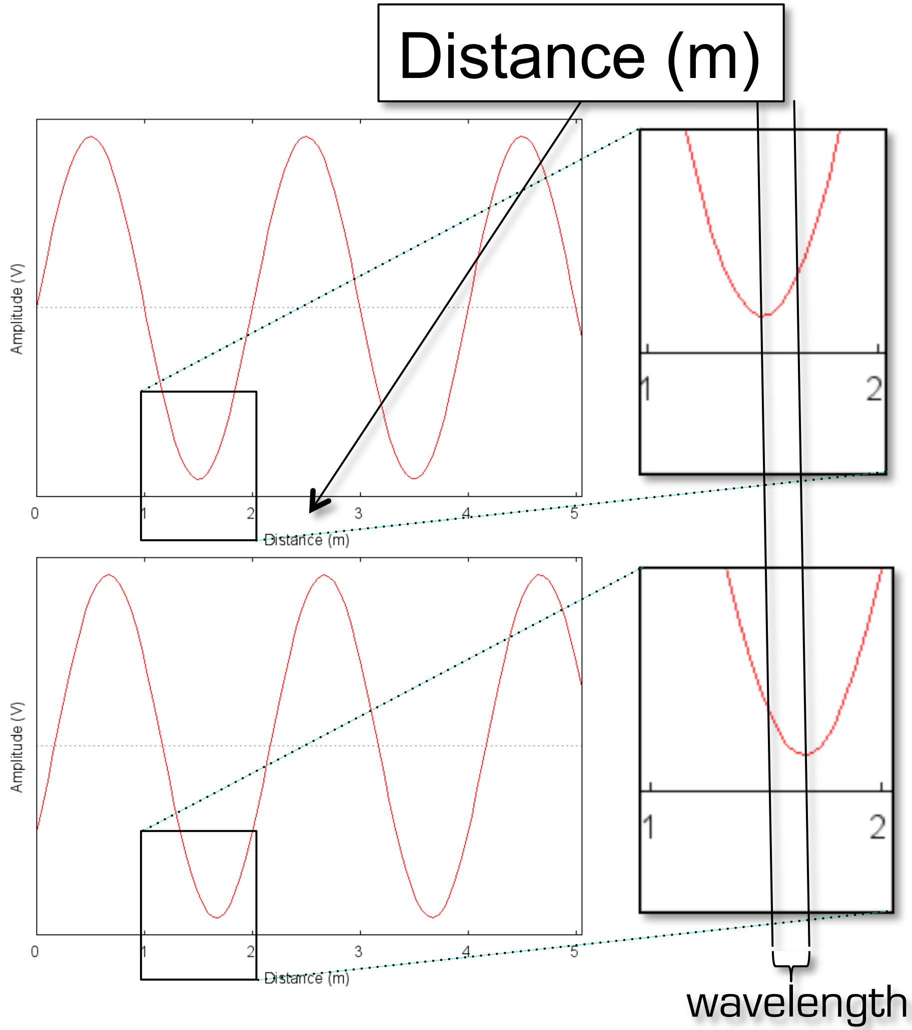
$$S_{A,f}(t + \phi) = A \times \sin(2\pi ft + \phi)$$

Phases of frequency 0



Wavelength

The distance in meters (milli,micro,nano) between identical position of the wave (e.g.: peak amplitude) after one period (1/frequency).



λ: wavelength (in meter)

$$\lambda = \frac{v}{f}$$

where

v: speed of a wave in a medium (meter/second)

f: frequency (1/second)

Wavelength

The distance in meters (milli,micro,nano) between identical position of the wave (e.g.: peak amplitude) after one period (1/frequency).

v for light in vacuum:

299 792 458 m/s

f for red light:

400–484 THz (10^{12}Hz)

λ of red light in vacuum:

619-749 nm (10^{-9}m)

λ: wavelength (in meter)

$$\lambda = \frac{v}{f}$$

where

v: speed of a wave in a medium (meter/second)

f: frequency (1/second)

Analog information coding

Sender manipulates

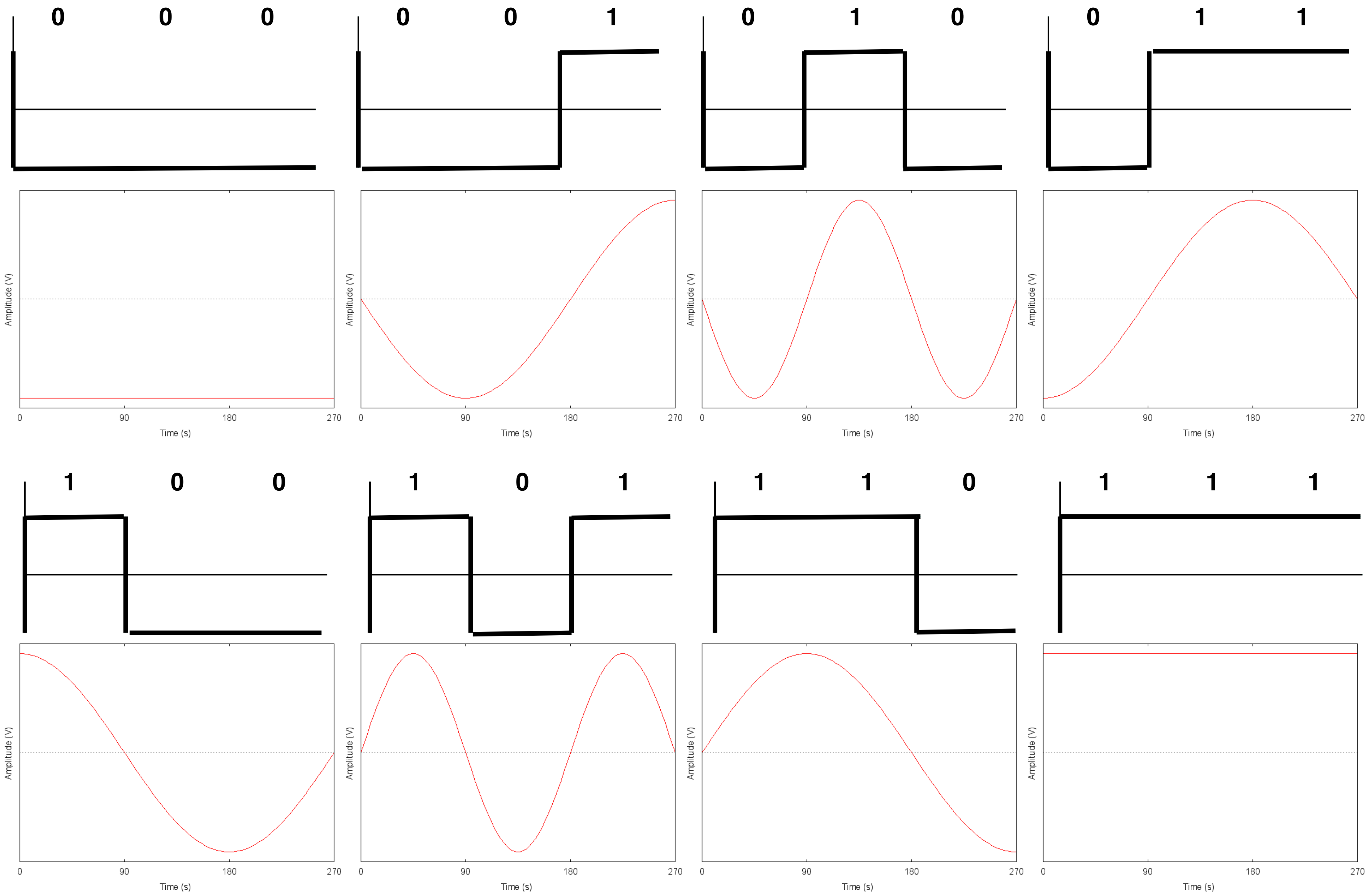
- frequency, ← presence or absence of a harmonic
- amplitude and ← presence or absence of a voltage level
- phase ← time shift of a wave

to encode different signals

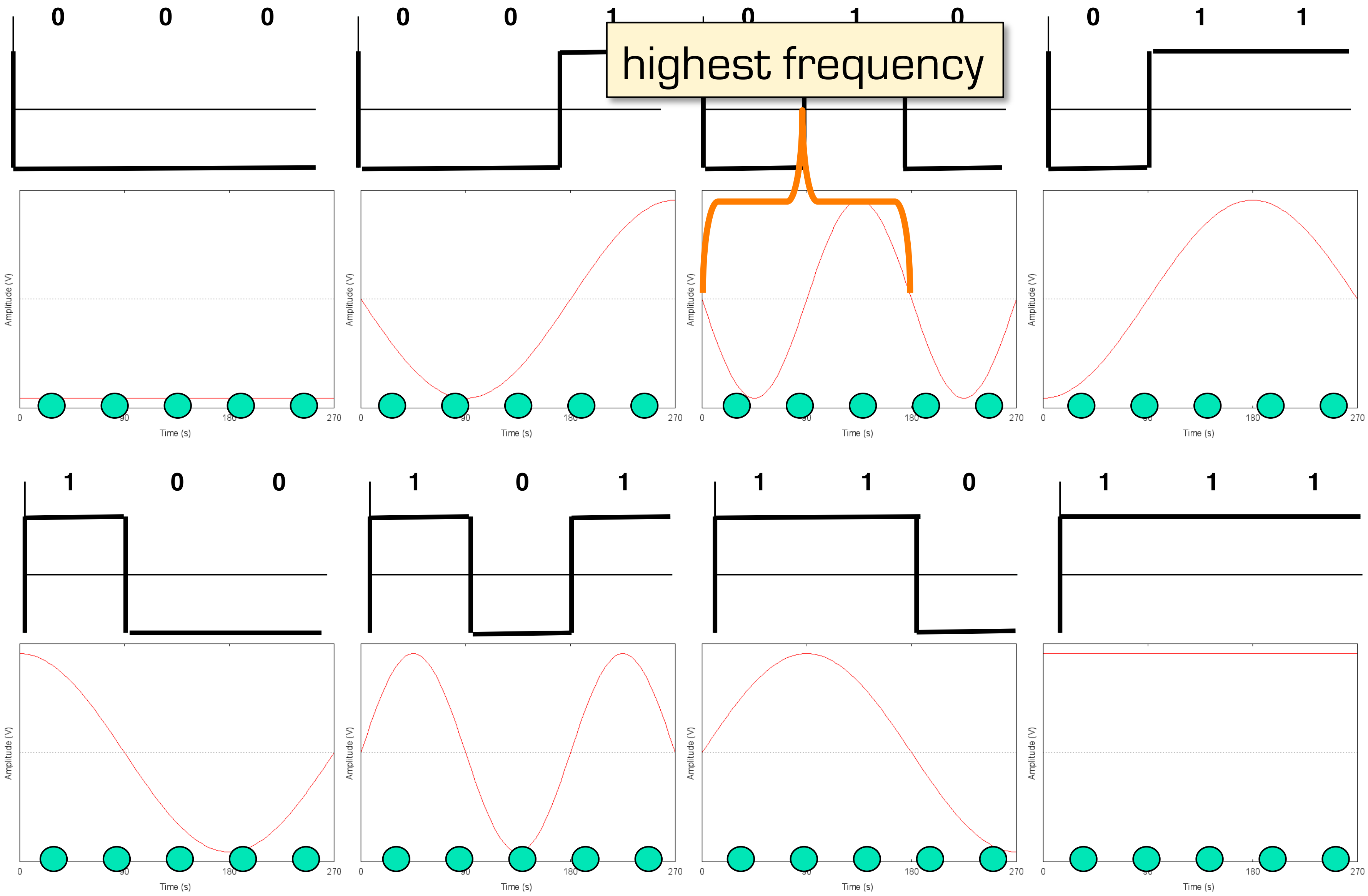
Receivers transform back to information

- derive their Fourier series parameters A and f at the receiving end
- derive Φ from a known time base

Coding digital information with analog signal



Sampling rate > 2 highest frequency



Data rate vs. signaling rate

Signaling rate:

number of times per time unit (second) the signal parameter may change

v_S, measured in bauds (1/s), symbols/second

Data rate:

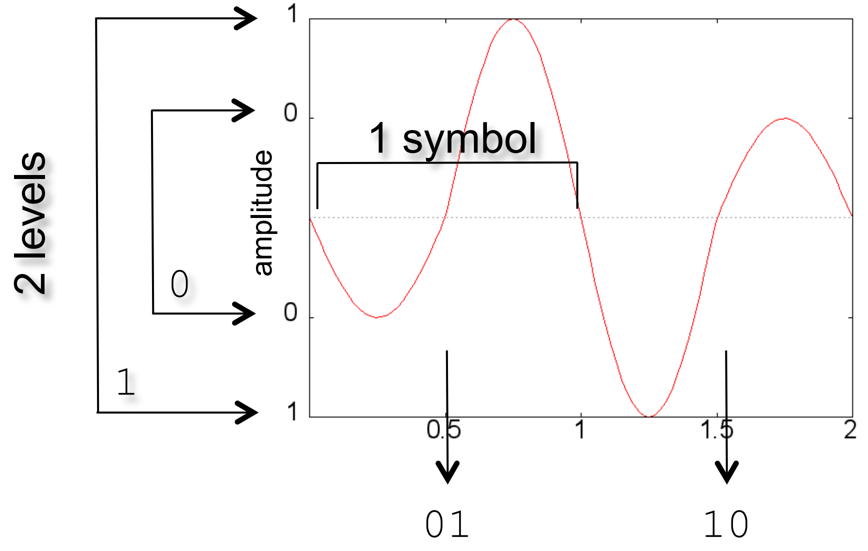
number of bits transmitted per time unit (second)

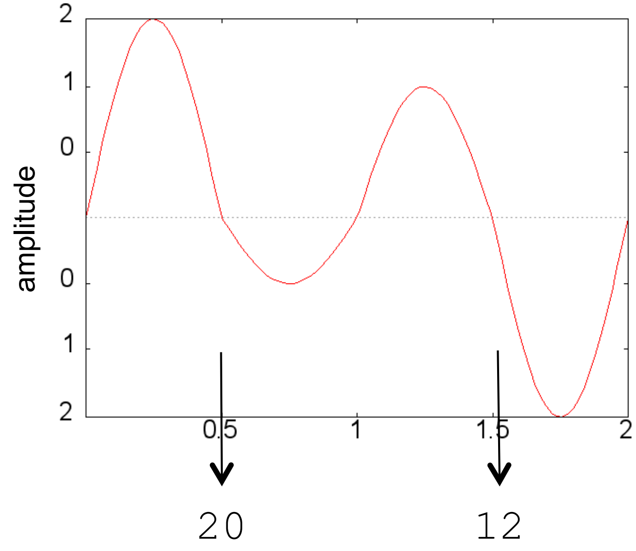
v_B, measured in bits per second (bit/s)

How many bits per symbol, i.e. $v_S \leftrightarrow v_B$:

1. binary signal: $v_B = v_S$
2. synchronization, clock, redundancy part of encoding: $v_B < v_S$
3. one symbol carries several bits (eg.: 00, 01, 10, 11): $v_B > v_S$
   - for symbol with n values: $v_B = v_S \text{ floor}(\log_2(n))$
   - common: n = 2 (binary/bit), 3 (ternary), 4 (quarternary/DIBIT)
     8 (octonary/TRIBIT), 10 (denary)

Baud Rate and Bit Rate





two bits per symbol, allows binary code
00->00, 01->01, 10->10, 11->11

9 states but 8 binary values: three bits per symbol
00->000, 01->001, 02->010, 10->011,
11->100, 12->101, 20->110, 21->111

BAUD RATE

measure of number of symbols (characters) transmitted per unit of time

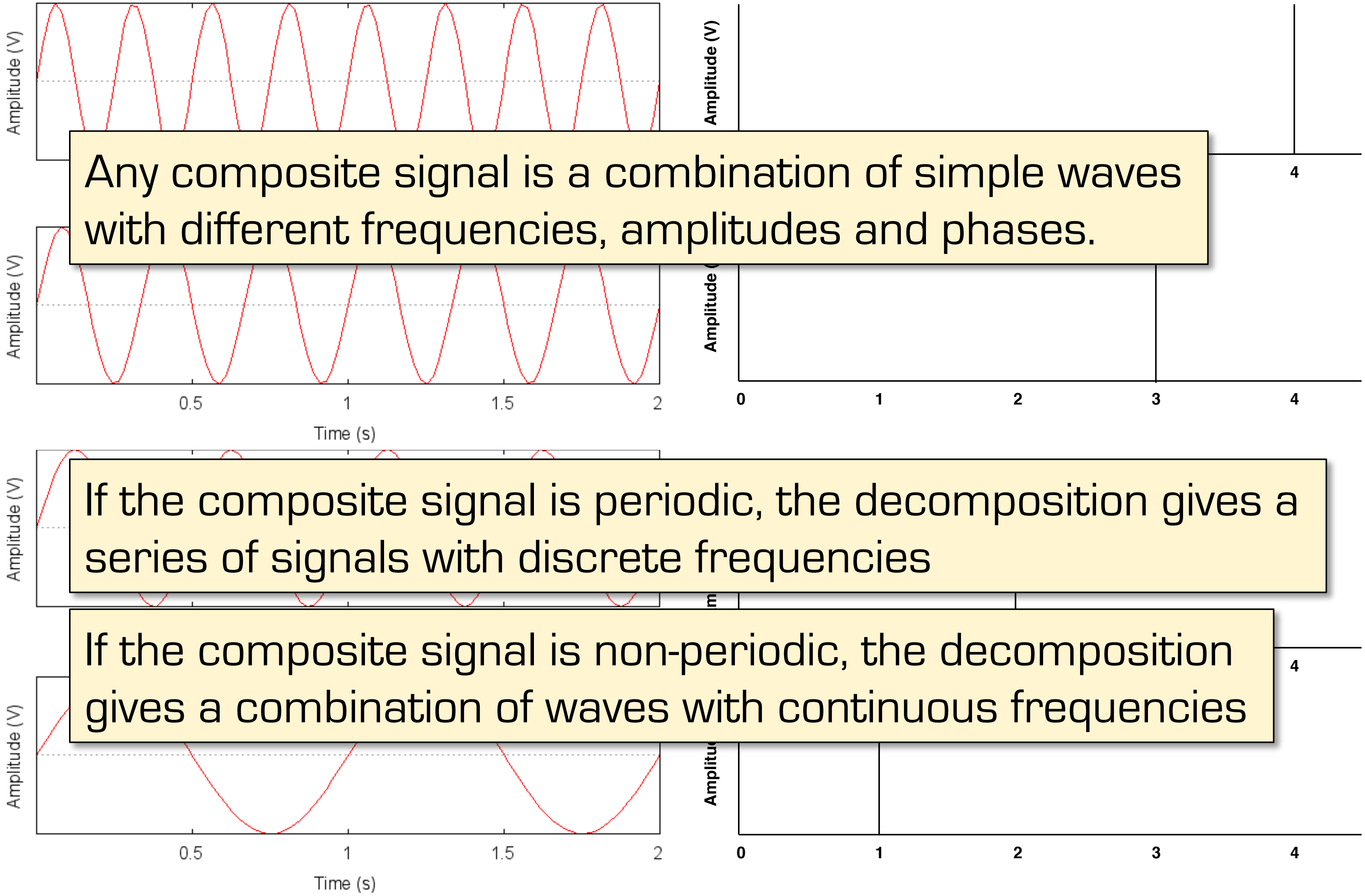
- signal speed, number of signal changes per second:
  changes in amplitude, frequency, phase
- each symbol normally consist of a number of bits
- so the baud rate will only be the same as the bit rate when there is one bit per symbol

BIT RATE

number of bits transferred per second (bps)

- bit rate may be higher than baud rate ("signal speed")
- because one signal value may transfer several bits
- e.g. above same baud rate, different bit rate (if x has have same dimension)

Composite signal

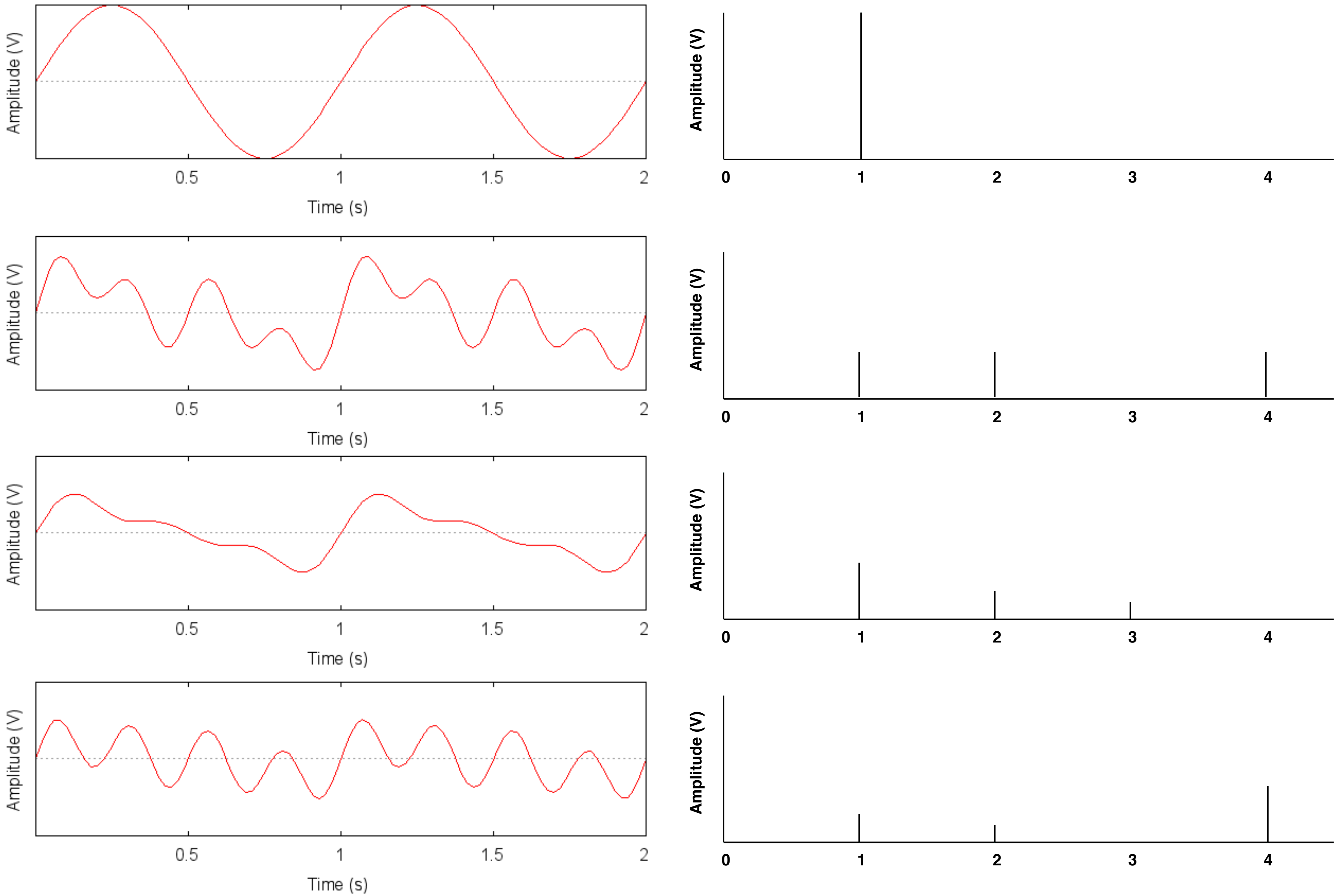


Any composite signal is a combination of simple waves with different frequencies, amplitudes and phases.

If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies

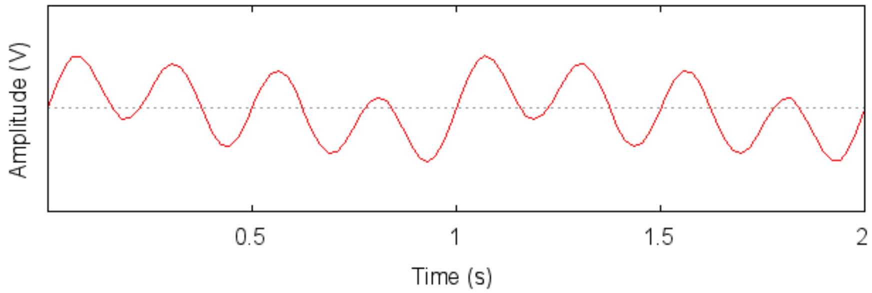
If the composite signal is non-periodic, the decomposition gives a combination of waves with continuous frequencies

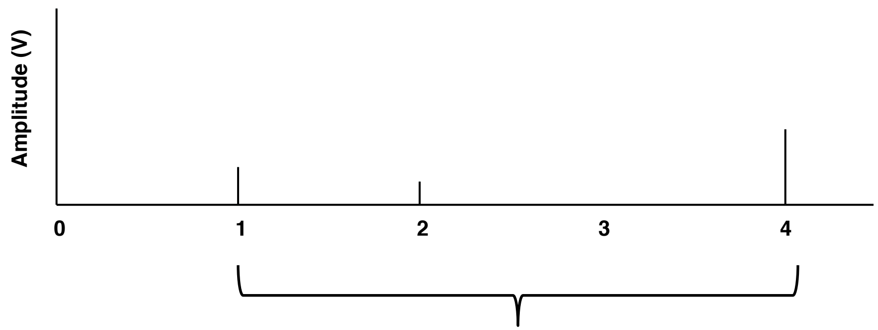
Composite signal



Bandwidth

The range of frequencies in a composite signal is its **bandwidth**

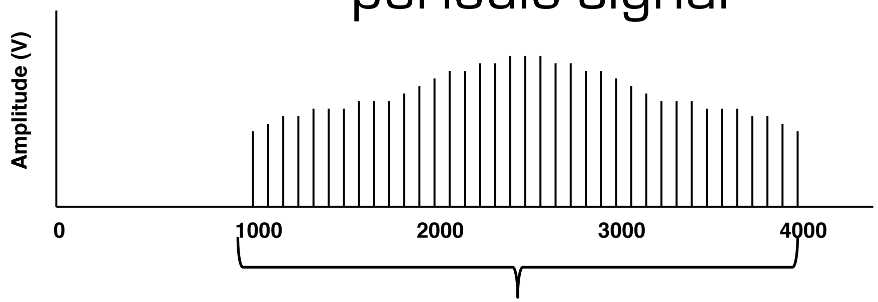




bandwidth = 4-1 = 3

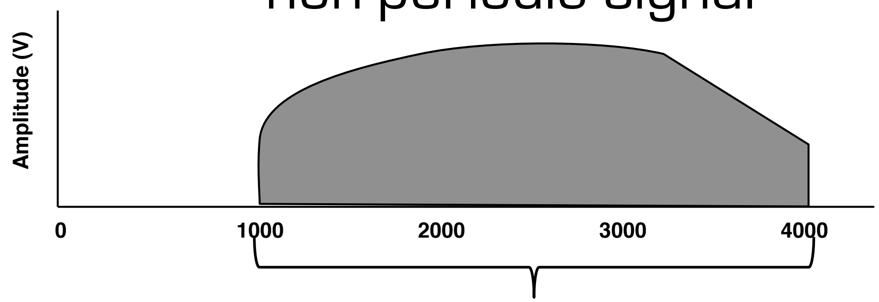
both for periodic and non-periodic signals

periodic signal



bandwidth = 3000

non-periodic signal



bandwidth = 3000

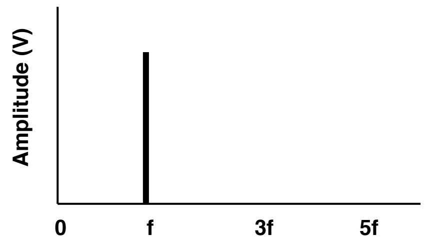
Digital information coding *(approach 1)*

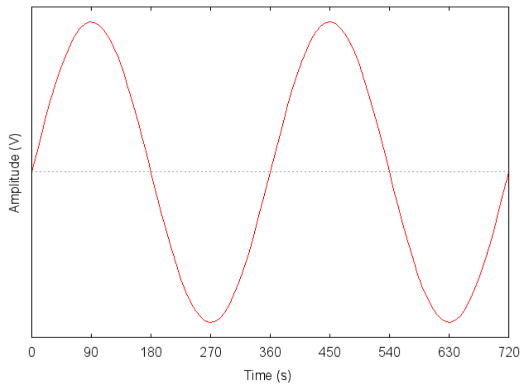
Indirect transmission of digital signals

- approximate signaling flanks by composition of harmonic frequencies and amplitudes
- allows to restrict between upper and lower frequencies

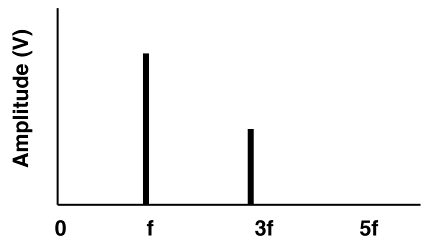
- used bandwidth (max frequency – min frequency)
- “can be restricted within a band”

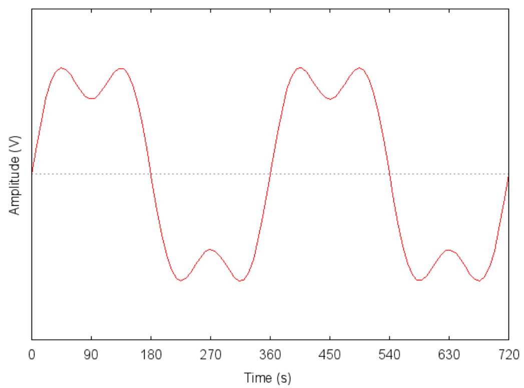
Digital information coding *(approach 1)*

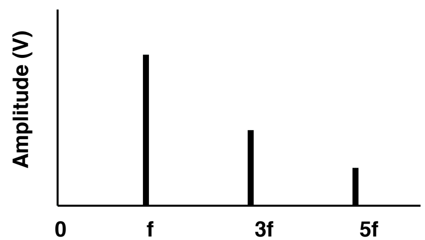


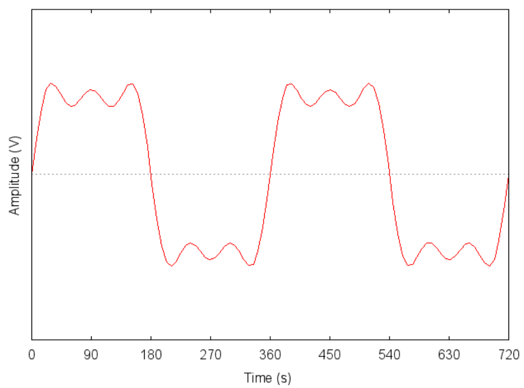


better approximation of digital signal with several frequencies of analog signal









uses more bandwidth without increasing the signal rate

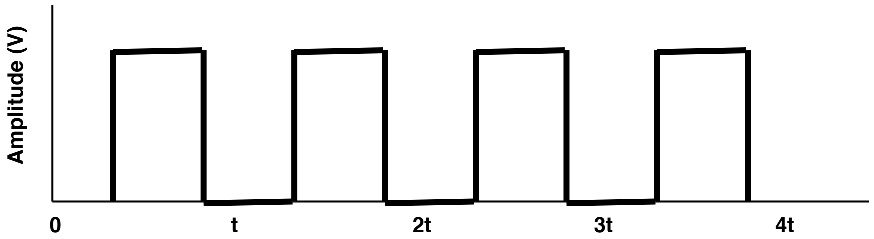
Digital information coding *(approach 2)*

Direct transmission of digital signals

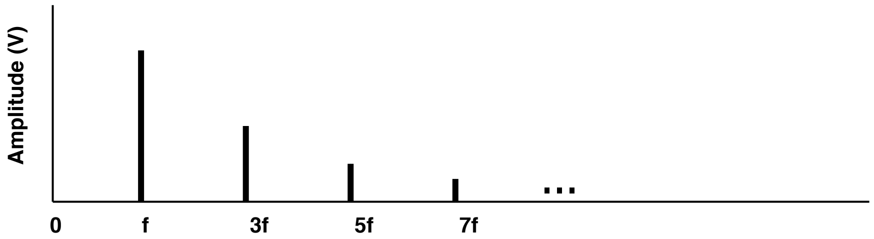
- presence of absence of voltage indicates bits 1 and 0
- is received as a distorted, composite signal
- read voltage (amplitude) directly
- separate time base
- ignore frequency and phase
  - and their potential for carrying information

Digital information coding *(approach 2)*

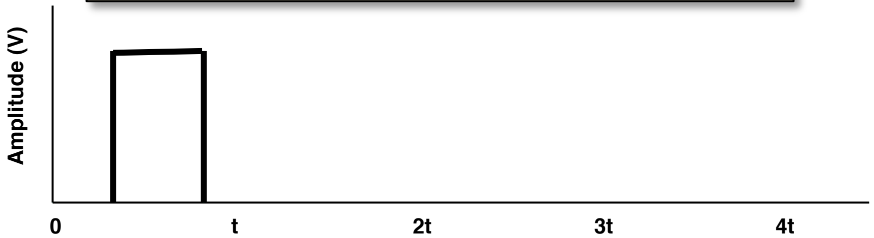
periodic digital signal



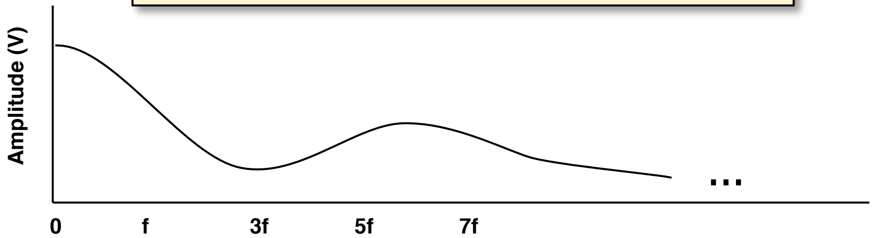
it is a composite signal
its bandwidth is infinite



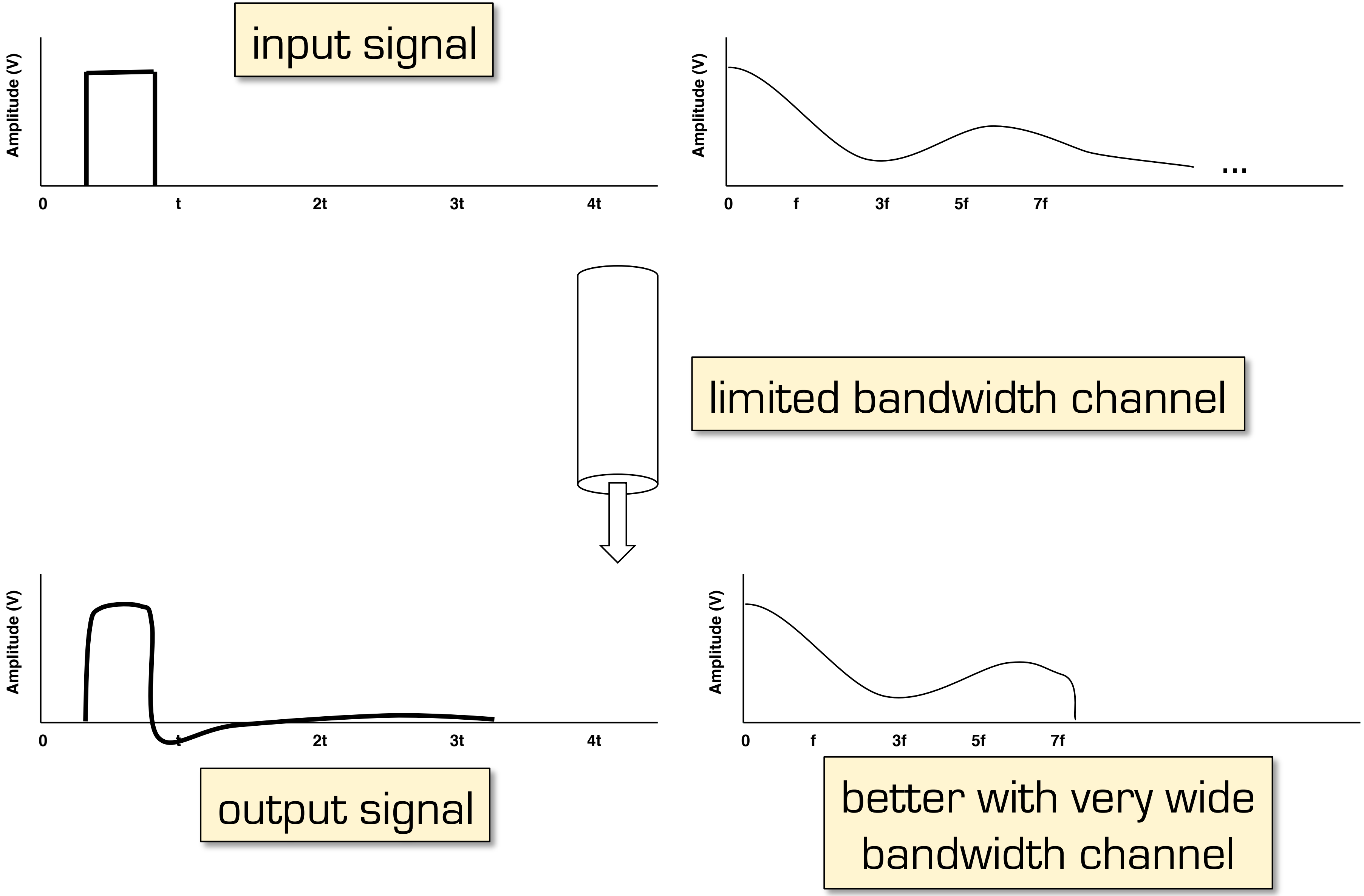
non-periodic digital signal
(e.g. 1 one-bit)



infinite bandwidth
continuous frequencies

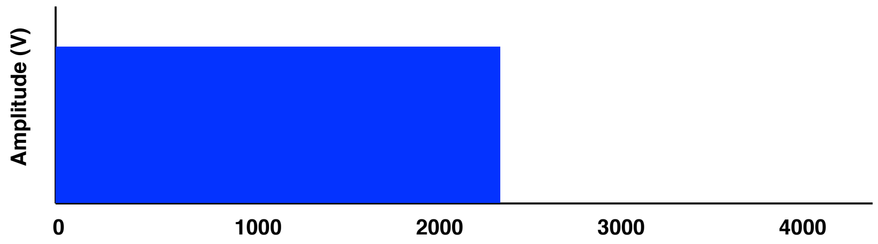


Digital information coding *(approach 2)*



Bandwidth

Baseband

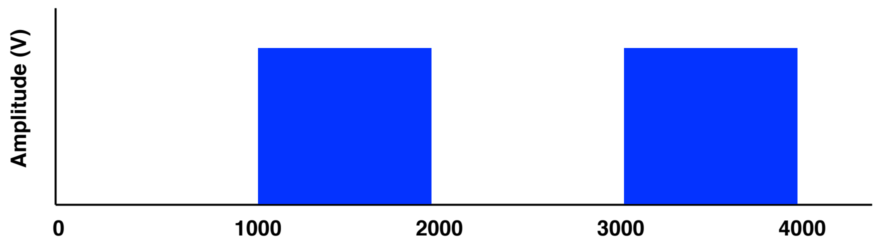


Includes frequencies very close to 0

Typical for electrical signals over cables

Can be used with approaches 1 and 2

Passband



A range of frequencies that is isolated for processing through a bandpass filter

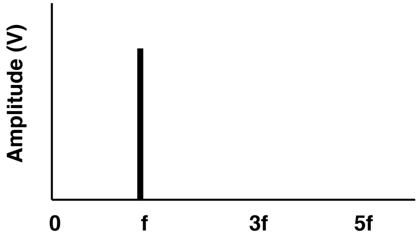
Necessary for wireless channels
Typical for optical cables

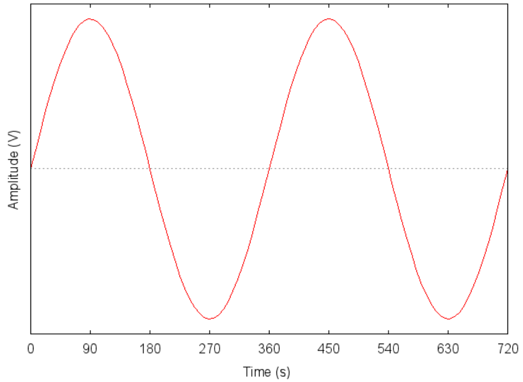
Can be used with approach 1

Nyquist's theorem

Maximum data rate that can be transmitted over a **noiseless** channel

Nyquist's theorem





Maximum data rate of a channel

For a noiseless channel (and perfect sampling),
Nyquist has defined the theoretical maximum bit rate.

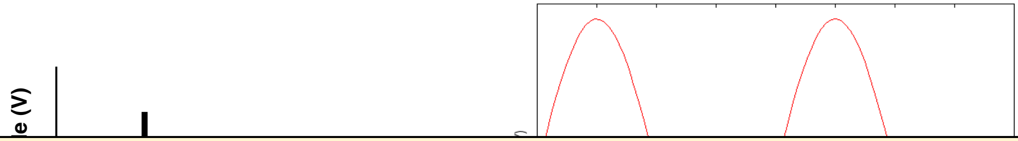
$$C = 2 \times B \times \log_2 L \quad \textit{bit/second}$$

2: upper and lower peak

B: bandwidth (Hz)

L: #levels, $\log_2(L)$: #bits

Nyquist's theorem



Interesting

- also valid when bandwidth range does not start at 0
- ie. when we have been allocated part of a spectrum

But

- we cannot distinguish (higher) frequencies outside our spectrum
- a low-pass filter is needed to remove them before sampling

$$C = 2 \times B \times \log_2 L \quad bit/second$$

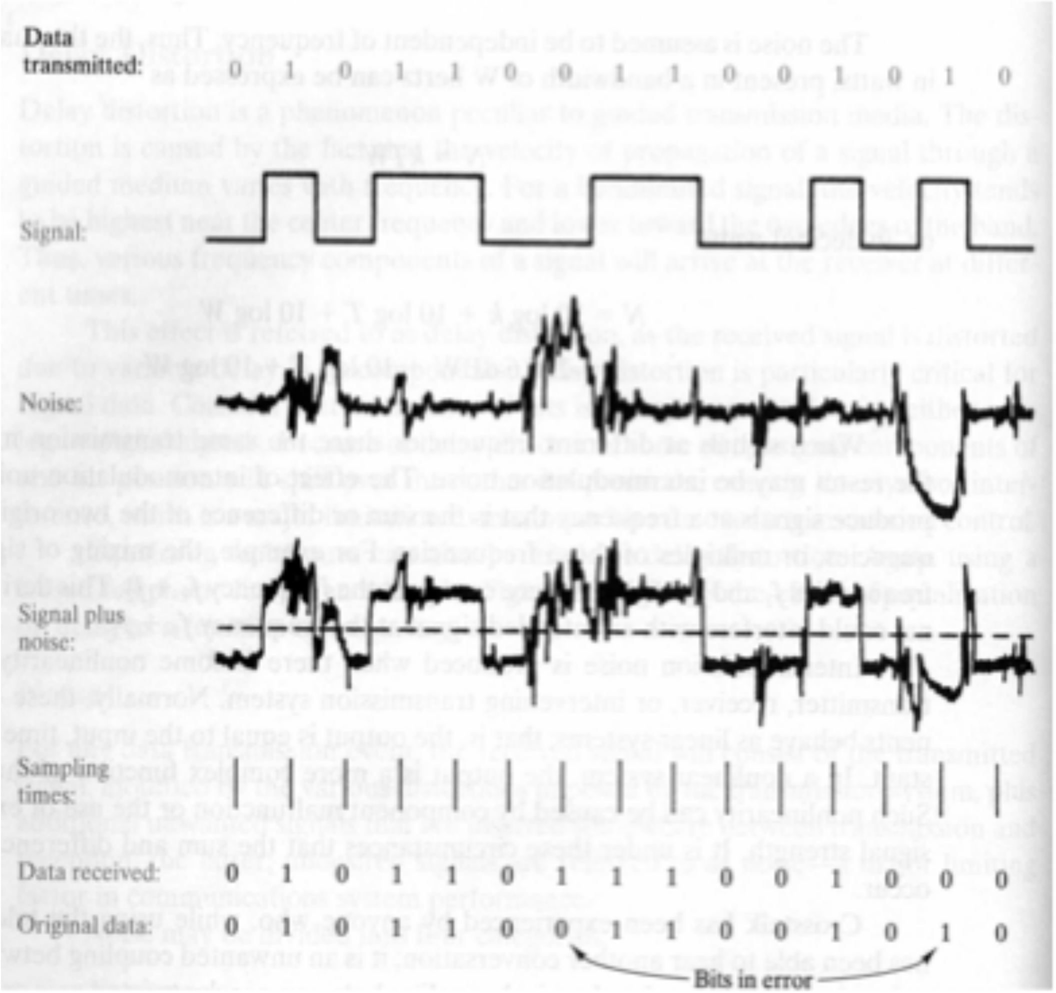
2: upper and lower peak

B: bandwidth (Hz)

L: #levels, $\log_2(L)$: #bits

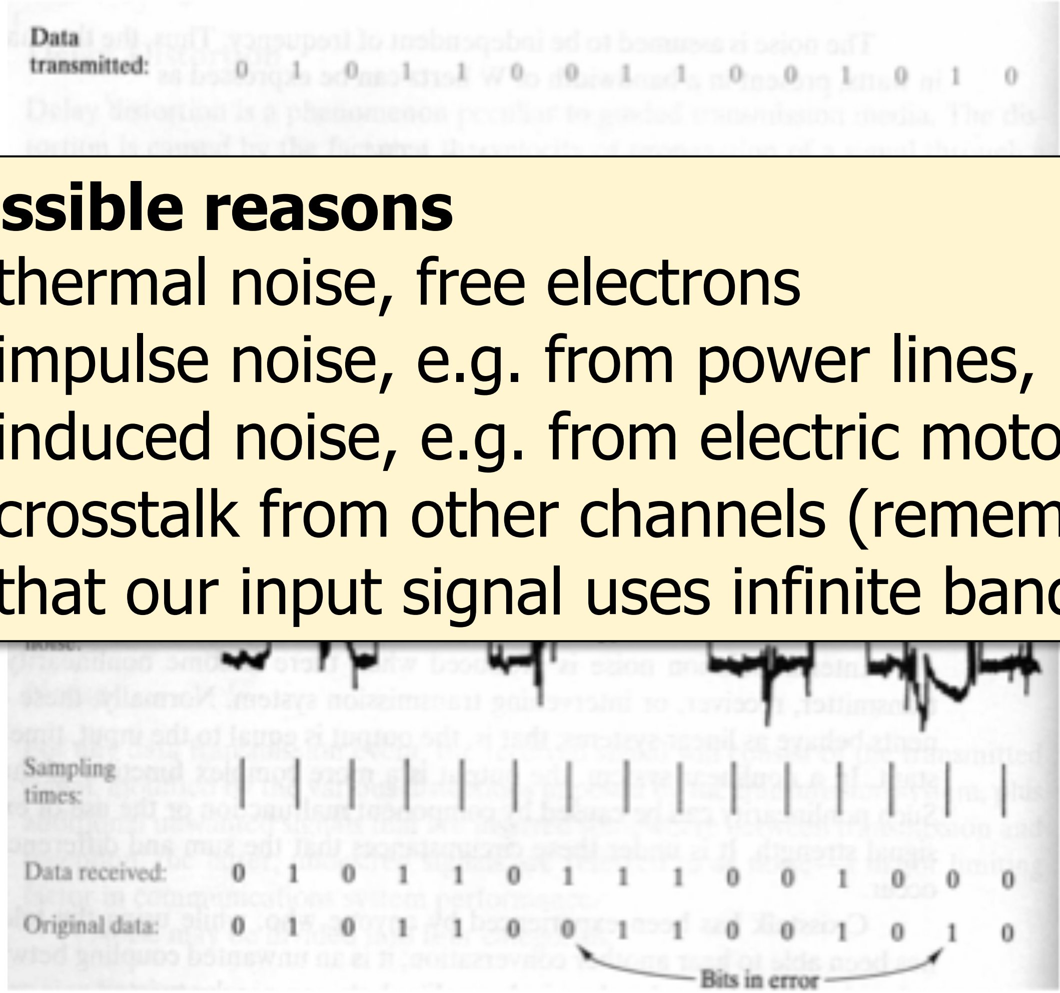
Shannon's Capacity

Most often, we have noise on a channel



Shannon's Capacity

But most often, we have noise on a channel



possible reasons

- thermal noise, free electrons
- impulse noise, e.g. from power lines, lightning
- induced noise, e.g. from electric motors
- crosstalk from other channels (remember that our input signal uses infinite bandwidth!)

Shannon's Capacity

We cannot avoid bit errors from noise

But Shannon has introduced a formula that determines the highest **theoretical** data rate for a noise channel

C: capacity (bps)

B: bandwidth (Hz)

$$C = B \times \log_{10}(1 + SNR)$$

the signal-to-noise ratio (SNR)

Shannon's Capacity

C: capacity (bps)

B: bandwidth (Hz)

$$C = B \times \log_{10}(1 + SNR)$$

the signal-to-noise ratio (SNR)

We need the relative strength of the signal with respect to the noise to compute it:

SNR = average signal power / average noise power

Careful!

SNR is often specified in decibel (dB)

You need

$$SNR_{dB} = 10 \log_{10}(SNR)$$

Part 2: Information coding

Information coding

- Binary Encoding
- Non-return-to-zero, inverted
- Manchester Encoding
- Differential Manchester Encoding

Multiplexing Techniques

- Frequency Multiplexing
- Time Division Multiplexing
- Multiplexer and Concentrator

Digital Information – Digital Transmission

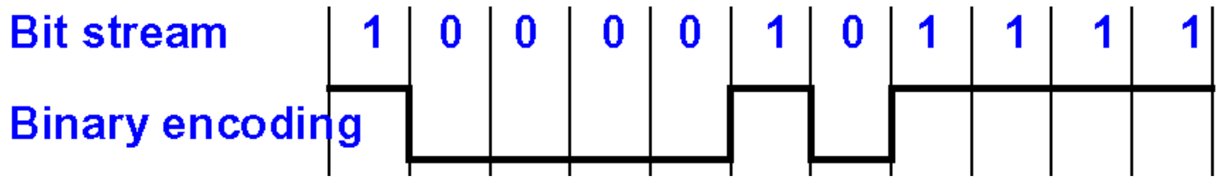
Digital transmission

- high bit rate
- sender/receiver synchronization
  - common understanding of phase
  - clock recovery
- signal levels around 0V (lower power)
  - error protection

Coding techniques

- binary encoding, non-return to zero-level (NRZ-L)
  - 1: high level
  - 0: low level
- return to zero (RZ)
  - 1: clock pulse (double frequency) during interval
  - 0: low level
- Non-return-to-zero, inverted
- Manchester Encoding
- Differential Manchester Encoding
- ...

Binary Encoding



Binary encoding (NRZ, Non-return-to-zero):

- "1": voltage on high
- "0": voltage on low

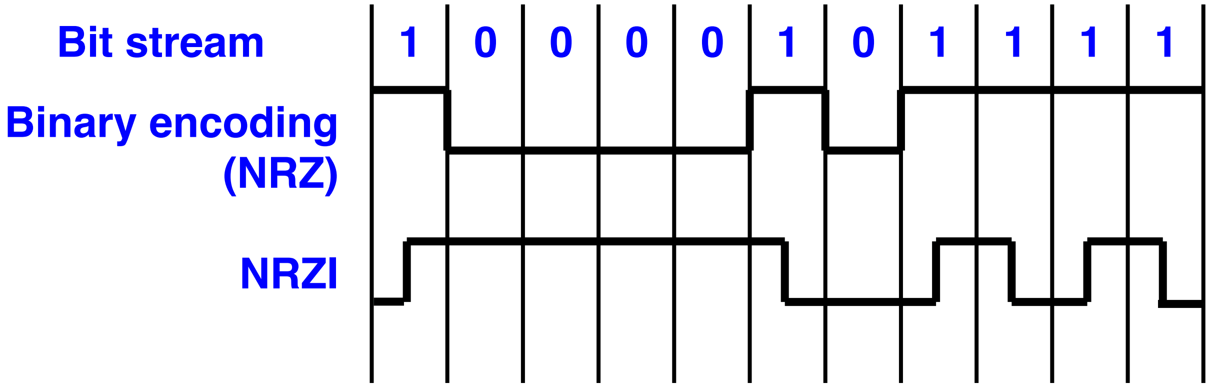
i.e.

+ simple, cheap

+ good utilization of the bandwidth (1 bit per symbol)

- no "self-clocking" feature

Non-return-to-zero, inverted



Non-return-to-zero, inverted:

- "1": change in the level
- "0": no change in the level

USB uses opposite convention

- change on 0, no change on 1

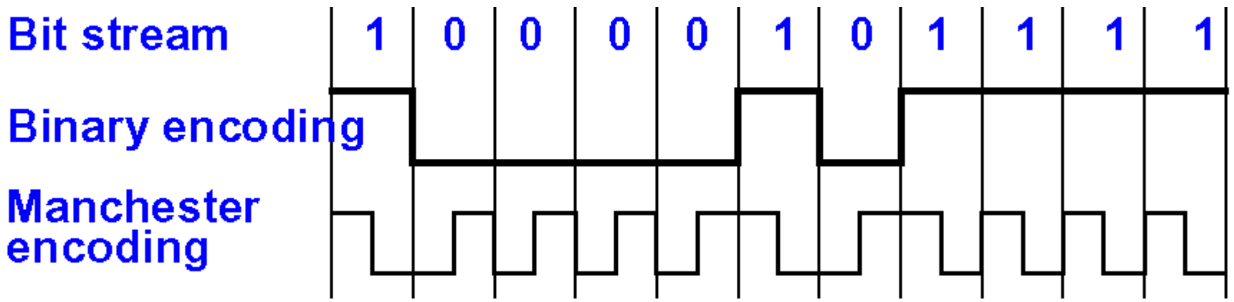
\+ simple

\+ 1 bit per symbol

– no "self-clocking"

– clock must be ensured by bit stuffing

Manchester Encoding



Bit interval is divided into two partial intervals: I1, I2

- "1":
  I1: high, I2: low 

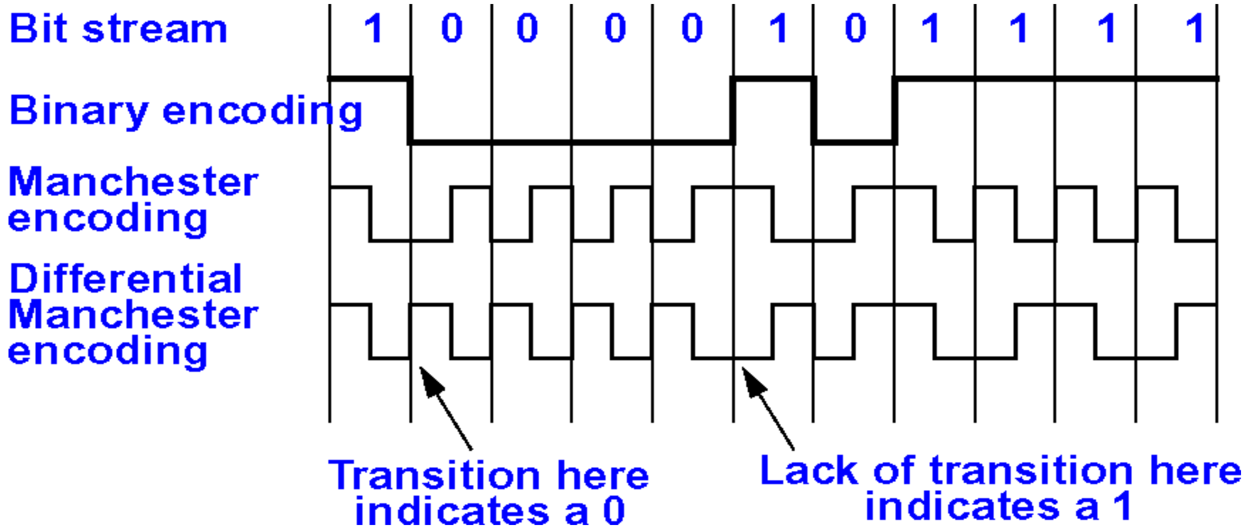
- "0":
  I1: low, I2: high 

+ good "self-clocking" feature

– 0,5 bits per symbols

Application: 802.3 (CSMA/CD)

Differential Manchester Encoding



Differential Manchester Encoding:

- bit interval divided into two partial intervals:
  - "1": no change in the level at the beginning of the interval
  - "0": change in the level

+ good "self-clocking" feature
+ low susceptibility to noise because only the signal's polarity is recorded. Absolute values are irrelevant.
– 0,5 bit per symbol
– complex

INF3190 - Data Communication

Physical Layer (cnt'd)

Carsten Griwodz

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with slides from: Ralf Steinmetz, TU Darmstadt

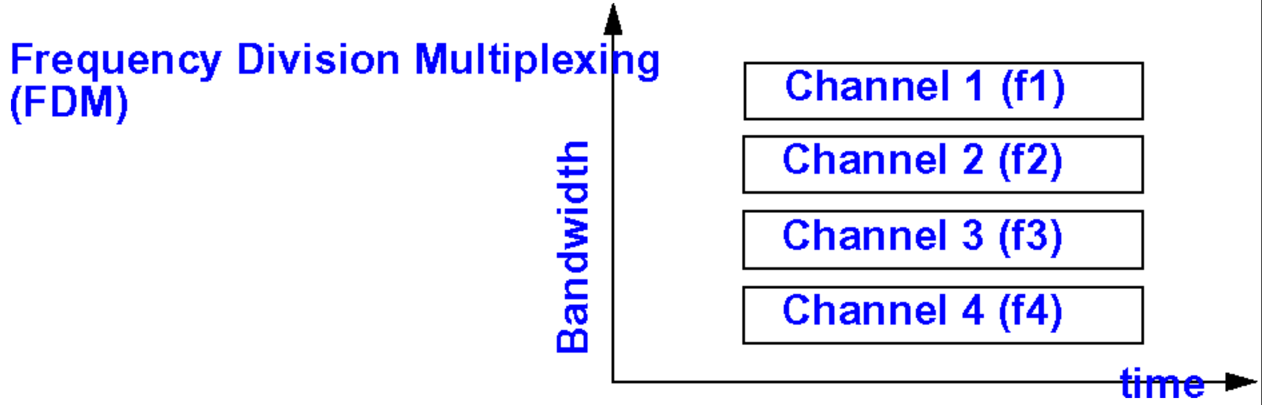
Multiplexing Techniques

Cost for implementing and maintaining either a narrowband or a wideband cable are almost the same

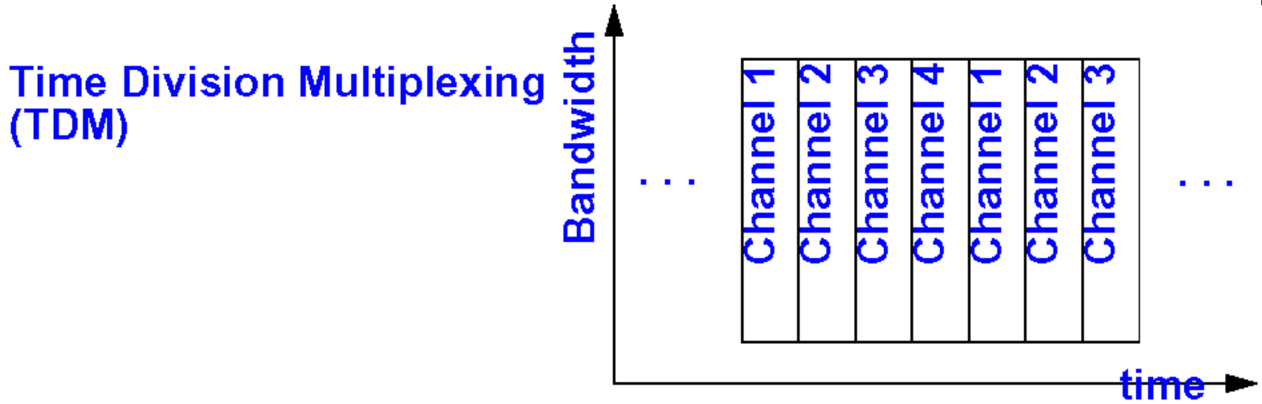
Multiplexing many conversations onto one channel

Two types

- FDM (Frequency Division Multiplexing)



- TDM (Time Division Multiplexing)



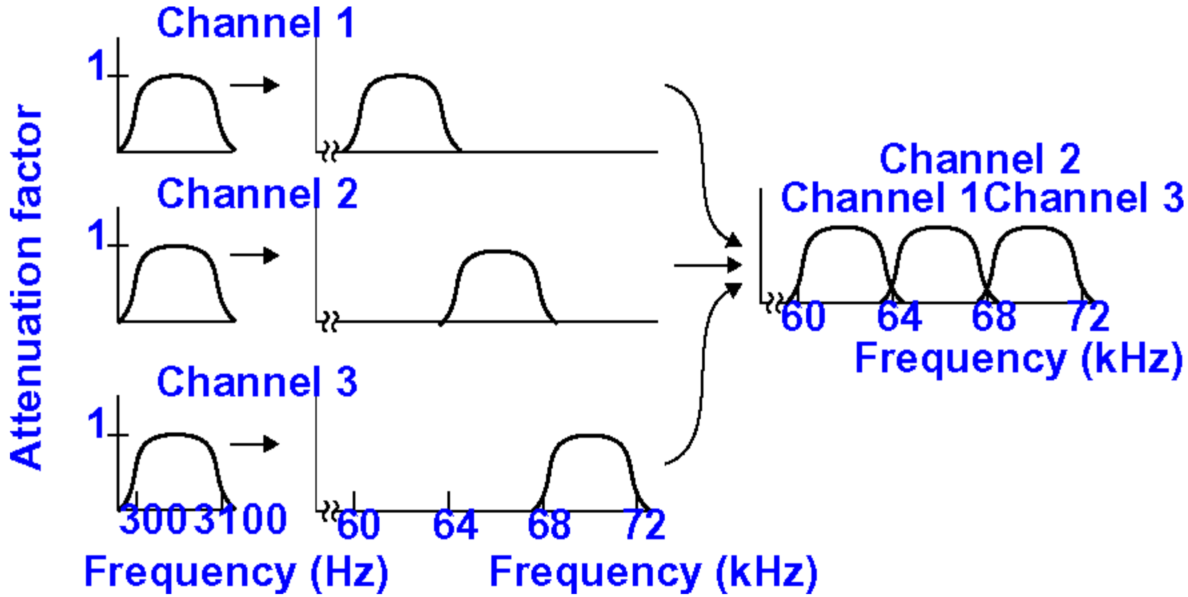
Frequency Multiplexing

Principle

- frequency band is split between the users
- each user is allocated one frequency band

Application

- example: multiplexing of voice telephone channels: phone, cable-TV



- filters limit voice channel to 3 000 Hz bandwidth
- each voice channel receives 4 000 Hz bandwidth
  - 3 000 Hz voice channel
  - 2 x 500 Hz gap (guard band)

Time Division Multiplexing

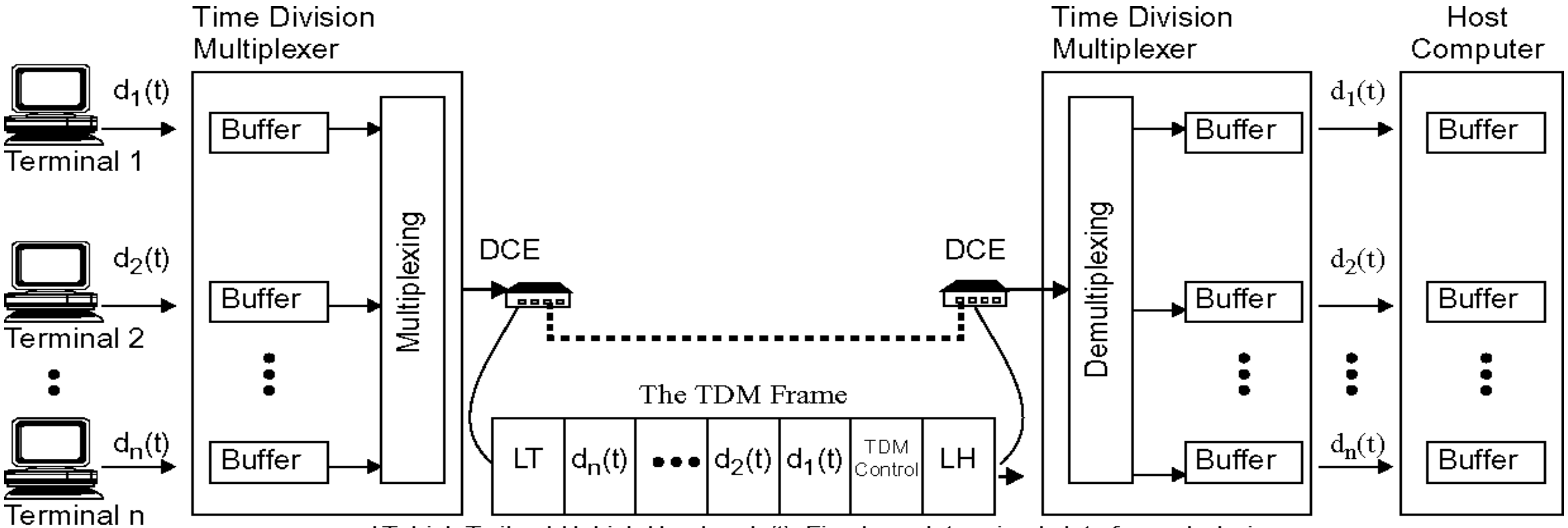
Principle

- user receives a time slot
- during this time slot he has the full bandwidth

$$\sum_{i=1}^{n} d_i(t) = d_0(t)$$

Application

- multiplexing of end systems, but also
- in transmission systems



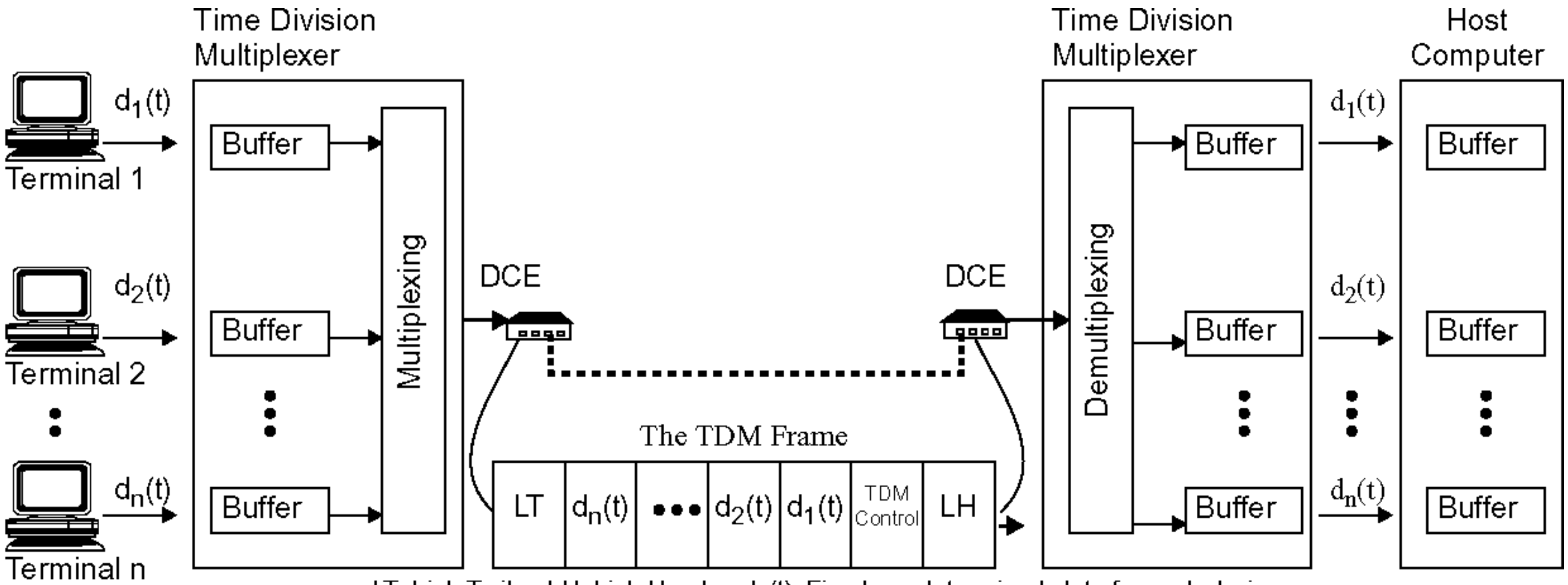
LT: Link Trailer, LH: Link Header, $d_n(t)$: Fixed, predetermined slots for each device,
TDM Control: Identification of specific TDM controls (may not exist on some TDMs)

Multiplexer and Concentrator

MULTIPLEXER

- INPUT from various links in predefined order
- OUTPUT at one single link in the same order

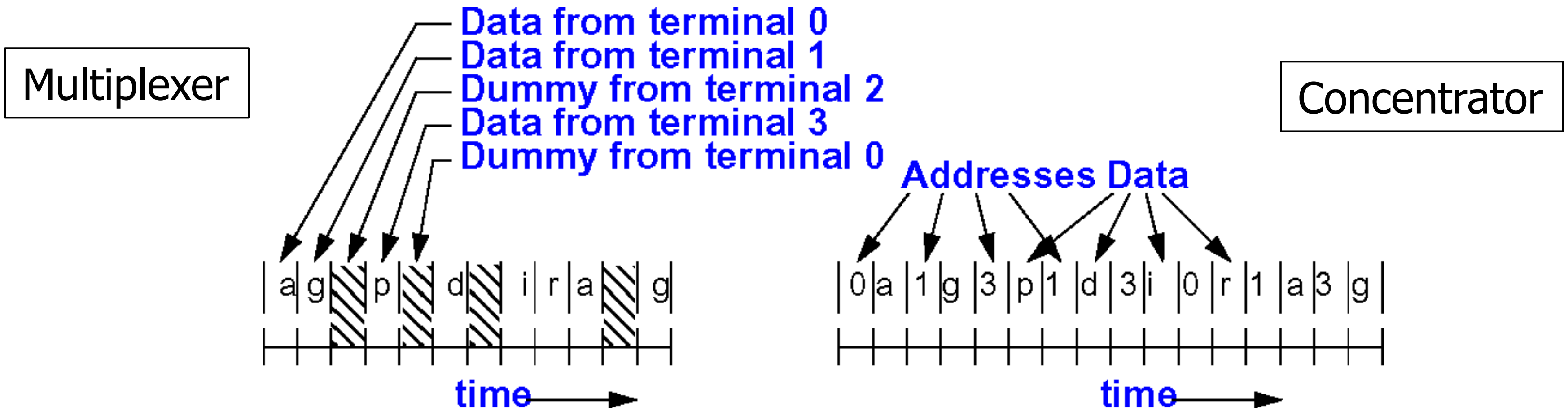
$$\sum_{i=1}^{n} C_i^{IN} = C^{OUT}$$



LT: Link Trailer, LH: Link Header, $d_n(t)$: Fixed, predetermined slots for each device,
TDM Control: Identification of specific TDM controls (may not exist on some TDMs)

Disadvantage: waste of time slots if station is not sending

Multiplexer and Concentrator



Concentrator

- INPUT from several links
- OUTPUT at one single link
- no fixed slot allocation,
  instead sending of (station addresses, data)

$$\sum_{i=1}^{n} c_i^{IN} > c^{OUT}$$

PROBLEM: All stations use maximum speed for sending

- "Solution": internal buffers

addressing: a link layer task