Digital vs. Analog Transmission

Two forms of *transmission*:

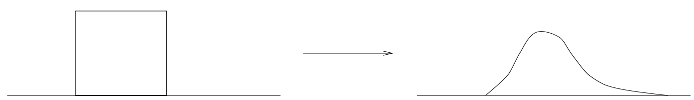
- digital transmission: data transmission using square waves
- analog transmission: data transmission using all other waves

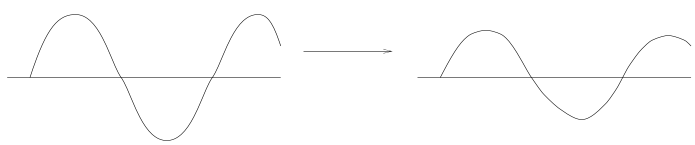
Four possibilities to consider:

- analog data via analog transmission
  → "as is" (e.g., radio)
- analog data via digital transmission
  → sampling (e.g., voice, audio, video)
- digital data via analog transmission
  → broadband & wireless
- digital data via digital transmission
  → baseband (e.g., Ethernet)

Why consider digital transmission?

Common to both: problem of *attenuation*.





- decrease in signal strength as a function of distance
- increase in attenuation as a function of frequency

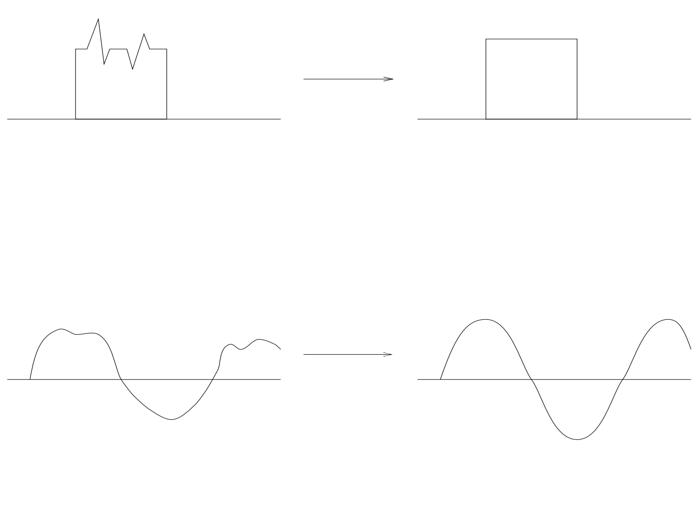
Rejuvenation of signal via amplifiers (analog) and repeaters (digital).

Delay distortion: different frequency components travel at different speeds.

Most problematic: effect of noise

$\longrightarrow$ thermal, interference, ...

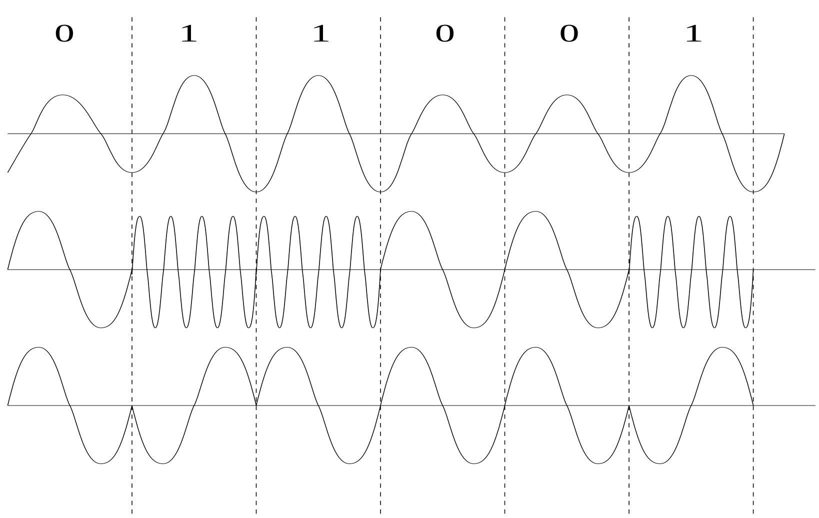
- Analog: Amplification also amplifies noise—filtering out just noise, in general, is a complex problem.
- Digital: Repeater just generates a new square wave; more resilient against ambiguitity.



Analog transmission of digital data

Three pieces of information to manipulate: amplitude, frequency, phase.

- Amplitude modulation (AM): encode bits using amplitude levels.
- Frequency modulation (FM): encode bits using frequency differences.
- Phase modulation (PM): encode bits using phase shifts.



Baud rate vs. bit rate

Baud rate: Unit of time within which carrier wave can be altered for AM, FM, or PM.

$\longrightarrow$ signalling rate

$\longrightarrow$ e.g., clock

Not synonymous with bit rate: e.g., AM with 8 levels, PM with 8 phases

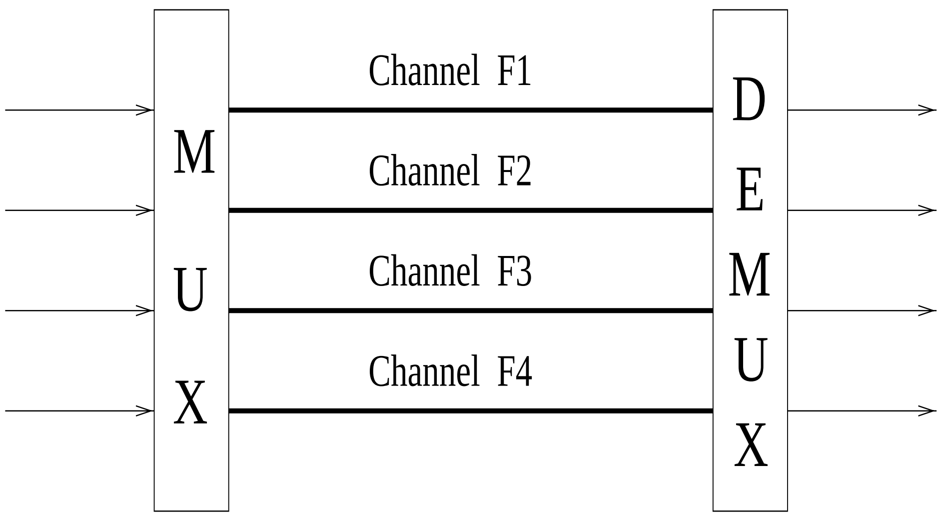
$\longrightarrow$ bit rate (bps) = 3 $\times$ baud rate

. . . less than one bit per baud?

Broadband vs. baseband

Presence or absence of carrier wave: allows many channels to co-exist at the same time

⟶ frequency division multiplexing (FDM)



Ex.: AM radio (535 kHz–1705 kHz)

⟶ tuning to specific frequency: Fourier transform

⟶ coefficient of Fourier transform!

Ex.: FM radio

⟶ 88 MHz–108 MHz

⟶ 200 kHz slices

⟶ how might it work?

⟶ better or worse than AM?

Ex.: Digital radio

⟶ digital audio radio service

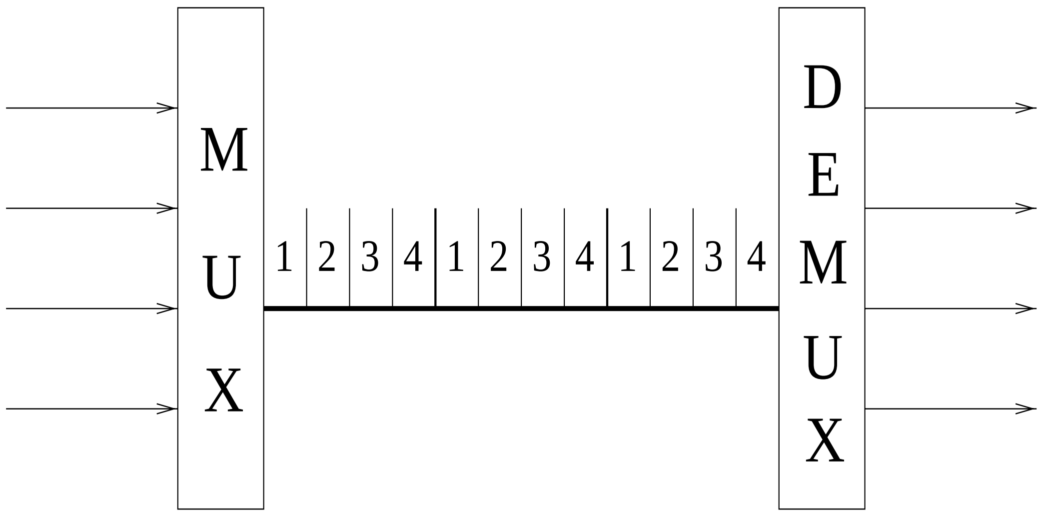
⟶ GEO satellites (a.k.a. satellite radio)

⟶ uses 2.3 GHz spectrum (a.k.a. S-band)

⟶ e.g., XM, Sirius

In the absence of carrier wave, can still use multiplexing:

$\longrightarrow$ time-division multiplexing (TDM)



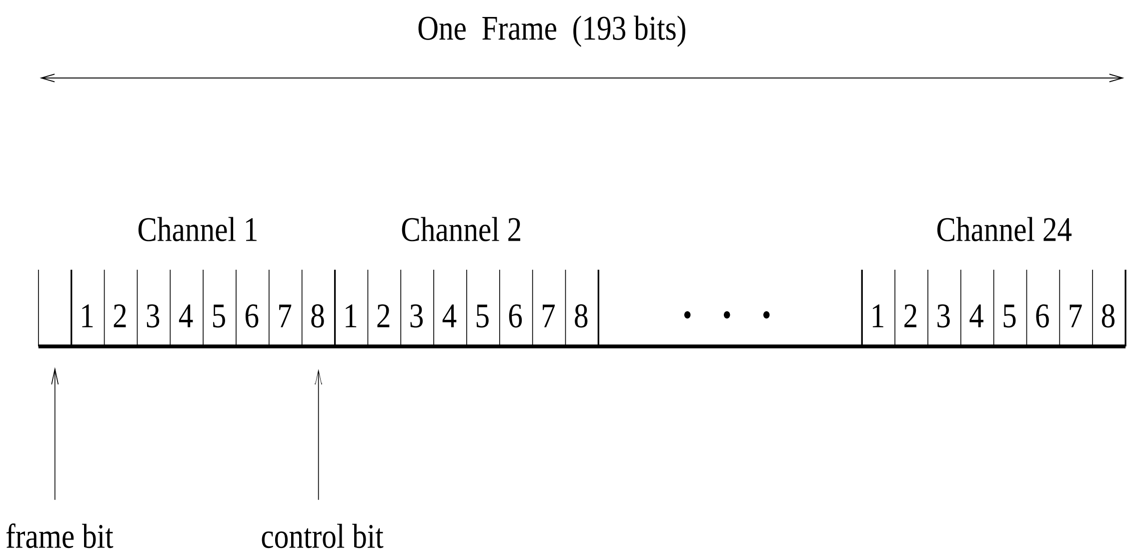
- digital transmission of digital data

  $\rightarrow$ e.g., telephony backbone network

- digital transmission of analog data

  $\rightarrow$ PCM (e.g., PC sound cards), modem

Example: T1 carrier (1.544 Mbps)



- 24 simultaneous users
- 7 bit quantization

Assuming 4 kHz telephone channel bandwidth, Sampling Theorem dictates 8000 samples per second.

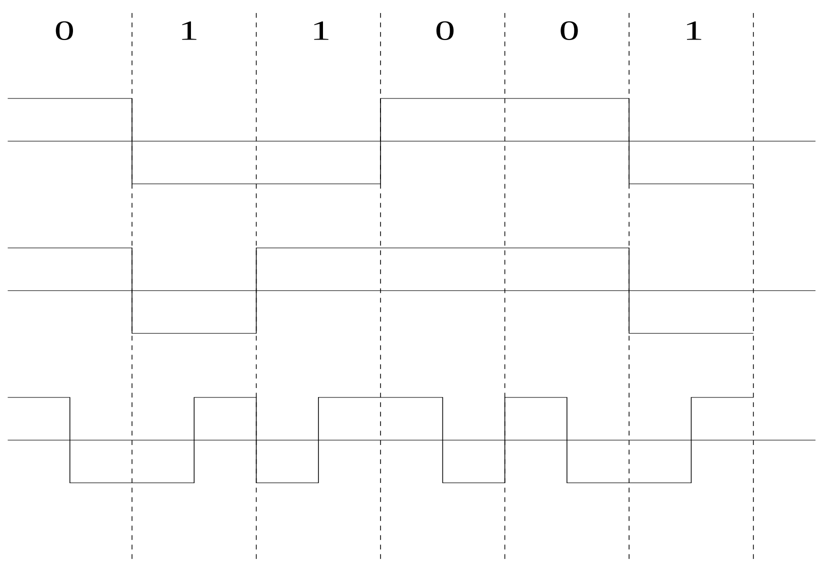
$\longrightarrow$ 125 μsec inter-sample interval

Bandwidth = $8000 \times 193 = 1.544$ Mbps

Digital transmission of digital data

Direct encoding of square waves using voltage differentials; e.g., -15V–+15V for RS-232-C.

- NRZ-L (non-return to zero, level)
- NRZI (NRZ invert on ones)
- Manchester (biphase or self-clocking codes)



⟶ baud rate vs. bit rate of Manchester?

Trade-offs:

- NRZ codes—long sequences of 0's (or 1's) causes synchronization problem; need extra control line (clock) or sensitive signalling equipment.
- Manchester codes—synchronization achieved through self-clocking; however, achieves only 50% efficiency vis-à-vis NRZ codes.

4B/5B code

Encode 4 bits of data using 5 bit code where the code word has at most one leading 0 and two trailing 0's.

0000 $\leftrightarrow$ 11110, 0001 $\leftrightarrow$ 01001, etc.

$\longrightarrow$ at most three consecutive 0's

$\longrightarrow$ efficiency: 80%

Multiplexing techniques:

- TDM
- FDM
- mixture (FDM + TDM); e.g., TDMA
- CDMA (code division multiple access) or spread spectrum

  → wireless communication

  → competing scheme with TDMA

Code Division Multiplexing

Direct sequence:

To send bit sequence $x = x_1x_2 \ldots x_n$, use pseudorandom bit sequence $y = y_1y_2 \ldots y_n$ to compute

$$\begin{aligned} z &= z_1z_2 \ldots z_n \\ &= (x_1 \oplus y_1)(x_2 \oplus y_2) \ldots (x_n \oplus y_n) \end{aligned}$$

To decode bit sequence $z = z_1z_2 \ldots z_n$, compute

$$x = z \oplus y$$

Ex.: $x = 10010$, $y = 01011$

$\longrightarrow \quad z = x \oplus y = 10010 \oplus 01011 = 11001$

$\longrightarrow \quad z \oplus y = 11001 \oplus 01011 = 10010$

- data rate usually slower than code rate

  → 1 data bit encoded using $r \geq 1$ code bits

  → $|y| = r \cdot |x|$

  → what's good about it?

  → "spreading"

- multiplexing of N senders achieved via a set of chipping codes

$$\{y^1, y^2, \ldots, y^N\}$$

$\longrightarrow$ $x^1 \oplus y^1 + x^2 \oplus y^2 + \cdots + x^N \oplus y^N$

$\longrightarrow$ how does receiver i recover its message x^i?

. . . slight additional twist needed

Frequency hopping:

Use pseudorandom number sequence as key to index a set of carrier frequencies $f_1, f_2, \ldots, f_m$.

$\longrightarrow$ frequency spreading

Receiver with access to pseudorandom sequence can decode transmitted signal.

$\longrightarrow$ receiver's tuner must jump around

$\longrightarrow$ code narrowband input as broadband output

Benefits:

- more secure against eavesdropping

  $\longrightarrow$ confidentiality

- resistant to jamming

  $\longrightarrow$ must jam a wider spectrum: more difficult

- noise resistance

  $\longrightarrow$ code rate r

- graceful degradation

Terminology:

- DSSS (direct sequence spread spectrum)
- FHSS (frequency hopping spread spectrum)

  → single user coding
- CDMA if multiplexing N simultaneous users

Ex.:

⟶ wireless LAN (WLAN, a.k.a. Wi-Fi): DSSS

⟶ cellular (e.g., Sprint PCS, Verizon): CDMA

Competing with CDMA cellular: (almost) all the rest!

⟶ AT&T Wireless, Cingular, etc.

⟶ uses TDMA (also called GSM)