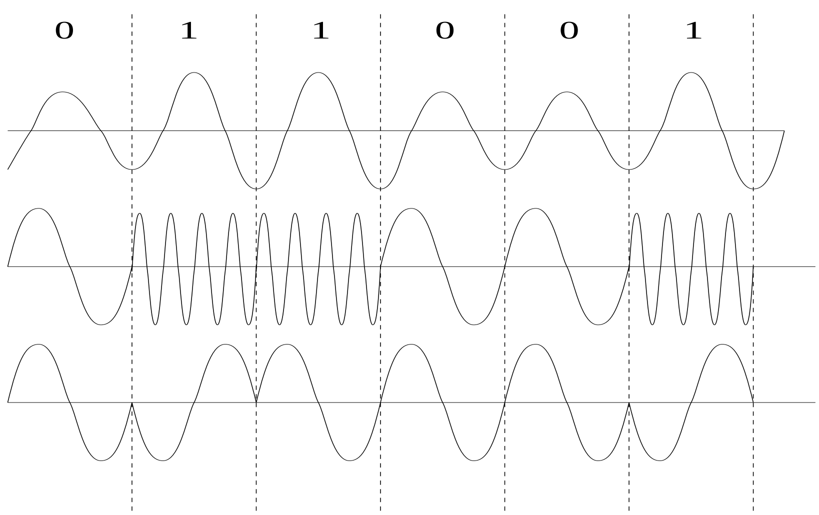
Analog transmission (sine curves) of digital data (bits):

→ hiding bits in the coefficient

→ but not the only way

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



FM radio uses . . . FM!

AM radio uses . . . AM!

iPod & radio experiment uses . . . ?

Why is FM radio clearer ("high fidelity") than AM radio?

Why not PM radio?

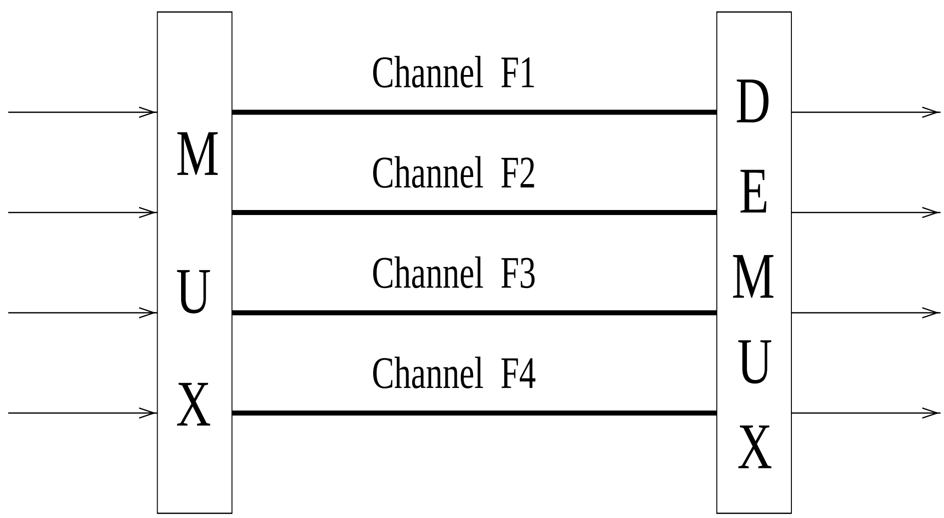
Broadband uses . . . ?

Broadband: multiple carrier frequencies with AM

$\longrightarrow$ frequency division multiplexing (FDM)

$\longrightarrow$ baseband: single carrier frequency

Ex.: FDM with 4 carrier frequencies F1, F2, F3, F4



Ex.: AM radio (535 kHz–1705 kHz)

$\longrightarrow$ tuning to specific frequency: Fourier transform

$\longrightarrow$ coefficient (magnitude) carries bit information

Ex.: FM radio

- ⟶ 88 MHz–108 MHz
- ⟶ 200 kHz slices
- ⟶ how does it work?
- ⟶ better or worse than AM?

Ex.: Digital radio

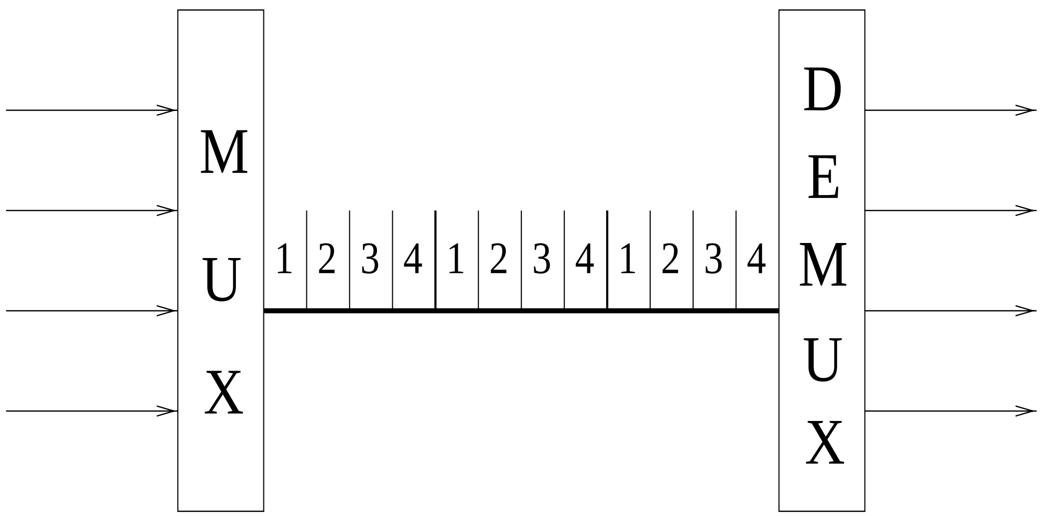
- ⟶ digital audio radio service
- ⟶ GEO satellites (a.k.a. satellite radio)
- ⟶ uses 2.3 GHz spectrum (a.k.a. S-band)
- ⟶ e.g., XM, Sirius

Ex.: WLAN

- ⟶ uses 2.4 GHz spectrum (802.11b/g)
- ⟶ US: 11 channels (i.e., carrier waves)

Baseband: single carrier wave

$\longrightarrow$ time-division multiplexing (TDM)



- digital transmission of analog data

  $\rightarrow$ landline or cellular voice: first digitized

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

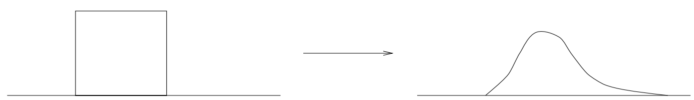
- digital transmission of digital data

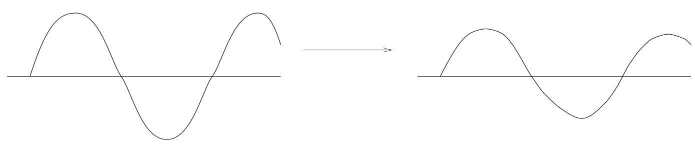
  $\rightarrow$ e.g., telephony backbone network

- also: use square waves in TDM (why?)

Why consider digital transmission (i.e., square waves)?

Common to both: problem of *attenuation*.





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

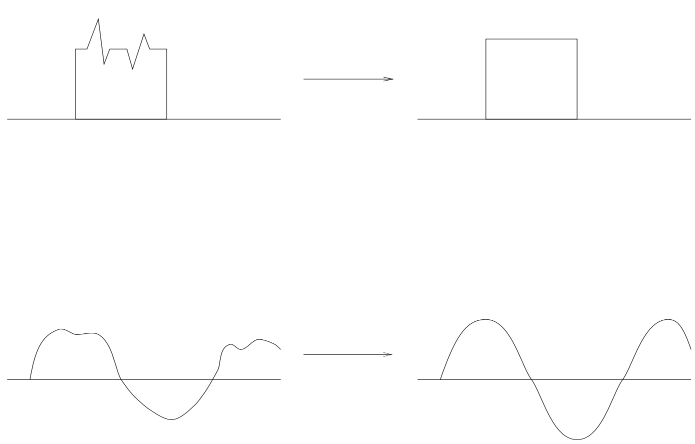
Rejuvenation of signal via amplifiers (analog) and repeaters (digital).

Delay distortion: different frequency components travel at different speeds.

Most problematic: effect of noise

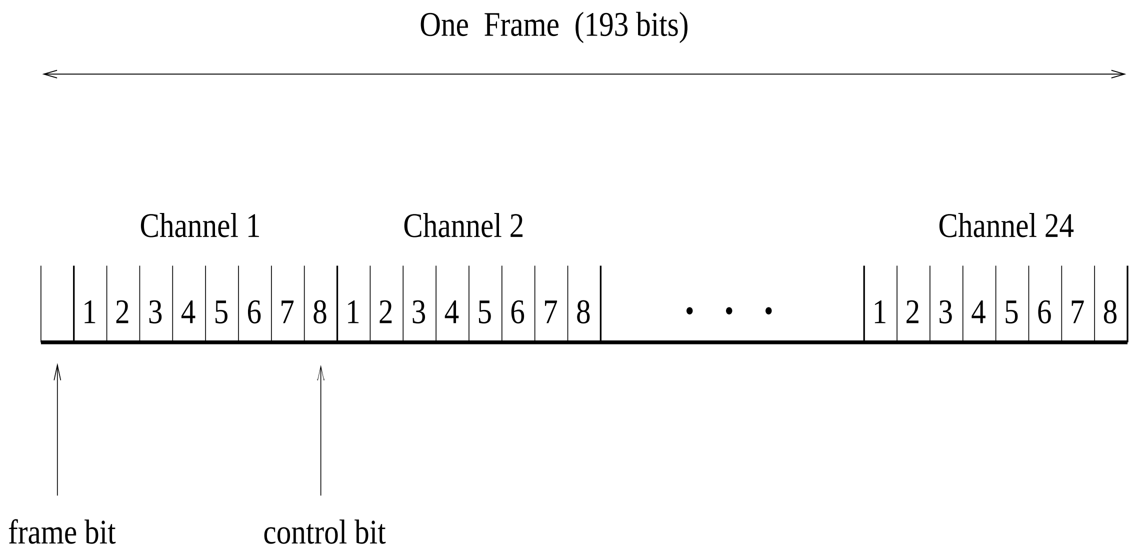
$\longrightarrow$ thermal, interference, ...

- 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.



Ex.: Baseband TDM

$\longrightarrow$ T1 carrier (1.544 Mbps)



- 24 simultaneous users
- 7 bit quantization

8000 samples per second (from voice application)

$\longrightarrow$ 125 μsec inter-sample interval

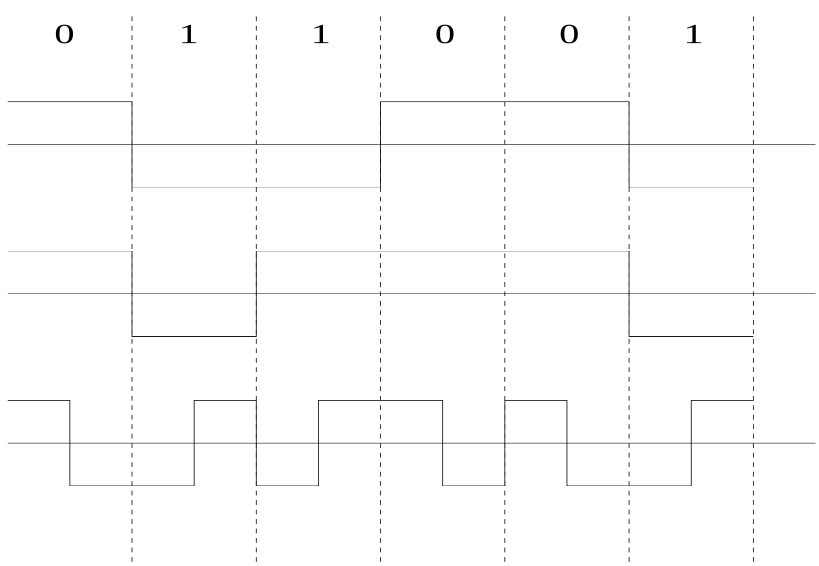
Bandwidth $= 8000 \times 193 = 1.544$ Mbps

Digital transmission of digital data:

Using square waves to represent bits:

$\longrightarrow$ methods and issues

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



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

  → e.g., Sprint vs. Cingular