Multiplexing and Modulation

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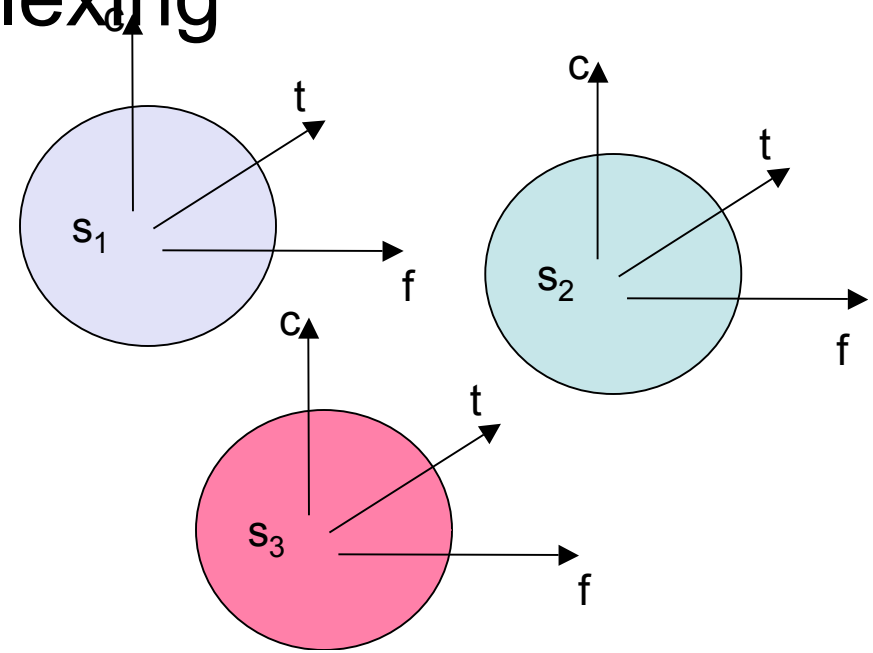
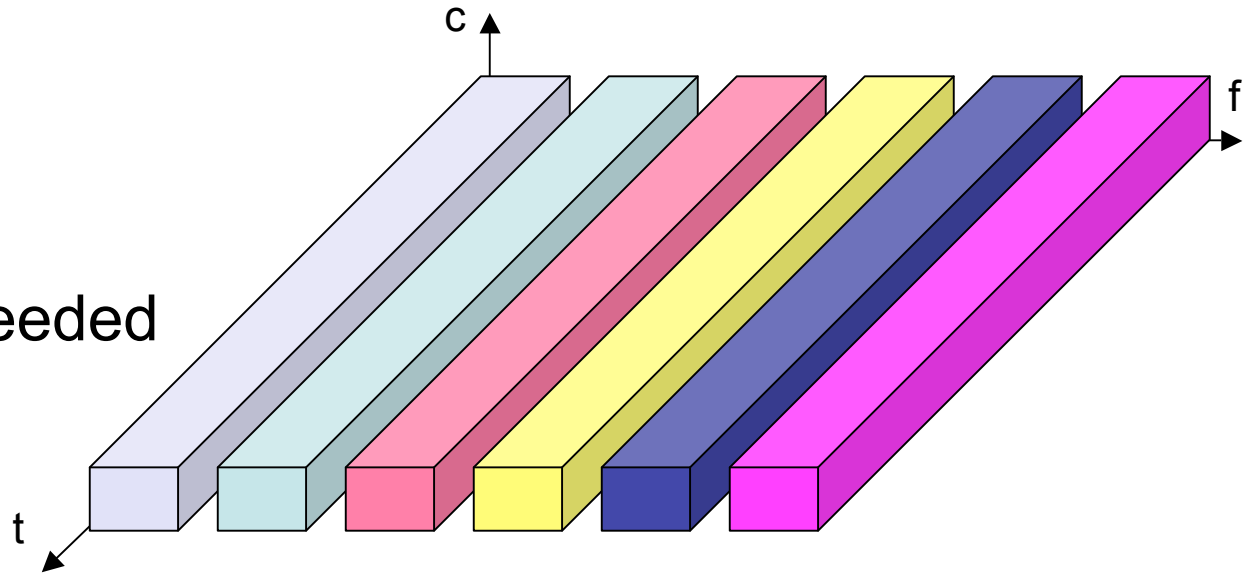
Multiplexing

- Goal: multiple use of a shared and limited medium, with maximum utilisation and minimum interference
- Multiplexing in four dimensions:
  - Space, time, frequency and code
- Space Division Multiplexing (SDM)
  - Channels separated in physical space
  - Guard spaces needed between channels



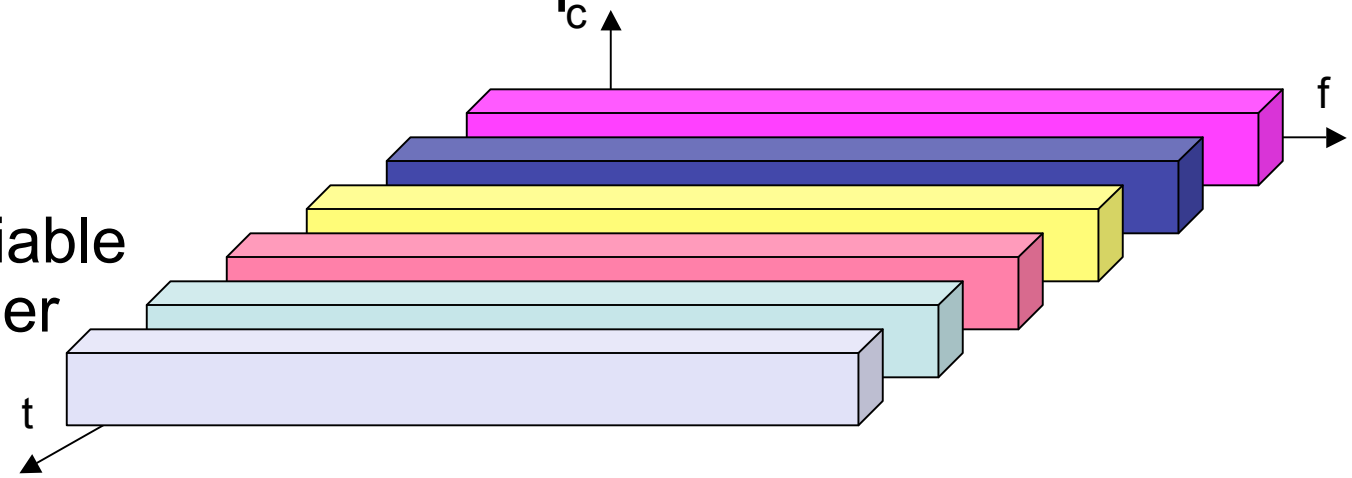
Frequency Division Multiplexing (FDM)

- Separation of available spectrum intro smaller frequency bands
- Each channel uses a certain band for the whole time
- Advantages
  - No dynamic coordination needed
  - Works for analog signals
- Disadvantages
  - Waste of bandwidth for short transmissions
  - Fixed maximum number of senders



Time Division Multiplexing (TDM)

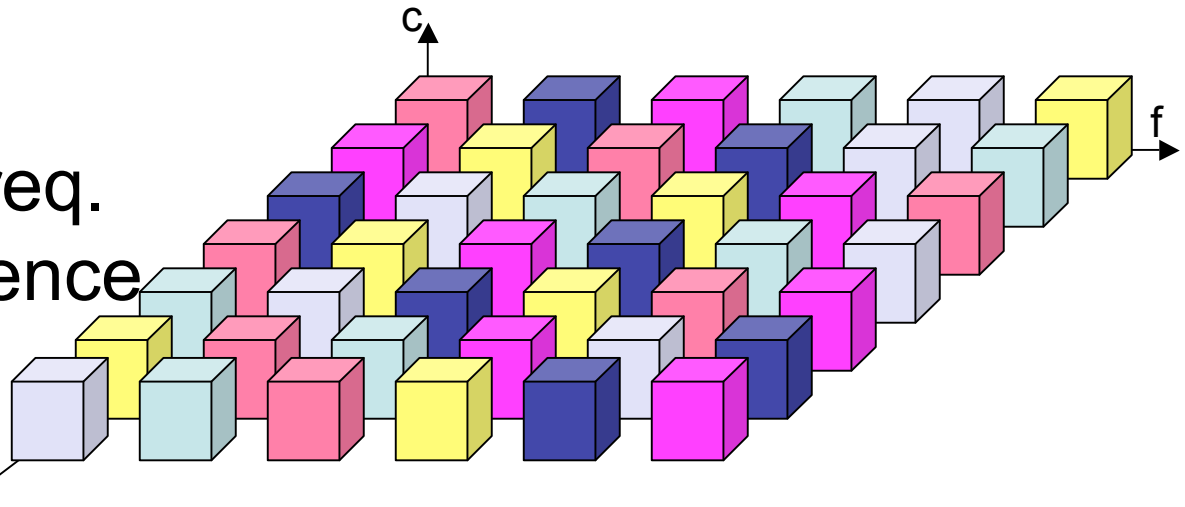
- A channel gets spectrum for a time slot
- Guard spaces: time gaps between periods of medium use
- More flexible for typical mobile communications
- When two transmissions overlap: co-channel interference
- Advantages
  - Flexibility, variable slots per sender
  - Can support many users



- Disadvantages: synchronisation
  - Very precise clock
  - Distribution of synchronisation signal to all senders

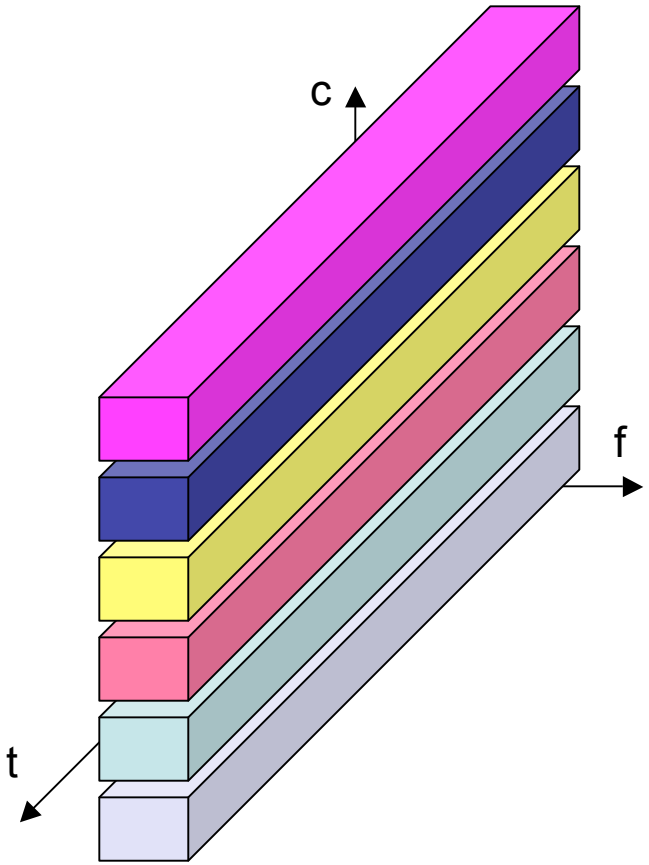
Time and Frequency Multiplexing

- Combination of TDM and FDM
- A channel gets a freq. band for a certain amount of time
- Advantages
  - Robust against freq. selective interference
  - Some protection against tapping
- Disadvantages
  - Precise coordination required



Code Division Multiplexing (CDM)

- All channels use the same freq. at the same time, each channel has its own code
  - Codes have to be orthogonal, separated, this is their guard space
- Advantages
  - Built-in security
  - Bandwidth efficient
  - No coordination and synchronisation necessary
- Disadvantages
  - Complexity on receiver
- Implemented using spread spectrum

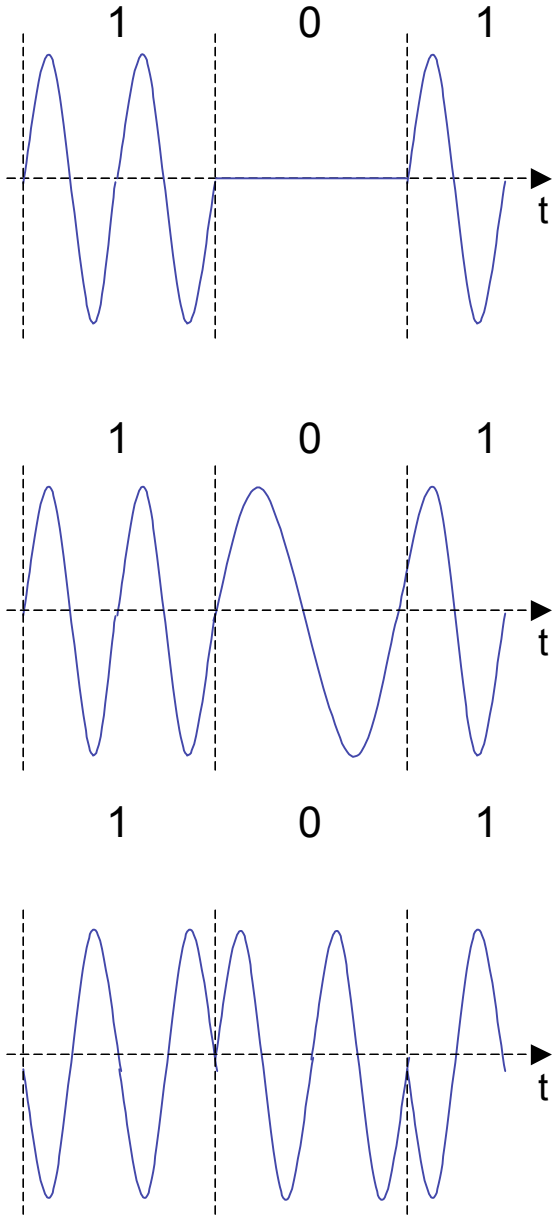


Modulation

- Motivation: to go from digital data to an electromagnetic signal
- Two steps
  - Digital modulation: digital data translated into analog baseband signal (1 Mbps -> 1 MHz)
  - Analog modulation: shift centre frequency of baseband signal to the radio carrier frequency
- Reasons for analog modulation
  - Antenna sizes: higher freqs -> smaller antennas
  - FDM: needs ability to use different carrier freqs.
  - Medium characteristics: different freqs. more suited to different environments or applications

Digital modulation

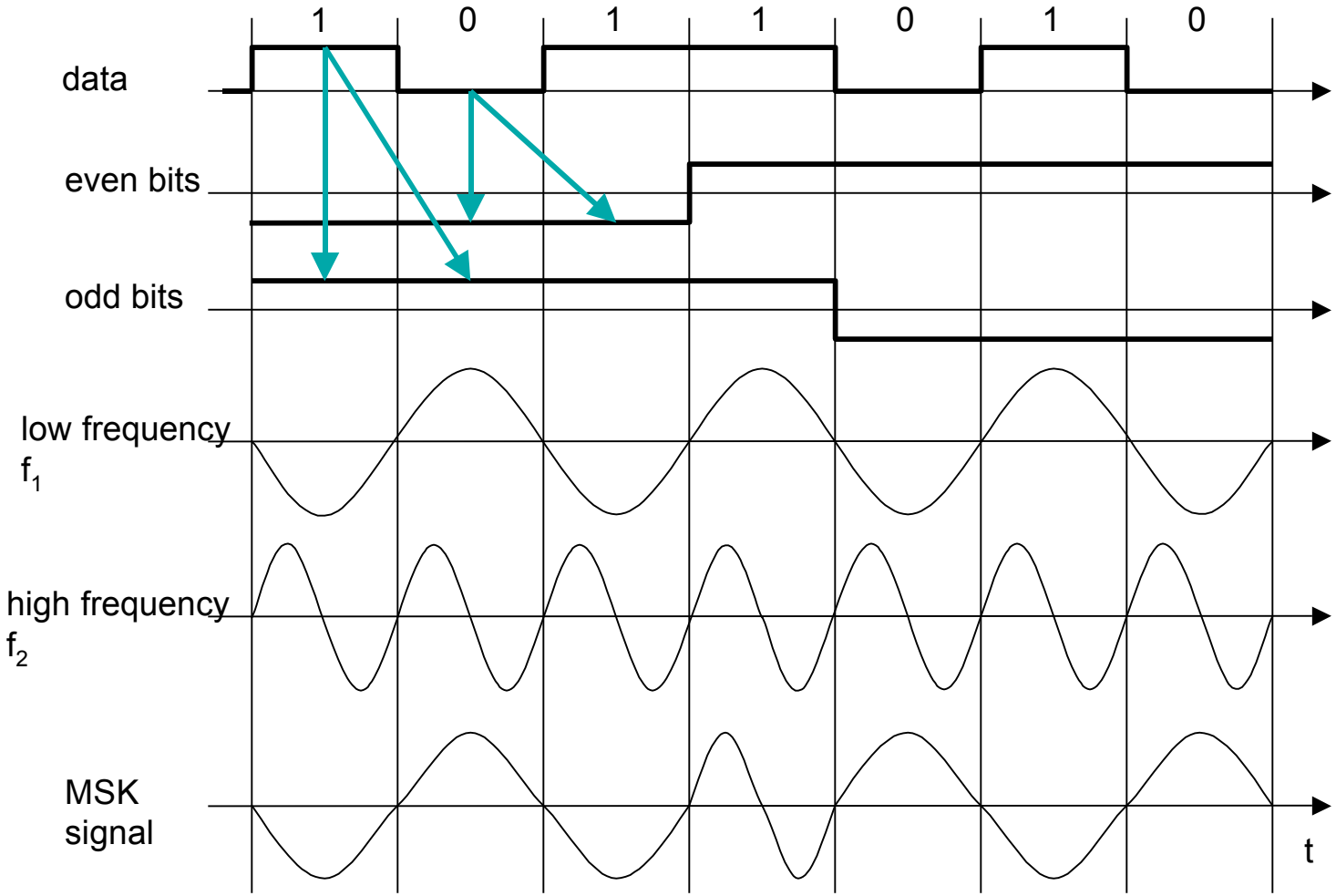
- Amplitude Shift Keying (ASK)
  - 0 and 1 represented by two different amplitudes
  - Simple, low bandwidth usage
  - Very susceptible to interference due to propagation effects
- Frequency Shift Keying (FSK)
  - Uses larger bandwidth than ASK
  - Less susceptible to errors
- Phase Shift Keying (PSK)
  - Higher complexity
  - Robust against interference



Advanced Frequency Shift Keying

- Minimum Shift Keying (MSK)
  - Binary FSK without abrupt phase changes
  - Uses two frequencies, f_1 and f_2 ($f_2 = 2 f_1$)
  - Separate signal into even and odd bit signals, with doubled bit duration
  - Signal generation rule, compare even/odd signals and:
    - Use f_2 if bits are equal, f_1 if different
    - Invert signal (180^o) if odd bit is 0
- Gaussian MSK: MSK with Gaussian lowpass filter
  - Reduces spectrum required
  - Used in GSM and other mobile standards

MSK example



bit	
even	0 1 0 1
odd	0 0 1 1
signal value	h n n h - - + +

h: high frequency
n: low frequency
+: original signal
-: inverted signal

Advanced Phase Shift Keying

- Binary PSK
  - Signal sine wave if bit = 0,inverted if bit = 1
  - Low spectral efficiency, robust
- Quadrature PSK
  - Two bits coded into one phase shift
  - Complex, requires frequent synchronisation
- Quadrature Amplitude Modulation (QAM)
  - Combination of PSK and ASK
  - Three amplitudes and 12 phases to code 4 bits per amplitude/phase change
- The more “points” the more difficult to recover from noise or ISI