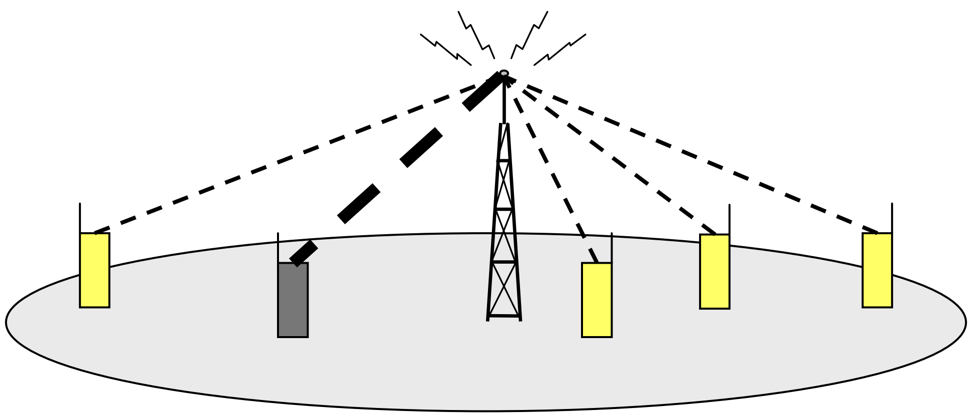
Multiplexing

CSE370

What is multiplexing?

- Multiple users share a medium with minimum or no interference.
- Example of interference: two people talking at the same time.

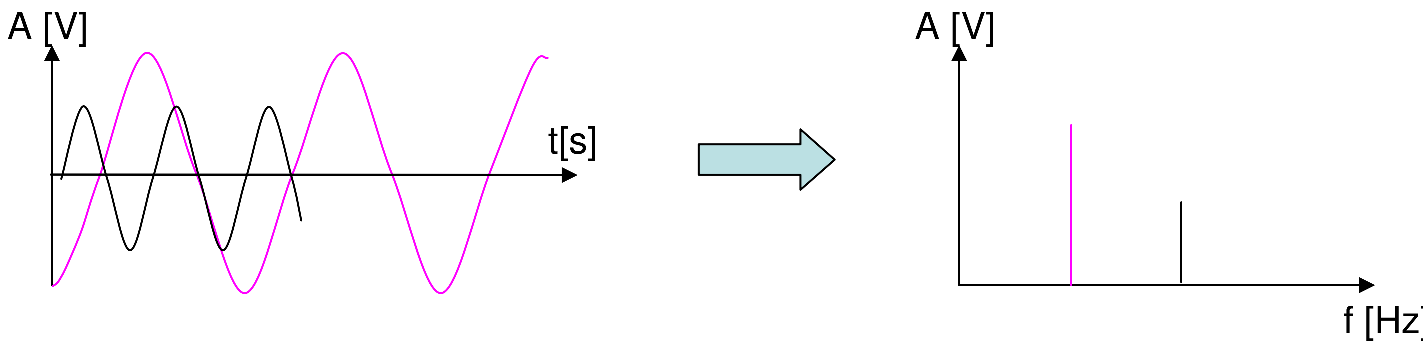


Use different frequency band

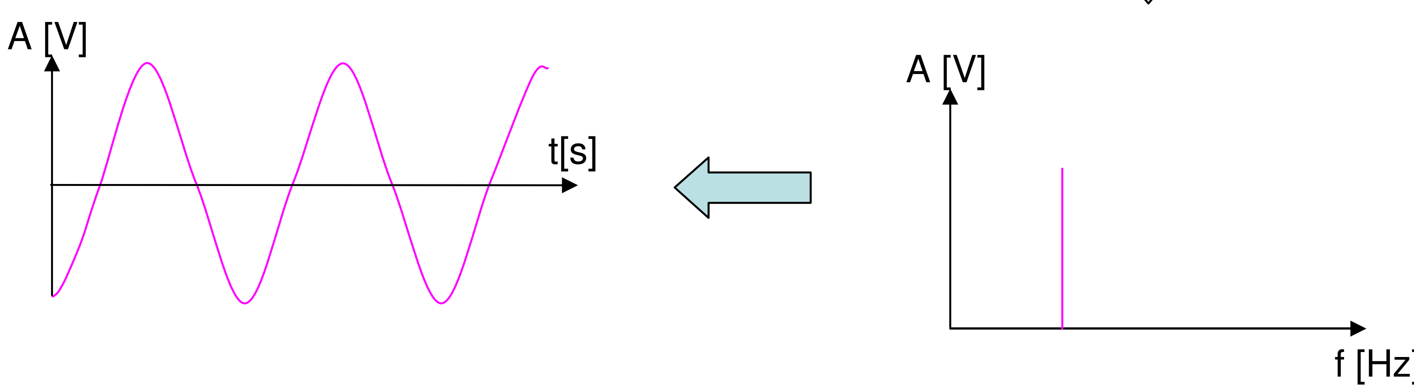
- If two signals are transmitted at the same time but the two signals have different frequency.
- By using Fourier transform, we can single out the signals within certain frequency band. ➔ filter out the other signals (noises).

Time-Domain v.s. Frequency-Domain

- Fourier transform

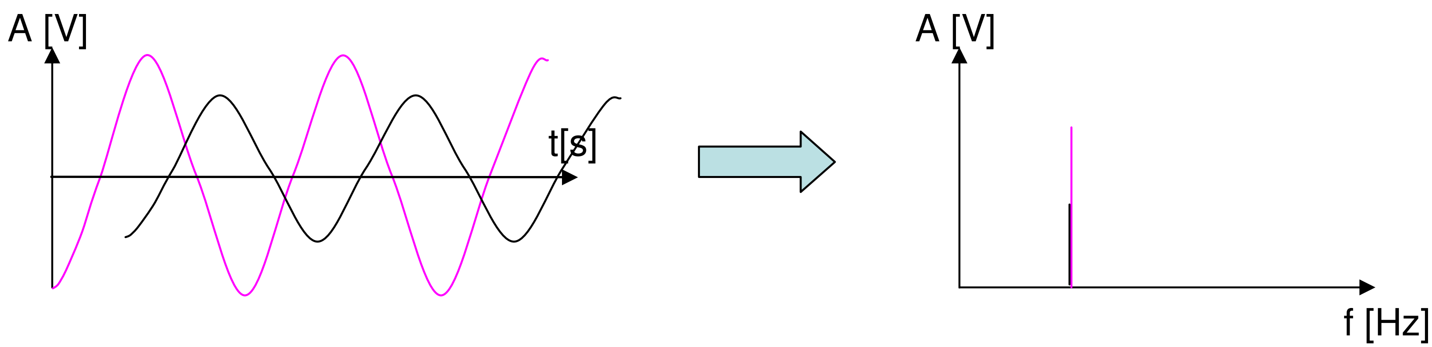


- Inverse Fourier transform

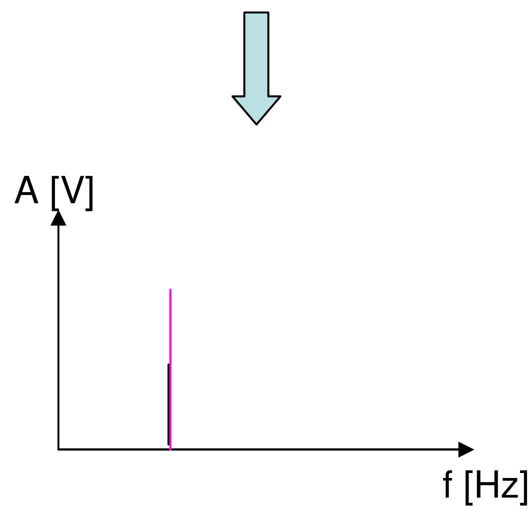


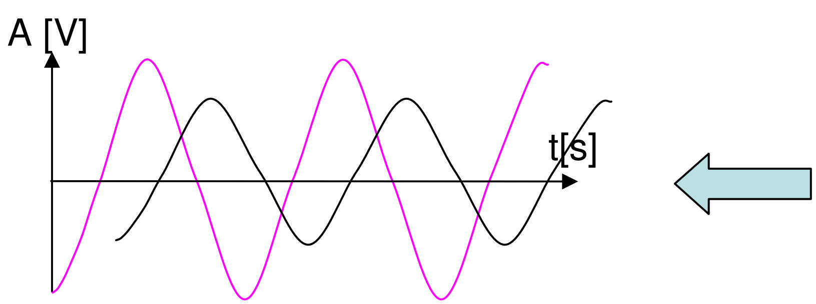
Time-Domain v.s. Frequency-Domain

- Fourier transform



- Inverse Fourier transform

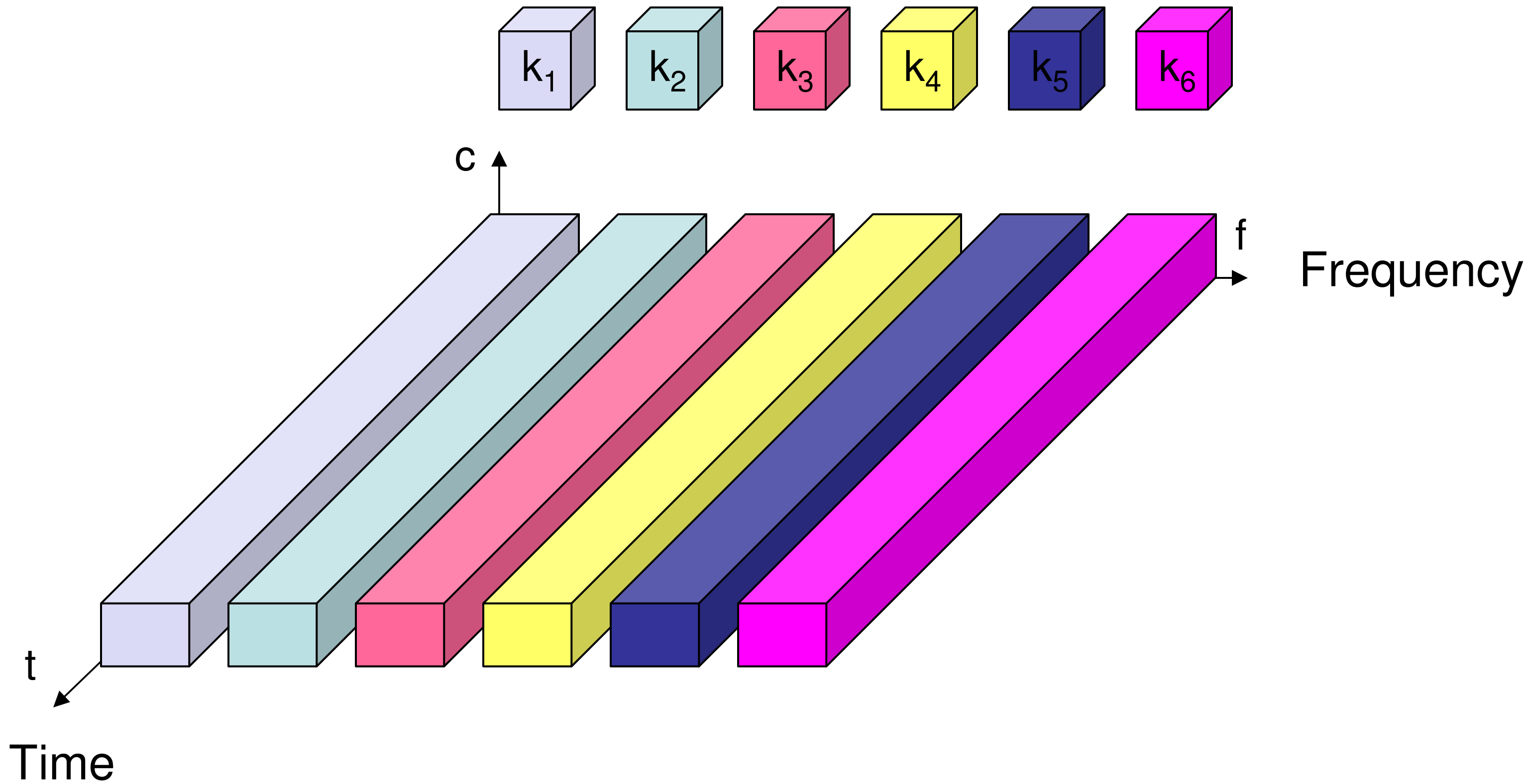




Frequency division multiplexing

- Frequency division multiplexing (FDM)
  - Frequency spectrum is divided into several non-overlapping frequency bands.
  - Each user uses a unique band.
- Radio stations
  - Each radio station has its own frequency.
- Receiver:
  - Tune in to the specific sender.

Frequency division multiplexing



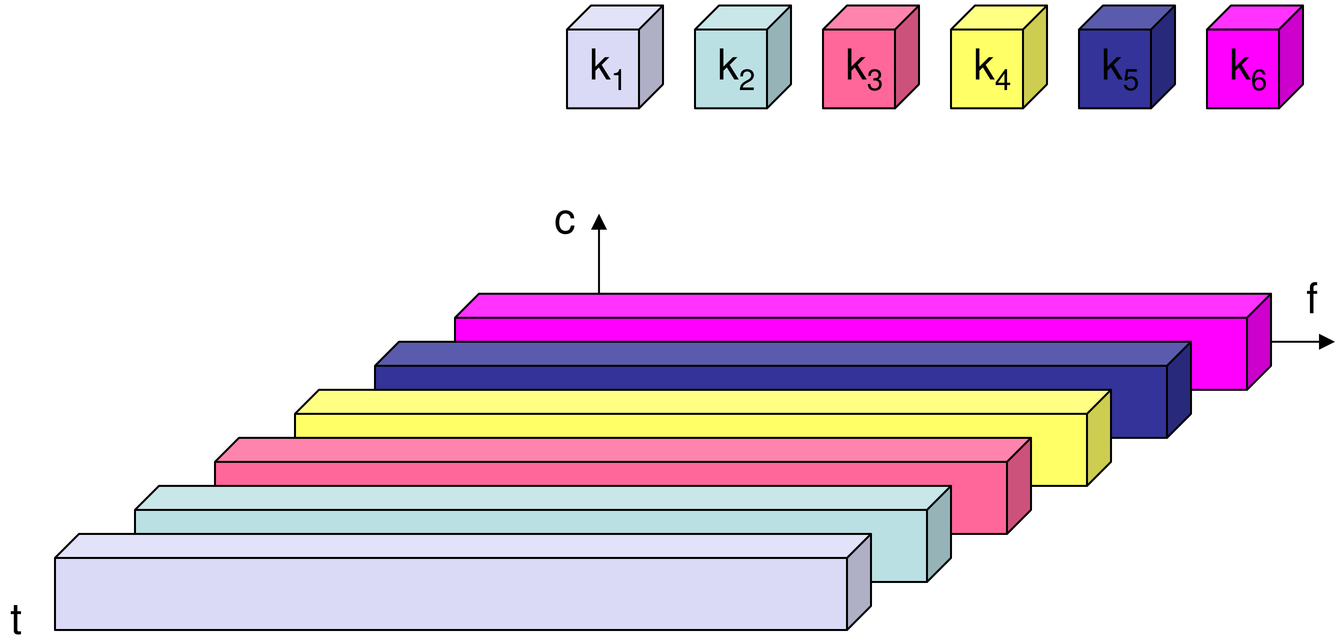
Frequency division multiplexing

- Advantage:
  - The senders can send signals continuously.
  - Works for analog signals too.
  - no dynamic coordination necessary
- Disadvantage:
  - Frequency is scarce resources.
  - Radio broadcasts 24 hours a day, but mobile communication only takes place for a few minutes.
  - A separate frequency for each possible communication scenario is a tremendous waste of frequency resources.
  - Inflexible: one channel idle and the other one busy.

Time division multiplexing

- All senders use the same frequency but at different points in time.
- A channel gets the whole spectrum for a certain amount of time: one guy talks at a time.
- Precise synchronization is needed.
  - All senders have precise clocks and scheduling.
  - Or, there has to a way to distribute synchronization signals.
  - Receivers have to listen to the right frequency at exactly the right points in time.
  - Flexible, adaptive to users with different loads.

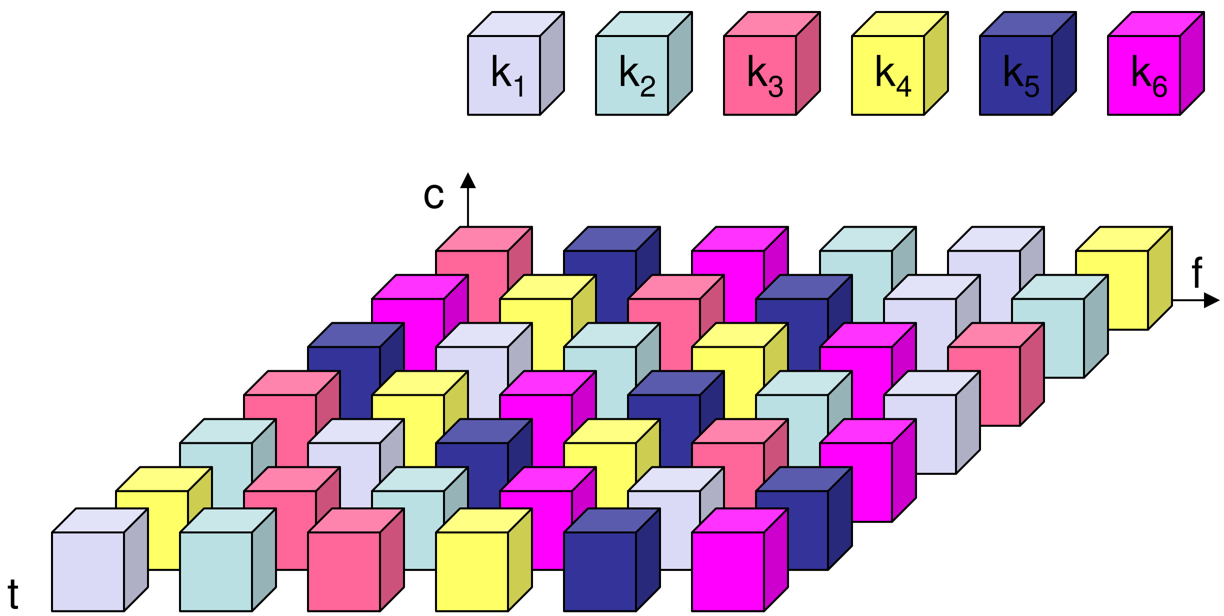
Time division multiplexing



Time and frequency multiplex

- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time.
- Example: GSM
  - (**G**lobal **S**ystem for **M**obile Communications), one of the leading cellular systems.
  - GSM was introduced in 1991.
  - As of the end of 1997, GSM service was available in more than 100 countries and has become the *de facto* standard in Europe and Asia.

Time and frequency multiplex



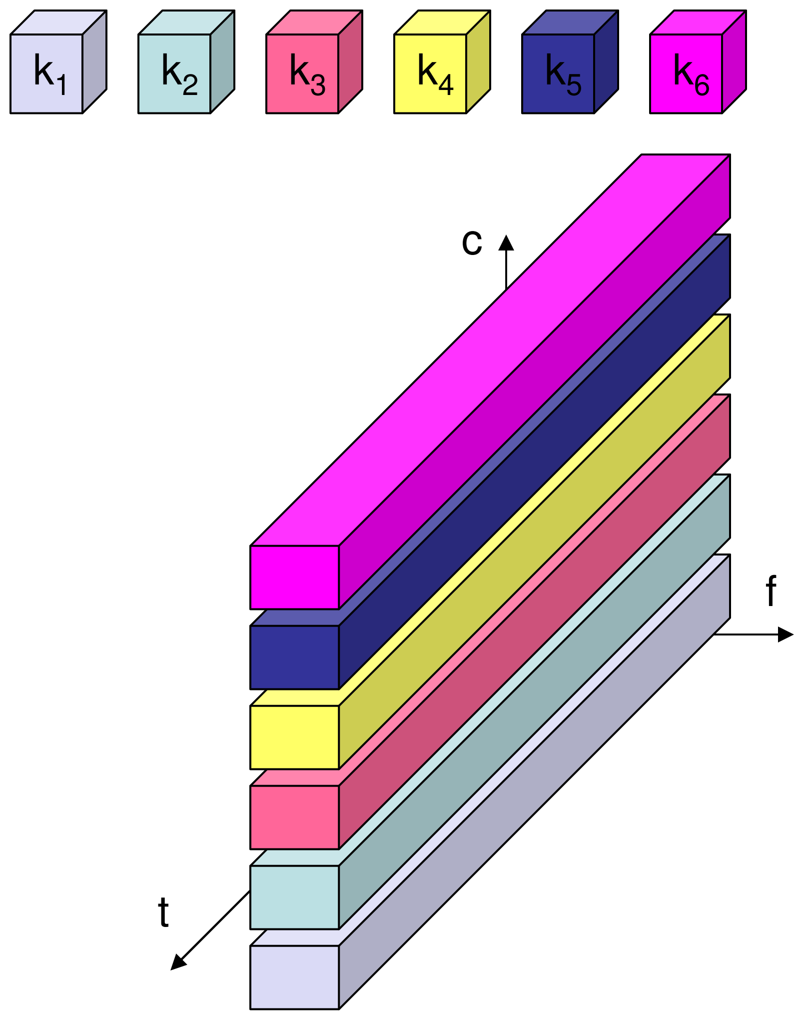
Time and frequency multiplex

- Advantages:
  - better protection against tapping
  - protection against frequency selective interference (e.g., interference in a certain small frequency band)
  - higher data rates compared to code multiplex (we'll talk later)
- but: precise coordination required
  - Two senders will interfere if they choose the same frequency at the same time.

Code division multiplexing

- Each channel has a unique code
- All channels use the same spectrum at the same time
- First used in military applications due to its inherent security features.
- Now used in many civil applications due to low processing power.
- Basic intuition: people talk different languages in a party.

Code division multiplexing



Code division multiplexing

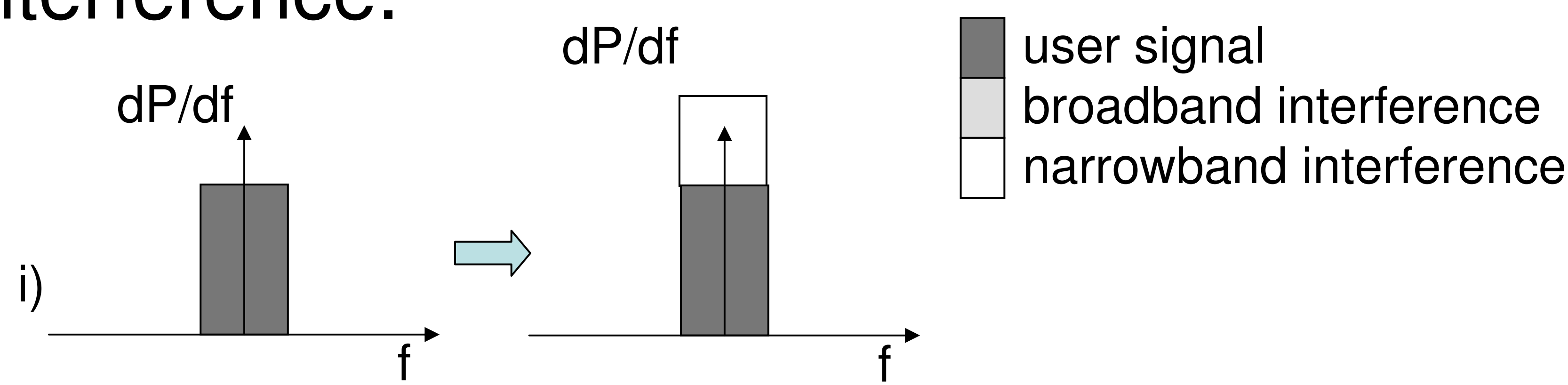
- If the listener doesn’t know the language, the signals are received but useless.
- In military applications, it is preferred to have the signals look like random noise, so as to stay undetected.
- But with a special code, the receiver can “decode” the signal.
- Good protection against tapping and interference.
- Code space is also a lot larger than frequency space.
- We can assign individual code to individual sender.

Code division multiplexing

- Disadvantages:
  - High complexity of the receiver – decoding cost.
  - A receiver has to know the code so as to separate the useful signal from the rest signals and the background noise.
  - A receiver must be precisely synchronized with the transmitter to apply the decoding correctly.
  - All the signals received by the receiver should have equal strength, otherwise some signals drain others.
- It is realized by using Spread Spectrum.

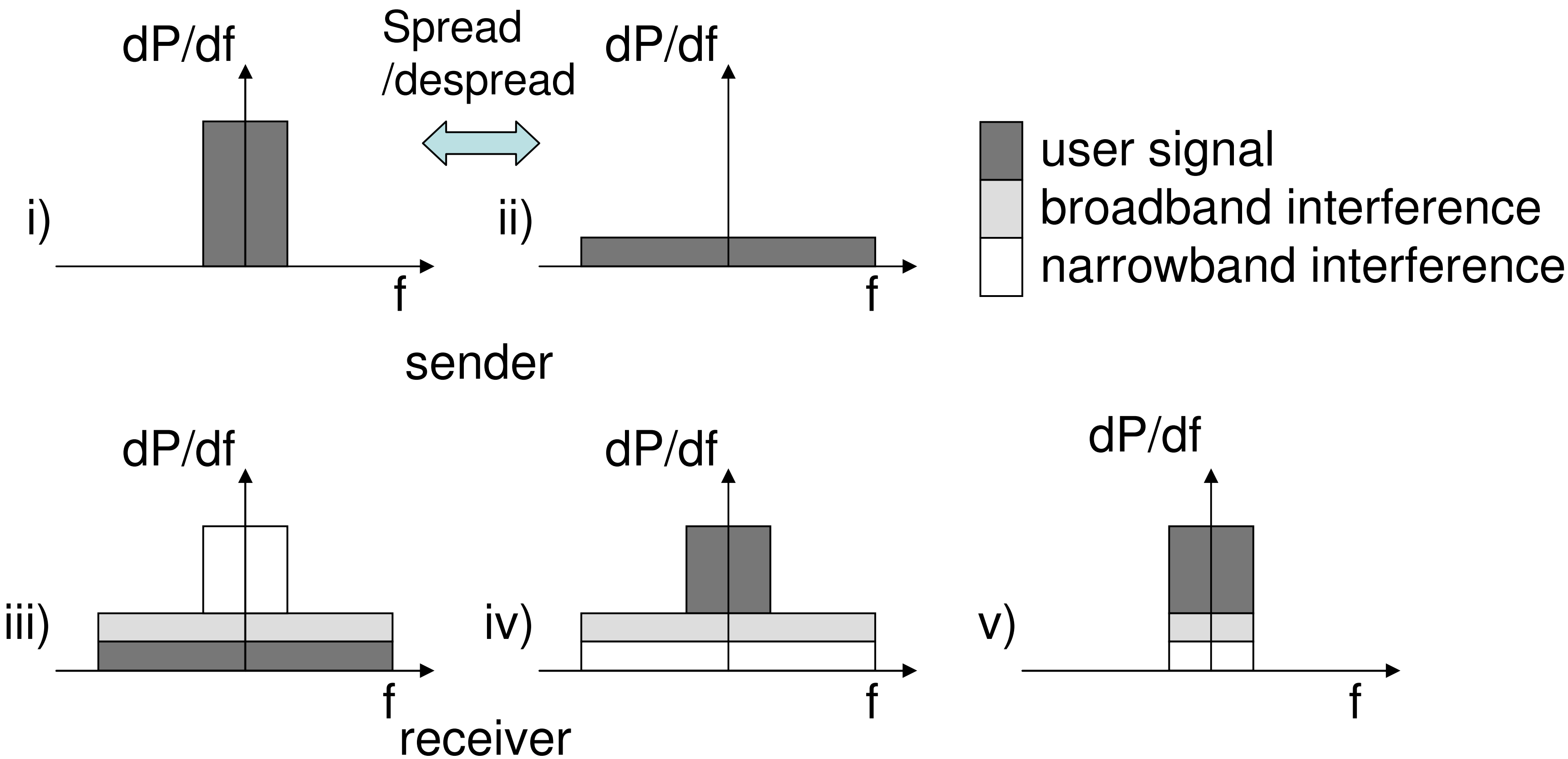
Spread spectrum

- A signal with a narrow frequency band is now spread to a wide frequency band.
- Sounds stupid…
- Reason: protection against narrowband interference.

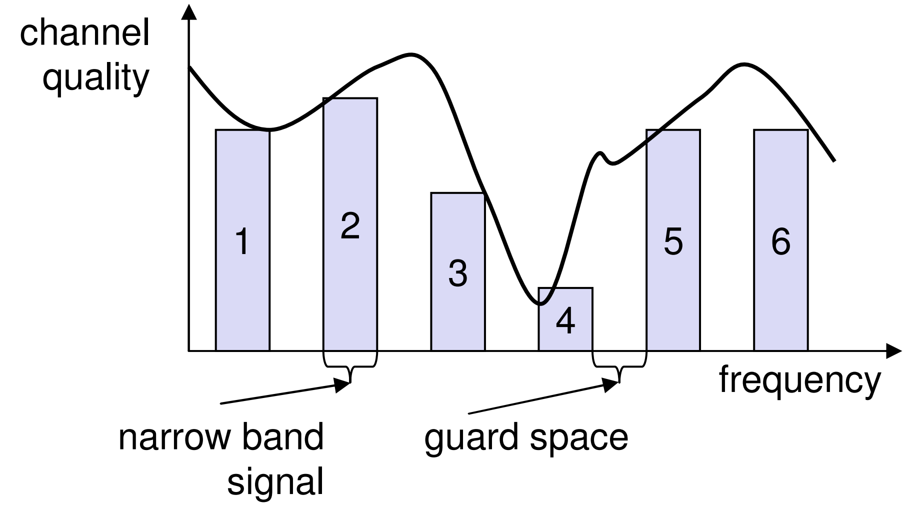


Spread spectrum

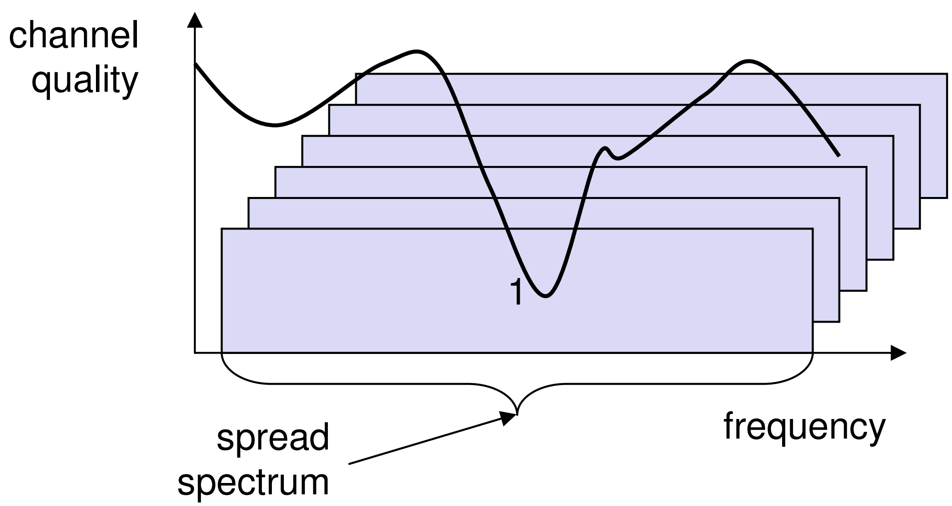
- Against narrowband interference



Spread spectrum for several channels



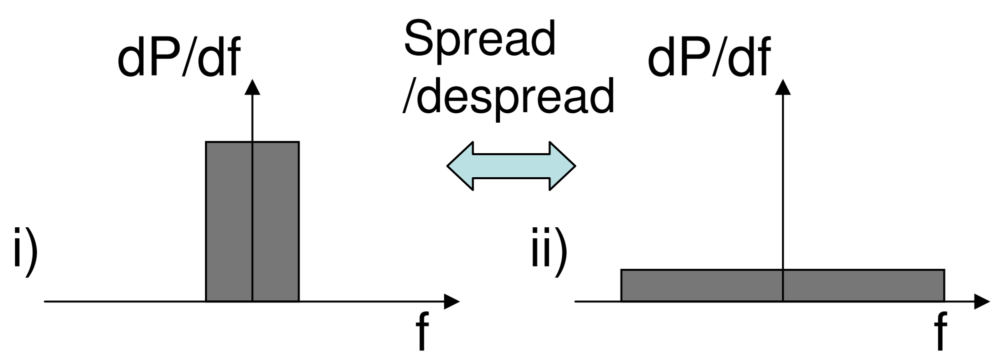
narrowband channels



spread spectrum channels

Spread spectrum

- The narrowband signal is turned into a broadband signal with the same total energy.
- The power of the broadband signal is much lower → as low as the background noise.
- Appealing for military application: stay undetected! & no interference.

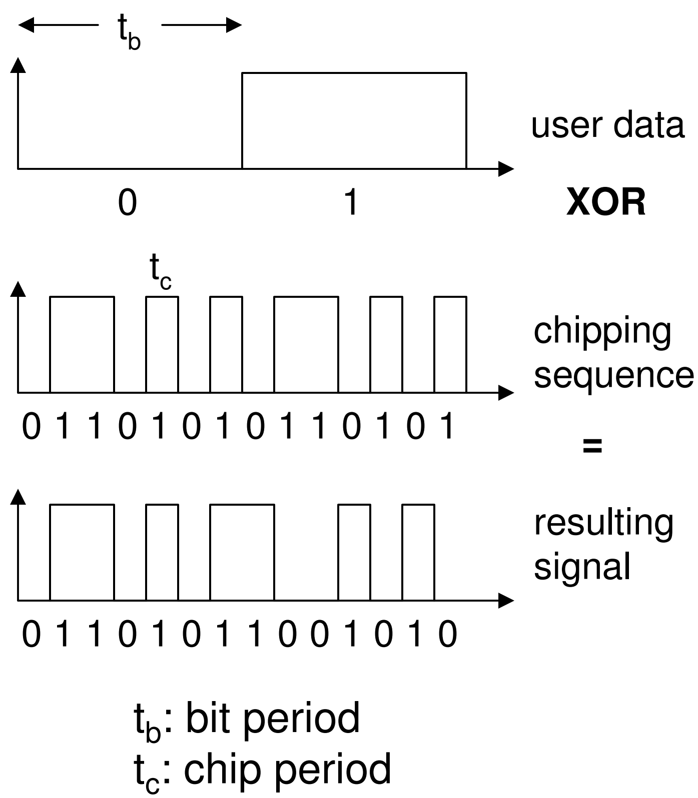


Spread spectrum

- More and more appealing to everyday applications: frequencies are scarce resources.
- We just add in a low-power broadband signal on top of current narrow band applications.
- Used in US cellular phone systems.
- Drawbacks:
  - Increased complexity of receivers. (less a problem due to cheaper processors)
  - Need a large frequency band.
  - It still increases the background noise level.

DSSS (Direct Sequence Spread Spectrum)

- XOR of the signal with pseudo-random number (chipping sequence)
  - many chips per bit (e.g., 128) result in higher bandwidth of the signal
  - Chip sequence looks like random noise.
- Spreading factor: s=tb/tc ➔ the bandwidth of the resulting signal.

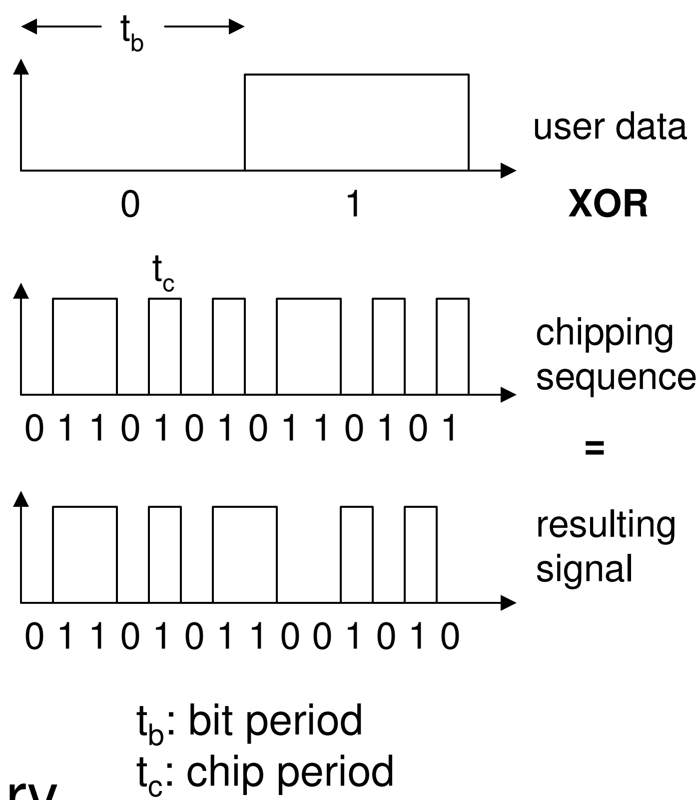


DSSS (Direct Sequence Spread Spectrum)

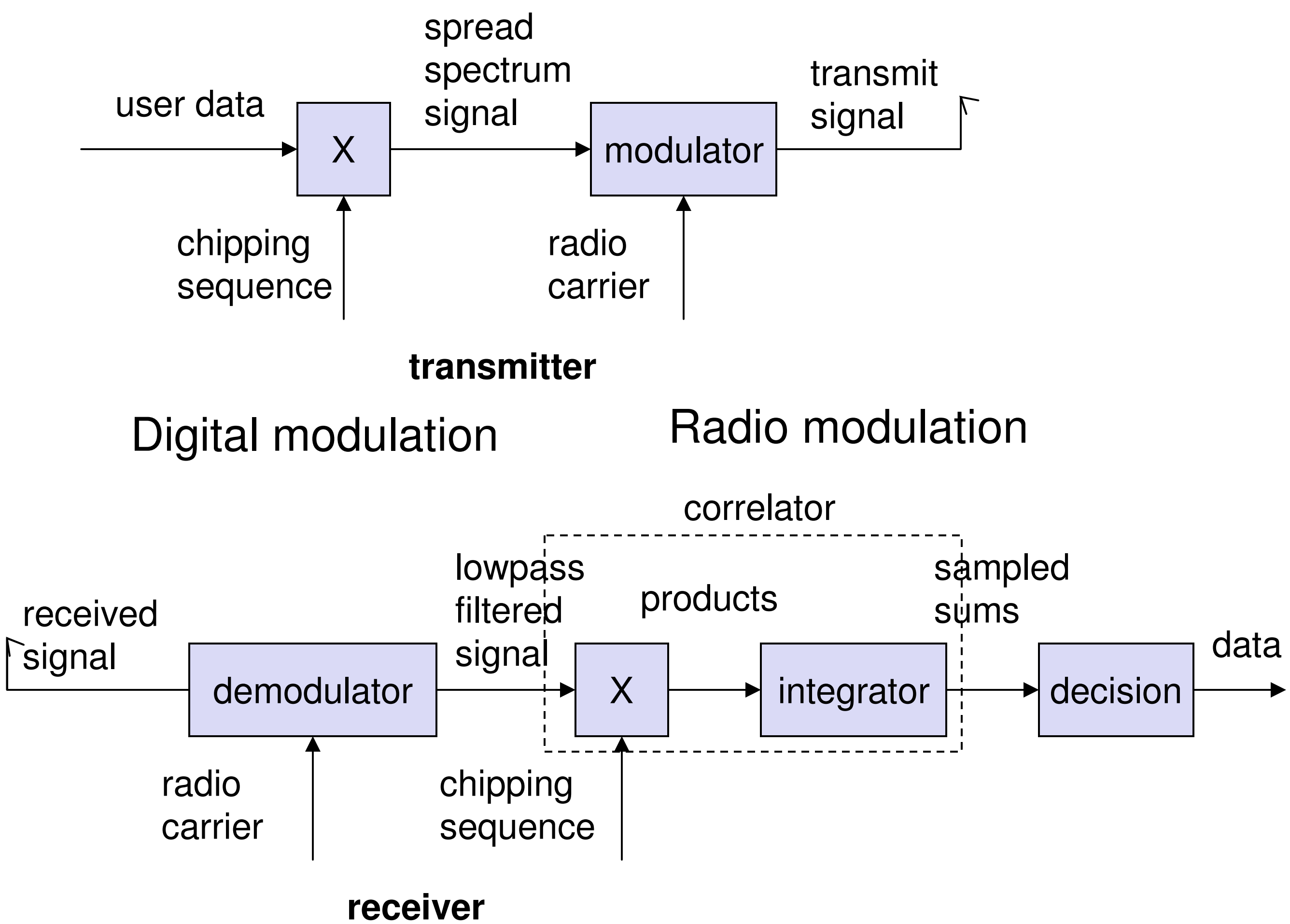
- Civil applications use spreading factors between 10 and 100, military applications use factors up to 10,000.
- Wireless LANs (IEEE 802.11) use 10110111000, called Barker code.

DSSS (Direct Sequence Spread Spectrum)

- Advantages
  - reduces frequency selective fading
  - in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover
- Disadvantages
  - precise power control necessary



DSSS (Direct Sequence Spread Spectrum)



DSSS (Direct Sequence Spread Spectrum)

- At the receiver side, basically reverse all operations.
- If there is noise, some bits might be flipped.
- Input data: 01
- XOR with Barker code 10110111000.
- We get 1011011100001001000111
- Receiver XOR with Barker code
- Get 0000000000011111111111
- Add up each 11 bits, get 0 (11)➔ 01

DSSS (Direct Sequence Spread Spectrum)

- At the receiver side, basically reverse all operations.
- If there is noise, some bits might be flipped.
- Input data: 01
- XOR with Barker code 10110111000.
- We get 1010010100001001100111
- Receiver XOR with Barker code
- Get 0001001000001111011111
- Add up each 11 bits, get 2 (10)➔ 01

rounding

DSSS (Direct Sequence Spread Spectrum)

- Synchronization is important!
- Multi-path fading causes a problem.
  - The receiving signal is shifted and added up on itself!
  - Rake receiver: detect the strongest correlation.

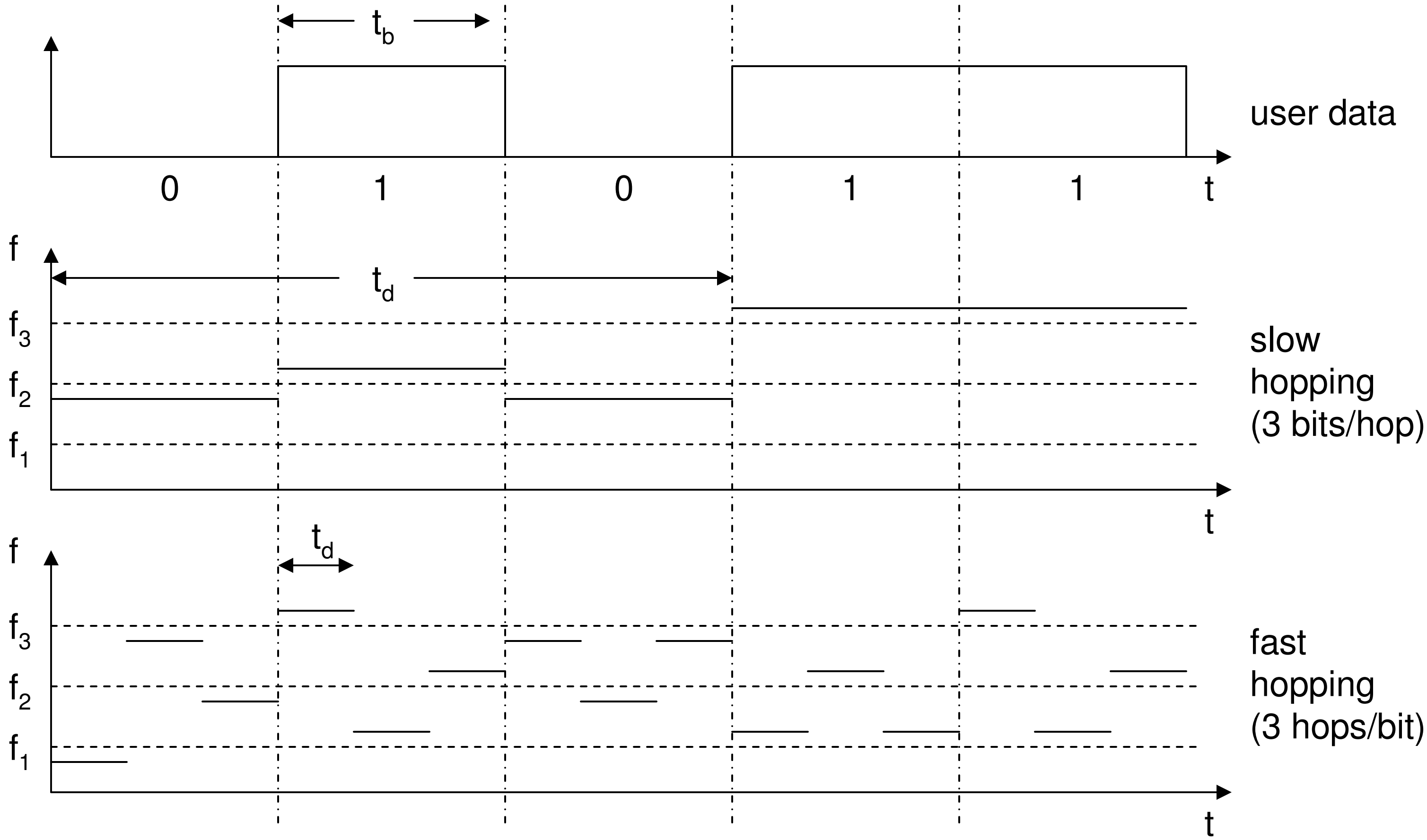
FHSS (Frequency Hopping Spread Spectrum)

- Total bandwidth is split into many channels of smaller bandwidths.
- Transmitters and receivers stay on one of these channels for a certain time and then hop to another channel.
- Implements FDM and TDM.
- The pattern of channel usage is called hopping sequence.
- The time spend on a channel with a certain frequency is called dwell time.

FHSS (Frequency Hopping Spread Spectrum)

- Slow hopping:
  - Transmitter uses one frequency for several bits periods.
- Fast hopping:
  - Transmitter changes the frequency several times during the transmission of a single bit.

FHSS (Frequency Hopping Spread Spectrum)



t_b: bit period t_d: dwell time

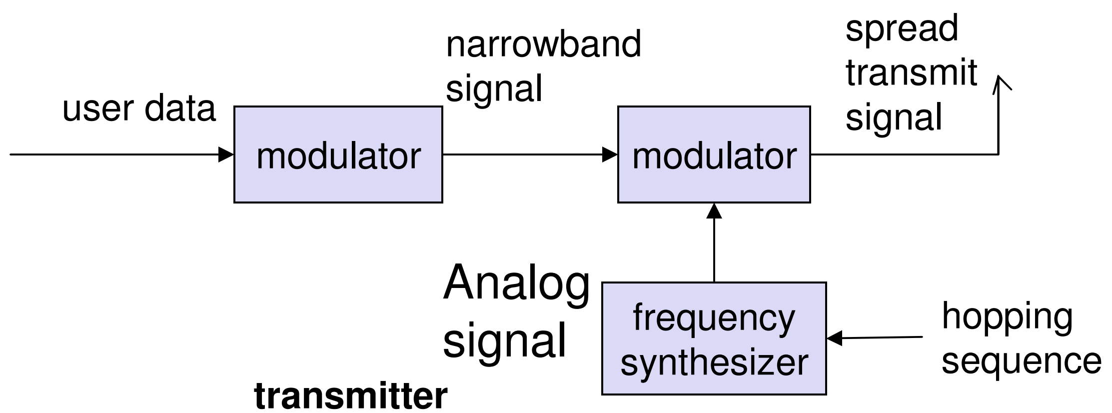
FHSS (Frequency Hopping Spread Spectrum)

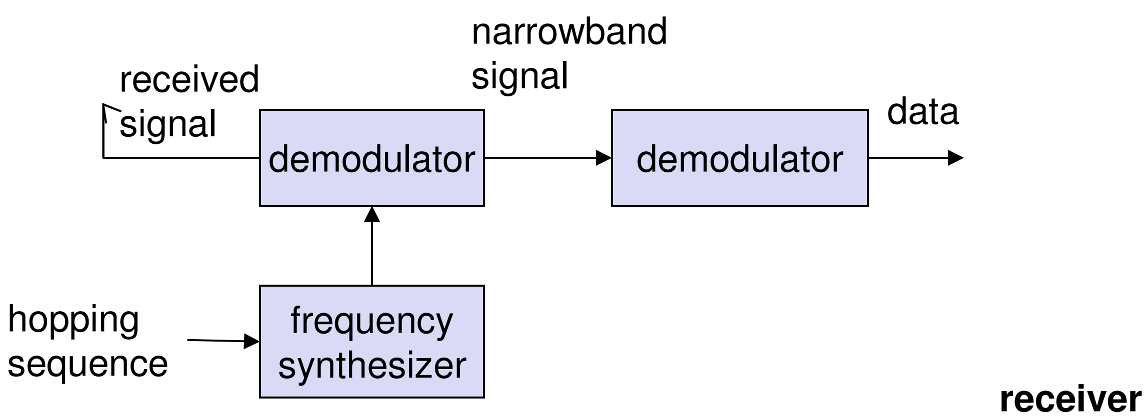
- Slow hopping:
  - Cheaper, with relaxed tolerances.
  - Not as immune to narrowband interference as fast hopping
- Fast hopping:
  - More complex
  - Overcome narrowband interference as they only stick to one frequency for a very short time.

FHSS (Frequency Hopping Spread Spectrum)

- Bluetooth uses FHSS.
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS
  - simpler to detect

FHSS (Frequency Hopping Spread Spectrum)





Summary

- Multiplexing
- Frequency division multiplexing
- Time division multiplexing
- Time and frequency multiplex
- Code division multiplexing
- Spread spectrum
- Direct Sequence Spread Spectrum
- Frequency Hopping Spread Spectrum