Chapter 9: Spread Spectrum

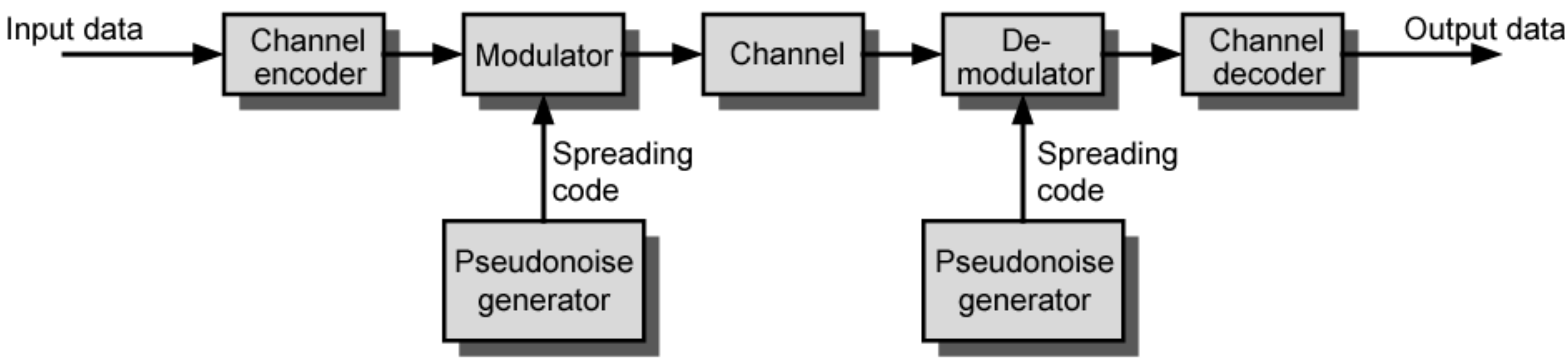
Spread Spectrum

- Important encoding method for wireless communications
- Spread data over wide bandwidth
- Makes jamming and interception harder
- Frequency hoping
  - Signal broadcast over seemingly random series of frequencies
- Direct Sequence
  - Each bit is represented by multiple bits in transmitted signal
  - Chipping code

Spread Spectrum Concept

- Input fed into channel encoder
  - Produces narrow bandwidth analog signal around central frequency
- Signal modulated using sequence of digits
  - Spreading code/sequence
  - Typically generated by pseudonoise/pseudorandom number generator
- Increases bandwidth significantly
  - Spreads spectrum
- Receiver uses same sequence to demodulate signal
- Demodulated signal fed into channel decoder

General Model of Spread Spectrum System



Spread Spectrum Advantages

- Immunity from various noise and multipath distortion
  - Including jamming
- Can hide/encrypt signals
  - Only receiver who knows spreading code can retrieve signal
- Several users can share same higher bandwidth with little interference
  - Cellular telephones
  - Code division multiplexing (CDM)
  - Code division multiple access (CDMA)

Pseudorandom Numbers

- Generated by algorithm using initial seed
- Deterministic algorithm
  - Not actually random
  - If algorithm good, results pass reasonable tests of randomness
- Need to know algorithm and seed to predict sequence

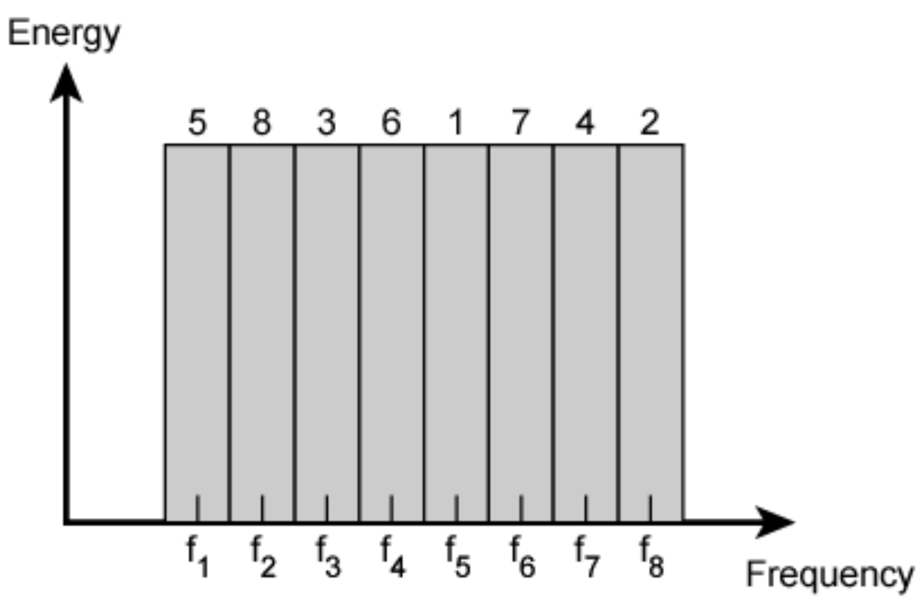
Frequency Hopping Spread Spectrum (FHSS)

- Signal broadcast over seemingly random series of frequencies
- Receiver hops between frequencies in sync with transmitter
- Eavesdroppers hear unintelligible blips
- Jamming on one frequency affects only a few bits

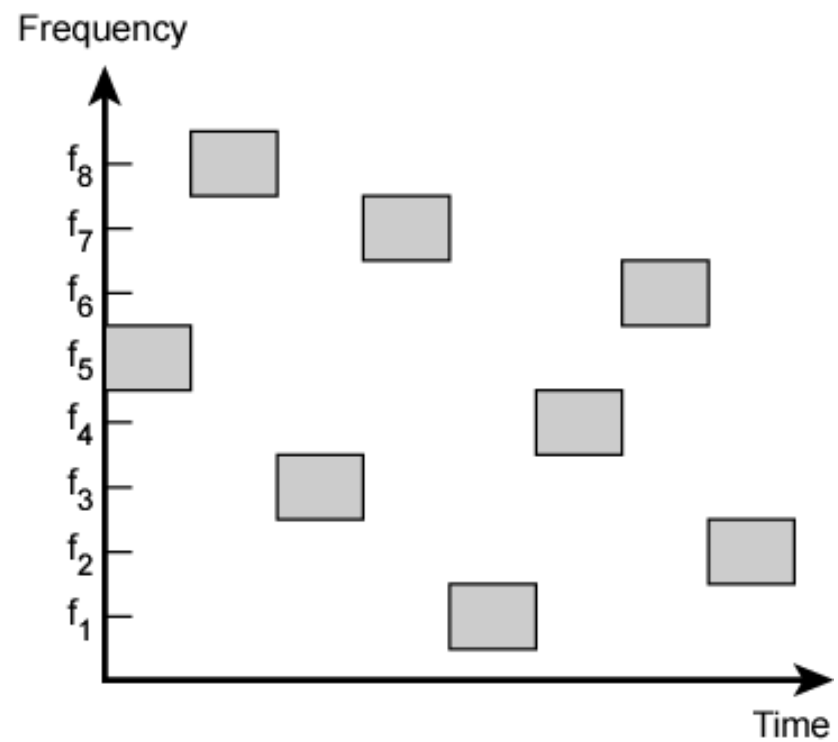
Basic Operation

- Typically 2^k carriers frequencies forming 2^k channels
- Channel spacing corresponds with bandwidth of input
- Each channel used for fixed interval
  - 300 ms in IEEE 802.11
  - Some number of bits transmitted using some encoding scheme
    - May be fractions of bit (see later)
  - Sequence dictated by spreading code

Frequency Hopping Example

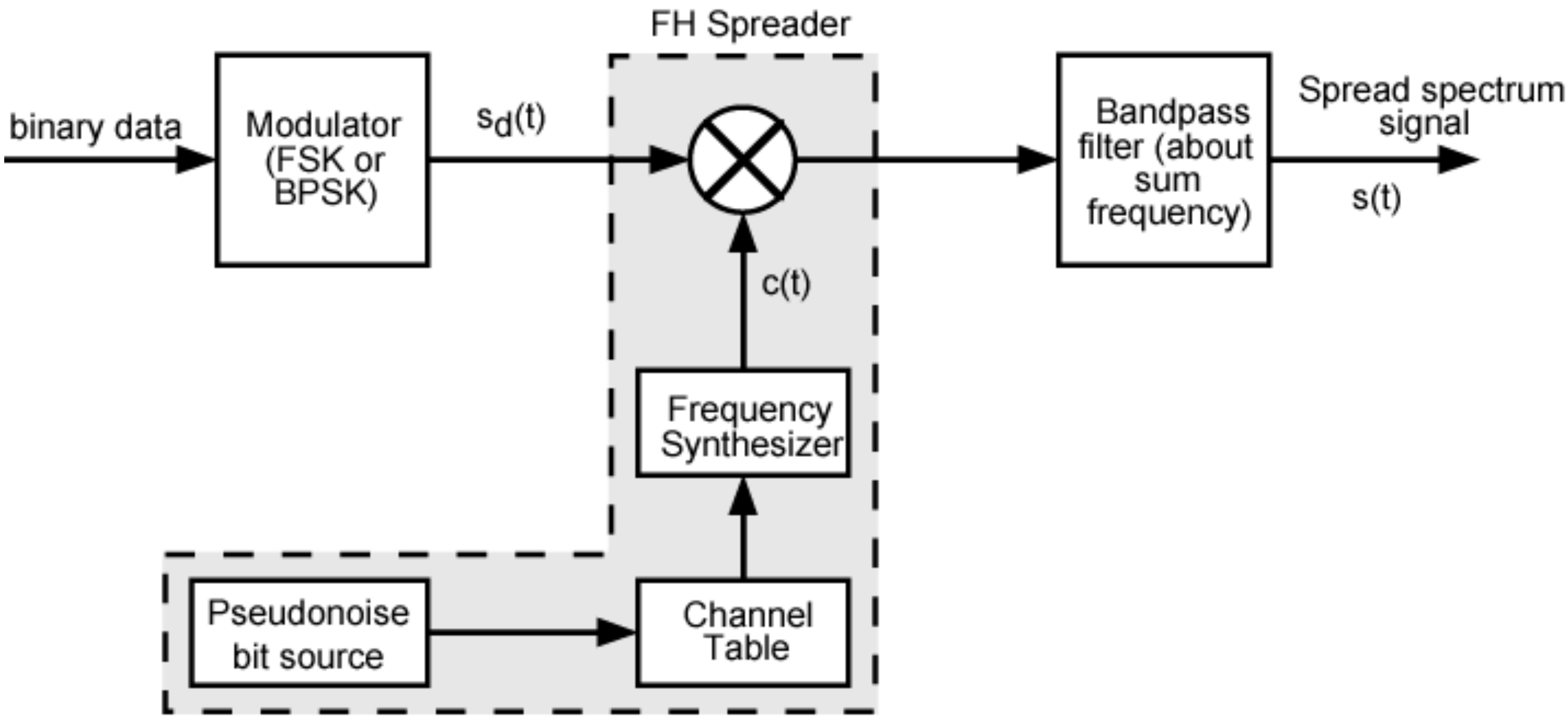


(a) Channel assignment

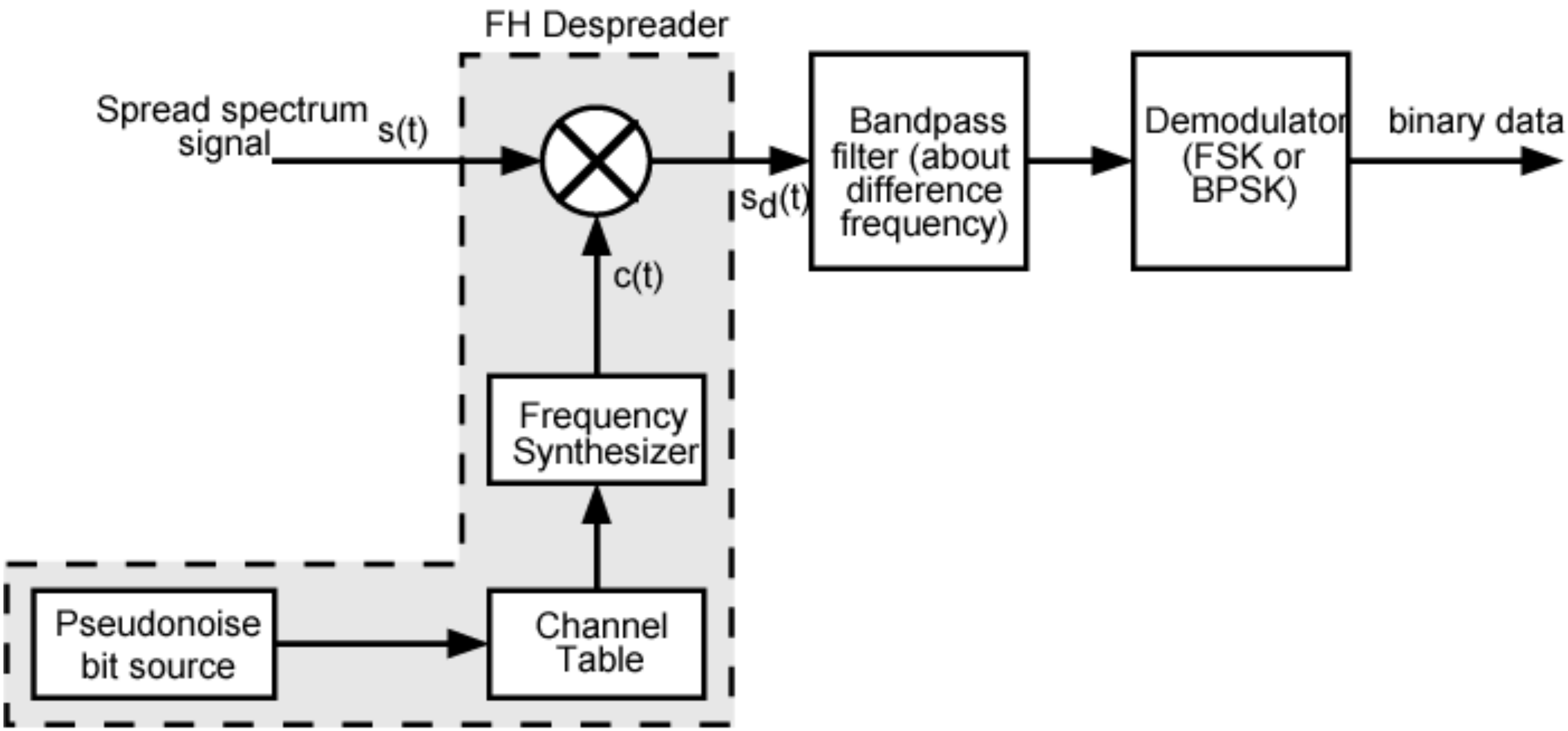


(b) Channel use

Frequency Hopping Spread Spectrum System (Transmitter)



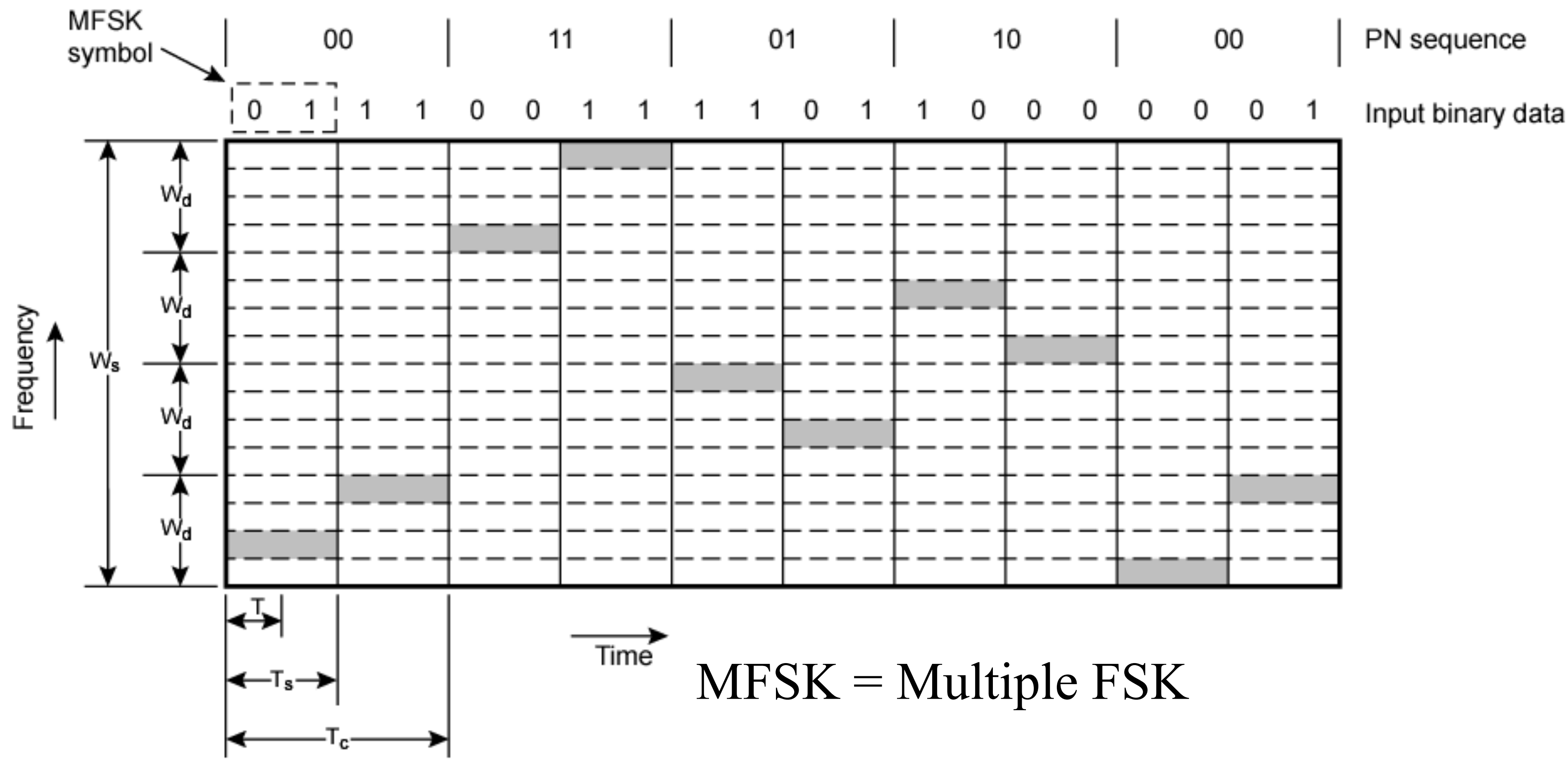
Frequency Hopping Spread Spectrum System (Receiver)



Slow and Fast FHSS

- Frequency shifted every T_c seconds
- Duration of signal element is T_s seconds
- Slow FHSS has $T_c \geq T_s$
- Fast FHSS has $T_c < T_s$
- Generally fast FHSS gives improved performance in noise (or jamming)

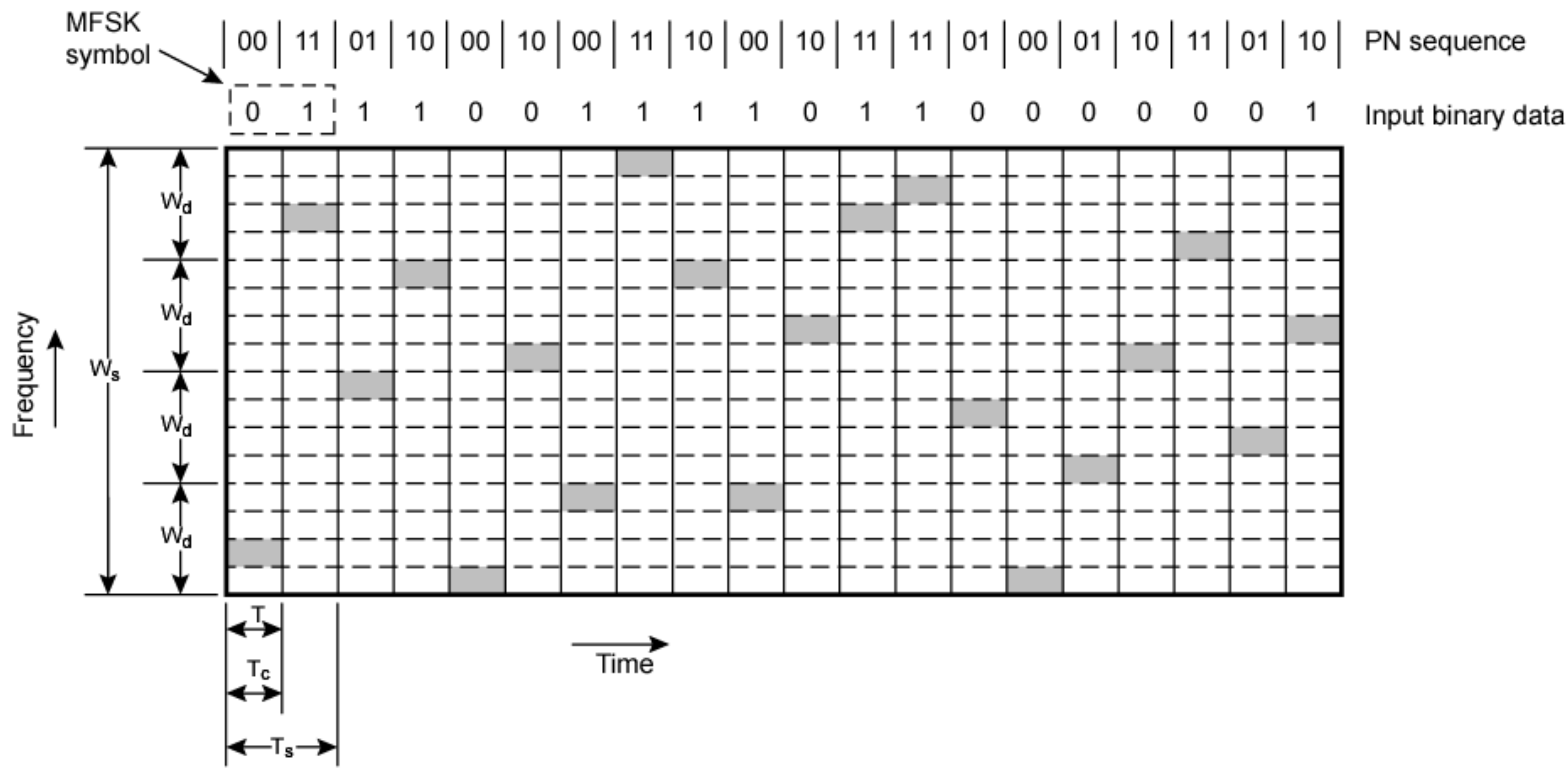
Slow Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)



MFSK = Multiple FSK

M is the number of different signal elements, frequencies to encode data, 2^k is the number of channels, each of width W_d

Fast Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)



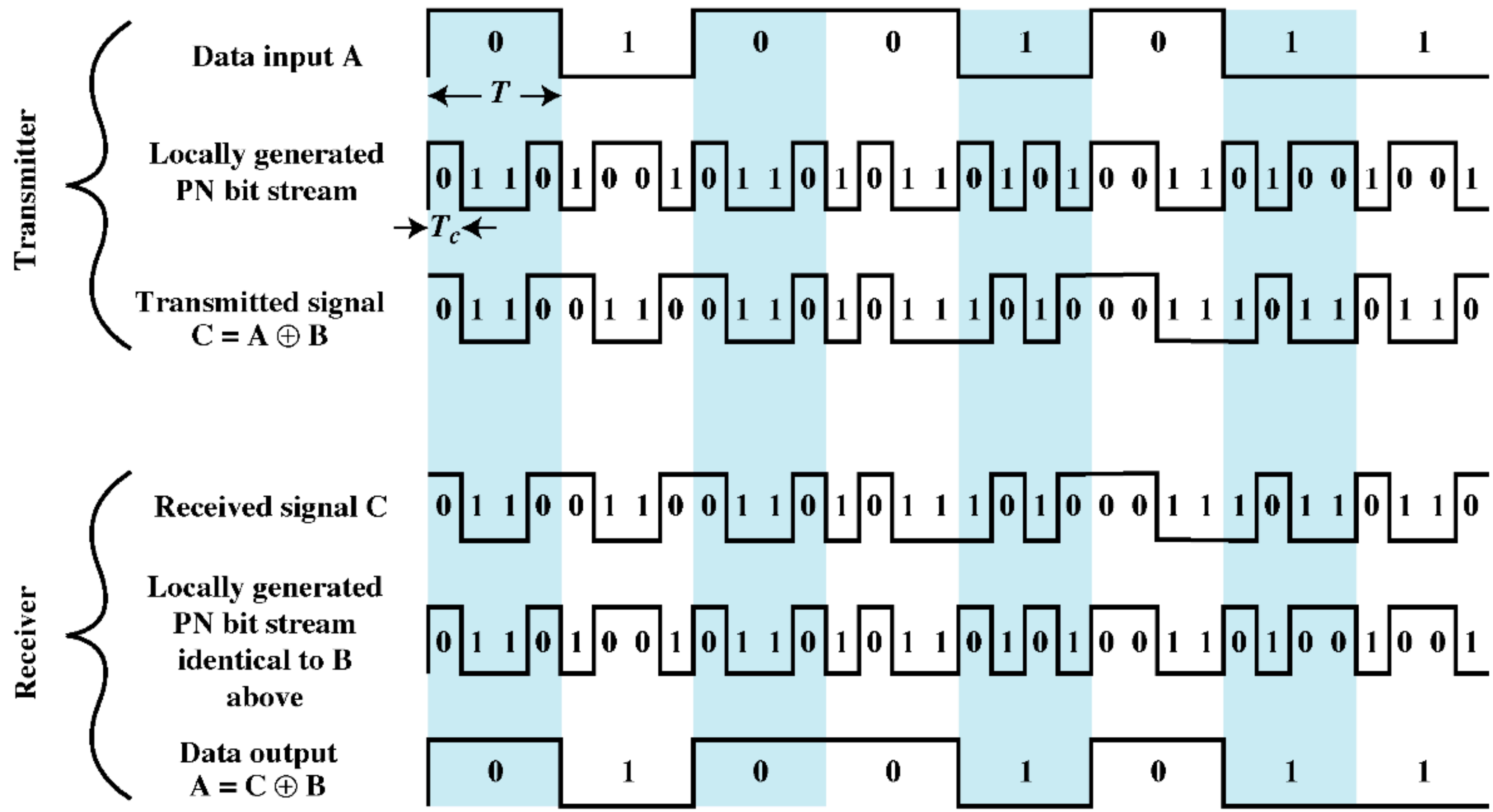
FHSS Performance Considerations

- Typically large number of frequencies used
  - Improved resistance to jamming

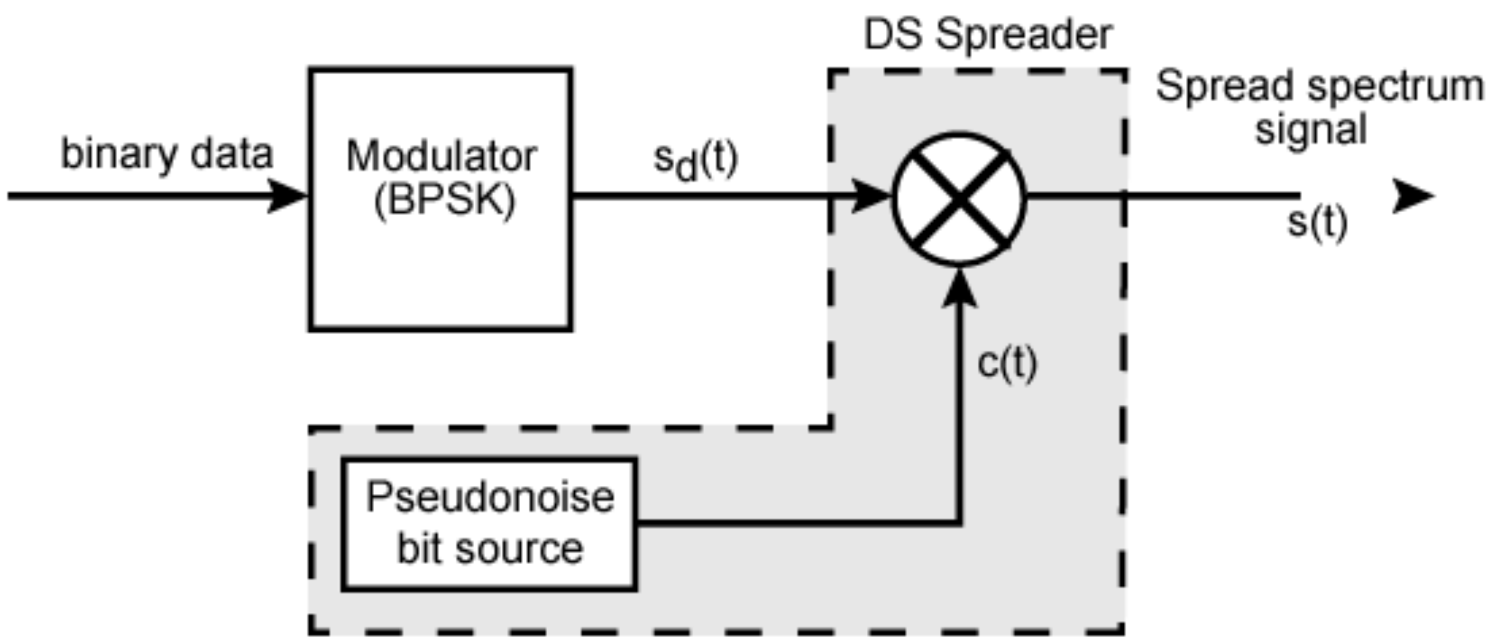
Direct Sequence Spread Spectrum (DSSS)

- Each bit is represented by multiple bits using spreading code
- Spreading code spreads signal across wider frequency band
  - In proportion to number of bits used
  - e.g., 10 bit spreading code spreads signal across 10 times bandwidth of 1 bit code
- One method:
  - Combine input with spreading code using XOR
    - Input bit 1 inverts spreading code bit
    - Input zero bit doesn't alter spreading code bit
  - Data rate equal to original spreading code
- Performance similar to FHSS

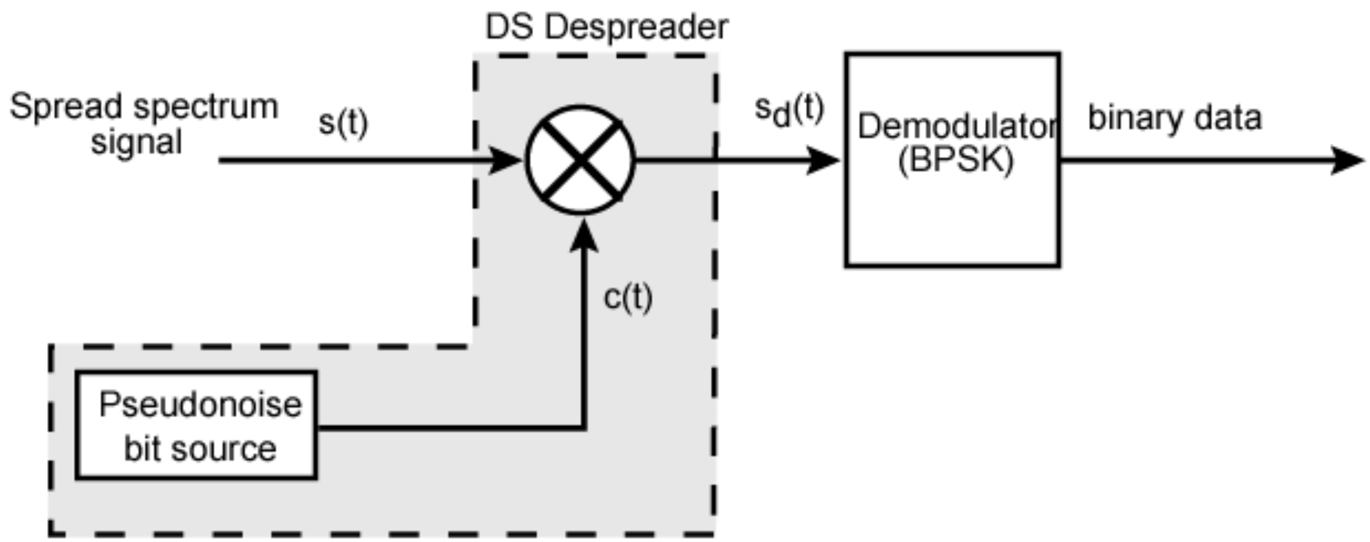
Direct Sequence Spread Spectrum Example



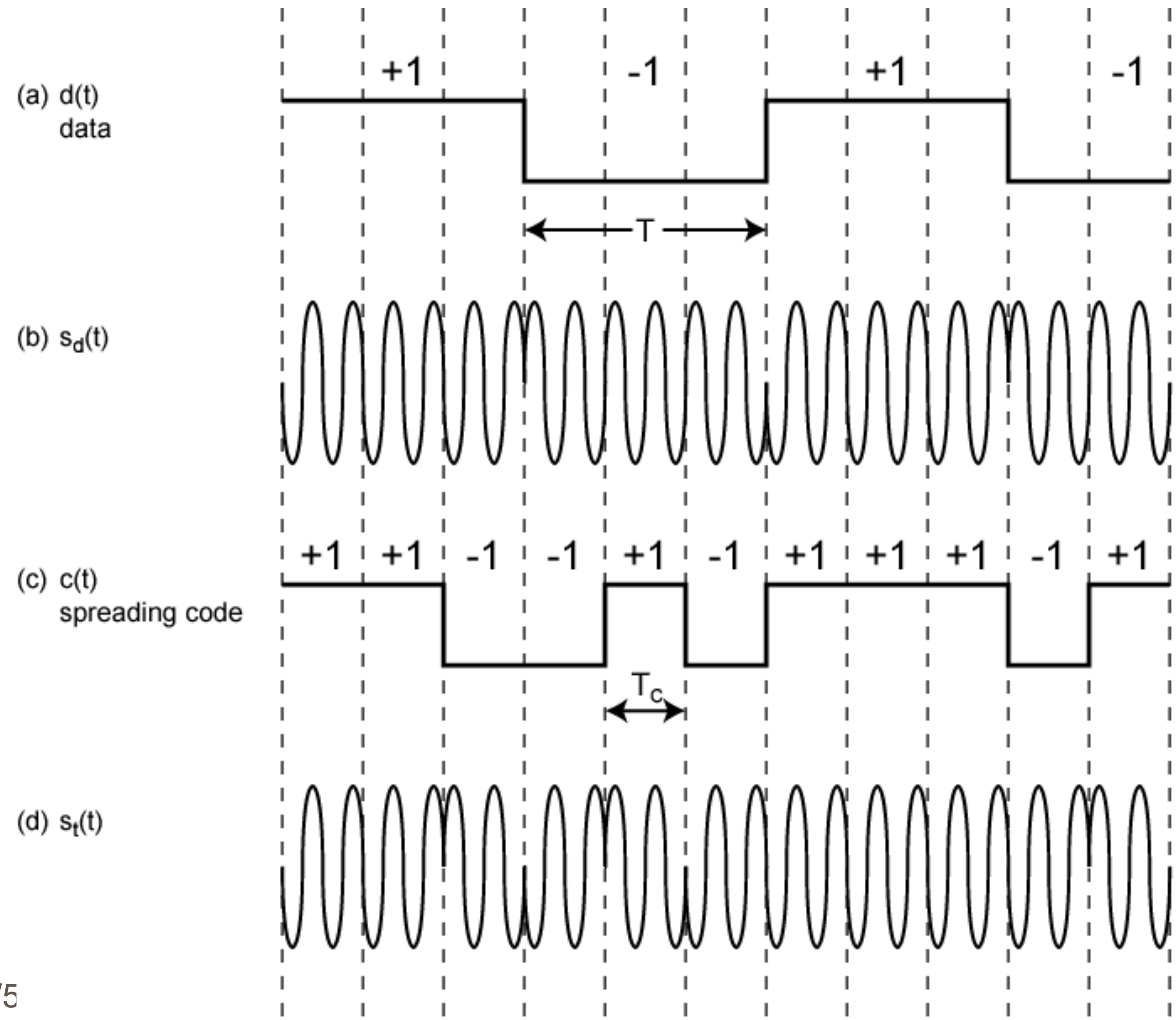
Direct Sequence Spread Spectrum Transmitter



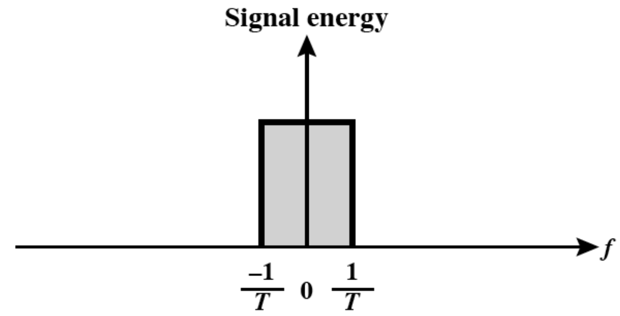
Direct Sequence Spread Spectrum Receiver



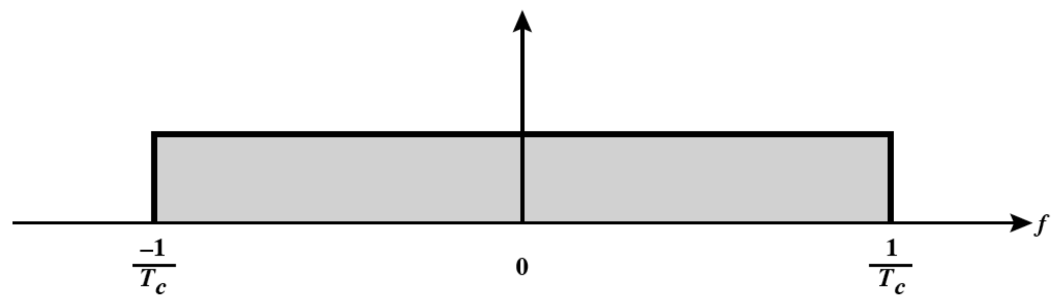
Direct Sequence Spread Spectrum Using BPSK Example



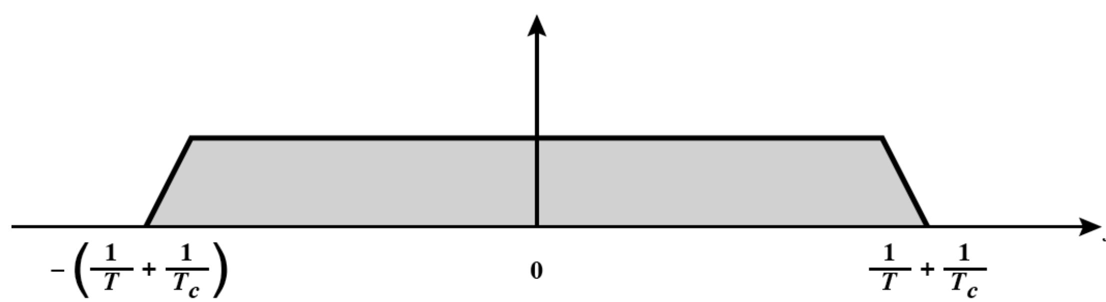
Approximate Spectrum of DSSS Signal



(a) Spectrum of data signal



(b) Spectrum of pseudonoise signal

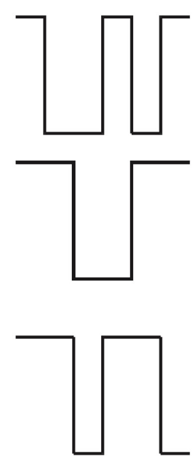


(c) Spectrum of combined signal

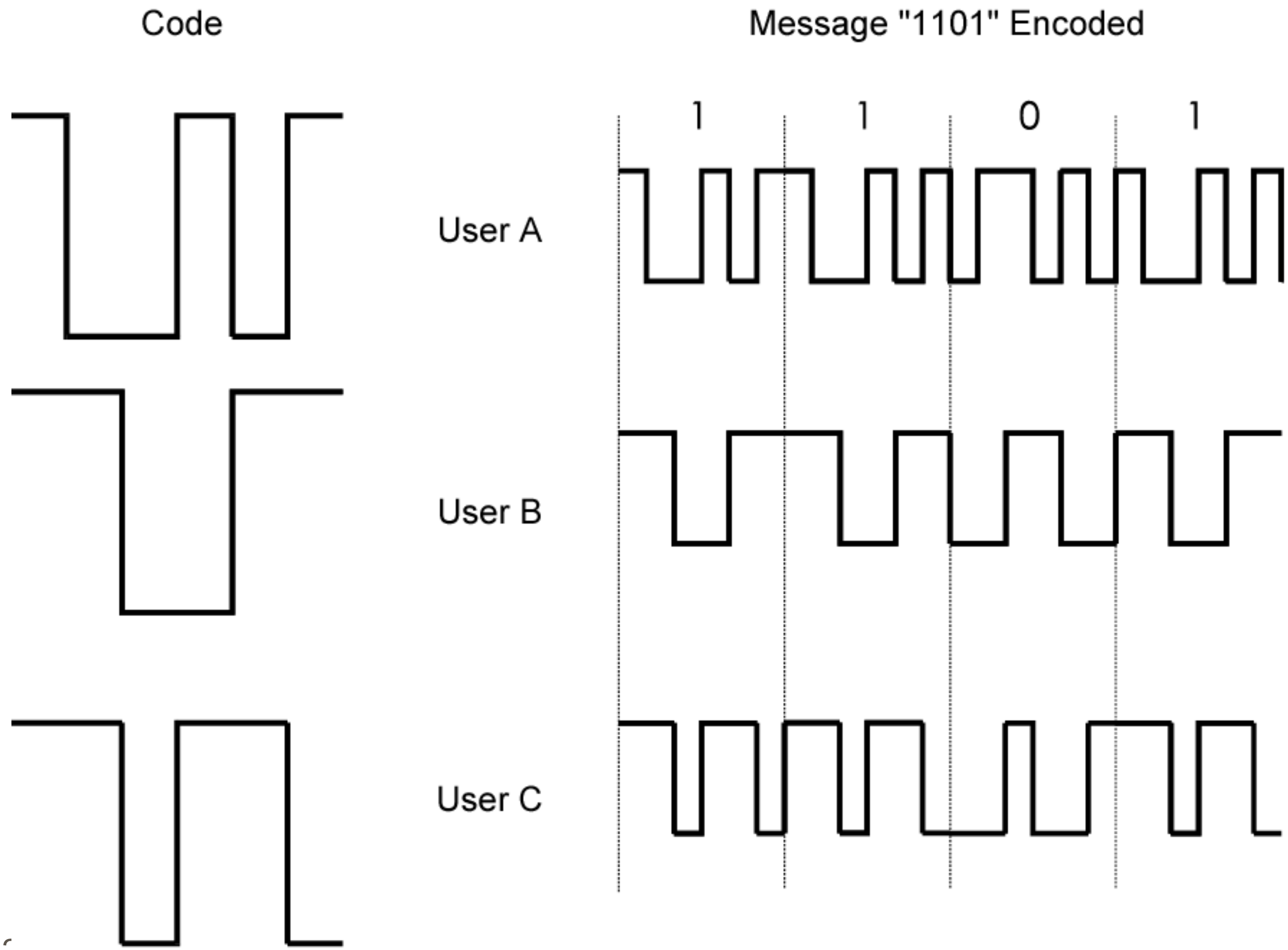
Code Division Multiple Access (CDMA)

- Multiplexing Technique used with spread spectrum
- Start with data signal rate *D*
  - Called bit data rate
- Break each bit into *k* chips according to fixed pattern specific to each user
  - User's code
- New channel has chip data rate *kD* chips per second
- E.g. *k*=6, three users (A,B,C) communicating with base receiver R
  - Code for A = <1,-1,-1,1,-1,1>
  - Code for B = <1,1,-1,-1,1,1>
  - Code for C = <1,1,-1,1,1,-1>

Code



CDMA Example



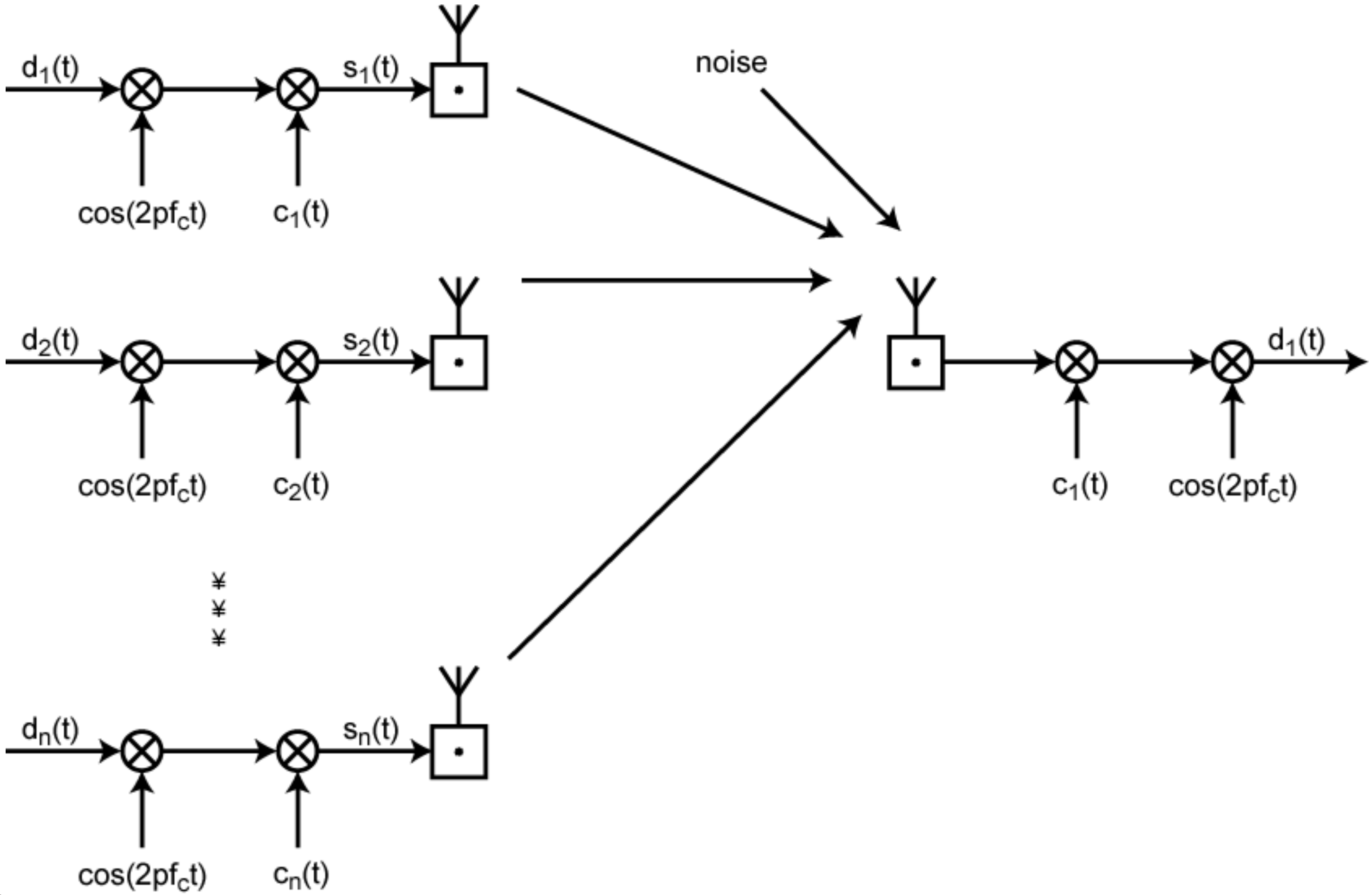
CDMA Explanation

- Consider A communicating with base
- Base knows A's code
- Assume communication already synchronized
- A wants to send a 1
  - Send chip pattern <1,-1,-1,1,-1,1>
    - A's code
- A wants to send 0
  - Send chip[pattern <-1,1,1,-1,1,-1>
    - Complement of A's code
- Decoder ignores other sources when using A's code to decode
  - Orthogonal codes

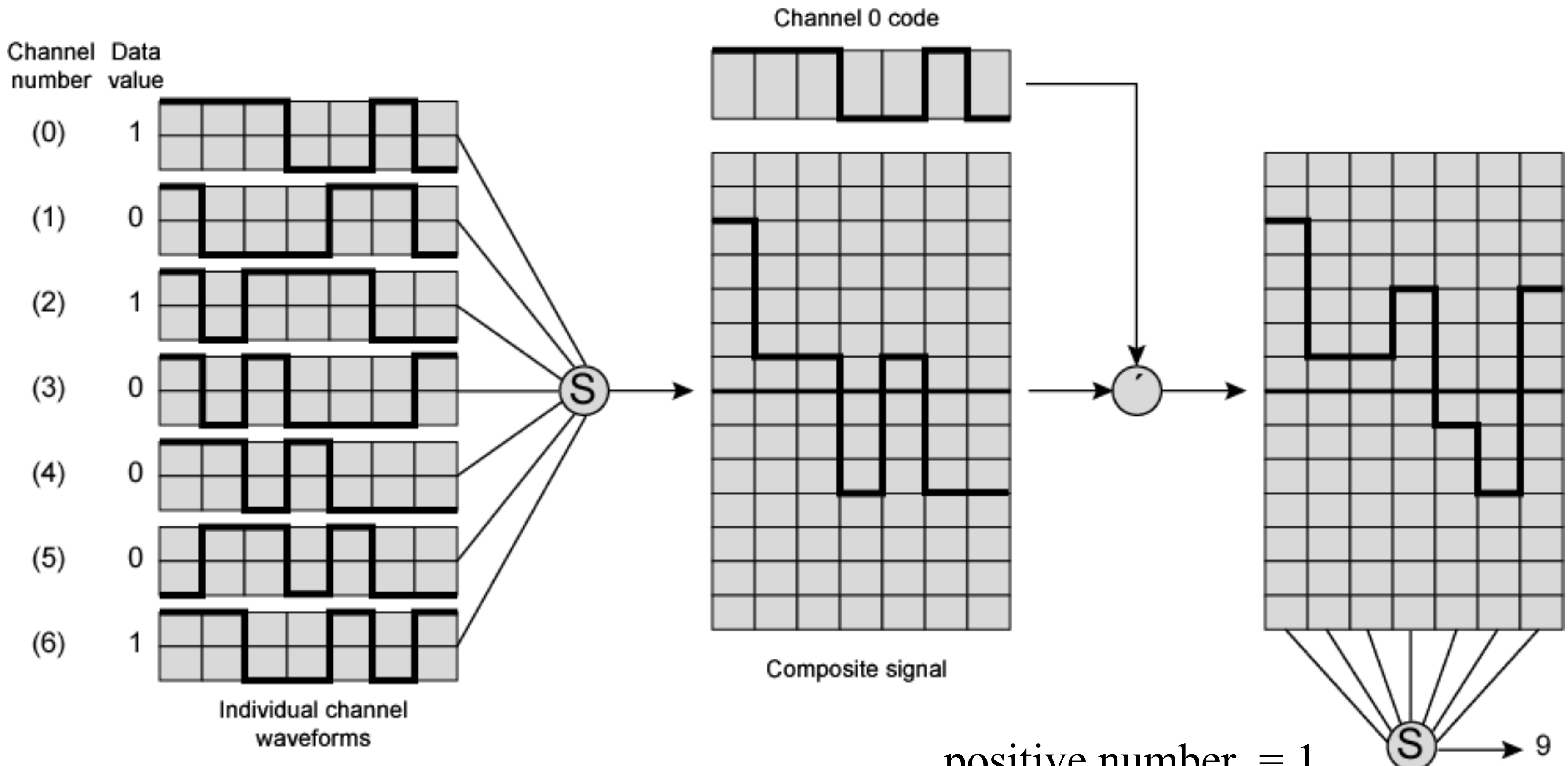
CDMA for DSSS

- *n* users each using different orthogonal PN sequence
- Modulate each users data stream
  - Using BPSK
- Multiply by spreading code of user

CDMA in a DSSS Environment



Seven Channel CDMA Encoding and Decoding



positive number = 1
negative number = 0

Summary

- looked at use of spread spectrum techniques, e.g.,
  - FHSS
  - DSSS
  - CDMA