EEN 1043/EE452 Wireless and Mobile Communication

Spread Spectrum

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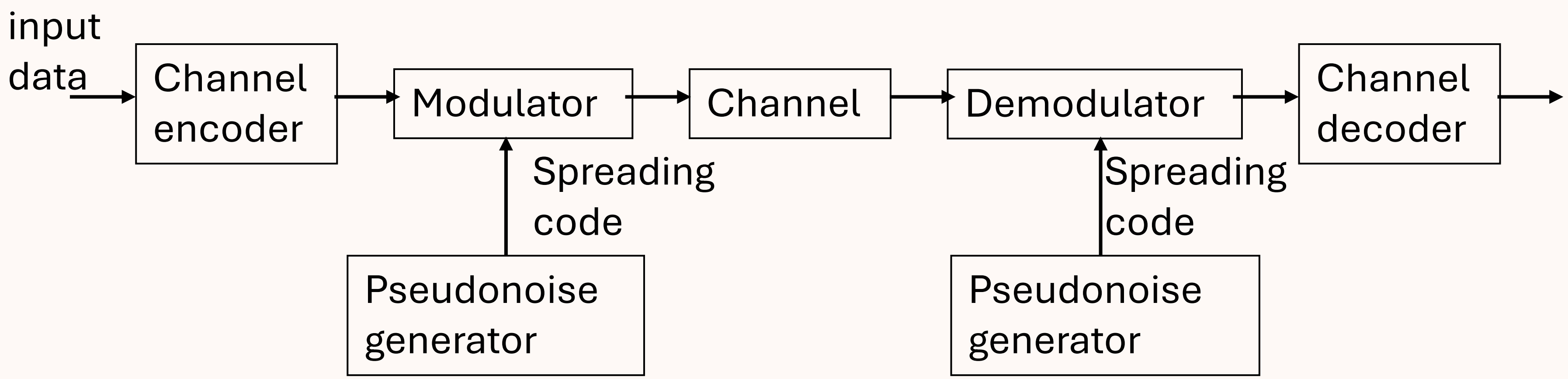
Concept of Spread Spectrum

- The essential idea is to spread the information signal over a wider bandwidth to make jamming and interception difficult
- Initially it was developed for military and intelligence purpose.



Why use Spread Spectrum Technique?

- Immunity from various noise and multipath distortion
  - Including jamming
- Can hide/encrypt signals
  - Only receiver who knows spreading code can retrieve signal

Pseudo Random 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

Types of Spread Spectrum

- Frequency Hopping Spread Spectrum
- Direct Sequence Spread Spectrum
- Code Division Multiple Access

Frequency Hopping Spread Spectrum

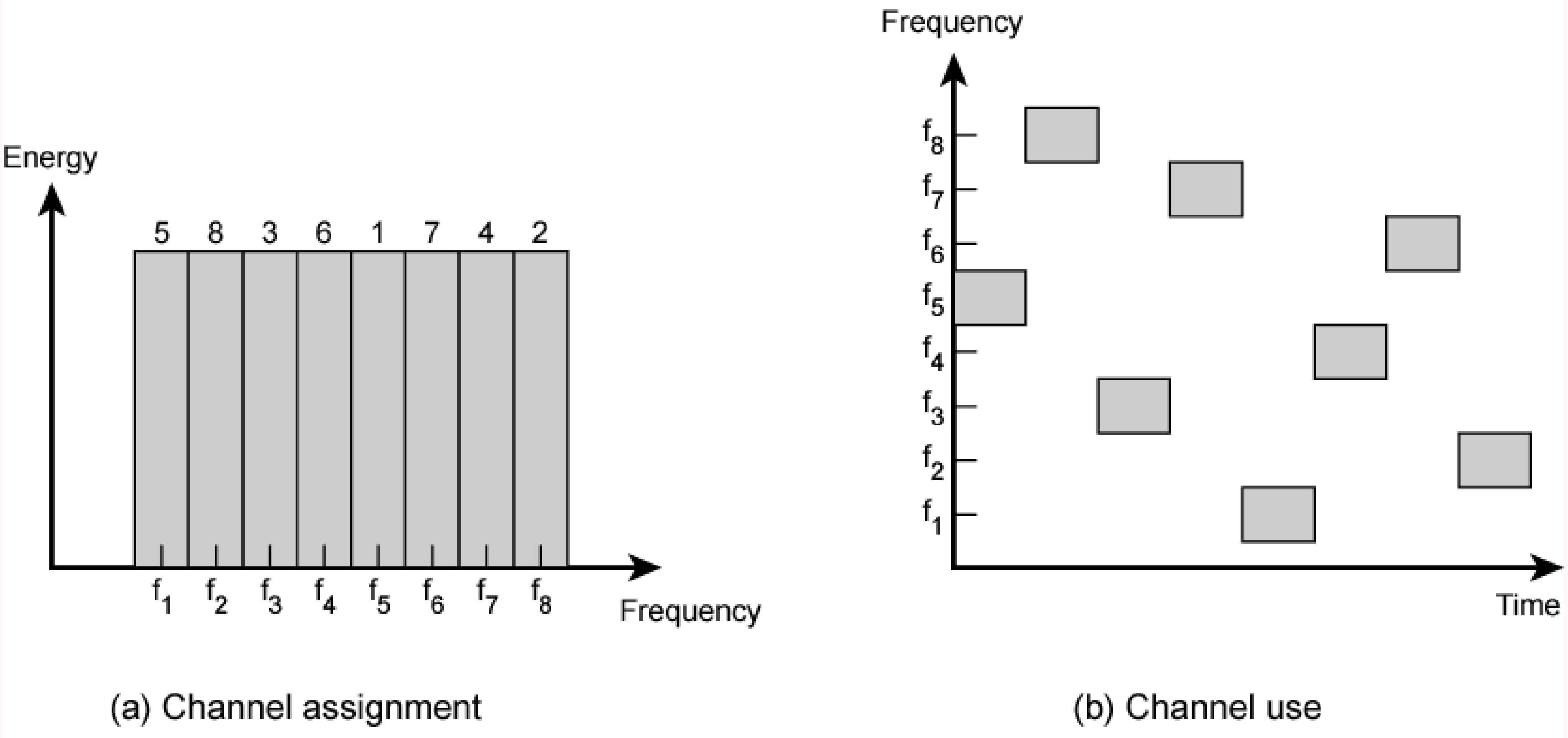
Frequency Hopping Spread Spectrum

- 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

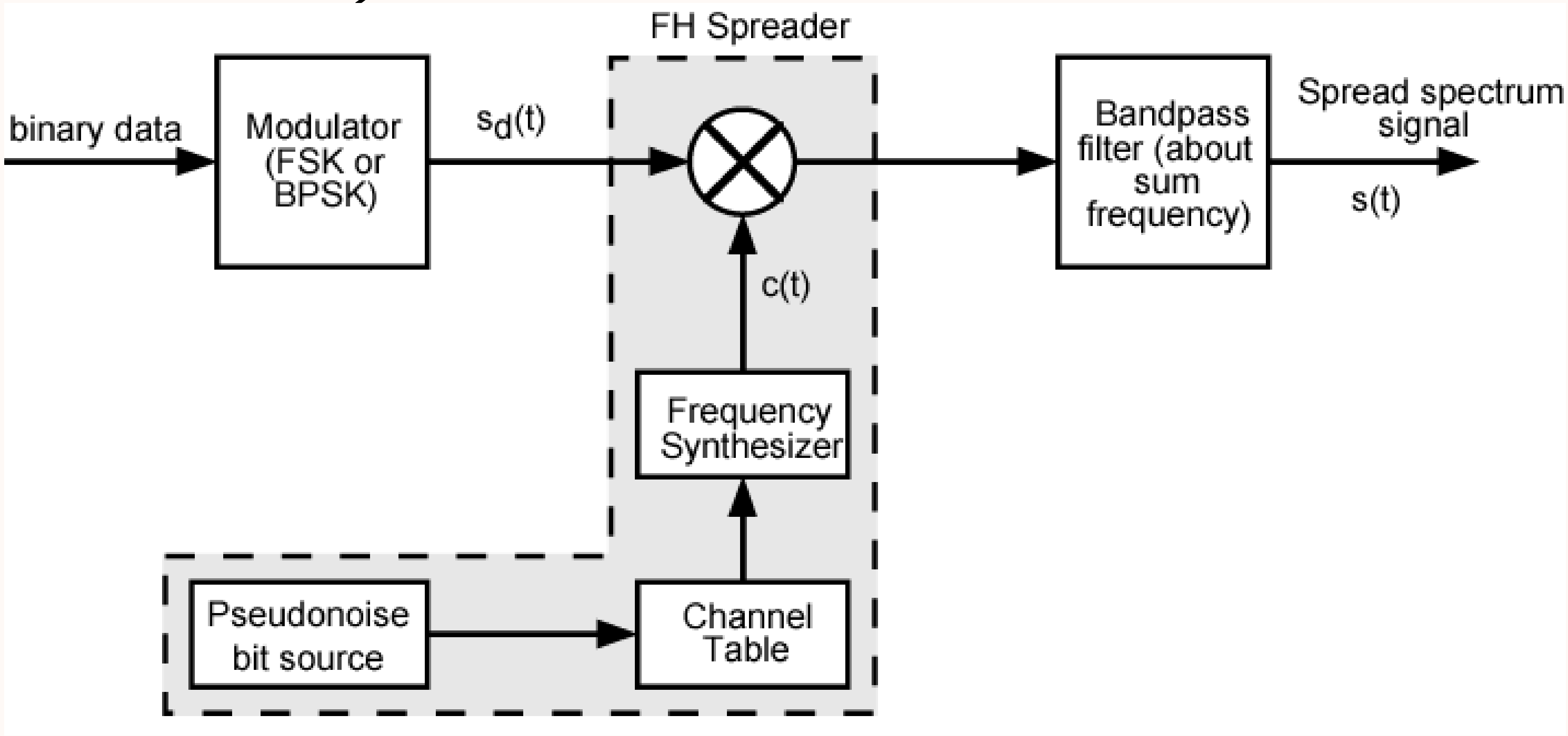
Basic Operation

- 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



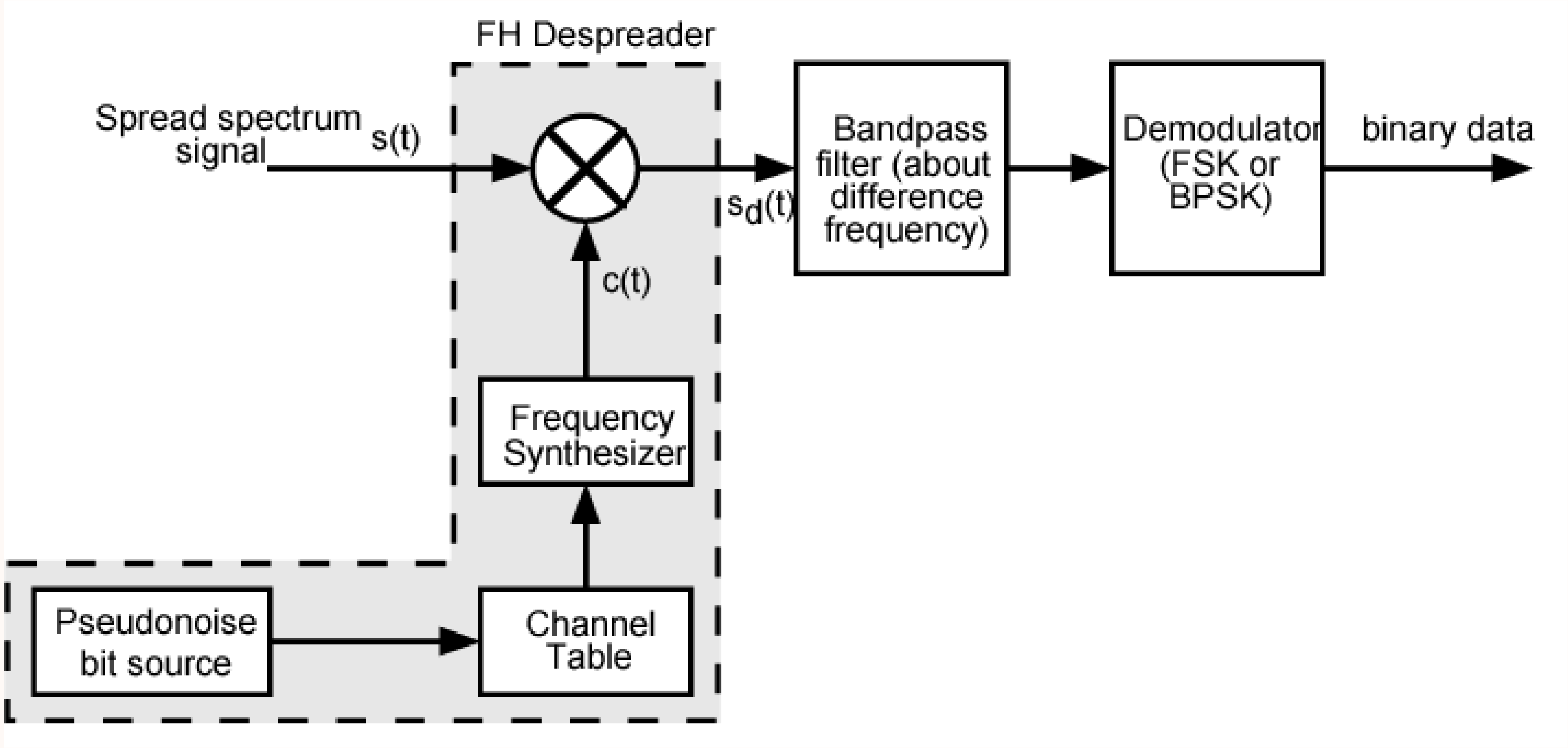
Frequency Hopping Spread Spectrum System (Transmitter)



Frequency Hopping Spread Spectrum System (Transmitter)

- At the sender
  - $s_d(t) = A\cos(2\pi(f_0 + 0.5(b_i + 1)\Delta f)t)$ for $iT < t < (i+1)T$ where
    - A is the amplitude of the signal
    - f_0 is the base frequency
    - b_i is the value of the i^{th} bit of data
      - +1 for binary 1 and -1 for binary 0
    - Δf is the frequency separation
    - T is the bit duration
  - $p(t) = s_d(t)\,c(t) = A\cos(2\pi(f_0 + 0.5(b_i + 1)\Delta f)t)\cos(2\pi f_i t)$ where
    - c(t) is the spread spectrum signal (also called *chipping signal*)
  - Using $\cos(x)\cos(y) = ½\cos(x+y) + ½\cos(x-y)$ we get
    - $p(t) = 0.5A\,[\cos(2\pi(f_0 + 0.5(b_i + 1)\Delta f + f_i)t)$
      $+ \cos(2\pi(f_0 + 0.5(b_i + 1)\Delta f - f_i)t)]$
  - The bandpass filter blocks the difference frequency leaving
    - $s(t) = 0.5A\cos(2\pi(f_0 + 0.5(b_i + 1)\Delta f + f_i)t)$

Frequency Hopping Spread Spectrum System (Receiver)



Frequency Hopping Spread Spectrum System (Receiver)

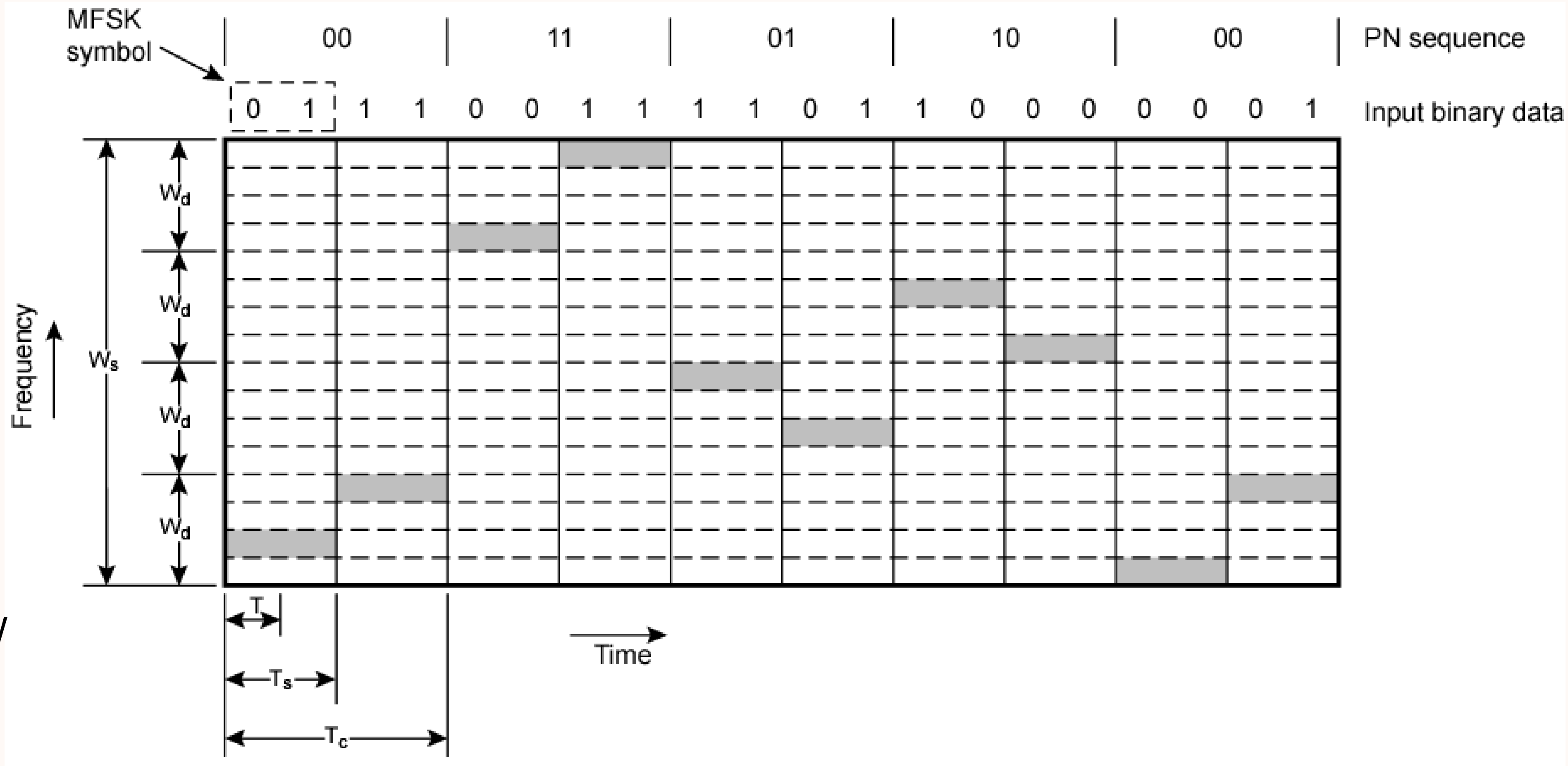
- At the receiver
  - $s(t) = 0.5A\,[\ \cos(\ 2\pi\ (f_0 + 0.5(\ b_i + 1)\ \Delta f + f_i\ )\ t\ )$
  - $p(t) = s(t)\ c(t) = 0.5\ A \cos(\ 2\pi\ (f_0 + 0.5(\ b_i + 1)\ \Delta f + f_i\ )\ t\ ) \cos(2\pi f_i t)$
  - Using $\cos(x)\cos(y) = ½ \cos(x+y) + ½ \cos(x-y)$ we get
    - $p(t) = 0.25A\,[\ \cos(\ 2\pi\ (f_0 + 0.5(\ b_i + 1)\ \Delta f + 2f_i\ )\ t\ )$
      $+ \cos(\ 2\pi\ (f_0 + 0.5(\ b_i + 1)\ \Delta f\ )\ t\ )\ ]$
  - The bandpass filter blocks the sum frequency leaving
    - $s_d(t) = 0.25A\ \cos(\ 2\pi\ (f_0 + 0.5(\ b_i + 1)\ \Delta f\ )\ t\ )$

Slow and Fast FHSS

- Frequency shifted every T_c seconds
- For data rate R, the duration of a bit is $T = 1/R$
    - Thus the duration of the signal element is $T_s = LT = L/R$ (L bits per symbol)
- 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)

$$W_s = CW_d$$



K=2

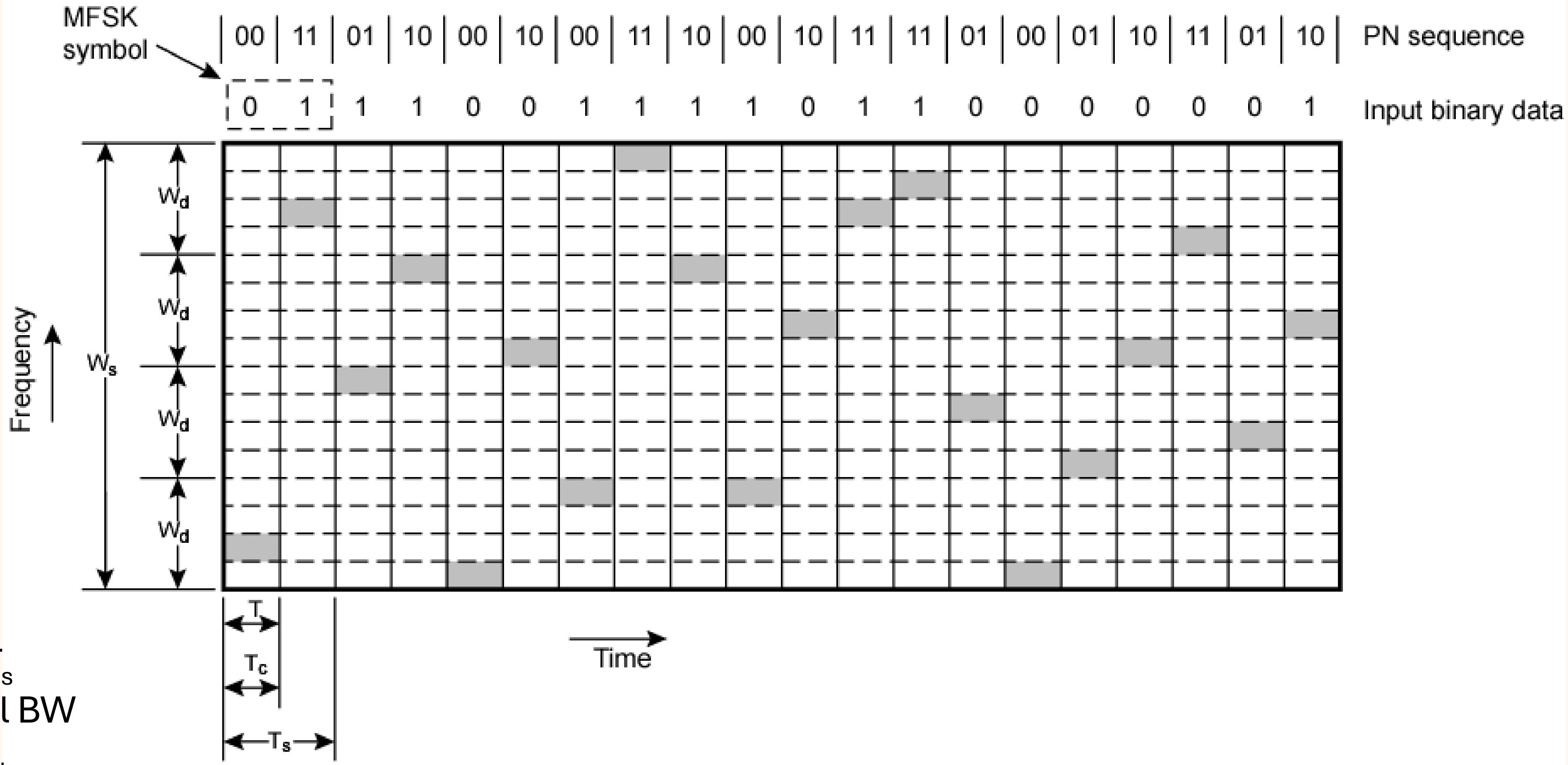
M=4

$T_c=2T_s=4T$

W_d=signal BW

$W_s= 2^k W_d$

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



K=2
M=4
$T_c = T = 1/2T_s$
W_d=signal BW
$W_s = 2^k W_d$

FHSS Performance Considerations

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

Example

- A system transmits at 30kbps, sending 3 bits/symbol. The time between hops for a FHSS system is 0.125 ms. Is the system using slow frequency hop spread spectrum or fast frequency hop spread spectrum?
- R=30kbps
- $R_s = \frac{R}{L} = 10k$ symbols per sec
- $T_s = \frac{1}{R_s} =$ 0.1 ms/symbol
- $T_c = 0.125ms$ per frequency hop
- $T_c < T_s$ it is fast frequency hop spread spectrum

FHSS

- Typically, for FHSS $W_s >> W_d$
  - Large value of k leads to good resistance to noise and jamming.
- Example: Resistance to signal jamming.
  - MFSK transmitter with bandwidth W_d and fixed power S_j on signal carrier frequency. Suppose the jammer is fixed power.
    - Ratio of signal energy per bit to Jammer interference power of
      - $E_b/I_j = E_b W_d/S_j$
      - If frequency hopping is used, then a jammer must jam all 2^k frequencies. With fixed power jammer, this reduces the jamming power in a single frequency band to $S_j/2^k$.
        - The signal to noise ratio, or process gain is $G_p = 2^k = W_s/W_d$.

Direct Sequence Spread Spectrum DSSS

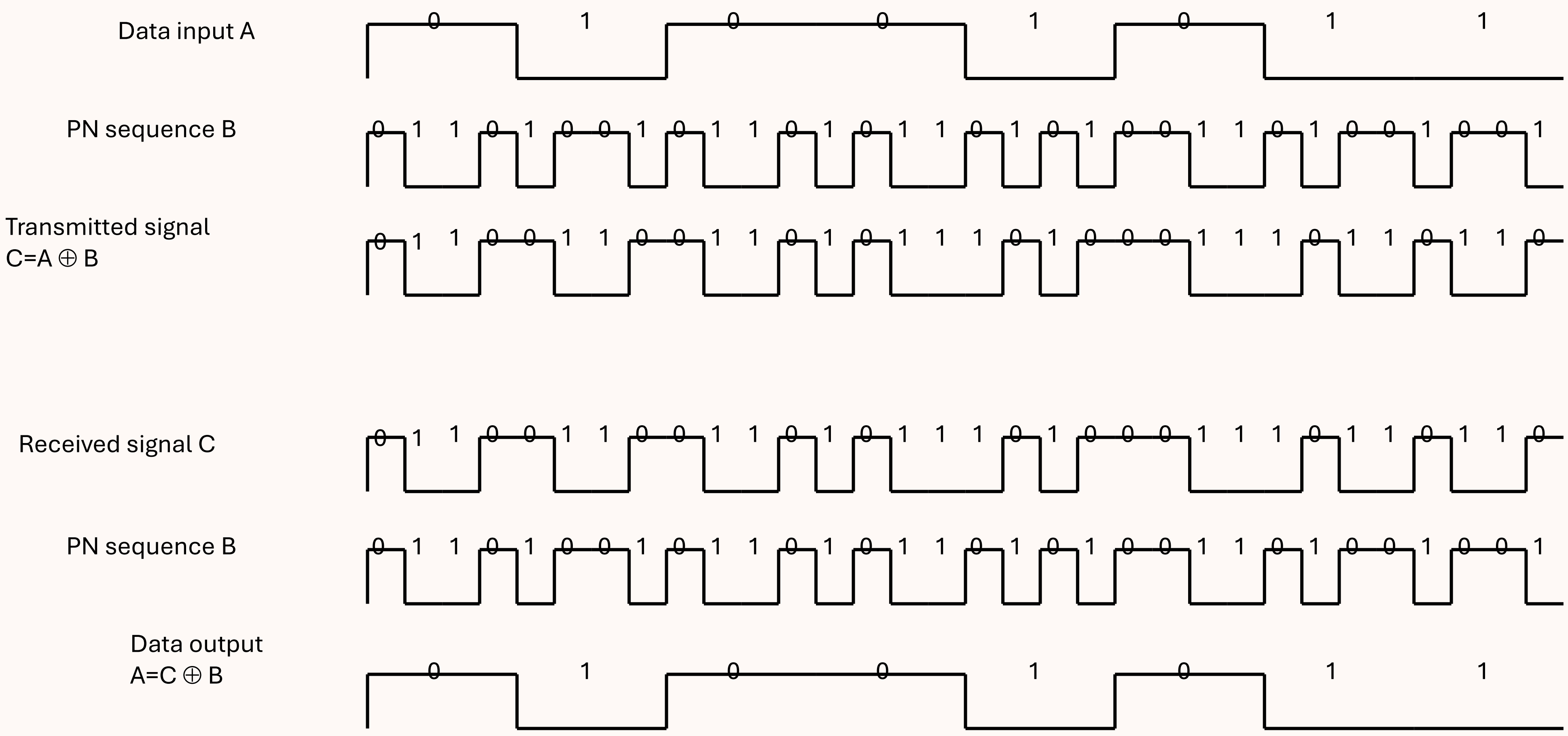
Exclusive OR
0 XOR 0 = 0
0 XOR 1 = 1
1 XOR 0 = 1
1 XOR 1 = 0

DSSS

- Each bit represented by multiple bits using spreading code
- Spreading code spreads signal across wider frequency band
  - In proportion to number of bits used
  - 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

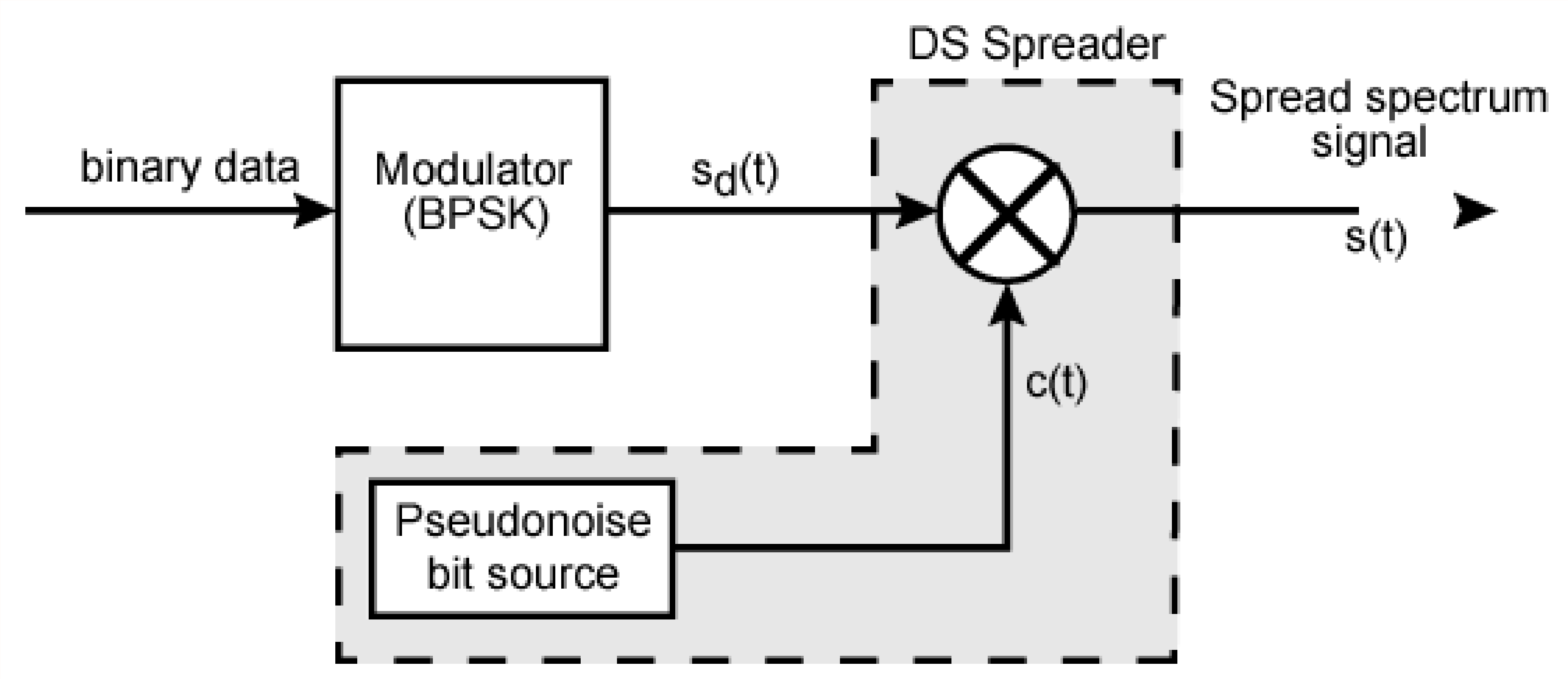
DSSS

- Direct Sequence Spread Spectrum (DSSS) is another form of spread spectrum using Binary Phase Shift Keying.
  - Let $s_d(t) = A\, d(t) \cos(2\pi f_c t)$ where
    - A is the amplitude
    - d(t) is +1 for binary bit ‘1’ and –1 for binary bit ‘0’
    - f_c is the carrier frequency
  - XOR can be accomplished by multiplying $s_d(t)$ by c(t) where c(t) represents the chipping sequence.
    - $s(t) = s_d(t)\, c(t)$
    - Note this can be achieved by either
      - Multiplying the data stream d(t) and c(t) together and performing BPSK or
      - Performing BPSK and then multiplying by c(t)
  - Note that c(t)xc(t)=1
    - So when s(t) is multipled by c(t) at the receiver, $s_d(t)$ is recovered.

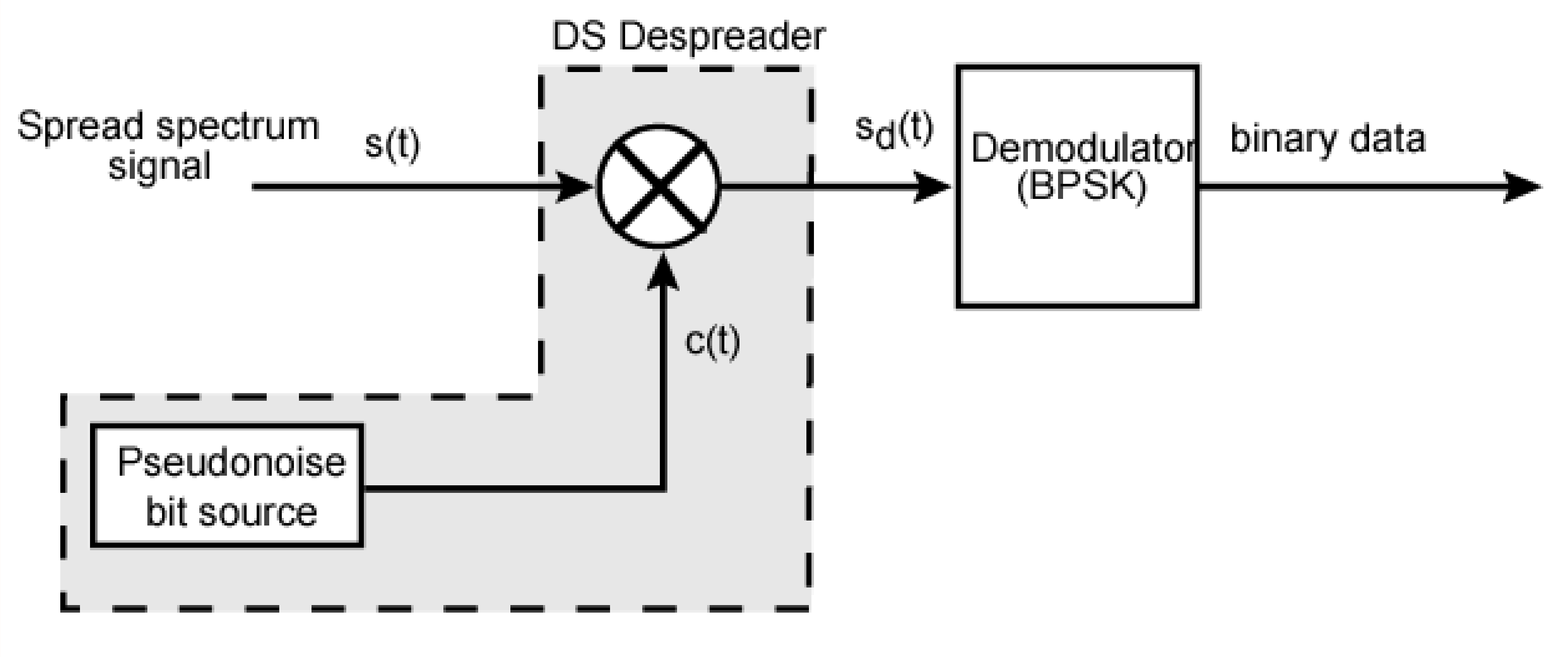


Data input A
0 1 0 0 1 0 1 1
PN sequence B
0 1 1 0 1 0 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0 0 1 1 0 1 0 0 1 0 0 1
Transmitted signal
C=A ⊕ B
0 1 1 0 0 1 1 0 0 1 1 0 1 0 1 1 1 0 1 0 0 0 1 1 1 0 1 1 0 1 1 0
Received signal C
0 1 1 0 0 1 1 0 0 1 1 0 1 0 1 1 1 0 1 0 0 0 1 1 1 0 1 1 0 1 1 0
PN sequence B
0 1 1 0 1 0 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0 0 1 1 0 1 0 0 1 0 0 1
Data output
A=C ⊕ B
0 1 0 0 1 0 1 1

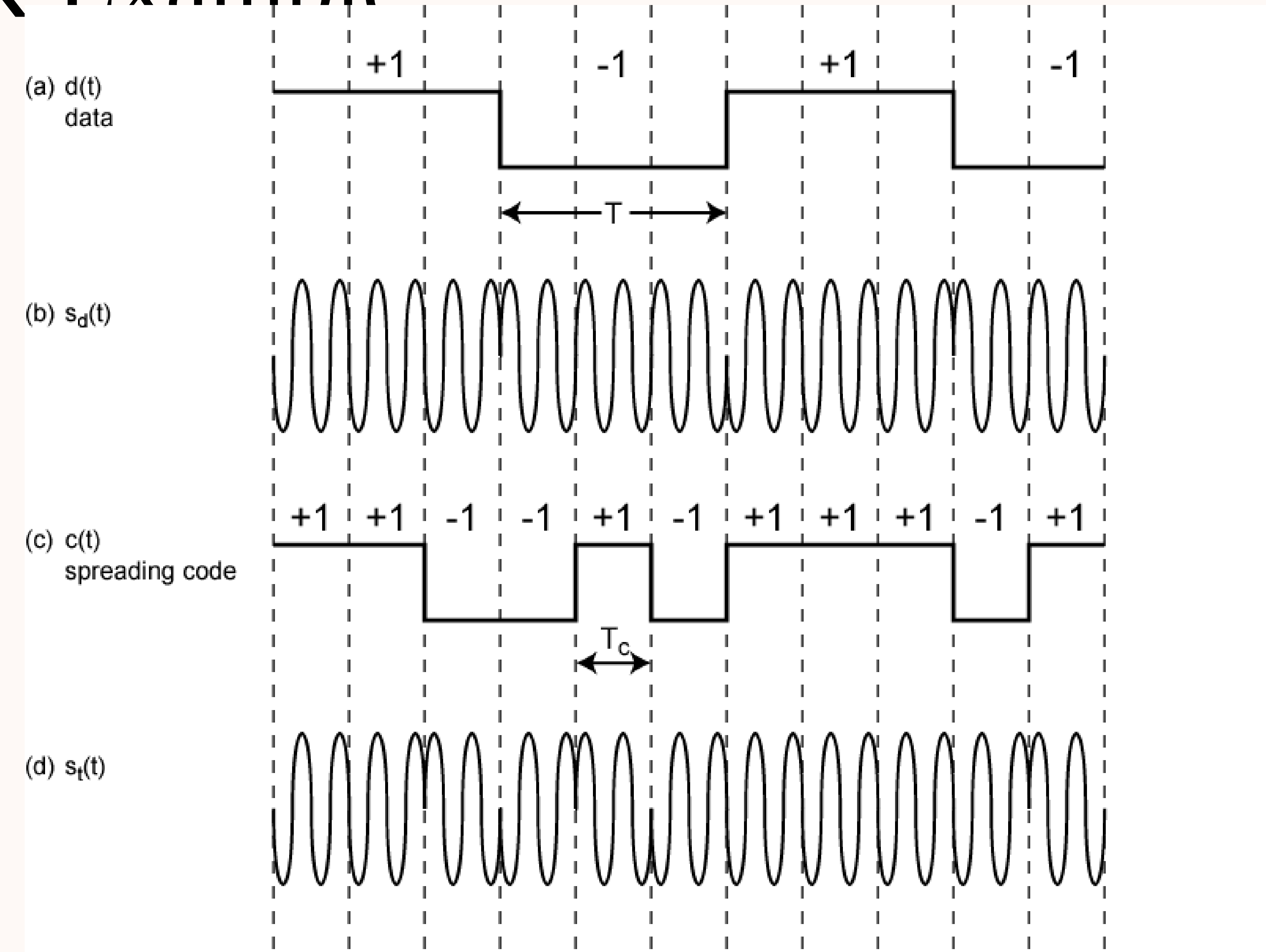
Direct Sequence Spread Spectrum Transmitter



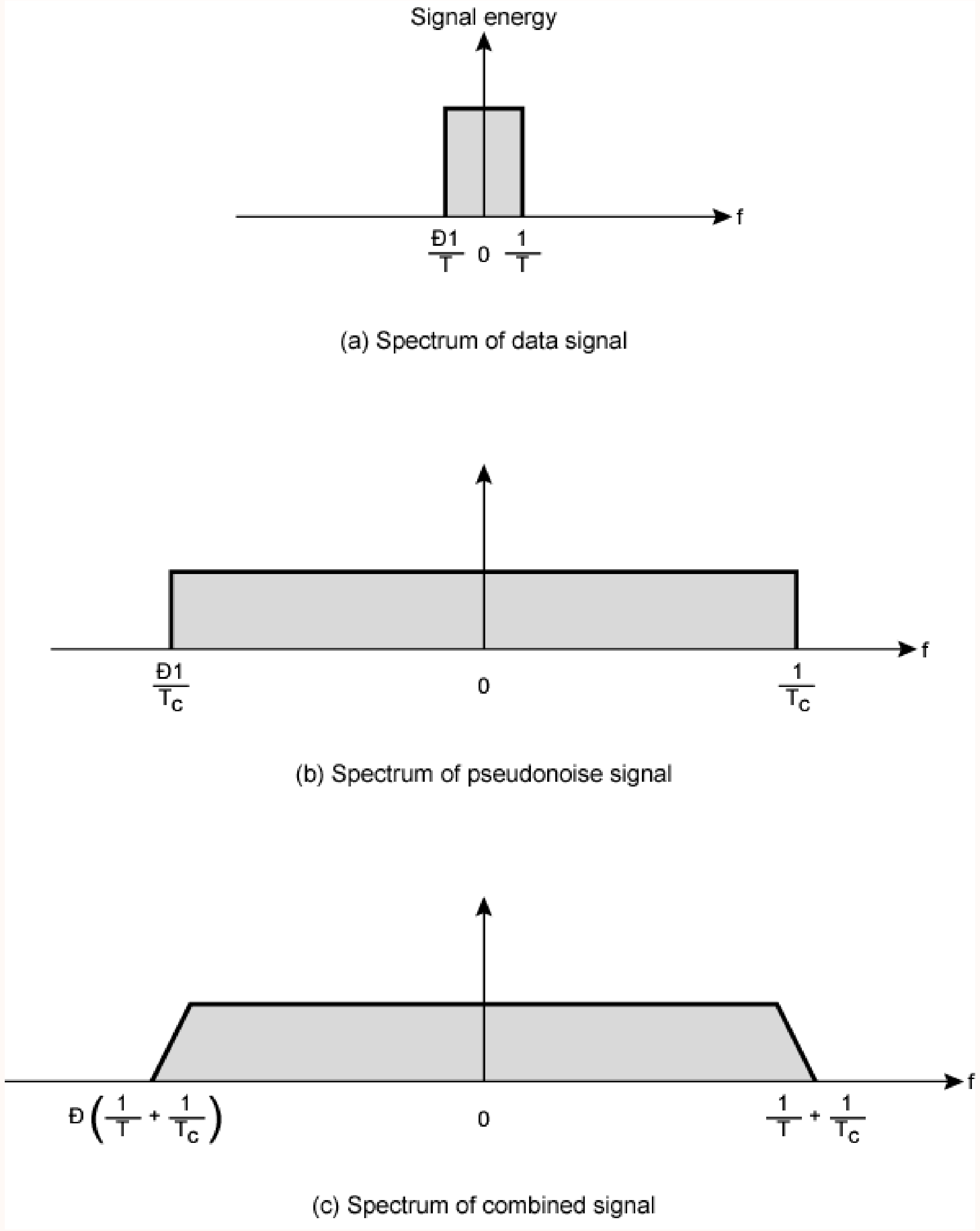
Direct Sequence Spread Spectrum Transmitter



Direct Sequence Spread Spectrum Using BPSK Example



Approximate Spectrum of DSSS Signal

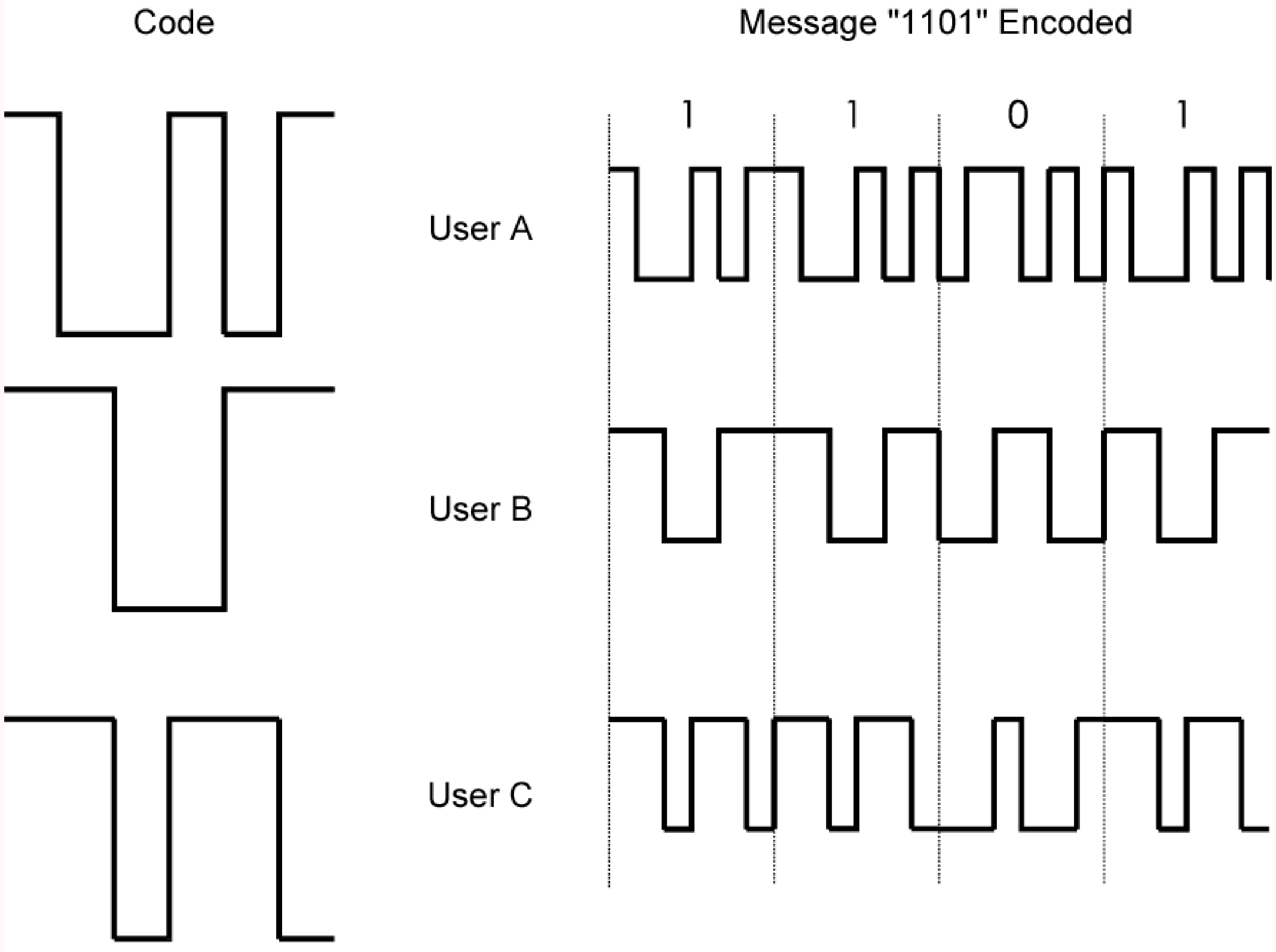


Code Division Multiple Access (CDMA)

- 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>

CDMA Example

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>



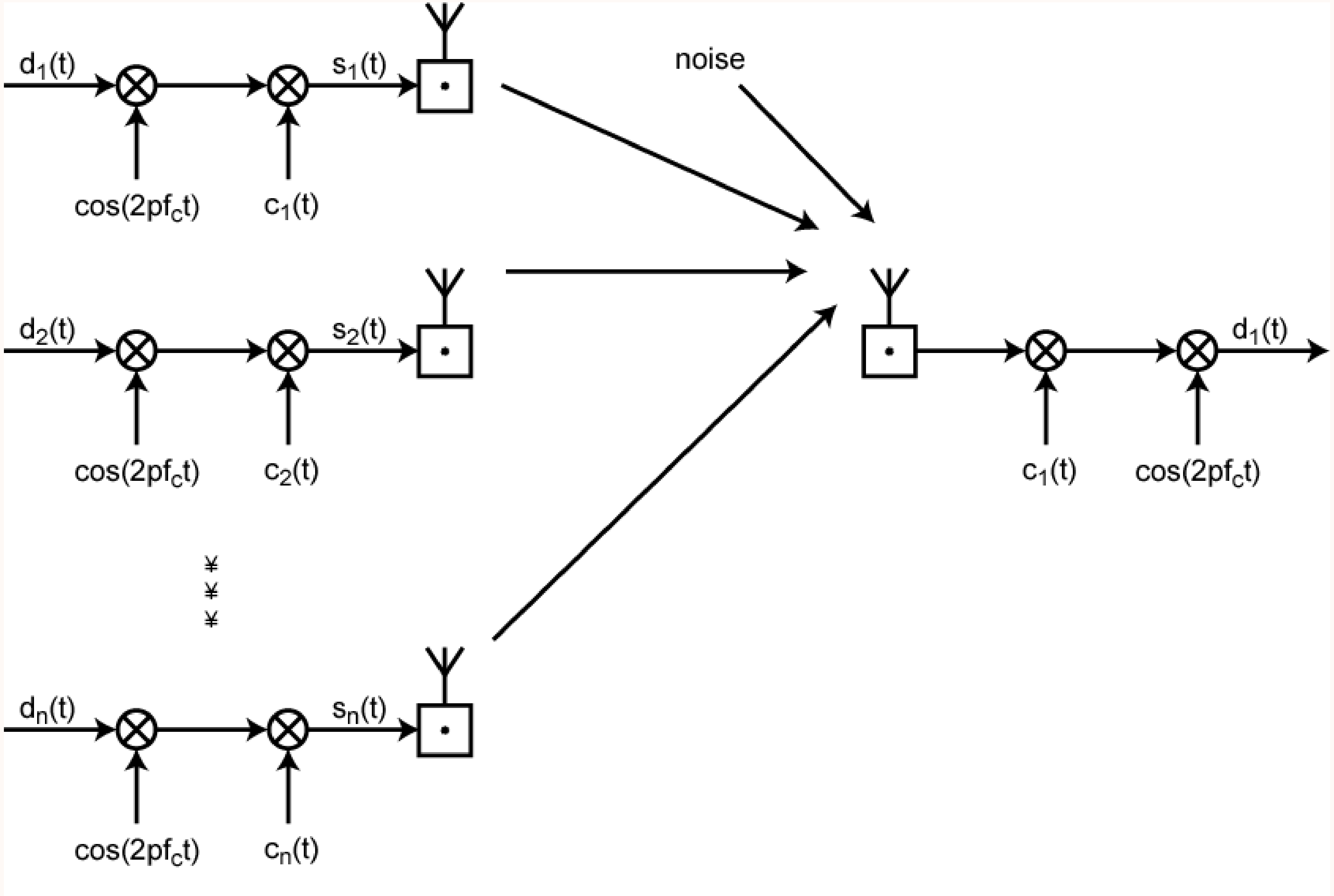
CDMA Explanation

- 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



Summary

- Spread spectrum techniques provide immunity to frequency selective fading effects.
  - Relatively simple to implement.
- CDMA can be used to share the spectrum amongst multiple users.
  - Need orthogonal or near orthogonal chipping codes.
- Sensitive to multipath delay effects.
- Chapter 9 William Stallings