Bandpass Digital System (5)

LC 5-13

Lecture 23, 2008-12-9

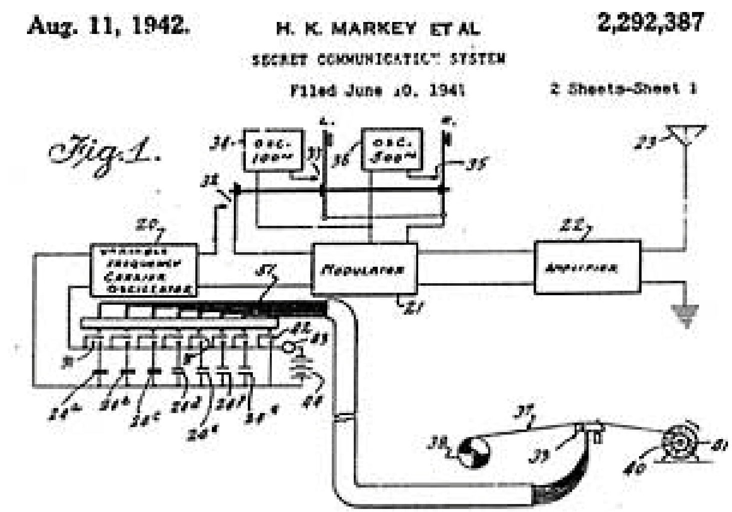
Introduction

- Spread spectrum techniques
  - Energy generated at a single frequency is deliberately spread over a wide band of frequencies
  - Transmitters use a sequential noise-like signal structure to spread the normally narrowband information signal
  - Receivers correlates received signal to retrieve original signal
  - Increasing resistance to interference, prevent eavesdropping, or for multi-access, etc
- History
  - Invented by Hedy Lamarr (1940)
  - Used in military since 1950s

Hedy Lamarr (1914-2000)

- Actress, innovator

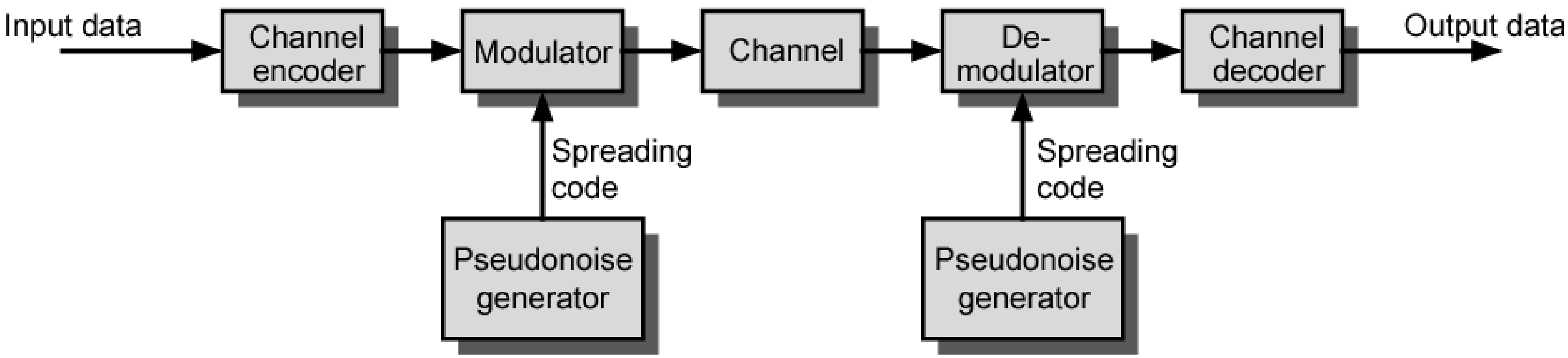
http://www.ieee-virtual-museum.org/collection/people.php?taid=&id=1234751&lid=1



Films have a certain place in a certain time period. Technology is forever.

Spread-Spectrum System

- The signal occupies a bandwidth much in excess of the minimum bandwidth necessary to send the information.
- Spreading is accomplished by means of a spreading signal, often called a code signal, which is independent of the data.
- At the receiver, despreading is accomplished by the correlation of the received spread signal with a synchronized replica of the spreading signal used to spread the information.



Benefits of Spread Spectrum

- Anti-jamming
  - Jamming: intentional interference, noise
  - Jamming usually has fixed energy, limited bandwidth (narrowband)
  - Narrowband jamming can be filtered out
- High security:
  - Signal energy are distributed to a wider bandwidth
  - Power density becomes low
  - Low probability of interception/ detection

Applications

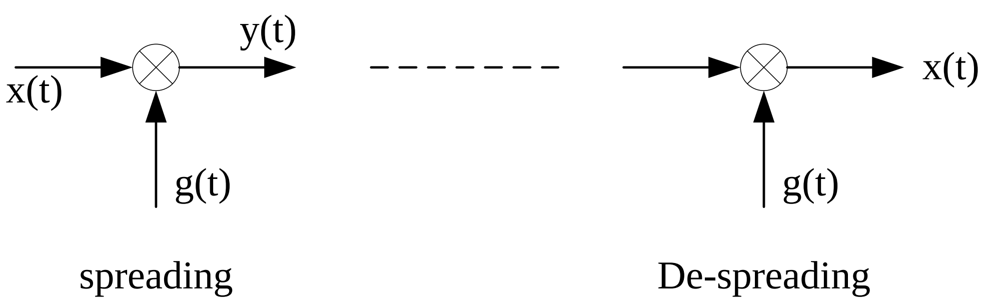
- Security: military usage
- Anti-jamming/noise: military, wireless LAN
  - Jamming: transmission of radio signals that disrupt communications
- Multiple access: high capacity in mobile phone
  - A communication link shared by many users
- High-resolution ranging: GPS
  - Uncertainty in the delay measurement is inversely proportional to the bandwidth of the signal pulse.

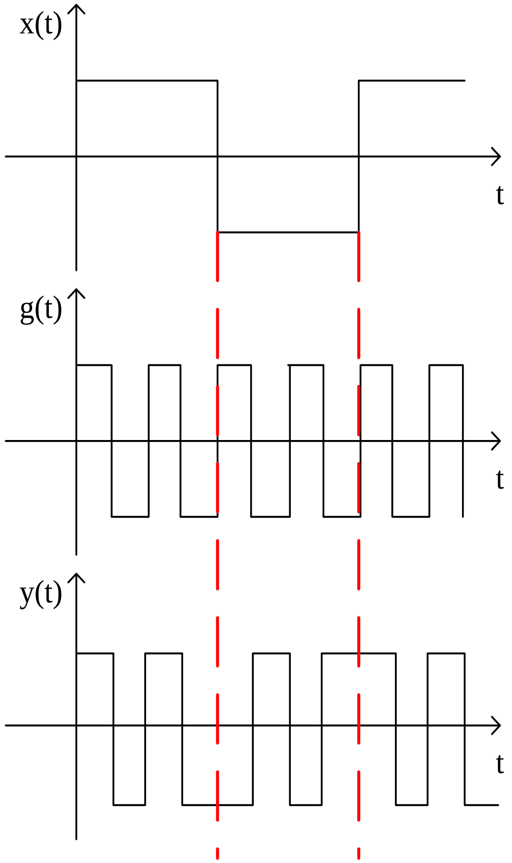
Method of spread spectrum

- DS-SS: direct sequence spread spectrum
  - Multiply each information symbol by a sequence of pseudo noise
- FH-SS: Frequency hopping spread spectrum
  - Rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver
- Comparison of DS-SS and FH-SS
  - DS-SS: High capacity possible with advanced signal processing, flexible for variable data rates. Need power control. Processing gain is more limited.
  - FH-SS: suitable for ad hoc networks, no need power control, limited data rate

DS-SS Model

- Use a pseudo-noise (PN) sequence to spread signal
- PN sequence:
  1. Appear random noise (has $\delta(t)$-like autocorrelation)
  2. Deterministic: can be generated deterministically by both transmitter and receiver

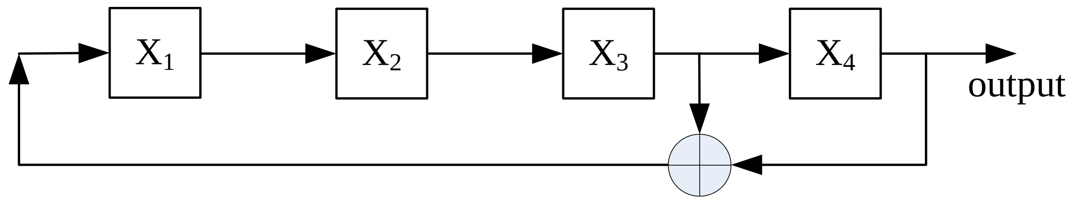




Pseudo-Noise Sequences

- A sequence of “1” & “0” with noise-like auto-correlation
- Random properties
  - Balance: in each period of the sequence, the number of binary ones differs from the number of binary zeros by at most one digit.
  - Run: A run is defined as a sequence of a single type of binary digit(s). Run Length is the number of digits in the run. It is desirable that about 1/2 the runs of each type are of length 1, about ¼ are of length 2, 1/8 are of length 3, and so on.
  - Correlation: zero cross-correlation between different sequences with various shifts

Linear Feedback Shift Register



- Suppose Initial State of register is 1000, the succession of register states:

  1000 0100 0010 1001 1100 0110 1011 0101 1010 1101 1110 1111 0111 0011 0001 1000
- Since the last state 1000, is the same as the initial state. The register repeats the foregoing sequence after 15 clock pulses.
- The output sequence is 000100110101111

  Balance: 7 ”0” and 8 ”1”

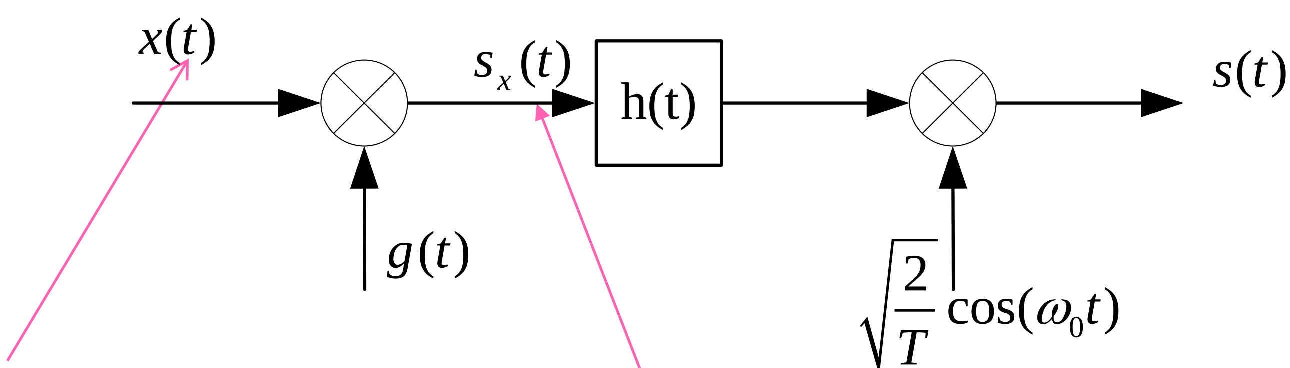
  Run: 4 “0” runs, length of 1: 2, length of 2: 1, length of 3: 1

  Correlation: $R(\tau) = N/p$, p is the period, N is the number of agreements minus number of disagreements of one period with a τ position cyclic shift) $R(1) = -1/15$

DS-SS

- BPSK DSSS modulation

$$s(t)=\sqrt{\frac{2}{T}}\cos(\omega_0 t)\,x(t)\,g(t)$$



Bit rate: R_b chip rate: R_c

bit interval T_b chip interval T_c

Processing gain: (# of PN chips per bit)

Demodulator

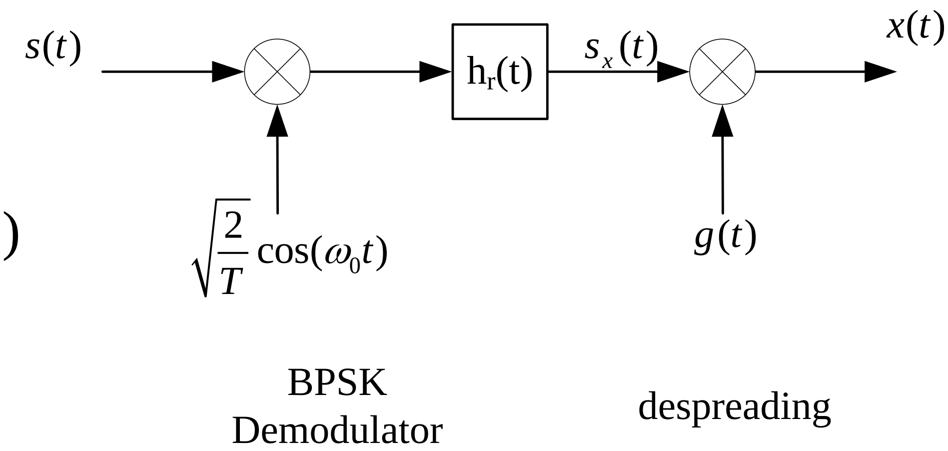
- Two possible schemes

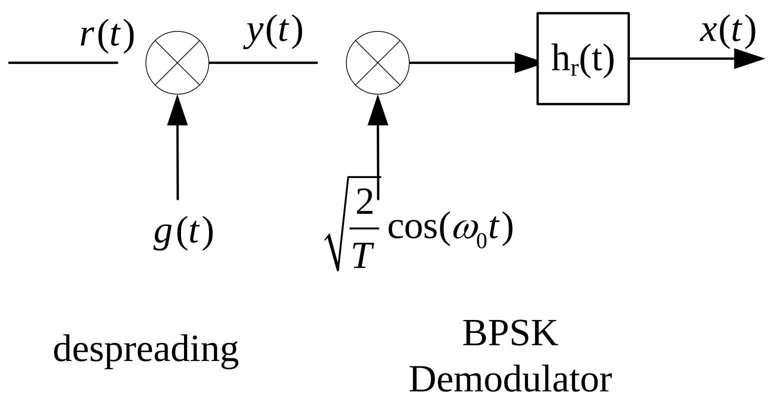
$$r(t) = s(t) = \sqrt{\frac{2}{T}} \cos(\omega_0 t) x(t) g(t)$$

$$y(t) = r(t) g(t)$$

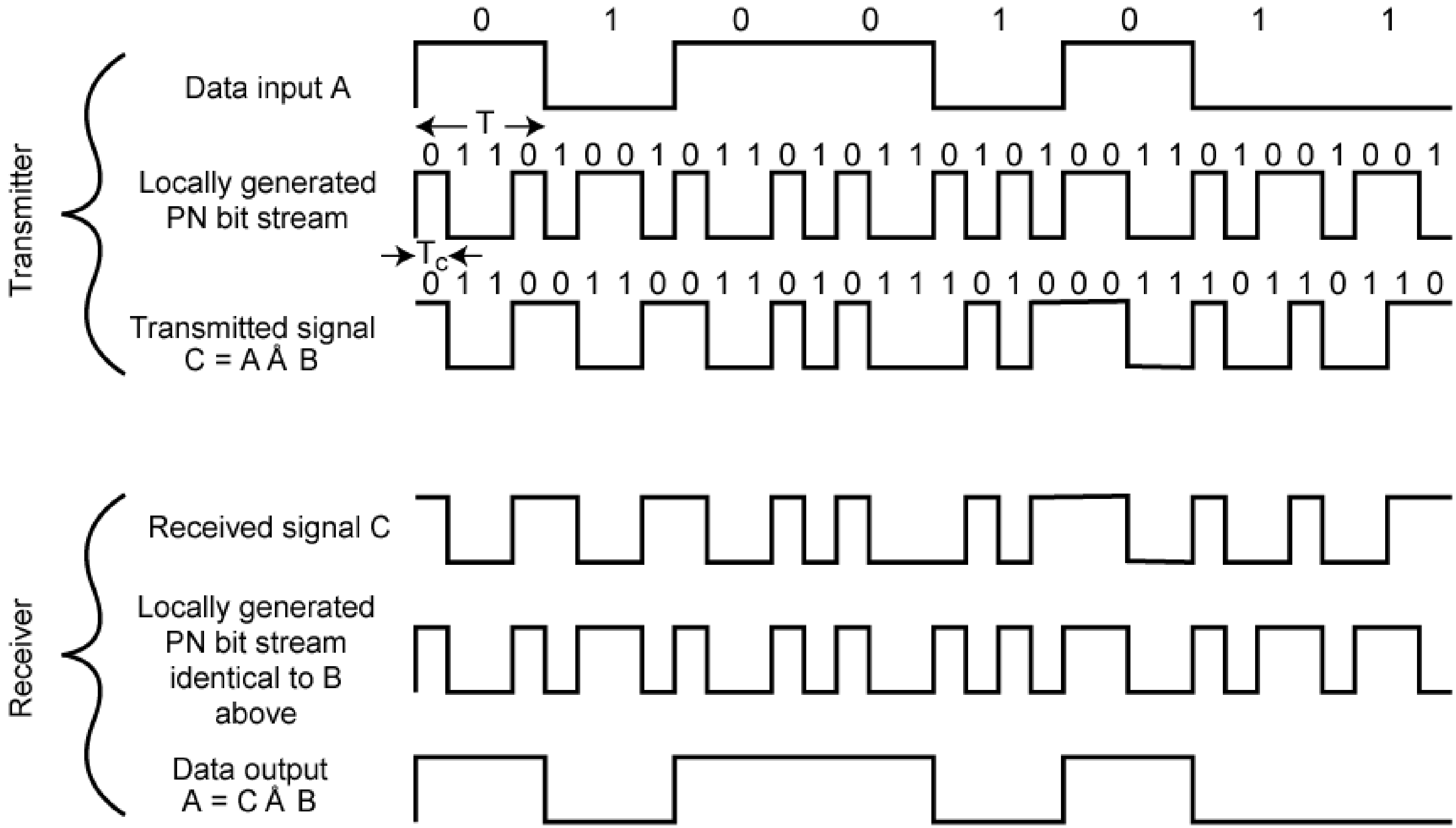
$$= \sqrt{\frac{2}{T}} \cos(\omega_0 t) x(t) g(t) \times g(t)$$

$$= \sqrt{\frac{2}{T}} \cos(2\pi f_c t) x(t)$$



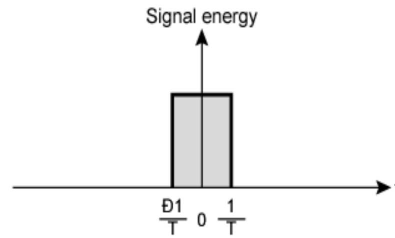


Example Waveforms



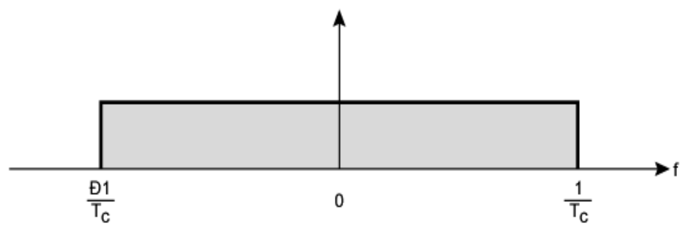
Approximate Spectrum of DS-SS Signal

V(f)



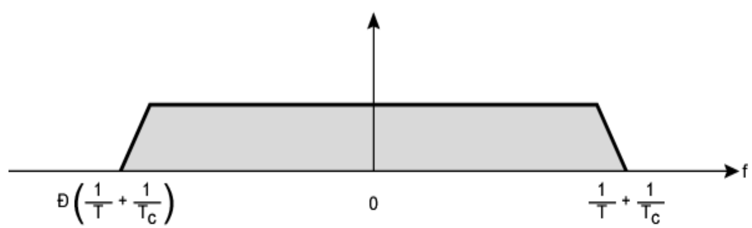
(a) Spectrum of data signal

C(f)



(b) Spectrum of pseudonoise signal

V(f)*C(f)



(c) Spectrum of combined signal

Processing Gain and Anti-jamming Capability

- Narrowband interference $i(t)$, wideband spread-spectrum signal $s(t)$, received signal $r(t)$.

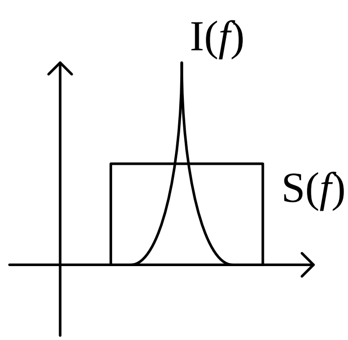
$$r(t) = s(t) + i(t) = \sqrt{2/T}\, x(t) g(t) \cos(\omega_0 t) + i(t)$$

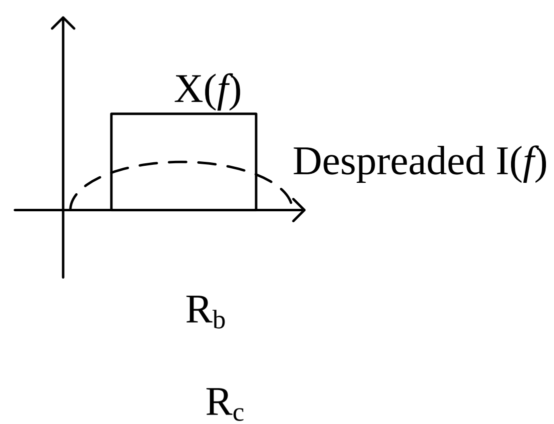
- Despreading:

$$y(t) = r(t) g(t) = \sqrt{2/T}\, x(t) \cos(\omega_0 t) + i(t) g(t)$$

- Demodulation:

$$\left[y(t) \sqrt{\frac{2}{T}} \cos(\omega_0 t) \right]_{LP} = x(t) + \left[i(t) g(t) \sqrt{\frac{2}{T}} \cos(\omega_0 t) \right]_{LP}$$





- Assume $i(t)$ as fixed power P_J. Power density is $J_0 = \frac{P_J}{R_c}$
- Jammer power fall in the signal bandwidth R_b is:

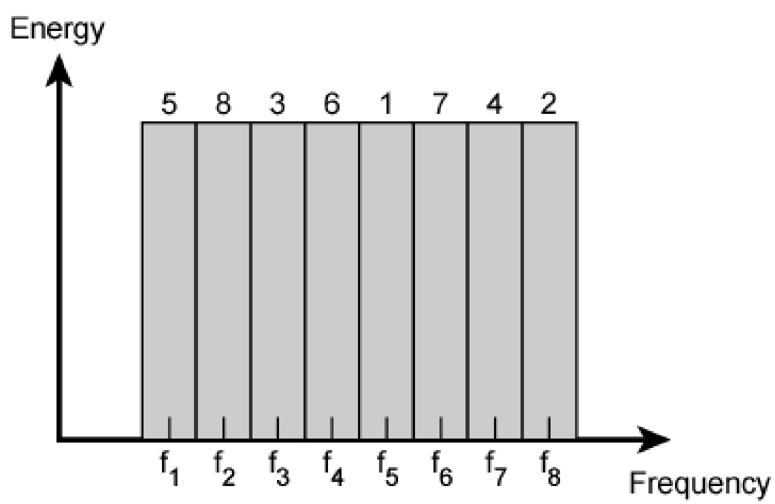
$$N_J = J_0 R_b = P_J \frac{R_b}{R_c} = \frac{P_J}{L}$$

- SIR (signal-to-interference ratio) enhancement:

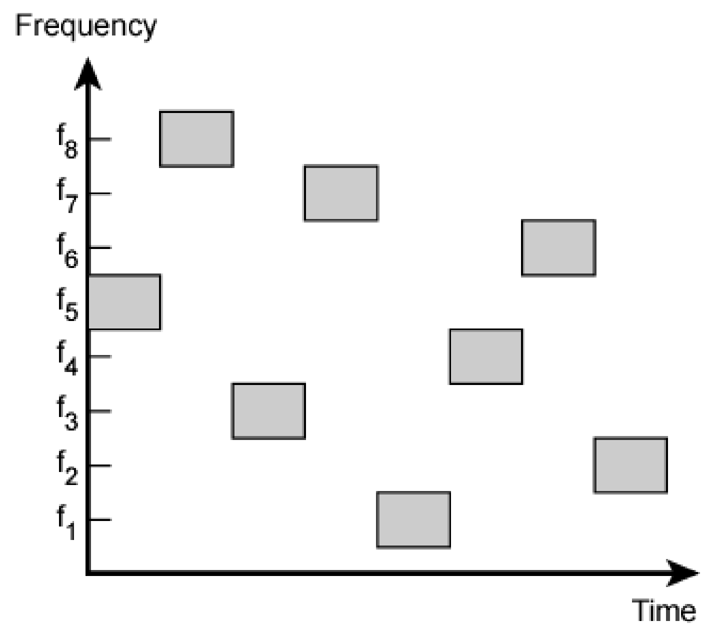
$$\text{Input SIR} \quad \frac{P_S}{P_J} \Rightarrow \frac{P_S}{P_J} L \quad \text{Output SIR}$$

- Observations
  - Interference power reduced by L times
  - SIR increased by L times (L: processing gain)

Frequency Hopping

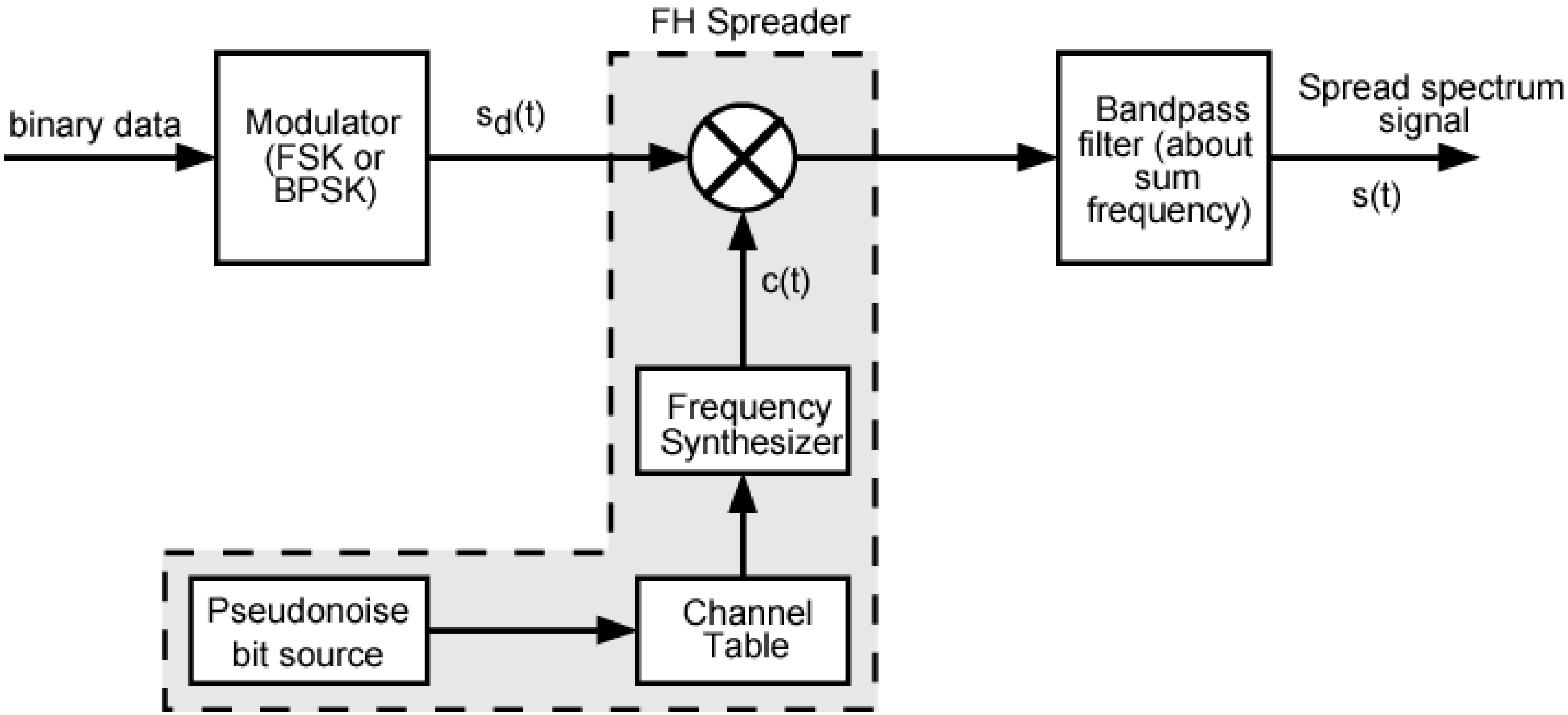


(a) Channel assignment



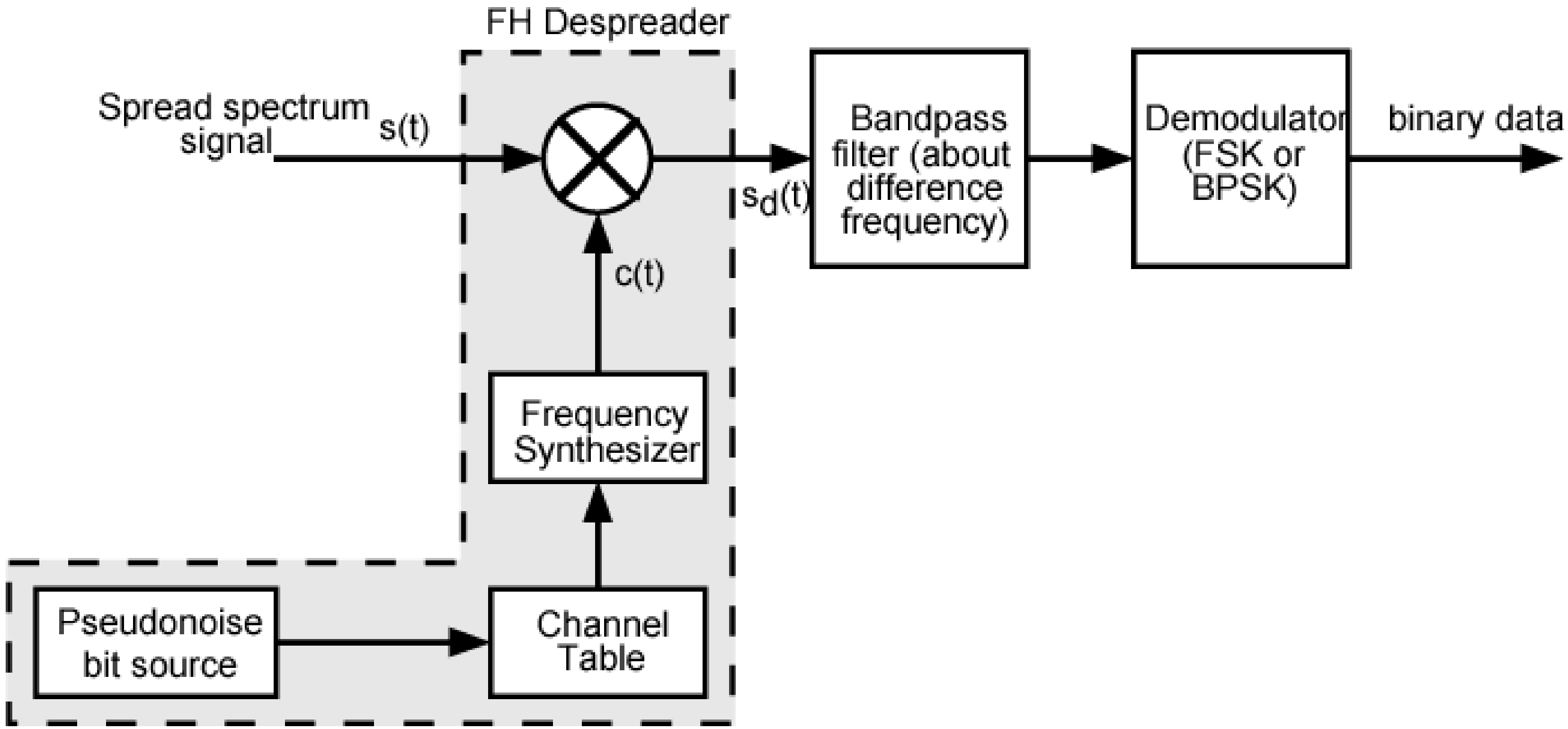
(b) Channel use

Modulator



FH Spreader
binary data
Modulator (FSK or BPSK)
$s_d(t)$
c(t)
Bandpass filter (about sum frequency)
Spread spectrum signal
s(t)
Frequency Synthesizer
Pseudonoise bit source
Channel Table

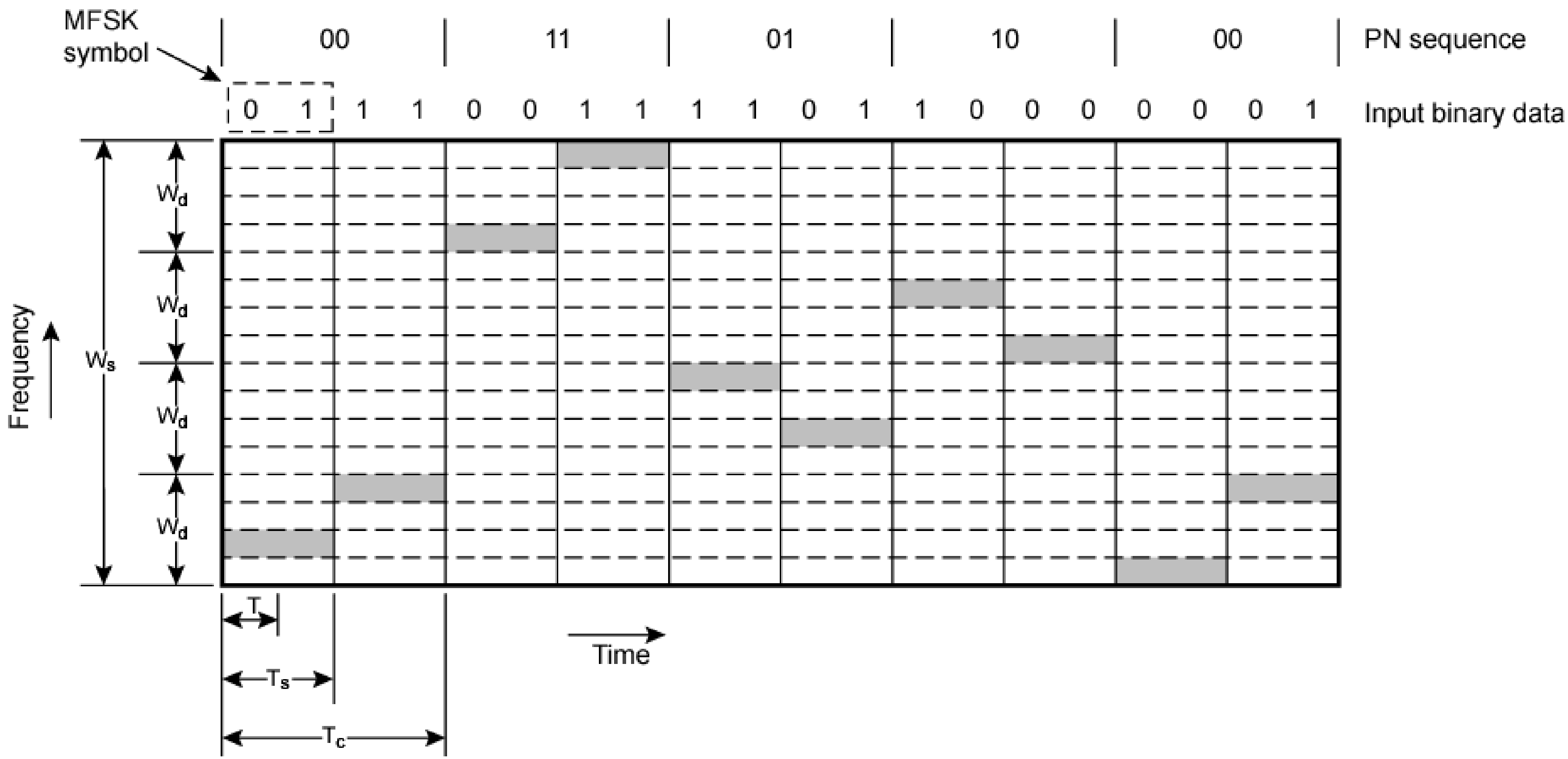
Demodulator



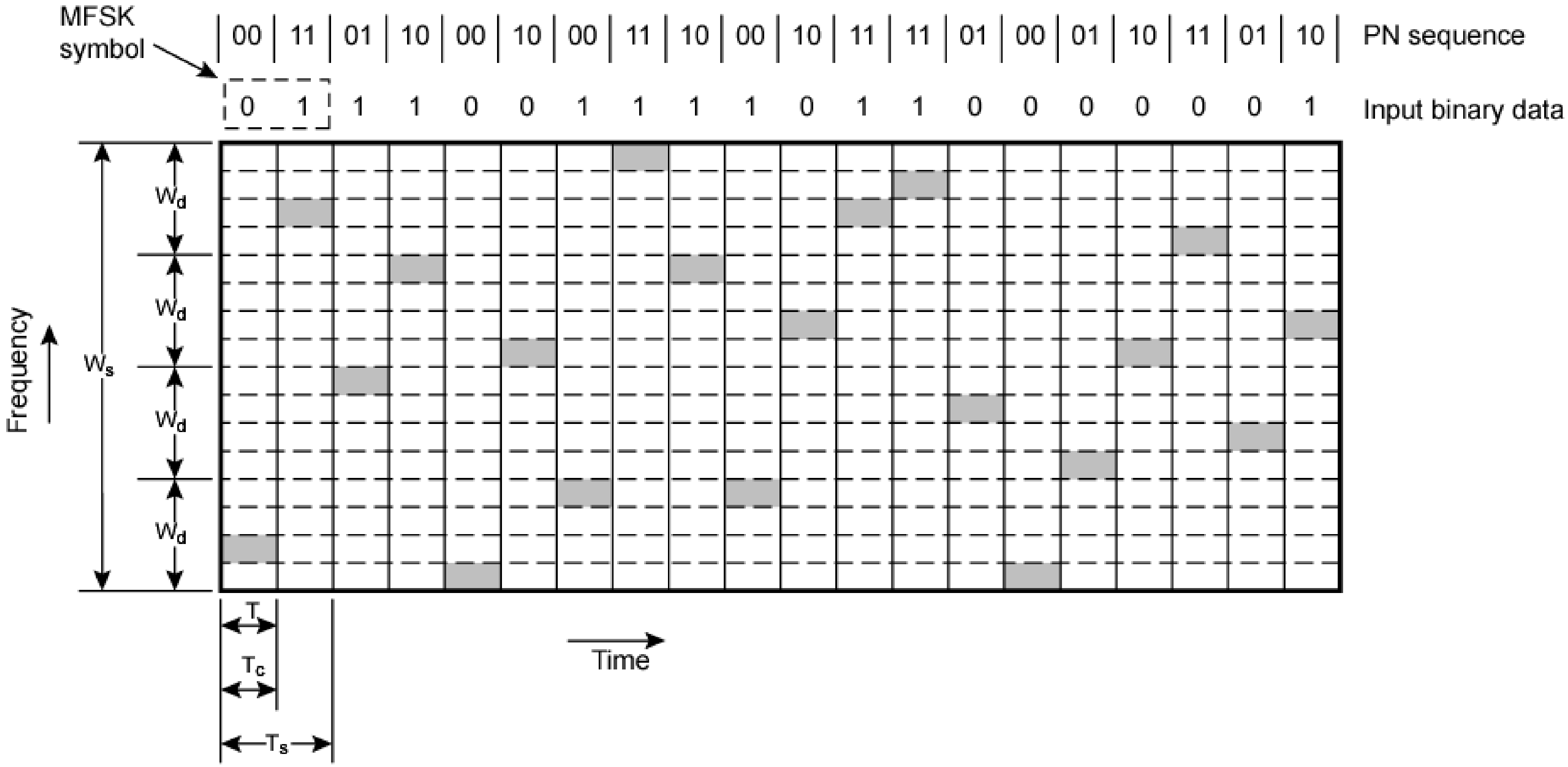
Slow and Fast FHSS

- 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)

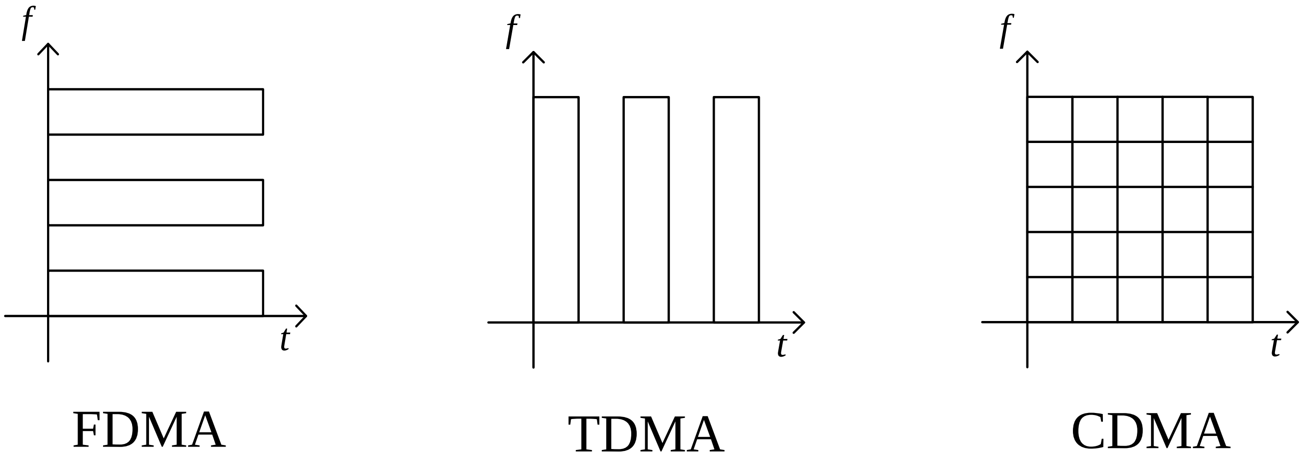


Fast Frequency Hop Spread Spectrum Using MFSK (M=4, k=2)



Multiple Access

- FDMA: frequency division multiple access
- TDMA: time division multiple access
- CDMA: code division multiple access
  - DS-CDMA, FH-CDMA
  - Not divide the channel by time/frequency, but encode data with special codes and uses the signal structure for demultiplexing



Homework

- LC 5-78, 5-79