

**KFUPM-EE DEPT.**  
**EE573- Digital Communications II**  
**Dr. Ali Muqaibel**  
**Spread Spectrum**  
Summary of Main Points, v. 1.0

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- **Introduction**
  - Definition of Spread Spectrum and Bandwidth Expansion Factor
  - Major Applications (Jamming, anti-jamming, covert, CDMA, radar)
  - Definition of CDMA
  - Coding and pseudo-randomness
- **Types of Spread Spectrum**
  - Direct Sequence Spread Spectrum (DSSS)
  - Frequency Hopping Spread Spectrum (FHSP)
- **Model of DSSS Digital Communication System** *see figure 13.1-1*
  - Integration of Coding
- **Types of Interference (Jamming)**
  - Broadband, narrowband, tone, multi-tone
  - Continuous, pulsed
  - Fixed, time varying
- **Type of modulation considered and when?**
  - PSF and FSK
- **Modulator Demodulator digital Circuits (13.2)**
- **Error Rate Performance of the Decoder (13.2.1)**
  - Jamming Margin, Jammer to signal ratio (JSR), processing gain,...etc with example
  - Performance of the un-coded system
  - Hard decision versus soft decision decoding
  - Derivation for the performance of SS under different jamming Conditions. See to examples 13.2-1 and 13.2-2
  - Performance under Pulsed Jamming (Partial Time Jamming)
    - Interleaving
    - Performance under different codes
- **Generation of PN Sequences**
  - Criteria:
    - Auto-correlation
    - Cross-correlation
  - Maximum Length Shift Register
  - Gold Sequences
  - Welsh Bound
  - Kasami Codes
- **Frequency Hopping (FH)**
  - Definition
  - Features
  - Slow Frequency Hopping (SFH) vs Fast Frequency Hoping (FFH)
  - Detection Procedure
  - Processing Gain
  - Performance of SFH in Jamming Environments
    - Broadband Jamming
    - Partial-band Jamming
- **Comparison FH vs. DS (7 points)**
- **CDMA Practical Example:** Forward and reverse link IS-95 (748-753)
- **CDMA vs. TDMA/FDMA :** Viterbi debating himself in three published papers.
- **Check Matlab for useful CDMA and SS codes**

# "Spread Spectrum Signals for Digital Communications"

→ Bandwidth  $W$  is much greater than the info rate  $R$  (bit/sec)

$$\text{Bandwidth Expansion Factor } B_e = \frac{W}{R} \gg 1$$

→ Redundancy is introduced to overcome interference (Radio & Satellite)

① Coding is an efficient method for introducing redundancy.

② pseudo randomness signal appear like noise & difficult to be received by the non-intended receivers.

## \* Major Applications:

①. Combating / Suppressing jamming / interference due to other users / self-interference (multipath)

CDMA  
③ Capacity  
Qualcomm  
lic. !

② Hiding / secure communication. / privacy.  
LPI: Low-probability-of-intercept. (detect)

\* Comm Security  
vs.  
Info Security

⇒ other application of SS in Radar (time delay, Velocity) ranging.

• Jamming (assumed to know the overall channel bandwidth & type of modulation (PSK, FSK, ...etc.))

• CDMA: allow multiple users to simultaneously use a common channel for transmission of information

Code Division Multiple Access (KEY = Code)

room  
Example

Objective: (Coverage)

① Types of SS  $\begin{cases} \rightarrow \text{Direct Sequence SS (DSSS)} \\ \rightarrow \text{Freq. Hopping SS (FHSS)} \end{cases}$

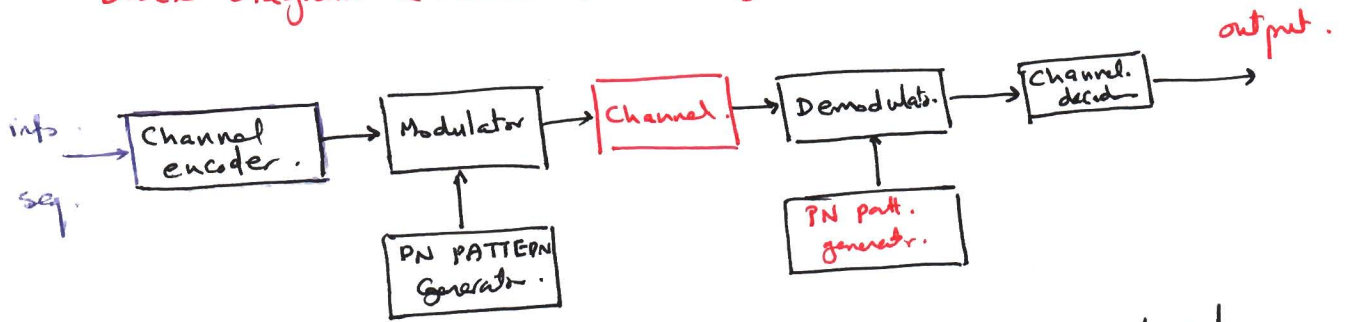
② AntiJamming (AJ) performance.

## Types of SS:

- ① PSK + PN seq  $\Rightarrow$  Direct Sequence (DS) or.  
pseudo-noise (PN) (or QPSK)
  - ② M-ary FSK + PN  $\Rightarrow$  the pseudorandom seq. selects the  
freq. of the transmitted seq. randomly  $\Rightarrow$  frequency-hopped.  
(FH)
- other types exists.

# 13.1 MODEL of SS Digital Comm. Sys.

Block Diagram (Model of SS digital Comm. Sys.) . Fig. (13.1-1)



→ The Channel encoder @ no cost! ; Coding is usually employed to enhance the gain.

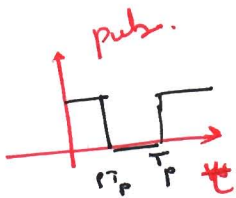
→ Synchronization. (of PN sequence)

Initially, training! Transmit a fixed PN bit pattern that the receiver will recognize in the presence of interference with high probability.

→ Interference:

1-4 have same effect on DSSS

(Jamming) options.



- Its ch/s depends on its origin
- ① broad band / narrowband / tone / multi tone } Military.
- ② Continuous / pulsed (discontinuous)
- fixed / time variant.



• In CDMA we could have multi user interference.

• If the interference is broad band, it may be characterized by an equivalent AWGN

Objective: (more details)

- performance evaluation of SS in the presence of NB / Broad band. interference.
- Two types of modulation are considered.

PSK if phase coherence is possible for time longer than  $\frac{1}{W}$ .  
 FSK if phase coherence is not possible (time variant channels). (air craft).

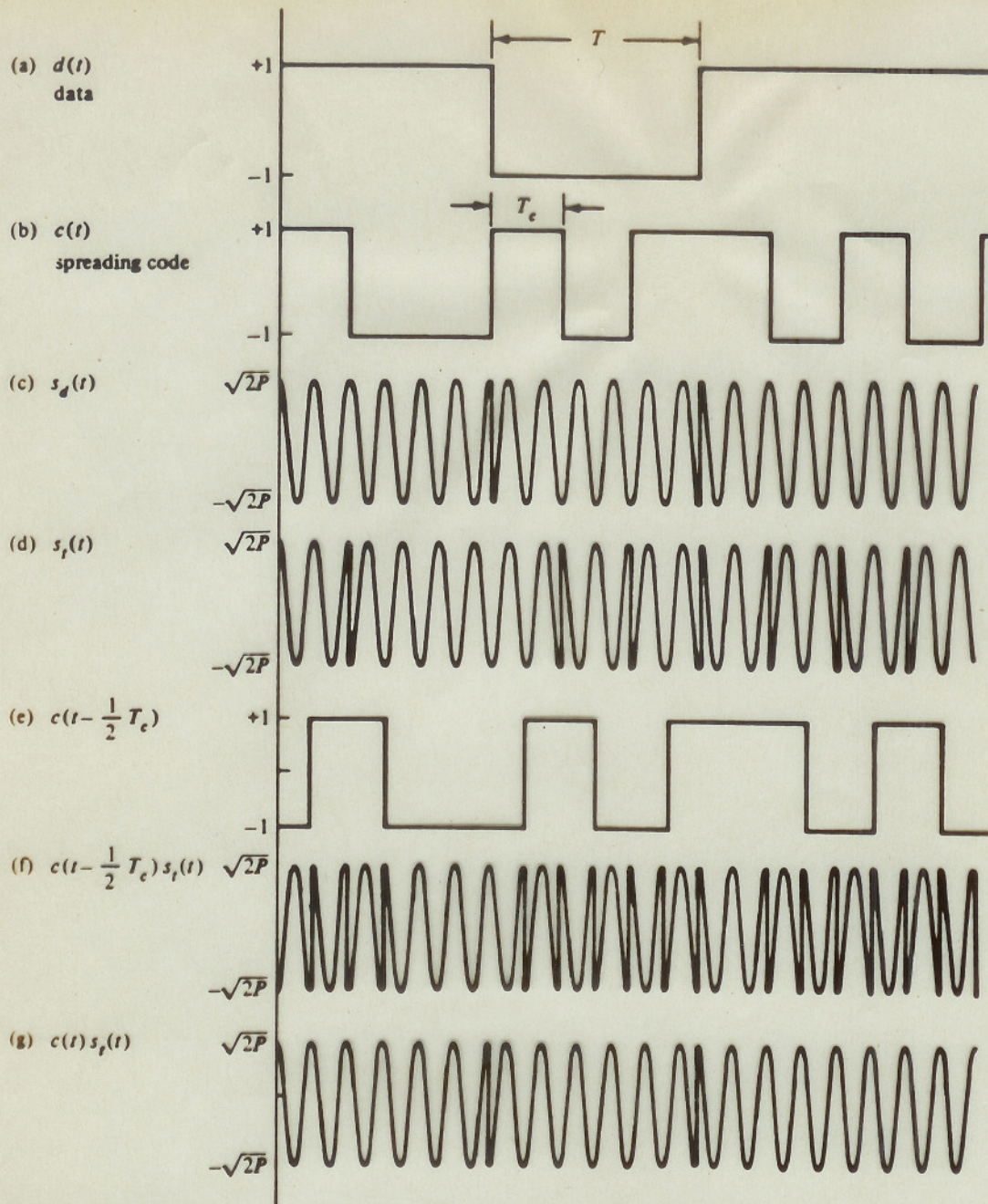


FIGURE 8-5. BPSK direct-sequence spreading and despreading.

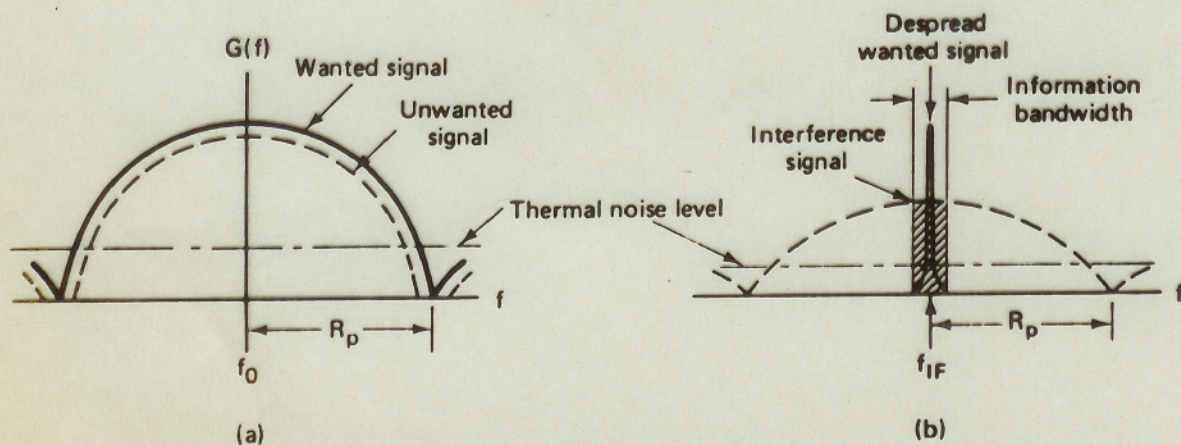
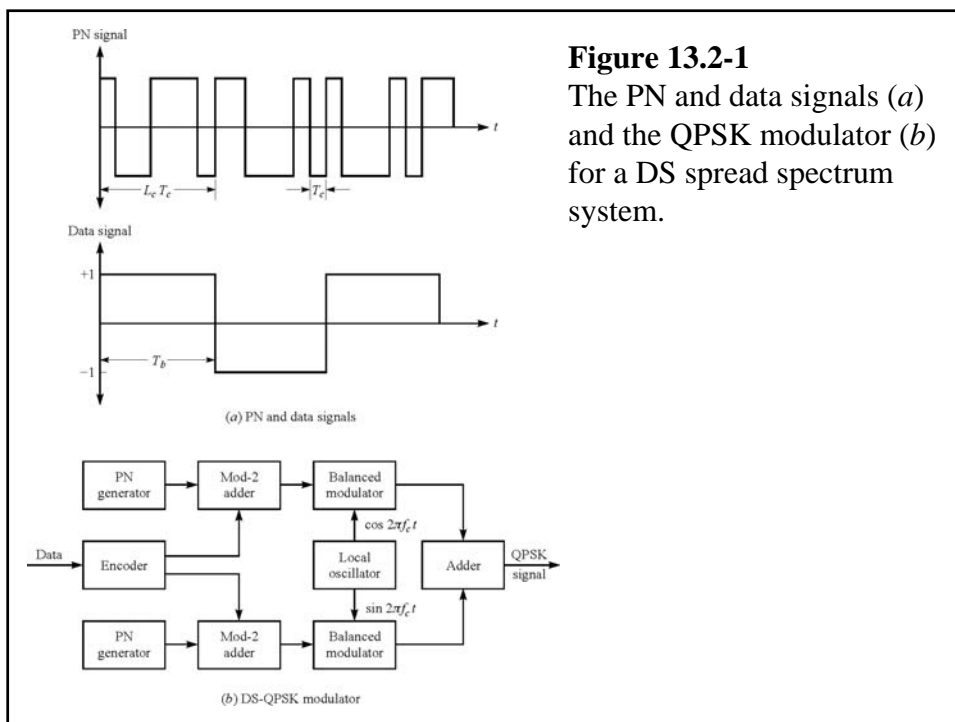
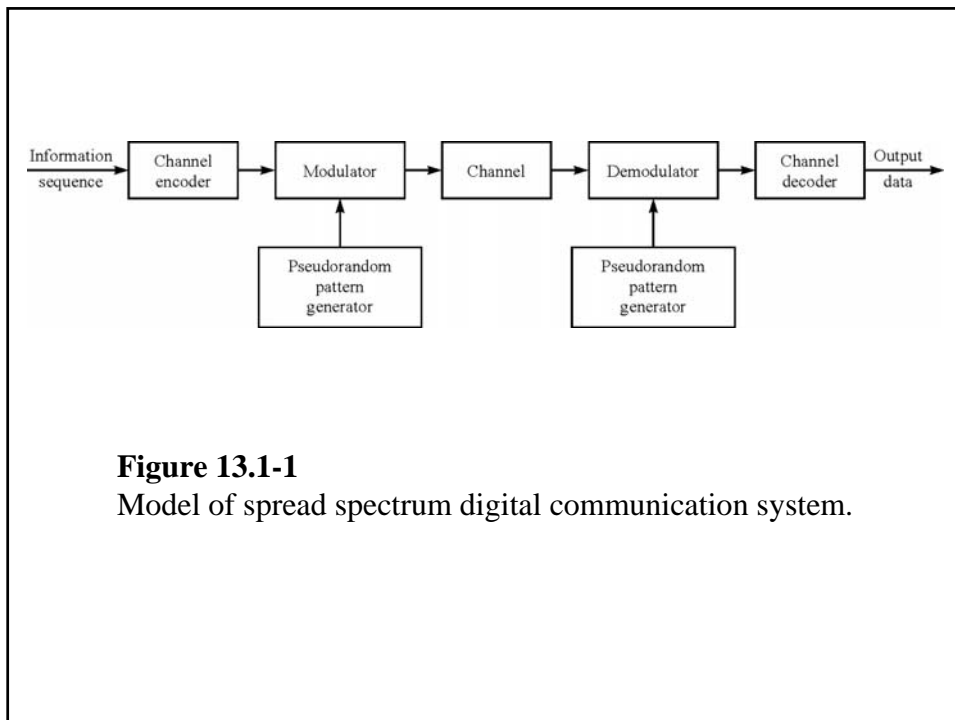
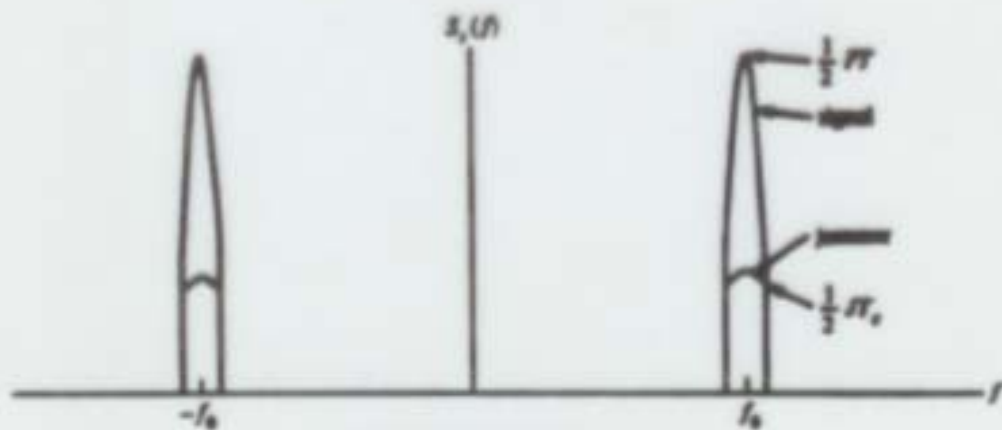
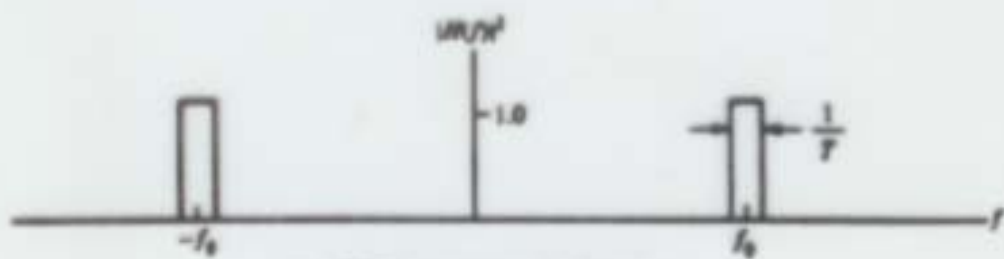
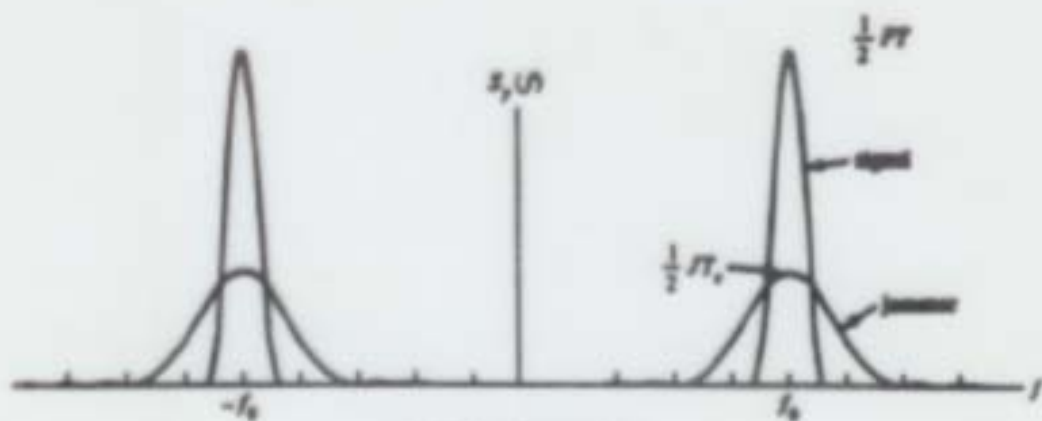
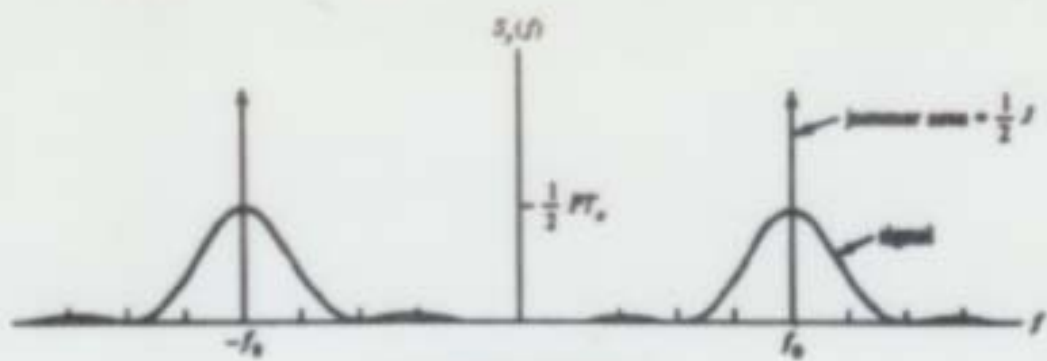


Figure 10.26 Spread-spectrum signal detection. (a) Spectrum at the input to receiver. (b) Spectrum after correlation with the correct and synchronized PN code.





### 13.2 DSSS signal.

→ Revisit the model. (Fig. 13.1-1)

$$\text{info rate} = R \frac{\text{bits}}{\text{sec.}}$$

$$\text{Bandwidth} = W \text{ Hz} \quad (\text{available}). \quad \text{assume BPSK}$$

The phase of the carrier is shifted pseudorandomly according to the pattern from PN generator, at a rate  $W$  times  $\frac{1}{\text{sec}}$

$$W = \frac{1}{T_c}$$

$T_c$ : duration of the pulse chip interval ← Basic element in DSSS

$$T_b = \frac{1}{R}$$

duration of a rectangular pulse: (time of transmission for a bit).

### • Bandwidth Expansion Factor.

$$B_e = \frac{W}{R} = \frac{T_b}{T_c}$$

In practice  $\frac{T_b}{T_c}$  is integer.  $L_c$ : # of chips per info. bit.

# of phase shifts during one bit transmission.

Using  $(n, k)$  code.

$$n = k L_c$$

to transmit  $n$  time available is  $k T_b$   
for convolutional code  $R_c = \frac{k}{n} = \frac{1}{L_c}$

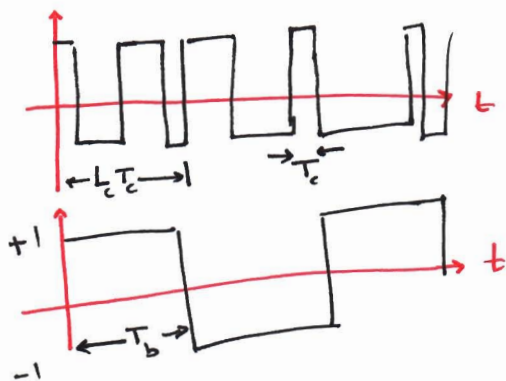


Figure. 13.2-1

$$\text{Bandwidth of } p(t) = \frac{1}{T_c}$$

$$= g(t) = \frac{1}{T}$$

$$= p(t)g(t) \approx \frac{1}{T} + \frac{1}{T_c} \approx \frac{1}{T_c}$$

Forming the DS:

(Modulator)

let  $b_i = i^{th}$  bit chip of the PN sequence (0, 1)  
 $c_i = i^{th}$  bit from the encoder.

①  $a_i = b_i \oplus c_i$  (Same  $\Rightarrow a_i = 0$  otherwise 1)

then use a BPSK modulator.

See Figure below

$$g_i(t) = \begin{cases} g(t - iT_c) & (a_i = 0) \\ -g(t - iT_c) & (a_i = 1) \end{cases}$$

② Other alternative:

modulation of  $c_i$ 's first

$$g_i(t) = (2c_i - 1) g(t - iT_c)$$

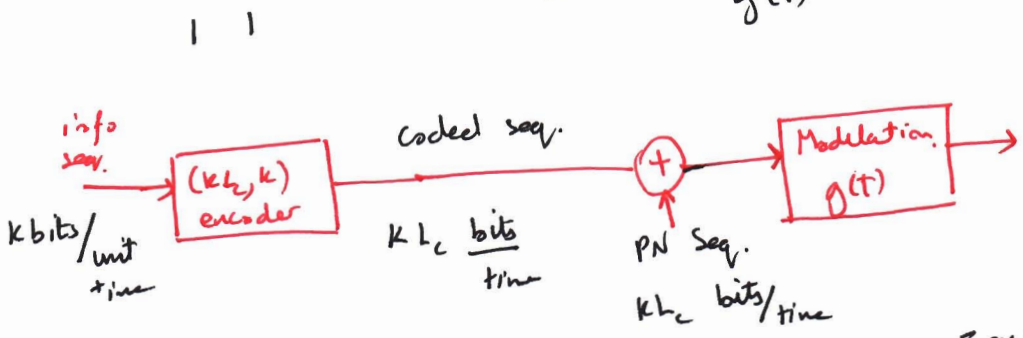
output of the PN seq.

$$p_i(t) = (2b_i - 1) p(t - iT_c)$$

Multiplying Both

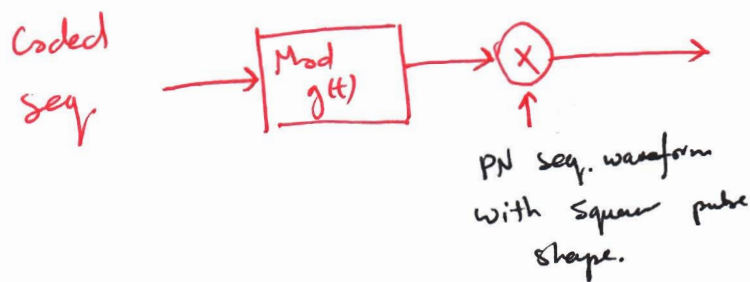
$$g_i(t) = (2b_i - 1)(2c_i - 1) g(t - iT_c)$$

$b_i$	$c_i$	$b_i \oplus c_i = a_i$	$g_i^{(1)}$	$(2b_i - 1)$	$(2c_i - 1)$	$g_i^{(2)}$
0	0	0	$g(t)$	1	1	$g(t)$
0	1	1	$-g(t)$	-1	-1	$-g(t)$
1	0	1	$-g(t)$	-1	1	$-g(t)$
1	1	0	$g(t)$	1	1	$g(t)$



Easier to implement

①



Easier to understand demodulation

②

Equivalent can be used for coded or uncoded sys.

# (DS modulator)

The received signal for the  $j^{\text{th}}$  code element

"no-despreading yet"

$$r_j(t) = p_j(t) c_j(t) + z(t) \quad jT_c \leq t \leq (j+1)T_c$$

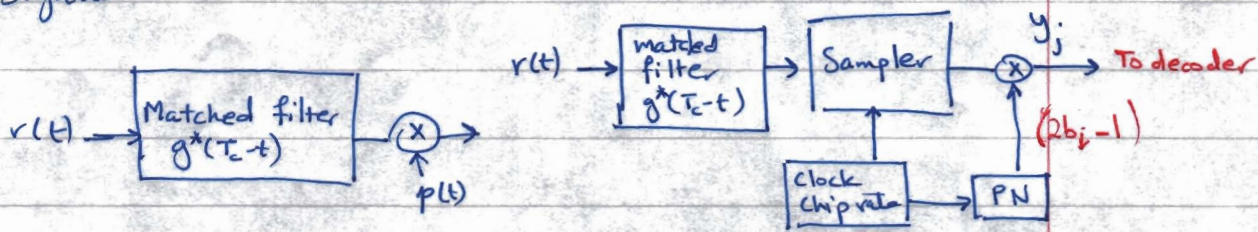
$$= (2b_j - 1) (2c_j - 1) g(t - jT_c) + z(t)$$

assumed to be stationary random process with zero mean

See Figure 13.2.2

Possible Demodulator structures for PN spread spectrum signals

Signals



multiplying by  $(2b_i - 1)$  takes out the effect of the PN sequence  
 other implementations are shown in Figure 13.2.2 (b) & (c)

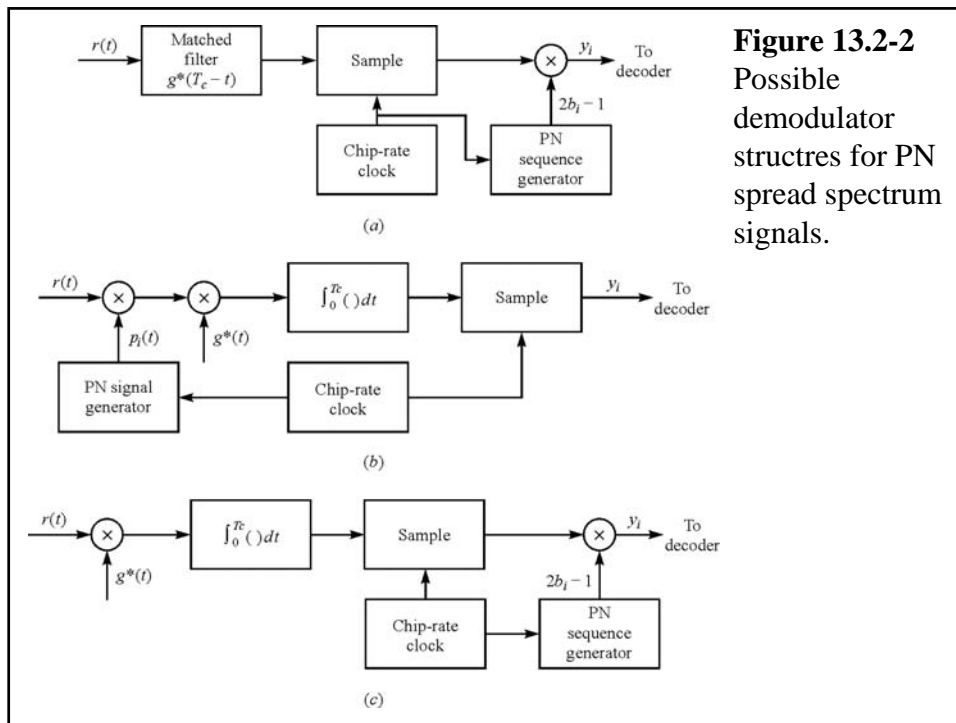
In 13-2-2 (b) we are multiplying before filtering

(c) we are using a correlator instead of a matched Filter

optimality of matched filter assume "Gaussianity"

if  $z(t)$  is not Gaussian  $\Rightarrow$  no optimality.

if noise distribution is not known, we still can use it.



**Figure 13.2-2**  
Possible demodulator structures for PN spread spectrum signals.

### 13.2.1 Error Rate Performance of the Decoder. p733

Codeed (They might not have enough coding background).

The processing gain & the jamming margin. p738.

$$E_b = P_{av} T_b = \frac{P_{av}}{R} \quad \begin{array}{l} E_b \\ \text{Energy per bit in terms of average power } P_{av}. \\ T_b: \text{ bit interval.} \end{array}$$

$\frac{P_{av}}{J_{av}}$  signal to jamming power ratio.

$J_0$ : The power spectral density for the jamming signal. (+  $N_0$ )

$$J_0 = \frac{J_{av}}{W}$$

$$\frac{E_b}{J_0} = \frac{P_{av}/R}{J_{av}/W} = \frac{W/R}{J_{av}/P_{av}} \quad \begin{array}{l} \frac{W}{R} = \frac{T_b}{T_c} = B_c = L_c = G_p. \\ \text{usually } > 1 \end{array}$$

processing gain: the advantage gained over the jammer that is obtained by expanding the BW of the transmitted signal.

let  $E_b/J_0$  be interpreted as SNR required a specified error rate performance. and

$W/R$  available bandwidth expansion factor.

$\frac{J_{av}}{P_{av}}$  Jamming margin. of DSSS sys.  
i.e. the largest value that  $\frac{J_{av}}{P_{av}}$  can take and still satisfy  $P_e$

Before.  
→ Page 7.5 ←

Example  
suppose we which to maintain  $P_e \leq 10^{-6}$ . The system has  
what is the jamming margin?

$$\frac{W}{R} = 1000.$$

For  $P_e = 10^{-6}$  we require  $\frac{E_b}{J_0} = 10.5 \text{ dB}$

$$G_p = 30 \text{ dB}$$

$$\therefore \text{Jamming margin} = 30 - 10.5 = 19.5 \text{ dB}$$

That is the received signal can be detected reliably (at  $P_e = 10^{-6}$ ) even when the interference is up to 100 times the received signal.

⇒ One can design the sys for a given jamming margin.

→ See in class practice  
p.8