SPREAD-SPECTRUM TECHNIQUES:
A BRIEF OVERVIEW

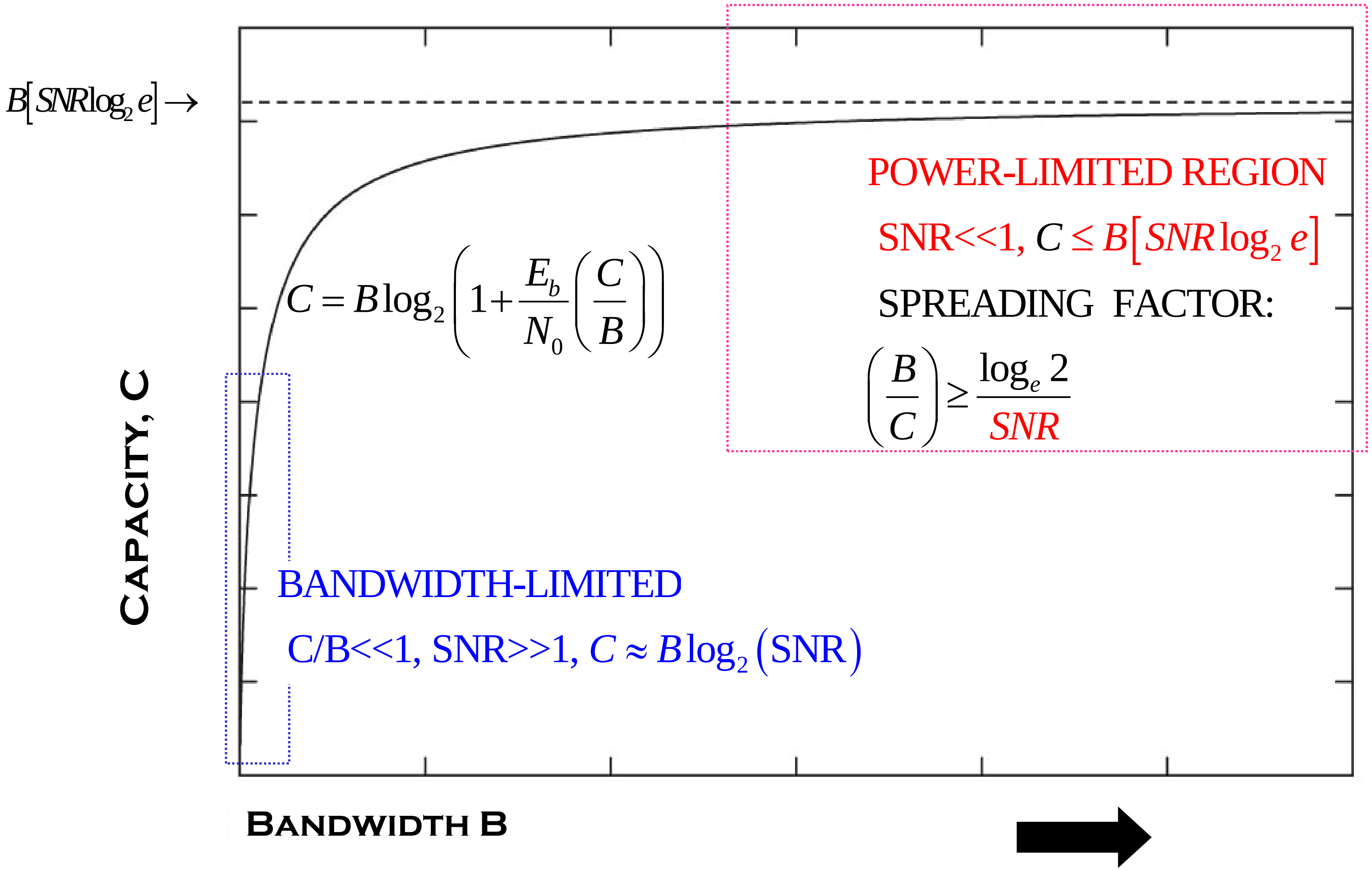
SS: AN OVERVIEW

- Spread Spectrum (SS) is a means of transmission in which the signal occupies a bandwidth in **excess** of the minimum necessary to send the information.
- Wideband FM could be classified as a SS technique. RF spectrum produced is much wider than baseband signal. FM "Processing Gain": $SNR_{out} = 3\beta^2 SNR_{in}$

  $\beta = \Delta f / fm$: MODULATION INDEX (DEVIATION RATIO)

  FM Bandwidth (Carson's rule): $BW = 2fm\,(1 + \beta)$
- The bandwidth spread is accomplished by means of a **code** which is **independent** of the data, and a synchronized reception with the code at the receiver is used for **de-spreading** and subsequent data recovery.
- SS can hide signal below noise (DS) or makes it hard to track (FH):
  - Direction Sequence (DS): Modulated signal multiplied by faster chip sequence
  - Frequency Hopping (FH): Narrowband signal hopped over wide bandwidth
- Also used as a multiple access technique

A SIMPLIFIED VIEW FROM CAPACITY FORMULA

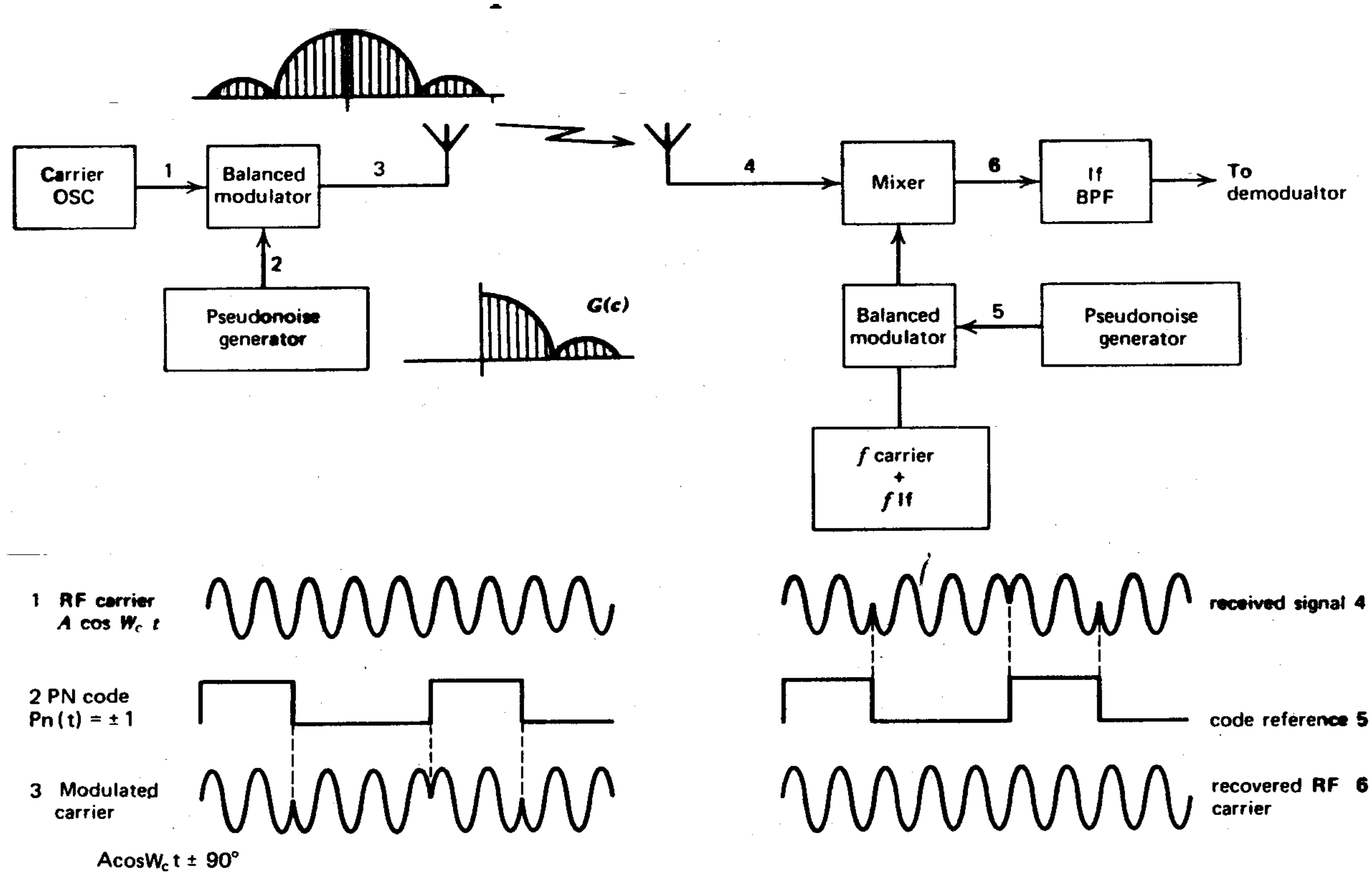


REASONS FOR SPREAD SPECTRUM:

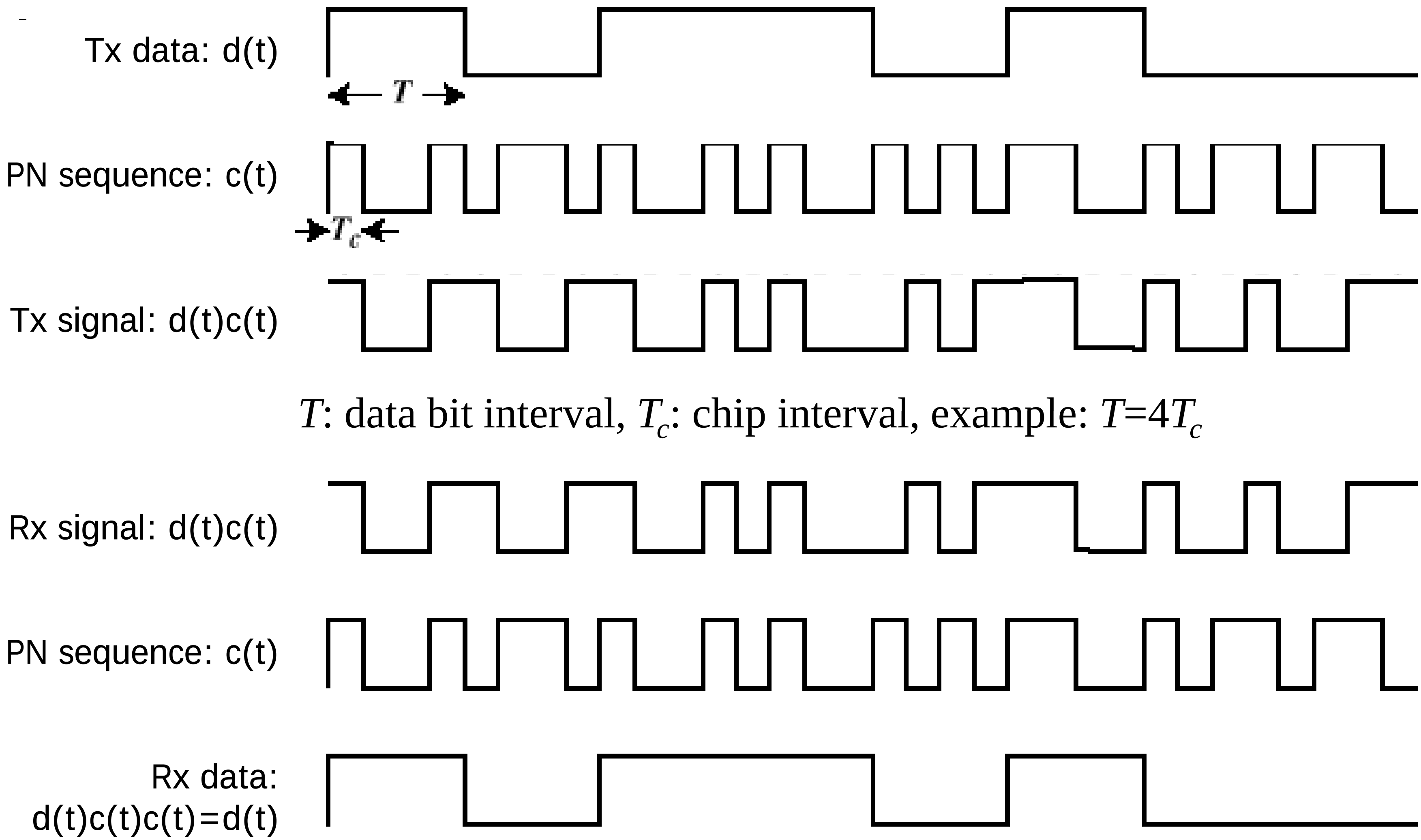
- Anti-Jamming
- Anti-Interference (e.g., multipath distortion)
- Low Probability of intercept (LPI) (or detector LPD): LPD communication systems are designed to make their detection as difficult as possible by anyone but the intended receiver.
- Multiple-Access Communications: Several users can independently use the same higher bandwidth with very little interference
- High Resolution Ranging (e.g. GPS)
- Accurate Universal Timing

DIRECT-SEQUENCE SPREAD SPECTRUM TECHNIQUES:

Fast pseudo-randomly generated sequence causes phase transitions in the carrier containing data.

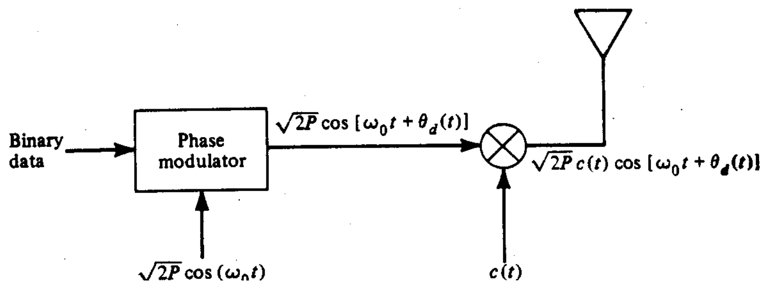


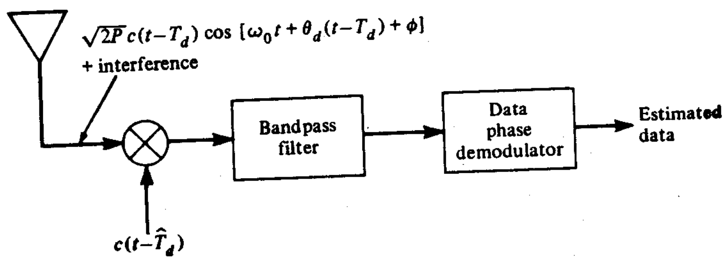
DIRECT-SEQUENCE TRANSCEIVER

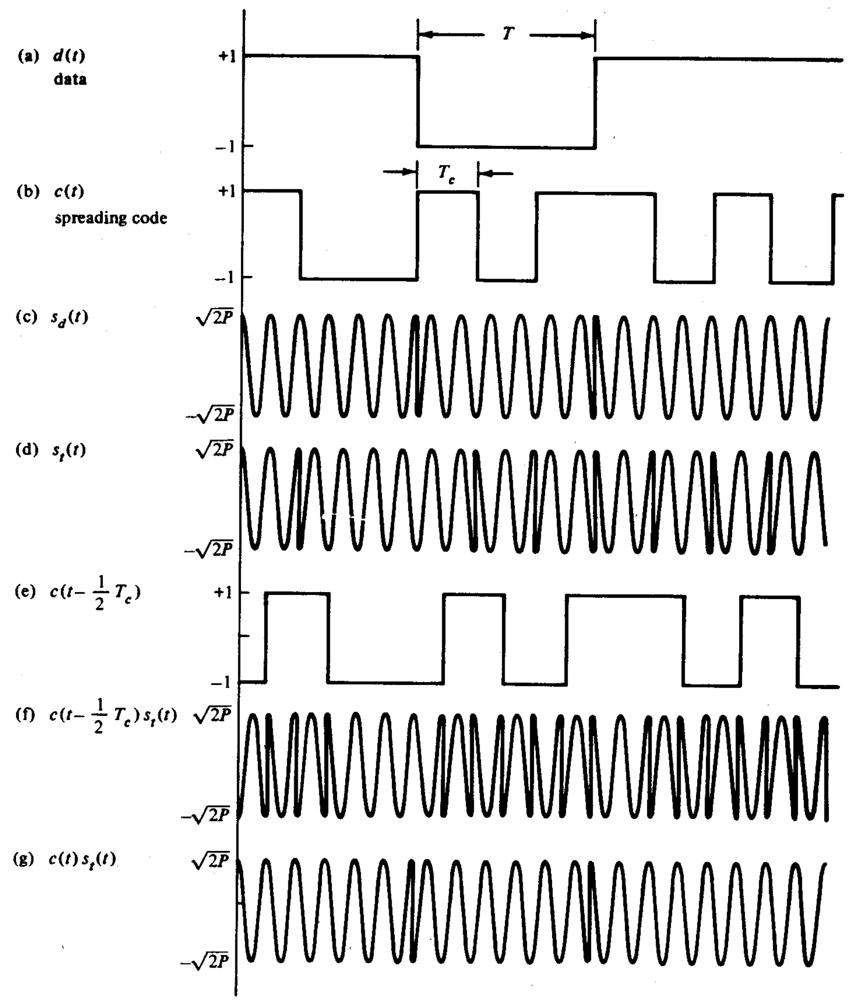


EXAMPLE OF DS SPREADING AND DESPREADING

DIRECT-SEQUENCE BPSK

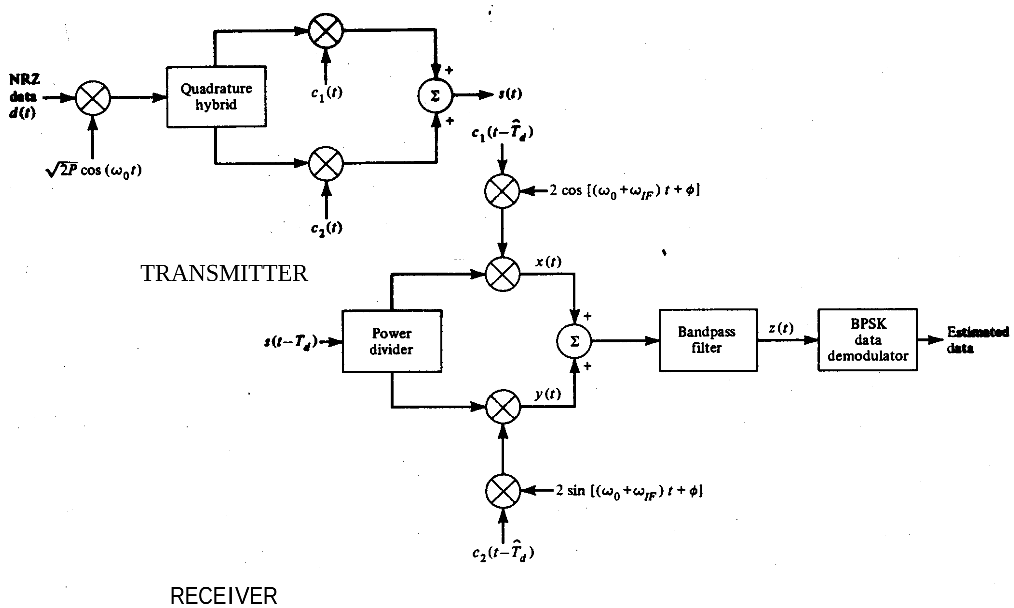




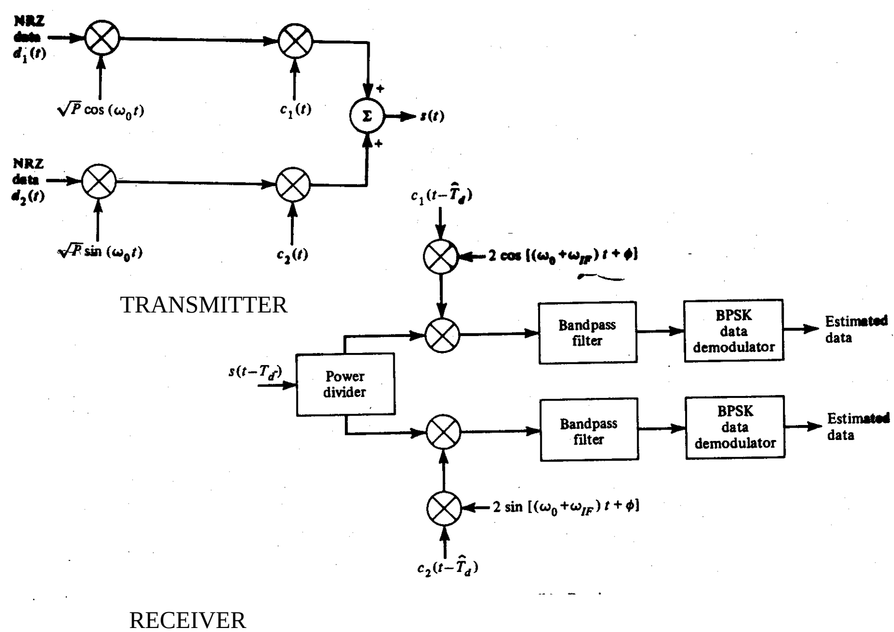


DS-QPSK

- DS-QPSK has same performance as DS-BPSK, but uses one-half the transmission bandwidth.
- It is more difficult to detect (Low Probability of detection, LPD, applications)
- It is less sensitive to some types of jamming.



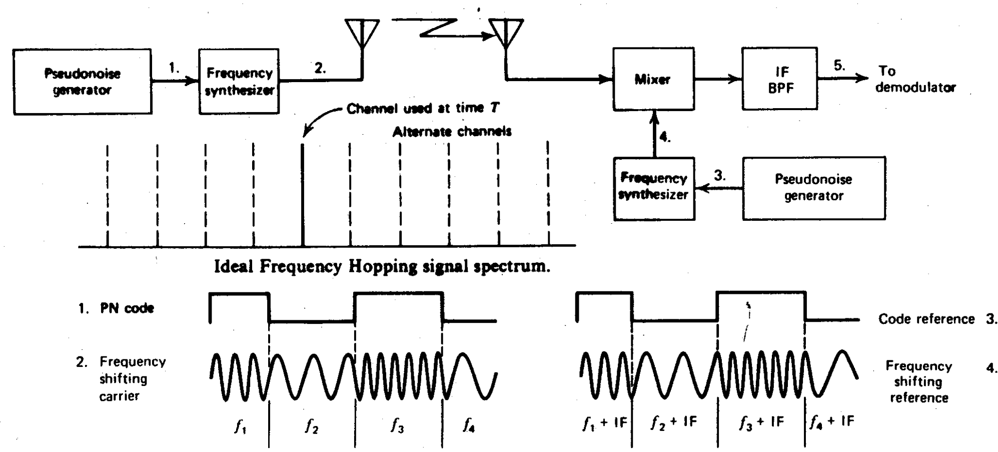
DS-QPSK

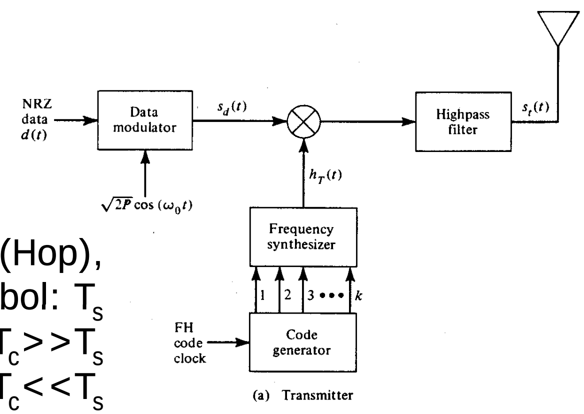


DS-QUADRATURE BPSK

FREQUENCY-HOPPING (FH)

Carrier is caused to shift frequency in a pseudo-random manner.



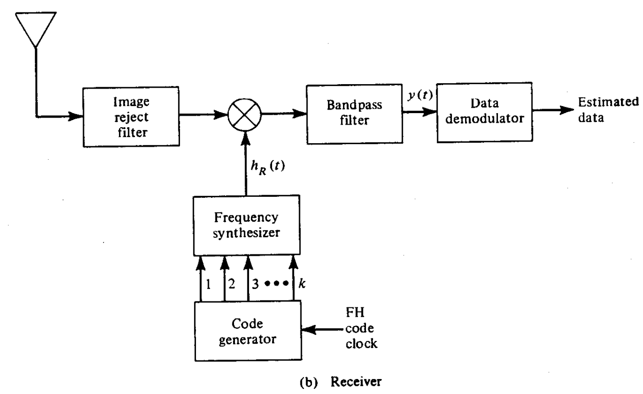


Duration of frequency synthesizer output: T_c (Hop),

Duration of data symbol: T_s

Slow Hopping: $T_c >> T_s$

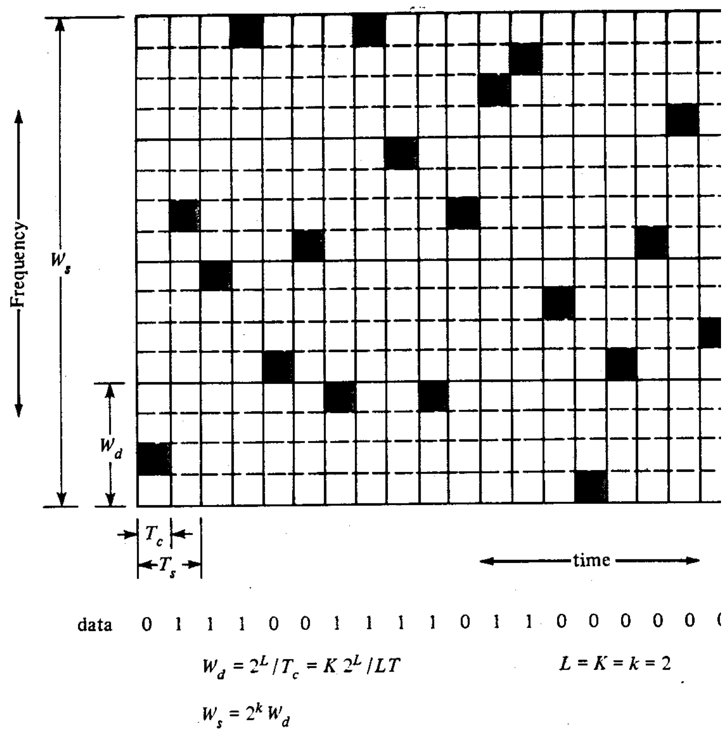
Fast Hopping: $T_c << T_s$



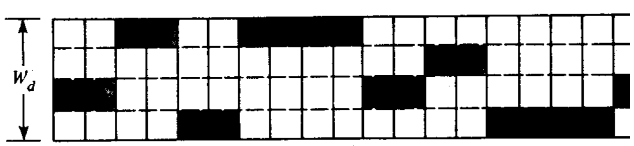
Carrier frequency is changed in a pseudo-random manner.

Most FH systems use either non-coherent or differential demodulation schemes because of the difficulty of building truly coherent frequency synthesizers as well as code tracking requirements.

EXAMPLE OF FH-4FSK



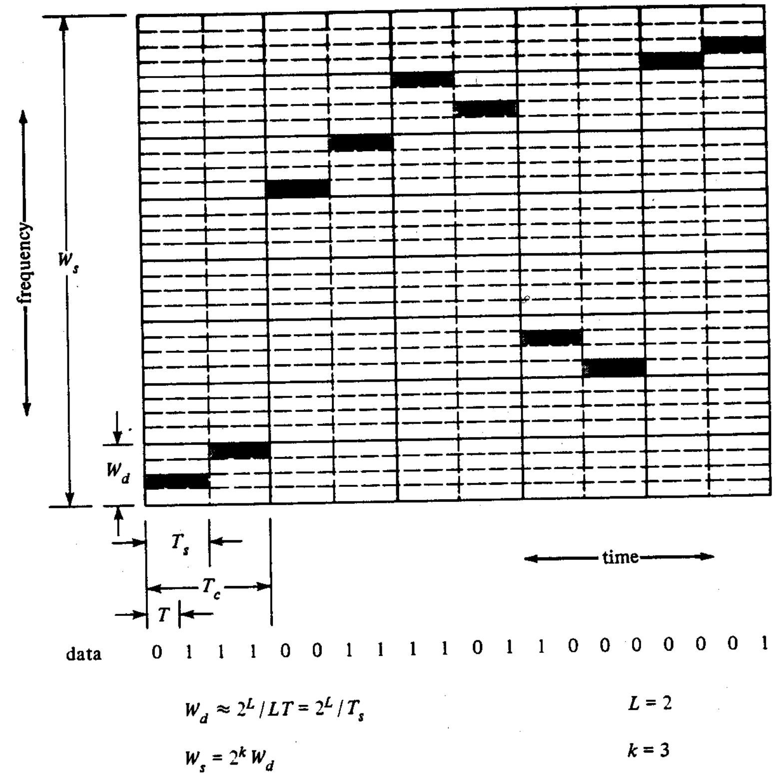
FH-4FSK FREQUENCY PATTERN



4FSK FREQUENCY PATTERN

w_d: data bandwidth
W_s: FH bandwidth

FAST HOPPING, $T_C < T_S$



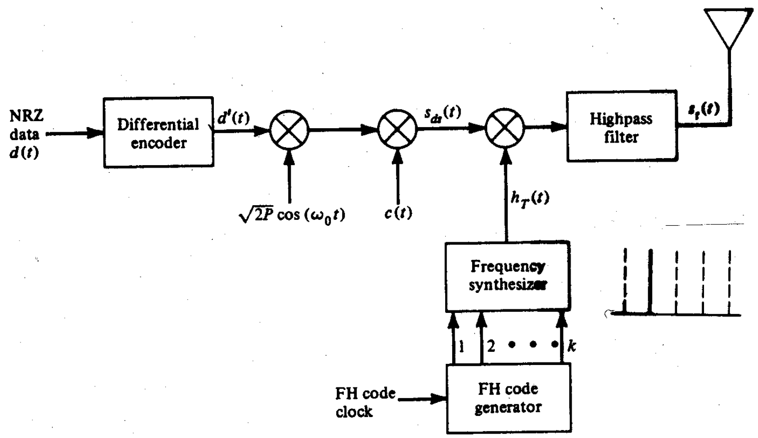
FH-4FSK FREQUENCY PATTERN

4FSK FREQUENCY PATTERN

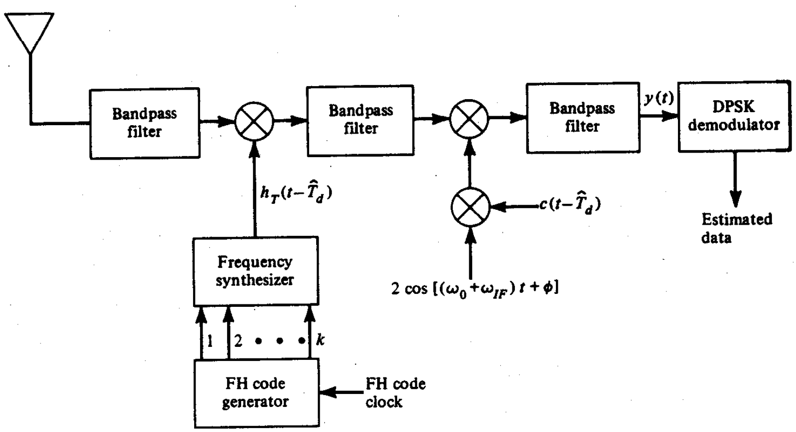
w_d: data bandwidth
W_s: FH bandwidth

SLOW HOPPING, $T_C > T_s$

HYBRID DS/FH TECHNIQUES:



(a) Transmitter



(b) Receiver

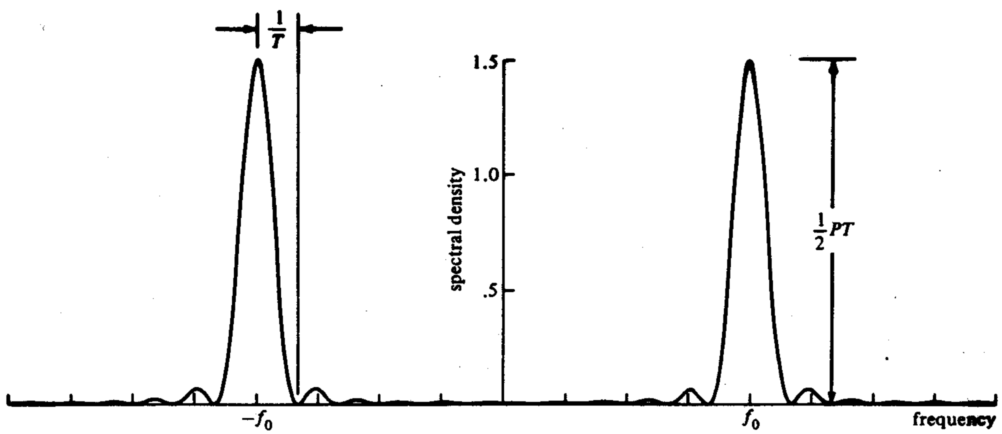
DS AND FH SYSTEMS

•NEED OF ERROR CORRECTION CODING IN FH SYSTEMS: Given a large-power jammer in a frequency slot, errors will occur every time this slot is used. This yields an average error probability of i/N where N is the number of frequency slots over which the signal can hop. Error correction coding is needed to overcome this problem

DS can have more synchronization difficulties due to high-speed operation and long initial acquisition time.

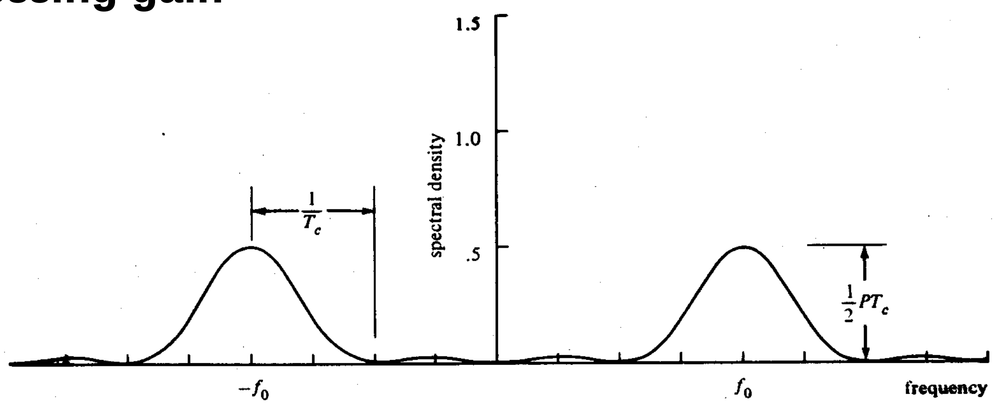
DS spectrum looks relatively uniform (except for very short codes).

SPECTRA OF MODULATED & SS SIGNALS



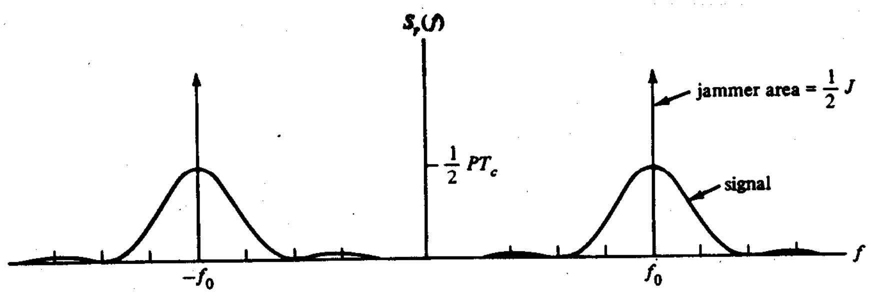
PSD OF MODULATED SIGNAL

With SS: **processing gain**
$P_G = R_C/R = T/T_c$

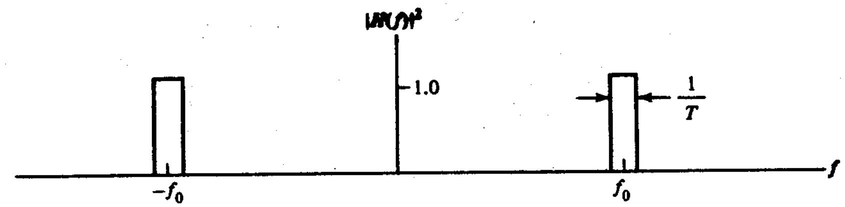


PSD OF MODULATED SS SIGNAL

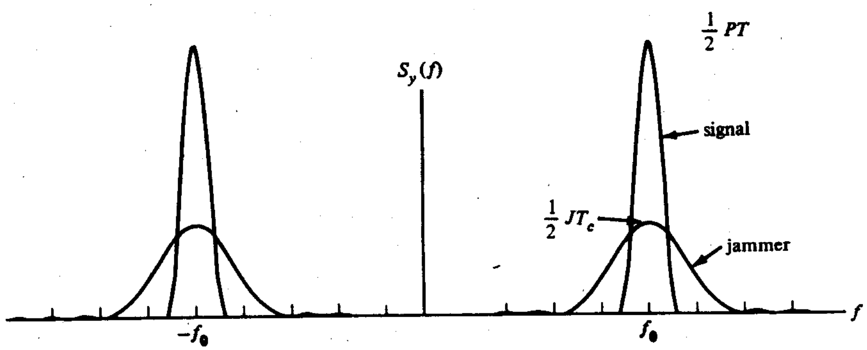
SINGLE-TONE JAMMER



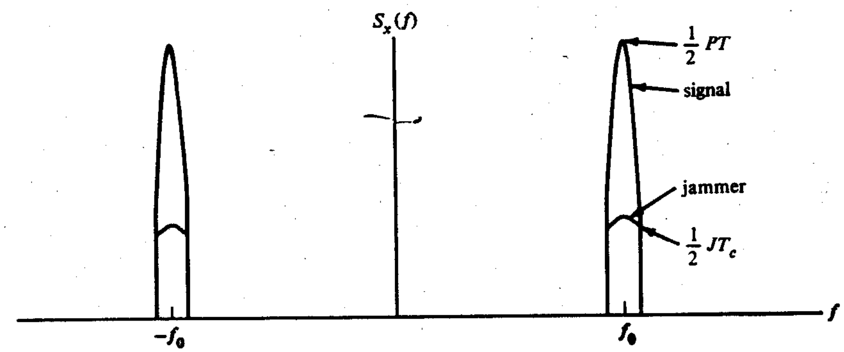
SS SIGNAL AND JAMMER



RESPONSE OF SIGNAL BPF (IDEAL)



SS SIGNAL AND JAMMER AFTER DESPREADING



OUTPUT OF BPF (IDEAL)

Single-tone jammer is at the center frequency.
Without SS, the signal-to-jammer power ratio is exactly S/J.
With SS, the signal-to-jammer power ratio after de-spreading (at demodulator input after IF filtering) is increased to P_G[S/J], i.e., improved by a factor equal to the **processing gain**.

PULSE-NOISE JAMMING

Main signal: Tx bit rate R, energy per bit: E_b, average power: $S=E_bR$,
PULSE-NOISE JAMMER: transmits pulses of band-limited white Gaussian noise with total average power J referred to the receiver front-end.
Pulse duty factor: e
Bandwidth: W (Transmission bandwidth),
jamming power spectra density: $J_o=J/[eW]$

WITHOUT SS: W=R

Bit error probability of a coherent BPSK in an AWGN environment:

$$P_b = Q\left(\sqrt{2E_b / N_o}\right)$$

During the pulse-noise jamming: $\left[E_b / N_o\right] \Rightarrow \left[E_b / \left(N_o + J_o\right)\right] = \left(\left[N_o / E_b\right] + \left[J / S\right]\right)^{-1}$

Average bit error probability with pulse-noise jamming:

$$P_{bJ} = (1-e)Q\left(\sqrt{2E_b / N_o}\right) + eQ\left(\sqrt{2E_b / \left[N_o + J_o\right]}\right)$$

The jammer selects emax to maximize Pb!

$$P_{bJ,\max} \approx \left(\sqrt{2\pi e}\left[E_b / (J / W)\right]\right)^{-1}$$

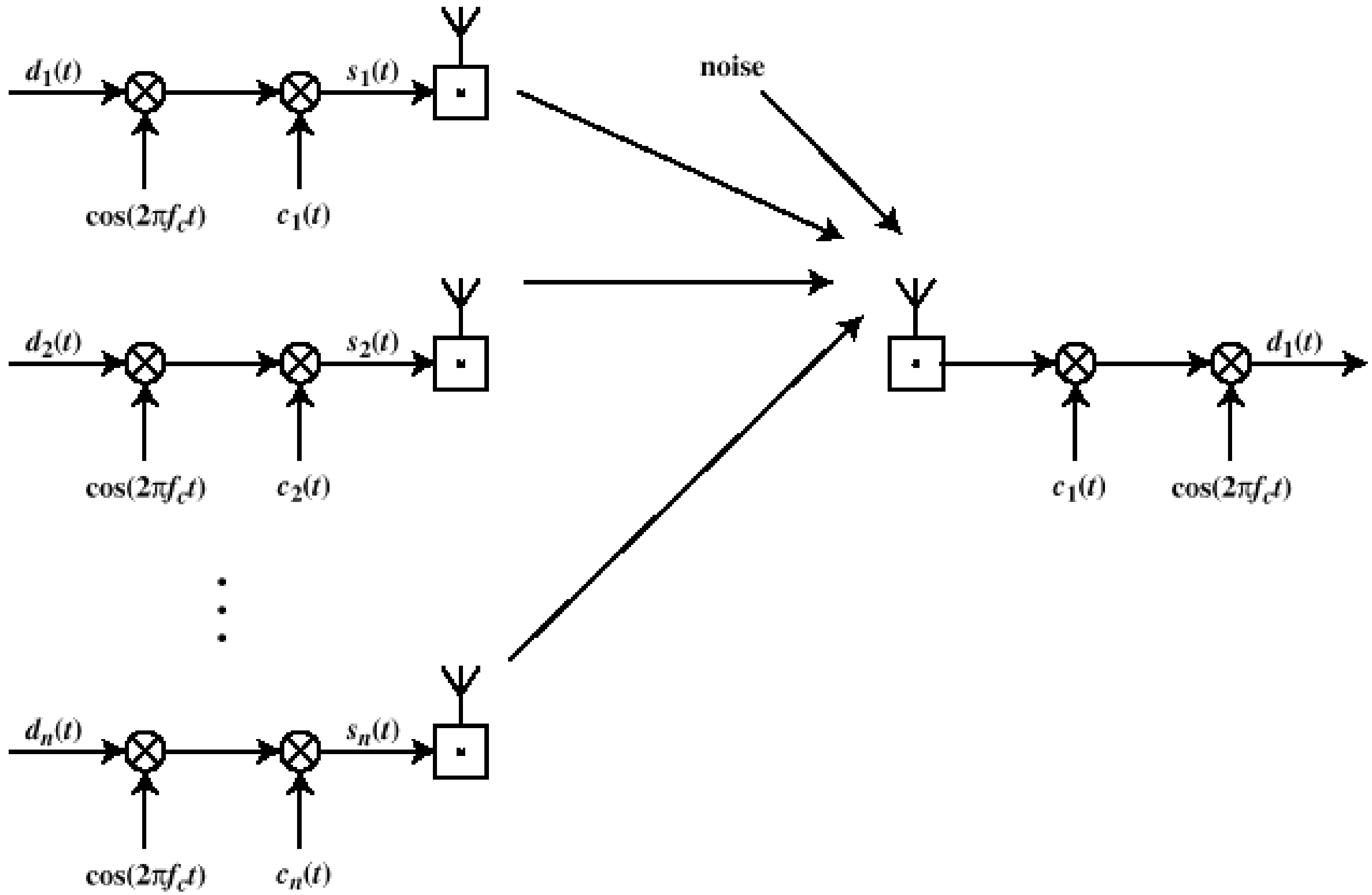
processing gain with SS

Pulse-noise jammer with wide bandwidth: W = R_c (transmission bandwidth)
With SS: **processing gain** $P_G = R_C / R$
During the pulse-noise jamming:

$$[E_b / N_o] \Rightarrow [E_b / (N_o + J_o)] = \left([N_o / E_b] + [(J / eR_c) / (S / R)] \right)^{-1} = \left([N_o / E_b] + [(J / eS) / P_G] \right)^{-1}$$

$$P_G >> 1 \Rightarrow [(J / eS) / P_G] \approx 0 \text{ (greatly reduced)}, \ [J / S]: \text{Jammer-to-Signal Power Ratio}$$

The **jamming margin** is the largest value that the ratio J/S can take and still satisfy the specified performance (error probability).



Code-Division Multiple Access (CDMA) using DS