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Spread Spectrum

Chapter 7



Spread Spectrum

- Input is fed into a channel encoder
 - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
 - Spreading code or spreading sequence
 - Generated by pseudonoise, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted



Spread Spectrum

- On receiving end, digit sequence is used to demodulate the spread spectrum signal
- Signal is fed into a channel decoder to recover data

Spread Spectrum

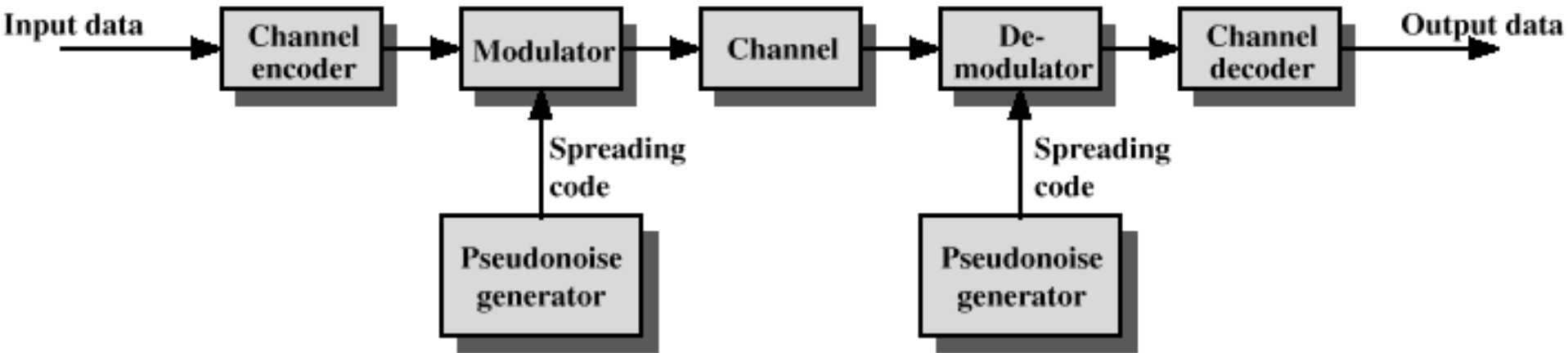


Figure 7.1 General Model of Spread Spectrum Digital Communication System



Spread Spectrum

- What can be gained from apparent waste of spectrum?
 - Immunity from various kinds of noise and multipath distortion
 - Can be used for hiding and encrypting signals
 - Several users can independently use the same higher bandwidth with very little interference

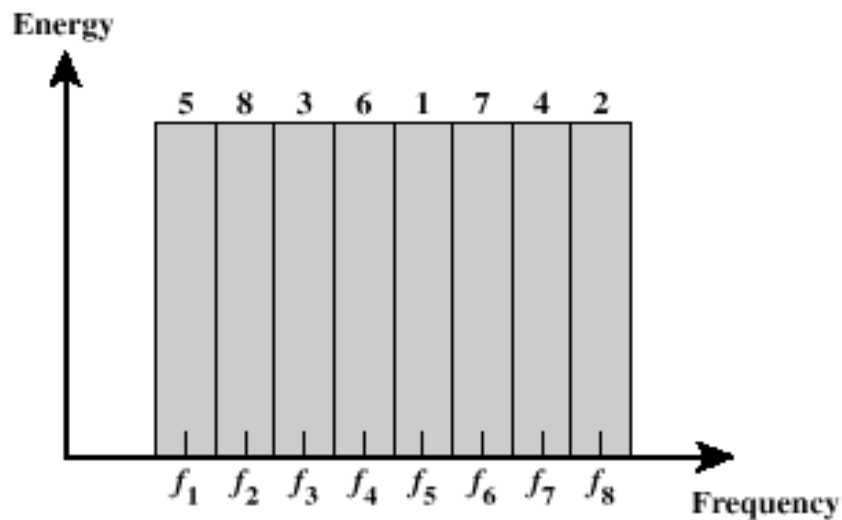
Frequency Hopping Spread Spectrum (FHSS)

- Signal is broadcast over seemingly random series of radio frequencies
 - A number of channels allocated for the FH signal
 - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
 - Transmitter operates in one channel at a time
 - Bits are transmitted using some encoding scheme
 - At each successive interval, a new carrier frequency is selected

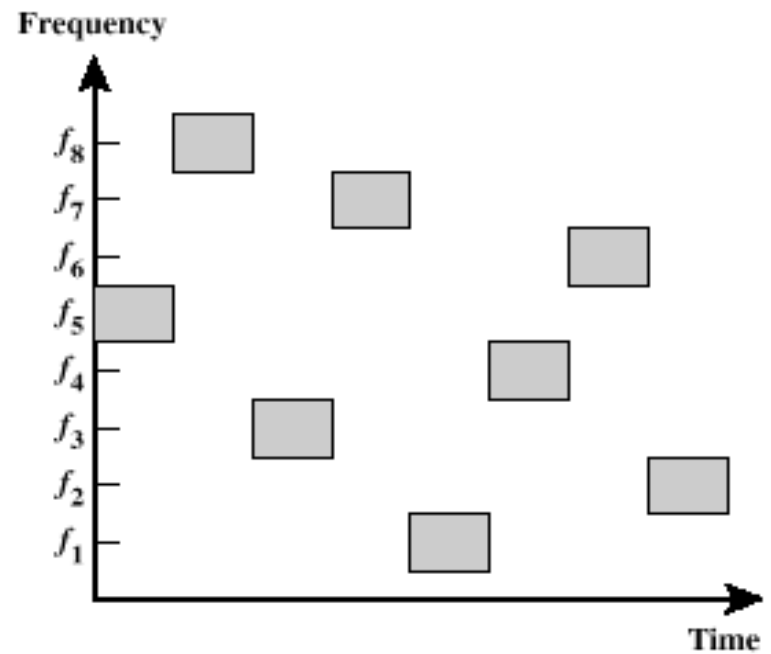
Frequency Hopping Spread Spectrum

- Channel sequence dictated by spreading code
- Receiver, hopping between frequencies in synchronization with transmitter, picks up message
- Advantages
 - Eavesdroppers hear only unintelligible blips
 - Attempts to jam signal on one frequency succeed only at knocking out a few bits

Frequency Hopping Spread Spectrum



(a) Channel assignment



(b) Channel use

Figure 7.2 Frequency Hopping Example

FHSS Using MFSK

- MFSK signal is translated to a new frequency every T_c seconds by modulating the MFSK signal with the FHSS carrier signal
- For data rate of R :
 - duration of a bit: $T = 1/R$ seconds
 - duration of signal element: $T_s = LT$ seconds
- $T_c \geq T_s$ - slow-frequency-hop spread spectrum
- $T_c < T_s$ - fast-frequency-hop spread spectrum



Considerations

- Large number of frequencies used
- Results in a system that is quite resistant to jamming
 - Jammer must jam all frequencies
 - With fixed power, this reduces the jamming power in any one frequency band

Sequence Spread Spectrum (DSSS)

- Each bit in original signal is represented by multiple bits in the transmitted signal
- Spreading code spreads signal across a wider frequency band
 - Spread is in direct proportion to number of bits used
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR (Figure 7.6)

Sequence Spread

0 1 0 0 1 0 1 1

Data input A

$\leftarrow T \rightarrow$

Locally generated
PN bit stream

0 1 1 0 1 0 0 1 0 1 1 0 1 0 1 0 1 0 0 1 1 0 1 0 0 1 0 0 1

$\rightarrow T_c \leftarrow$

Transmitted signal
 $C = A \oplus B$

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

Locally generated
PN bit stream
identical to B
above

Data output
 $A = C \oplus B$

Figure 7.6 Example of Direct Sequence Spread Spectrum

DSSS Using BPSK

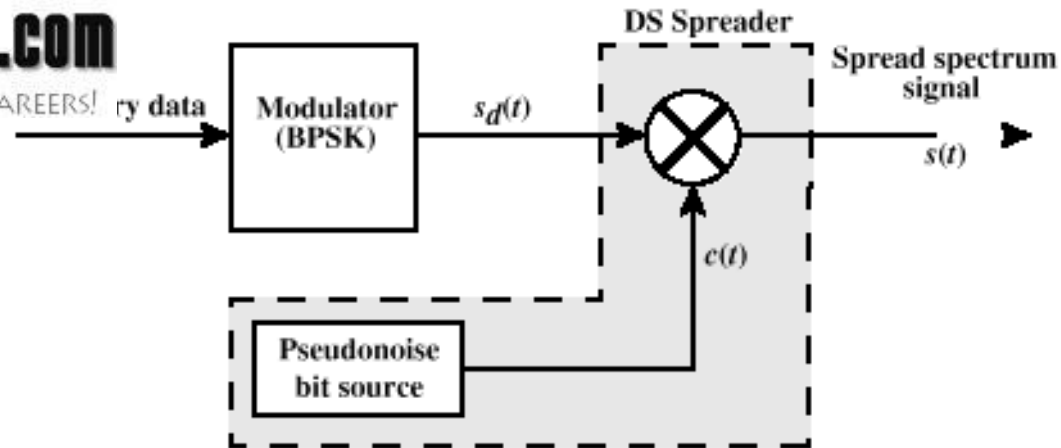
- Multiply BPSK signal,

$$s_d(t) = A d(t) \cos(2\pi f_c t)$$

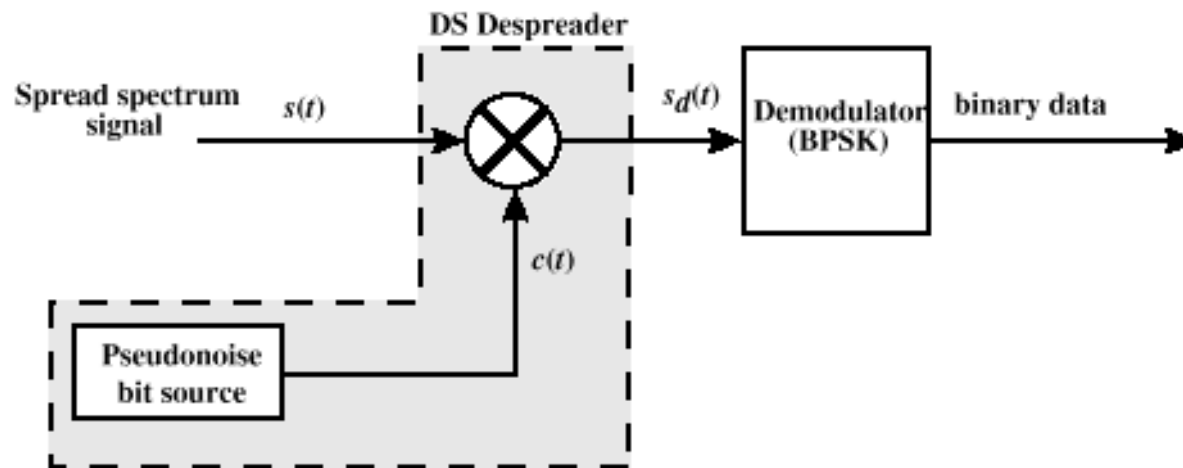
by $c(t)$ [takes values +1, -1] to get

$$s(t) = A d(t)c(t) \cos(2\pi f_c t)$$

- A = amplitude of signal
- f_c = carrier frequency
- $d(t)$ = discrete function [+1, -1]
- At receiver, incoming signal multiplied by $c(t)$
 - Since, $c(t) \times c(t) = 1$, incoming signal is recovered



(a) Transmitter



(b) Receiver

Figure 7.7 Direct Sequence Spread Spectrum System

Division Multiple Access (CDMA)

- Basic Principles of CDMA
 - D = rate of data signal
 - Break each bit into k *chips*
 - Chips are a user-specific fixed pattern
 - Chip data rate of new channel = kD



CDMA Example

- If $k=6$ and code is a sequence of 1s and -1s
 - For a '1' bit, A sends code as chip pattern
 - $\langle c1, c2, c3, c4, c5, c6 \rangle$
 - For a '0' bit, A sends complement of code
 - $\langle -c1, -c2, -c3, -c4, -c5, -c6 \rangle$
- Receiver knows sender's code and performs electronic decode function

$$S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6$$

- $\langle d1, d2, d3, d4, d5, d6 \rangle$ = received chip pattern
- $\langle c1, c2, c3, c4, c5, c6 \rangle$ = sender's code



CDMA Example

- User A code = $\langle 1, -1, -1, 1, -1, 1 \rangle$
 - To send a 1 bit = $\langle 1, -1, -1, 1, -1, 1 \rangle$
 - To send a 0 bit = $\langle -1, 1, 1, -1, 1, -1 \rangle$
- User B code = $\langle 1, 1, -1, -1, 1, 1 \rangle$
 - To send a 1 bit = $\langle 1, 1, -1, -1, 1, 1 \rangle$
- Receiver receiving with A's code
 - (A's code) x (received chip pattern)
 - User A '1' bit: 6 \rightarrow 1
 - User A '0' bit: -6 \rightarrow 0
 - User B '1' bit: 0 \rightarrow unwanted signal ignored

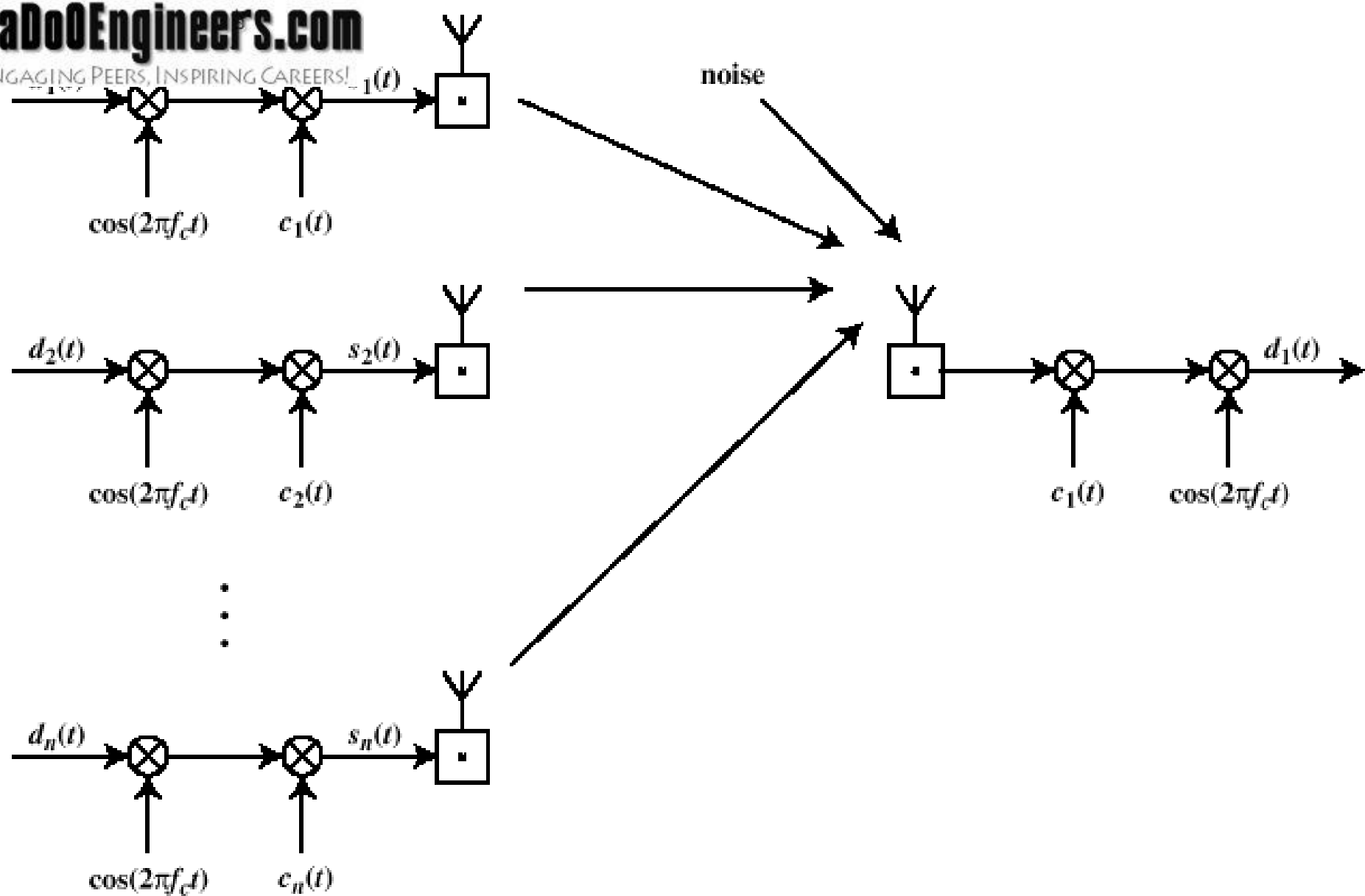


Figure 7.11 CDMA in a DSSS Environment

Properties of Spreading Sequences

- Spreading Sequence Categories
 - PN sequences
 - Orthogonal codes
- For FHSS systems
 - PN sequences most common
- For DSSS systems not employing CDMA
 - PN sequences most common
- For DSSS CDMA systems
 - PN sequences
 - Orthogonal codes



PN Sequences

- PN generator produces periodic sequence that appears to be random
- PN Sequences
 - Generated by an algorithm using initial seed
 - Sequence isn't statistically random but will pass many test of randomness
 - Sequences referred to as pseudorandom numbers or pseudonoise sequences
 - Unless algorithm and seed are known, the sequence is impractical to predict



Important PN Properties

- Randomness
 - Uniform distribution
 - Balance property
 - Run property
 - Independence
 - Correlation property
- Unpredictability

Implementation

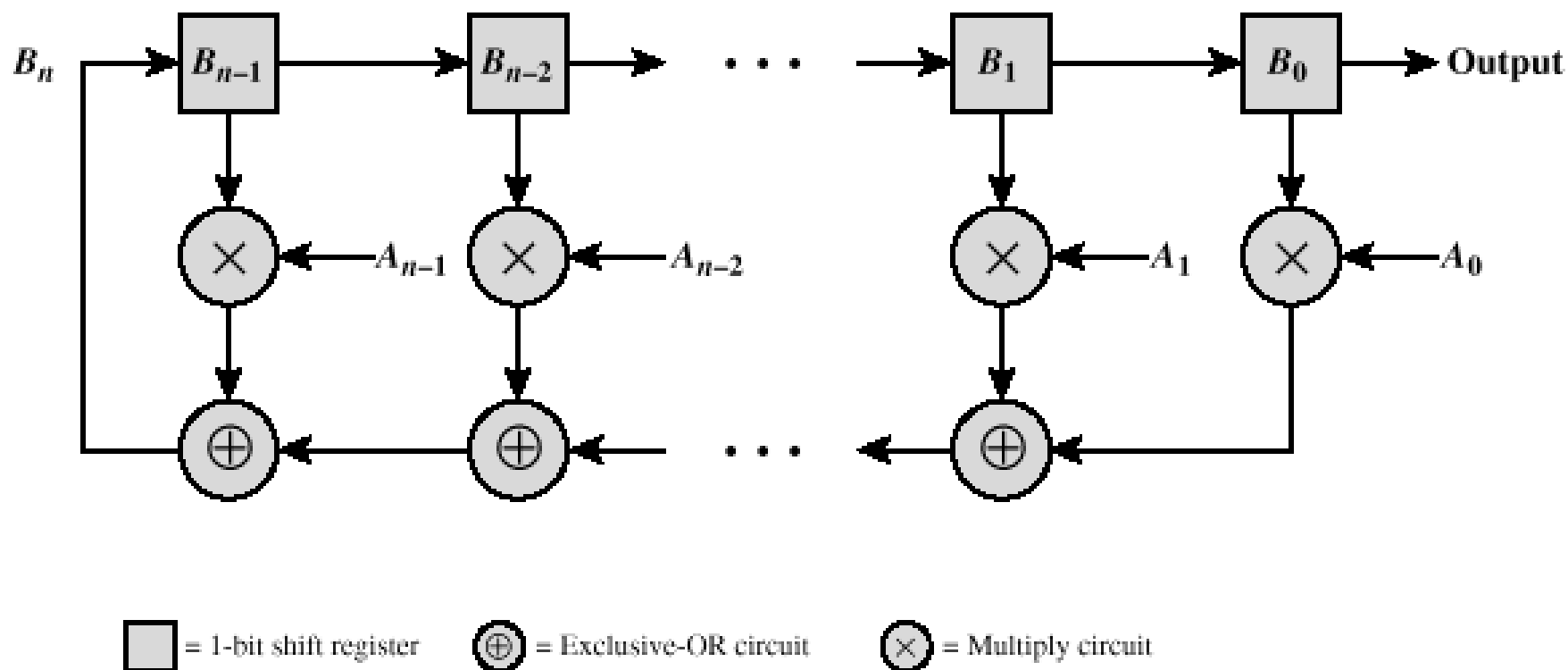


Figure 7.12 Binary Linear Feedback Shift Register Sequence Generator

Properties of M-Sequences

- Property 1:
 - Has 2^{n-1} ones and $2^{n-1}-1$ zeros
- Property 2:
 - For a window of length n slid along output for $N (=2^{n-1})$ shifts, each n -tuple appears once, except for the all zeros sequence
- Property 3:
 - Sequence contains one run of ones, length n
 - One run of zeros, length $n-1$
 - One run of ones and one run of zeros, length $n-2$
 - Two runs of ones and two runs of zeros, length $n-3$
 - 2^{n-3} runs of ones and 2^{n-3} runs of zeros, length 1

Properties of M-Sequences

- Property 4:
 - The periodic autocorrelation of a ± 1 m-sequence is

$$R(\tau) = \begin{cases} 1 & \tau = 0, N, 2N, \dots \\ -\frac{1}{N} & \text{otherwise} \end{cases}$$



Definitions

- Correlation

- The concept of determining how much similarity one set of data has with another
- Range between -1 and 1
 - 1 The second sequence matches the first sequence
 - 0 There is no relation at all between the two sequences
 - -1 The two sequences are mirror images

- Cross correlation

- The comparison between two sequences from different sources rather than a shifted copy of a sequence with itself

Advantages of Cross Correlation

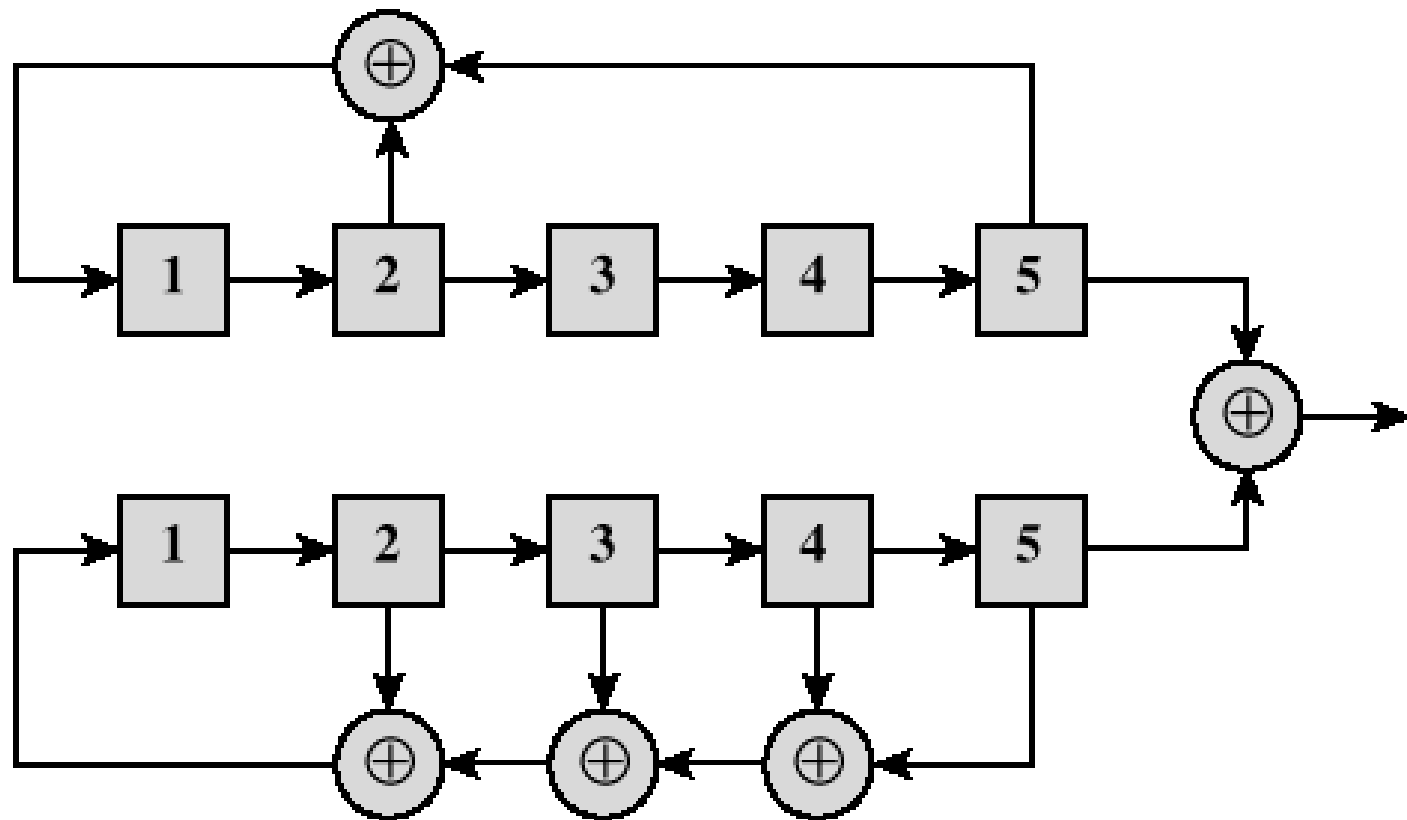
- The cross correlation between an m-sequence and noise is low
 - This property is useful to the receiver in filtering out noise
- The cross correlation between two different m-sequences is low
 - This property is useful for CDMA applications
 - Enables a receiver to discriminate among spread spectrum signals generated by different m-sequences



Gold Sequences

- Gold sequences constructed by the XOR of two m-sequences with the same clocking
- Codes have well-defined cross correlation properties
- Only simple circuitry needed to generate large number of unique codes
- In following example (Figure 7.16a) two shift registers generate the two m-sequences and these are then bitwise XORed

Gold Sequences



(a) Shift-register implementation



Orthogonal Codes

- Orthogonal codes
 - All pairwise cross correlations are zero
 - Fixed- and variable-length codes used in CDMA systems
 - For CDMA application, each mobile user uses one sequence in the set as a spreading code
 - Provides zero cross correlation among all users
- Types
 - Welsh codes
 - Variable-Length Orthogonal codes



Walsh Codes

- Set of Walsh codes of length n consists of the n rows of an $n \times n$ Walsh matrix:

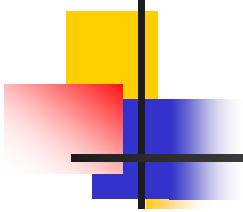
- $W_1 = (0)$ $W_{2n} = \begin{pmatrix} W_n & W_{2n} \\ W_n & \overline{W_n} \end{pmatrix}$

- n = dimension of the matrix
- Every row is orthogonal to every other row and to the logical not of every other row
- Requires tight synchronization
 - Cross correlation between different shifts of Walsh sequences is not zero

al Multiple Spreading

Approach

- Spread data rate by an orthogonal code (channelization code)
 - Provides mutual orthogonality among all users in the same cell
- Further spread result by a PN sequence (scrambling code)
 - Provides mutual randomness (low cross correlation) between users in different cells



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