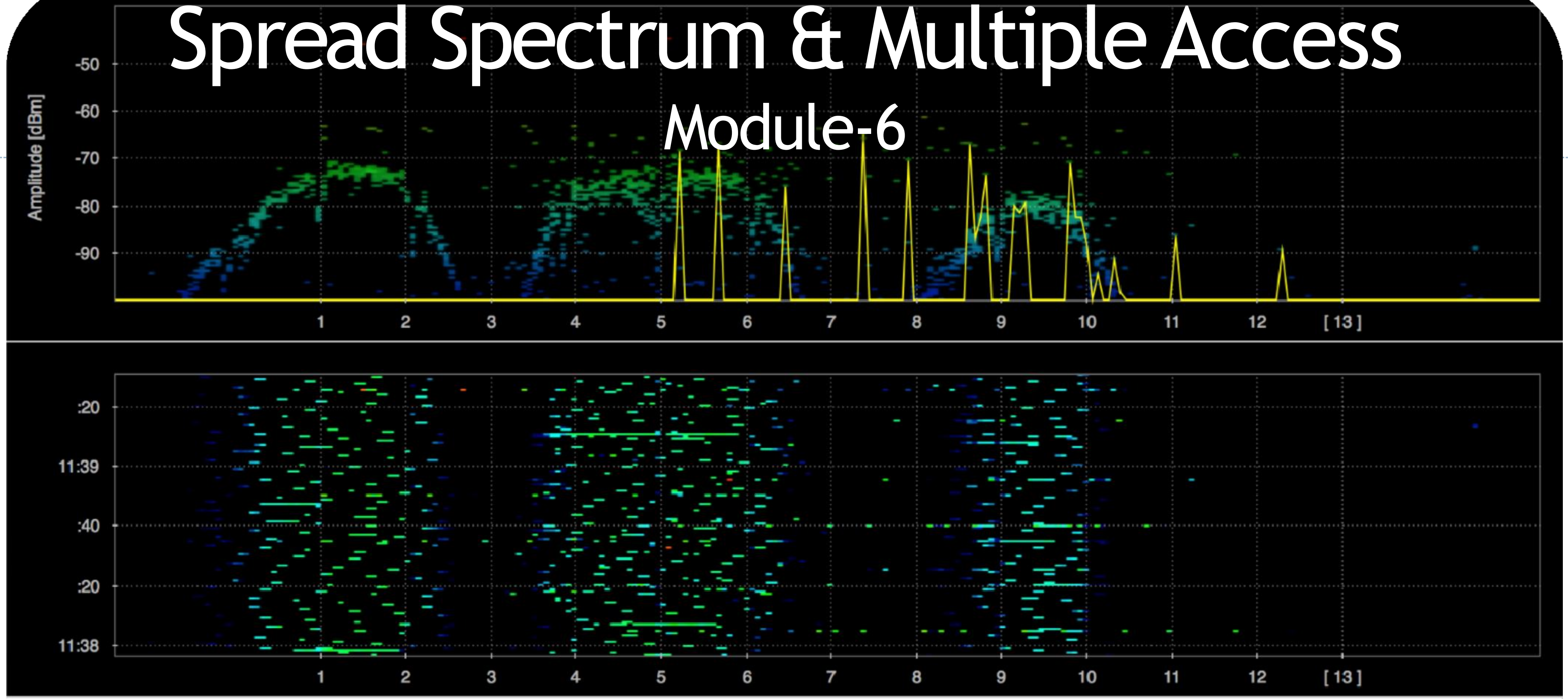
Spread Spectrum & Multiple Access

Module-6



MAC	SSID	RSSI	Channel	Vendor	Security	Max Rate	Noise	Last Seen	Mode
38:d5:47:db:a6:8c	Mayfield_5G	-48	36 + 40		WPA2 PSK	216	0	11:39:29 AM	802.11A
38:d5:47:db:a6:88	Mayfield_2G	-53	9		WPA2 PSK	195	0	11:39:29 AM	Unknown
f4:f5:e8:69:a1:6a	MayfieldNetGF	-37	5		WPA2 PSK	195	-95	11:39:29 AM	Unknown
f4:f5:e8:69:a1:6b	MayfieldNetGF	-48	149 + 153		WPA2 PSK	195	0	11:39:29 AM	802.11A
f4:f5:e8:81:55:c6	lemontree1	-82	11		WPA2 PSK	195	0	11:39:29 AM	Unknown
0f:25:00:ff:a8:a4	MayfieldNetNew	-58	157 + 161		WPA2 PSK	450	0	11:38:19 AM	Unknown
f4:f5:e8:81:55:c7	lemontree1(5)	-90	149 + 153		WPA2 PSK	195	0	11:38:54 AM	802.11A
00:25:00:ff:a8:a3	MayfieldNetNew	-45	1	Apple, Inc	WPA2 PSK	195	-95	11:39:29 AM	Unknown
00:25:00:ff:a8:a4	MayfieldNetNew	-58	157 + 161	Apple, Inc	WPA2 PSK	450	0	11:39:29 AM	Unknown
00:1f:f3:f9:6f:f9	MayfieldNetNew	-68	157 + 161	Apple, Inc	WPA2 PSK	300	0	11:39:29 AM	Unknown

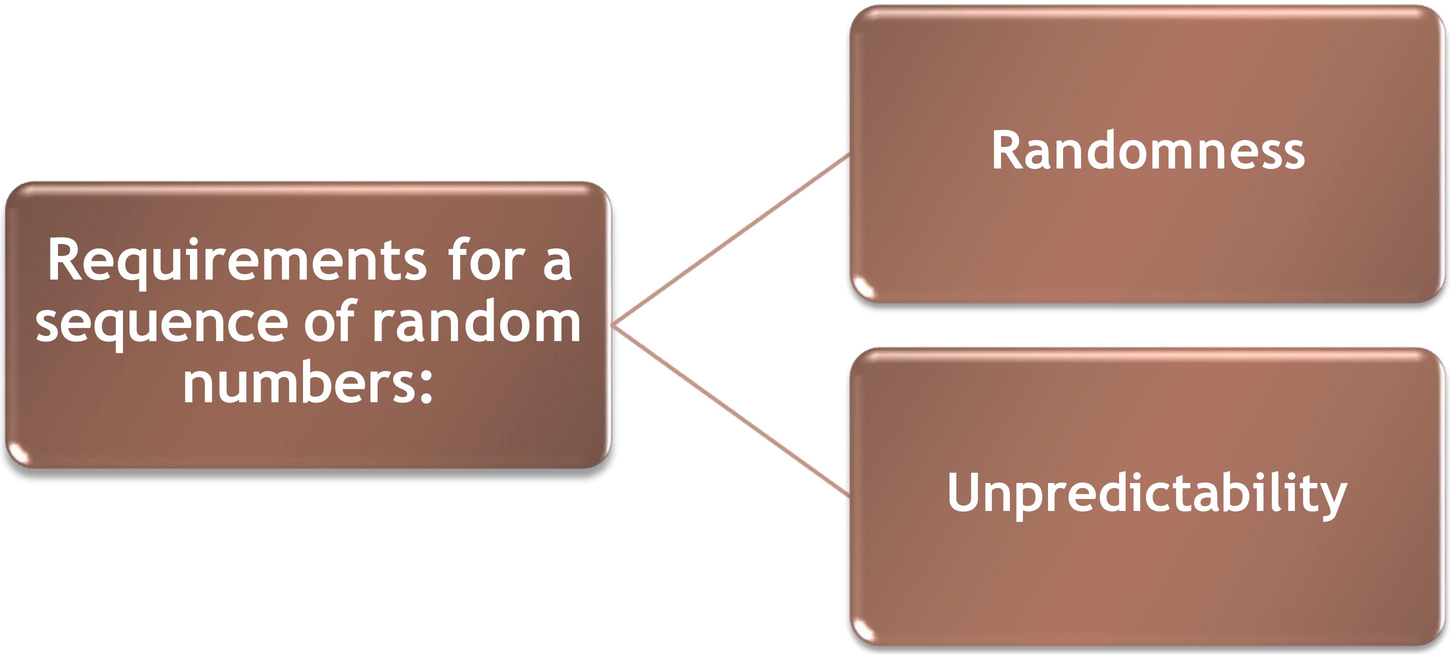
Topics to be discussed

- Generation of PN sequence and its properties
- Direct sequence spread spectrum
  - Processing gain,Probability of error,Anti-jam characteristics
- Frequency hopped spread spectrum
  - Slow and fast frequency hopping
- Multiple access techniques -TDMA, FDMA, CDMA

Introduction

- *Spread Spectrum* is a means of transmission in which the data sequence occupies a bandwidth in excess of the minimum bandwidth necessary to send it
- It is accomplished before the transmission through the use of a code that is independent of the data sequence
- The same code is used in the receiver to despread the received signal so that the original data sequence may be recovered
- It has the ability to reject *interference* whether it be the *unintentional* inference by another user or *intentional* interference by a hostile transmitter

Principles of Pseudorandom Number Generation



Principles of Pseudorandom Number Generation

Randomness

- The following two criteria are used to validate that a sequence of numbers is random:

Uniform distribution:

- The distribution of bits in the sequence should be uniform
- That is, the frequency of occurrence of ones and zeros should be approximately equal.

Independence:

- No one subsequence in the sequence can be inferred from the others.

Principles of Pseudorandom Number Generation

Unpredictability

- Successive numbers of the sequence are unpredictable.
- With "true" random sequences each number is statistically independent of other numbers in the sequence and therefore unpredictable
- True random numbers are seldom used.
- Rather,sequences of numbers that appear to be random are generated by some algorithm.
- In this latter case, care must be taken that an opponent not be able to predict future elements of the sequence on the basis of earlier elements.

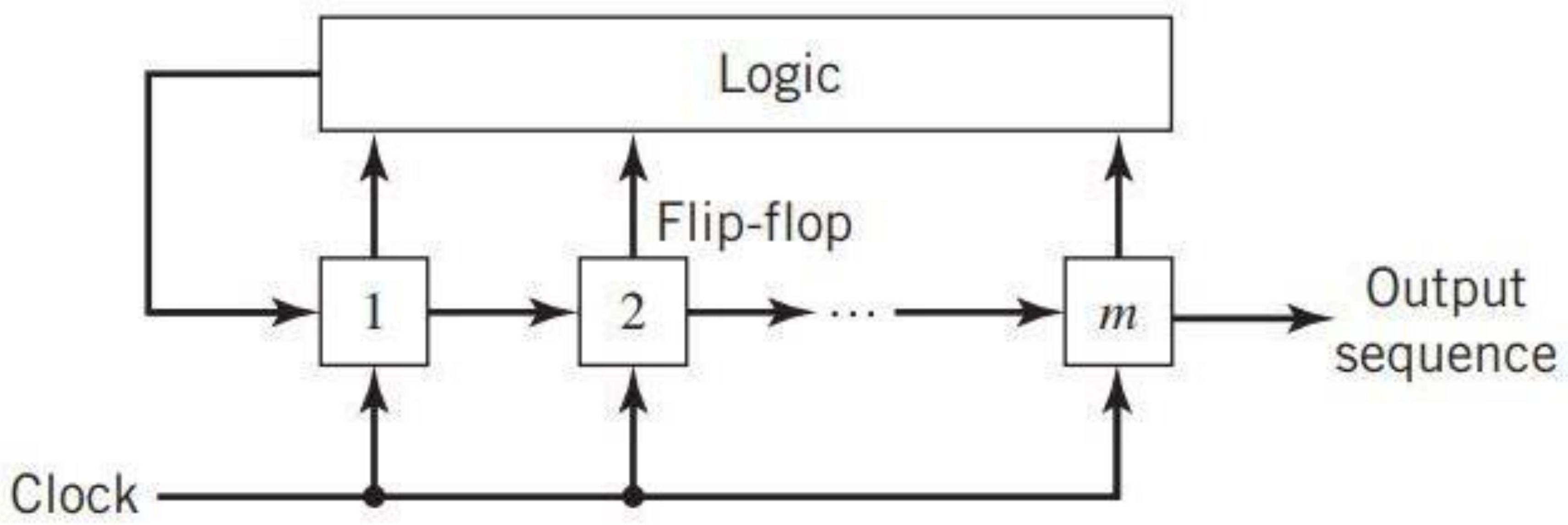
Principles of Pseudorandom Number Generation

Pseudorandom Numbers

- Wireless applications typically make use of algorithmic techniques for random number generation.
- These algorithms are deterministic and are not statistically random.
- However, if the algorithm is good, the resulting sequences will pass many reasonable tests of randomness.
  - Frequency test,
  - Runs test ,Autocorrelation test, Gap test, Poker test
- Such numbers are referred to as **pseudorandom numbers**.

Pseudo-Noise Sequences

"A pseudo-noise (PN) sequence is a periodic binary sequence with a noise-like waveform generated by a feedback shift register"



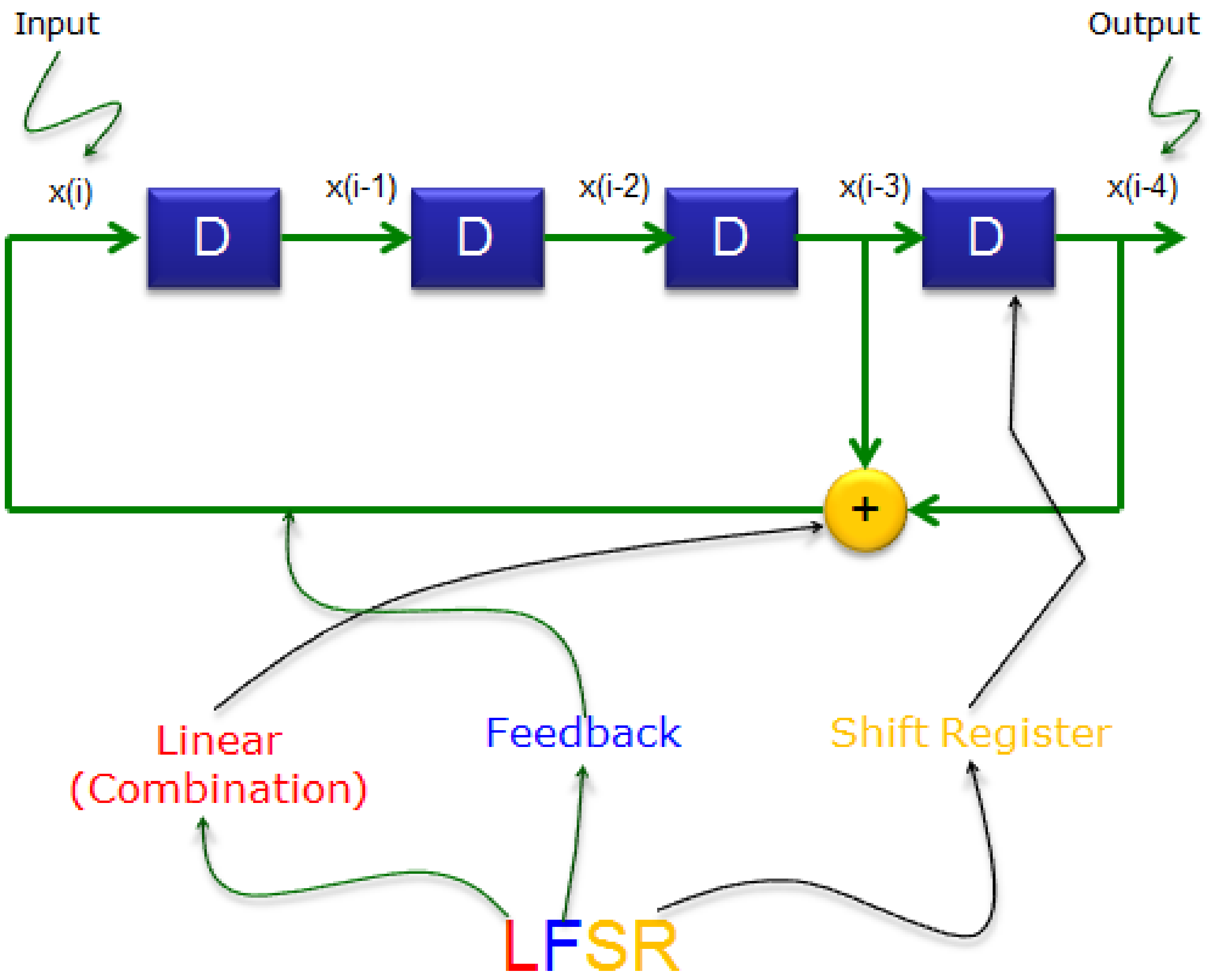
Pseudo-Noise Sequences

- A feedback-shift register consists of:

i. *shift register* made up of m flip-flops regulated by a single timing *clock*

ii. *logic circuit* interconnected to form a multiloop *feedback* circuit

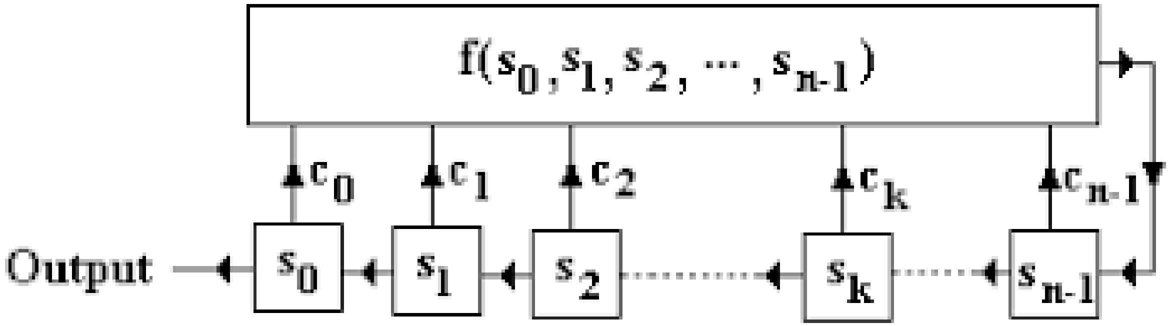
- The PN sequence so generated is determined by the length m of the shift register, its initial state and the feedback logic



Pseudo-Noise Sequences

- Let $S_j\,(k)$ denote the state of the jth flip-flop after the kth clock pulse represented by 0 or 1
- The state of the shift register after the k th clock pulse is defined by the set $\{s_1(k), s_2(k), \dots, s_m(k)\}$, where $k \geq 0$
- From the definition of a shift register, we have:

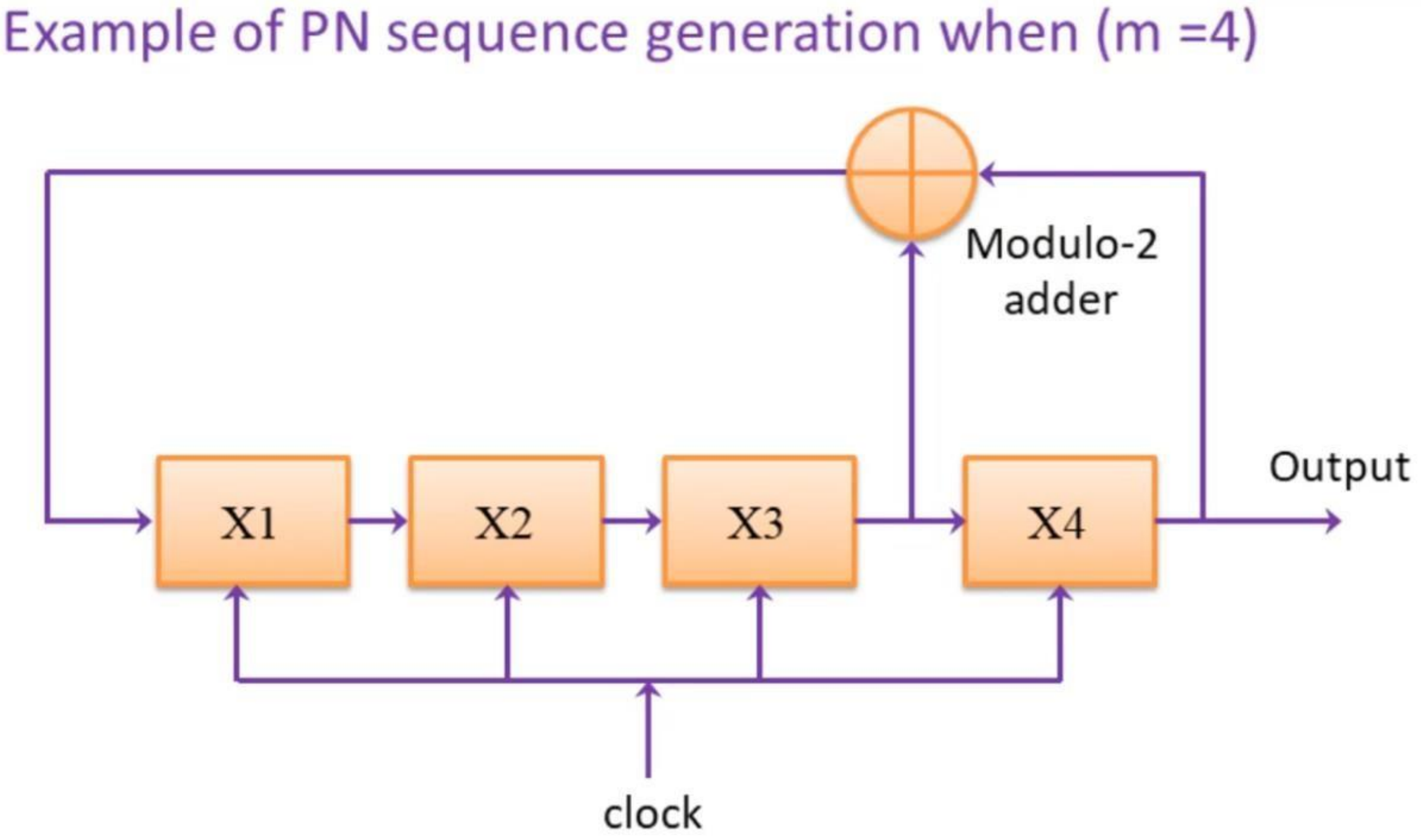
$$s_j\,(k+1) = s_{j\,-1}(k), \left\{ \begin{array}{c} k \geq 0 \\ 1 \leq j \leq m \end{array} \right.$$



Pseudo-Noise Sequences

- With a total of number of m flip-flops, the number of possible states of the shift register is at most 2^m
- Thus, the PN sequence generated must eventually become *periodic* with a period of at most 2^m
- A feedback shift register is said to be linear when the feedback logic consists entirely of *modulo-2 adders*
- The *zero-state* is *not* permitted in this case
- The period of a PN-sequence produced by a linear feedback shift register with m flip-flops cannot exceed $2^m - 1$
- When the period is exactly $2^m - 1$, the PN sequence is called a *maximal-length sequence* or simply *m-sequence*

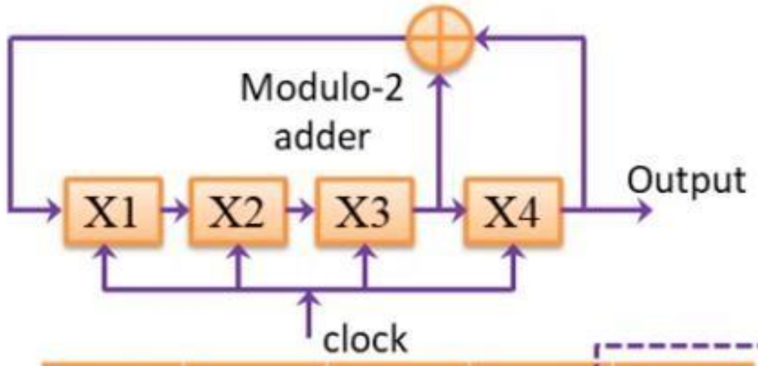
Pseudo-Noise Sequences



PN sequence generator for m=4

Pseudo-Noise Sequences

Example of PN sequence generation when (m =4)



Clock	X1	X2	X3	X4
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	1	0	0	1
5	1	1	0	0
6	0	1	1	0
7	1	0	1	1
8	0	1	0	1

Clock	X1	X2	X3	X4
9	1	0	1	0
10	1	1	0	1
11	1	1	1	0
12	1	1	1	1
13	0	1	1	1
14	0	0	1	1
15	0	0	0	1
16	1	0	0	0

Pseudo-Noise Sequences

- Since we are taking the output from X4 hence the output of the PN sequence is given as:

0 0 0 1 0 0 1 1 0 1 0 1 1 1 1 Length =15

- We need to map this sequence in the stream of -1 and +1 in order to modulate. Hence simple mapping looks like:

-1 -1 -1 +1 -1 -1 +1 +1 -1 +1 -1 +1 +1 +1 +1

Properties of Maximal-Length Sequences

i. In each period of a maximal-length sequence, the number of 1s is always one more than the number of 0s.This is called as ***balance property***

ii. Among the runs of 1s and 0s in each period of the sequence, one-half runs of each kind are of length 1, one-fourth of two, one-eight of three and so on. This is called as ***run property***

iii. The autocorrelation function of a maximal-length sequence is periodic and binary-valued. This is called as ***correlation property***

Properties of Maximal-Length Sequences

Balance Property:

-1 -1 -1 +1 -1 -1 +1 +1 -1 +1 -1 +1 +1 +1 +1

Number of (+1)=8

Number of (-1)=7

- In each period, the number of “1” is always one more than the number of “0”. This property is called “balance property.”

- For large value of maximum length sequence (N) the probability of (-1) is equal to the probability of (+1).

Properties of Maximal-Length Sequences

Run property:

- Run is noting but the string of continuous values.

$$\underbrace{-1\ -1\ -1}\ \underbrace{+1}\ \underbrace{-1\ -1}\ \underbrace{+1\ +1}\ \underbrace{-1}\ \underbrace{+1}\ \underbrace{-1}\ \underbrace{+1\ +1\ +1\ +1}$$

Total number of runs are given by: $\dfrac{N+1}{2} = \dfrac{(15+1)}{2} = 8$

- In general run of length of n (bits) can be given as:

$$\text{run of length of n} = \frac{1}{2^n} \times \text{ total number of runs}$$

$$\text{run of length of 1} = \frac{1}{2^1} \times 8 = 4$$

Properties of Maximal-Length Sequences

$$\underbrace{-1\ \ -1\ \ -1}\ \underbrace{+1}\ \underbrace{-1\ \ -1}\ \underbrace{+1\ \ +1}\ \underbrace{-1}\ \underbrace{+1}\ \underbrace{-1}\ \underbrace{+1\ \ +1\ \ +1\ \ +1}$$

$$\text{run of length of } 2 = \frac{1}{2^2} \times 8 = 2$$

$$\text{run of length of } 3 = \frac{1}{2^3} \times 8 = 1$$

- Among the runs of 1s and 0s in each period of the sequence, one-half runs of each kind are of length 1,one-fourth of two,one-eight of three and so on.This is called as ***run property***

Properties of Maximal-Length Sequences

- The autocorrelation function of PN sequence is given as:

$$R(d) = \frac{1}{N}\sum_{n=0}^{N} c(n)c(n-d)$$

where

N=length of PN sequence

d=shift in the sequence

c(n)=±1

For d=0 we have

$$R(0) = \frac{1}{N}\sum_{n=0}^{N} c(n)c(n) = \frac{1}{N}\sum_{n=0}^{N} c(n)^2$$

Properties of Maximal-Length Sequences

$$R(0) = \frac{1}{N}\sum_{n=0}^{N} 1 = \frac{1}{N} \bullet N$$

$$R(0) = 1$$

- For d=1

$$R(1) = \frac{1}{N}\sum_{n=0}^{N} c(n)c(n-1)$$

c(n) = -1 -1 -1 +1 -1 -1 +1 +1 -1 +1 -1 +1 +1 +1 +1

- c(n-1) will be given by shifting by 1 to the c(n) as:

c(n-1) = +1 -1 -1 -1 +1 -1 -1 +1 +1 -1 +1 -1 +1 +1 +1

Properties of Maximal-Length Sequences

- c(n)c(n-1) would have been calculated as:

c(n) = -1 -1 -1 +1 -1 -1 +1 +1 -1 +1 -1 +1 +1 +1 +1

c(n-1) = +1 -1 -1 -1 +1 -1 -1 +1 +1 -1 +1 -1 +1 +1 +1

c(n) c(n-1) = -1 +1 +1 -1 -1 +1 -1 +1 -1 -1 -1 -1 +1 +1 +1

$$R(1) = \frac{1}{N}\sum_{n=0}^{N} c(n)c(n-1) = \frac{1}{15}\bullet(-8+7)$$

$$R(1) = -\frac{1}{15}$$

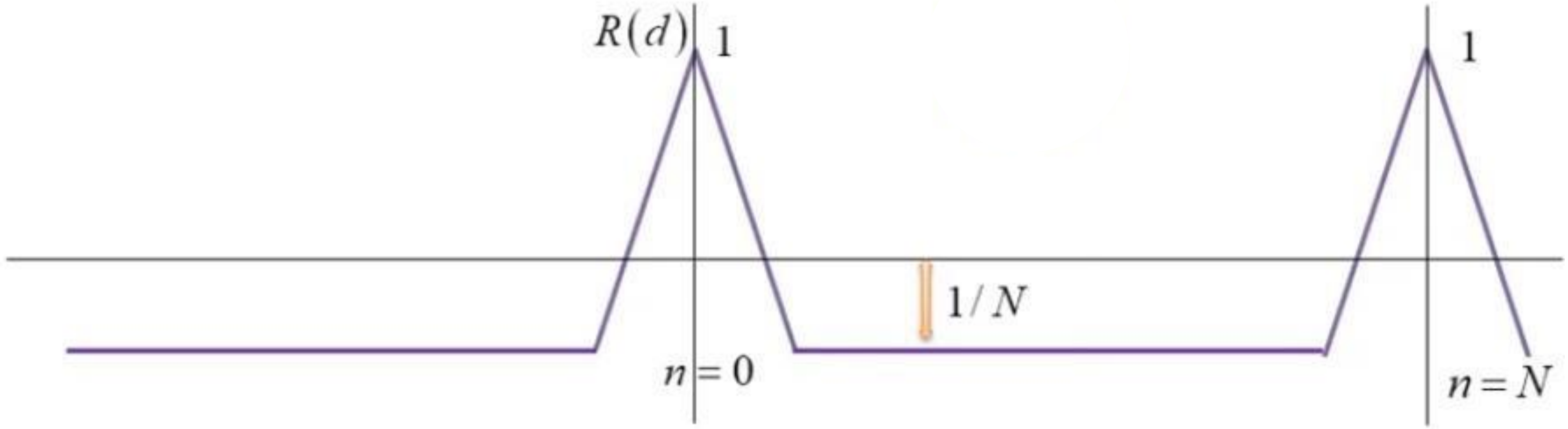
- Similarly it can be shown that:

$$R(2) = R(3).....R(14) = -\frac{1}{15}$$

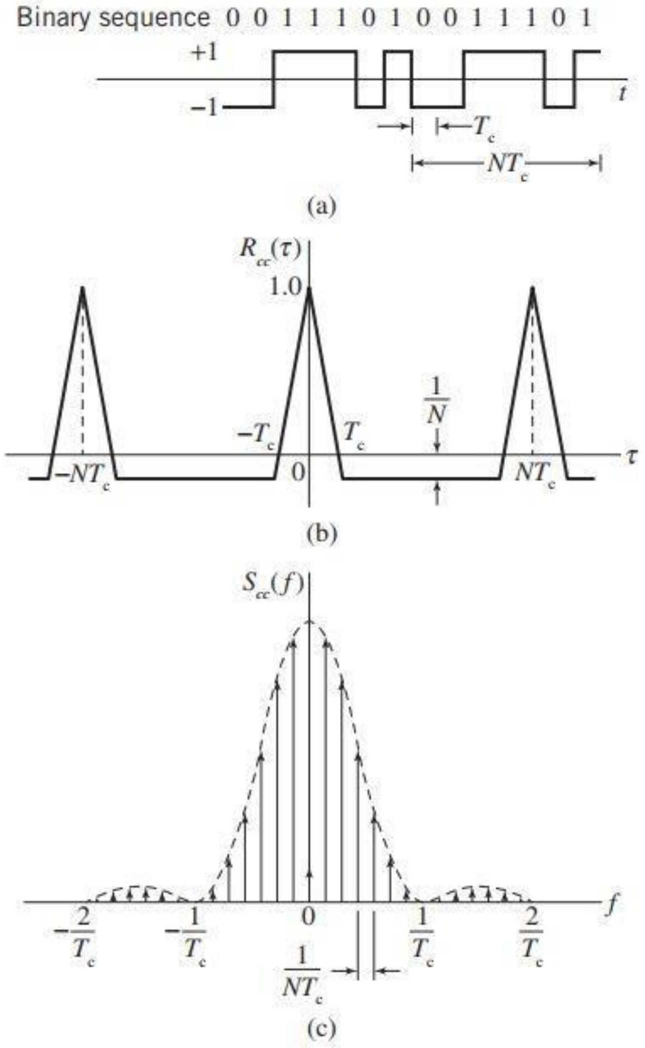
Properties of Maximal-Length Sequences

- In general we can say that the autocorrelation of PN sequence can be given as:

$$R(d) = \begin{cases} 1 & d = 0 \\ -\dfrac{1}{N}, & d \neq 0 \end{cases}$$



Properties of Maximal-Length Sequences



(a) Waveform of maximal-length sequence for length m = 3 or period N = 7,

(b) Autocorrelation function,

(c) Power spectral density