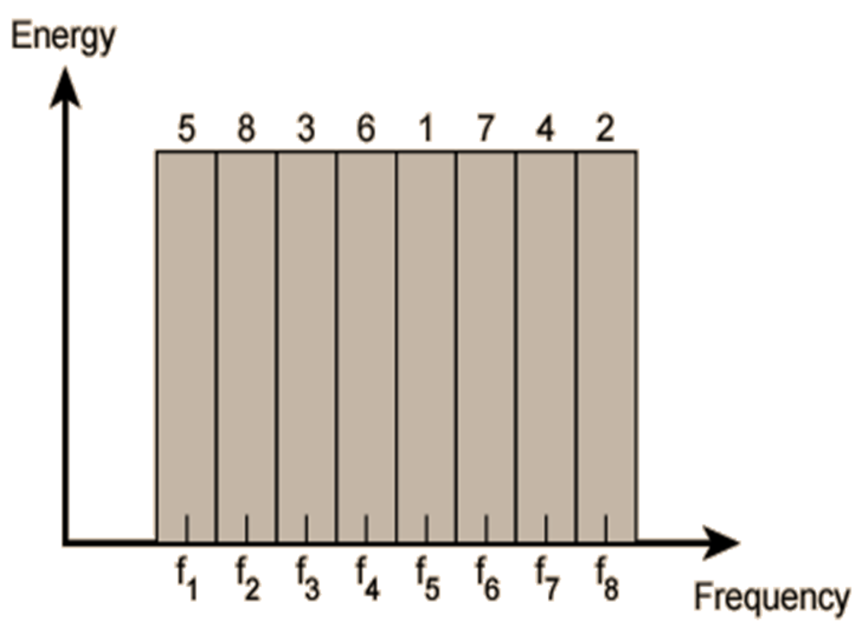
Frequency Hopping

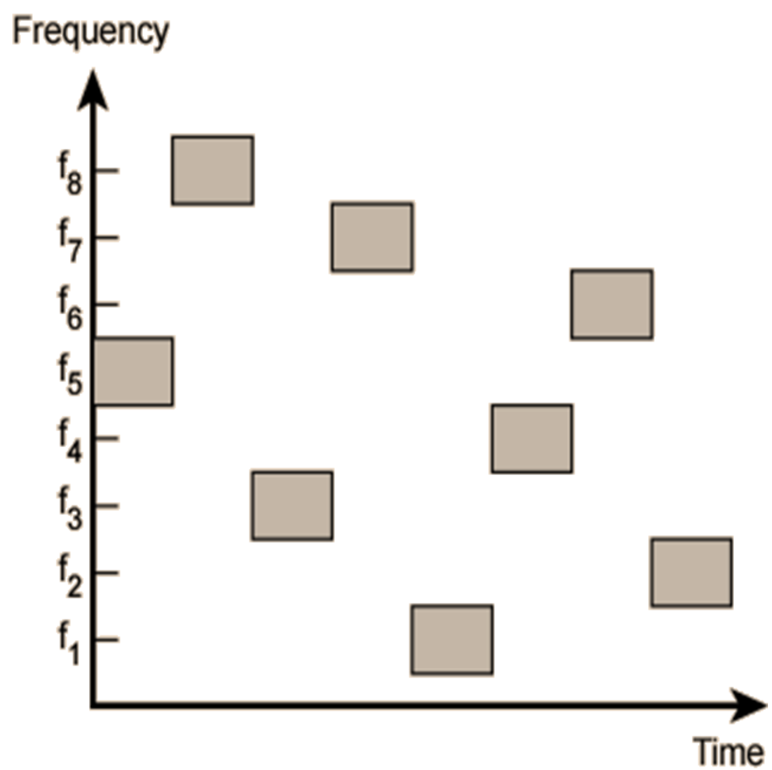
- Signal broadcast over semi random series of frequencies
    - ✓ Channel spacing corresponds with bandwidth of input
    - ✓ Each channel used for fixed interval, example 300 ms in IEEE 802.11
- No of frequency choice and the rate of hoping depends on the particular use of the system.
- Receiver hops between frequencies in sync with transmitter
- Eavesdroppers hear unintelligible blips
- Jamming on one frequency affects only a few bits

FH Example

Like FSK with large no. of discrete frequencies, randomly chosen based on chip code combined with information.



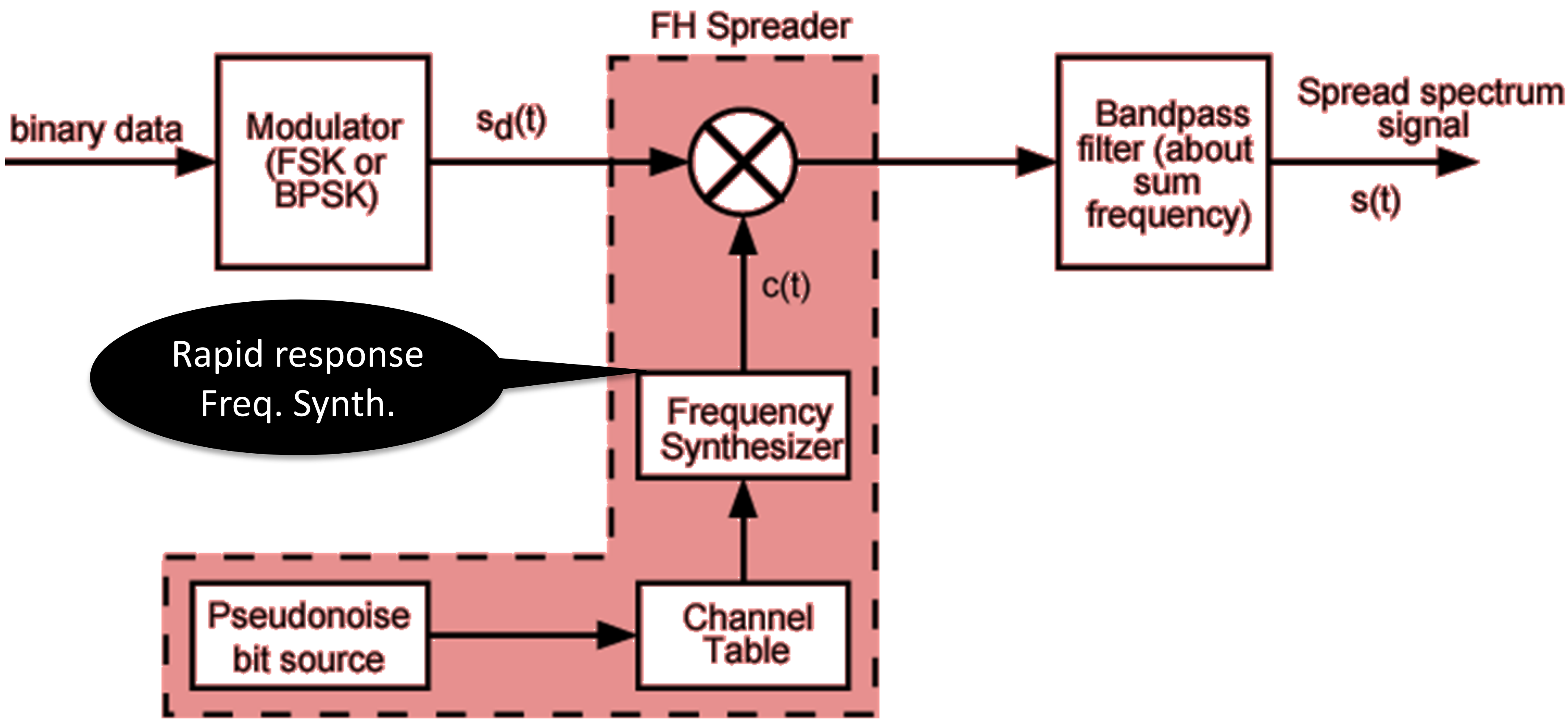
(a) Channel assignment



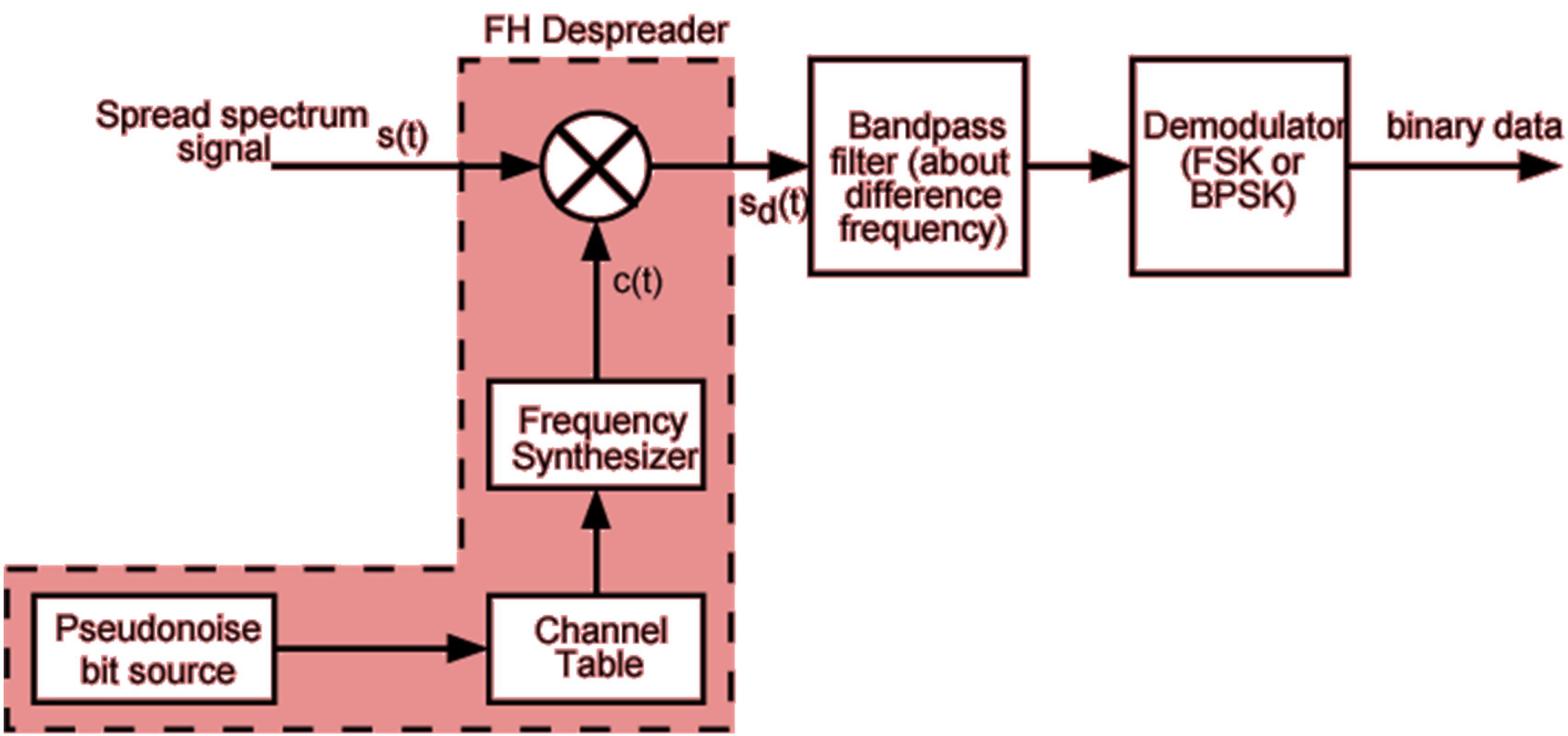
(b) Channel use

FHSS

Transmitter

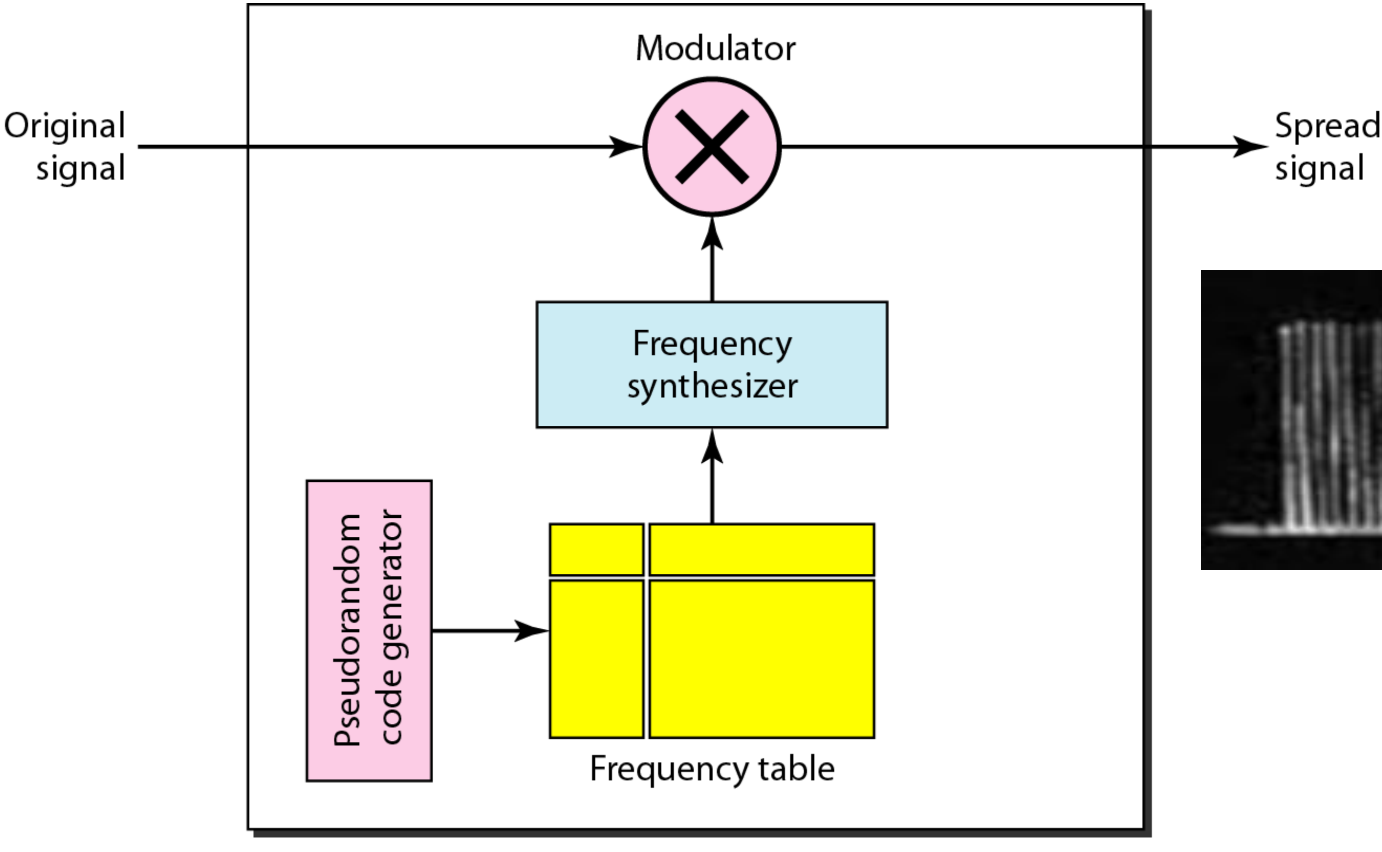


Receiver

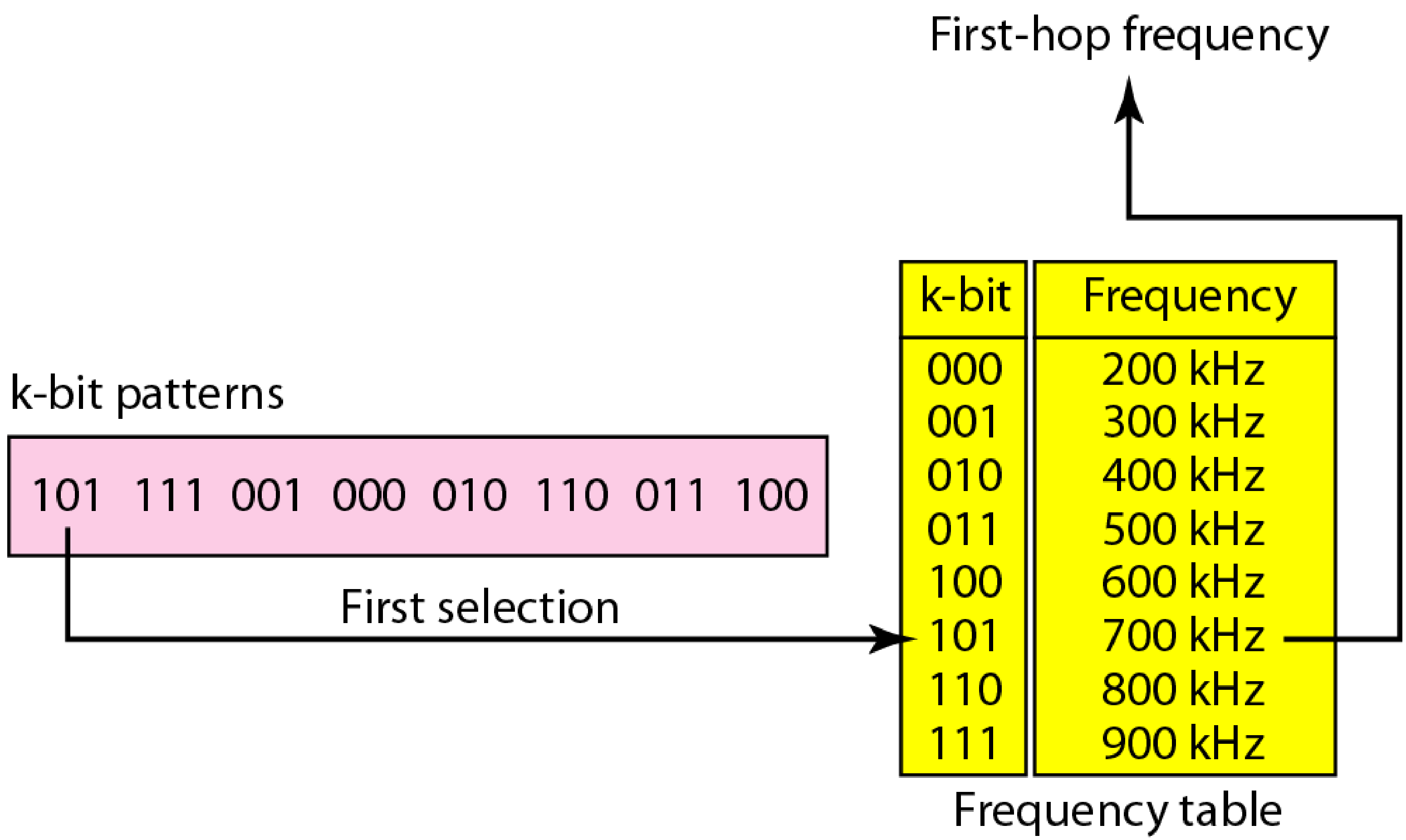


FH Despreader
Spread spectrum signal
s(t)
sd(t)
c(t)
Bandpass filter (about difference frequency)
Demodulator (FSK or BPSK)
binary data
Frequency Synthesizer
Pseudonoise bit source
Channel Table

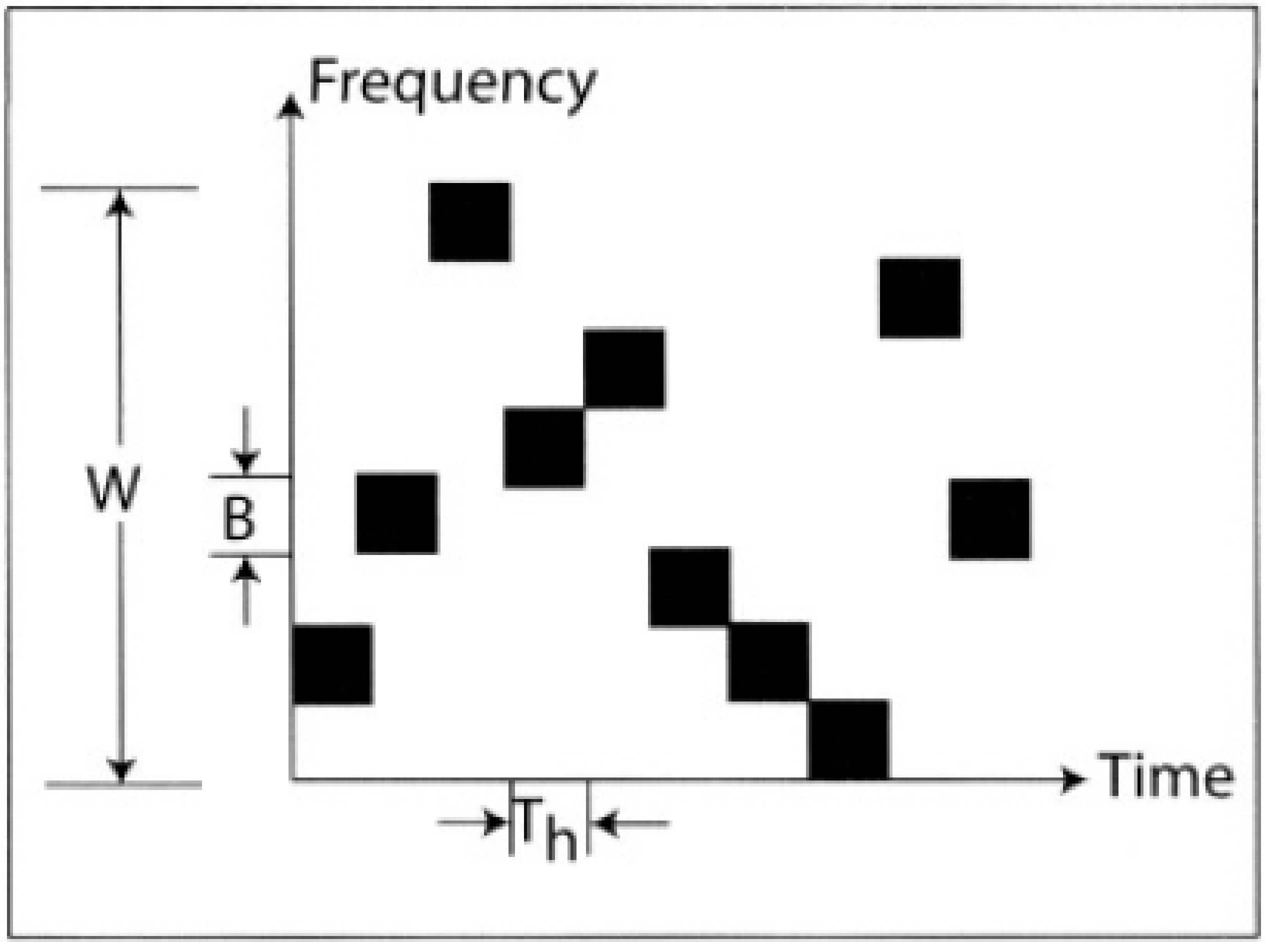
Frequency hopping spread spectrum (FHSS)



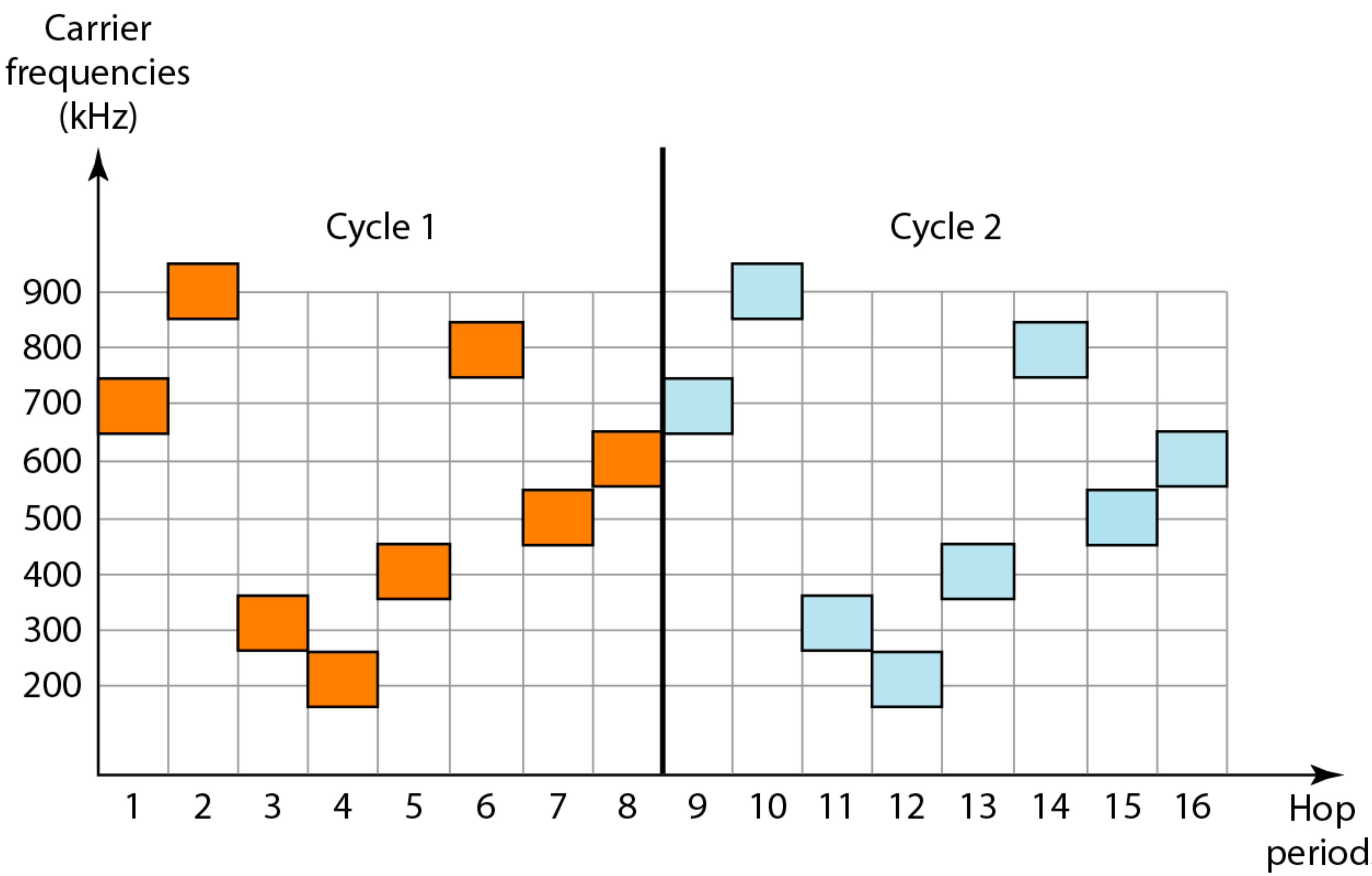
Frequency selection in FHSS



FH Pattern



FHSS cycles



Carrier frequencies (kHz)
Cycle 1
Cycle 2
900
800
700
600
500
400
300
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop periods

DS & FH

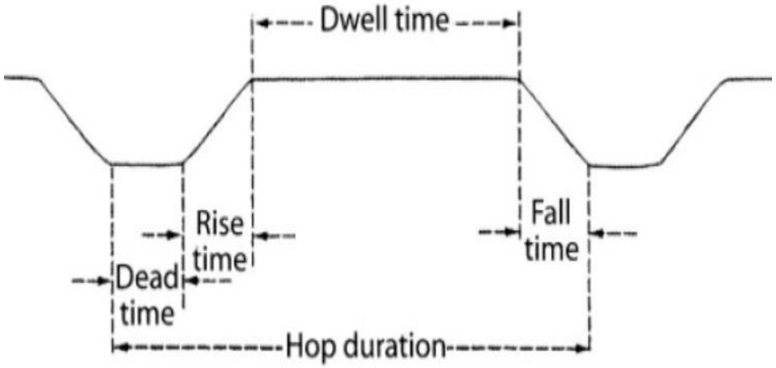
- In general, FH devices use less power and are cheaper, but the performance of DS is usually better and more reliable.
- When FH and DS systems are constrained to use the same fixed bandwidth, then DS systems have an inherent advantage.
- FH systems reject interference by avoiding it, whereas DS systems reject interference by spreading it.

- The effects of any other forms of radio communications operating in narrow bands of the spectrum will be minimized (signal—will only affect a small part of the signal).

- Such interference that occurs will result in only a slightly reduced quality of voice transmission, or a small loss of data. Since data networks acknowledge successful receipt of data, any missing pieces will trigger a request to transmit the lost data.

- Instantaneous output, ideally is single frequency and over a time is rectangular (same power in every channel)
  - This can be seen for narrowband Freq. hopper (28 ch.)

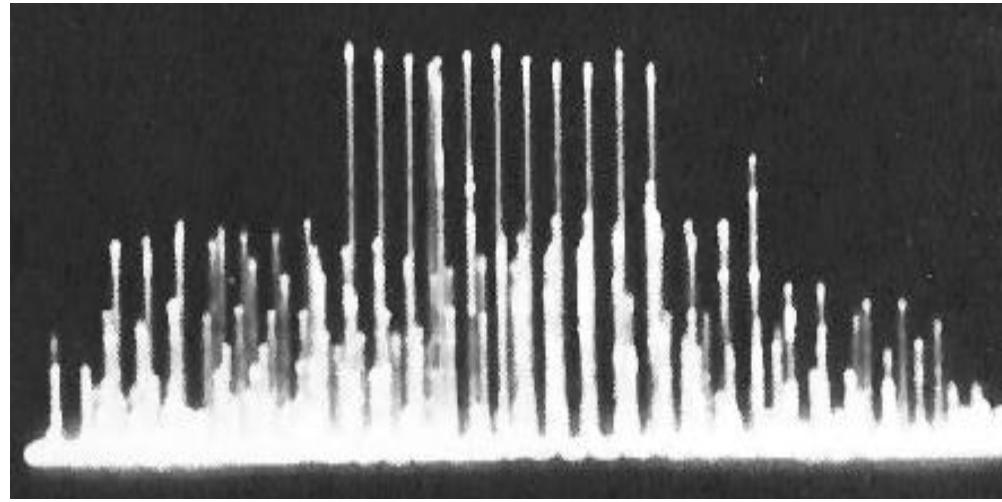
- However, in practice is composite of desired and undesired frequencies; by hopping and by products.
  - For wideband freq. hopper (several thousands ch.)
  - Spurious freq. because of rectangular pulse → sinc spectrum



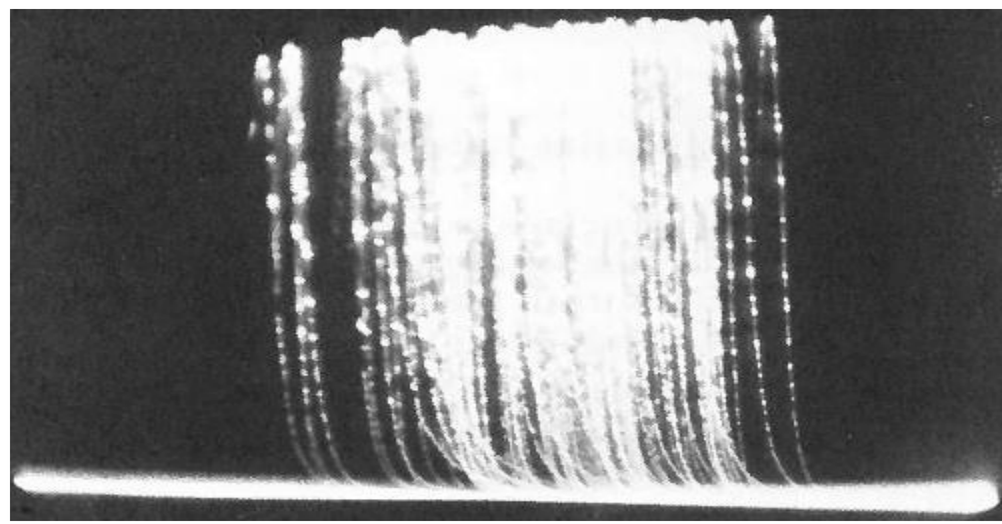
- How important is to have flat spectrum?

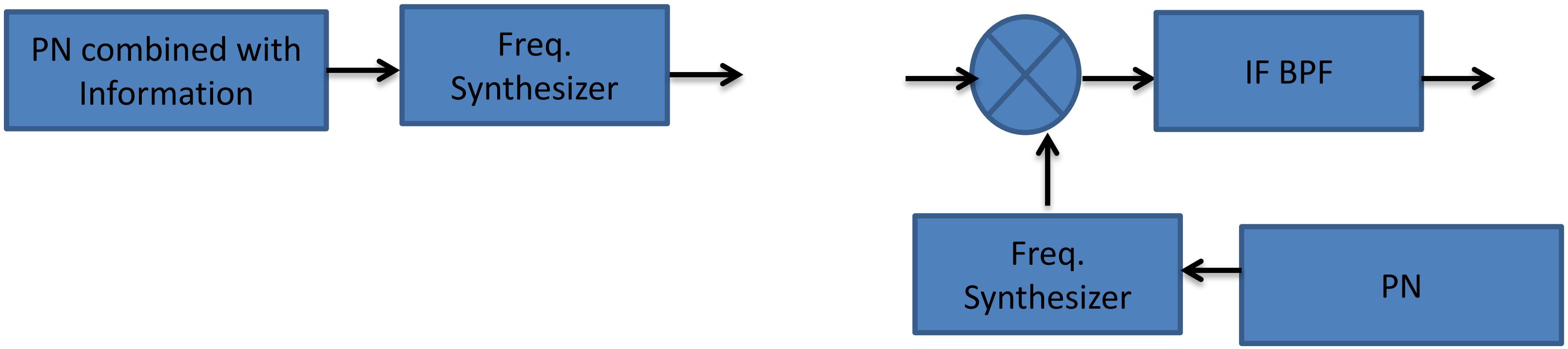
Non ideal FH

- FH exists with interference



- To suppress the spurious, pulse shaping is needed.





- IF filter would reject all the signals out its band
  - ✓ CW signal at the receiver input ....
  - ✓ A signal with bandwidth as local PN ....

$G_P = N$ number of frequency channels

$= BW_{SS}/BW$ for contiguous channels

However, if inter-channel interference is considered, G_P is reduced

Frequency Hopping Rate R_h & Number of channels N

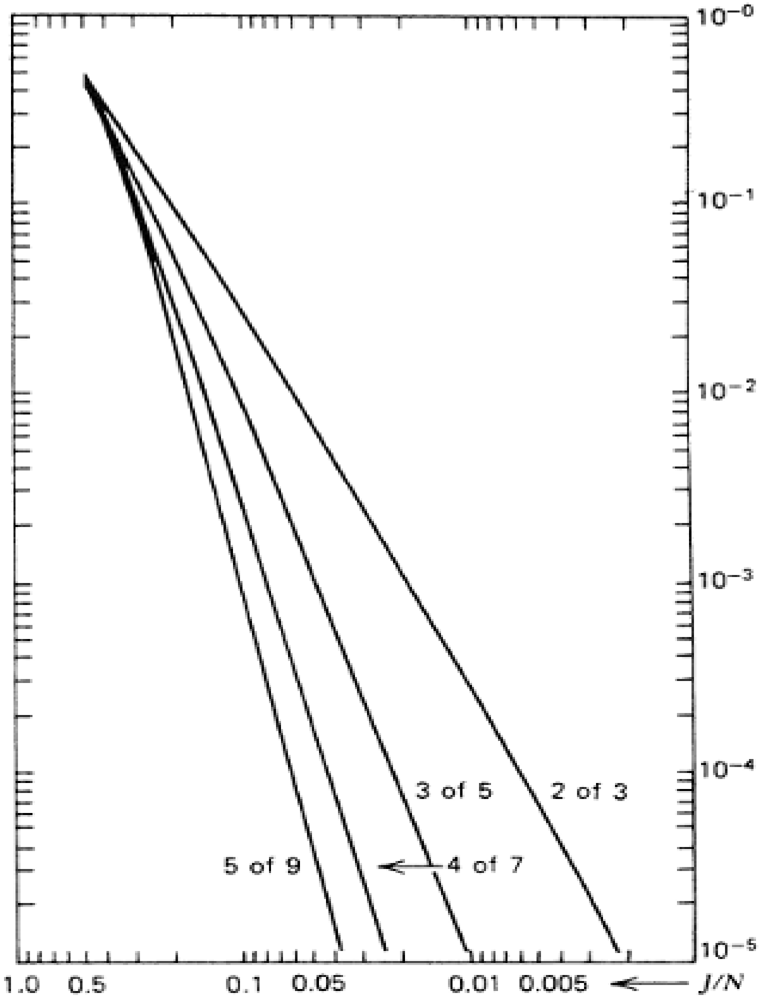
- R_h depends on
  - *Type and rate of information*
  - *Redundancy if applied*
  - *Distance to nearest interferer*

- N affects on error rate, ex. N=1000 → M_j=30db if interference is evenly distributed over the band, and single narrowband Interferer causes 10^{-3} error rate

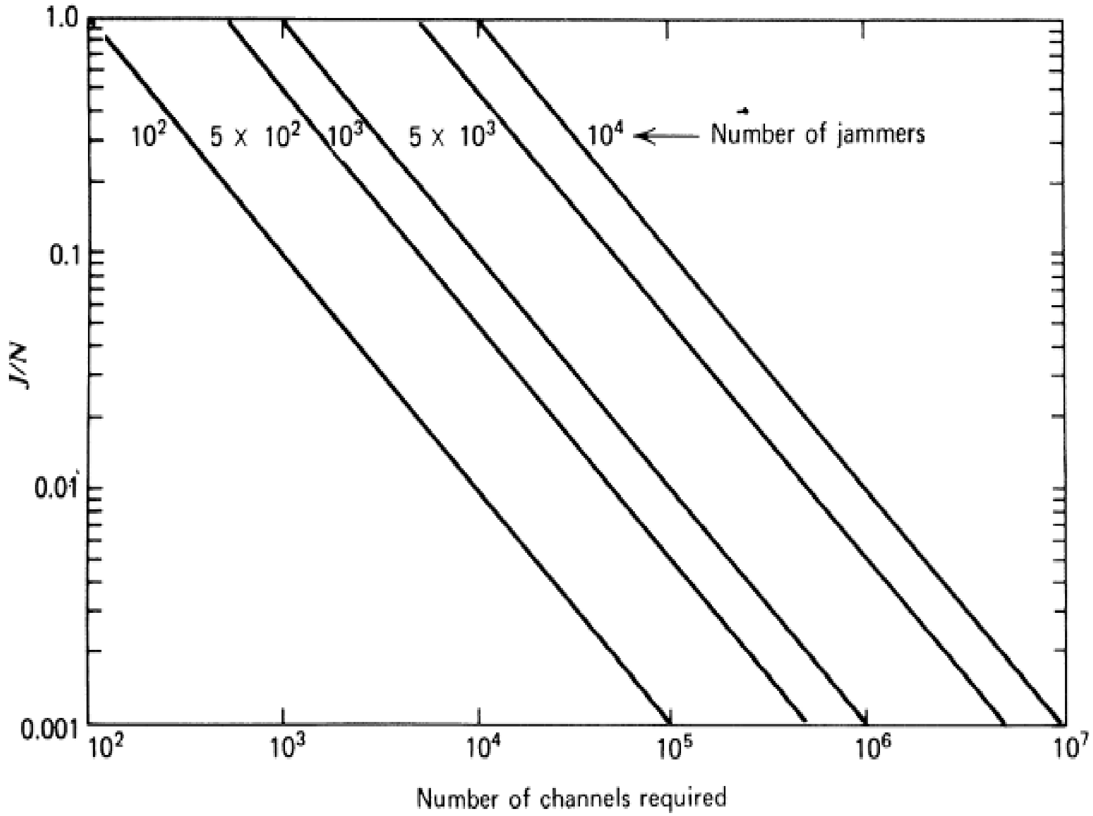
Error rate R_e= J/N, J is number of interferer with power equal or greater than signal power

Redundancy

- Assume FSK with FH
- chip decision is made by comparing the power in f_o and f_1
- Error occurs if interference power in f_o exceeds power in intended $f_{1,}$ and vice versa
- Assume redundancy
  - Ex: three frequencies for each bit → decision is made based on two out of three (majority bit decision) → error rate is greatly reduced 10^{-3} (1 chip/bit)→ 10^{-6} (3chips/bit).
  - More complex, Freq. synthesizer hope rate is three times faster
  - Higher bandwidth (i.e larger N)



10−0
10−1
10−2
10−3
10−4
10−5
Error rate
3 of 5
2 of 3
5 of 9
4 of 7
1.0
0.5
0.1
0.05
0.01
0.005
J/N



1.0
0.1
0.01
0.001
J/N
10²
5 × 10²
10³
5 × 10³
10⁴
Number of jammers
10²
10³
10⁴
10⁵
10⁶
10⁷
Number of channels required

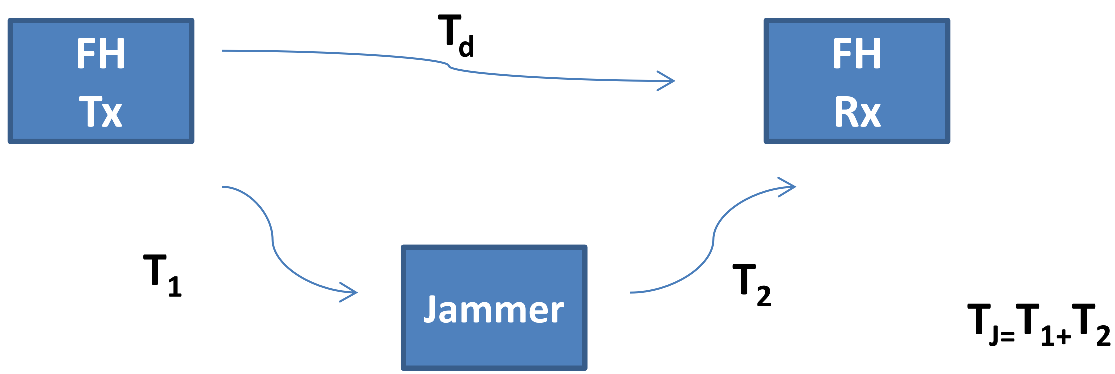
however,

- Channel codes are more essential for FH systems than for DS systems.
  - Because partial-band interference is a more pervasive threat than high-power pulsed interference.

- Multipath signals arrive the receiver with lower level than the desired signal → so is not of concern.
- In contrast to a jammer who receives from FH transmitter, amplifies it, modulates with noise (or transmit the complement key if it is known).
- So, FH transmitter has to hop to new frequency before the jammer can respond to the last one, i.e. hop rate

$R_h > 1/(T_J - T_d)$

- For mobile applications, R_h faster as possible



Repeat Jammer

- Jammer who follow the intended signal from frequency to another has effect as a single frequency jammer has on a non hopping signal.
- To avoid repeat jammer, use non coherent detection

Example FH on-off keying

  - when jammer detects the transmission of ONE and repeat helps the intended receiver to make correct decision.
  - However, if jammer's signal arrives the receiver as identical to the desired signal but out of phase (almost impossible) → incorrect decision
  - If ZERO is transmitted, FH transmitter sends nothing and jammer can guess as random a frequency as ONE is sending
  - Prob. Of error is J/N

However,

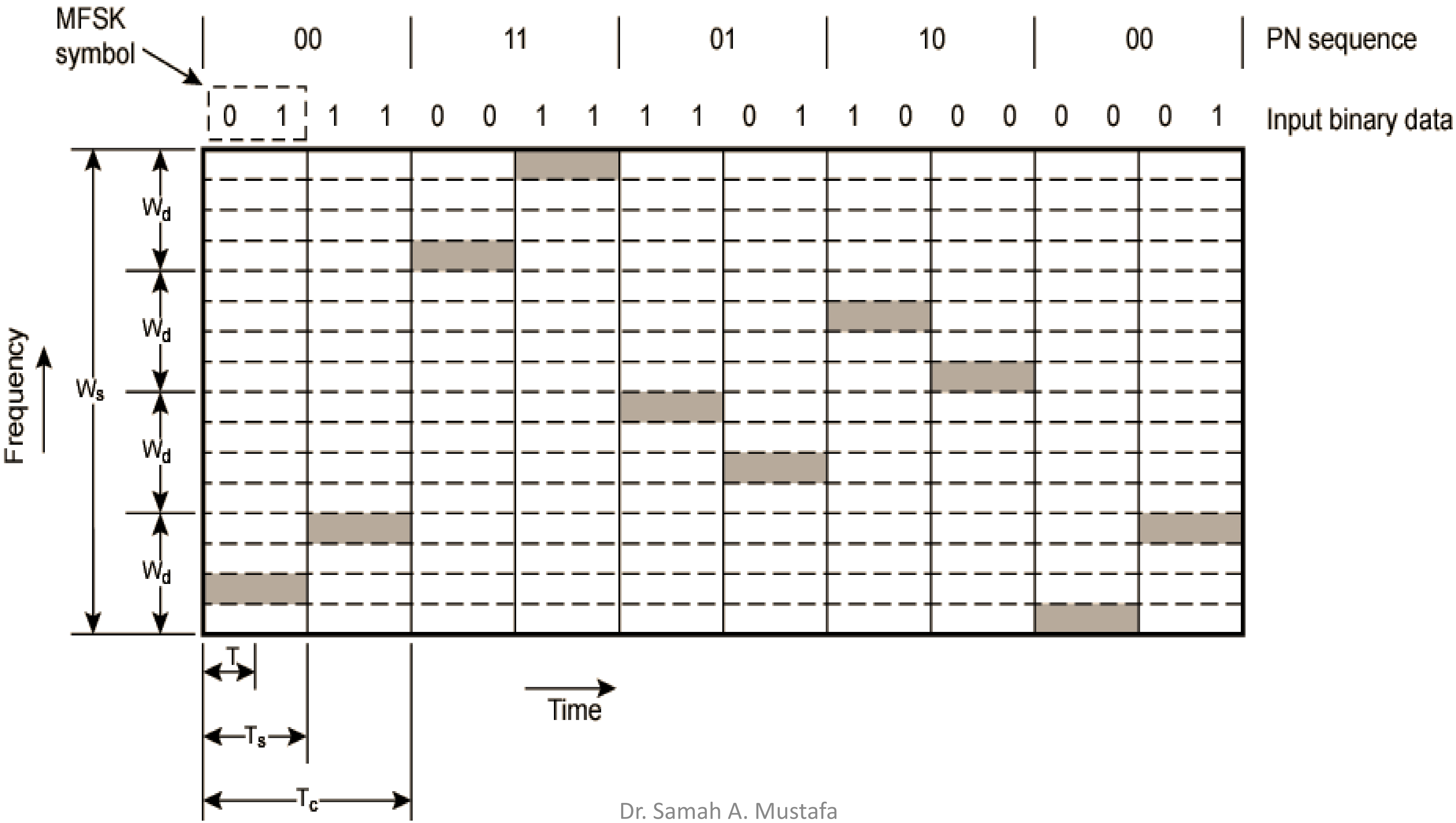
- for M-ary, a block of $\log_2 M$ bits is sent by one of a set of M frequencies.
- N/M sets of frequencies are available
- lower chip rate and loss in G_P (G_P=10log N/M)
- higher error rate and lower jamming margin: interferer hits only one of M-1 non intended freq. for transmission → block error
- Error rates gets related to J/N/M

Slow and Fast FH

- 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)

- Typically large number of frequencies used
  - Improved resistance to jamming

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



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