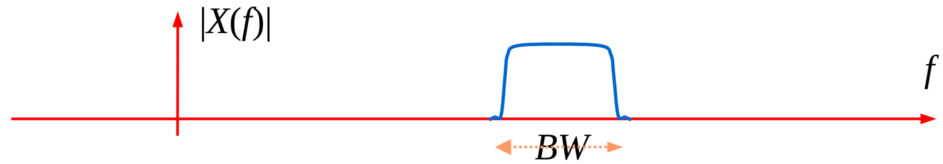
Spread Spectrum

(Part 1)

by Erol Seke

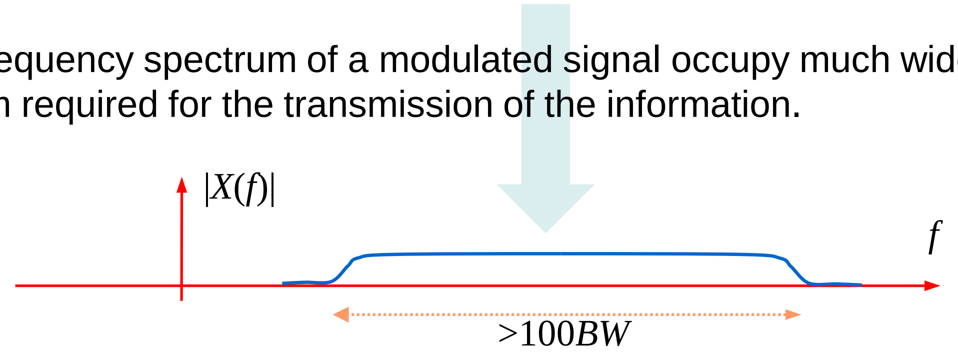
For the course "Communications"

ESKİŞEHİR OSMANGAZİ UNIVERSITY



What is it? :

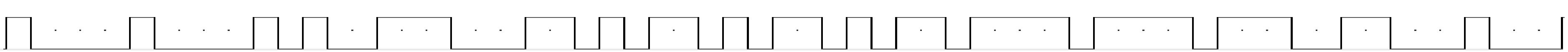
Making the frequency spectrum of a modulated signal occupy much wider band than minimum required for the transmission of the information.



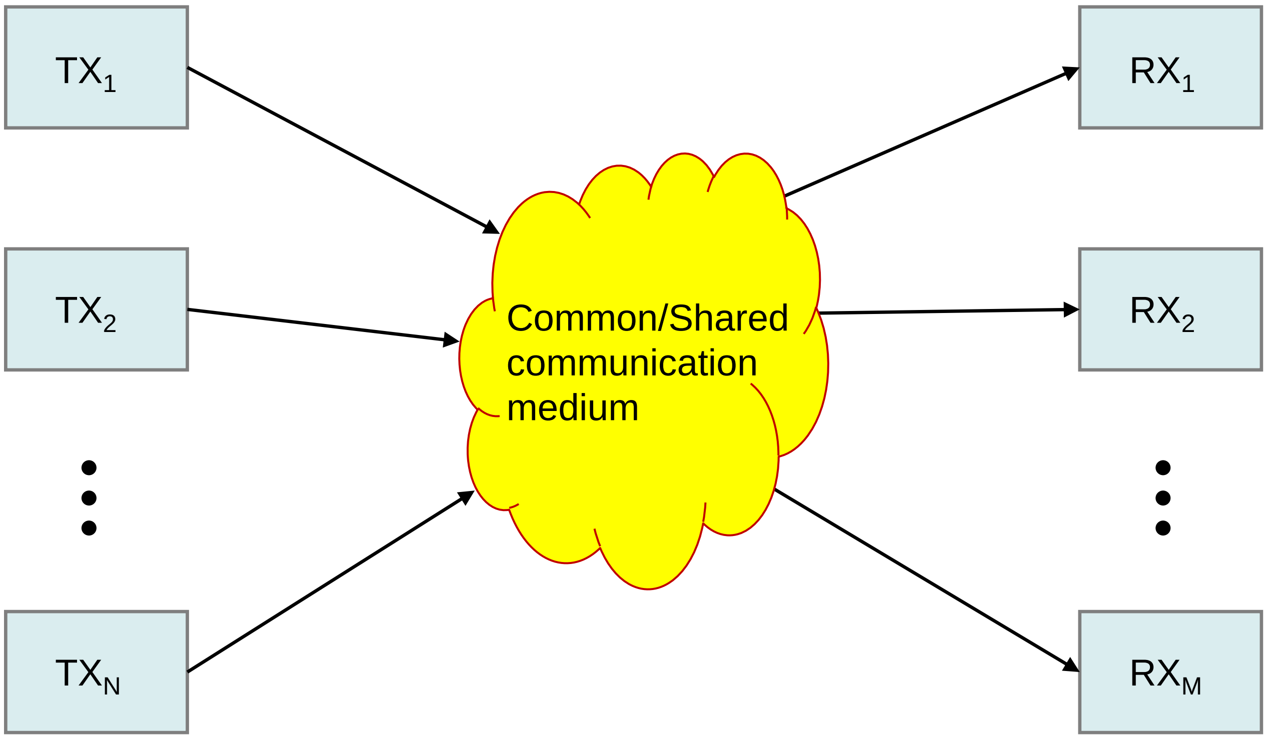
Why? :

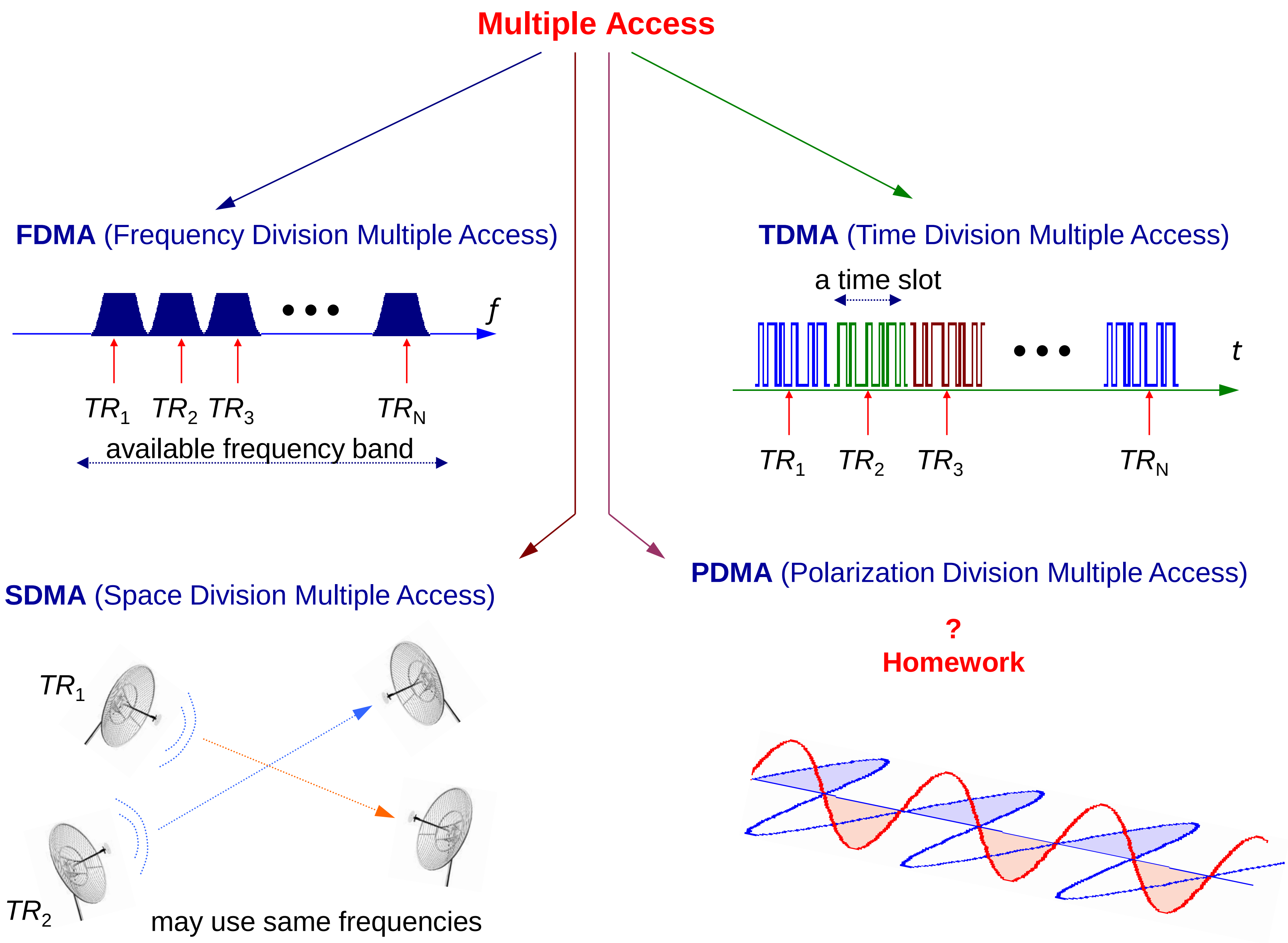
By spreading the signal through a wider frequency spectrum, we

1. Make the signal harder to detect by unintended listeners.
2. Make the signal more robust against intentional or unintentional interference.
3. Obtain better time resolution in applications where the signal is used to measure the delay in the channel.
4. Do MA (multiple access).



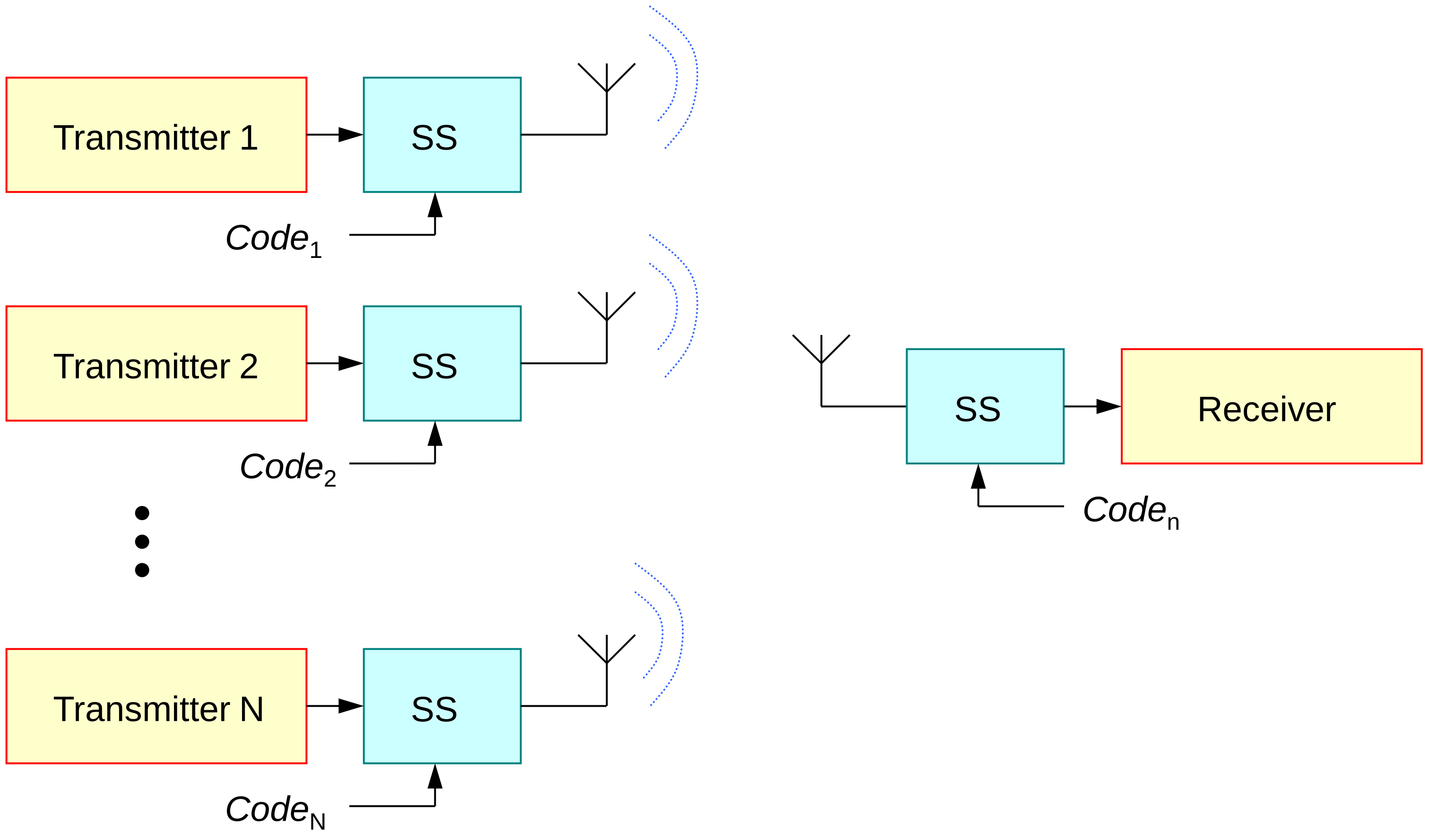
Multiple Access





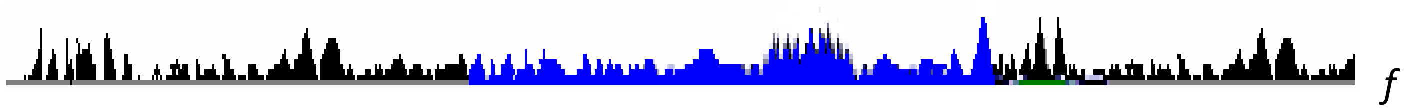
Multiple Access
FDMA (Frequency Division Multiple Access)
f
TR1 TR2 TR3 TRN
available frequency band
TDMA (Time Division Multiple Access)
a time slot
t
TR1 TR2 TR3 TRN
SDMA (Space Division Multiple Access)
TR1
TR2
may use same frequencies
PDMA (Polarization Division Multiple Access)
?
Homework

CDMA (Code Division Multiple Access)



Correlation between PN_n and PN_m (n≠m) is expected to be zero (orthogonal)
Only the correct signal is recovered at the receiver.

Protection Against Interference



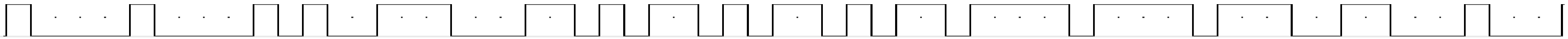
used band

strong narrow band intentional interference

wide band thin intentional interference

fading bands (e.g. atmospheric)

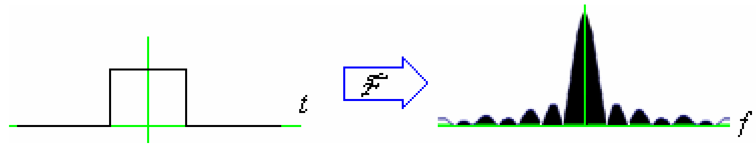
Unless the interference signal is both wide enough and powerful enough, spreading provides good level of protection against intentional/unintentional attacks.



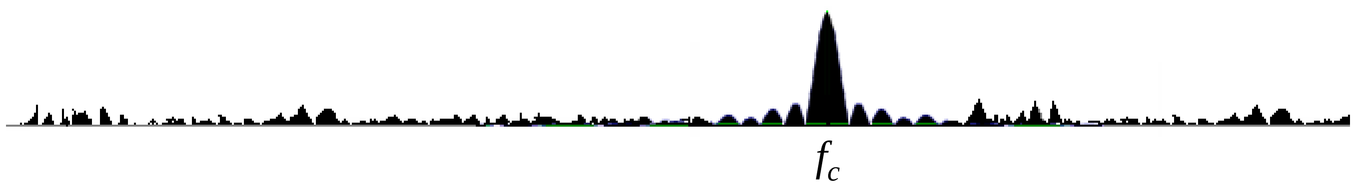
Spreading Methods

- Direct Sequence Spread Spectrum (DSSS)
- Frequency Hopping Spread Spectrum (FHSS)
- Time Hopping Spread Spectrum (THSS, OFDM)
- Hybrid Methods

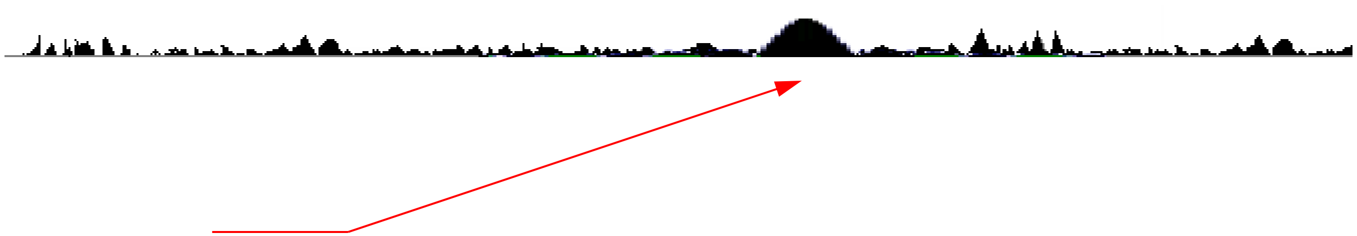
A binary pulse and its mag-frequency spectrum



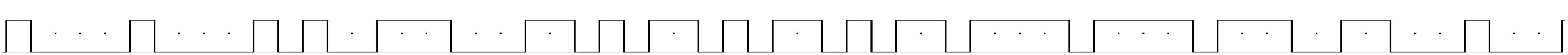
Carrier with f_c is modulated with the random binary pulses (+ ambient noise)



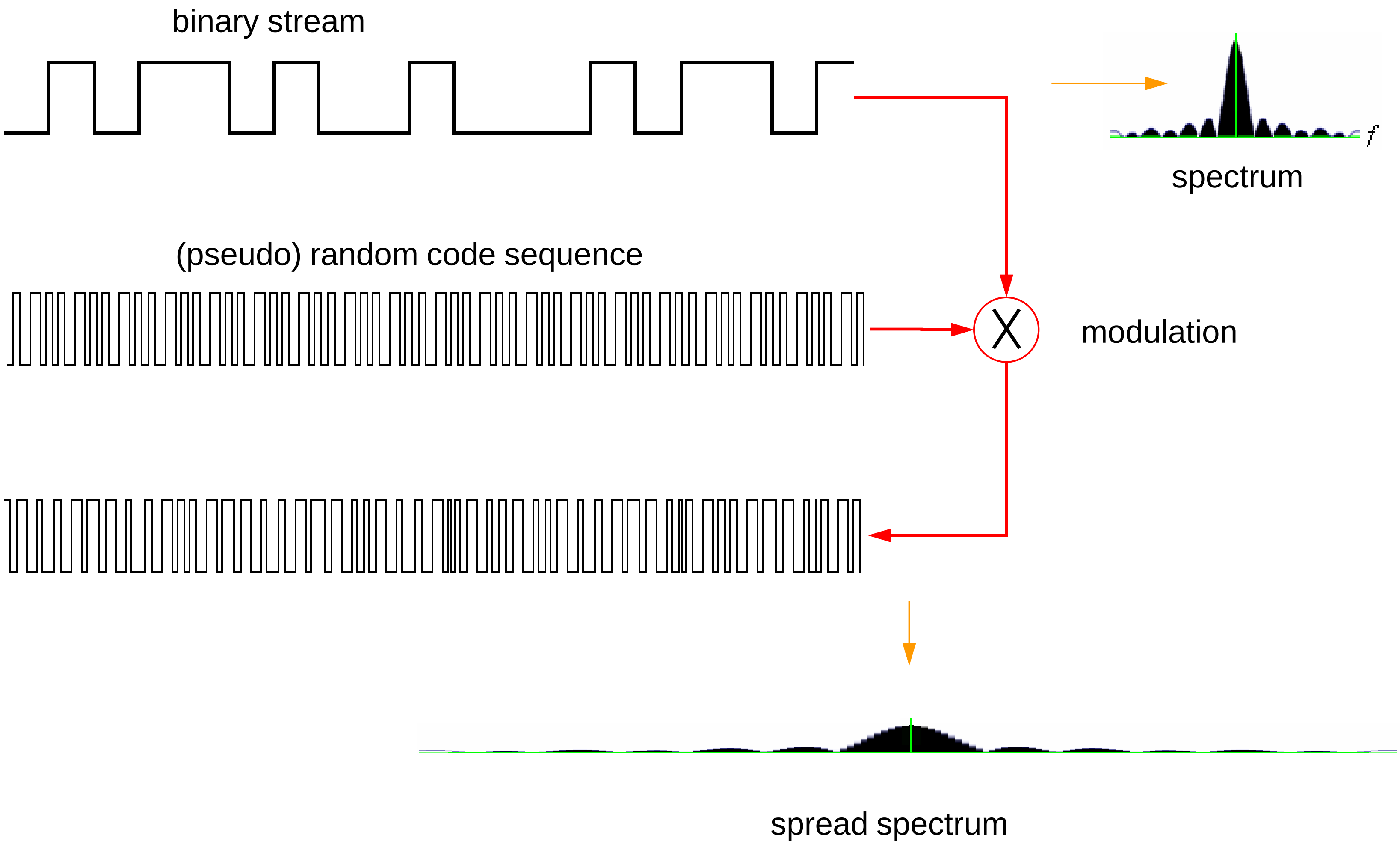
Spectrum of the modulated signal is spread

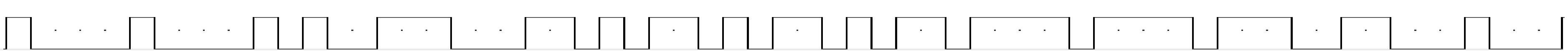


Unless you know its there, it is a lot difficult to detect its existence and jam transmission

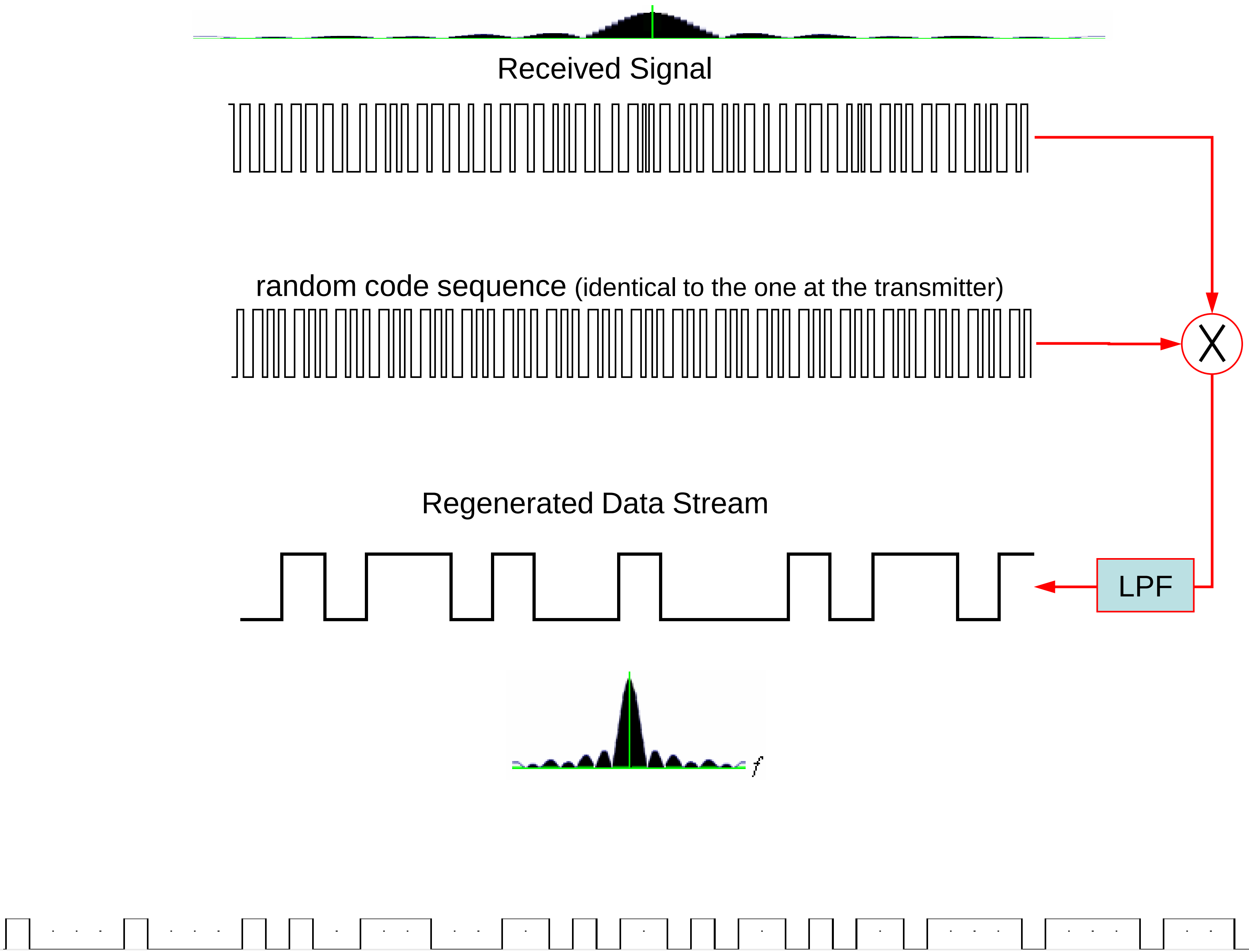


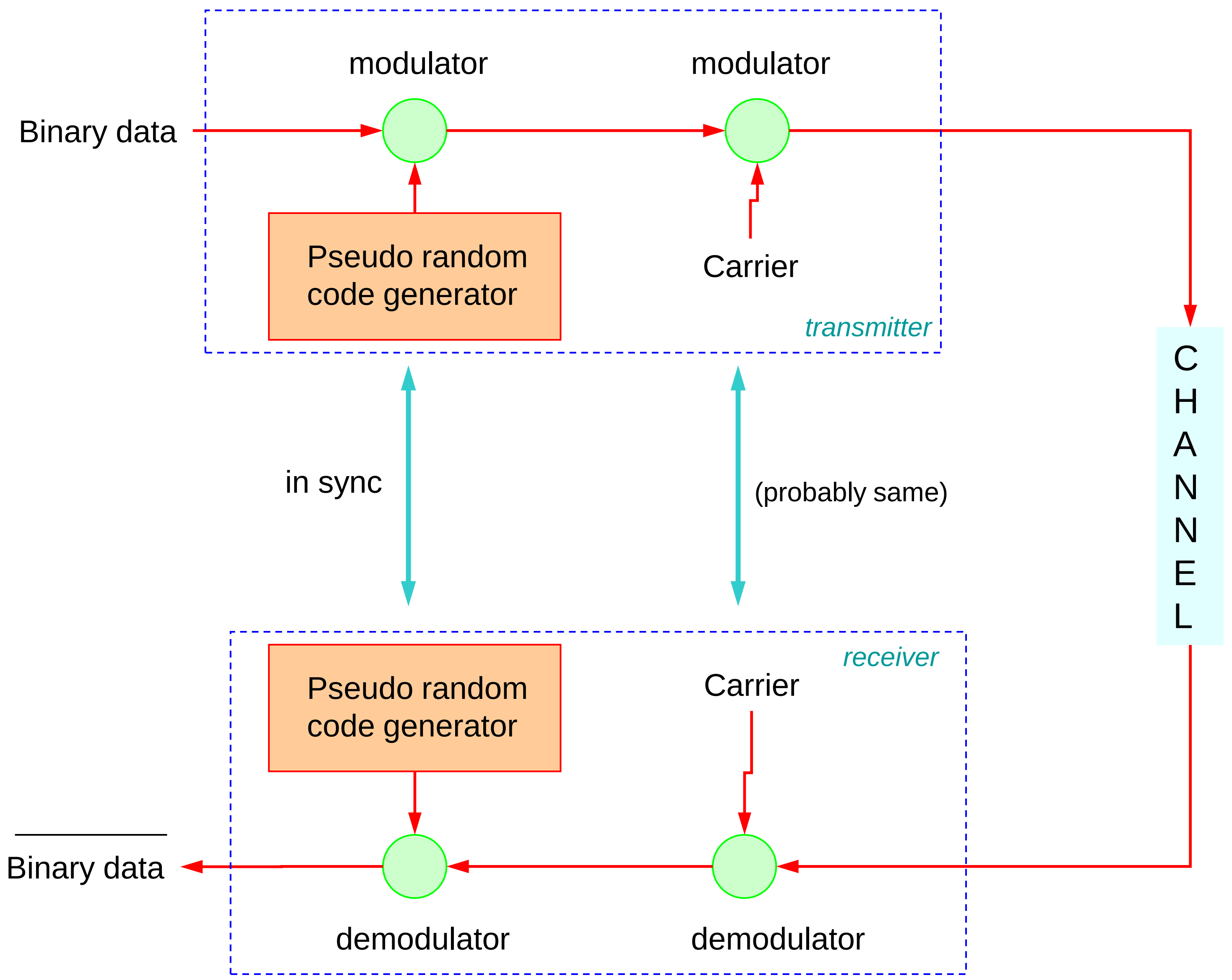
Direct Sequence Spread Spectrum (DSSS)

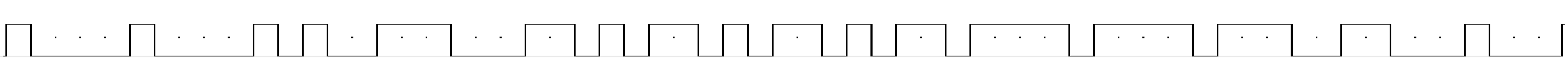




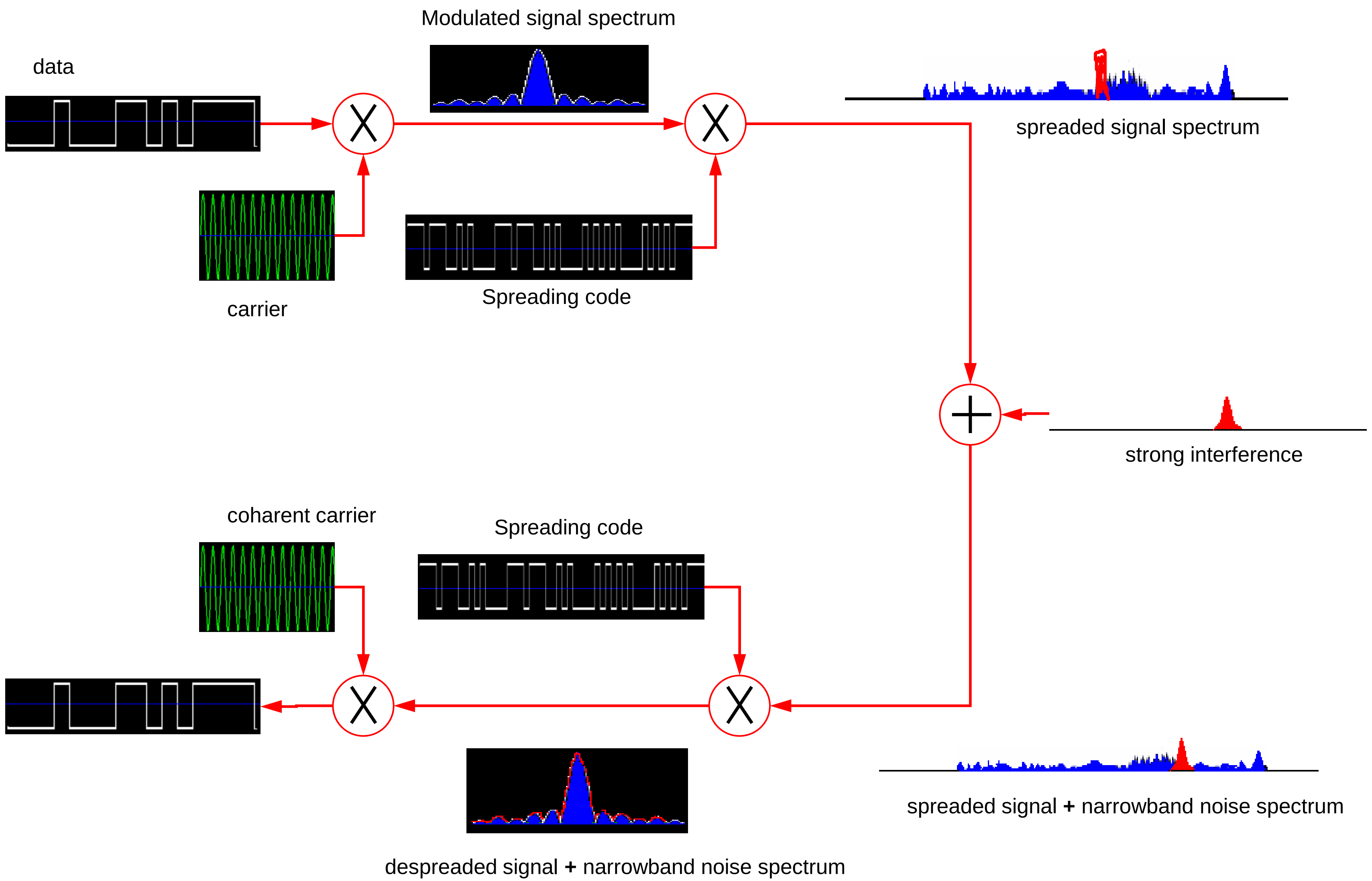
Despreading




modulator
modulator
Binary data
Pseudo random code generator
Carrier
transmitter
C H A N N E L
in sync
(probably same)
receiver
Pseudo random code generator
Carrier
Binary data
demodulator
demodulator



Protection against narrowband interference

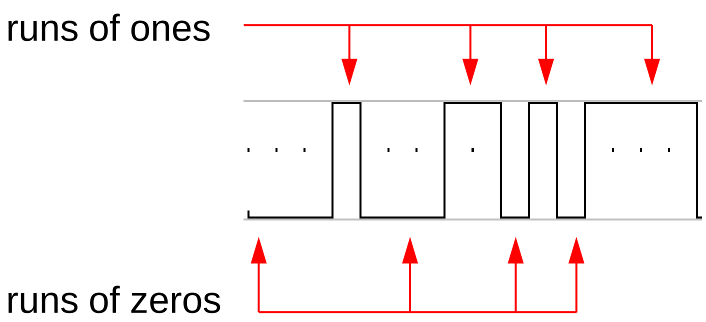


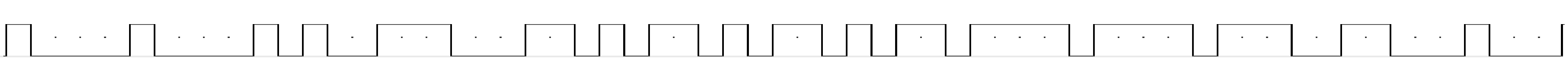
Pseudorandom Sequences

The PN sequences are deterministic, but have statistical properties similar to sampled white noise

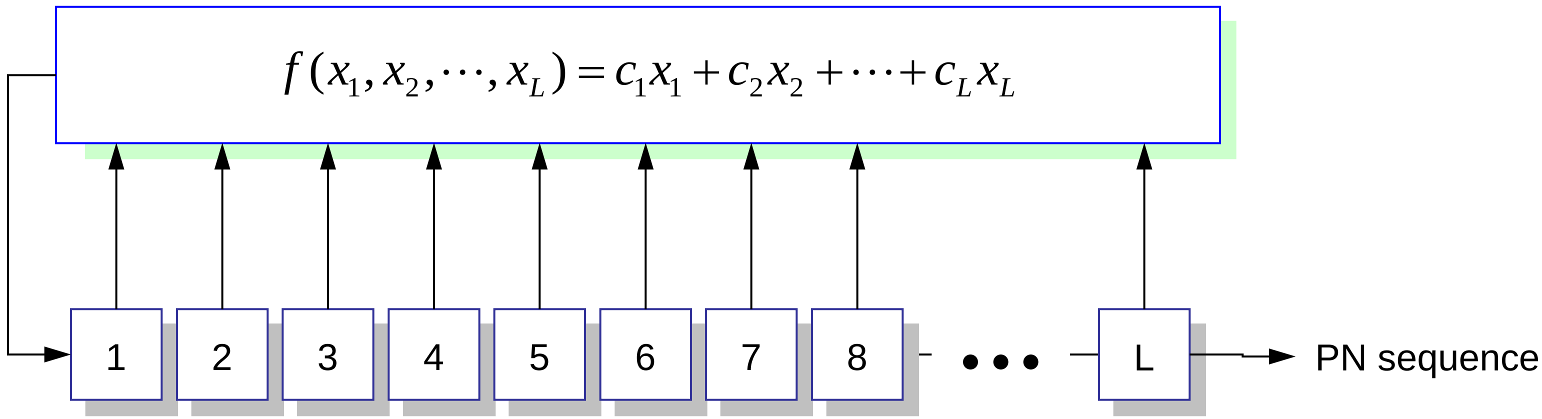
Desired properties of a PN sequence

1. *Balance* : The numbers of binary zeros and ones in the sequence differs by at most one.
2. *Run* : Half the runs are 1 *chip*, 1/4th of the runs are 2 chips, 1/8'th of the runs are 3 chips ...
3. *Correlation* : Numbers of matches and unmatches differ by at most one when the sequence is chip by chip compared with its cyclic shifts





Shift Register Type PN Sequence Generators

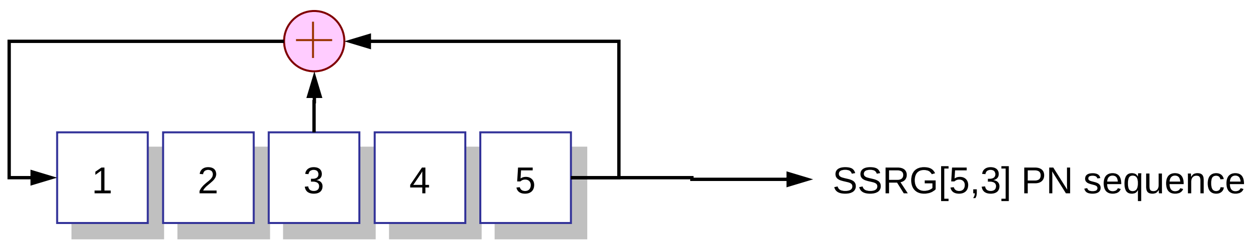


c_i's are either 1 or 0

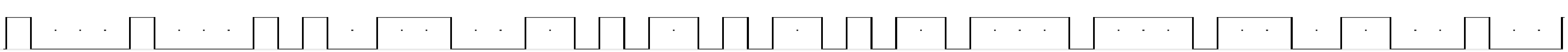
summations are in modulo-2 arithmetic (XOR)

If the length of the sequence is $2^L - 1$ then
the sequence is called *maximal-length* sequence or *m-sequence*

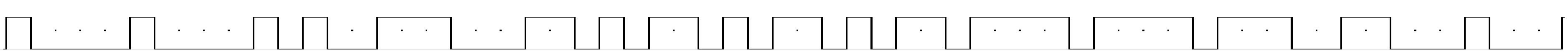
Example



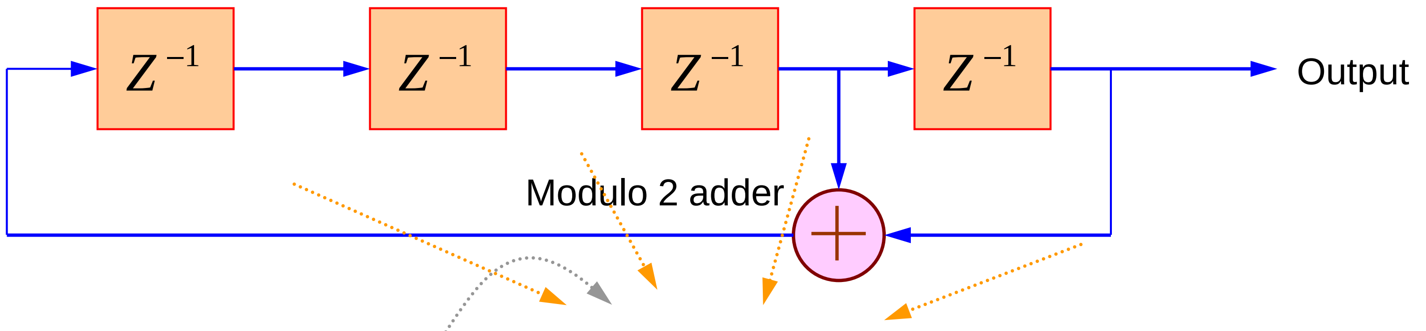
0000101011101100011111001101001



L	length	feedback taps	# m-sequences
2	3	[2,1]	2
3	7	[3,1]	2
4	15	[4,1]	2
5	31	[5,3] [5,4,3,2] [5,4,2,1]	6
6	63	[6,1] [6,5,2,1] [6,5,3,2]	6
7	127	[7,1] [7,3] [7,3,2,1] [7,4,3,2] [7,6,4,2] [7,6,3,1] [7,6,5,2] [7,6,5,4,2,1] [7,5,4,3,2,1]	18
8	255	[8,4,3,2] [8,6,5,3] [8,6,5,2] [8,5,3,1] [8,6,5,1] [8,7,6,1] [8,7,6,5,2,1] [8,6,4,3,2,1]	16
9	511	[9,4] [9,6,4,3] [9,8,5,4] [9,8,4,1] [9,5,3,2] [9,8,6,5] [9,8,7,2] [9,6,5,4,2,1] [9,7,6,4,3,1] [9,8,7,6,5,3]	48
10	1023	[10,3] [10,8,3,2] [10,4,3,1] [10,8,5,1] [10,8,5,4] [10,9,4,1] [10,8,4,3] [10,5,3,2] [10,5,2,1] [10,9,4,2] [10,6,5,3,2,1] [10,9,8,6,3,2] [10,9,7,6,4,1] [10,7,6,4,2,1] [10,9,8,7,6,5,4,3] [10,8,7,6,5,4,3,1]	60
11	2047	[11,2] [11,8,5,2] [11,7,3,2] [11,5,3,2] [11,10,3,2] [11,6,5,1] [11,5,3,1] [11,9,4,1,] [11,8,6,2,] [11,9,8,3] [11,10,9,8,3,1]	176



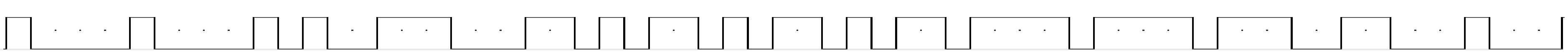
Another Example with 4 Registers



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

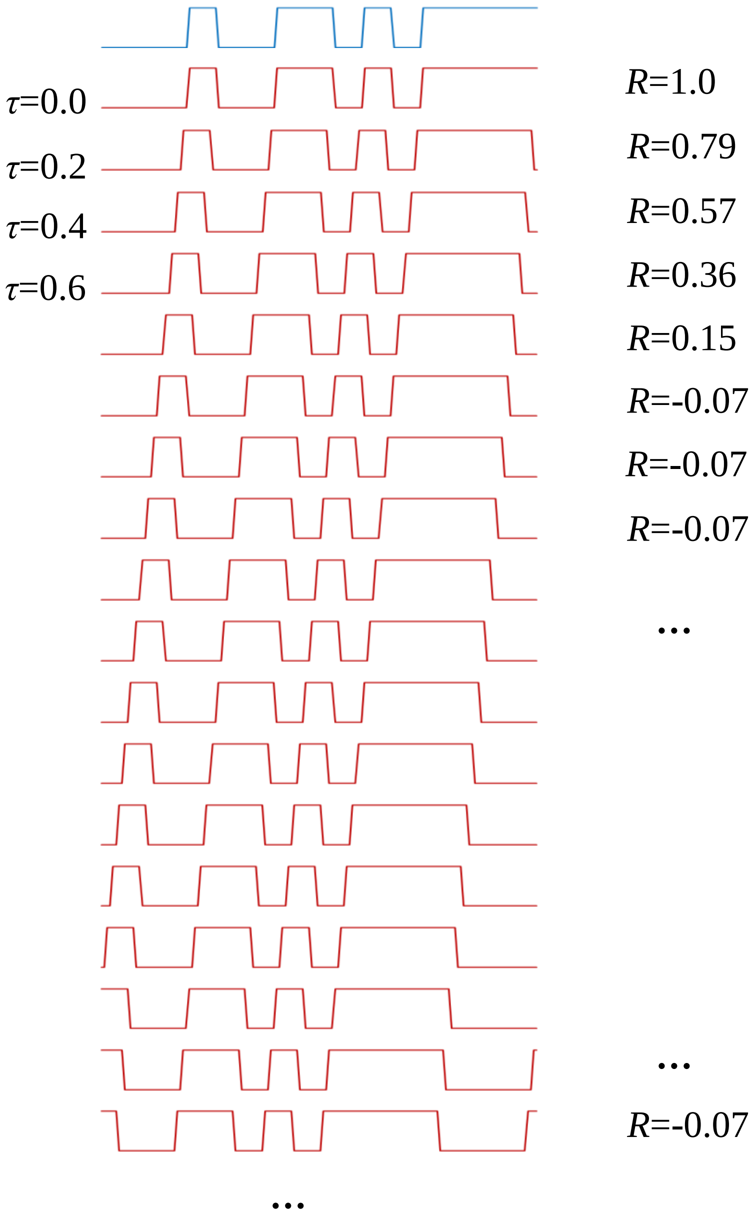
Cycle

We have all possible states for 4 registers (except 0000). Such a sequence is called *maximal length*

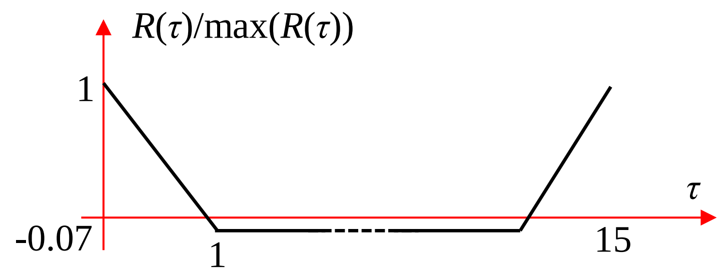


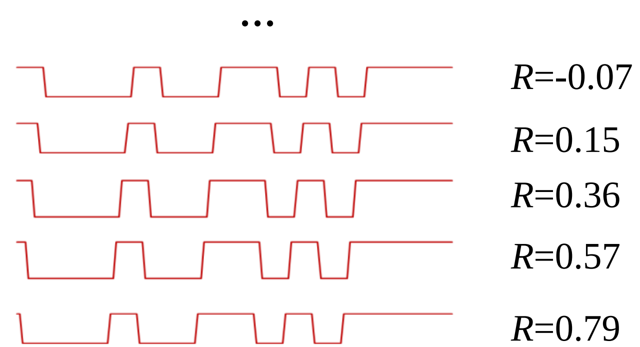
Normalized Autocorrelation of PN Sequences

$$R(\tau) = \int_0^T x(t)x(t+\tau)dt$$

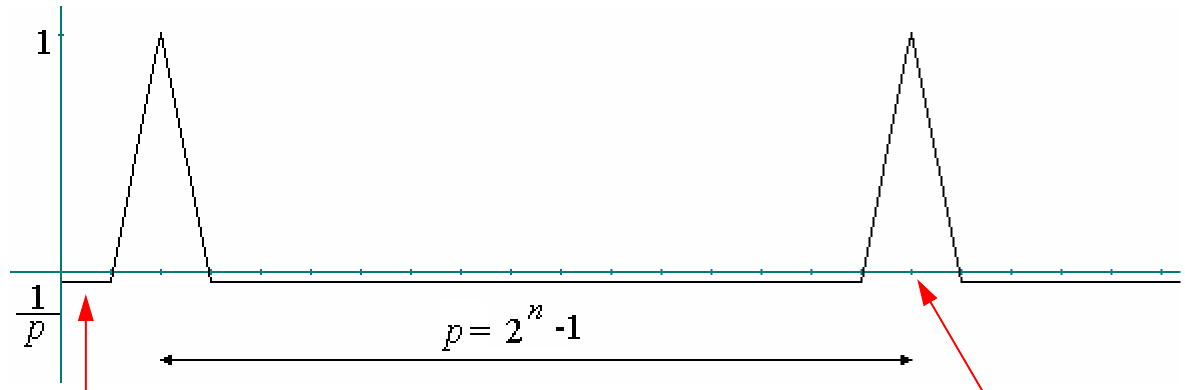


normalized circular autocorrelation





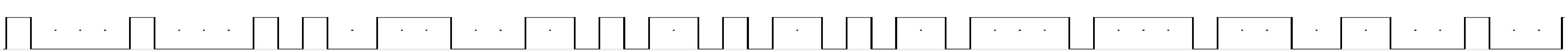
Normalized Autocorrelation of PN Sequences



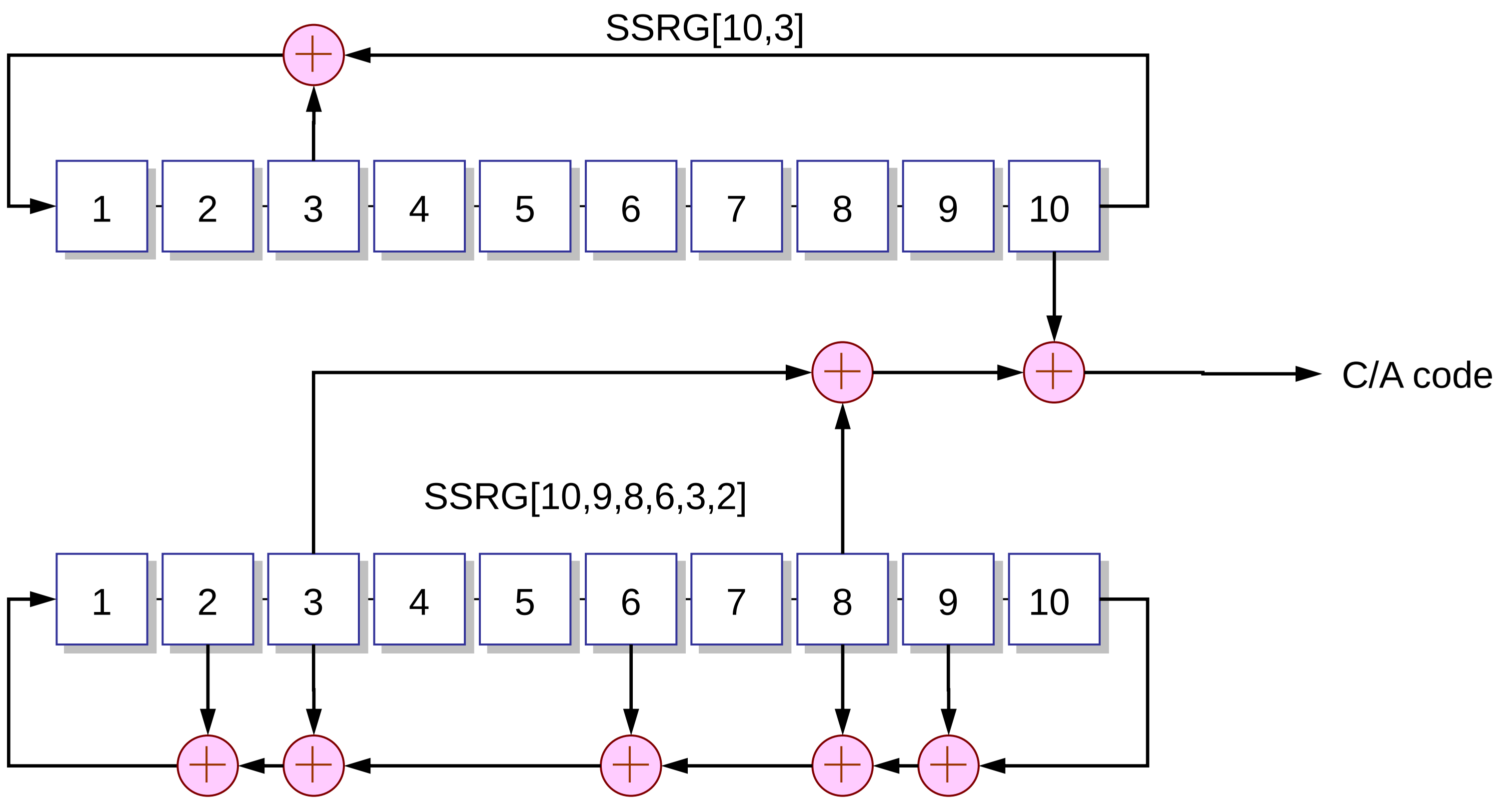
Perfect correlation here

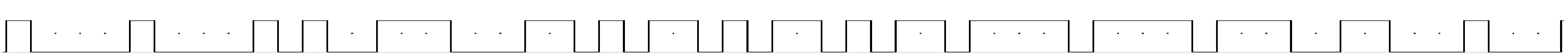
Any cyclic shift greater than 1 results in -1/p value for normalized autocorrelation function

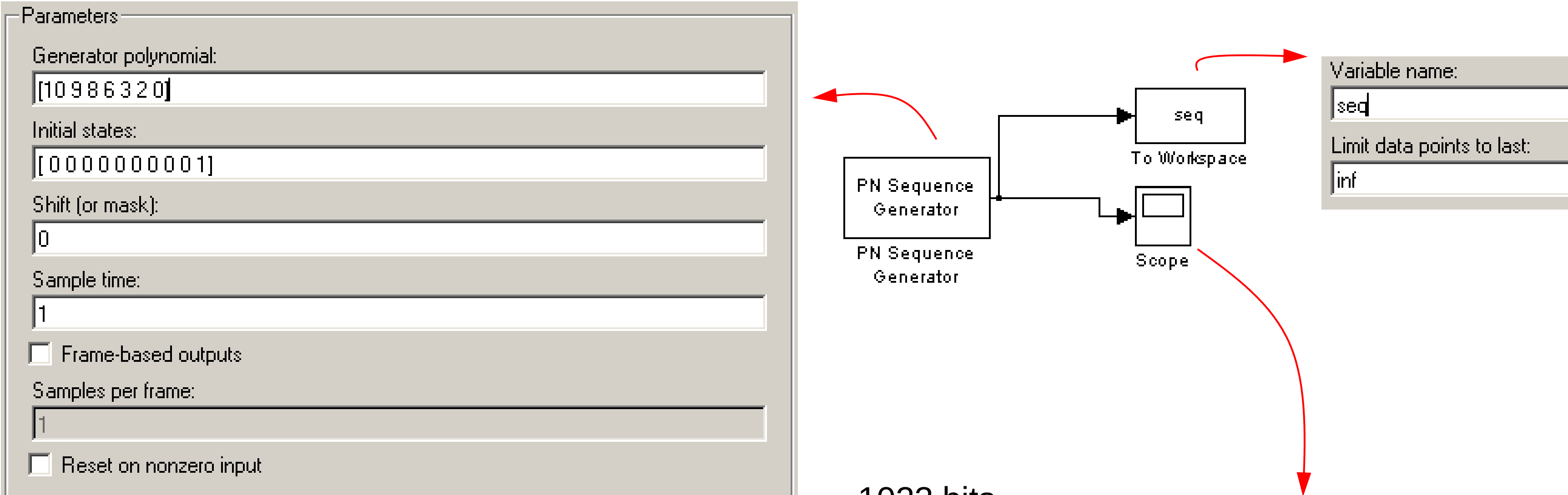
This is the autocorrelation of the sequence 000100110101111.
So, this sequence satisfies desired correlation property.



Another Example Used in GPS





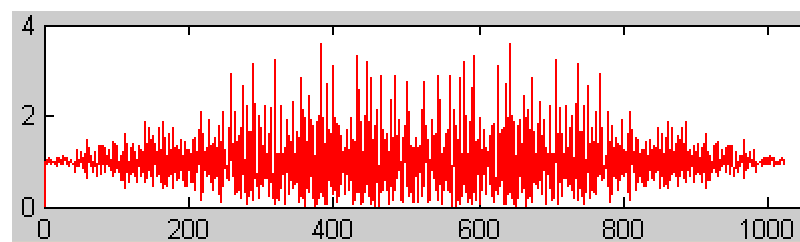


1023 bits

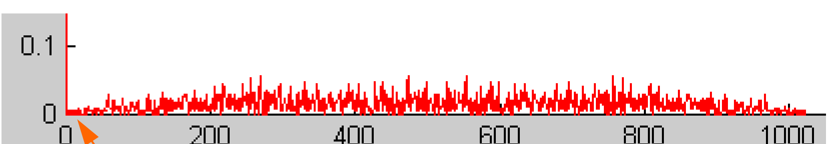
(Make ±1 binary antipodal signal)

```
O=2*(seq.signals.values-0.5);
```

```
plot(abs(fft(O)).^2/1024);
```




```
plot(abs(ifft(abs(fft(O)).^2))/1024);
```



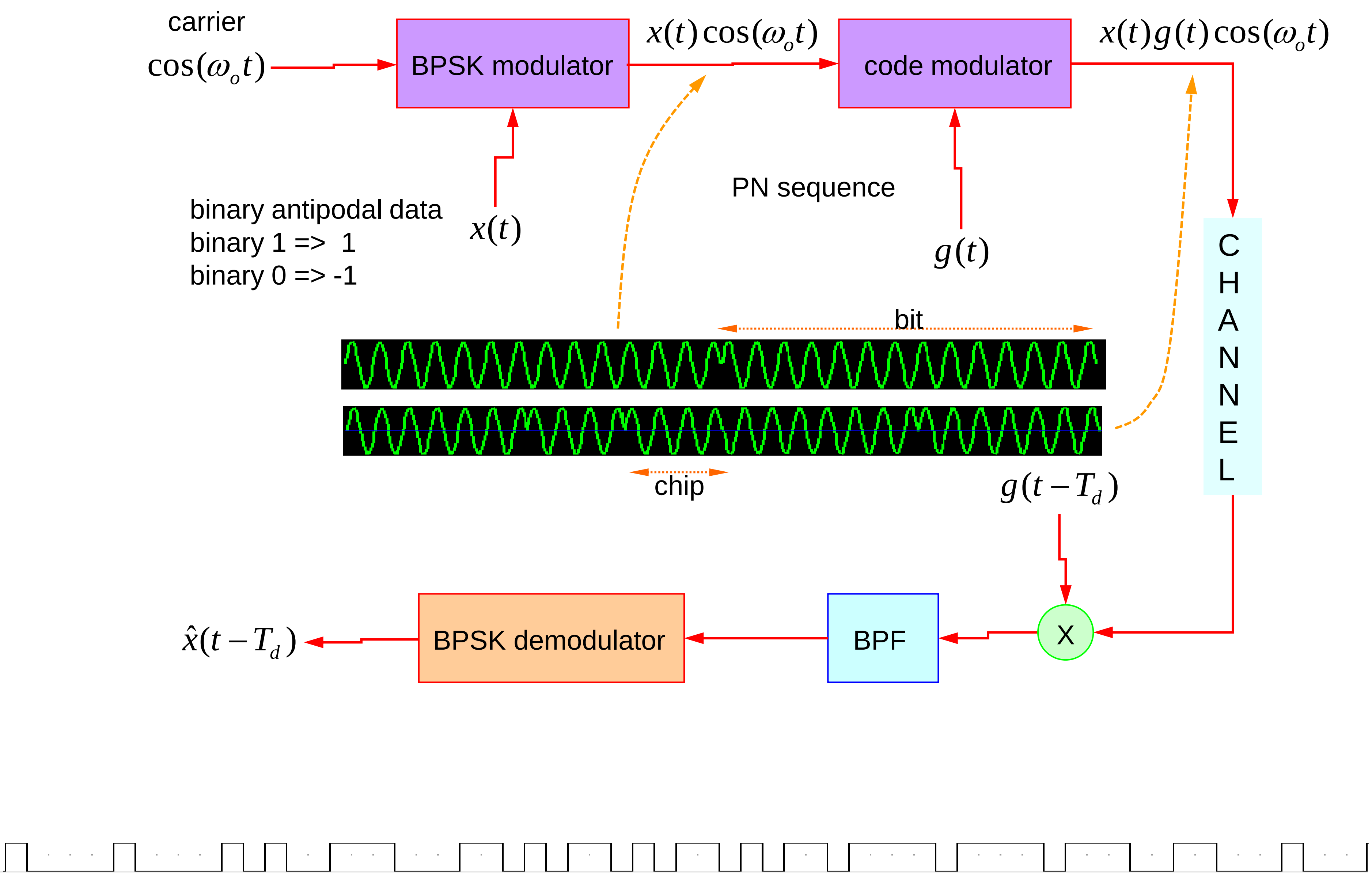
Autocorrelation (via FFT)

full correlation at τ =0 (truncated here)

power spectrum

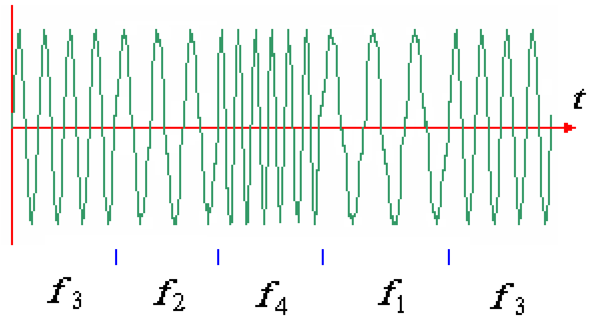
(Doesn't look like ps of white noise**!** What is wrong**?** Hmw)

BPSK with DSSS



Frequency Shift Keying (FSK)

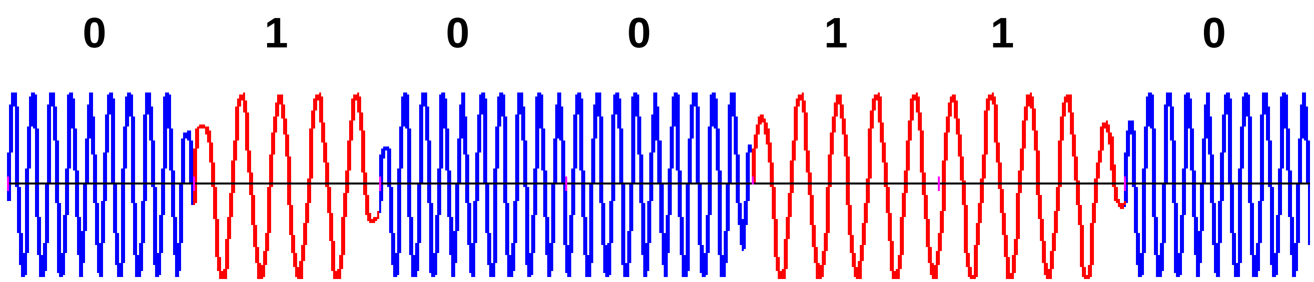
Each symbol (with *r* bits) is represented by one of *M* different frequencies

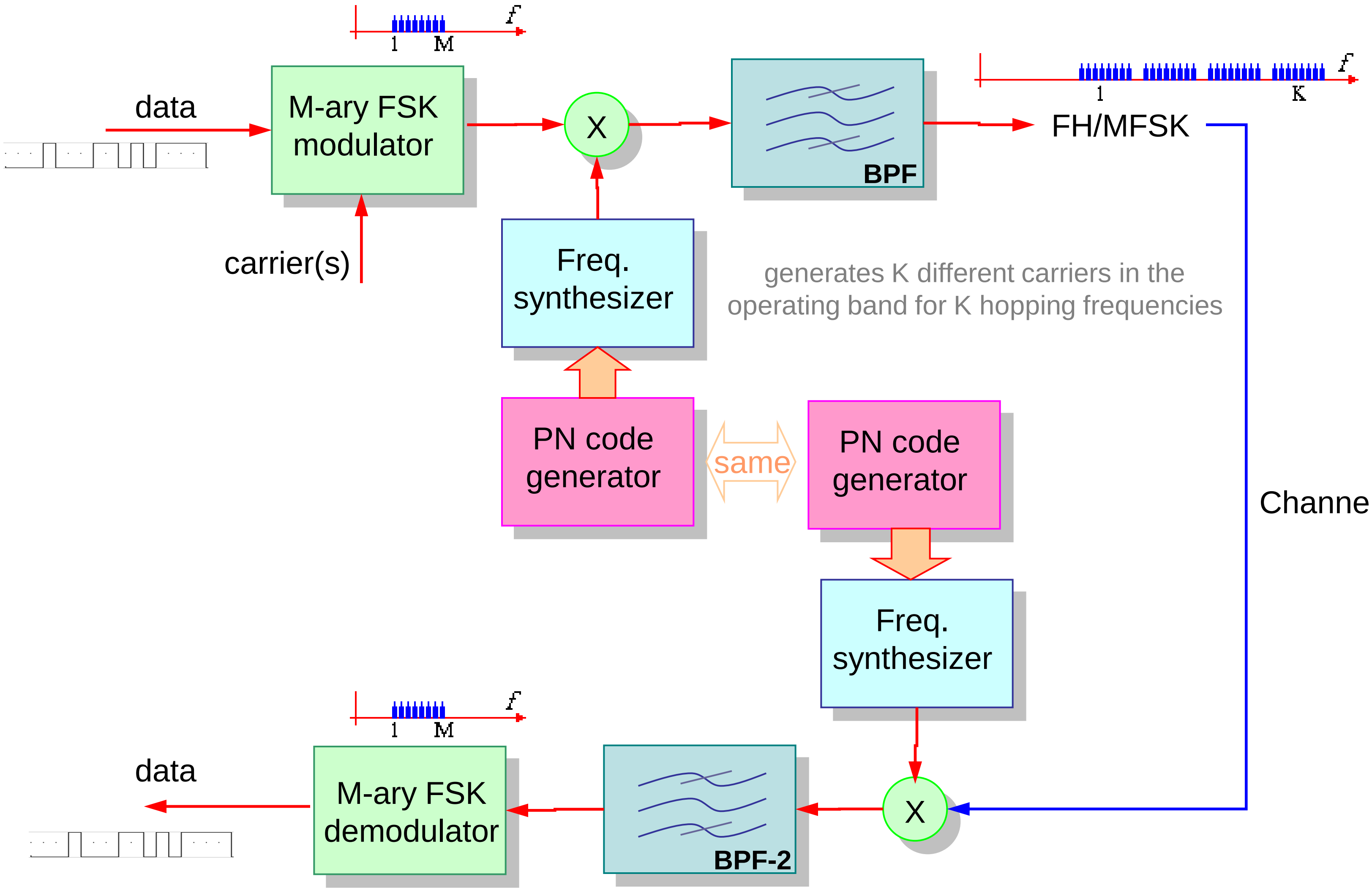


M-ary FSK

$$M = 2^r \quad \text{or} \quad r = \log_2 M$$

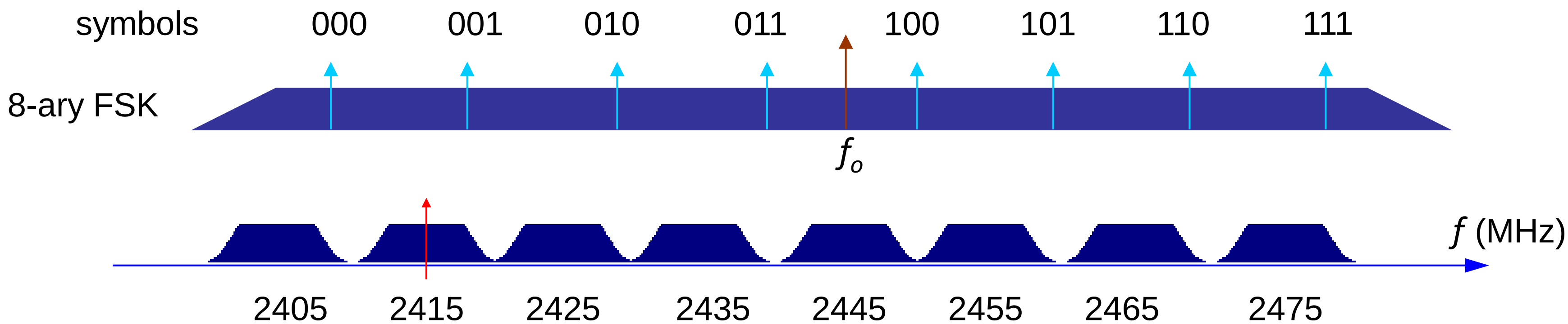
Example   Binary FSK $r = 1 \quad M = 2$

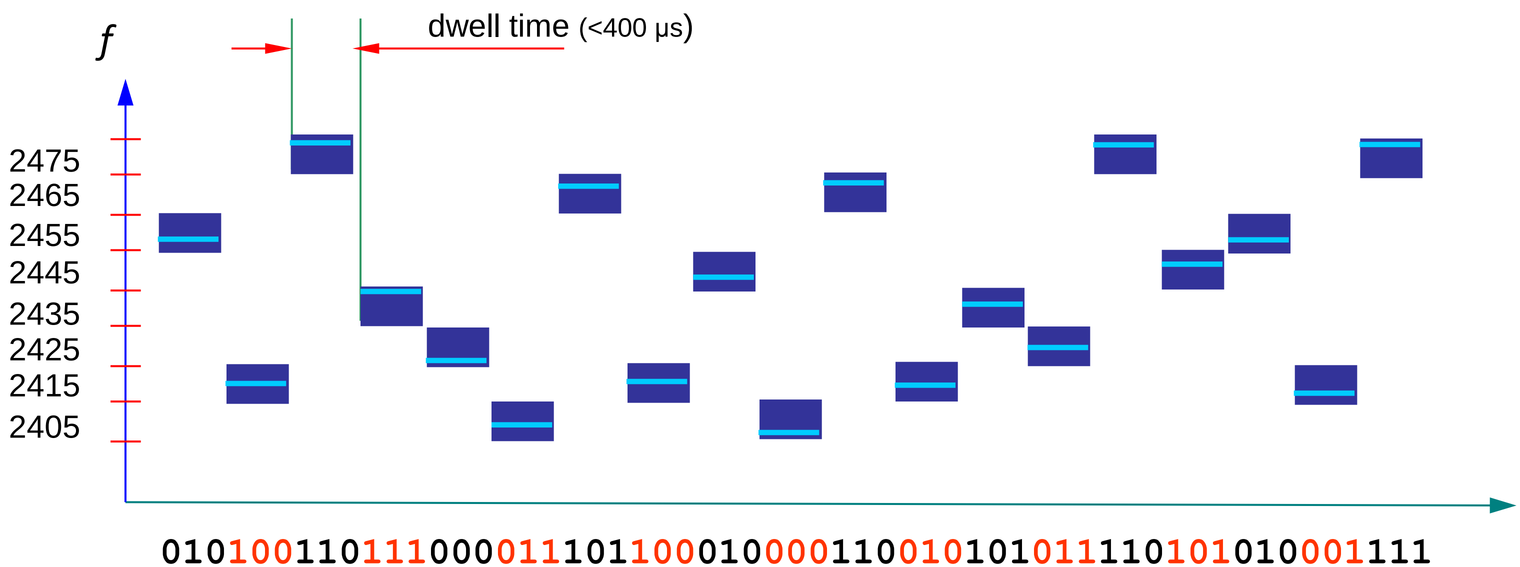




f
1
M
data
M-ary FSK modulator
carrier(s)
X
Freq. synthesizer
BPF
f
1
K
FH/MFSK
generates K different carriers in the operating band for K hopping frequencies
PN code generator
same
PN code generator
Channel
Freq. synthesizer
f
1
M
data
M-ary FSK demodulator
BPF-2
X

Example Consider an 8-ary FSK communication system.
Apply FHSS with $8=2^3$ hopping channels within 2.4-2.48 GHz ISM band.

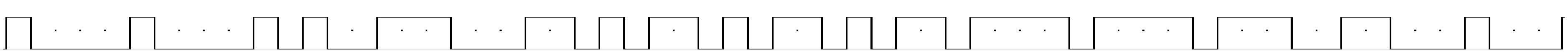




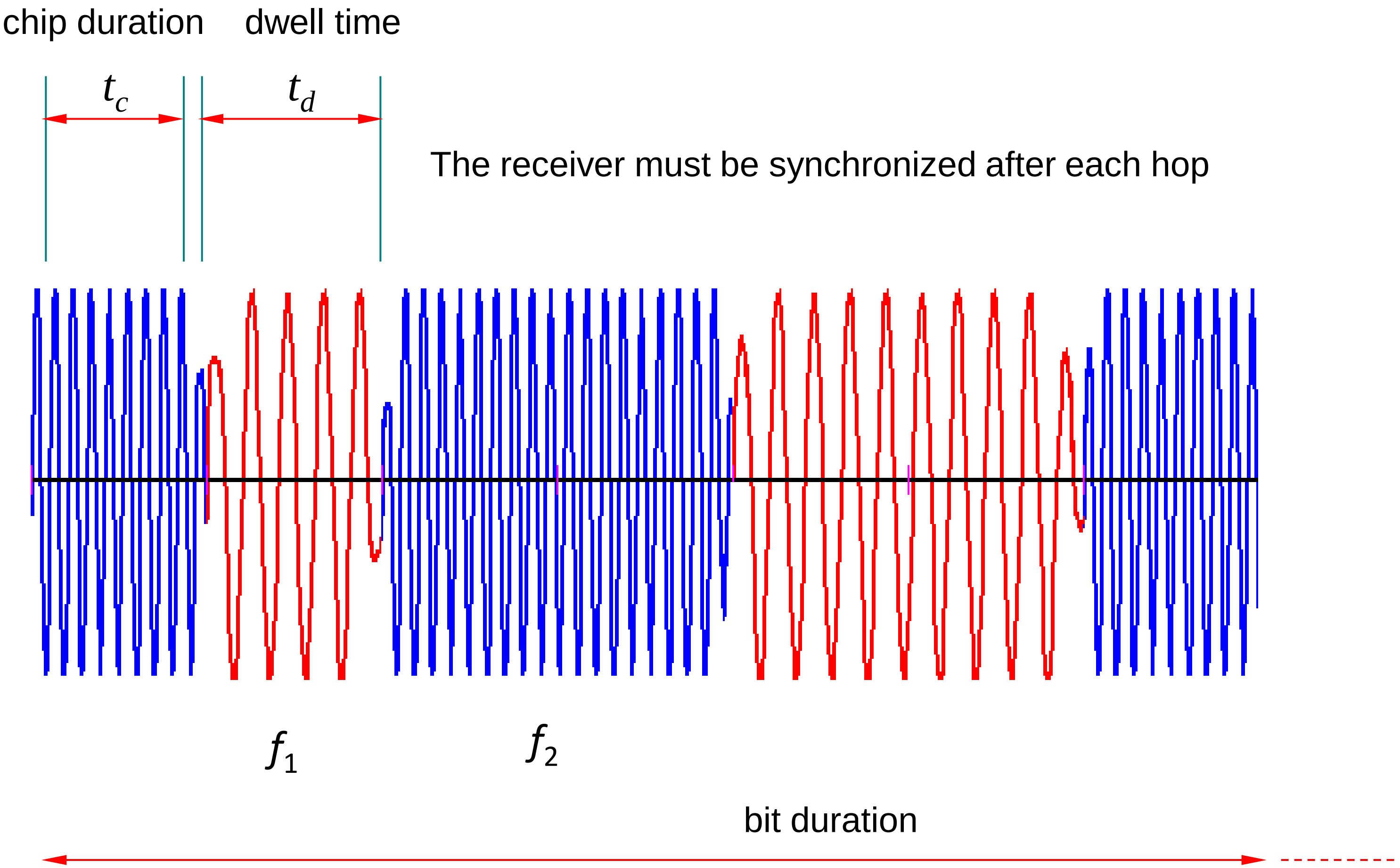
010100110111000011101100010000110010101011110101010001111

Example binary stream

Q: Assume 2 khops/sec. What is the bit rate?

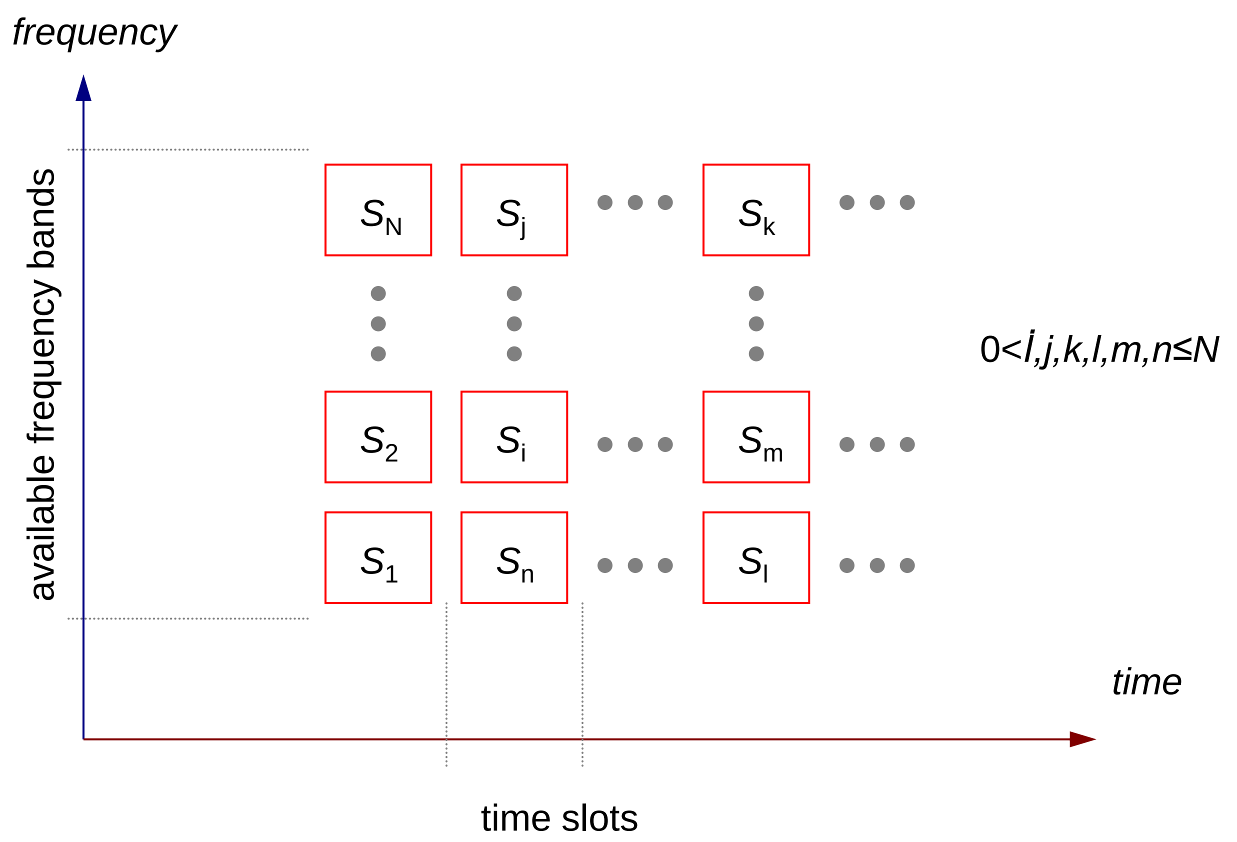


Dwell Time



The receiver must be synchronized after each hop

CDMA with FHSS



Bluetooth

2.4 - 2.4835 GHz ISM band is divided into 79 channels (1 MHz each plus some guarding)

ISM: Industrial, Scientific, Medical

Channel is changed 1600 times per second (hop frequency)

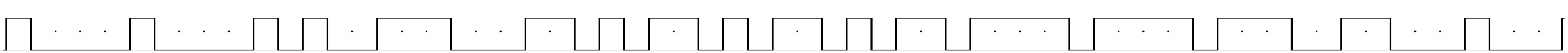
ver-1.1 → 723.1 kbit/s (1 Mbit/s)
ver-1.2 → 723.1 kbit/s (1 Mbit/s)
ver-2.1 → 2.1 Mbit/s (3 Mbit/s)

Dwell time is 625 μs.

802.11 (wireless network) also operates in 2.4 GHz band.
They interfere with each other.

Bluejacking: Sending of unsolicited messages over Bluetooth to Bluetooth-enabled devices

Bluesnarfing: Unauthorized access through a Bluetooth connection



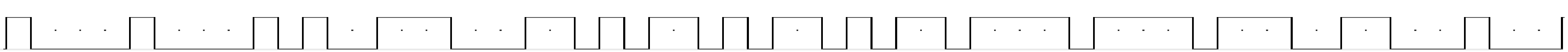
		throughput	rate	
802.11a 1999	5 GHz	23 Mbit/s	54 Mbit/s	OFDM
802.11b 1999	2.4 GHz	4.3 Mbit/s	11 Mbit/s	DSSS
802.11g 2003	2.4 GHz	19 Mbit/s	54 Mbit/s	OFDM
802.11n 2008	2.4, 5 GHz	74 Mbit/s	248 Mbit/s	MIMO-OFDM
802.11y 2008	3.7 GHz	23 Mbit/s	54 Mbit/s	OFDM
...				
802.11ax 2019	2.4-6 GHz	160 Mbit/s	9608 Mbit/s	MIMO-OFDM

Several sub-bands with QAM on each
Also used in ADSL, DVB-T, powerline

also cordless phones, GPS

DBPSK (1 Mbit/s)
DQPSK (2 Mbit/s)

		802.11b @2.4 GHz		802.11g @2.4 GHz		802.11a @5.2 GHz	
Mbps	Carrier	Mandatory	Optional	Mandatory	Optional	Mandatory	Optional
1	Single	Barker		Barker			
2	Single	Barker		Barker			
5.5	Single	CCK	PBCC	CCK	PBCC		
6	Multi			OFDM	CCK-OFDM	OFDM	
9	Multi				OFDM, CCK-OFDM		OFDM
11	Single	CCK	PBCC	CCK	PBCC		
12	Multi			OFDM	CCK-OFDM	OFDM	
18	Multi				OFDM, CCK-OFDM		OFDM
22	Single				PBCC		
24	Multi			OFDM	CCK-OFDM	OFDM	
33	Single				PBCC		
36	Multi				OFDM, CCK-OFDM		OFDM
48	Multi				OFDM, CCK-OFDM		OFDM
54	Multi				OFDM, CCK-OFDM		OFDM



END

(to be continued)