Spread Spectrum

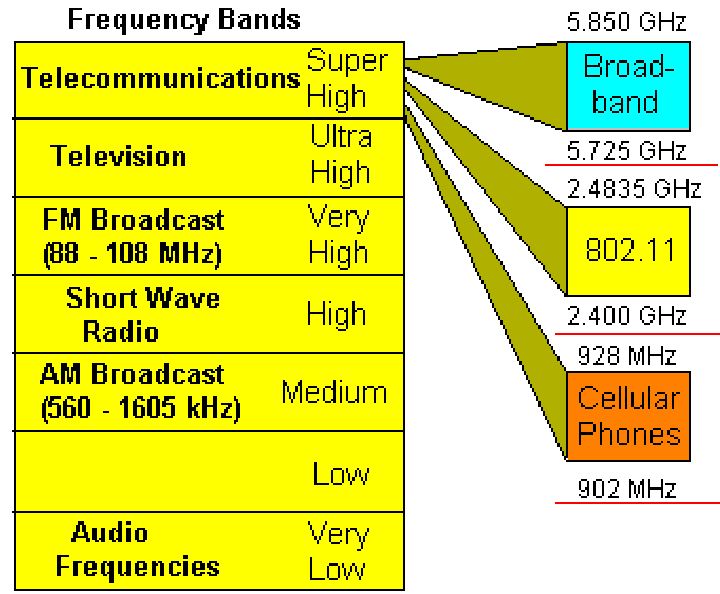
Last updated: 5/5/2011

Overview

- Notes

Frequency Bands (ISM and U-NII)

- Differ in output frequency and power



- The FCC has specified two basic band categories for license free use
  - ISM
  - UNII

- Industrial, Scientific, and Medical (ISM)
  - 915 MHz
    - Obsolete and expensive
  - 2.4 GHz
    - Used by 802.11, 802.11b, and 802.11g
    - FCC specifies use from 2.4000 GHz to 2.4835 GHz
  - 5.8 GHz
    - 5.725 GHz to 5.875 GHz
    - Not used by 802.11, especially 802.11a

- Unlicensed National Information Infrastructure (UNII)
  - Lower band (UNII-1)
    - 5.15 GHz to 5.25 GHz
    - 40 mW output power
  - Middle band (UNII-2)
    - 5.25 GHz to 5.35 GHz
    - 200 mW output power
  - Upper band (UNII-3)
    - 5.725 GHz to 5.825 GHz
    - 800 mW output power

White Space

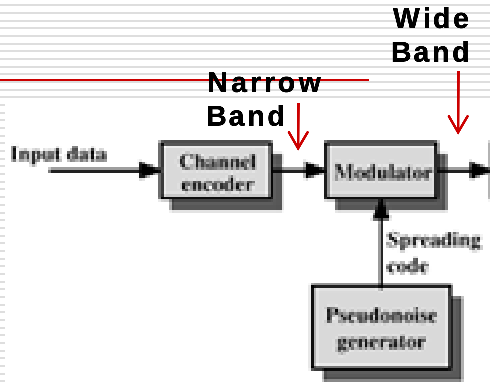
Frequency Bands (2010)

- White space refers to the 6-MHz channels left unused by TV broadcasters in the 54- to 698-MHz range—channels 2 through 51
- In any given local region, TV stations are assigned frequencies several channels apart from one another to prevent interference
- White space refers to the unused gaps
- Also known as WiFi on steroids
  - like television signals – can range for miles and travel through obstructing entities that would block a standard wireless broadband signal

TV AND WHITE-SPACE FREQUENCIES

CHANNEL	FREQUENCY RANGE (MHz)	CHANNEL	FREQUENCY RANGE (MHz)
VHF LOW-BAND		UHF (Cont'd)	
2	54 to 60	24	530 to 536
3	60 to 66	25	536 to 542
4	66 to 72	26	542 to 548
5	76 to 82	27	548 to 554
6	82 to 88	28	554 to 560
FM BROADCAST	88 to 108	29	560 to 566
AIRCRAFT	118 to 135	30	566 to 572
HAM RADIO	144 to 148	31	572 to 578
MOBILE/ MARINE	150 to 173	32	578 to 584
VHF HIGH-BAND		33	584 to 590
7	174 to 180	34	590 to 596
8	180 to 186	35	596 to 602
9	186 to 192	36	602 to 608
10	192 to 198	37	608 to 614
11	198 to 204	38	614 to 620
12	204 to 210	39	620 to 626
13	210 to 216	40	626 to 632
UHF		41	632 to 638
14	470 to 476	42	638 to 644
15	476 to 482	43	644 to 650
16	482 to 488	44	650 to 656
17	488 to 494	45	656 to 662
18	494 to 500	46	662 to 668
19	500 to 506	47	668 to 674
20	506 to 512	48	674 to 680
21	512 to 518	49	680 to 686
22	518 to 524	50	686 to 692
23	524 to 530	51	692 to 698

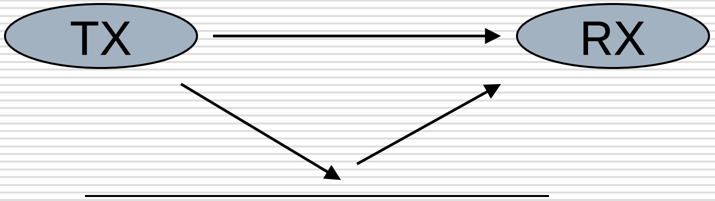
Modulation Techniques



- Spread Spectrum Modulation
  - Used to transmit analog or digital signals
  - The basic idea is to transmit over wide bandwidth
    - **Low power peak with bandwidth**
  - Used in wireless communications
  - Typically requires no FCC licensing (cheap) – narrow-band signals often require FCC licensing
- Advantages
  - Less susceptible to ISI (overlapping data bits due to multipath)
  - Cannot be jammed using narrow-band
- Applications
  - Military communications; cordless phones, cell phone systems, GPS, Bluetooth, WLAN. WPAN

Delay Spread

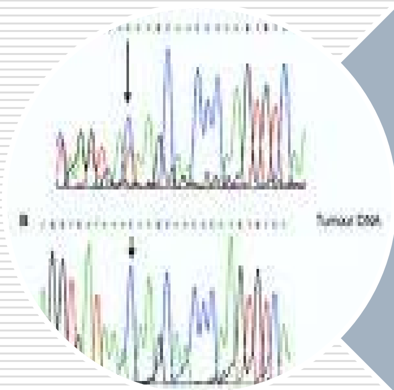
- Resulted due to Intersymbol Interference (ISI)
  - A form of multipath
  - Can cause errors
- The idea of SS is to tolerate large delay spread



Spread Spectrum Modulation Techniques - Background

Frequency Hopping

- Invented in 1940 by Hedy Lamarr



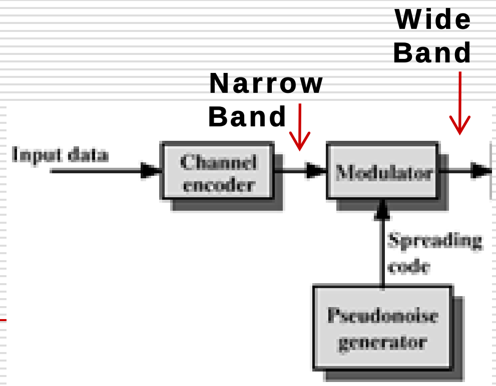
Direct Sequence

- More recent type of SSM

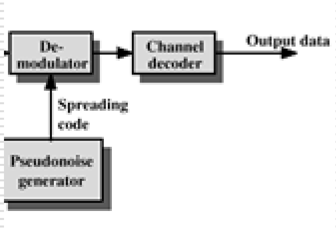
Spread Spectrum Modulation - Background

- Initially developed by military (hard to decode or jam)
- Used in military for the past 50 years
- Its commercial use started in 1980

Spread Spectrum Model



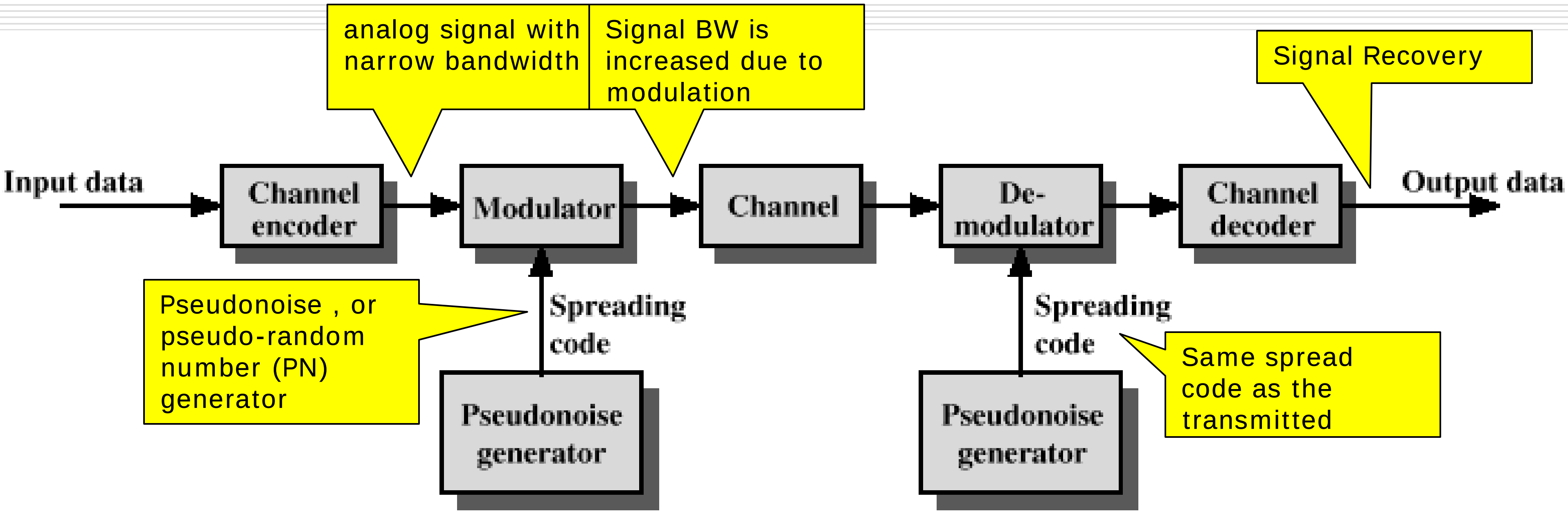
- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - Spreading code or spreading sequence
  - Generated by pseudonoise, or pseudo-random number (PN) generator
- Effect of modulation is to increase bandwidth of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



Spread Spectrum Model

- 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



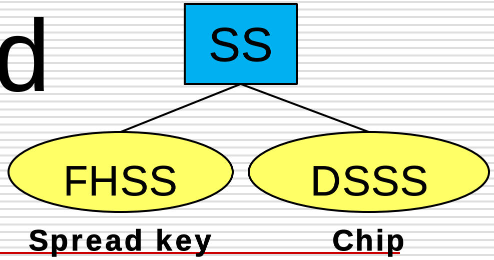
Spread Spectrum

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

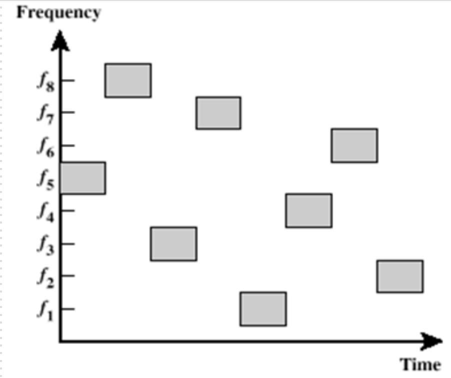
Spread Spectrum Types

- Frequency Hoping Spread Spectrum (FHSS)
- Direct Sequence Spread Spectrum (DSSS)
- Other types:
  - OFDM (recognized as spread spectrum)
  - HR-DSSS (high-rate DSCC)

Frequency Hoping Spread Spectrum (FHSS)



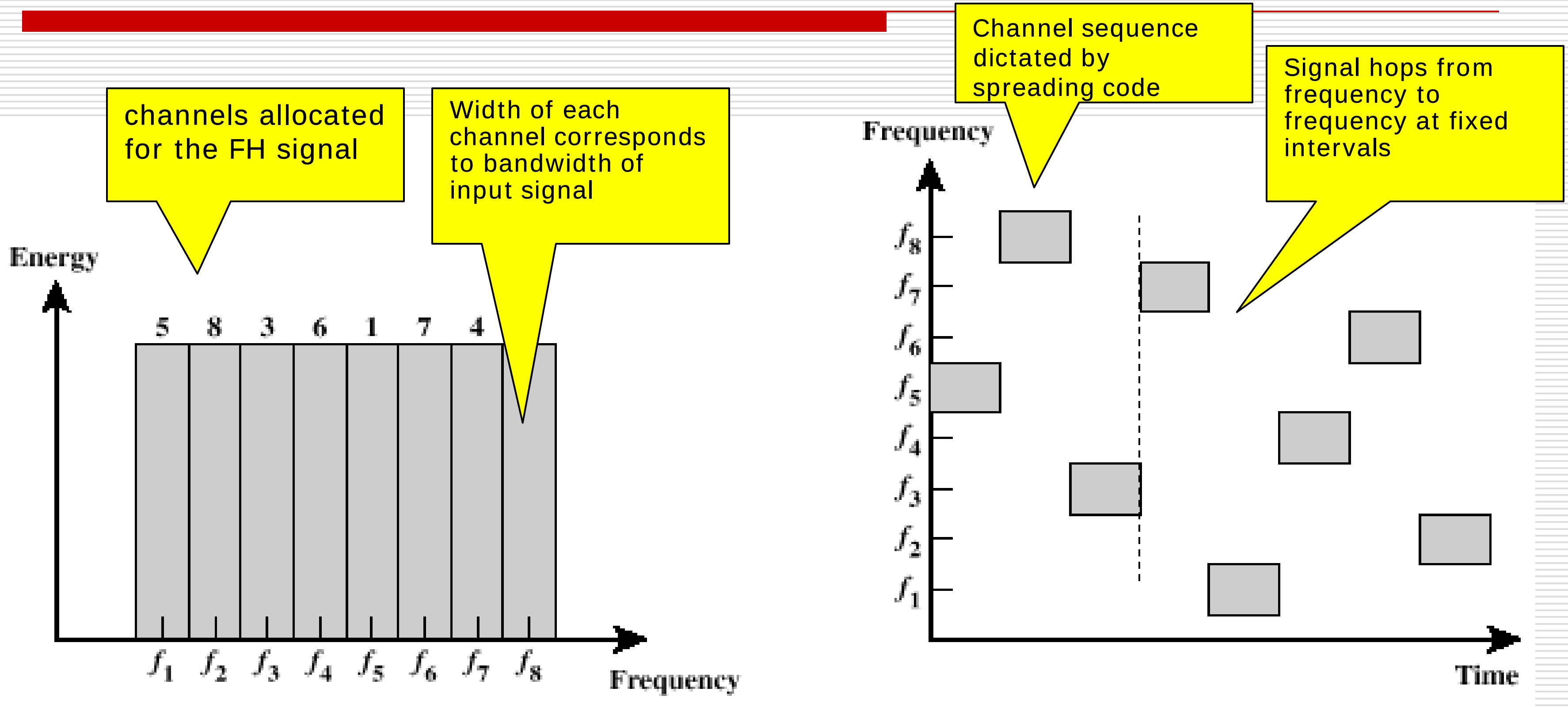
- Signal is broadcasted over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
  - Transmitter operates in one channel at a time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



Frequency Hoping 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 Hoping Spread Spectrum



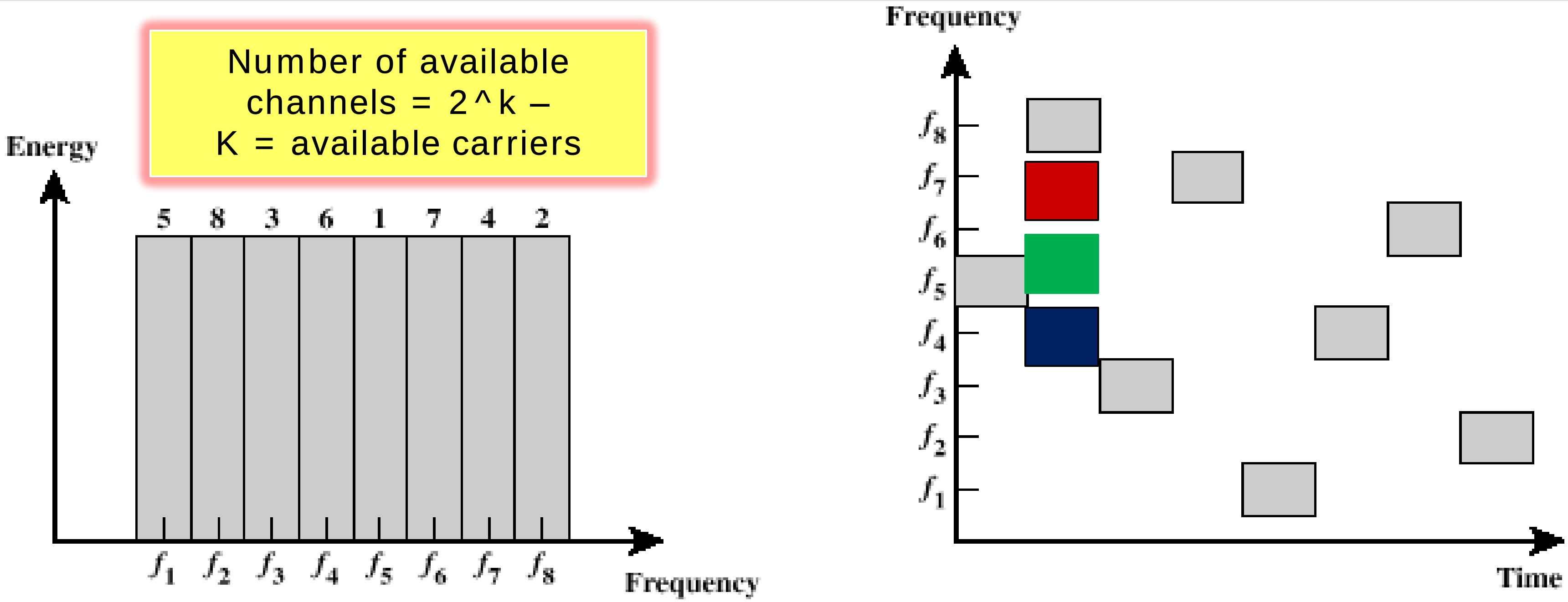
(a) Channel assignment

(b) Channel use

Receiver will be hopping between frequencies in synchronization with transmitter

Frequency Hoping Spread Spectrum

Number of available channels = 2^k –
K = available carriers



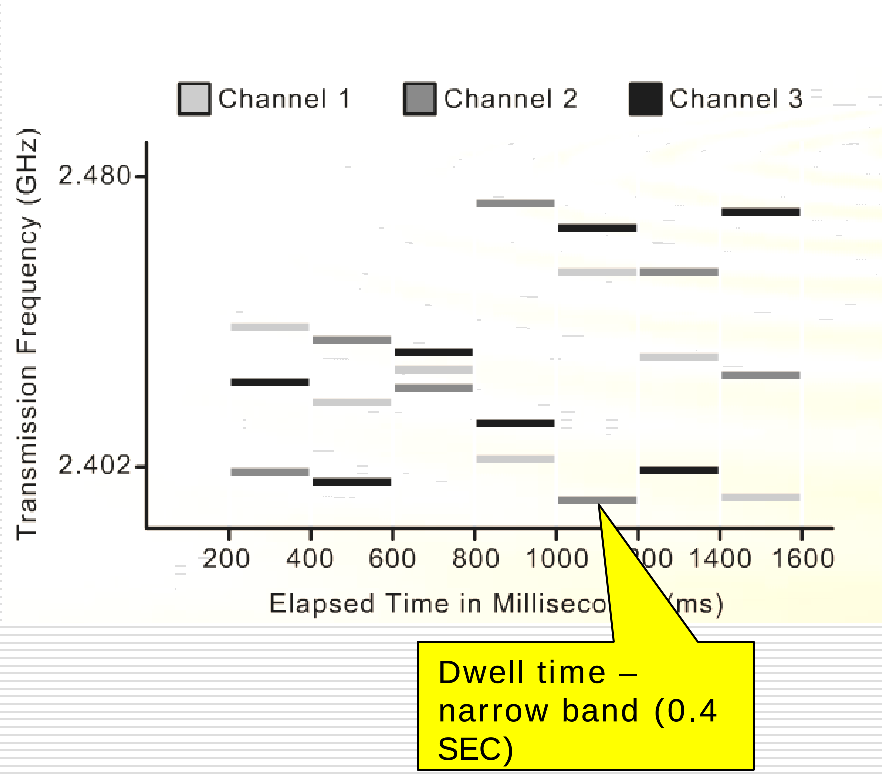
(a) Channel assignment

(b) Channel use

Multiple users can be using the same channel

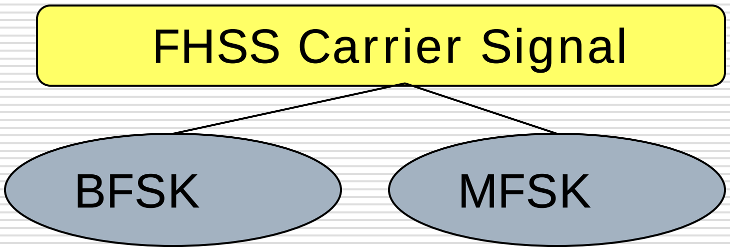
FHSS

- Requires synchronization
- Frequency hopping is time dependent
- Orthogonal hopping sequence
  - Resulting in high throughput
- The energy is spread over wide range
  - Jamming requires large power over the entire range of frequencies
- The hopping sequence must be knows to RX (spread key)



FHSS Parameter Setting

- Hop pattern (random)
  - Hopping order
- Hop index (how to generate the random number; hopping must be orthogonal)
  - Sequence number
- How to perform the synchronization
  - Using a Beacon frequency
- Dwell time (msec)
  - The smaller the more spreading impact
- Hope time (micro-second)
  - Overhead time (f1 changing to f2)
- Hoping channel
  - No wider than 1 MHz (FCC)
  - Use all channels equally
  - Number of hops per band (80.11 75 hops)
- Frequencies of operation
  - U-NII or ISM
- Output power
  - FCC or IEEE compliant (IEEE is more stringent!)

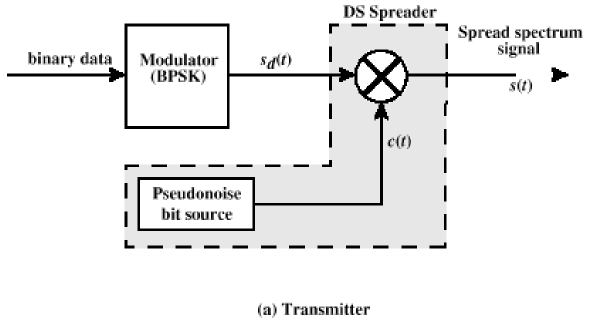


FHSS Using MFSK

- 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

M frequencies to represent each symbol (in MFSK)
Each PN is modulated with k symbols
2^k frequencies are required using FHSS
MFSK bandwidth will be Wd=Mfd (fd is the frequency spacing)
Total bandwidth using FHSS will be Ws= 2^k Wd

FHSS Using BFSK - Example

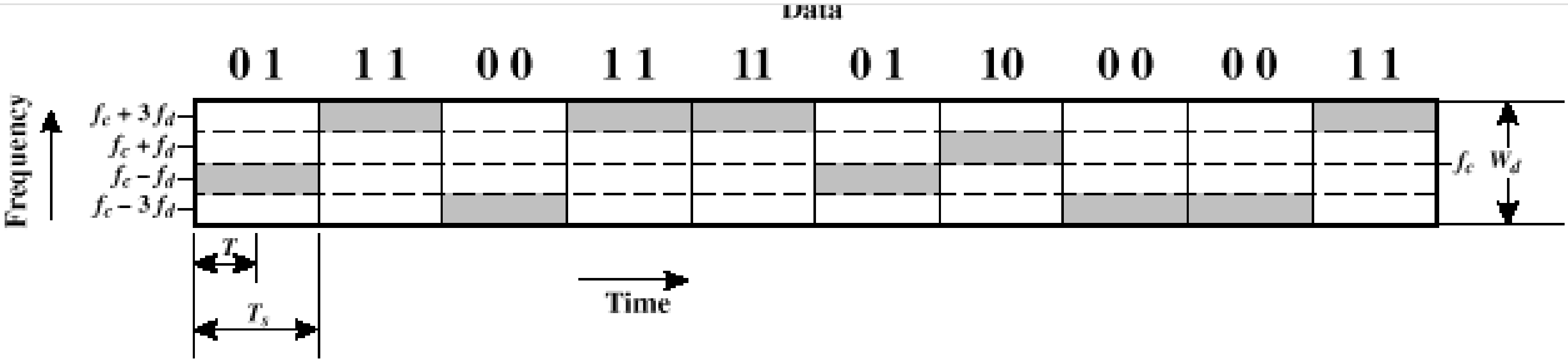


- Assume BFSK: fo and $f0+\Delta f$
  - If transmit +1→ f0
  - If transmit -1→ $f0+\Delta f$
- The modulator is simply a multipliers
  - $C(t) = \cos(2\pi f_i t)$; f_i is the frequency at the ith bit
- Hence, during the ith bit interval, the frequency of the transmitted signal will be $fo+fi$ or $fo+f_i+\Delta f$

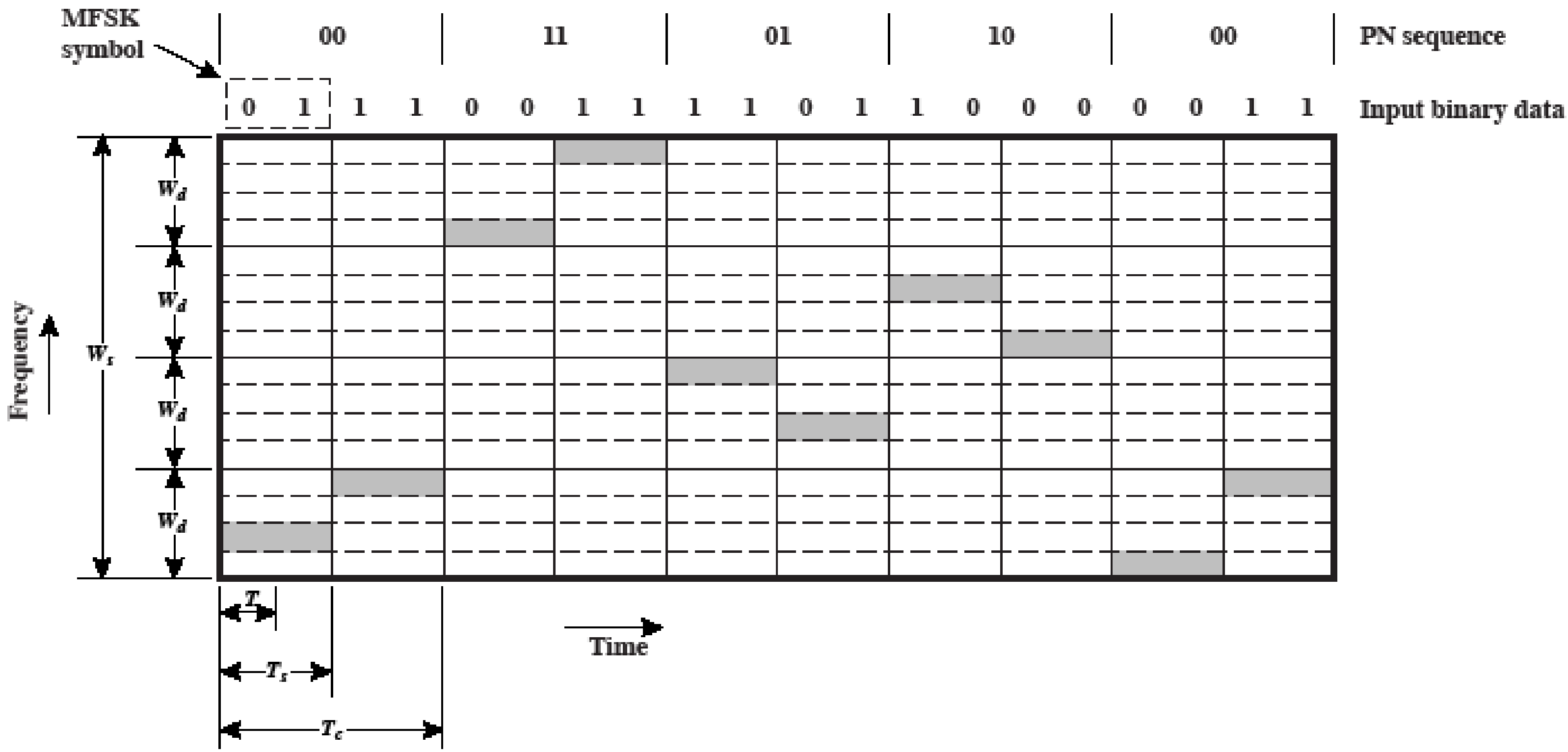
Refer to your notes! (C & D)

Multiple Frequency-Shift Keying (MFSK) - Example

Assume M=4 → 4 frequencies
20 bit stream: we send 2 bits per frequency
Note: Ts = 2Tb = Symbol period
Total BW = 2M.fd



MFSK Frequency Use ($M = 4$)

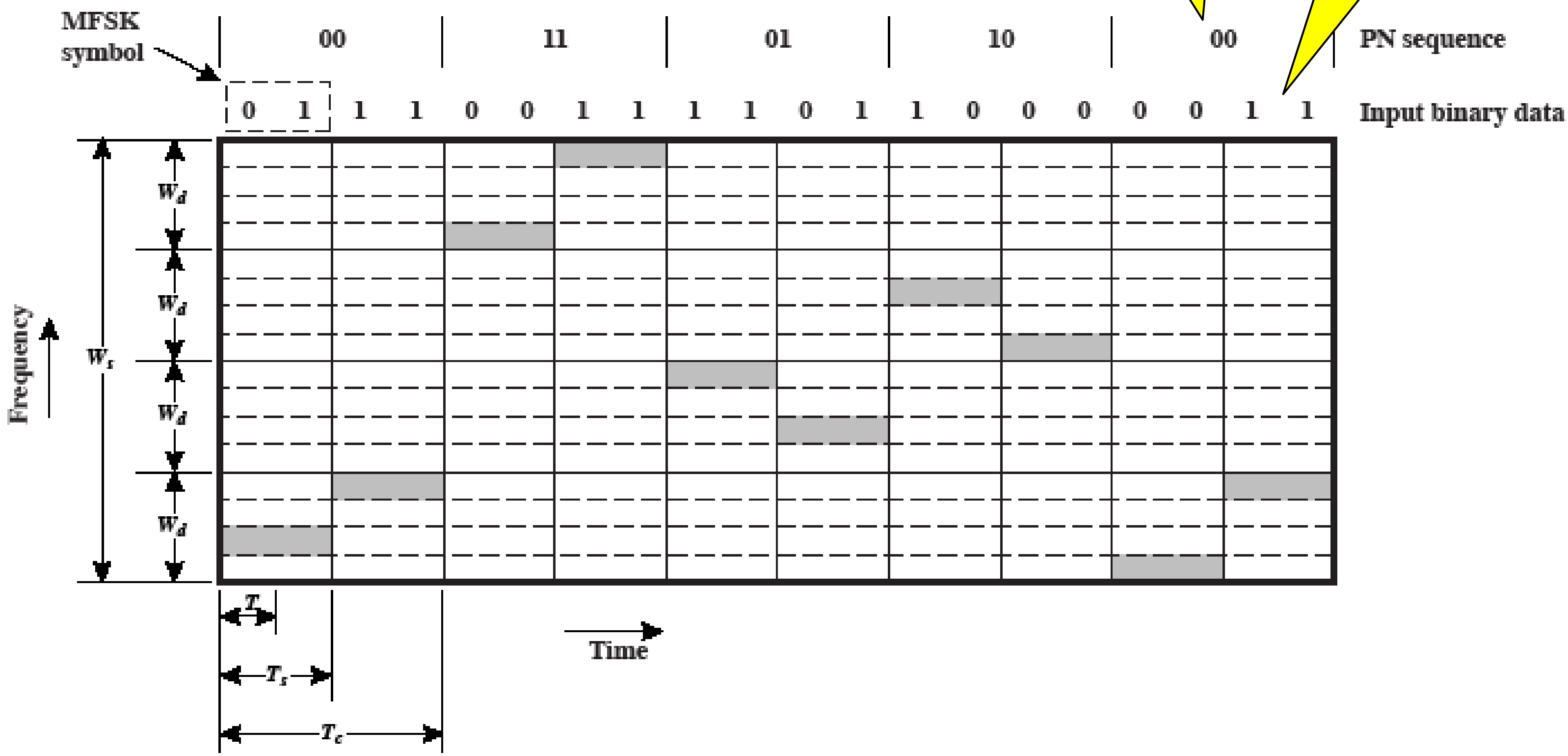


Wideband frequency→ less power per symbol!

k=2 ; 2^4 codes
Tc>Ts→ Ts=4Tc
Each signal element generates one tone
Ws=4xWd

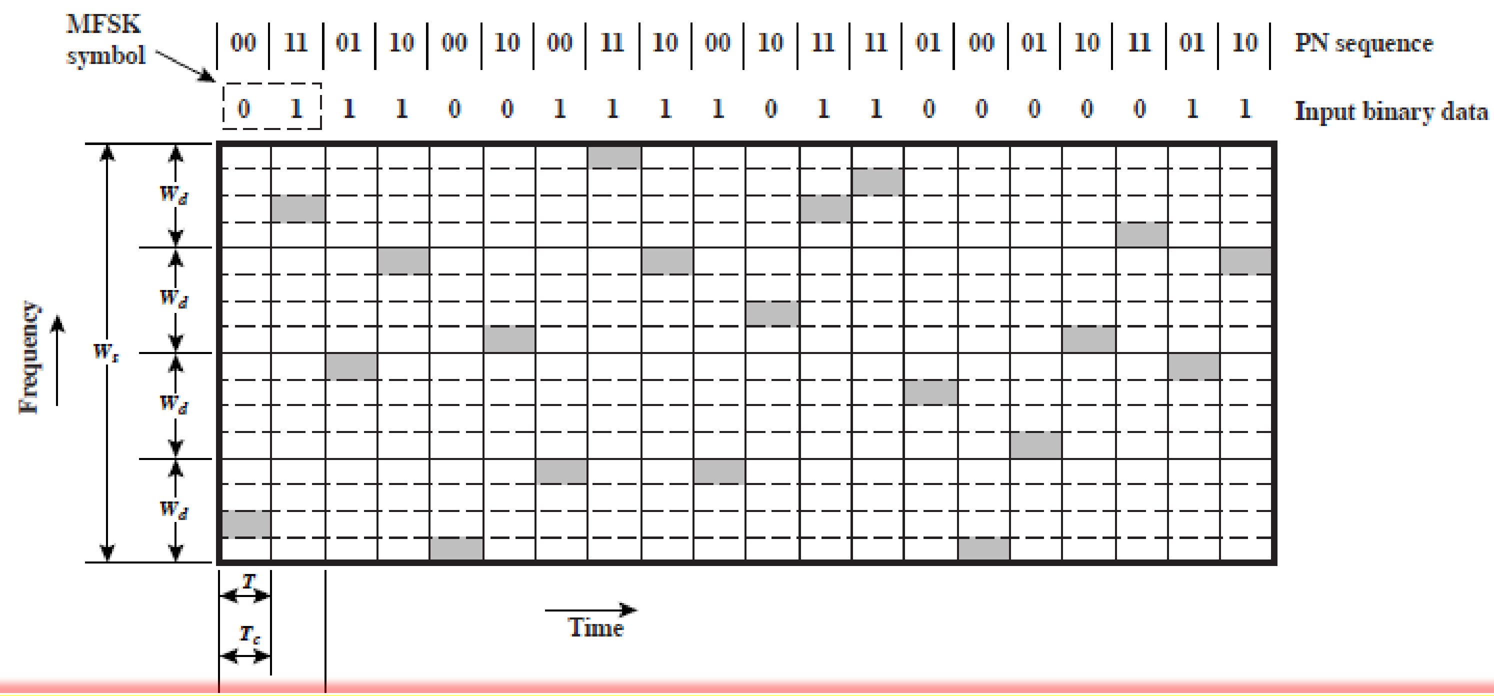
PN Sequence (hoping sequence)

Signal element



Refer to your notes! (A)

Fast Frequency-Hop SS Using MFSK M=4; k=2 (Tc<Ts)



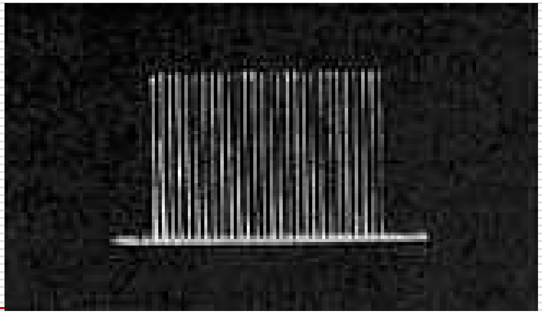
More hoping→ even harder to jam!

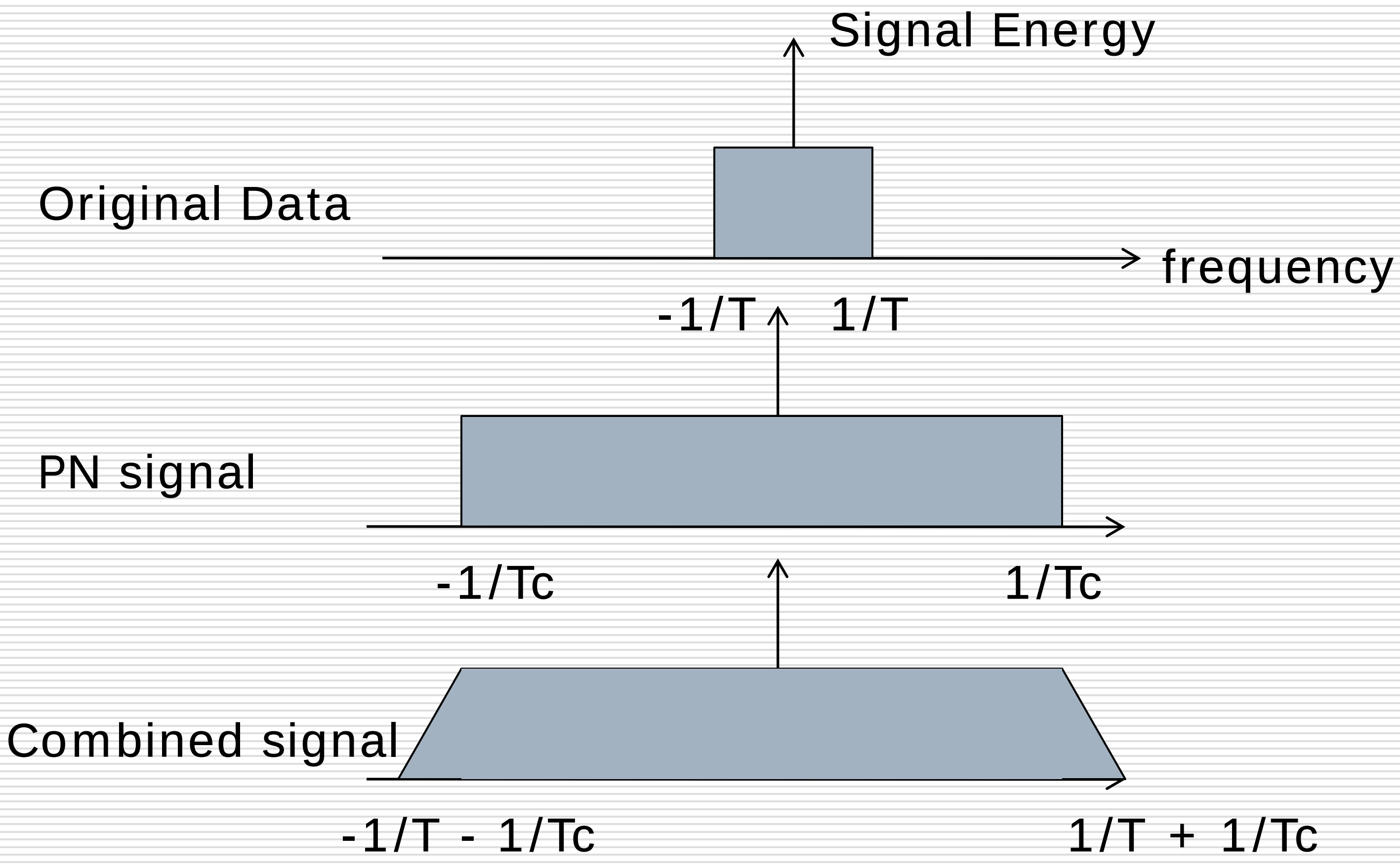
Resistance to noise and Jamming

- 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

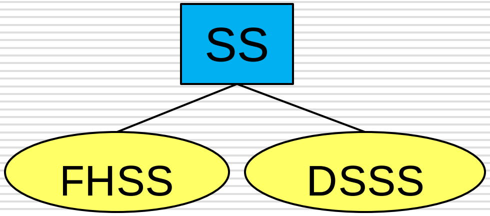
Refer to your notes! (B)

Signal Spectrum





Direct 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 – It is not fixed
- One technique combines digital information stream with the spreading code bit stream using exclusive-OR

$$1 \oplus 1 = 0$$
$$0 \oplus 0 = 0$$
$$1 \oplus 0 = 1$$
$$0 \oplus 1 = 1$$

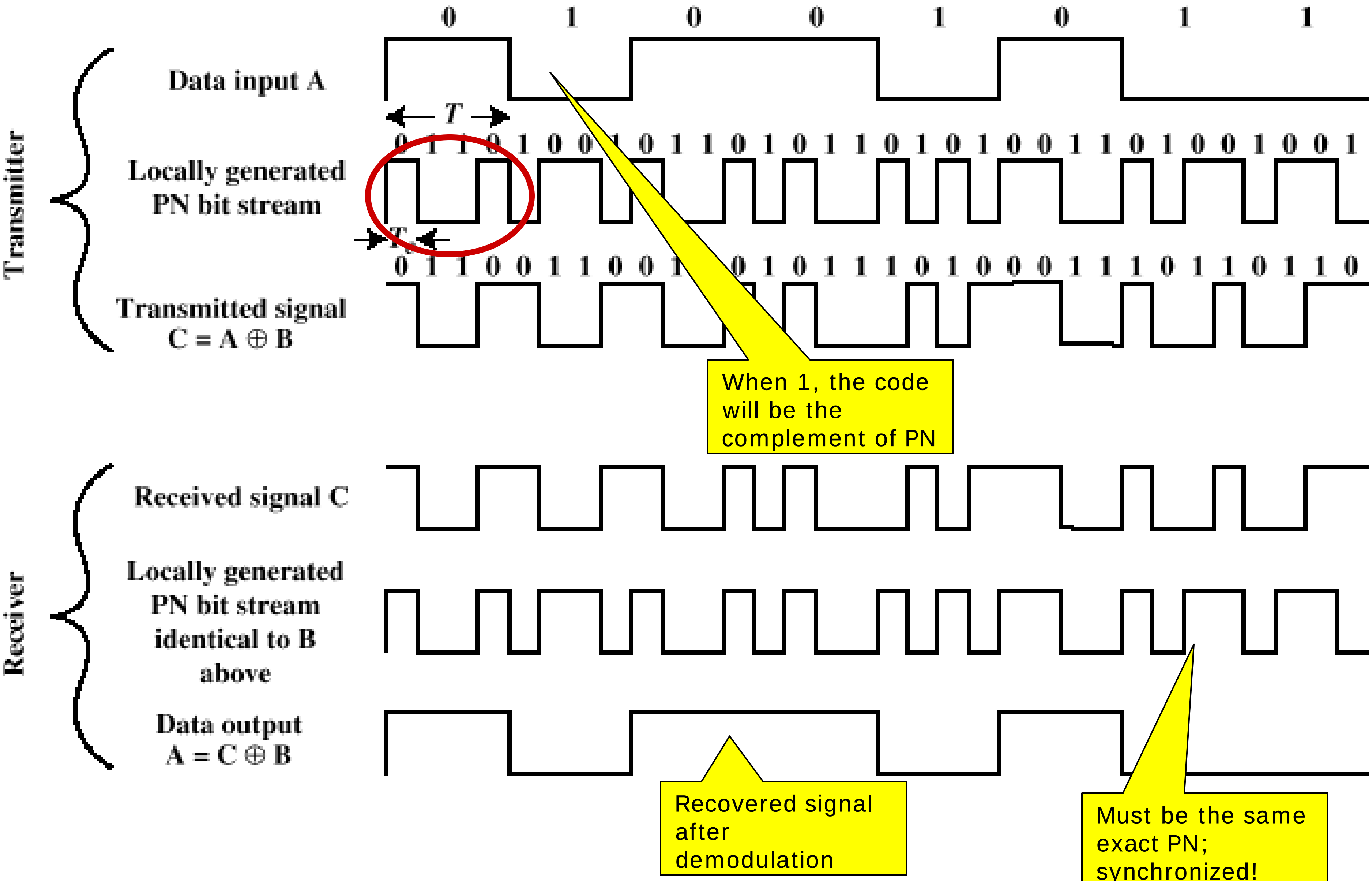
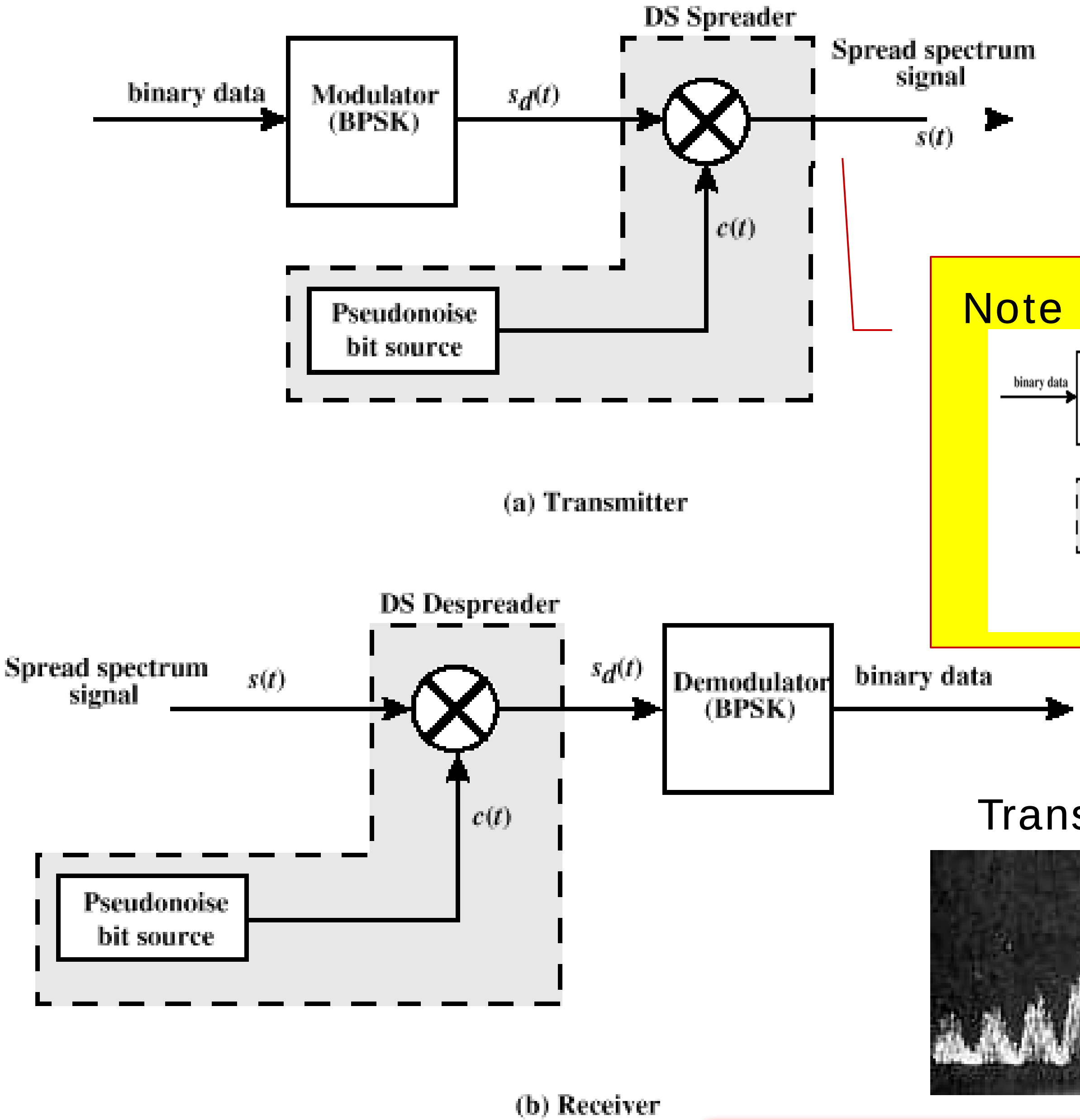
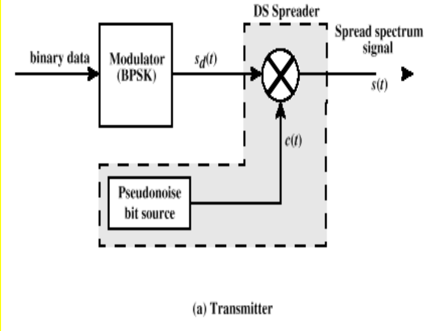


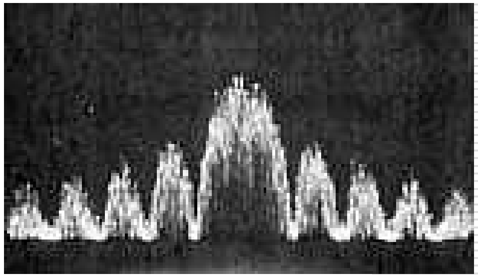
Figure 7.6 Example of Direct Sequence Spread Spectrum



Note the difference:



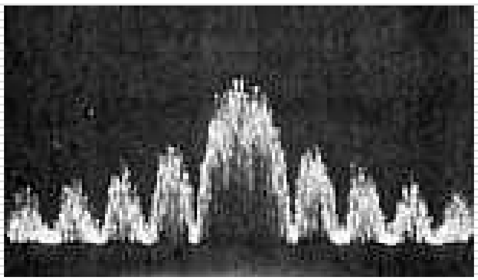
Transmitted SS

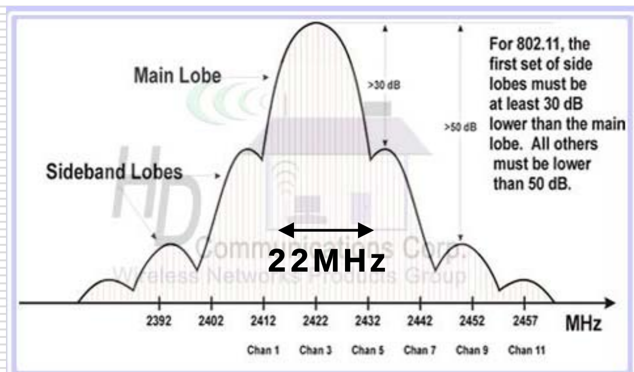


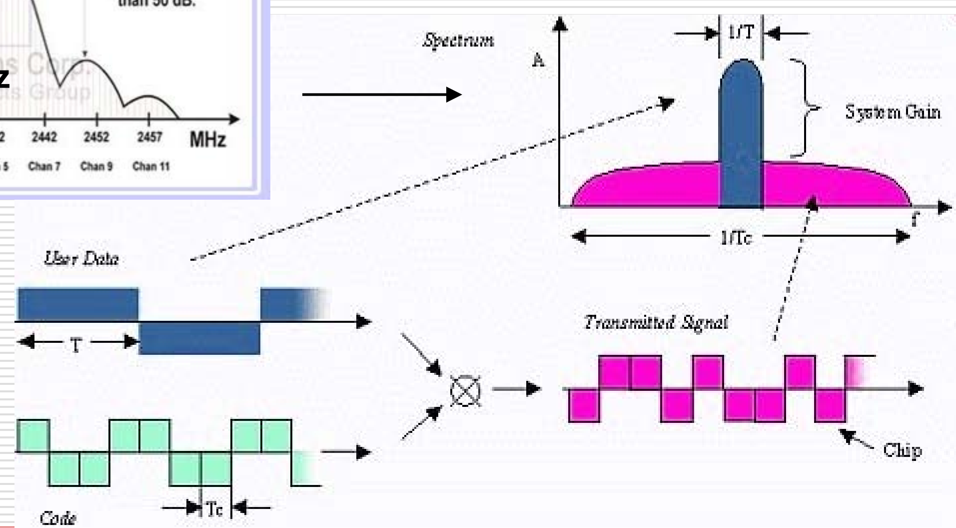
Refer to your notes! (C & D)

Figure 7.7 Direct Sequence Spread Spectrum System

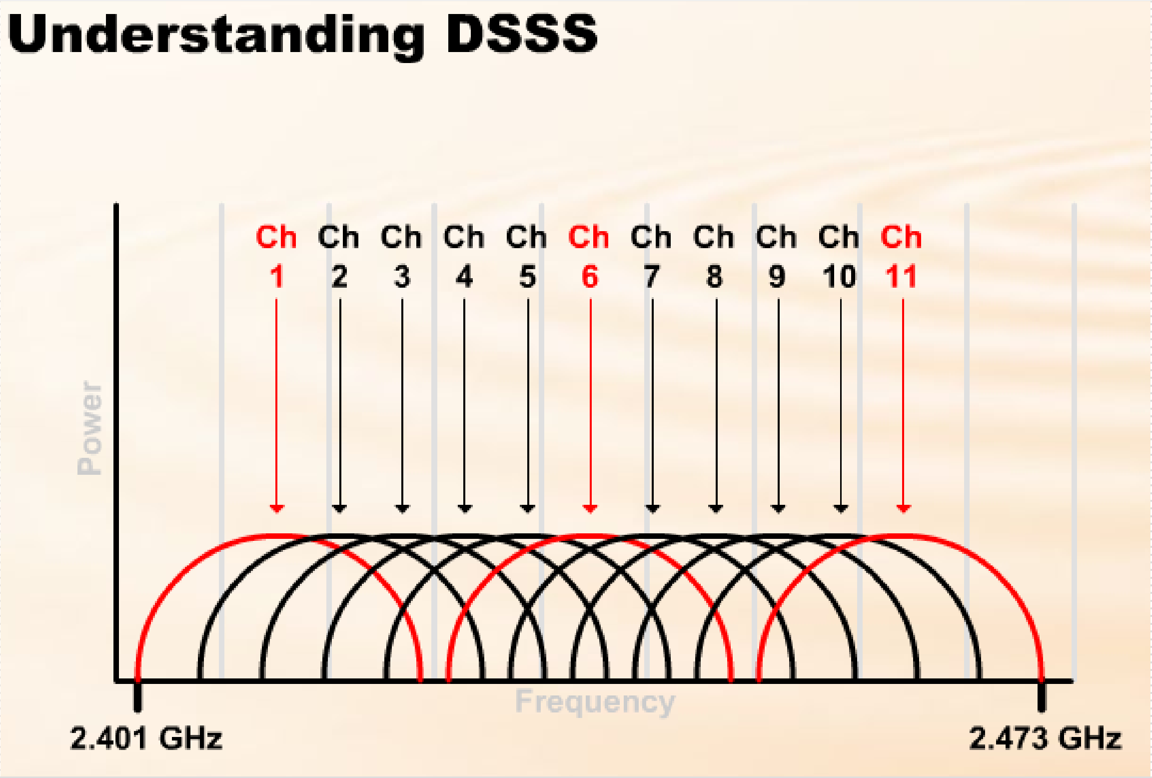
Direct Sequence Spread Spectrum (DSSS) – Spectrum







DSSS in 802.11 / 802.11b

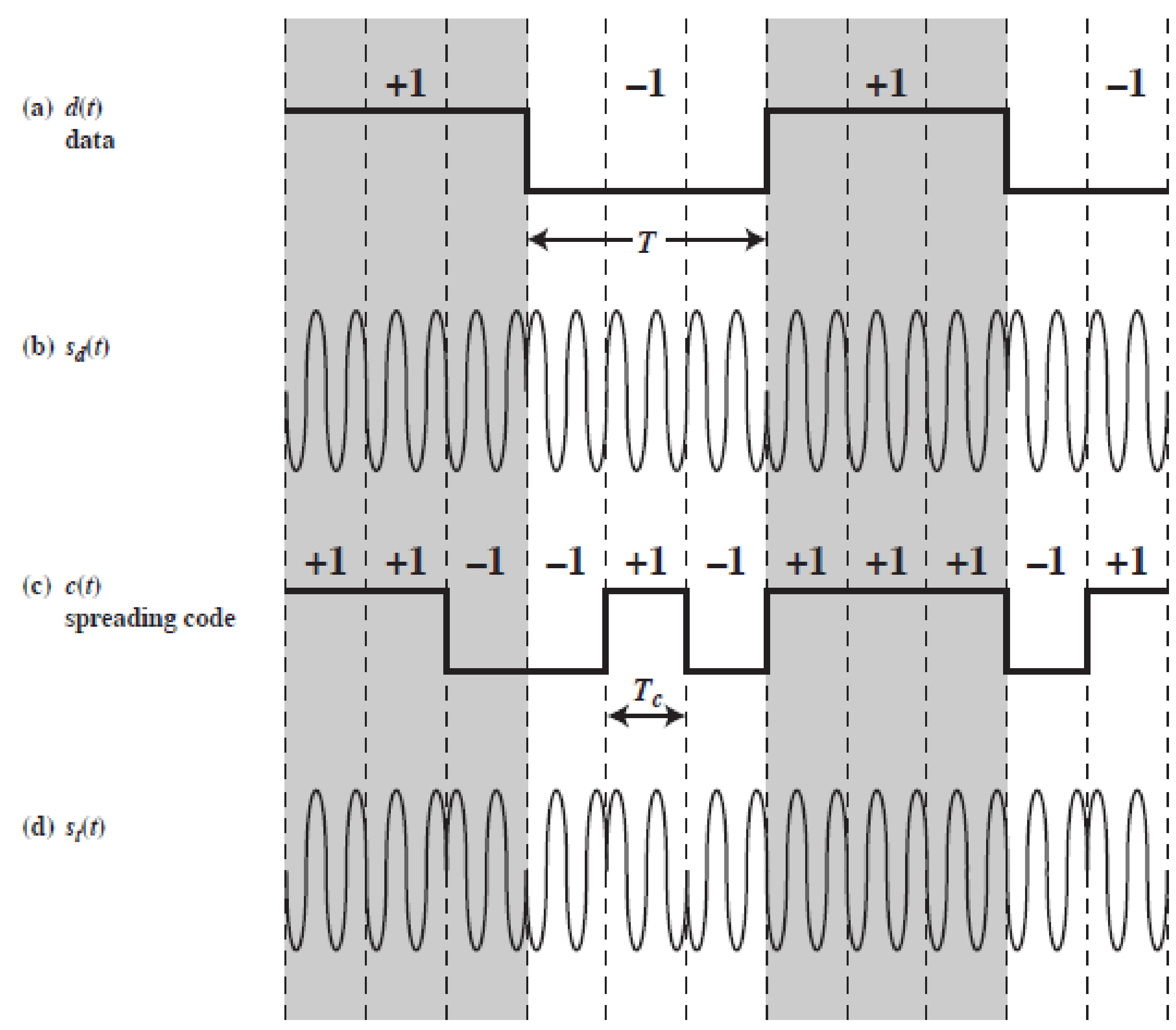


DSSS Using BPSK

Modulate then Spread!

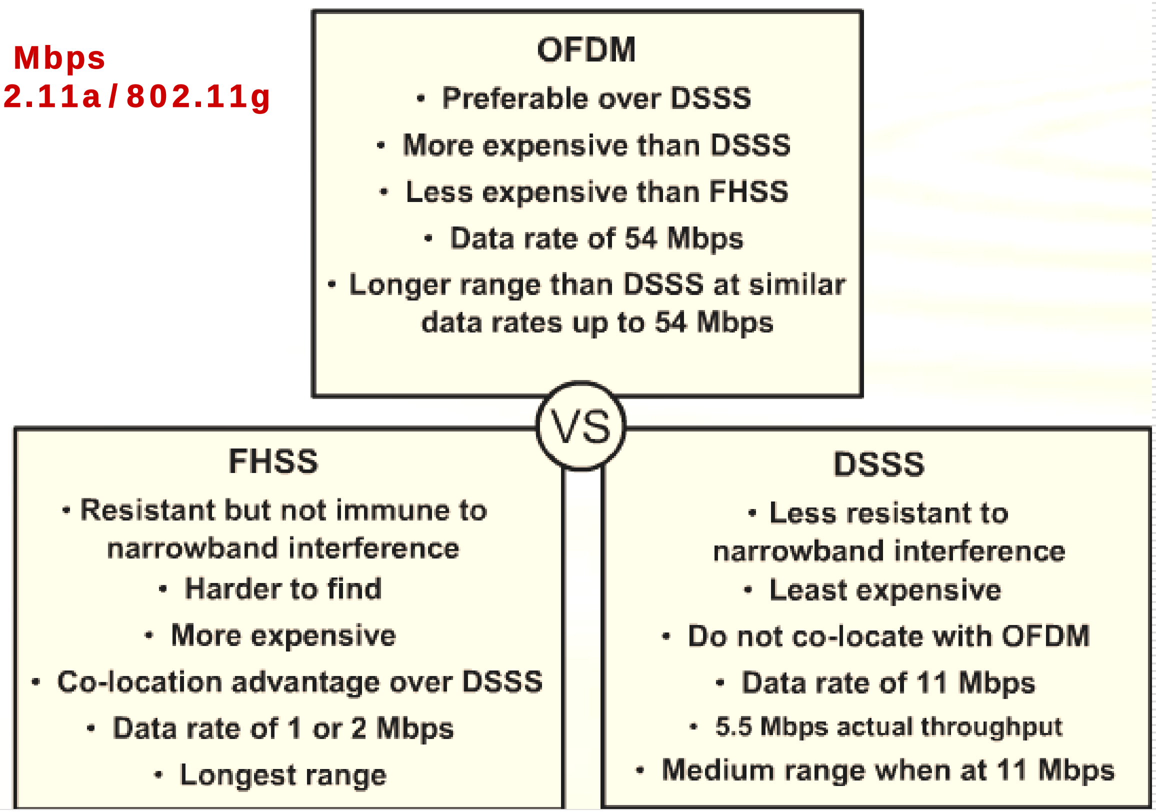
Tc<T
Note that PN changing (k=3)

In this case the final spread code is being subject to BPSK modulation



Comparing Spread Spectrum Techniques

54 Mbps
802.11a / 802.11g



1,2 Mbps
Bluetooth

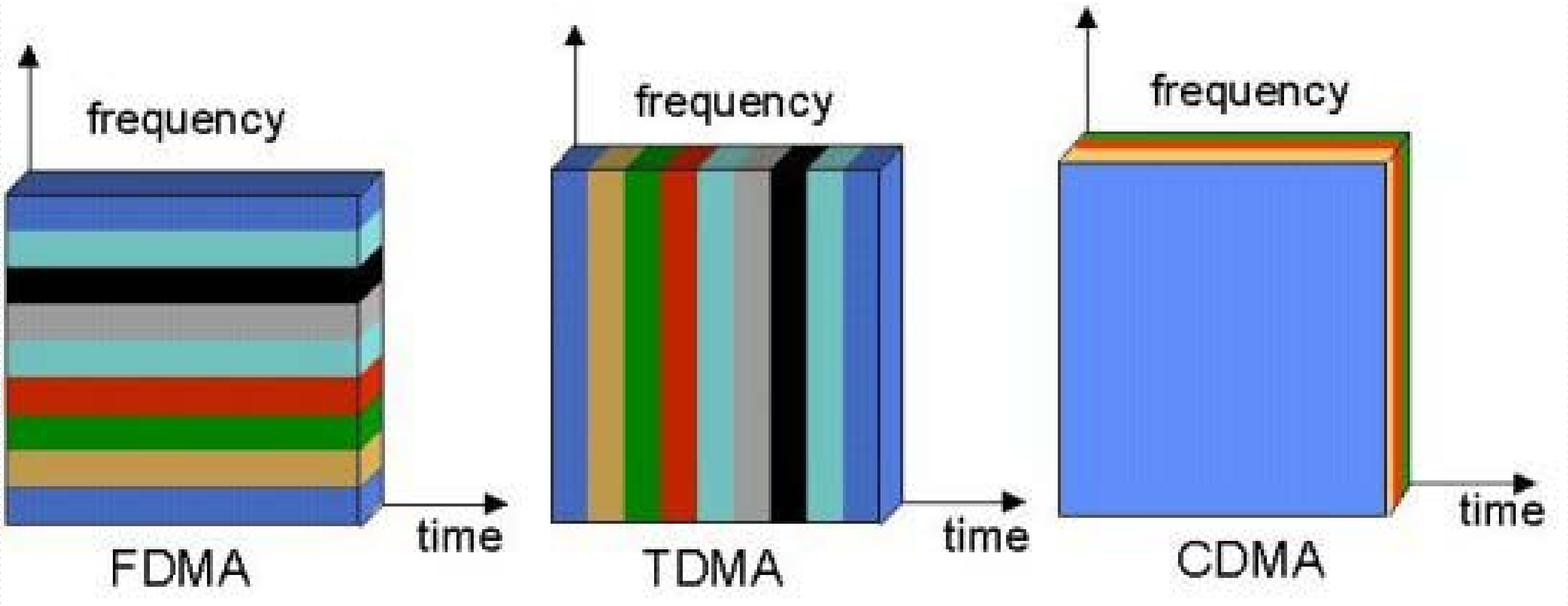
1,2,5.5,11 Mbps
802.11b

Most expensive / Most used / ISM

Review of Multiplexing Techniques

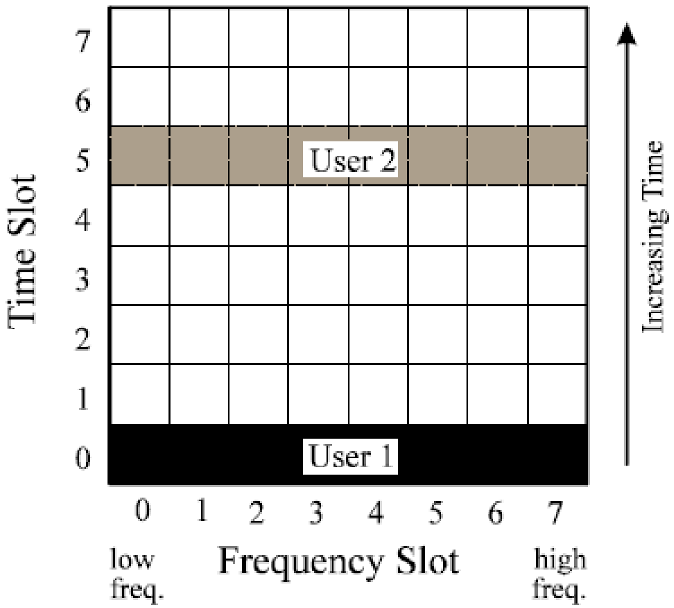
- Notes

Comparison
wireless air interface technology



Review - TDMA

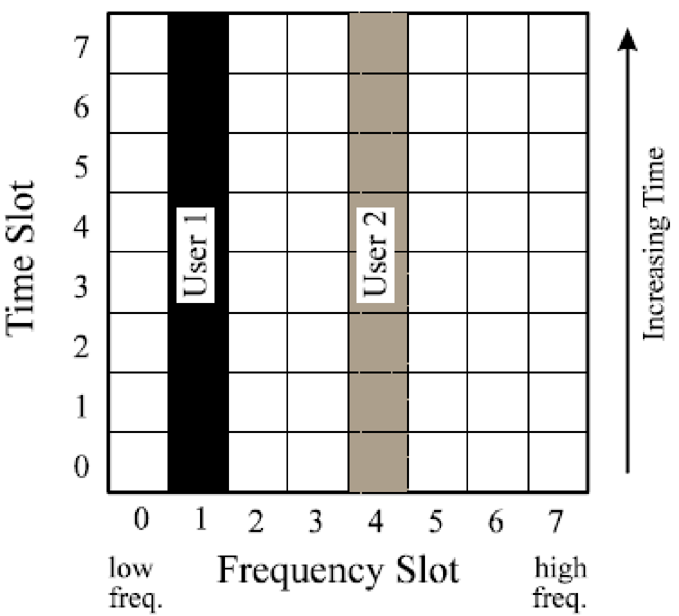
Time Division Multiple Access (TDMA)



- Each user can use *all* available frequencies, for a limited period. The user must not transmit until its next turn.
- High bit rates required, therefore possible problems with intersymbol-interference.
- Flexible allocation of resources (multiple time slots).
- Used in second generation digital networks, such as GSM (Europe), and D-AMPS (USA).

Review – FDMA (assume 2 users)

Frequency Division Multiple Access (FDMA)



- Each user is assigned a unique frequency for the duration of their call.
- Severe fading and interference can cause errors.
- Complex frequency planning required. Not flexible.
- Used in analogue systems, such as TACS (Europe), and AMPS (USA).

Code-Division Multiple Access (CDMA)

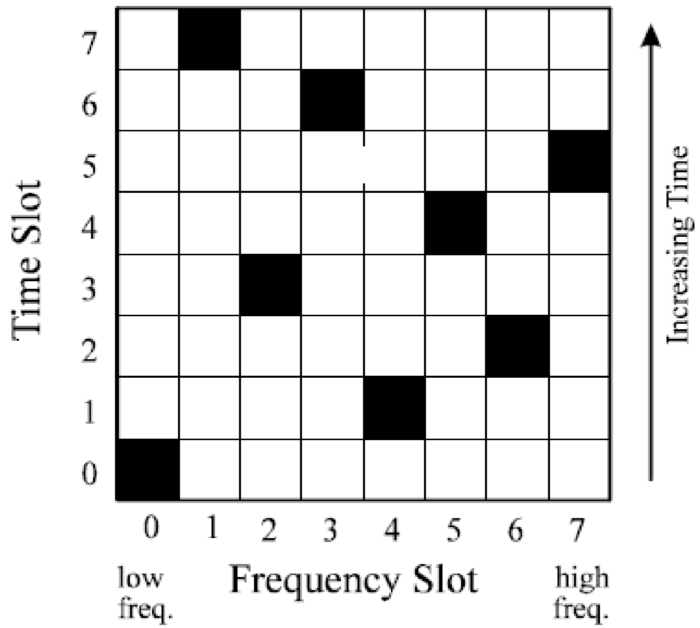
- Cellular wireless air interface technology
- Developed by Qualcomm in 1989
- First deployed commercially in 1995
- Considered as the main infrastructure for 3G and 4G systems
- Evolution of CDMA
  - CdmaOne (2G CDMA)
  - Cdma2000 (3G CDMA)

Code-Division Multiple Access (CDMA) - Basics

- Multiple-access technology
  - It is based on spread spectrum digital techniques
  - Allows separation of signals, which are concurrent in time and frequency
  - The signal appears on the entire wideband spectrum
  - At the receiver all other signals are rejected except the desired signal

CDMA

Frequency Hopping
Code Division Multiple Access (FH-CDMA)



- Each user regularly *hops* frequency over the available spectrum.
- Users are distinguished from each other by a unique hopping pattern (or *code*).
- Interference is randomised.
- Used in Bluetooth™

Code-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
    - The chip has k bits
  - Chip data rate of the new CDMA channel = *kD*

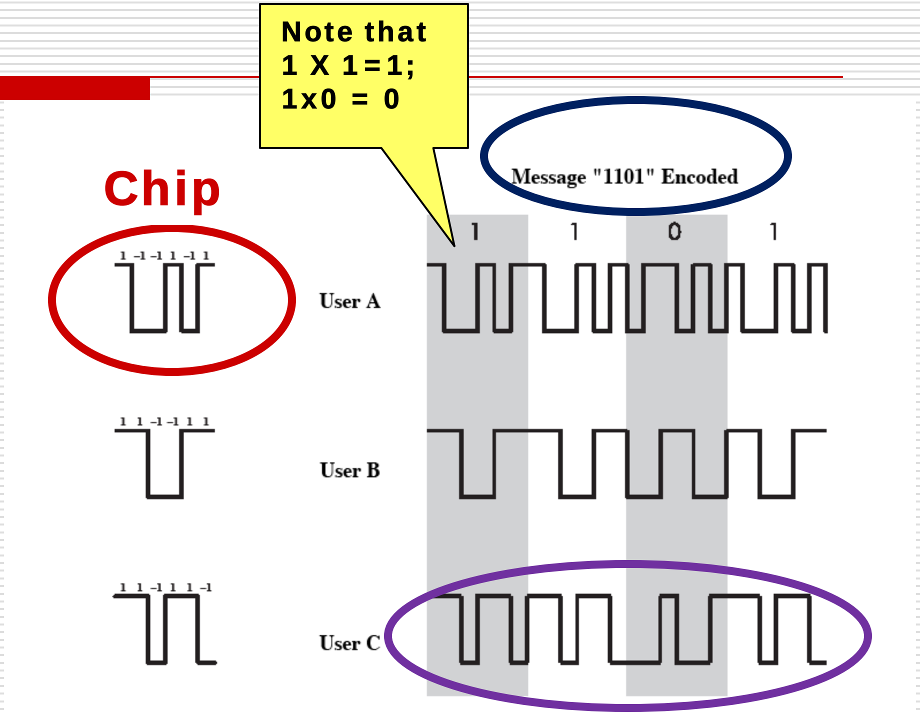


Figure 7.10 CDMA Example

- Example:
  - Assume the incoming data rate is 10 Mbps. How long dose it take to receive 1101?
  - Using CDMA, the chip has 6 bits. What is the total bit rate for the generated CDMA signal?

CDMA General Operation

- If $k=6$ and code is a sequence of 1s and -1s
  - For a ‘1’ bit, A sends code as chip pattern
    - <c1, c2, c3, c4, c5, c6>
  - For a ‘0’ bit, A sends complement of code
    - <-c1, -c2, -c3, -c4, -c5, -c6>
- Receiver knows sender’s code and performs electronic decode function
    - <d1, d2, d3, d4, d5, d6> = received chip pattern
    - <c1, c2, c3, c4, c5, c6> = sender’s code

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

CDMA Example

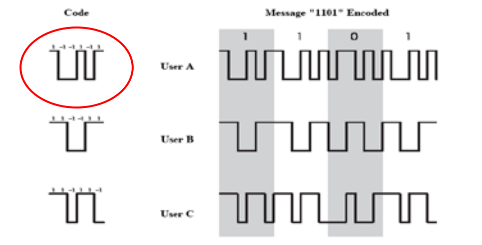


Figure 7.10 CDMA Example

- User A code : c=<1, –1, –1, 1, –1, 1>
  - To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code :<1, 1, –1, – 1, 1, 1>
  - To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A's code
  - (A's code) x (received chip pattern)
    - User A '1' bit: 6 -> 1
    - User A '0' bit: -6 -> 0
    - User B '1' bit: 0 -> unwanted signal ignored

(a) User's codes

User A	1	–1	–1	1	–1	1
User B	1	1	–1	–1	1	1
User C	1	1	–1	1	1	–1

(b) Transmission from A

Transmit (data bit = 1)	1	–1	–1	1	–1	1	
Receiver codeword	1	–1	–1	1	–1	1	
Multiplication	1	1	1	1	1	1	= 6

Su(1)

Transmit (data bit = 0)	–1	1	1	–1	1	–1	
Receiver codeword	1	–1	–1	1	–1	1	
Multiplication	–1	–1	–1	–1	–1	–1	= –6

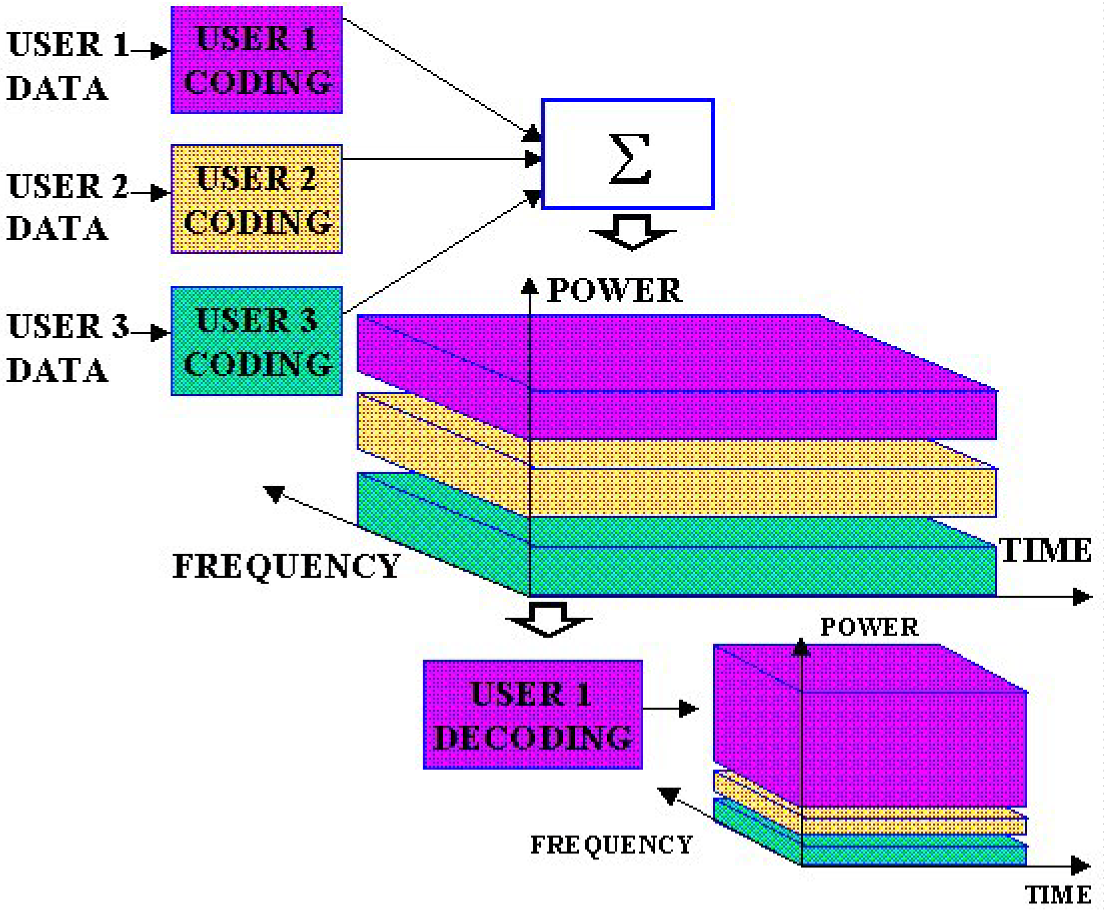
Su(0)

(c) Transmission from B, receiver attempts to recover A's transmission

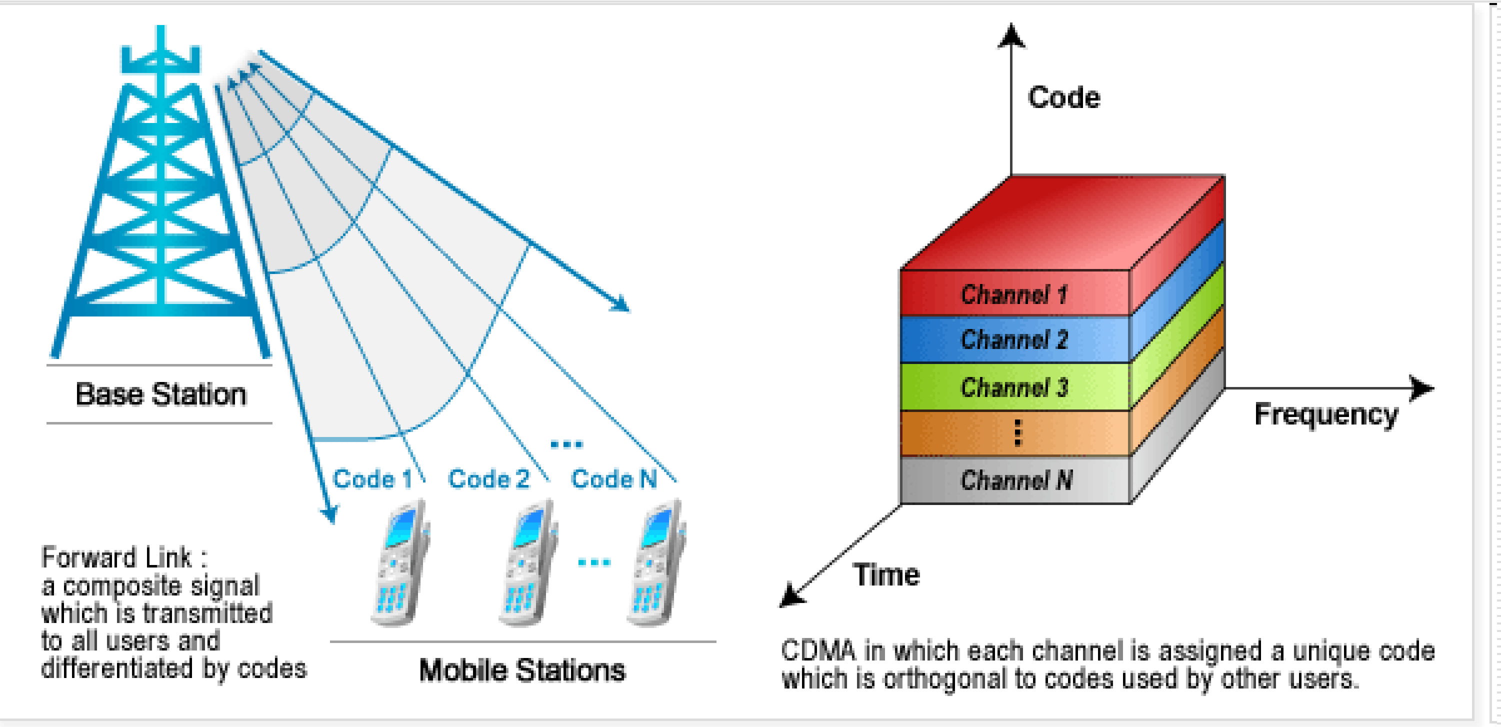
Transmit (data bit = 1)	1	1	–1	–1	1	1	
Receiver codeword	1	–1	–1	1	–1	1	
Multiplication	1	–1	1	–1	–1	1	= 0

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

CDMA General Operation – Power Level

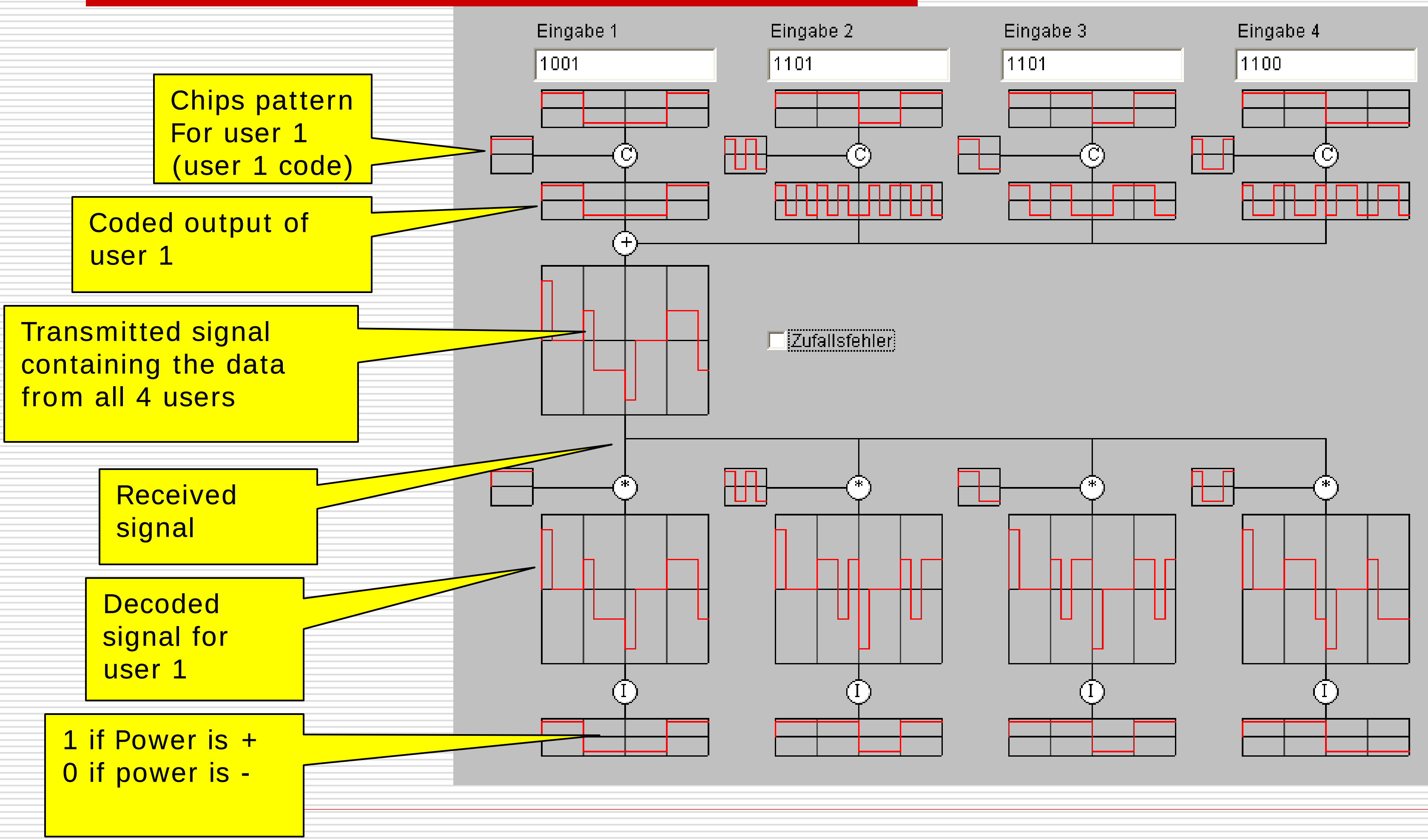


Cell Phone Communications Using CDMA



http://www.celltrek.com/sub03_technologies/sub03_08.php

Example



http://www.dpunkt.de/mobile/code/cdma.html

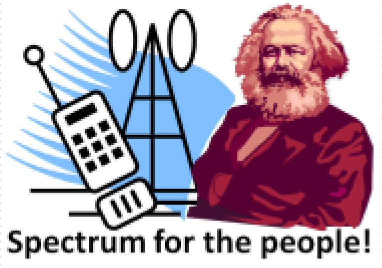
References

1. http://www.dsptutor.freeuk.com/analyser/guidance.html
2. -**CDMA Coding Demo Applet**
   Jörg Roth
   German applet that demonstrates CDMA multiple access coding. Allows user to see the process of coding/decoding in real time. Excellent demo, site is in German language.
3. Digital modulation direct sequence, Code Division Multiple Access (DS-CDMA), frequency hopping Code Division Multiple Access (FH-CDMA), Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), pdf file
4. Good tutorial on CDMA http://www.umtsworld.com/technology/cdmabasics.htm
5. A very good applet: http://www.intuitor.com/statistics/SprSpecApp/SpreadSpectrum.htm

Questions –

- Chapter 7: 1-7 & 14

References



- Digital Society: http://www.digitalsociety.org/2011/01/wi-fi-was-never-a-substitute-for-wireless-carriers/