System-on-Chip Applications

Introduction to Wireless Communication System

Outline

- Communication Systems
- Mobile Phone Generations
- Bandwidth for Mobile Phone Generations
- Multiple Access
  - FDMA
  - TDMA
  - CDMA
  - OFDM
  - OFDMA

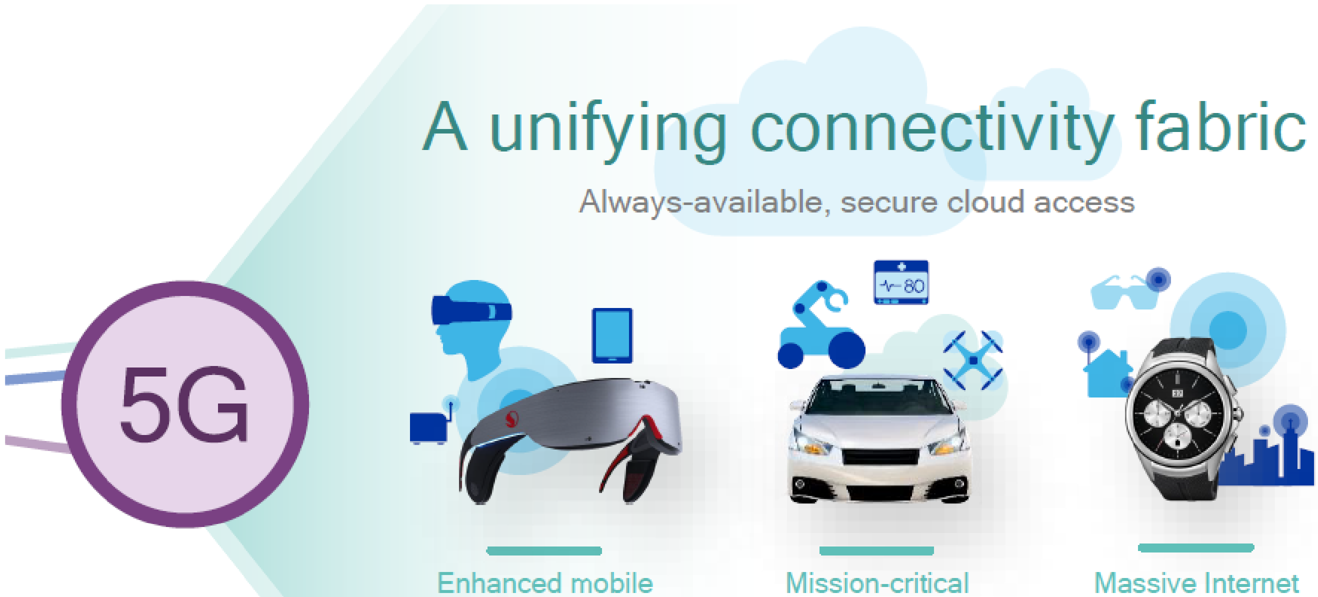
Mobile Phone Evolution

Mobile phone: a portable cordless phone originally for voice communication in a cellular system

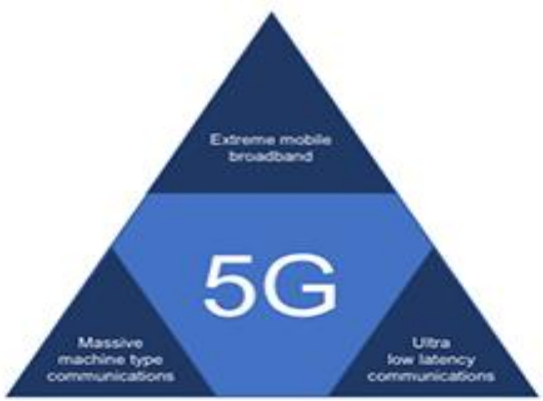
	Definition	Standard	Multiple Access
1G	Analog Voice	AMPS	FDMA
2G	Digital Voice	GSM	TDMA/CDMA
3G	Digital Data	3GPP	WCDMA
4G	Digital/Real-time multimedia	LTE/WiMAX	OFDMA
5G	Enhanced mobile	5GNR(New Radio) with LTE	OFDMA/MIMO/Beamforming

- AMPS-Advanced Mobile Phone System
- GSM-Global System for Mobile Communications
- 3GPP-3rd Generation Partnership Project
- LTE-long term evolution.
- CDMA-1.25Mhz bandwidth, WCDMA(wideband)-5MHz bandwidth

5G Applications



1 ms	Latency
10 Gbps	Peak data rate
100 Mbps	Anywhere, anytime
1000 Gbps	Per square km capacity
10000x Capacity vs. 2010	Capacity vs. 2010
100000x Connected devices	Per square km
1000000 IoT Device density	Per square km



Cellular Revolution and Evolution

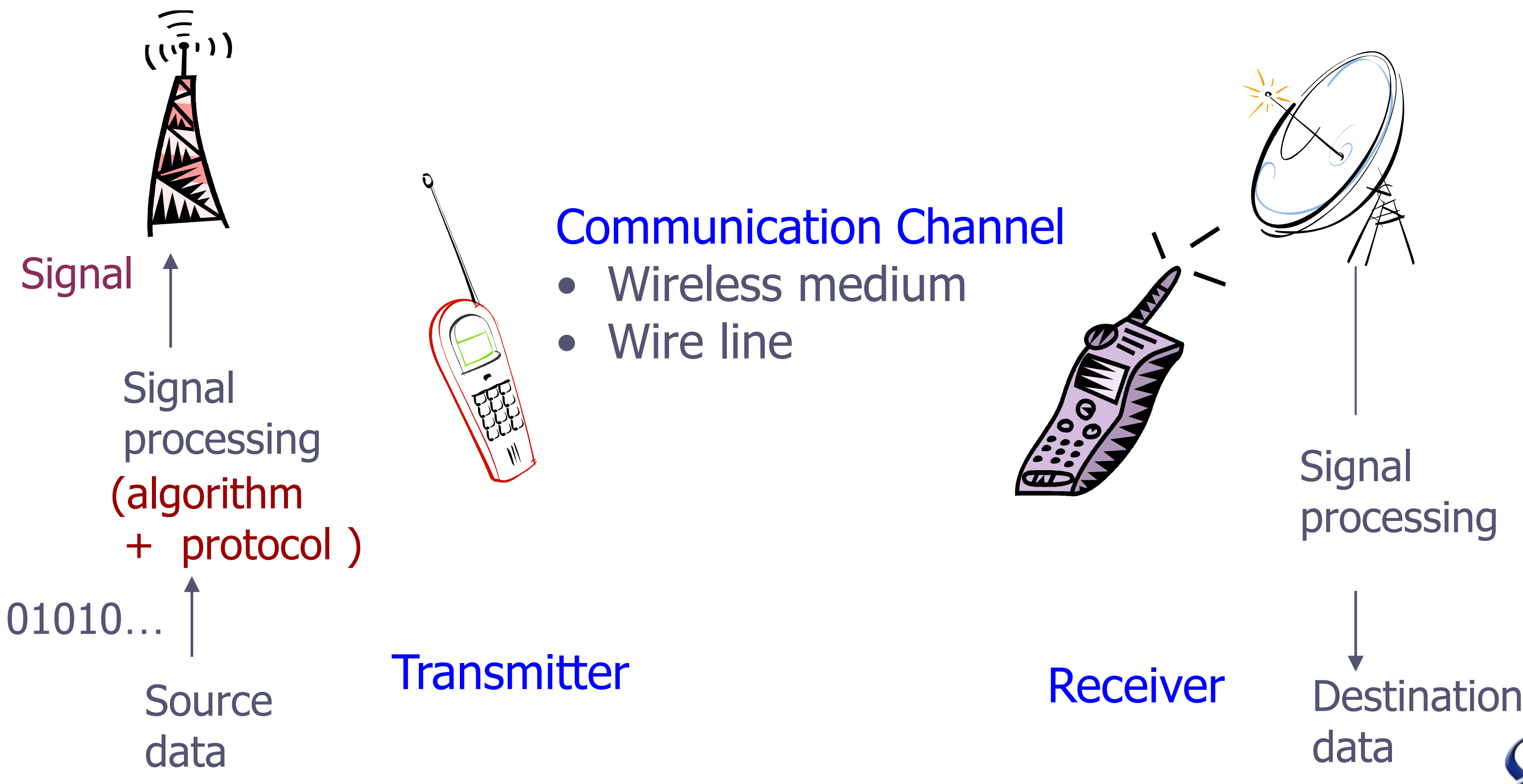
- **1st generation: analog technology (for voice)**
  - Analog signal, AMPS system -Frequency Division Multiple Access (FDMA)
- **2nd generation: digital architecture (voice & data)**
  - Time Division Multiple Access (TDMA)
  - Spread spectrum signal
  - Frequency hopping GSM architecture
    - In Europe
  - Spread-spectrum CDMA technology
    - In US, parts of Asia
- **3nd generation: digital architecture (Multimedia)**
  - WCDMA
- **4th generation: digital architecture (faster Multimedia)**
  - OFDMA

Cellular Revolution and Evolution

- **5th generation: digital architecture (Enhanced Mobile Broadband)**
  - OFDMA
  - MIMO
  - Beamforming
  - Advanced Antenna Systems (AAS)
- **5G Features**
  - 20 Gigabits-per-second (Gbps) peak data rates
  - 100+ Megabits-per-second (Mbps) average data rates
  - 10x decrease in network latency over 4G

Communication
A Signal Processing System

- **Modern communication = digital communication**
  - Analog RF front end, ADC/DAC, Algorithm, Protocol
  - Transmitter, Channel, Receiver



Signal Frequency Range

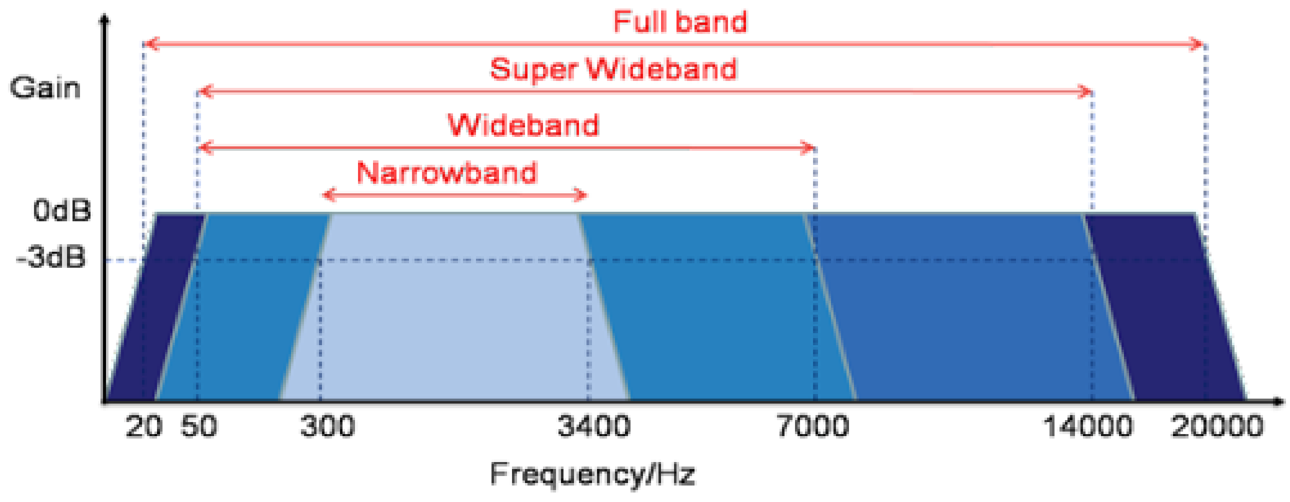
Table 6.1. Frequency Ranges of Selected Signals

Electrocardiogram	0.05 to 100 Hz
Audible sounds	20 Hz to 15 kHz
AM radio broadcasting	540 to 1600 kHz
HD component video signals	Dc to 25 MHz
FM radio broadcasting	88 to 108 MHz
Cellular phone	824 to 894 MHz and 1850 to 1990 MHz
Satellite television downlinks (C-band)	3.7 to 4.2 GHz
Digital satellite television	12.2 to 12.7 GHz

Bandwidth(BW)

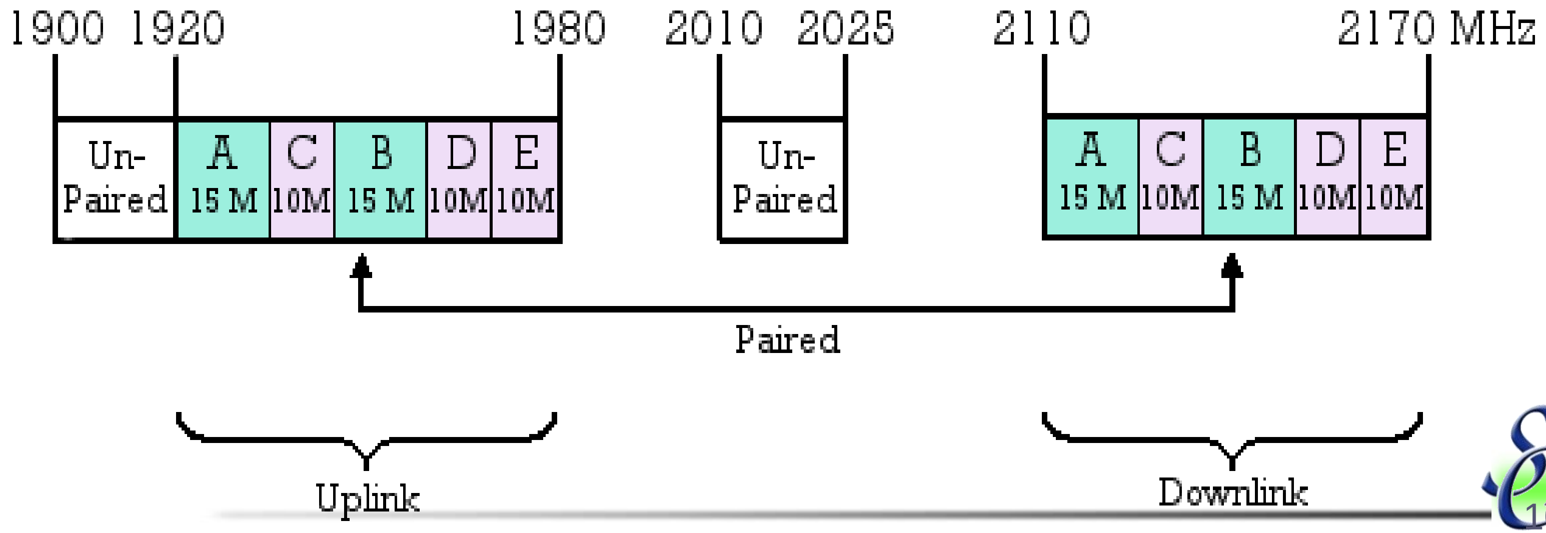
Def: diff between max and min
frequency of a signal.

•BW of a voice signal: 3KHz
a voice signal –
min freq 0.3KHz (Hz)
max freq 3.3KHz



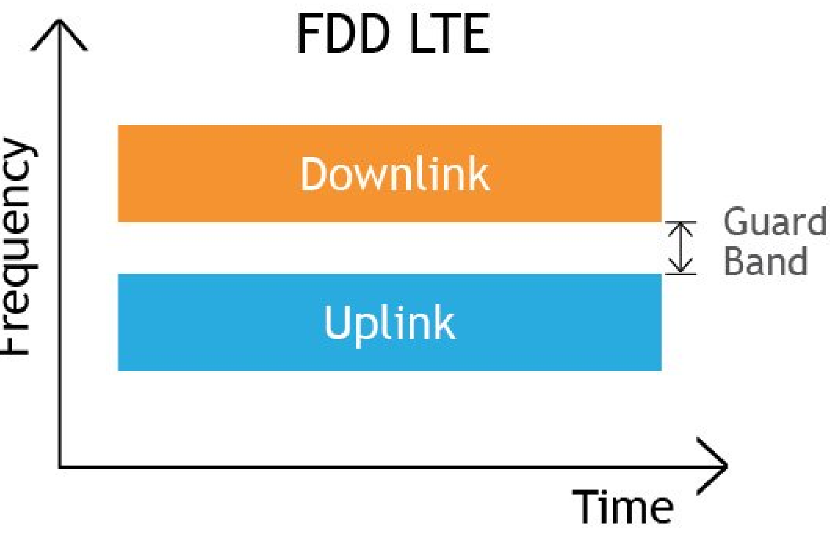
2G/3G Spectrum(freq band)

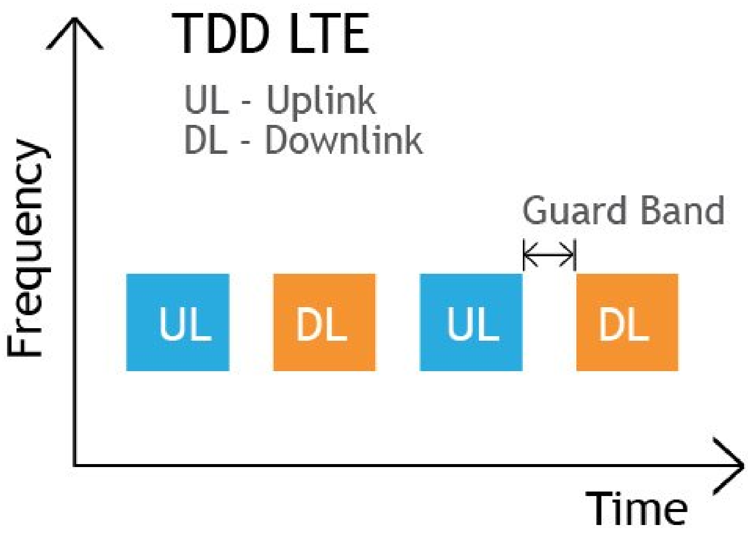
- USA (MHz)
  2G (GSM) --824-849, 869-894
  3G --1710–1755
- Europe (MHz)
  3G– 1900-1980, 2110-2170
- Paired BW: "2x15MHz"
  - Lower band– 15 MHz
  - Upper band – 15 MHz
- FDD - Frequency Division Duplex



4G Spectrum Paired Bandwidth(BW)

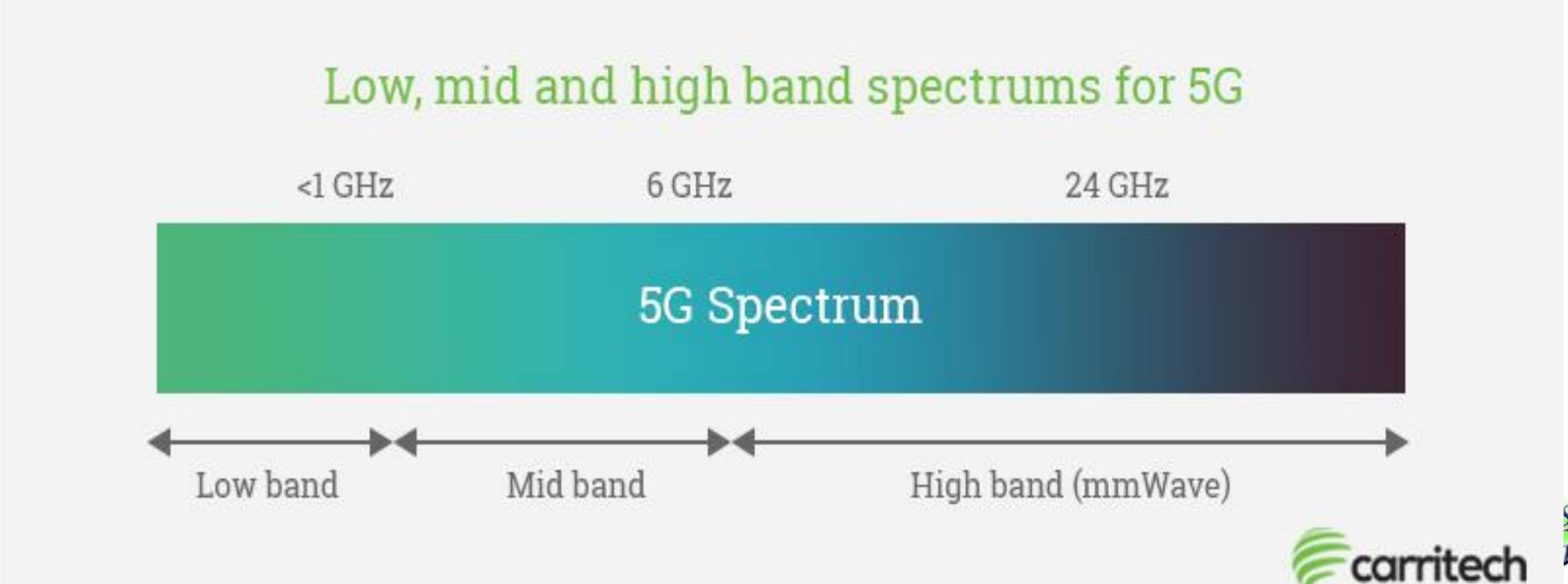
- **4G—2496MHz–2690MHz (USA)**
- Paired BW: "2x15MHz"
  - Lower band– 15 MHz
  - Upper band – 15 MHz
- TDD LTE - Time Division Duplex
- FDD LTE - Frequency Division Duplex





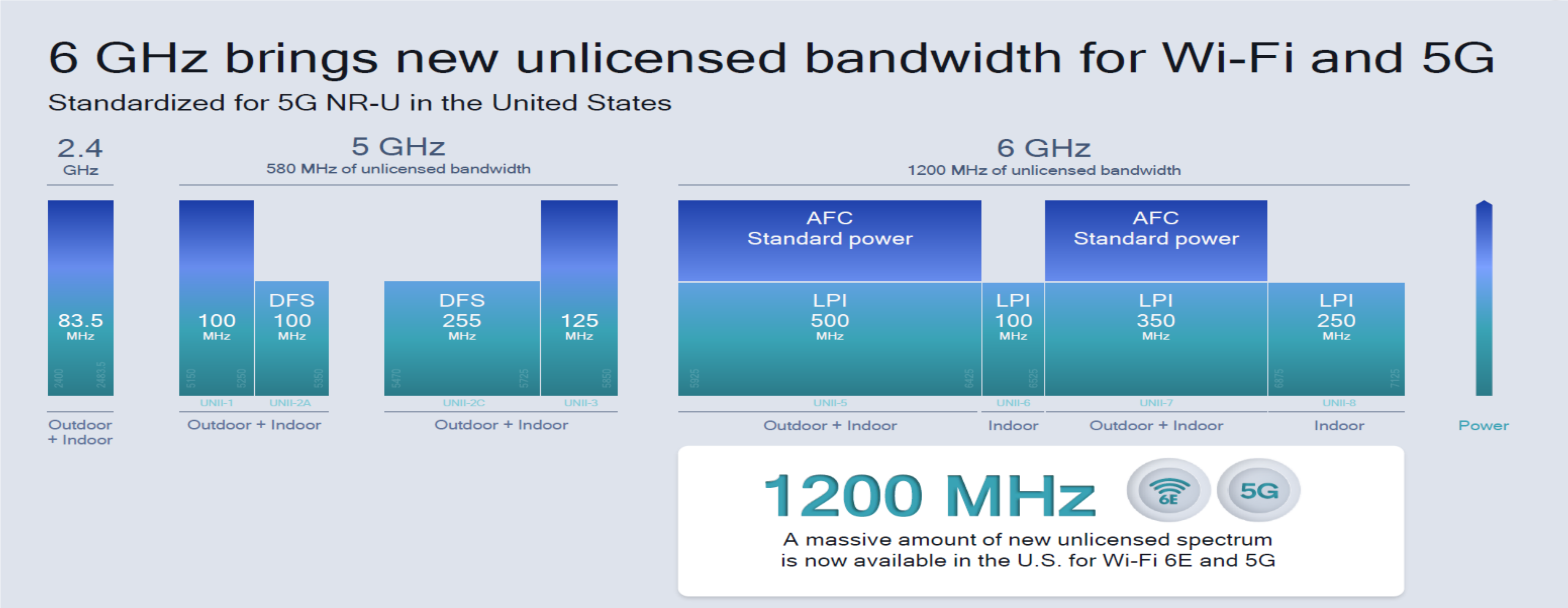
5G Spectrum

- USA
  - 5G---
    - Low Band <1GHz
    - Mid Band ~6GHz
    - High Band
      - frequency above 24GHz is called mmWAVE



5G Low and Mid Band

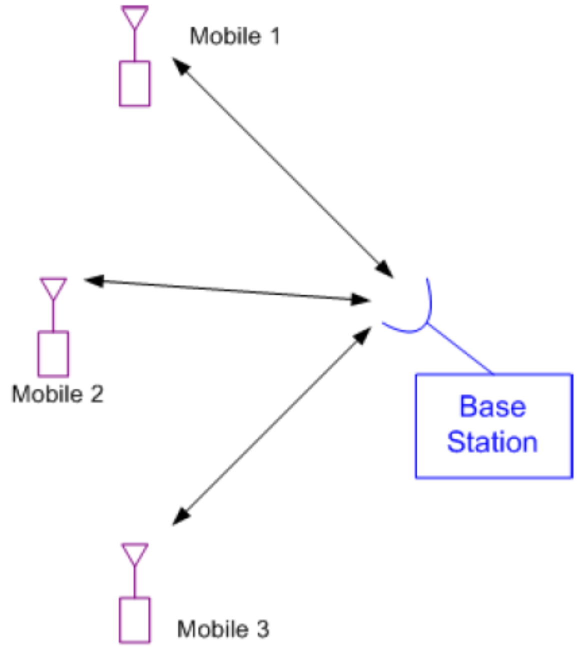
- 5GNR
  - 5GHz DFS (Dynamic frequency selection), Wi-Fi detects Military radar signal needs to select other frequency
  - 6GHz LPI (low probability intercept) –
    - by frequency hopping
    - DSSS (Direct Sequence Spread Spectrum)
  - AFC (Automated Frequency Coordination (AFC) **enables unlicensed access to the 6 GHz band by coordinating shared spectrum between Standard Power Access Points and incumbent Point-to-Point microwave licensees**



Multiple Access

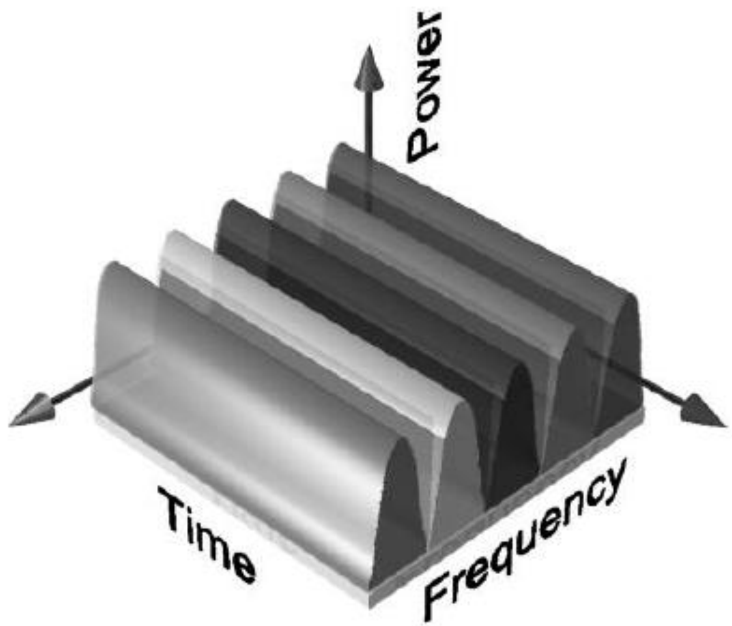
- Multiple users want to communicate in a common geographic area
- Cellular example: Many people want to talk on their cell phones.
- Problem:

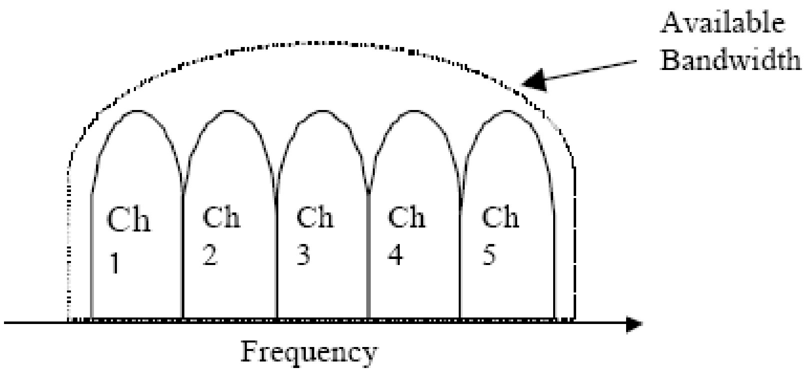
How should we share our resources so that as many users as possible can communicate simultaneously?



FDMA (Frequency Division Multiple Access) Review

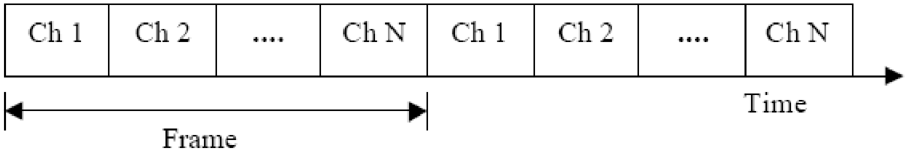
- Spectrum is subdivided into narrow band channels
- Each narrow band is allocated to a single user



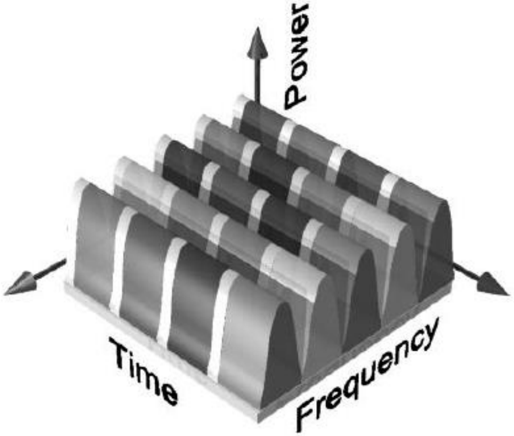


TDMA(Time Division Multiple Access)

- Each user is allocated to a small time slot



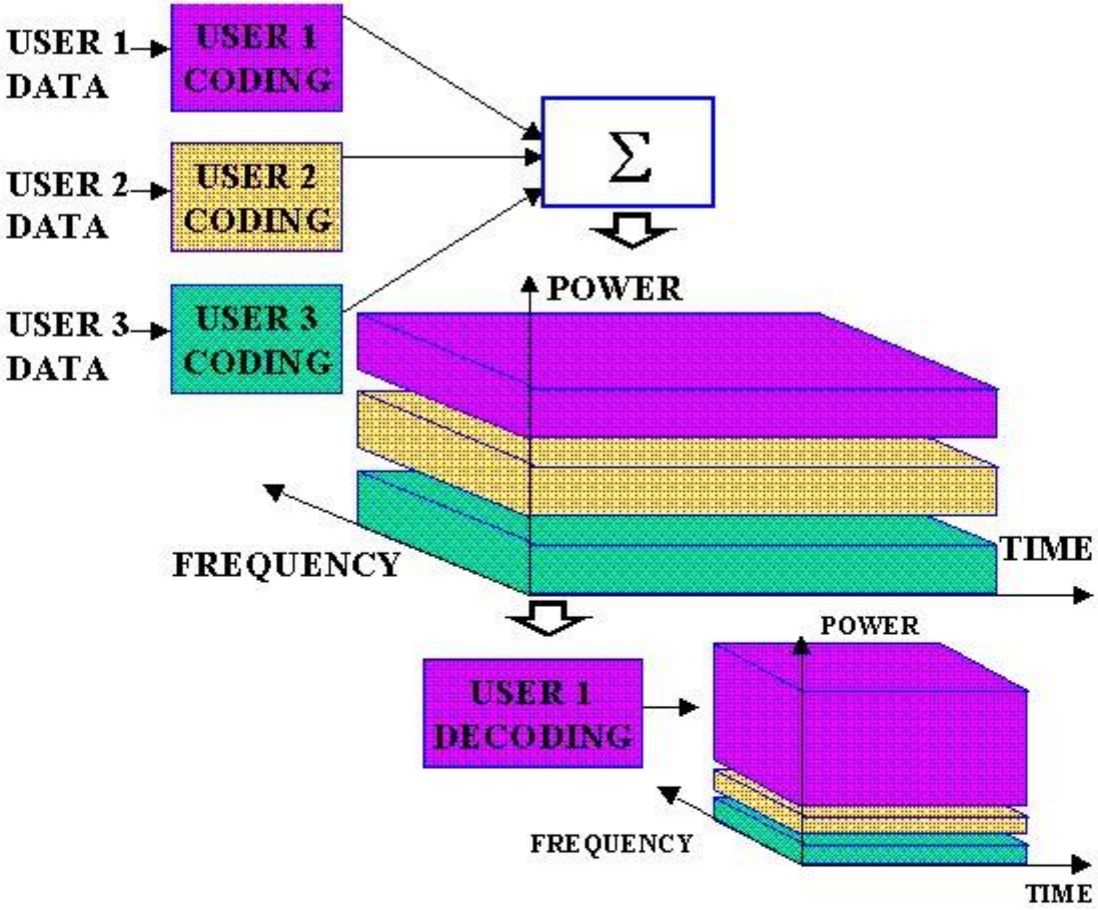
- TDMA/FDMA hybrid



TDMA / FDMA hybrid, showing that the bandwidth is split into frequency channels and time slots

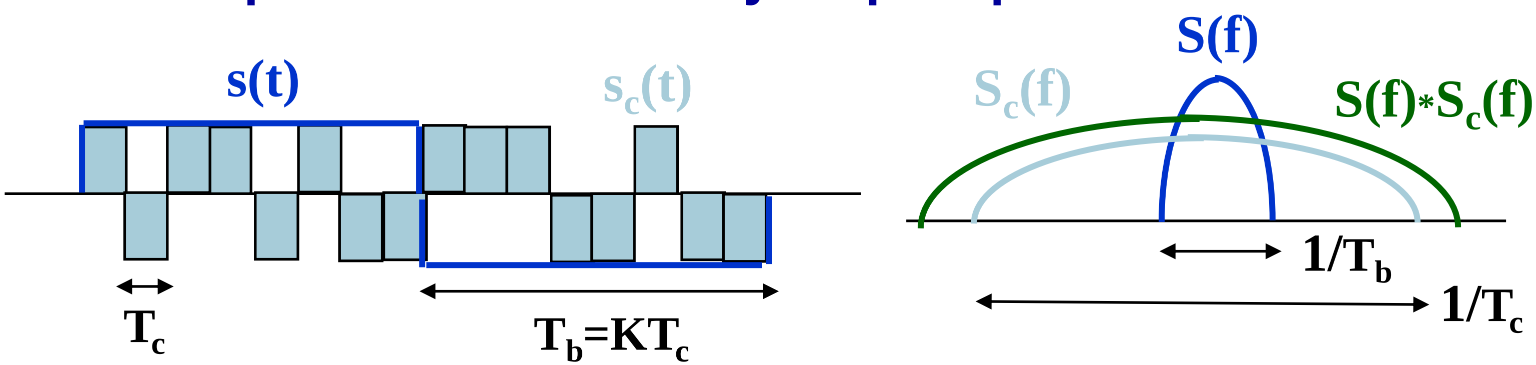
Code-Division Multiple Access (CDMA)

- Spread Spectrum and special coding
- Use the whole frequency band and whole time slot

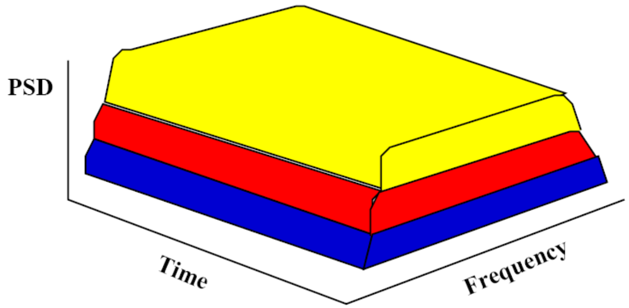


Direct Sequence Spread Spectrum(DSSS)

- **DSSS: the signal is coded over very high bandwidth to transmit the information below the noise level**
- Bit sequence modulated by chip sequence



- Spreads bandwidth by large factor (K)
- Despread by multiplying by $s_c(t)$ again ($s_c(t)=1$)
- Reduce ISI and narrowband int

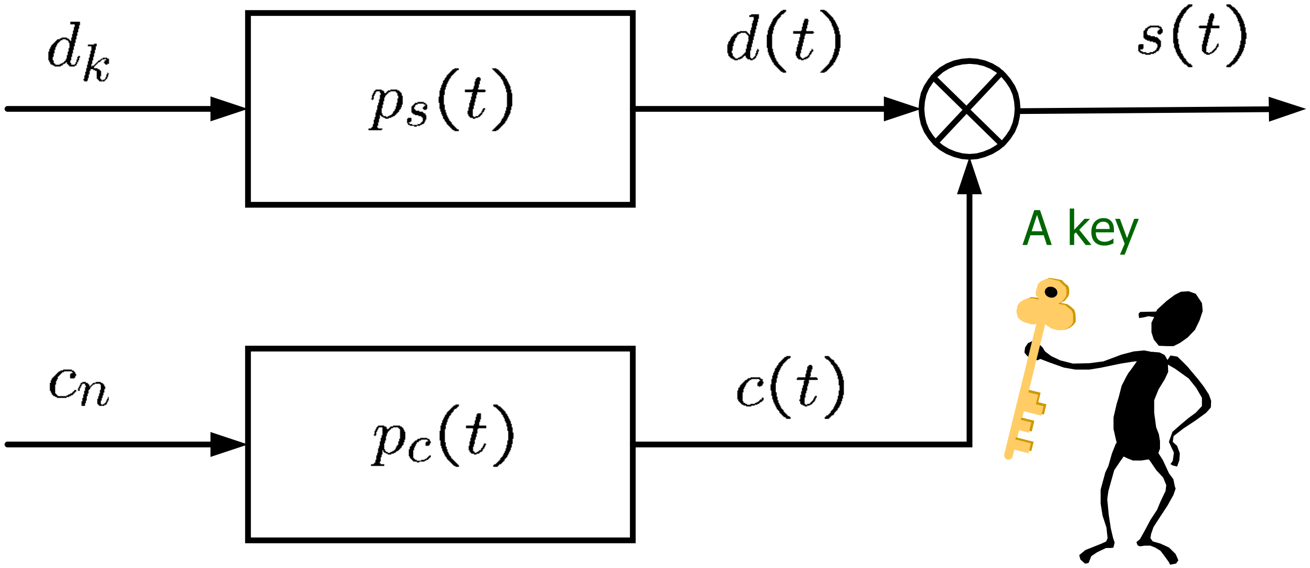


Spread Spectrum

- **Transmission bandwidth is much larger than information bandwidth**
- **Bandwidth does not depend on the informational signal**
- **Processing gain = transmitted bandwidth / information bandwidth**
- **Classification**
  - Direct sequence: data is scrambled by user specific pseudo noise code at the transmitter side
  - Frequency hopping: signal is spread by changing the frequency over the transmitted time of the signal

Spreading

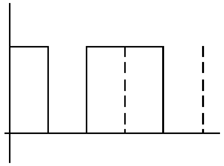
At receiver: data is descrambled by the same key (specific pseudo noise code) at the transmitter side



$$s(t) = d(t)c(t)$$

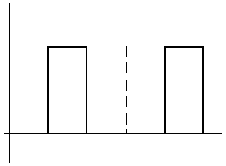
Example

To transmit a 0 the station use a unique "chip sequence":



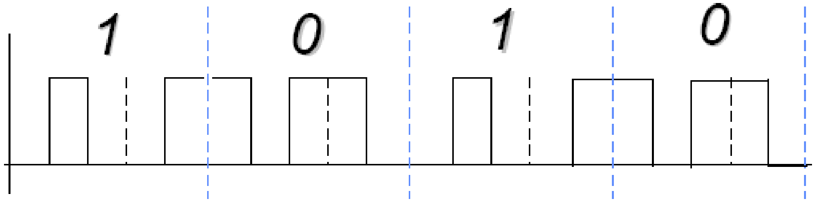
1 0 1 1 0

To transmit a 1 the station use the one's complement of its chip sequence:

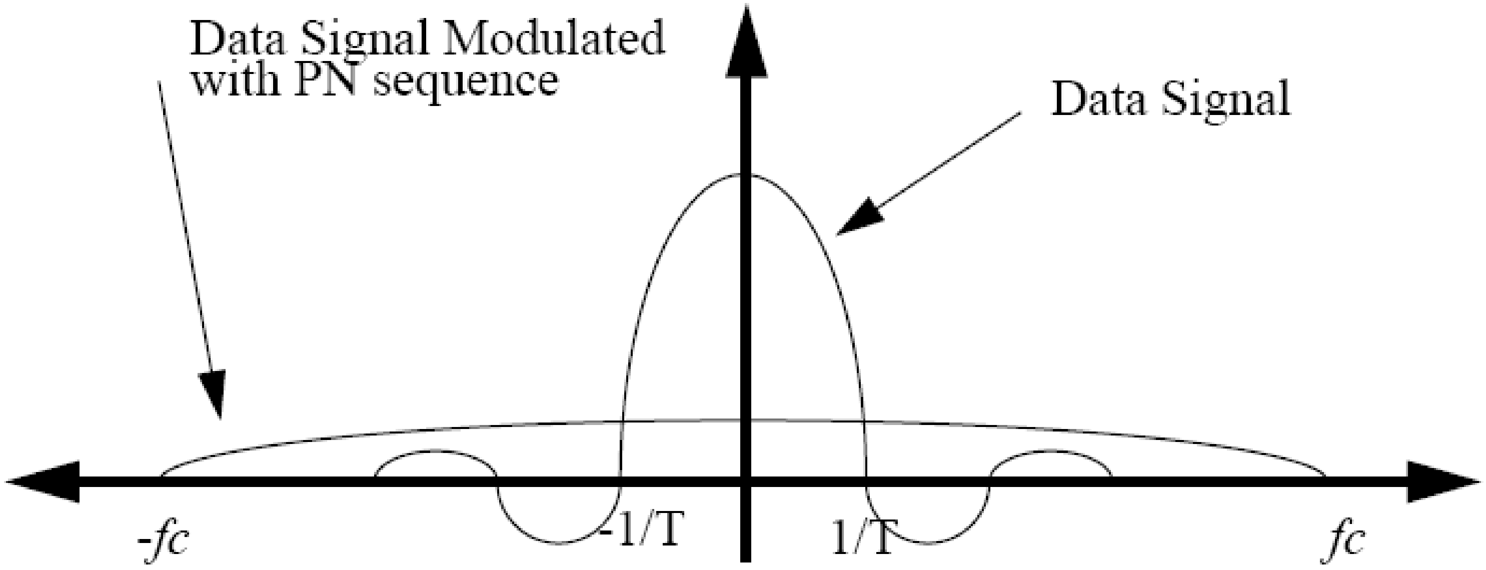


0 1 0 0 1

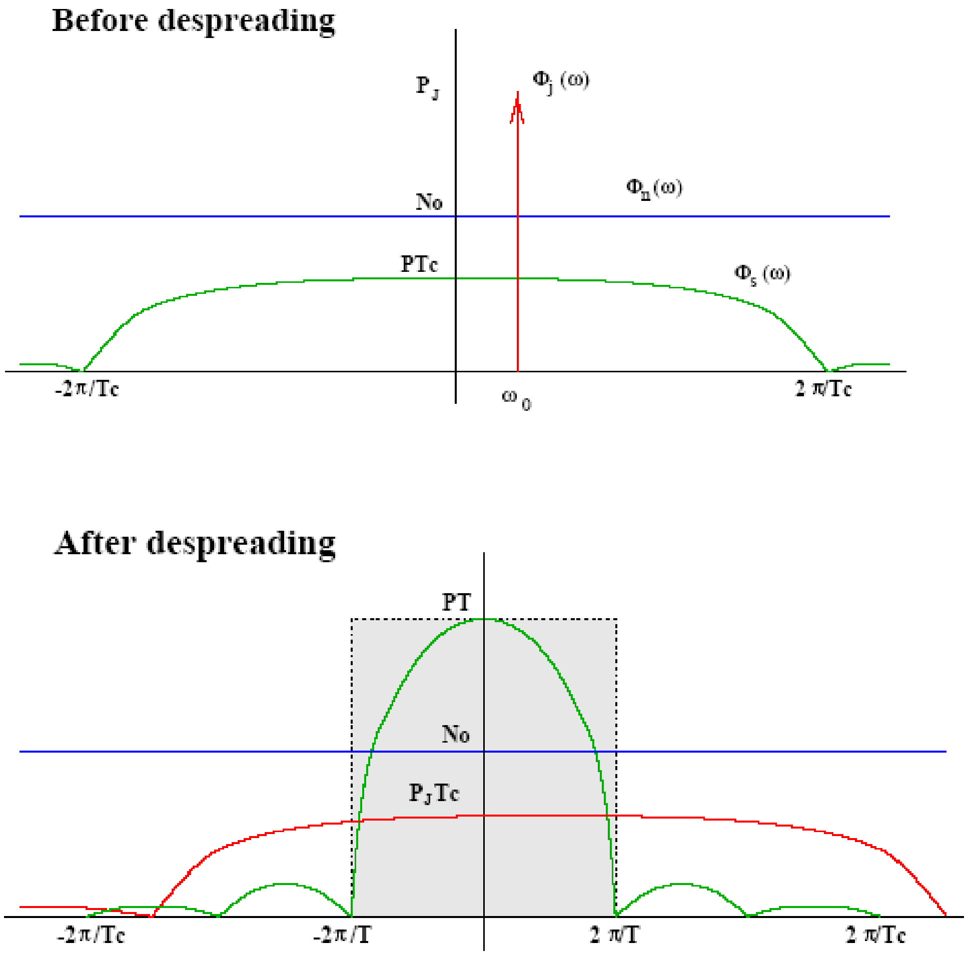
Therefore if data is 1010 it will transmit:



Spread in Frequency Domain



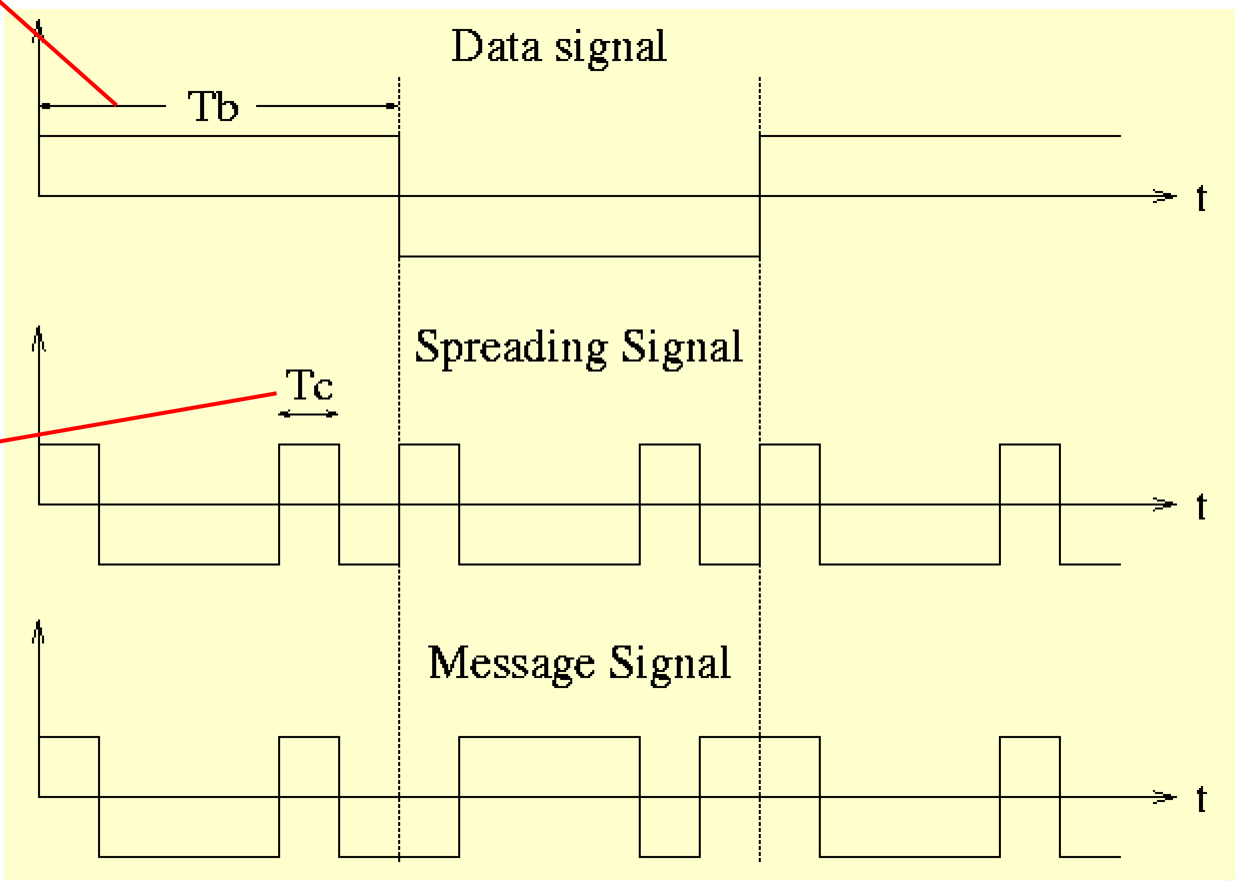
Despreading in Spectrum Domain



Processing Gain (Spreading Factor)

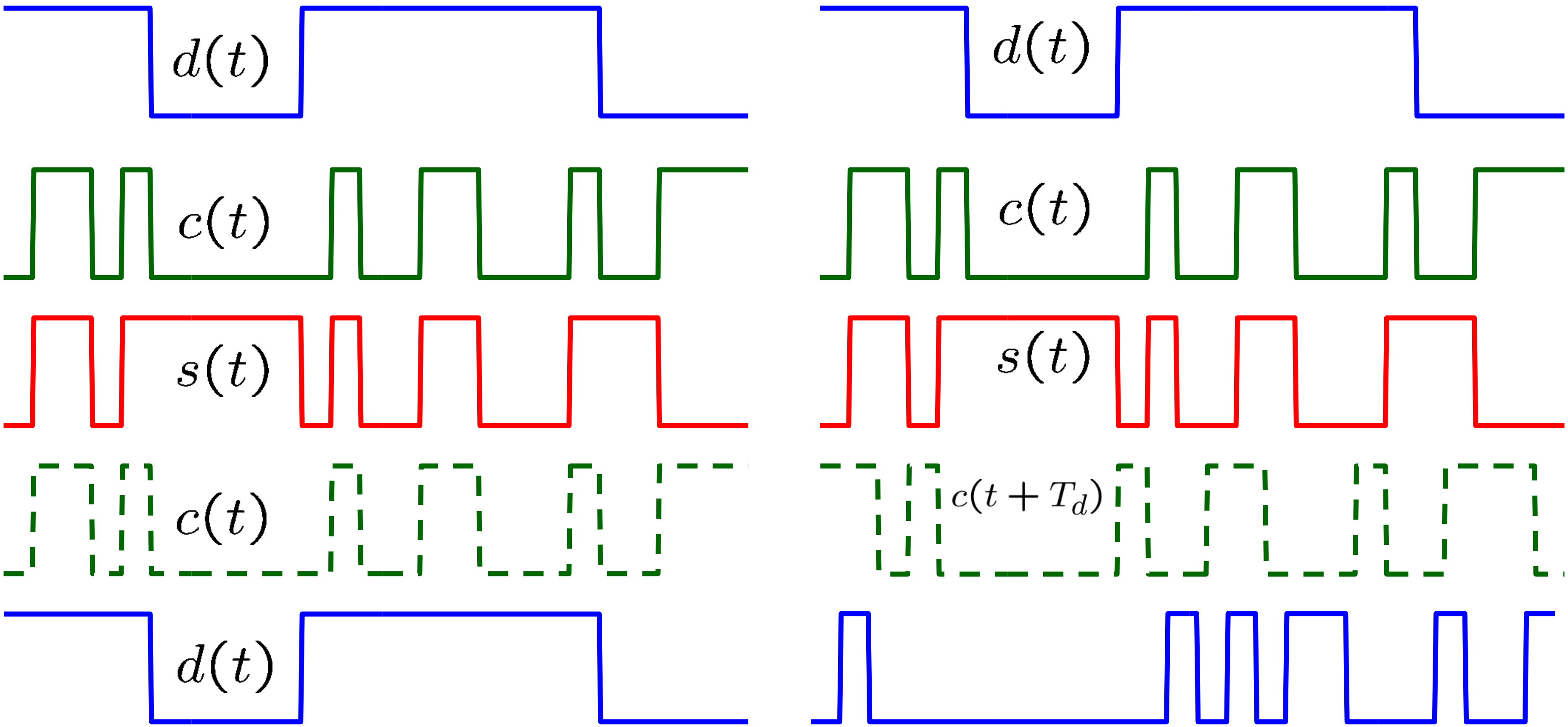
Period of one data bit

PG = SF = Tb / Tc



Period of one chip

Mistiming



CDMA Example

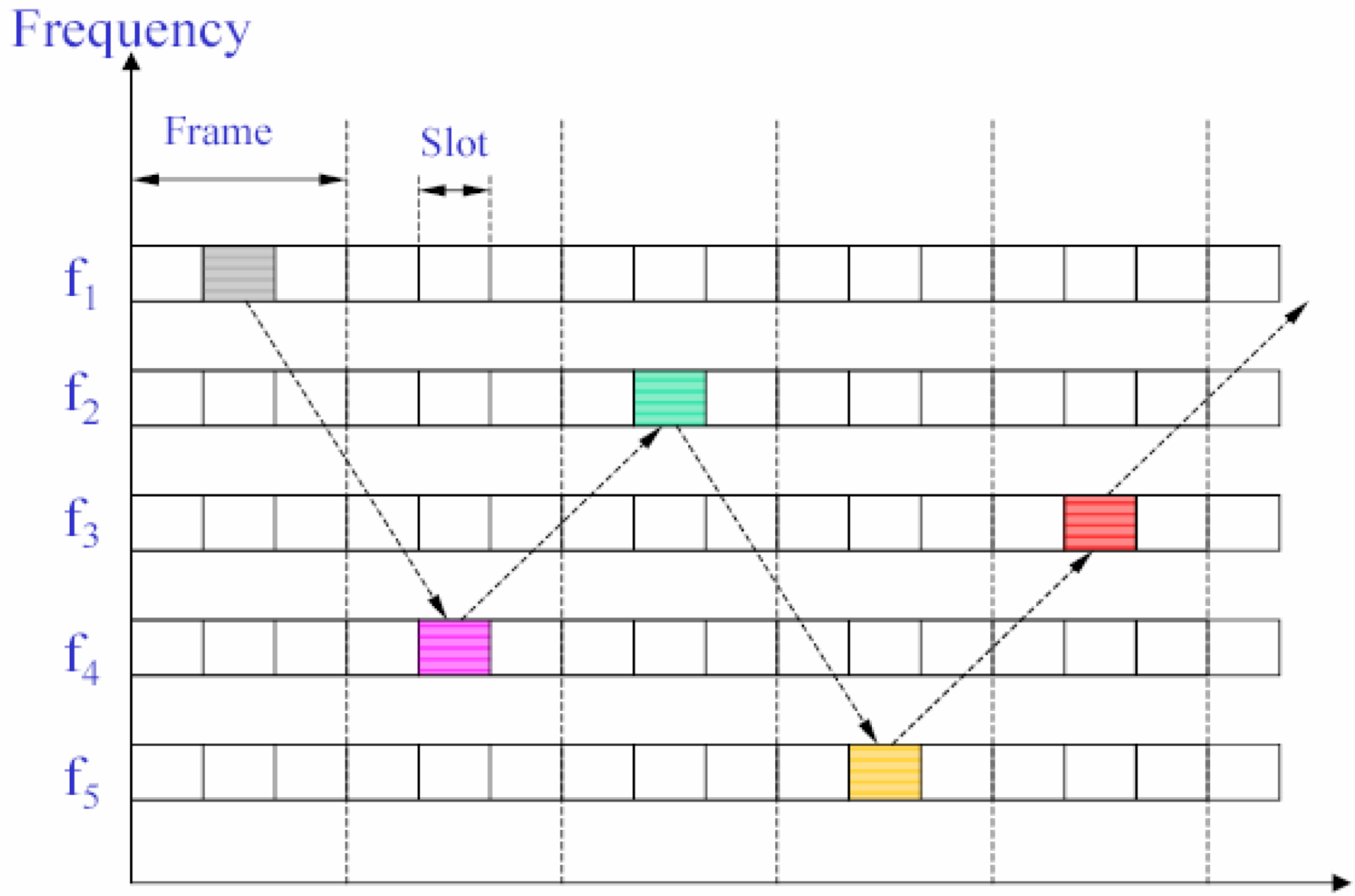
- **User A code = <1, –1, –1, 1, –1, 1>**
  - To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- **User B code = <1, 1, –1, – 1, 1, 1>**
  - To send a 1 bit = <1, 1, –1, –1, 1, 1>
- **Receiver receiving with A’s code**
  - (A’s code) x (received chip pattern)
    -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

Advantages of CDMA

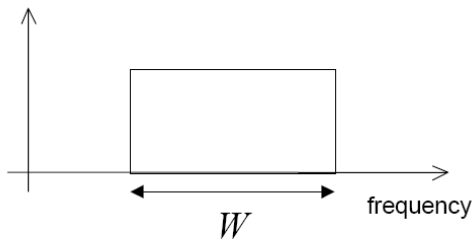
- Low power spectral density
- Interference limited operation
- Privacy due to unknown random codes
- Reduction of multi-path effects
- Random access possibilities

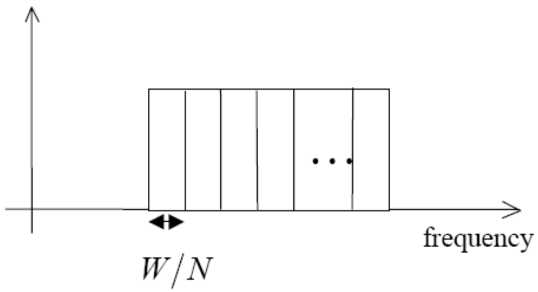
Frequency Hopping

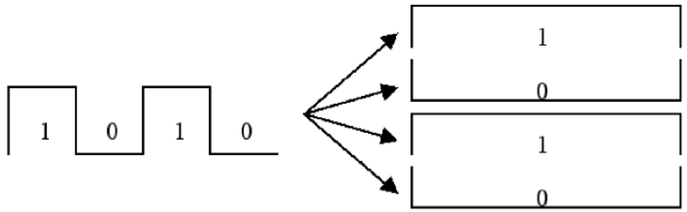
- Frequency hopping: signal is spread by changing the frequency over the transmitted time of the signal under psudo random code



Multicarrier System (1)

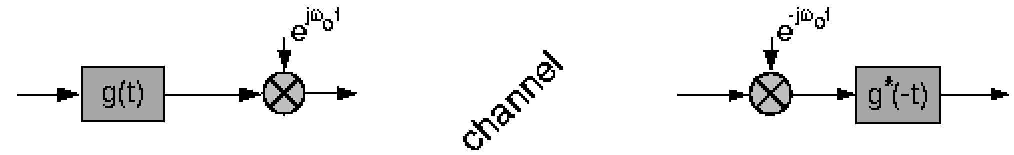




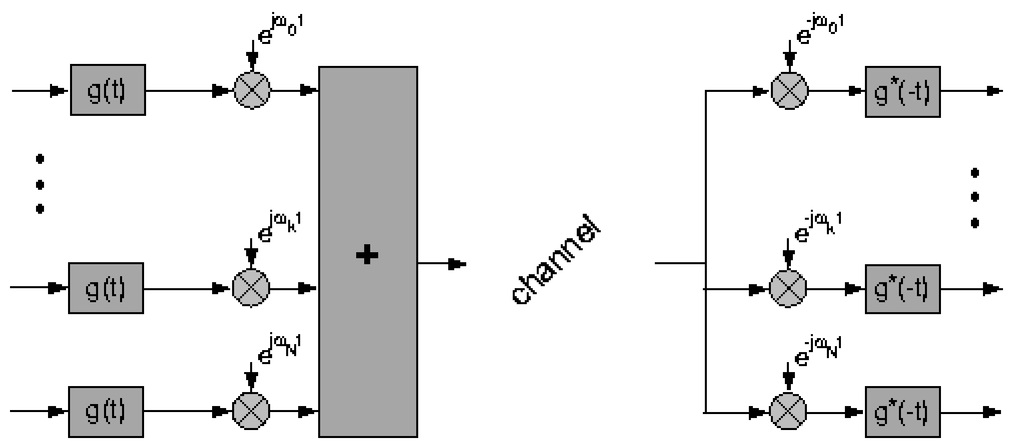


- **Single carrier system**
  - Single representing each bit uses all of the available spectrum
- **Multicarrier system**
  - Available spectrum divided into many narrow bands
  - Data is divided into parallel data streams each transmitted on a separate band

Multicarrier System (2)

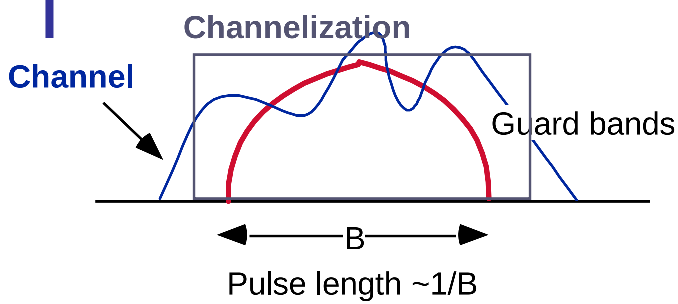


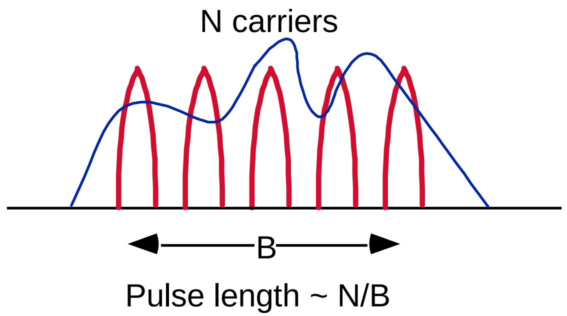
Conventional system



Multicarrier system

Multicarrier System (3)





Similar to FDM technique

– Data are transmited over **only one carrier**

– Data are shared among **several carriers** and simultaneously transmitted

Drawbacks

- **Selective Fading**
- **Very short pulses**
- **ISI is compartively long**
- **EQs are then very long**
- **Poor spectral efficiency because of band guards**

Advantages

- **Flat Fading per carrier**
- **N long pulses**
- **ISI is comparatively short**
- **N short EQs needed**
- **Poor spectral efficiency because of band guards**

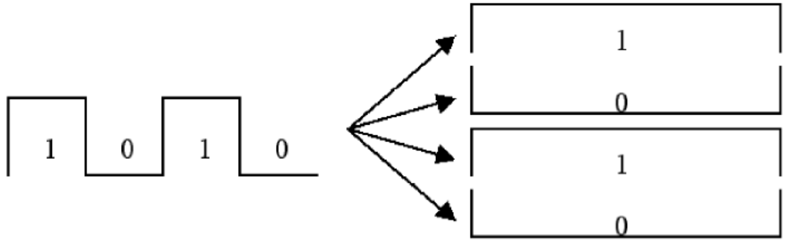
Furthermore

- It is easy to exploit Frequency diversity
- It allows to deploy 2D coding techniques
- Dynamic signalling

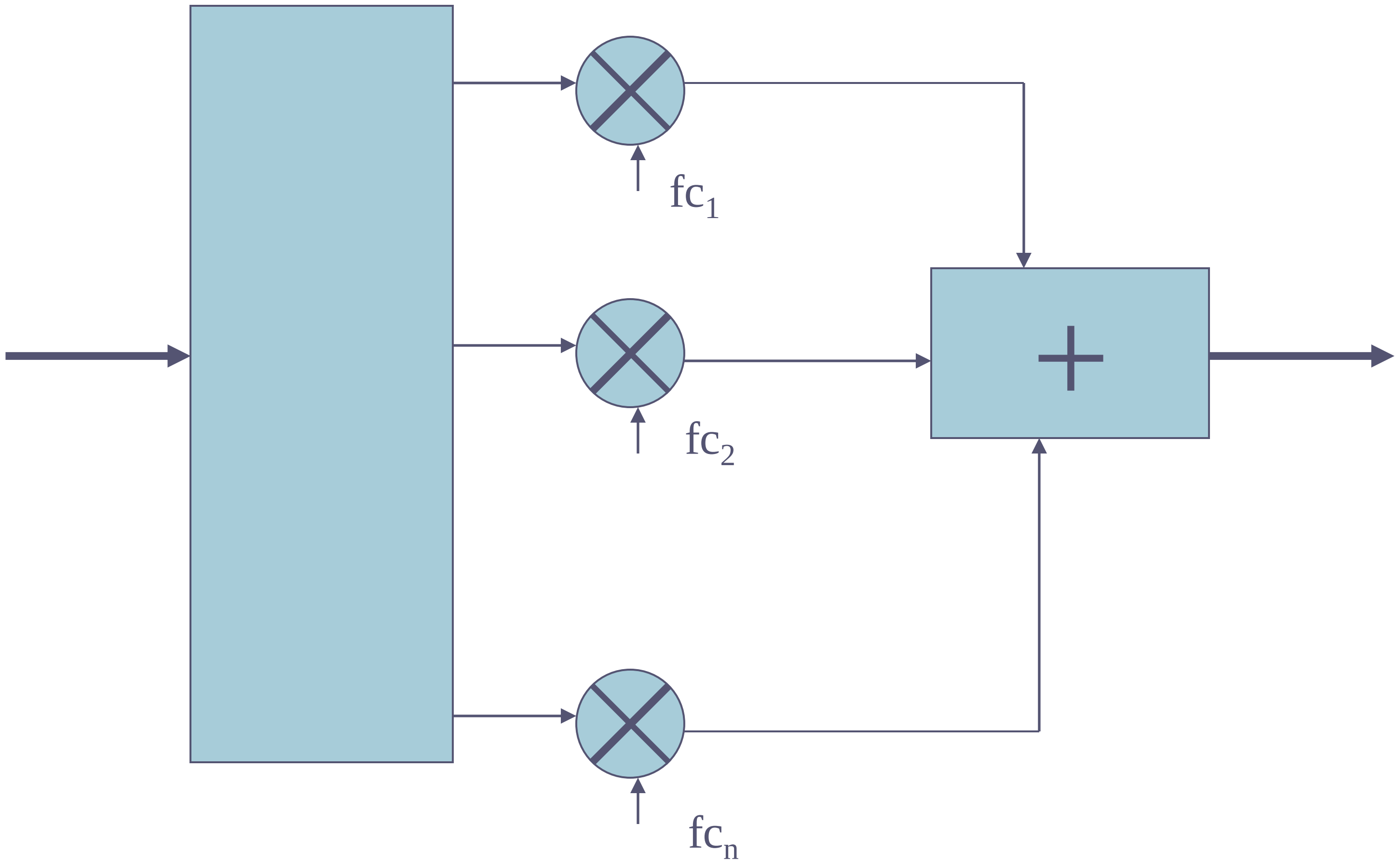
So, the idea of Multicarrier Approach

- **The basic concept here…**

  to transmit the serial data stream on different carriers after breaking it into a group of low rate parallel streams.
- **Thus, increasing the time period of the symbols.**
- **This is FDM**

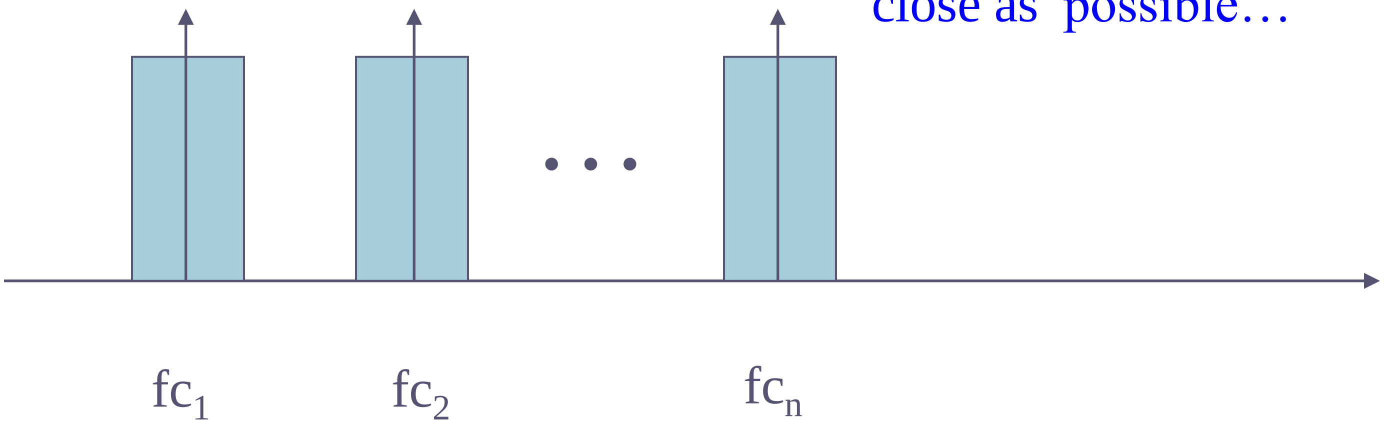


The Implementation of FDM



FDM Spectra

need to bring the carriers as close as possible…



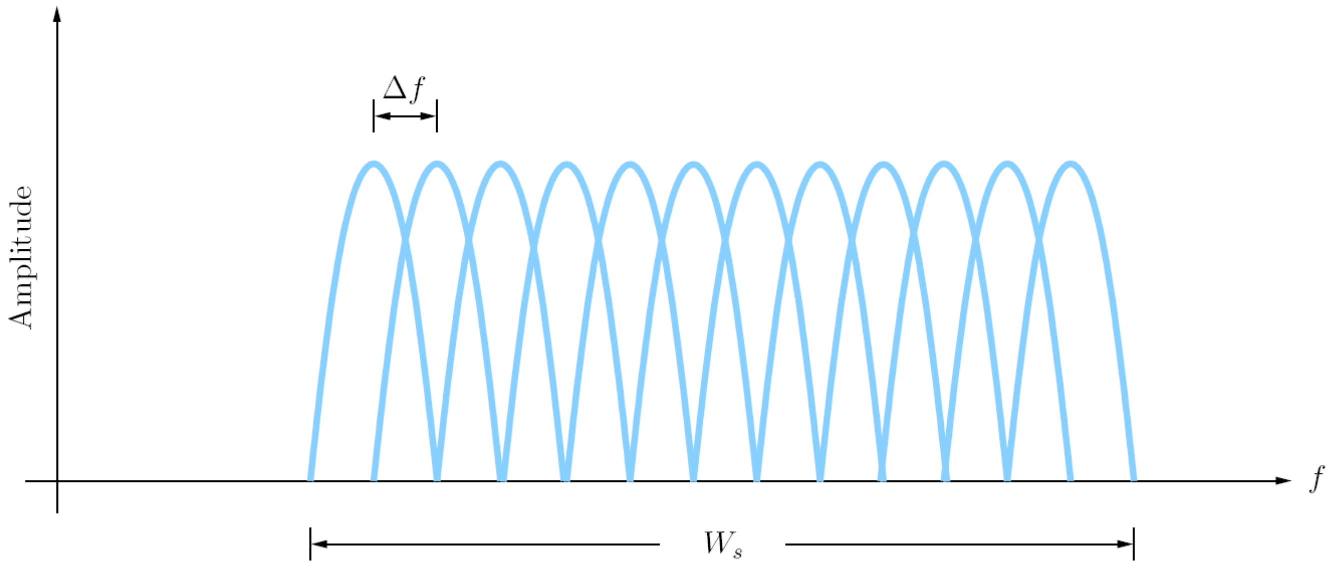
- **Bandwidth efficiency ?**
- **Guard Band essential !**

To improve the spectral efficiency:

Eliminate band guards between carriers

To use orthogonal carriers (allowing overlapping)

OFDM Spectra

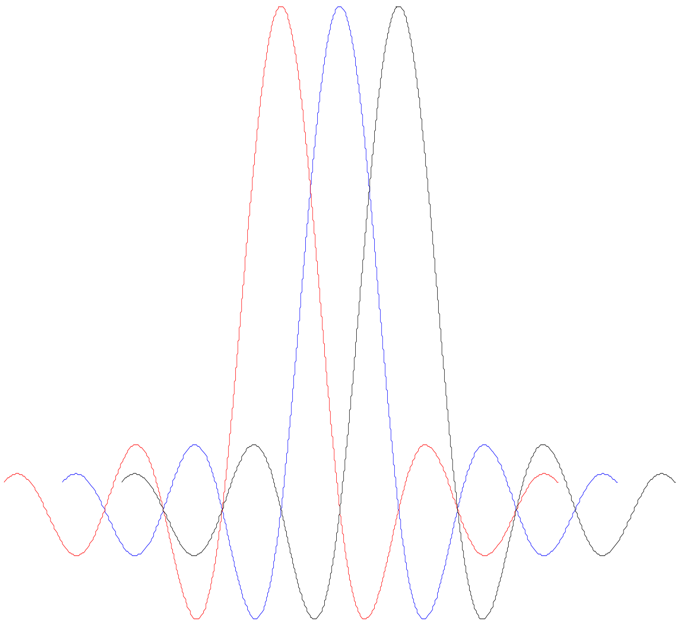


- **No guard band between the different narrowbands is needed**
- **A very flexible scheme (frequency and time dimension)**
  - Can be easily adapted to the multipath fading channel

Orthogonality, The Best Way

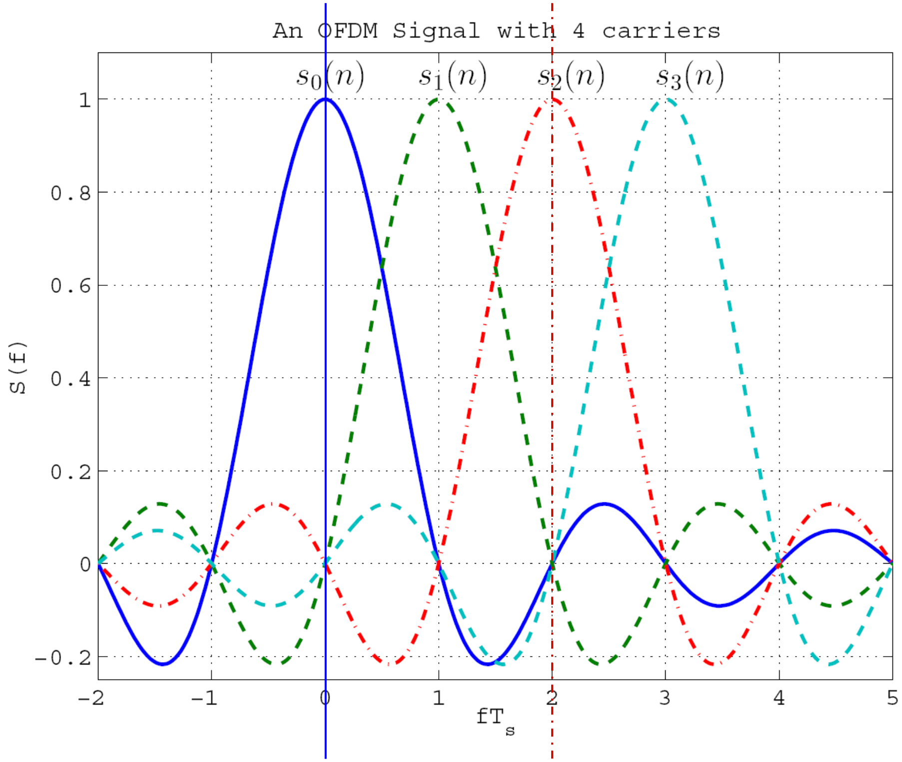
- Sub carriers overlap
- But the peaks of sub carriers at the nulls of the adjacent ones.
- Received signal sampled at these peaks-so no inter carrier interference

- This is OFDM



OFDM Spectra

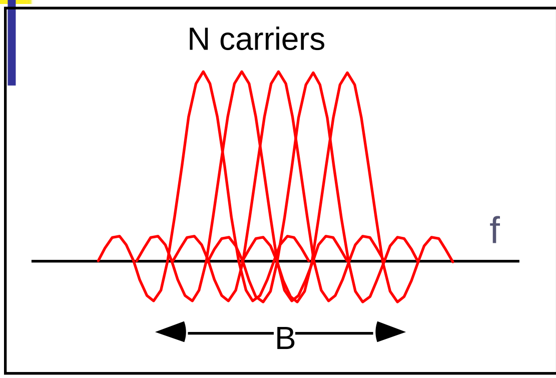
Orthogonal ?



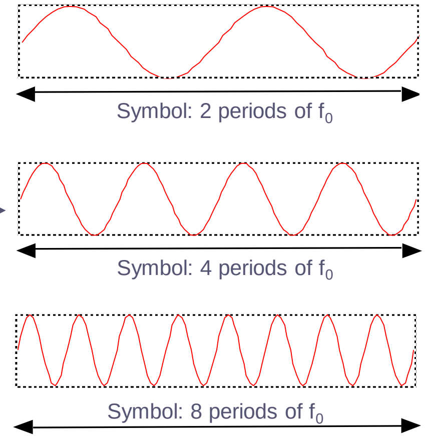
- **Note that the symbol is just sampling at *f=k/T***

$$\boxed{X\left(\frac{k}{T}, nT\right) \quad = \quad s_k(n), \qquad k = 0, 1, \cdots, N-1}$$

Orthogonal Frequency Division Modulation (OFDM)



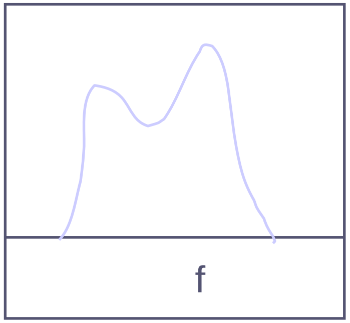
Data coded in frequency domain



+

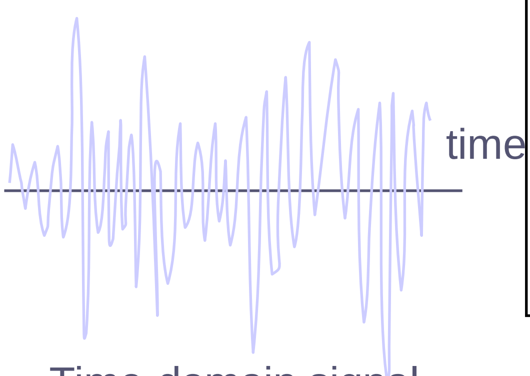
Transformation to time domain: each frequency is a sine wave in time, all added up.

Transmit

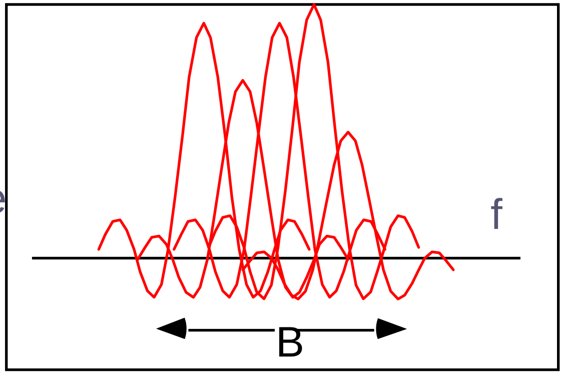


Channel frequency response

Receive



Time-domain signal

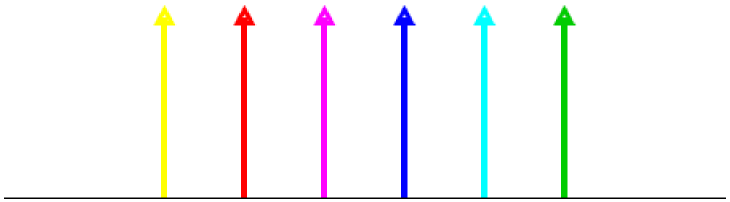


Frequency-domain signal

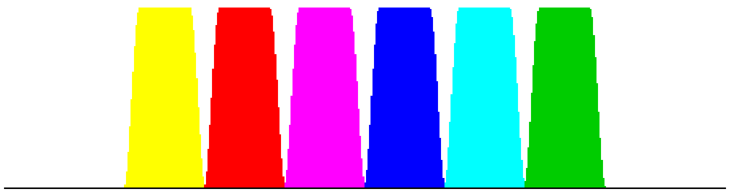
Decode each frequency bin separately

Multi-carrier Modulation Systems

Subcarriers

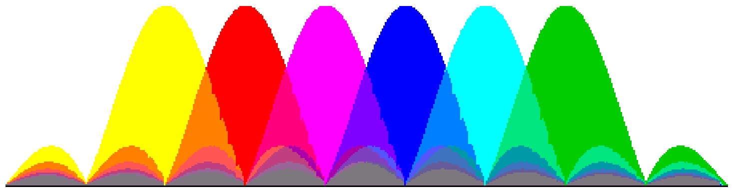


Fraction Spaced Multicarrier Modulation

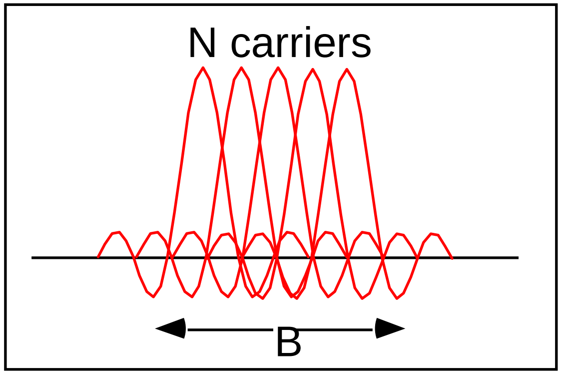


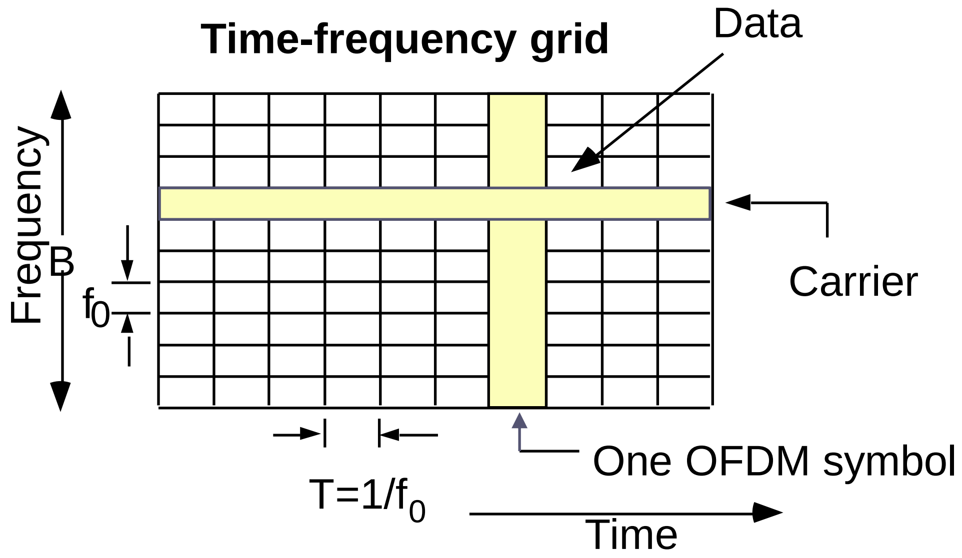
FDM

OFDM with rectangular pulses



OFDM Features





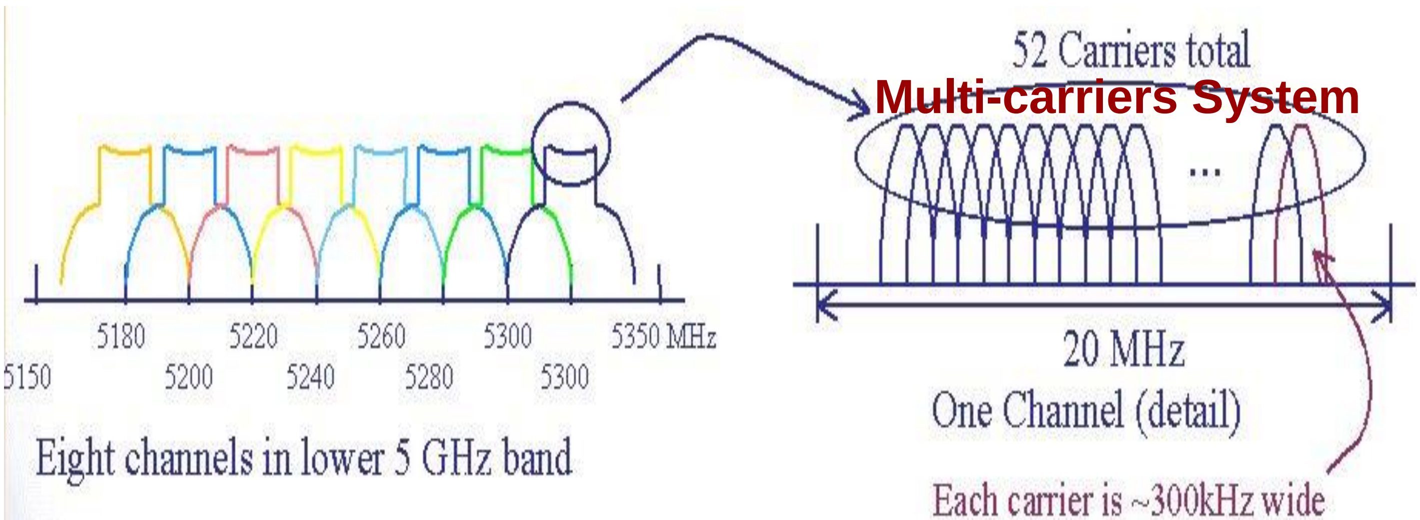
Features

– **No intercarrier guard bands**
– **Controlled overlapping of bands**
– **Maximum spectral efficiency (Nyquist rate)**
– **Easy implementation using IFFTs**
– **Very sensitive to freq. synchronization**

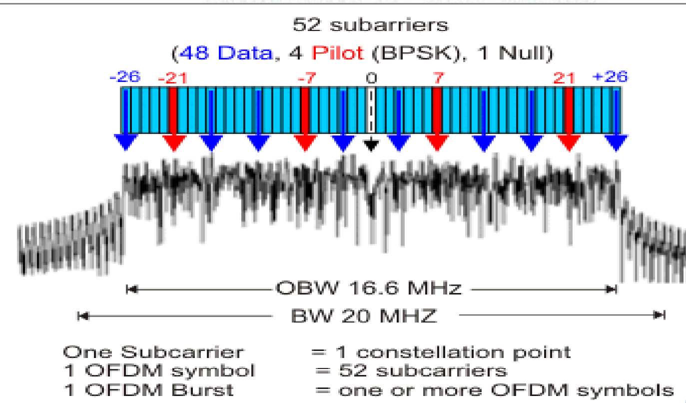
Intercarrier Separation = 1/(symbol duration)

OFDM(Orthogonal Frequency Division Multiplexing)

- 802.11a Spectrum and Allocation(original wireless area network)



802.11a OFDM PHY Parameters	
BW	20 MHZ
OBW	16.6 MHZ
Subcarrer Spacing	312.5 Khz (20MHz/64 Pt FFT)
Information Rate	**6**/9/**12**/18/**24**/36/48/54 Mbits/s
Modulation	BPSK, QPSK, 16QAM, 64QAM
Coding Rate	1/2, 2/3, 3/4
Total Subcarriers	52 (Freq Index -26 to +26)
Data Subcarriers	48
Pilot Subcarriers*	4 (-21, -7, +7, +21) *Always BPSK
DC Subcarrier	Null (0 subcarrier)

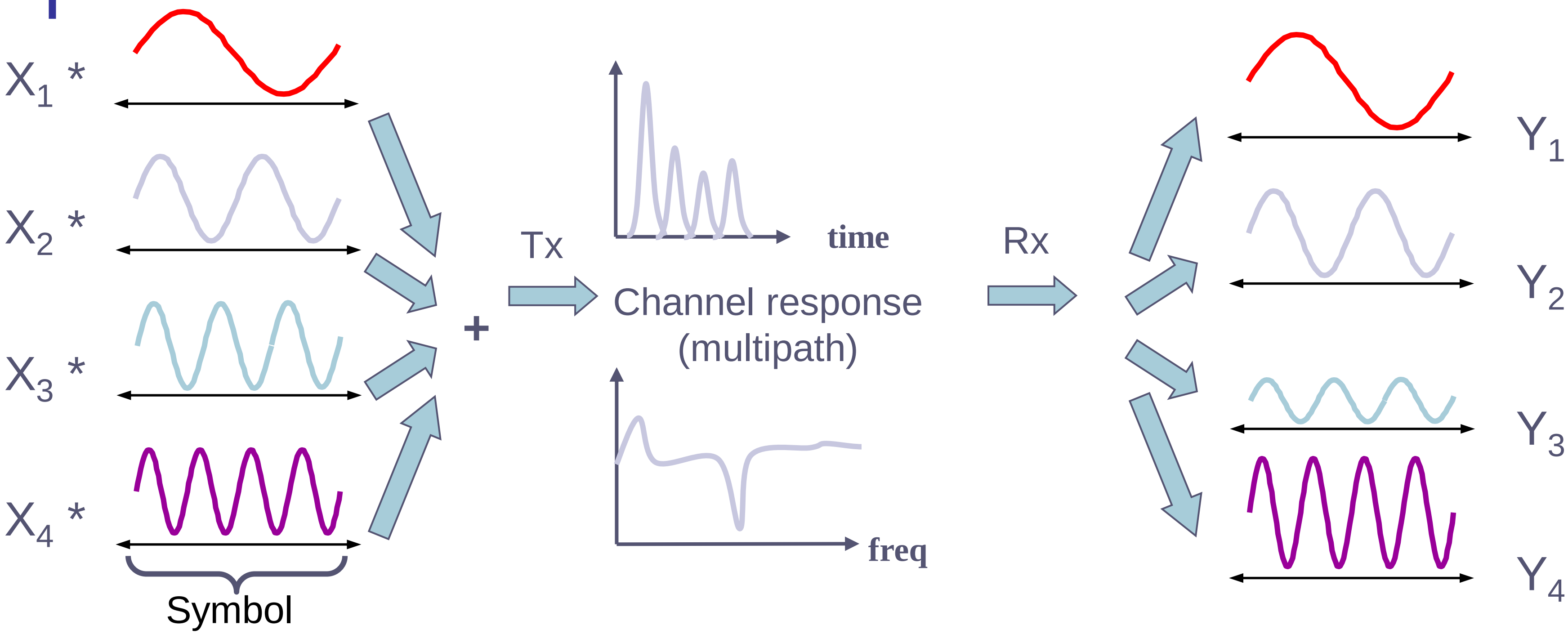


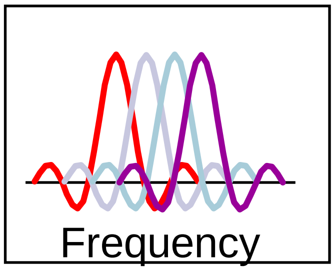
802.11a OFDM Physical Parameters

OFDM System

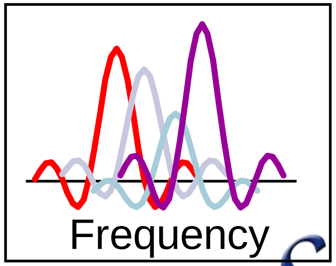
- Multicarrier, or multitone modulation
- On the wired side, it is used for variant digital subscriber line (DSL) systems.
- On the wireless side, it is the basis for several television and radio broadcast applications, as well as digital local area network

OFDM Modulation

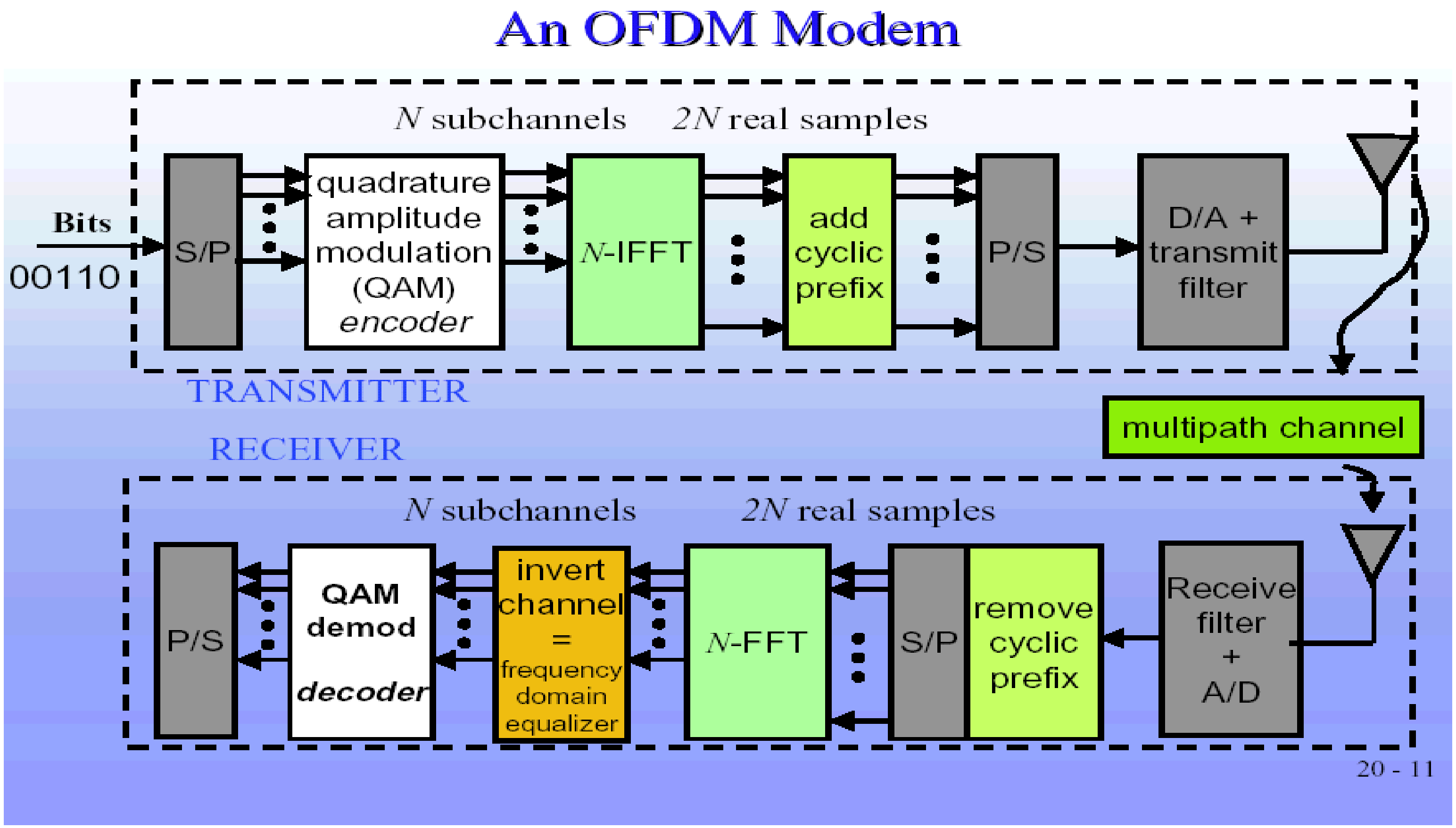




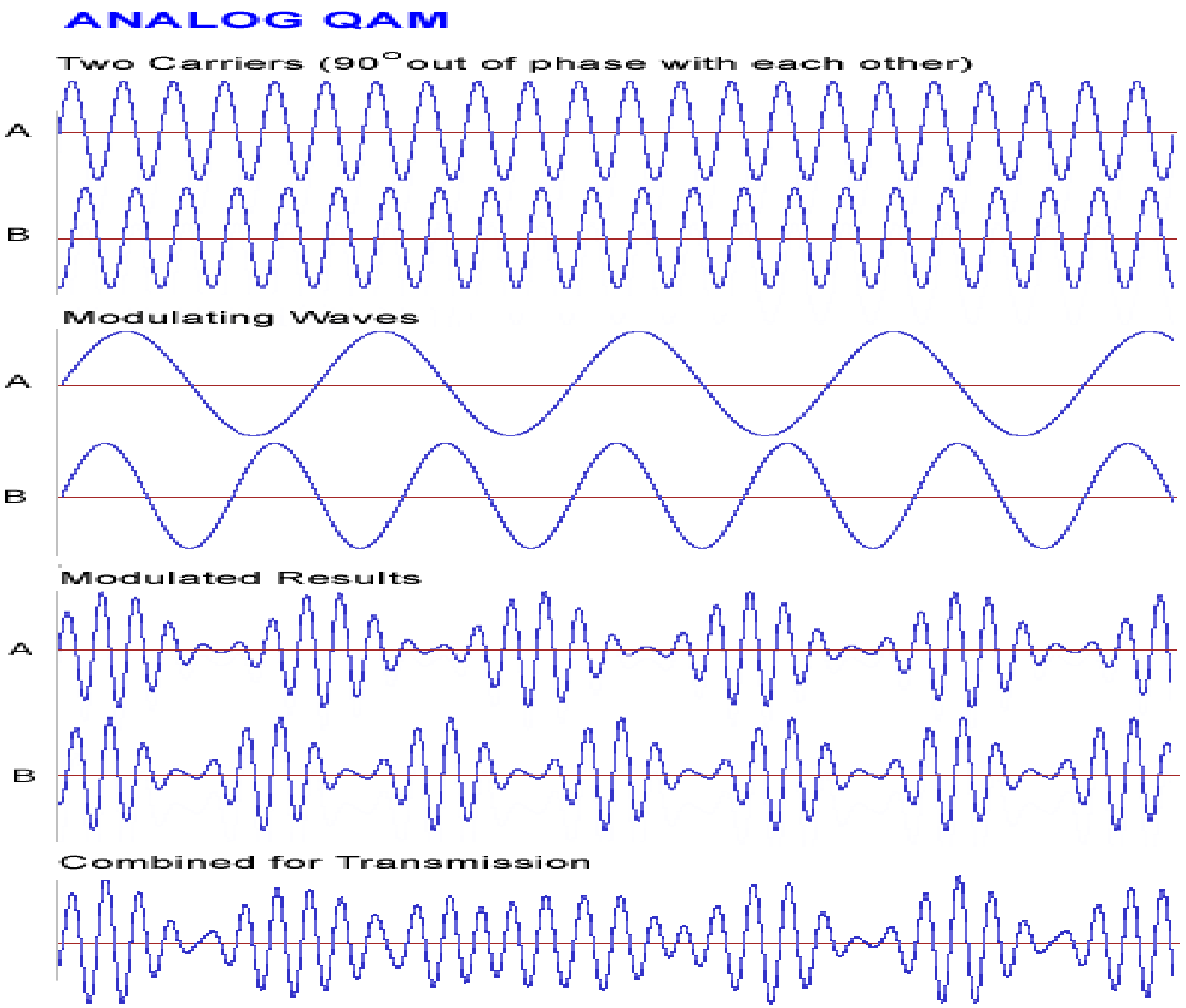
- Different data per tone
- Multipath just scales tones
- Tones remain orthogonal even with multipath



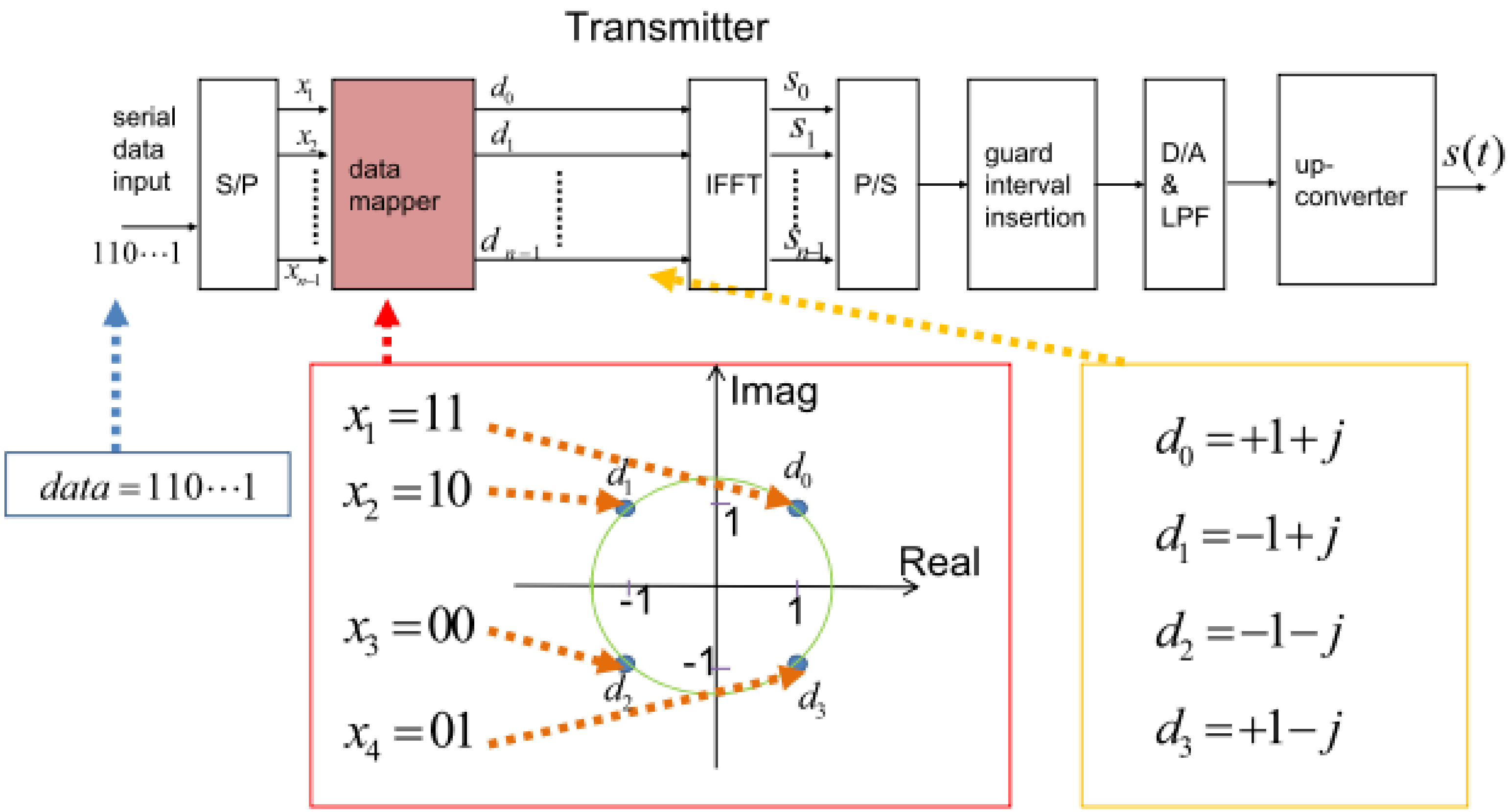
OFDM Implementation



QAM(Quadrature amplitude modulation)



Data mapping (Digital QAM)

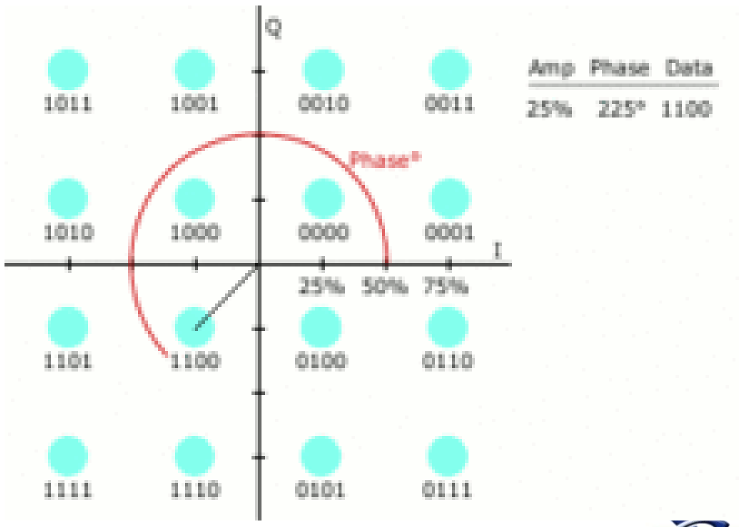


Data mapping (Digital QAM)

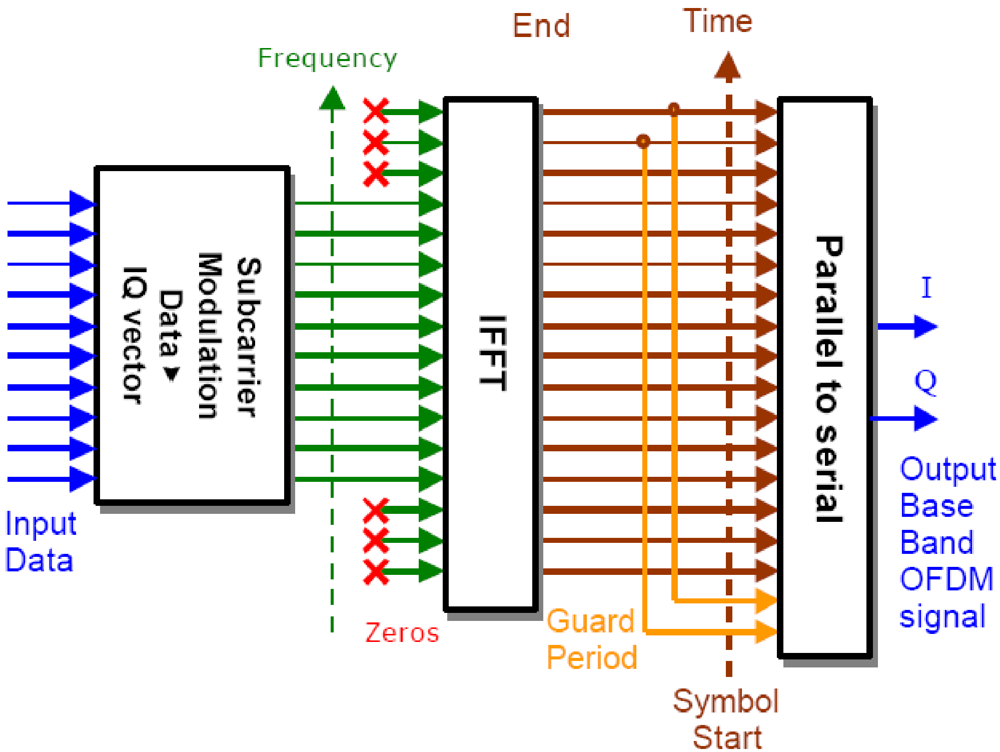
- The number of points corresponding to the number of bits per symbol.
- QAM constellations consist of points arranged in a square such as 16QAM, 64QAM, 256 QAM
- Higher-order constellation, it is possible to transmit more bits per symbol
- Higher-order constellation,

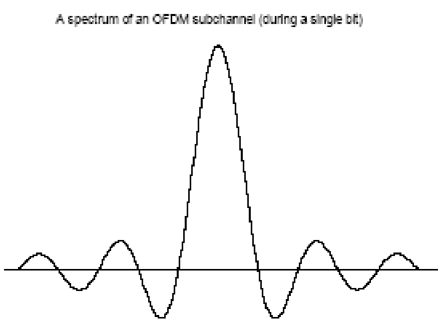
  points are closer,

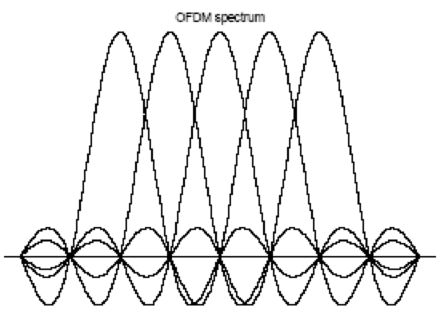
  less reliable to noise



FFT, Key Function in OFDM

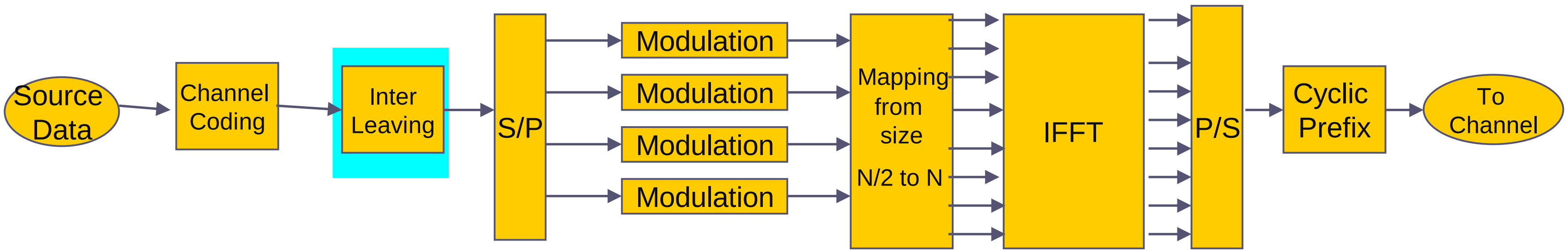


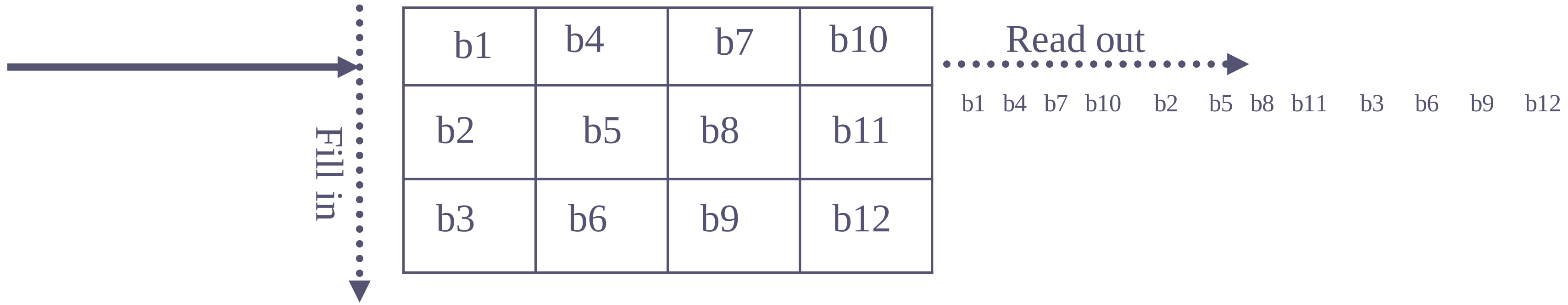




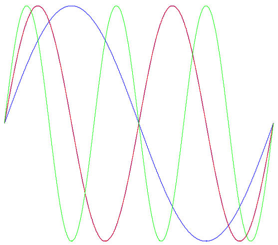
Interleaving

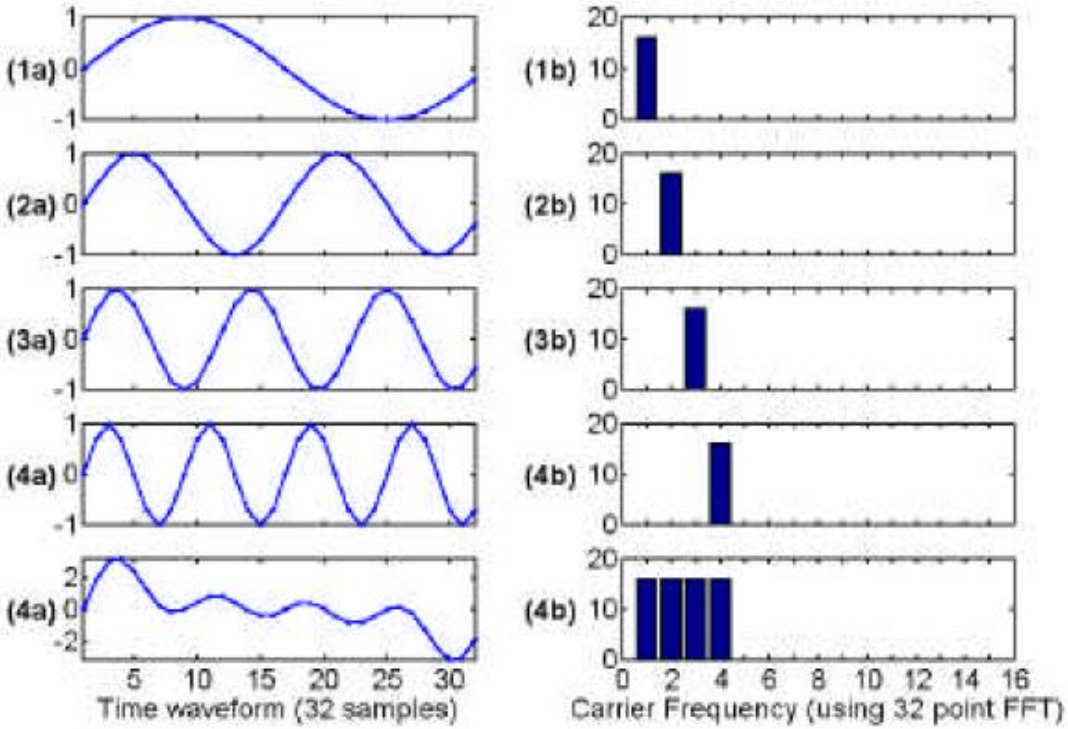
Interleaving is used on OFDM is to spread the errors out in the bit-stream that is presented to the error correction decoder



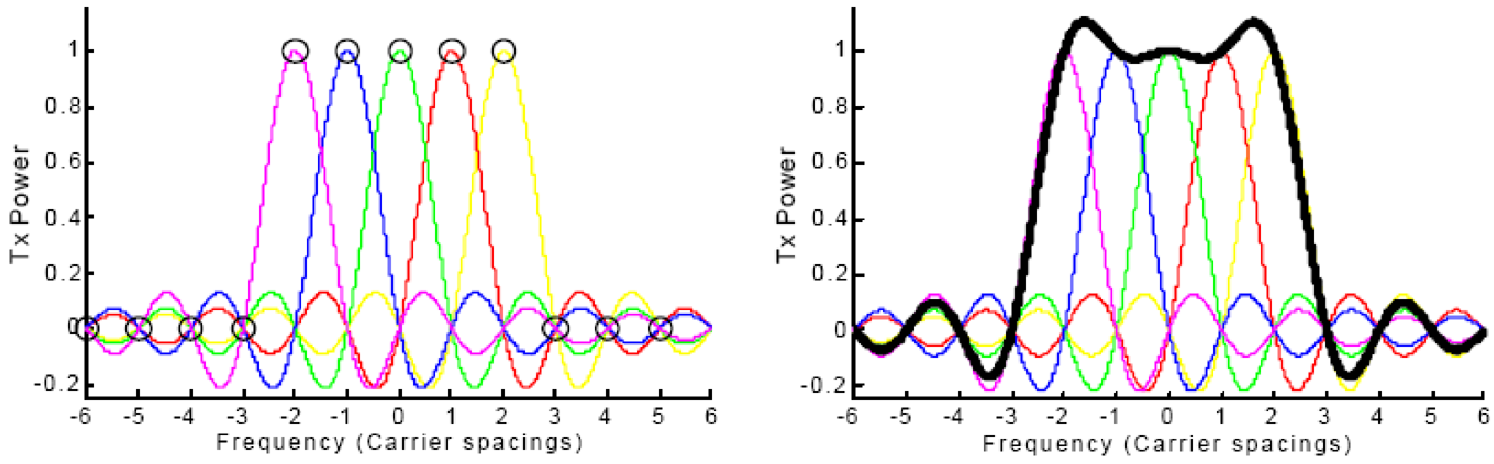


Time Domain Construction of OFDM Signal



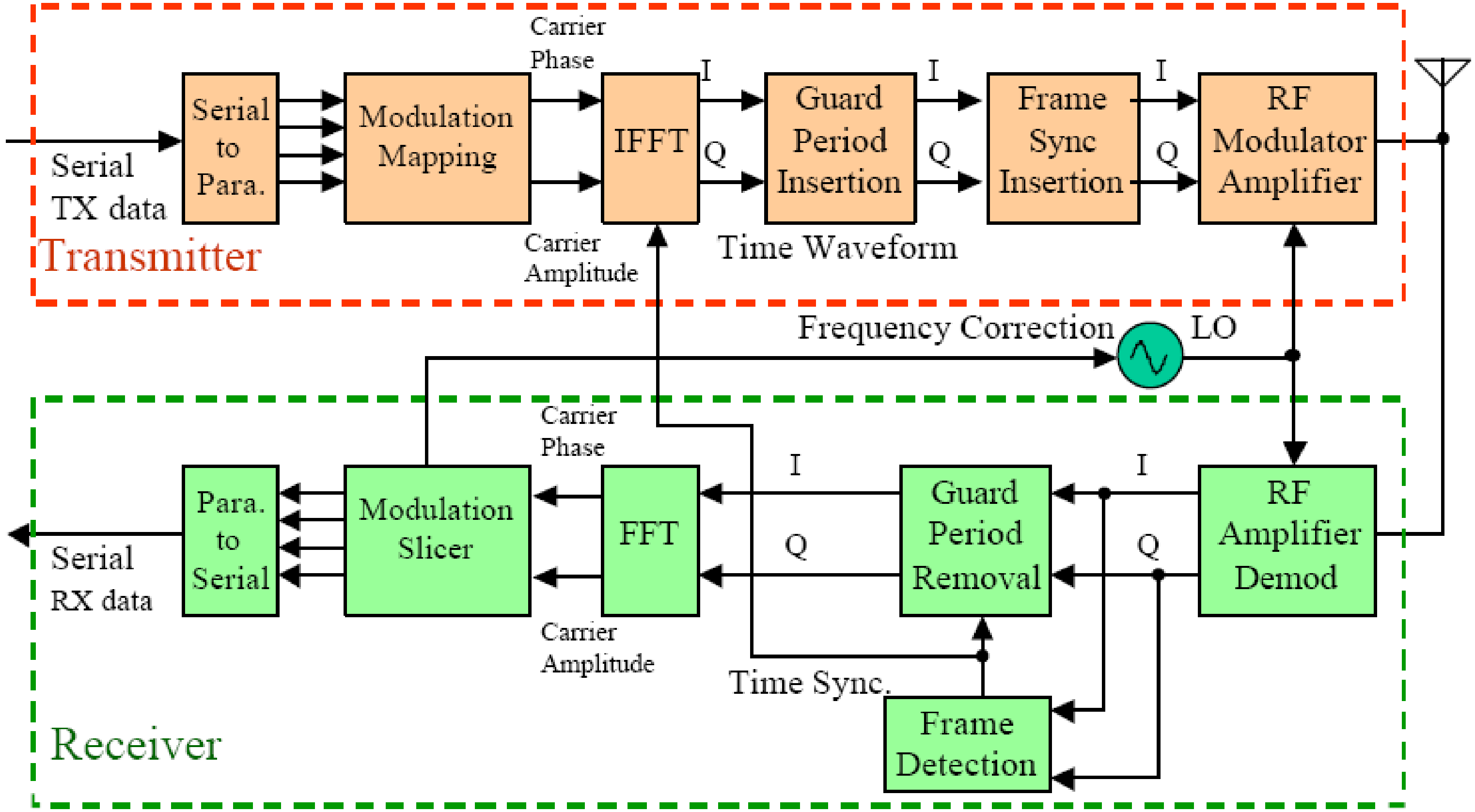


Frequency Response of the Subcarriers in 5-tone OFDM signal



(a) (b)

Block Diagram of a Basic OFDM tranceiver



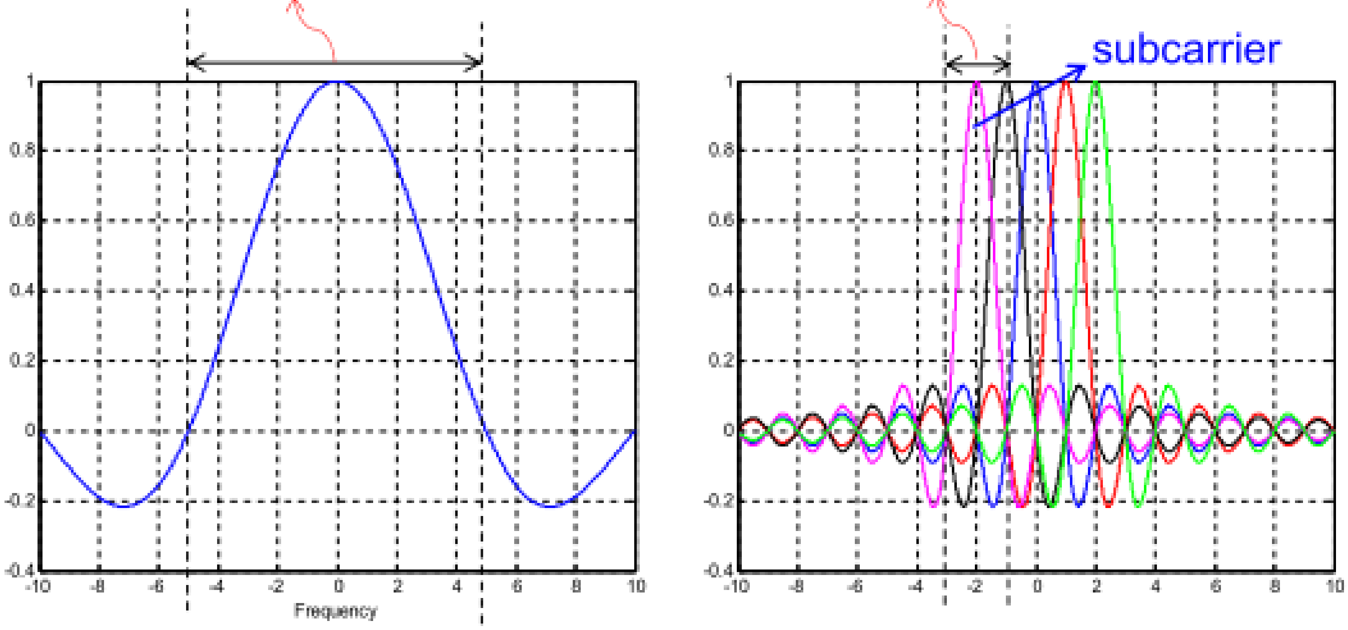
Adversarial frequency selective channel

Single carrier system

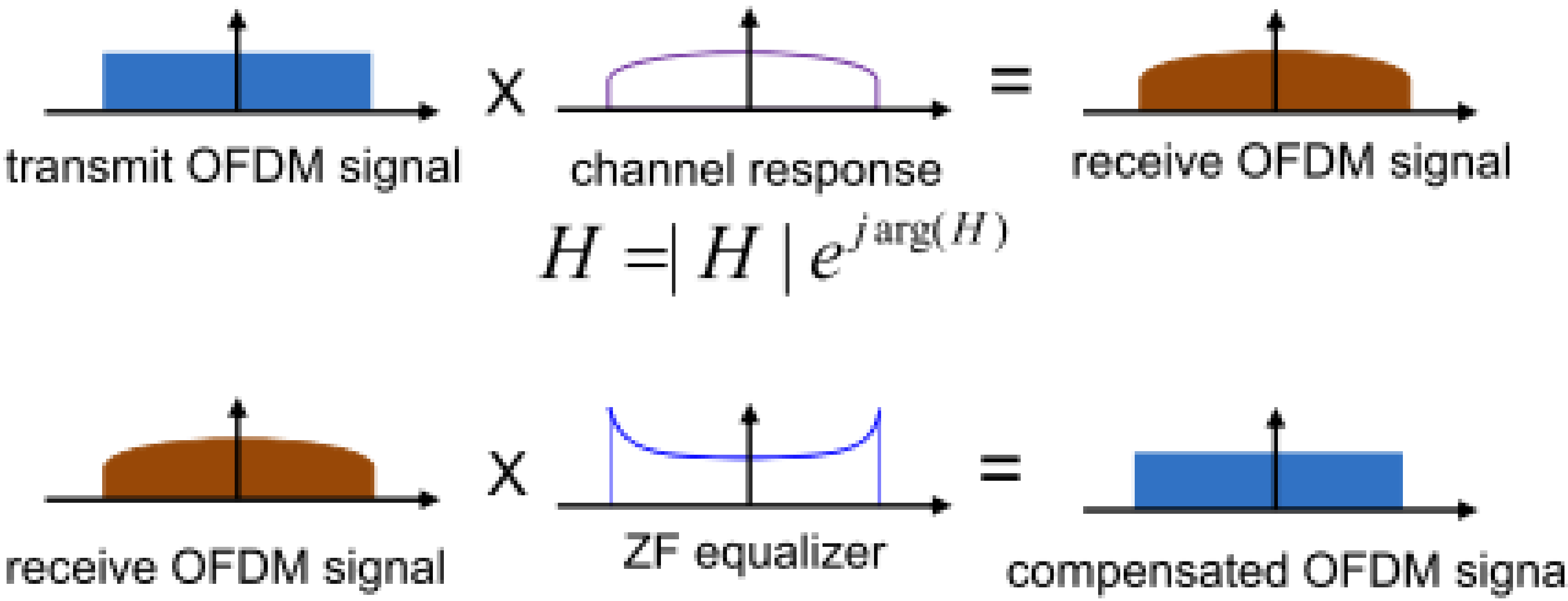
OFDM system

Channel response is narrow. OFDM equalizers are usually easier design.

channel response is wide



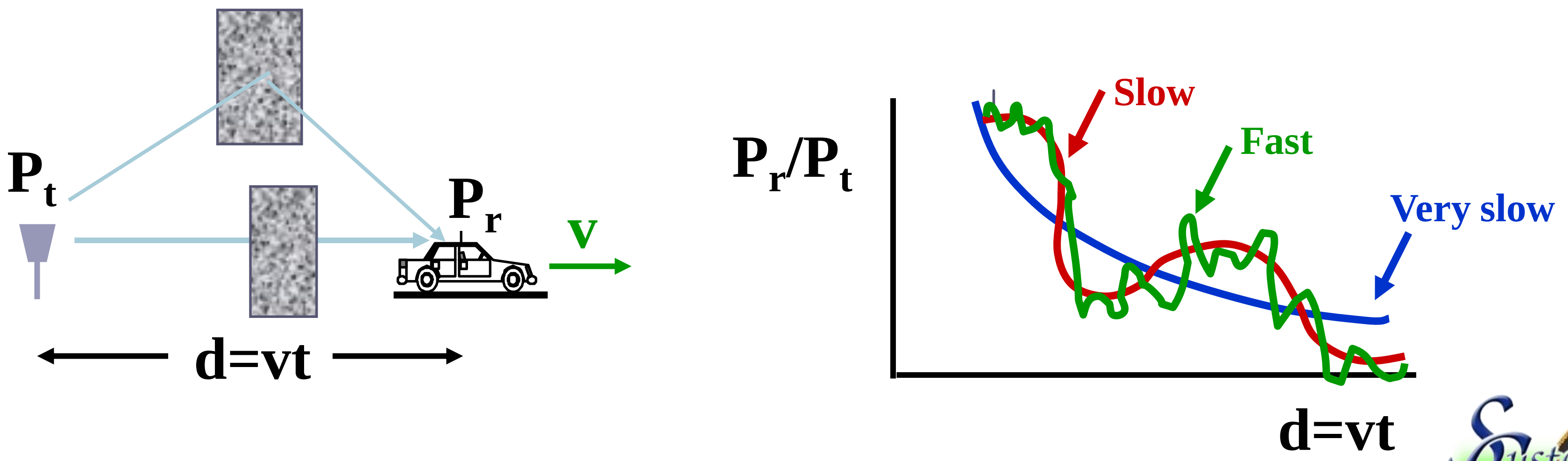
Equalizer



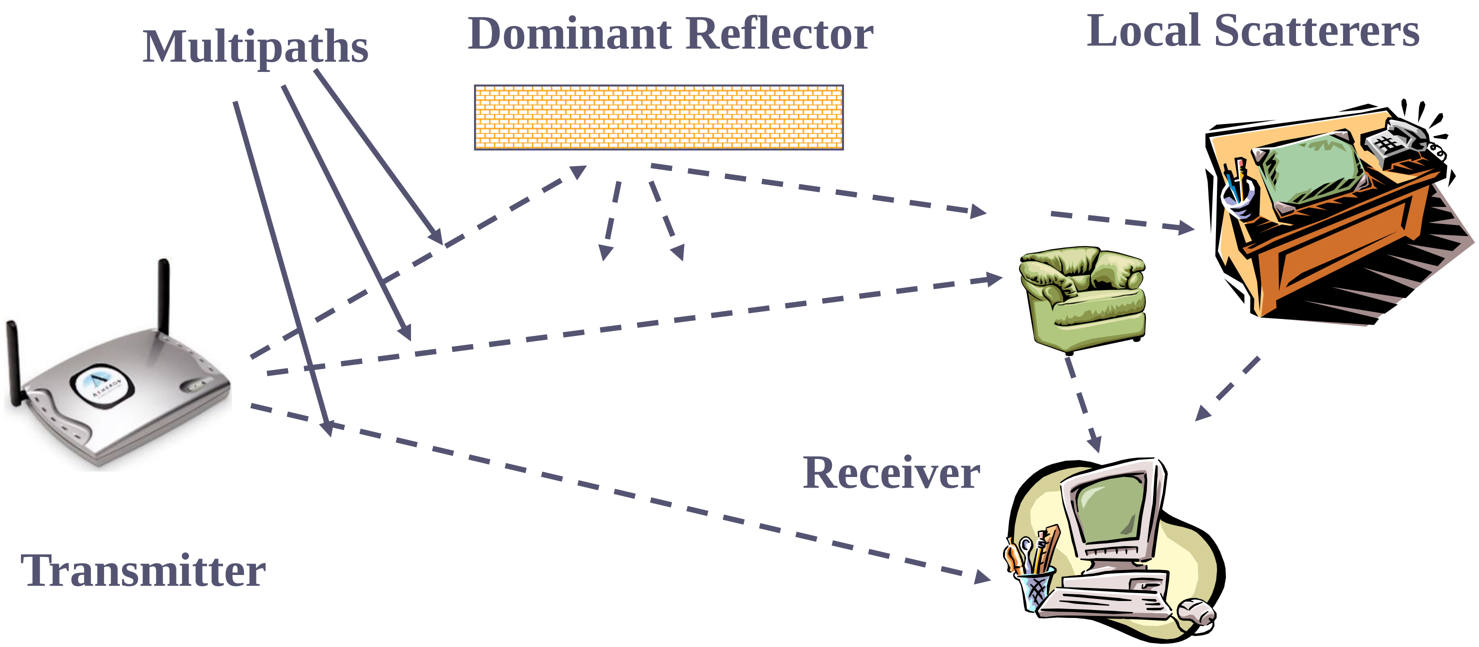
Zero forcing (ZF equalizer): ZF function = inverse of channel response

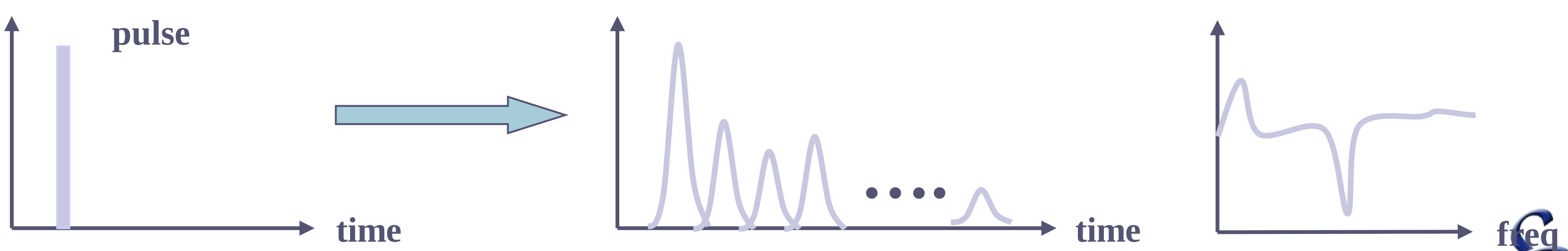
Propagation Characteristics

- Path Loss (includes average shadowing)
- Shadowing (due to obstructions)
- Multipath Fading

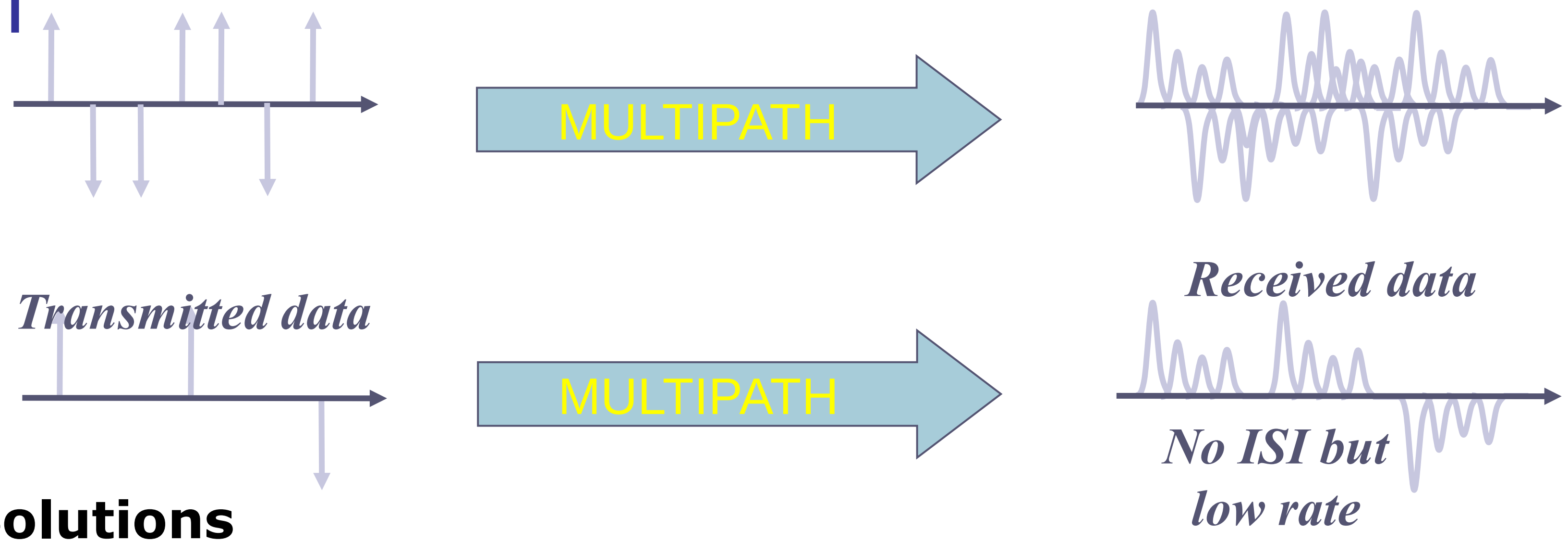


Wireless Channel: Multipath Effects





Inter-Symbol Interference (ISI)



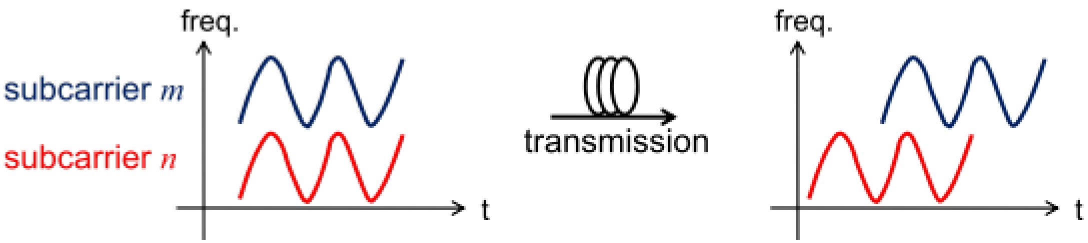
Solutions

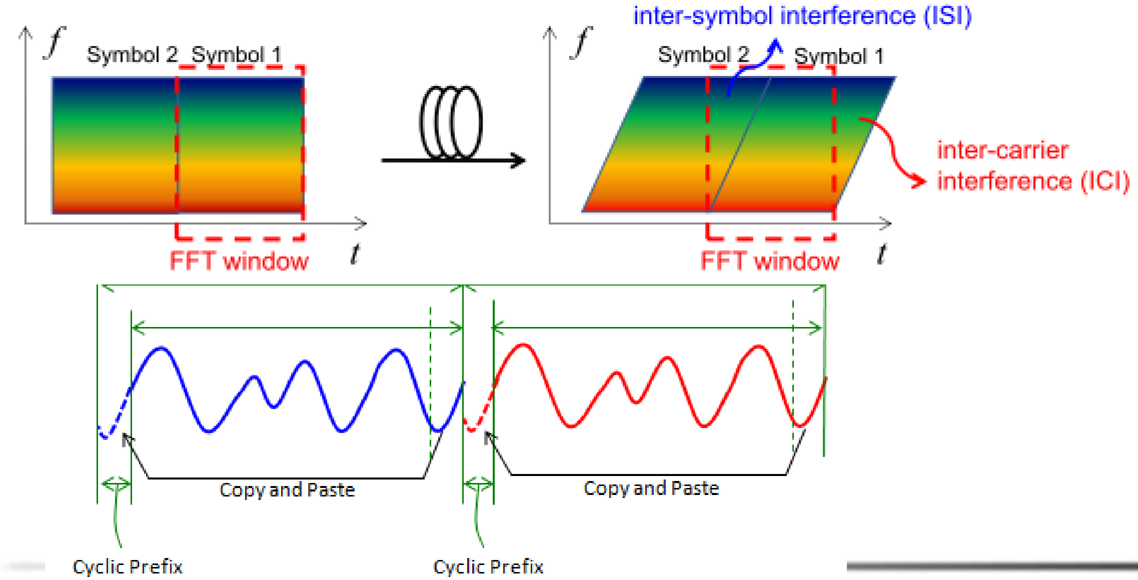
- **Lower data rate**

- **Equalization or combining**
  - Complexity, performance (TDMA or CDMA)
- **Code as multiple low-rate streams**
  - Each stream at different frequency - OFDM

Guard Interval

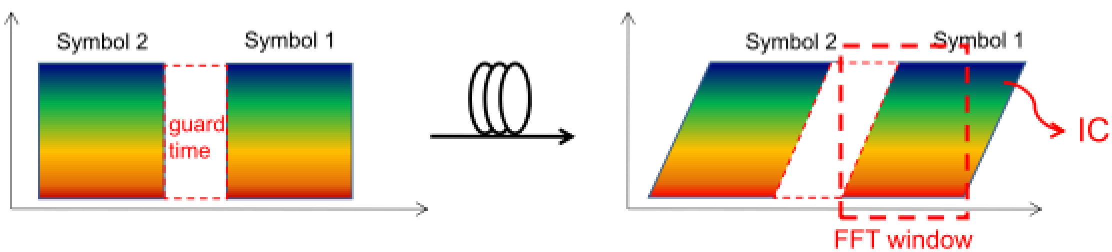
- Inter Symbol Interference (ISI)
- Inter Carrier Interference (ICI)
- Inter Cyclic Prefix (Guard interval) (GI)-is to introduce immunity to propagation delays, echoes and reflections.

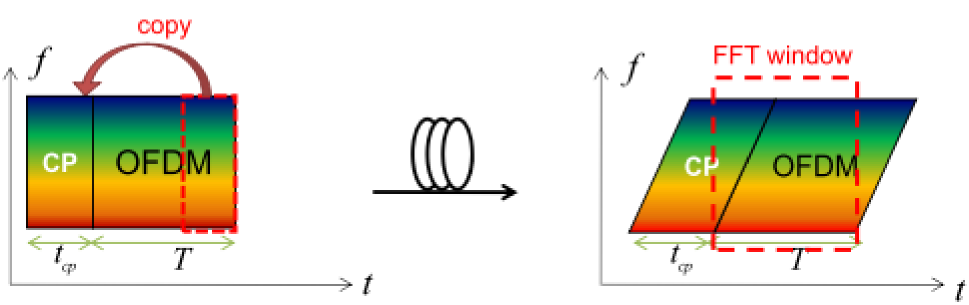




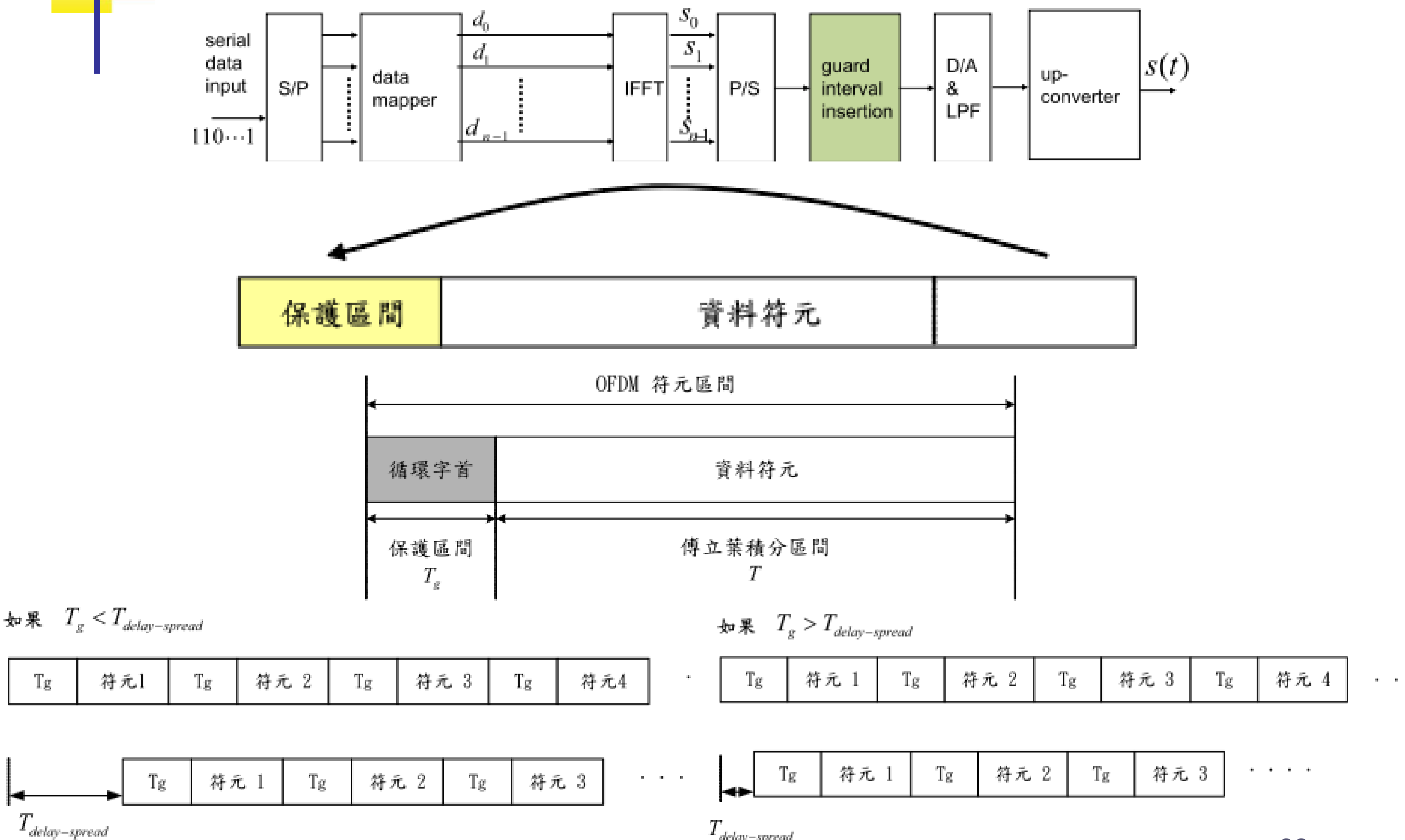
Guard Interval and Cyclic Prefix

- GI solve ISI problem
  - Subcarrier lost orthogonal property and cause Inter Carrier Interference, ICI)
  - To solve this issue, waveform inside GI must be continuous with the signal waveform
  - Copy the same OFDM signal waveform inside GI
  - Copy end of the signal to the front of the transmitted signal, the copy signal is called Cyclic Prefix, CP.
  - Cyclic Extension OFDM signal -Periodic discrete signal





Guard Interval and Cyclic Prefix

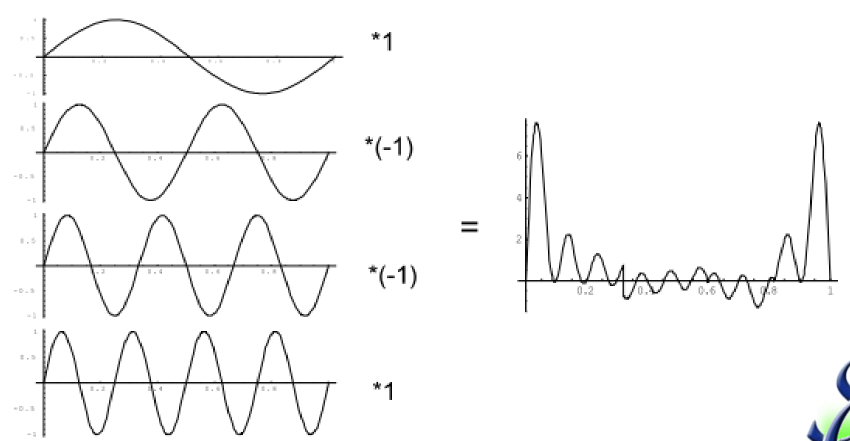


Advantage of OFDM

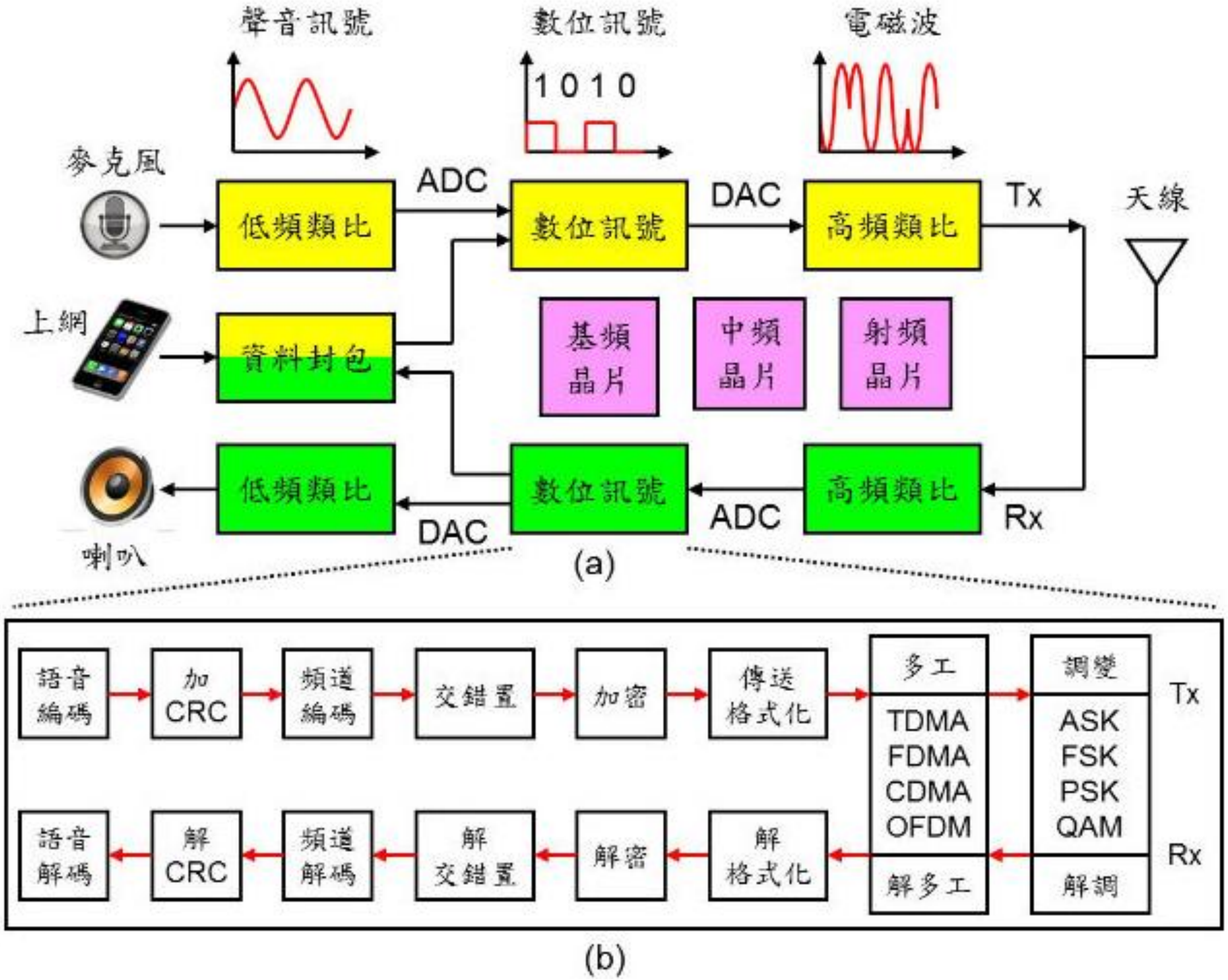
- Compared with traditional FDM, it has more bandwidth benefits.
- It can resist the influence of delay spread and multi-path effect, and does not require a complicated time domain equalizer, which can reduce complexity.
- It can reduce the impact on frequency selective channels and can be solved with a simple equalizer.

Disadvantage of OFDM

- The transmitter and receiver need to be synchronized accurately, otherwise it will cause ISI and ICI.
- Excessively high PAPR (Peak-to-Average Power Ratio)
  - It may be that the linear region of the power amplifier is exceeded, causing non-linear distortion. A power amplifier with a higher backoff factor is required, which increases the cost.
  - Or cause the signal range is too large when doing analogy and digital quantization, and the signal range becomes too large, causing quantization errors and increasing the complexity and cost of ADC/DAC.



OFDM application in cell phone



What's OFDMA

- Use the OFDM not only as a modulation scheme but also as part of the multiple access technique.
- By applying a spreading code in frequency domain, multiple access in OFDMA is realized by providing each user with a fraction of the available number of sub-carriers.
- OFDMA avoids the relatively large guard bands that are necessary in FDMA to separate different users.

OFDMA Example

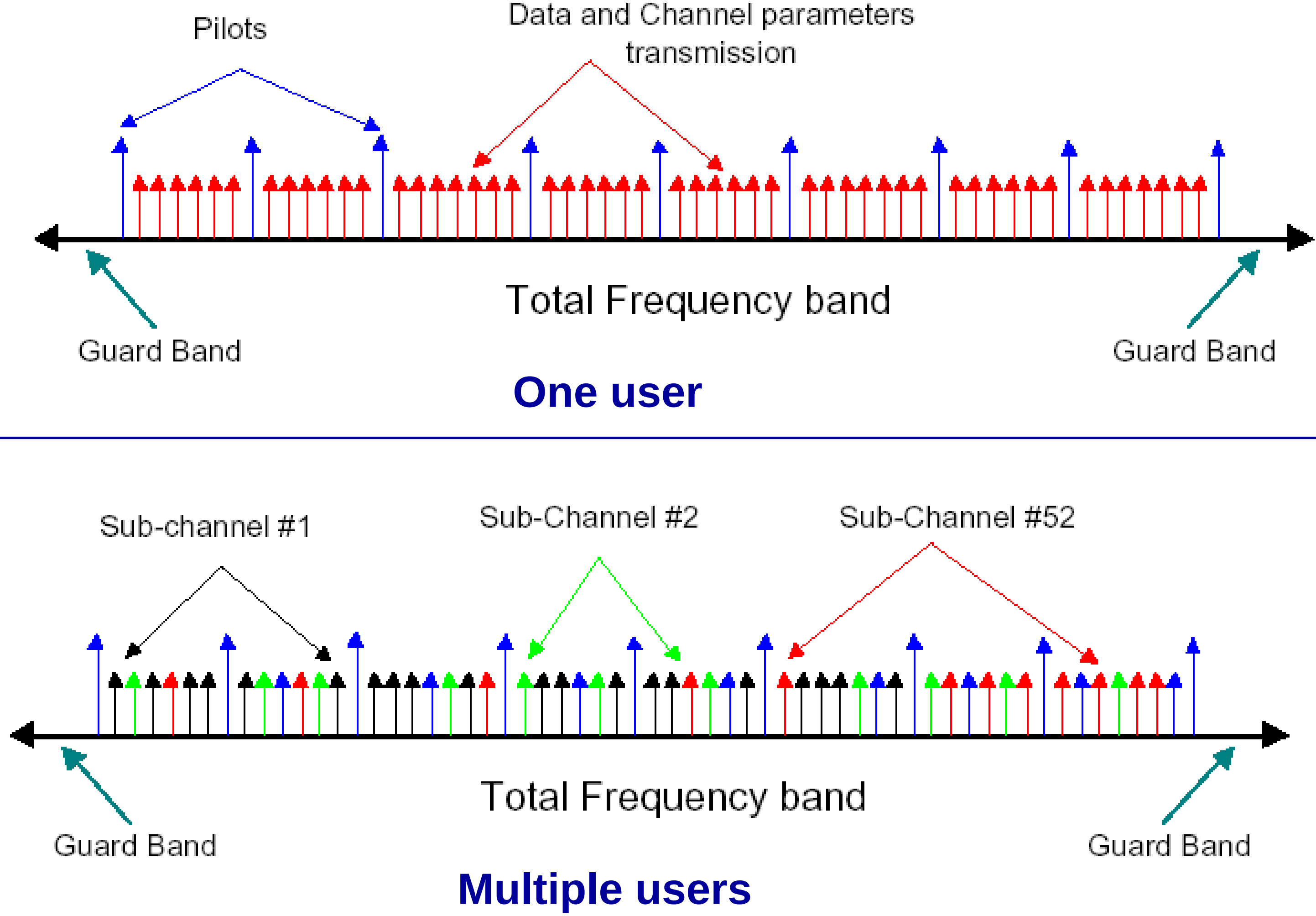
- **The time-frequency plot of seven OFDMA users, which all have a fixed set of sub-carriers every four time slots.**

frequency

A		D		A		D		A		D	
A		D		A		D		A		D	
A	C	E		A	C	E		A	C	E	
A	C	E		A	C	E		A	C	E	
B		E	G	B		E	G	B		E	G
B		E	G	B		E	G	B		E	G
B		F	G	B		F	G	B		F	G
B		F	G	B		F	G	B		F	G

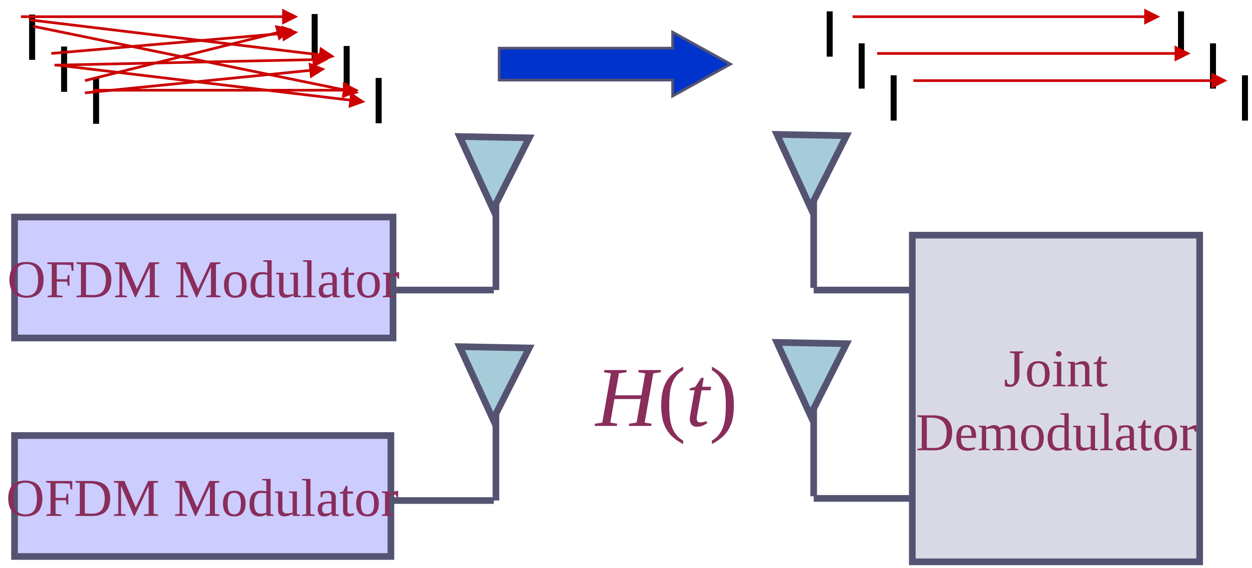
time

OFDM *v.s.* OFDMA



Multiple Input Multiple Output (MIMO)

- **MIMO systems have multiple (*r*) transmit and receiver antennas**



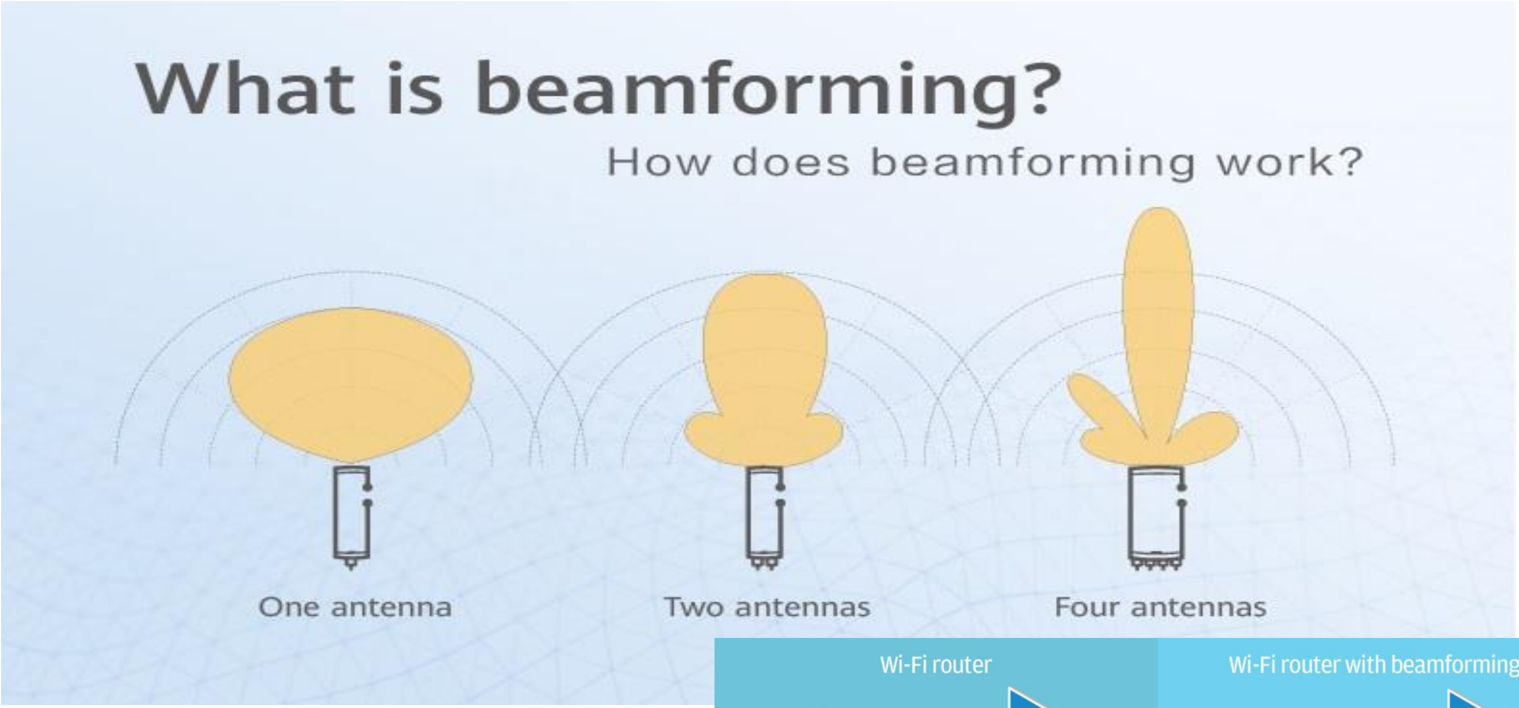
- **With perfect channel estimates at TX and RX, decomposes into *r* independent channels**
  - *r*-fold capacity increase over SISO system
  - Demodulation complexity reduction
  - Can also use antennas for diversity (beamforming)
  - Leads to capacity versus diversity tradeoff in MIMO

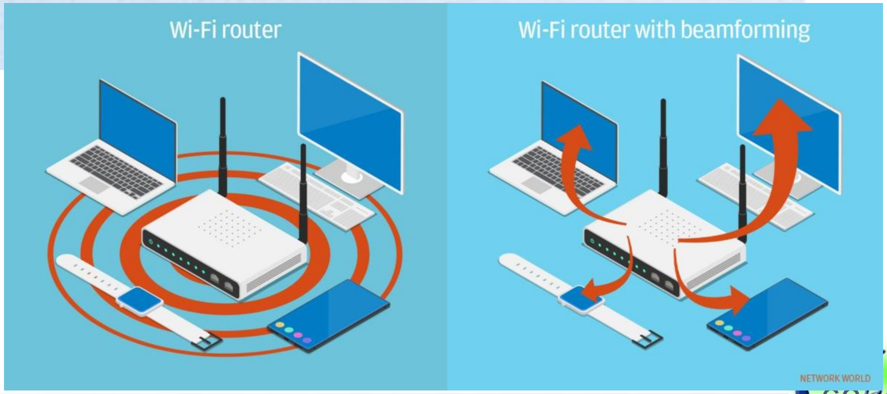
OFDM and MIMO Systems

- Increase channel capacity
  - Between the MIMO access point and the MIMO client, multiple spatial streams can be sent and received at the same time.
  - The channel capacity can increase linearly with the number of antennas.
  - Increase the channel capacity without increasing the bandwidth and antenna transmission power, the spectrum utilization rate can be increased.
- Improve channel reliability
  - Using the spatial multiplexing gain and spatial diversity gain
  - Multiple antennas can be used to suppress channel fading and reduce bit error rate.

Beamforming

- Sensor arrays cause signals at particular angles with constructive interference while others not



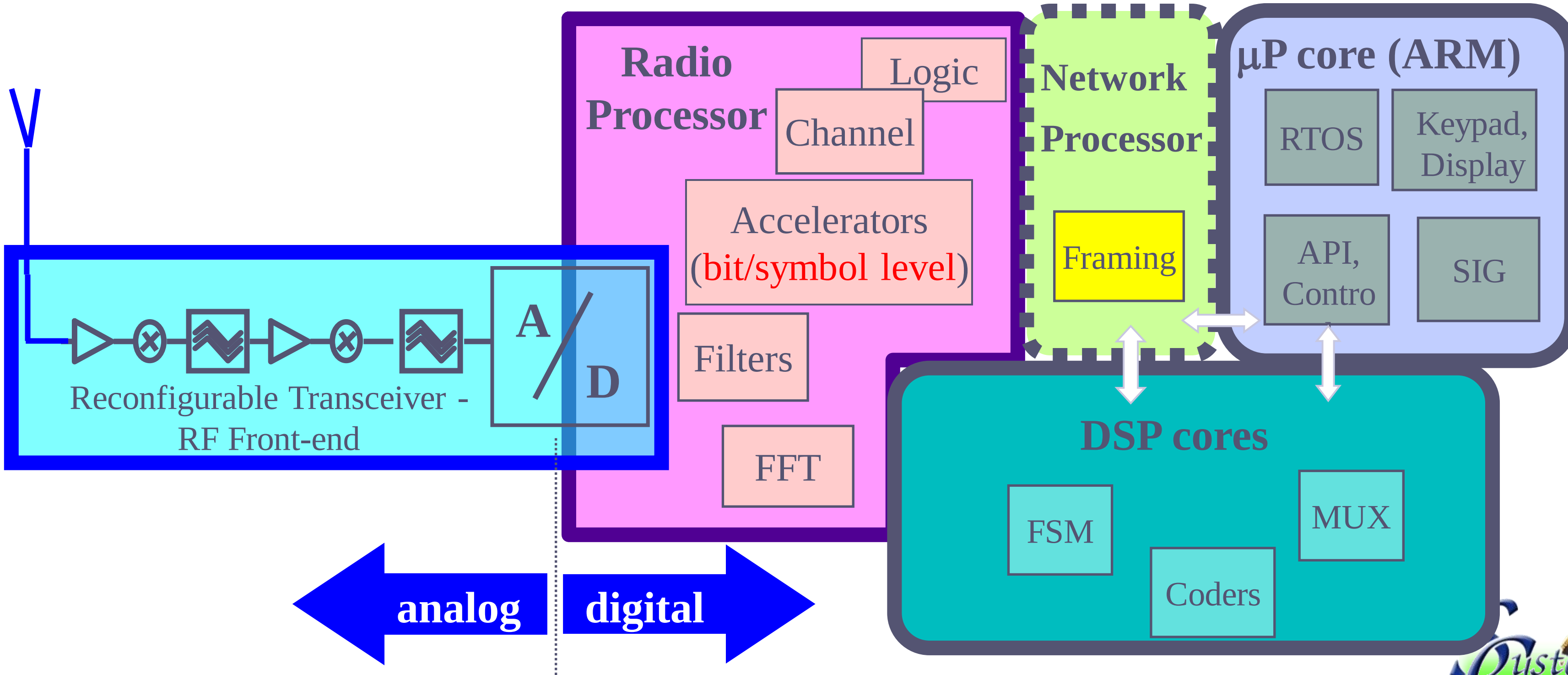


A Unified Wireless Platform

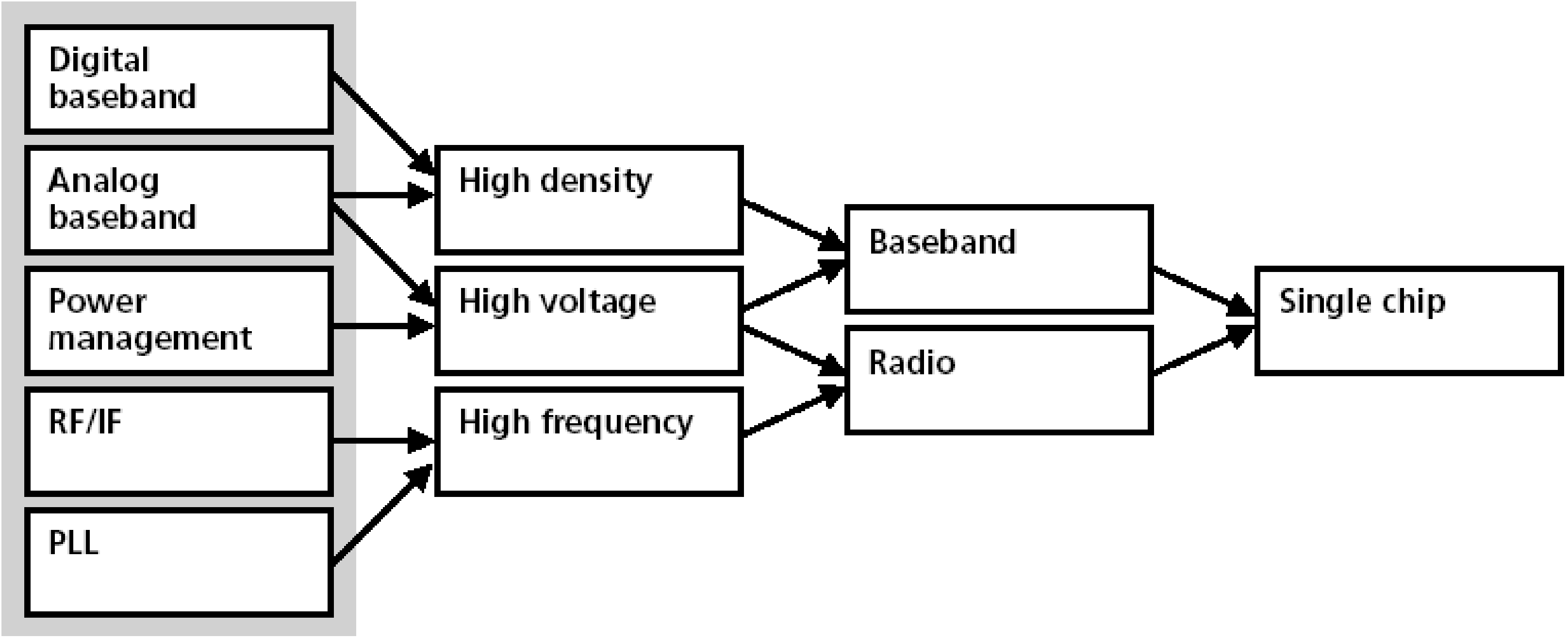
Analog RF Circuits

Communication Algorithms

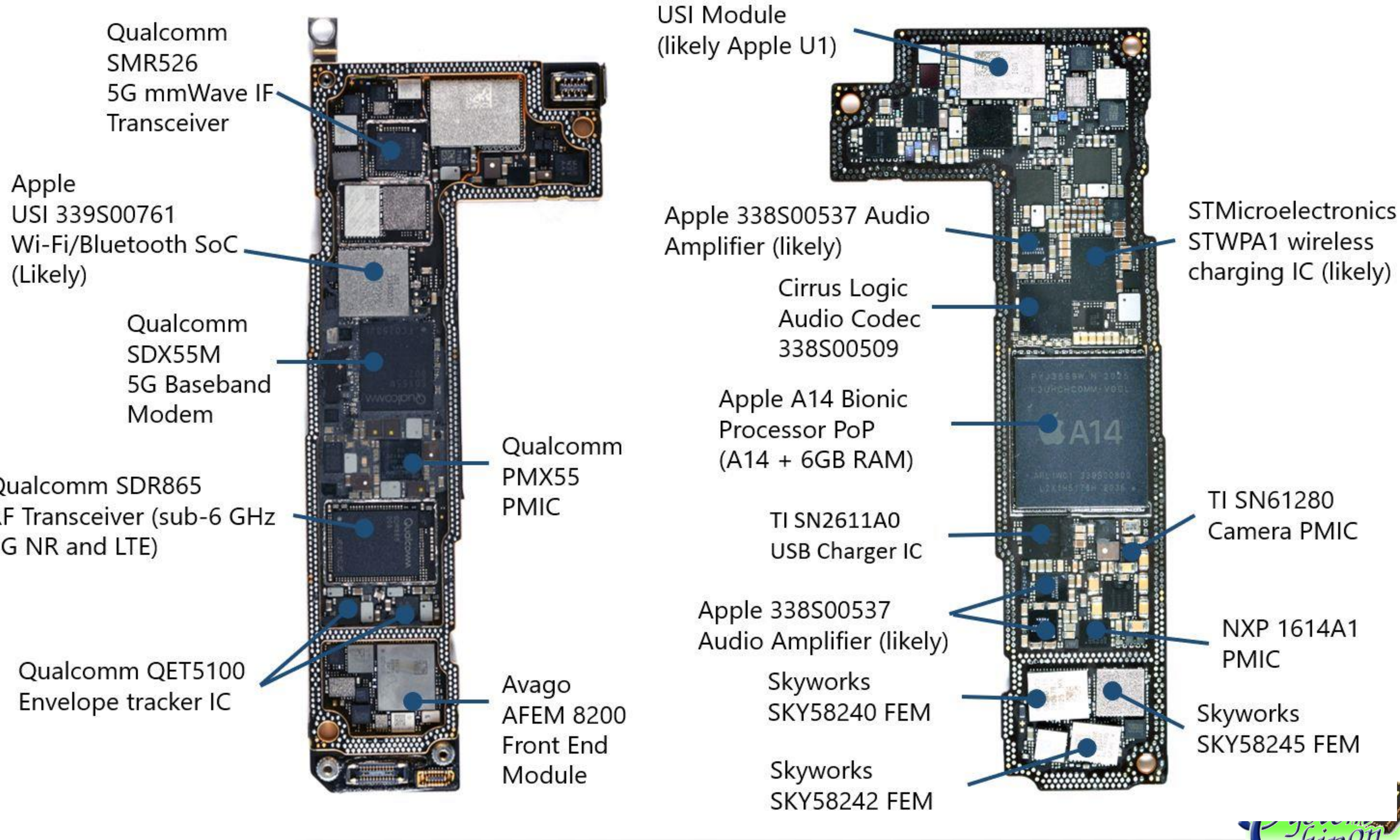
Protocols



Single Chip Approach

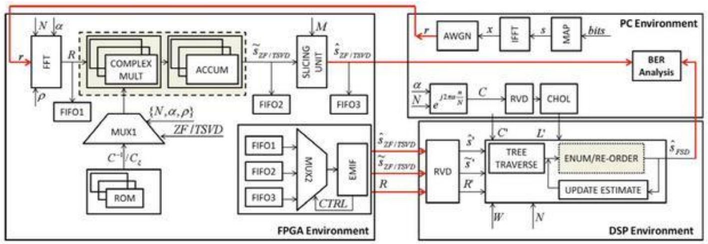


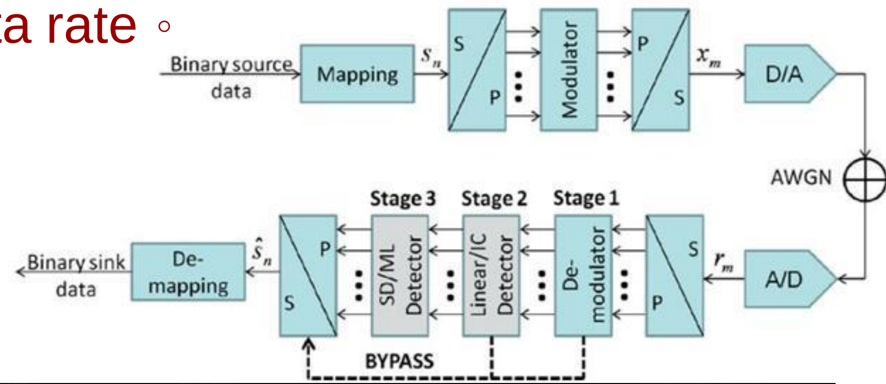
iPhone 12 System



Intel Baseband Processor-Modem

- **Intel PMB9960 (XMM7660)**
  - 3GPP Release 14, LTE Modem。
  - Downlink（Cat 19）supports 1.6 Gbps data rate，
  - Uplink supports 150 Mbps data rate。

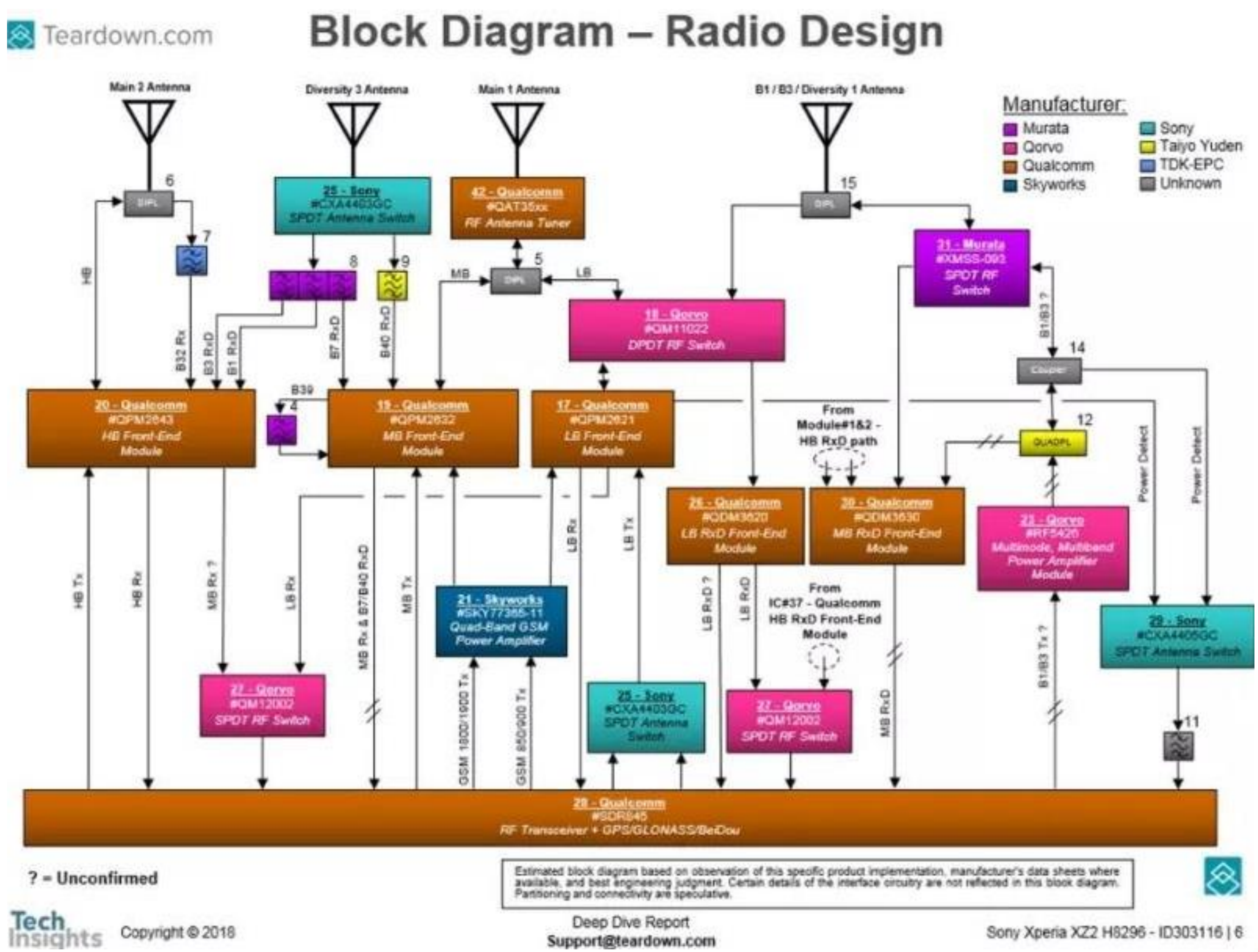




Technical Specifications	
Baseband	Intel® X-GOLD™ 766 baseband
Transceiver	Intel® SMARTi™ 8 RF transceiver
Standards & Performance	3GPP Release 14 LTE FDD/TDD 1.6Gbps/150Mbps LAA Support TD-SCDMA 2.8/2.2 Mbps DC-HSPA+ Cat 24, 42Mbps GNSS – 4 Mode
Transceiver Capabilities	LTE-FDD LTE-TDD UMTS/WCDMA TD-SCDMA CDMA/EVDO GSM/EDGE
Carrier Aggregation	LTE FDD/TDD/Hybrid DL 7CA UL 2CA 4x4 MIMO
Modulation	LTE UL-64QAM; DL-256QAM
RF Bands	More than 45 LTE bands simultaneous; including 3.5GHz/5GHz
SIM Support	LTE/LTE Dual SIM Dual Standby (DSDS)

品牌	Intel	Qualcomm	Qualcomm
處理器	XMM 7560 LTE	Snapdragon X20 LTE	Snapdragon X16 LTE
晶圓製程	14nm Intel	10nmLPE	10nm LPE /14nm LPP
處理器	APPLE A12	Qualcomm S845	Qualcomm S835
LTE類別	LTE CAT.16 (下行)	LTE CAT.18 (下行)	LTE CAT.16 (下行)
	LTE CAT.13 (上行)	LTE CAT.13 (上行)	LTE CAT.13 (上行)
下行功能	5*20 MHz CA	5x20 MHz CA	4x20 MHz CA
	最高256-QAM	最高256-QAM	最高256-QAM
	4X4 MIMO	4x4 MIMO(3CA)	4x4 MIMO(2CA)+2*2(1CA)
	最多10個Downlink Streams	最多12個Downlink Streams	最多10個Downlink Streams
上行功能	3x20Mhz	2x20 MHz CA	2x20 MHz CA
		高達2x 75Mbps LTE流	高達2x 75Mbps LTE流
	最高64-QAM	最高64-QAM	最高64-QAM
		上行鏈路數據壓縮	上行鏈路數據壓縮
峰值下載速度	1 Gpbp	1.2 Gbps	1 Gbps
峰值上傳速度	225 Mbps	150 Mbps	150 Mbps

RF Module



Teardown.com
Block Diagram – Radio Design
Main 2 Antenna
Diversity 3 Antenna
Main 1 Antenna
B1 / B3 / Diversity 1 Antenna
Manufacturer:
Murata
Qorvo
Qualcomm
Skyworks
Sony
Taiyo Yuden
TDK-EPC
Unknown
25 - Sony
#CXA4403GC
SPDT Antenna Switch
42 - Qualcomm
#QAT35xx
RF Antenna Tuner
31 - Murata
#XMSS-093
SPDT RF Switch
18 - Qorvo
#QM11022
DPDT RF Switch
20 - Qualcomm
#QPM2643
HB Front-End Module
19 - Qualcomm
#QPM2632
MB Front-End Module
17 - Qualcomm
#QPM2621
LB Front-End Module
26 - Qualcomm
#QDM3620
LB RxD Front-End Module
30 - Qualcomm
#QDM3630
MB RxD Front-End Module
23 - Qorvo
#RF5420
Multimode, Multiband Power Amplifier Module
21 - Skyworks
#SKY77365-11
Quad-Band GSM Power Amplifier
27 - Qorvo
#QM12002
SPDT RF Switch
25 - Sony
#CXA4403GC
SPDT Antenna Switch
27 - Qorvo
#QM12002
SPDT RF Switch
29 - Sony
#CXA4405GC
SPDT Antenna Switch
28 - Qualcomm
#SDR845
RF Transceiver + GPS/GLONASS/BeiDou
DIPL
Coupler
QUADPL
6
7
8
9
5
4
15
14
12
11
HB
MB
LB
B32 Rx
B3 RxD
B1 RxD
B7 RxD
B40 RxD
B39
B1/B3 ?
From Module#1&2 - HB RxD path
From IC#37 - Qualcomm HB RxD Front-End Module
Power Detect
Power Detect
HB Tx
HB Rx
MB Rx ?
LB Rx
MB Rx & B7/B40 RxD
MB Tx
GSM 1800/1900 Tx
GSM 850/900 Tx
LB Rx
LB Tx
LB RxD ?
LB RxD
MB RxD
B1/B3 Tx ?
? = Unconfirmed
Estimated block diagram based on observation of this specific product implementation, manufacturer's data sheets where available, and best engineering judgment. Certain details of the interface circuitry are not reflected in this block diagram. Partitioning and connectivity are speculative.
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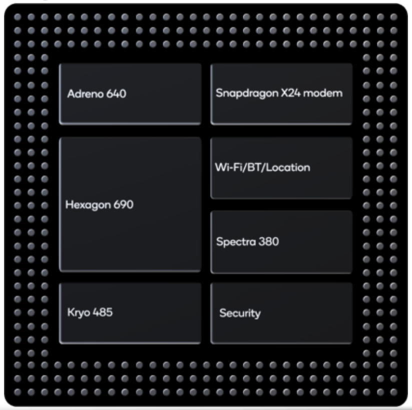
Deep Dive Report
Support@teardown.com
Sony Xperia XZ2 H8296 - ID303116 | 6

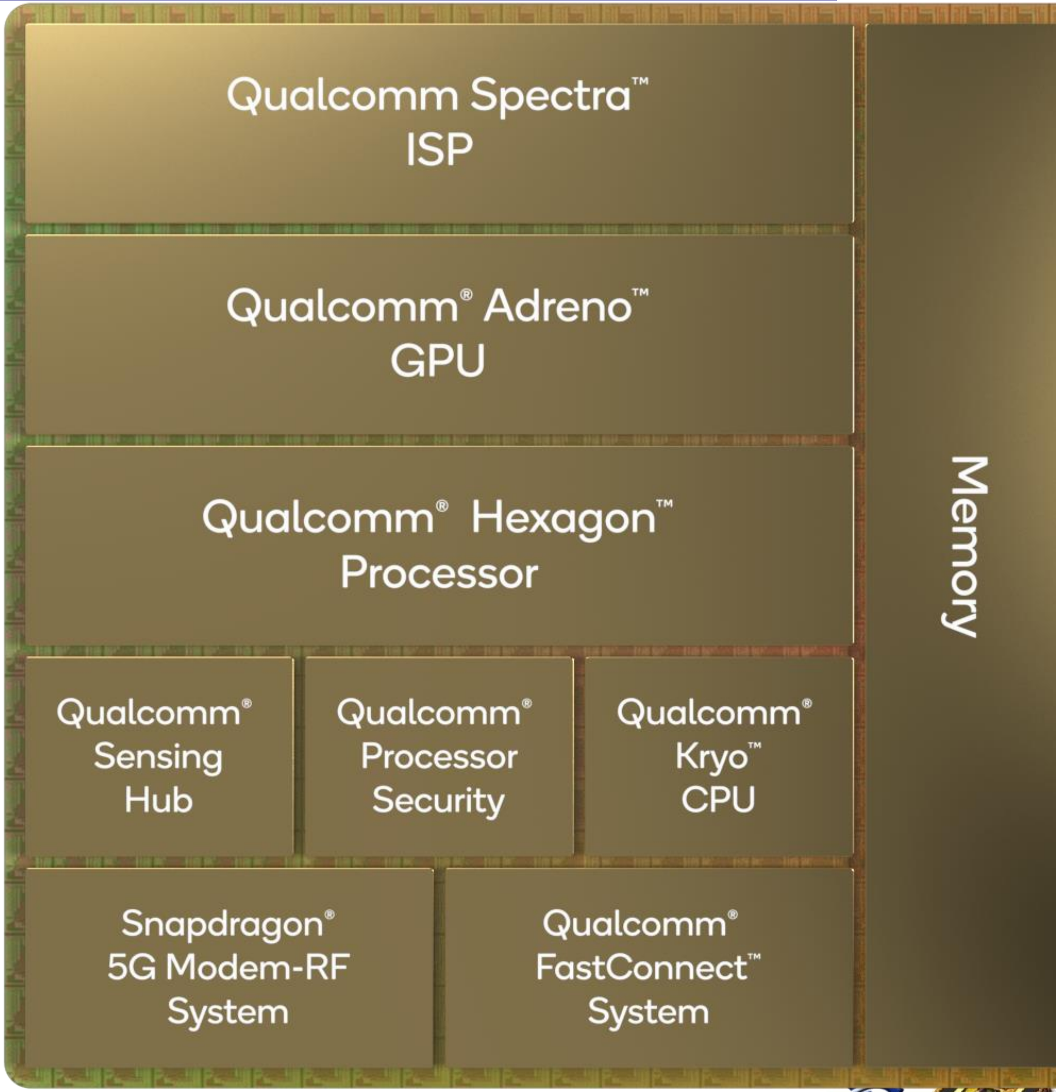
Qualcomm Snapdragon 855

- 64-bit ARM LTE system
- TSMC 7nm process
- Kryo 485 CPU architecture
- The operating clock is
  2.84GHz + 2.42GHz + 1.80GHz
- Adreno 640 GPU
- Hexagon 690 DSP
- Spectra 380 ISP
- Snapdragon X24 LTE、Snapdragon X50 5G



Qualcomm Snapdragon 8 Gen 2

- 5G+5G/4G Dual SIM
- TSMC 4nm process
- Kryo CPU architecture
- The operating clock is 3.2GHz
- Adreno 640 GPU
- Hexagon 690 DSP
- WiFi 7
- 8K HDR at 60fps
- ISP
- Qualcomm AI engine



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- http://www.2cm.com.tw/technologyshow_content.asp?sn=1403210010
- http://www.rajar.co.uk/
- https://read01.com/43mo4Q.html
- http://cacafly.com/?p=10230
- http://www.taiwanradio.org.tw/modules/tinyd2/index.php?id=3
- http://b048.hcu.edu.tw/ezcatfiles/b048/img/img/425/CIC0106.pdf