RF Communication Circuit Design

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Syllabus

1. Introduction to Wireless Systems (2)
2. Resonators and Impedance Matching (3)
3. Small-Signal Amplifiers (3)

Midterm (1)

4. Noise and Distortion in Microwave System (3)
5. Low Noise and Power Amplifiers (2)
6. Oscillators and Mixers (3)

Final (1)

❖ Textbook

- D.M. Pozar, Microwave Engineering, 3rd Ed., John Wiley & Sons, Inc. 2005. (總經銷商：台北市歐亞書局；02-89121188)

❖ References

- D.M. Pozar, Microwave and RF Design of Wireless Systems, John Wiley & Sons, Inc. 2000.
- T.C. Edwards, Foundations of Interconnect and Microstrip Design, 3rd Ed
- C. Bowick, RF Circuit Design
- R. Ludwig and P. Bretchko, RF Circuit Design
- G. Gonzalez, Microwave Transistor Amplifiers, 2nd Ed
- S.C. Cripps, RF Power Amplifiers for Wireless Communication

❖ Prerequisite

- Circuit Theory, Electronics, Electromagnetics
- Microwave Engineering, Communication System

❖ Grading

- Midterm 50% (After Chap 3, Open book w/o solutions manual)
- Final 50% (After Chap 6, Open book w/o solutions manual)
- 4 Quizs 20% (After Chaps 1,2,4,5, Closed book w/ 1 A4 paper)

❖ Covering for exams

- 1st quiz : Lecture note §1, Textbook §2, §3(1-3,5,7,8), §13(2-6)
- 2nd quiz: Lecture note §2, Textbook §2, §4(1-5), §5(1-3), §6(1,2,6)
- Midterm: Lecture note §1-3, Related content in textbook and refs
- 3rd quiz: Lecture note §4, Textbook §10(1,2), §13(1,2)
- 4th quiz: Lecture note §5, Textbook §11(3,5)
- Final: Lecture note §4-6, Related content in textbook and refs

等第制成績 (Grade)	等第積分 Grade Point	百分制分數區間 （小數點第一位四捨五入至整數）	系統百分制分數 （建議老師打百分時，採此欄之分數）
A+	4.3	90~100	95
A	4.0	85~89	87
A-	3.7	80~84	82
B+	3.3	77~79	78
B	3.0	73~76	75
B- （研究生及格標準）	2.7	70~72	71
C+	2.3	67~69	68
C	2.0	63~66	65
C- （學士班及格標準）	1.7	60~62	61
D	1.0	50~59	55
E	0.8	40~49	45
F	0	39（含）以下	20
X	0	0	0

A+：所有目標皆達成且超越期望

A：所有目標皆達成

A-：所有目標皆達成，但需一些精進

B+：達成部分目標，且品質佳

B：達成部分目標，但品質普通

B-：達成部分目標，但有些缺失

C+：達成最低目標

C：達成最低目標，但有些缺失

C-：達成最低目標但有重大缺失

D：未達成最低目標

E：未達成最低目標，且令人失望

F：所有目標皆未達成

X：因故不核予成績

（例如考試全部 0 分、考試作弊 0 分、缺課達二分之一學期 0 分、操行 0 分等等）

Chapter I

Introduction to Wireless Systems

Outline

1. Wireless Systems
2. Design and Performance Issues
3. Wireless System Components

1. Wireless Systems

❖ Classification of Wireless Systems

- Wireless System – A system allows the communication of information between two points without the use of a wired connection.
- Media – include ultrasonic, infrared, optical, and radio-frequency (RF)

Comparison	Data rate	Immunity to interference	Propagation being blocked
Ultrasonic	low	poor	Difficult but low velocity
Infrared and optical	high	good	easy
RF	Moderate to high	Moderate to good	difficult

❖ RF History

- J.C. Maxwell (1831-1879) built up the EM theory.
- H. Hertz (1857-1894) verified the EM propagation along wire experimentally.
- G. Marconi (1874-1937) invented the idea of wireless communication and developed the first practical commercial radio communication system.
- E.H. Armstrong (1890-1954) invented superheterodyne architecure and frequency modulation (FM).

❖ Categorization of Wireless Systems

1. According to the nature and placement of users

- Point-to-point: microwave link
- Point-to-multipoint: AM and FM broadcast, TV broadcast, paging, GPS, TVRO, VSAT, LMDS
- Multipoint-to-multipoint: cellular, WLAN

2. According to directionality of communication

- Simplex: Communication occurs in one direction, e.g. broadcast radio and TV, paging, GPS, TVRO
- Half-duplex: Communication occurs in two directions, but not simultaneously, e.g. Walky Talky, Ham radio, Trunk radio
- Full-duplex: Communication occurs in two directions simultaneously, e.g. cellular, microwave link, LMDS, cellular, WLAN, VSAT. It requires a duplexing technique to avoid interference between transmitted and received signal, e.g. FDD, TDD.

❖ Major Worldwide Cellular and PCS Telephone Systems

- 1st generation: Analog modulation (FM) and frequency division multiple access (FDMA), e.g. AMPS, NMT, NTT.
- 2nd generation: Digital modulation and time- or code-division multiple access (TDMA, CDMA) , e.g. PCS, GSM, PDC.
- 3rd generation: Digital modulation and code-division multiple access, e.g. W-CDMA, CDMA-2000.
- Beyond 3rd generation: Digital modulation and orthogonal frequency division multiplexing (OFDM), e.g. WiMAX, LTE.

❖ Wireless System Frequencies

Wireless System	Operating Frequency
Advanced Mobile Phone Service (AMPS)	T: 824–849 MHz R: 869–894 MHz
Global System Mobile (European GSM)	T: 880–915 MHz R: 925–960 MHz
Personal Communications Services (PCS)	T: 1710–1785 MHz R: 1805–1880 MHz
US Paging	931–932 MHz
Global Positioning Satellite (GPS)	L1: 1575.42 MHz L2: 1227.60 MHz
Direct Broadcast Satellite (DBS)	11.7–12.5 GHz
Wireless Local Area Networks (WLANs)	902–928 MHz 2.400–2.484 GHz 5.725–5.850 GHz
Local Multipoint Distribution Service (LMDS)	28 GHz
US Industrial, Medical, and Scientific bands (ISM)	902–928 MHz 2.400–2.484 GHz 5.725–5.850 GHz

T/R = mobile unit transmit/receive frequency.

❖ Major Worldwide Cellular and PCS Telephone Systems

Standard	Country	Year of Introduction	Type	Frequency Band (MHz)	Modulation	Channel Bandwidth
NTT	Japan	1979	Cellular	860–940	FM	25 kHz
NMT-450	Europe	1981	Cellular	453–468	FM	25 kHz
AMPS	United States	1983	Cellular	824–894	FM	30 kHz
E-TACS	Europe	1985	Cellular	872–950	FM	25 kHz
C-450	Germany	1985	Cellular	450–466	FM	20 kHz
NMT-900	Europe	1986	Cellular	890–960	FM	12.5 kHz
JTACS	Japan	1988	Cellular	860–925	FM	25 kHz
GSM	Europe	1990	PCS	890–960	GMSK	200 kHz
IS-54	United States	1991	PCS	824–894	DQPSK	30 kHz
NAMPS	United States	1992	Cellular	824–894	FM	10 kHz
IS-95	United States	1993	PCS	824–894	QPSK	1.25 MHz
PDC	Japan	1993	Cellular	810–1513	DQPSK	25 kHz
NTACS	Japan	1993	Cellular	843–922	FM	12.5 kHz

❖ International Digital PCS System Standards at 900 MHz

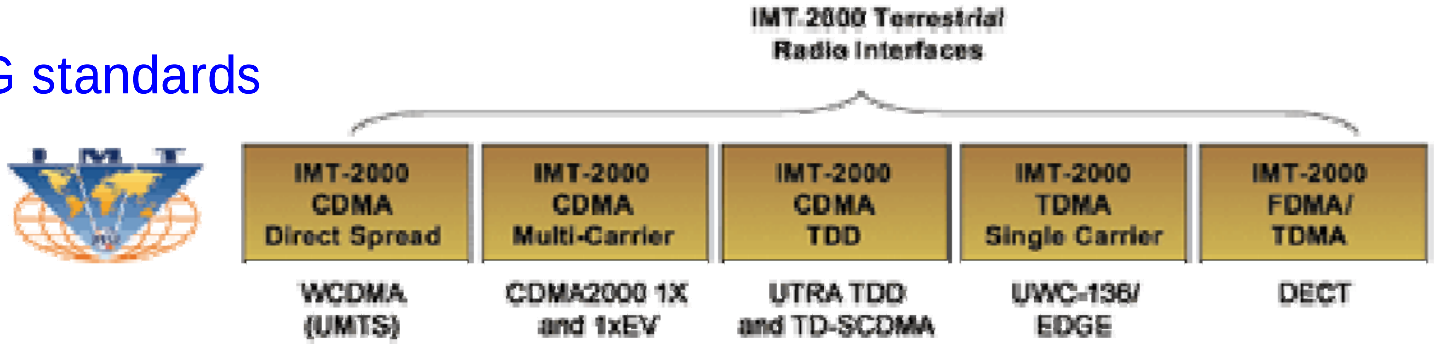
PCS System	IS-54/IS-136	IS-95	GSM
Transmit Frequency (RVC)	824–849 MHz	824–849 MHz	890–915 MHz
Receive Frequency (FVC)	869–894 MHz	869–894 MHz	935–960 MHz
Duplexing Method	FDD	FDD	FDD
Multiple Access Method	TDMA	CDMA	TDMA
Channel Bandwidth	30 kHz	1.25 MHz	200 kHz
Modulation	QPSK	QPSK	GMSK
Channel Bit Rate	48.6 kbps	1,228.8 kbps	270.833 kbps
Users per Channel	3	64	8
User Bit Rate	8 kbps	1.2–9.6 kbps	13 kbps
Number of Users	2,496	15,960	992

- Interim Standard (IS) are communication standards that have been agreed upon by members of the Telecommunications Industry Association (TIA).

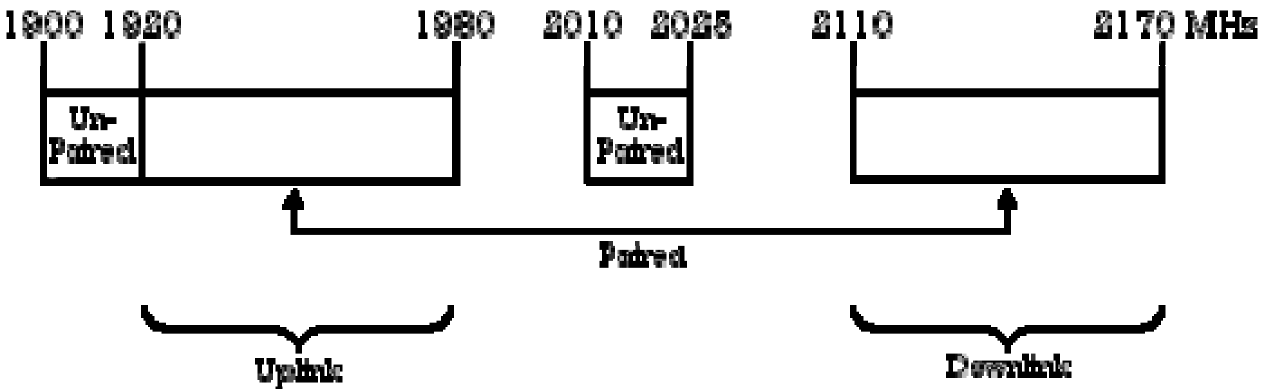
❖ 3G Systems

IMT-2000 is the term used by the International Telecommunications Union (ITU) for a set of globally harmonized standards for third generation (3G) systems. The main frequency bands for IMT-2000 are 1885-2025 MHz and 2110-2200 MHz. Some additional bands are 806-960 MHz, 1710-1885 MHz and 2500-2690 MHz.

3G standards



W-CDMA (UMTS) band



❖ WiMAX and LTE Systems

Beyond 3G (B3G) is a term used to describe the next complete evolution in wireless communications. A B3G system will be able to provide a comprehensive IP solution where voice, data and streamed multimedia can be given to users on an "Anytime, Anywhere" basis, and at higher data rates than previous generations. The examples include: 1. **WiMAX** - Worldwide Interoperability for Microwave Access 2. **LTE** – Long Term Evolution.

	WiMAX 802.16e	WiMAX 802.16m	LTE
Network Equipment Availability	2007	2010	2009
Handset Availability	2008	2011	2010
Standard Body	IEEE & WiMAX Forum	IEEE & WiMAX Forum	3GPP
Spectrum band Plan	TDD	TDD, FDD	FDD
Frequency*	2300, 2500, 3300 3500, 3700	Under 6 GHz TBD	700, 850, 900, 1800 1900, 2100, 2500
Channel Bandwidth	3.5, 5, 7,8.75,10 MHz	Scalable bandwidth 5 – 20 MHz TBD	1.4,1.6,3.5.10.15.20 MHz
Channel Throughput	~3.5 Mbps / Hz downlink *35 Mbps, 1 Sector, 10 MHz channel*	~5.0 Mbps / Hz downlink *50 Mbps, 1 Sector, 10 MHz channel*	~5.0 Mbps / Hz downlink *50 Mbps, 1 Sector, 10 MHz channel*
Spectrum Type	Licensed		
Radio Technology DL	Scalable OFDMA		
Radio Technology UL	Scalable OFDMA		
Antennas	MIMO & Advanced Antenna Techniques		
Core Technology	Flat, All IP		
Application Layer	IMS		
IPR	More distributed than existing 3GPP & 3GPP2 networks		
Application	VoIP, Data, Video		
Terminal Variety	Fixed CPE, Mobile handsets, Data Cards, Consumer Electronics		
User Plane Latency	<20 ms	<5 ms	<5 ms
Control Plane Latency	<100 ms	<100 ms	<100 ms

❖ Commercial Wireless Satellite Systems

System	Organization	Number of Satellites	Orbit	Operational Date
INMARSAT-M	Inmarsat	5	GEO	1996
MSAT	AMSC, TMI	2	GEO	
Iridium	Motorola	66	LEO	1998
Globalstar	Loral, Qualcomm	48	LEO	2000
ICO Global	Hughes	10	MEO	2000
Odyssey	TRW	12	MEO	2000

- Advantages over cellular systems: Capability to cover any location on earth including oceans, deserts and mountains.
- Disadvantages: It requires high-transmit power, high-gain antenna, and line-of-sight path for mobile users because of weak received-signal level.
- GEO: Geosynchronous Earth Orbit, applications like VSATs.
- LEO: Low Earth Orbit, applications like satellite telephones.
- MEO: Medium Earth Orbit, applications like mobile communications, GPS.

❖ Wireless Local Area Networks (WLANs)

- WLANs – provides connections between computers over short distances.
- Operating in the Industrial, Scientific, and Medical (ISM) bands.
- Examples like IEEE 802.11, HIPERLAN, Bluetooth and Zigbee.

❖ Ultra-Wideband (UWB)

- UWB – is a technology for transmitting information spread over a large bandwidth (>500 MHz or 20% of the center frequency) that should, in theory and under the right circumstances, be able to share spectrum with other users.
- Federal Communications Commission (FCC) authorizes the unlicensed use of UWB in the range of 3.1 to 10.6 GHz.
- Main application is in Wireless Personal Area Network (WPAN) based on IEEE802.15 standard, while a rival technology, 60 GHz WPAN, is catching up.

❖ Radio Frequency Identification (RFID)

- RFID systems – are used to examine personal ID information wirelessly in inventory tracking, shipping, toll collection, personal security access, etc.
- Operating in the ISM band.
- Comparison with barcode reader:

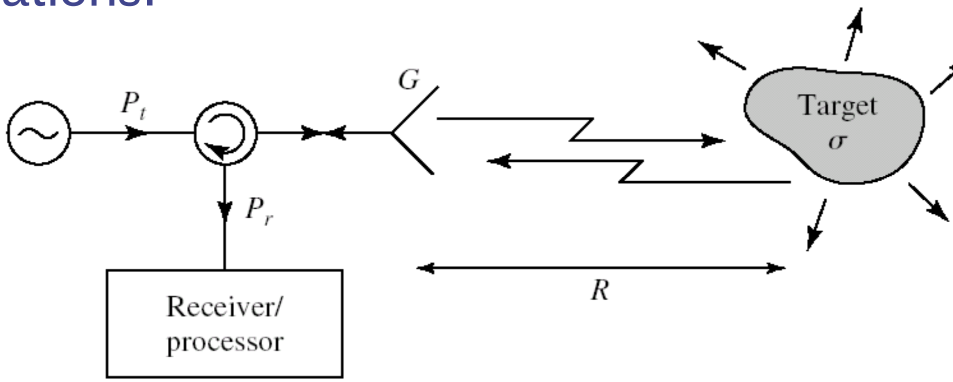
parameters		Data density	Influence of dirt/covering	Influence of direction	Reading speed	Maximum distance	cost
Barcode		low	high	limited	low	short	low
RFID		high	No influence	No influence	fast	long	high

❖ Radar systems

- Radar – or Radar Detection And Ranging, is one of the most conventional applications of microwave technology. In its basic operation, a transmitter sends out a signal which is partly reflected by a distant target, and then detected by a sensitive receiver.

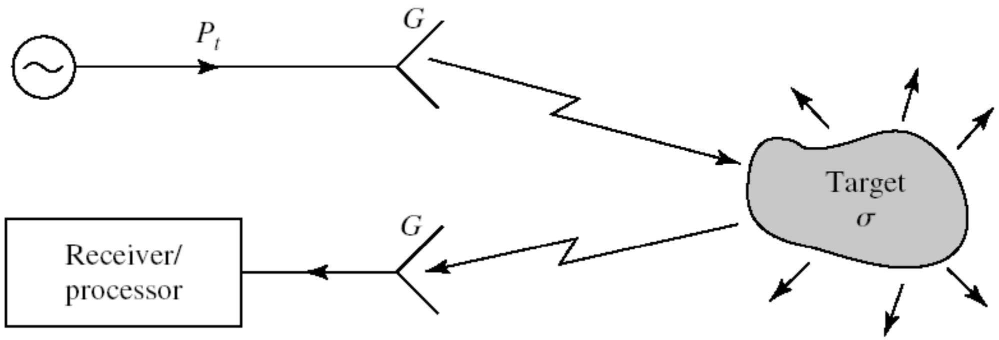
- Pulse radar – is used to determine target distance by measuring the round-trip time of a pulse microwave signal.
- Doppler radar – is used to determine target speed by measuring the Doppler frequency shift.
- Synthetic-aperture radar (SAR) - is a form of pulse radar attached to an aircraft or satellite for remote sensing (radar image processing) applications.

Monostatic radar system



(a)

Bistatic radar system



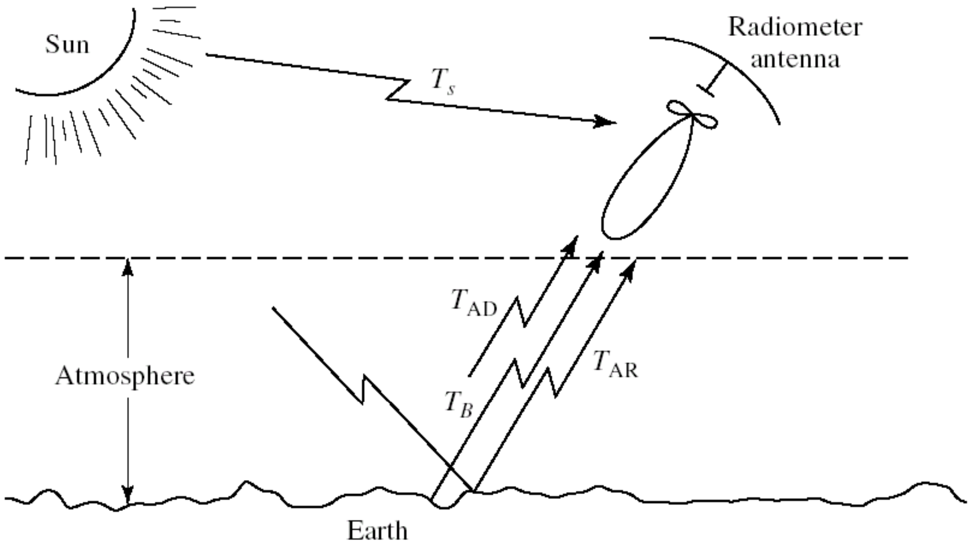
(b)

- Radar cross section (RCS) – is used to characterize a radar target and defined as the ratio of scattered power to incident power density ($= P_s / S_t$). The RCS of a target depends on the frequency and polarization of the incident wave, and on the incident and reflected angles relative to the target.

Target	**(m^2)**
Bird	0.01
Missile	0.5
Person	1
Small plane	1-2
Bicycle	2
Small boat	2
Fighter plane	3-8
Bomber plane	30-40
Large airliner	100
Truck	200

❖ Radiometer System

- Radiometer – is a passive radar based on a sensitive receiver to develop information about a target solely from the microwave portion of the blackbody radiation (noise) that it either emits directly or reflects from surrounding bodies.
- Environmental applications include measurement of soil moisture, flood mapping, snow/ice cover mapping, ocean surface windspeed, atmospheric temperature/humidity profile, etc.
- Astronomy applications include planetary mapping, solar emission mapping, galactic object mapping, measurement of cosmological background radiation. etc.



2. Design and Performance Issue

❖ Choice of Operating Frequency

➢ Availability of spectrum

Radio and Microwave Frequency Bands:

Medium frequency (MF)	300 kHz to 3 MHz
High frequency (HF)	3 MHz to 30 MHz
Very high frequency (VHF)	30 MHz to 300 MHz
Ultra high frequency (UHF)	300 MHz to 3 GHz
L band	1–2 GHz
S band	2–4 GHz
C band	4–8 GHz
X band	8–12 GHz
Ku band	12–18 GHz
K band	18–26 GHz
Ka band	26–40 GHz

Commercial Radio and Television Frequencies:

AM broadcast radio	535–1605 kHz
FM broadcast radio	88–108 MHz
VHF television (channels 2–4)	54–72 MHz
VHF television (channels 5–6)	76–88 MHz
UHF television (channels 7–13)	174–216 MHz
UHF television (channels 14–83)	470–890 MHz

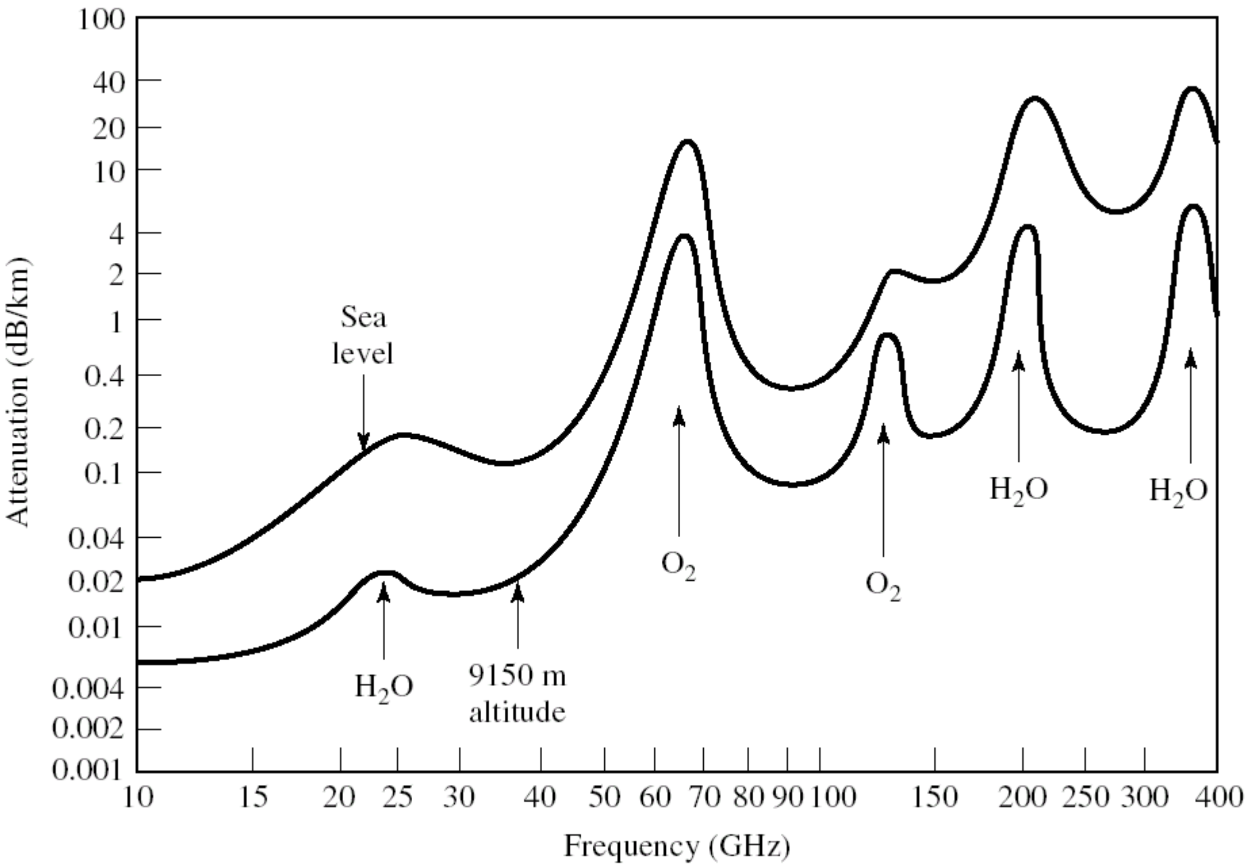
Other system frequencies:

AMPS (mobile unit)	824–849 MHz (T), 869–894 MHz (R)
European GSM (mobile unit)	880–915 MHz (T), 925–960 MHz (R)
PCS (mobile unit)	1710–1785 MHz (T), 1805–1880 MHz (R)
Paging	931–932 MHz
GPS	1575 MHz (L1), 1227 MHz (L2)
DBS	11.7–12.5 GHz
ISM bands	902–928 MHz
	2.400–2.484 GHz
	5.725–5.850 GHz

- Noise – (1) increases sharply at frequencies below 100 MHz due to lightning, ionospheric ducting, engine ignition, EMI from consumer electrical equipments, etc, and (2) increases steadily at frequencies above 10 GHz due to thermal noise of the atmosphere and interstellar radiation.
- Antenna gain – increases with frequency for a fixed antenna size.
- Bandwidth: High data rate requires a correspondingly high RF bandwidth, which is easier to obtain at high frequencies than at low frequencies.
- Cost: Operation at high frequencies requires higher cost because (1) the gain and efficiency of RF transistors decrease with frequency and (2) component cost increases with frequency.
- Propagation characterisitics: At lower frequencies, signals have lower path loss and can more easily pass through or around obstructions than at higher frequencies.

- Atmospheric effects: At frequencies below 10 GHz, the atmosphere has little attenuation effect on the strength of a signal. In some instance the system frequency may be chosen at a point of maximum atmospheric attenuation. An example is the 60 GHz WPAN.

Average atmospheric attenuation versus frequency



❖ Multiple Access and Duplexing

- Multiple access methods - include FDMA, TDMA, CDMA, etc, and are used to accommodate as many simultaneous users as possible.
- Duplexing: FDD provides more isolation between transmitter and receiver than TDD. FDD with half-duplex can achieve better isolation than FDD with full-duplex.

❖ Circuit Switching versus Packet Switching

- Circuit switching networks - are used often in hardwired and wireless telephone systems that provide a direct physical circuit between the communication parties for the duration of call.
- Packet switching networks – are used often in internet and data communication systems that divide messages and data into packets of fixed length and can provide multiple paths to send these packets between any two points in the network.
- Circuit switching networks have better QoS but lower efficiency in comparison with packet switching networks.

❖ Propagation

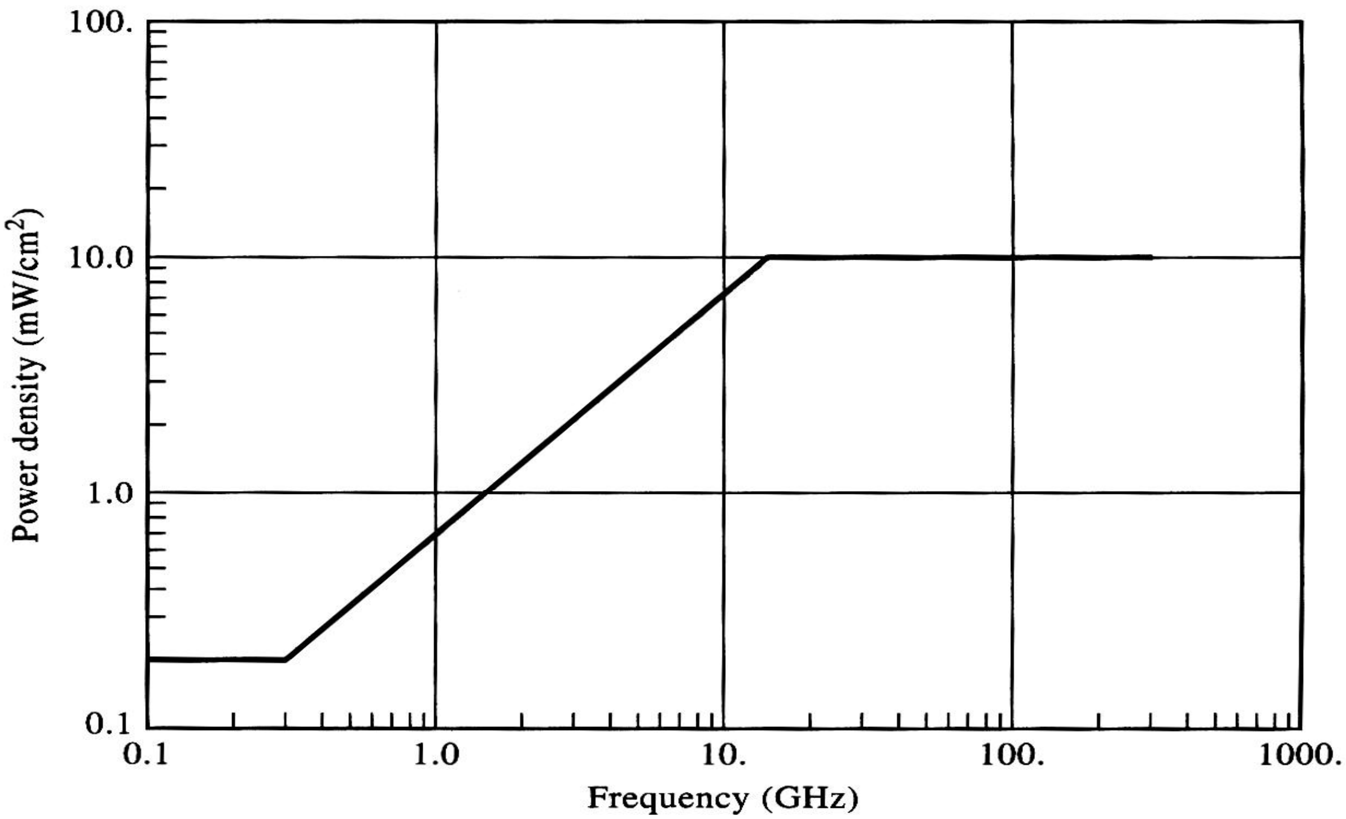
- Multiple-path reflection – can cause rapid variations in the amplitude of the received signal over relatively short distances or time intervals. These effects are referred to as fading.
- Many of the most sophisticated techniques used in wireless communications have been developed primarily to alleviate the fading effects. These include spread spectrum techniques, the use of antenna diversity, sophisticated modulation methods, and error-correcting codes, etc.

❖ Radiated Power and Safety

- The human body absorbs RF and microwave energy and converts it to heat. Such microwave heating is most dangerous in the brain, eyes, genitals, and stomach organs.
- The recommended safe power density limit is lower at lower frequencies because EM fields penetrate the human body more easily at lower frequencies than at higher frequencies.

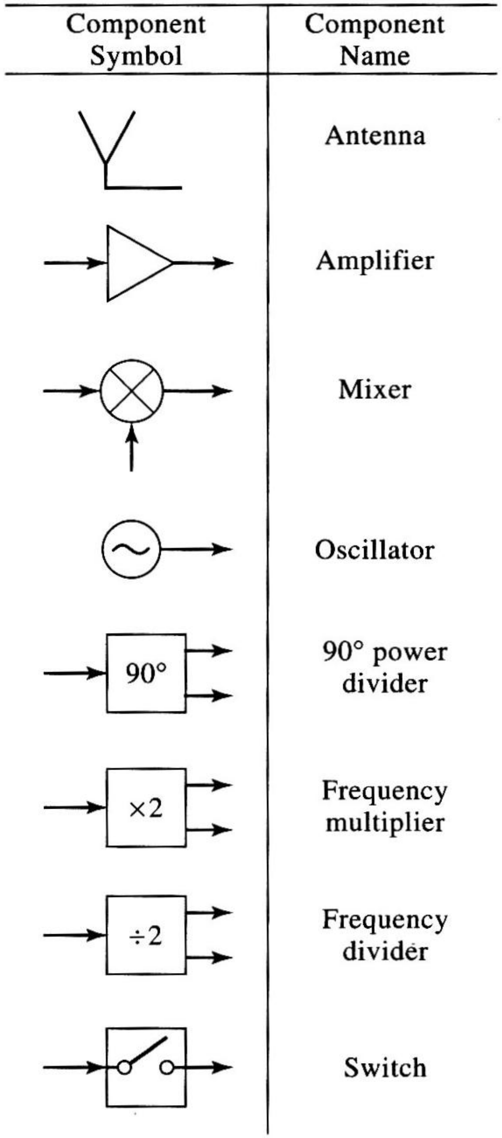
- The recommended safe power density limit is higher at higher frequencies because most of the power absorption at high frequencies tends to occur near the skin surface.
- The sun radiates a power density as high as 100 mW/cm^2 on a clear day.

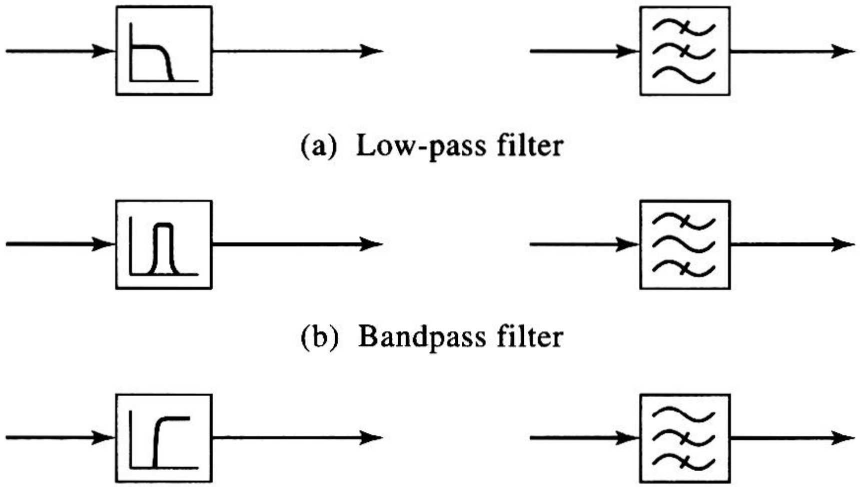
IEEE Standard C95.1



3. Wireless System Components

❖ Commonly Used Symbols of RF Components



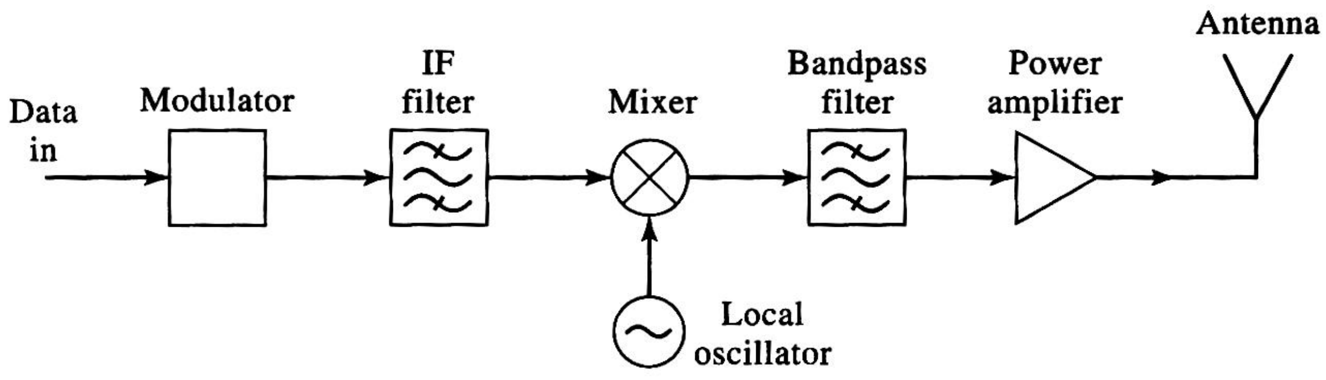


(a) Low-pass filter

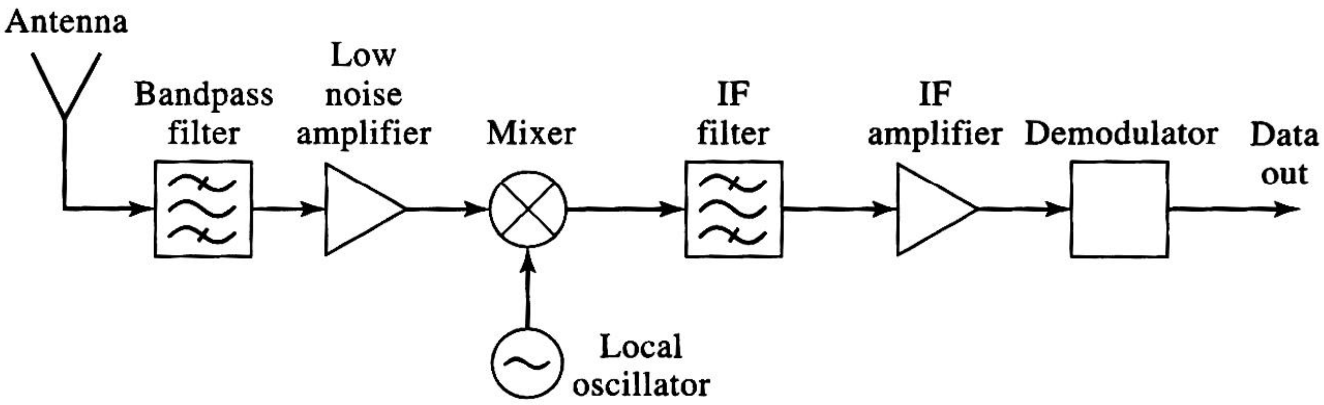
(b) Bandpass filter

(c) High-pass filter

❖ Block Diagram of a Basic Radio System



(a) Transmitter



(b) Receiver

- This architecture was first called superheterodyne and patented in 1917 by Armstrong.

❖ Antennas

- Important characteristics – include operating frequency, size, and gain.

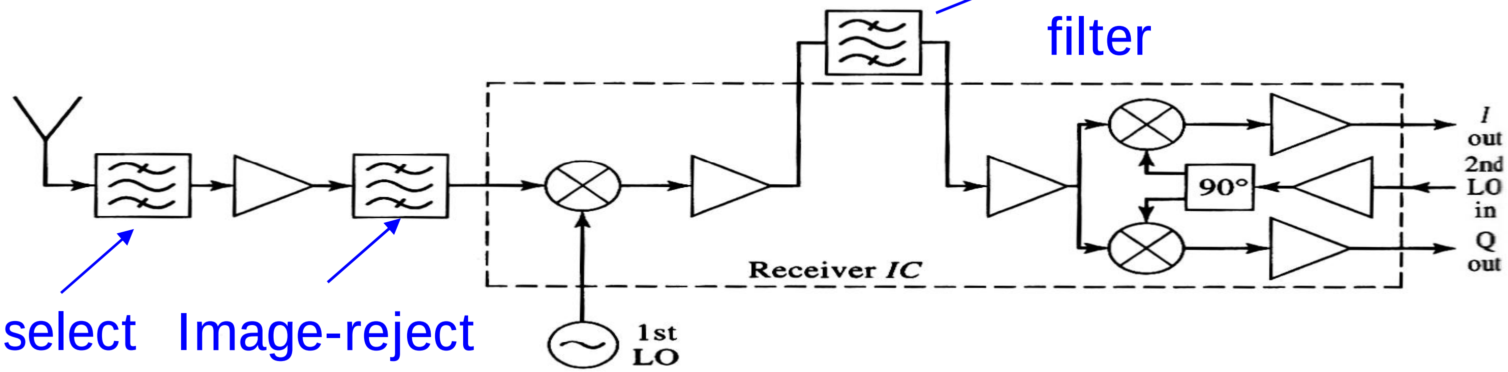
$$G_D(\theta,\phi) = \frac{4\pi}{\lambda^2} A_e(\theta,\phi)$$

- Low-gain antennas: Examples include dipoles, monopoles, and whip antennas. Their radiation patterns are nearly omni-directional.
- High-gain antennas: Examples include reflector antennas (parabolic disk) and patch arrays. Their radiation patterns are highly directional.
- Smart antennas: Examples include phased arrays and adaptive arrays. Their main beams of radiation patterns can be changed electronically.

❖ Filters

- Important parameters – include cut-off frequency, insertion loss, out-of-band attenuation rate (skirt factor).
- Low integrability with IC: For example, in a GSM RF module the band-select, image-reject, and channel-select filters are usually off-chip components.

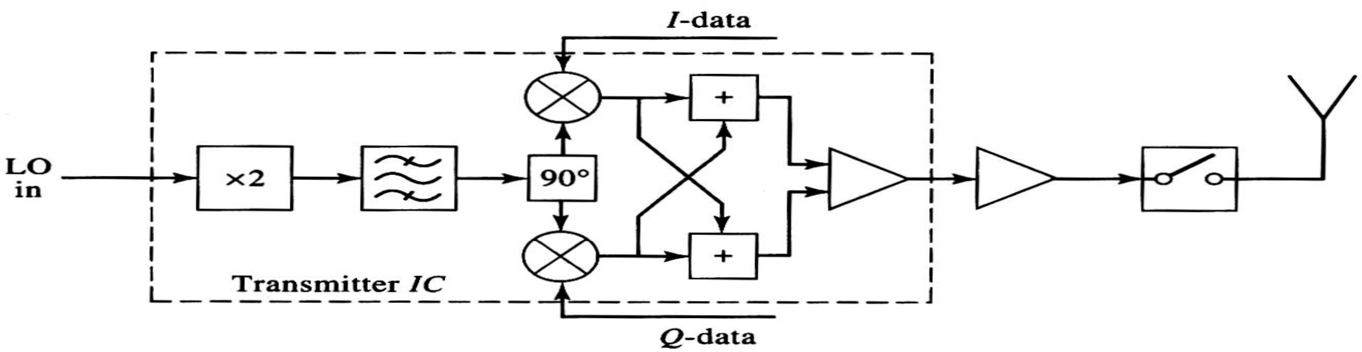
Channel-select filter



Band-select filter

Image-reject filter

(a) GSM 900 MHz Receiver



(b) GSM 900 MHz Transmitter

- Dielectric Resonator (DR) band-pass filters – are dominant in use at RF and microwave frequencies for selecting the receive or transmit frequency range. They have features of moderately sharp cut-off (high Q), low insertion loss, and small size.
- Surface Acoustic Wave (SAW) band-pass filters – are dominant in use at intermediate frequency (IF) for selecting the channel frequency range. They have features of extremely sharp cut-off but high insertion loss.
- Waveguide resonator band-pass filters – are dominant in use at millimeter-wave frequencies. They have features of sharp cut-off and extremely low insertion loss but relatively large size and high cost.

❖ Amplifiers

- Three main categories: Low-noise amplifiers, power amplifiers, and high-gain amplifiers.
- Important parameters – include power gain, noise figure, intercept points, low dc supply voltage and power consumption.
- Advanced semiconductor technologies for RF amplifiers include Si, GaAs, and SiGe.

Mixers

- A mixer is a three-port component that performs frequency conversion to ideally form the sum and difference frequencies from two sinusoidal inputs.
- Two main categories: Passive (diode) mixers and active (transistor) mixers
- Important parameters – include conversion loss/gain, noise figure, intercept points, port-to-port isolation, low dc supply voltage and power consumption.

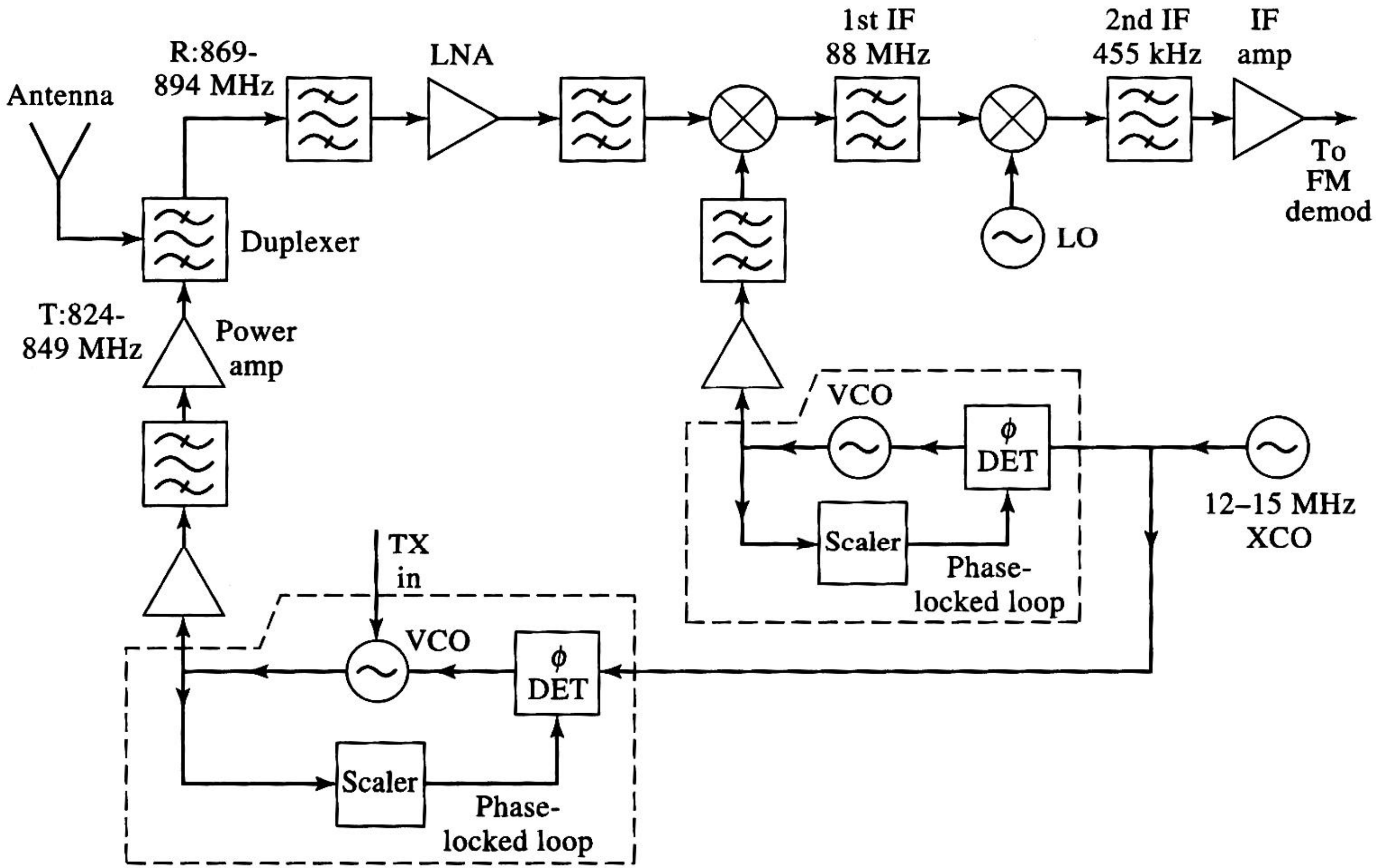
Oscillators

- An oscillator is constructed by active component (transistor) to provide the power of oscillation and passive component (resonator) to select the frequency of oscillation.
- Choice of resonator – includes LC tank and crystal.

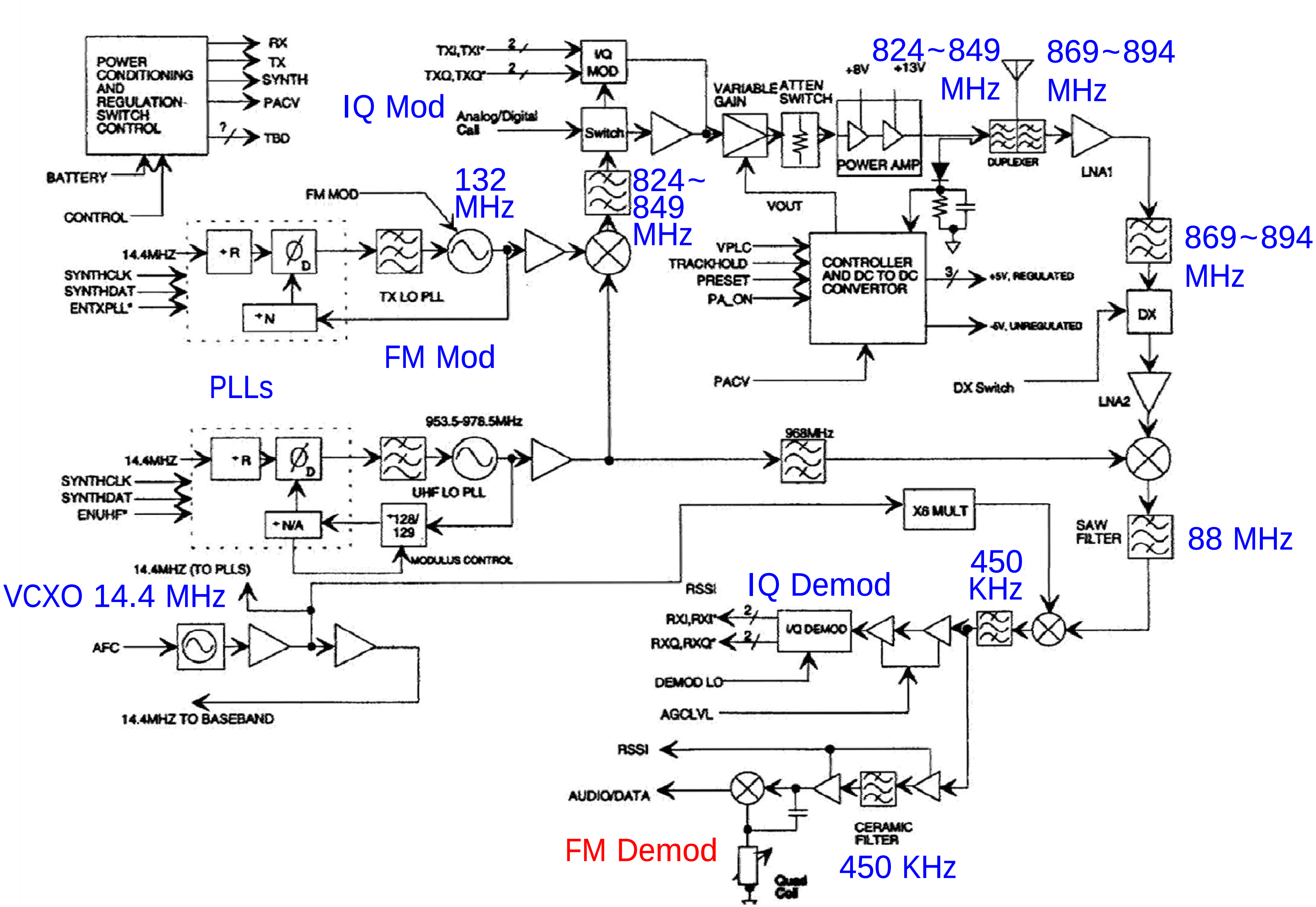
Resonator	Advantages	Disadvantages
LC tank	Wide tuning range	Output frequencies are very susceptible to variations in temperature, supply voltage, and load impedance.
Crystal	Very accurate and stable output frequencies	Very narrow tuning range

- Frequency synthesizers (Phase locked loops, PLLs) – can provide output frequencies that are tunable with very high accuracy and are dominant for use in the local oscillators (LO) in modern wireless systems.
- Important parameters of frequency synthesizers (PLLs) – include frequency tuning range, frequency switching time, frequency resolution, phase noise, cost, low dc supply voltage and power consumption.

❖ RF Front-End of an AMPS Mobile Telephone System



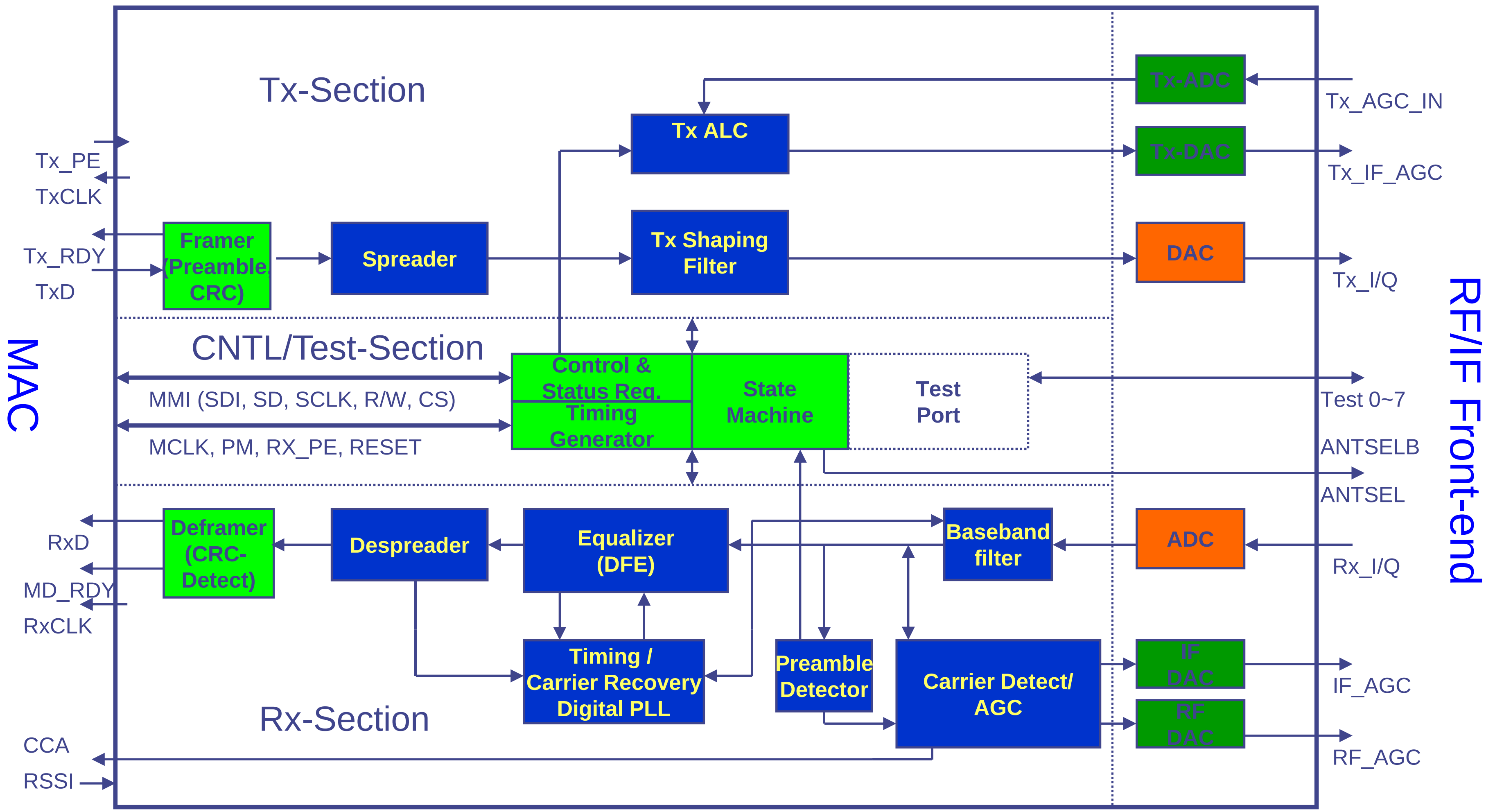
❖ RF Front-End of an IS-55 Mobile Telephone System



➢ IS-55 is a dual mode system to accommodate AMPS and IS-54.

❖ Baseband Processing

WLAN (IEEE 802.11b) baseband processor



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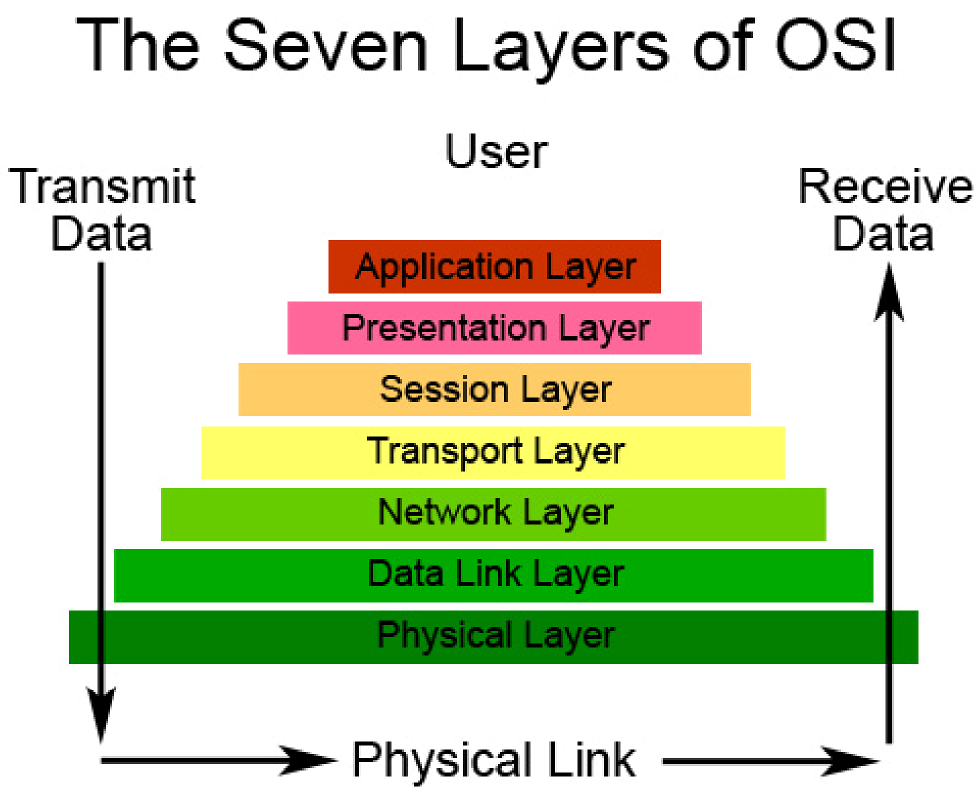
❖ Physical Layer

- Physical layer - is the first and lowest layer in the seven-layer Open System Interconnection (OSI) model of communication networking. It consists of the basic hardware transmission technologies of a network, and typically includes an RF front-end and a baseband processor



❖ Bibliography

- D.M. Pozar, Microwave Engineering, 3rd Ed., §13(2-6)
- D.M. Pozar, Microwave and RF Design of Wireless Systems, §1

❖ Quiz 1

- Covering: Lecture note §1, Textbook §2, §3(1-3,5,7,8), §13(2-6)
- Closed book w/ 1 A4 paper