计算机网络通信基础

Communication Technologies of Computer Network

(For Postgraduate)

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第4章 Transmission Media(传输媒介)

4.1 Overview

---classified as guided or unguided

- **guided**: wire/optical fiber.
- **unguided**: wireless, employ an **antenna** for transmitting through air, vacuum, or water.

---characteristics and quality determined by **medium** and **signal**

- in unguided media, **bandwidth** produced by the **antenna** is more important.

  (A) signals at lower frequencies are omnidirectional (全向);

  (B) At higher frequencies, it is possible to focus the signal into a directional beam, eg., light beam.

- in guided media, **medium** is more important.

---key concerns are data rate and distance

- the greater the data rate, the farther the distance.

第4章 Transmission Media(传输媒介)

4.1 Overview

4.2 Design Factor

4.3 Twisted Pair

4.4 Coaxial Cable

4.5 Optical Fiber

4.6 Wireless Transmission

4.2 Design Factor

---bandwidth

- higher **bandwidth** of a **signal** gives higher **data rate**, while all other factors (as follows) remaining constant.

---transmission **impairments** (损耗)

- eg. attenuation (衰减), limit the **distance**.
- For guided media, twisted pair generally suffers more impairment than coaxial cable, which in turn suffers more than optical fiber.

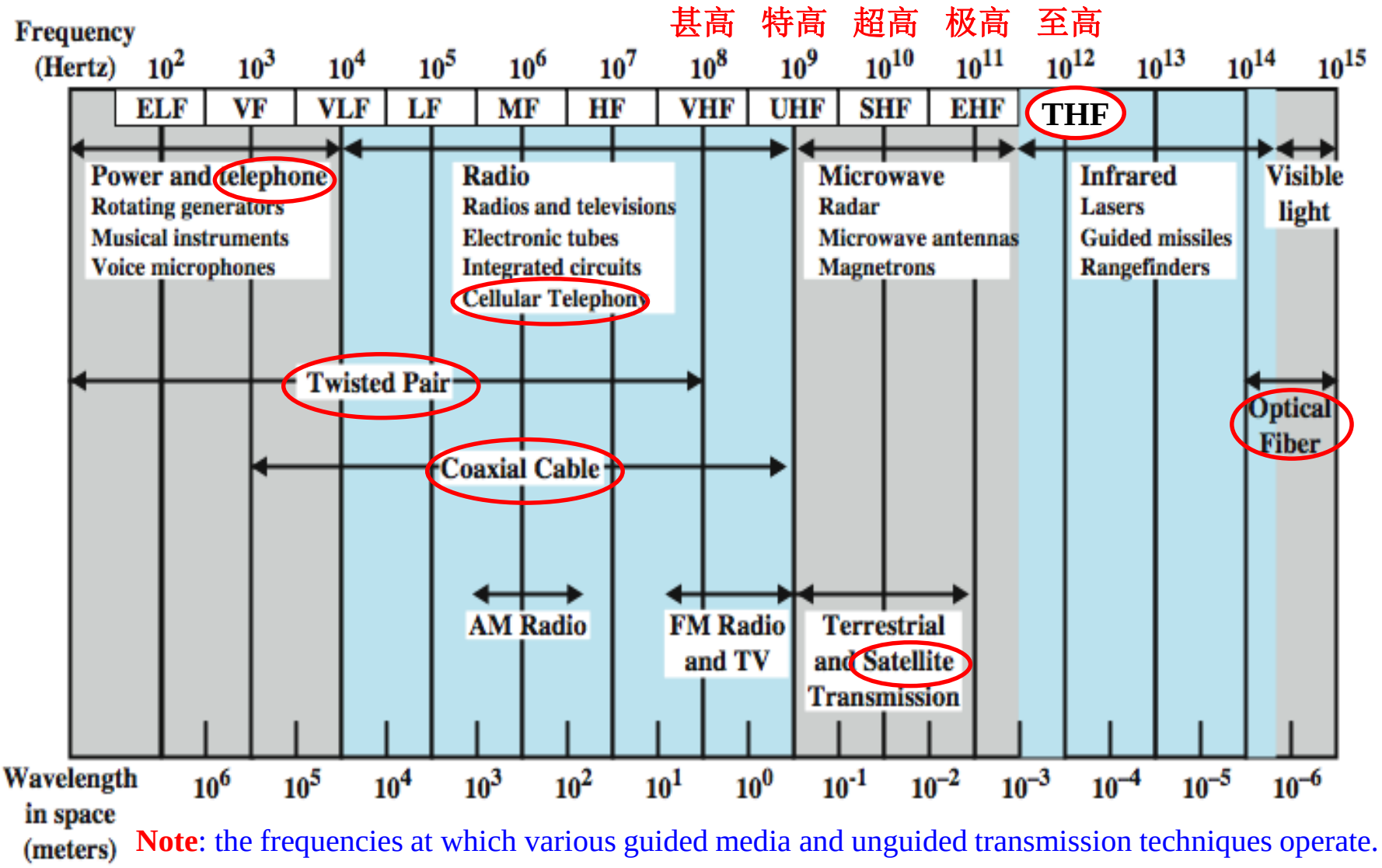
---interference (干扰)

- For guided media, interference can be caused by emanations from nearby cables.
- Interference can also be experienced from **unguided** transmissions.

---number of receivers in guided media

- more receivers introduces more attenuation in **shared** link.

Electromagnetic Spectrum (William Stallings, 8e)



Note: the frequencies at which various guided media and unguided transmission techniques operate.

ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency
THF = Tremendously high frequency

4.2 Design Factor

Point-to-Point Transmission Characteristics of Guided Media (GLOV**98**)
(update needed)

	Frequency Range	**Typical Attenuation**	**Typical Delay**	**Repeater Spacing**
Twisted pair (with loading)	0 ~ 1.1 MHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km
Twisted pairs (multi-pair cables)	0 ~ 100 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 ~ 1 GHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	186 ~ 370 THz	0.2 to 0.5 dB/km	5 μs/km	100 km

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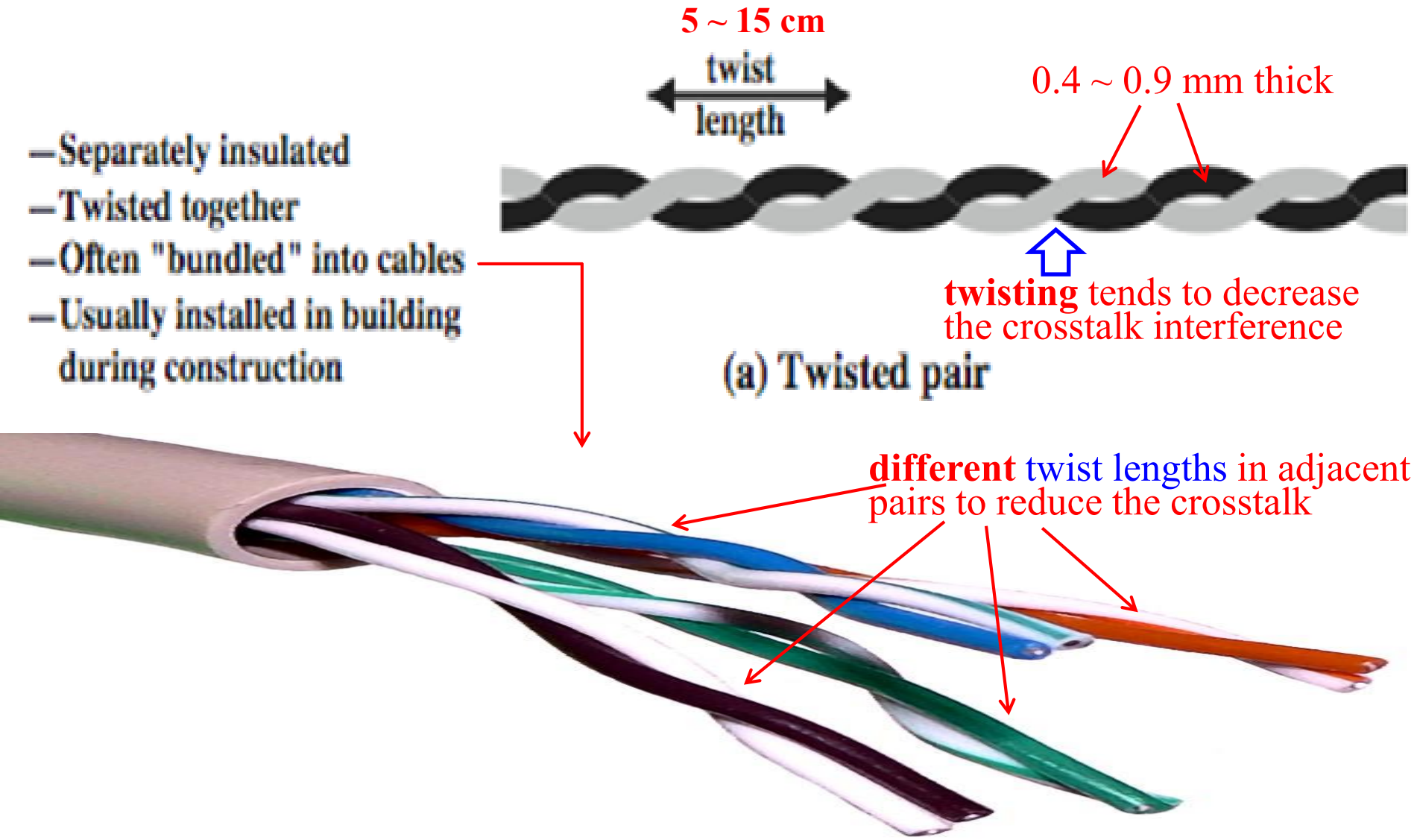
4.3 Twisted Pair



4.3 Twisted Pair

(a) Category 3 UTP

different twist lengths also in categories

(b) Category 5 UTP

4.3 Twisted Pair

- Twisted Pair - Transmission Characteristics

--- analog

- needs amplifiers every 5~6 km.

---digital

- can use either analog or digital signals.
- needs a repeater every 2~3 km.

---limitation

- distance
- bandwidth (for analog signal), 1 MHz(?).
- data rate (for digital signal), 1 Mbps (long distance) ~ 10 Gbps (short distance).

---susceptible to interference and noise

4.3 Twisted Pair

- Unshielded vs. Shielded TP

---unshielded Twisted Pair (**UTP**)

- ordinary telephone wire.
- cheapest.
- easiest to install.
- suffers from external electromagnetic interference (**EMI**), including interference from nearby twisted pair and from noise generated in the environment.

---shielded Twisted Pair (**STP**)

- metal braid or sheathing that reduces interference.
- more expensive.
- harder to handle (thick, heavy).

---in a variety of **categories** - see **EIA** (Electronic Industries Association)/**TIA** (Telecommunications Industries Association) - **568** (published in **1991**)

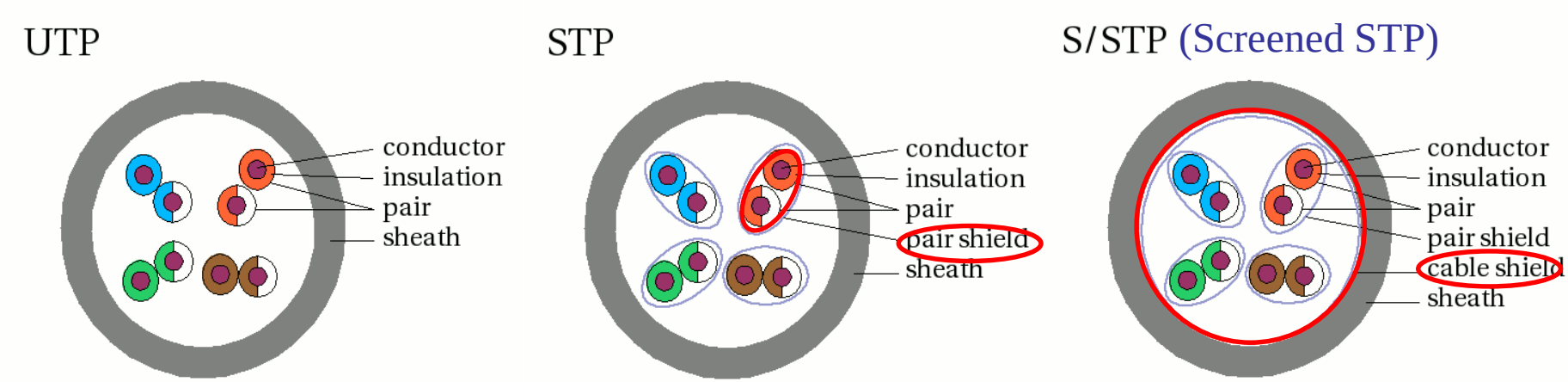
4.3 Twisted Pair

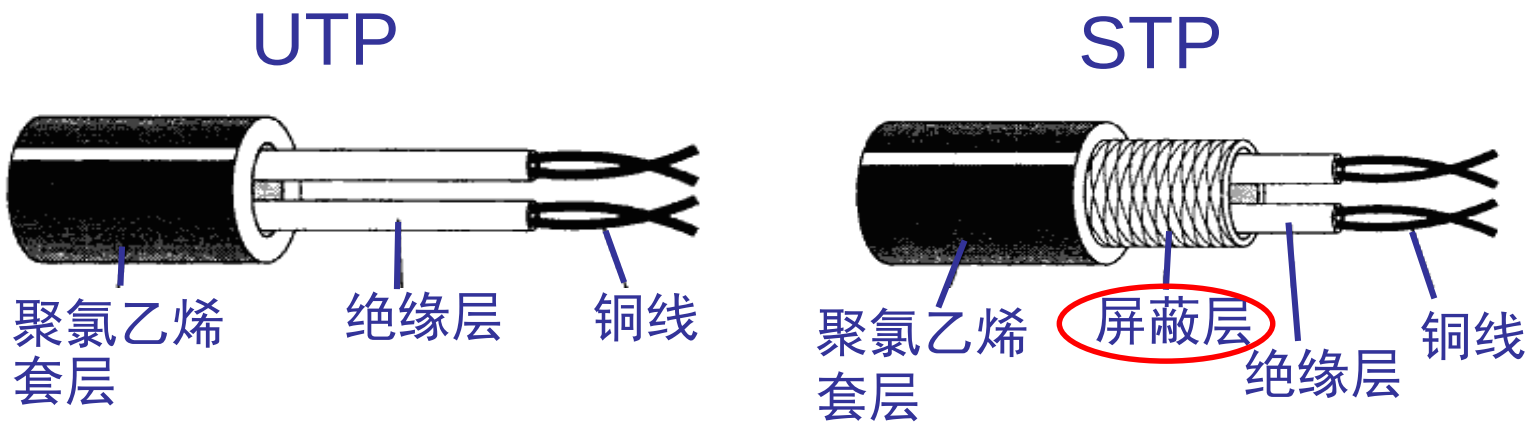
◆ UTP Categories

	Category 3 Class C	Category 5 Class D	Category 5E	Category 6 Class E	Category 7 Class F
Bandwidth	16 MHz	100 MHz	100 MHz	250 MHz 500MHz (Cat 6a)	600 MHz 1GHz (Cat 7a)
Cable Type	UTP	UTP/FTP	UTP/FTP	UTP/FTP	SSTP
Standards	EIA-568-A	EIA-568-A	EIA-568-B	EIA-568-B	ISO/IEC 11801
Typical Application	Telephone 10 Mbps LAN	100Mbps LAN	1Gbps LAN	10Gbps LAN (Cat 6a)	10Gbps LAN

FTP: Foil TP; SSTP: Shielded Screen TP

4.3 Twisted Pair





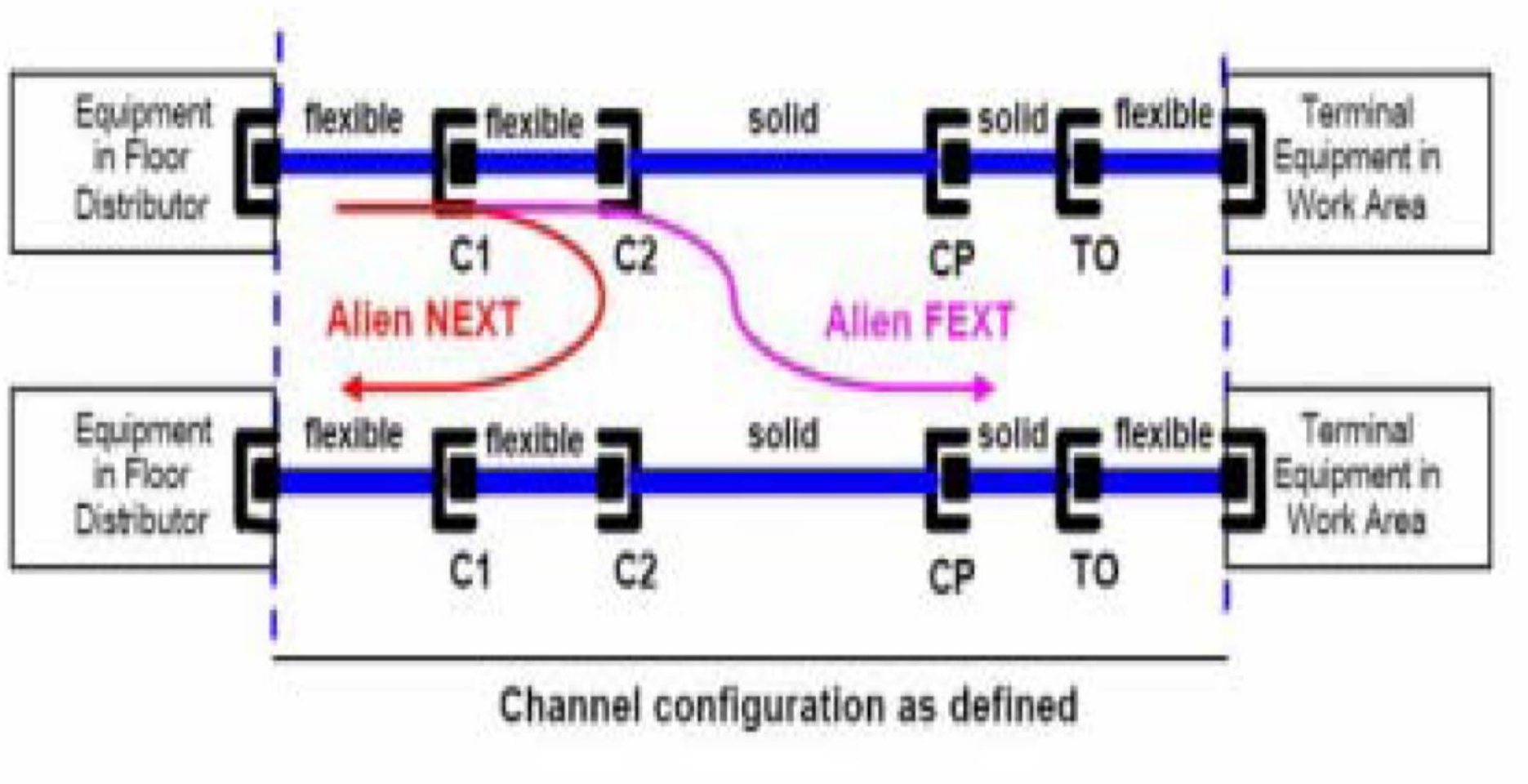
4.3 Twisted Pair

◆ Comparison of STP and UTP

	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
Frequency (MHz)	Category 3 UTP	Category 5 UTP	150Ω STP	Category 3 UTP	Category 5 UTP	150Ω STP
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25	—	10.4	6.2	—	41	47.5
100	—	22.0	12.3	—	32	38.5
300	—	—	21.4	—	—	31.3

Near End Crosstalk (NEXT, 近端串扰): near transmitted signal is picked up by near receiving pair.

4.3 Twisted Pair



FEXT: Far End Crosstalk (远端串扰)

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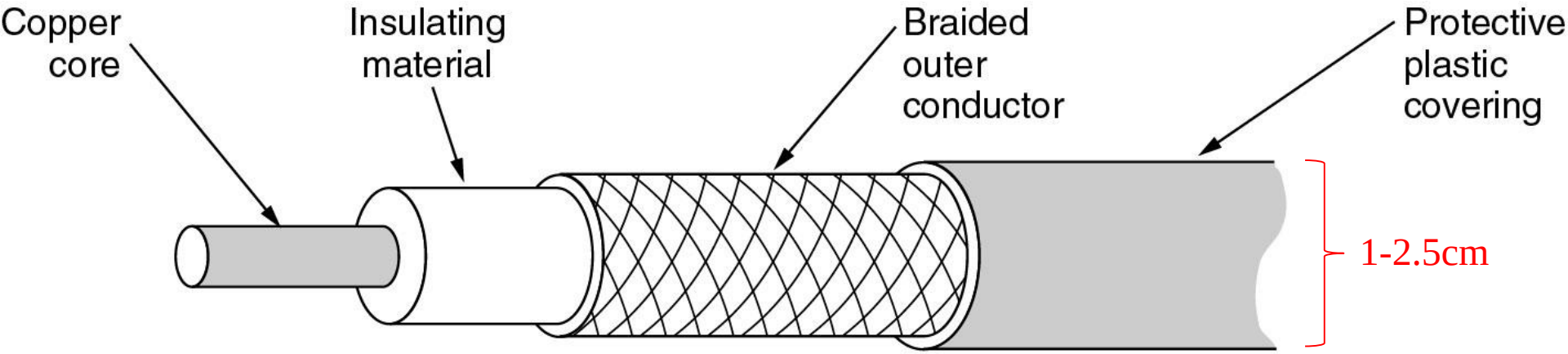
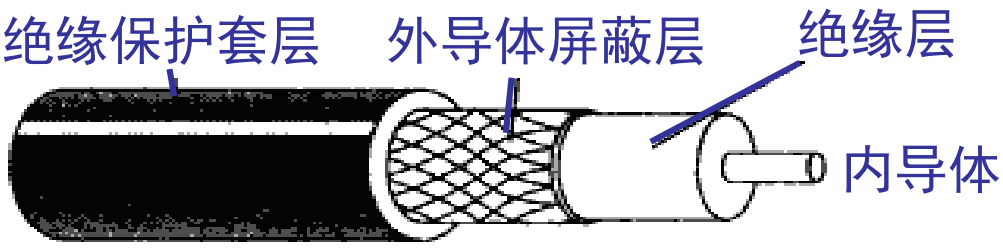
4.4 Coaxial Cable

- Structure





4.4 Coaxial Cable

◆ Coaxial Cable - Transmission Characteristics

---categorized into 50Ω (thin, baseband) and 75Ω (thick, broadband).

---superior frequency characteristics to TP.

---performance limited by attenuation & noise, eg., thermal noise, and inter-modulation noise (while FDM).

---mainly used in cable TV (75Ω), early in Ethernet (50Ω or 75Ω).

---**analog signals**

- amplifiers every few km.
- closer spacing required if higher frequencies are used.
- up to 1GHz.

---**digital signals**

- repeater every 1km.
- closer spacing needed for higher data rates.

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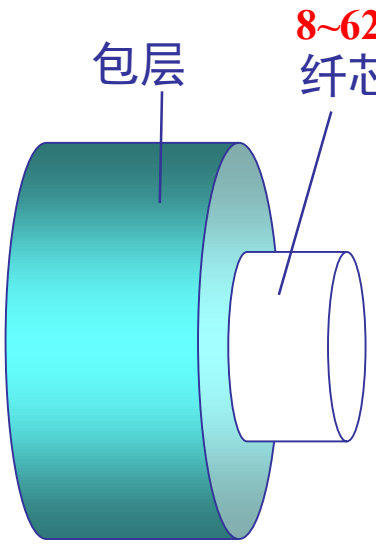
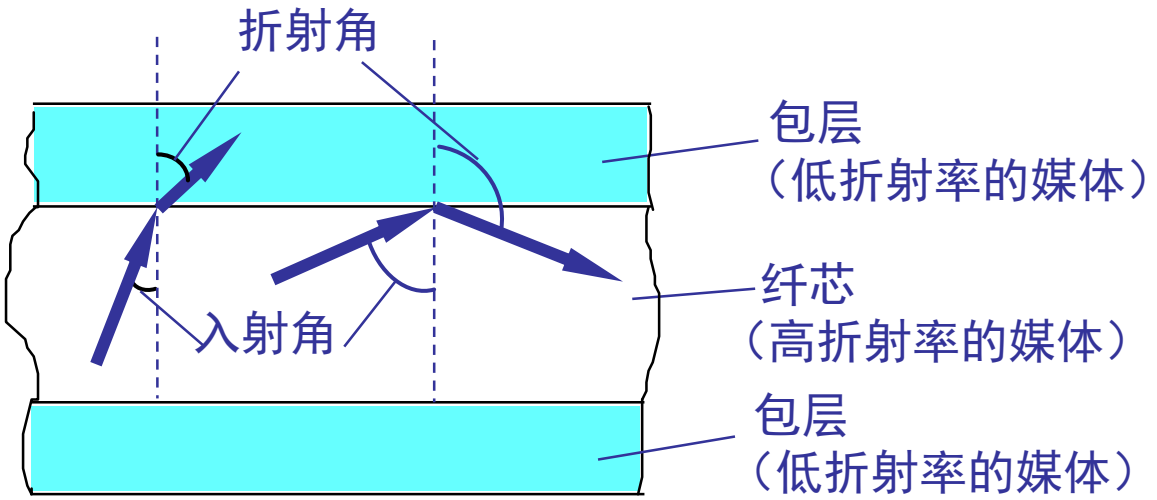
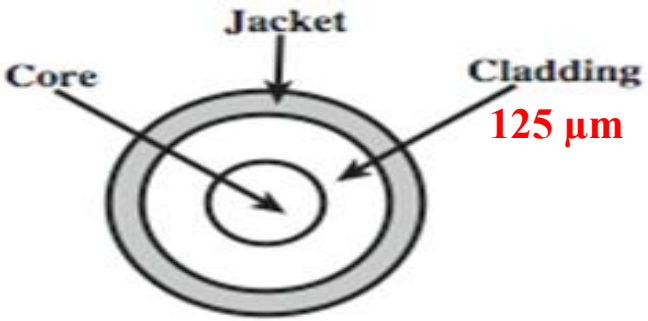
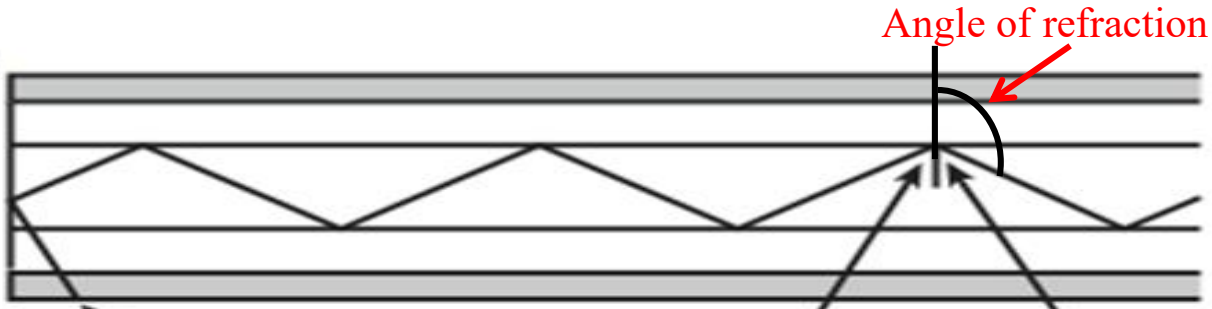


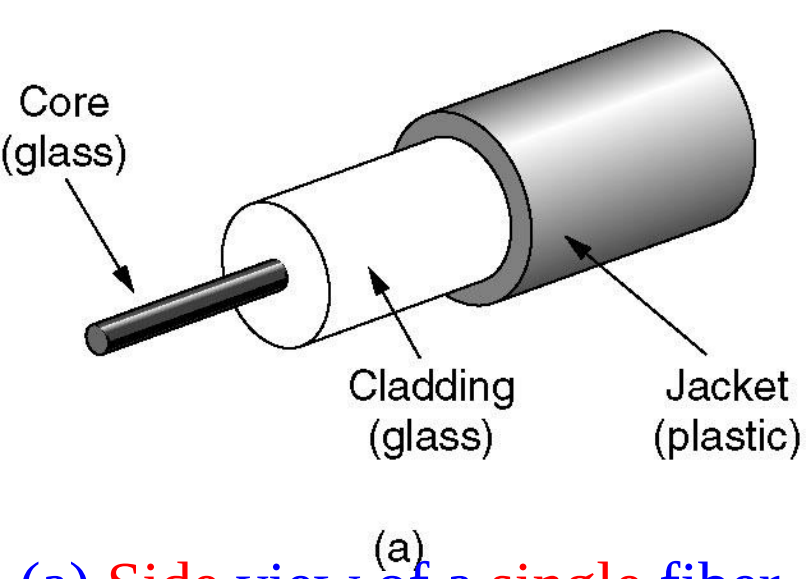


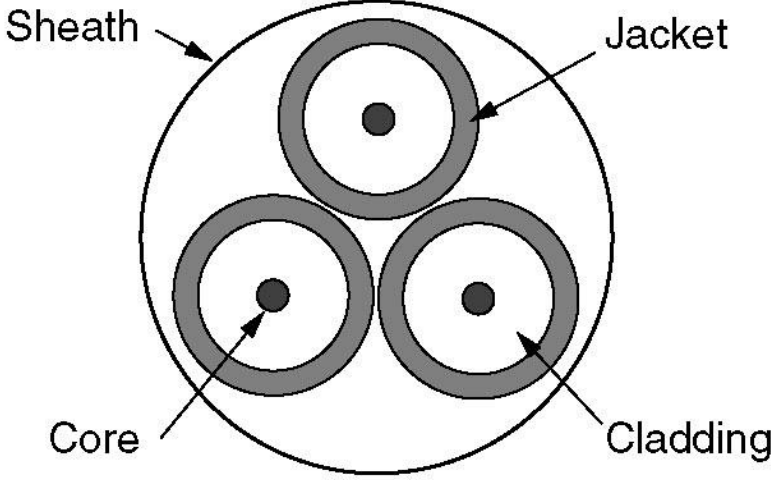




—Glass or plastic core
—Laser or light emitting diode
—Specially designed jacket
—Small size and weight

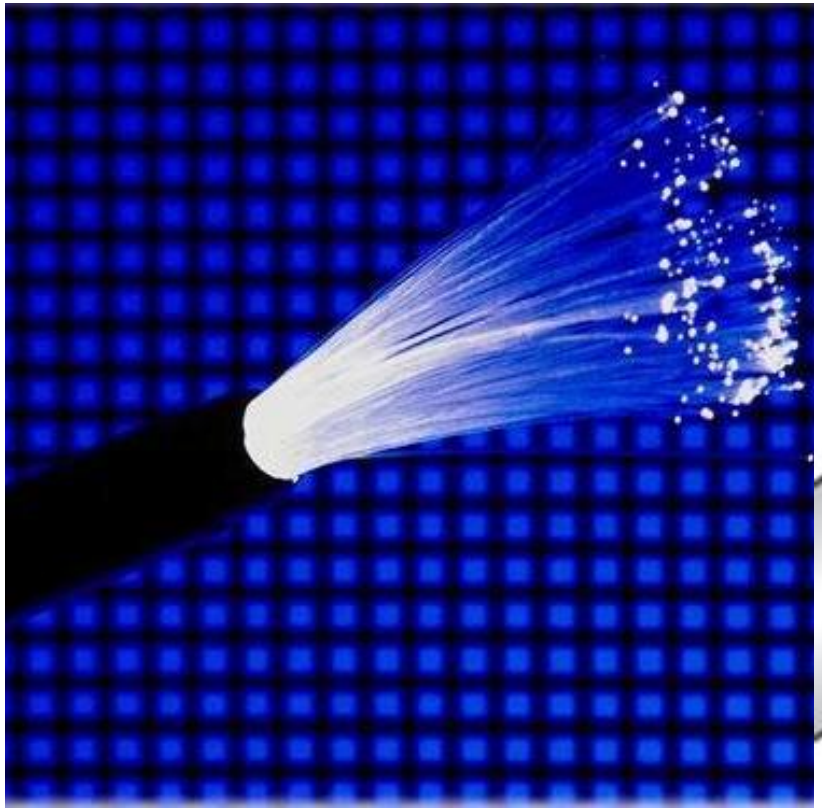
Light at less than critical angle is absorbed in jacket

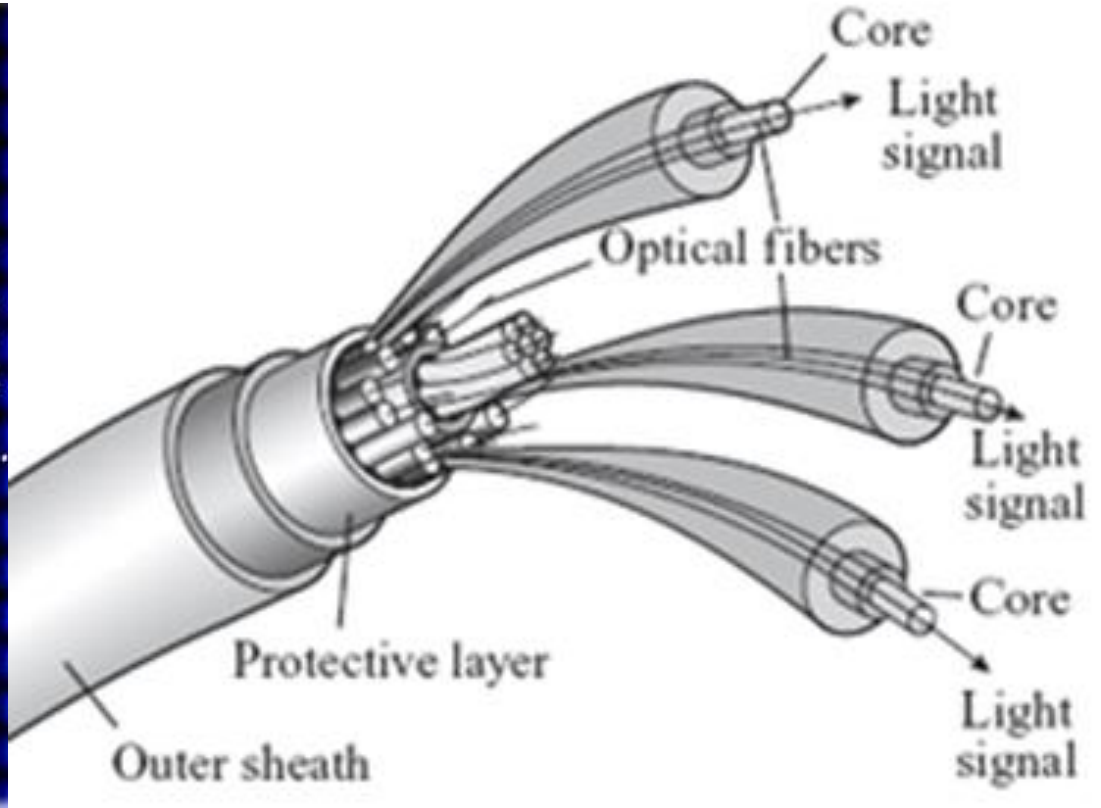




(a) (b)

(a) Side view of a single fiber. (b) End view of a sheath with three fibers.





4.5 Optical Fiber

◆ Optical Fiber - Benefits

---greater capacity

- data rates of hundreds of Gbps over tens of kilometers.

(A) for coaxial cable, maximum of **hundreds of Mbps** over about 1 km.

(B) for twisted pair, just **a few Mbps** over 1 km, or up to **100 Mbps to 10 Gbps** over a few tens of meters.

---smaller size & weight

---lower attenuation

---electromagnetic isolation

- not affected by external electromagnetic fields.

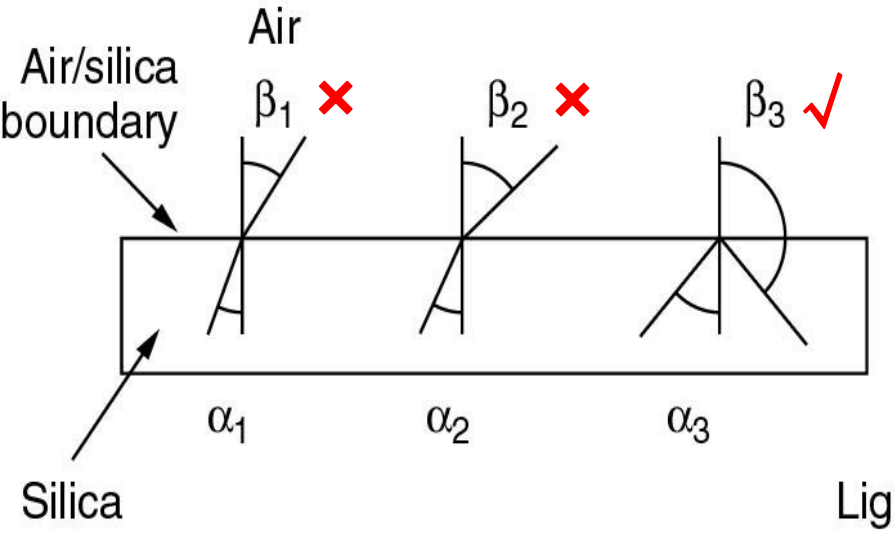
---high degree of security from eavesdropping

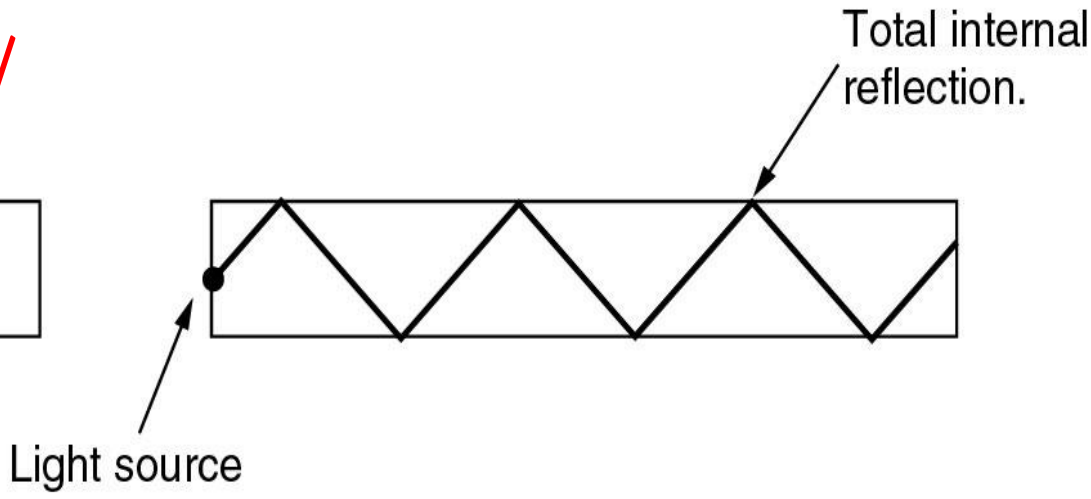
- inherently difficult to tap.

---greater repeater spacing

- tens of km at least.

◆ working principle

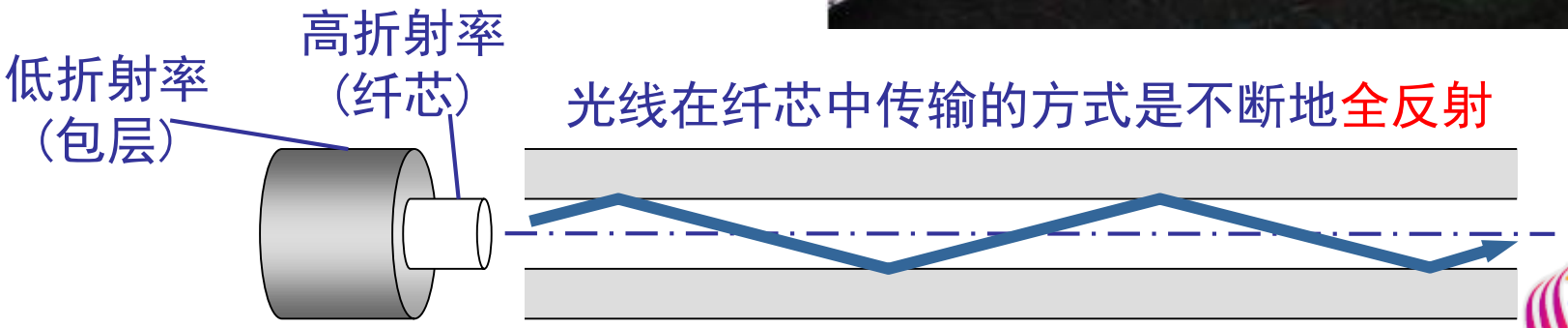




(a) (b)

(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

(b) Light trapped by total internal reflection.



4.5 Optical Fiber

◆ Optical Fiber - Transmission Characteristics

--- uses total internal reflection (全反射) to transmit light

- effectively acts as wave guide for 10^{14} to 10^{15} Hz.

---can use several different light sources

- Light Emitting Diode (LED, 发光二极管)

  cheaper, wider operating temperature range, longer life.

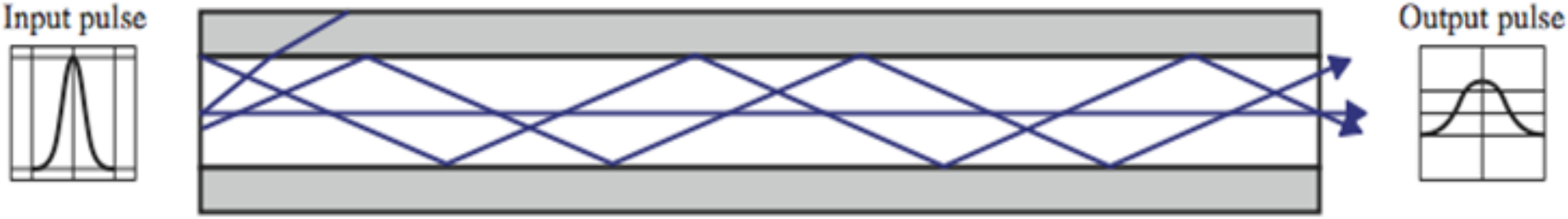
- Injection Laser Diode (ILD , 注入激光二极管)

  more efficient, has greater data rate.

---relation of wavelength, transmission mode & data rate

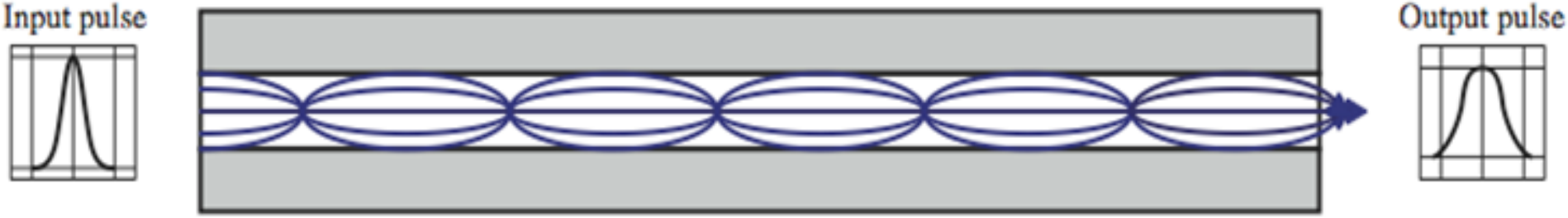
- single mode and multimode can support several different wavelengths of light and can employ laser or LED light sources.

Optical Fiber Transmission Modes



(a) Step-index multimode

Note: step-index (阶跃/突变) multimode, referring to the variety of angles that will reflect, multiple propagation paths exist. best suited for transmission over very short distances.



(b) Graded-index multimode

light at the periphery arrives at a receiver at about the same time as the straight rays in the core axis. often used in LANs – Graded-index (渐变式) multimode.

core radius is reduced, only a single angle or mode can pass: the axial ray. typically used for long-distance applications.

(c) Single mode

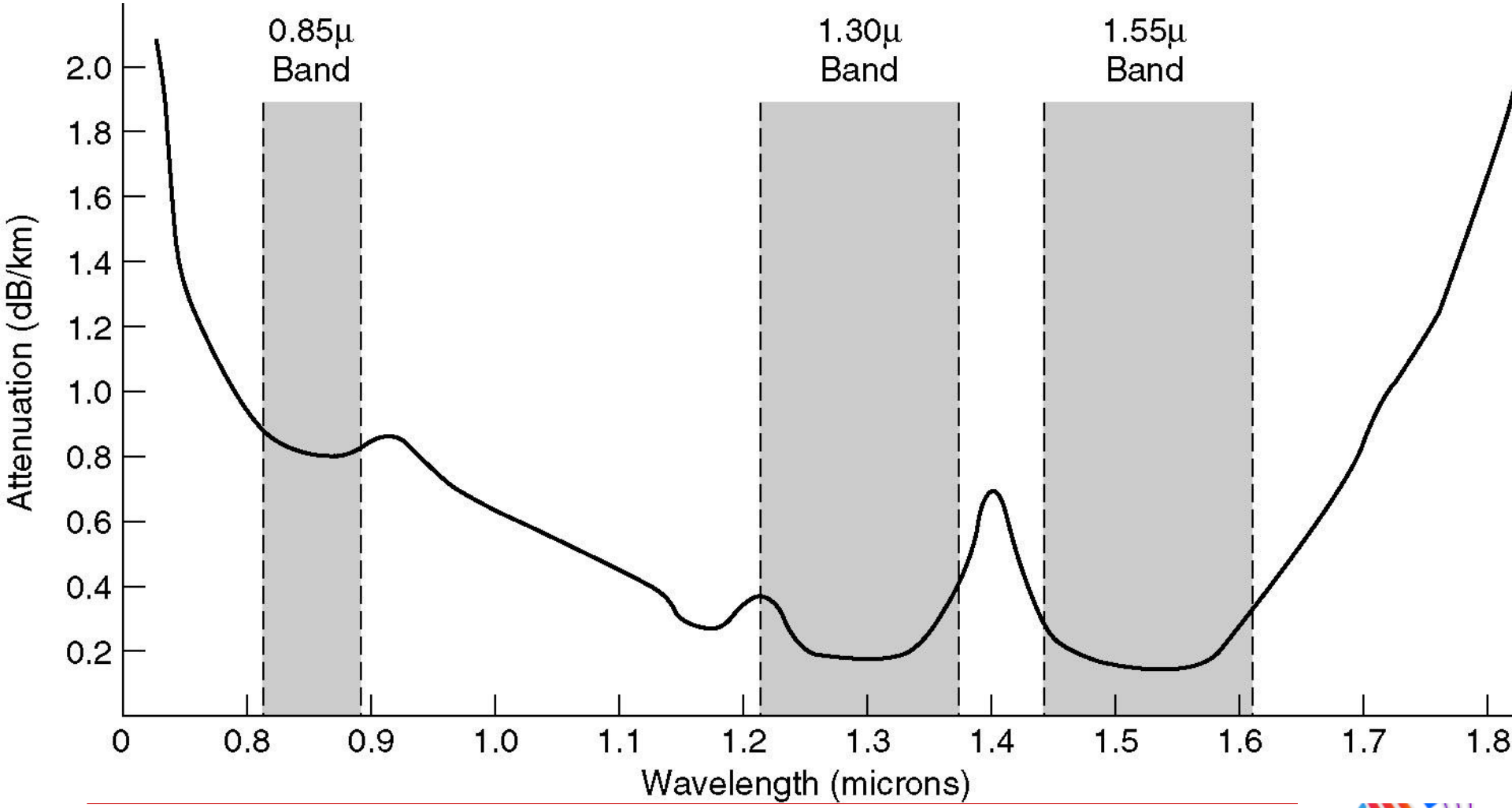
4.5 Optical Fiber

A comparison of semiconductor diodes and LEDs as light sources (Tanenbaum, 4e)

Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

4.5 Optical Fiber

Attenuation of light through fiber in the infrared region (Tanenbaum, 4e)



4.5 Optical Fiber

◆ Frequency Utilization for Fiber Applications

Wavelength (in vacuum) range (nm)	Frequency Range (THz)	Bandwidth (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333	33		Multimode	LAN
1280 to 1350	234 to 222	12	S	Single mode	Various
1528 to 1561	196 to 192	4	C	Single mode	WDM
1561 to 1620	192 to 185	7	L	Single mode	WDM

注：第一列为真空中的波长，因光在光纤中的传播速度比光速低(约2/3c)，故光纤中的实际波长要比第一列的短。

4.5 Optical Fiber

- Frequency Utilization for Fiber Applications

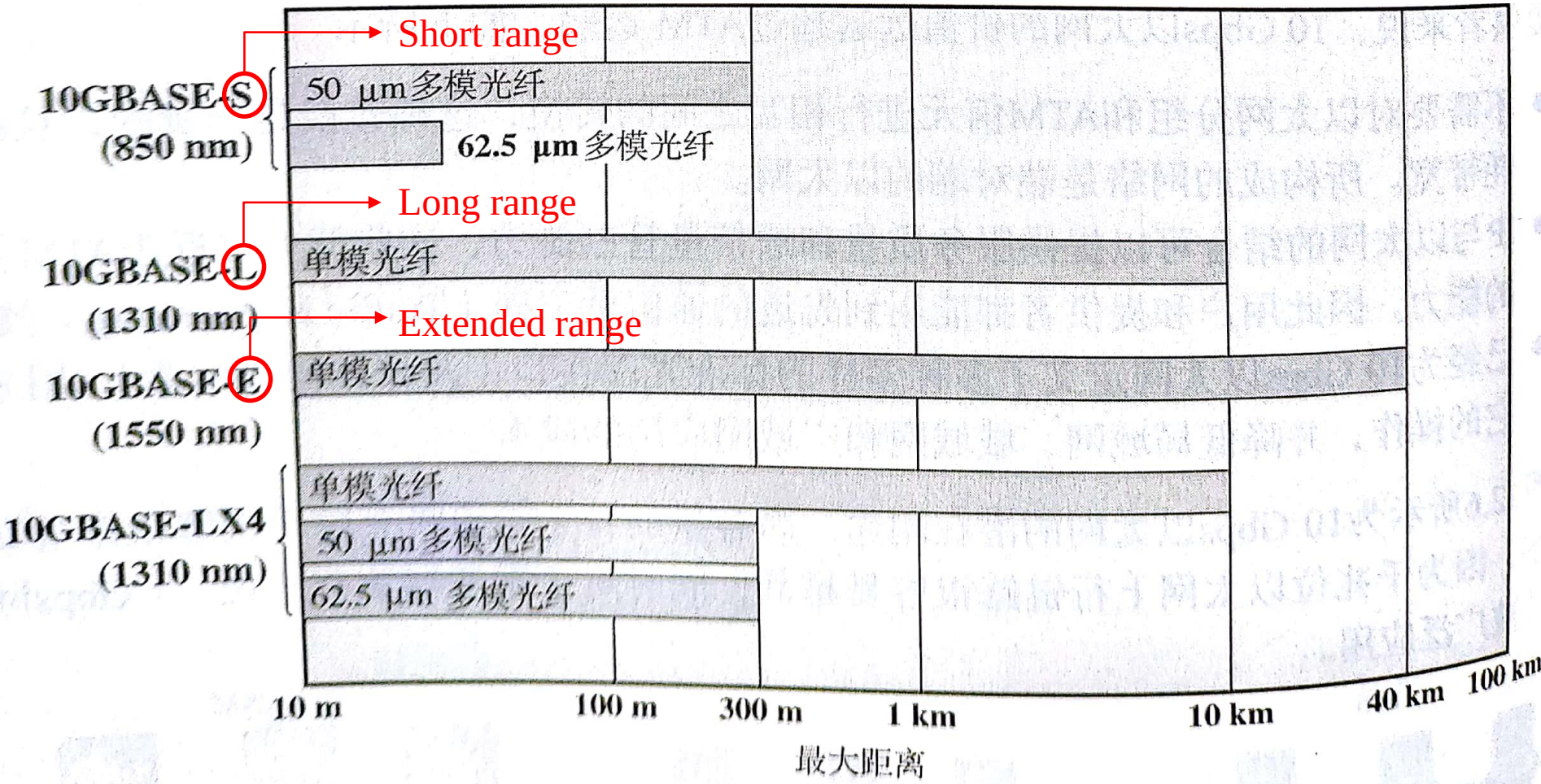


图12.7 10 Gbps以太网距离选项（对数刻度）

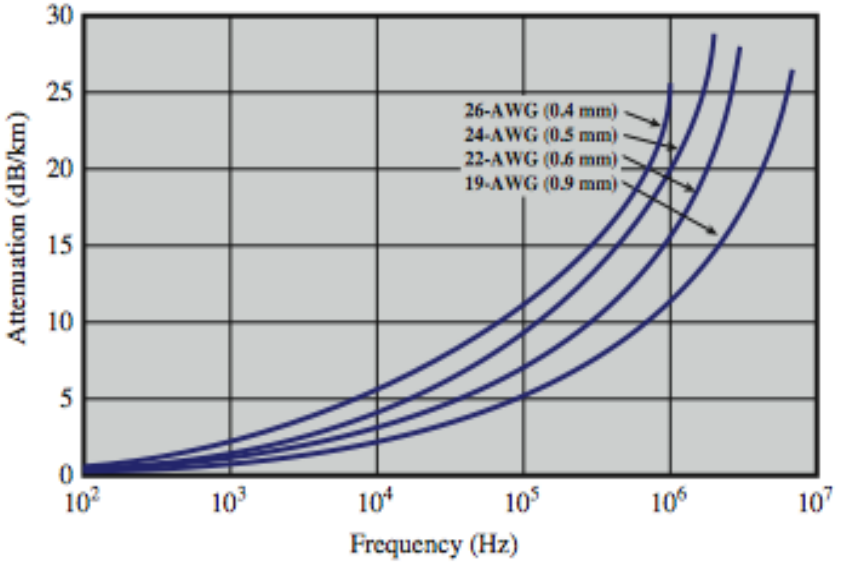
4.5 Optical Fiber

◆ 光纤的波段与窗口(与前表有出入，此表应准确)

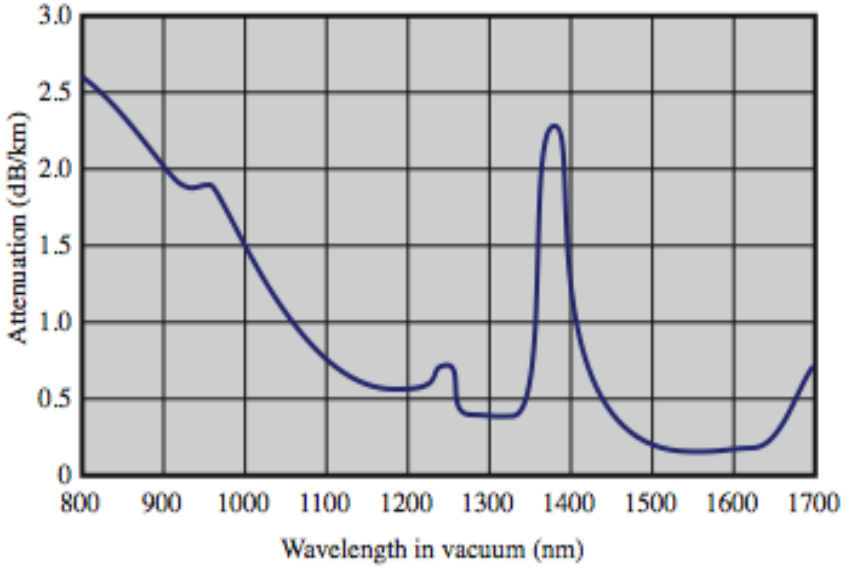
频带	窗口	波长范围(nm)	频率范围(THz)
	1	850(770-910)	
O带(Original band)原始波段	2	1260-1360	237.9-220.4
E带(Extended band)扩展波段	5	1360-1460	220.4-205.3
S带(Short wavelength band)短波长波段		1460-1530	205.3-195.9
C带(Conventional band)常规波段	3	1530-1565	195.9-191.6
L带(Longer wavelength band) 长波长波段	4	1565-1625	191.6-184.5
U带(Ultra-length wavelength band)超长波段		1625-1675	184.5-179.0

注：2002年5月ITU-T将光纤通信系统光波段划分为O、E、S、C、L和U等6个波段。多模光纤850nm称为第1窗口，单模光纤O带为第2窗口，C带称第3窗口，L带为第4窗口，E带为第5窗口。

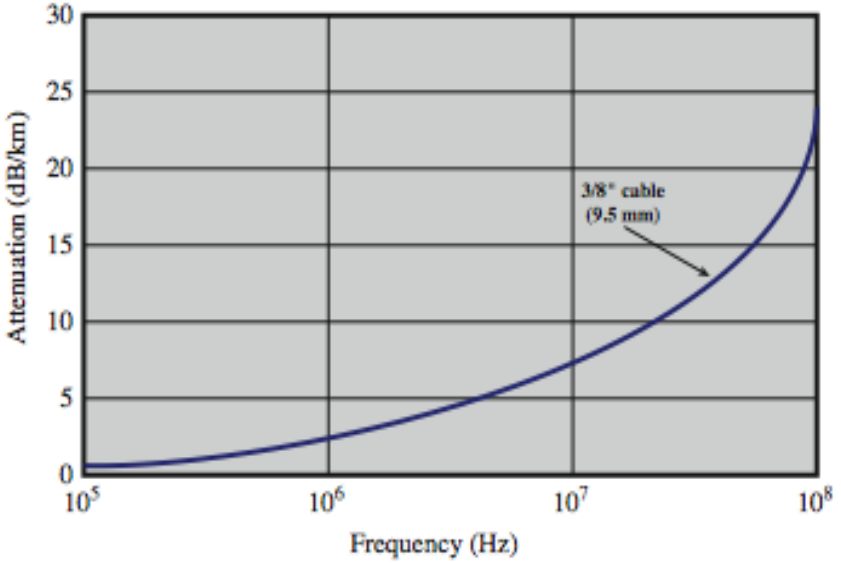
Attenuation in Guided Media



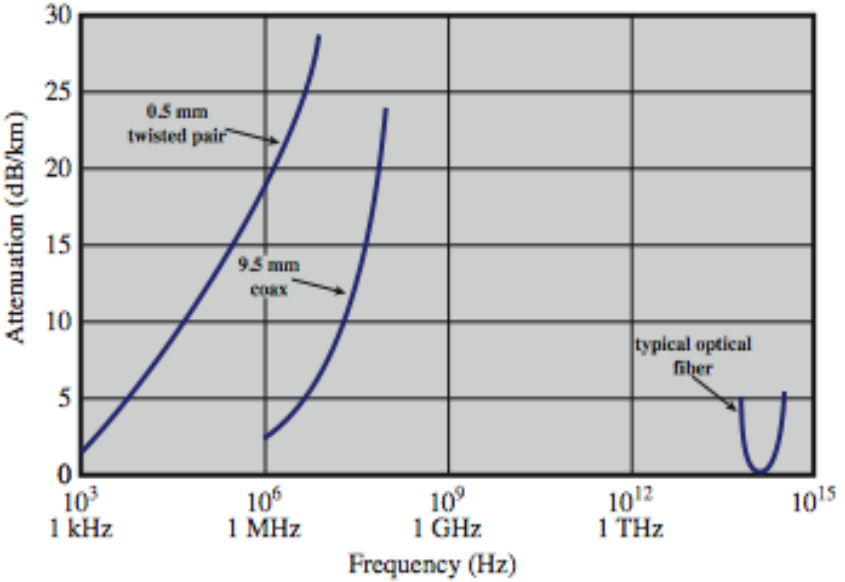
(a) Twisted pair (based on [REEV95])



(c) Optical fiber (based on [FREE02])



(b) Coaxial cable (based on [BELL90])



(d) Composite graph

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4.6 Wireless Transmission

1. Frequency (3大可用频率范围)

---30MHz to 1GHz (Broadcast radio range，射频区)

- suitable for **omnidirectional** (全向) applications.
- At VLF-MF, can pass through buildings easily, but not easily for high frequencies from HF.

**根据波的衍射特性，当波长大于或相当于障碍物的尺寸时，波才能明显地绕到障碍物的后面。地面上的障碍物一般不太大，长波可以很好地绕过它们。中波和中短波也能较好地绕过，短波和微波由于波长过短，绕过障碍物较困难。

--- 2GHz to 40GHz (Microwave frequencies，微波频率)

- highly **directional** (定向).

  **Above 100MHz, the waves travel in nearly straight lines (Tanenbaum, 4e).

- quite suitable for point-to-point transmission (do not pass through buildings well).
- also used for satellite communications.
- Problem: absorption by water(>4GHz), multipath fading(多径衰落).

4.6 Wireless Transmission

---3×10^{11} to 2×10^{14} Hz (Infrared, 红外线)

- useful to local point-to-point and multipoint applications within confined areas, eg., a single room.

---Ultraviolet light, X-ray & Gamma ray

- hard to produce & modulate.
- Do not propagate well through buildings.
- dangerous to living things.

4.6 Wireless Transmission

2. Politics of the Electromagnetic Spectrum

---Frequency allocation organization

- FCC (Federal comm. commission), USA.
- ITU-R.
- 信息产业部无线电管理局，China.

---three allocation algorithms (early): **beauty contest** (nice story, maybe lead to bribery, corruption), **lottery** (resell), **auction** (debt).

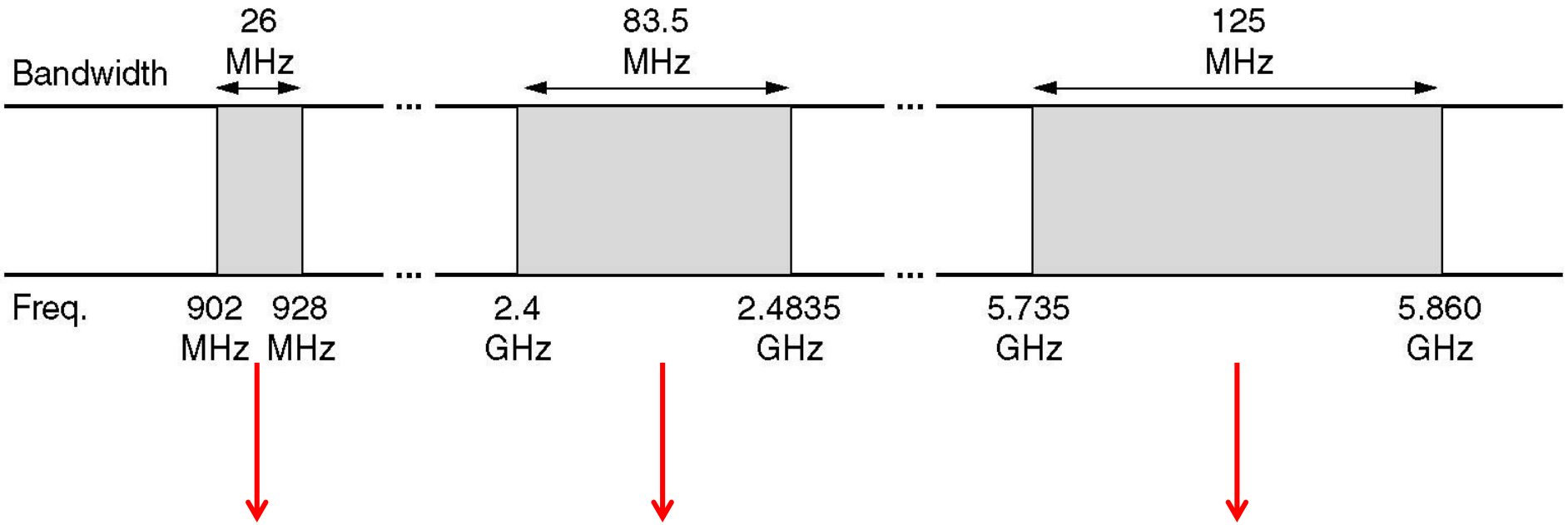
---not allocate, but regulate the power, and set aside some frequency bands.

---**ISM** (Industrial, scientific, medical) bands (set aside)

- Unlicensed usage.
- Use spread spectrum techniques (FCC, and other countries).\
- ISM bands varies somewhat from country to country.

4.6 Wireless Transmission

The ISM bands in the United States



Works best but crowded

- Available in most countries.
- subject to interference from microwave ovens and radar.
- Used by Bluetooth and 802.11 WLAN.

- New and undeveloped.
- 802.11a will use this band.

中国无线电频率分配

名称	甚低频	低频	中频	高频	甚高频	特高频	超高频	极高频
符号	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
频率	3-30 kHz	30-300 kHz	0.3-3 MHz	3-30 MHz	30-300 MHz	0.3-3 GHz	3-30 GHz	30-300 GHz
波段	超长波	长波	中波	短波	米波	分米波	厘米波	毫米波
波长	1000km	10km	1km	100m	10m	1m	10cm	10mm
传播特性	空间波为主	地波为主	地波与天波	天波与地波	空间波即视波	LOS即视距传播	LOS	LOS
主要用途	海岸潜艇通信；远距离通信；超远距离导航	越洋通信；中距离通信；地下岩层通信；远距离导航	船用通信；业余无线电通信；移动通信；中距离导航	远距离短波通信；国际定点通信	电离层散射(30-60 MHz)；流星余迹通信；人造电离层通信(30-144MHz)；对空间飞行体通信；移动通信	小容量微波中继通信(352-420MHz)；对流层散射通信(700-10000MHz)；中容量微波通信(1.7-2.4GHz)	大容量微波中继通信(3.6-4.2GHz、5.85-8.5GHz)数字通信；卫星通信；国际海事卫星通信(1.5-1.6GHz)	再入大气层时的通信；波导通信

4.6 Wireless Transmission

移动通信频率划分(China)

			中国移动	中国联通	中国电信
2G	GSM 900	上行	890-909 MHz	909-915 MHz	825-840 MHz
		下行	935-954 MHz	954-960 MHz	870-885 MHz
		带宽	19/19 MHz	6/6 MHz	15/15 MHz
	GSM 1800	上行	1710-1725 MHz	1745-1755 MHz	
		下行	1805-1820 MHz	1840-1850 MHz	
		带宽	15/15 MHz	10/10 MHz	
3G		标准	TD-SCDMA	WCDMA	CDMA2000
		上行	1880-1900 MHz	1940-1955 MHz	1920-1935 MHz
		下行	2010-2025 MHz	2130-2145 MHz	2110-2125 MHz
		带宽	15/15 MHz	15/15 MHz	15/15 MHz

4.6 Wireless Transmission

4G通信频率划分

2013.12.4，发放TD-LTE牌照。2015.2.27，工信部正式向中国电信、中国联通颁发了第2张4G业务牌照，即FDD-LTE牌照。表中蓝色为2019.2.18发放。

		中国移动	中国联通	中国电信
4G TD-LTE	F频段	1880-1900 MHz		
	E频段	2320-2370 MHz	2300-2320 MHz	2370-2390 MHz
	D频段	2575-2635 MHz	2555-2575MHz	2635-2655 MHz
	带宽	130 MHz	40 MHz	40 MHz
4G LTE FDD		-	-	824-835MHz/869-880MHz
		-	1955-1980MHz	1755-1785MHZ
		-	2145-2170MHz	1850-1880MHz
		-		1920-1940/2110-2130MHz
	带宽	-	50 MHz	71 MHz

4.6 Wireless Transmission

5G通信频率划分

2019.6.6，工信部正式向中国电信、中国移动、中国联通、中国广电发放了5G商用牌照。

三大运营商 2G/3G/4G/5G 频率分配表

运营商	上行频率 MHz	下行频率 MHz	频宽 MHz		制式	
中国移动	885-892	930-937	7	22	GSM900	2G
	1710-1725	1805-1820	15		GSM1800	2G
	2010-2025	2010-2025	15	15	TD-SCDMA	3G
	892-904	937-949	12	12	LTE-FDD	4G
	1880-1890	1880-1890	10	60	TD-LTE	4G
	2320-2370	2320-2370	50			
	2515-2675	2515-2675	160	260	IMT-2020	5G
	4800-4900	4800-4900	100			
中国联通	1745-1755	1840-1850	10	10	GSM	2G
	1940-1955	2130-2145	15	15	WCDMA	3G
	904-915	949-960	11	21	LTE-FDD	4G
	1755-1765	1850-1860	10			
	2300-2320	2300-2320	20	20	TD-LTE	4G
	3500-3600	3500-3600	100	100	IMT-2020	5G
中国电信	（825-840）	（870-885）	15	15	CDMA/FDD	2G/4G
	1920-1935	2110-2125	15	15	CDMA2000	3G
	826.7-837.7	871.7-876.7	5	5	LTE-FDD	4G
	1765-1780	1860-1875	15	15	LTE-FDD	4G
	2370-2390	2370-2390	20	20	TD-LTE	4G
	3400-3500	3400-3500	100	100	IMT-2020	5G

4.6 Wireless Transmission

中国广播及电视频率划分表

波段	频率	电台间隔	用途
LF (LW)	120-300 kHz	—	长波调幅广播
MF (AM)	525-1605 kHz	9 kHz	中波调幅广播
HF (SW)	3.5-29.7 MHz	9 kHz	短波调幅广播及单边带通讯
VHF (FM)	88-108 MHz	150 kHz	调频广播及数据广播
VHF	48.5-92 MHz	8 MHz	电视及数据广播
VHF	167-223 MHz	8 MHz	电视及数据广播
UHF	223-443 MHz	8 MHz	电视及数据广播
UHF	443-870 MHz	8 MHz	电视及数据广播

4.6 Wireless Transmission

3. Antennas (天线)

---electrical conductor used to **radiate or collect** electromagnetic energy.

---**transmission antenna**

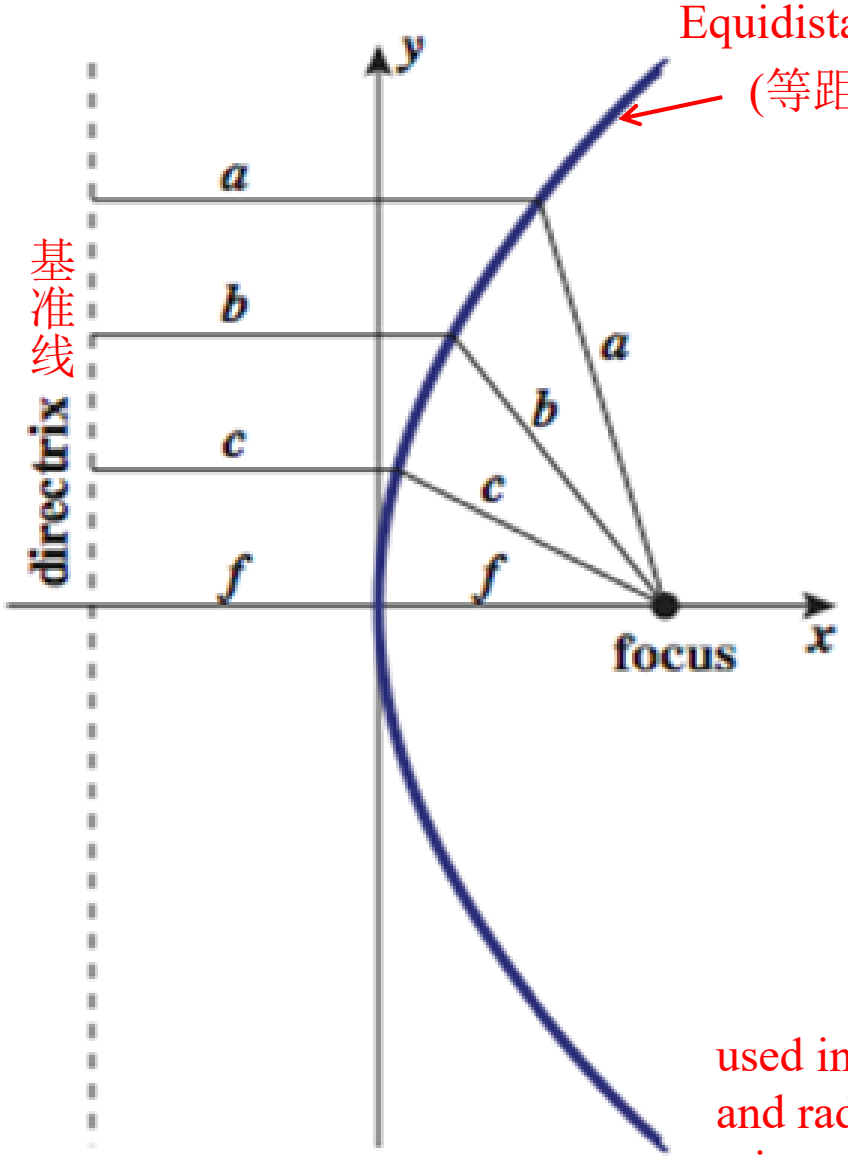
- radio frequency electrical energy from transmitter is converted to electromagnetic energy by antenna.
- radiated into surrounding environment.

---**reception antenna**

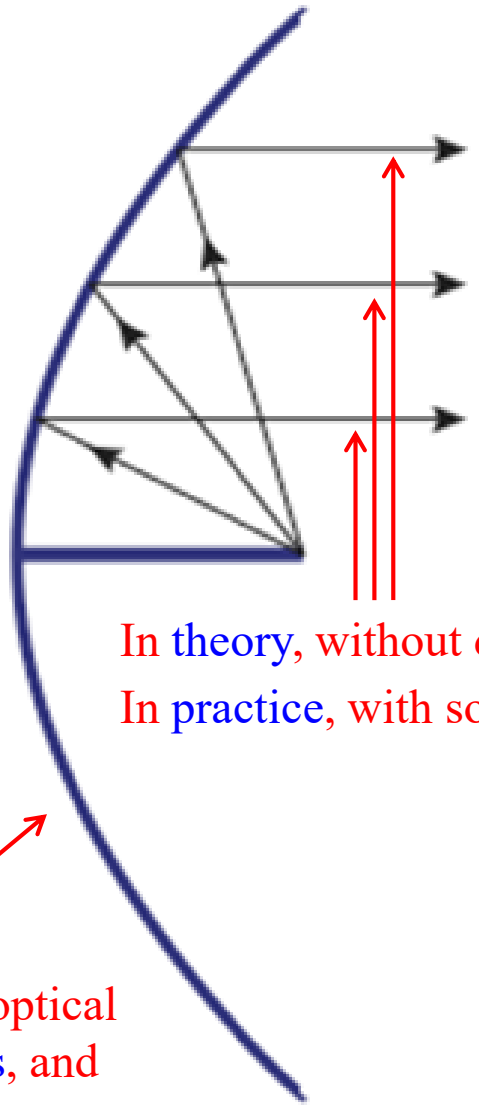
- electromagnetic energy impinging on antenna is converted to radio frequency electrical energy.
- fed to receiver.

---same antenna is often used for both transmission and reception.

4. Parabolic Reflective Antenna (抛物面反射天线, 定向天线)



(a) Parabola



In theory, without dispersion;
In practice, with some dispersion.

used in headlights, optical and radio telescopes, and microwave antennas.

(b) Cross-section of parabolic antenna showing reflective property

4.6 Wireless Transmission

5. Terrestrial (陆地/地面) Microwave

--- used for long haul telecommunications, also used in short point-to-point links between buildings.

---requires fewer repeaters (10~100km apart) but line of sight (视线).

---use a parabolic dish (about 3m in diameter) to focus a narrow beam onto a receiver antenna.

---1-40GHz frequencies, higher frequencies give higher data rates

- for long-haul telecomm, 4~6GHz, 11GHz (newly added).
- 12GHz band used to provide TV signals to local CATV (Community antenna television or cable TV, 有线电视).
- for short point-to-point link, 22GHz band.

4.6 Wireless Transmission

- 部分典型系统的带宽与数据率

典型的数字微波性能表

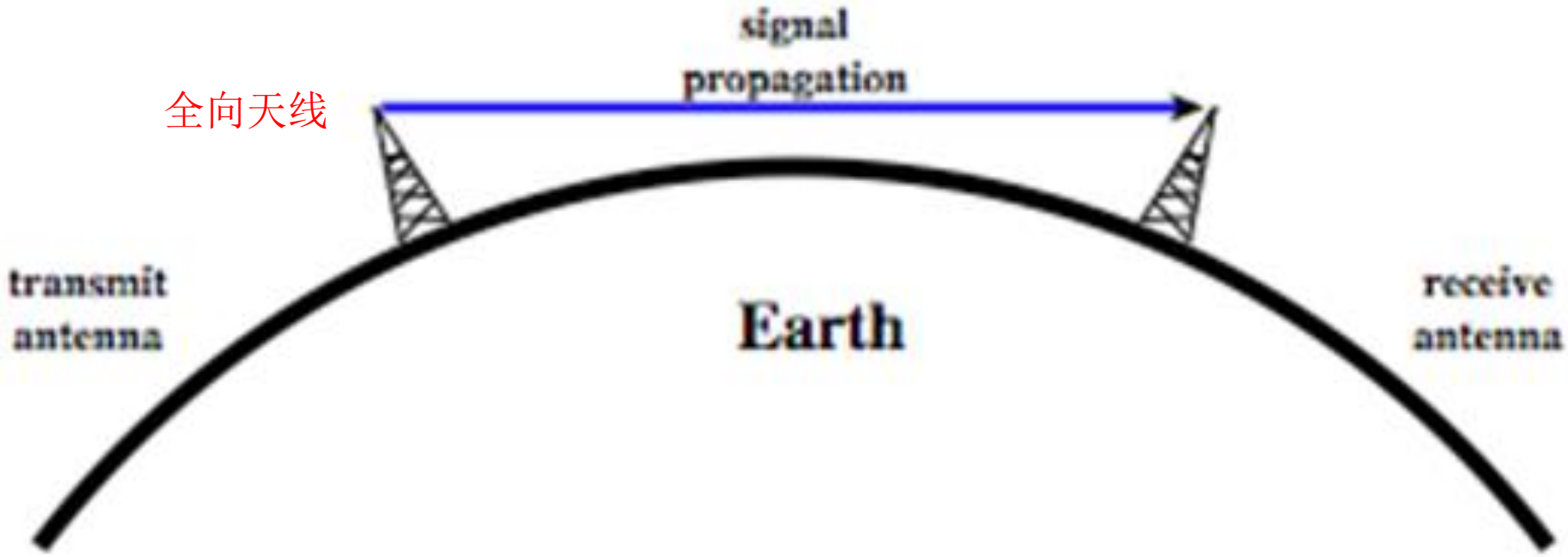
波段(GHz)	带宽(MHz)	数据率(Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

---main source of loss is attenuation

- distance, rainfall (especially for above 10GHz).

---interference is another source of impairment.

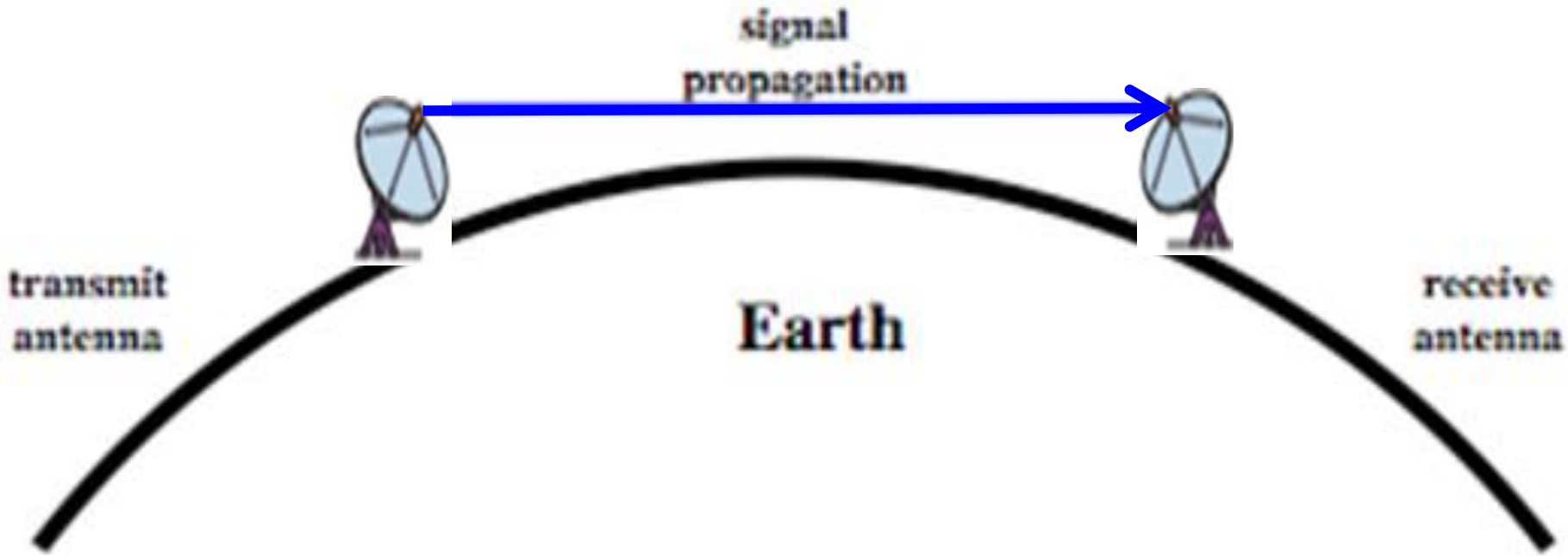
4.6 Wireless Transmission



(c) Line-of-sight (LOS) propagation (30MHz~2GHz)

a signal above 30 MHz is not reflected by the ionosphere (电离层, 80-800km high).

4.6 Wireless Transmission



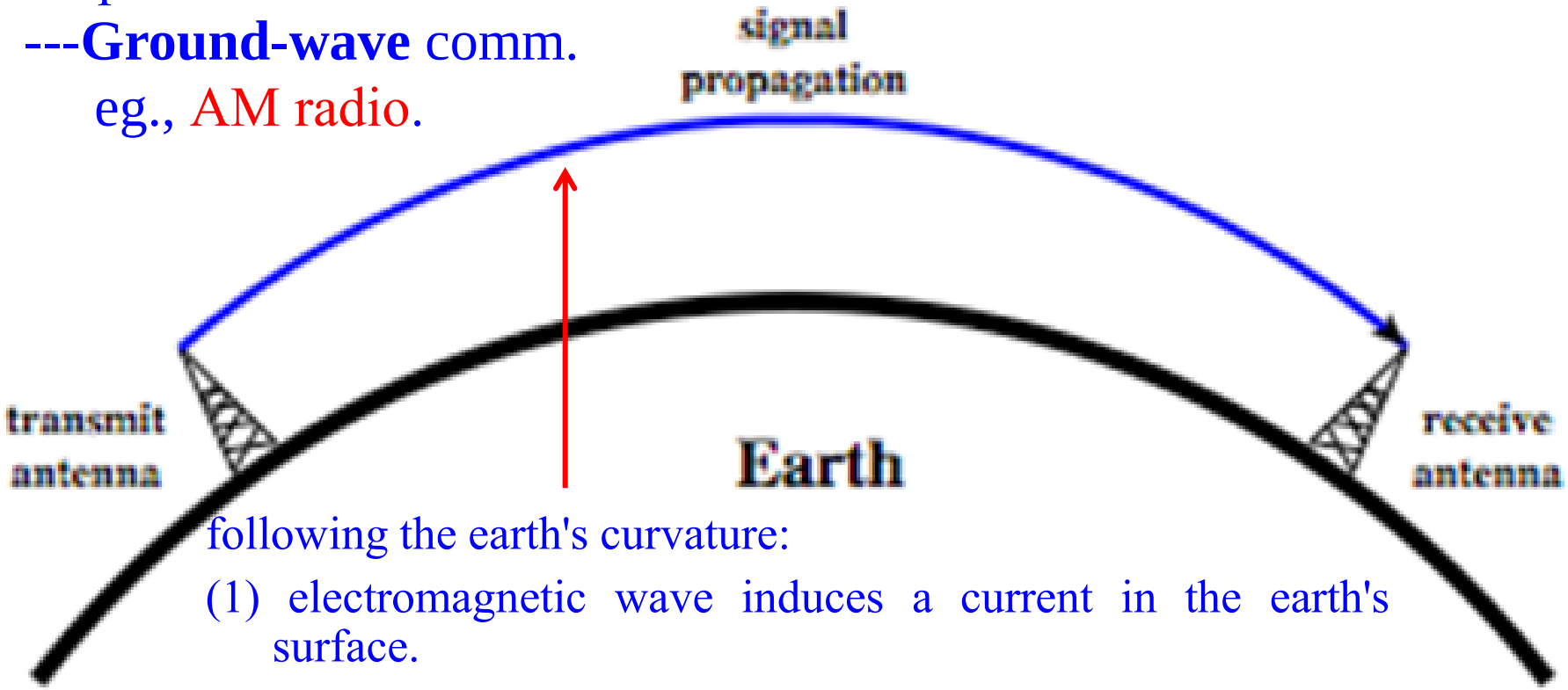
(c) Line-of-sight (LOS) propagation (above 2GHz)

4.6 Wireless Transmission

- Other two forms of propagation for the signals with different frequencies

  ---**Ground-wave** comm.

  eg., AM radio.



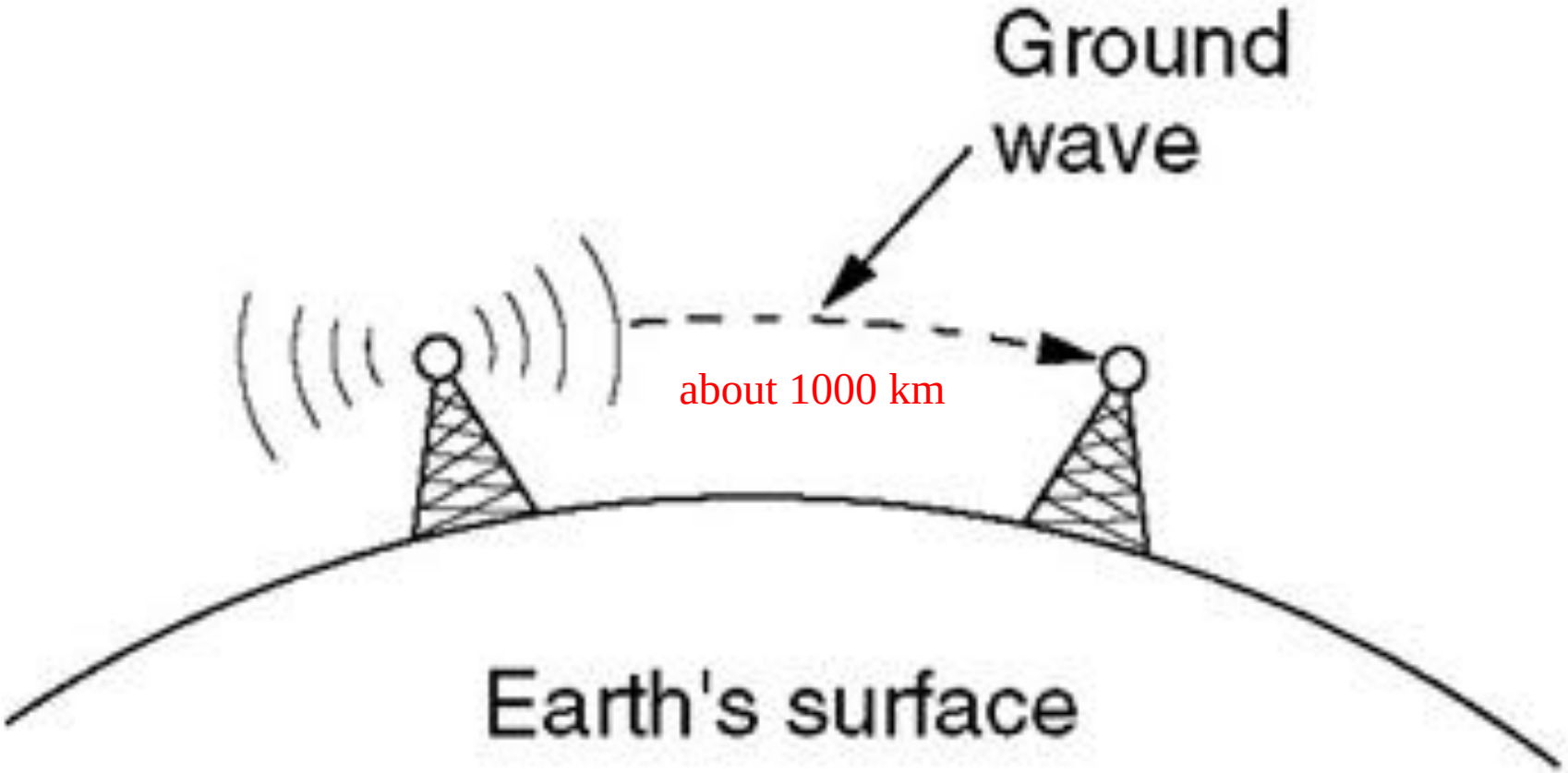
following the earth's curvature:

(1) electromagnetic wave induces a current in the earth's surface.

(2) Electromagnetic waves in this frequency range are scattered by the atmosphere.

(a) Ground-wave propagation (below 2 MHz)

4.6 Wireless Transmission

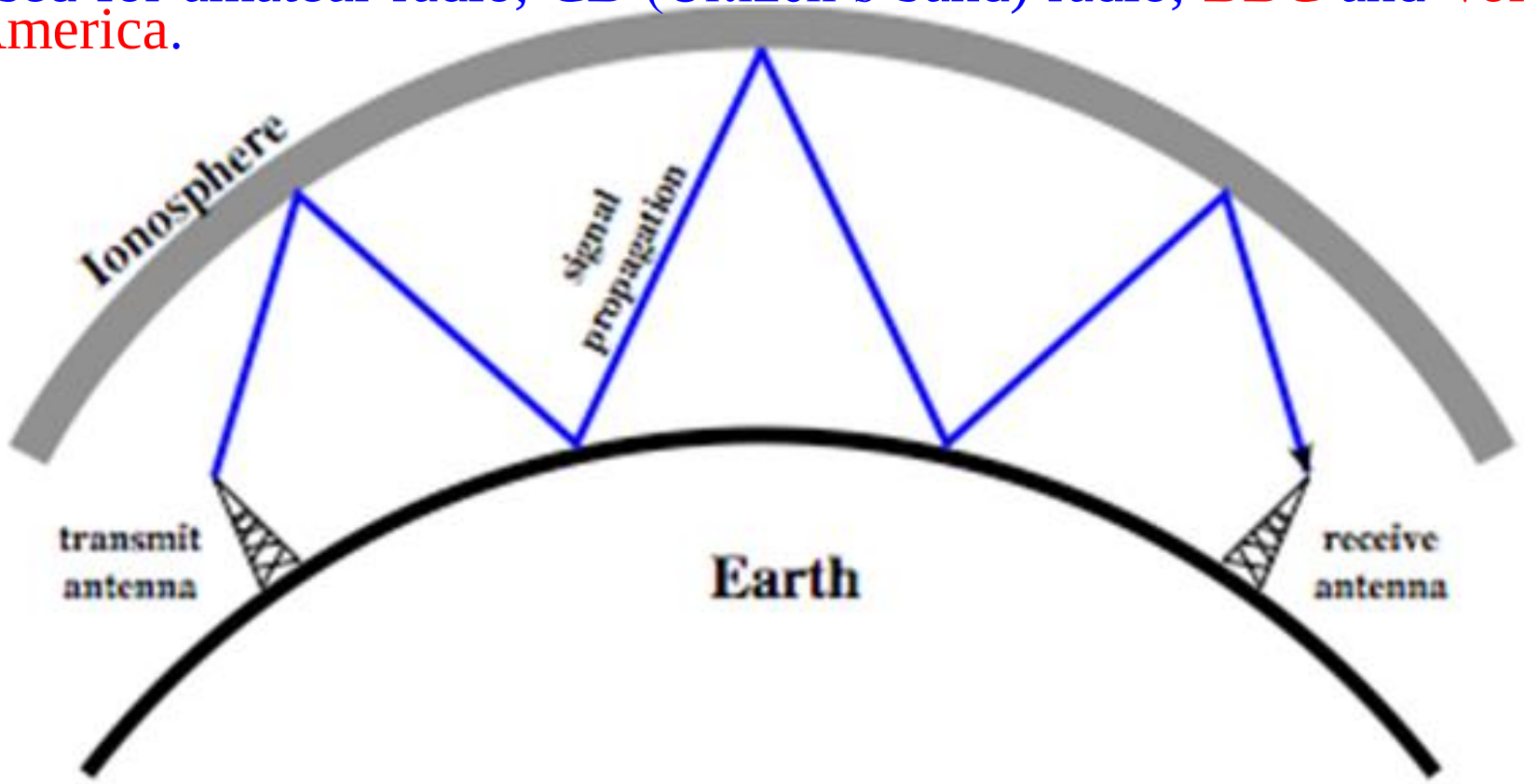


In the VLF, LF(Maritime radio), and MF(AM radio) bands, radio waves follow the curvature of the earth.

4.6 Wireless Transmission

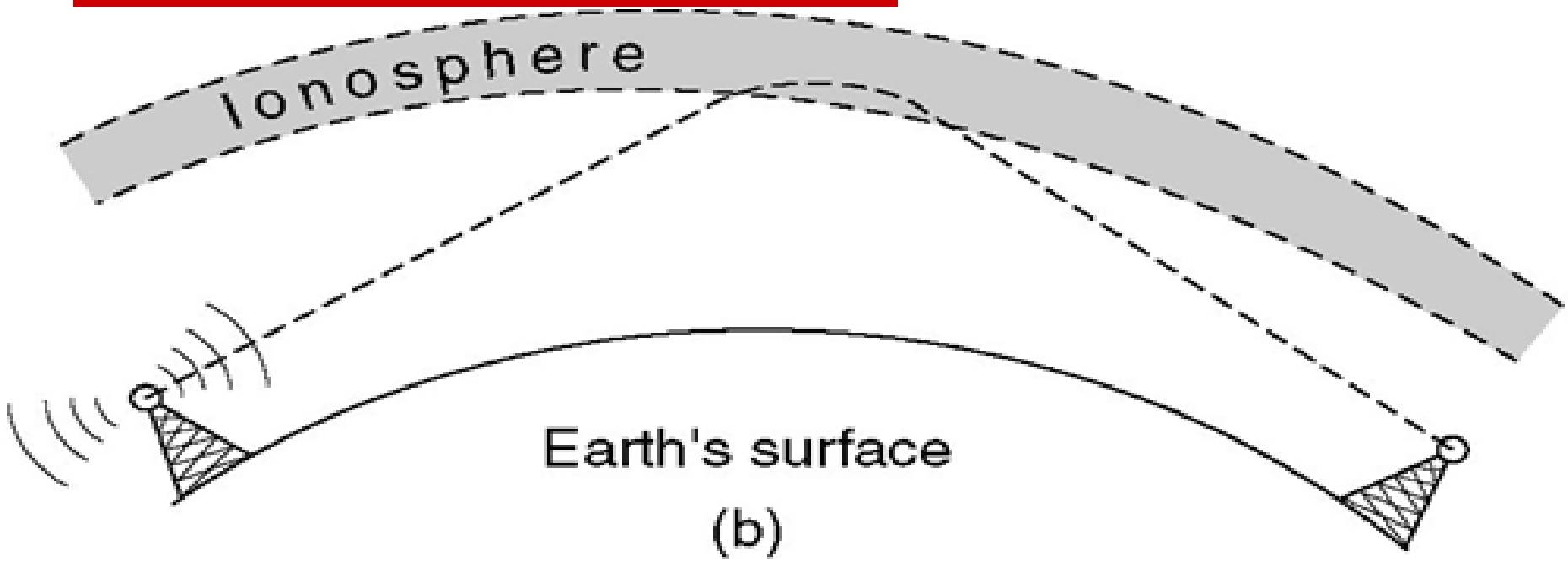
---Sky-wave comm.

used for amateur radio, CB (Citizen's band) radio, BBC and Voice of America.



(b) Sky-wave propagation (2 to 30 MHz)

4.6 Wireless Transmission



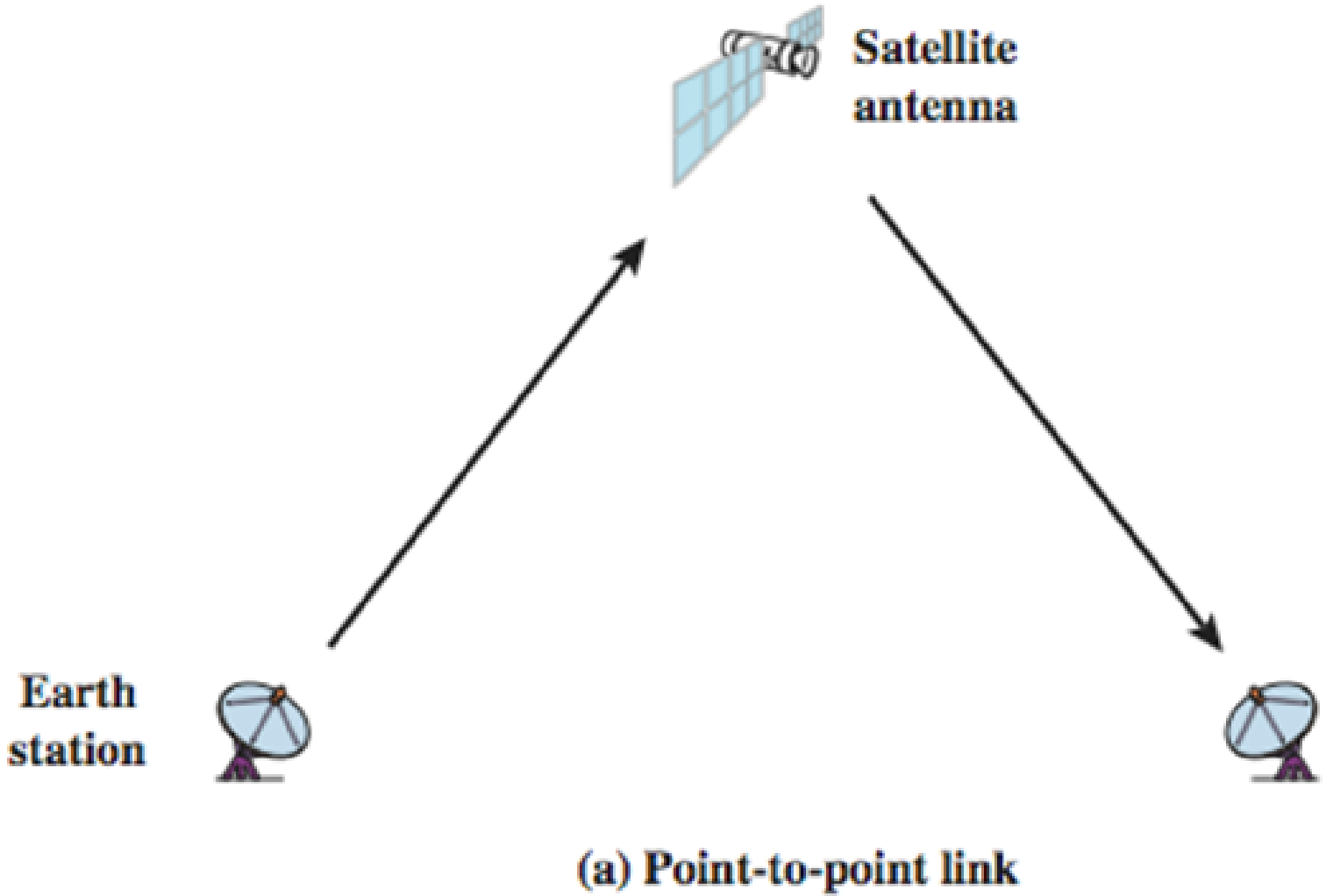
(b)

---电离层对于不同波长的电磁波表现出不同的特性。

- 波长短于10m（above 30MHz）的**微波**能穿过电离层。
- 波长超过3000km的**长波**，几乎会被电离层全部吸收。
- **中波**(MF)/**中短波**/**短波**(HF)，波长越短，电离层对它吸收少而反射多；电离层不稳定，对中波和中短波，白天吸收多，晚上吸收少。
- **短波**(HF) 最适宜天波传播，它可被电离层反射到几千千米以外。

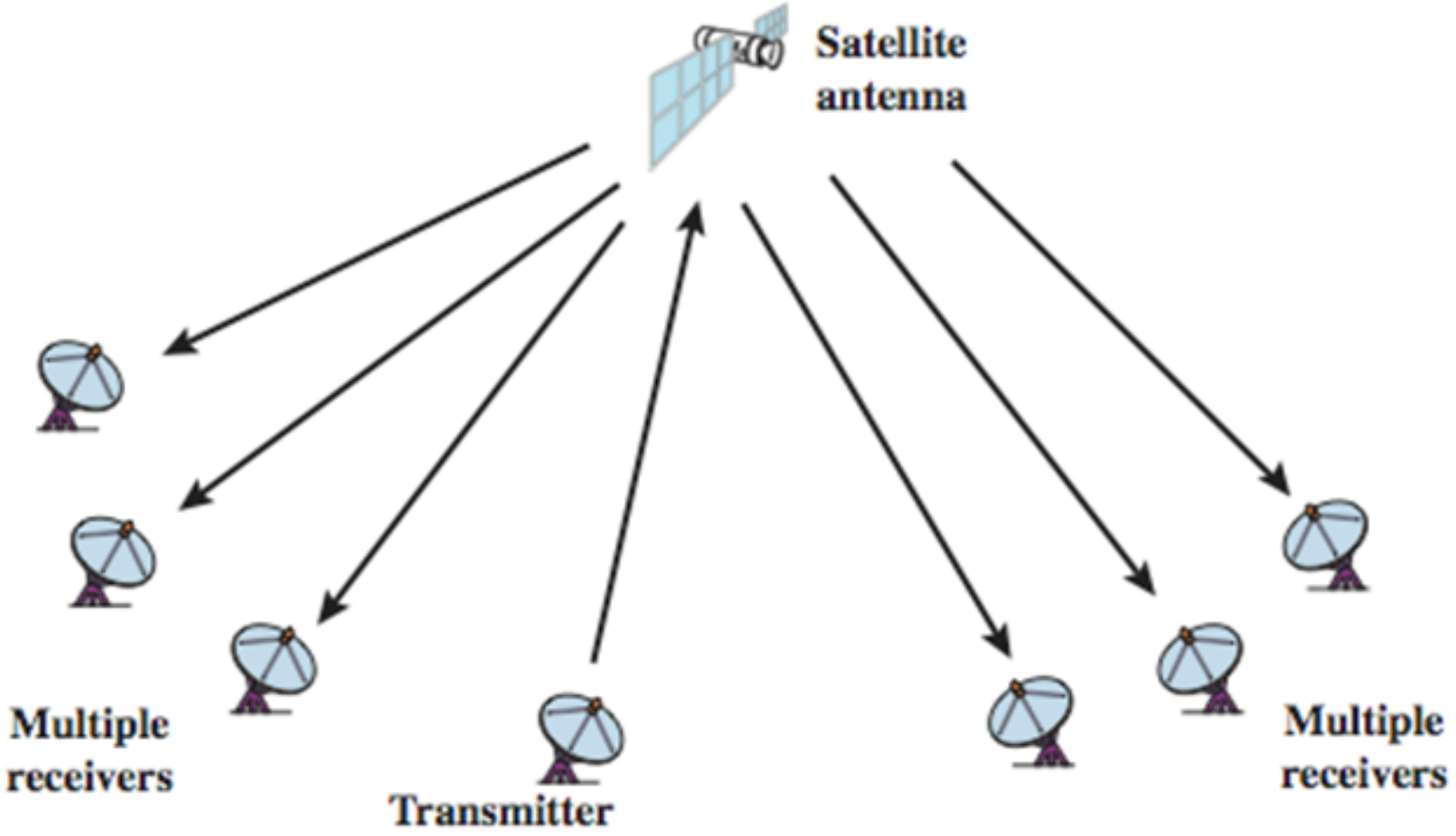
4.6 Wireless Transmission

6. Satellite Microwave



(a) Point-to-point link

4.6 Wireless Transmission



(b) Broadcast link

4.6 Wireless Transmission

--- satellite is relay station.

---receives on one frequency band (uplink, from earth to satellite), amplifies or repeats signal and transmits on another frequency (downlink).

- optimum frequency range for satellite transmission: 1~10 GHz.
- 4/6-GHz(saturated), **uplink** 5.925-6.425 GHz & **downlink** 3.7-4.2 GHz.
- 12/14-GHz, **uplink** 14-14.5GHz; **downlink** 11.7-12.2GHz.
- 20/30-GHz, **uplink** 27.5-30GHz; **downlink** 17.7-20.2GHz.

4.6 Wireless Transmission

The principal satellite bands (Tanenbaum, 4e)

Band	Downlink (GHz)	Uplink (GHz)	Bandwidth (MHz)	Problems
L	1.5	1.6	15	Low bandwidth; **crowded**
S	1.9	2.2	70	Low bandwidth; **crowded**
C	**4.0**	**6.0**	500	Terrestrial interference
Ku (K under)	**11**	**14**	500	Rain
Ka (K-above)	**20**	**30**	3500	Rain; equipment cost

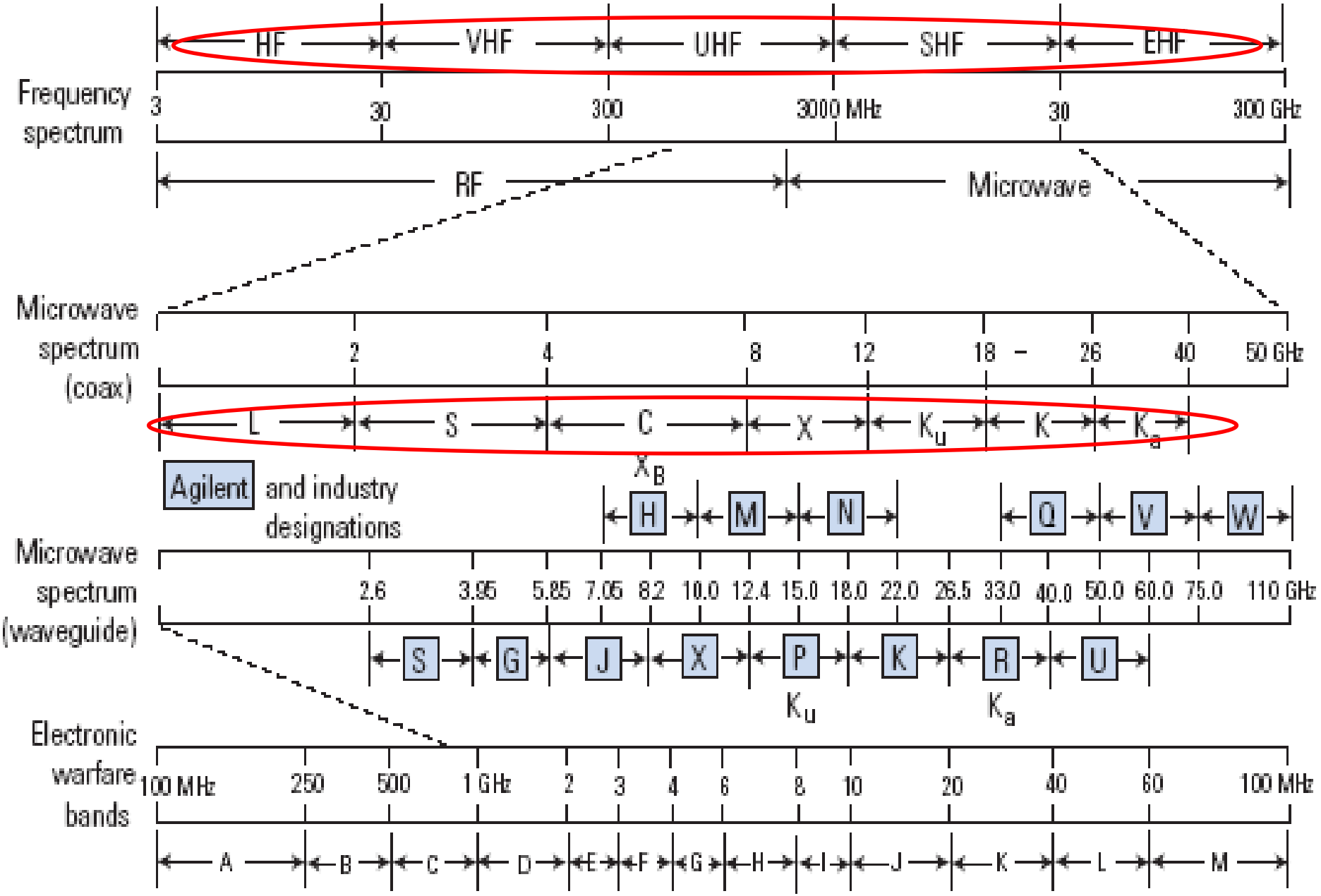
注：K band指中心波长1.5cm的电磁波。

4.6 Wireless Transmission

The satellite bands

波段名称	频率范围(GHz)	波长范围(mm)
L (Long)	1 - 2	300.00 - 150.00
S (Short)	2 - 4	150.00 - 75.00
C (Compromise of S & X)	4 - 8	75.00 - 37.50
X (eXtended)	8 - 12	37.50 - 25.00
Ku (K under)	12 - 18	25.00 - 16.67
K (Kurtz，德语"短"意)	18 - 27	16.67 - 11.11
Ka (K above)	27 - 40	11.11 - 7.50
Q波段	30 - 50	10.00 - 6.00
U波段	40 - 60	7.50 - 5.00
V波段	50 - 75	6.00 - 4.00
E波段	60 - 90	5.00 - 3.33
W波段	75 - 110	4.00 - 2.73
F波段	90 - 140	3.33 - 2.14
D波段	110 - 170	2.73 - 1.76

Frequency band data



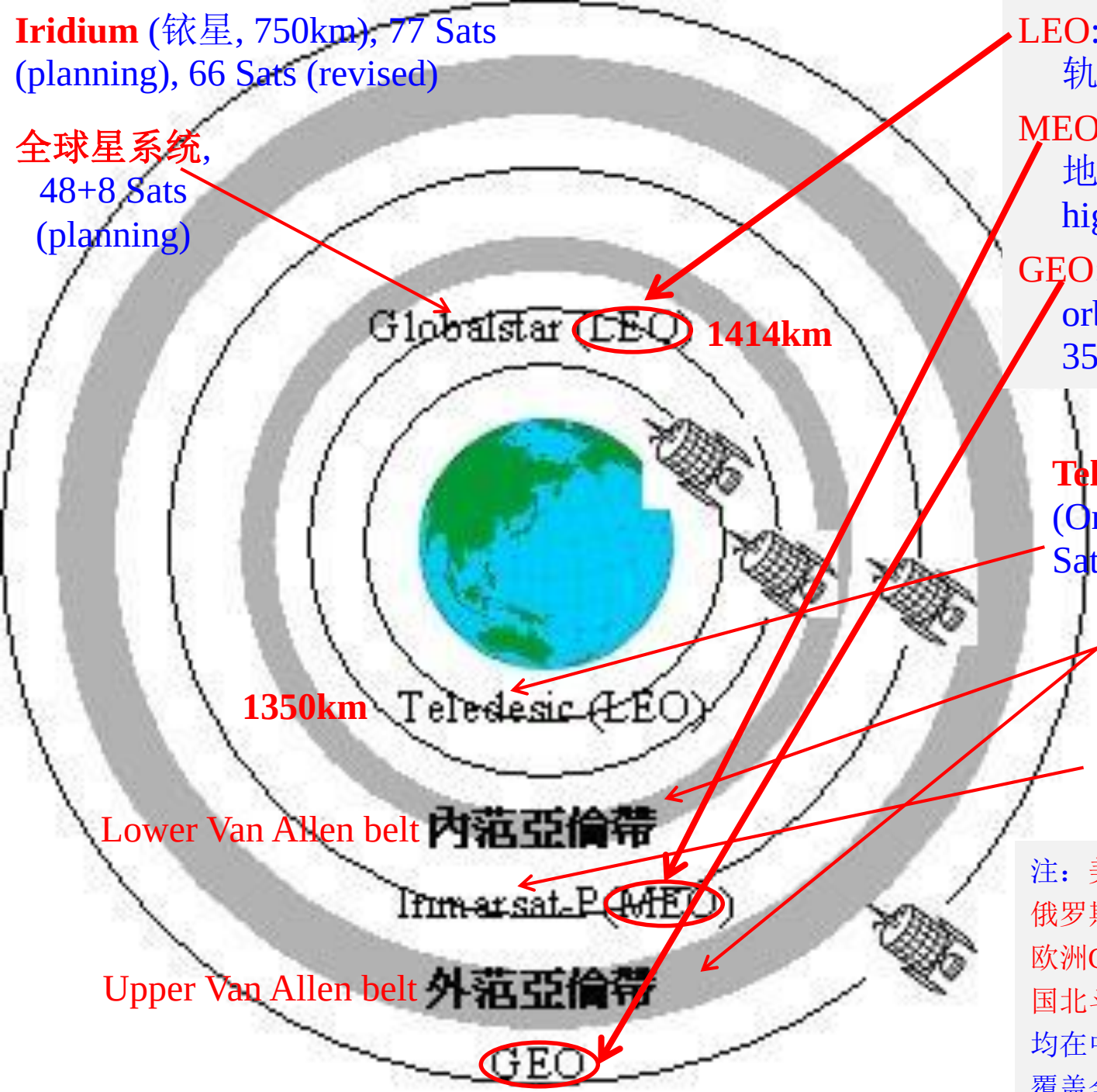
4.6 Wireless Transmission

---typically requires geo-stationary orbit (地球同步轨道) so as to be within the line of sight of its **earth stations** at all times

- height of 35,784km.
- two satellites using the same frequency band spaced apart to avoid the interference with each other

  (A) 4^o spacing in the 4/6-GHz band.

  (B) 3^o spacing at 12/14-GHz band.



Iridium (铱星, 750km), 77 Sats (planning), 66 Sats (revised)

全球星系统, 48+8 Sats (planning)

LEO: Low earth orbit (近地轨道), 100~1,000+km high.

MEO: Medium earth orbit (中地轨道), 3,000~15,000km high.

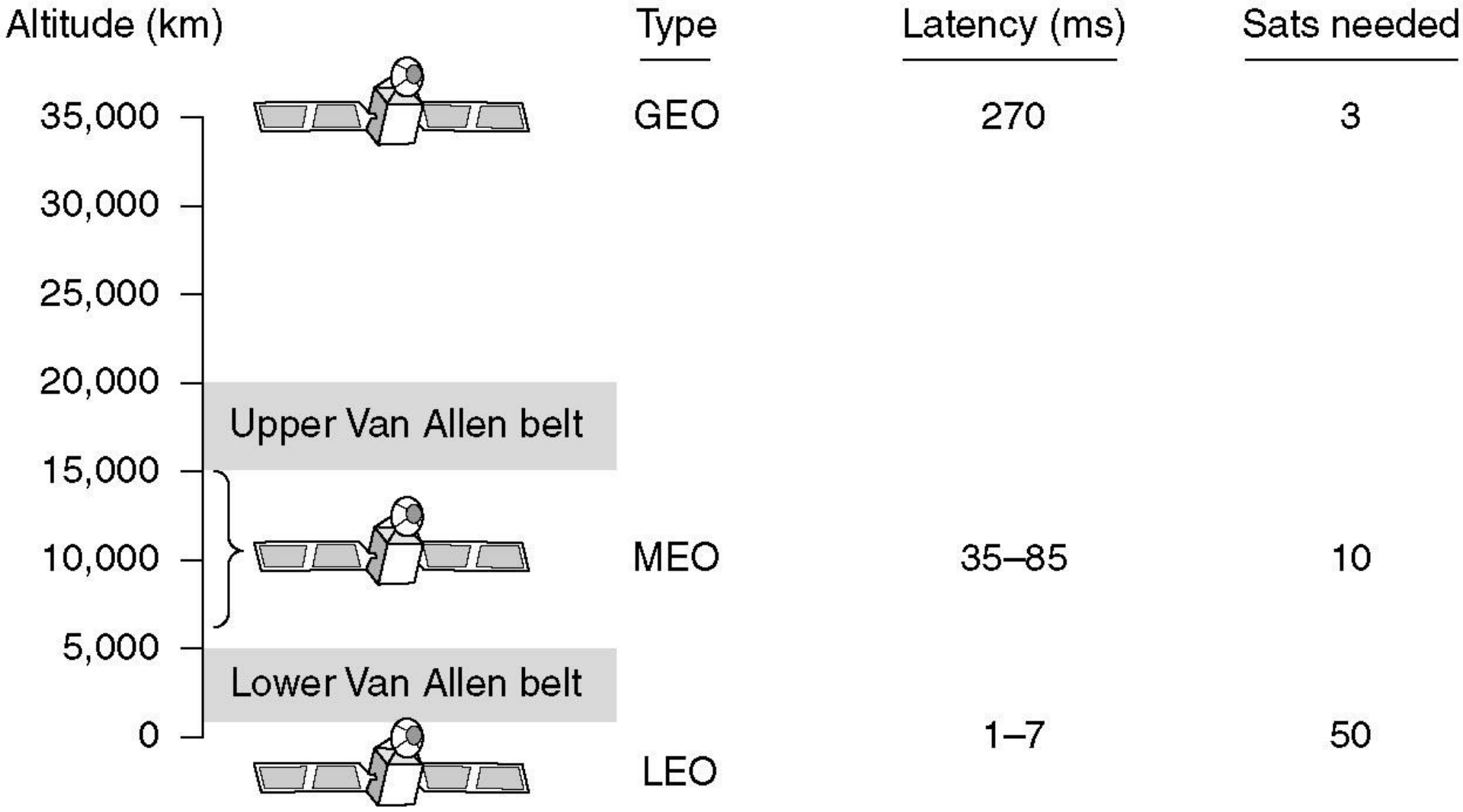
GEO: Geo-stationary earth orbit (地球同步轨道), 35,784km high.

Teledesic system, 840 Sats (Orig.), decreased to 288 Sats, halted on 2002.10.1.

Van Allen belt放射带

国际海事卫星 (International Maritime Satellite, INMARSAT)

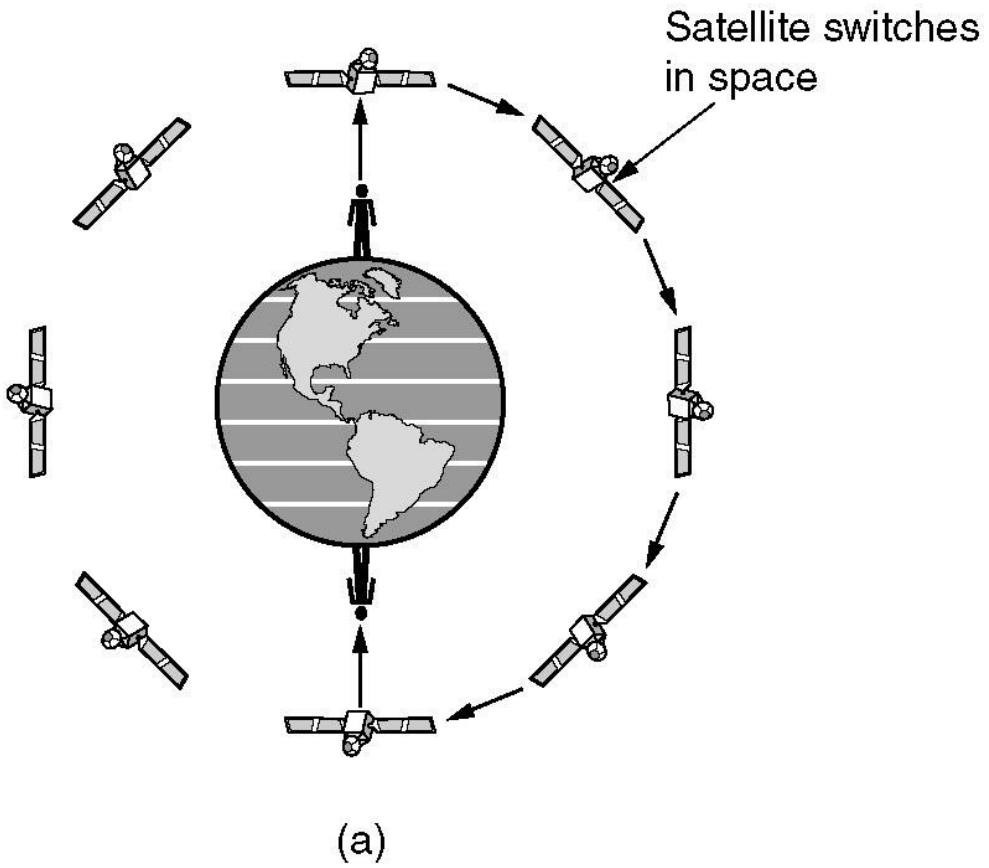
注：美国GPS (21+3, 20,200km)、俄罗斯GLONASS (24+5, 19,100km)、欧洲Galileo (27+3, 24,126km)、中国北斗COMPASS(30+5, 21,500km)均在中高圆轨道(预计2020年完成，覆盖全球接近四分之三的面积)。

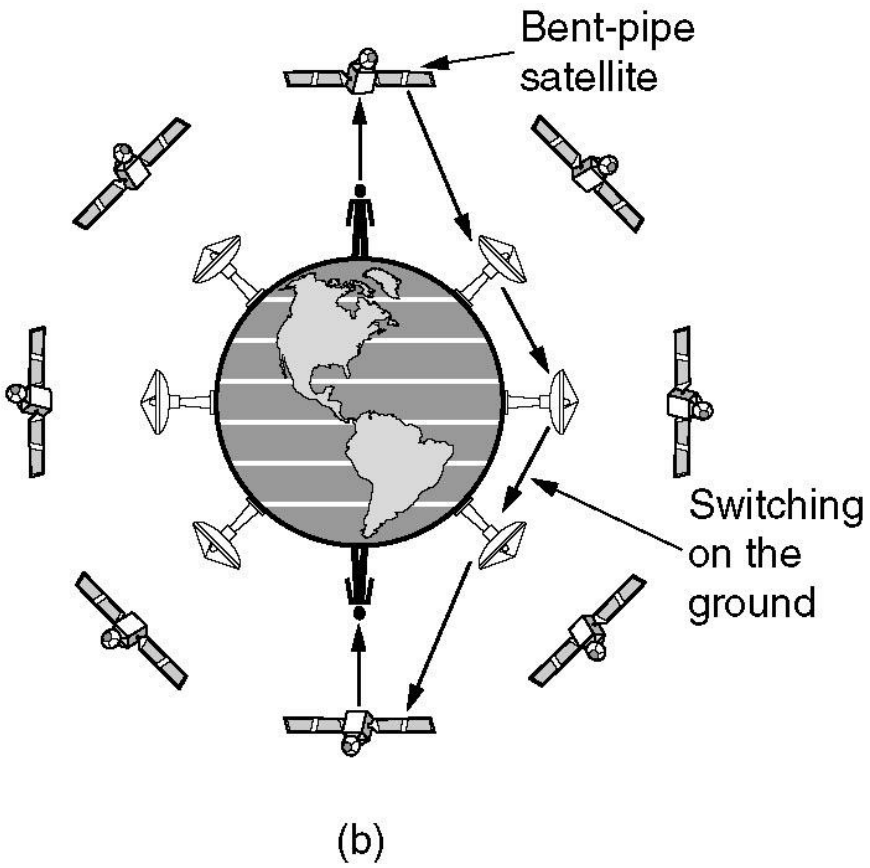


Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

From Tanenbaum (4e)

4.6 Wireless Transmission





(a) Relaying in space (Iridium). (b) Relaying on the ground (Globalstar).

From Tanenbaum (4e)

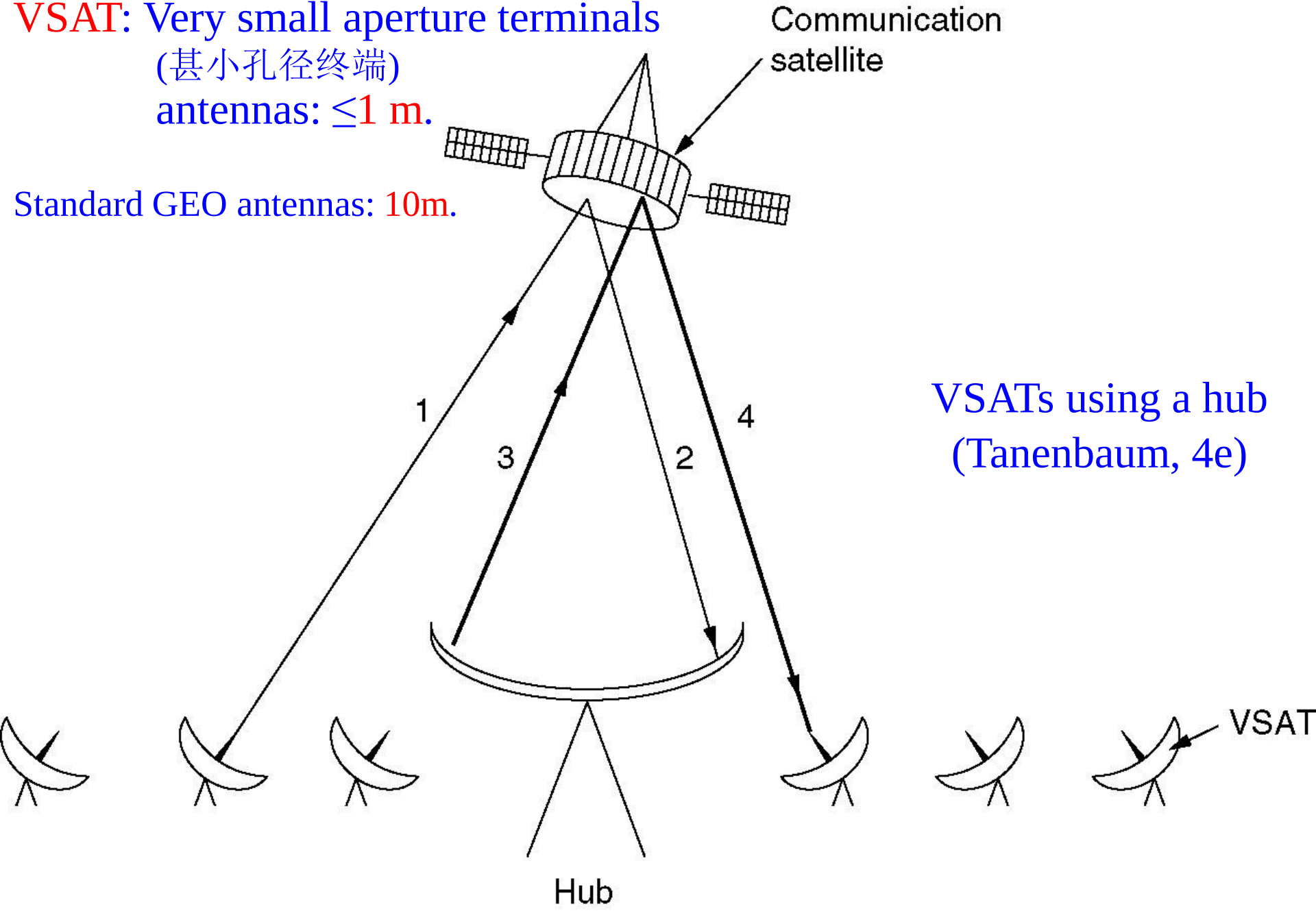
4.6 Wireless Transmission

---typical uses

- television
- long distance telephone
- private business networks
- global positioning

VSAT: Very small aperture terminals
(甚小孔径终端)
antennas: ≤1 m.

Standard GEO antennas: 10m.



VSATs using a hub
(Tanenbaum, 4e)

4.6 Wireless Transmission

7. Broadcast Radio

---Radio waves, easy to generate, travel long distances, and penetrate buildings easily (at low frequencies, i.e., VLF, LF and MF, eg, portable radio set).

---**Radio**: 3kHz to 300GHz.

---use **Broadcast Radio** (informal term), 30MHz - 1GHz, for:

- FM radio.
- UHF and VHF television.
- Cellular telephone.

---is omnidirectional (note that **microwave is directional**), so does not require dish-shaped antennas, that is, transmitter and receiver do not have to be carefully aligned physically.

---still need line of sight.

---suffers from multipath interference (at high freq., i.e., HF and VHF, do not pass through buildings well)

- reflections from land, water, other objects

4.6 Wireless Transmission

8. Some **Impairments** to Wireless Line of Sight Transmission

--- Free space loss

- loss of signal power with distance.

---Atmospheric Absorption

- from water vapour (22GHz) and oxygen (60GHz) absorption.
- Rain and fog cause scattering of radio wave.

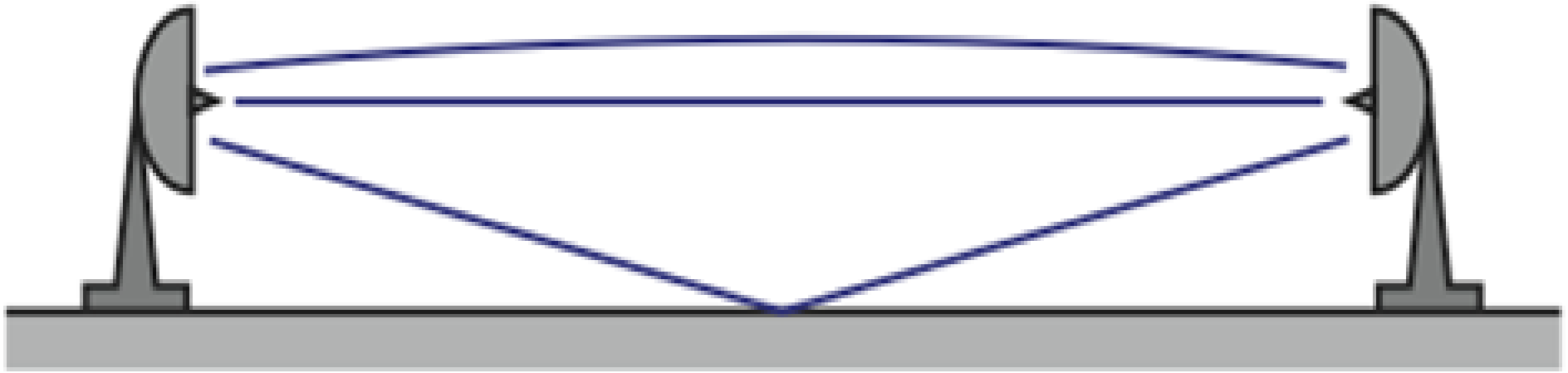
---Multipath

- multiple interfering signals from reflections.

---Refraction (折射)

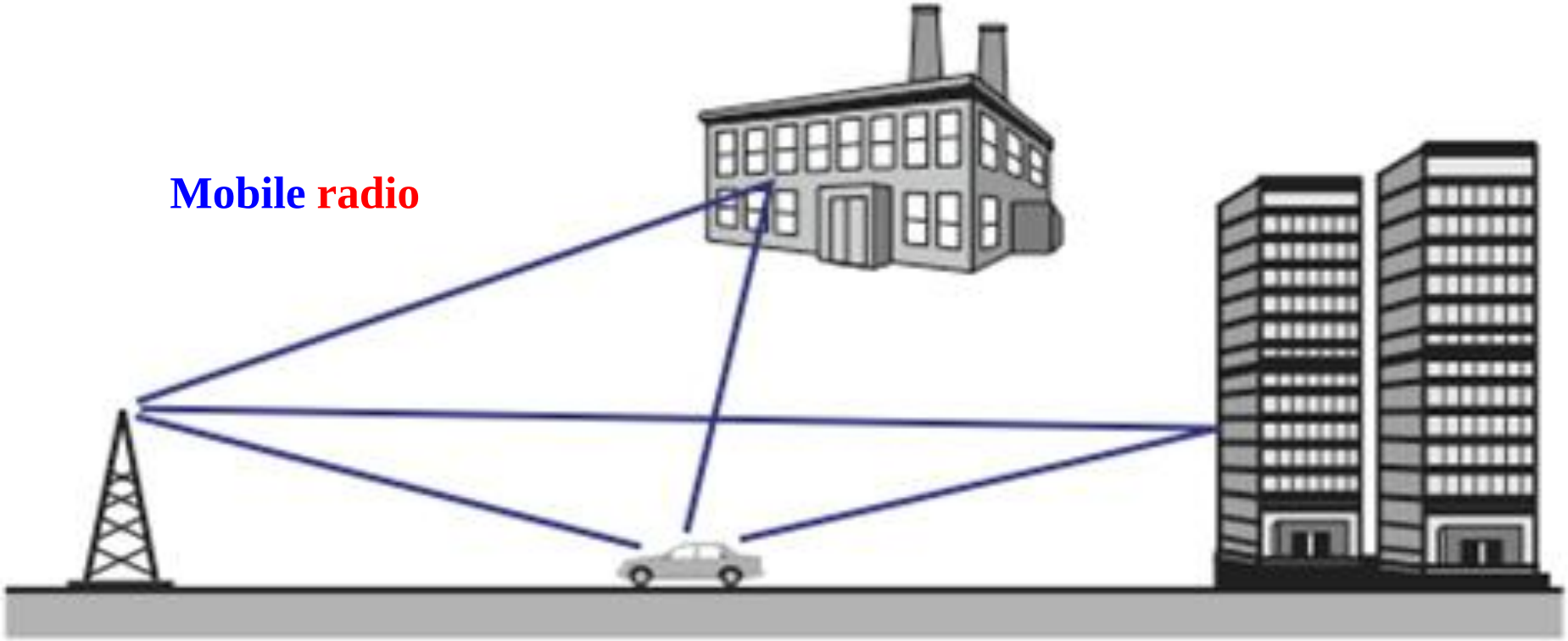
- bending signal (radio wave) away from receiver.

Multipath Interference



Microwave line of sight

Mobile radio



4.6 Wireless Transmission

9. Infrared

---are relatively directional, cheap, and easy to build, but blocked by walls.

**In general, from long-wave radio toward visible light, the waves behave more and more like light, and less and less like radio.

---Transceivers (收发器) must be within line of sight (or reflection).

---no frequency allocation issue (because of no licenses required).

---typical uses

- TV remote control.

**you can not control your neighbor's television with your TV remote control.

- IRD port (红外端口).