

THE PHYSICAL LAYER

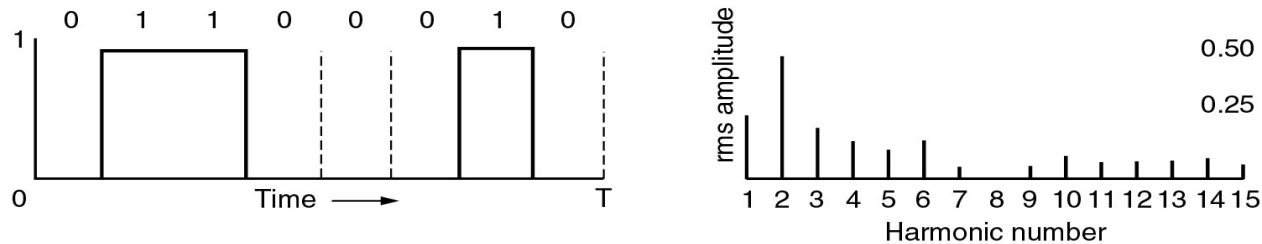
Data Communication - Links

The Theoretical Basis for Data Communication

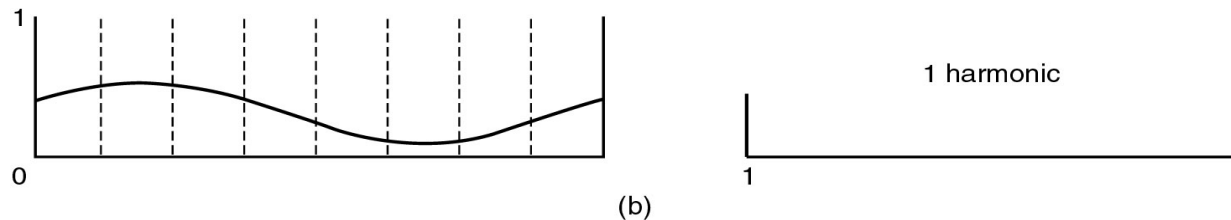


- Bandwidth-Limited Signals
- Maximum Data Rate of a Channel

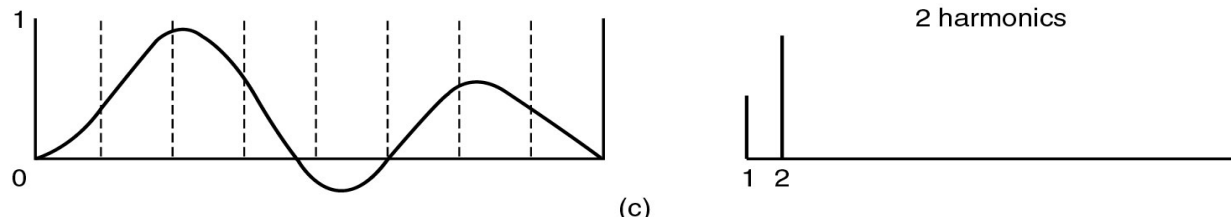
Bandwidth-Limited Signals



(a)



(b)

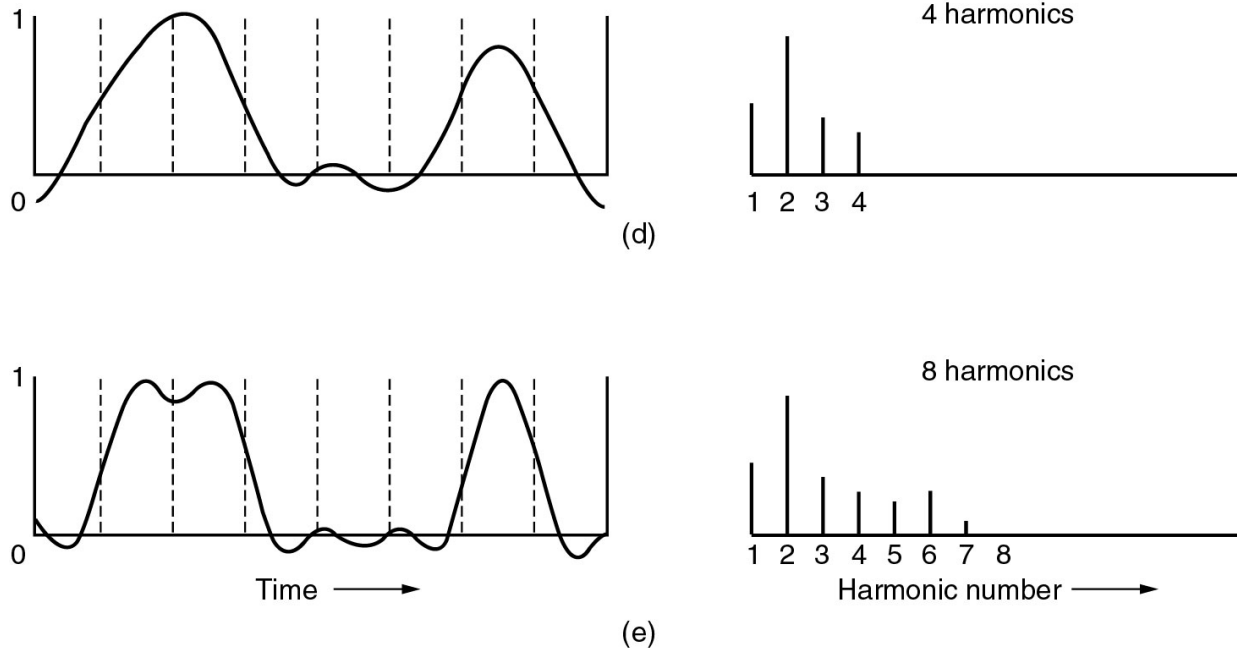


(c)

A binary signal and its root-mean-square Fourier amplitudes.

(b) – (c) Successive approximations to the original signal.

Bandwidth-Limited Signals (2)



(d) – (e) Successive approximations to the original signal.

Bandwidth-Limited Signals (3)

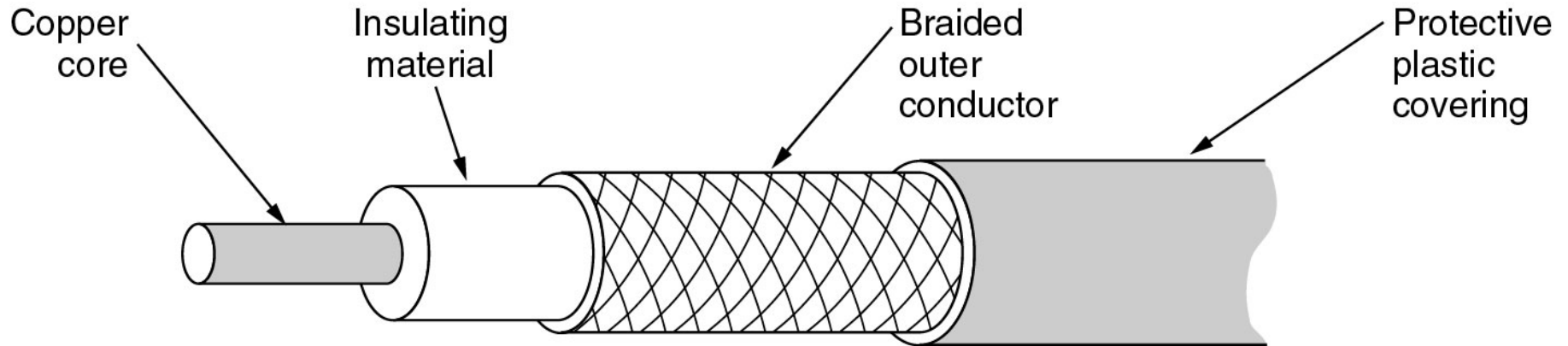
Relation between data rate and harmonics.

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Guided Transmission Data

- Coaxial Cable
- Twisted Pair
- Fiber Optics

Coaxial Cable



Twisted Pair



(a)



(b)

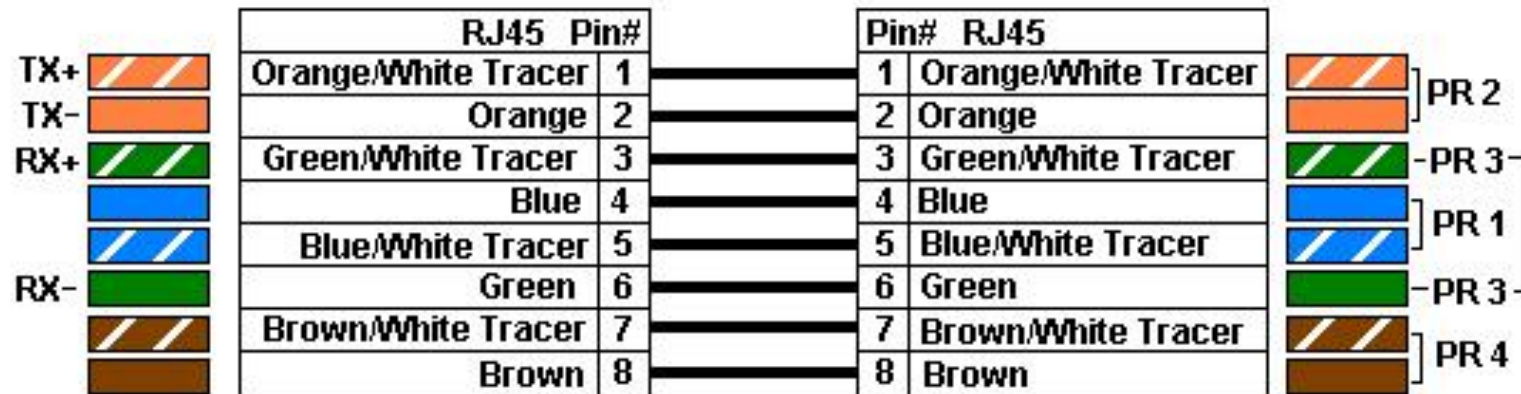
(a) Category 3 UTP.

(b) Category 5 UTP.

Cat5 Cabling Guide

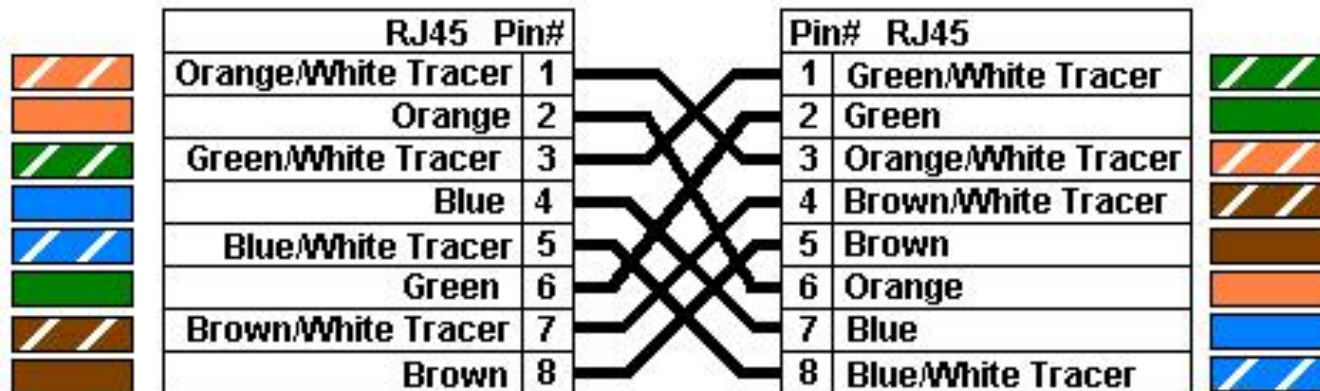
Color Standard
EIA/TIA T568B

Ethernet Patch Cable



Color Standard
EIA/TIA T568B

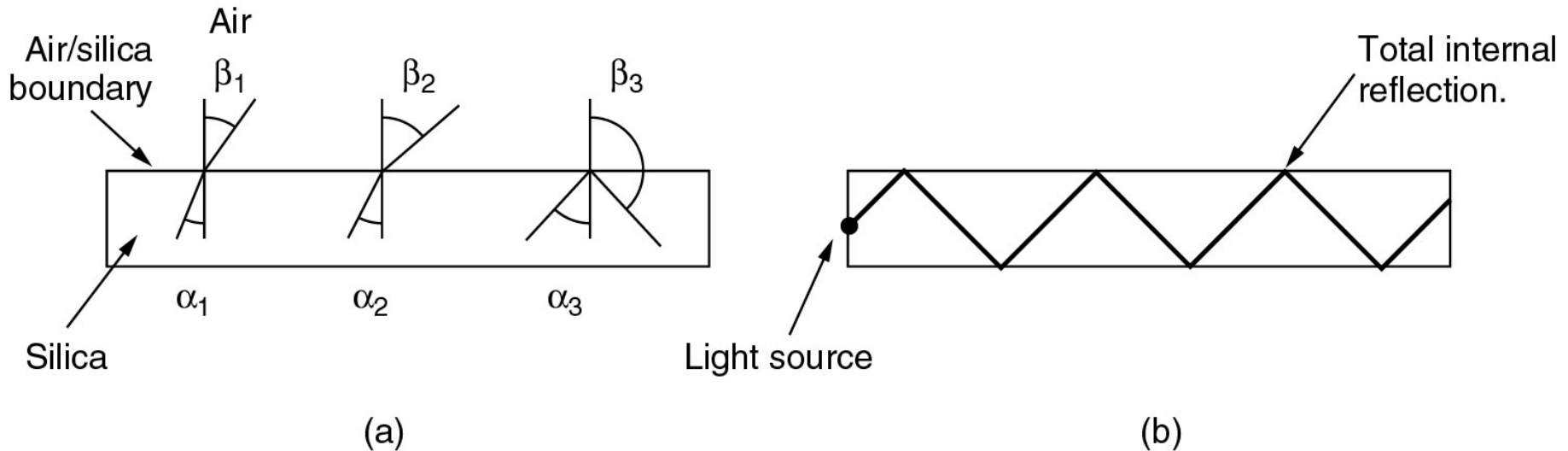
Ethernet Crossover Cable



Twisted Pair - Categories

Name ⇅	Typical construction ⇅	Bandwidth ⇅	Applications ⇅	Notes ⇅
Level 1		0.4 MHz	Telephone and modem lines	Not described in EIA/TIA recommendations. Unsuitable for modern systems. ^[9]
Level 2		4 MHz	Older terminal systems, e.g. IBM 3270	Not described in EIA/TIA recommendations. Unsuitable for modern systems. ^[9]
Cat 3	UTP ^[10]	16 MHz ^[10]	10BASE-T and 100BASE-T4 Ethernet ^[10]	Described in EIA/TIA-568. Unsuitable for speeds above 16 Mbit/s. Now mainly for telephone cables ^[10]
Cat 4	UTP ^[10]	20 MHz ^[10]	16 Mbit/s ^[10] Token Ring	Not commonly used ^[10]
Cat 5	UTP ^[10]	100 MHz ^[10]	100BASE-TX & 1000BASE-T Ethernet ^[10]	Common for current LANs. Superseded by Cat5e, but most Cat5 cable meets Cat5e standards. ^[10]
Cat 5e	UTP ^[10]	100 MHz ^[10]	100BASE-TX & 1000BASE-T Ethernet ^[10]	Enhanced Cat5. Common for current LANs. Same construction as Cat5, but with better testing standards. ^[10]
Cat 6	UTP ^[10]	250 MHz ^[10]	10GBASE-T Ethernet	ISO/IEC 11801 2nd Ed. (2002), ANSI/TIA 568-B.2-1. Most commonly installed cable in Finland according to the 2002 standard EN 50173-1.
Cat 6A	U/FTP, F/UTP	500 MHz	10GBASE-T Ethernet	Adds cable shielding. ISO/IEC 11801 2nd Ed. Am. 2. (2008), ANSI/TIA-568-C.1 (2009)
Cat 7	F/FTP, S/FTP	600 MHz	10GBASE-T Ethernet or POTS/CATV/1000BASE-T over single cable	Fully shielded cable. ISO/IEC 11801 2nd Ed. (2002)
Cat 7A	F/FTP, S/FTP	1000 MHz	10GBASE-T Ethernet or POTS/CATV/1000BASE-T over single cable	Uses all four pairs. ISO/IEC 11801 2nd Ed. Am. 2. (2008)
Cat 8/8.1	U/FTP, F/UTP	1600-2000 MHz	40GBASE-T Ethernet or POTS/CATV/1000BASE-T over single cable	In development (ANSI/TIA-568-C.2-1, ISO/IEC 11801 3rd Ed.)
Cat 8.2	F/FTP, S/FTP	1600-2000 MHz	40GBASE-T Ethernet or POTS/CATV/1000BASE-T over single cable	In development (ISO/IEC 11801 3rd Ed.)

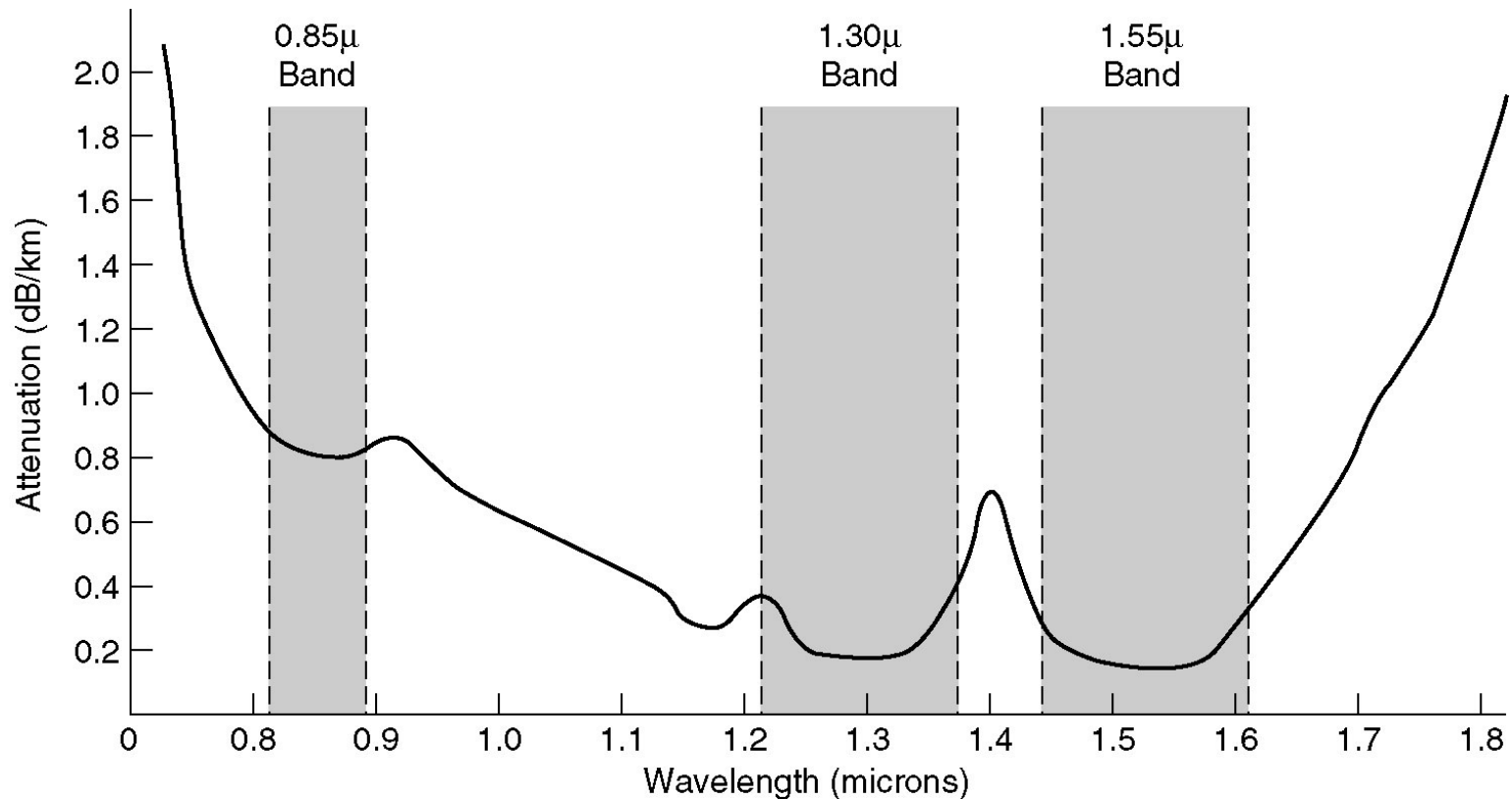
Fiber Optics



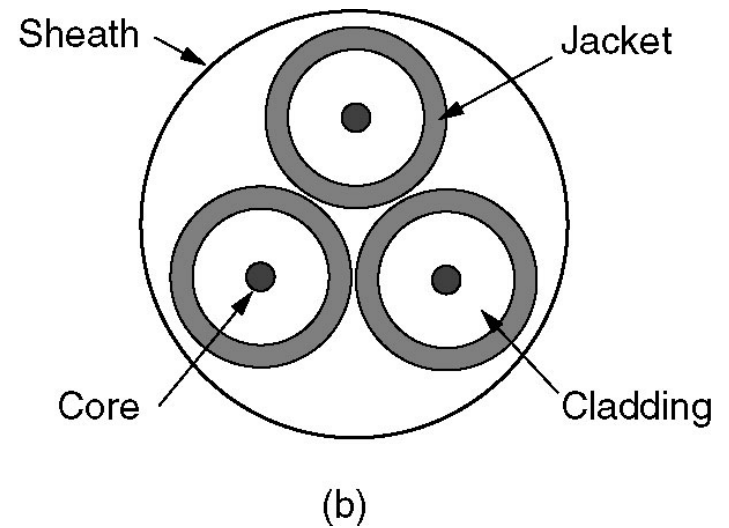
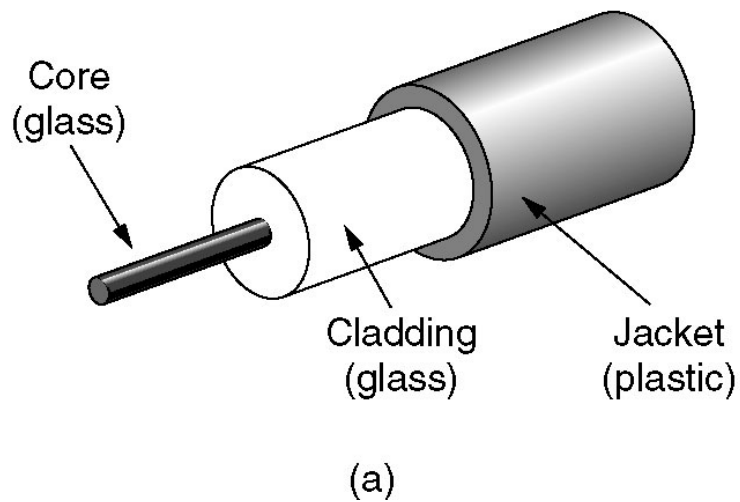
- (a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.
- (b) Light trapped by total internal reflection.

Transmission of Light through Fiber

Attenuation of light through fiber in the infrared region.



Fiber Cables



(a) Side view of a single fiber.

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

Fiber Cables – Light Sources

A comparison of semiconductor diodes and LEDs as light sources.

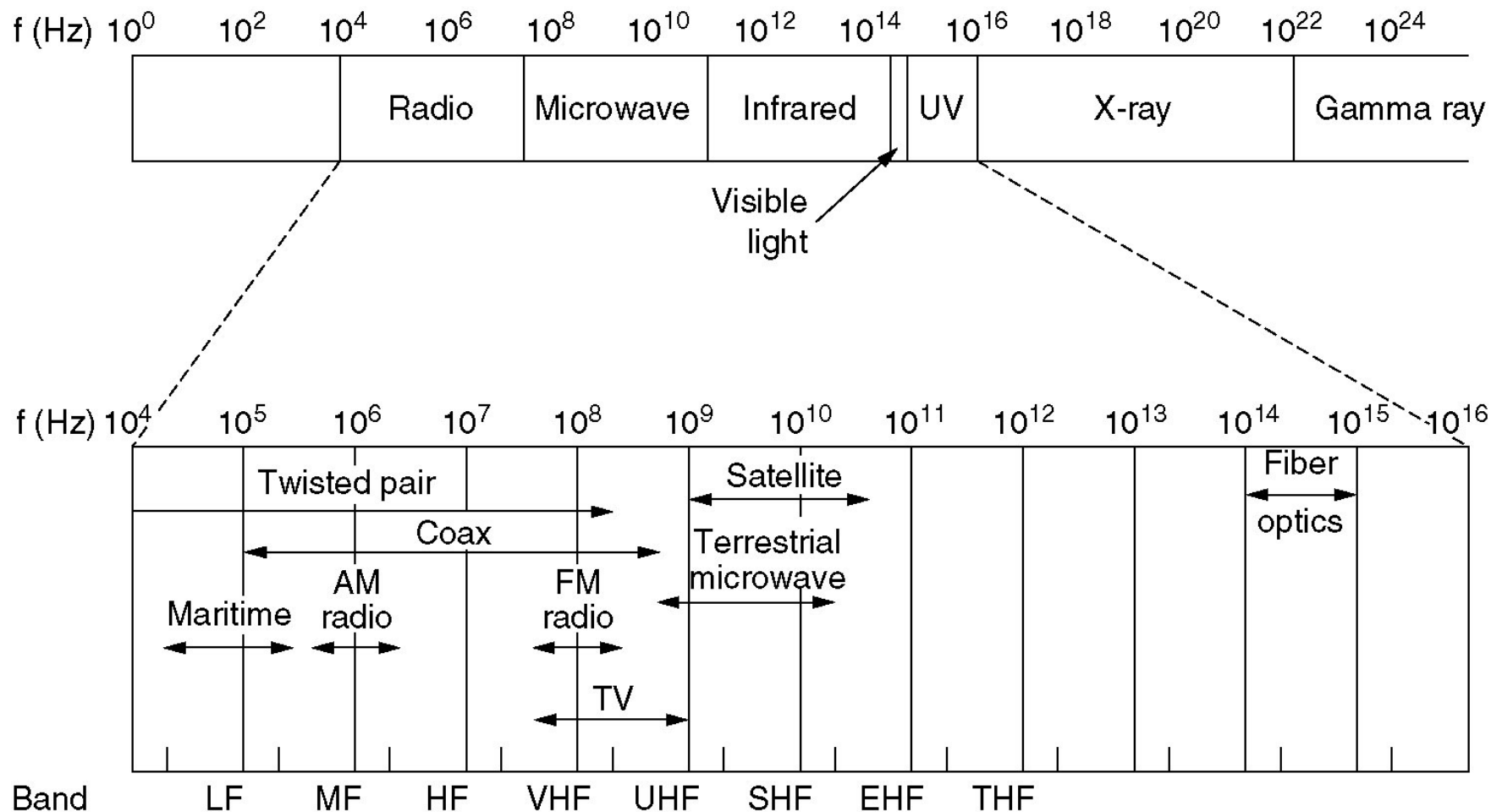
Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Wireless Transmission

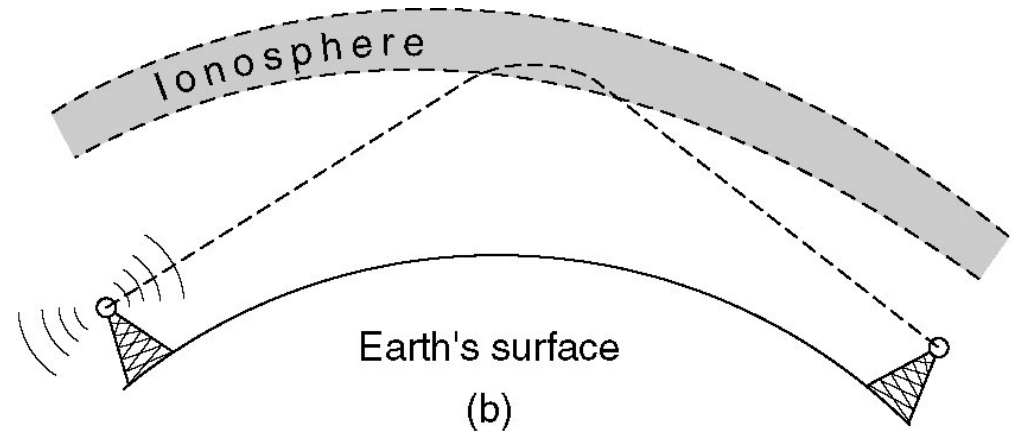
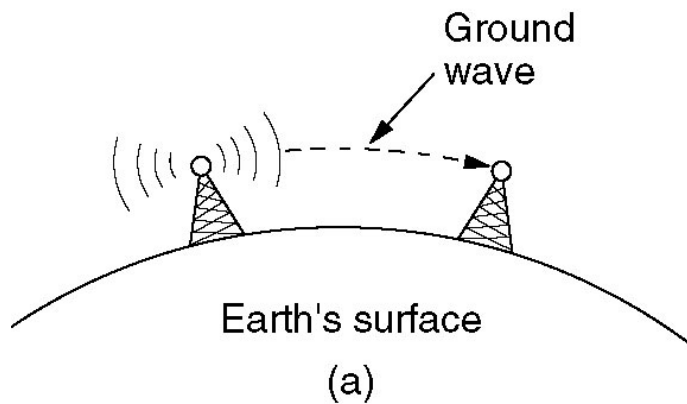
- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission

The Electromagnetic Spectrum

The electromagnetic spectrum and its uses for communication.



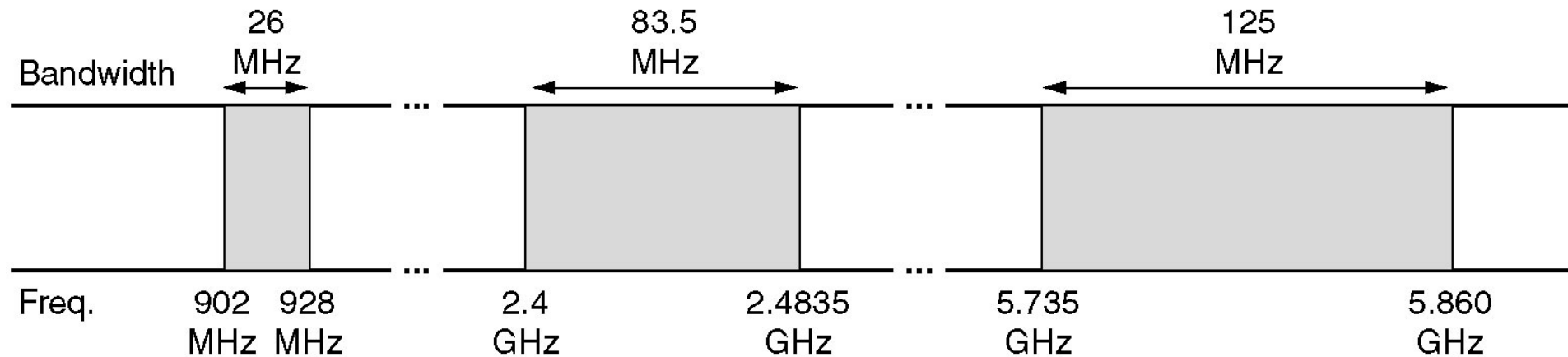
Radio Transmission



- (a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.
- (b) In the HF band, they bounce off the ionosphere.

Politics of the Electromagnetic Spectrum

The ISM bands in the United States.

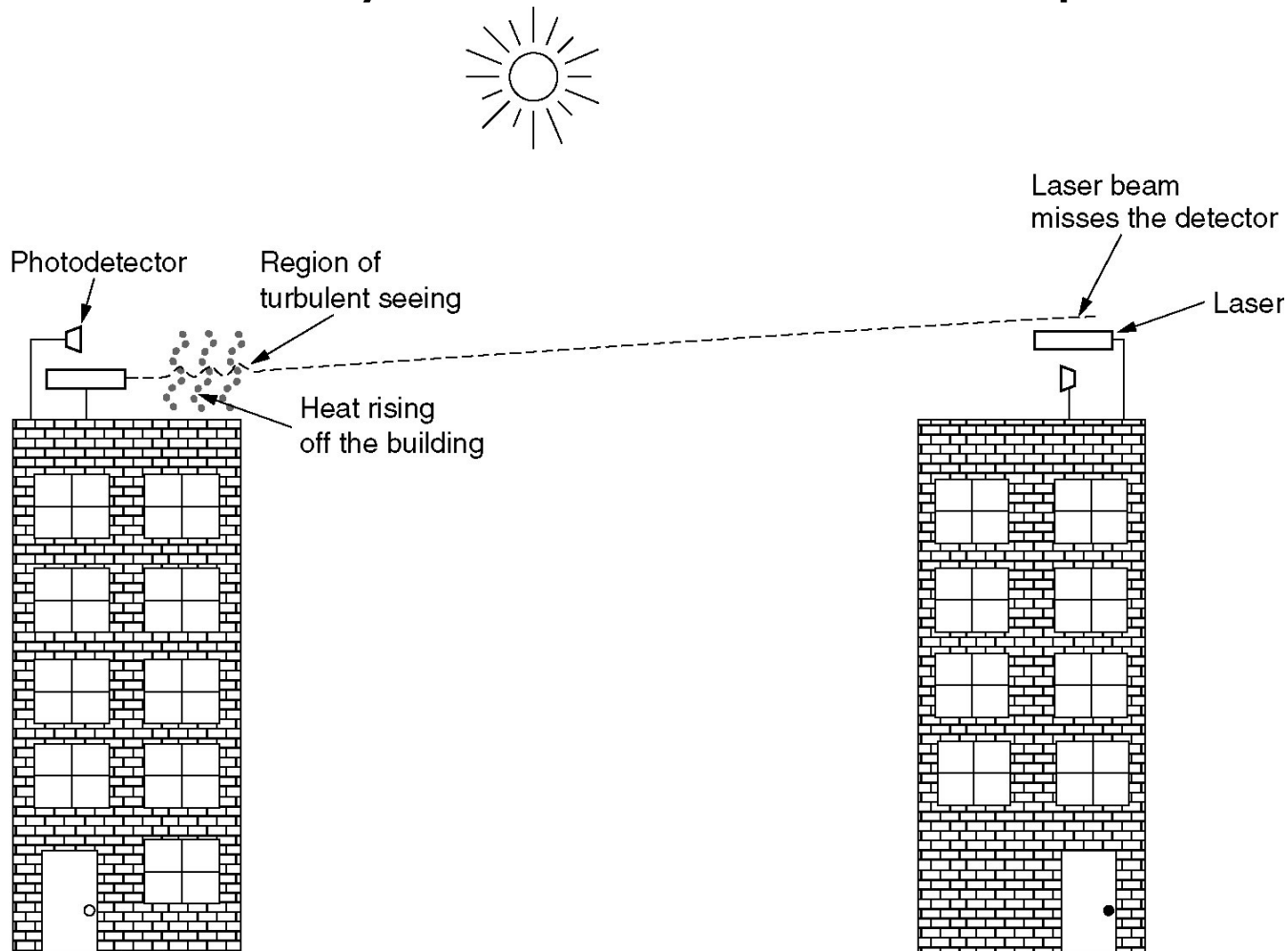


Use of the Frequencies

Frequency range		Type	Center frequency	Availability	Licensed users
6.765 MHz	6.795 MHz	A	6.78 MHz	Subject to local acceptance	FIXED SERVICE & Mobile service
13.553 MHz	13.567 MHz	B	13.56 MHz	Worldwide	FIXED & Mobile services except Aeronautical mobile (R) service
26.957 MHz	27.283 MHz	B	27.12 MHz	Worldwide	FIXED & MOBILE SERVICE except Aeronautical mobile service
40.66 MHz	40.7 MHz	B	40.68 MHz	Worldwide	Fixed, Mobile services & Earth exploration-satellite service
433.05 MHz	434.79 MHz	A	433.92 MHz	only in Region 1 , subject to local acceptance	AMATEUR SERVICE & RADIOLOCATION SERVICE , additional apply the provisions of footnote 5.280
902 MHz	928 MHz	B	915 MHz	Region 2 only (with some exceptions)	FIXED, Mobile except aeronautical mobile & Radiolocation service; in Region 2 additional Amateur service
2.4 GHz	2.5 GHz	B	2.45 GHz	Worldwide	FIXED, MOBILE, RADIOLOCATION, Amateur & Amateur-satellite service
5.725 GHz	5.875 GHz	B	5.8 GHz	Worldwide	FIXED-SATELLITE , RADIOLOCATION, MOBILE, Amateur & Amateur-satellite service
24 GHz	24.25 GHz	B	24.125 GHz	Worldwide	AMATEUR, AMATEUR-SATELLITE , RADIOLOCATION & Earth exploration-satellite service (active)
61 GHz	61.5 GHz	A	61.25 GHz	Subject to local acceptance	FIXED, INTER-SATELLITE , MOBILE & RADIOLOCATION SERVICE
122 GHz	123 GHz	A	122.5 GHz	Subject to local acceptance	EARTH EXPLORATION-SATELLITE (passive), FIXED, INTER-SATELLITE, MOBILE, SPACE RESEARCH (passive) & Amateur service
244 GHz	246 GHz	A	245 GHz	Subject to local acceptance	RADIOLOCATION, RADIO ASTRONOMY , Amateur & Amateur-satellite service

Lightwave Transmission

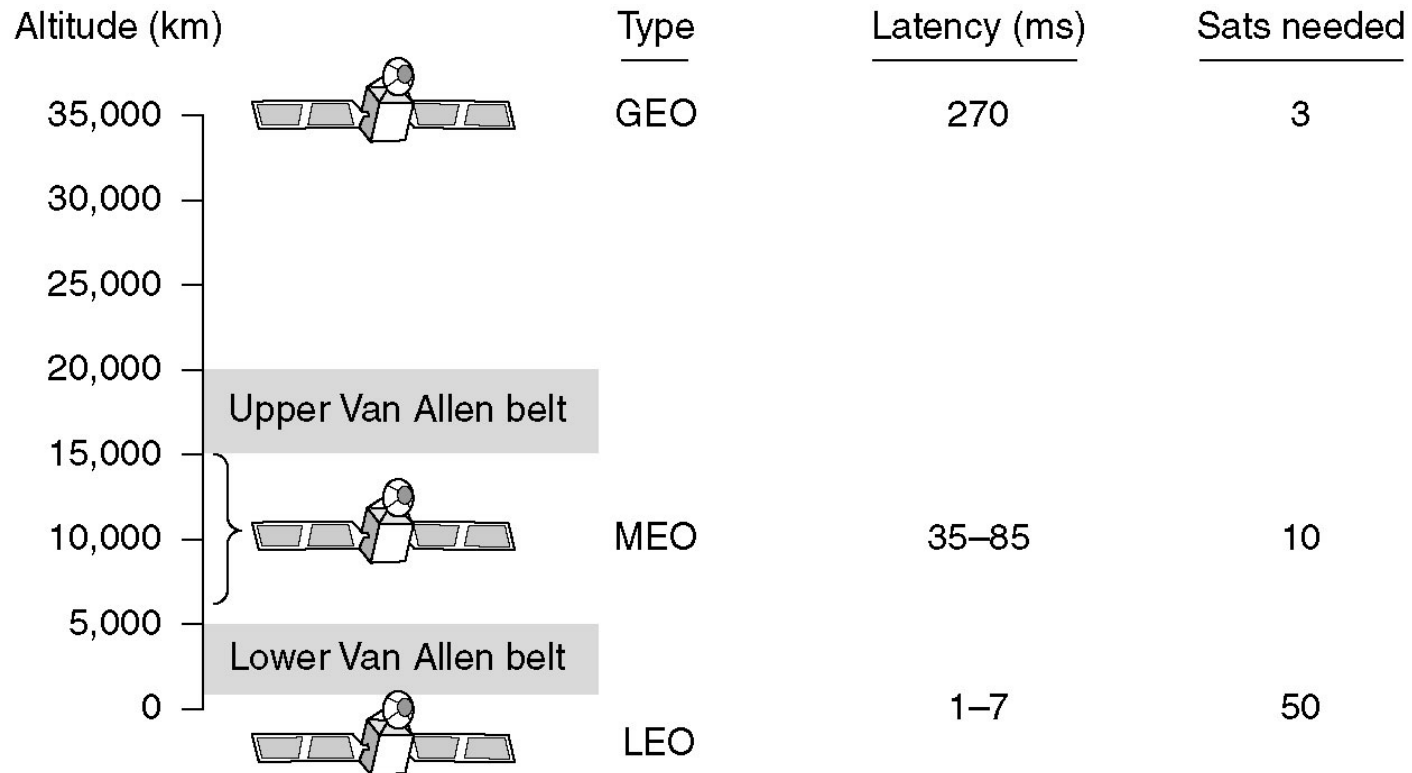
A bidirectional system with two lasers is pictured here.



Communication Satellites

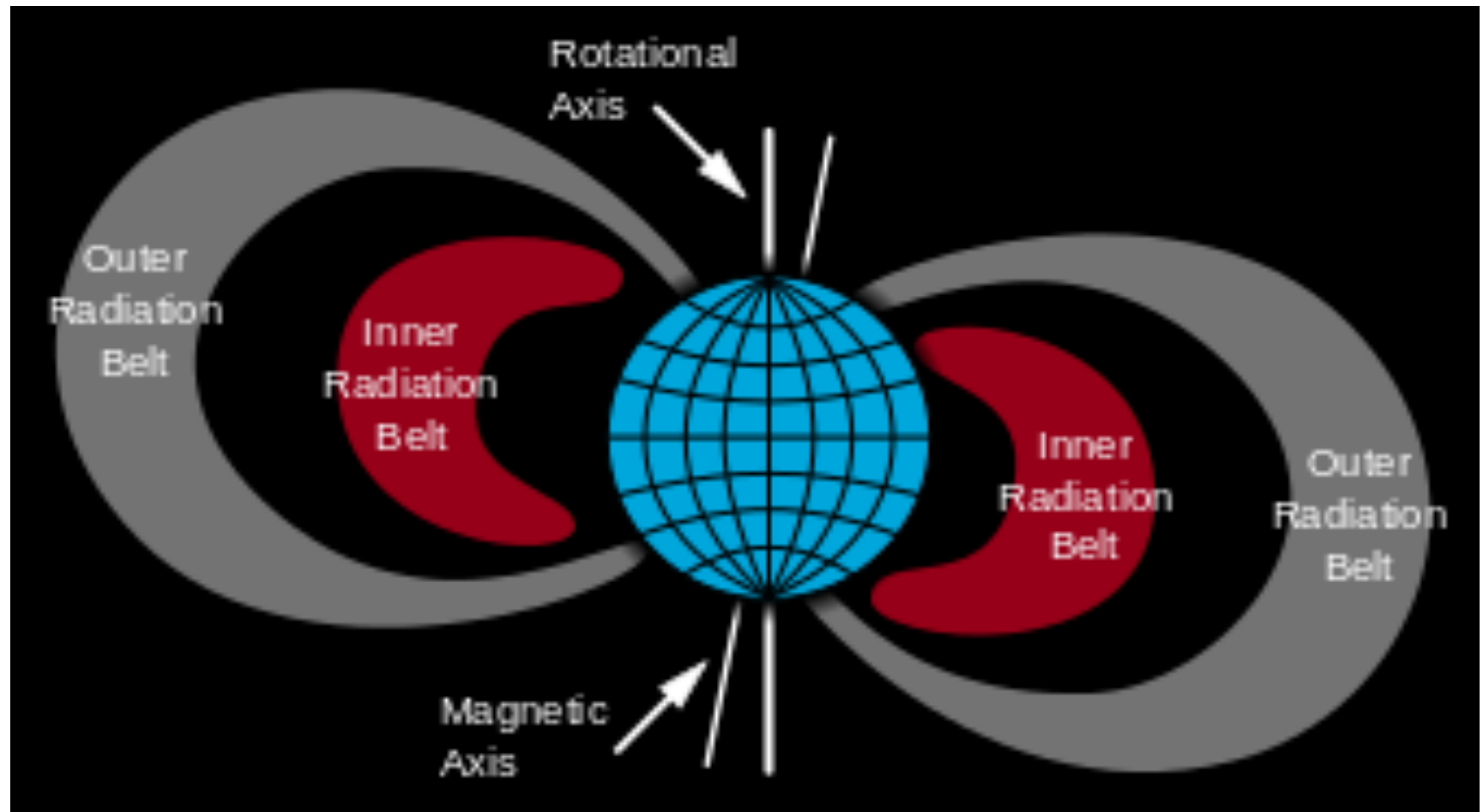
- Geostationary Satellites
- Medium-Earth Orbit Satellites
- Low-Earth Orbit Satellites
- Satellites versus Fiber

Communication Satellites



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

Van Alan Belts

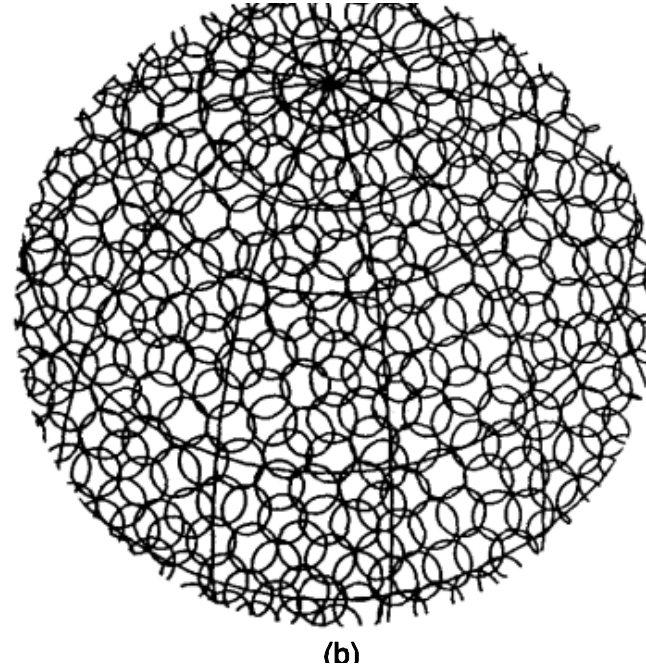
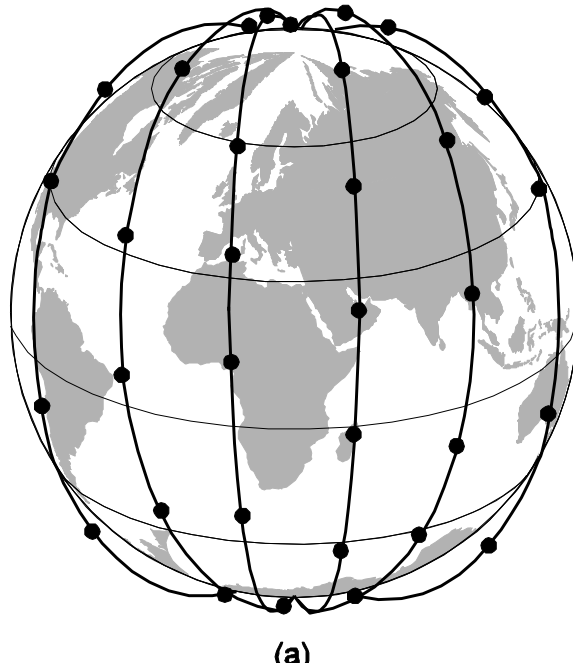


Communication Satellites - Frequencies

The principal satellite bands.

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

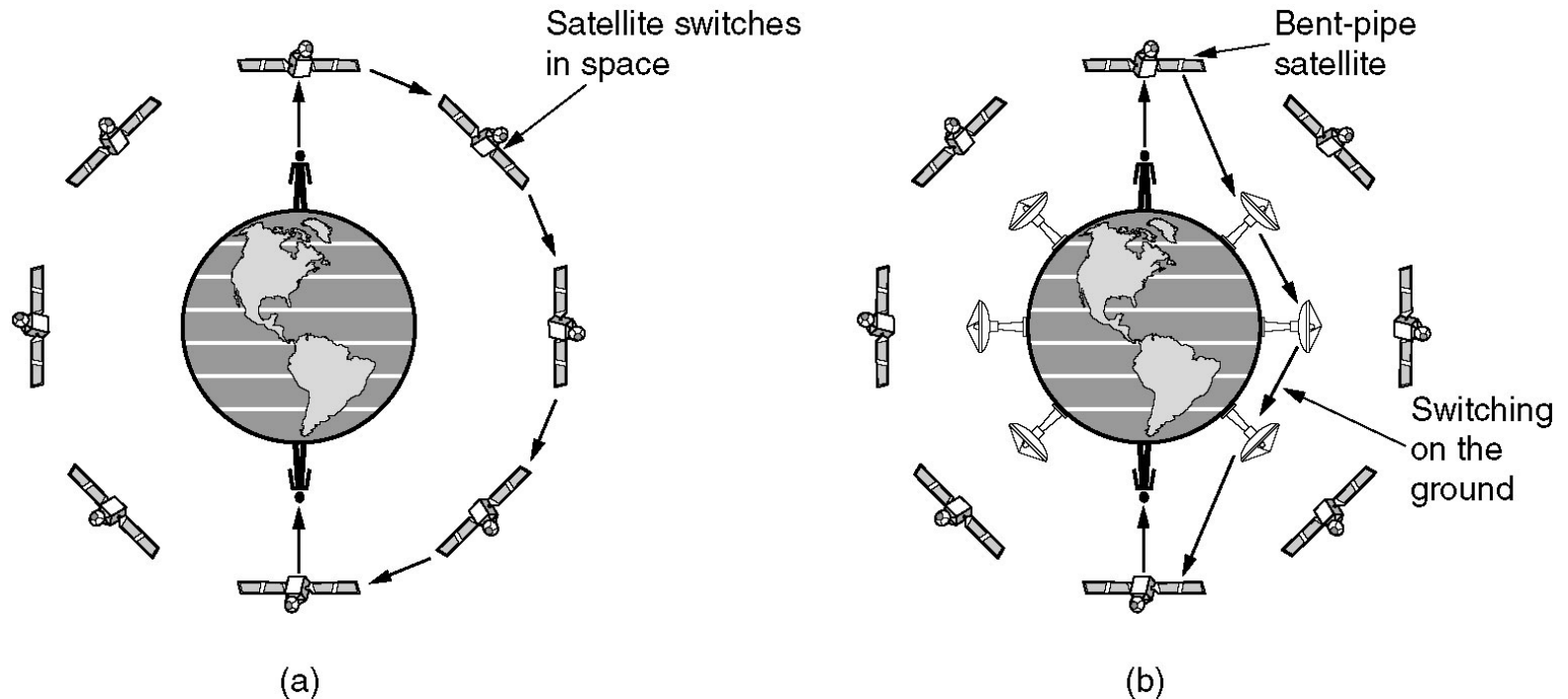
Low-Earth Orbit Satellites - Iridium



(a) The Iridium satellites from six necklaces around the earth.

(b) 1628 moving cells cover the earth.

Globalstar



(a) Relaying in space.

(b) Relaying on the ground.