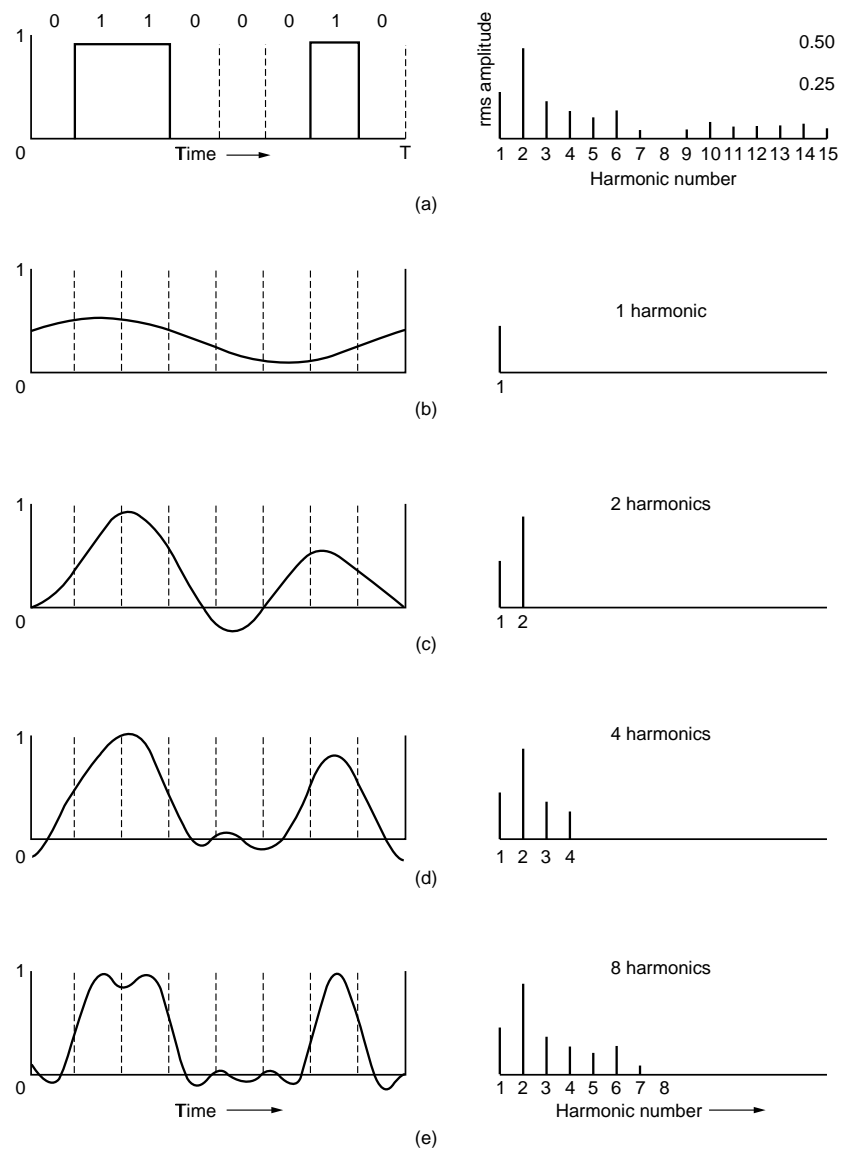


# 2

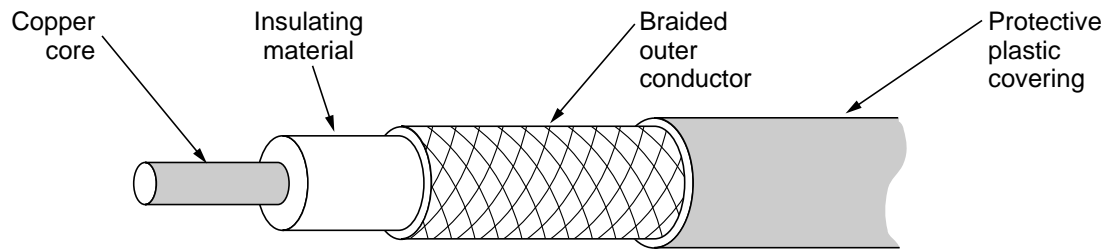
## THE PHYSICAL LAYER



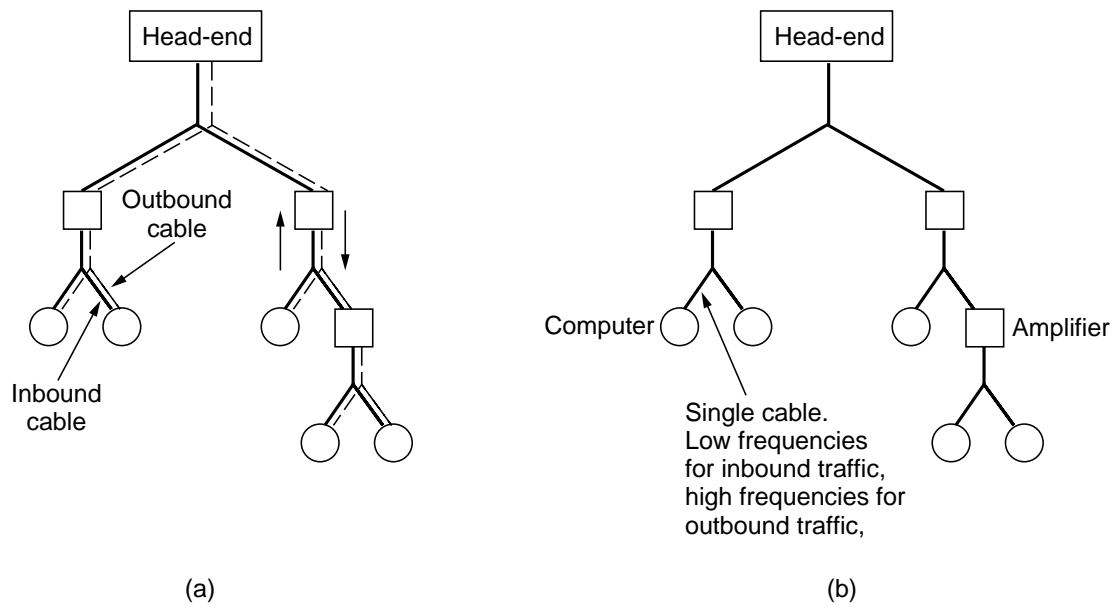
**Fig. 2-1.** (a) A binary signal and its root-mean-square Fourier amplitudes. (b)-(e) Successive approximations to the original signal.

| <b>Bps</b> | <b>T (msec)</b> | <b>First harmonic (Hz)</b> | <b># Harmonics sent</b> |
|------------|-----------------|----------------------------|-------------------------|
| 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                       |

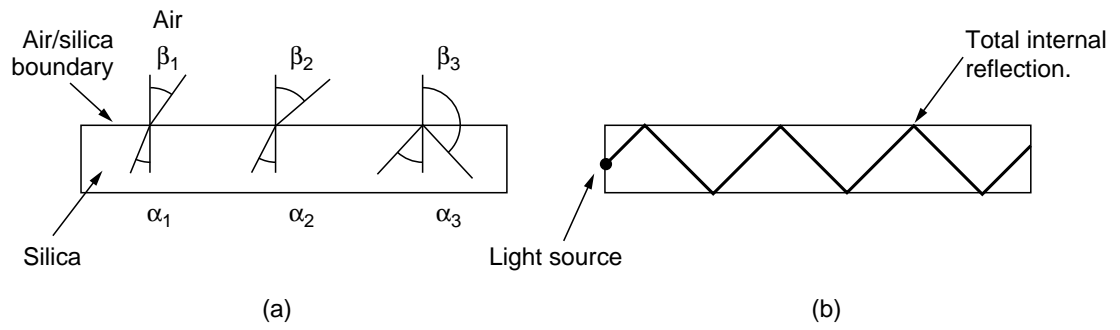
**Fig. 2-2.** Relation between data rate and harmonics.



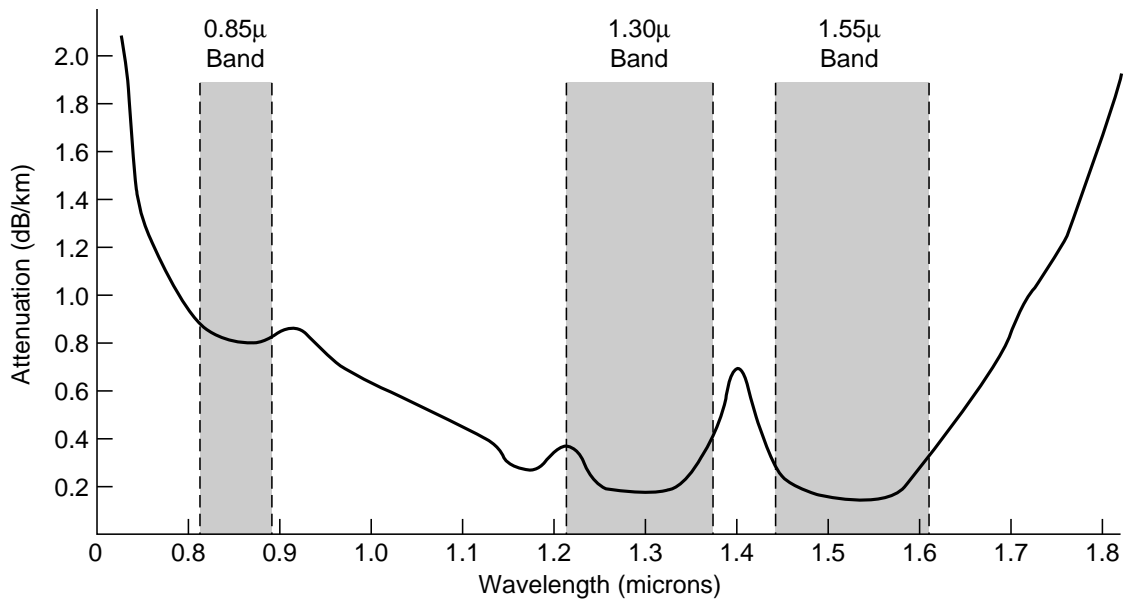
**Fig. 2-3.** A coaxial cable.



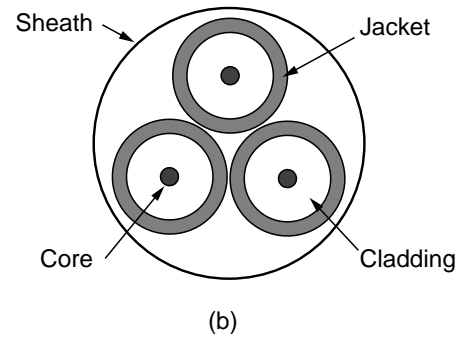
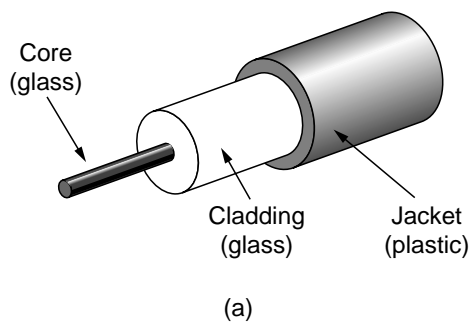
**Fig. 2-4.** Broadband networks. (a) Dual cable. (b) Single cable.



**Fig. 2-5.** (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.



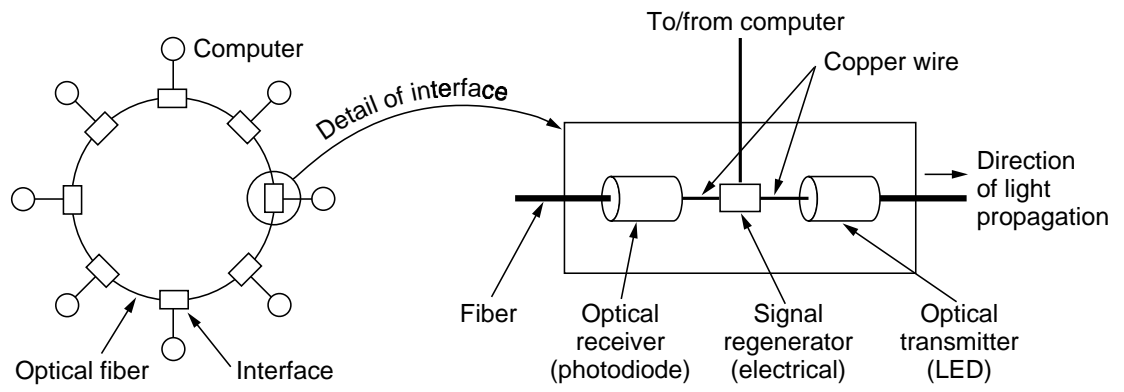
**Fig. 2-6.** Attenuation of light through fiber in the infrared region.



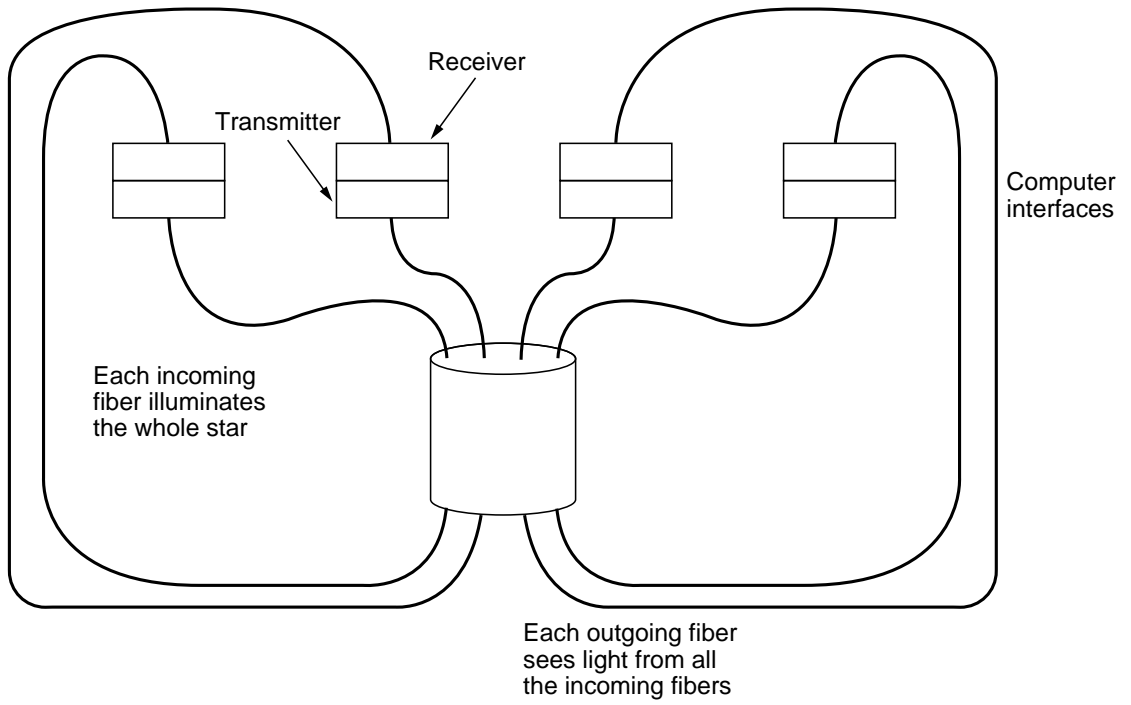
**Fig. 2-7.** (a) Side view of a single fiber. (b) End view of a sheath with three fibers.

| <b>Item</b>             | <b>LED</b> | <b>Semiconductor laser</b> |
|-------------------------|------------|----------------------------|
| Data rate               | Low        | High                       |
| Mode                    | Multimode  | Multimode or single mode   |
| Distance                | Short      | Long                       |
| Lifetime                | Long life  | Short life                 |
| Temperature sensitivity | Minor      | Substantial                |
| Cost                    | Low cost   | Expensive                  |

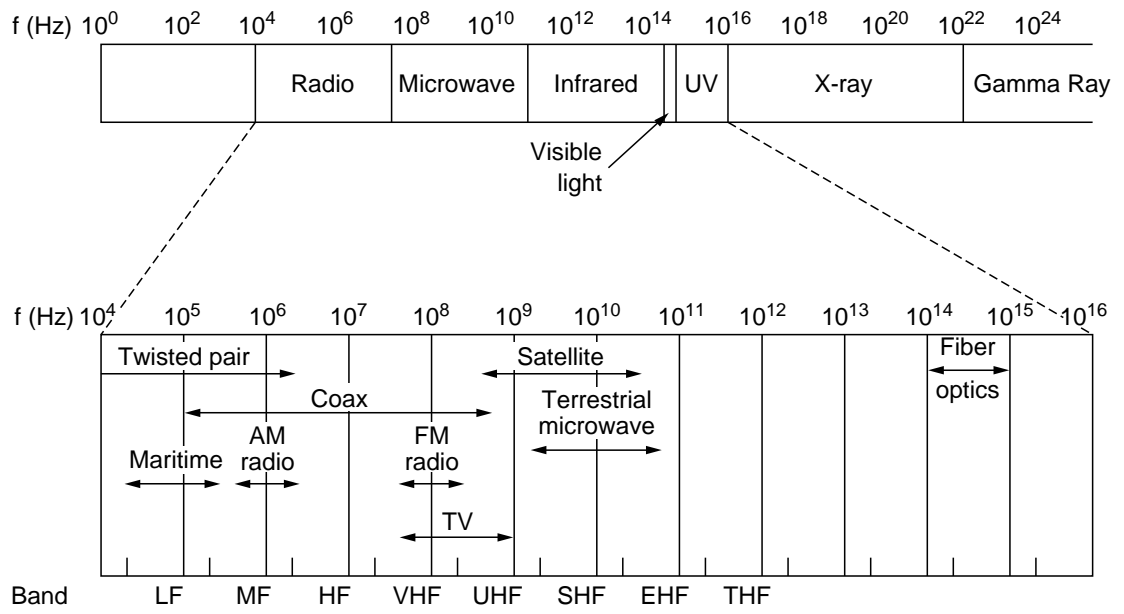
**Fig. 2-8.** A comparison of semiconductor diodes and LEDs as light sources.



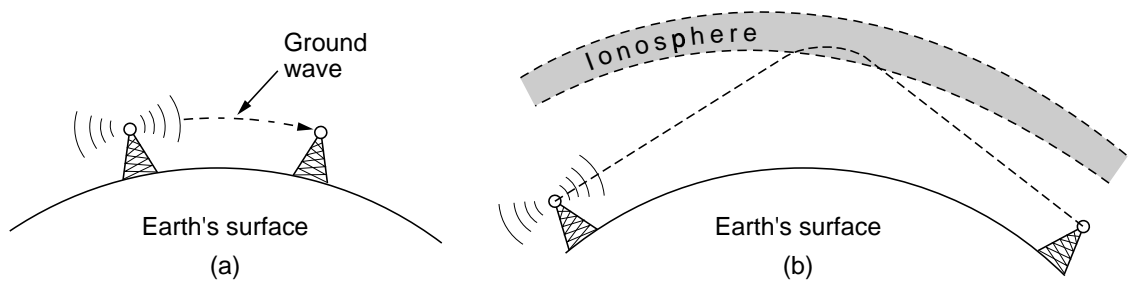
**Fig. 2-9.** A fiber optic ring with active repeaters.



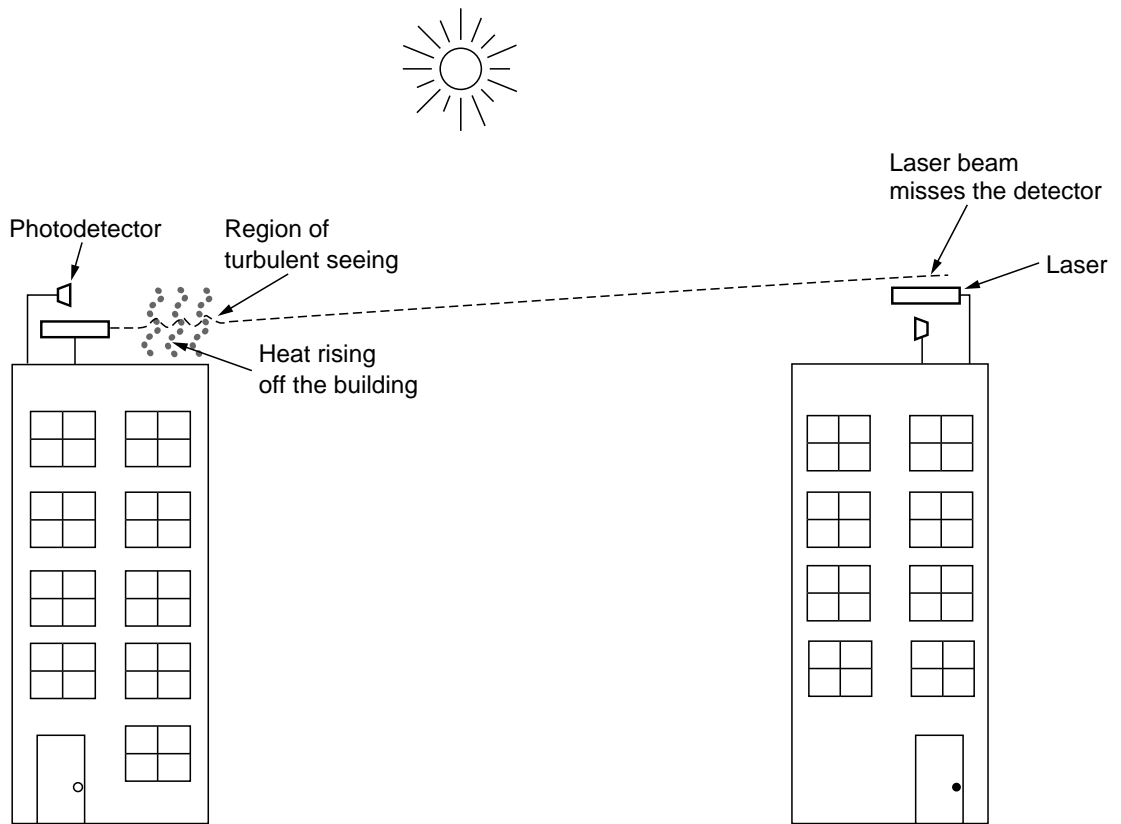
**Fig. 2-10.** A passive star connection in a fiber optics network.



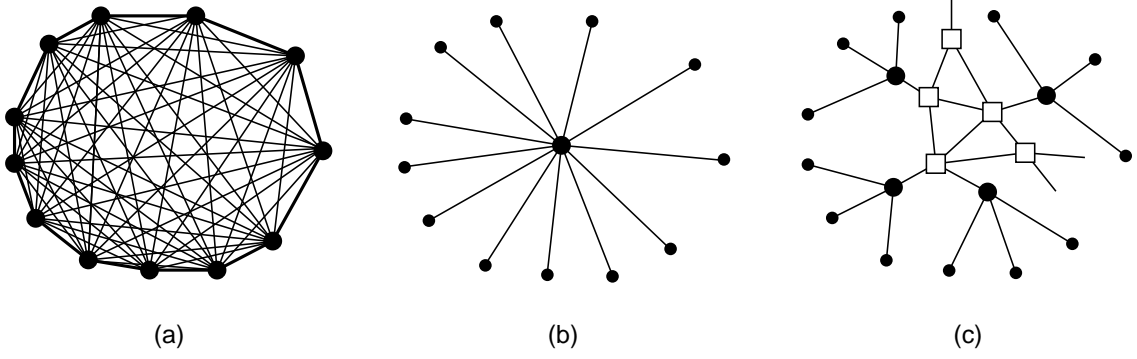
**Fig. 2-11.** The electromagnetic spectrum and its uses for communication.



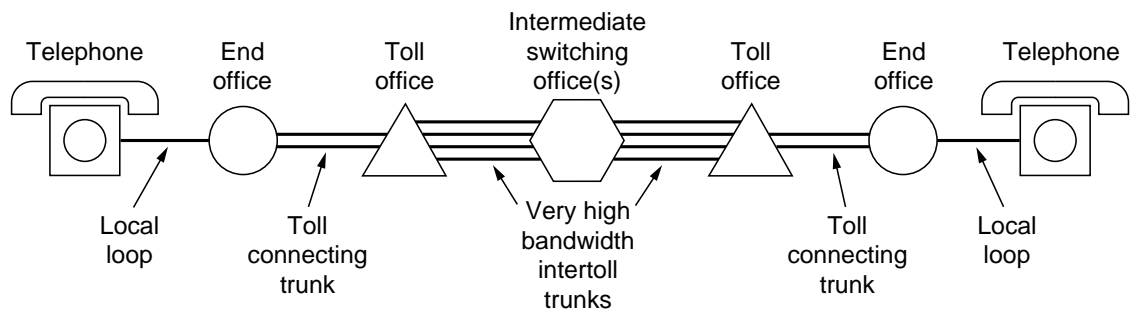
**Fig. 2-12.** (a) In the VLF, VF, and MF bands, radio waves follow the curvature of the earth. (b) In the HF they bounce off the ionosphere.



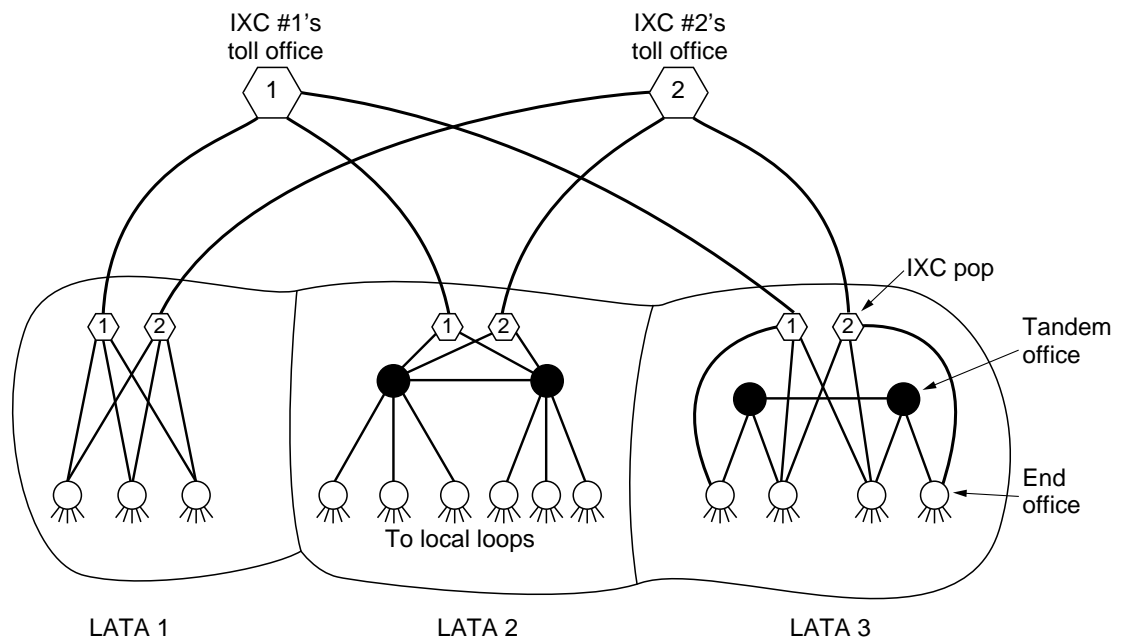
**Fig. 2-13.** Convection currents can interfere with laser communication systems. A bidirectional system, with two lasers, is pictured here.



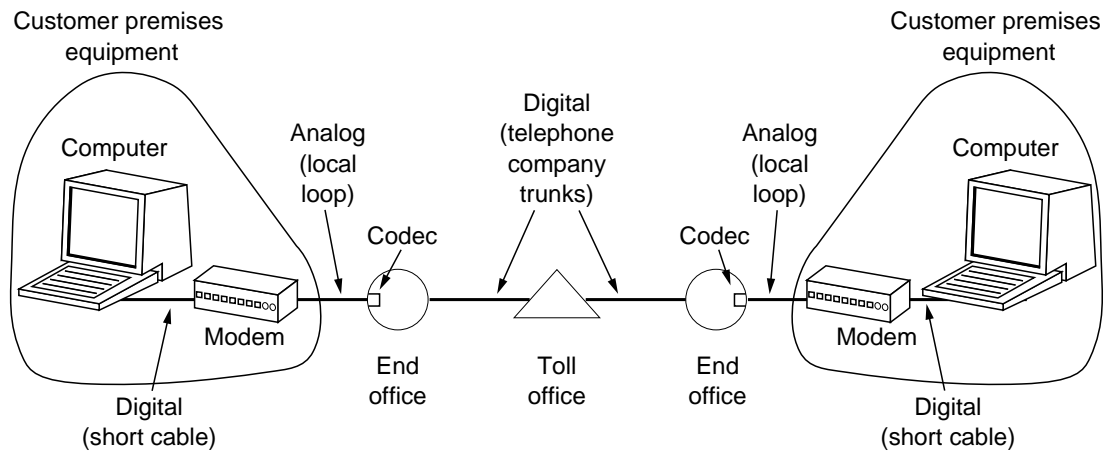
**Fig. 2-14.** (a) Fully interconnected network. (b) Centralized switch. (c) Two-level hierarchy.



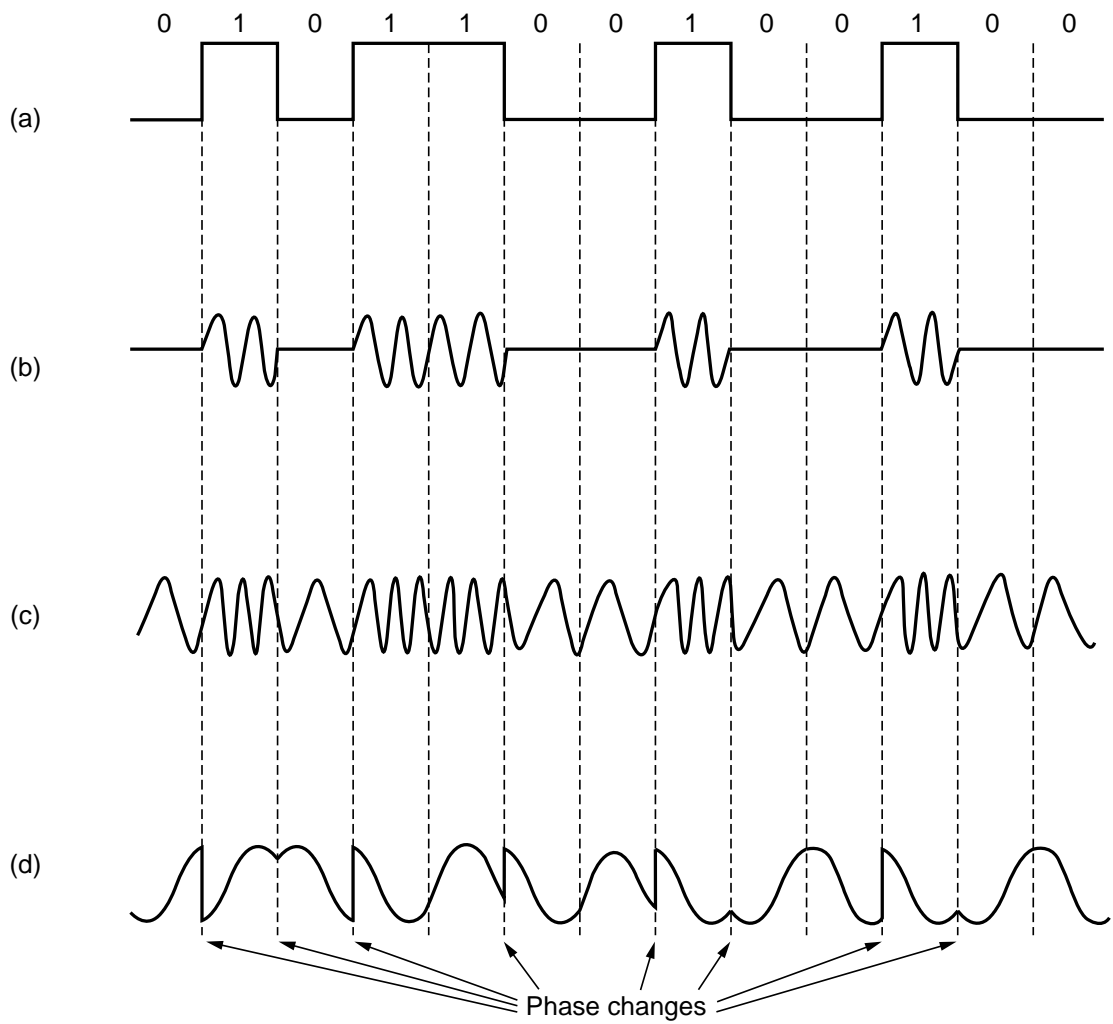
**Fig. 2-15.** Typical circuit route for a medium-distance call.



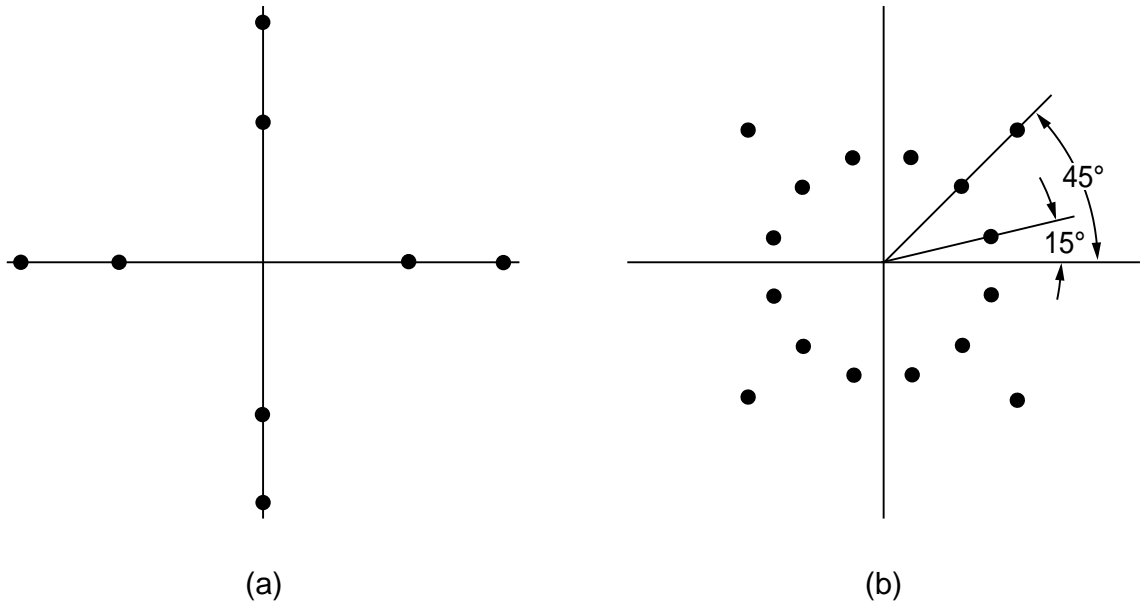
**Fig. 2-16.** The relationship of LATAs, LECs, and IXCs. All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is in it.



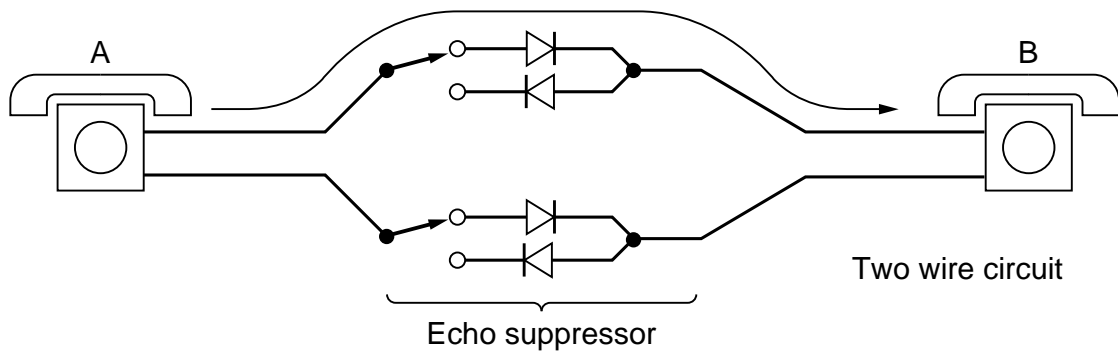
**Fig. 2-17.** The use of both analog and digital transmission for a computer to computer call. Conversion is done by the modems and codecs.



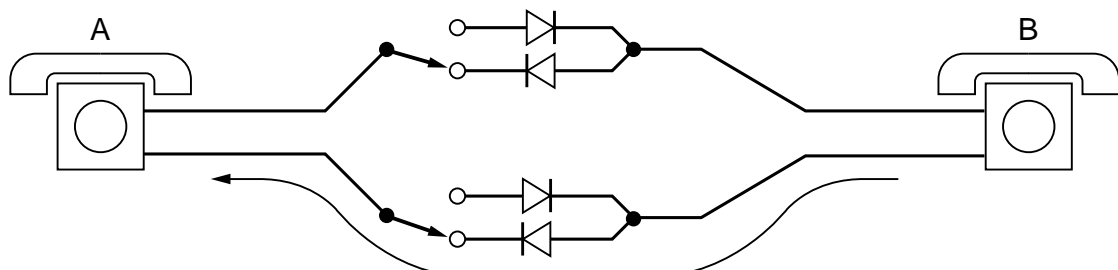
**Fig. 2-18.** (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.



**Fig. 2-19.** (a) 3 bits/ baud modulation. (b) 4 bits/ baud modulation.

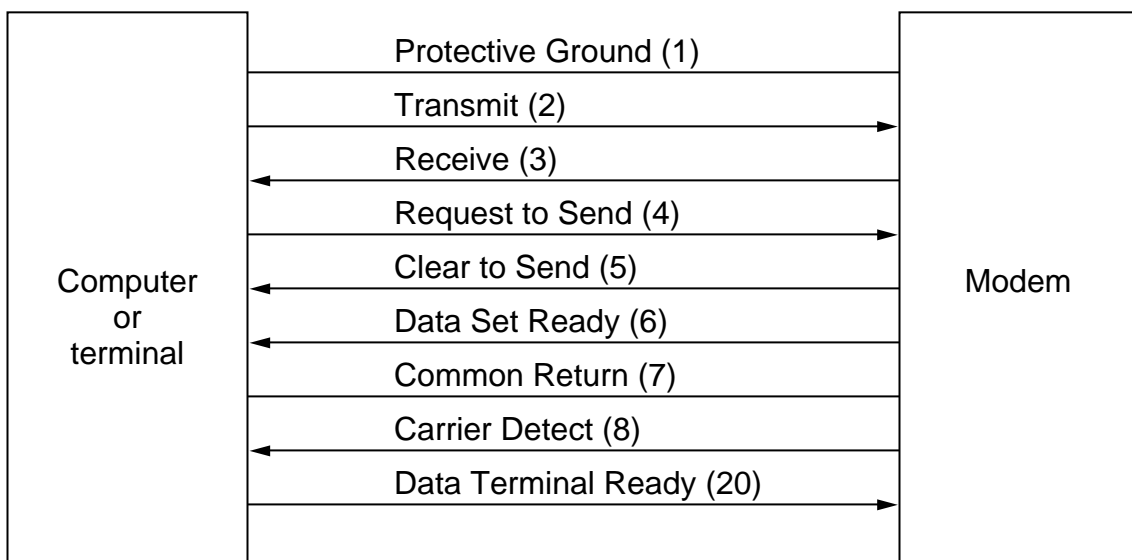


(a)



(b)

**Fig. 2-20.** (a) A talking to B. (b) B talking to A.

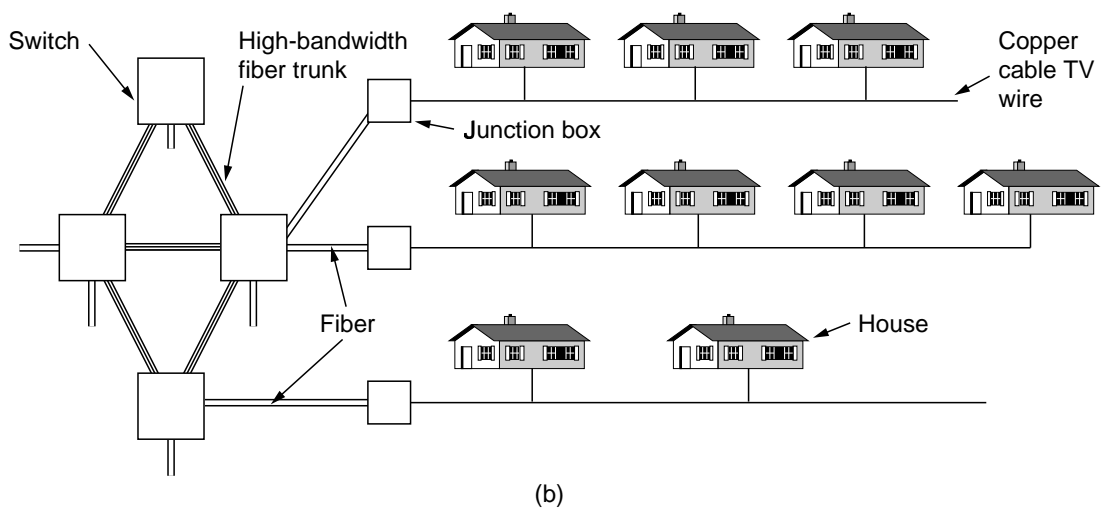
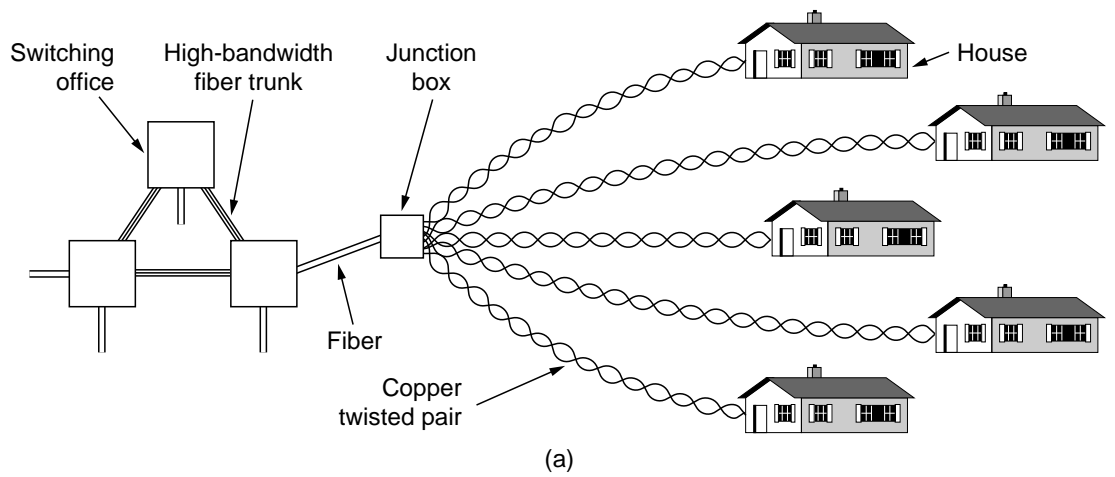


**Fig. 2-21.** Some of the principal RS-232-C circuits. The pin numbers are given in parentheses.

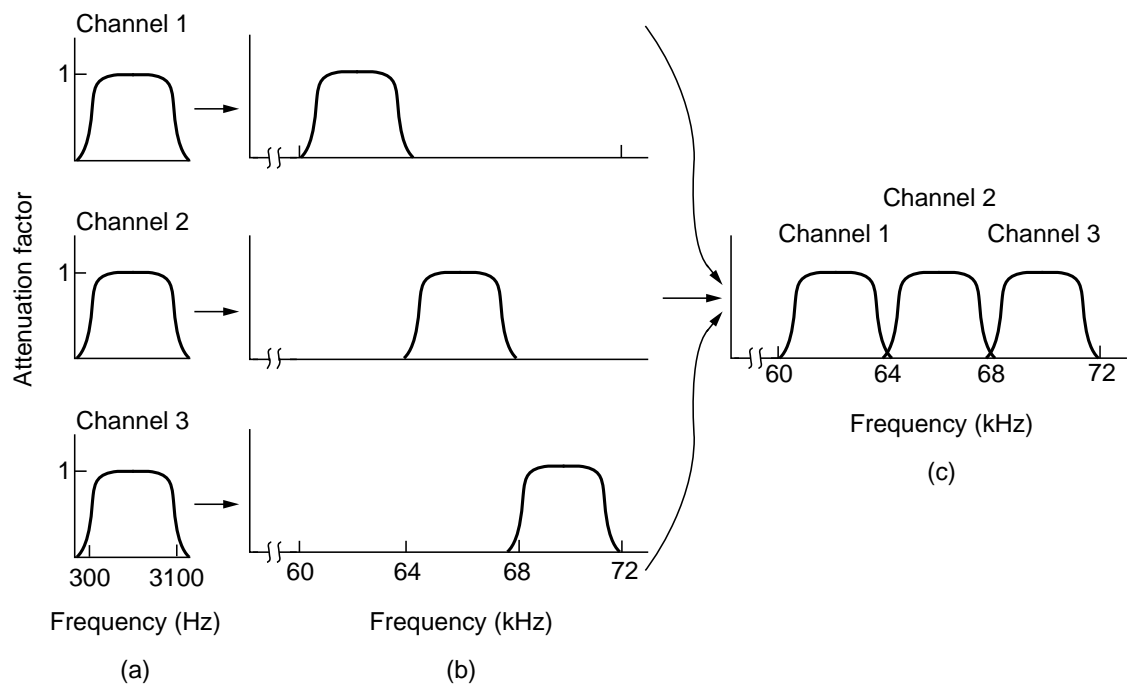
| RS-232-C   |  |  | CCITT V .24   |  |   | RS-449   |   |   |
|--|--|--|---|--|---|--|---|---|
| Code   | Pin  | Circuit  | Code  | Pin  | Circuit   | Code   | Pin   | Circuit   |
| AA<br>AB   | 1<br>7   | Protective ground<br>Signal ground   | 101<br>102  | 1<br>7   | Protective ground<br>Signal ground  | _ SG<br>SC<br>RC   | 1<br>19<br>37<br>20   | Signal ground<br>Send common<br>Receive common  |
| BA<br>BB   | 2<br>3   | Transmitted data<br>Received data  | 103<br>104  | 2<br>3   | Transmitted data<br>Received data   | SD<br>RD   | 4, 22<br>6, 24  | Send data<br>Receive data   |
| CA<br>CB<br>CC<br>CD<br>CE<br>CF<br>CG<br>CH<br>CI | 4<br>5<br>6<br>20<br>22<br>8<br>21<br>23<br>18 | Request to send<br>Clear to send<br>Data set ready<br>Data terminal ready<br>Ring indicator<br>Line detector<br>Signal quality<br>DTE rate<br>DCE rate | 105<br>106<br>107<br>108<br>125<br>109<br>110<br>111<br>112 | 4<br>5<br>6<br>20<br>22<br>8<br>21<br>23<br>18 | Request to send<br>Ready for sending<br>Data set ready<br>Data terminal ready<br>Calling indicator<br>Line detector<br>Signal quality<br>DTE rate<br>DCE rate | RS<br>CS<br>DM<br>TR<br>IC<br>RR<br>SQ<br>SR<br>SI<br>IS<br>NS<br>SF | 7, 25<br>9, 27<br>11, 29<br>12, 30<br>15<br>13, 31<br>33<br>16<br>2<br>28<br>34<br>16 | Request to send<br>Clear to send<br>Data mode<br>Terminal ready<br>Incoming call<br>Receiver ready<br>Signal quality<br>Signaling rate<br>Signaling indicators<br>Terminal in service<br>New signal<br>Select frequency |
| DA<br>DB<br>DD                                     | 24<br>15<br>17                                 | DTE timing<br>DCE timing<br>Receiver timing  | 113<br>114<br>115   | 24<br>15<br>17                                 | DTE timing<br>DCE timing<br>Receiver timing   | TT<br>ST<br>RT   | 17, 25<br>5, 23<br>8, 26  | Terminal timing<br>Send timing<br>Receive timing  |
| SBA<br>SBB<br>SCA<br>SCB<br>SCF                    | 14<br>16<br>19<br>13<br>12                     | Transmitted data<br>Received data<br>Request to send<br>Clear to send<br>Line detector   | 118<br>119<br>120<br>121<br>122                             | 14<br>16<br>19<br>13<br>12                     | Transmitted data<br>Received data<br>Line signal<br>Channel ready<br>Line detector  | SSD<br>SRD<br>SRS<br>SCS<br>SRR                                      | 3<br>4<br>7<br>8<br>2   | Send data<br>Receive data<br>Request to send<br>Clear to send<br>Receiver ready   |
|  |  |  |   |  |   | LL<br>RL<br>TM   | 10<br>14<br>18  | Local loopback<br>Remote loopback<br>Test mode  |
|  |  |  |   |  |   | SS<br>SB   | 32<br>36  | Select standby<br>Standby indicator   |

Secondary Channel

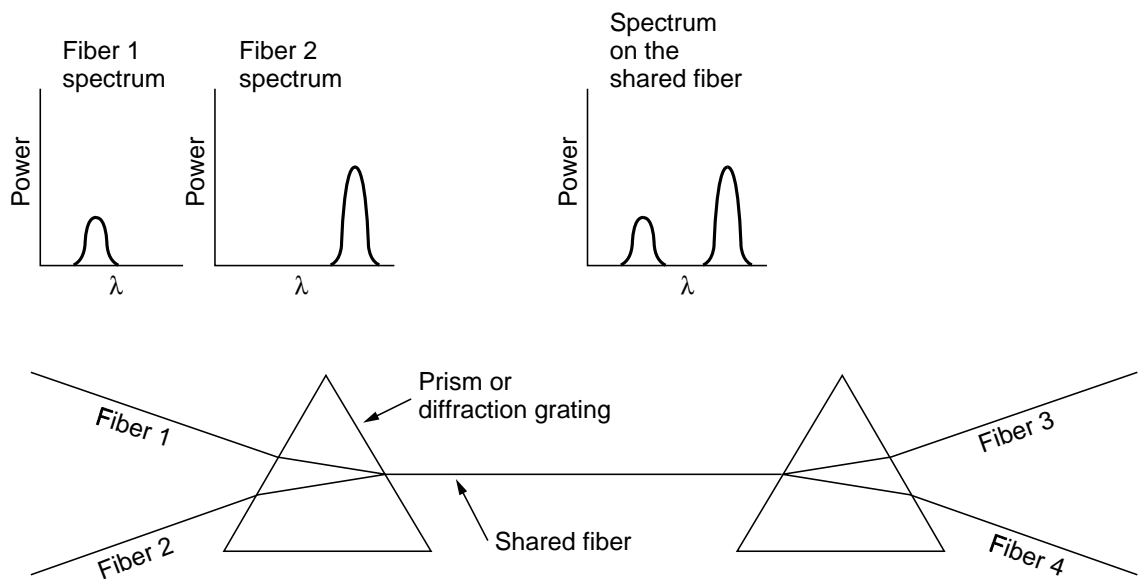
**Fig. 2-22.** Comparison of RS-232-C, V.24, and RS-449.



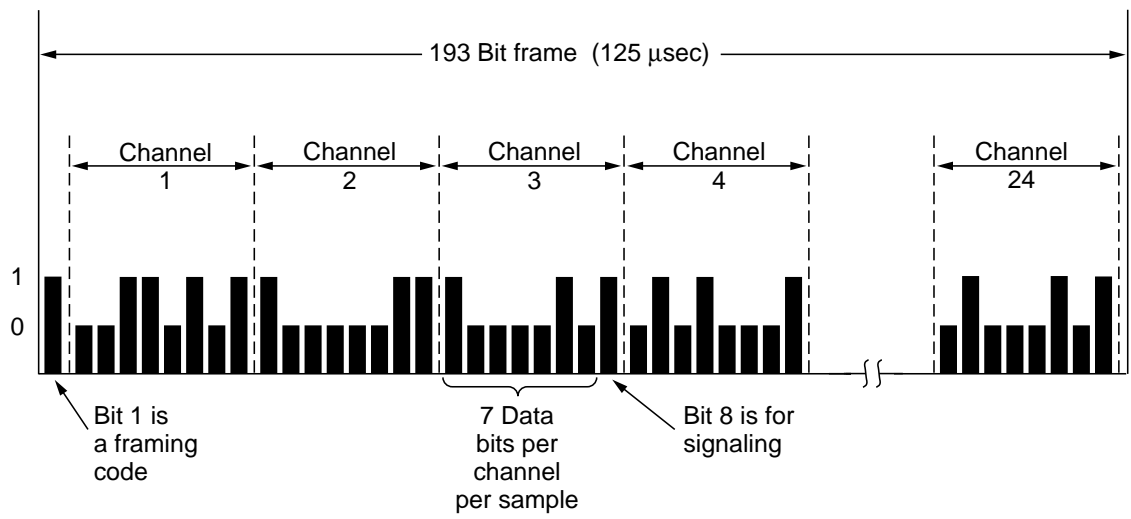
**Fig. 2-23.** Fiber to the curb. (a) Using the telephone network. (b) Using the cable TV network.



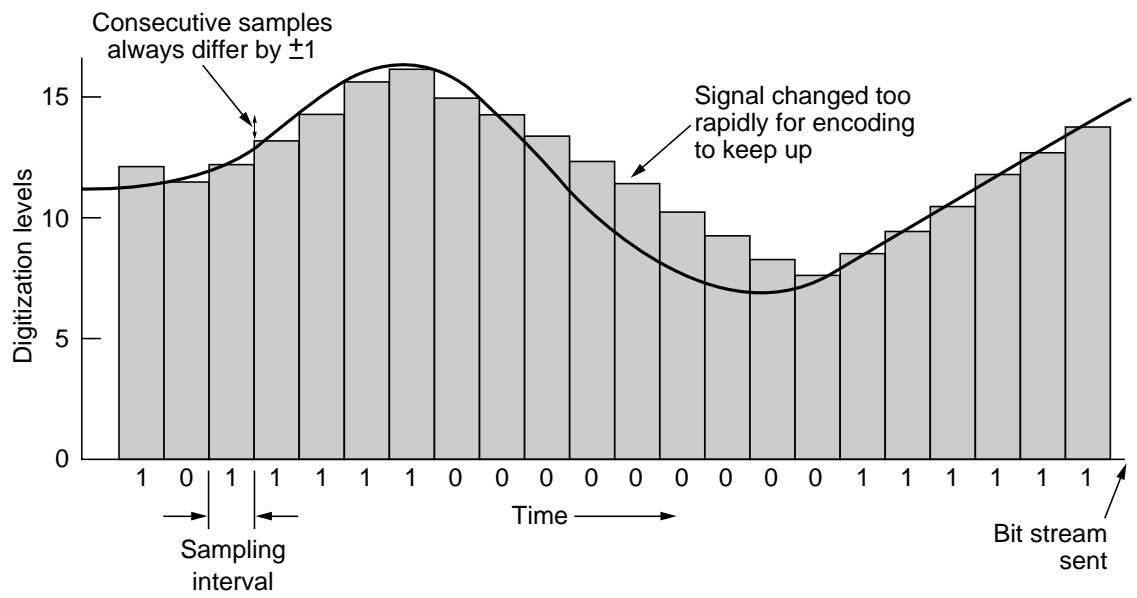
**Fig. 2-24.** Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.



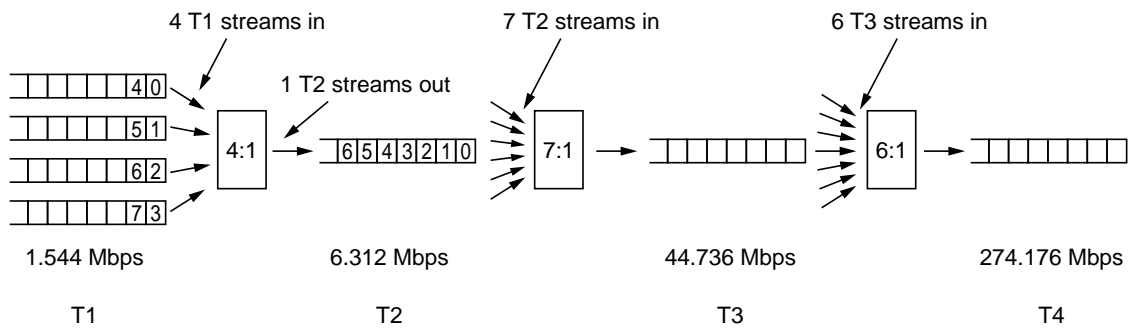
**Fig. 2-25.** Wavelength division multiplexing.



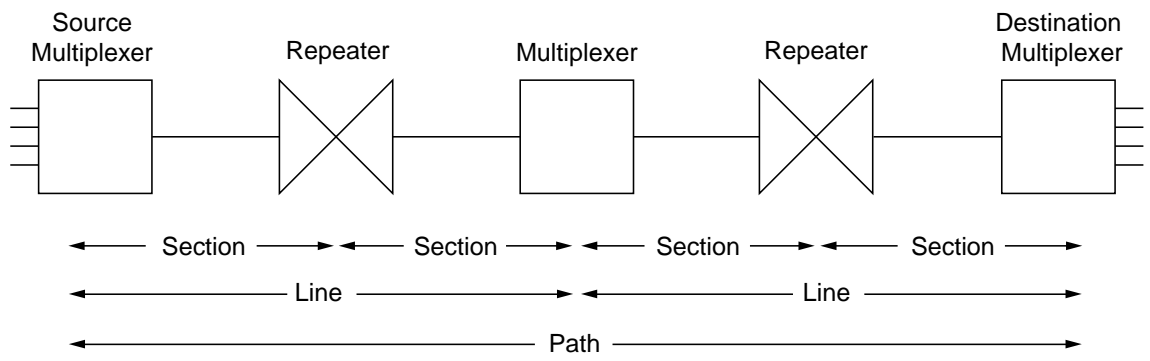
**Fig. 2-26.** The T1 carrier (1.544 Mbps).



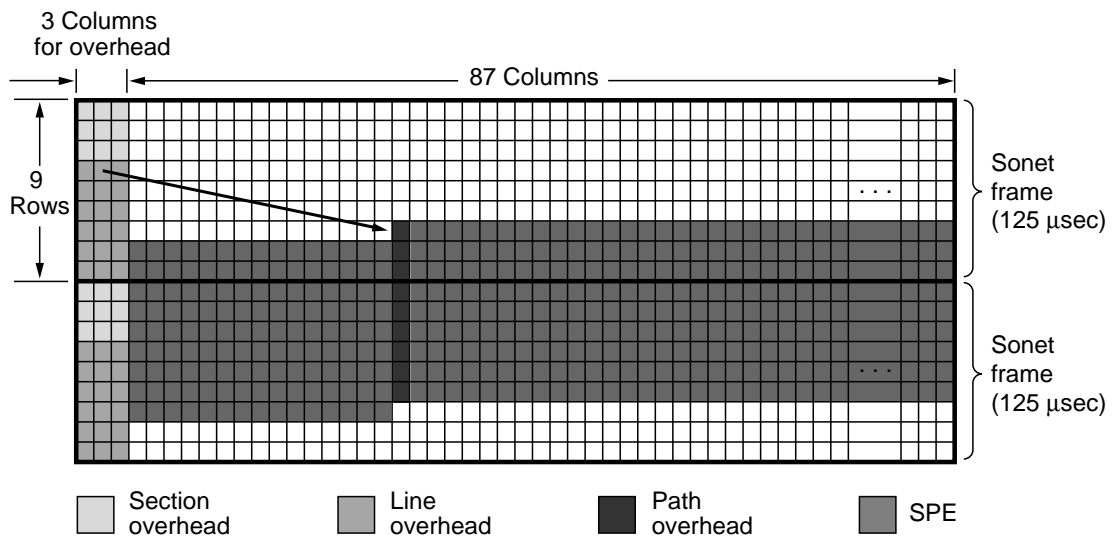
**Fig. 2-27.** Delta modulation.



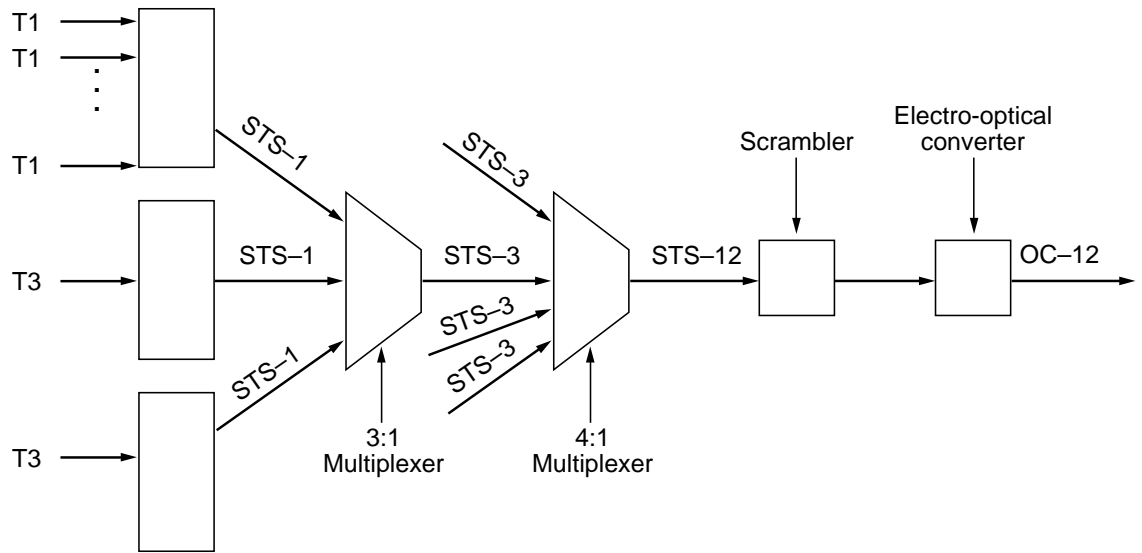
**Fig. 2-28.** Multiplexing T1 streams onto higher carriers.



**Fig. 2-29.** A SONET path.



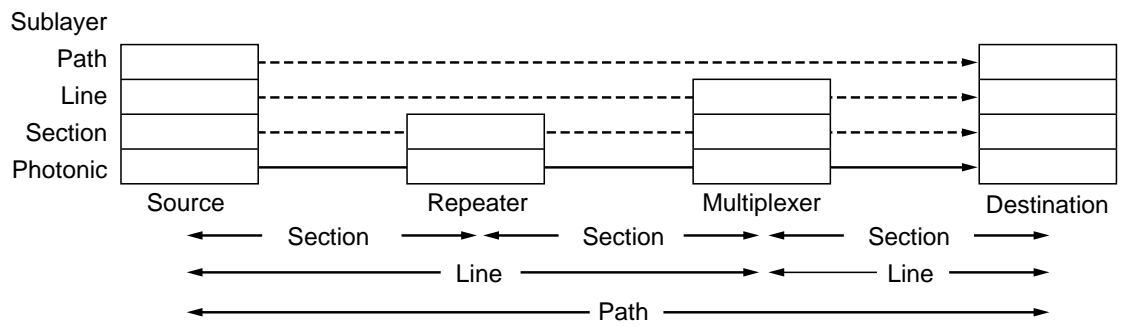
**Fig. 2-30.** Two back-to-back SONET frames.



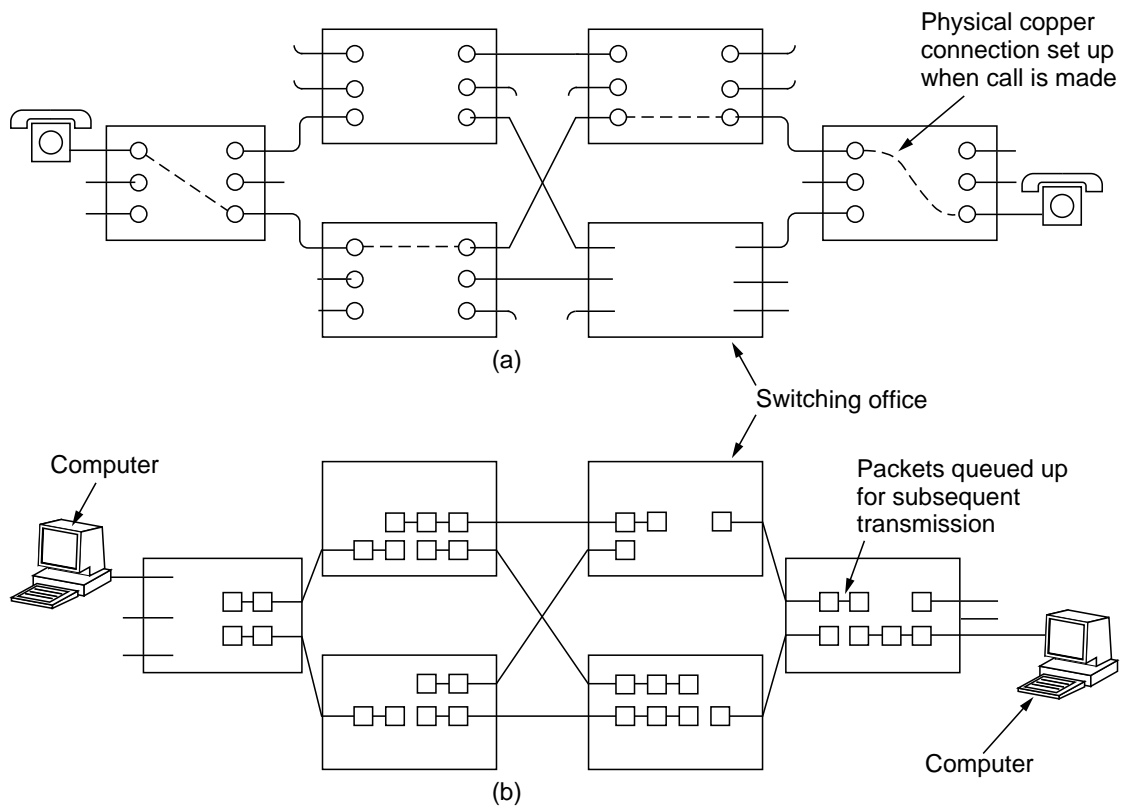
**Fig. 2-31.** Multiplexing in SONET.

| SONET      |         | SDH     | Data rate (Mbps) |          |          |
|------------|---------|---------|------------------|----------|----------|
| Electrical | Optical | Optical | Gross            | SPE      | User     |
| STS-1      | OC-1    |         | 51.84            | 50.112   | 49.536   |
| STS-3      | OC-3    | STM-1   | 155.52           | 150.336  | 148.608  |
| STS-9      | OC-9    | STM-3   | 466.56           | 451.008  | 445.824  |
| STS-12     | OC-12   | STM-4   | 622.08           | 601.344  | 594.432  |
| STS-18     | OC-18   | STM-6   | 933.12           | 902.016  | 891.648  |
| STS-24     | OC-24   | STM-8   | 1244.16          | 1202.688 | 1188.864 |
| STS-36     | OC-36   | STM-12  | 1866.24          | 1804.032 | 1783.296 |
| STS-48     | OC-48   | STM-16  | 2488.32          | 2405.376 | 2377.728 |

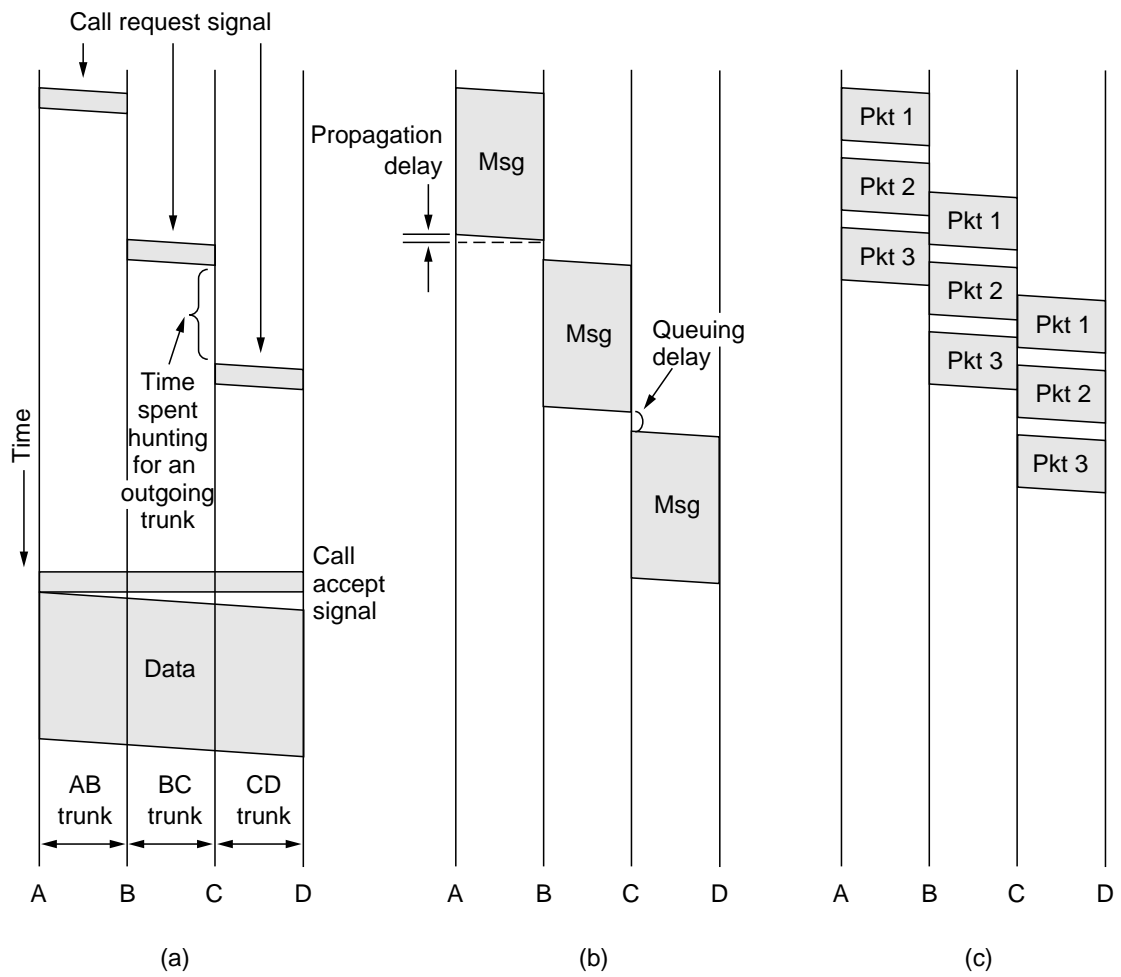
**Fig. 2-32.** SONET and SDH multiplex rates.



**Fig. 2-33.** The SONET architecture.



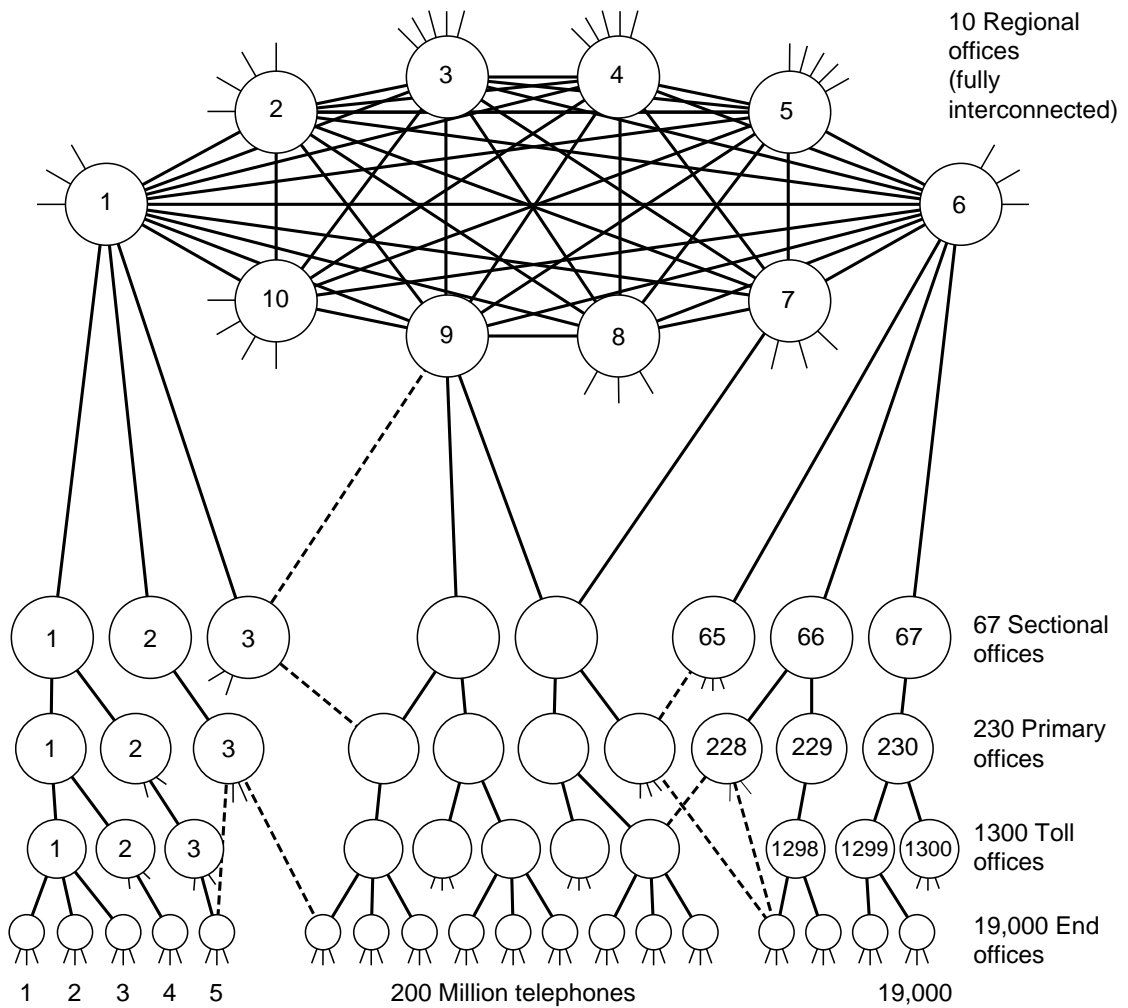
**Fig. 2-34.** (a) Circuit switching. (b) Packet switching.



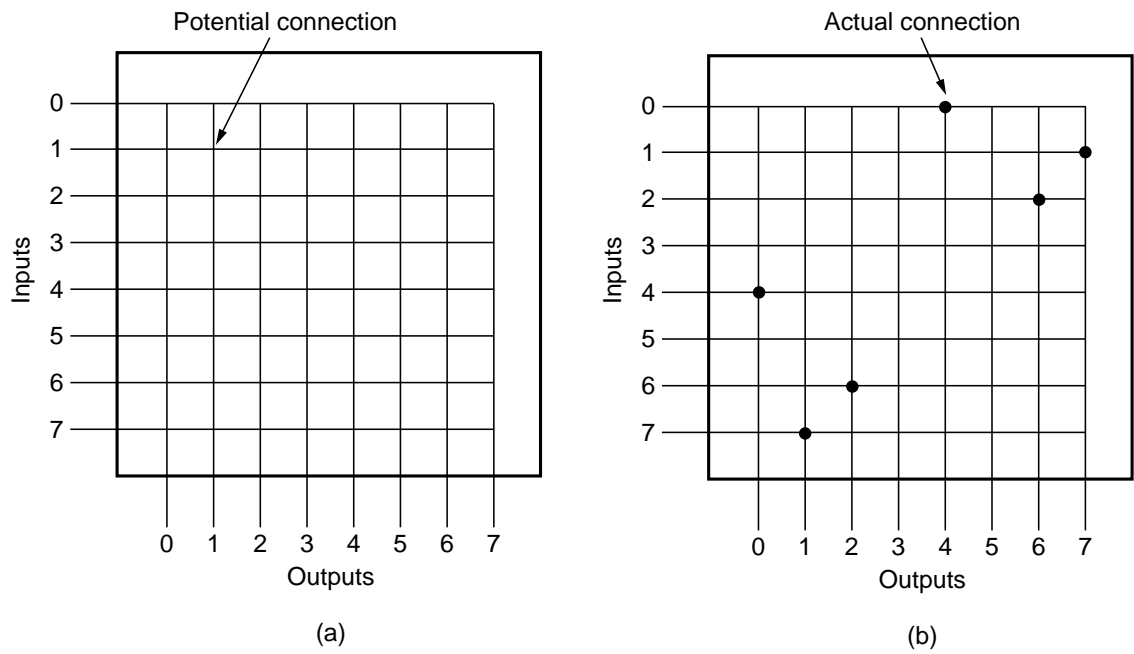
**Fig. 2-35.** Timing of events in (a) circuit switching, (b) message switching, (c) packet switching.

| <b>Item</b>                        | <b>Circuit-switched</b> | <b>Packet-switched</b> |
|------------------------------------|-------------------------|------------------------|
| Dedicated "copper" path            | Yes                     | No                     |
| Bandwidth available                | Fixed                   | Dynamic                |
| Potentially wasted bandwidth       | Yes                     | No                     |
| Store-and-forward transmission     | No                      | Yes                    |
| Each packet follows the same route | Yes                     | No                     |
| Call setup                         | Required                | Not needed             |
| When can congestion occur          | At setup time           | On every packet        |
| Charging                           | Per minute              | Per packet             |

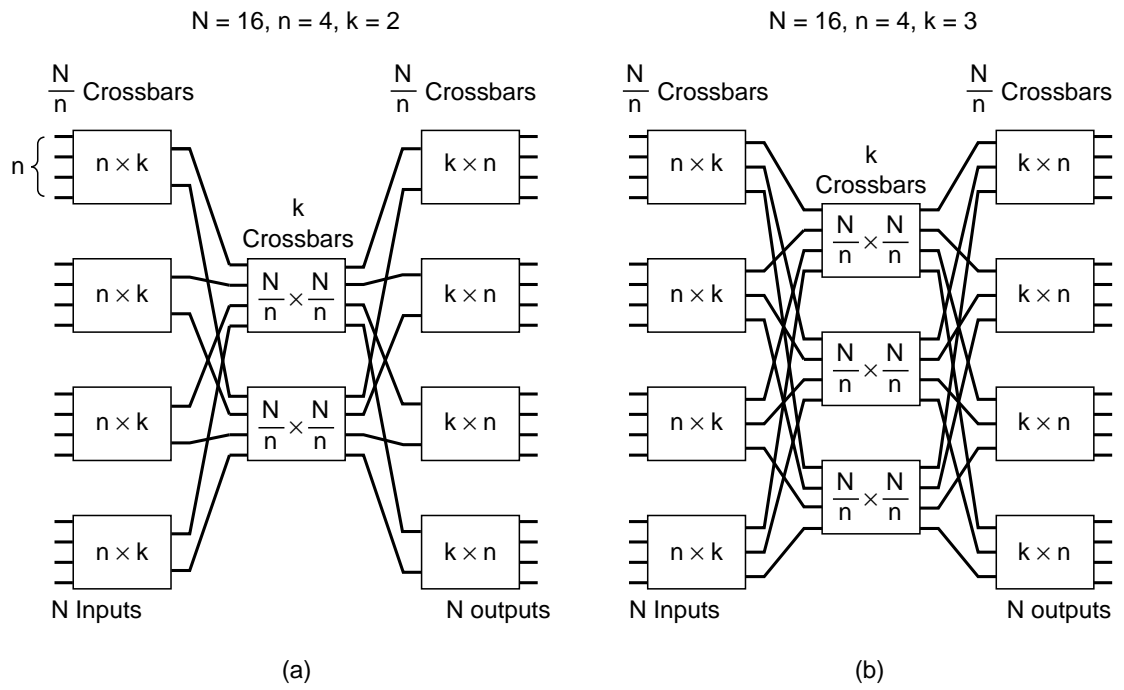
**Fig. 2-36.** A comparison of circuit-switched and packet-switched networks.



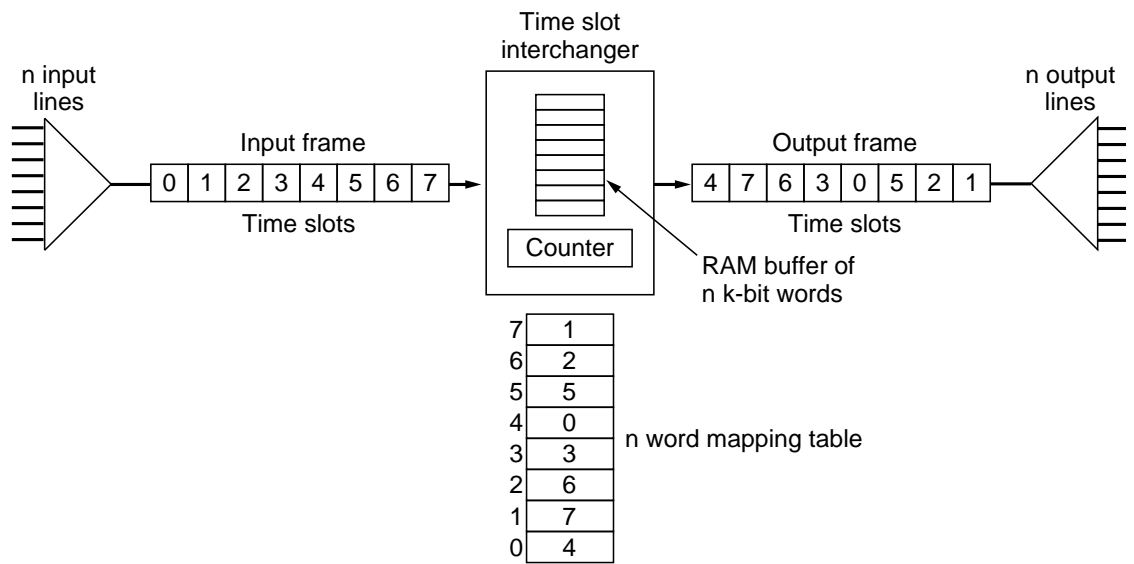
**Fig. 2-37.** The AT&T telephone hierarchy. The dashed lines are direct trunks.



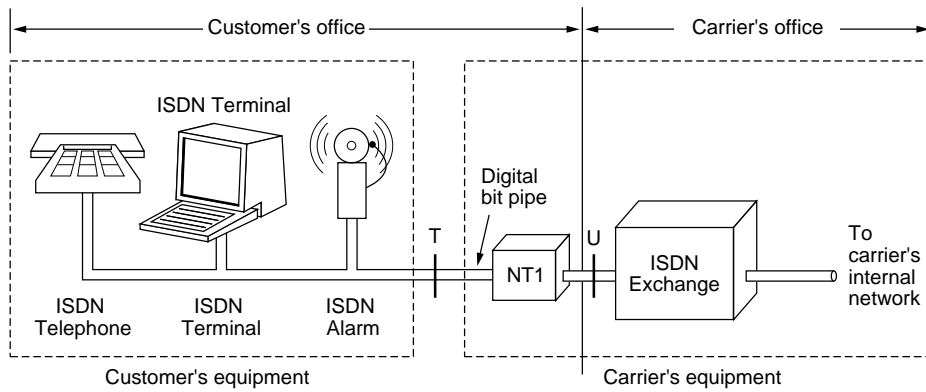
**Fig. 2-38.** (a) A crossbar switch with no connections. (b) A crossbar switch with three connections set up: 0 with 4, 1 with 7, and 2 with 6.



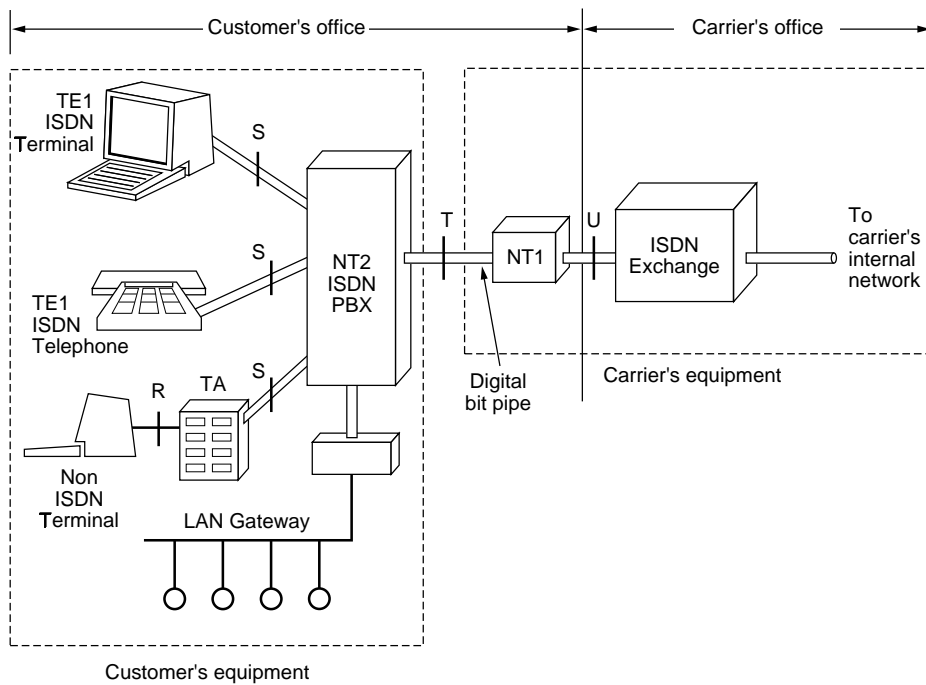
**Fig. 2-39.** Two space division switches with different parameters.



**Fig. 2-40.** A time division switch.

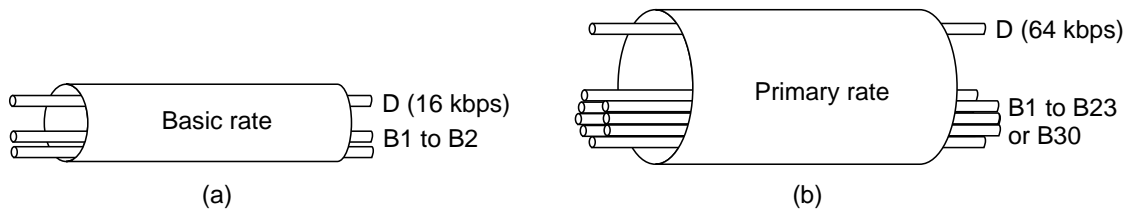


(a)

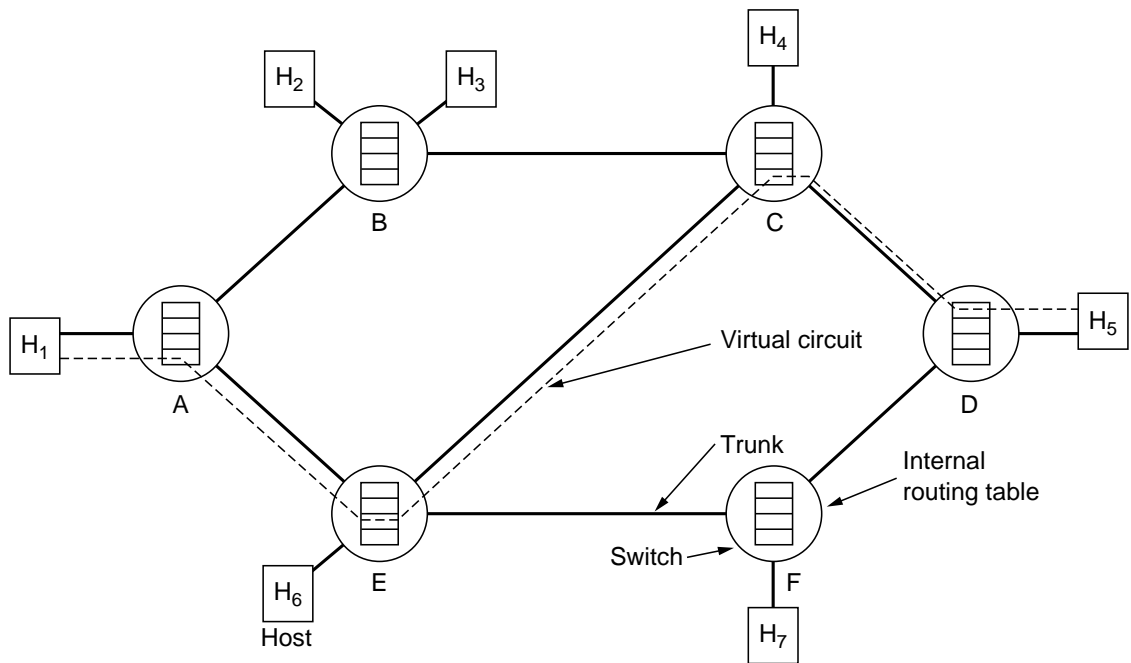


(b)

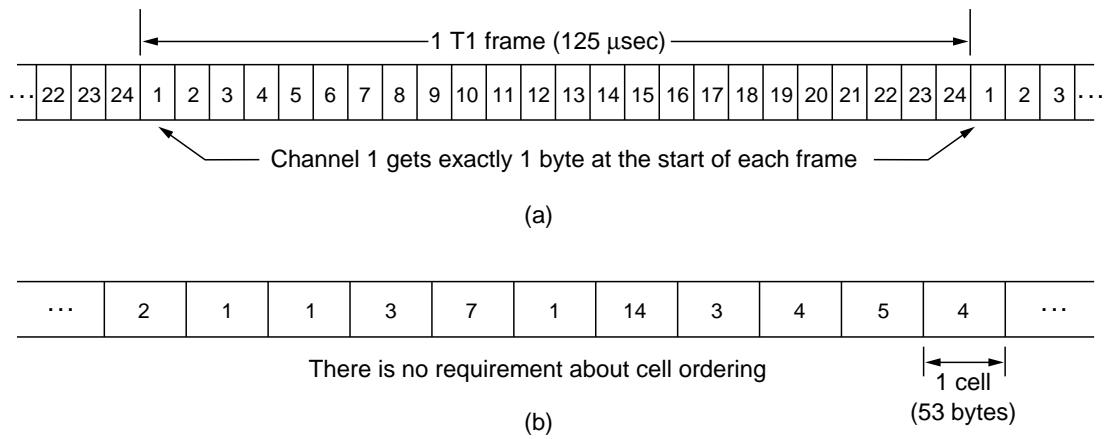
**Fig. 2-41.** (a) Example ISDN system for home use. (b) Example ISDN system with a PBX for use in large businesses.



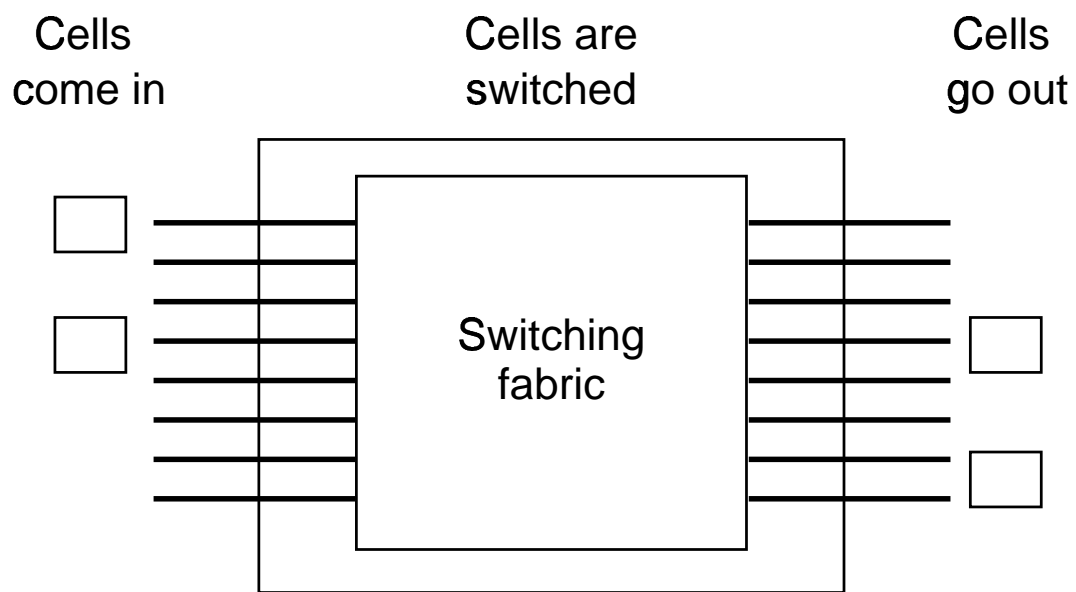
**Fig. 2-42.** (a) Basic rate digital pipe. (b) Primary rate digital pipe.



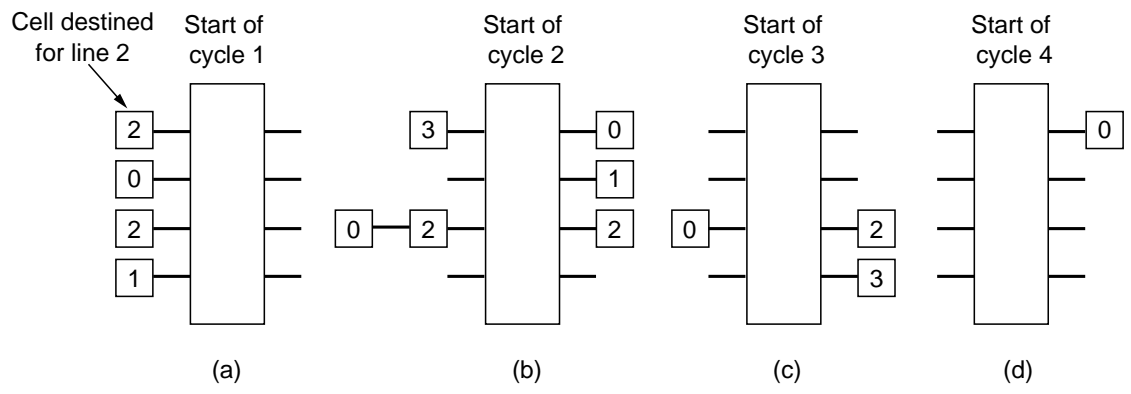
**Fig. 2-43.** The dotted line shows a virtual circuit. It is simply defined by table entries inside the switches.



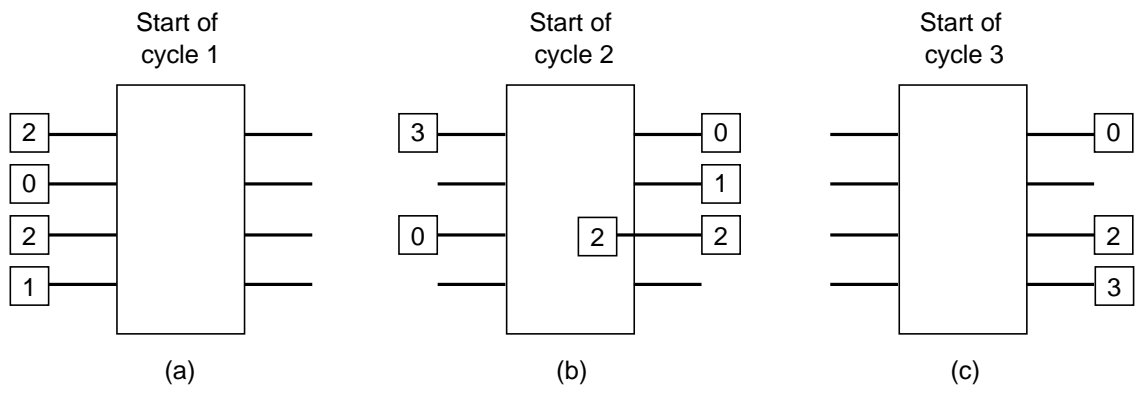
**Fig. 2-44.** (a) Synchronous transmission mode. (b) Asynchronous transmission mode.



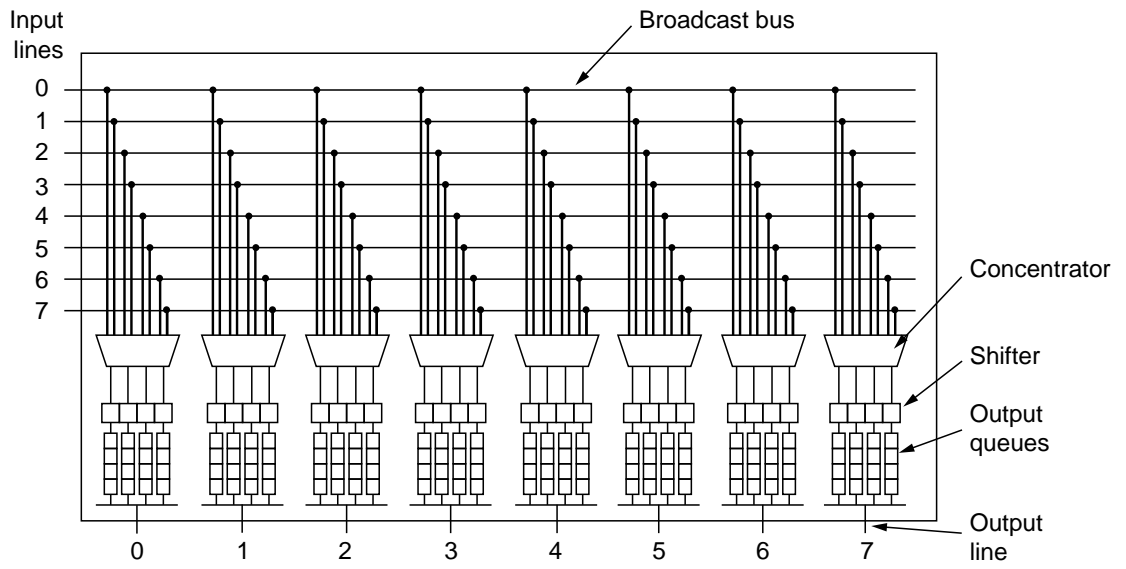
**Fig. 2-45.** A generic ATM switch.



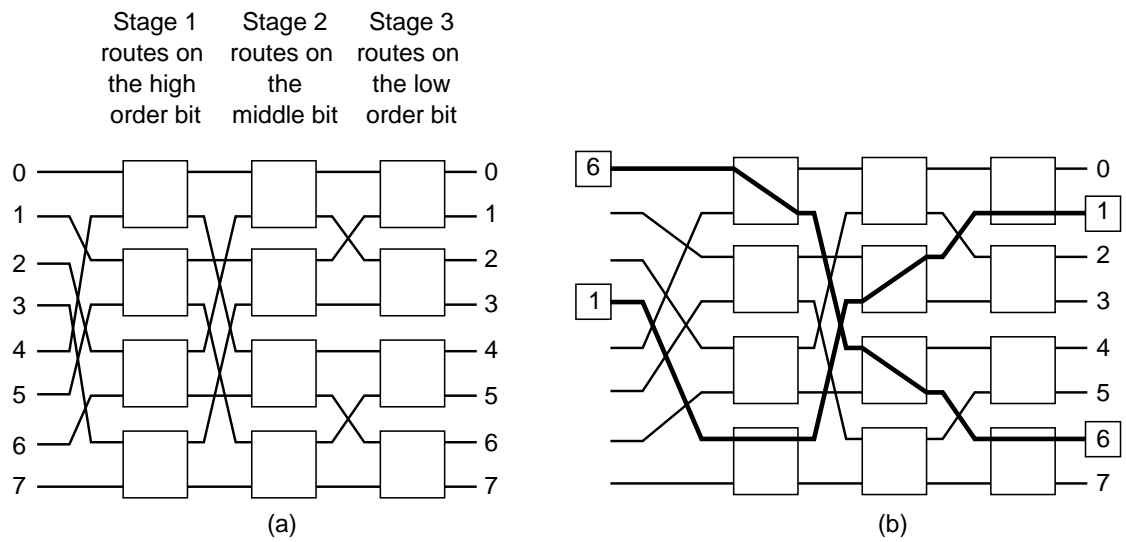
**Fig. 2-46.** Input queuing at an ATM switch.



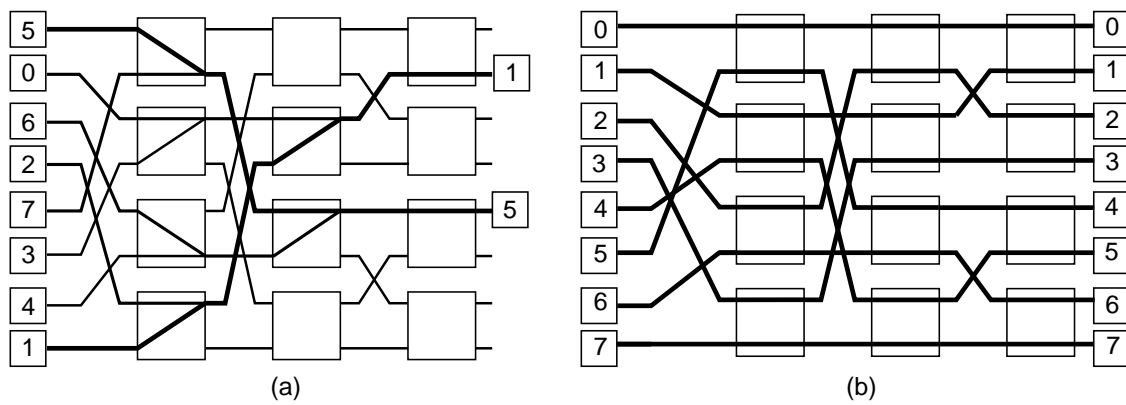
**Fig. 2-47.** Output queueing at an ATM switch.



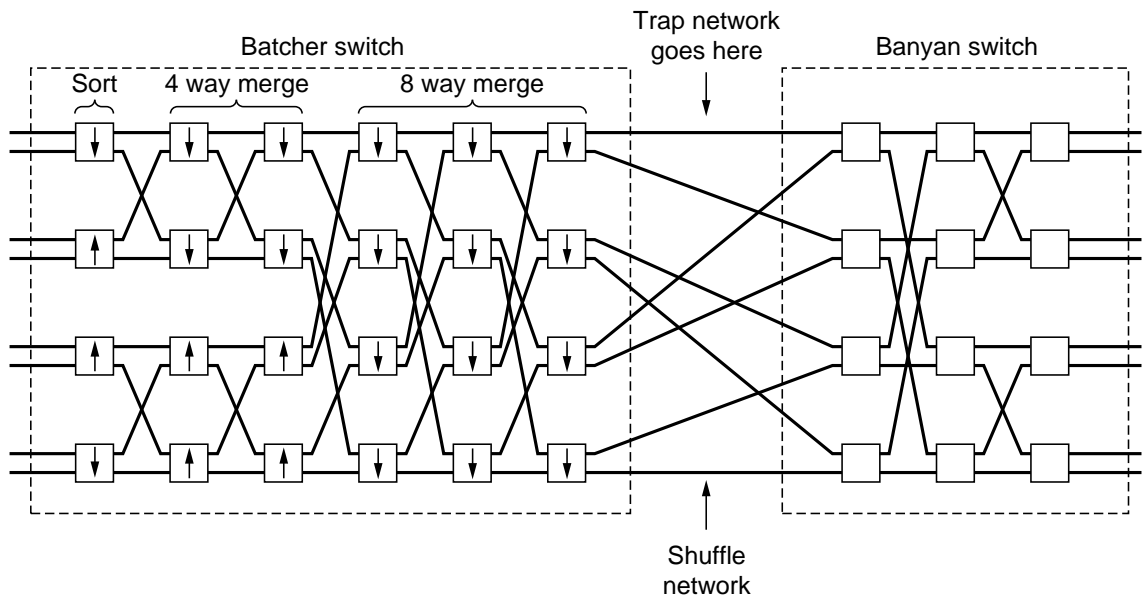
**Fig. 2-48.** A simplified diagram of the knockout switch.



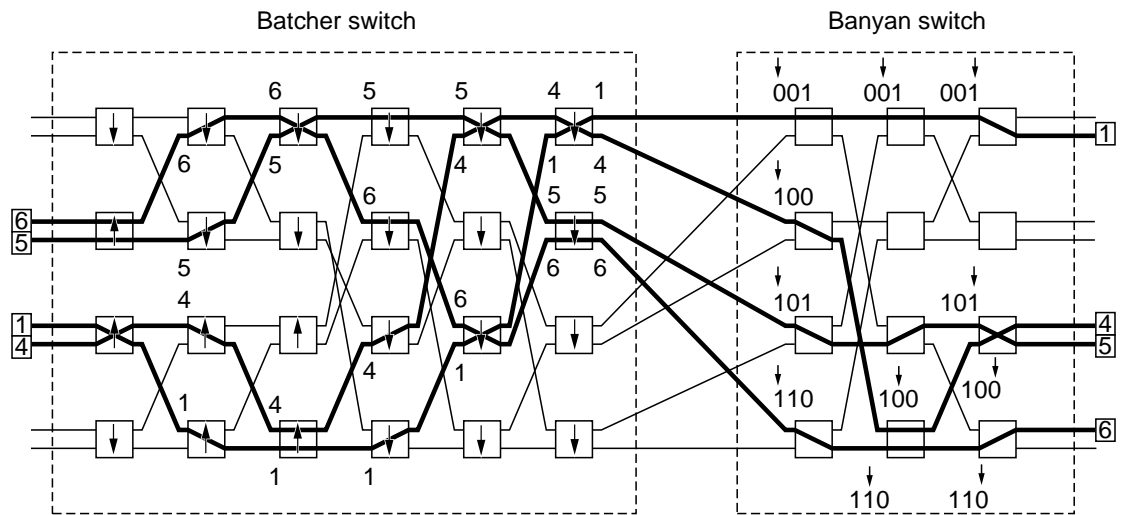
**Fig. 2-49.** (a) A banyan switch with eight input lines and eight output lines. (b) The routes that two cells take through the banyan switch.



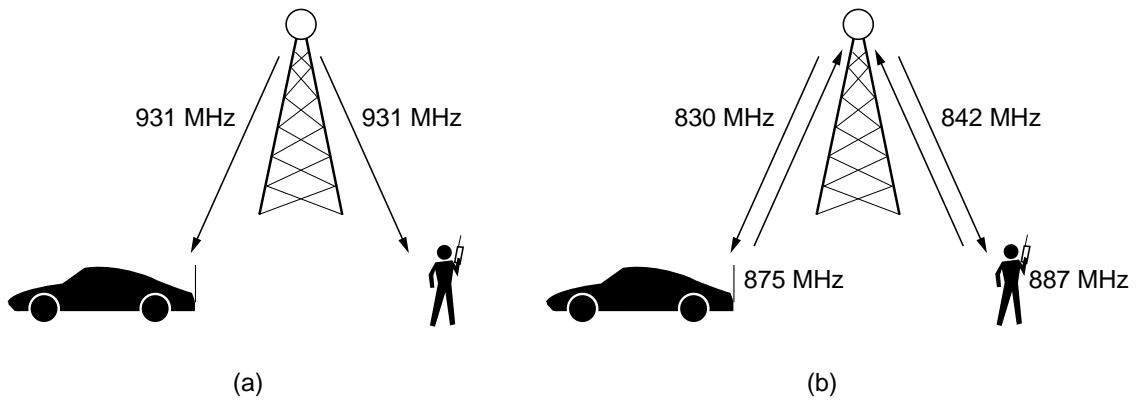
**Fig. 2-50.** (a) Cells colliding in a banyan switch. (b) Collision-free routing through a banyan switch.



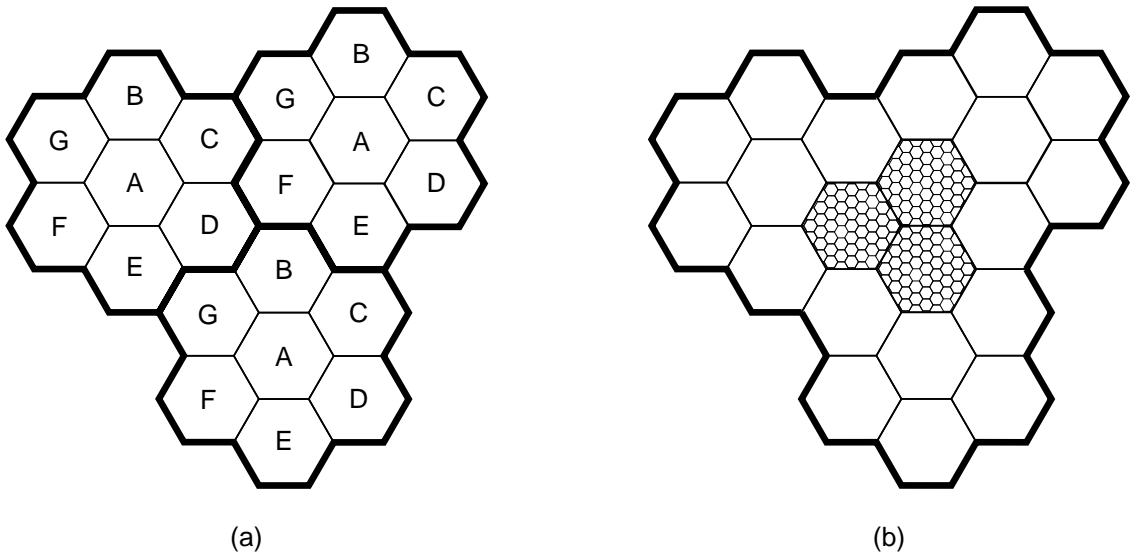
**Fig. 2-51.** The switching fabric for a Batcher-banyan switch.



**Fig. 2-52.** An example with four cells using the Batcher-banyan switch.



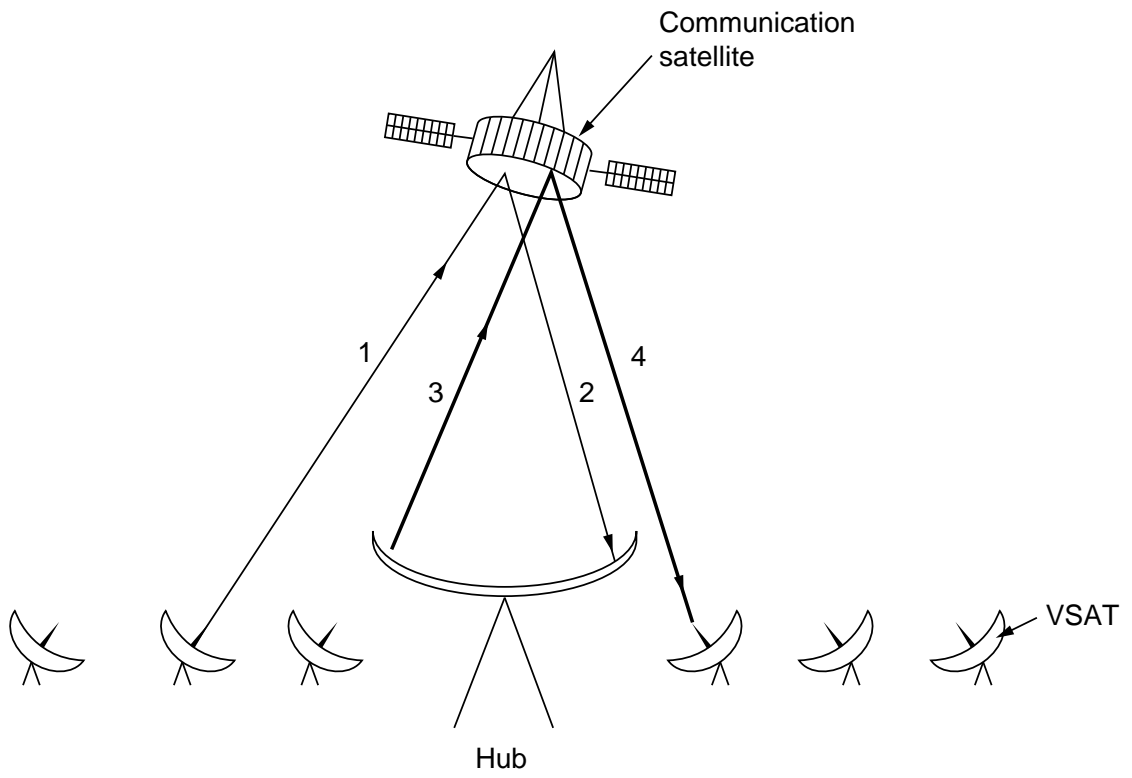
**Fig. 2-53.** (a) Paging systems are one way. (b) Mobile telephones are two way.



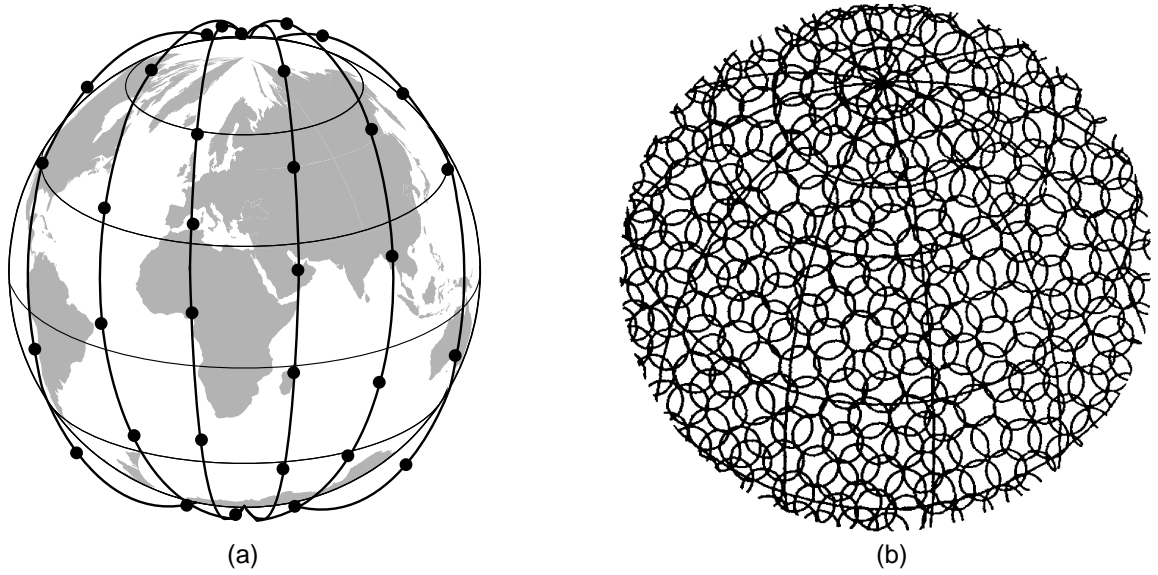
**Fig. 2-54.** (a) Frequencies are not reused in adjacent cells. (b) To add more users, smaller cells can be used.

| <b>Band</b> | <b>Frequencies</b> | <b>Downlink (GHz)</b> | <b>Uplink (GHz)</b> | <b>Problems</b>          |
|-------------|--------------------|-----------------------|---------------------|--------------------------|
| C           | 4/6                | 3.7–4.2               | 5.925–6.425         | Terrestrial interference |
| Ku          | 11/14              | 11.7–12.2             | 14.0–14.5           | Rain                     |
| Ka          | 20/30              | 17.7–21.7             | 27.5–30.5           | Rain; equipment cost     |

**Fig. 2-55.** The principal satellite bands.



**Fig. 2-56.** VSATs using a hub.



**Fig. 2-57.** (a) The Iridium satellites form six necklaces around the earth. (b) 1628 moving cells cover the earth.