to answer or not depending on the number being displayed. Caller ID is available in some states but not in others for privacy and other reasons.

Caller ID Block: Allows you to prevent your telephone number from appearing on a Caller ID display device when you are making a call. Instead, the party you are calling will see "Private Number" on their display when their telephone is ringing.

12.4 MULTIPLEXING

Multiplexing
Combining of two or more signals and transmitting them onto a single transmission line.

Demultiplexing
Separating *multiplexed* signals received on a single transmission line and distributing them to several individual circuits.

In communications, *multiplexing* is the process of combining two or more signals and transmitting them over a single transmission link. *Demultiplexing* is the reverse process of separating the multiplexed signals at the receiving end of the transmission link. The link can be any of the transmission media discussed earlier. Multiplexing results in the efficient use of the communications link. Trunk circuits within the PSTN use multiplexing techniques to combine several signals. The number of signals that can be multiplexed together is directly related to available *space, time,* and *bandwidth.* Space is required for the medium to exist in, and time is required for multiple signals to be transmitted and received. Perhaps the single most important factor in multiplexing is bandwidth. Bandwidth is necessary to accommodate the related frequency components of the multiplexed signals. The greater the bandwidth, the greater the number of signals that can be multiplexed. For digital signals, transmission speed is directly related to the available bandwidth. Wideband transmission media such as coaxial cable, microwave, and fiber-optic links, for example, have the capacity to multiplex several thousand voice signals together. There are three fundamental classifications of multiplexing:

1. Space-division multiplexing (SDM)
2. Frequency-division multiplexing (FDM)
3. Time-division multiplexing (TDM)

Multiplexing has become an essential part of the communication system today. It is necessary for us to understand the concept of multiplexing and how it results in efficient use of the communications channel.

12.4.1 Space-Division Multiplexing

Space-Division Multiplexing (SDM)
Multiplexing that utilizes physical space to combine multiple signals into a single, bundled transmission cable.

Space-division multiplexing (SDM) is simply the combining of physically separate signals into a bundled cable. It would not make sense to have a unique set of telephone poles or underground trenches for each telephone subscriber. Subscriber loop and trunk circuits are, therefore, combined. The shared use of space is attained in SDM. Because large volumes of space are not always available to contain cables, TDM or FDM are often combined with SDM.

12.4.2 Frequency-Division Multiplexing

Frequency-Division Multiplexing (FDM)
Multiplexing that utilizes the frequency domain to send multiple signals simultaneously over a channel's available bandwidth.

Frequency-division multiplexing (FDM) utilizes a channel's available bandwidth to send multiple signals simultaneously. By modulating several subcarriers with independent telephone signals, a composite signal can be generated and modulated onto a main carrier. The carrier is then transmitted onto a channel. SDM is consequently minimized. Figure 12-25(a) depicts FDM of three sine waves: 1, 2, and 3 kHz. Three

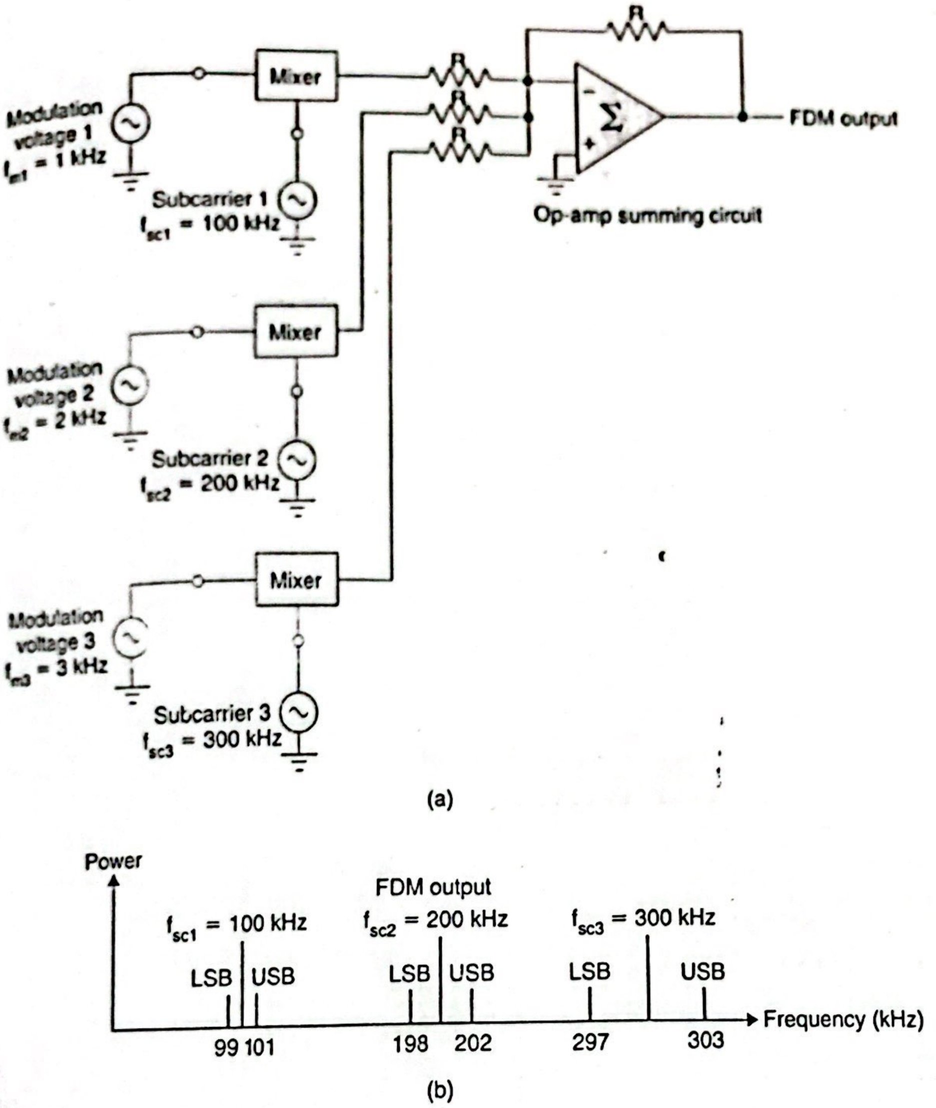

FIGURE 12-25
(a) Three independent sine waves mixed with subcarrier frequencies to produce the FDM output; (b) frequency spectrum of the FDM output signal.

subcarriers (100, 200, and 300 kHz) are mixed with the three independent modulating voltages. The output of each (nonlinear) mixer is electrically summed together to produce the given FDM output. The resulting frequency spectrum is shown in Figure 12-25(b).

12.4.2.1 Hierarchy of the Bell System's FDM Groups To standardize the telecommunications highways of the world, the Bell System has formed a hierarchy of *groups* that classify the number of voice channels that are multiplexed together before they are sent onto a trunk circuit (Figure 12-26). The trunk circuit may be microwave, fiber, or coax. Groups may also be multiplexed together to form higher groups in the hierarchy before transmission. The 300- to 3400-Hz telephone voice

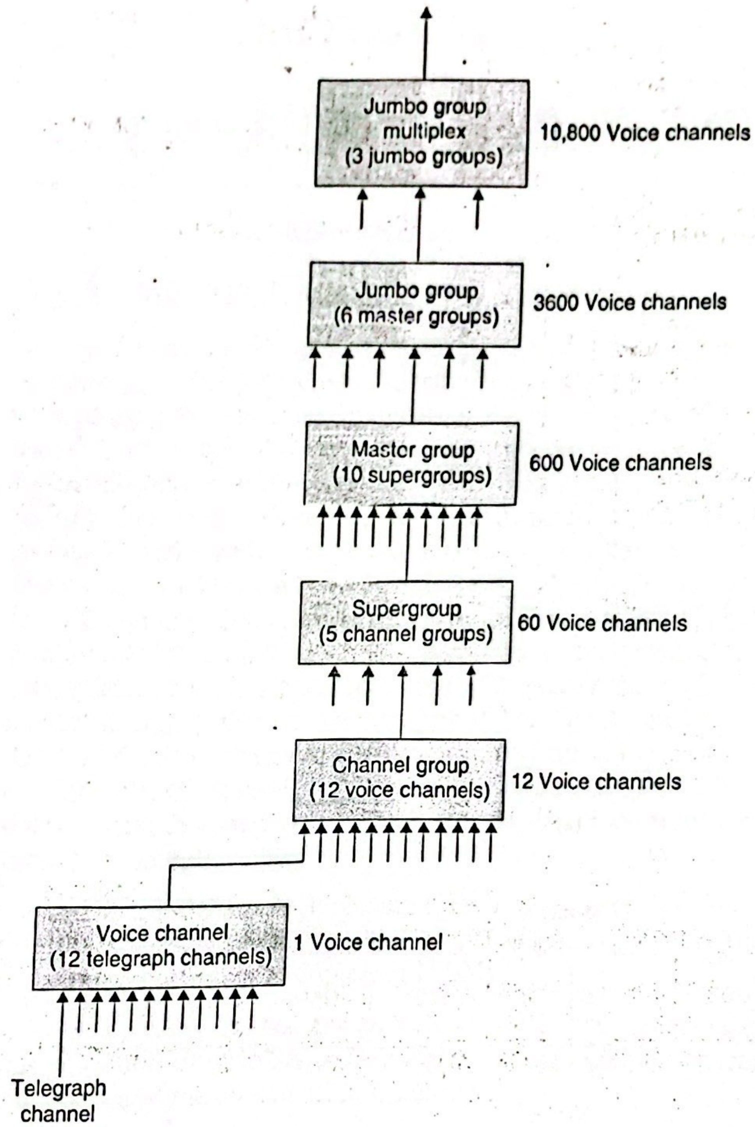

FIGURE 12-26
Hierarchy of the Bell System FDM groups.

channel is regarded as the fundamental building block of the hierarchy. A single voice channel can be further divided into 12 telegraph channels.

At the bottom of the hierarchy is the *telegraph channel.* A telegraph channel contains messages sent by telegraph equipment such as a Teletype terminal. The electrical impulses from the Teletype are used to frequency modulate a tone. As many as 12 tones can be modulated by 12 independent Teletypes to produce a composite signal that is sent over a single voice channel. The composite signal has no frequency components outside the voice-grade channel of 300 to 3400 Hz.

Twelve voice channels make up a *channel group.* By multiplexing five channel groups, a total of 60 voice channels is combined to form a *supergroup.* Ten supergroups form a *master group* containing 600 voice channels. Six master groups form a *jumbo group* of 3600 voice channels. At the top of the hierarchy is the *jumbo-group multiplex.* The jumbo-group multiplex is formed by multiplexing three jumbo groups together for a total of 10,800 voice channels. The Bell System L5 Carrier discussed earlier contains 20 coaxial tubes, each tube carrying a jumbo-group multiplex signal. Ten are used for transmitted signals, and 10 are for received signals. Thus, 108,000 (10 transmit and 10 receive jumbo-group multiplex signals) simultaneous telephone calls are possible through a combination of both SDM and FDM on the L5 carrier.

Figure 12-27(a) illustrates how 12 voice channels are frequency-division multiplexed together to form the basic channel group of composite signals. Each voice channel is mixed by a balanced modulator with subcarriers separated by 4 kHz. This technique is referred to as *single-sideband suppressed carrier (SSBSC);* 4-kHz bandpass filters are used to separate adjacent voice channels and filter the lower sideband (LSB) of each signal. This prevents sidebands from spilling into adjacent channels. The 12 lower sidebands are electrically summed together and further filtered to produce the FDM channel group output. A *pilot tone* of 104.08 kHz is sent with the channel group output signal for monitoring and demodulation purposes at the receiving end.

Single-sideband Suppressed Carrier (SSBSC)
An amplitude modulation (AM) technique that suppresses the carrier frequency and one of the sidebands. Realizes a significant power savings.

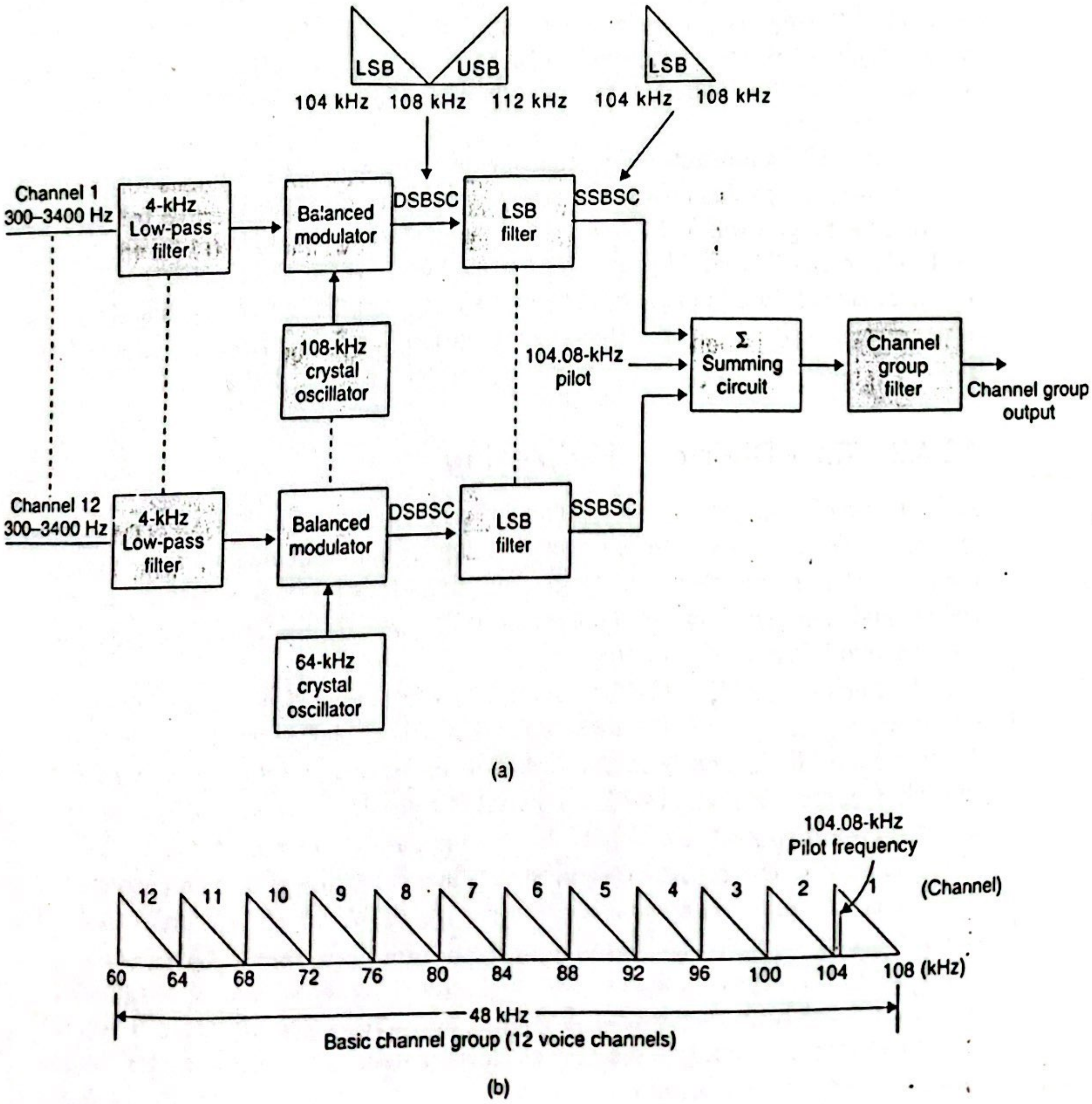

FIGURE 12-27
(a) Formation of the Bell System's channel group; (b) frequency distribution of the channel group.

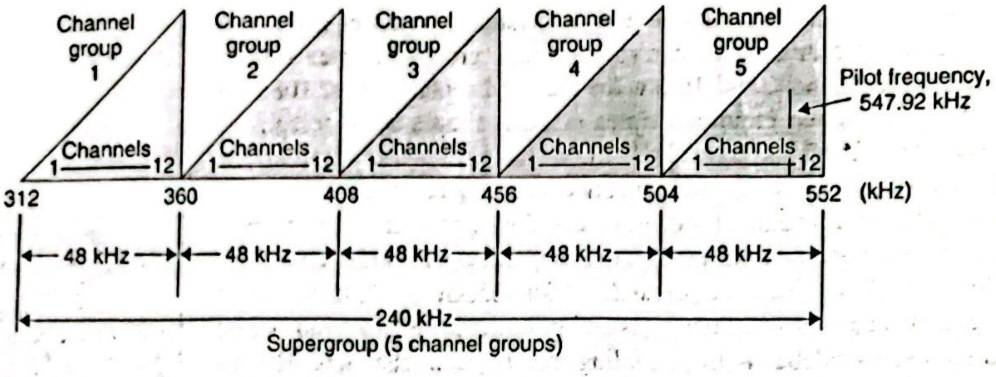

FIGURE 12-28
Frequency distribution of the Bell System supergroup.

The distribution of frequencies for the channel group is shown in Figure 12-27(b). A triangle is typically used to denote the distributed frequency spectrum as a result of mixing. The triangle, when facing as shown, denotes the selection of the LSB signals. LSB signals are said to be *inverted sidebands;* that is, the higher frequencies of the voice channel become the lower frequencies of the translated frequency spectrum.

Figure 12-28 illustrates the frequency distribution of signals for the supergroup. Five channel groups that make up a supergroup are translated to a frequency band occupying the range from 312 to 512 kHz, a bandwidth of 240 kHz (5 channel groups × 48 kHz each). The FDM process is repeated here. The upper-sideband (USB) frequencies are selected in the formation of a supergroup. Note that the triangle for the supergroup is opposite that of the channel group due to the selection of the USB. Higher frequencies appear at the higher end of the distributed spectrum.

12.4.3 Time-Division Multiplexing

Time-Division Multiplexing (TDM)
Multiplexing that utilizes the time domain to interleave multiple signals onto a single transmission line.

Analog-to-Digital Converter (ADC)
Used to convert an analog signal to a digital signal through quantization.

Pulse-Code Modulation (PCM)
Modulation technique that converts an analog signal into a digital bit stream for transmission.

A third form of multiplexing is called *time-division multiplexing (TDM).* Before 1960, telecommunications was predominantly analog transmission, with FDM serving as the major form of multiplexing. Since then, time-division multiplexed PCM (pulse-code modulation) has dominated the scene and become the preferred method of transmission onto PSTN trunk circuits.

In contrast to FDM, TDM involves the distribution of multiple signals in the *time domain,* whereas in FDM, these signals are distributed in the *frequency domain.* Another major distinction between these two forms of multiplexing is that FDM is an analog process, whereas TDM is a digital process. In TDM, several analog signals are sampled and converted to digital bit streams through the use of *analog-to-digital (A/D) converters.* The process of converting the analog signal into an encoded digital value is referred to as *pulse-code modulation (PCM).* In TDM, signals from several sources are digitized and *interleaved* to form a PCM signal. The time-division multiplexed PCM signal is then transmitted onto a single channel. When the digital bit stream is received, the reverse process is performed. The bit stream is *demultiplexed* and converted back to the original analog signals, and the analog signals are routed to their final destination.

Figure 12-29 illustrates the concept of TDM. Four analog signals are contiguously sampled and digitized by an 8-bit A/D converter. The interleaved binary serial