Radio broadcasting

The transmission, via radio-frequency electromagnetic waves, of audible program material for direct reception by the general public. Electromagnetic waves can be made to travel or propagate from a transmitting antenna to a receiving antenna. By modifying the amplitude, frequency, or relative phase of the wave in response to some message signal (a process known as modulation), it is possible to convey information from the transmitter to the receiver. In radio broadcasting, this information usually takes the form of voice or music. *See Electrical communications; Electromagnetic wave transmission; Modulation; Radio.*

Radio broadcasting occurs in four frequency bands (**Fig. 1**). So-called longwave broadcasting is permitted by international agreement in a portion of the low-frequency band from 150 to 290 kHz in Europe. The most widely used broadcast band is in the medium-frequency (mf) range between 525 and 1700 kHz. It is commonly known as AM after amplitude modulation, the technique employed. So-called shortwave broadcasting is permitted worldwide in eight fre-

AM Medium-Frequency Band

This section discusses the more important technical aspects of AM broadcasting as it is currently used.

AM transmission standards. Broadcast stations in the medium-frequency band use amplitude modulation of a carrier wave to transmit information. The amplitude of the wave is modified in response to the changing amplitude of an audible voice or music signal. The AM receiver detects these amplitude changes and converts them back into audible signals, which can then be amplified and reproduced on acoustical transducers or speakers. *See Radio receiver; Radio transmitter.*

The audible frequency range is generally considered to extend from 20 to 20,000 Hz. As a practical matter, AM broadcasting transmissions are limited to a range of 50 to 10,000 Hz. Because of transmission components and directional antennas, the fidelity of many stations is more severely restricted, resulting in voice transmission that is still acceptable but music transmission that is of relatively low fidelity.

In North and South America and the Caribbean (ITU Region 2), AM stations are assigned to frequencies spaced 10 kHz apart. In most of the rest of the world, stations are spaced at 9-kHz intervals.

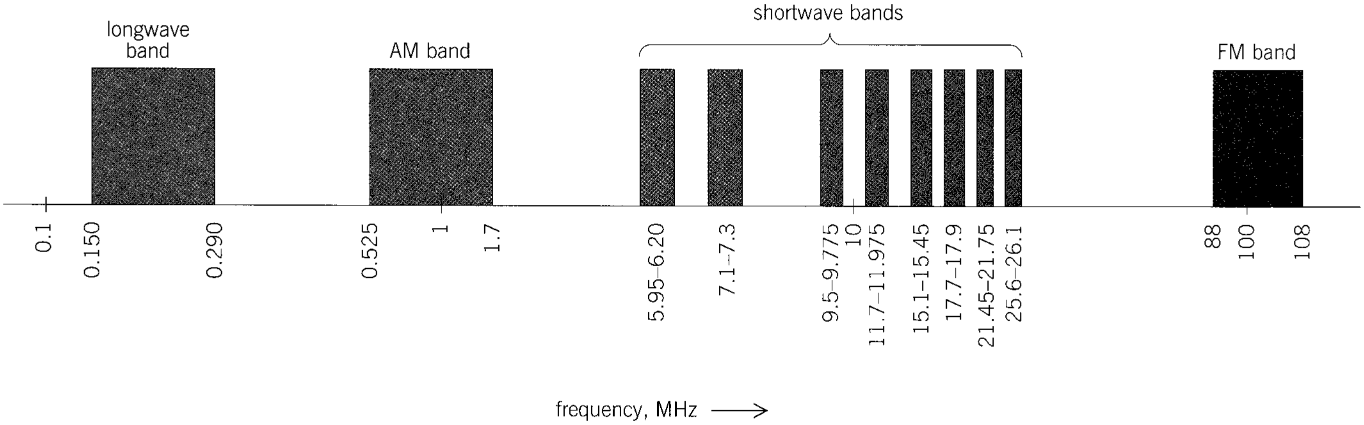

Fig. 1. The four frequency bands used in radio broadcasting.

In the United States, the maximum permitted power is 50 kW. The vast majority of AM stations in the United States operate with 5 kW or less. Stations are often licensed with higher power levels for daytime than nighttime hours to allow for the increased potential for interference at night. In other parts of the world, AM transmitters operate at much greater power levels, with 1-MW power levels rather common in Europe, the Mediterranean, and the Middle East.

AM station allocation criteria. The fundamental concept in allocating and licensing broadcast stations is to limit interference from one station to the service area of another. For AM stations, the service area is defined as those locations receiving a signal level greater than 0.5 millivolt per meter. Because of atmospheric noise and unregulated artificial noise sources such as appliances, automobiles, and electrical systems, as a practical matter the 0.5-mV/m signal level may provide useful service only in electrically quiet rural areas. In urban areas, a signal level of 2 mV/m or higher may be necessary to overcome noise and provide useful service. *See Electrical interference; Electrical noise.*

To protect this service area, other stations on the same frequency (cochannel stations) are required to locate far enough away, or limit their transmitting power, so that their interfering signal is less than 5% of the desired station's signal strength at the boundary of the desired station's 0.5-mV/m service area, a 20:1 ratio of desired signal to undesired signal. For stations on adjacent channels (± 10 kHz difference in carrier frequency), the required ratio is 1:1. This latter ratio is used primarily in the Western Hemisphere as an allocation standard; different, more restrictive, adjacent-channel ratios are used in other countries. Additionally, less restrictive desired-to-undesired signal ratios, or prohibitions on overlapping field-strength contours, are also employed when the frequency separation between stations is ±20 and ±30 kHz.

During nighttime hours a cochannel interference protection ratio of 20:1 is also employed. In addition, during nighttime hours the 0.5-mV/m, 50%-time sky-wave signal service area of stations in the highest class (class A) may also be protected from interference.

Transmitting antennas. An AM station may use a single tower for an antenna, resulting in an omnidirectional radiation pattern; or two or more transmitting towers to augment the radiation in certain directions while suppressing it in others, in order to comply with station allocation criteria. Such a directional antenna is developed by making use of the geometric relationship of the towers, and the relative amplitudes and phases of the currents in each tower, to create controlled constructive and destructive phase interference relationships in the desired directions. Directional antennas that use three to six towers are common, and stations with up to 12 towers have been built.

Since the allocation restrictions may be different during the daytime and nighttime hours, many stations employ two different directional antennas. **Figure 2** shows the daytime and nighttime radiation patterns for a three-tower directional antenna used by an AM station. The radiation from the antenna is expressed in millivolts per meter at 1 km (0.62 mi) from the antenna. *See Antenna (electromagnetism).*

Medium-frequency signal propagation. AM broadcast signals propagate from the transmitter by three mechanisms: ground-wave, space-wave, and sky-wave.

Ground waves travel along the ground surface (the boundary between the Earth and the atmosphere). Because they are surface waves, they penetrate into the ground, resulting in the energy being diminished because of losses in the ground. The degree of energy lost or signal attenuation is a function of the conductivity and permittivity of the near-surface ground, the frequency of operation, and the presence of any major surface discontinuities such as mountain ranges. The conductivity along the transmission path is the quantity primarily used to determine the extent of ground-wave propagation. The conductivity along salt-water paths can be as high as 5000 millisiemens per meter, while rocky terrain can have conductivities as low as 0.1 mS/m. Fertile farmland, alluvial plains, and other flat open areas can have conductivities ranging from 4 to 30 mS/m. Depending on the frequency, power level, and conductivity, useful ground-wave signals can propagate from a few tens of miles out to several hundred miles from the station.

The current flowing in the antenna also produces space waves, which travel through the atmosphere from transmitter to receiver. Space-wave propagation is usually limited by intervening terrain obstacles or the curvature of the Earth. Consequently, space-wave propagation is not as important for AM broadcasting as ground-wave and sky-wave propagation.

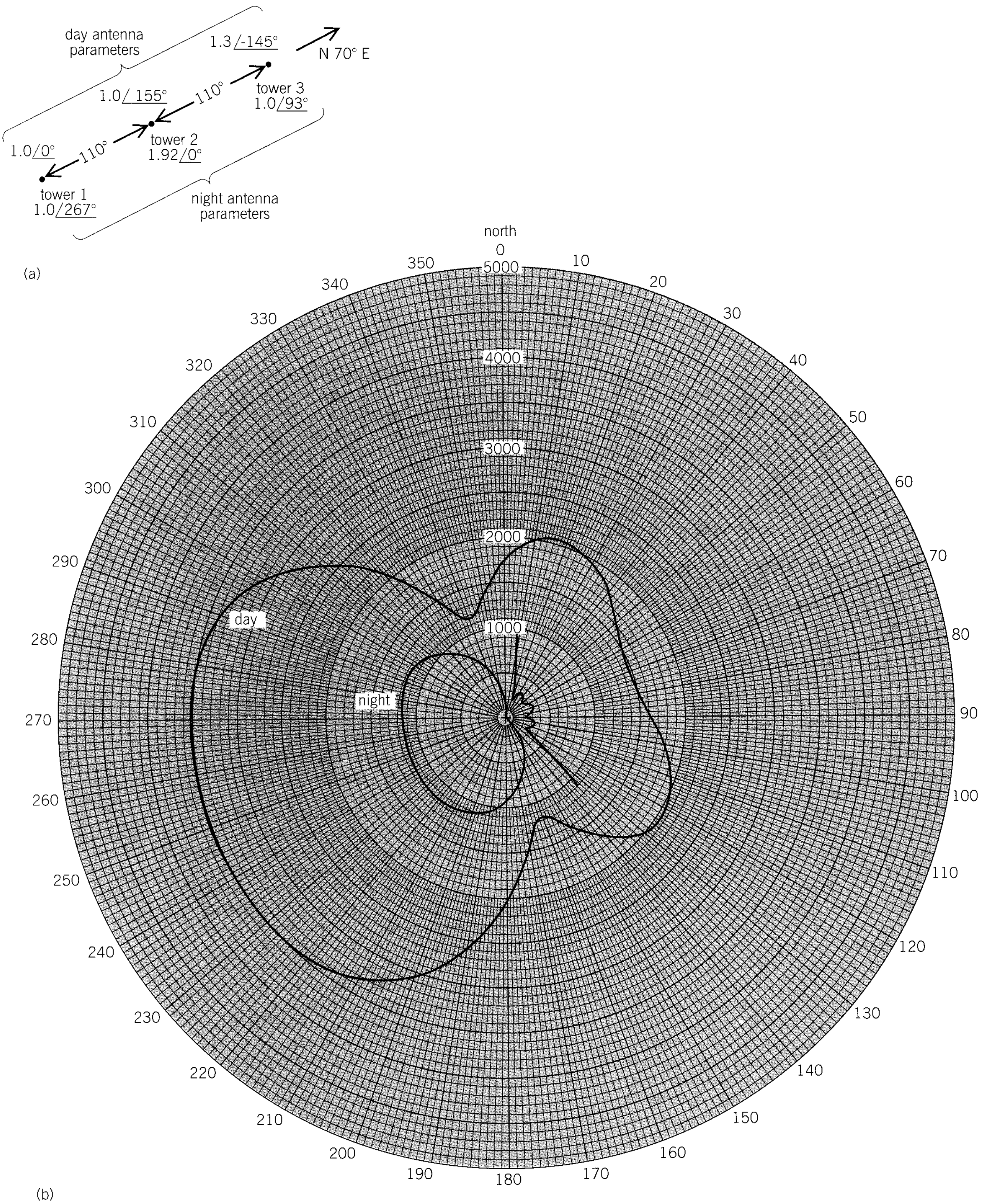

Fig. 2. Directional antenna array of the AM station KLOK in San Jose, California, broadcasting at 1170 kHz. (*a*) Configuration of array. Spacing between towers is given in electrical degrees. For the frequency of 1170 kHz, 1 electrical degree = 2.3 ft = 0.71 m and 110° = 257 ft = 78 m. The antenna parameters shown are field ratios and relative phases for each tower. (*b*) Resulting daytime (power = 50 kW) and nighttime (power = 5 kW) radiation patterns. The radiation from the antenna is expressed in millivolts per meter at 1 km (0.62 mi) from the antenna.

Sky-wave propagation occurs when space waves directed toward the ionosphere are reflected toward the Earth. This phenomenon can result in substantial signal strengths at distances of several hundred miles from the antenna. AM sky-wave propagation occurs primarily during nighttime hours by reflections from the E and F layers of the ionosphere at about 60 and 130 mi (100 and 220 km) altitude above the Earth's surface, respectively. During daytime hours the Sun's radiation ionizes the D layer of the ionosphere at about 40 mi (60 km) altitude above the Earth's surface. When the D layer is ionized, it tends to absorb and scatter the skyward-directed space waves from the AM antenna, thus preventing them from reaching the reflective E and F layers. As nighttime approaches, the ionization of the D layer diminishes, and so the AM signals pass through it to the E and F layers. The reflected sky waves increase in amplitude to levels at which they can provide useful service or substantial interference to other stations. *See* IONOSPHERE; RADIO-WAVE PROPAGATION.

Broadcast service area. The daytime ground-wave signal level protected by allocation criteria is usually 0.5 mV/m, although much higher signal strengths may be necessary to overcome noise from atmospheric and artificial sources, especially in highly urbanized areas. The extent of ground-wave service may be determined by using theoretical calculations or by measurements of the field strengths. The accuracy of the theoretical prediction method is limited primarily by the limited accuracy of the available conductivity data taken from maps, and secondarily by the approximate nature of the simple mathematical formulas used to calculate radiation from the antenna. Field-strength measurements provide an inefficient but definitive method of assessing station coverage.

During nighttime hours, the service area for most AM stations (other than class A stations) is usually limited by interference from other cochannel stations. In such cases, the service area is confined to the locations where the desired ground-wave field strength is 20 times greater than the RSS (root of the sum of the squares) of all the strongest interference signals on the channel at a given location. Because of interference during the night, the useful service may be limited to areas inside the 2.5 to 25 mV/m ground-wave contours. For low-power stations, this may be only 10 mi (16 km) or less from the transmitter.

For the highest class of stations (class A), nighttime service is protected by the allocation criteria to the 0.5-mV/m, 50%-time sky-wave contour. Because such service is subject to the time variations and fading of sky-wave propagation, the 0.5-mV/m, 50%-time contour is considered to be a secondary service area.

Figure 3 shows a plot of the theoretically predicted daytime and nighttime service areas for the station whose radiation patterns were shown in Fig. 2. The daytime service area is taken to be the 0.5-mV/m ground-wave contour, while the nighttime service area is limited by cochannel interference as described above to 8.37 mV/m. The distances to the contours vary because of radiation variations in the directional antenna and because of the different ground conductivity values in the region around the station, including that of salt water in San Francisco Bay.

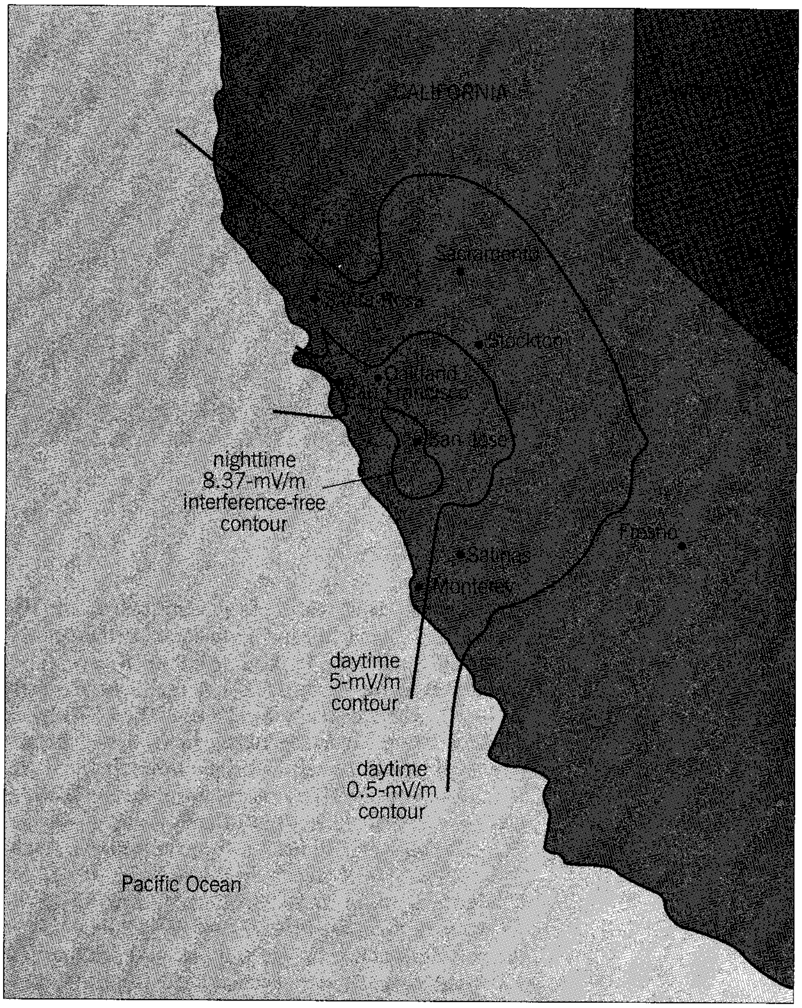

Fig. 3. Predicted daytime and nighttime interference-free field strength coverage contours of the AM station KLOK in San Jose, California.

AM stereo. In the United States, the Federal Communications Commission (FCC) has declined to designate a standard AM stereo transmission system. By 1990, approximately 600 stations, about 12% of the AM stations in the United States, operated in stereo. Of these, approximately 500 stations used a phase-modulation-type system, while another 100 used an independent-sideband system with the left and right channels transmitted on the lower and upper sidebands to form a complete composite AM stereo signal. *See* PHASE MODULATION; STEREOPHONIC RADIO TRANSMISSIONS.

FM VHF BAND

FM broadcasting has become the dominant broadcast service in the United States primarily because of its better fidelity and its superior reception, which is less subject to noise and interference than that of AM.

FM transmission standards. Information is conveyed by frequency modulation or deviation of a carrier wave. In the United States, the carrier frequency may be deviated ±75 kHz around the assigned carrier frequency. The carrier frequencies, or channels, are spaced at 200-kHz intervals in the United States; a few other countries use slightly different channel spacings.

Nearly all FM stations transmit in stereo. A stereo audio signal consists of left and right channels. For broadcasting, the stereo signal is constructed at audio

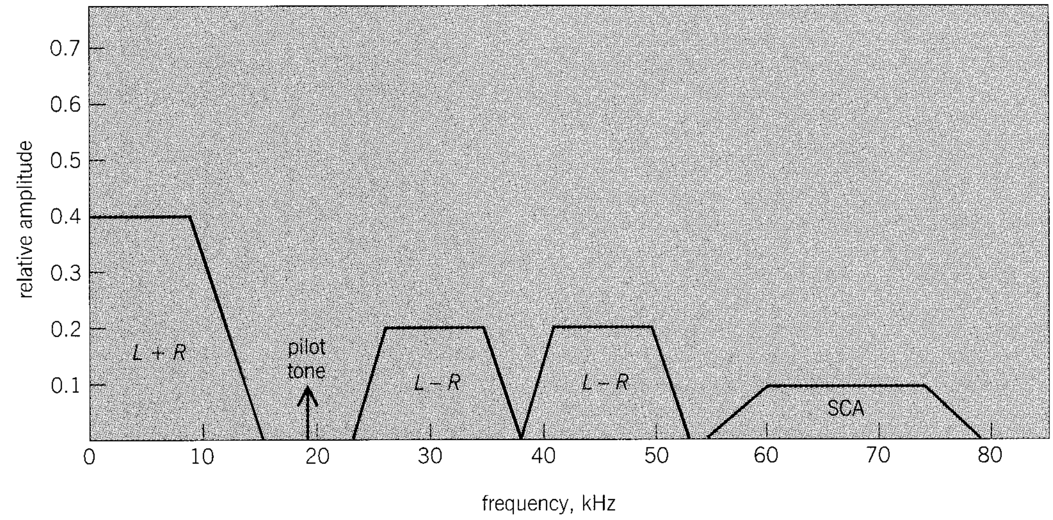

Fig. 4. FM broadcast baseband frequency spectrum.

or baseband frequencies before being sent to the FM transmitter. The baseband frequency portion of the spectrum from 0 to 15 kHz (**Fig. 4**) is used for a signal that is the sum of the left and right channels ($L + R$). The frequency band from 23 to 53 kHz is used for an amplitude-modulated signal that is the difference between the left and right channels ($L - R$). A pilot tone at 19 kHz is also transmitted so that the receiver can recognize when a stereo signal is present. The pilot tone is also used to synchronize the detection of the $L - R$ signal. In the receiver, the ($L + R$) signal is added to and subtracted from the ($L - R$) signal to yield separate $2L$ and $2R$ audio signals at the receiver output. In this way the two separate left and right channels are reconstructed from the composite signal. This stereo transmission method was chosen so that it would be compatible with monaural FM broadcasts, which use only the 0–15-kHz ($L + R$) signal.

The power of FM stations is limited by regulatory agencies so that the degree of coverage and potential interference to other stations is limited. A wide range of station classes has evolved using power levels from 3 to 100 kW. For FM, the allowed power rating is the effective radiated power (ERP) from the antenna, not the transmitter power. The effective radiated power is approximately equal to the transmitter power multiplied by the antenna gain minus any system losses.

FM station allocation criteria. FM stations are assigned to channels in the United States by using a fixed-distance separation table between transmitter sites. The amount of required separation depends on the station class, which in turn depends on the allowed effective radiating power and antenna height above average terrain (HAAT). For the highest class of station (class C) with 100 kW effective radiating power and 1969 ft (600 m) antenna height above average terrain, the required separation for stations on the same channel is 180 mi (290 km). Required separations are less for stations of lower class and for stations that are separated in frequency by ±200, ±400, or ±600 kHz.

Rather than use a fixed-distance separation scheme, some other countries use desired-to-undesired signal ratios to determine station locations to avoid interference. In still other countries, FM frequencies are freely assigned with no plan for protecting service areas or limiting interference.

Vhf signal propagation. The service area of an FM station depends on the propagation of space waves from the transmitter to the receiver. Ground waves and sky waves, which are the dominant propagation mechanisms for AM broadcasting, are unimportant in the vhf band. Space waves propagate through the atmosphere and are diffracted around, and reflected off, mountains, buildings, and other objects. Propagation within areas that have an unobstructed line-of-sight from transmitter to receiver is most reliable and predictable. When obstructions lie along the path, the FM signal strength is attenuated below the level that would exist for a line-of-sight path of the same length. The amount of attenuation can be calculated by using simple physical models based on diffraction theory. The accuracy of the calculation is reduced by the inability of simple models to account for real hills and mountains. *See Diffraction.*

Because of reflections that occur with vhf FM transmission, a condition known as multipath can exist. Multipath occurs when signals from more than one direct or reflected signal source arrive at the receiver. The combination of these signals can be such that they destructively interfere with each other, resulting in diminished signal strength and distorted program reproduction.

The degree of signal diffraction and reflection that occurs depends on the reception location, and can vary with time because of changing atmospheric or other propagation path conditions. For this reason, vhf FM broadcast signal strengths are usually described statistically. For example, the field strength level exceeded 50% of the time at 50% of the locations is denoted F(50,50). A higher-reliability signal level is one exceeded 90% of the time at 90% of the locations, denoted F(90,90).

FM vhf service area. The primary service area of FM stations is generally taken as that area where the F(50,50) signal strength exceeds 1.0 mV/m. In the United States, the FCC requires each station to have a city of primary service, where the F(50,50) signal level must exceed 3.16 mV/m.

For FCC purposes, the service area of an FM station can be found by using a set of curves showing field strength as a function of distance, effective radiated power, and antenna height above average terrain. For the highest class of station (class C), the 1.0 mV/m service extends to about 60 mi (96 km) according to FCC curves. In flat terrain, with a high antenna, the effective service may be rendered with field strengths much less than 1.0 mV/m, resulting in service areas that extend to 130 mi (210 km) or more from the transmitter.

Because of mountains and other obstructions, FM signal strength does not decrease monotonically with distance, but may fluctuate with distance (as well as with time). Consequently, the FCC propagation curves provide only an approximation of FM service. By explicitly taking into account signal attenuation over terrain obstacles (mountains), a more realistic estimation of FM service may be obtained. **Figure 5** shows the 3.16-mV/m service area for a 100-kW FM station. The broken line is the predicted FCC service area, while the solid lines show the service area prediction with terrain obstructions considered. The "islands" within the broken line are locations where the signal strength falls below 3.16 mV/m because of terrain obstacles.

Subcarrier transmission. To achieve greater utility from their transmitting facilities, FM broadcast stations have taken advantage of baseband spectrum space above 53 kHz for so-called subsidiary communication authorization (SCA) transmissions. For stereo stations, any frequency between 53 and 99 kHz may be used for an SCA, although the frequencies of 67 and 75 kHz are typically used. An SCA centered at 67 kHz is shown in Fig. 4. The amount of power that can be devoted to the SCA is limited to 10% of the total station power, but within these loose technical constraints an FM broadcast station may transmit a wide variety of audio and digital signals on the

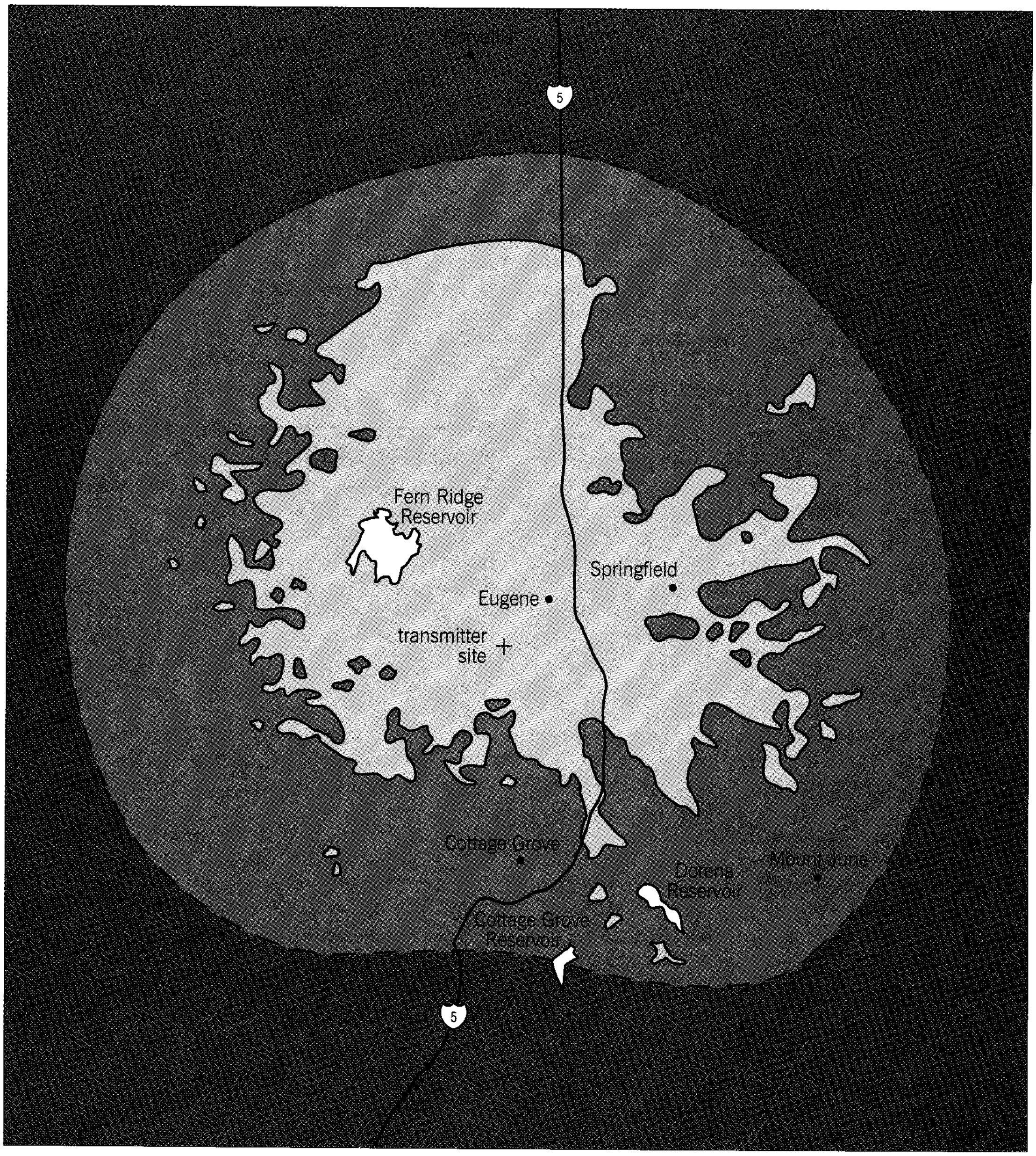

Fig. 5. Predicted 3.16-mV/m coverage contour for the 100-kW station KUGN in Eugene, Oregon. The broken line represents coverage based on FCC field strength curves. The solid lines and "islands" represent a more realistic depiction of coverage that explicitly takes into account terrain obstructions.

SCA. Because the SCA signal is not detected by a normal FM stereo receiver, but requires a special receiver that is distributed to a limited audience (who usually pay for the service), SCA transmission services are sometimes referred to as narrowcasting rather than broadcasting. SCAs carry a wide range of services including background music, stock market data, and sophisticated nationwide paging services with watchband receivers that can automatically scan the FM frequency band and lock in on the FM broadcast station transmitting the appropriate digital coded message on the SCA. *See Radio paging systems.*

SHORTWAVE BROADCASTING

For reaching audiences in foreign countries or other distant places, shortwave broadcasting is most often used. Nearly 600 million shortwave radio receivers are in use worldwide.

Technical standards. Shortwave broadcasting is permitted worldwide in eight frequency bands from 5950 to 26,100 kHz. The assigned transmitting frequencies are spaced at 5-kHz intervals, resulting in a limited usable audio bandwidth. Voice transmissions are most effective, while music transmissions have limited fidelity.

Double-sideband (DSB) amplitude modulation is usually employed, although to make better use of the spectrum space some single-sideband (SSB) transmission is used. In single-sideband transmission, one sideband of a normal double-sideband signal is suppressed, thus reducing the occupied frequency bandwidth by about one-half without sacrificing audio bandwidth. The penalty with single-sideband transmission is that a more complex and stable receiver is required for suitable reception.

Transmitter powers for shortwave stations range from 1 to 500 kW, with the higher powers commonly used. Transmitters are normally coupled to high-gain directional transmitting antennas, which can result in effective radiated powers of several megawatts.

Frequency assignments. Four times each year, a shortwave station desiring to transmit to particular areas conducts a theoretical computer study of the propagation conditions from its transmitter site to the reception area for a coming season. The result of the study is a list of proposed frequency assignments and times when those frequencies are put to best use. This list is then submitted through the national government to the ITU. The ITU analyzes the frequency and time requests from all countries and then publishes a list of so-called incompatibilities or potential interference problems 3 months before the season begins. During this 3-month period, stations with conflicts have the opportunity to resolve them in bilateral agreements. In most cases, the interference conflicts can be resolved so that 85–90% of the transmissions will not suffer interference when operation for the season actually begins (based on the theoretical predictions).

To take best advantage of the varying propagation conditions throughout the day, a shortwave station may shift frequencies every 4 h to different bands, or redirect particular frequencies to different reception areas. The operating frequencies and schedules of a station may become quite complex.

Shortwave signal propagation. Shortwave signals propagate via sky waves that are reflected one or more times from the E and F layers of the ionosphere. Multiple reflections are possible because a signal can also bounce off the Earth's surface after reflecting off the ionosphere in a "Ping-Pong" effect. With multiple reflections, signals can propagate around the Earth, reaching countries distant from the broadcasting station. Because the degree of ionization of the E and F layers varies with the Sun's radiation, shortwave propagation is highly dependent on the solar illumination along the transmission path between the transmitter and the receiver.

Shortwave service areas. Several factors limit the reception of a shortwave signal, chief among them being atmospheric noise, interference, and signal fading. Through the use of high-gain antennas, shortwave stations can target a desired reception area by concentrating the energy in that direction. Usually a signal strength of 0.25 to 1.0 mV/m, 50% of the time, is needed in the targeted service area to overcome atmospheric noise and provide good reception. It may be impossible to overcome a strong cochannel interference source, and sometimes such interference has been used to deliberately jam reception of another signal. Signal fading is a result of the varying conditions of the ionosphere; however, usable signal strengths can sometimes exist for several hours even with changing atmospheric conditions.

Harry R. Anderson

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