MICROWAVE RADIO COMMUNICATIONS : INTRODUCTION

Microwaves are generally described as electromagnetic waves with frequencies that range from approximately 500 MHz to 300 GHz or more. Therefore, microwave signals, because of their inherently high frequencies, have relatively short wavelengths, hence the name “micro” waves. For example, a 100-GHz microwave signal has a wave length of 0.3 cm, whereas a 100-MHz commercial broadcast-band FM signal has a wavelength of 3 m. The wavelengths for microwave frequencies fall between 1 cm and 60 cm, slightly longer than infrared energy. For full-duplex (two-way) operation as is generally required of microwave communications systems, each frequency band is divided in half with the lower half identified as the *low band* and the upper half as the *high band.* At any given radio station, transmitters are normally operating on either the low or the high band, while receivers are operating on the other band.

Intrastate or *feeder service* microwave systems are generally categorized as *short haul* because they are used to carry information for relatively short distances, such as between cities within the same state. *Long-haul* microwave systems are those used to carry information for relatively long distances, such as *interstate* and *backbone* route applications. Microwave radio system capacities range from less than 12 voice-band channels to more than 22,000 channels. Early microwave systems carried frequency-division- multiplexed voice-band circuits and used conventional, non-coherent frequency-modulation techniques. More recently developed microwave systems carry pulse-code-modulated time-division-multiplexed voice-band circuits and use more modern digital modulation techniques, such as phase-shift keying (PSK) or quadrature amplitude modulation (QAM).

Figure 1 shows a typical layout for a microwave radio link. Information originates and terminates at the terminal stations, whereas the repeaters simply relay the information to the next downlink microwave station. Figure 1a shows a microwave radio link comprised of two terminal stations (one at each end) that are interconnected by three repeater stations. As the figure shows, the microwave stations must be geographically placed in such a way that the terrain (lakes, mountains, buildings, and so on) do not interfere with transmissions between stations. This sometimes necessitates placing the stations on top of hills, mountains, or tall buildings. Figure 1b shows how a microwave radio link appears from above. Again, the geographic location of the stations must be carefully selected such that natural and man-made barriers do not interfere with propagation between stations. Again, sometimes it is necessary to construct a microwave link around obstacles, such as large bodies of water, mountains, and tall buildings.

Microwave Radio Communications and System Gain

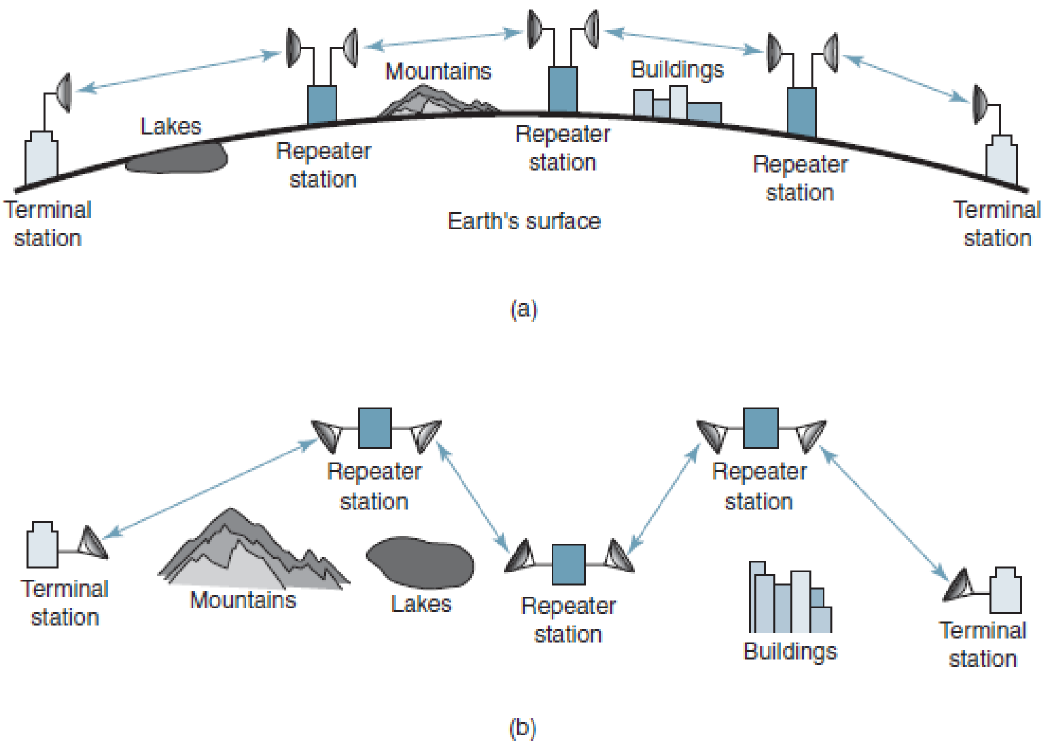


FIGURE 1 Microwave radio communications link: (a) side view; (b) top view

ADVANTAGES AND DISADVANTAGES OF MICROWAVE RADIO

Microwave radios propagate signals through Earth's atmosphere between transmitters and receivers often located on top of towers spaced about 15 miles to 30 miles apart. Therefore, microwave radio systems have the obvious advantage of having the capacity to carry thousands of individual information channels between two points without the need for physical facilities such as coaxial cables or optical fibers. In addition, radio waves are better suited for spanning large bodies of water, going over high mountains, or going through heavily wooded terrain that impose formidable barriers to cable systems.

Advantages of Microwave Radio

1. Radio systems do not require a right-of-way acquisition between stations.
2. Each station requires the purchase or lease of only a small area of land.

3. Because of their high operating frequencies, microwave radio systems can carry large quantities of information.
4. High frequencies mean short wavelengths, which require relatively small antennas.
5. Radio signals are more easily propagated around physical obstacles such as water and high mountains.
6. Fewer repeaters are necessary for amplification.
7. Distances between switching centers are less.
8. Underground facilities are minimized.
9. Minimum delay times are introduced.
10. Minimal crosstalk exists between voice channels.
11. Increased reliability and less maintenance are important factors.

Disadvantages of Microwave Radio

1. It is more difficult to analyze and design circuits at microwave frequencies.
2. Measuring techniques are more difficult to perfect and implement at microwave frequencies.
3. It is difficult to implement conventional circuit components (resistors, capacitors,inductors, and so on) at microwave frequencies.
4. Transient time is more critical at microwave frequencies.
5. It is often necessary to use specialized components for microwave frequencies.
6. Microwave frequencies propagate in a straight line, which limits their use to line of-sight applications.

ANALOG VS DIGITAL MICROWAVE

A vast majority of the existing microwave radio systems are frequency modulation, which of course is analog. Recently, however, systems have been developed that use either phase shift keying or quadrature amplitude modulation, which are forms of digital modulation. Analog microwave radio is an older technology, rapidly being replaced by a variety of digital microwave radio technologies. This shift occurred because, in general, digitizing signal transmission improves network performance and capacity.

NEED TO DIGITAL MICROWAVE

The modern communication is towards digital transmission to digitize the analog signals, PCM techniques are used. Digital techniques are widely becoming popular for application in switching and multiplexing , thus necessitating the use of a new transmission means on radio for the medium and high capacities both for long haul application and junction working of inter exchanges, in urban areas . Radio links for direct transmission of PCM signals at standard bit rates of 2,8,34 and 140 MB/ Sec.

Facilities found by using digital microwave are mentioned below :-

a) Radio repeaters being of re-generative type will give an error free output and there is no accumulation of noise from hop to hop.
b) Better circuit quality up to threshold level of the radio receiver.
c) Total system economy is better.
d) Since transmission system is digital , more operational advantages are found, like storage, retransmission etc. of information can be easily achieved .
e) For data transmission, digital radio is more efficient.
f) In digital multiplexing, the number of channels loaded does not affect the performance.

FREQUENCY MODULATION Vs. AMPLITUDE MODULATION

In FM, the amplitude of the modulated carrier signal is kept constant while its frequency is varied by the modulating message signal. Thus, FM signals have all their information in the *phase* or *frequency* of the carrier. This provides a ***nonlinear and very rapid improvement in reception quality*** once a certain minimum received signal level, called the FM threshold, is achieved.

In amplitude modulation (AM) schemes, there is a ***linear relationship between the quality of the received signal and the power of the received signal*** since AM signals superimpose the exact relative amplitudes of the modulating signal onto the carrier. Thus, AM signals have all their information in the *amplitude* of the carrier.

FM offers many advantages over amplitude modulation (AM), which makes it a better choice for many mobile radio applications.

Frequency modulation has ***better noise immunity*** when compared to amplitude modulation. Since signals are represented as frequency variations rather than amplitude variations, FM signals are ***less susceptible to atmospheric and impulse noise***, which tend to cause rapid fluctuations in the amplitude of the received radio signal. Also, message amplitude variations do not carry information in FM, so ***burst noise does not affect FM system performance*** as much as AM systems, provided that the FM received signal is above the FM threshold.

FM offers ***superior qualitative performance in fading*** when compared to AM. Also, in an FM system, it is possible to tradeoff bandwidth occupancy for improved noise performance.

Unlike AM, in an FM system, ***the modulation index, and hence bandwidth occupancy, can be varied to obtain greater signal-to-noise performance***. It can be shown that, under certain conditions, the FM signal-to noise ratio improves 6 dB for each doubling of bandwidth occupancy. This ability of an FM system to trade bandwidth for SNR is perhaps the most important reason for its superiority over AM.

AM signals are able to occupy less bandwidth as compared to FM signals, since the transmission system is linear. In modern AM systems, susceptibility to fading has been dramatically improved through the use of in-band pilot tones which are transmitted along with the standard AM signal. The modern AM receiver is able to monitor the pilot tone and rapidly adjust the receiver gain to compensate for the amplitude fluctuations.

An FM signal is a ***constant envelope*** signal, due to the fact that the envelope of the carrier does not change with changes in the modulating signal. Hence the transmitted power of an FM signal is constant regardless of the amplitude of the message signal. The constant envelope of the transmitted signal allows efficient Class C power amplifiers to be used for RF power amplification of FM. In AM, however, it is critical to maintain linearity between the applied message and the amplitude of the transmitted signal, thus linear Class A or AB amplifiers, which are not as power efficient, must be used. The issue of amplifier efficiency is extremely important when designing portable subscriber terminals since the battery life of the portable is tied to the power amplifier efficiency. Typical efficiencies for Class C amplifiers are 70%, meaning that 70% of the applied DC power to the final amplifier circuit is converted into radiated RF power. Class A or AB amplifiers have efficiencies on the order of 30-40%. This implies that for the same battery, constant envelope FM modulation may provide twice as much talk time as AM.

Frequency modulation exhibits a so-called ***capture effect characteristic***. The capture effect is a direct result of the rapid nonlinear improvement in received quality for an increase in received power. If two signals in the same frequency band are available at an FM receiver, the one appearing at the higher received signal level is accepted and demodulated, while the weaker one is rejected. This inherent ability to pick up the strongest signal and reject the rest makes FM systems very resistant to co-channel interference and provides excellent subjective received quality. In AM systems, on the other hand, all of the interferers are received at once and must be discriminated after the demodulation process.

While FM systems have many advantages over AM systems, they also have certain ***disadvantages***.

FM systems require a ***wider frequency band*** in the transmitting media (generally several times as large as that needed for AM) in order to obtain the advantages of reduced noise and capture effect.

FM transmitter and receiver equipment is also ***more complex*** than that used by amplitude modulation systems. Although frequency modulation systems are tolerant to certain types of signal and circuit nonlinearities, special attention must be given to phase characteristics.

Both AM and FM may be demodulated using inexpensive non-coherent detectors. AM is ***easily demodulated using an envelope detector whereas FM is demodulated using a discriminator or slope detector***. AM may be detected coherently with a product detector, and in such cases AM can outperform FM in weak signal conditions since FM must be received above threshold.

FREQUENCY MODULATED MICROWAVE RADIO SYSTEM

Microwave radio systems using FM are widely recognized as providing flexible, reliable, and economical point-to-point communications using Earth's atmosphere for the transmission medium. FM microwave systems used with the appropriate multiplexing equipment are capable of simultaneously carrying from a few narrowband voice circuits up to thousands of voice and data circuits. FM microwave radio is very often the most economical means for providing communications circuits where there are no existing metallic cables or optical fibers or where severe terrain or weather conditions exist.

A simplified block diagram of an FM microwave radio is shown in Figure 2.

The *baseband* is the composite signal that modulates the FM carrier and may comprise one or more of the following:

1. Frequency-division-multiplexed voice-band channels

2. Time-division-multiplexed voice-band channels

3. Broadcast-quality composite video or picturephone

4. Wideband data

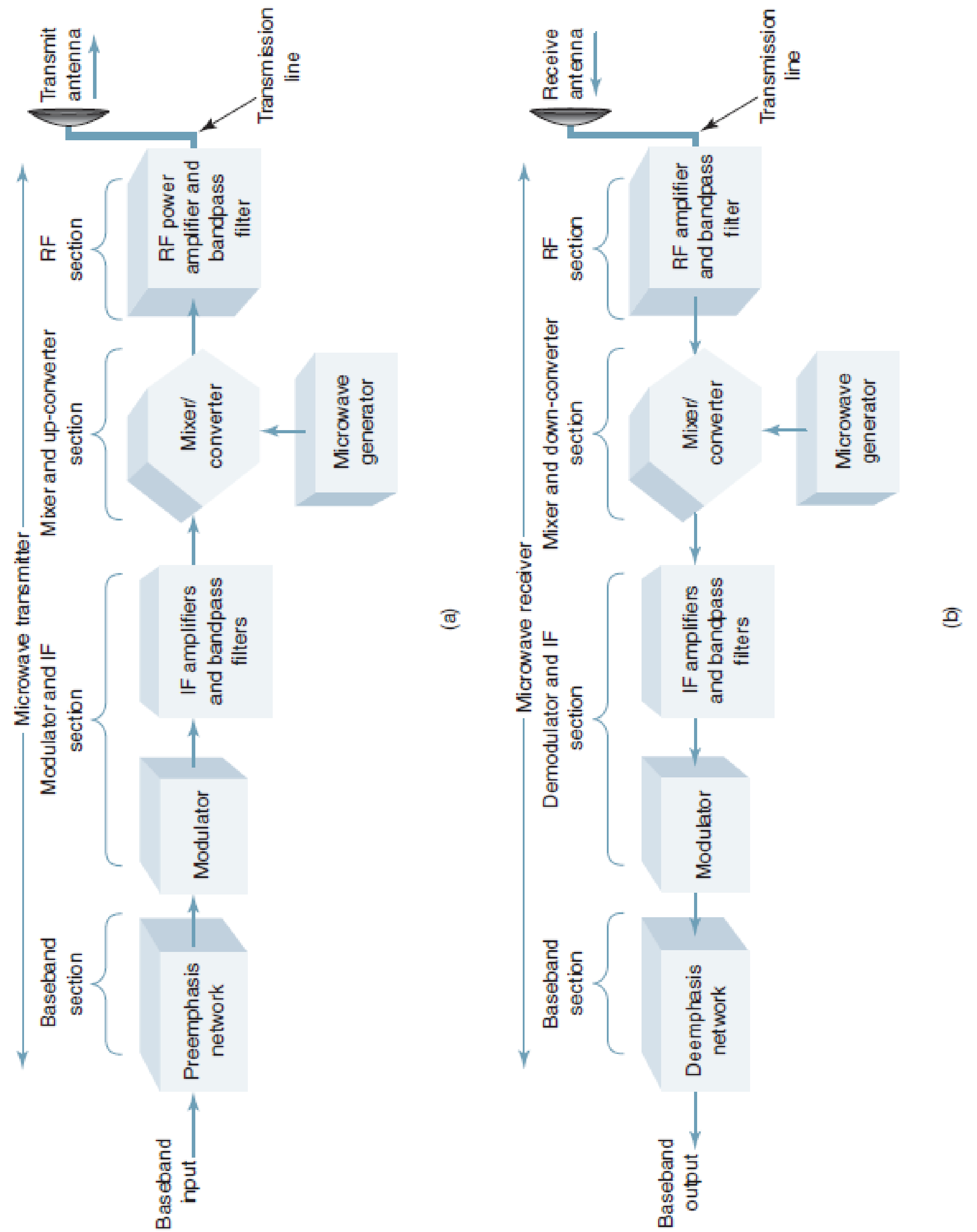


FIGURE 2 Simplified block diagram of a microwave radio: (a) transmitter; (b) receiver

FM Microwave Radio Transmitter

In the FM *microwave transmitter* shown in Figure 2a, a *pre-emphasis* network precedes the FM deviator. The pre-emphasis network provides an artificial boost in amplitude to the higher baseband frequencies. This allows the lower baseband frequencies to frequency modulate the IF carrier and the higher baseband frequencies to phase modulate it. This scheme ensures a more uniform signal-to-noise ratio throughout the entire baseband spectrum. An FM deviator provides the modulation of the IF carrier that eventually becomes the main microwave carrier. Typically, IF carrier frequencies are between 60 MHz and 80 MHz, with 70 MHz the most common. *Low-index* frequency modulation is used in the FM deviator. Typically, modulation indices are kept between 0.5 and 1. This produces a *narrowband* FM signal at the output of the deviator. Consequently, the IF bandwidth resembles conventional AM and is approximately equal to twice the highest baseband frequency.

The IF and its associated sidebands are up-converted to the microwave region by the mixer, microwave oscillator, and band-pass filter. Mixing, rather than multiplying, is used to translate the IF frequencies to RF frequencies because the modulation index is unchanged by the heterodyning process. Multiplying the IF carrier would also multiply the frequency deviation and the modulation index, thus increasing the bandwidth. Microwave generators consist of a crystal oscillator followed by a series of frequency multipliers. For example, a 125-MHz crystal oscillator followed by a series of multipliers with a combined multiplication factor of 48 could be used to a 6-GHz microwave carrier frequency. The channel-combining network provides a means of connecting more than one microwave transmitter to a single transmission line feeding the antenna.

FM Microwave Radio Receiver

In the FM microwave receiver shown in Figure 2b, the channel separation network provides the isolation and filtering necessary to separate individual microwave channels and direct them to their respective receivers. The band-pass filter, AM mixer, and microwave oscillator down-convert the RF microwave frequencies to IF frequencies and pass them on to the FM demodulator. The FM demodulator is a conventional, *non-coherent* FM detector (i.e., a discriminator or a PLL demodulator). At the output of the FM detector, a de-emphasis network restores the baseband signal to its original amplitude-versus-frequency characteristics.

FM MICROWAVE RADIO REPEATERS

The permissible distance between an FM microwave transmitter and its associated microwave receiver depends on several system variables, such as transmitter output power, receiver noise threshold, terrain, atmospheric conditions, system capacity, reliability objectives, and performance expectations. Typically, this distance is between 15 miles and 40 miles. Long-haul microwave systems span distances considerably longer than this. Consequently, a single-hop microwave system, such as the one shown in Figure 2, is inadequate for most practical system applications. With systems that are longer than 40 miles or when geographical obstructions, such as a mountain, block the transmission path, *repeaters* are needed. A microwave repeater is a receiver and a transmitter placed back to back or in tandem with the system. A simplified block diagram of a microwave repeater is shown in Figure 3. The repeater station receives a signal, amplifies and reshapes it, and then retransmits the signal to the next repeater or terminal station down line from it.

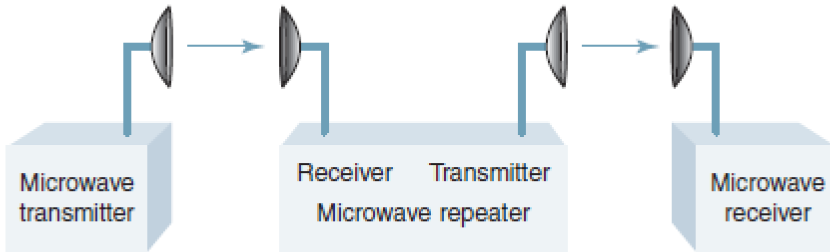


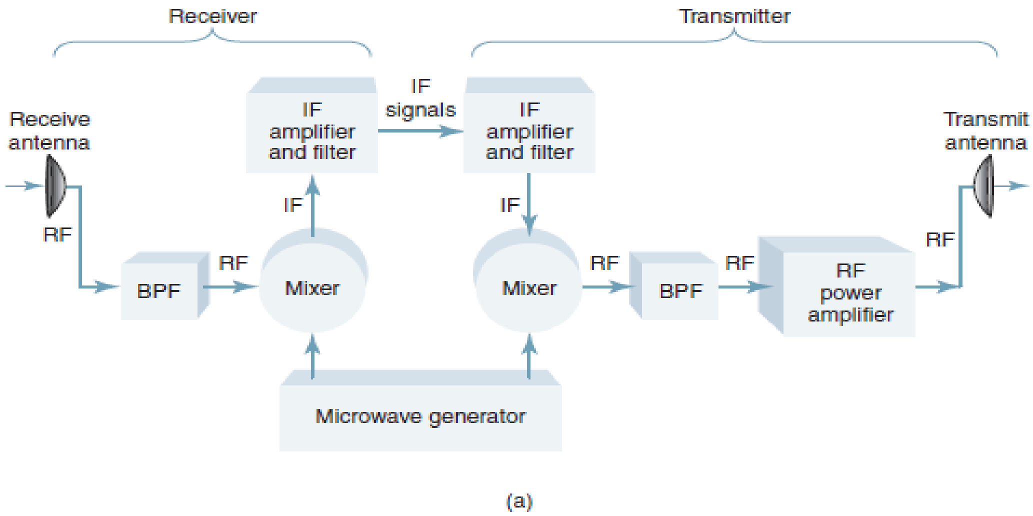
FIGURE 3 Microwave repeater

The location of intermediate repeater sites is greatly influenced by the nature of the terrain between and surrounding the sites. Preliminary route planning generally assumes relatively flat areas, and path (hop) lengths will average between 25 miles and 35 miles between stations. In relatively flat terrain, increasing path length will dictate increasing the antenna tower heights. Transmitter output power and antenna gain will similarly enter into the selection process. The exact distance is determined primarily by line-of-site path clearance and received signal strength. For frequencies above 10 GHz, local rainfall patterns could also have a large bearing on path length. In all cases, however, paths should be as level as possible. In addition, the possibility of interference, either internal or external, must be considered.

Basically, there are ***three types of microwave repeaters***: ***IF, baseband, and RF*** (see Figure 4). IF repeaters are also called *heterodyne* repeaters.

IF repeaters are also called Heterodyne repeater. With an IF repeater (Figure 4a), the received RF carrier is down-converted to an IF frequency, amplified, reshaped, up converted to an RF frequency, and then retransmitted. The signal is never demodulated below IF. Consequently, the baseband intelligence is unmodified by the repeater. With a baseband repeater (Figure 4b), the received RF carrier is down-converted to an IF frequency, amplified, filtered, and then further demodulated to baseband. The baseband signal, which is typically frequency-division-multiplexed voice-band channels, is further demodulated to a master group, super group, group, or even channel level. This allows the baseband signal to be reconfigured to meet the routing needs of the overall communications network. Once the baseband signal has been reconfigured, it FM modulates an IF carrier, which is up-converted to an RF carrier and then retransmitted.

Figure 4c shows another baseband repeater configuration. The repeater demodulates the RF to baseband, amplifies and reshapes it, and then modulates the FM carrier. With this technique, the baseband is not reconfigured. Essentially, this configuration accomplishes the same thing that an IF repeater accomplishes. The difference is that in a baseband configuration, the amplifier and equalizer act on baseband frequencies rather than IF frequencies. The baseband frequencies are generally less than 9 MHz, whereas the IF frequencies are in the range 60 MHz to 80 MHz. Consequently, the filters and amplifiers necessary for baseband repeaters are simpler to design and less expensive than the ones required for IF repeaters. The disadvantage of a baseband configuration is the addition of the FM terminal equipment.



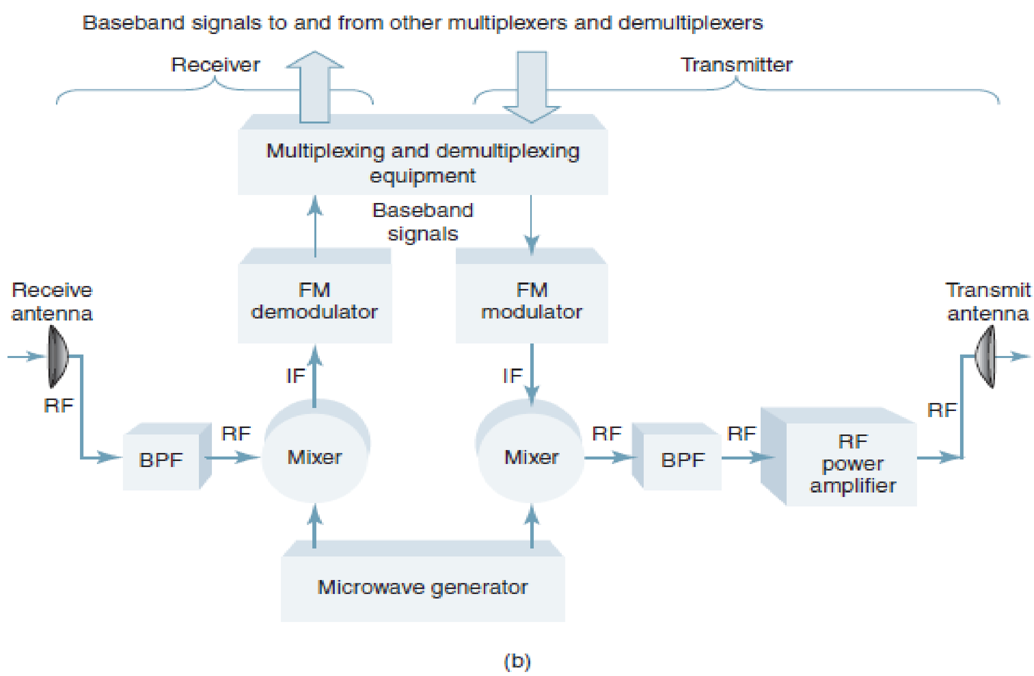
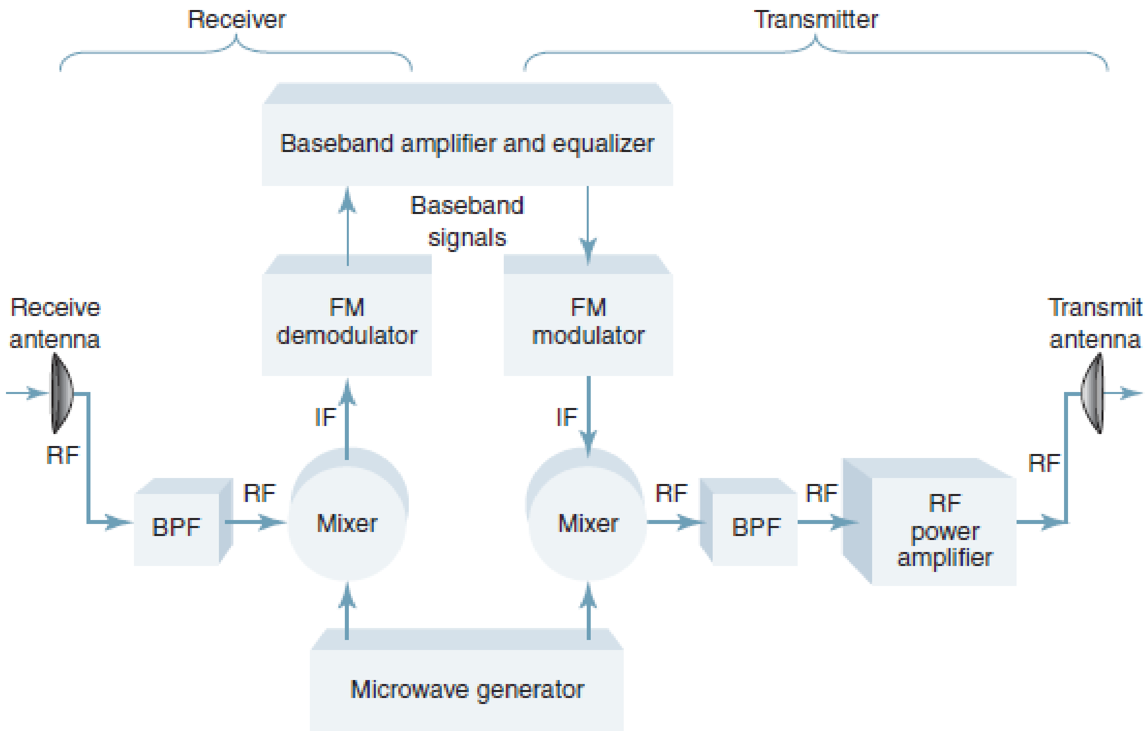
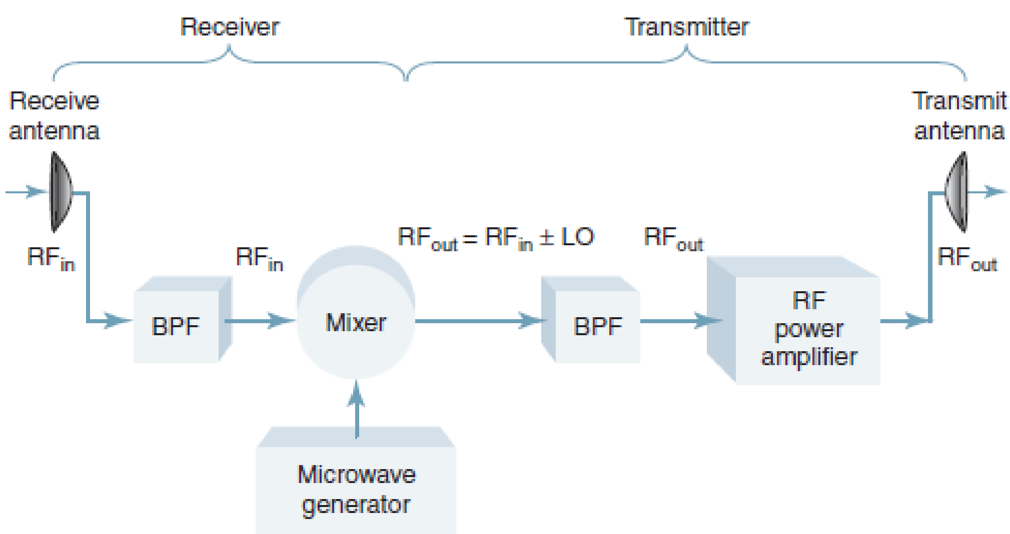


FIGURE 4 Microwave repeaters: (a) IF; (b) baseband; (*Continued*)



(c)



(d)

FIGURE 4 (*Continued*) Microwave repeaters: (c) baseband; (d) RF

Figure 4d shows an RF-to-RF repeater. With RF-to-RF repeaters, the received microwave signal is not down-converted to IF or baseband; it is simply mixed (heterodyned) with a local oscillator frequency in a nonlinear mixer. The output of the mixer is tuned to either the sum or the difference between the incoming RF and the local oscillator frequency, depending on whether frequency up- or down-conversion is desired. The local oscillator is sometimes called a *shift oscillator* and is considerably lower in frequency than either the received or the transmitted radio frequencies. For example, an incoming RF of 6.2 GHz is mixed with a 0.2-GHz local oscillator frequency producing sum and difference frequencies of 6.4 GHz and 6.0 GHz. For frequency up-conversion, the output of the mixer would be tuned to 6.4 GHz, and for frequency down-conversion, the output of the mixer would be tuned to 6.0 GHz. With RF-to-RF repeaters, the radio signal is simply converted in frequency and then reamplified and transmitted to the next down-line repeater or terminal station. Reconfiguring and reshaping are not possible with RF-to-RF repeaters.

DIVERSITY

Microwave systems use *line-of-site* transmission; therefore a direct signal path must exist between the transmit and the receive antennas. Consequently, if that signal path undergoes a severe degradation, a service interruption will occur. Over time, radio path losses vary with atmospheric conditions that can vary significantly, causing a corresponding reduction in the received signal strength of 20, 30, or 40 or more dB. This reduction in signal strength is temporary and referred to as *radio fade*. Radio fade can last for a few milliseconds (short term) or for several hours or even days (long term). Automatic gain control circuits, built into radio receivers, can compensate for fades of 25 dB to 40 dB, depending on system design; however, fades in excess of 40 dB can cause a total loss of the received signal. When this happens, service continuity is lost.

Diversity suggests that there is more than one transmission path or method of transmission available between a transmitter and a receiver. In a microwave system, the purpose of using diversity is to increase the reliability of the system by increasing its availability.When there is more than one transmission path or method of transmission available, the system can select the path or method that produces the highest-quality received signal. Generally, the highest quality is determined by evaluating the carrier-to-noise (C/N) ratio at the receiver input or by simply measuring the received carrier power. Although there are many ways of achieving diversity, the most common methods used are frequency, space, polarization, hybrid, or quad.

Frequency Diversity

Frequency diversity is simply modulating two different RF carrier frequencies with the same IF intelligence, then transmitting both RF signals to a given destination. At the destination, both carriers are demodulated, and the one that yields the better-quality IF signal is selected. Figure 5 shows a single-channel frequency-diversity microwave system.

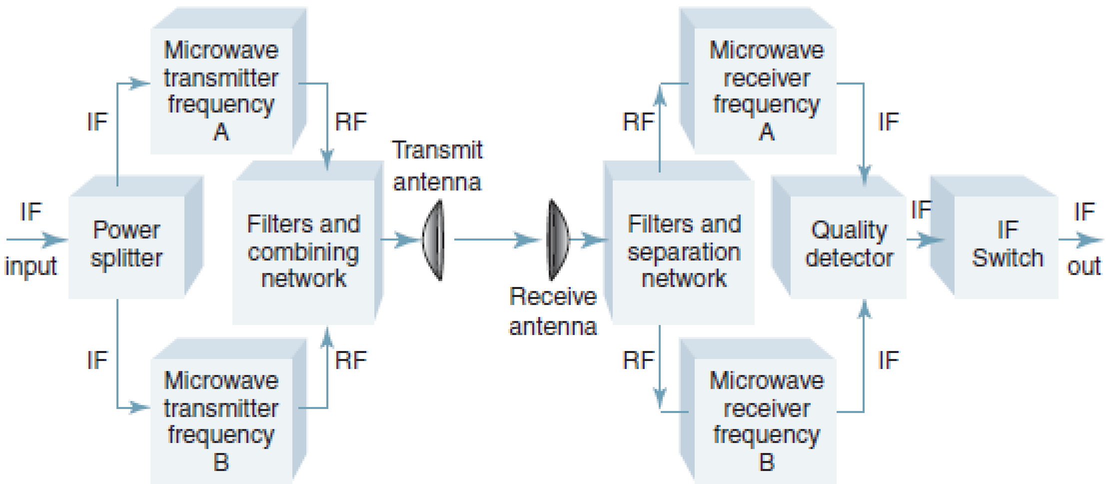


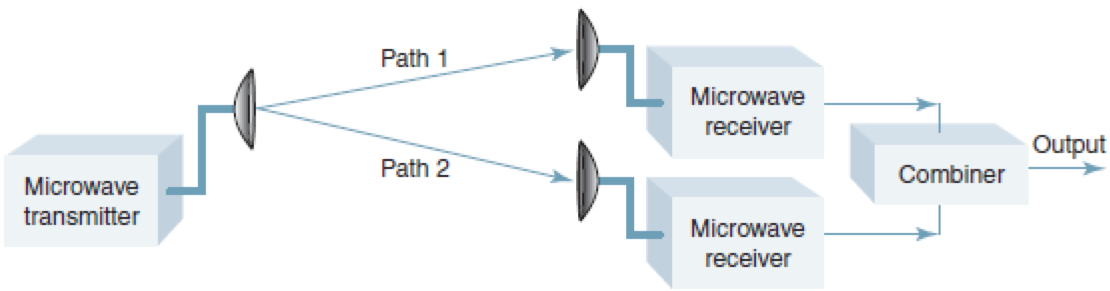
FIGURE 5 Frequency diversity microwave system

In Figure 5a, the IF input signal is fed to a power splitter, which directs it to microwave transmitters A and B. The RF outputs from the two transmitters are combined in the channel-combining network and fed to the transmit antenna. At the receive end (Figure 5b), the channel separator directs the A and B RF carriers to their respective microwave receivers, where they are down-converted to IF. The quality detector circuit determines which channel, A or B, is the higher quality and directs that channel through the IF switch to be further demodulated to baseband. Many of the temporary, adverse atmospheric conditions that degrade an RF signal are frequency selective; they may degrade one frequency more than another. Therefore, over a given period of time, the IF switch may switch back and forth from receiver A to receiver B and vice versa many times.

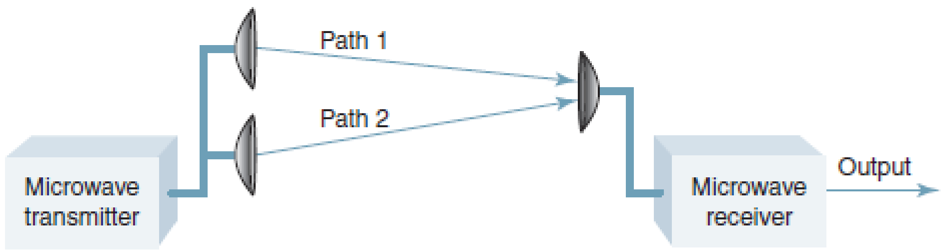
Frequency-diversity arrangements provide complete and simple equipment redundance and have the additional advantage of providing two complete transmitter-to-receiver electrical paths. Its obvious disadvantage is that it doubles the amount of frequency spectrum and equipment necessary.

Space Diversity

With space diversity, the output of a transmitter is fed to two or more antennas that are physically separated by an appreciable number of wavelengths. Similarly, at the receiving end, there may be more than one antenna providing the input signal to the receiver. If multiple receiving antennas are used, they must also be separated by an appreciable number of wavelengths. Figure 6 shows two ways to implement space diversity. Figure 6a shows a space diversity system using two transmit antennas, whereas Figure 6b shows a space diversity system using two receive antennas. The rule is to use two transmit antennas or two receive antennas but never two of each.



(a)



(b)

FIGURE 6 Space diversity: (a) two receive antennas; (b) two transmit antennas

When space diversity is used, it is important that the electrical distance from a transmitter to each of its antennas and to a receiver from each of its antennas is an equal multiple of wavelengths long. This is to ensure that when two or more signals of the same frequency arrive at the input to a receiver, they are in phase and additive. If received out of phase, they will cancel and, consequently, result in less received signal power than if simply one antenna system were used. Adverse atmospheric conditions are often isolated to a very small geographical area. With space diversity, there is more than one transmission path between a transmitter and a receiver.

When adverse atmospheric conditions exist in one of the paths, it is unlikely that the alternate path is experiencing the same degradation. Consequently, the probability of receiving an acceptable signal is higher when space diversity is used than when no diversity is used. An alternate method of space diversity uses a single transmitting antenna and two receiving antennas separated vertically. Depending on the atmospheric conditions at a particular time, one of the receiving antennas should be receiving an adequate signal. Again, there are two transmission paths that are unlikely to be affected simultaneously by fading.

Space diversity is more expensive than frequency diversity because of the additional antennas and waveguide. Space diversity, however, provides efficient frequency spectrum usage and a substantially greater protection than frequency diversity.

Polarization Diversity

With *polarization diversity,* a single RF carrier is propagated with two different electromagnetic polarizations (vertical and horizontal). Electromagnetic waves of different polarizations do not necessarily experience the same transmission impairments. Polarization diversity is generally used in conjunction with space diversity. One transmit/receive antenna pair is vertically polarized, and the other is horizontally polarized. It is also possible to use frequency, space, and polarization diversity simultaneously.

Receiver Diversity

Receiver diversity is using more than one receiver for a single radio-frequency channel. With frequency diversity, it is necessary to also use receiver diversity because each transmitted frequency requires its own receiver. However, sometimes two receivers are used for a single transmitted frequency.

Quad Diversity

Quad diversity is another form of hybrid diversity and undoubtedly provides the most reliable transmission; however, it is also the most expensive. The basic concept of quad diversity is quite simple: It combines frequency, space, polarization, and receiver diversity into one system. Its obvious disadvantage is providing redundant electronic equipment, frequencies, antennas, and waveguide, which are economical burdens.

Hybrid Diversity

Hybrid diversity is a somewhat specialized form of diversity that consists of a standard frequency-diversity path where the two transmitter/receiver pairs at one end of the path are separated from each other and connected to different antennas that are vertically separated as in space diversity. This arrangement provides a space-diversity effect in both directions— in one direction because the receivers are vertically spaced and in the other direction because the transmitters are vertically spaced. This arrangement combines the operational advantages of frequency diversity with the improved diversity protection of space diversity. Hybrid diversity has the disadvantage, however, of requiring two radio frequencies to obtain one working channel.

PROTECTION SWITCHING ARRANGEMENTS

To avoid a service interruption during periods of deep fades or equipment failures, alternate facilities are temporarily made available in a *protection switching* arrangement. The general concepts of protection switching and diversity are quite similar: Both provide protection against equipment failures and atmospheric fades. The primary difference between them is, simply, that diversity systems provide an alternate transmission path for only a single microwave link (i.e., between one transmitter and one receiver) within the overall communications system. Protection switching arrangements, on the other hand, provide protection for a much larger section of the communications system that generally includes several repeaters spanning a distance of 100 miles or more. Diversity systems also generally provide 100% protection to a single radio channel, whereas protection switching arrangements are usually shared between several radio channels.

There are ***two types*** of protection switching arrangements: ***hot standby and diversity***. With hot standby protection, each working radio channel has a dedicated backup or spare channel. With diversity protection, a single backup channel is made available to as many as 11 working channels. Hot standby systems offer 100% protection for each working radio channel. A diversity system offers 100% protection only to the first working channel to fail. If two radio channels fail at the same time, a service interruption will occur.

Hot Standby

Figure 7a shows a single-channel hot standby protection switching arrangement. At the transmitting end, the IF goes into a *head-end bridge*, which splits the signal power and directs it to the working and the spare (standby) microwave channels simultaneously. Consequently, both the working and the standby channels are carrying the same baseband information. At the receiving end, the IF switch passes the IF signal from the working channel to the FM terminal equipment. The IF switch continuously monitors the received signal power on the working channel and, if it fails, switches to the standby channel. When the IF signal on the working channel is restored, the IF switch resumes its normal position.

Diversity

Figure 7b shows a diversity protection switching arrangement. This system has two working channels (channel 1 and channel 2), one spare channel, and an *auxiliary* channel. The IF switch at the receive end continuously monitors the receive signal strength of both working channels. If either one should fail, the IF switch detects a loss of carrier and sends back to the transmitting station IF switch a VF (*voice frequency*) tone-encoded signal that directs it to switch the IF signal from the failed channel onto the spare microwave channel. When the failed channel is restored, the IF switches resume their normal positions. The auxiliary channel simply provides a transmission path between the two IF switches. Typically, the auxiliary channel is a low-capacity low-power microwave radio that is designed to be used for a maintenance channel only.

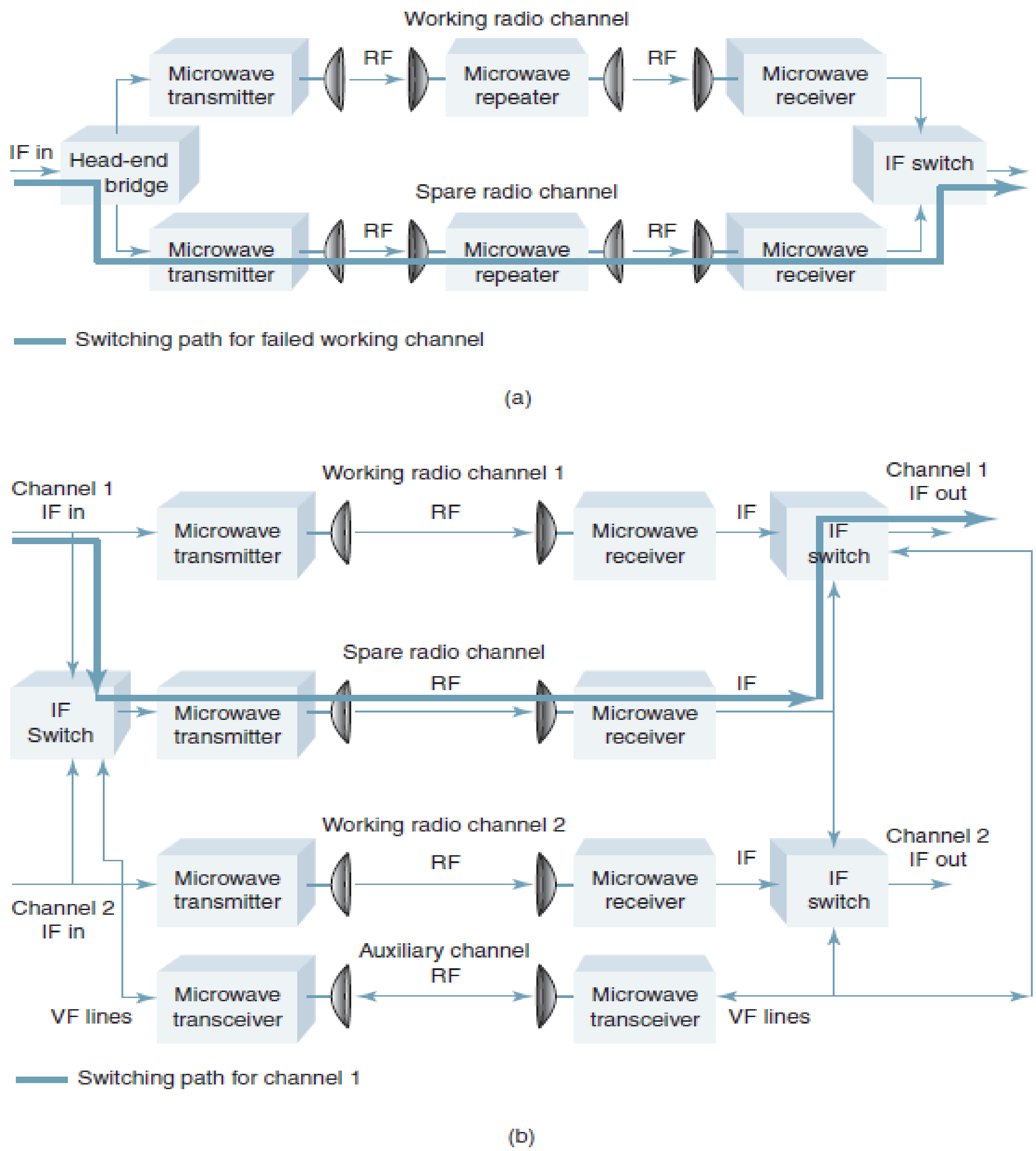


FIGURE 7 Microwave protection switching arrangements: (a) hot standby; (b) diversity

Reliability

The number of repeater stations between protection switches depends on the *reliability objectives* of the system. Typically, there are between two and six repeaters between switching stations. As you can see, diversity systems and protection switching arrangements are quite similar. The primary difference between the two is that diversity systems are permanent arrangements and are intended only to compensate for temporary, abnormal atmospheric conditions between only two selected stations in a system. Protection switching arrangements, on the other hand, compensate for both radio fades and equipment failures and may include from six to eight repeater stations between switches. Protection channels also may be used as temporary communication facilities while routine maintenance is performed on a regular working channel. With a protection switching arrangement, all signal paths and radio equipment are protected.

Diversity is used selectively—that is, only between stations that historically experience severe fading a high percentage of the time. A statistical study of outage time (i.e., service interruptions) caused by radio fades, equipment failures, and maintenance is important in the design of a microwave radio system. From such a study, engineering decisions can be made on which type of diversity system and protection switching arrangement is best suited for a particular application. Figure 8 shows a comparison between diversity and protection switching.

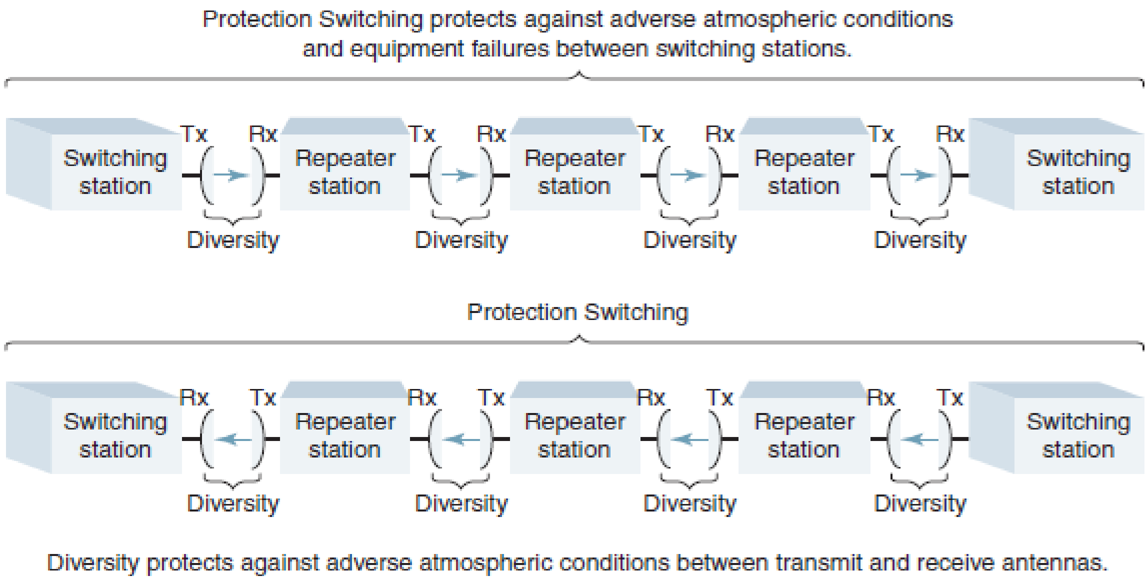


FIGURE 8 Comparison between diversity and protection switching

As shown in the figure, protection switching arrangements protect against equipment failures in any of the electronic equipment (transmitters, receivers, and so on) in any of the microwave stations between the two switching stations. Diversity, however, protects only against adverse atmospheric conditions between a transmit antenna and a receive antenna.

FM MICROWAVE RADIO STATIONS

Basically, there are two types of FM microwave stations: terminals and repeaters. *Terminal stations* are points in the system where baseband signals either originate or terminate.

Repeater stations are points in a system where baseband signals may be reconfigured or where RF carriers are simply "repeated" or amplified.

Terminal Station

A terminal station consists of four major sections: the ***baseband, wireline entrance link (WLEL), FM-IF, and RF sections***. Figure 9 shows a block diagram of the baseband, WLEL, and FM-IF sections. As mentioned, the baseband may be one of several different types of signals. For our example, frequency-division-multiplexed voice-band channels are used.

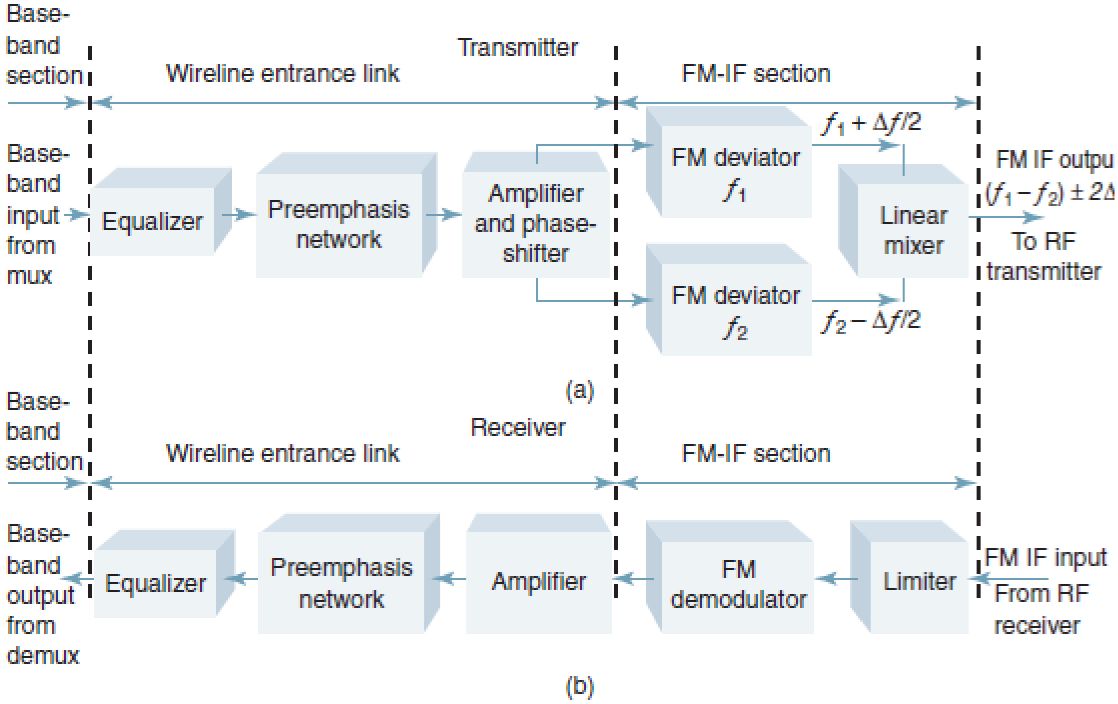


FIGURE 9 Microwave terminal station: (a) transmitter; (b) receiver

Wireline entrance link: Often in large communications networks, the building that houses the radio station is quite large. Consequently, it is desirable that similar equipment be physically placed at a common location (i.e., all frequency-division-multiplexed [FDM] equipment in the same room). This simplifies alarm systems, providing dc power to the equipment, maintenance, and other general cabling requirements. Dissimilar equipment may be separated by a considerable distance. For example, the distance between the FDM equipment and the FM-IF section is typically several hundred feet and in some cases several miles. For this reason, a wireline entrance link (WLEL) is required. ***A WLEL serves as the interface between the multiplex terminal equipment and the FM-IF equipment.*** A WLEL generally consists of an amplifier and an equalizer (which together compensate for cable transmission losses) and level-shaping devices commonly called pre- and de-emphasis networks.

IF section: The FM terminal equipment shown in Figure 9 generates a frequency- modulated IF carrier. This is accomplished by mixing the outputs of two deviated oscillators that differ in frequency by the desired IF carrier. The oscillators are deviated in phase opposition, which reduces the magnitude of phase deviation required of a single deviator by a factor of 2. This technique also reduces the deviation linearity requirements for the oscillators and provides for the partial cancellation of unwanted modulation products. Again, the receiver is a conventional non-coherent FM detector.

RF section: A block diagram of the RF section of a microwave terminal station is shown in Figure 10. The IF signal enters the transmitter (Figure 10a) through a protection switch. The IF and compression amplifiers help keep the IF signal power constant and at approximately the required input level to the transmit modulator (*transmod*).

A ***transmod*** is a balanced modulator that, when used in conjunction with a microwave generator, power amplifier, and bandpass filter, up-converts the IF carrier to an RF carrier and amplifies the RF to the desired output power. Power amplifiers for microwave radios must be capable of amplifying very high frequencies and passing very wide bandwidth signals. *Klystron tubes, traveling-wave tubes* (TWTs), and *IMPATT* (impact/avalanche and transit time) diodes are several of the devices currently being used in microwave power amplifiers. Because high-gain antennas are used and the distance between microwave stations is relatively short, it is not necessary to develop a high output power from the transmitter output amplifiers. Typical gains for microwave antennas range from 10 dB to 40 dB, and typical transmitter output powers are between 0.5 W and 10 W. A ***microwave generator*** provides the RF carrier input to the up-converter. It is called a microwave generator rather than an oscillator because it is difficult to construct a stable circuit that will oscillate in the gigahertz range. Instead, a crystal-controlled oscillator operating in the range 5 MHz to 25 MHz is used to provide a base frequency that is multiplied up to the desired RF carrier frequency.

An ***isolator*** is a unidirectional device often made from a ferrite material. The isolator is used in conjunction with a channel-combining network to prevent the output of one transmitter from interfering with the output of another transmitter. The RF receiver (Figure 10b) is essentially the same as the transmitter except that it works in the opposite direction. However, one difference is the presence of an IF amplifier in the receiver. This IF amplifier has an *automatic gain control* (AGC) circuit. Also, very often, there are no RF amplifiers in the receiver. Typically, a highly sensitive, low-noise balanced demodulator is used for the receive demodulator (receive mod). This eliminates the need for an RF amplifier and improves the overall signal-to-noise ratio. When RF amplifiers are required, high-quality, *low-noise amplifiers* (LNAs) are used. Examples of commonly used LNAs are tunnel diodes and parametric amplifiers.

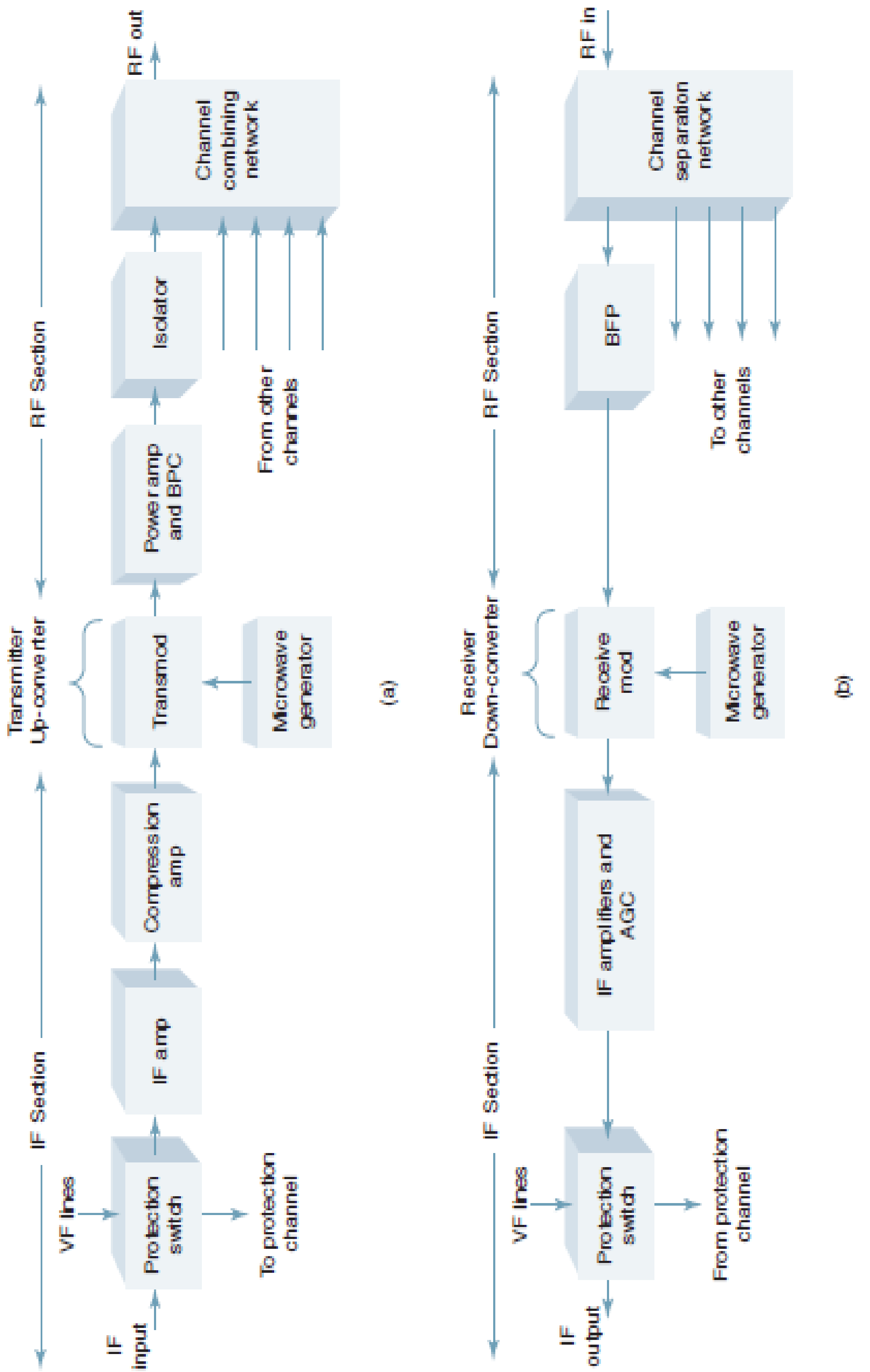


FIGURE 10 Microwave terminal station: (a) transmitter; (b) receiver

MICROWAVE REPEATER STATION

Figure 11 shows the block diagram of a microwave IF repeater station. The received RF signal enters the receiver through the channel separation network and band pass filter. The receivemod down-converts the RF carrier to IF. The IF AMP/AGC and equalizer circuits amplify and reshape the IF. The equalizer compensates for *gain-versus-frequency nonlinearities* and *envelope delay distortion* introduced in the system. Again, the transmod up-converts the IF to RF for retransmission. However, in a repeater station, the method used to generate the RF microwave carrier frequencies is slightly different from the method used in a terminal station. In the IF repeater, only one microwave generator is required to supply both the transmod and the receive mod with an RF carrier signal. The microwave generator, shift oscillator, and shift modulator allow the repeater to receive one RF carrier frequency, down-convert it to IF, and then up-convert the IF to a different RF carrier frequency.

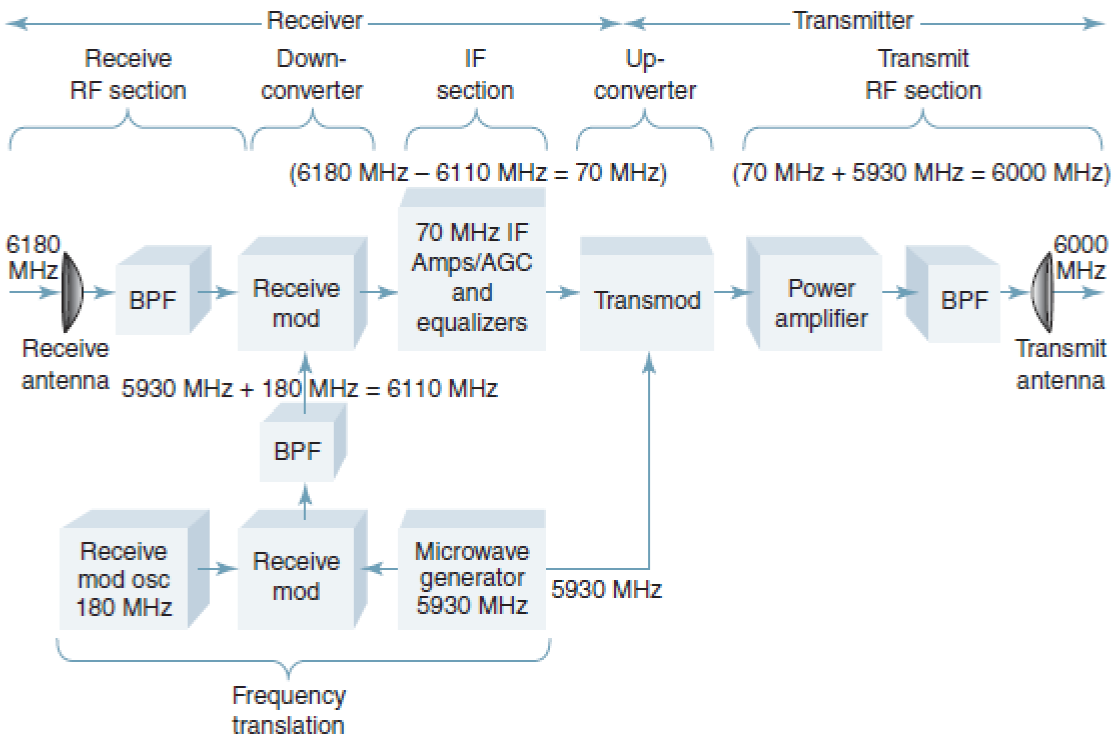


FIGURE 11 Microwave radio IF repeater block diagram

It is possible for station D to receive the transmissions from both station B and station C simultaneously (this is called *multihop interference* and is shown in Figure 12a). This can occur only when three stations are placed in a geographical straight line in the system. To prevent this from occurring, the allocated bandwidth for the system is divided in half, creating a low-frequency and a high-frequency band. Each station, in turn, alternates from a lowband to a high-band transmit carrier frequency (Figure 12b).

If a transmission from station B is received by station D, it will be rejected in the channel separation network and cause no interference. This arrangement is called a high/low microwave repeater system. The rules are simple: If a repeater station receives a low-band RF carrier, then it retransmits a high-band RF carrier and vice versa. The only time that multiple carriers of the same frequency can be received is when a transmission from one station is received from another station that is three hops away. This is unlikely to happen. Another reason for using a high/low-frequency scheme is to prevent the power that "leaks" out the back and sides of a transmit antenna from interfering with the signal entering the input of a nearby receive antenna. This is called *ringaround.*

All antennas, no matter how high their gain or howdirective their radiation pattern, radiate a small percentage of their power out the back and sides, giving a finite *front-to-back* ratio for the antenna. Although the frontto- back ratio of a typical microwave antenna is quite high, the relatively small amount of power that is radiated out the back of the antenna may be quite substantial compared with the normal received carrier power in the system. If the transmit and receive carrier frequencies are different, filters in the receiver separation network will prevent ringaround from occurring.

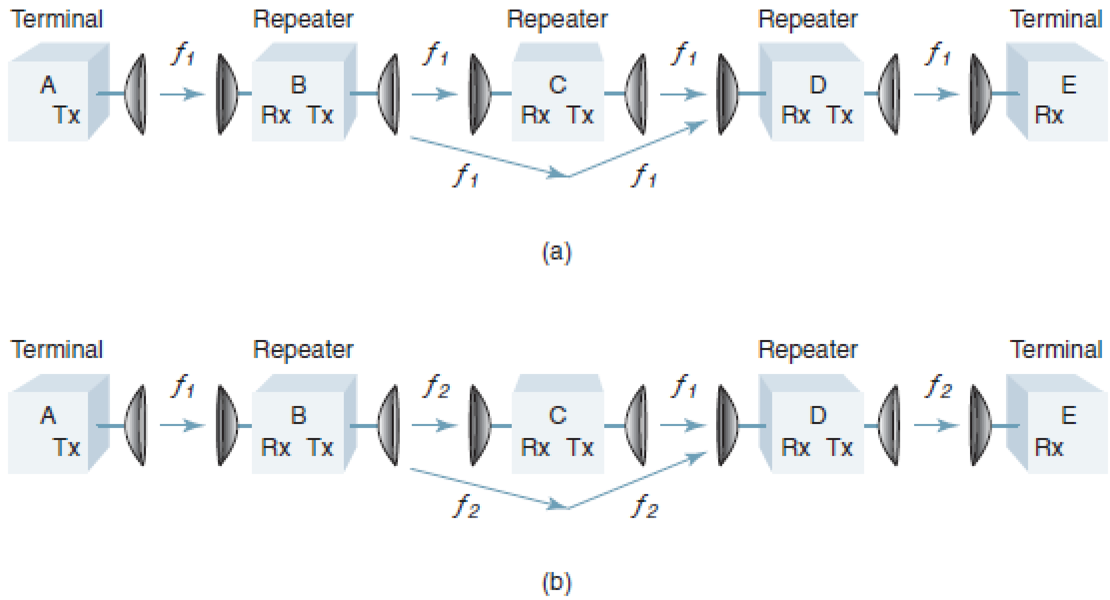


FIGURE 12 (a) Multihop interference and (b) high/low microwave system

A high/low microwave repeater station (Figure 12b) needs two microwave carrier supplies for the down- and up-converting process. Rather than use two microwave generators, a single generator with a shift oscillator, a shift modulator, and a bandpass filter can generate the two required signals. One output from the microwave generator is fed directly into the transmod, and another output (from the same microwave generator) is mixed with the shift oscillator signal in the shift modulator to produce a second microwave carrier frequency. The second microwave carrier frequency is offset from the first by the shift oscillator frequency. The second microwave carrier frequency is fed into the receive modulator.

LINE OF SIGHT PATH CHARACTERISTICS

The normal *propagation paths* between two radio antennas in a microwave radio system are shown in Figure 14. The *free-space path* is the *line-of-sight path* directly between the transmit and receive antennas (this is also called the *direct wave*). The *ground-reflected wave* is the portion of the transmit signal that is reflected off Earth's surface and captured by the receive antenna. The *surface wave* consists of the electric and magnetic fields associated with the currents induced in Earth's surface. The magnitude of the surface wave depends on the characteristics of Earth's surface and the electromagnetic polarization of the wave. The sum of these three paths (taking into account their amplitude and phase) is called the *ground wave*. The *sky wave* is the portion of the transmit signal that is returned (reflected) back to Earth's surface by the ionized layers of Earth's atmosphere.

All paths shown in Figure 14 exist in any microwave radio system, but some are negligible in certain frequency ranges. At frequencies below 1.5 MHz, the surface wave provides the primary coverage, and the sky wave helps extend this coverage at night when the absorption of the ionosphere is at a minimum. For frequencies above about 30 MHz to 50 MHz, the free-space and ground-reflected paths are generally the only paths of importance. The surface wave can also be neglected at these frequencies, provided that the antenna heights are not too low. The sky wave is only a source of occasional long-distance interference and not a reliable signal for microwave communications purposes. In this chapter, the surface and sky wave propagations are neglected, and attention is focused on those phenomena that affect the direct and reflected waves.

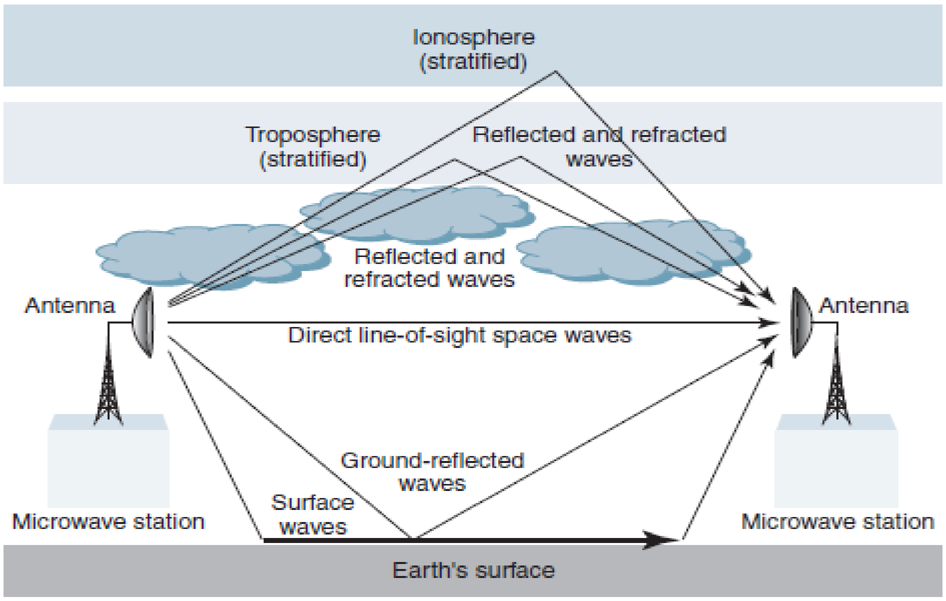


FIGURE 14 Microwave propagation paths

Free-Space Path Loss

Free-space path loss is often defined as the loss incurred by an electromagnetic wave as it propagates in a straight line through a vacuum with no absorption or reflection of energy from nearby objects. Free-space path loss is a misstated and often misleading definition because no energy is actually dissipated. Free-space path loss is a fabricated engineering quantity that evolved from manipulating communications system link budget equations, which include transmit antenna gain, free-space path loss, and the effective area of the receiving antenna (i.e., the receiving antenna gain) into a particular format. The manipulation of antenna gain terms results is a distance and frequency-dependent term called *free-space path loss.*

Free-space path loss assumes ideal atmospheric conditions, so no electromagnetic energy is actually lost or dissipated—it merely spreads out as it propagates away from the source, resulting in lower relative power densities. A more appropriate term for the phenomena is *spreading loss.* Spreading loss occurs simply because of the inverse square law. The mathematical expression for free-space path loss is

$$L_p = \left(\frac{4\pi D}{\lambda}\right)^2 \quad (1)$$

and because $\lambda = \frac{c}{f}$, Equation 14-26 can be written as

$$L_p = \left(\frac{4\pi f D}{c}\right)^2 \quad (2)$$

where L_p = free-space path loss (unitless)
D = distance (kilometers)
f = frequency (hertz)
λ = wavelength (meters)
c = velocity of light in free space (3 × 108 meters per second)

Converting to dB yields

$$L_p(\text{dB}) = 10 \log \left(\frac{4\pi f D}{c}\right)^2 \quad (3)$$

or

$$L_p(\text{dB}) = 20 \log \left(\frac{4\pi f D}{c}\right) \quad (4)$$

Separating the constants from the variables gives

$$L_p = 20 \log \left(\frac{4\pi}{c}\right) + 20 \log f + 20 \log D \quad (5)$$