Chapter 19: Commercial Communication Systems

Chapter 19 Objectives

At the conclusion of this chapter, the reader will be able to:

- ∉ Compare and contrast commercial and public-service communication systems and standards with those of the general broadcast industry.
- ∉ Describe the differences between analog and digital-based systems.
- ∉ Explain the purpose of components in a repeater system.
- ∉ Describe the alignment procedure for repeater duplexers.
- ∉ Describe the operation and configuration of a typical digital radio system such as P25.
- ∉ Develop plans for troubleshooting and correcting interference problems in a radio system.

Most people think of radio and wireless technologies in terms of radio and TV broadcasting, cellular telephones, and the like. In terms of total radio spectrum activity, these services are actually only a small piece of the action. If you've ever been a passenger on a commercial flight, traveled on a ship, or even listened to a weather forecast, you've indirectly benefitted from the use of commercial radio.

Radio is used by a wide variety of users including law enforcement, airlines, the military, government and public safety agencies (such as the National Oceanic and Atmospheric Administration, or NOAA), as well as countless businesses. These systems may generally be classified as *commercial* systems. They are designed for reliability, speed, ease, and utility of use, and may be used for much more than just sending voice. NOAA, for example, has an extensive network of satellite, radar and telemetry (remote measurement) equipment that collects information about atmospheric and weather conditions throughout the world. This information is used to not only predict weather, but also warn citizens of dangerous storms.

An FCC Commercial Radiotelephone Operator License is required for anyone who intends to perform maintenance and repair on transmitting equipment aboard ships and aircraft, as well as the ground stations that communication with them. The FCC commercial license is often used as a measuring stick for employability in the industry, even where it's not directly required by law. By learning the theory in this book, you are become well-prepared to pass this examination.

Finally, Amateur Radio is a service that is closely tied to commercial radio. Amateurs (also known as hams) have greatly contributed to the development of commercial technologies and also have historically benefitted from the availability of surplus equipment from commercial and military operations. Many people who work in this field possess an amateur radio license in addition to their commercial license. Being involved in amateur radio is an excellent introduction to many of the standards used in the commercial communications industry.

19-1 Commercial Systems Overview

In order to better understand commercial systems, let's first talk about some of their unique characteristics, and develop a picture of the commercial "landscape." The following are some key points about commercial radio.

- ∉ Commercial services typically employ VHF and UHF frequencies in narrow-band FM analog and digital modes, with a few exceptions, such as air band (aircraft) voice communication, which uses the 118 MHz to 138 MHz frequency range in AM mode. (AM is used in the air band deliberately; when two or more stations accidentally transmit together, that is immediately evident in an AM receiver, where it might not be so in FM due to the capture effect.) There are still applications in the high-frequency range (3 to 30 MHz) as well that include broadcasting, military and emergency communication, and so forth.

- ∉ Commercial radio consists of many licensed FCC services and is generally *channelized* and *coordinated*. The FCC issues a station license for each transmitter or group of transmitters to be used, and the license always specifies the frequencies authorized for use, the authorized transmitted power level, and the geographic location. As you may recall, VHF and UHF communications are primarily line-of-sight, with 50 miles being a typical maximum range between base station and mobile. This range limitation enables frequency re-use, but still requires careful coordination to prevent interference. The FCC does not provide coordination itself - - third-party agencies specific to each radio service handle coordination duties.

MAIN | ADMIN | LOCATIONS | FREQUENCIES

Call Sign	KNCK623	Radio Service	PW - Public Safety Pool, Conventional
Status	Active	Auth Type	Regular
Dates			
Grant	01/26/2012	Expiration	04/02/2022
Effective	01/26/2012	Cancellation	
Control Points			
1	201 S. PEARL, SUITE 203, MIAMI, PAOLA, KS P: (913)294-4377		

Licensee

FRN	0006321277 (View Ownership Filing)	Type	Governmental Entity
Licensee			
MIAMI, COUNTY OF 201 S. Pearl, Suite 203 PAOLA, KS 66071-6275		P:(913)294-4377 F:(913)294-3228 E:RHOLTZ@MIAMICOUNTYKS.ORG	

MAIN | ADMIN | LOCATIONS | FREQUENCIES

Call Sign	KNCK623	Radio Service	PW - Public Safety Pool, Conventional

3 Total Locations
10 Locations per Summary Page

Locations Displayed:
All | Fixed | Mobile | Itinerant | Temp Fixed | 6.1m

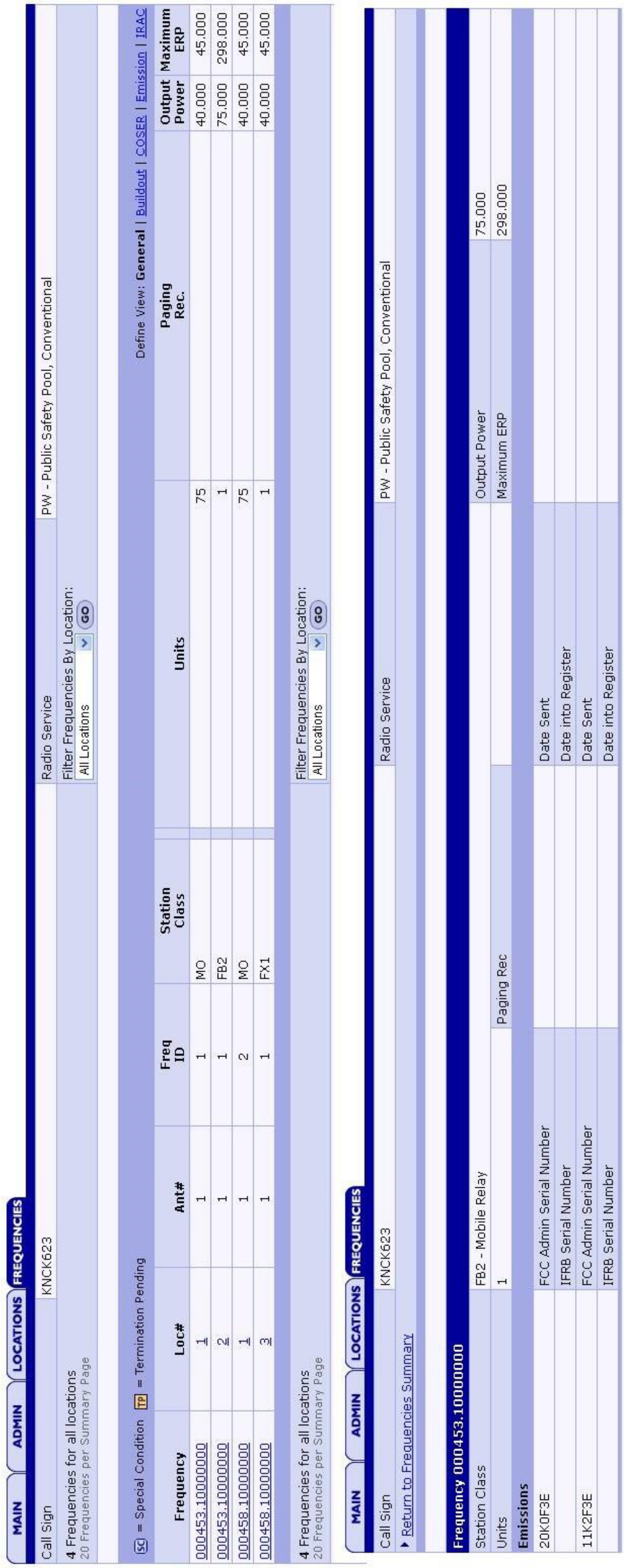
SC = Special Condition   TP = Termination Pending

Location	Transmitter Address /Area of Operation	Latitude, Longitude	Status
1 - Mobile	MIAMI County, KS		
2 - Fixed	2 KM north of KS68 @ 271st & Woodland PAOLA, KS MIAMI County	38-38-37.0 N, 094-48-51.9 W	p
3 - 6.1 meter control station	KS		

3 Total Locations
10 Locations per Summary Page

Locations Displayed:
All | Fixed | Mobile | Itinerant | Temp Fixed | 6.1m

Figure 19-1 (Part 1 of 2): License Data from FCC-ULS for Miami County, KS . Retrieved from http://wireless2.fcc.gov/UlsApp/UlsSearch/licenseLocSum.jsp?licKey=1197924.



MAIN | ADMIN | LOCATIONS | FREQUENCIES

Call Sign	KNCK623	Radio Service	PW - Public Safety Pool, Conventional
4 Frequencies for all locations 20 Frequencies per Summary Page		Filter Frequencies By Location: All Locations GO	

SC = Special Condition TP = Termination Pending

Define View: **General** | Buildout | COSER | Emission | IRAC

Frequency	Loc#	Ant#	Freq ID	Station Class	Units	Paging Rec.	Output Power	Maximum ERP
000453.10000000	1	1	1	MO	75		40.000	45.000
000453.10000000	2	1	1	FB2	1		75.000	298.000
000458.10000000	1	1	2	MO	75		40.000	45.000
000458.10000000	3	1	1	FX1	1		40.000	45.000

4 Frequencies for all locations
20 Frequencies per Summary Page

Filter Frequencies By Location: All Locations GO

MAIN | ADMIN | LOCATIONS | FREQUENCIES

Call Sign	KNCK623	Radio Service	PW - Public Safety Pool, Conventional

▸ Return to Frequencies Summary

Frequency 000453.10000000

Station Class	FB2 - Mobile Relay			Output Power	75.000
Units	1	Paging Rec		Maximum ERP	298.000
Emissions					
20K0F3E	FCC Admin Serial Number		Date Sent		
	IFRB Serial Number		Date into Register		
11K2F3E	FCC Admin Serial Number		Date Sent		
	IFRB Serial Number		Date into Register		

Figure 19-1 (Part 2 pf 2): License Data from FCC-ULS for Miami County, KS . Retrieved from http://wireless2.fcc.gov/UlsApp/UlsSearch/licenseLocSum.jsp?licKey=1197924.

Figure 19-1 illustrates the FCC license issued to public safety in Miami, County Kansas. The license is for the radio system used by their sheriff's department. Data about FCC licenses can be freely obtained from the FCC Universal Licensing System (ULS) database at http://wireless.fcc.gov/uls/. Complex organizations such as law enforcement typically have multiple frequencies and transmitters authorized for use.

We'll delve into the details of FCC licenses shortly.

∉ Not all commercial systems employ voice. An increasing number of systems use encryption to make eavesdropping difficult. As an example, the lowest portion of the air band between 108 and 117.95 MHz is split into 200 narrow-band channels of 50 kHz. These are reserved for navigational aids such as VHF Omnidirectional Radar (VOR) beacons, and precision approach systems such as the Instrument Landing System (ILS), which are used to assist during aircraft landing, especially when visibility is poor and visual flight rules are no longer in effect. VOR and ILS transmit precision-timed navigation signals instead of voice.

Functional Segments

Commercial communication systems may be divided into functional segments, each of which performs part of the work.

∉ The *mobile or end-segment* of the system includes physical radio and data terminal equipment, which includes hand-held and mobile radios, data processing equipment (such as mobile computers for accessing police dispatch and report data), as well as application-specific devices such as GPS receivers. GPS receivers are commonly used to track the speed, and location of commercial delivery vehicles, as well as the habits of their drivers. GPS is also quite handy in public safety and law enforcement.

∉ The *fixed* segment consists of the physical base stations and repeaters that establish communications with devices in the mobile segment, as well as any relay stations. Relay stations are used to carry information between base stations in large systems. Base stations and repeaters are expensive and critical components of the system. In order to deliver acceptable quality of service over a large metropolitan area, fixed segment antennas must be on high supporting structures, often several hundred feet in height.

Interpreting FCC License Data

There are several key pieces of information on every FCC station license. This information includes the locations, frequencies, usages, and permitted emission types of all transmitters, as well as the location of the *control point* for the transmitters. The control point is the location at which the control operator function is accomplished. The control operator is the person designated by the station licensee to be responsible for compliance with FCC rules. In Figure 19-1, the control point for the station is shown as 201 S. Pearl, Suite 203, Paola, KS.

The license shown has three different locations, numbered 1, 2, and 3, one of which is precisely specified (the fixed station, "FB2", Location 2 - given in exact coordinates). No location is given for mobiles (Location 1 - unspecified). Additionally, the license has a control station ("FX1", Location 3 - unspecified) with an antenna at or below about 6 meters above ground. Licensees are not required to report the location of control stations meeting this criterion.

Referring to Part 2 of Figure 19-1, you can see that two different frequencies are allocated to the licensee, 453.100 and 458.100 MHz. The mobiles (MO) may transmit on either 453.100 or 458.100 MHz (we'll see why in a moment). There is a FB2 station that can transmit on 453.100 MHz. The station class FB2 means "Fixed Base 2," which in FCC usage refers to a relay station that retransmits what it receives from other stations - - in other words, a *repeater*. In normal operation, the mobiles transmit on 458.100 MHz, which is the input frequency of the repeater. The repeater can then re-transmit the mobile messages on 453.100 MHz. Table 19-1 is a brief overview of the "Station Class" designators and their meanings.

You'll notice that the mobiles can also transmit on 453.100 MHz. This is the repeater output frequency, and this capability is used to maintain communication when the repeater is unreachable or out of service. Mobiles employ *talk-around* to bypass the repeater and communicate directly on its output frequency.

There is an FX1 station (FX1 means "fixed control station"). The FX1 station location is not given, but wherever it's located, it transmits on the repeater input frequency. An operator in a fixed location can talk using the repeater and reach the mobiles from the FX1 station. (Some systems are not set up this way - - some will simply have a FB "fixed base" station that transmits directly to mobiles without the use of a repeater. Such system may or may not have a FB2 repeater station.)

Station Class Code	Purpose of Station (Usage)
FB	Base Station - A station at a specified site authorized to communicate with mobile stations.
FB2	Mobile Relay - A repeater.
FX1	Control Station - A base station that operates through a repeater in the same way as a mobile station.
FXO	Operational Fixed Station - A transceiver which may operate as a link between two or more fixed locations.
MO	Mobile Station - A station intended to be used while in motion or during halts at unspecified points. It includes hand-held transmitter, and within certain limitations, may also include boats and aircraft.

Table 19-1: Common FCC Station Class Designators

Finally, if you go to the FCC website and click on any of the frequencies shown in Figure 19-1, you'll see the permitted emissions for each transmitter. The *emission* specifies the bandwidth, type of modulation, and what kind of information is represented by the emitted radio signal. Radio Reference is an online resource that can help you understand the many FCC emission designators. In the case of the FB2 mobile relay station, the transmitter is authorized to transmit emissions 20K0F3E (FM analog voice with 25 kHz bandwidth and 5 kHz maximum deviation) and 11K2F3E (FM analog voice with 12.5 kHz bandwidth and 2.5 kHz maximum deviation).

Public safety users are a large fraction of commercial radio users. These agencies rely on radio to provide reliable communications that are vital to the preservation of life and property. They must be licensed by the FCC, and very specific information about stations is given on each station license.

Components of commercial radio systems are typically built very rugged to withstand harsh treatment and conditions, and have minimal controls for the end-user to operate so that they may focus on the task at hand rather than the mechanics of the actual radio communication. In particular, police, fire, and emergency medical service (EMS) personnel are exposed daily to high-danger, high-stress situations. It's to their advantage to have a communication system with the simplest possible user interface.

Section Checkpoint

19-1 List the features of commercial communication systems that differentiate them from those of other services, such as broadcasting.
19-2 What frequency bands are most commonly used by commercial systems?
19-3 What is meant by the term "channelization?"
19-4 What are at least three key pieces of information on an FCC-issued station license?
19-5 List the three segments typical of commercial communication systems.
19-6 What kind of information other than voice are often sent though commercial communication systems?
19-7 Why is AM still used for aircraft communication?
19-8 What online service can be used to verify licensing data in the United States?

19-2 System Components for Voice Communication

Regardless of whether a communication system is implemented in analog or digital form, the layout of a voice communication system is fairly straightforward, as illustrated in Figure 19-2.

Figure 19-2 illustrates all the components you'll normally see in a commercial system. End-users in this system have been issued hand-held radios, but automotive and other mobile installations are also usually part of a complete system. Hand-held radios usually have power outputs of 5 watts or less, and utilize a flexible "rubber duck" antenna that's built to be rugged, but unfortunately, is not a very effective radiator.

A very small system may only have a few hand held radios, and no other components at all. In a small system, radios all transmit and receive on the same frequency; we refer this to as *simplex* operation. The system in the figure has two repeaters and two relay stations; the relay stations are usually microwave links that couple distant systems and allow them to interoperate.

Figure 19-2: Components of a Voice Communication System

All the radio transmitters used in a particular system must be FCC type-accepted for use in that application.

Older systems almost exclusively use FM to carry information. Prior to 2013, the standard configuration for FM transceivers in U.S. systems was for 25 kHz channel bandwidths, and 5 kHz maximum deviation.

The FCC mandated that all commercial systems be "narrowbanded" to a 12.5 kHz channel width on or before January 1, 2013. Narrowbanded equipment uses a maximum FM deviation of 2.5 kHz. Ultimately, the FCC has announced the goal for all systems to eventually utilize 6.25 kHz channels, though at the time of this writing, no date has been given for that to be accomplished. Narrowbanding allows many more users to be accommodated within the limited range of VHF and UHF frequencies available for commercial and public safety use.

Base Segment

The base segment in Figure 19-2 features special stations we call *repeaters*. A repeater is a station that is designed to simultaneously listen on one frequency, referred to as the *input frequency*, and retransmit everything it receives on the *output frequency*. In order to use a repeater, a radio must be programmed to operate in *duplex* mode. The mobile radio transmits on the frequency assigned to the repeater input, and receives on the frequency assigned to the repeater output.

Repeaters are usually located in high locations within a geographic area; this may mean mountaintops in some parts of the country, and natural ridges in others. A well-placed and designed repeater can extend the range of communication from a mile or two for radios that talk directly to each other (simplex communication) to over a hundred miles for repeaters located in a high location.

The *coverage* or *footprint* of a repeater refers to the useable communications area it can serve. It's generally determined by several factors, most important of which is the geographic location of the repeater station itself. Locations high on a mountain top or ridge can provide exceptional coverage. Terrain effectively blocks all radio signals, so even a modest hill between a mobile and base can stop communication. Other facts that determine range are the local RF noise floor at the repeater site (which can be strongly influenced by how crowded it is with equipment sharing tower space), the repeater's RF output power (usually less than 200 watts for most applications), and at upper UHF frequencies, humidity and weather conditions. Commercial geographic mapping software is available that can map repeater coverage areas.

In its simplest form, the base segment may consist of just one repeater and a station antenna. However, radio towers and real estate are very expensive, so it's common for a single tower structure to house multiple repeater systems, cellular telephone base stations and antennas, and other equipment; professional installers are required for determining the location and installation method of each system at a tower site.

Figure 19-3 illustrates a typical repeater station tower-top installation, and figure 19-4 shows the equipment at ground level.

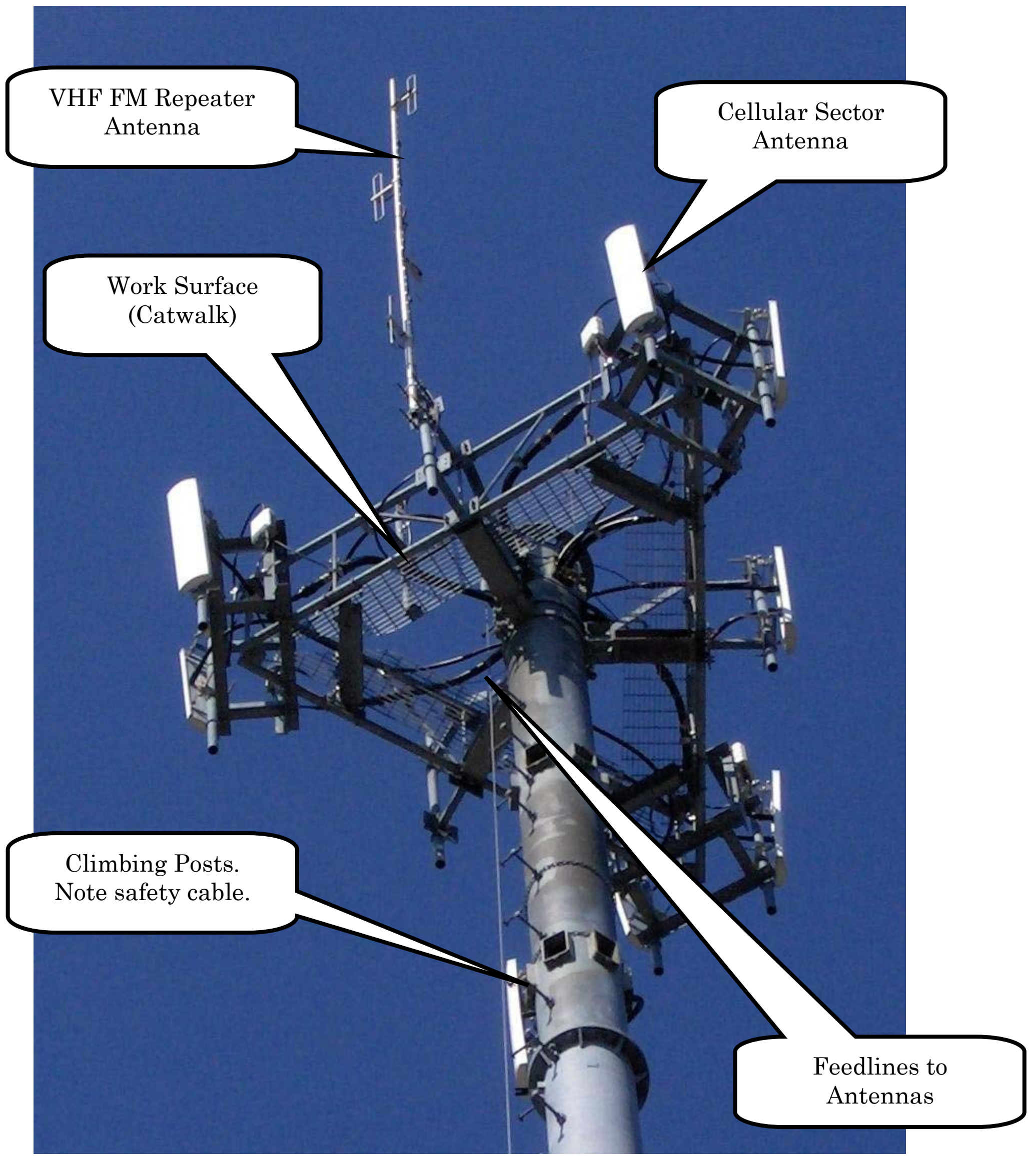


Figure 19-3: Antennas on a Cellular Tower

The top of any radio tower is a very busy place. If you look carefully at Figure 19-3, you'll see that it contains a six-sector cellular site, a VHF repeater antenna, a UHF repeater antenna, several telemetry service antennas (small square boxes), plus extra vertical pipe mounts for additional antennas that weren't yet installed when this photograph was taken.

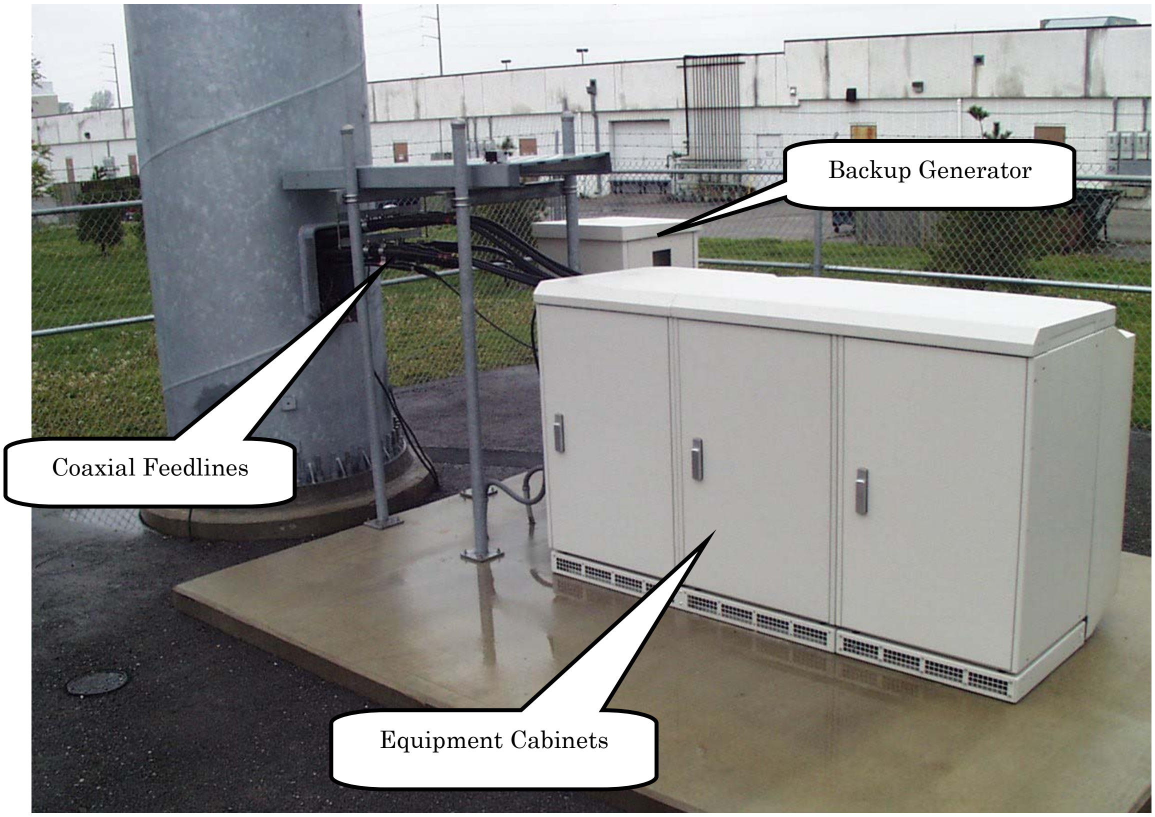


Figure 19-4: Equipment at Ground Level

At ground level (Figure 19-4) the actual repeater equipment is maintained in weatherproof cabinets, as shown in the figure. In this particular installation, you can see many coaxial cables *entering* the tower (you can see them exiting at the top in Figure 19-3). For tubular towers this is quite typical; many installations within residential areas employ them as they're extremely strong and don't usually require guy wires, which conserves valuable real estate on the ground. As is typical for equipment installed in any public location, the repeater site is surrounded by a fence with a locking gate. This measure is intended to protect persons from accidental contact with the equipment.

If you see an installation like this within your neighborhood, by all means take the opportunity to examine it from the safety zone outside the fence. If you're lucky, you may get the opportunity to observe people working within the installation.

Trunking

More complex systems (typically in public service, not in commercial use) must cover more than one geographic area and be able to share channel resources among many users. Trunking systems are used to take care of these needs. A trunked system can allow multiple entities (such a police and fire department) to share the same physical radio network without interfering with each other, and the same time, allowing intercommunication when required, for example, during an emergency requiring joint response. Trunking protocols come in many varieties; their functions are to manage the use of frequencies by end-users (effectively allowing a small number of frequencies to be shared with many users), improve reliability by bypassing system faults (such as blocked channels), and effectively simplify system management by the use of *talkgroups*. The future of this technology belongs to purely digital systems such as P25, DMR (digital mobile radio), and NXDN; we'll examine P25 later in this chapter.

Section Checkpoint

19-9 What kind of modulation is generally used for analog commercial radios?
19-10 What is narrowbanding, and what did licensees have to do to comply?
19-11 In a narrowbanded analog system, what is the standard channel bandwidth?
19-12 What is meant by the terms "simplex" and "duplex" in radio communications?
19-13 What typical range can be expected from hand-held radios in simplex mode?
19-15 How much distance can be covered with typical hand-held radios when a repeater is in use?
19-14 What determines the coverage of a repeater?
19-15 What are the functions of trunking protocols?

19-3 Repeater Systems and Components

Repeaters are the workhorses of the commercial communications world. The basic function of a repeater is to do exactly what its name says - - it receives a signal, processes it, and retransmits it over a wide area. That doesn't sound too complicated, and in concept it is not. Figure 19-5 illustrates the block diagram of a generic single-site repeater system.

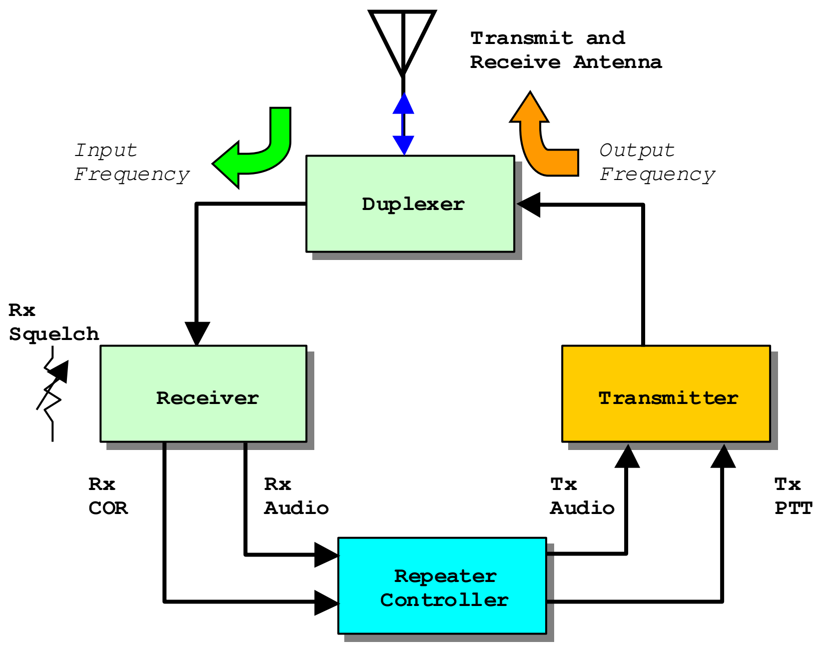


Figure 19-5: Signal Flow in a Single-Site Repeater

Repeater Signal Flow

The signal flow in Figure 19-5 is fairly straightforward. When a mobile unit transmits, the antenna at the site picks up the signal. The signal passes through a special component called a duplexer, which allows the signal to freely pass into the receiver as long as it is on the correct frequency - - which for a repeater is called the *input frequency*.

The receiver then measures the strength of the signal and compares it to the *squelch* setting. Squelch is a circuit within the receiver that makes a simple yes-or-no decision about the incoming signal. If there is no signal, or the signal is too weak, the squelch circuit mutes the receiver output, and turns off the carrier operated relay (COR) output. COR is in essence a digital on-off output from the receiver that indicates whether or not a suitable input signal is present.

An analog receiver usually has an adjustment for the squelch. It should be set just tight enough to not falsely trigger on noise at the site, and at the same time, still respond to the weakest expected incoming signal.

The receiver in its most common form has two outputs; these are the COR output, which indicates when something is being received, and the audio output, which is the demodulated information signal. Many repeater cabinets have a small audio amplifier and loudspeaker within that's connected to the receiver's output; this allows a technician to immediately determine whether or not the receiver is working without the need for any test equipment.

The audio and COR signals pass into the *repeater controller*. The controller's primary job is to activate the transmitter when an incoming signal is detected (according to the COR status), and process the audio prior to retransmission.

The repeater controller has some other important jobs as well. It is responsible for monitoring the total transmitter key-down time; if this time exceeds a pre-set limit, the controller times out and shuts off the transmitter. Transmitter timeouts are not required by FCC rules for most services, but may be enabled by the operator. Additionally, the FCC requires that all repeaters send an identification or ID signal every 10 minutes or so while they're in operation. The ID may be in Morse code, or a recorded voice message. The ID gives the station callsign - - useful to know if a problem arises (such as interference from the transmitter), or some other technical problem arises.

The *transmitter* receives two signals from the controller, the Tx "push to talk" (PTT) signal, which commands the transmitter to key down (begin transmitting), and the audio, which contains the received message, along with the periodic ID and any other information desired.

The transmitter output passes into the transmitter port of the duplexer, and from there goes right back out to the antenna - - the same antenna that is receiving the relatively weak signal from the mobile station. That's a pretty good trick if you think about it - - a typical repeater transmitter pushes out 100 watts or more to the antenna, while at the same time its receiver is "listening" on that same antenna and is typically extracting less than a nanowatt of power from the mobile unit's transmission. How can this possibly work?

<u>It works because the repeater receives and transmits on two different frequencies that are separated with the help of the duplexer</u>. The duplexer is a very high quality set of filters precisely aligned to allow only the input frequency to reach the receiver, while allowing only the chosen transmit (output) frequency to reach the antenna. The difference between the transmit and receive frequencies is sometimes called the *offset*, however, offset values are not uniformly standardized throughout the world. Because of this, people in the commercial world tend to think of repeaters in terms of the raw input and output frequencies, and may not even think about offset. Let's do an example to illustrate how this works.

Example 19-1

An FM repeater system is transmitting a power of 50 watts on a frequency of 157.000 MHz. A mobile unit located 10 km away is transmitting 5 watts EIRP over a clear path on 157.600 MHz, the correct input frequency for this repeater; as a result, at the repeater receiver input, the received signal strength is 307.8 σV. Assuming that the system impedance is 50 ohms, calculate:

a) The frequency offset of the repeater system
b) The power being received from the mobile station
c) The received power in dBm
d) The transmitted power in dBm
e) The decibel difference between the transmitted and received signals

Solution
a) The frequency offset is simply the difference between receive and transmit frequencies of the <u>repeater</u> as shown in Equation 19-1.

$$f_{OFFSET} = f_{RX} - f_{TX} \quad (19\text{-}1)$$

$$f_{OFFSET} = f_{RX} - f_{TX} = 157.600 MHz - 157.000 MHz = 0.6 MHz = \underline{\underline{600\ kHz}}$$

We would simply say that this "machine" (the repeater) has a positive 600 kHz offset.

b) Since we know that the system impedance is 50 ohms, we can use Ohm's law to calculate the received power as follows:

$$P_R = \frac{V_R^2}{Z_0} = \frac{(307.8\ \mu V)^2}{50\ \Omega} = 1.895 \times 10^{-9}\ W = \underline{\underline{1.895\ nW}}$$

c) To calculate dBm, decibels with respect 1 mW, we use Equation 19-2:

$$(19\text{-}2)\quad dBm = 10\log\left(\frac{P}{1mW}\right)$$

So at the receiver:

$$P_R(dBm) = 10\log\left(\frac{P_R}{1mW}\right) = 10\log\left(\frac{1.895nW}{1mW}\right) = \underline{\underline{-57.2dBm}}$$

d) We can again use Equation 19-2 to express the transmitted power in dBm:

$$P_T(dBm) = 10\log\left(\frac{P_T}{1mW}\right) = 10\log\left(\frac{50W}{1mW}\right) = \underline{\underline{46.99\ dBm - 47\ dBm}}$$

e) To compare absolute decibel power levels, we simply subtract them:

$$P_{DIFF}(dBm) = P_{OUT}(dBm) - P_R(dBm) = 46.99\ dBm - (-57.2\ dBm) = \underline{\underline{104.2\ dB}}$$

IMPORTANT: *Note that when we subtract two absolute decibel values (such as 47 dBm and -57.2 dBm), the answer is now in relative decibels*. The "m" (milliwatt) unit suffix is simply dropped. The answer above says that the transmitted signal is 104.2 dB (26,240,373,012 times) stronger than what arrived at the receiver. That's quite impressive in itself - - and in fact, the -57.2 dBm received signal is actually quite strong for a typical modern FM repeater receiver (which can typically "hear" signals down to -120 dBm) and would be heard with "full quieting" (no audible noise) by a listener.

Example 19-2

You've just been told that the company's repeater on 157.54 MHz, with a 600 kHz positive offset, seems to be down. None of the mobile units can bring up the machine (they key their microphones and nothing happens in response), and it's interfering with company operations. At the repeater site, you do a visual inspection and all seems okay from that perspective - - the power lights are on, nothing appears to be smoked, but the repeater refuses to transmit. You notice that the COR indicator lamp on the receiver seems to be lit steadily, indicating that the receiver is picking up a signal.

a) What frequency would you tune a portable receiver to in order to check on the "input" of the machine?
b) If there has been a steady signal on the input for at least several minutes, what might have happened, and how would you correct it?

Solution
a) Equation 19-1 tells us that $f_{OFFSET} = f_{RX} - f_{TX}$, so we can find the receive frequency by simply adding the positive 600 kHz offset. Therefore:

$$f_{RX} = f_{TX} + f_{OFFSET} = 157.540MHz + 0.600MHz = \underline{\underline{158.140MHz}}$$

You should therefore tune the portable receiver to 158.140 MHz to listen for an interfering carrier.

b) A repeater may have a *time-out timer* to prevent it from transmitting more than a few minutes at a time, though this is not required by the FCC. In this case, a continuous input signal will time out the repeater, and it will stop transmitting.

Even if the repeater isn't equipped with a time-out timer, any continuous signal on the input can cause the repeater to appear unresponsive to end-users by jamming their transmissions.