# Contents

Chapter 18

# Repeaters

For decades, FM has been a dominant mode of Amateur Radio operation. FM and repeaters fill the VHF and UHF bands, and most hams have at least one handheld or mobile FM radio. Thousands of repeaters throughout the country provide reliable communication for amateurs operating from portable, mobile and home stations. Now, Amateur Radio is beginning to see the emergence of digital voice modulation, though analog is expected to dominate for the foreseeable future. The first part of this chapter, by Paul M. Danzer, N1II, describes FM voice repeaters. Later sections, contributed by Jim McClellan, N5MIJ, and Pete Loveall, AE5PL, of the Texas Interconnect Team, cover more recent developments in D-STAR digital voice and data repeaters. Gary Pearce, KN4AQ, contributed updates to the chapter. Material on DMR was contributed by John Burningham, W2XAB.

**Chapter 18 — CD-ROM Content**

**Supplemental Articles**

- "From Analog to D-STAR" by Gary Pearce, KN4AQ
- "Discovering D-STAR" by Larry Moxon, K1KRC
- "D-STAR Uncovered" by Pete Loveall, AE5PL
- "Operating D-STAR" by Gary Pearce, KN4AQ

## 18.1 A Brief History

Few hams today don't operate at least some VHF/UHF FM, and for many hams, FM *is* Amateur Radio. That wasn't always the case.

Until the late 1960s, the VHF and UHF Amateur Radio bands were home to a relatively small number of highly skilled operators who used CW and SSB for long distance communication and propagation experiments. This operation used just a small fraction of the spectrum available at 50 MHz and above. A somewhat larger number of hams enjoyed low power, local operation with AM transceivers on 6 and 2 meters. Our spectrum was underutilized, while public safety and commercial VHF/UHF two-way operation, using FM and repeaters, was expanding rapidly.

The business and public-safety bands grew so rapidly in the early 1960s that the FCC had to create new channels by cutting the existing channels in half. Almost overnight, a generation of tube-type, crystal-controlled FM equipment had to be replaced with radios that met the new channel requirements. Surplus radios fell into the hands of hams for pennies on the original dollar. This equipment was designed to operate around 150 MHz and 450 MHz, just above the 2 meter and 70 cm amateur bands. It was fairly easy to order new crystals and retune them to operate inside the ham bands. Hams who worked in the two-way radio industry led the way, retuning radios and building repeaters that extended coverage. Other hams quickly followed, attracted by the noise-free clarity of FM audio, the inexpensive equipment, and the chance to do something different.

That initial era didn't last long. The surplus commercial equipment was cheap, but it was physically large, ran hot and consumed lots of power. By the early 1970s, manufacturers recognized an untapped market and began building solid-state equipment specifically for the Amateur Radio FM market. The frequency synthesizer, perfected in the mid-1970s, eliminated the need for crystals. The stage was set for an explosion that changed the face of Amateur Radio. Manufacturers have added plenty of new features to equipment over the years, but the basic FM operating mode remains the same.

In the 1980s, hams experimenting with data communications began modulating their FM radios with tones. *Packet radio* spawned a new system of *digipeaters* (digital repeaters).

Digitized audio has been popular since audio compact discs (CDs) were introduced in the 1980s. In the 1990s, technology advanced enough to reduce the bandwidth needed for digital audio, especially voice, to be carried over the Internet and narrowband radio circuits. The first digital-voice public safety radio systems (called APCO-Project 25) appeared and a variety of Internet voice systems for conferencing and telephone-like use were developed.

Hams are using VHF/UHF digital voice technology, too. The Japan Amateur Radio League (JARL) developed a true ham radio standard called D-STAR, a networked VHF/UHF repeater system for digital voice and data that is beginning to make inroads around the world. Hams are also using surplus Project 25 (or just P25) radios. Another digital voice system, generically known as DMR (Digital Mobile Radio) and by the Motorola trade name MOTOTRBO, is being adapted from commercial service to the ham bands.

## 18.2 Repeater Overview

Amateurs learned long ago that they could get much better use from their mobile and portable radios by using an automated relay station called a *repeater*. Home stations benefit as well — not all hams are located near the highest point in town or have access to a tall tower. A repeater, whose basic idea is shown in **Fig 18.1**, can be more readily located where the antenna system is as high as possible and can therefore cover a much greater area.

### 18.2.1 Types of Repeaters

The most popular and well-known type of amateur repeater is an FM voice system on the 144 or 440 MHz bands. Amateurs operate many repeaters on the 29, 50, 222, 902 and 1240 MHz bands as well, but 2 meters and 70 cm are the most popular. Tens of thousands of hams use mobile and handheld radios for casual ragchewing, emergency communications, public service activities or just staying in touch with their regular group of friends during the daily commute.

While the digital voice modes are gaining ground, FM is still the most popular mode for voice repeaters. Operations are *channelized* — all stations operate on specific, planned frequencies, rather than the more or less random frequency selection employed in CW and SSB operation. In addition, since the repeater receives signals from mobile or fixed stations and retransmits these signals simultaneously, the transmit and receive frequencies are different, or *split*. Direct contact between two or more stations that listen and transmit on the same frequency is called operating *simplex*.

Individuals, clubs, emergency communications groups and other organizations all sponsor repeaters. Anyone with a valid amateur license for the band can establish a repeater in conformance with the FCC rules. No one owns specific repeater frequencies, but nearly all repeaters are *coordinated* to minimize repeater-to-repeater interference. Frequency coordination and interference are discussed later in this chapter. Operational aspects are covered in more detail in *The ARRL Operating Manual*.

#### BEYOND FM VOICE

In addition to FM voice, there are several other types of ham radio repeaters.

**ATV (amateur TV)** — ATV repeaters are used to relay wideband television signals in the 70 cm and higher bands. They are used to extend coverage areas, just like voice repeaters. ATV repeaters are often set up for *cross-band* operation, with the input on one band (say, 23 cm) and the output on another (say, 70 cm). More information on ATV repeaters may be found in the **Image Communications** supplement on the *Handbook* CD.

**Digital voice** — Repeaters for D-STAR digital voice and data signals are discussed later in this chapter. There are also some P25 and DMR repeaters operating in the Amateur service (see the **Digital Communications**

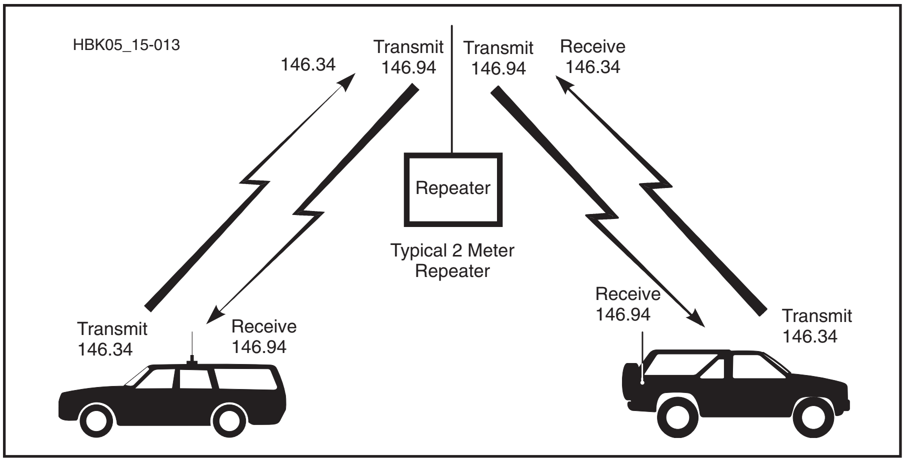


**Fig 18.1 — Typical 2 meter repeater, showing mobile-to-mobile communication through a repeater station. Usually located on a hill or tall building, the repeater amplifies and retransmits the received signal on a different frequency.**

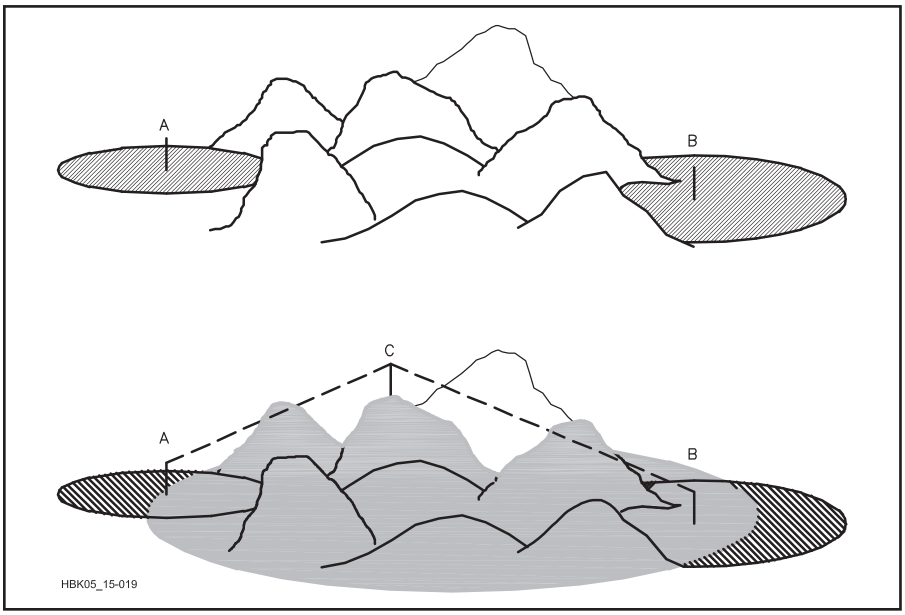


**Fig 18.2 — In the upper diagram, stations A and B cannot communicate because their mutual coverage is limited by the mountains between them. In the lower diagram, stations A and B can communicate because the coverage of each station falls within the coverage of repeater C, which is on a mountaintop.**

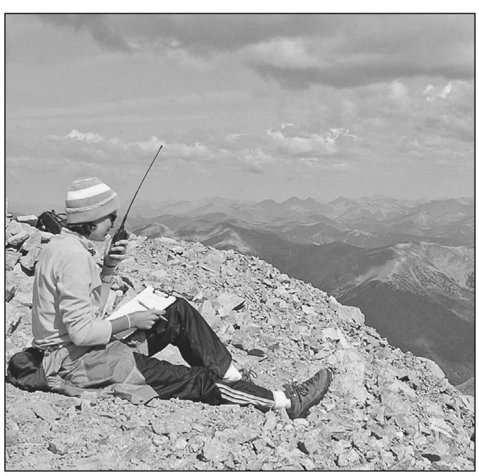

**Fig 18.3 — In the Rocky Mountain west, handheld transceivers can often cover great distances, thanks to repeaters located atop high mountains. [Photo courtesy Rachel Witte, KCØETU, and Bob Witte, KØNR]**

supplement on the *Handbook* CD for additional information.)

**Digipeaters** — Digital repeaters are used primarily for packet communications, including APRS (the Amateur Packet/position Reporting System). They can use a single channel (single port) or several channels (multi-port) on one or more VHF and UHF bands. See the **Digital Modes** chapter and the **Digital Communications** supplement on the *Handbook* CD for details of these systems.

**Multi-channel (wideband)** — Amateur satellites are the best-known examples. Wide bandwidth (perhaps 50 to 200 kHz) is selected to be received and transmitted so all signals in bandwidth are heard by the satellite (repeater) and retransmitted, usually on a different VHF or UHF band. See the **Space Communications** supplement on the *Handbook* CD for details.

## 18.2.2 Advantages of Using a Repeater

When we use the term *repeater* we are almost always talking about transmitters and receivers on VHF or higher bands, where radio-wave propagation is normally line of sight. Don't take "line of sight" too literally. VHF/UHF radio signals do refract beyond what you can actually see on the horizon, but the phrase is a useful description. (See the **Propagation of Radio Signals** chapter for more information on these terms.)

We know that the effective range of VHF and UHF signals is related to the height of each antenna. Since repeaters can usually be located at high points, one great advantage of repeaters is the extension of coverage area from low-powered mobile and portable transceivers.

**Fig 18.2** illustrates the effect of using a repeater in areas with hills or mountains. The same effect is found in metropolitan areas, where buildings provide the primary blocking structures.

Siting repeaters at high points can also have disadvantages. Since most repeaters have co-channel neighbors (other repeaters operating on the same channel) less than 150 miles away, there may be times when your transceiver can receive both. But since it operates FM, the *capture effect* usually ensures that the stronger signal will capture your receiver and the weaker signal will not be heard — at least as long as the stronger repeater is in use.

It is also simpler to provide a very sensitive receiver, a good antenna system, and a slightly higher power transmitter at just one location — the repeater — than at each mobile, portable or home location. A superior repeater system compensates for the low power (5 W or less), and small, inefficient antennas that many hams use to operate through them. The repeater maintains the range or coverage we want, despite our equipment deficiencies. If both the handheld transceiver and the repeater are at high elevations, for example, communication is possible over great distances, despite the low output power and inefficient antenna of the transceiver (see **Fig 18.3**).

Repeaters also provide a convenient meeting place for hams with a common interest. It's usually geographic — your town, or your club. A few repeaters are dedicated to a particular interest such as DX or passing traffic. Operation is channelized, and usually in any area you can find out which channel — or repeater — to pick to ragchew, get highway information or whatever your need or interest is. The conventional wisdom is that you don't have to tune around and call CQ to make a contact, as on the HF bands. Simply call on a repeater frequency — if someone is there and they want to talk, they will answer you. But with a few dozen repeaters covering almost any medium size town, you probably use the scan function in your radio to seek activity.

### EMERGENCY OPERATIONS

When there is a weather-related emergency or a disaster (or one is threatening), most repeaters in the affected area immediately spring to life. Emergency operation and traffic always take priority over other ham activities, and many repeaters are equipped with emergency power sources just for these occasions. See **Fig 18.4**.

Almost all Amateur Radio emergency organizations use repeaters to take advantage of their extended range, uniformly good coverage and visibility. Most repeaters are well known — everyone active in an area with suitable equipment knows the local repeater frequencies.

## 18.2.3 Repeaters and the FCC

Repeaters are specifically authorized by the FCC rules. For a brief period when the repeater concept was new in the amateur service, the FCC required special repeater licenses identified by a "WR" call sign prefix and a fairly complex application process. While that complexity is gone, repeaters are still restricted to certain band segments and have lower maximum power limits. But most of the "rules" that make our repeater systems work are self-imposed and voluntary. Hams have established frequency coordination, band plans, calling frequencies, digital protocols and rules that promote efficient communication and interchange of information.

FCC rules on prohibited communication have also been somewhat relaxed, allowing hams to communicate with businesses, and allowing employees of emergency-related agencies and private companies to participate in training and drills while "on the clock." There are significant restrictions to this operation, so for the latest rules and how to interpret them, see *QST* and the ARRL website, **www.arrl.org**.

**Fig 18.4 — During disasters, repeaters over a wide area are used solely for emergency-related communication until the danger to life and property is past. [Photo courtesy Eugene Kramer, WA9TZL]**

# 18.3 FM Voice Repeaters

Repeaters normally contain at least the sections shown in **Fig 18.5**. Repeaters consist of a receiver and transmitter plus a couple more special devices. One is a *controller* that routes the audio between the receiver and transmitter, keys the transmitter and provides remote control for the repeater licensee or designated control operators.

The second device is the *duplexer* that lets the repeater transmit and receive on the same antenna. A high power transmitter and a sensitive receiver, operating in close proximity within the same band, using the same antenna, present a serious technical challenge. You might think the transmitter would just blow the receiver away. But the duplexer keeps the transmit energy out of the receiver with a series of tuned circuits. Without a duplexer, the receiver and transmitter would need separate antennas, and those antennas would need to be 100 or more feet apart on a tower. Some repeaters do just that, but most use duplexers. A 2 meter duplexer is about the size of a two-drawer filing cabinet. See **Fig 18.6**.

Receiver, transmitter, controller, and duplexer: the basic components of most repeaters. After this, the sky is the limit on imagination. As an example, a remote receiver site can be used to extend coverage (**Fig 18.7**).

The two sites can be linked either by telephone ("hard wire") or a VHF or UHF link. Once you have one remote receiver site, it is natural to consider a second site to better hear those "weak mobiles" on the other side of town (**Fig 18.8**). Some of the stations using the repeater are on 2 meters while others are on 70 cm? Just link the two repeaters! (See **Fig 18.9**).

For even greater flexibility, you can add an auxiliary receiver, perhaps for a NOAA weather channel (**Fig 18.10**).

The list goes on and on. Perhaps that is why so many hams have put up repeaters.

## 18.3.1 FM Repeater Operation

There are almost as many operating procedures in use on repeaters as there are repeaters. Only by listening can you determine the customary procedures on a particular machine. A number of common operating techniques are found on many repeaters, however.

One such common technique is the transmission of *courtesy tones*. Suppose several stations are talking in rotation — one following another. The repeater detects the end of a transmission of one user, waits a few seconds, and then transmits a short tone or beep. The next station in the rotation waits until the beep before transmitting, thus giving any other station wanting to join in a brief period to transmit their call sign. Thus the term *courtesy tone* — you are politely pausing to allow other stations to join in the conversation.

Another common repeater feature that encourages polite operation is the *repeater timer*. A 3-minute timer is actually designed to comply with an FCC rule for remotely controlled stations, but in practice the timer serves a more social function. Since repeater operation is channelized — allowing many stations to use the same frequency — it is

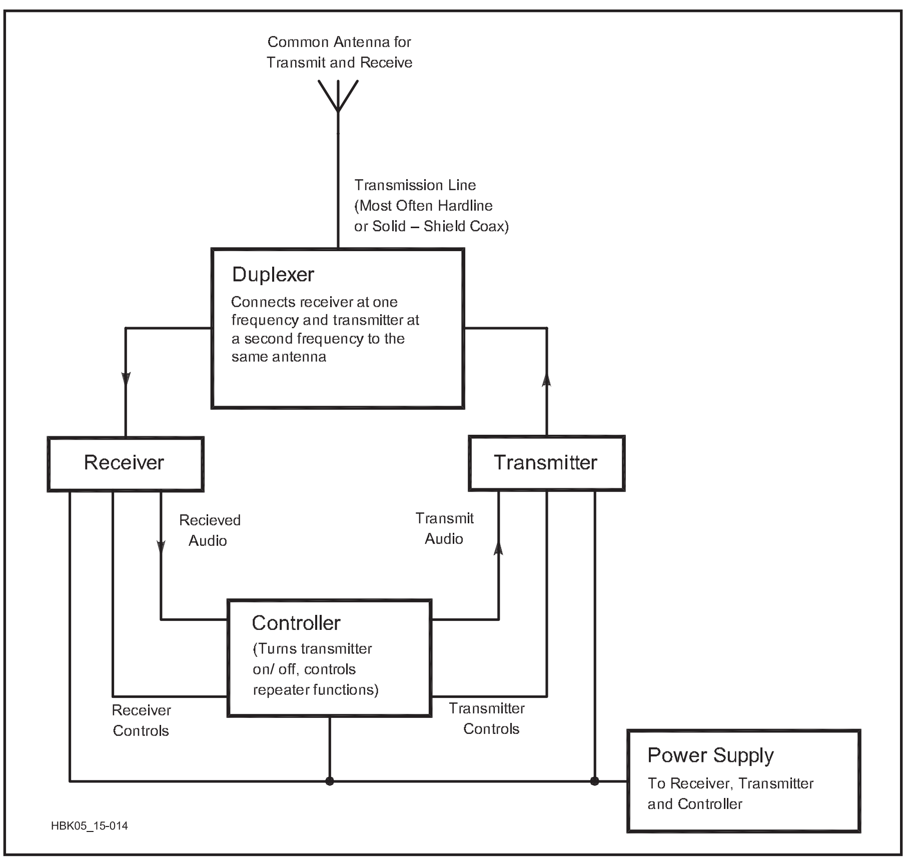


**Fig 18.5 — The basic components of a repeater station. In the early days of repeaters, many were home-built. Today, most are commercial, and are far more complex than this diagram suggests.**


**Fig 18.6 — The W4RNC 2 meter repeater includes the repeater receiver, transmitter and controller in the rack. The large object underneath is the duplexer. [Photo courtesy Gary Pearce, KN4AQ]**

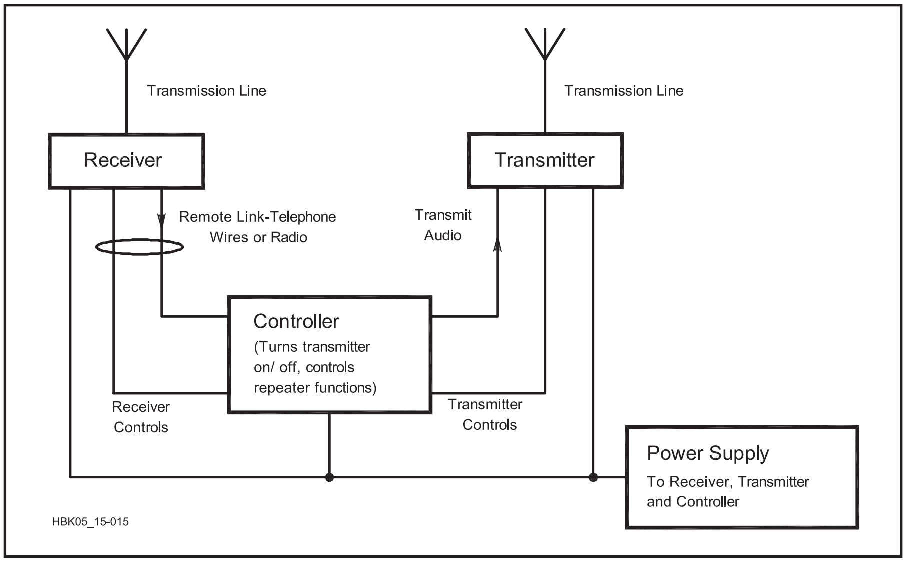


**Fig 18.7 — Separating the transmitter from the receiver can extend the repeater's coverage area. The remote receiver can be located on a different building or hill, or consist of a second antenna at a different height on the tower.**

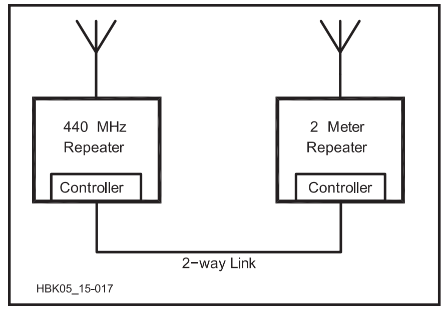


**Fig 18.9 — Two repeaters using different bands can be linked for added convenience.**

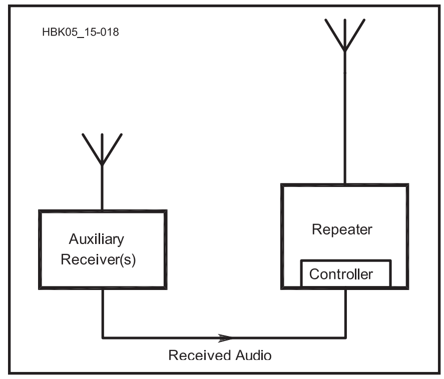


**Fig 18.10 — For even greater flexibility, you can add an auxiliary receiver.**

polite to keep your transmissions short. If you forget this little politeness many repeaters simply cut off your transmission after 2 or 3 minutes of continuous talking. If the repeater "times out," it remains off the air until the station on the input frequency stops transmitting.

A general rule, in fact law — both internationally and in areas regulated by the FCC — is that emergency transmissions always have priority. These are defined as relating to life, safety and property damage. Many repeaters are voluntarily set up to give mobile

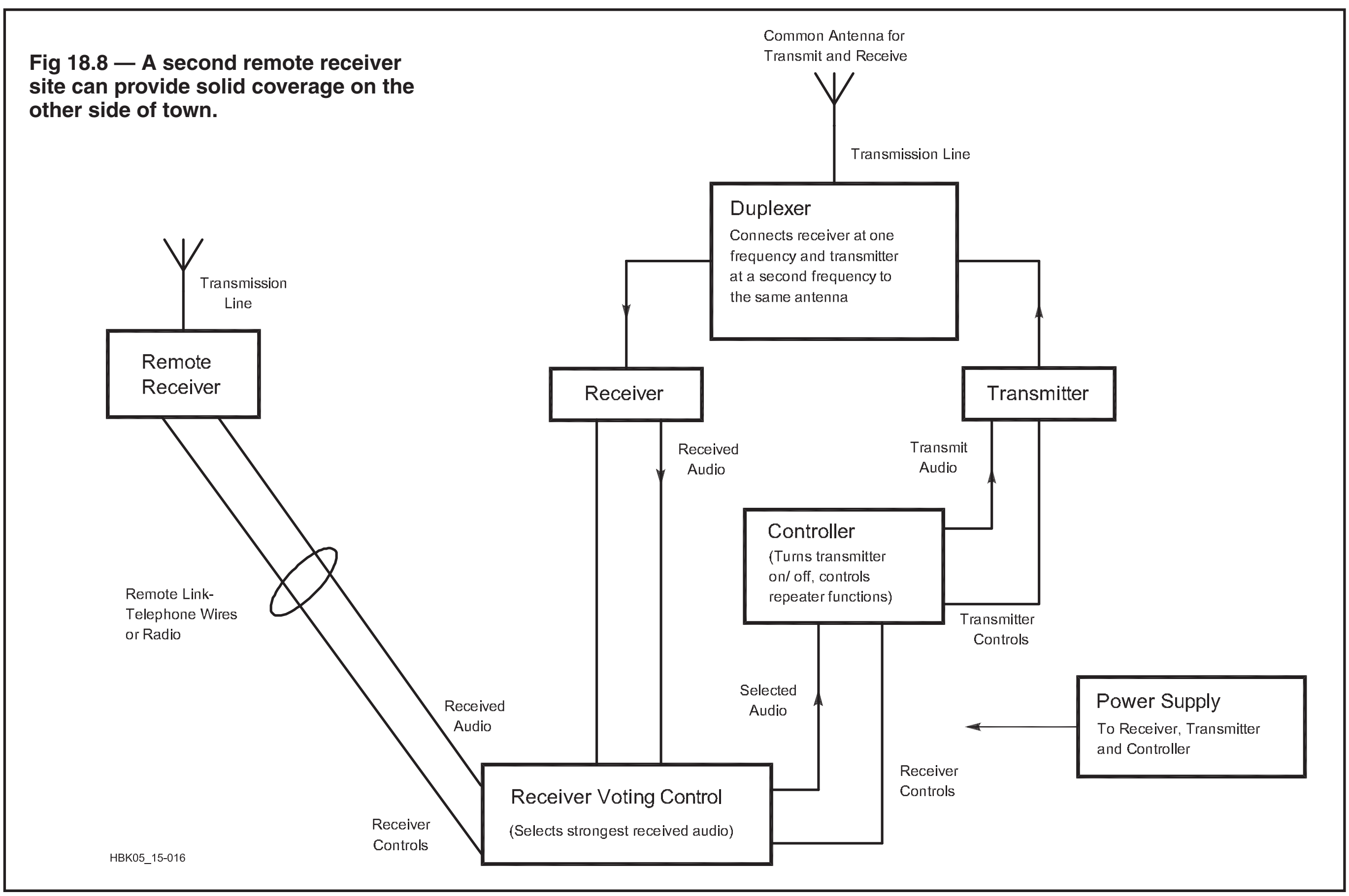


**Fig 18.8 — A second remote receiver site can provide solid coverage on the other side of town.**

stations priority, at least in checking into the repeater. If there is going to be a problem requiring help, the request will usually come from a mobile station. This is particularly true during rush hours; some repeater owners request that fixed stations limit their use of the repeater during these hours.

Some parts of the country have one or more *closed repeaters*. These are repeaters whose owners wish, for any number of reasons, to not make them available for general use. Often they require transmission of a *subaudible* or *CTCSS* tone (discussed later). Not all repeaters requiring a CTCSS tone are closed — many open repeaters use tones to minimize interference among machines in adjacent areas using the same frequency pair. Other closed repeaters require the transmission of a special tone sequence to turn on. It is desirable that all repeaters, including generally closed repeaters, be made available at least long enough for the presence of emergency information to be made known.

Repeaters have many uses. In some areas they are commonly used for formal traffic nets, replacing or supplementing HF nets. In other areas they are used with tone alerting for severe weather nets. Even when a particular repeater is generally used for ragchewing it can be linked for a special purpose. As an example, an ARRL volunteer official may hold a periodic section meeting across her state, with linked repeaters allowing both

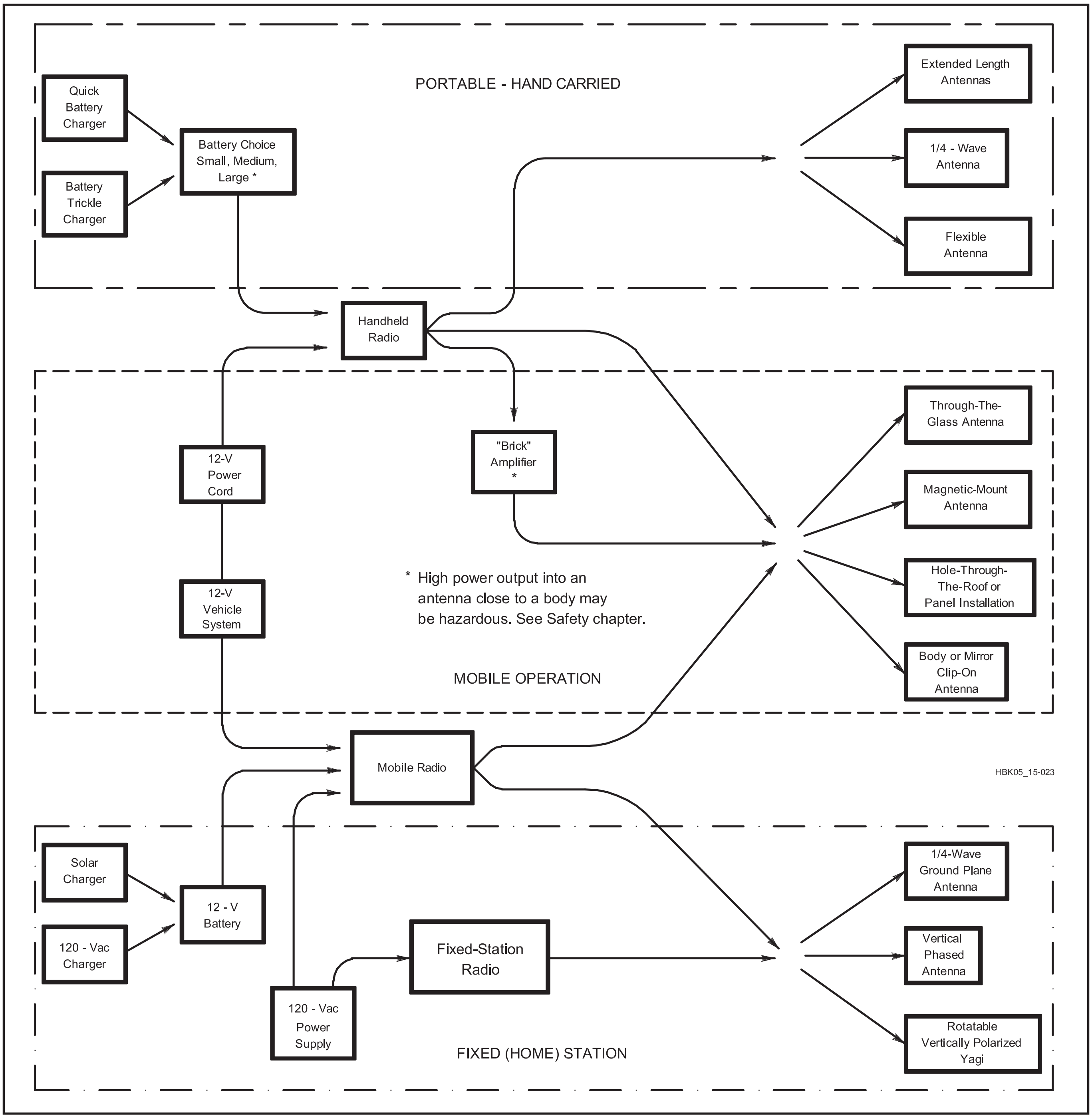


**Fig 18.11 — Equipment choices for use with repeaters are varied. A handheld transceiver is perhaps the most versatile type of radio, as it can be operated from home, from a vehicle and from a mountaintop.**

announcements and questions directed back to her.

One of the most common and important uses of a repeater is to aid visiting hams. Since repeaters are listed in the *ARRL Repeater Directory* and other directories, hams traveling across the country with mobile or handheld radios often check into local repeaters asking for travel route, restaurant or lodging information. Others just come on the repeater to say hello to the local group. In most areas courtesy prevails — the visitor is given priority to say hello or get the needed help.

Detailed information on repeater operating techniques is included in a full chapter of the *ARRL Operating Manual*.

## 18.3.2 Home, Mobile and Handheld Equipment

There are many options available in equipment used on repeaters. A number of these options are shown in **Fig 18.11**.

### HANDHELD TRANSCEIVERS

A basic handheld radio with an output power of 500 mW to 5 W can be used almost anywhere — in a building, walking down a street, or in a car.

Several types of antennas can be used in the handheld mode. The smallest and most convenient is a rubber flex antenna, known as a "rubber duck," a helically wound antenna encased in a flexible tube. Unfortunately, to obtain the small size the use of a wire helix or coil produces a very low efficiency.

A quarter-wave whip, which is about 19 inches long for the 2 meter band, is a good choice for enhanced performance. The rig and your hand act as a ground plane and a reasonably efficient result is obtained. A longer antenna, consisting of several electrical quarter-wave sections in series, is also commercially available. Although this antenna usually produces extended coverage, the mechanical strain of 30 or more inches of antenna mounted on the radio's antenna connector can cause problems. After several months, the strain may require replacement of the connector.

Most newer handheld radios are supplied with lithium-ion (Li-ion) batteries. These high-capacity batteries are lightweight and allow operation for much longer periods than the classic NiCd battery pack. Charging is accomplished either with a "quick" charger in an hour or less or with a trickle charger overnight. See the **Power Sources** chapter for more information on batteries.

Power levels higher than 7 W may cause a safety problem on handheld units, since the antenna is usually close to the operator's head and eyes. See the **Safety** chapter for more information.

For mobile operation, an external antenna provides much greater range than the "rubber duck" as discussed in the following Mobile Equipment section. A power cord plugs into the vehicle cigarette lighter so that the battery remains charged, and a speaker-microphone adds convenience. In addition, commercially available "brick" amplifiers can be used to raise the output power level of the handheld radio to 50 W or more. Many hams initially go this route, but soon grow tired of frequently connecting and disconnecting all the accessories from the handheld and install a permanent mobile radio.

### MOBILE EQUIPMENT

Compact mobile transceivers operate from 11-15 V dc and generally offer several transmit power levels up to about 50 W. They can operate on one or more bands. Most common are the single band and dual-band transceivers. "Dual-band" usually means 2 meters and 70 cm, but other combinations are available, as are radios that cover three or more bands.

Mobile antennas range from the quick and easy magnetic mount to "drill through the car roof" assemblies. The four general classes of mobile antennas shown in the center section of Fig 18.11 are the most popular choices. Before experimenting with antennas for your vehicle, there are some precautions to be taken.

*Through-the-glass antennas:* Rather than trying to get the information from your dealer or car manufacturer, test any such antenna first using masking tape or some other temporary technique to hold the antenna in place. Some windshields are metalicized for defrosting, tinting and car radio reception. Having this metal in the way of your through-the-glass antenna will seriously decrease its efficiency.

*Magnet-mount or "mag-mount" antennas* are convenient if your car has a metal roof or trunk. The metal also serves as the ground plane. They work well, but are not a good long-term solution. Eventually they'll scratch the car's paint, and the coax run through a door can be subject to flexing or crimping and can eventually fail.

*Through-the-roof antenna mounting:* Most hams are squeamish about drilling a hole in their car roof, unless they intend to keep the car for a long time. This mounting method provides the best efficiency, however, since the (metal) roof serves as a ground plane. Before you drill, carefully plan and measure how you intend to get the antenna cable down under the interior car headliner to the radio. Be especially careful of side-curtain air bags. Commercial two-way shops can install antennas and power cables, usually for a reasonable price.

*Trunk lip and clip-on antennas:* These antennas are good compromises. They are usually easy to mount and they perform acceptably. Cable routing must be planned. If you are going to run more than a few watts, do not mount the antenna close to one of the car windows — a significant portion of the radiated power may enter the car interior.

More information on mobile equipment may be found in the **Assembling a Station** and **Antennas** chapters.

### HOME STATION EQUIPMENT

Most "base station" FM radios are actually mobile rigs, powered either from rechargeable batteries or ac-operated power supplies. Use of batteries has the advantage of providing back-up communications ability in the event of a power interruption. Some HF transceivers designed for fixed-station use also offer operation on the VHF or VHF/UHF bands, using SSB and CW in addition to FM. Using them means that you will not be able to monitor a local FM frequency while operating HF.

The general choice of fixed-location antennas is also shown in Fig 18.11. Most hams use an omnidirectional vertical, but if you are in an area between two repeaters on the same channel, a rotatable Yagi may let you pick which repeater you will use without

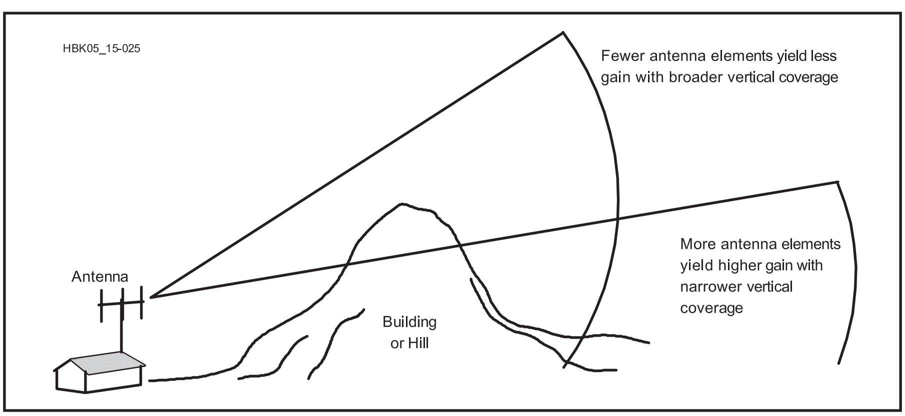


**Fig 18.12 — As with all line-of-sight communications, terrain plays an important role in how your signal gets out.**

interfering with the other repeater. Vertical polarization is the universal custom, since it is easiest to accomplish in a mobile installation. VHF/UHF SSB operation is customarily horizontally polarized. An operator with a radio that does both has a tough choice, as there can be a serious performance hit between stations using cross-polarized antennas.

Both commercial and homemade ¼-λ and larger antennas are popular for home use. A number of these are shown in the **Antennas** chapter. Generally speaking, ¼-λ sections may be stacked up to provide more gain on any band. As you do so, however, more and more power is concentrated toward the horizon. This may be desirable if you live in a flat area. See **Fig 18.12**.

### 18.3.3 Coded Squelch and Tones

*Squelch* is the circuit in FM radios that turns off the loud rush of noise with no signal present. Most of the time, hams use *noise squelch*, also called *carrier squelch*, a squelch circuit that lets any signal at all come through. But there are ways to be more selective about what signal gets to your speaker or keys up your repeater. That's generically known as *coded squelch*, and more than half of the repeaters on the air require you to send coded squelch to be able to use the repeater.

#### CTCSS

The most common form of coded squelch has the generic name *CTCSS* (Continuous Tone Coded Squelch System), but is better known by the nickname "tone." Taken from the commercial services, subaudible tones are generally not used to keep others from using a repeater but rather are a method of minimizing interference from users of the same repeater frequency. CTCSS tones are sine-wave audio tones between 67 and 250 Hz, that are added to the transmit audio at a fairly low level. They are *sub*audible only because your receiver's audio circuit is supposed to filter them out. A receiver with CTCSS will remain silent to all traffic on a channel unless the transmitting station is sending the correct tone. Then the receiver sends the transmitted audio to its speaker.

For example, in **Fig 18.13** a mobile station on hill A is nominally within the normal coverage area of the Jonestown repeater (146.16/76). The Smithtown repeater, also on the same frequency pair, usually cannot hear stations 150 miles away. The mobile is on a hill and so he is in the coverage area of both Jonestown and Smithtown. Whenever the mobile transmits both repeaters hear him.

The common solution to this problem, assuming it happens often enough, is to equip the Smithtown repeater with a CTCSS decoder and require all users of the repeater to transmit a CTCSS tone to access the repeater. Thus, the mobile station on the hill does not come through the Smithtown repeater, since he is not transmitting the required CTCSS tone.

**Table 18.1** shows the available CTCSS tones. Most radios built since the early 1980s have a CTCSS encoder built in, and most radios built since the early 1990s also have a CTCSS *decoder* built in. Newer radios have a "tone scan" feature that will hunt the tone, *if* the repeater ouput includes a tone. Most repeaters that require tone also transmit their tone, but they don't have to. Listings in the *ARRL Repeater Directory* include the CTCSS tone required, if any.

**Table 18.1**
**CTCSS Tone Frequencies**
The purpose of CTCSS is to reduce cochannel interference during band openings. CTCSS equipped repeaters would respond only to signals having the CTCSS tone required for that repeater. These repeaters would not respond to weak distant signals on their inputs and correspondingly not transmit and repeat to add to the congestion. The standard ANSI/EIA frequency codes, in hertz, are as follows:

| | | |
|---|---|---|
| 67.0 | 118.8 | 179.9 |
| 69.3 | 123.0 | 183.5 |
| 71.9 | 127.3 | 186.2 |
| 74.4 | 131.8 | 189.9 |
| 77.0 | 136.5 | 192.8 |
| 79.7 | 141.3 | 199.5 |
| 82.5 | 146.2 | 203.5 |
| 85.4 | 151.4 | 206.5 |
| 88.5 | 156.7 | 210.7 |
| 91.5 | 159.8 | 218.1 |
| 94.8 | 162.2 | 225.7 |
| 97.4 | 165.5 | 229.1 |
| 100.0 | 167.9 | 233.6 |
| 103.5 | 171.3 | 241.8 |
| 107.2 | 173.8 | 250.3 |
| 110.9 | 177.3 | 254.1 |
| 114.8 | | |

If your local repeater sends a CTCSS tone, you can use your decoder to monitor just that repeater, and avoid hearing the co-channel neighbor, intermod or the annoying fizzes of nearby consumer electronics. Radios typically store CTCSS frequency and mode in their memory channels.

#### DIGITAL-CODED SQUELCH (DCS)

A newer form of coded squelch is called *DCS* (Digital-Coded Squelch). DCS appeared in commercial service because CTCSS didn't provide enough tones for the many users. DCS adds another 100 or so code options. DCS started showing up in Amateur Radio transceivers several years ago and is now a standard feature in most new radios. Open repeaters generally still use CTCSS rather than DCS, since many older radios still in use don't have DCS.

#### DTMF

In the days before widespread use of cell phones, one of the most attractive features of repeaters was the availability of autopatch services that allowed a mobile or portable station to use a standard telephone DTMF (dual-tone multi-frequency, or Touch-Tone) key pad to connect the repeater to the local telephone line and make outgoing calls.

Although autopatches see less use today, DTMF key pads are still used for sending

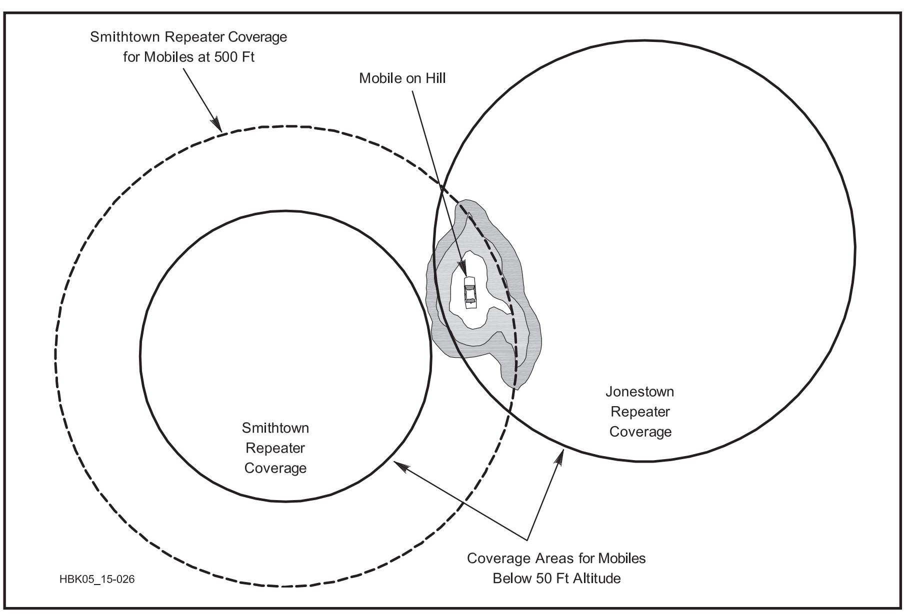


**Fig 18.13 — When two repeaters operate on the same frequencies, a well-situated operator can key up both repeaters simultaneously. A directional antenna may help.**

control signals. DTMF can also be used as a form of squelch, to turn a receiver on, though it's more often used to control various functions such as autopatch and talking S meters. Some repeaters that require CTCSS have a DTMF "override" that puts the repeater into carrier-squelch mode for a few minutes if you send the proper digits. Other applications for DTMF tones include controlling linked repeaters, described in a later section.

**Table 18.2** shows the DTMF tones. Some keyboards provide the standard 12 sets of tones corresponding to the digits 0 through 9 and the special signs # and *. Others include the full set of 16 pairs, providing special keys A through D. The tones are arranged in two groups, usually called the low tones and high tones. Two tones, one from each group, are required to define a key or digit. For example, pressing 5 will generate a 770-Hz tone and a 1336-Hz tone simultaneously.

The standards used by the telephone company require the amplitudes of these two tones to have a certain relationship.

**Table 18.2**
**Standard Telephone (DTMF) Tones**

| | *Low Tone Group* | | *High Tone Group* | |
|---|---|---|---|---|
| | *1209 Hz* | *1336 Hz* | *1477 Hz* | *1633 Hz* |
| 697 Hz | 1 | 2 | 3 | A |
| 770 Hz | 4 | 5 | 6 | B |
| 852 Hz | 7 | 8 | 9 | C |
| 941 Hz | * | 0 | # | D |

### 18.3.4 Frequency Coordination and Band Plans

Since repeater operation is channelized, with many stations sharing the same frequency pairs, the amateur community has formed coordinating groups to help minimize conflicts between repeaters and among repeaters and other modes. Over the years, the VHF and UHF bands have been divided into repeater and non-repeater sub-bands. These frequency-coordination groups maintain lists of available frequency pairs in their areas (although in most urban areas, there are no "available" pairs on 2 meters, and 70 cm pairs are becoming scarce). A complete list of frequency coordinators, band plans and repeater pairs is included in the *ARRL Repeater Directory*.

Each VHF and UHF repeater band has been subdivided into repeater and nonrepeater channels. In addition, each band has a specific *offset* — the difference between the transmit frequency and the receive frequency for the repeater. While most repeaters use these standard offsets, others use "oddball splits." These nonstandard repeaters are generally also coordinated through the local frequency coordinator. **Table 18.3** shows the standard frequency offsets for each repeater band.

FM repeater action isn't confined to the VHF and UHF bands. There are a large handful of repeaters on 10 meters around the US and the world. "Wideband" FM is permitted only above 29.0 MHz, and there are four band-plan repeater channels (outputs are 29.62, 29.64, 29.66 and 29.68 MHz), plus the simplex channel 29.60 MHz. Repeaters on 10 meters use a 100 kHz offset, so the corresponding inputs are 29.52, 29.54, 29.56 and 29.58 MHz. During band openings, you can key up a repeater thousands of miles away, but that also creates the potential for interference generated when multiple repeaters are keyed up at the same time. CTCSS would help reduce the problem, but not many 10 meter repeater owners use it and too many leave their machines on "carrier access."

**Table 18.3**
**Standard Frequency Offsets for Repeaters**

| *Band* | *Offset* |
|---|---|
| 29 MHz | –100 kHz |
| 52 MHz | Varies by region<br>–500 kHz, –1 MHz, –1.7 MHz |
| 144 MHz | + or –600 kHz |
| 222 MHz | –1.6 MHz |
| 440 MHz | + or –5 MHz |
| 902 MHz | 12 MHz |
| 1240 MHz | 12 MHz |

### 18.3.5 Narrowbanding

We noted in the previous section that in most urban areas, there are no "available" frequencies for new repeaters. And you might recall from our short history section at the beginning of this chapter that the Amateur Radio FM boom began when the business and public-safety services ran out of room and had to buy all new radios. Their solution to overcrowding, mandated by the FCC, was to reduce the spectrum used for each channel. In the 1960s, that meant reducing the modulation ("deviation") of FM signals from 15 kHz to 5 kHz, and splitting each channel in two. Hams inherited the 15 kHz deviation radios (called "wideband" at the time), but soon adopted the 5 kHz "narrowband" standard.

History is repeating itself. Our spectrum neighbors are again out of room, and the FCC is again requiring them to reduce deviation, from 5 kHz (now called "wideband"), to 2.5 kHz (the new "narrowband"). It's been postponed for several years, but is finally happening.

Will hams follow suit and create space for more repeaters in our own crowded bands? So far, the answer is "no." While most Amateur Radio FM equipment built in the past decade has a "narrow" option that reduces the deviation and incorporates tighter receive filters, we still have a lot of legacy equipment in the field, and no corporate or municipal budget to draw on to replace it. Most of our repeaters are still made of old hardware converted from commercial service. Few repeater councils have seriously considered adjusting frequency coordination to accommodate narrowbanding. No one expects the FCC to require hams to adopt narrowbanding.

What *is* happening is the placement of D-STAR digital repeaters, which are especially "narrow" already, in between the channels occupied by analog FM repeaters. Since there is still some spectrum overlap, the D-STAR repeaters must also be a good distance away from their new adjacent-channel neighbors — 30 to 50 miles — to reduce the field strength of all the signals involved.

To help you understand how this all works, we'll explain that the terminology "5 kHz" and "2.5 kHz" deviation for analog FM signals is misleading. It refers to the peak frequency shift a modulated signal takes *in one direction* from the center frequency. But the FM signal moves both up and down from that center, and has some sidebands as well. The actual spectrum used by a "5 kHz" FM signal peaks at 16 kHz and the "narrow" 2.5 kHz signal hits 11 kHz on peaks — not much of a savings. The digital D-STAR signal is about 6.25 kHz wide. The digital signals fill their spectrum completely, all the time, and don't vary with modulation.

Narrowbanding may become a voluntary practice in Amateur Radio, though *your* use would be "mandated" by remaining compatible with narrowbanded repeaters. It's not on the horizon as of this edition of the *Handbook.*

### 18.3.6 Linked Repeaters

Most repeaters are standalone devices, providing their individual pool of coverage and that's it. But a significant number of repeaters are linked — connected to one or more other repeaters. Those other repeaters can be on other bands at the same location, or they can be in other locations, or both. Linked

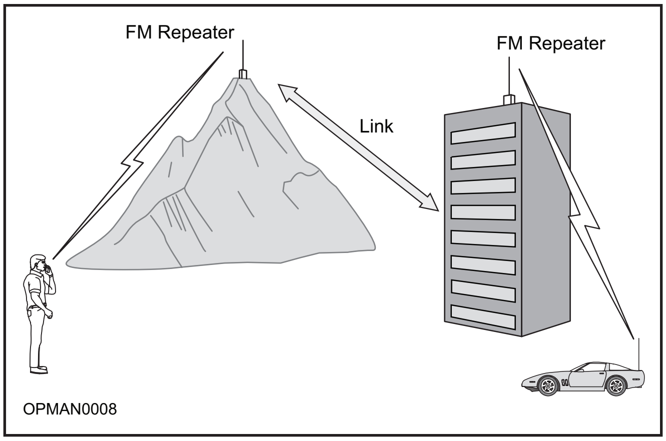


Fig 18.14 — Repeater linking can greatly expand VHF/UHF communication distances. Repeater links are commonly made via dedicated radio hardware or via the Internet.

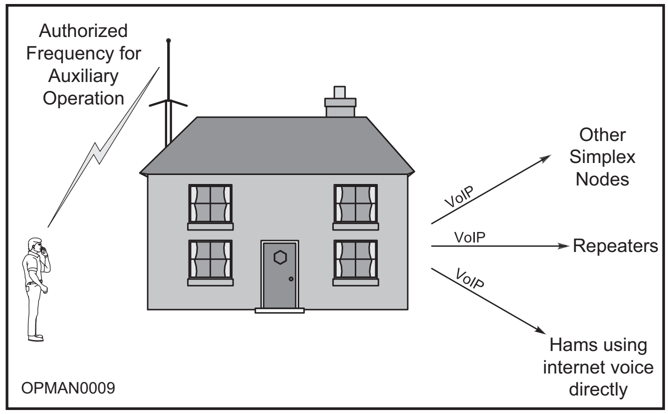


Fig 18.15 — A diagram of a VoIP simplex node. If a control operator is not physically present at the station location and the node is functioning with wireless remote control, the control link must follow the rules for *auxiliary* operation.

repeaters let users communicate between different bands and across wider geographic areas than they can on a single repeater. **Fig 18.14** shows an example.

There are many ways to link repeaters. Repeaters on the same tower can just be wired together, or they may even share the same controller. Repeaters within a hundred miles or so of each other can use a radio link — separate link transmitters and receivers at each repeater, with antennas pointed at each other. Multiple repeaters, each still about 100 miles apart, can "daisy-chain" their links to cover even wider territory. There are a few linked repeater systems in the country that cover several states with dozens of repeaters, but most radio-linked repeater systems have more modest ambitions, covering just part of one or two states.

Repeater linking via the Internet has created the ability to tie repeaters together around the world and in nearly unlimited number. We'll talk more about Internet linking in the next section.

There are several ways linked repeaters can be operated, coming under the categories of *full-time* and *on demand*. Full-time linked repeaters operate just as the name implies — all the repeaters in a linked network are connected all the time. If you key up one of them, you're heard on all of them, and you can talk to anyone on any of the other repeaters on the network at any time. You don't have to do anything special to activate the network, since it's always there.

In an on-demand system, the linked repeaters remain isolated unless you take some action, usually by sending a code by DTMF digits, to connect them. Your DTMF sequence may activate all the repeaters on the network, or the system may let you address just one specific repeater, somewhat like dialing a telephone. When you're finished, another DTMF code drops the link, or a timer may handle that chore when the repeaters are no longer in use.

### INTERNET LINKING

The Internet and *Voice over Internet Protocol* (VoIP) has expanded repeater linking exponentially, making worldwide communication through a local repeater commonplace. Two Internet linking systems, IRLP and EchoLink, have reached critical mass in the US and are available almost everywhere. The D-STAR and DMR digital systems also have a significant Internet linking component. A brief overview is included here; more information may be found in the **Digital Communications** supplement on the *Handbook* CD.

#### IRLP

The Internet Radio Linking Project (IRLP) is the most "radio" based linking system. User access is only via radio, using either simplex or repeater stations, while linking is done using VoIP on the Internet. An IRLP system operator establishes a *node* by interfacing his radio equipment to a computer with an Internet connection, and then running IRLP software. Once that's set up, repeater users send DTMF tones to make connections, either directly to other individual repeater or simplex nodes (**Fig 18.15**), or to *reflectors* — servers that tie multiple nodes together as one big party line.

The direct connections work like on-demand linked repeaters. You dial in the node number you want to connect to and access code (if required), and you are connected to the distant repeater. Once connected, everyone on both ends can communicate. When finished, another DTMF sequence takes the link down. Someone from a distant repeater can make a connection to you as well.

Reflectors work like a hybrid between on-demand and full-time linked repeaters. You can connect your local repeater to a reflector and leave it there all day, or you can connect for a special purpose (like a net), and drop it when the event is over.

#### EchoLink

EchoLink requires a PC with sound card and appropriate software. It allows repeater connections like IRLP, and it has Conference Servers, similar to IRLP reflectors that permit multiple connections. The big difference is that EchoLink allows individuals to connect to the network from their computers, without using a radio.

The EchoLink conference servers all have more or less specific functions. Some are just regional gathering places, while some are region, topic or activity based (SKYWARN and National Hurricane Center Nets, Jamboree on the Air, and so on).

You can connect your EchoLink-enabled computer to your base station radio fairly easily through a sound card, and create an on-air node. Don't pipe EchoLink to a local repeater without permission from the repeater owner, though.

If you decide to create a full-time link from a computer to a repeater, consider using a dedicated UHF link frequency rather than just a base station on the repeater input. This applies to IRLP connections as well. Of course, the Internet is infrastructure dependent, and both power and Internet access can be interrupted during storms or other disasters.

## D-STAR Network Overview

The D-STAR specification defines the repeater controller/gateway communications and defines the general D-STAR network architecture. The diagram shown here as Fig 18.A1 is taken from the English translation of the D-STAR specification:

The Comp. IP and Own IP are shown for reference if this were a DD communications. As they do not change and are not passed as part of the D-STAR protocol, they can safely be ignored for the purposes of the following explanation.

Headers 1 through 4 are W$1QQQ calling W$1WWW. Headers 5 through 8 are W$1WWW calling W$1QQQ. Note that "Own Callsign" and "Companion Callsign" are never altered in either sequence. The "Destination Repeater Callsign" and the "Departure Repeater Callsign" are changed between the gateways. This is so the receiving gateway and repeater controller know which repeater to send the bit stream to. It also makes it easy to create a "One Touch" response as ICOM has done by simply placing the received "Own Callsign" in the transmitted "Companion Callsign", the received "Destination Repeater Callsign" in the transmitted "Departure Repeater Callsign", and the received "Departure Repeater Callsign" in the transmitted "Destination Repeater Callsign".

Use of the "special" character "/" at the beginning of a call sign indicates that the transmission is to be routed to the repeater specified immediately following the slash. For instance, entering "/K5TIT B" in the "Companion Callsign" would cause the transmission to be routed to the "K5TIT B" repeater for broadcast. Using the above example, W$1QQQ would put "/W$1SSS" in the "Companion Callsign" for the same sequence 1 through 4 to occur. At the W$1VVV gateway, however, the "/W$1SSS" in the "Companion Callsign" would be changed to "CQCQCQ". All stations within range of W$1SSS would see the transmission as originating from W$1QQQ and going to CQCQCQ just like that station was local (but the "Departure Repeater Callsign" would be "W$1VVV G" and the "Destination Repeater Callsign" would be "W$1SSS"). Replying would still be done the same way as before since the received "Companion Callsign" is ignored when programming the radio to reply.

Every "terminal" (station) has an IP address assigned to it for DD purposes. The address is assigned from the 10.0.0.0/8 address range. The D-STAR gateway is always 10.0.0.2. The router to the Internet is always 10.0.0.1. The addresses 10.0.0.3-31 are reserved for local-to-the-gateway (not routable) use. What this makes possible is the ability to send Ethernet packets to another station by only knowing that terminal's IP address and the remote station can directly respond based solely on IP address. This is because the gateway software can correlate IP address with call sign and ID. This makes it possible to route DD Ethernet packets based on the "Companion Callsign" or based on IP address with "Companion Callsign" set to "CQCQCQ". — *Pete Loveall, AE5PL*

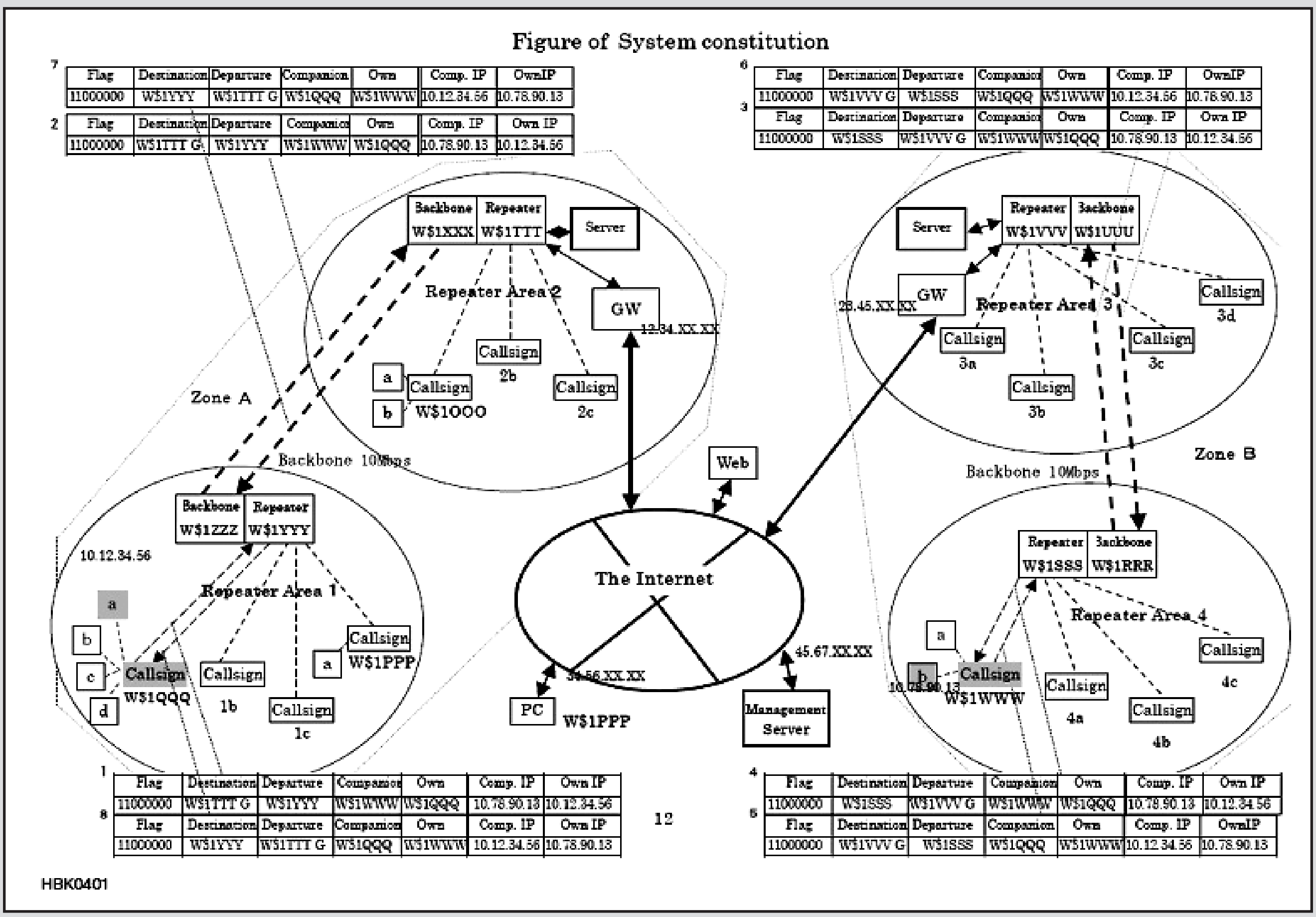


**Fig 18.A1 — A D-STAR system overview.**

# 18.4 D-STAR Repeater Systems

D-STAR is a digital protocol developed by the Japan Amateur Radio League (JARL) that takes Amateur Radio into the 21st century. D-STAR is a bit-streaming protocol able to encapsulate voice and low speed data (DV) or higher speed Ethernet data (DD). Because the protocol is entirely digital (GMSK modulation is used for amateur station transceivers and the respective repeaters), signaling is carried entirely out-of-band (ie, control codes are a separate part of the data stream from the voice or Ethernet information). When looking at the D-STAR repeater systems, it is important to keep that aspect in mind. Amateurs are more familiar with in-band signaling (DTMF tones, for example) in the analog world. Additional information on D-STAR may be found in the **Digital Communications** supplement on the *Handbook* CD.

## 18.4.1 D-STAR Station IDs

The D-STAR specification defines a protocol that can be used for simplex communication or repeater operations. When used simplex, the D-STAR radios function similarly to analog radios with the additional capability to enable selective listening based on station ID (call sign and a character or space). To operate through a repeater, you must know the repeater's station ID as well as the frequency the repeater is on. In this case, consider the repeater's station ID equivalent to a unique CTCSS tone in the analog world.

The D-STAR specification defines all station IDs as seven upper-case alphanumeric characters (space padded) and one upper-case alphanumeric station identifier (which may also be a space). In other words, W1AW can operate multiple D-STAR stations where the first seven characters of the station ID are "W1AW<space><space><space>" (three space characters follow W1AW) and the eighth character may be a space or upper-case alphanumeral. The G2 gateway software restricts the eighth character to a space or upper-case alphanumeral. For instance, two stations could operate at the same time using "W1AW<space><space><space> " and "W1AW<space><space><space>P".

To talk to someone via D-STAR, you need to set your radio with four station IDs:

- your station ID (MYCALL)
- their station ID (URCALL)
- your local repeater station ID (RPT1)
- your local gateway station ID (RPT2).

MYCALL is always set to your call sign, followed by a character or space. RPT1 is set to your local repeater's station ID (the repeater call sign, followed by a character or space).

If you want to talk locally through the repeater:

- Set URCALL to CQCQCQ.
- Set RPT2 to your local gateway station ID (this isn't needed for local communication, but allows some new network functions to operate, and has become the default recommendation).

The power of the D-STAR protocol becomes evident when D-STAR *gateways* are implemented, providing interconnectivity between repeater systems. This interconnectivity is the same whether you are using voice or Ethernet data.

To talk to someone elsewhere in the D-STAR world, beyond your local area:

- Set URCALL to the other station's ID.
- Set RPT2 to your local gateway station ID.

The RPT2 setting is very important. You don't need to know where the other station is. You simply tell your local repeater to send your bit stream (everything is digital) to the local gateway so that gateway can determine where to send it next. The local gateway looks at URCALL (remember, this is part of the bit stream) and determines where that station was heard last. It then sends the bit stream on to that remote gateway, which looks at URCALL again to determine which repeater at the far end should transmit the bit stream.

Sounds complex? Yes, the implementation can be complex but the user is shielded from all of this by simply setting the four station IDs. **Fig 18.16** shows an example.

## 18.4.2 Station Routing

There are several different ways to set the destination station ID using URCALL:

- If URCALL is set to CQCQCQ, this means "don't go any farther."
- If URCALL is set to the remote station's ID and RPT2 is set to the local gateway, this means "gateway, send my bit stream to be transmitted out the repeater that the remote station was last heard on."
- If URCALL is set to/followed by a remote *repeater* station ID, and RPT2 is set to the local gateway, this means "gateway, send my bit stream to be transmitted out the repeater designated."

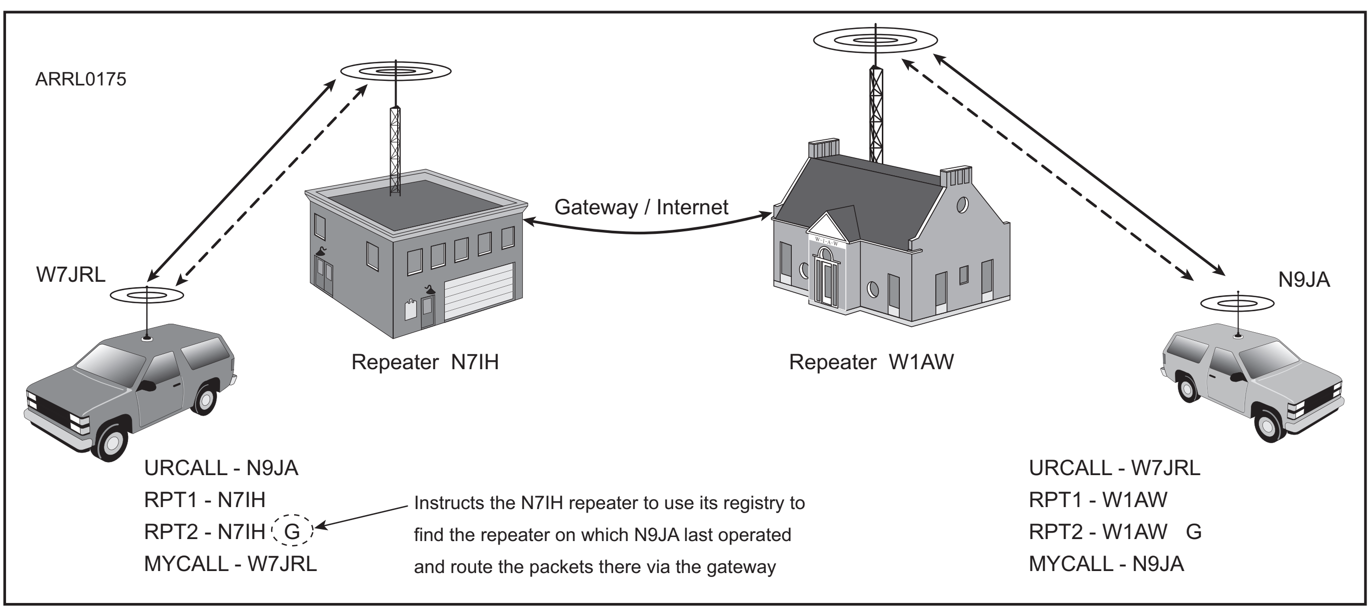


**Fig 18.16 — The necessary call sign set to make a call on a remote D-STAR repeater by using a gateway.**

Some people mistakenly call this "call sign routing." In fact, this is "station routing" because you are specifying the station you want to hear your bit stream (voice or Ethernet data). This is not source routing because the source station is only defining what station they want to talk to; it is up to the gateways to determine routing (very similar to Internet routers).

You can specify a destination but you have no guarantee that:

1) The designated station is on the air to receive your transmission.

2) The repeater that the designated station is using is not busy.

3) Other factors will not prevent your bit stream from reaching the designated station.

Station routing is similar to your address book. In your address book you may have a work number, home number, cell number, fax number and email address for a person. How do you know which one to contact them at? Maybe the email address is best if you want to send them data (equivalent to the station ID for their Ethernet data radio). Maybe the cell phone number if that is what they normally have with them (equivalent to their hand-held transceiver station ID).

How do I know if they heard me? When they talk (or send Ethernet data) back to you. D-STAR is connectionless. Therefore, there is no equivalence in D-STAR to repeater linking as we think of it in the analog world. However, there have been independent implementations of linking of repeaters similar to the linking we see with IRLP (see the section on *DPlus*).

In all cases of D-STAR repeater use, all digital voice (DV) signals with a proper RPT1 are always repeated so everyone hears your transmission through the repeater, regardless of the other settings. Ethernet data (DD) signals are not repeated on frequency because the "repeater" is actually a half-duplex Ethernet bridge operating on a single frequency.

For more details, see the sidebar, "D-STAR Network Overview."

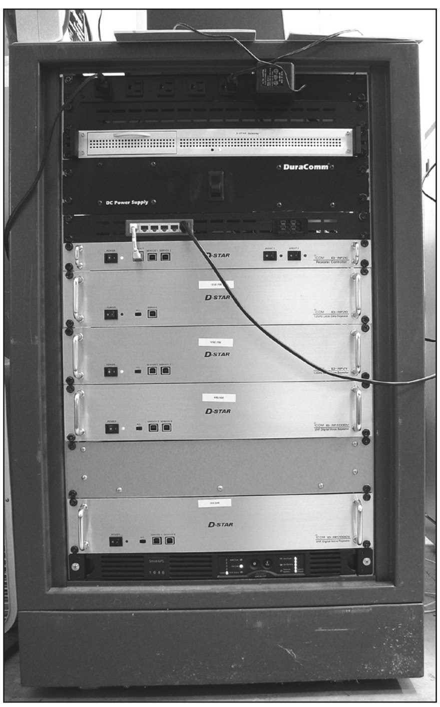

**Fig 18.17 — A full rack of D-STAR equipment on the bench of Jim McClellan, N5MIJ. Top to bottom: ICOM IP-RPC2 controller, ID-RP2V 1.2-GHz voice repeater, ID-RP4000 440 MHz voice and data repeater, a blank panel and an ID-RP2000 146 MHz voice and data repeater.**

### 18.4.3 Enhancing D-STAR Operation with *DPlus*

Because D-STAR is a true digital protocol, repeaters have no need for decoding the audio transmitted as bits from each radio. As mentioned previously, this requires all signaling to be out-of-band (with regard to the voice or Ethernet data).

Applications can be built to work with this out-of-band signaling to implement enhancements to the base product without modifying those products. One of these applications is *DPlus*, software that runs on the D-STAR Gateway computer at the repeater site. It provides many capabilities and more are being added as the software develops.

A key concept is the capability to link repeaters either *directly* (everything heard on one repeater is heard on another) or *indirectly* through a *reflector* (everything sent to a reflector is reflected back out to all linked repeaters). A reflector is a special version of *DPlus* that runs on a standalone computer that is not part of a repeater system. Linking and unlinking a repeater is done by altering the contents of URCALL according to the *DPlus* documentation. (These features continue to evolve, so specific operating commands are not covered here.)

There is no way to directly link two DD "repeaters." Because DD is Ethernet bridging, however, full TCP support is available, allowing each individual station to make connections as needed to fit their requirements.

For a station to make use of a linked repeater, the station must have URCALL set to CQCQCQ and RPT2 set to the local gateway. If RPT2 is not set to the local gateway, *DPlus* running on the local gateway computer will never see the bit stream and therefore not be able to forward the bit stream to the linked repeater or reflector. This is why setting RPT2 for your local gateway should be your default setting.

If your radio is set for automatic low-speed data transmission, remember that low-speed data is carried as part of the digital voice bit stream and is not multiplexed. Therefore, any low-speed data transmission will block the frequency for the time the transmission is occurring. Caution: if you are using a linked repeater or if you have set URCALL to something other than CQCQCQ, your bit stream will be seen by all stations that are on the other end of that transmission. A reflector could have over 100 other repeaters listening to your transmission.

### 18.4.4 D-STAR Repeater Hardware

D-STAR repeaters are a bit different from the FM repeaters with which we're all familiar. A quick comparison will help to illustrate.

A complete FM repeater consists of at least three identifiable components. A receiver receives the original signal and demodulates it. The demodulated audio is routed to a controller, where it is mixed with other audio. The resulting combined audio signal is routed back to one or more transmitters. At least one additional source of audio is present in the controller, as it is a legal requirement to ID the repeater transmitter correctly. A well-constructed system includes validation that the levels and frequency response of the processed audio are consistent and true to the originally transmitted signals.

A D-STAR repeater's block diagram looks very similar, but functions very differently. A receiver receives the original signal and demodulates it. That signal is passed to a controller, which then drives one or more transmitters. The most significant difference is that there is no audio involved! D-STAR is a digital protocol. All required manipulation of information is performed in the digital domain, including the necessary ID functions. Most existing D-STAR repeaters do not contain the vocoders necessary to recover audio information, so there exists no local speaker or microphone. There is also no level-setting to consider with D-STAR.

#### D-STAR REPEATER OPTIONS

There is much discussion about "homebrew" D-STAR repeaters. The two most common approaches are to modify an existing FM repeater to pass the digital signal, or to wire two radios back-to-back. Both approaches provide the desired extended RF coverage, but fail to accurately process the digital signal. Thus both approaches fall short in either functional capability or in legality of the transmitted signal.

It is relatively simple to modify an existing FM repeater to pass the digital signal. The limitations of this approach are that there can be no additional capability added (for example, a D-STAR Gateway), since the digital signal is never decoded. Additionally, this method lacks the ability to encapsulate

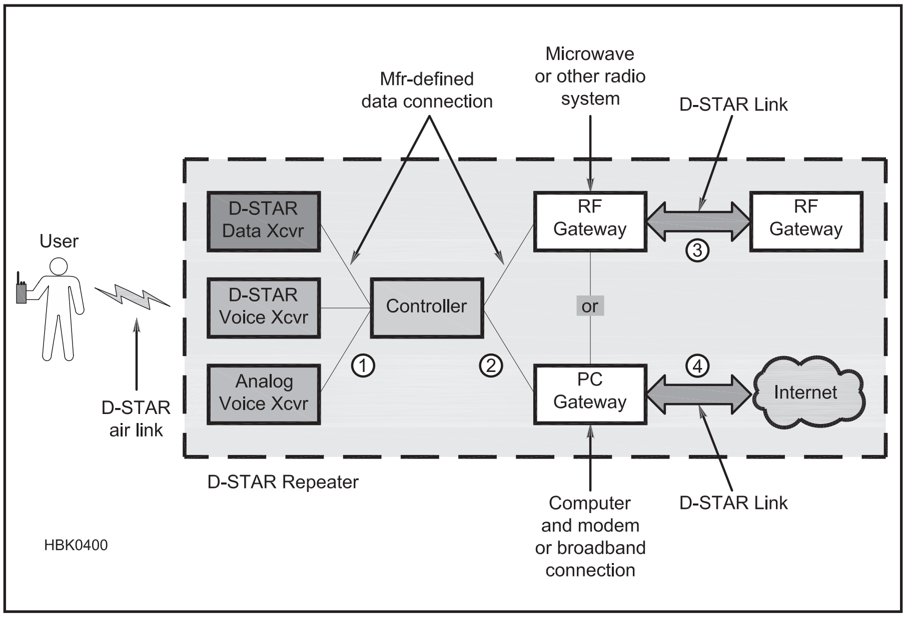


**Fig 18.18 — Internal and external connections of a D-STAR repeater stack.**

the ID for the repeater transmitter into the transmitted data.

It is also very simple to wire two D-STAR radios back-to-back, such that the incoming signals are retransmitted. Again, the functionality is limited by the inability to process the entire data stream. This approach presents an additional consideration, as the radio used as a transmitter does not process the data stream as is done in the D-STAR repeater system, and the ID of the originating transmitter is lost, replaced by the ID of the "repeater" transmitter.

Current commercially produced D-STAR repeaters are designed to be used across a broad frequency range. They do not have some of the tight front-end filtering provided by our familiar FM repeaters, so repeater builders must provide that front-end filtering externally. Installing additional band-pass filters between the antenna and the repeater will significantly improve the performance of the system. This is true for both digital voice (DV) repeaters and digital data (DD) access points.

Following good engineering practices will ensure good performance of the system. A properly constructed and installed D-STAR repeater can exhibit performance improvements of 15% or more in range, as compared to a comparably constructed FM repeater. This performance gain comes from the combination of the forward error correction (FEC) contained in the transmitted signal, and the fact that the radiated power is contained within a narrower bandwidth.

D-STAR is an exciting new system for the amateur community, providing significant opportunities for us to develop applications and implementations using capabilities we've never had before. We truly are limited only by our imaginations. The growth of the world-wide D-STAR network illustrates the level of interest in the technology by both amateurs and our served agencies. Amateurs are once again developing at the leading edge of technology. What we do with the new tools is up to us. How will you use D-STAR?

# 18.5 Digital Mobile Radio (DMR)

*The following section is based on information contributed by John Burningham, W2XAB, from "Amateur Radio Guide to Digital Mobile Radio" (see Reference section). Additional information on DMR is available in the* ***Digital Modes*** *chapter and at the websites listed in the References and Bibliography section of this chapter.*

Digital Mobile Radio (DMR) was developed by the European Telecommunications Standards Institute (ETSI) and is used worldwide by professional mobile radio users. It supports both fully-digital and dual-mode (analog/digital) operation.

DMR is organized as three tiers. Tier I is a single-channel specification originally developed for the European unlicensed dPMR446 service. It is a single-channel FDMA (Frequency Division, Multiple Access) 6.25 kHz bandwidth; the standard supports peer-to-peer (mode 1), repeater (mode 2) and linked repeater (mode 3) configurations. The use of the Tier I standard has been expanded into radios for use in other than the unlicensed dPMR446 service. Tier I is similar to traditional amateur one-user-at-a-time operation.

Tier II consists of two alternating TDMA (Time Division, Multiple Access) time slots in a single 12.5 kHz-wide channel, supporting peer-to-peer and repeater mode, resulting in a spectrum efficiency of 6.25 kHz per channel. Each time slot can be dedicated to either voice and/or data depending on the system configuration. The IP Site Connect (IPSC) protocol for interconnecting repeaters over the Internet is vendor-specific and is not part of the ETSI standards at this time. Most amateur implementation of DMR uses voice on both time slots.

Tier III builds upon Tier II, adding trunking operation involving multiple repeaters at a single site. Not all manufacturers' trunking implementations are compatible with Tier III. Vendor-specific protocols have expanded the trunking to multiple site operations.

Tier II transmissions (emission designators FXD and FXE) were approved for amateur use in the U.S. in 2014 and amateurs have since implemented Motorola MOTOTRBO and Hytera infrastructure networks. The current implementation of DMR utilizes the DSVI AMBE+2 vocoder as licensed software by agreement of the manufacturers, although it is not specified by the ETSI standard. Any manufacturer's DMR radio that can be configured for Tier II use will work with any Tier II system, although some manufacturers offer proprietary features.

IPSC protocols from different manufacturers are incompatible and bridging technology between systems as not yet been made available. The most popular current amateur DMR networks use the MOTOTRBO system.

To comply with FCC rules, DMR radios for commercial and government users do not offer "front-panel programming" to the user. Thus, the radios require a programming cable and software to set frequencies for each channel. Some radios support Bluetooth® and over-the-air programming, as well. While no manufacturer currently offers DMR technology for the Amateur Service, that could change at any time.

# 18.6 Other Digital Voice Repeater Technologies

P25 (or APCO Project 25) is a digital voice system designed for public safety (police, fire, EMS, and so on). It was developed in the 1990s to update the FM infrastructure. After about 10 years, the first P25 radios were retired and acquired by hams, who built P25 repeaters around the country. So far, though, they have not developed a digital P25 network.

Yaesu released System Fusion in 2013 using a C4FM digital voice stream with handheld units, mobile rigs, and repeaters available. An updated Internet bridge between repeaters (WIRES-X) to the System Fusion system has been announced but was not yet available in early 2015. System Fusion supports both full-digital and analog/digital operation.

Until recently there were no open-source vocoders that could generate a good-quality voice signal at the low bit-rates required for the narrowband digital voice technologies. As described in the **Digital Modes** chapter, *CODEC2* is an open-source vocoder developed by VK5DGR that provides good performance without licensing fees. It has been implemented for both HF and VHF/UHF operation.

# 18.7 Glossary of FM and Repeater Terminology

***Access code*** — One or more numbers and/or symbols that are keyed into the repeater with a DTMF tone pad to activate a repeater function, such as an autopatch.

***Autopatch*** — A device that interfaces a repeater to the telephone system to permit repeater users to make telephone calls. Often just called a "patch."

***Carrier-operated relay (COR)*** — A device that causes the repeater to transmit in response to a received signal. Solid state versions may be called COS (carrier-operated switch).

***Channel*** — The pair of frequencies (input and output) used by a repeater, or a single frequency used for simplex.

***Channel step*** — The difference (in kHz) between FM channels. The common steps are 15 and 20 kHz for 2 meter repeaters, 20 kHz for 222 MHz repeaters, and 25 kHz for 440 MHz repeaters. Closer spacing is beginning to be used in some congested areas.

***Closed repeater*** — A repeater whose access is limited to a select group (see ***open repeater***).

***Control operator*** — The Amateur Radio operator who is designated to "control" the operation of the repeater, as required by FCC regulations.

***Courtesy tone*** — An audible indication that a repeater user may go ahead and transmit.

***Coverage*** — The geographic area within which the repeater provides communications.

***Crossband*** — A repeater with its input on one band and output on another.

***CTCSS*** — Abbreviation for continuous tone-controlled squelch system, a subaudible tone sent with an FM voice transmission to access a repeater.

***DCS*** — Digital Coded Squelch. A newer version of CTCSS that uses a subaudible digital code instead of an analog tone to selectively open a receiver's squelch.

***Digipeater*** — A packet radio (digital) repeater, usually using store-and-forward on a single frequency.

***DTMF*** — Abbreviation for *dual-tone multifrequency,* commonly called Touch Tone, the series of tones generated from a keypad on a ham radio transceiver (or a regular telephone).

***Duplex or full duplex*** — A mode of communication in which a user transmits on one frequency and receives on another frequency simultaneously (see ***half duplex).***

***Duplexer*** — A device that allows the repeater transmitter and receiver to use the same antenna simultaneously.

***Frequency coordinator*** — An individual or group responsible for assigning frequencies to new repeaters without causing interference to existing repeaters.

***Full quieting*** — A received signal that contains no noise.

***Half duplex*** — A mode of communication in which a user transmits at one time and receives at another time.

***Handheld*** — A small, lightweight portable transceiver small enough to be carried easily.

***Hang time*** — A few seconds of repeater carrier following a user transmission that allows others who want to access the repeater a chance to do so; the *courtesy beep* sounds during the hang time.

***Input frequency*** — The frequency of the repeater's receiver (and your transceiver's transmitter).

***Intermod — Intermodulation distortion (IMD)***, the unwanted mixing of two strong RF signals that causes a signal to be received on an unintended frequency.

***Key up*** — To turn on a repeater by transmitting on its input frequency.

***Li-ion*** — Lithium-ion battery. Longer life, smaller and lighter than NiCd, Li-ion batteries are becoming more popular for use with handheld radios.

***Machine*** — A repeater system.

***Mag mount*** — Magnetic mount, an antenna with a magnetic base that permits quick installation and removal from a motor vehicle or other metal surface.

***NiCd*** — A nickel-cadmium battery that may be recharged many times; often used to power portable transceivers. Pronounced *NYE-cad*.

***NiMH*** — Nickel-metal-hydride battery; rechargeable, offers more capacity and lighter weight than an NiCd battery. Often used to power portable transceivers.

***Offset*** — the spacing between a repeater's input and output frequencies.

***Open repeater*** — a repeater whose access is not limited.

***Output frequency*** — the frequency of the repeater's transmitter (and your transceiver's receiver).

***Over*** — A word used to indicate the end of a voice transmission.

***Repeater Directory*** — An annual ARRL publication that lists repeaters in the US, Canada and other areas.

***Separation*** — The difference (in kHz) between a repeater's transmitter and receiver frequencies, also called the *offset*, or *split*. Repeaters that use unusual separations, such as 1 MHz on 2 meters, are sometimes said to have "oddball splits."

***Simplex*** — A mode of communication in which users transmit and receive directly on the same frequency.

***Squelch tail*** — The noise burst heard in a receiver that follows the end of an FM transmission, before the squelch circuit turns off the speaker.

***Time-out*** — To cause the repeater or a repeater function to turn off because you have transmitted for too long.

***Timer*** — A device that measures the length of each transmission and causes the repeater or a repeater function to turn off after a transmission has exceeded a certain length.

***Tone pad*** — An array of 12 or 16 numbered keys that generate the standard telephone dual-tone multifrequency (***DTMF***) dialing signals. Resembles a standard telephone keypad. (see ***autopatch***).

# 18.8 References and Bibliography


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