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Chapter 18

Repeater Systems

For decades, FM has been a mainstay 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.

Digital voice systems are now beginning to dominate new installations. Along with the well-established D-STAR (now offered by Kenwood as well as Icom), Yaesu's System Fusion and Digital Mobile Radio (DMR) are two popular new systems. DMR makes extensive use of the internet to build hybrid systems similar to the trunking systems used by public service agencies. A whole new era of repeater-based communications is at hand.

The repeater overview material was written by Gary Pearce, KN4AQ. FM analog repeaters are described by Paul Danzer, N1II. The section on D-STAR, originally by Texas Interconnect Team members Jim McClellan, N5MIJ, and Pete Loveall, AE5PL, was updated by John Davis, WB4QDX, and Ed Woodrick, WA4YIH. John Burningham, W2XAB, continues to maintain the DMR section, and Cory Sickles, WA3UVV, has updated the System Fusion and P25 sections.

18.1 Amateur Repeater 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 also using VHF/UHF digital voice technology. 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. Yaesu has developed a hybrid analog/digital system called System Fusion. Another digital voice system, generically known as DMR (Digital Mobile Radio) and by the Motorola trade name MOTOTRBO, is being adapted from commercial service for the ham bands. Hams are also using surplus Project 25 (or just P25) radios.

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 **Figure 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*. Special operating notes for the digital repeaters are included in the sections on each mode.

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.

Figure 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 **Figure 18.3**).

Repeaters also provide a convenient meeting place for hams with a common interest.

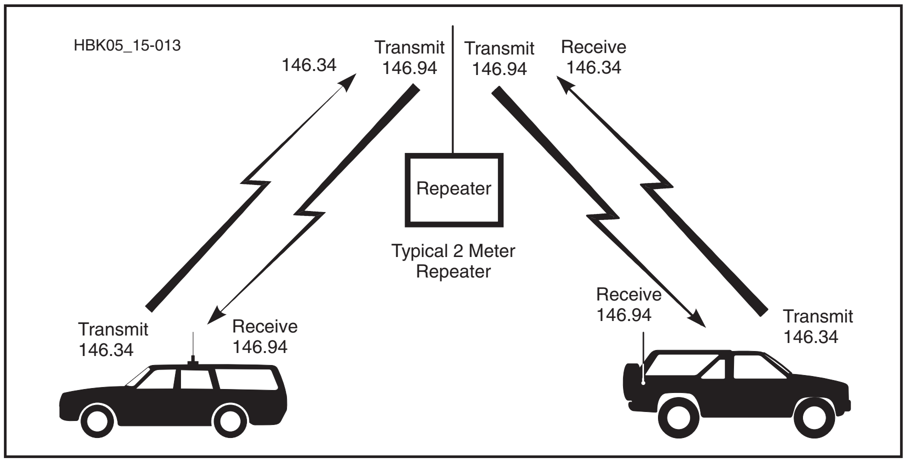


Figure 18.1 — Typical 2 meter repeater, showing mobile-to-mobile communication through a repeater station. Usually located on a hill or tall building, the repeater amplifies and retransmits the received signal on a different frequency.

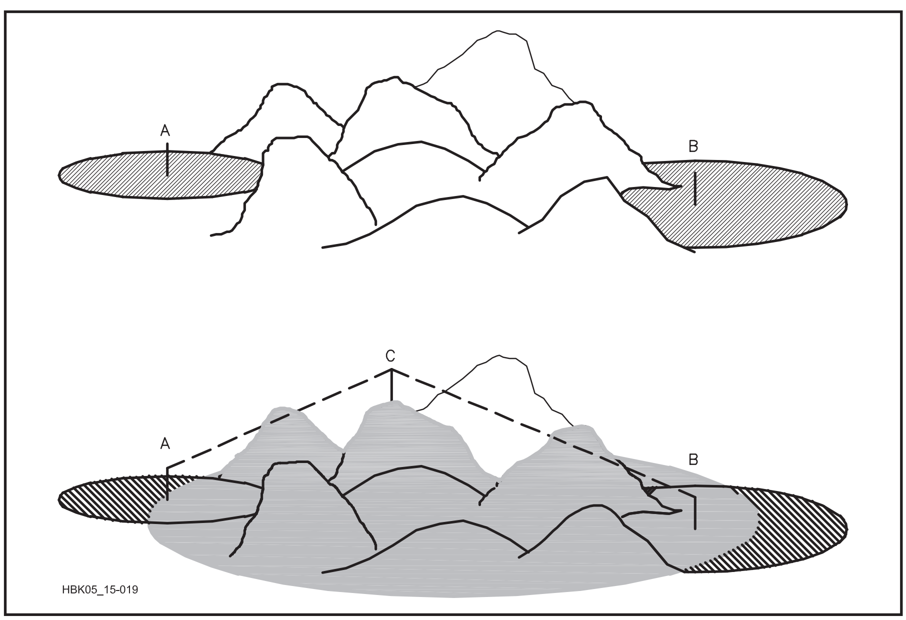


Figure 18.2 — In the upper diagram, stations A and B cannot communicate because their mutual coverage is limited by the mountains between them. In the lower diagram, stations A and B can communicate because the coverage of each station falls within the coverage of repeater C, which is on a mountaintop.

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 **Figure 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 Digital Voice Repeater Systems

Digital voice (DV) transmits digitized audio speech as a digital data stream over the RF or wired media. The process of converting between analog voice and the digital data stream utilizes a vocoder (voice encoder). A package of software or firmware that performs the encoding and decoding of the speech is called a codec (coder-decoder). The transmitted DV data stream is encapsulated inside a protocol that handles the addressing and communication management. For a sender and receiver to communicate, both must be using the same vocoder and protocol.

See the **Digital Protocols and Modes** chapter for more information about amateur radio DV modes. The websites listed in the References and Bibliography section of this chapter also contain information about the DV modes and their repeater systems.

DIGITAL VS ANALOG VOICE

If you are used to operating on analog FM repeaters, you will have noticed that the audio quality degrades gradually. As a station's signal into the repeater gets weaker there is an increase in noise bursts mixed with the audio until the signal gets so weak that the station can no long access the repeater, or you cannot understand the audio because of noise. Similarly, as you move further from the repeater you will start hearing the same noise as the repeater's transmitted signal gets weaker. A combination of a station's weak signal into a repeater and a repeater's weak signal to the listener degrades usability faster.

All the major DV technologies include *forward error correction* (FEC), which can correct limited errors, slightly extending the usable range and improving communication quality. Better quality receivers can operate at a lower noise floor, and higher power transmitters and higher gain antenna systems will also extend coverage of both analog and digital systems.

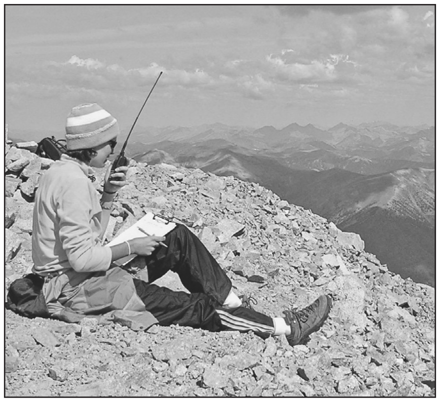


Figure 18.3 — In the Rocky Mountain west, handheld transceivers can often cover great distances, thanks to repeaters located atop high mountains. [Photo courtesy Rachel Witte, KCØETU, and Bob Witte, KØNR]

For DV repeaters the audio quality remains the same for both input and output to the edge of the coverage range. At that point, the audio becomes broken (missing portions of the speech) caused by lost packets in the digital protocol. Further signal degradation causes complete signal loss. (The same effect is seen on digital television [DTV] as the image becomes pixilated and finally is dropped completely.) The internet can also drop packets used for transferring the audio data stream between repeaters and bridges, causing the same broken audio affect.

DIGITAL VOICE SYSTEMS

DV repeaters can operate as standalone stations but are usually linked together using the internet to form a repeater system. The interface between a repeater and the internet is usually referred to as a gateway. Each type of system then uses a proprietary protocol specific to that technology to communicate information between the repeater gateways. Operation of these repeater systems and descriptions of the user functions and features are discussed in separate sections later in this chapter.

Once digitized, the voice information in a DV system remains in digital form until it is converted to audio for the user to hear. Repeater systems only retransmit the digital data stream. They do not process the voice

Figure 18.4 — Repeaters provide communication over a wide area to support disaster relief, emergency communication, and public service. They allow portable and mobile stations to communicate effectively with each other and with served agencies and event management. The operators shown here (F-B AE5MT, KE5YBC, and KE5NCR) are supporting an Oklahoma City marathon, getting valuable training while providing a service to the community. (Photo by Frank Tassone, KE5KQL)

Hotspots — What Are They?

A "hotspot" is an interface constructed with a very low power transceiver that interconnects to the internet through an attached computer that is external or integrated to the hotspot. This is similar to a Wi-Fi access point. The user's radio communicates with the hotspot transceiver, which then interacts with the desired repeater via the internet, performing any necessary translations between the digital voice (DV) protocols.

Some hotspots currently available include the DV4mini, openSPOT, DVMEGA, MMDVM, and Micro Node Nano-DV. Most hotspots support DMR, D-STAR, System Fusion, NXDN, and P25 protocols. Hotspots for DMR are supported by both the Brandmeister and DMRplus networks and offer connectivity to other networks.

A hotspot also allows a user outside the coverage area of a repeater to access parts of the network using their radio. The hotspot then connects to the desired repeater via the internet, similarly to EchoLink.

information as analog audio. Digital data such as IDs, addressing or routing information, user data messages, and other data structures may or may not be relayed with the digital voice, depending on the type of system and the configuration of the repeaters and gateway equipment.

D-STAR and System Fusion protocols both include the amateur's call sign in the transmitted digital data. DMR utilizes a Radio ID number for users and repeaters that amateurs must obtain from DMR-MARC (Motorola Amateur Radio Club), which serves as a central registry for worldwide amateur users.

DIGITAL VOICE SYSTEM STANDARDS

The primary DV technologies utilized for repeater systems in the amateur VHF/UHF bands are D-STAR (Digital Smart Technologies for Amateur Radio), DMR (Digital Mobile Radio), System Fusion, and P25. Both D-STAR and System Fusion were designed specifically for the amateur radio market. Developed by the European Telecommunications Standards Institute (ETSI) for government and commercial users, DMR has been adapted for amateur radio use. P25 is an adaptation of the APCO Project 25 standard.

D-STAR is supported by Icom and Kenwood according to the standard originally developed for the Japanese Amateur Radio League (JARL). Yaesu is the only manufacturer for System Fusion. There are over a dozen manufacturers producing DMR compatible equipment including Motorola Solutions, Hytera, Broadcom, Vertex Standard, TYT, Connect Systems, BFDX, Kirisun, and Kenwood.

18.2.4 Non-Voice Repeater Uses

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** chapter in the online content.

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 Protocols and Modes** chapter and the **Digital Communications** chapter in the *Handbook's* online content 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** chapter in the *Handbook's* online content for details.

18.2.5 Repeaters and FCC Regulations

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**.

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 18.1** 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 18.1
Standard Frequency Offsets for Repeaters

Band	*Offset*
29 MHz	–100 kHz
52 MHz	Varies by region –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 FM Voice Repeaters

Repeaters normally contain at least the sections shown in **Figure 18.5**. Repeaters consist of a receiver and transmitter plus two more special devices. One is a *controller*, which 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*, which 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 and 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 **Figure 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 (**Figure 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 (**Figure 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 **Figure 18.9**).

For even greater flexibility, you can add an auxiliary receiver, perhaps for a NOAA weather channel (**Figure 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

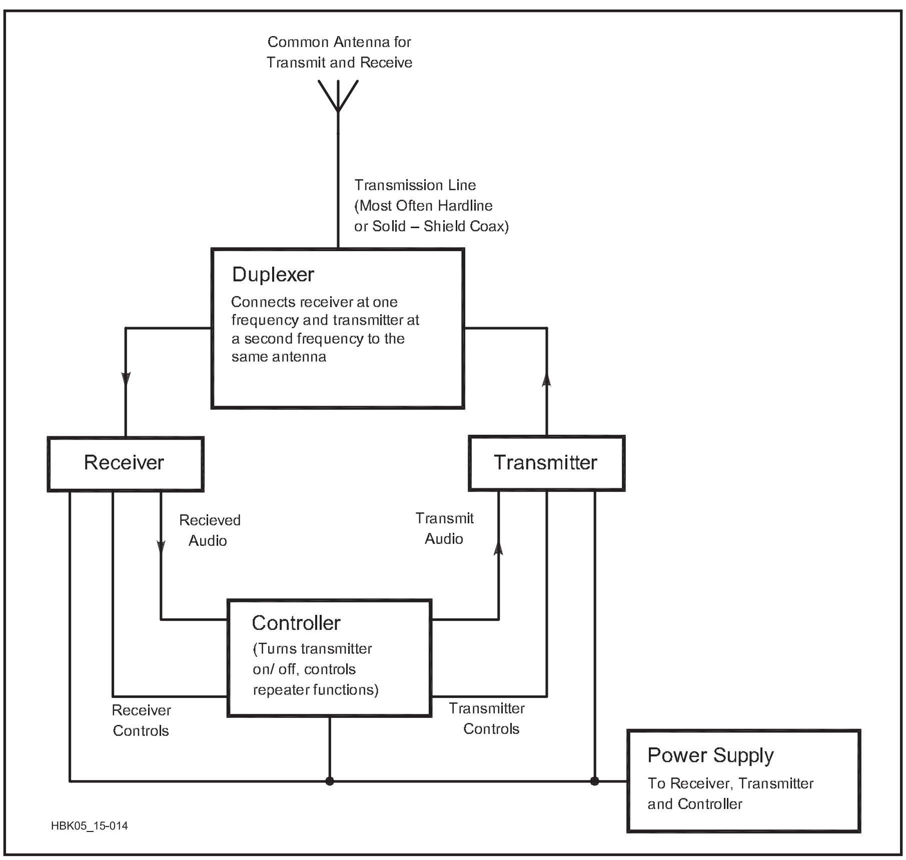


Figure 18.5 — The basic components of a repeater station. In the early days of repeaters, many were home-built. Today, most are commercial, and are far more complex than this diagram suggests.

Figure 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]

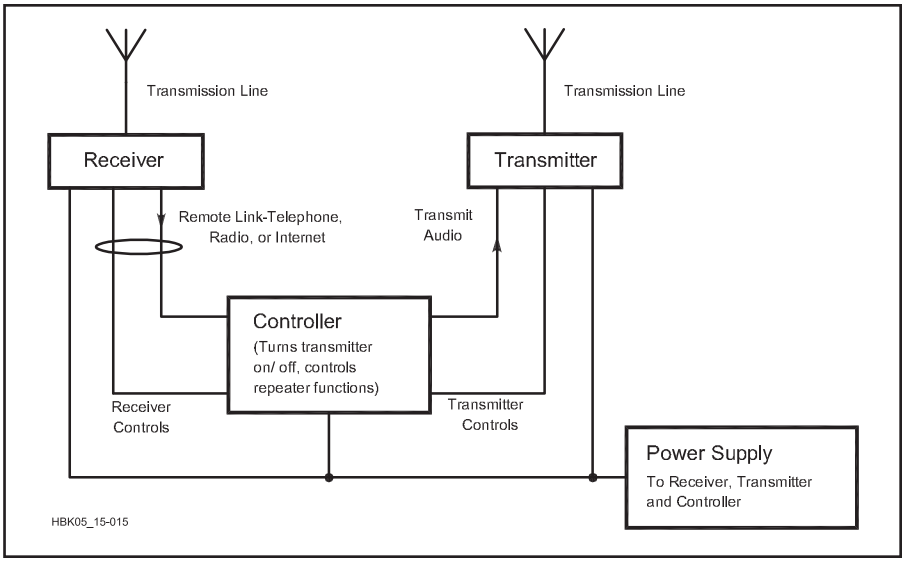


Figure 18.7 — Separating the transmitter from the receiver can extend the repeater's coverage area. The remote receiver can be located on a different building or hill, or consist of a second antenna at a different height on the tower.

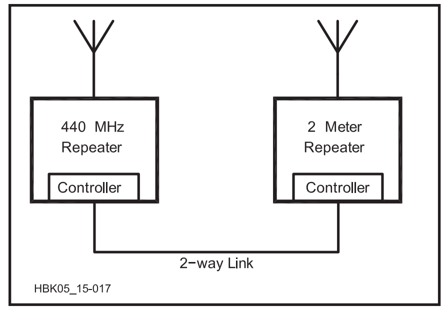


Figure 18.9 — Two repeaters using different bands can be linked for added convenience.

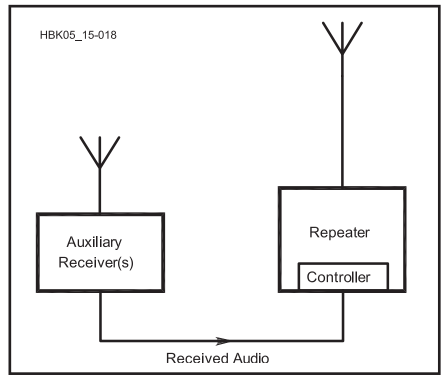
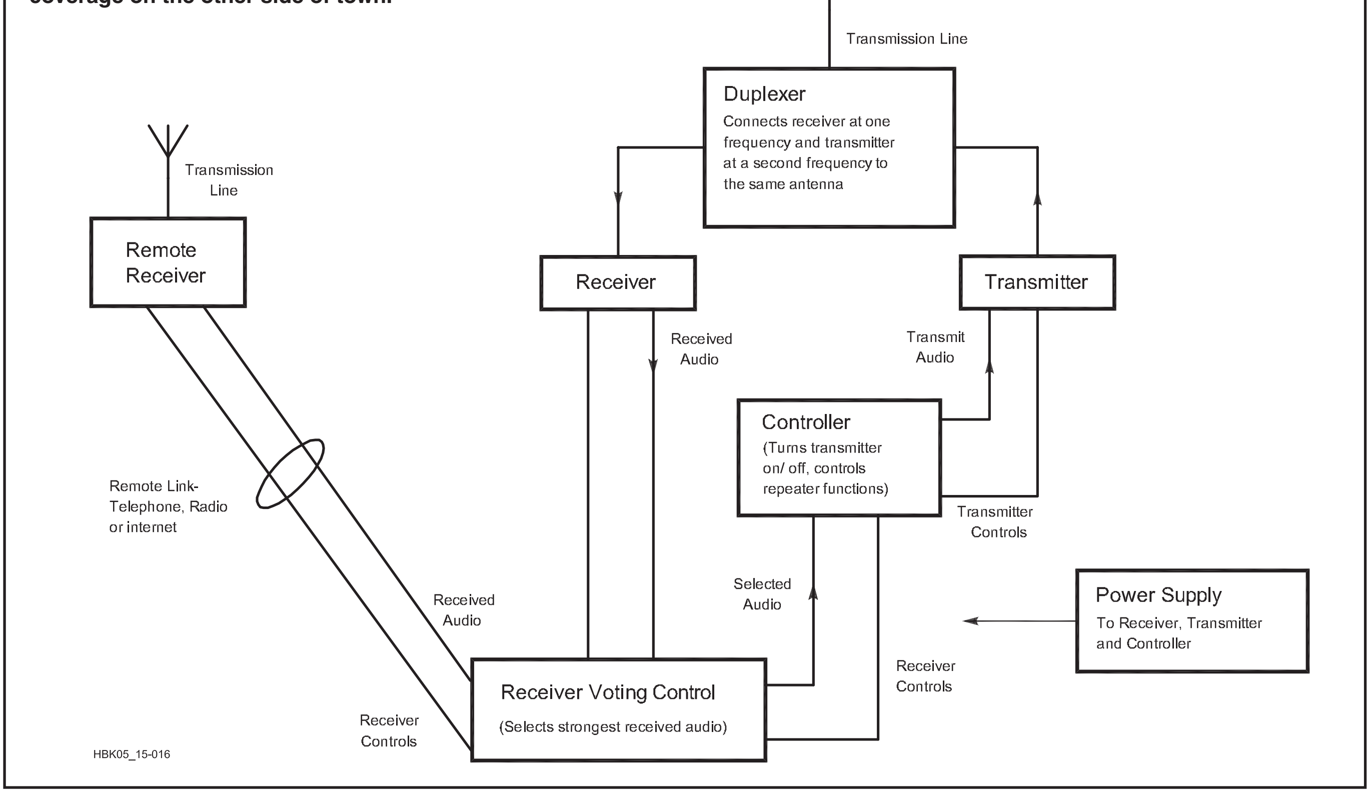


Figure 18.10 — For even greater flexibility, you can add an auxiliary receiver.

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



stations to use the same frequency — it is 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 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, ARRL volunteer officials may hold periodic section meetings across their state with linked repeaters allowing both announcements and questions directed back to them.

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 **Figure 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 **Safe Practices** 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 radio 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 permanently mounted assemblies. The four general classes of mobile antennas shown in the center section of Figure 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-body antenna mounting: Most hams are reluctant to drill a hole in their car roof or trunk, unless they intend to keep the car for a long time. This mounting method provides the best efficiency, however, since the metal body panel serves as a ground plane. Before you drill, carefully plan and measure how you intend to get the antenna cable past headliners or trim 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

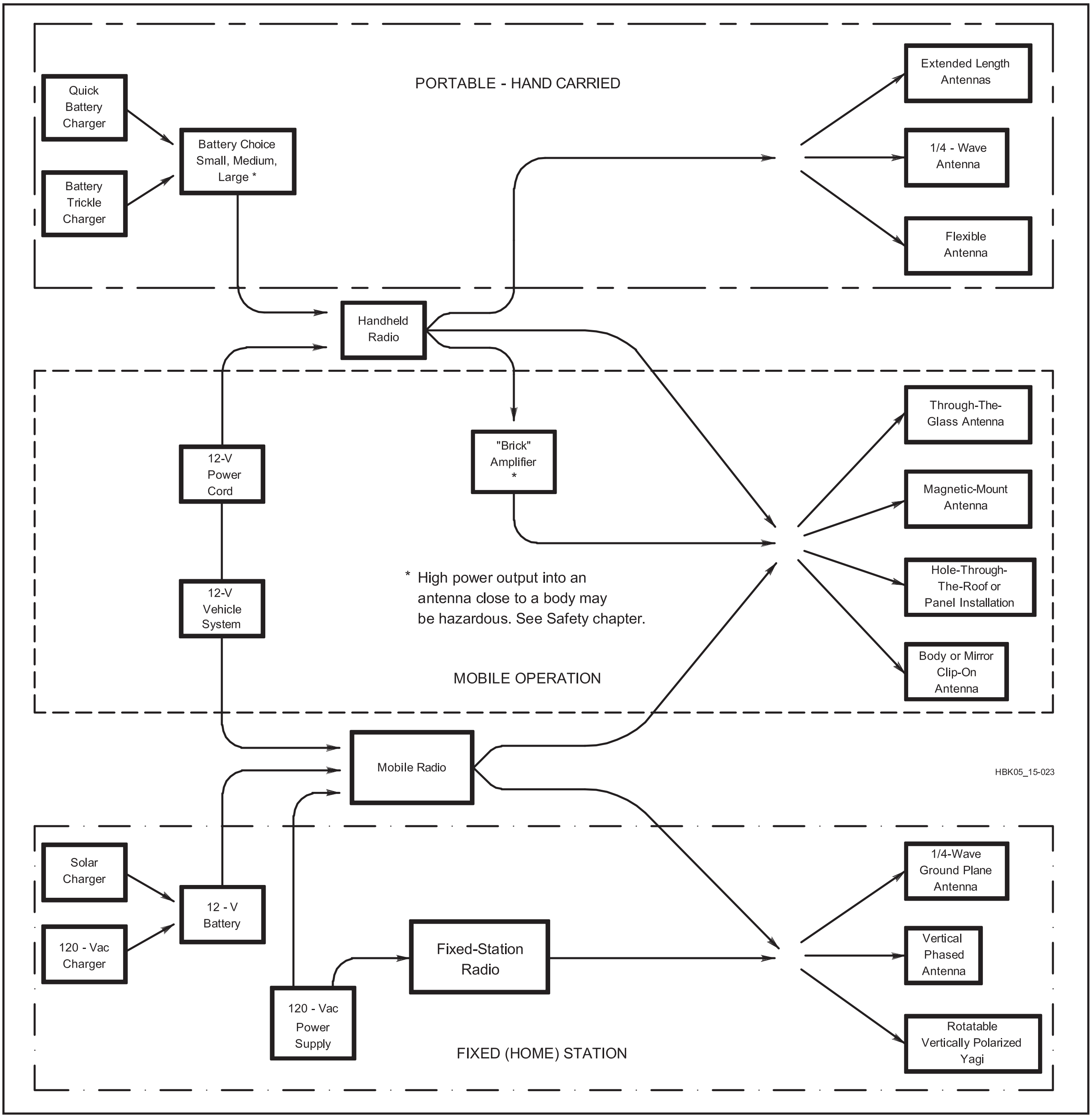


Figure 18.11 — Equipment choices for use with repeaters are varied. A handheld transceiver is perhaps the most versatile type of radio, as it can be operated from home, from a vehicle and from a mountaintop.

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 Figure 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 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 $\frac{1}{4}$-λ and larger antennas are popular for home use. A number of these are shown in the **Antennas** chapter. Generally speaking, $\frac{1}{4}$-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 **Figure 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 it 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 **Figure 18.13** a mobile station on a hill 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 it is in the coverage area of both Jonestown and Smithtown. Whenever the mobile transmits both repeaters hear it.

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 18.2 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 output 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.

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.

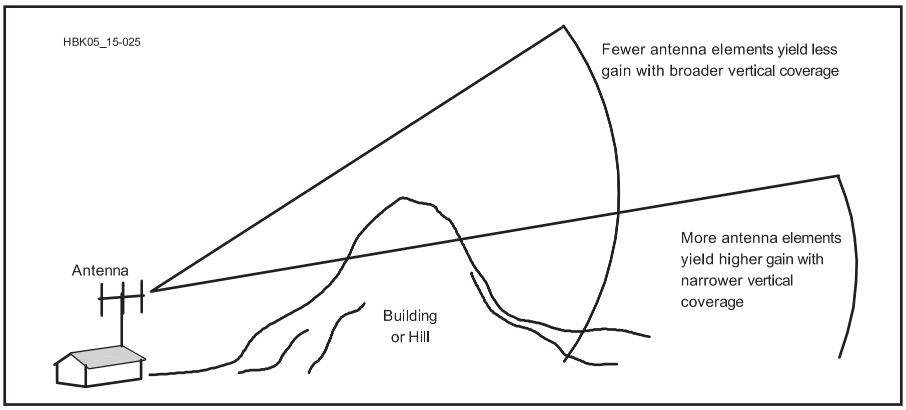


Figure 18.12 — As with all line-of-sight communications, terrain plays an important role in how your signal gets out.

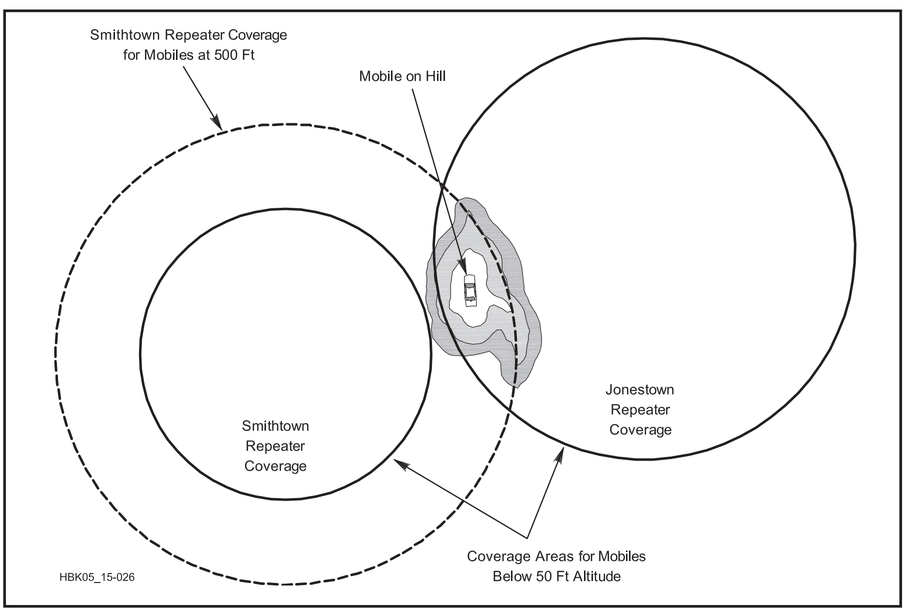


Figure 18.13 — When two repeaters operate on the same frequencies, a well-situated operator can key up both repeaters simultaneously. A directional antenna may help.

Table 18.2

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:

	114.8	177.3
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		254.1

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 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 18.3 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.

18.3.4 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 spectrum 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").

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.*

18.3.5 Linked Repeaters

Most repeaters are standalone devices, providing their individual pool of coverage and nothing else. 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 repeaters let users communicate between different bands and across wider geographic areas than they can on a single repeater. **Figure 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 makes it possible 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.

Table 18.3
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

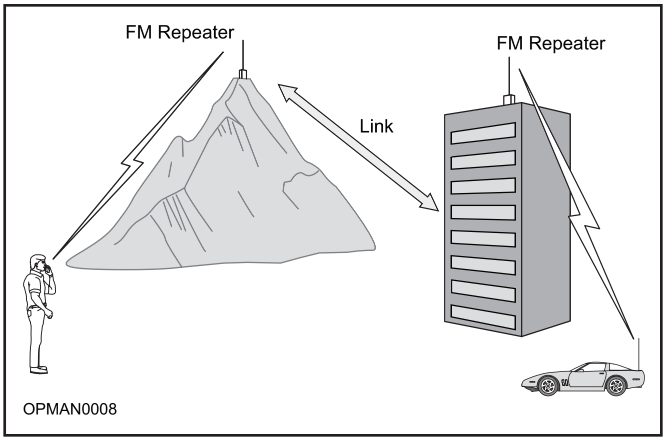


Figure 18.14 — Repeater linking can greatly expand VHF/UHF communication distances. Repeater links are commonly made via dedicated radio hardware or via the Internet.

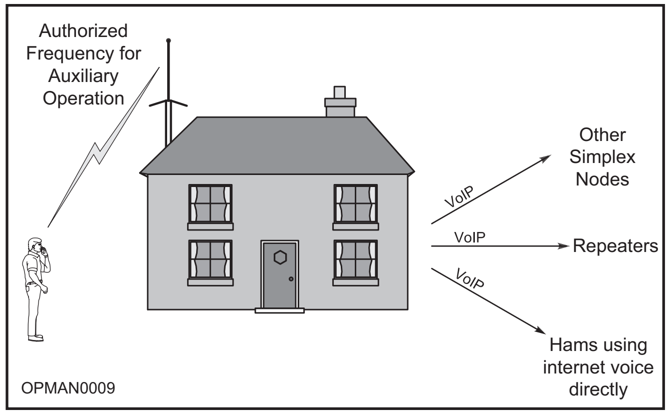


Figure 18.15 — A diagram of a VoIP simplex node. If a control operator is not physically present at the station location and the node is functioning with wireless remote control, the control link must follow the rules for *auxiliary* operation.

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** online chapter.

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. IRLP system operators establish a node by interfacing their 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 repeaters or simplex nodes (**Figure 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.

18.4 D-STAR Repeater Systems

18.4.1 D-STAR System Overview

A D-STAR repeater system consists of one or more RF modules and a controller. This configuration allows for fixed, handheld, or mobile communications on one or more of the attached RF modules. While there are D-STAR systems with a single RF module, there are a number of "full stack" repeaters that have one of each type of module connected, 2 m voice, 70 cm voice, 23 cm voice, and 23 cm data.

An overview of the D-STAR system, "D-STAR — For the Second Century of Amateur Radio" is available at **www.icomamerica.com/en/downloads/DownloadDocument.aspx?Document=366**. A detailed discussion of the D-STAR specification is contained in a three-part *QEX* article by John Gibbs, KC7YXD, in the Jul/Aug, Sep/Oct, and Nov/Dec 2003 issues. These articles are available at **www.icomamerica.com/en/products/amateur/dstar/dstar/default.aspx** in the Downloads area. See the **Digital Protocols and Modes** chapter for more information about the D-STAR protocol.

D-STAR NETWORKS

To communicate within the D-STAR international network, D-STAR controllers are commonly connected to a gateway computer with *CentOS*, the Icom gateway software, and the additional modules *dplus* (by Robin Cutshaw, AA4RC) and *DStarMonitor* (by Pete Loveall, AE5PL). These additional third-party, amateur-developed modules greatly enhance the functionality of the D-STAR environment and are now considered a base part of the system. (See the section User-Created Features and Tools later in this section.)

Operation within Japan and outside of Japan varies due to differences in regulatory requirements. Inside Japan, gateway computers only run the Icom gateway software. Outside of Japan, additional software is installed to provides enhanced functionality.

Outside of Japan, *dplus* or its derivatives are used to implement repeater linking. Linking repeaters connects RF modules together so that anything heard on one is heard on the other. A link is a semi-permanent connection during which all traffic that is heard on one module is echoed to a destination system. Users hearing a call on linked repeaters do not need to program their radios to respond. Talking with a remote user is the same as talking with a local user.

D-STAR STATION ROUTING

Station routing is used to direct the controller and gateway to send a user's signal to a specific RF module anywhere in the world or to the specific RF module from which another user was last heard. In this situation, only the user's radio is configured to access the remote system. Users who want to respond to a remote user's call must configure their radio to respond to the remote user. This is simplified by the RX CS function on D-STAR radios. The RC CS function automatically configures the radio to the correct response route. Station routing only works between two repeaters and requires all stations participating in a contact to have their radios programmed appropriately.

D-STAR TRUST SERVER

A vital part of a D-STAR system is the gateway server, which networks a single system into a D-STAR network via a *trust server*. The trust server provides a central, master database to look up users and their associated system. The trust server database consists of a list of registered users, the last repeater on which a user was heard, and a list of the D-STAR repeaters. It periodically updates each registered gateway server.

This allows amateur radio operators to respond to calls made to them, regardless of their location on the D-STAR network. Currently, the global D-STAR trust server is maintained by a group of dedicated D-STAR enthusiasts from the Dallas-based Texas Interconnect Team (**www.k5tit.org**).

18.4.2 D-STAR Station IDs

In D-STAR, each station is identified with a *user station ID*. These are usually call signs consisting of six upper-case alphanumeric characters (space padded to the right). Before utilizing D-STAR, the radio must be programmed with a station ID ("My Call Sign"). User call signs are left-justified with spaces to the right. Additional characters are not recommended. If you have multiple radios, the same call sign should be used on all radios.

Repeater modules require a unique call sign different from other users or repeater modules on the network. While seventh and eighth characters of the call sign fields are not used for user station IDs, they are used for repeater module IDs. They are used for repeater module designation to denote which module is being utilized and/or *dplus* functions.

A common implementation of module designation is:

A — 1.2 GHz voice or data
B — 440 MHz voice
C — 146 MHz voice

The position of the module identifier can be the seventh or eighth character, depending on what the command is doing. For example, WD4STR•B or W1AW•••B are examples of repeater call signs (• represents a space).

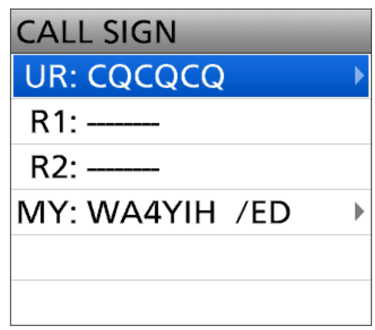
18.4.3 Configuration of Station ID Fields

The D-STAR protocol can be used for simplex communication or repeater operation depending on how the radio is configured. In the following examples, a typical D-STAR radio screen is shown with abbreviations for the four station IDs. (UR is URCALL, MY is MYCALL, R1 is RPT1, and R2 is RPT2.)

When used for simplex communication, D-STAR radios function similarly to analog radios. To call a station using simplex:

- Set UR to CQCQCQ.
- Set RPT1 is not used
- Set RPT2 is not used
- Set MY to the calling station's ID.

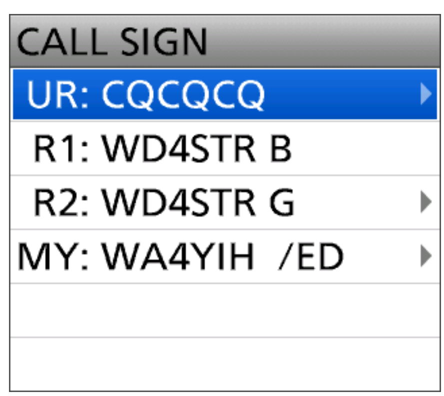
RPT1 and RPT2 are disabled in simplex mode.



D-STAR Simplex Configuration

Radio programming changes slightly for repeater operation. To operate through a repeater, specify the repeater's station ID as well as the frequency of the repeater. To then call a station using the repeater, configure the radio with four station IDs:

- Set UR to CQCQCQ.
- Set RPT1 to a local gateway station ID.
- Set RPT2 to a local gateway station ID.
- Set MY to the calling station's ID.



D-STAR Repeater Configuration

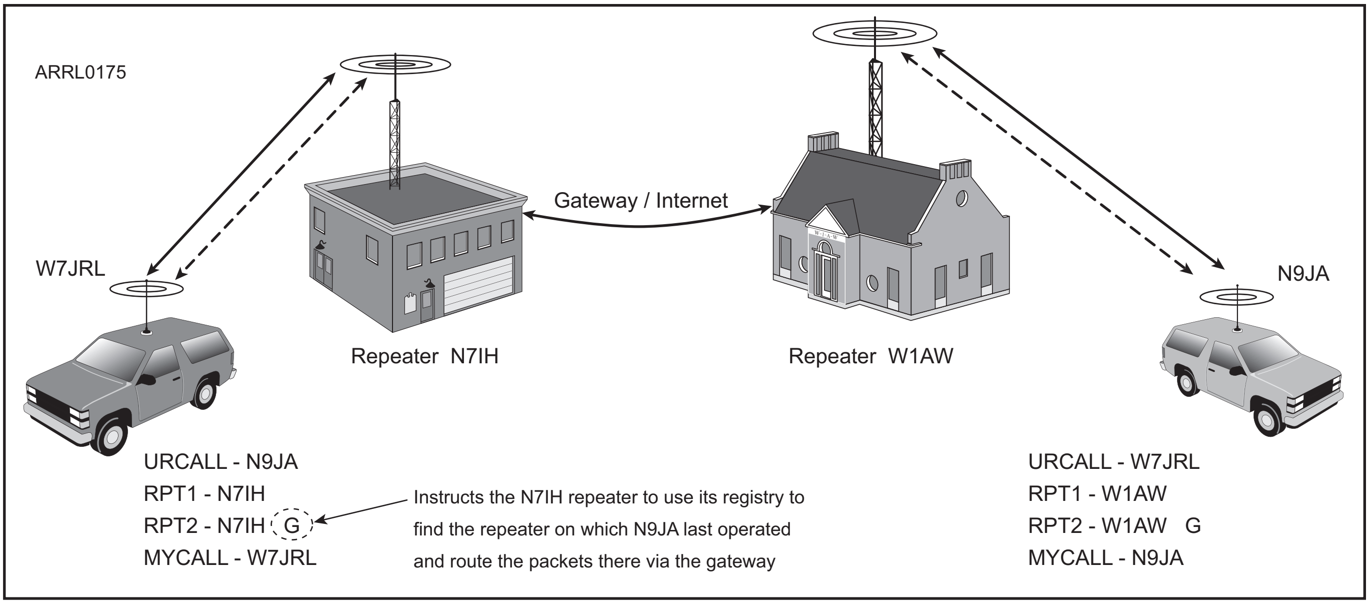
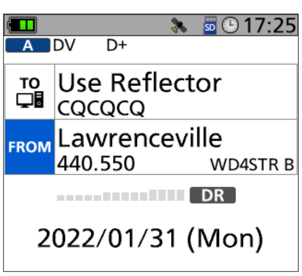


Figure 18.16 — Configuring D-STAR radios for repeater operation. (*Courtesy of the D-STAR Calculator dstarinfo.com/dstar-web-calculator.aspx*.)

In this example, the repeater module WD4STR B (on 440.55 MHz) is being used. The WD4STR repeater's gateway is addressed as WD4STR G. Figure 18.16 illustrates how D-STAR users would communicate using this programming to access a repeater system.

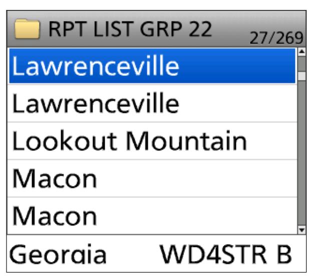
18.4.4 DR Mode

DR Mode effectively hides the relatively complex configuration of the URCALL, RPT1, RPT2, and MYCALL fields, providing a "No programming required" approach. (This is a mode of operation, not a digital transmission mode.) The use of DR mode is enhanced with increased memory space and GPS in the radio. After initially entering a calling station ID, in DR mode only two fields must be entered, TO and FROM. The first action is to choose a nearby repeater in the FROM field.



D-STAR Use Reflector

The FROM field presents the options of **Repeater List**, **Nearest Repeater**, and **TxHistory**. The repeater list provides a selection of the repeaters that are preprogrammed into the radio. (All D-STAR radios after 2012 come with a set of D-STAR repeaters preprogrammed into the radio from the factory. This database will need to be updated regularly with the latest changes and additions by downloading the latest copy from **dstarinfo.com/RepeaterDownloads.aspx**.)



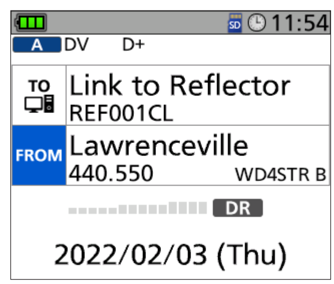
D-STAR Repeater List

Once a repeater is selected, all information needed will have been automatically entered into the radio. To simplify a long list of repeaters, **Nearest Repeater** will provide only a list of the nearest repeaters. This is determined by the GPS location of the radio and geolocation information for each repeater.

Next, use the TO field to select the function desired. For most contacts, select **Use Reflector - CQCQCQ** (**Use Repeater – CQCQCQ** in older radios). Figure 18.16 shows how the reflector is used.

Note: A common mistake is to use **CQCQCQ**. This is not to be confused with **Use Reflector - CQCQCQ**. Calls using the basic **CQCQCQ** will only be heard on the local repeater. Unless linking or unlinking a repeater, select **Use Reflector – CQCQCQ.**

The **Reflector – Link to Reflector** feature can be used to link a repeater to a reflector. To request a repeater or a hotspot to link to a reflector, choose **Reflector – Link to Reflector** and choose the reflector that you want to link to. Press the PTT for about a second and, if accepted, the repeater will link to the specified repeater or reflector.



D-STAR Link to Reflector Configuration

18.4.5 D-STAR Reflectors

In addition to linking RF modules between repeaters, *dplus* created a network of virtual repeaters called *reflectors*. Reflectors allow multiple physical repeaters to connect to a single location on the network. This allows all users listening to a linked RF module to hear and talk to other users connected via linked repeaters on the same reflector. When a user transmits on one repeater, that transmission is heard on all connected repeaters. The reflector is software installed in a data center with high-speed internet connectivity that allows many repeaters to connect at once.

D-STAR reflectors have a status page that can be accessed from the internet at **[reflector ID].dstargateway.org** (i.e. **REF001.dstargateway.org**). Note that the module designator is not used in the URL. The status page has a list of repeaters that are connected to each port on the reflector.

Other types of reflectors have been created since the introduction of dplus. These reflector IDs start with designators such as XRF, DCS, or XLX. Each different reflector system may have slightly different features but are essentially the same.

18.4.6 User Registration

Registration refers to the listing of a user call sign on the D-STAR network. This allows a user to be called from remote repeaters and to access D-STAR network functions such as linking repeaters or accessing the D-STAR network from the internet. Historically, registration was performed by accessing a local repeater. This caused problems because an administrator was required to approve the registration. To remedy this issue, a centralized registration system has been created at **regist.dstargateway.org**.

Follow the instructions, especially entering a call sign in upper case and remembering the password used. Once complete, an email notification will be sent in a few hours with additional instructions to complete registration. Registration is then accepted by all D-STAR systems — do not attempt to register anywhere else.

18.4.7 D-STAR Data Modes

In D-STAR, there are two modes: DV (Digital Voice) and DD (Digital Data). The DV mode provides voice and slow-speed data. The DD mode provides a data throughput of 128 kbps and is only available at 1.2 GHz and above because it has a 300 kHz bandwidth. (See the **Digital Protocols and Modes** chapter section on D-STAR for more information about DV and DD modes.)

DV MODE

DV utilizes a 4,800-bps data stream with an RF signal half the width of a standard analog FM signal. Within the signal, 2,400 bps is used for voice, 1,200 bps is used for forward error correction (FEC) of the codec data, and the remaining 1,200 bps is used for non-voice data.

Before the introduction of the Icom ID-51 Plus2, serial data was available to the user at an effective rate of about 960 bps. Since the introduction of the Icom ID-51 Plus2 and the Kenwood TH-D74, a second data option has been made within the DV protocol in which the serial data rate is 3,480 bps and utilizes the entire channel.

In DV slow speed data mode, both voice and data can be transported at the same time. In DV high speed data mode, voice is not available.

DD MODE

The DD mode provides 128 kbps data throughput and utilizes 150 kHz of RF spectrum, which FCC regulations allow at 1.2 GHz and above. The only radios that support the DD mode are the original Icom ID-1 and Icom ID-9700, as well as the 1.2 GHz DD repeater modules.

In radios supporting DD, the data stream is implemented as Ethernet. A collection of D-STAR radios on the same frequency effectively emulates an Ethernet hub. The radios can also operate through a D-STAR DD repeater. Because DD is implemented as Ethernet, applications do not require special configurations to communicate with each other. A standard application such as email can function without any modification using the D-STAR DD mode for connectivity.

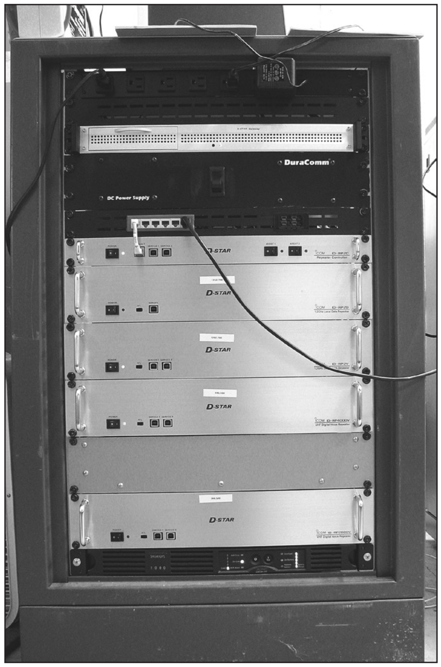


Figure 18.17 — A full rack of D-STAR equipment on the bench of Jim McClellan N5MIJ. Top to bottom: ICOM IP-RPC2 controller, ID-RP2V 1.2-GHz voice repeater, ID-RP4000 440 MHz voice and data repeater, a blank panel, and an ID-RP2000 146 MHz voice and data repeater.

18.4.8 D-STAR Repeaters

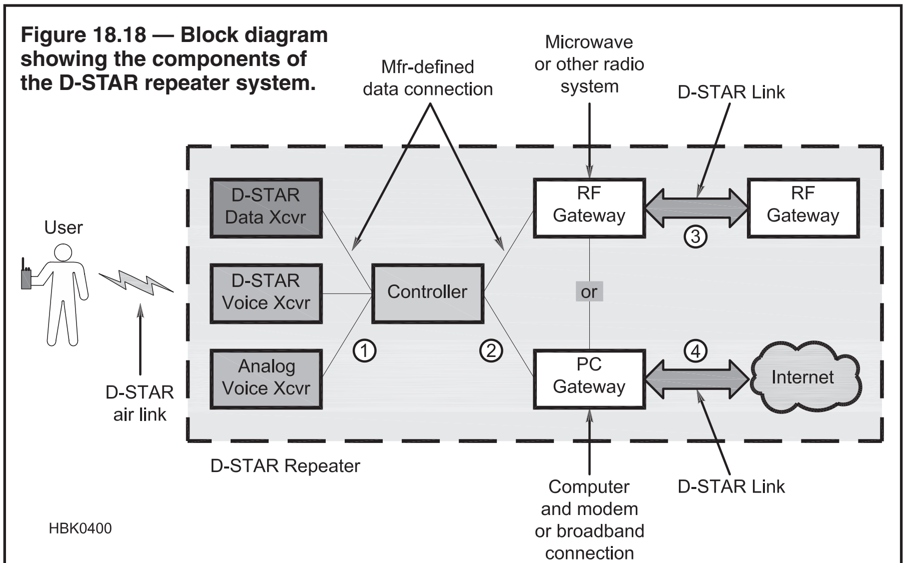
Icom has provided three generations of D-STAR repeaters. See **icomamerica.com/en/amateur** for the current set of equipment. The first generation (2003) was short-lived and very limited in distribution, consisting of a 23 cm DD module, a 23 cm DV / Controller module, and a microwave link for connecting repeaters together.

The second, widely deployed generation (2006, updated in 2020) consists of a controller module, plus repeater modules for 2 meter DV, 70 cm DV, 23 cm DV, and 23 cm DD. The DD module is not a repeater — it operates simplex with a single antenna connection. See **Figure 18.17** for a second-generation repeater "stack."

In 2020 Icom released a completely updated set of repeaters. This third-generation repeater stack has integrated controllers in each RF module that can be activated. The new repeaters support FM and D-STAR and are based on RF direct sampling and a FPGA platform.

The RF modules and a controller can operate as a stand-alone repeater system without a gateway. A user on the 2 meter repeater can talk with other users in the 2 meter repeater. Using station routing, users can talk across the modules, i.e. a 2 meter user can talk to a 23 cm user. To communicate with the worldwide D-STAR network, a gateway computer is required. **Figure 18.18** shows a block diagram of the D-STAR system, including repeaters, reflectors, and hotspots.

Figure 18.18 — Block diagram showing the components of the D-STAR repeater system.



D-STAR Network Overview

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

The Comp. IP and Own IP are shown for reference as 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 as if that station were 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. This makes possible 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*

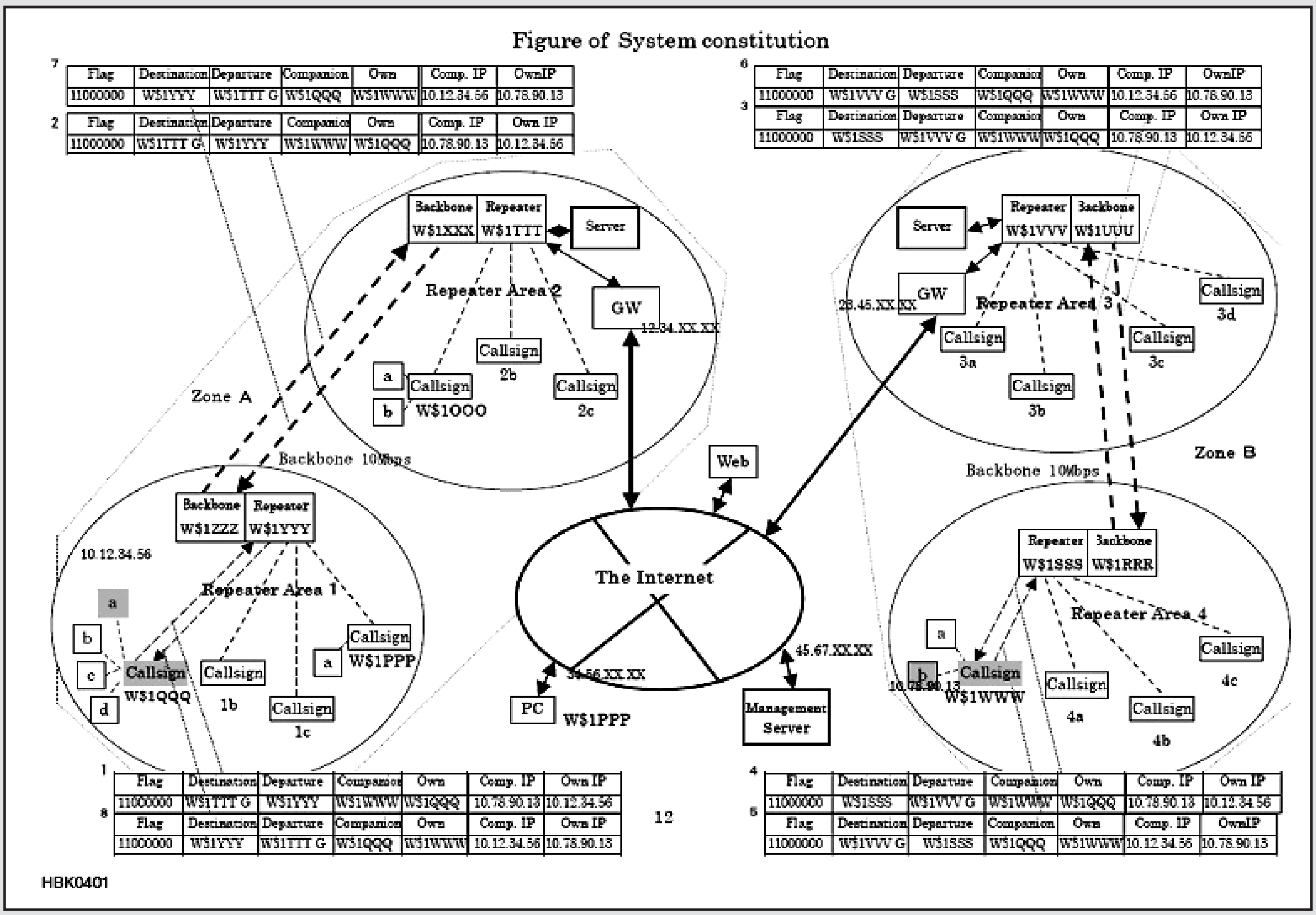


Figure 18.A1 — A D-STAR system overview.

18.4.9 D-STAR Gateways

Internet access from a repeater's gateway computer is required to talk to the reflectors, other repeaters, and the trust server. This access does not require a fixed address but does require inbound connectivity. This allows the trust server and other repeaters to reach the gateway server. Latency on the circuit should be low, to support the VOIP UDP connections. (See the Icom Gateway Control Software RS-RP3C Set Up Instructions [for Revision 3] documentation for minimum computer requirements and protocol port assignments.)

Two applications are often present on the gateway computer along with the Icom gateway software: *dplus* creates the network of *reflectors* that link repeaters, and *DSTARMonitor* relays APRS or NMEA type data to the APRS internet network. Both are described in the following section.

18.5.10 User-Created Features and Tools

D-STAR has benefited from a strong user community developing hardware, products, and applications over the last decade. The D-STAR architecture, utilizing the gateway computer running *CentOS*, a Linux distribution, allows users to develop applications and add features and additional functionality to D-STAR.

The following are a sample of the developments taking place. Many individuals and groups have created similar products. Many of these products have been extended to include DMR and other digital voice systems The two websites with the most current D-STAR information are **www.dstarinfo.com** and **www.dstarusers.org**.

D-STAR SOFTWARE APPS

The *dplus* application, developed by Robin Cutshaw, AA4RC, creates reflectors which function as "conference bridges" linking repeaters together via the internet. Users may link repeaters to reflectors with commands from a D-STAR radio to create networks of linked repeaters. *dplus* reflectors are designated as REFnnnx (ex. REF030C for reflector 030 and the letter A, B, C, or D designating a separate reflector module). Nearly 100 *dplus* reflectors are in operation worldwide. Developers of other reflectors designated as DCS, XRF, and XRX also link repeaters and users worldwide.

DStarMonitor (by Pete Loveall, AE5PL) creates a DPRS-to-APRS gateway that captures DPRS packets (APRS packets sent via D-STAR, see the **Digital Protocols and Modes** chapter) and relays them to the APRS network. Although it doesn't natively appear on the APRS RF network (unless IGated specifically), it does appear in all the online APRS tools. DPRS has been implemented in software with *DStarMonitor* running on many D-STAR gateways and *DPRS Interface* available for most computers at **www.aprs-is.net/dprs**.

Dan Smith, KK7DS, developed *D-RATS* with public service users in mind. In addition to chat, *D-RATS* supports file/photo downloads, bulletins, forms, email, and a sophisticated mapping capability. It also has a "repeater" functionality that allows sharing a D-STAR radio data stream over a LAN. The repeater feature is interesting in an environment where the radio would be physically separated from the software user, as in an emergency operations center. Current developments and downloads are available at **groups.io/g/d-rats** and **DSTARInfo.com**.

DSTARRepeater and *ircDDBGateway*, created by Jonathan Naylor, G4KLX, implement D-STAR functions on non-Icom repeater hardware (**github.com/g4klx/DStarRepeater**). A version of this software runs on the Raspberry Pi, which is the basis for many of the hotspots now in use.

PI-STAR by Andy Taylor, MWØMWZ runs on a Raspberry Pi (**www.pistar.uk**). It is a general-purpose digital voice package for several repeater systems, and includes an integrated UI for monitoring and controlling the *DSTARRepeater* and *ircDDBGateway* software.

D-STAR HOTSPOTS

One of the first hardware D-STAR projects, also developed by AA4RC, is the DV Dongle (**www.opendstar.org/tools**), which contains the AMBE codec chip and a USB interface to allow a computer user to talk with other D-STAR voice users much the way EchoLink users can connect to the system with a PC. The *DV Tool* software is written in Java to provide cross-platform support.

AA4RC also created the Digital Voice Access Point (DVAP). This device does not include the AMBE codec but uses a GMSK transceiver instead. The DVAP is a portable access point for D-STAR radios to access the D-STAR network via the internet.

Satoshi Yasuda, 7M3TJZ/AD6GZ, created a D-STAR node adapter or hotspot that connects to a standard simplex FM radio and allows a nearby D-STAR radio user to access the D-STAR network. It can connect to repeaters and reflectors worldwide, even though no local D-STAR repeater may be available. The system requires that the FM radio be accurately configured for a clean signal and loses the D-STAR benefit of only consuming 6.25 kHz of bandwidth. More information can be found online at **www.d-star.asia**.

Most current devices (as of early 2022) use the AMBE+2 chip, an enhanced version of the vocoder from DVSI. The AMBE+2 vocoder not only supports D-STAR digital but is also compatible with APCO Project 25 (P25), DMR, and Yaesu System Fusion, allowing hotspots to support D-STAR, DMR, P25, and System Fusion in one device.

18.5 Digital Mobile Radio (DMR)

The following sections are contributed by John Burningham, W2XAB, from "Amateur Radio Guide to Digital Mobile Radio" (see Reference section).

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.

Amateurs have implemented DMR with over 8,437 repeaters and 181,423 users registered worldwide as of September 2021. A majority of the repeaters are interconnected via the internet. There are a number of US amateur international, regional, and state networks. Most are interconnected with the cBridge/TL-NET, Brandmeister, and DMRplus based networks.

Used commercial DMR gear is available, but new DMR radios are now available with street prices within the range of a typical ham budget ($100 to over $2,000). DMR mobile and handheld radios are referred to as "user radios" to distinguish them from repeaters.

18.5.1 DMR Standards

DMR is divided into three tiers. Tier I is a single channel specification originally for the European unlicensed dPMR446 service. It is a single-channel FDMA 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 II is a 2-slot TDMA 4FSK 12.5 kHz wide peer-to-peer and repeater mode specification, resulting in a spectrum efficiency of 6.25 kHz per channel. Each time slot can be either voice and/or data, depending upon system needs. Most amateur radio implementations of DMR are using 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 implementation is compatible with Tier III. Vendor-specific protocols have expanded trunking to multiple-site operations. Any Tier III-capable radio will also work on Tier II systems but neither will work on Tier I.

DMR Tier II is being implemented in amateur networks with commercial DMR repeaters along with homebrew repeaters using MMDVM (Multi-Mode Digital Voice Modem) interfaces. The IP-based protocols used by different repeater manufacturers are not compatible. It is doubtful the equipment manufacturers will ever standardize for business reasons, but conversion (a "bridge") between the multiple vendor protocols is possible. Any DMR (Tier II) user (mobile or handheld) radio will work on any Tier II system, although some manufacturers offer proprietary features for their infrastructure.

DMR VOCODER

The current implementation of DMR utilizes the DSVI AMBE+2 vocoder by agreement of the manufacturers; it is not specified in the ETSI standard. Many of the radio manufacturers have implemented the vocoder in licensed software, while others use a DSVI IC. The AMBE+2 vocoder is a more recent technology than the AMBE-2000/2020 vocoder used by D-STAR.

DMR NETWORKS

Amateur DMR networks operate the same from the end user perspective. The amateur DMR networks are built on servers that support gateway interconnects and conference bridging. These networks can be divided into the Motorola Solution's MOTOTRBO-specific infrastructure (cBridge/TL-NET) and infrastructure that supports different vendor IP protocols (Brandmeister, DMPplus). Not all the amateur DMR repeaters are connected to the wide area networks; some are standalone either because they have yet to obtain an ISP connection at their repeater site, or because the repeater is only intended for local communications. Some repeater systems are operating in dual-mode (analog/digital), which allows the repeater to support both digital and legacy analog users. MOTOTRBO repeaters operating in dual-mode do not support interconnection via the internet using their proprietary IPSC protocol (see below).

Some hams have installed DMR repeaters in a vehicle, using 3G/4G/5G cellular wireless services for internet access. Others have implemented remote bases to interconnect to other networks or radios; it is important to remember that the wide area networks typically have policies restricting interconnected traffic, but what is implemented locally and stays local is acceptable. FCC regulations regarding commercial and business traffic must be followed when transferring content to and from the internet.

TWO-SLOT TDMA

DMR Tier II/Tier III occupies a 12.5 kHz bandwidth shared between two channels using Time-Division Multiple Access (TDMA), resulting in a spectrum efficiency of 6.25 kHz per channel. Each time slot can carry either voice and/or data depending on system design. The time slots are called Time Slot 1 (TS1) and Time Slot 2 (TS2). You can think of the two time slots as separate channels.

For the amateur, this means one repeater allows two separate channels at the same time. Currently most amateur DMR repeater system implementations utilize both channels for voice and some limited text messaging. Normally one time slot is used for wide-area and the second for local and regional.

For repeater operators, a single two-slot TDMA repeater offers a significant savings over two stand-alone repeaters to obtain two separate communication channels, as only one repeater and one antenna system is required.

The two-slot TDMA implemented in DMR uplinks (portable/mobile to repeater) uses a 30-ms window for each time slot; the 30-ms is further divided into a 27.5-ms frame and a 2.5-ms gap. This means when transmitting, your transmitter is only turned on for 27.5 ms every 60 ms, resulting in about a 40% battery savings on transmit.

The DMR repeater transmits a continuous data stream even if only one time slot is being used; the 2.5-ms uplink gap is replaced with a CACH burst (Common Announcement Channel) that is used for channel management and low-speed signaling.

The 27.5-ms frame consists of a total of 264 bits; a 108-bit payload, 48-bit SYNC or embedded signaling, and a second 108-bit payload for a total of 216 bits of payload per frame. The vocoder must compress 60 ms of audio with FEC (forward error correction) into 216 bits of data for transmission. The 2.5 ms gap is used as guard time to allow for PA ramping (turn-on time) and propagation delay.

IPSC AND BRIDGES

IP Site Connect (IPSC) is a vendor-specific repeater feature offered by some manufacturers. Note that MOTOTRBO repeaters will only interconnect over the internet with other MOTOTRBO repeaters because it is not part of the ETSI specifications and the manufacturers don't want to interconnect their infrastructures. IPSC is not part of the current ETSI standards.

The Motorola Solutions MOTOTRBO IPSC implementation allows up to 15 MOTOTRBO repeaters operating in DMR mode to be connected on a fully meshed IPv4 network, with one of the repeaters or a bridge serving as a Master and the others as Peers. Any traffic originating on one of the interconnected repeaters is relayed over the IP network to each of the other repeaters. The Peers will first establish a connection with the Master and obtain the database of the other Peers along with their IPv4 and port addresses.

The more repeaters in this fully meshed IPSC network, the more IP network bandwidth is required for each repeater. To expand beyond the limits of a basic IPSC network requires the utilization of a bridge to interconnect the different IPSC networks. Rayfield Communications (c-Bridge) and BridgeCom Systems (TL-Net) are the current commercial preference in North America. In the European market, SmartPTT is common. These bridges require static IPv4 addresses and larger network bandwidths than individual repeaters. Besides the commercial bridging products, Brandmeister and DMRplus are available.

18.5.2 DMR Structure

TALK GROUPS (TG)

Talk Groups (TG) are a way for groups of users to share a time slot without distracting and disrupting other users of the time slot. It should be noted that only one TG can be using a time slot at one time on a repeater. If your radio is not programmed to listen to a TG, you will not hear traffic of that TG. In this regard it is similar to coded squelch, discussed earlier in this chapter. Talk Groups can be considered as conference bridges that are used to interconnect multiple users; other technologies use the term *reflectors*, or *rooms*.

The MOTOTRBO-based network supports many Talk Groups on TS1, including World Wide (TG1), North America (TG3), World Wide English (TG13), and DMR-Plus USA (TG133). TS2 is for local, state, and regional traffic. Check with your local repeater operator to find out what Talk Groups/Time Slots are available on a repeater. Other networks such as Brandmeister and DMRplus have their own assignment of TGs. While many TGs are shared between different networks, this is not true for all TGs, even if the different networks are using the same TG number.

There are TGs implemented for individual states and regions on many networks. Some TGs are available all the time, others only at preprogrammed times, or they require a local user to activate PTT for the TG to enable it for a programmed time. Since only one TG can be transmitting at a time on a time slot, many systems will disable other TGs when a local user is active on a different TG on the time slot. Be courteous and try to use TGs that tie up the fewest number of repeaters if you are going to have a long contact. Further information about specific Talk Groups can be found on the DMR-MARC, Brandmeister, DMRplus, and regional group websites.

ZONES

User DMR radios support *zones*. Zones are a way to organize channels, much like file folders or directories on your computer. A zone is just a grouping of individual channels. Some model radios may limit the number of channels per zone and the number of zones allowed.

You could program zones for local channels (DMR or analog), another zone for a neighboring state, and a zone for business and government channels. For example, you could program a zone to include all of the NWS Weather Channels. If you do program non-amateur channels in your radio, make sure they are receiver-only unless you are licensed to use them as required by FCC 90.427(b).

ENCRYPTION AND DMR

The DMR standard also supports private calls (one-to-one), encryption, and data. Private calls are not allowed by most of the amateur networks, and many consider private calls inappropriate for amateur radio. Private calls can tie up large number of repeaters across the network and can't be heard by other users. Encryption is not legal for amateur radio in the US and in most other parts of the world. Data and text messaging is supported on some networks.

18.5.3 DMR Channels

On a DMR radio, a channel is a combination of frequency, Color Code (CC), time slot (TS), and TG. A single repeater may occupy six or more programmed channels, depending on the number of TGs available.

COLOR CODES

DMR repeaters use CCs like analog repeaters use CTCSS or DCS. To access a repeater, you must program your radio to use the same CC as the repeater. There are 16 different CCs (CC0-CC15). The use of Color Codes is not optional on DMR systems. If your Color Code is not set correctly, you will not be able to access the repeater. Many repeater councils are assigning CCs with frequency assignments.

ADMIT CRITERIA

The Admit Criteria determines when your radio can transmit. The recommended setting for repeater channels is COLOR CODE FREE; this configures your radio to work with your own digital system. You should configure the radio in Call Criteria to FOLLOW ADMIT CRITERIA. Simplex channels should be configured as ALWAYS for both Admit Criteria and ALWAYS or FOLLOW TX in Call Criteria.

18.5.4 DMR Equipment

USER RADIOS

There are many sources of new and used DMR radios. Presently a majority of them are professional (commercial) radios marketed primarily to commercial radio users, but some include features for the amateur market. If you want to purchase a new DMR radio for ham use, you can easily find a dealer. Some dealers are "ham friendly" and will offer reasonable discounts to hams. Check with other DMR users or on DMR-related websites for further information.

You can also search on eBay and other online flea markets for both new and used radios. Larger hamfests may also have DMR dealers or sellers in their flea markets or vendor areas. Here are a few things you need to know before buying a DMR radio:

New or Used — For used DMR radios, it is buyer beware! Remember that you will not be able to repair a non-working DMR radio unless you have the technical skills and necessary test equipment, and that test equipment can cost hundreds of times the cost of the radio. The street price for new DMR radios is $100 to $2,000. Used, higher quality, name-brand radios, such as Motorola or Hytera, typically sell for more than brand-new radios from newer entrants into the DMR market. Higher priced radios usually have more features, are better constructed, and can handle more abuse than less expensive radios. For the average amateur, one of the new lower-cost radios is a good initial purchase.

Some of the newer DMR radios are Android-based, such as Motorola's ION (street price of under $2,000) and RFinder B-1 (street price of $1,000).

VHF, UHF, or 900 MHz — UHF is the most commonly used band for DMR, but because military radar takes priority in some US areas, VHF repeaters may be the local choice. There are only a few amateur 902 – 928 MHz DMR repeaters in the US. If you are purchasing UHF equipment, make sure it covers the amateur band (420 – 450 MHz) from the factory.

Programming Software — Some manufacturers supply programming software at no cost. Motorola Solutions charges approximately $175 for a three-year subscription (which covers all their models within a region) to their software and updates. Many DMR radios typically do not allow keyboard programming because they are sold in the professional market. If a vendor charges for the programming software, do not ask another ham to bootleg a copy for you. If you have a legal copy, you may program radios for others, but you cannot legally distribute the software.

Programming Cable — Some radios use standard USB cables for programming, while others use cables that can cost more than $80.

Number of Channels — Some radios have as few as two channels, while others have as more than 1,000 channels. You will need a channel for each combination of frequency, CC, TS, and TG. You can easily use six or more memory channels for each DMR repeater.

Display or Non-Display — Some radios have only a channel selector knob, while others have displays (monochrome or color) that show TG and ID information. Some displays only show channel numbers.

Visually Impaired Operators — Consideration must be given to the channel selection knob on the radios. Most of the non-display models have channel selection knobs that have fixed stops instead of 360-degree continuous rotation to allow the operator to find channel one. Some LCD display models also have fixed stops on the channel-selector knob; these include some Hytera and CSI radios. Many models offer programmable voice announcements.

DTMF Keypad — Some radios have a 12-button DTMF keypad. MOTOTRBO repeaters support an optional proprietary autopatch feature (Digital Telephone Interconnect) that only works with MOTOTRBO radios.

GPS — GPS is available on some models, but DMR does not natively support APRS (Amateur Packet Reporting System). On professional networks, one of the time slots is typically allocated for location reporting and is interconnected to server-based dispatch applications. GPS will shorten battery life if it is enabled. FCC identification requirements must be complied with if transmitting GPS or other data.

Bluetooth and Wi-Fi — Some higher-end radios have Bluetooth built in for wireless headsets and programming. Wi-Fi is also available on some models. This is a great feature at work and home to listen without bothering others. Some radios with Bluetooth support data and programming via the Bluetooth wireless connection to the radio. Some models have Bluetooth adapters available as options. Bluetooth and Wi-Fi will shorten battery life if enabled.

Analog —Most radio models support analog FM. Current FCC rules require narrowband for most commercial/government services. For DMR radios from some manufacturers, this requires a programming entitlement key or a different version of the programming software if you require wideband FM, which is still used on many amateur analog repeaters.

External Antenna on Portable — Not all portable radios support the connection of an external antenna, except for testing and alignment purposes. Using an adapter to connect an external antenna can place undue stress on the portable antenna connector, which may result in premature equipment failure and expensive repair. If you are going to use an external antenna adapter, use an adapter cable that uses miniature coaxial cable to reduce stress on the radio's connector.

Portable (Handheld) or Mobile — Portable models are typically available in the 2 – 5 W range. Mobile radios are available with a maximum of 10 – 45 W. A portable is recommended as a first DMR radio unless you live beyond the handheld coverage of your local DMR repeater. If you spend significant time in your vehicle commuting, you will find a mobile radio a good investment. Mobile radios can also be used as a base station with the addition of an external power supply.

External Amplifier — Many external amplifiers will not work with DMR radios unless they are specifically designed to meet the fast-switching requirements of TDMA on DMR.

CODE PLUGS

A *code plug* is simply a radio's configuration file. The user programs their code plug from scratch or starts with one made available by a local group. This file is uploaded to the radio and should also be saved on your computer as a backup. You can also download the code plug from a radio to modify it. Building a code plug can take many hours, especially if you want to program hundreds of channels. The code plug can also contain a contact list of Radio IDs, call signs, and names to be displayed. You can find copies of configured code plugs online for different models of radio; check first with your local group. All DMR radios support a limited number of entries in the Contact List — there are over 200,000 individual radio IDs currently assigned.

18.5.5 DMR Operation

SIMPLEX

On the professional side of DMR, *Talk-Around* refers to operating simplex on a repeater output channel. Doing so allows for direct communication while still being able to hear the repeater. The benefit of operating simplex on a repeater output channel is that it allows users to directly contact other users listening on the repeater output frequency. Amateurs typically use dedicated simplex channels so as not to interfere with repeaters. The amateur DMR community has published a list of recommended simplex frequencies to be used instead of operating simplex on repeater outputs. **Table 18.4** shows recommended simplex DMR frequencies and configuration.

Avoid creating conflict with non-DMR analog users. Do not use 146.520 or 446.000, the national analog simplex channels. Avoid repeater inputs and outputs, locally used non-DMR simplex channels, satellite sub-bands, and any other frequencies that could disrupt other amateur communications.

ACCESSING A DMR REPEATER

To access a DMR repeater, set the frequency, CC, TS, and TG. When a transmitter is keyed (pressing PTT), an access-request signal is sent to the repeater and the repeater responds to permit transmitting. If a repeater's acknowledgement is not received, the radio will stop transmitting and a negative confirmation tone will be heard. This is one of the advantages of TDMA: allowing bidirectional communications between user radio and the repeater when transmitting. The repeater can also signal the radio to stop transmitting if there is contention on the network because more than one station is transmitting at a time.

Not all DMR repeaters are interconnected on the internet. Internet connectivity may not be available at the repeater site, or not available at a reasonable cost. Some repeater operators may just prefer to keep their repeater for local usage only without connecting to the larger regional and worldwide networks.

OPERATING USING DMR

If you are unsure of "DMR etiquette," spend some time listening to others operate. Be considerate and learn the preferred operating style. A good practice for learning any new mode, system, or protocol: listen, listen, listen.

To place a call to another station, or to make a general call, announce your Talk Group because some users may be scanning or have radios without a display. Avoid calling CQ.

When you are talking on one of the wide area TGs, hundreds of repeaters will be tied up. If you are unable to move to a more localized TG, be considerate of the other users on the network. When one TG is active, other TGs on the same time slot will be blocked. Leave time between transmissions so others can break in. Remember that emergency traffic always has priority over all other traffic.

Table 18.4

Recommended Simplex DMR Frequencies and Configuration

	Frequency (MHz)
UHF	441.000, 446.500, 446.075, 433.450
VHF	145.790, 145.510

Channel configuration: TG99 / CC1 / TS1 / Admit Criteria: Always / In Call Criteria: TX or Always+

18.6 System Fusion

Yaesu released the initial specification for System Fusion in 2013. System Fusion supports digital voice and data in a 12.5 kHz narrow-band channel at 9,600 bps, using C4FM modulation over VHF (144 – 148 MHz) and UHF (430 – 450 MHz). System Fusion's low-level modulation and packet structure are discussed in the **Digital Protocols and Modes** chapter. Unless noted otherwise, references to "System Fusion" in this section apply to all versions of System Fusion equipment.

All System Fusion repeaters are configurable for VHF (144 – 148 MHz) or UHF (440 – 450 MHz) operation. VHF and UHF operation can be selected as required. All repeater models are configured through a touch-screen interface to set call sign, input frequency, output frequency, CTCSS or DCS setting, power level, mode selection, and so on. By using the lowest (5 W) power setting and a suitable attenuator, a variety of power amplifiers can be used.

Firmware upgrades are available for transceivers, including discontinued models manufactured prior to the release of System Fusion II in 2017. Specific support levels of DG-ID memories (see below) and accessibility vary by transceiver. All updated transceivers can access and control unrestricted WIRES-X nodes.

CALL SIGN IDENTIFICATION

Call sign identification is embedded within the digital transmission packets. When powered up for the first time, a System Fusion transceiver prompts users to enter their call sign. This establishes station identification. There is no requirement for advance call sign registration or a subscriber ID in order to get on the air.

18.6.1 System Fusion Versions

SYSTEM FUSION I

The original DR-1 repeater was produced in 2014 for a beta testing program. The DR-1X repeater was then released as the production model. There is a significant difference between the internal controllers in the DR-1 and DR-1X. Note that while many DR-1 (beta) repeaters are installed and in daily use as standalone assets, they were not designed to be directly connected to external controller and networking interfaces in the same manner as the DR-1X (production). System Fusion I is supported by DR-1 and DR-1X repeaters.

SYSTEM FUSION II

System Fusion II adds new features and configuration options and is supported by DR-2X repeaters and enhanced controllers for DR-1X repeaters. For a time, Yaesu offered a DR-1X trade-in program toward the purchase of a DR-2X. The traded-in repeaters were then refurbished, enhanced, and sold as DR-1XFR models. Note that during the upgrade, no changes were made to the exterior and labeling. The most reliable way to determine the difference between a DR-1X and DR-1XFR is by examining the firmware versions.

DR-2X repeaters were released in 2017, along with an internal controller upgraded from DR-1X repeaters. DR-2X repeaters also provide intelligent thermal control for higher duty-cycle operation at full power. DR-2X repeaters feature a second receiver and additional over-the-air controls. The DR-2X can also be commanded to transmit on a second (alternate), pre-assigned frequency using an additional RF connector.

DSQ (Digital Squelch) has been renamed DG-ID (Digital Group Identification). It provides a means of adding selective access for individual repeaters, repeater groups, and WIRES-X nodes. The DG-ID mantissa is 00 ~ 99, with 00 used as a "hear all" setting.

DP-ID (Digital Personal Identification) is transceiver-specific and may be used to designate authorized control operators on a given DR-2X, by inclusion within that repeater's registry. DP-ID can also be used on an ad-hoc basis to aggregate sets of radios within a given DG-ID designation.

18.6.2 System Fusion Modes

System Fusion supports three modes of operation: voice full rate (Voice FR) mode, data full rate (Data FR) mode, or voice/data (V/D) mode. Voice FR mode is typically displayed on System Fusion transceivers as "VW" and Voice/Data as "DN." The two full-rate modes use the entire 9,600 bps channel for their respective voice or data payloads, whereas the V/D mode splits the channel into two 4,800 bps streams, with voice information on one and data on the other. Data is currently limited to image files and internally generated data such as GPS, call sign, and routing elements. There is no external access to the data stream.

System Fusion repeaters can be configured in a combination of modes. While the older DR-1X repeaters are capable of operation in a purely analog mode, this prevents digitally equipped users from accessing the repeater. The repeaters can also be configured to allow analog or digital reception, while forcing the output to analog only. While this configuration allows both analog and digital users to coexist, it does so in a constrained fashion. Analog-output mode strips away GPS, call sign, and other information from a digital-mode input signal. Operating in purely digital mode is also possible, effectively locking out analog FM operation. This is typically implemented when there is more than one System Fusion repeater operating in a given area.

AMS CONFIGURATION

The hybrid Automatic Mode Select (AMS) operates in both FM analog and System Fusion digital modes. This supports both analog FM into analog FM out, and digital into digital out. In this configuration, analog users are not suddenly "disconnected" from a repeater and other analog-only capable operators. Also, digital users are free to take full advantage of available features.

When configured in AMS, digital users can hear an analog call placed on the repeater in between transmission exchanges. The transceivers will switch to analog, automatically allowing them to communicate with the analog station. This allows both analog and digital users to share a repeater and does not require all users to switch to digital simultaneously.

Analog FM users can avoid hearing digital transmissions by enabling their transceiver's TONE SQUELCH feature to match the repeater's transmitted continuous tone coded subaudible squelch (CTCSS) or digital coded squelch (DCS) signal. Watching for a visual "channel busy" indicator on the analog users' transceivers or enabling the BUSY CHANNEL LOCKOUT feature will prevent accidental interference when digital communications are taking place.

Repeater networking options allow remote nodes or "points of presence" in cases where internet connectivity is not locally available. This enables systems without internet service to be integrated into a repeater network. Further, digital and analog signaling is supported throughout the WIRES-X (Wide-coverage Internet Repeater Enhancement System) networking protocols.

18.6.3 System Fusion Network

WIRES-X NETWORK OPERATION

WIRES-X nodes normally consist of a transceiver, a Windows-based computer executing the WIRES-X node software, and the WIRES-X interface. Alternately, a "local" configuration is possible, using the repeater as a replacement for the transceiver. With the acquisition of the HRI-200 WIRES-X interface, a node registration is required in order to enable secure communications to the network. A WIRES-X network map is presented in **Figure 18.19**.

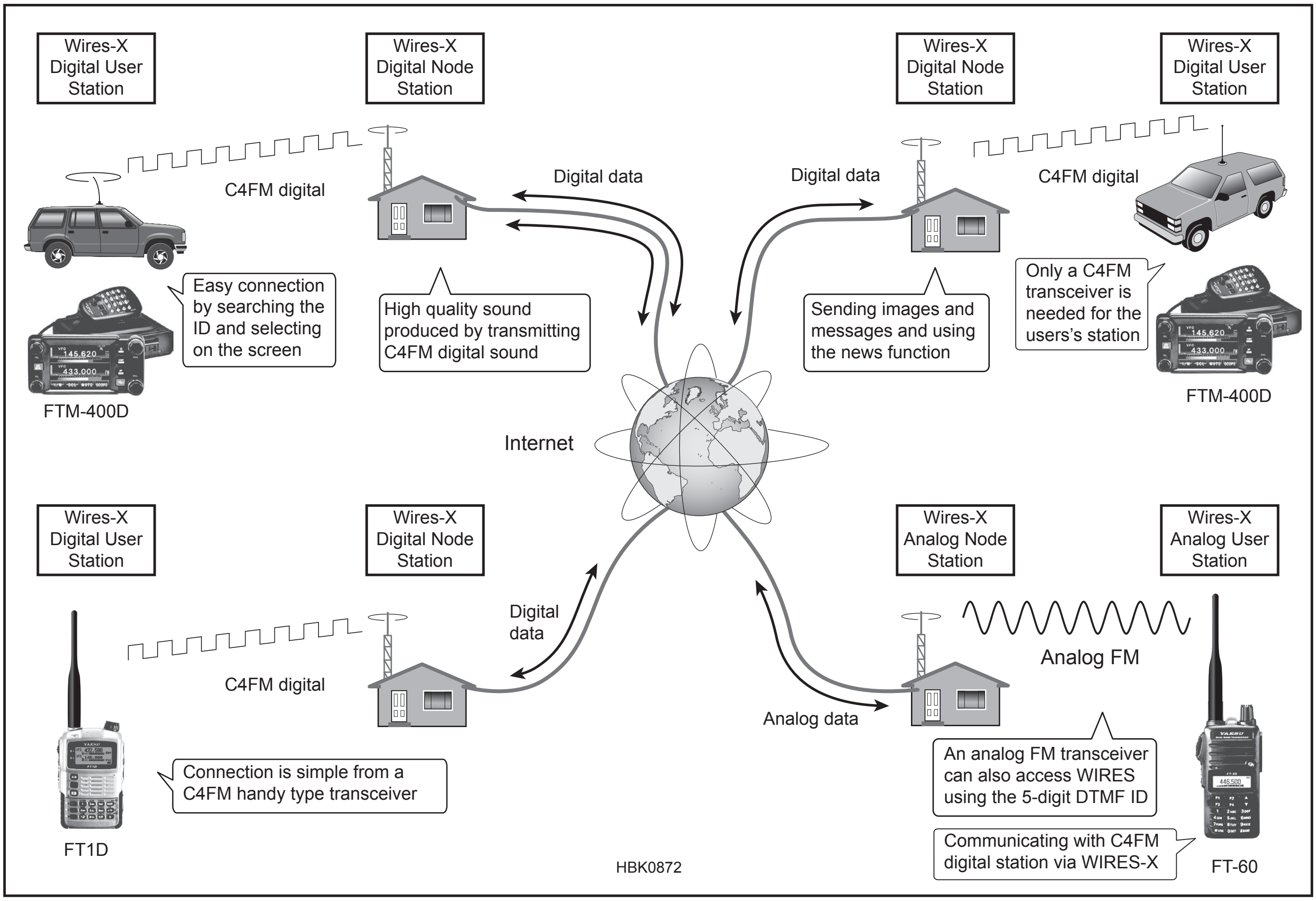


Figure 18.19 — System Fusion I configuration. (*Graphic courtesy of Yaesu.*)

WIRES-X presently supports nodes and "rooms." Each is assigned a number, although rooms can have alphanumeric identifiers ("America Link," "Keystone-Wide," and so on). Compatible digital transceivers can select rooms and nodes with scrollable menus. Analog FM transceivers operating through analog WIRES-X nodes can access rooms and other nodes through use of the numeric identifiers, using the DTMF pad on a suitable microphone or portable radio. (See IMRS section below.)

Transceivers with enhanced feature sets allow for the adhoc selection of different rooms. In a digital setting, room lists may be scrolled through on the display and selected, as desired. In an analog setting, rooms are not listed but may be selected through a direct entry of the desired room's numeric identifier. Although not as popular, mixed rooms — accommodating both analog and digital audio — are supported.

WIRES-X remote nodes can be used as portals with the network or as a means to network a given System Fusion repeater. Remote nodes are supported by all variants of the DR-2X and DR-1X, including the beta DR-1. Remote nodes may make use of the HRI-200 WIRES-X interface or certain mobile, or portable transceiver models can be used as a PDN (Personal Digital Node) without the need for the HRI-200. See the Yaesu product specifications to determine which models support PDN operation.

While an HRI-200 equipped node can be set for analog or digital operation, a PDN is by definition digital-only. With PDN, the DP-ID of the transceiver serves as the node registration identifier.

INTERNET-LINKED MULTIPLE REPEATER SYSTEM (IMRS)

IMRS is a networking structure supported by System Fusion II DR-2X controllers. While WIRES-X is server-based, IMRS utilizes a peer-to-peer architecture using TCP/IP. IMRS allows a number of repeaters to be interconnected and accessed via DG-ID entries assigned to individual repeaters, depending on how the overall repeater group's system administrator configures the repeater network. Some examples: A DG-ID of 01 may be used to access only a local DR-2X. A DG-ID of 11 may access a group of DR-2X repeaters within a county. A DG-ID 21 may access DR-2X repeaters across a region, state, province, and so on.

In System Fusion II, WIRES-X nodes, through the use of DG-ID, can be used to bridge normally non-connected IMRS groups together, or to add the users of a room into an IMRS group. The DR-2X can support IMRS or direct connection of the HRI-200 for WIRES-X, but not both at the same time, due to shared signal lines. An IMRS-enabled repeater with a remote WIRES-X node avoids this limitation.

18.6.4 Third-Party Enhancements and Options

External repeater controllers can be attached via the repeater signal and control interface connections on rear panel HD-15 and 10-pin Mini-DIN connectors. Along with external repeater controllers, analog transceivers with suitable "flat audio" connections (no pre/de-emphasis) may also be attached to further support analog linking or digital voice to analog communications conversions. Adapter cable sets are available that enable a microcontroller to read and assert the correct sequence of signals required for Automatic Mode Select configuration.

Following publication of the Common

Air Interface (CAI) specification for System Fusion, a number of third-party additions have been offered for the repeaters. Protocol converters, typically operating in conjunction with Raspberry Pi3/4 and Arduino single-board computers, may allow the support of other DV functions with the DR-1X. DR-2X and DR-1XFR design enhancements may not support a given third-party protocol converter. Interfacing with analog repeater controllers is unaffected.

Other products in the "hot spot" category allow System Fusion repeaters and transceivers to connect through alternate networking schemes. As such, it is possible to use a System Fusion transceiver and network interface to communicate with other DV methodologies, while staying completely within the digital domain.

18.7 APCO Project 25 (P25)

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. P25 was the first commonly adopted digital voice methodology used by radio amateurs.

The Project 25 Network Exchange (P25NX) designed by NX7Y allows owners of Motorola Quantar P25-enabled repeaters to inexpensively and easily network their repeaters. Established as a worldwide network, there are now four talkgroups: World Wide, North America, Europe, and Pacific, plus three tactical channels within each talkgroup. Efforts are also being undertaken to allow alternative P25 capable repeaters to be networked with P25NX.

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