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FM/Repeaters—Inside Amateur Radio's "Utility" Mode

D-STAR
Digital Voice for VHF/UHF

VHF/UHF D-STAR radios are making their way into the U.S. ham radio community. What is this new technology and how will it benefit the ham radio enthusiast?

Digital Modulation

Unless you were unconscious for the last two decades, you have noticed that digital technology has swept through most types of electronic devices, creating more capability and changing primarily analog devices into digital wonders. Analog music media such as the conventional LP record and magnetic tape have been replaced by digitally-encoded CD-ROMs. More recently, the rise of the Internet and digital audio formats (e.g., MP3) has changed how music is created and distributed. Closer to home for ham radio enthusiasts, the cellular telephone, originally deployed with analog FM technology, has largely migrated to digital-modulation techniques. Digital technology allows mobile-phone service providers to provide cost-effective voice communications while adding services such as text messaging and web surfing, all while improving the spectral efficiency of their networks.

Meanwhile, those of us who enjoy using FM simplex and repeaters on the VHF and higher amateur bands are still using good old analog FM. Edwin H. Armstrong first described the use of *frequency modulation* in 1936.[1] The first practical two-way FM radio-telephone mobile system in the world was implemented in 1940 for the Connecticut State Police. Let's consider 1940 the start of what we know today as two-way FM radio. That was 65 years ago! Perhaps it is time to move to new technology.

We have already seen digital technology wiggle its way into our inherently analog radios. Modern FM transceivers have digitally-synthesized frequency control circuits, digital storage of channel information, serial ports for loading configurations, and computer software to control these rigs. Packet radio uses AX.25 digital protocols to provide an error-free data transmission mechanism, but the underlying modulation generally is still analog FM. The next step may be a truly integrated approach to voice and data.

Photo A. The ICOM IC-2200H is a conventional 2-meter FM transceiver with D-STAR digital operation available as an option. (Photo courtesy of ICOM America)

Digital Modulation in Amateur Radio

The Japanese government funded the development of the D-STAR standard, a digital radio format designed specifically for amateur radio. The Japan Amateur Radio League (JARL) administered the development of this open standard, and ICOM is the first equipment manufacturer to market D-STAR radios.

There are three distinct types of D-STAR transmissions with varying bandwidth required. The **DV** format is the narrowest modulation scheme, using a data rate of 4800 b/s to support simultaneous voice and data transmissions. Digitized voice is transmitted using 3600 b/s, leaving 1200 b/s for data transmission. D-STAR transceivers on 146 MHz and 440 MHz use this modulation format, since it results in a narrow 6-kHz signal bandwidth. I think of this mode as having a single voice channel, plus a digital channel similar to 1200-baud packet rates. This mode won't be great at moving large files, but it will handle lower speed data requirements. Photo A shows a 2-meter rig that offers D-STAR operation as an option.

The **DD** format is a *data-only* mode that provides a 128-kb/s transfer rate, occupying a bandwidth of 130 kHz. This mode is too wide for the VHF bands and is

Modulation Type	Band	Digital Rate
DV	146 MHz, 440 MHz, 1.2 GHz	4.8kb/s
DD	1.2 GHz	128 kb/s
Backbone	10 GHz	10 Mb/s

Table 1. Summary of available D-STAR modulation formats.

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Photo B. The ID-1 transceiver is a 1.2-GHz transceiver that includes analog FM and D-STAR formats (DV and DD). (Photo courtesy of ICOM America)

offered by ICOM only on its 1.2-GHz rig. (The 1.2-GHz radio also offers DV format, as well as conventional analog FM.) Rounding out the D-STAR system is a 10-GHz backbone link that operates at 10 Mb/s. This radio link is intended for linking repeaters together on the ham bands without depending on any phone line or Internet connection. The data rates listed for these D-STAR formats are the nominal bit rates, but the use of *Forward Error Correction (FEC)* means that the actual throughput will be somewhat less.

I'll focus on D-STAR from the point of view of a typical FM ham radio user, most likely operating on 146 MHz or 440 MHz, using the DV D-STAR format.

D-STAR Technology

D-STAR is an open protocol, but one that was developed with amateur radio in mind. While being ham radio oriented, D-STAR still takes advantage of technology and standards from other communications industries.

Since D-STAR uses digital modulation, the analog voice signal is converted to digital format by an analog-to-digital converter.[2] These digital samples are further compressed by an AMBE® (Advanced Multi-Band Excitation) vocoder circuit. The vocoder takes advantage of the characteristics of human speech to compress the digital data stream into a much more compact set of data, minimizing the on-the-air bandwidth required. Vocoders vary in the quality of speech that they reproduce, and the AMBE vocoder gets high marks for speech quality.

The digital stream of bits goes out over the air using the modulation method known as 0.5GMSK (Gaussian Minimum Shift Keying). Roughly speaking, GMSK passes the digital input stream through a Gaussian low-pass filter which rounds off the edges of the waveform. This rounded waveform drives an FM modulator to produce the GMSK-modulated signal, resulting in a signal that is very efficient in terms of occupied bandwidth.

D-STAR transmissions are not compatible with the existing analog FM and sound like white noise when received on an FM radio. D-STAR radios provide backward compatibility with existing radios by including a conventional FM mode. The user selects whether he or she wants the radio to operate in analog or digital mode.

The D-STAR standard includes a position reporting feature that is similar to APRS®. D-STAR radios have NMEA interface for taking in position information from a GPS receiver. Basically, this data stream transmits the GPS coordinates at a time interval specified by the user. This transmission is *not* directly compatible with APRS, since APRS uses conventional packet radio, while the D-STAR information is encoded in the D-STAR digital format. Some hams are experimenting with gateways that pipe the D-STAR data into the APRS Internet System (APRS-IS), a collection of servers that track APRS reports.

Every D-STAR transmission has the station's callsign embedded in the digital stream. This makes identification automatic, sort of like Caller ID on a telephone. This enables other features such as "call sign squelch" so that you can monitor for transmissions from a specific station.

Repeater Systems

D-STAR supports a comprehensive linked repeater system. Repeaters can be linked together digitally either via the Internet or via radio on the 10-GHz ham band. When you transmit to a D-STAR repeater, your callsign is automatically registered with that repeater and shared around the D-STAR system. Each transmission contains routing information for where on the system the signal should be heard.

This may sound like a capability similar to the repeater linking that can be done using IRLP or Echolink®. These Internet linking systems use conventional FM over the air and convert to digital before sending the information over the Internet. D-STAR uses digital data throughout the system, including the initial RF link. The digital encoding in the signal makes the routing of signals from one repeater to another automatic, without the need for establishing (and later breaking) a communications link. In fact, D-STAR uses a different paradigm entirely, where each transmission is routed according to its embedded callsign-routing information. Since the signal routing is all digital, there will be no degradation of signal-to-noise ratio as the signal traverses the system. Compare this to repeater systems linked via analog methods, where each link tends to introduce a bit of noise.

D-STAR Benefits

Some hams look at D-STAR technology and get hooked instantly because it is new, cool digital technology. Of course, others ask the question "What is the benefit of D-STAR, as my analog FM rig works just fine?" Like most emerging technologies, the benefits of D-STAR may not be understood completely until the technology has been around for a while. The benefits of D-STAR fall into three major categories:

Spectral efficiency. The DV format of D-STAR has a bandwidth of 6 kHz, compared to 16 kHz for analog FM with 5-kHz deviation.[3] This implies that we could at least double the number of repeaters or simplex channels in a particular frequency band. Given that all repeater pairs in the 2-meter band are in use in many locations, this could have a dramatic impact on how the band is used. (Of course, this raises all kinds of sticky issues on how this change would occur. That is, existing repeater owners and users may not be motivated to change out their equipment.)

Routing information encoded in voice channel. The DV format has the transmitting station's callsign, the destination repeater, and other information

Photo C. The K5TIT rack of D-STAR gear includes (in order, starting near the top of the rack) a D-STAR repeater controller, 1.2-GHz voice repeater, 1.2-GHz data radio, 146-MHz voice repeater, and 446-MHz voice repeater. (Photo courtesy of Jim McClellan, N5MIJ)

encoded into every transmission. This encoded data enables automatic identification (“Caller ID”), selective calling (“Call Sign Squelch”), automatic logging of stations heard, and signal routing through a D-STAR repeater system.

Text and Position Messaging. Digitally-encoded position information can be sent, assuming a GPS receiver is connected to the D-STAR rig. The user can also manually enter the position information or a short text message. An external TNC is not required.

These benefits are from the perspective of an FM voice user. Clearly, D-STAR also offers other benefits for data-only radio use. In particular, the DD format offers the fastest turn-key digital radio baud rates for amateur radio use.

D-STAR Deployments

Not surprisingly, D-STAR usage took off first in Japan, with an unknown number of 1.2-GHz D-STAR repeaters on the air, all operated by the JARL.

This technology is in the early stages of deployment in the U.S., with a number of D-STAR pioneers trying out this new ham radio format. According to Ray Novak, N9JA, of ICOM America, there are approximately 15 D-STAR repeater sites on the air in the U.S., with three of them linked to the Internet. The activity on these three repeaters (and any others that add the Internet connection) is shown on the D-STAR users’ website at <http:// www.dstarusers.org>.

The most active D-STAR group seems to be the Texas Interconnect Team, in the Dallas area, with club callsign K5TIT. This group has an active website devoted to D-STAR topics at <http://www. k5tit.org>. They have D-STAR repeaters on these bands: 146 MHz, 440 MHz, and 1.2 GHz (photo C). The group recently conducted the first U.S. field trial of ICOM’s 146-MHz and 440-MHz D-STAR repeaters.

The Chester County Amateur Radio Special Interest Group (W3DES) in Chester County, Pennsylvania is a hotbed of activity on 1.2-GHz D-STAR, with several 1.2-GHz repeaters on the air.

New York City also has a 1.2-GHz D-STAR repeater in place. Rich Moseson, W2VU, the editor of *CQ* magazine, recently had the opportunity to use that system to talk with Jim, N5MIJ, on the K5TIT Dallas machine. Rich reports that the system worked well and the digital audio was “crystal clear.” A recent article on the ARRL website (December 14, 2005: <http:// www.arrl.org/news/stories/2005/12/14/1/>) announced the deployment of a 1.2-GHz D-STAR repeater at W1AW. This machine was donated by ICOM and is being configured to connect to the Internet.

D-STAR is not just for repeaters, and there are a number of people out there running D-STAR 2-meter simplex. Since the digital transmissions are incompatible with analog FM, it is best to avoid any popular FM simplex frequencies. Most of the 2-meter D-STAR activity takes place in the “miscellaneous and experimental modes” section of the ARRL band from 145.50 to 145.80 MHz. There is no designated D-STAR calling frequency for use on a national basis, but 145.60 MHz, 145.61 MHz, and 145.67 MHz are often used. A recent poll on the ICOM D-STAR forums chose 145.60 MHz as an easy-to-remember D-STAR calling frequency.

Performance

When digital technology is used to transmit a voice signal and compression is used to minimize the required bandwidth, it raises questions about the audio quality. If the audio is not sampled often enough or the analog-to-digital conversion is too coarse, the audio quality can suffer. I have not used D-STAR on the air, but I have listened to recordings of D-STAR transmissions under varying conditions. John Habbinga, KC5ZRQ, recorded a weak-signal audio test using a mobile station and comparing DV audio and analog FM. This audio recording is available in MP3 format on the web at <http://www.lubbock-radio.net/D-STAR -vs-FM.mp3>. My impression is that with reasonable-strength signals, the D-STAR audio quality is very good, with just a hint of the digital vocoder “twang” that is common in digital cell phones. Reports from D-STAR users seem to agree with this assessment.

Like other digital-modulation techniques, D-STAR audio tends to drop out when in a fringe area, as opposed to gradually getting noisy like analog FM. If you listen to the KC5ZRQ recording, you will hear these dropouts when the signal gets weak. When John switches over to analog FM under the same working conditions, the signal is recognizable, but covered in noise. (Make sure you listen to the whole recording, since the weakest signal strength occurs near the end.)

Photo D. A photo of the ID-800H used for D-STAR experimentation by Pierre, AL7OC. (Photo courtesy of Pierre Loncle, AL7OC)

In his report on the Texas Interconnect Team field trial of the VHF/UHF repeaters, Jim McClellan, N5MIJ, writes:

> Range was excellent. The systems were simultaneously compared with a comparably equipped analog FM repeater, located at the same site. The nature of the digital signals used by D-STAR enabled us to have full copy in places where the signal of the FM repeater had dropped into the noise. There was no “noisy but readable” signal as you have on FM.
>
> Intelligibility was also excellent. Even at extreme range, voices are clear and readily identifiable. Voice quality is not as good as experienced on FM, but excellent for digital signals.

The June 2005 issue of *QST* has a great review of the IC-2200H mobile radio and the IC-V82 handheld rig, along with the technical evaluation of the D-STAR performance. (This is available online to ARRL members.) The ARRL performed a laboratory test of D-STAR weak-signal performance using a pair of IC-2200H 2-meter transceivers with the UT-118 D-STAR option installed.[4] They reported a similar result, but gave D-STAR the clear advantage over analog FM:

> We found solid, virtually noise free communication, equivalent to analog “full quieting” at any analog SINAD above about 6 dB. Note that while analog copy was usable at that level it was quite noisy, and a signal at least 10 dB stronger would be required for comfortable copy in analog mode with about 22 dB SINAD required for full analog quieting.

Keep in mind that this is a test on the lab bench in a controlled environment. It shouldn’t surprise us if real world, mobile operating conditions produce a different result.

The narrower bandwidth (6 kHz) of D-STAR should provide an advantage over the wider bandwidth of conventional FM (16 kHz), *all other things being equal.* Narrower bandwidth means there is less noise introduced into the receiver with which the signal has to compete.

Pierre Loncle, AL7OC, and Albert Noe, KL7NO, have been experimenting with D-STAR on 146 MHz and 440 MHz simplex around Fairbanks, Alaska. Using two ICOM ID-800H transceivers (photo D), they have compared analog FM and DV in a variety of conditions. Pierre reports:

> The coverage in deep fringe areas is slightly better in FM mode in that the human brain does a better job separating speech from noise than digital processors … if we lose our digital voice channel and switch to analog FM, the FM signal may still be copyable, but very noisy and of poor voice quality.
>
> We have also noted that the digital voice mode is more susceptible to interference from impulse noise … such as digital devices that are radiating a lot of RFI.

Thus we see some variation in the experiences that hams are having with D-STAR, which is to be expected with any new technology. The ham community will gain a better understanding of the fine points of D-STAR operating through experience.

The generally accepted method for specifying analog receiver sensitivity is *signal-to-noise ratio.* More precisely, the method used for analog FM is SINAD (signal-plus-noise-plus-distortion to noise-plus-distortion) ratio. The receiver sensitivity is specified as the signal level that produces a 12-dB SINAD ratio in the recovered audio. Digital modulation has the characteristic of being solid as long as the bits are received correctly, but has audio drop outs when the bits are corrupted. The analog methods of signal-to-noise ratio don’t apply directly to digital modulation, and the preferred method for specifying imperfections in the signal is *Bit Error Rate (BER).* For example, the sensitivity specification for the ID-800H dualband D-STAR rig is BER 1% at <0.35-µV signal level. In other words, the receiver sensitivity is specified as the signal level where 1% of the digital bits are in error. This Bit Error Rate specification indicates the need for a different way of looking at amateur radio performance.

Barriers to Adoption

D-STAR clearly is an exciting new technology with great potential. However, any new technology has barriers to adoption. One potential barrier is cost, since a standard 2-meter rig costs about $160, while a D-STAR rig is about twice that. Recent prices on the Internet showed the IC-2200H 2-meter FM rig at $160 and the UT-118 D-STAR option at $200. It’s interesting that the D-STAR option costs more than the 2-meter rig. Well, this is only one way to look at it. Another point of view is that for $360 you can buy a transceiver that does both good old analog FM and the latest emerging digital technology. Keep in mind that a basic VHF packet TNC costs about $180, so the UT-118 D-STAR option is similar in cost. Compare the cost of a D-STAR radio to a commercial radio capable of digital communications (APCO-25) and the D-STAR gear looks like a bargain.

Competition generally brings down the price of any product, so that raises the question of what do the other amateur radio manufacturers have planned? Clearly, ICOM is setting the pace in D-STAR equipment, with a complete line of VHF/UHF gear, including repeater equipment. According to Chip Margelli, K7JA, of Yaesu, Yaesu has no plans to offer D-STAR radio gear. The situation at Kenwood is less clear, since there have been sightings of Kenwood D-STAR gear in Japan, but Kenwood USA says there are no plans to introduce D-STAR equipment here. Perhaps more important is that as long as ICOM is the only game in town, it undermines the notion that D-STAR is an open, industry standard.

Another obvious barrier is the lack of repeater infrastructure. Most hams are going to be looking for some kind of repeater coverage in their area before spending extra dollars on D-STAR. Of course, this takes time. ICOM has offered a 1.2-GHz D-STAR for a while now, but repeater equipment for the more popular 146-MHz and 440-MHz bands is just now becoming available. The 146-MHz and 440-MHz repeaters in use at K5TIT are pre-production units, so we can expect to see this equipment available in early 2006. It will be interesting to see how many D-STAR systems pop up on the VHF/UHF bands in the next year or two.

Despite these barriers, D-STAR is a promising new technology. D-STAR is more than just digital modulation, as it provides a system approach to integrating voice and data communications. How the amateur radio community chooses to deploy this capability remains to be seen. Most likely, we can't envision all of the new applications that D-STAR will enable. Ray Novak, N9JA, sums it up well: "D-STAR is new technology. It opens up opportunities for new applications and features. This is fun!"

References

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"Digital Connection: D-STAR," Don Rotolo, N2IRZ, *CQ* magazine, February 2006.

Wrap Up

For more information on D-STAR, see the web resources listed with this column, especially the ICOM website and the K5TIT website (both with online discussion forums on D-STAR).

My thanks go to these people for their assistance with this article: Ray Novak, N9JA, Division Manager – Amateur Products, ICOM America; Jim McClellan, N5MIJ, Texas Interconnect Team; and Pierre Loncle, AL7OC.

I've started a weblog at <http://k0nr. blogspot.com> that covers VHF /UHF ham radio topics, including D-STAR. Take a look and drop me a note there or to my e-mail address: <bob@k0nr.com>.

73, Bob, KØNR

Notes

1. Armstrong technical paper on FM (IRE): <https://michael.industrynumbers. com/fm.pdf>.
2. For a good overview of digital voice, see Doug Smith's article in January 2002 *QST.*
3. Via Carson's Rule, BW = 2 × (Peak Deviation + Highest Modulating Frequency) = 2 (5 kHz + 3 kHz) = 16 kHz.
4. "Installation and Test of UT-118 Digital Voice Modules," Michael Tracy, KC1SX, *QST*, June 2005.