Amateur Radio Notes

by Toshen, KE0FHS
CQ · Base · D-STAR · DMR · Hotspots · Pi-Star

Diving into D-STAR – 1

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Revised: Jan 2023;

As of Jan 1, 2024, this site is no longer being updated. It will remain available for some time for legacy reference.

Most up-to-date version: amateurradionotes.com/d-star.htm

Disclaimer: These are my personal notes and opinions based on my experience using D-STAR, as well as by learning from what others are sharing. I pay for all my equipment and do not accept freebies in exchange for reviews. If anything needs correcting, please let me know.

Why bother?

When I first dove into D-STAR, I knew nearly nothing about digital voice and quickly found myself drowning in a big bowl of bewilderingly murky information soup. So if it's that bewildering, why even bother?

I'll jump a bit ahead here and share one tidbit: at one point early in my exploration of D-STAR, I linked to a reflector and heard a guy in San Diego, California chatting with a chap in Yorkshire, England. That was the moment I became hooked. Just think of it: worldwide communication with a Technician class license, a bit of effort and learning, and some fairly simple, relatively inexpensive equipment!

Of course, the real goal isn't to just listen but to actually chat with people. This is the story of how I got there.

> Today's amateur radio experimenter is as likely to use a keyboard as a soldering iron for experiments, and as a digital enthusiast, I can only cheer and encourage you to get involved and have some fun.
>
> – Don Rotolo, N21RZ, Vocoding: Creating Digital Voice

Dedicated to the faint of signal

This article is written from the point of view of someone who doesn't live within range of a digital voice (DV) repeater, someone for whom a personal, low-power hotspot is an important key to accessing a digital voice system, a gift that opens doors to the whole wide world.

The article unfolds over time, loosely following the stages of my own journey of discovery into D-STAR, which began in October 2016; however, I'm also going back and revising it as I learn more.

Hotspots and control operator responsibilities

Important! The regulations and best practices that apply to amateur radio—including use of frequencies, control of our stations, and on-air courtesy—also apply to our use of personal, low-power hotspots. It's our responsibility to understand and adhere to those regulations and best practices. My personal practice is that I power on my personal, low-power hotspots only when I'm monitoring and in control of them, adhere to my local band and frequency use plans, and leave adequate pauses between transmissions. For more about this, see Hotspot best practices.

Caveat

Because digital voice often relies on an internet connection, it may not be a reliable communication mode during a major emergency when the internet might be overwhelmed or offline, as happened to us during the 2013 flood that hit our area, the experience that inspired me to get into amateur radio. Beyond that possible limitation, it's an awesome advancement that continues the long history of exciting amateur radio innovation.

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1) What is digital voice?

The simple answer is that digital voice (DV) uses digital rather than analog audio. But what does that really mean? For me, it was all quite murky when I first started looking into it, and it took me quite a bit of exploring and head scratching to begin figuring it out.

This section provides an introduction to the basics of digital voice and personal, low-power hotspots, including links to some helpful websites, articles, and other content, in case you want to dive in more deeply. You also can find all the links together on the Notes page at the end of this article: Links to helpful resources.

1a) Alphabet soup

As I began flailing around in the digital voice murkiness, one of the first things I figured out is that it's actually a bit like a big bowl of ***alphabet soup*** … it's absolutely crazy how many acronyms are floating around!

Alphabetsoupese by Toshen, KE0FHS
Derived from an original photo
by Leo Reynolds. Some rights reserved.

Even worse, sometimes the acronyms are spelled out differently, which makes searching for information more challenging. Other times, it isn't easy to determine what an acronym actually stands for, for example, I've seen DCS defined three different ways (Digital Call Server, Digital Communication Systems, and Digital Call Service), and I'm still unsure which is correct. Perhaps it stands for Darn Confusing Stuff?!

Since there's no avoiding this craziness, you just have to accept it as part of the price of admission. And don't worry, by the end of this article, you'll be speaking "Alphabetsoupese" fluently!

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1b) Multiple systems

The next thing I understood is that D-STAR is just one of several digital voice systems being developed, though it's one of the earliest, and the first to be developed specifically for amateur radio use.

The Japan Amateur Radio League began development work on the Digital Smart Technologies for Amateur Radio (D-STAR) standard in the late 1990s and published it in 2001. It started to gain traction in the U.S. around 2006.

The D-STAR standard has been adopted primarily by two first-tier amateur radio equipment makers, first by Icom, the D-STAR trailblazer, and more recently by Kenwood. By now, it's being used by tens of thousands of amateur radio enthusiasts worldwide.

It's also an open standard (with the exception of the vocoder chip, which is discussed in the following note), so it's being used for lots of experimentation, and that means there's some interesting homebrew and small manufacturer hardware and software available.

Other digital voice systems being developed or adapted for use by hams:

- DMR, an open commercial standard developed and governed by the European Telecommunications Standards Institute, with equipment by Motorola, Hytera, Tytera, and others. Rapidly growing in the amateur radio community, with well over 100,000 hams with CCS7 IDs by 2019.
- System Fusion, a proprietary system for amateur radio by Yaesu.
- P25, a standard developed for North American public safety services. Governed by the Telecommunications Industry Association and others.
- NXDN Forum, an open commercial and public safety standard initially developed by Icom (implemented as IDAS) and Kenwood (implemented as NEXEDGE), and now overseen by members of the NXDN Forum.
- There also are a couple open systems slowly being developed for amateur radio, which are based on an open source speech codec (vocoder) called Codec 2. One is the M17 Project (more M17 info), and the other is called FreeDV.

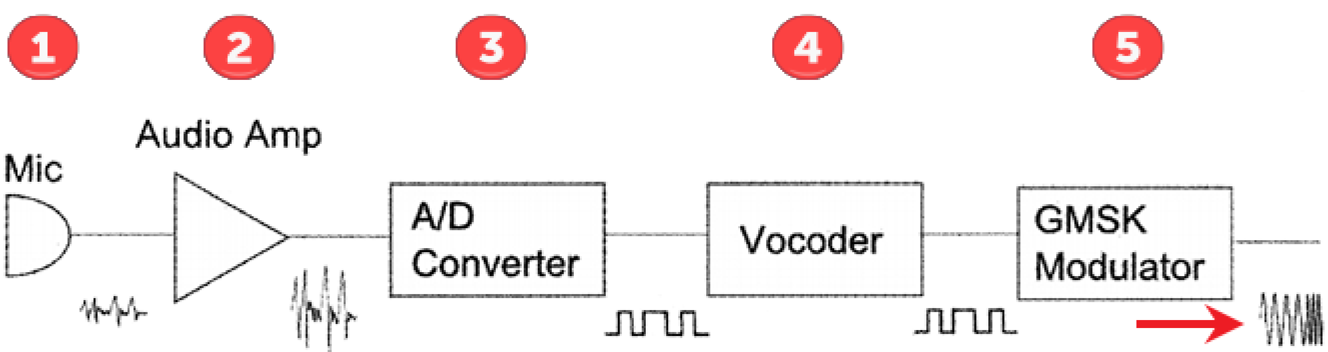
Thomas, W2XQ, has a good section of links to M17 resources on his site. For current info on the M17 and OpenHT projects: M17 Project on Mastodon.

Alphabetsoupese – example 1

You May Not Necessarily Need To Know This (YMN³TKT), but you'll come across these acronyms.

One thing the main DV systems being used by hams have in common is that they all compress digital audio using the Advanced Multi-Band Excitation (AMBE®) vocoder chips and software made by Digital Voice Systems, Inc. (DVSI).

Bob Witte's diagram shows the path the signal takes:



Simplified block diagram of
a D-STAR modulation system,
from A Look inside D-STAR Modulation
by Bob Witte, K0NR

1. Analog audio is captured by microphone.
2. Analog audio signal is amplified.
3. The Analog-to-Digital (A/D) converter converts audio signal to digital (zeros & ones).
4. The vocoder compresses the digitized audio and adds forward error correction.
5. Finally, the compressed digital audio is modulated onto the carrier wave. I've added a red arrow pointing at the modulated carrier wave, which I'll talk about a bit more in the next note.

There are a few different versions of the DVSI AMBE® Vocoder in use: AMBE®, AMBE+™, and AMBE+2™. The newer versions add improvements like better error correction and sound quality.

Because the DVSI AMBE® Vocoder software is proprietary, this is one area of digital voice—and the only area of D-STAR—that hams can't hack. For obvious reasons, some hams don't like that.

How does the vocoder work?

Simply digitizing an analog voice waveform actually results in needing more bandwidth than the analog original. To solve this conundrum, DVSI built upon research started at MIT to create the Multi-Band Excitation-based AMBE® Vocoder, which both minimizes bandwidth requirements and maximizes human voice fidelity.

> Instead of just digitizing a waveform, we can recognize that the human voice has some very predictable characteristics, and we can exploit those characteristics to dramatically reduce the digitized bandwidth while maintaining that "human voice" sound.
>
> Human speech has two major sound components, voiced and unvoiced. Voiced energy is periodic in nature, containing tones or frequencies, while unvoiced energy is like noise. To better understand this concept, say the word "wash" out loud. The first part of the sound is voiced at a relatively constant frequency, changing in its harmonic content, while the "sh" ending is unvoiced and essentially a burst of noise.
>
> – Don Rotolo, N21RZ, Vocoding: Creating Digital Voice

To simplify the complex and clever work being done: the AMBE® vocoder splits the human voice signal into frequency bands, then analyzes the audio energy of the major voice sound components in each band, creating a bandwidth efficient summary of the characteristics.

The amazing thing to me is that it sounds so good; I find it totally easy to identify people when listening to their digital transmissions, even if they're using radios with the older AMBE® and AMBE+™ chips.

For additional information, see DVSI's article: Voice Coding Overview.

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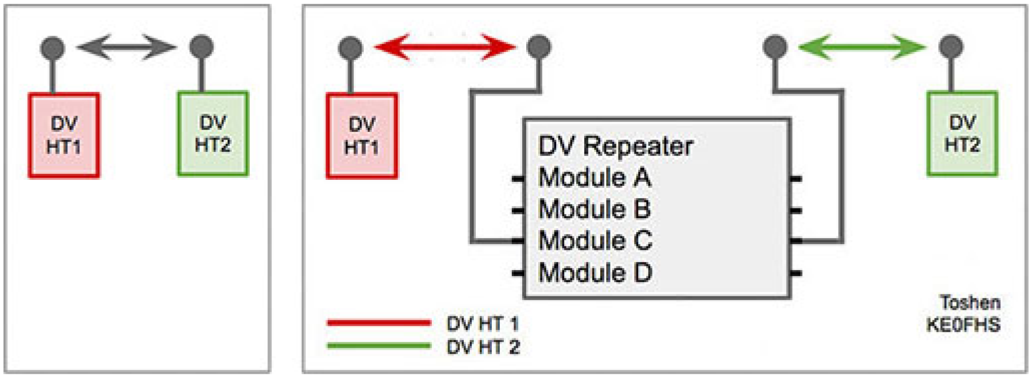
1c) Transceivers, repeaters, and reflectors … oh my!

Just as you can use analog transceivers in FM mode, you can use digital voice-capable transceivers in DV mode to talk directly from radio to radio simplex [1] or via a repeater (as long as it's a digital voice repeater).

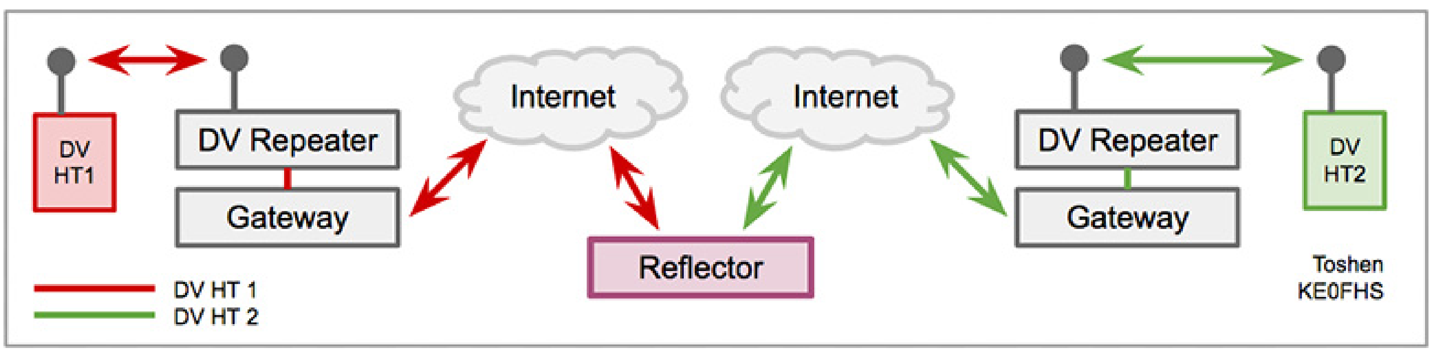


[1] The U.S. DV simplex frequencies are 145.670 (2 M) and 446.225 (70 cm).

Here's an example of the setup of DV mode radio-to-radio call via a DV repeater:

```
Radio:   DV HT1     DV HT2
Freq:    446.8625   446.8625
UR CALL: CQCQCQ     CQCQCQ
RPT1:    KC0DS B    KC0DS B
RPT2:
MY CALL: KE0FHS     N0AES
```

It gets even more interesting when digital voice repeaters are bridged together using D-STAR Repeater (DR) mode (a.k.a, Duplex mode), enabling groups of people, even far flung, to participate in something that's like a conference call.



Example of DR mode setup for linking to a reflector via local repeaters:

```
Radio:   DV HT1     DV HT2
Freq:    446.8625   145.2500
UR CALL: REF001CL   REF001CL
RPT1:    KC0DS  B   W0CDS  C
RPT2:    KC0DS  G   W0CDS  G
MY CALL: KE0FHS     N0AES
```

After linking to the reflector, everything is the same except:

```
UR CALL: CQCQCQ     CQCQCQ
```

Linking together in this way to participate in a call or net is a big part of what playing around in the worldwide D-STAR playground is all about.

In the D-STAR world, this technology is called "Reflectors" (transmissions are reflected to all repeaters linked to the reflector), while DMR calls it "Talkgroups" and System Fusion calls it "Rooms." D-STAR also has a new open routing system called QuadNet Smart Groups, which bridges users together in a similar fashion.

Here, too, there are multiple systems being developed and used simultaneously. Within just the D-STAR world, there are four main reflector systems as well as the open routing system:

1. REF – **The DPLUS reflector system**, a closed proprietary system developed by Robin Cutshaw, AA4RC, is the first generation of D-STAR reflectors and still much in use, especially in English-speaking countries. An example is REF001 in London, referred to as D-STAR's "Mega Reflector." REF directory.
2. XRF – **The Dextra X-Reflector system**, originally created by Scott Lawson, KI4KLF, is the second generation of D-STAR reflectors and is open source. XRF directory.
3. DCS – **The Digital Call Server reflector system**, a closed system developed by Torsten Schultze, DG1HT, and now run by Stefan, DL1BH, Peter, DG9FFM, and Rolf, HB9SDB. DCS updates and directory.
4. XLX – **The XLX reflector system**, being developed by Jean-Luc Boevange, LX3JL, and Luc Engelmann, LX1IQ, is an open system and the newest, which they describe as "the first and only multiprotocol Reflector system until now and supports all standard D-STAR protocols like DCS, Dextra and DPlus fully transparent." XLX reflectors directory.
5. Smart Groups – **The QuadNet open style routing system**, is based on an idea called STARnet by John Hays, K7VE, and first implemented by Jonathan Naylor, G4KLX, as StarNetServer. Tom, N7TAE, Colby, W1BSB, and the QuadNet team is now taking this idea to the next level with their new Smart Group Server: "A routing group is kind of like a reflector, but it is actually more like a repeater without the RF transceiver. A routing group can have many individual users 'subscribed' to it. Anyone subscribed to a group will hear all traffic on the Group."

To learn more:

- Reflections on Reflectors: A basic tutorial on DSTAR reflectors, 2018, by Bob Scott, W6KD.
- QuadNet2 USA IRC Network – D-STAR routing done open style!
- See also: QuadNet Smart Groups.

Fenced playgrounds

While there are some differences between the digital voice systems being used by hams—D-STAR, DMR, System Fusion, P25, NXDN—they share many similarities. Given their shared similarities, perhaps the most surprising thing is that they don't talk to each other. They are like three side-by-side playgrounds, all with similar swing sets and slides, but with arbitrary fences separating them.

Breaking down the fences

Fortunately, real progress breaking down the fences between the digital playgrounds began being made in 2018. An encouraging trend is the way newer hotspots have been incorporating software-based cross-mode transcoding capabilities. Both the MMDVM-based hotspots running Pi-Star and the SharRF openSPOT have supported software-based cross-modes for awhile now, for example: YSF2DMR, YSF2NXDN, YSF2P25, DMR2YSF, and DMR2NXDN.

Even better, in early 2020, SharkRF launched the openSPOT 3 hotspot. In addition to supporting software-based transcoding, it also incorporates some hardware-based transcoding, which finally will mean bridging DSTAR with some of the other modes.

The future?

Given the small size of the openSPOT 3, I hope it will be only a matter of time before these capabilities are incorporated right into the radios themselves. Want to talk over RF? Fine! Want to talk over the internet? Fine! Want to talk with someone using a different system? Fine! Hopefully, what will eventually matter most is who you want to talk with, more so than their type of equipment.

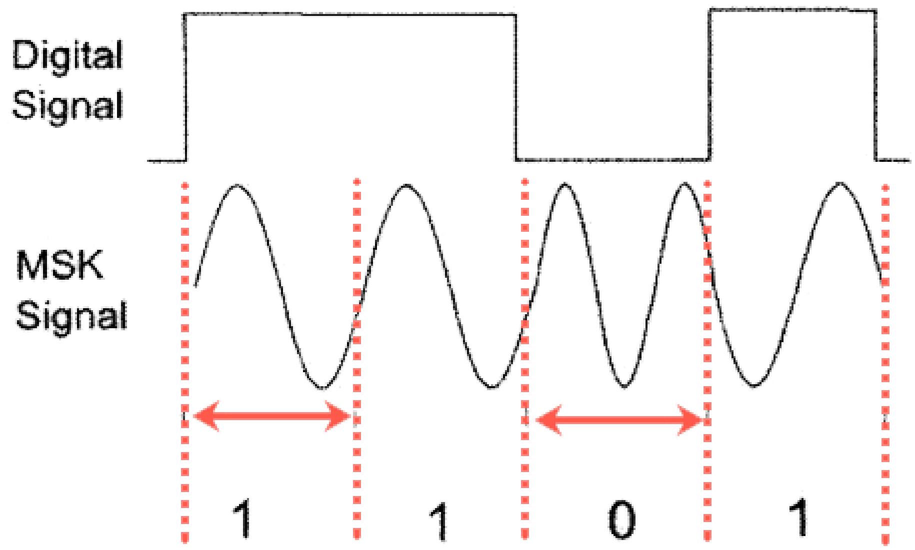
Alphabetsoupese – example 2

Here's another instance of YMN³TKT (You May Not Necessarily Need To Know This), but you'll come across these acronyms.

When transmitting, D-STAR modulates the frequency (encodes it onto the carrier wave) using Gaussian Minimum Shift Keying (GMSK), while DMR uses Four Frequency Shift Keying (4FSK), and System Fusion uses Continuous 4-level Frequency Modulation (C4FM).

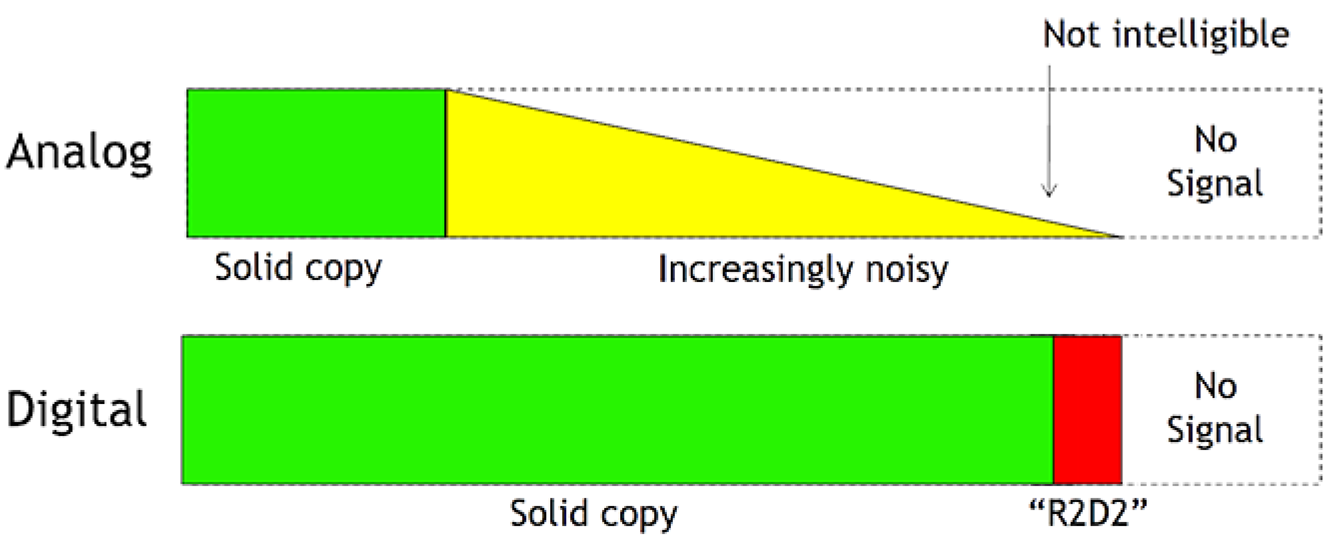
The Gaussian filter (named after mathematician Karl Gauss) that is used for GMSK creates a rounded, normal distribution waveform, which results in a narrower and more efficient bandwidth signal. The Minimum Shift Keying shifts the frequency of the signal to distinguish between zeros and ones.

The following illustration, to which I added red lines and arrows for clarity, shows the original digital signal and the resulting modulated carrier wave. You can see that a digital one was converted to one sine wave, while a digital zero was converted to 1.5 sine waves.



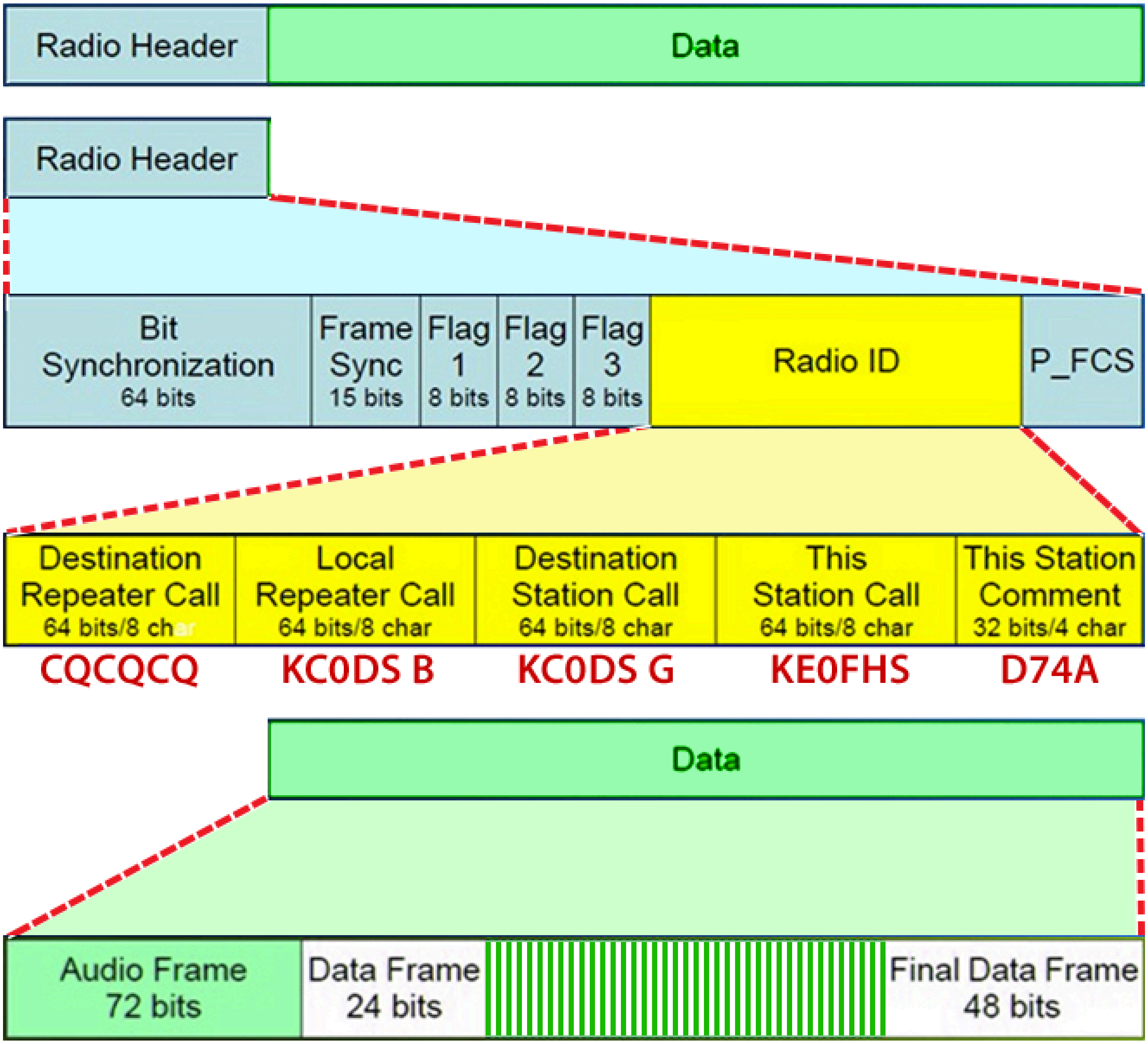
Example waveforms for MSK modulation, with
a digital input signal and the resulting MSK signal,
from A Look inside D-STAR Modulation
by Bob Witte, K0NR

Why is GMSK a good choice for amateur radio? In Intro to D-STAR, George Zafiropoulos, KJ6VU, states that it's relatively simple, which translates to lower cost, uses bandwidth efficiently, and the resulting signals have constant amplitude so they're not affected by amplifier nonlinearities, which translates to less noise, as he shows in the following diagram. "R2D2" refers to when a digital signal deteriorates and starts sounding like the character from the movie.)



Another couple of acronyms are for the multiplex method (how the signals are combined): D-STAR and System Fusion use Frequency Division Multiple Access (FDMA), while DMR uses Time Division Multiple Access (TDMA).

Here's another diagram derived from Intro to D-STAR that shows the digital format of D-STAR's 4800 bits per second (bps) signal, to which I added an example of my radio ID data:



When the digital voice signal is being transmitted, the 72-bit audio frames and 24-bit data frames alternate until the audio transmission is complete, after which a final 48-bit data frame is transmitted, signaling the end of the transmission.

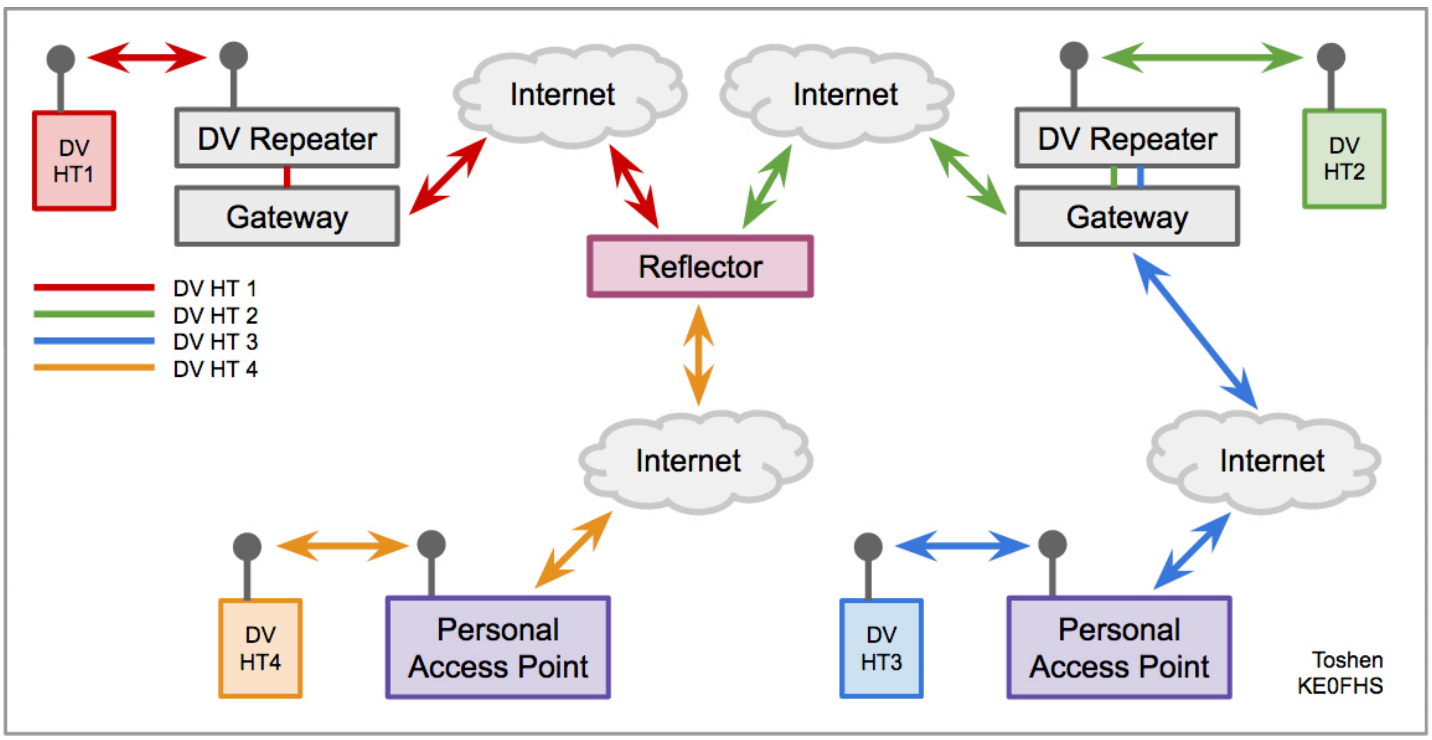
Note: At the beginning of his presentation, George Zafiropoulos, KJ6VU, thanks John Hays, K7VE, Debbie Fligor, N9DN, and Dan Smith, KK7DS for content he took from their presentations, but he doesn't specify which content each contributed. So I'll thank them all, too, in case these diagrams originally came from them.

More murky soup: Because of all of these acronyms, you'll see Yaesu System Fusion (YSF) sometimes also referred to as C4FM or C4FM-FDMA. I told you the alphabet soup can get murky!

1d) Hotspots (Personal access points)

This is where it gets really exciting and fun, at least for me. One more piece of the puzzle is figuring out how to get onto the digital system when you're not within radio range of a digital voice repeater.

Fortunately, there are innovative hams creating personal, low-power hotspots and software that enable a ham with internet connectivity to link directly to reflectors or DV repeaters (again, typically using DR or Duplex mode), bypassing the need to transmit from the radio to a DV repeater first. Basically, these hotspots act as your own personal repeater and gateway.



Example of DR mode setup for linking to a reflector via a hotspot:

```
Radio:   DV HT4
Freq:    446.2250
UR CALL: REF030CL
RPT1:    KE0FHS B
RPT2:    KE0FHS G
MY CALL: KE0FHS
```

After linking to the reflector, everything is the same except:

```
UR CALL: CQCQCQ
```

For more details about the setup for using a hotspot, see:

First QSO via a reflector!
Linking to a D-STAR repeater.

There's another nice aspect of the personal, low-power hotspots: since you link directly to a reflector via a hotspot, you don't tie up a DV repeater the way you would if you use your radio to send a command to the repeater to link it via its gateway to a reflector for your personal call on that reflector. This may make a hotspot interesting even for someone who lives within range of a DV repeater.

Understanding repeater and reflector modules

When you use a DV repeater, or link to a reflector, you use a specific module (a.k.a, port, node, or room), for example, module C on reflector REF001 = REF001 C, which, by the way, can be a lively gathering place for international chats.

From *Nifty E-Z Guide to D-STAR Operation* by Bernie, N6FN:

> The agreed upon practice for naming these modules is to add a letter designating the individual port after the main callsign for the system. Regardless of the length of the main callsign, the port designation is always placed in the 8th character position, preceded by as many spaces as necessary to fall in the 8th position.[2]

[2] *Exception:* When you send a command to link to a repeater or reflector, the module letter is placed in the 7th position and the letter L is placed in the eighth. More on this later.

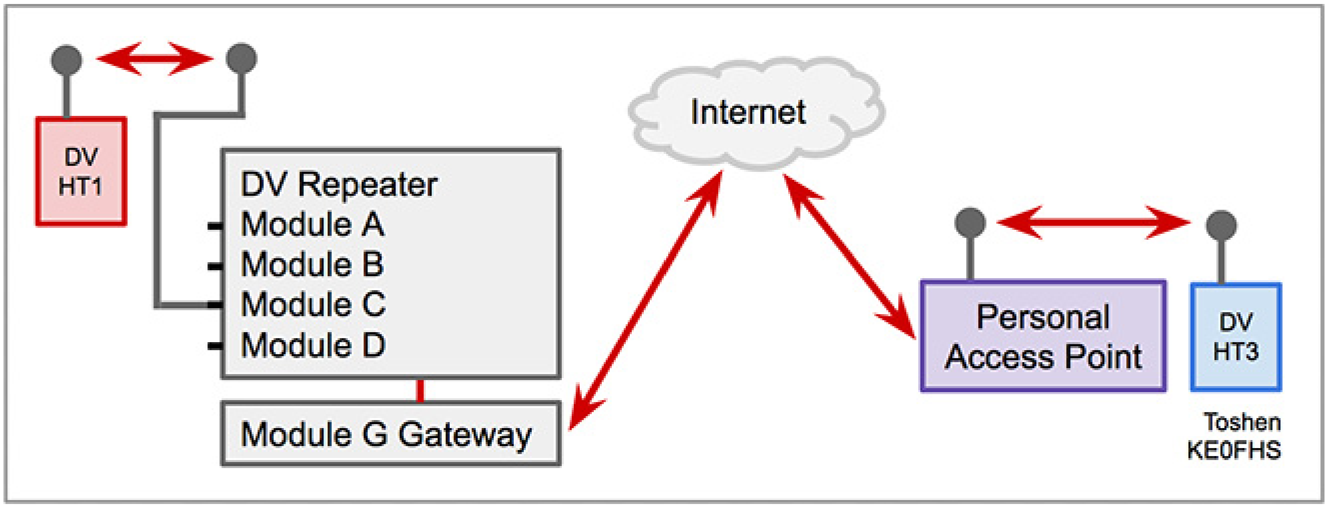
D-STAR repeaters typically have three modules for voice, and possibly an additional one for data. A repeater can be set up to use modules in various configurations, so you should double check the setup of any repeater you're going to be linking to; however, often they're used as follows:

Module A = 23 cm
Module B = 70 cm (UHF)
Module C = 2 M (VHF)
Module D = Digital data

Gateways are computer servers connected to repeaters that run software that enables them to act as "gateways" to the internet, enabling the repeaters to link to other remote repeaters and reflectors. They also enable hotspots to link to the repeaters via the internet.

Module G = Gateway

Here's a simplified view showing DV HT1 transmitting to and receiving from module C, while DV HT3 is using the gateway:



Note: When you link to a repeater via a hotspot device, the frequency of the module doesn't affect your ability to link, since you're linking via the internet, not RF. However, it still does matter since it affects who can hear you among the hams who are monitoring the repeater via RF. If you want to chat with hams who are monitoring the 70 cm module, you need to link to that module.

Trust system. Some U.S. gateways are registered with the USRoot Trust system (also referred to simply as US Trust or the Trust system), which is how callsign routing and other information is synchronized between the repeaters within the trust system. That way, for example, the entire system knows which repeater you were most recently active on.

Reflector modules are like chat rooms

Reflectors are a type of network server, and you can think of their modules as chat rooms:

- REF and older generations of XRF reflectors have five modules, A - E, where E is a special module for echo tests.
- XLX reflectors, DCS reflectors, and the latest 4th generation of XRF reflectors each have up to 26 modules, A - Z.

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