Untangling Digital Voice Above 50 MHz

D-STAR, DMR, C4FM, P25...it's an alphabet soup of choices in the VHF+ world.

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No doubt about it — comprehending the sheer variety of FM digital voice modes is a daunting task. Within 50 miles of my home in Massachusetts, there are five different digital technologies running on various repeaters. None of them are compatible with any of the others. Your results may vary, but if you are living in a reasonably populated area, chances are you have at least one or two digital systems within radio-shot of your house or commute.

If you're thinking of making the leap from analog FM to digital, the system that is best for you will depend on several factors. The most important question to ask is the most obvious: which modes are active in your area? Without a compatible digital repeater, you'll be confined to simplex operation. While there's nothing wrong with that — and many will say they prefer simplex — without a reasonably capable station you will be limited in range. Pick up a copy of the *ARRL Repeater Directory* or *TravelPlus* and see what digital repeaters are active in your vicinity.

As you explore the world of digital voice above 50 MHz, you'll hear about a number of different technologies. Fortunately, the list of those you are likely to encounter is fairly short:

An Icom ID-5100A D-STAR transceiver.

A Motorola mobile DMR rig.

The Yaesu FTM-400D System Fusion C4FM transceiver.

An Icom hand-held P25 transceiver.

Kenwood's NX-740 "NEXEDGE" NXDN transceiver.

APCO 25: Also referred to as simply "P25," this is an older technology that is found only in commercial land-mobile transceivers.

C4FM/System Fusion: While there are commercial versions of C4FM technology, the Amateur Radio implementation is provided by Yaesu as part of its "System Fusion" hardware. This is the newest Amateur Radio-centric digital system.

D-STAR: The most established digital system at the present time. Based on an open protocol developed in Japan, D-STAR is most often found in Icom products.

DMR: Digital Mobile Radio, or DMR, is an Amateur Radio adaptation of commercial land mobile technology. When this article was written, DMR was available only in commercial-grade transceivers. DMR has been increasing in popularity due to its somewhat lower cost and its spectrum efficiency. More about this later.

NXDN: Another commercial system that has been adapted to Amateur Radio use. NXDN is rather uncommon in the ham world, with a limited number of repeaters available.

If you have more than one mode present in your area, you will also want to know what sorts of interests are represented on the local repeaters. It is common for digital networks to be informally dedicated to certain interests. If you're interested in talking about DX and the local digital repeater talk is all about computer gadgets, you may feel out of place.

Linking and Group Communication

One of the biggest differences between digital modes is the linking capabilities of their repeaters. Linking is important because it can greatly expand the reach of your radio from local, to national and even global.

Some digital systems have no inherent linking capability. Others can be made to work with existing infrastructure such as IRLP or EchoLink. Some systems have their own extensive linking system built right into the protocol.

D-STAR provides two types of linking. The first is call sign routing. You can program your radio with the call sign of the station you want to reach, and then transmit into a local repeater that is configured as an Internet gateway (most are). The D-STAR network will figure out the repeater that the other station is on and route your transmission accordingly. The second form of D-STAR linking is through "reflectors" where several amateurs can meet and converse in turn.

Some repeater owners choose to have their gateway repeater linked to other specific repeaters by default. D-STAR users can also program their radios to instruct a repeater to connect to a specific repeater. On most systems, this will override the owner's default. Reflector linking is very similar to analog linking where multiple repeaters are linked through one of several "hub" repeaters. However, the D-STAR system allows for easier reconfiguration and also allows D-STAR repeaters to link to almost any other D-STAR repeater, as opposed to analog where the linking arrangements are well defined.

Like D-STAR, the Digital Mobile Radio (DMR) standard supports one-to-one (or "private") calls. However, due to resource concerns, these are discouraged on DMR networks. DMR's primary linking mechanism is through *talkgroups*. If you are familiar with public safety or commercial talkgroups, this is the same thing. Provided the repeaters involved are configured to allow it, all users on a particular talkgroup can talk to and hear all other users in the same talkgroup — regardless of the repeater they are using. DMR networks such as DMR-MARC or DCI have established specific talkgroup numbers for certain purposes. For instance, DMR-MARC's talkgroup 3172/TS1 is "Northeast USA Regional."

One word of caution about DMR, though: a number of manufacturers make radios for this standard. The linking protocols between manufacturers, such as between Motorola and Hytera, may be different. Other than the linking issue, almost all DMR radios will work with all others, regardless of manufacturer.

Yaesu System Fusion supports linking via the Internet in a manner somewhat similar to D-STAR, although the full details were not available at the time of this writing. System Fusion also offers "digital groups," somewhat analogous to talkgroups.

Table 1
Feature Comparison of Commonly Available Digital Voice Transceiver Technology

	C4FM	DMR	D-STAR	NXDN	P25
Manufacturer	Yaesu	Motorola, Hytera, CSI, Vertex, others	Icom	Icom, Kenwood	Motorola, Tait, Johnson, others
Availability	Amateur dealers	Commercial	Amateur dealers	Commercial	Commercial
Avg. Cost[1]	$300 to $600	$150 to $450	$300 to $700	$400 to $800	$300 to $900
Display	Multifunction	Minimal	Multifunction	Minimal	Minimal
Analog FM Compatibility[2]	Yes	No	Yes	No	No
Front Panel Programmable	Yes	No	Yes	No	No
Software Programmable	Optional	Yes	Optional	Yes	Yes
Dual Band Models	Yes	Yes	Yes	No	No
Extended Receive Coverage	Yes	No	Yes	No	No

[1]Average costs are based on average dealer selling prices for hand-held and mobile transceivers. For commercial transceivers, the average cost is based on various models offered on online sites such as eBay. It is important to note that commercial transceivers may incur additional costs for programming software.

[2]Although a number of commercial transceivers are not analog FM compatible, some offer repeater systems that are capable of operating in "mixed" analog/digital modes. In addition, the Yaesu System Fusion transceivers are capable of detecting analog FM and switching operating modes automatically.

Transceiver Considerations

Another thing to consider when choosing a digital radio technology is the unique capabilities the transceivers may offer. This is where radios designed for the amateur market can be quite different from those intended for commercial users. See Table 1.

All D-STAR and C4FM Yaesu System Fusion radios are analog-FM capable and both have dual-band models available. In other words, neither of these transceivers locks you exclusively into the digital world. You'll still have the ability to converse directly with your analog FM buddies. (Some D-STAR and all Yaesu System Fusion transceivers can detect the presence of analog FM and switch automatically.) Both technologies also have detailed frequency displays and allow you to tune any RF frequency, tone access audio frequency, and so on from the front panel.

In contrast, P25, NXDN, and DMR transceivers are digital only. They are intended for commercial use, so they lack many of the features hams might find familiar. In addition, channel setup requires special hardware and software. Once you program one of these rigs, the only way to change the functions (such as their channel frequencies) is to re-program. For instance, if you've set up a DMR radio for the New York City area and travel to Dayton, Ohio, your radio may not be very useful without re-programming for the DMR systems in the Dayton area.

Unique Features

Some commercial-grade digital transceivers offer a *roaming* feature. This allows you to program your radio with a collection of linked repeaters in your area. If you begin to travel beyond the range of the repeater you are currently on, the radio will automatically switch your frequency to a different repeater linked to the same talkgroup. This allows you to continue your conversation virtually uninterrupted.

The Yaesu System Fusion rigs include the provision to quickly capture and transmit low-resolution photos. This is accomplished with an optional camera microphone. When you snap a picture, the radio will switch to full digital mode and transmit the image to the other station, where it will be displayed automatically.

Standards vs Trade Names

So far in this article I've taken care to use mostly generic system names for the various digital protocols. In reality, certain manufacturers have their own trade names. *MOTOTRBO* is Motorola's name for DMR. You'll hear that name used a lot among DMR-active hams. Hytera calls its system *Hytera DMA*. NXDN is also known as IDAS on Icom equipment and NEXEDGE by Kenwood.

Why Can't These Radios Talk to Each Other?

If there is one thing that all these digital systems have in common, it is the fact that they are not *interoperable*. That is to say, they can't talk to one another, at least not while operating in digital mode. To understand why, we need to begin with good old analog FM.

In an analog system, your voice is used to modulate the FM carrier of the signal. The carrier changes frequency, back and forth, at a rate equal to the frequency of the audio source. The amount of frequency by which it changes is proportional to the volume of the audio source. So, a 146.52 MHz carrier modulated by a 1 kHz sine wave, may go from 146.519 MHz to 146.521 MHz and back at 1000 times per second. If the sine wave were made louder, the carrier may go from 146.518 MHz to 146.522 MHz, still at 1000 times per second.

In a digital system, the audio source goes through three extra steps. Step 1 occurs when the analog audio signal is sent to an analog-to-digital converter (ADC). The converter samples the electrical waveform at a certain sampling frequency, let's say 8 kHz. At 8000 times per second, the ADC will generate a binary code representing the voltage of the waveform at the sampling instant. For argument's sake, let's say it's a 12-bit value. Thus, the lowest possible waveform voltage might be a value of zero, and the highest might be 2^{11}. At this point, we might use that string of zeros and ones to modulate the carrier — but this would be very inefficient. First, the sampling rate is higher than the highest frequency of our voice. Second, in our example those twelve bits would need to be sent for every sample — we'd be modulating at 12 × the sampling rate, or 96 kHz just to keep up with the sampling data. Fortunately, there is a lot of redundancy in human speech — so we don't need to use such a direct method.

In our next new step, we use our first new term: *vocoder*. All modern systems use a vocoder — and you will hear vocoder names such as IMBE, AMBE, AMBE+2, or Codec2. A vocoder consists of several band-pass filters which analyze the speech waveform and convert it to a set of filter parameters. These filters are not the familiar capacitor/inductor types. The filters are implemented as programs on a Digital Signal Processor (DSP), which takes the digital values and runs them through particular algorithms. The exact algorithm depends on the type of vocoder used.

The new vocoder-compressed/processed output is now ready for our third new step — and another set of varying possibilities — *data framing*. After going through the vocoder to reduce the number of bits, we are now going to add bits back. The rules for doing this are called the *protocol*. The additional bits provide information to the receiver — such as where the data stream begins and ends, error checking codes, and miscellaneous data, called *metadata*, which may contain information such as the station ID. The output of the framer then goes to the modulator.

At this point in the process we are quite far from analog voice and deep into the world of bits and bytes. Depending on the methods in use, we've left all hope of interoperability well behind us!

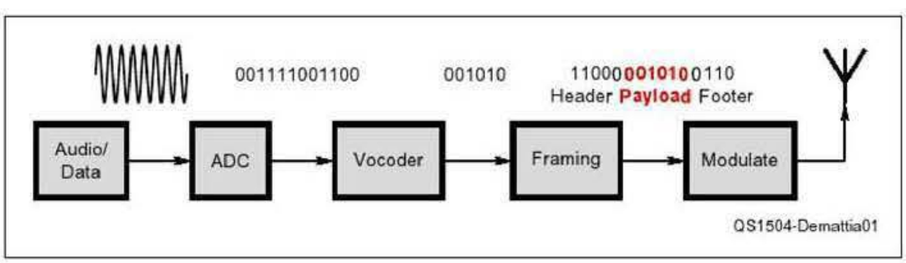

Figure 1 — From analog audio to a modulated digital signal.

Digital Modulation and Access

There are basically two things we can change in our RF carrier — its amplitude or its frequency. All current communications-grade systems vary the frequency of the carrier. APCO 25 (P25), NXDN, DMR, and Yaesu C4FM modulate to four different frequencies, thus they take two bits of the vocoder output at a time to select one of the frequencies. D-STAR modulates to two different frequencies, sending the vocoder output one bit at a time. In Table 2, the first digit in the modulation designator indicates the number of frequencies. "FSK" stands for *frequency shift keying*. "GMSK" stands for *Gaussian minimum shift keying*, which is a fancy way to indicate that the amount of frequency shift has been selected to occupy the least bandwidth possible.

Table 2
A Comparison of Digital Systems

Type	Codec	Modulation	Sharing	Access
P25 Phase 1	IMBE	4-FSK	FDMA	12-bit NAC
NXDN	AMBE+2	4-FSK	FDMA	6-bit RAN
D-STAR	AMBE	2-GMSK	FDMA	Call Signs
DMR	AMBE+2	4-FSK	TDMA	Color Codes
P25 Phase 2	AMBE+2	4-FSK	TDMA	12-bit NAC
System Fusion	AMBE+2	4-FSK	FDMA	Call Signs

You will note that the table has two more columns: "Sharing" and "Access." Sharing refers to how multiple transmitters share the spectrum. FDMA stands for "Frequency Domain Multiple Access," which means that different transmitters operate on different frequencies.

TDMA stands for "Time Domain Multiple Access," in which different transmitters operate on the same frequency, but at different times. This requires very accurate timing of the transmitters, but it allows DMR repeaters to carry two voice channels on the same frequency more-or-less simultaneously. If you are a user on a TDMA repeater, your transmitter only operates at 50% duty cycle, which saves battery power.

TDMA repeater systems are more spectral efficient than the other technologies we've discussed. A DMR repeater, for example, supports two communications channels within the spectrum required for a single channel D-STAR or C4FM system. This means that you can effectively pack twice the number of repeaters into any given amateur band.

The final column is "Access." In the analog world, CTCSS or DCS are types of access. To use an analog FM repeater, for example, you may have to program your transceiver to send a CTCSS tone, such as 77 Hz, along with your voice.

With digital technology, all of these factors — everything from encoding, to modulation, to access methods — combine to create systems that are essentially closed to any other method of communication.

The bottom line is this: if you try your hand at amateur digital communications on VHF+, choose your system carefully. As I said at the start of this article, explore the types of activities taking place in your area. Find out who is on the air, and what technologies they are using.

And if you discover that no activity exists, or at least none with the type of technology that is most attractive to you, consider becoming a pioneer. Gather some friends (or a club), purchase some hardware, and start having fun!

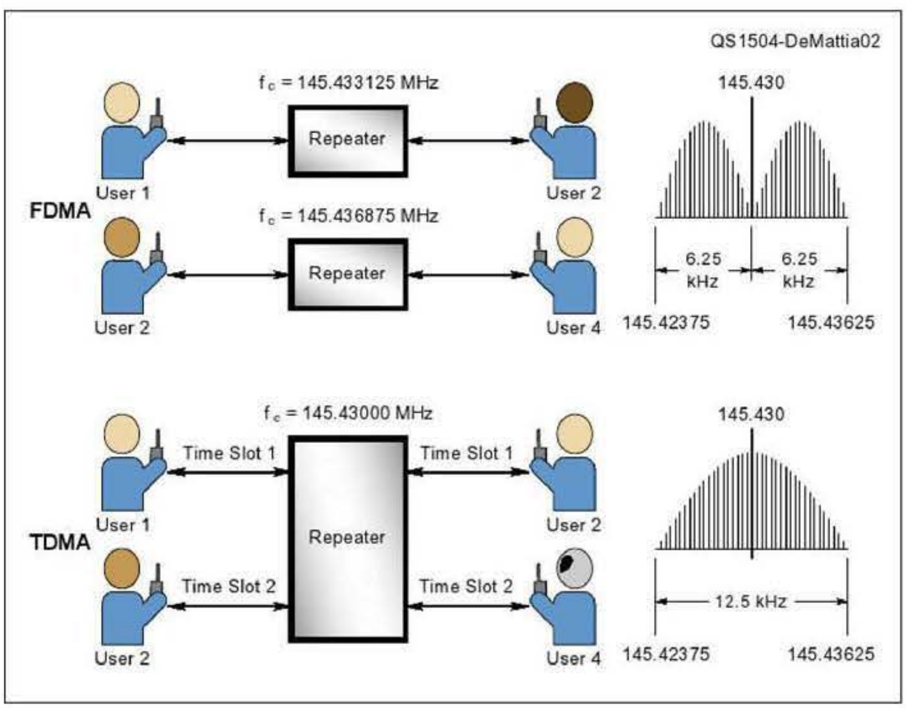

Figure 2 — Sharing the frequency: FDMA vs TDMA. With FDMA users must be on separate frequencies. In contrast, TDMA allows two stations to use a single frequency through precise allocation of transmit and receive time slots.

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