

# FM

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

# A Look Inside D-STAR Modulation

For the Winter 2006 issue of *CQ VHF*, I provided an overview of D-STAR radio technology. At that time, the technology was just starting to emerge onto the amateur radio scene, and the amateur radio community was just starting to understand how the technology worked. By now there are quite a few D-STAR repeaters on the air, and many radio amateurs have experienced D-STAR communications on the VHF and UHF bands.

As D-STAR enthusiasts have gotten their hands on the hardware, they have been experimenting with the various features. In typical ham fashion, the techies are reverse engineering and tinkering with the ICOM D-STAR equipment and in some cases even creating their own D-STAR designs.

### Block Diagram

In this column we'll examine the modulation scheme used in D-STAR, focusing on the signal-processing chain from the microphone to the modulator (figure 1). For digital modulation, we need to get the microphone audio into digital form and properly modulated onto the carrier, similar to analog modulation. In Figure 1, we see that the microphone audio is boosted by an amplifier to a suitable level for driving an *analog-to-digital (A/D) converter*. The A/D converter samples the microphone audio and converts it into

a series of digital numbers that represent the microphone waveform. The digitized audio is fed into the *vocoder*, which processes the waveform, still in digital form, to reduce the number of bits per second needed to represent the voice waveform. The vocoder drives the digital modulator circuit, which for D-STAR is a *GMSK (Gaussian Minimum Shift Keying)* modulator (more on that later). At the output of the *GMSK* modulator, we see the modulated *GMSK* signal, which drives the RF transmitter chain.

### GMSK

Before we dive into the topic of *GMSK*, we first need to review some other forms of digital modulation. One basic form of digital modulation is *Frequency Shift Keying*, or *FSK*. Radio amateurs have used *FSK* for decades, including using it to send radio teletype signals (*RTTY*) on the HF bands. The concept is simple: When the digital signal is a logical zero one frequency is output, and when the digital signal is a logical one a different frequency is output. The receiver on the other end has a demodulator circuit that detects the two frequencies and outputs the recovered digital signal accordingly.

A special type of *FSK* that is a little more efficient in terms of bandwidth is called *Minimum Shift Keying (MSK)*. *MSK* uses a frequency shift that maintains a specific relationship between the frequency of a logical zero and the frequency of a logical one: *The difference*

*between the two frequencies is one half of the bit rate.*

Mathematically, this can be expressed in terms of the *modulation index*:

$$m = \Delta f \times T$$

where:

$$\Delta f = |f_1 - f_0|$$

$$T = \text{period of one bit}$$

For *MSK*, the modulation index is 0.5.

Figure 2 shows this graphically, with a logical one creating a sine wave that just fits into one bit period. In this example, a logical zero has a higher frequency that fits *one-and-a-half cycles* into the bit period. Notice that the phases of the sine waves are controlled to prevent any phase discontinuities. Any discontinuities in the waveform result in a wider signal bandwidth, something that we want to avoid.

Conceptually, *MSK* can be created by driving an *FM* modulator with the digital signal, while maintaining a modulation index of 0.5. (The practical circuit implementation is likely to be more complicated than this, but we'll ignore that detail in this article.) The sharp edges of the digital input will tend to create a wide-bandwidth signal, so a shaping filter is often used to round out the waveform. When a *Gaussian filter* is used, the modulation is called *Gaussian Minimum Shift Keying*, or *GMSK* (figure 3).

Many different modulation formats have been developed for modern digital communications systems, each with their

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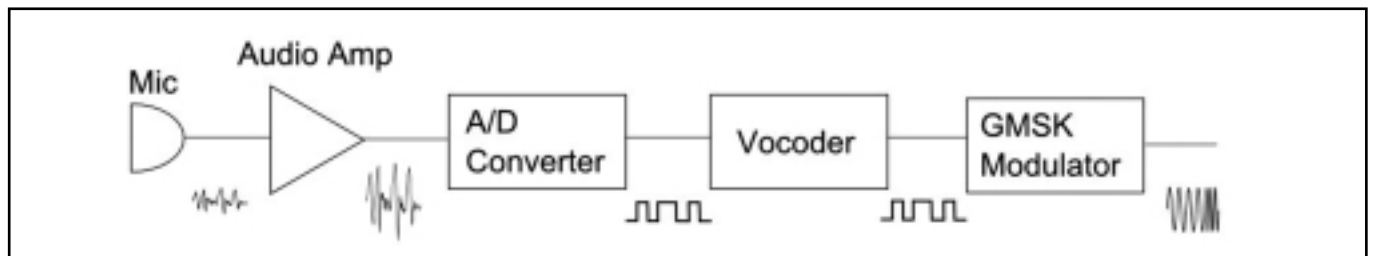


Figure 1. The simplified block diagram of a D-STAR modulation system.

own advantages and disadvantages. GMSK has some attractive properties that make it a good choice for mobile radio, including D-STAR. Compared to other digital modulation schemes, GMSK is relatively simple, resulting in a lower system cost. GMSK signals have constant amplitude, which means that GMSK is insensitive to amplifier nonlinearities. Higher efficiency Class-C amplifiers can be used to boost the signal without degrading the modulation format. (This is not true of some other digital modulation techniques.) GMSK also has good spectral efficiency, which is to say it packs a large chunk of digital information into a small bandwidth. The most common digital cell-phone format in use today (GSM) also uses GMSK.

It turns out that GMSK has quite a bit in common with good old analog FM. Both modulation formats produce a constant-amplitude signal, which makes them less susceptible to amplitude variations, including noise. All of the modulating information exists in the form of frequency/phase, and they both can use Class-C amplification.

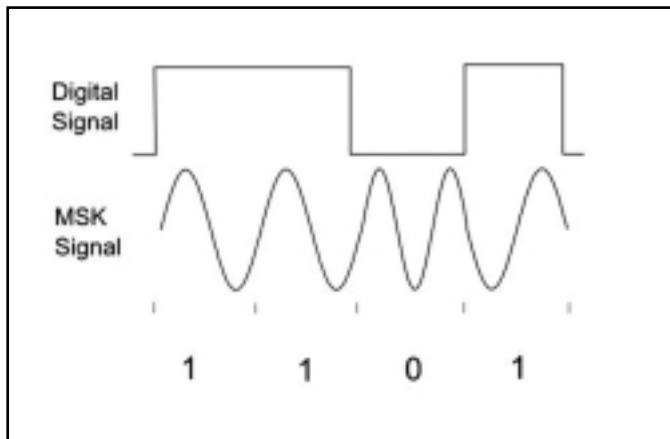


Figure 2. Example waveforms for MSK modulation, with a digital input signal and the resulting MSK signal.

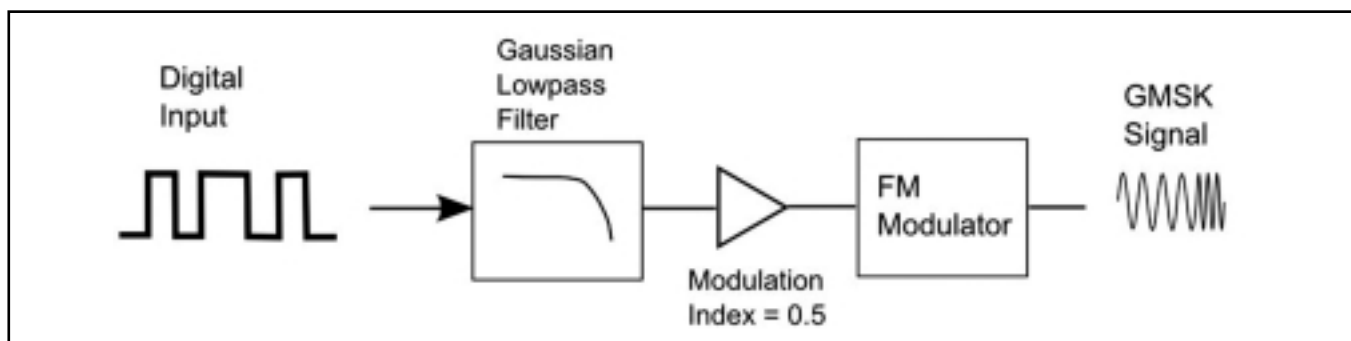


Figure 3. Simplified block diagram of the GMSK modulator.

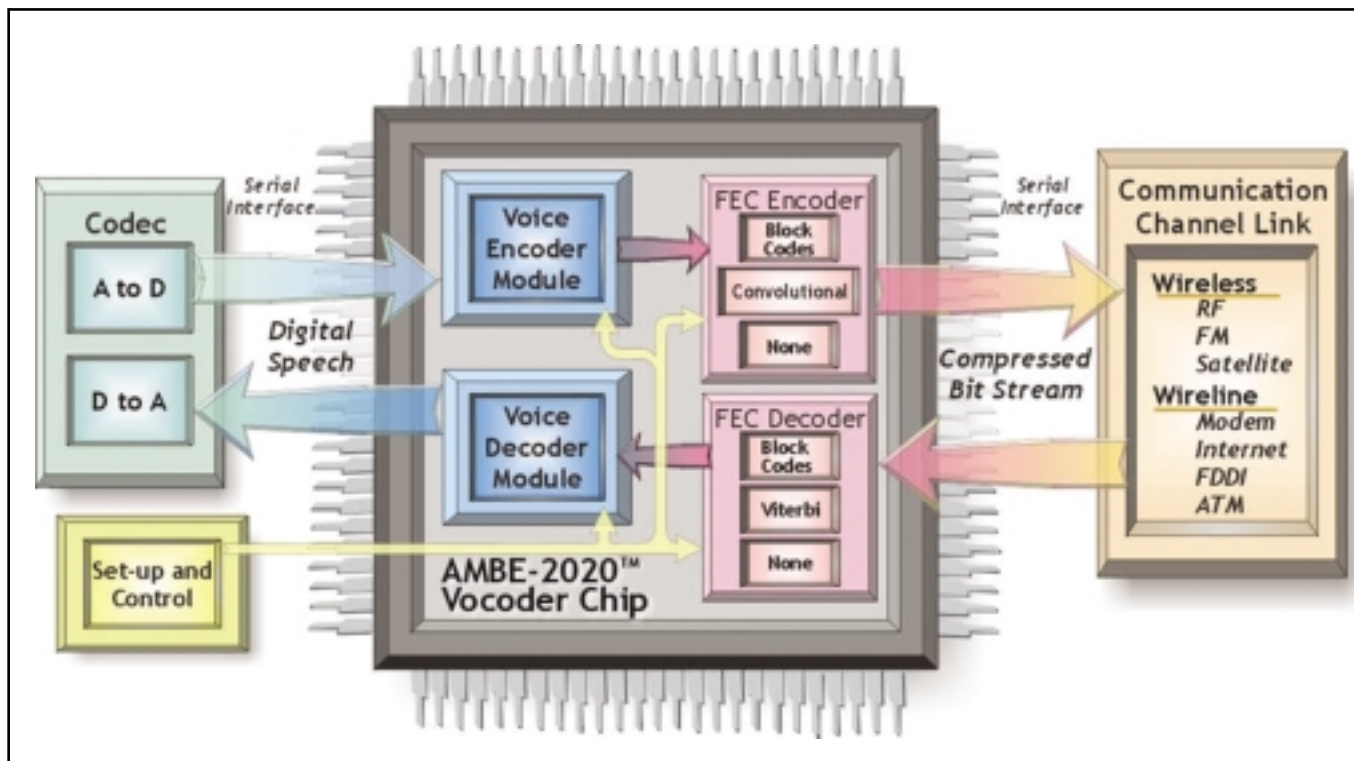


Figure 4. Block diagram of the AMBE-2020™ Vocoder. (Courtesy of DVSI, used with permission)



Figure 5. The IC-91AD is a dualband D-STAR handheld transceiver from ICOM. (Photo courtesy of rigpix.com)

One might be tempted to think that GMSK signals could pass through a conventional FM repeater, but in most cases this is unlikely. Conventional repeaters are set up for analog signals, rolling off the low-frequency response as they pass through the repeater, which distorts the D-STAR waveform. Some hams have been successful tweaking the frequency response of their repeater receiver-to-transmitter path for the express purposes of passing D-STAR signals, but your normal FM repeater will mostly likely not pass D-STAR. (The repeater may key up if carrier access is in use.) Just to be clear, D-STAR signals *cannot* be demodulated by conventional FM radios. D-STAR sounds like white noise on an FM receiver.

### Vocoder

The previous discussion describes how digital bits get modulated onto the RF signal, but we also need to pay attention to the number of bits per second we feed into the GMSK modulator. This has been one of the major challenges of radio communications using digital modulation—to keep the bit rate low enough to travel down a narrowband channel while still maintaining voice quality. The nominal

bandwidth for the DV form of D-STAR is 6 kHz wide and the A/D converter samples at 8 kHz. It is the job of the vocoder to cram 8 kHz worth of samples into this 6-kHz bandwidth. The vocoder takes the digitized analog signal and compresses it into the minimum number of bits required to keep it intelligible.

D-STAR uses the AMBE-2020™ Vocoder from Digital Voice Systems, Inc (DVSI); see figure 4. This vocoder uses a proprietary algorithm (Advanced Multi-Band Excitation, or AMBE®) to convert the 8-kHz sampled audio into a 3600-bps bit stream for D-STAR voice. This stream is combined with the 1200-bps data stream to produce the combined voice + data DV signal at 4800 bps. (We won't go into much detail here about the 1200-bps data stream other than to say that it can support a low-speed data connection simultaneously with the digital voice transmission.) In general, vocoders use the characteristics of human speech to create advanced compression algorithms to produce an intelligible and recognizable voice signal at the other end of the channel.

Like all vocoders, the AMBE-2020 has a noticeable “digital” sound to it, similar

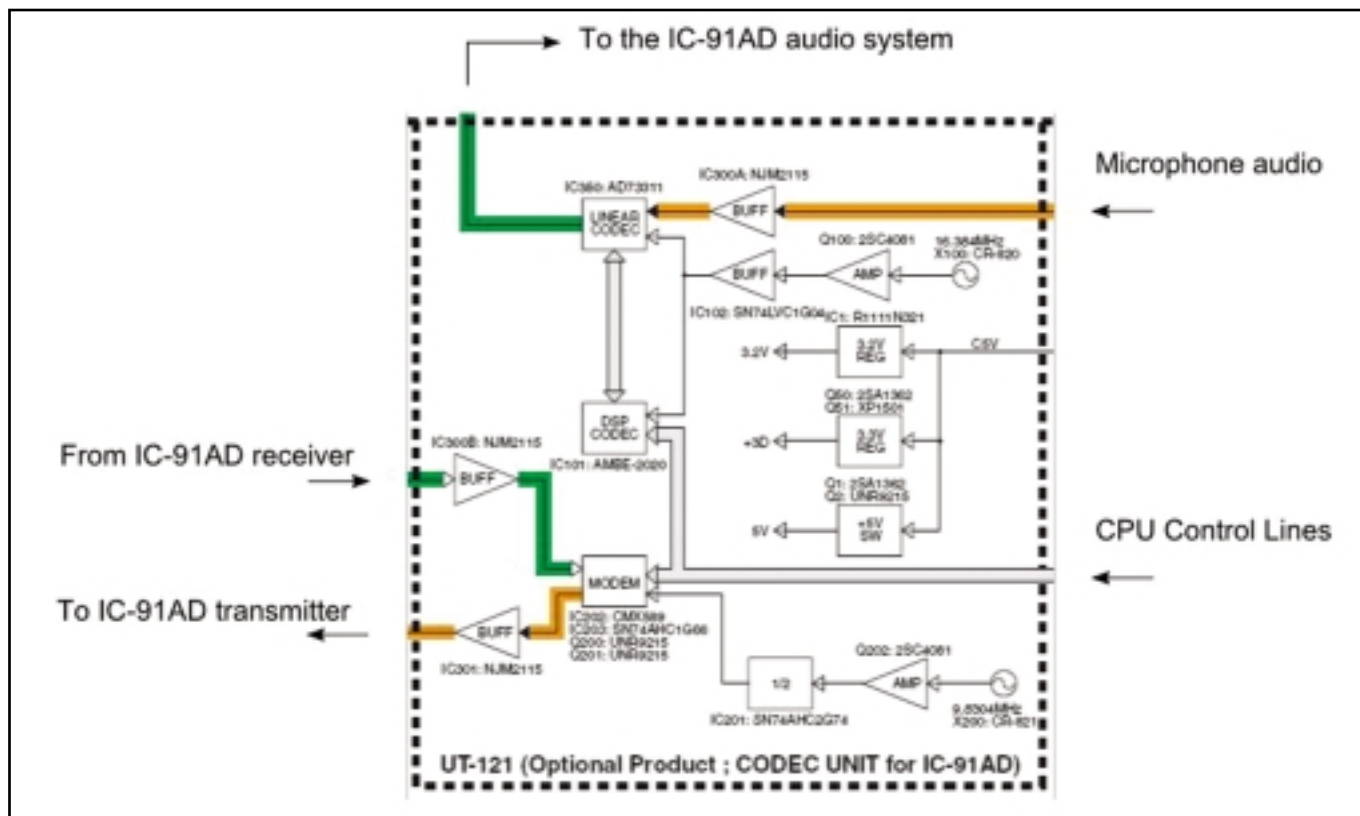


Figure 6. Block diagram of the UT-121, the D-STAR board used in the ICOM IC-91AD. (Copyright ICOM, used with permission)

to a typical digital mobile phone. To my ear, the sound quality is plenty good enough, although I agree that it doesn't sound quite as good as analog FM. These are *not* high-fidelity coding systems and are not very effective at handling anything but speech signals. Vocoders usually include special modes for capturing common signaling tones such as DTMF signals. The Utah VHF Society recently published some test results from transmitting non-voice signals over D-STAR, in an attempt to educate the amateur radio community about the characteristics of vocoders. (See the Utah VHF Society website listed in the References box.)

The AMBE-2020 implements *Forward Error Correction (FEC)*, which inserts redundant bits into the data stream so that errors introduced in the channel can be corrected. This is a common technique used in digital communications that allows the communication system to tolerate and correct low levels of errors in the digital transmission. Low levels of Bit Error Rate (BER) can cause a slight twang in the vocoder algorithm, but as the Bit Error Rate (BER) increases, the FEC will struggle to compensate, eventually falling apart. This gives us the experience of "going digital" when the audio breaks into a wacky, digitally-distorted noise.

Some hams have criticized the use of a proprietary vocoder in an amateur radio system. They argue that the spirit of amateur radio is experimentation and the choice of this vocoder gets in the way of that objective. For example, it would be really useful to implement the AMBE algorithm in software so that it can be deployed on a PC. Since the algorithm is protected by DVSI patents, the only legal choice is to buy the chip from DVSI. Some people have claimed that the chip is unaffordable, but they are available for approximately \$20 each, a reasonable price for an IC of this complexity.

## Typical D-STAR Design

Let's take a look at a typical D-STAR design, the ICOM UT-121, which is the D-STAR board used in the IC-91AD (figure 5). (This board is also the option that adds D-STAR to the IC-91A transceiver.) The block diagram of the UT-121 is shown in figure 6. At the top of the diagram, we have the Analog Devices AD73311, labeled "Linear Codec," which is a general-purpose mixed-signal interface circuit. It contains the A/D converter used to digitize the microphone audio, and the

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D/A converter for converting the received bits back into analog form to drive the speaker. Our discussion of figure 1 was about the transmitter path only, but there is an equivalent signal-processing chain that operates in the opposite direction—decoding the GMSK signal and extracting the original transmitted analog voice signal. The UT-121 has both of these signal-processing chains, with the major chips supplying functionality for both transmit and receive.

Near the left center of the diagram we see the "DSP Codec," which is the AMBE-2020 vocoder. The digitized audio from the AD73311 is fed to the vocoder to be digitally compressed and passed along to the GMSK modem chip below. The AMBE-2020 also decompresses the received bit stream and passes it along to the AD73311 to be converted back to analog form. The GMSK modem chip, the CMX589, is labeled "Modem" in figure 6. This chip provides

the GMSK transmit modulation and receive demodulation functions and interfaces to the RF sections of the transceiver. The other circuits shown in figure 6 are system clocks and power supplies required to support the ICs on the D-STAR board.

## Summary

This article provides a basic look at the modulation scheme used by D-STAR and the key circuits that make it work. My thanks goes to the many hams who are experimenting with the D-STAR mode and sharing their knowledge. One gathering point for these hams is the *dstar\_digital* Yahoo! Group.

Thanks for taking the time to read another one of my columns on the *Utility Mode*. I always enjoy hearing from readers, so stop by my blog at <<http://www.kØnr.com/blog>> or send me an e-mail.

73, Bob KØNR