

D-STAR, Part 3 of 3: Implementation

D'PRS™

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D-STAR, Part 3: Implementation

We've seen the "whys" and "hows" of D-STAR. Let's look at the hardware and possible uses for the system.

By John Gibbs, KC7YXD

This article, the final part of the series, investigates the block diagram and performance of the prototype equipment to better understand the design issues of a D-STAR digital radio.

The hardware used in testing the D-STAR standard is shown in Fig 1 and the performance of the mobile unit is summarized in Table 1. Some of this hardware is available today and we expect several manufacturers will offer hardware soon.

Recall that the D-STAR standard has only recently finalized the selection of the modulation and codec. Prototype testing demonstrated that GMSK modulation and the AMBE 2020 codec gives the best combination of spectral efficiency and robust communications.

The IF and RF parts of the block diagram (see Fig 2) of the ID-1 shows a straightforward dual-conversion

superheterodyne design that should look familiar to those experienced with analog rigs. However, several issues in a digital-radio IF are not clear from the block diagram.

IF Design Issues

The first issue with digital-radio IFs is that the group delay of the IF structure is critical. While analog radio designers can ignore phase linear-

ity, group-delay variations need to be less than about 10% of the data period to avoid excessive BER due to intersymbol interference.

The second issue with digital radio IFs is that IF bandwidth must be wider than that of an equivalent analog design. It must be wider so that significant energy does not fall near the band edges of the filter because there the group delay is not constant.

Table 1
ID-1 Specifications Summary

Operating frequency	1.2 GHz Amateur Radio Band	
Operating Modes (FDMA)	FM (analog voice) 0.5GMSK (digital voice / data)	
Data Rate	4.8 kbps (voice) / 128 kbps (data)	
CODEC	AMBE	
Data Interface	IEEE802.3 (10Base-T)	
RF Power	10 W/1 W	
Receive Sensitivity (typical)	FM 4.8 kbps GMSK Voice 128 kbps GMSK Data	-16 dBu -10 dBu + 2 dBu
Switching time	10 mS (digital mode)	
GMSK Modulation	Quadrature Modulator / FPGA (baseband)	

18225 69th Pl W
Lynnwood, WA 98037
kc7yxd@arrl.net

It often rises significantly and displays what are called “ears” (from their shape). This is particularly true in the receiver IF where transmitter and receiver relative-frequency tuning errors may cause the signal to be off center in the IF. Unfortunately, this increases the noise and interfering signals that pass through to the detector.

The quality of these IFs is measured by the sensitivity numbers in the specifications and in the “eye” diagrams in Fig 3. The well-open eye means that the receiver can easily distinguish between the plus and minus signal sent and therefore decode with very little BER. Fig 4 shows how the BER improves as S/N increases in the digital voice mode.

The final issue with digital radio IFs is the quality of the local oscillators. First, as implied above, the frequency reference must be accurate and temperature-stable if communication is to be established at UHF with a reasonably wide receiver IF. Second, the close-in phase noise of the local oscillators must be kept low, particularly if QPSK and other high-data-rate modulations are used. Excess oscillator noise can increase the BER just as effectively as actual channel impairments. One of the advantages of using GMSK is its relatively low sensitivity to these receiver problems, as shown in Fig 5.

Baseband Design Issues

The baseband hardware and modulators have far more obvious differences in this digital radio block diagram in Fig 2. For instance, on the transmitter side, the audio input is immediately converted to digital form, even if the radio is in the analog FM mode. This digital information is then signal-processed digitally and modulated onto the first IF. The modulation is accomplished by an I/Q modulator made with an FPGA. When teamed with DSP, an I/Q modulator is a very versatile component that can handle any form of modulation needed in the ID-1. It is even possible to produce narrowband-FM with the digitized voice. (The analog FM feature is desired for compatibility with existing analog radios.)

D-STAR Applications

D-STAR is very much a “blank slate,” waiting for amateurs to write upon it. We can exploit its capabilities for a variety of old and new uses. Here are a few of the many suggestions we have heard from the Amateur Radio community as possible applications of D-STAR.

Mobile and Portable Internet Access

The application that springs almost instantly to everyone’s mind is high-speed wireless Internet access. Part of the reason is that the Internet has become such an important communication and information tool in hams’ lives today. Another reason is all the hype built up around third-generation (3G) cell phones and the DOCOMO system in Japan. Yet, with today’s meltdown in telecommunication commerce, it could be years before a 3G phone system is deployed in the US. So, with the deployment of D-STAR, hams could once again have a leading technology that the rest of the population would envy and that might encourage more people to get their tickets.

In support of this vision of D-STAR as an Amateur Radio community growth agent, it is interesting to watch the reaction of inactive no-code hams. For a variety of reasons, they got their tickets, but never really got interested in the hobby. Often when they see a D-STAR demonstration, you can see their eyes light up and almost hear the gears turning in their head! Several

have said that a system like D-STAR would get them active again.

Because this is Amateur Radio, there will be some restrictions on this vision of high-speed wireless Internet. The FCC does not allow encryption, so there is no guarantee of privacy. Anyone can look over your shoulder and read your e-mail.

Some hams bring up the issue of advertising and pornography. Control operators will be responsible for the content passing through their repeaters exactly as they are today. However, this does not seem to be a very difficult issue. Inexpensive software exists today that can filter out this offending material. Control operators can easily incorporate so-called “kiddy filter” software into the repeater’s Internet interface. If the existing software does not quite fit our application, then resourceful hams will develop better software!

Then there is the issue of third-party traffic. Again, the control operator is responsible for ensuring that no illegal third-party traffic passes through his or her station.



Fig 1—Currently available hardware (counterclockwise, from upper right): RC-24 Control Head, ID-1 1.2 GHz transceiver, ID-RP1D 1.2 GHz data repeater, ID-RP1VS 1.2 GHz voice repeater, ID-RP1L 10 GHz backbone repeater and AH-1045/1080 parabolic antenna.

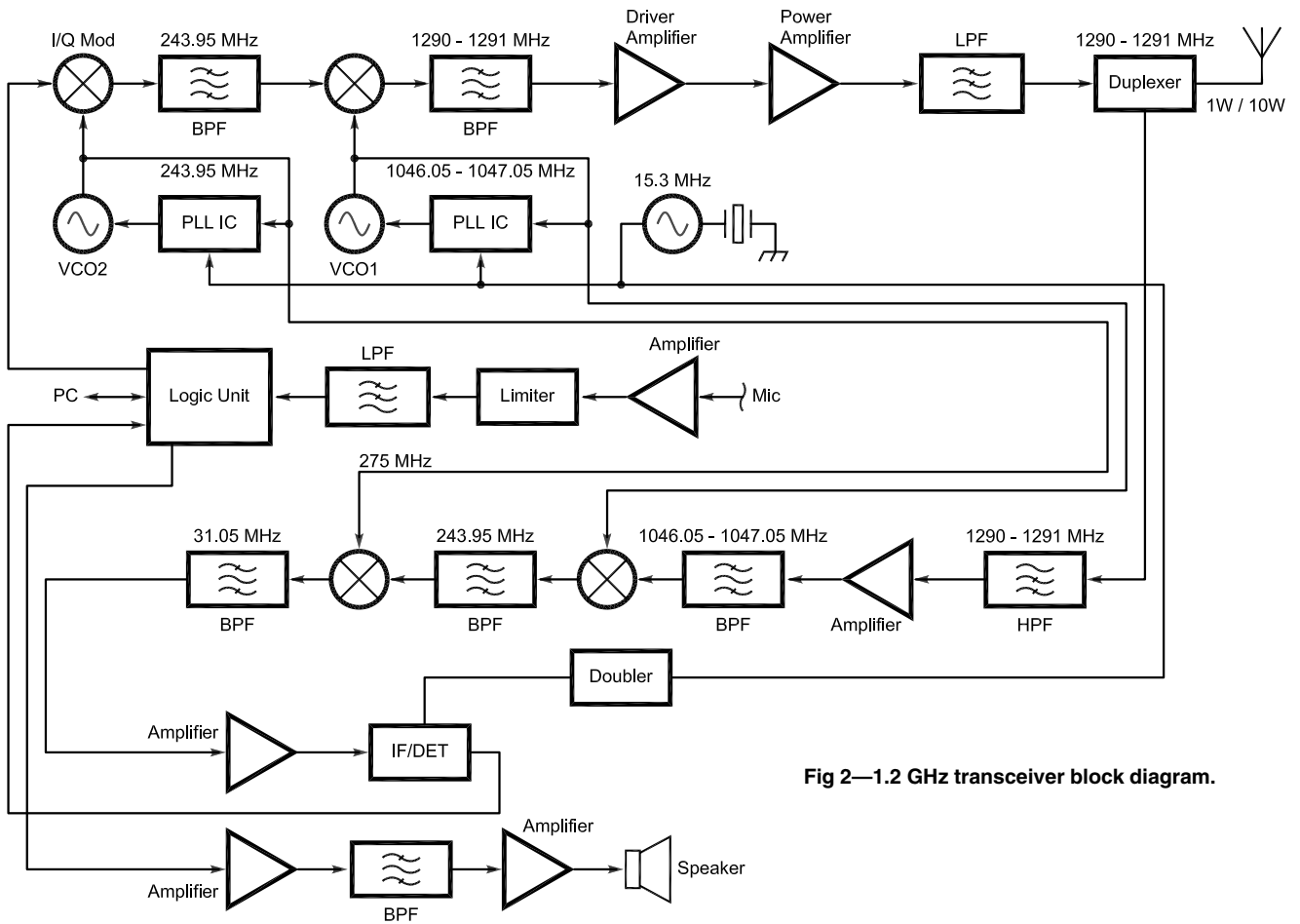


Fig 2—1.2 GHz transceiver block diagram.

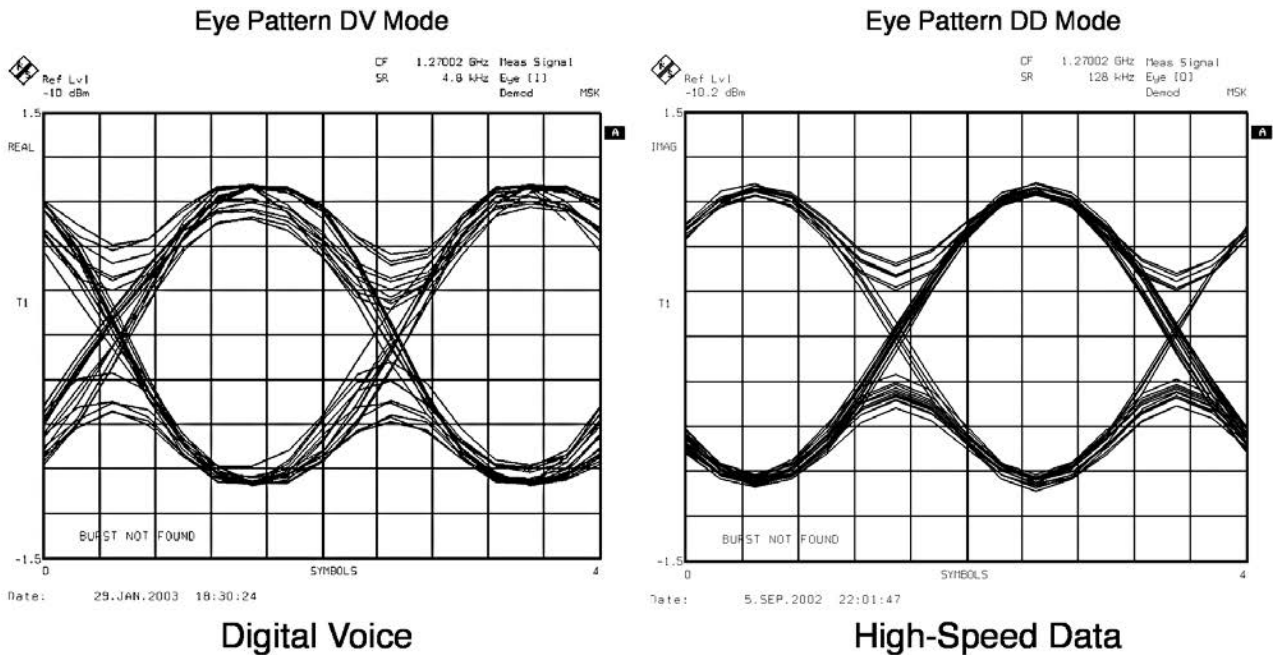


Fig 3—“Eye” patterns for digital voice (A) and high-speed data (B).

Combination of 802.11 and D-STAR

It would be surprising if manufacturers did not quickly develop a handheld D-STAR-compatible radio, but the high-speed data mode will necessarily have reduced range compared to a mobile rig with a good antenna and more power. What could you do if you wanted to connect a notebook computer to the Internet, but you are beyond the limited range of a handheld?

When hams have a range problem with handhelds on today's analog FM system, they sometimes cross-band repeat using their car's mobile radio. A similar solution could be implemented for high-speed data using D-STAR and a wireless LAN access point. A D-STAR mobile in your car could be cross-band (and cross-mode) connected to an access point installed in your car. Only an Ethernet cable is needed for this connection (no PC). If you already had a wireless LAN card in your notebook computer, you would be ready to go. Your notebook computer now has high-speed Internet access with the range of the high-power mobile.

Other High-Speed Data Applications

The Internet is so pervasive today that we sometimes forget that there are many other uses for high-speed data transmission. Here are two high-speed data applications that have arisen in D-STAR discussions.

Local Amateur Intranet: Rather than connecting to the Internet, a club-sponsored repeater could offer a wireless, wide-area Intranet. What might they put on the site? It certainly is a good place to make available the repeater system's operation guide and rules. To encourage D-STAR experimentation, it would be useful to have

posting of hams' experiences with the system as well as freeware and shareware that they have found useful in D-STAR operation.

Visitors to the area could download information they need, even at 3 AM. Are you looking for a good Mexican restaurant, or do you need a quiet motel away from the highway? The Intranet could have suggestions from other hams on file, and you could download maps, driving directions and even pictures.

The possibilities multiply enormously if your notebook computer has GPS. Now D-STAR can guide you exactly to your destination with accurate maps and directions that better reflect the local driving conditions than those provided by major services on the Internet. Local hams could help you avoid traffic problems caused by temporary road closures and accidents.

Emergency Communications: Another D-STAR Intranet application is

emergency communications. Even if the local D-STAR repeater were knocked out, temporary repeaters could quickly be assembled using two transceivers back-to-back. Training needs are minimized by using standard Internet browsers. When an operator comes onto the system, he can easily access stored files and bring himself up-to-date on the situation without distracting others.

Possible Add-Ons and Enhancements

We wrap up this discussion of the new D-STAR system with a treatment of the possible directions in which applications might evolve. D-STAR is not meant to be a turnkey communication system like the cell-phone system. Instead, it is an infrastructure that hams can use to meet current and future communication needs. Most importantly, it is a flexible, highly capable system that allows amateurs, them-

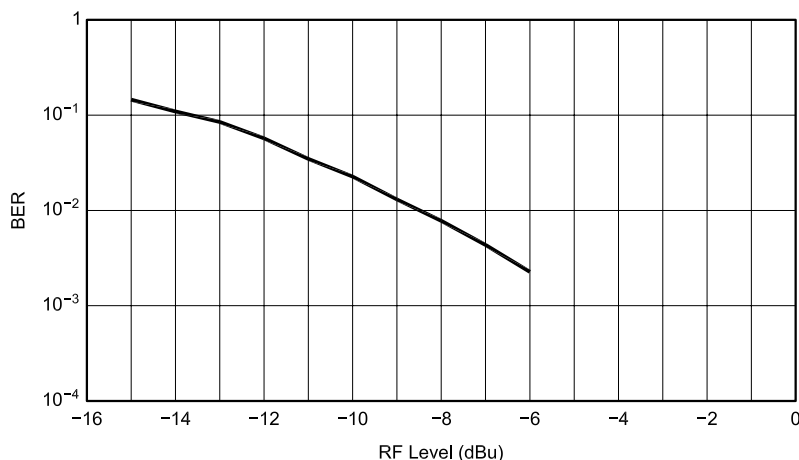


Fig 4—Bit-error rate versus RF level.

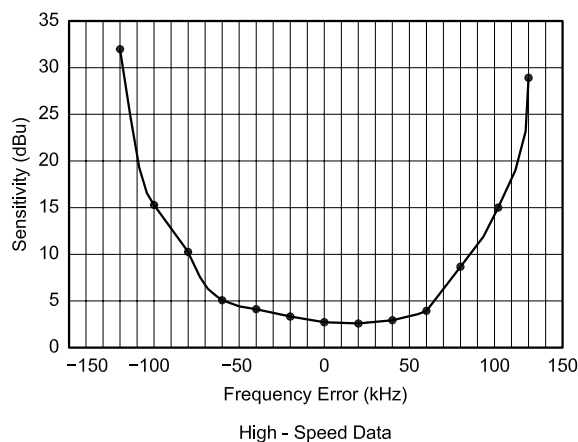
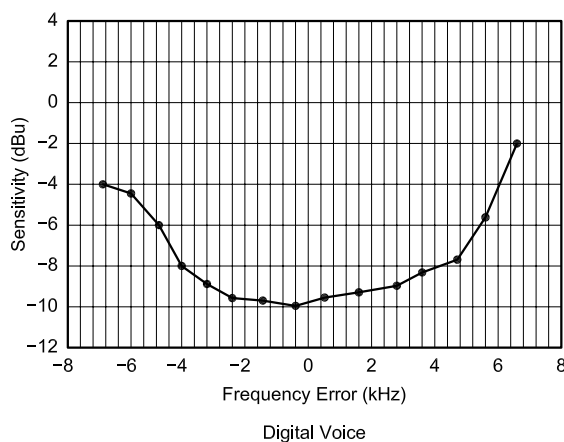


Fig 5—Frequency error versus sensitivity.

selves, to expand their service. Rather than depending on manufacturers to provide new features and applications, we expect the amateur community will develop add-ons to the system that will address the major goals of Amateur Radio including emergency communications, experimentation and just plain fun! Hams who have seen early demonstrations of the D-STAR system have generated the following ideas.

Power to the People!

We hams have our own opinions of how products should be designed and which features should be added. One of the great things about the D-STAR system is that for a large part, it is possible for us to try out our ideas and further the state of the art. Error correction is one area that is ripe for contribution by hams.

As data rates increase or as we push the range, decoding errors begin to be significant in any digital radio system. This is less of a problem for a properly designed digital voice system, because it is not significantly disturbed by BER levels that would render digital file transfers impossible. Yet any high-speed digital mode can use any help it can get.

Because of the importance of transferring data quickly and accurately, there has been a great deal of theoretical work done on coding and error correction. Tom McDermott, N5EG, gives a good introduction to the many coding techniques used in digital radio including Reed-Solomon, Golay and convolutional codes.¹ Newer codes called "turbo" codes have been developed that approach the theoretical limit on how fast information can be transmitted over a noisy band-limited channel.

However, these codes are only optimal if the interference is what we call AWGN (additive white Gaussian noise). This is true because the mathematics of AWGN is well understood. The bad news is that most of the impairments we find in real radio communications do not match this nice mathematical model. The good news is this is an opportunity for Amateur Radio to again advance the state of the art.

An interesting example of the possibilities of error correction is the ubiquitous CD player. A few years ago, I saw a demonstration of the power of the error correction used in CDs. The professor had drilled large holes in a CD and despite these obvious faults in the data stream, the music played perfectly without a click, pop or drop out! Perhaps some enterprising ham can discover the way to make just as

dramatic improvement in radio.

Interleaving Spreads Bursts of Errors

Wireless communication channels with fades of the signal power are prone to errors occurring in bursts. Burst errors can cause problems by breaking error-control codes when the number of errors exceeds the maximum number of correctable errors for the specific code used. For short bursts, intraframe interleaving improves performance by spreading the burst of errors over several different code words. For example, if four code words, each containing 23 bits that can correct up to 3-bit errors, are used in a frame consecutively, then a burst error 4 bits long will break a single code. However, if the four code words were interleaved (that is, bit 1 codeword 1, bit 1 codeword 2, bit 1 codeword 3, bit 1 codeword 4, bit 2 codeword 1, and so forth), each code word would contain only one error, which could easily be corrected. Since intraframe interleaving only modifies the bit ordering within the current frame, no additional delay is generally needed for implementation. If additional delay can be tolerated, interframe (more than just the current frame) interleaving can be used to further increase the performance with longer burst errors.

Mixed Voice and Data

As we saw in the section on the D-STAR standard, the proposed digital voice protocol has the ability to transmit low-speed user data simultaneously with voice. The first-generation D-STAR transceivers minimally support this feature. However, as new radios are introduced, it is expected that hams will develop applications that exploit this capability. Notice that in the D-STAR system, this is referred to as low-speed data. Yet the data rate is actually about 2400 baud, faster than the old 1200 baud of amateur systems (and yes, slower than the 9600 baud used in higher-speed systems).

What could we do with this feature? How about the equivalent of the Internet's "instant messaging"? With instant messaging, messages could be added by the sender or even from a third party (where legal) and added by the repeater. Imagine that you are in the middle of a contact when

- A DX alert displays on your mobile for a country you need, or
- A printer attached to your transceiver prints out route instructions to your club's Field Day site, or
- Your spouse sends you the grocery list and reminds you that the lawn needs mowing—well, maybe that

isn't such a good feature!

How about doing instant messaging one better and send instant pictures. The miniature cameras used recently in cellular phones are about 96×96 pixels; that is less than 10 kbits. So, a picture could be sent in less than 30 seconds simultaneously with a voice contact.

In a sense, this voice and data capability is like DSL: you can talk over the same channel while data are transmitted—although not at DSL speeds in this mode. The data you can send through this channel are limited only by your imagination. For instance, what do you think about mixing voice and next-generation APRS?

VoIP and D-STAR

VoIP voice communication is of course possible in the digital data mode because it does not matter what information is carried in the data. However, VoIP is not a very attractive method of communication via Amateur Radio today. It often suffers from poor voice quality scores due to the very long latency from the intensive signal processing and because the Internet does not give priority to voice packets.² These voice quality problems would certainly not be helped by the 128 kbps data rate of D-STAR.

Finally, VoIP on D-STAR is spectrally inefficient, requiring 130 kHz of bandwidth compared to less than 6 kHz for the highly compressed D-STAR digital voice mode. Still, for applications that require higher-speed data simultaneous with voice, inventive amateurs may find solutions to these problems.

Registration

The D-STAR proposal currently keeps a list of amateurs (call signs) who have accessed the system. So, if you want to call me, KC7YXD, you don't need to know the linking repeater. The system simply finds the repeater I last accessed and automatically routes your call to me. A logical extension of this capability is that if my radio is on the repeater frequency, the system can poll it and automatically register me onto that repeater.

This feature could be extended to keep a database at each repeater of each registered amateur's interests. How would our hobby change if you could call "CQ Collins radio collector" and automatically link to someone on the other side of the country or perhaps the other side of the world?

Roaming

Another feature that hams could add to the system is roaming. What if,

¹Notes appear on page 47.

when driving through an area, the repeater could download into the radio memory the frequencies and call signs of nearby D-STAR repeaters? Then as I drive away from the repeater, the radio is all set to access the next repeater. Never again sit down with a repeater book and program the radio before the next trip!

Of course, if we were to add GPS capability and the D-STAR repeater database held the footprints, calls and frequencies of adjacent repeaters, the radio could *automatically* switch repeater sites as you drive through an area!

Trunking

“Trunking” is a land-mobile-radio term for a system that uses multiple repeaters to support many contacts at once. Most trunking systems use a “home channel” for calling, then the system assigns a clear repeater frequency to complete the contact. The radios then automatically go to the assigned frequency. The basic advantage of trunking is that the system can support many more users simultaneously than with individual systems. Effectively, it lets one listen to all repeaters in an area by only monitoring

the home channel for a call. Since the D-STAR system sends call signs digitally, it is easy to envision a simple computer program that would monitor the home channel and alert me when I am being called.

Conclusion

Clearly, Amateur Radio is at a crossroads today. Technical and regulatory forces are pushing us out of our well-proven but inefficient ways. The possibilities that digital radio brings to our hobby are truly limited only by our imagination.

I hope this article has stirred your imagination and stimulated your interest in the possibilities of digital voice and high-speed data in Amateur Radio today. Perhaps you will be inspired to try the D-STAR system and maybe even develop applications or variations of the D-STAR system.

Recommended Reading

Visit www.dvsinc.com to read more about AMBE and to hear voice samples at various coding rates.

D.W. Griffin and J.S. Lim, “Multiband Excitation-Vocoder,” *IEEE Transactions on Acoustics, Speech and Signal Processing*, Vol 36, No 8, August 1988, pp 1223-1235.

Notes

¹*Wireless Digital Communications: Design and Theory*, Tom McCermott, N5EG, Tucson Amateur Packet Radio Corporation, 1996.

²The D-STAR digital voice mode addresses this problem by giving real-time data, such as voice, priority over repeater links.

At age 3, John exhibited early talents in electronics by “helping” his dad fix a TV. He plugged the speaker into a wall socket! Despite this traumatic start, he spent his youth building Heathkit and EICO equipment, repairing vacuum-tube radios and TVs and designing and building numerous homebrew projects including a Morse decoder high-school project built with resistor-transistor logic in the mid-1960s.

With BSE and MSEE degrees in control and communication theory, he has worked for Hewlett-Packard in the fields of spectrum and network analysis and frequency synthesis. He is currently the research department engineering manager at ICOM America, where his primary interests are digital communications and DSP. John has eight patents and is currently applying for four more.

An Extra class license holder, John usually is found on the HF bands, primarily operating PSK31. □□