HAM RADIO IN THE 21ST CENTURY

HAM RADIO TODAY DIFFERS GREATLY FROM THAT OF PAST YEARS, BUT IT STILL OFFERS **A FASCINATING WAY TO EXPLORE ELECTRONICS**. HERE'S A LOOK AT HOW IT HAS CHANGED AND WHAT IT HAS TO OFFER BOTH OLD HANDS AND NEWCOMERS ALIKE.

BY DOUG GRANT • K1DG

Many of today's experienced engineers got their start in electronics through amateur, or "ham," radio. (Many theories exist over the origin of the term "ham radio," but there is no consensus.) Over the years, however, the demands of these engineers' work, families, and communities took precedence, and many hams lost interest and let their licenses lapse. Meanwhile, with the rise of personal communications and Internet connectivity in homes, many young engineers never needed ham radio as a way to explore electronics. They've missed the opportunity that this fascinating hobby presents.

The first wireless communicators were by definition all amateurs. Guglielmo Marconi himself, generally regarded as the inventor of radio, once famously remarked that he considered himself an amateur. In the early days of radio, commercial, government, and amateur stations shared the same spectrum, sending broadband spark-generated transmissions modulated by on/off keying using Morse code to convey messages. This practice resulted in a horrendous amount of interference among services until the government stepped in and assigned various services to specific bands.

IMAGE(S): THINKSTOCK, SHUTTERSTOCK

Government and commercial stations were assigned the supposedly more useful, less-than-1500-kHz, long- and medium-wave spectrum, and the amateurs were banished to the less-than-200m wavelengths with frequencies higher than 1500 kHz. The experts of the day regarded these bands as worthless for long-distance communications.

The amateurs soon discovered that long-distance communications were actually *easier* at these frequencies. New allocations were then created to give government and commercial stations some of the "good" spectrum. However, a handful of slices of the spectrum were reserved for the amateurs. In the late 1960s, amateurs laid claim to all of the apparently useless frequencies higher than 30 GHz. Since then, as technology has marched on, other services have discovered that these frequencies are useful; amateurs currently enjoy exclusive rights to the frequencies greater than 300 GHz.

In the United States, Part 97 of Title 47 of the Code of Federal Regulations controls the amateur-radio service (**Reference 1**). It expresses the fundamental purpose of the amateur-radio service in the following principles: recognition and enhancement of the value of the amateur service to the public as a voluntary, noncommercial communication service, particularly with respect to providing emergency communications; continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art; encouragement and improvement of the amateur service through rules that provide for advancing skills in both the communications and the technical phases of the art; expansion of the reservoir within the amateur-radio service of trained operators, technicians, and electronics experts; and continuation and extension of the amateur's unique ability to enhance international goodwill.

AT A GLANCE

- The US amateur-licensing process no longer requires knowledge of Morse code—historically, a major impediment for many individuals.
- The signal-processing capabilities of a sound-card-equipped PC that connects to an HF single-sideband or a VHF FM transceiver have driven the emergence of new modes.
- Most high-performance HF and VHF transceivers now use digital-signal-processing technology for at least some of the modulation, demodulation, and filtering functions.
- Ham operators have always been enthusiastic tinkerers, often building their equipment from discarded pieces of consumer electronics they find in their neighborhoods.
- Ham radio brings new aspects to other hobbies, such as mountaintop hiking and orienteering.

LICENSING

Part 97 requires that amateur stations obtain licenses before they can transmit. The process for getting a ham-radio license has evolved over the years. Long ago, an applicant had to pass a rigorous technical exam that included drawing schematics from memory. The exams have changed considerably. All of the questions are now multiple-choice and cover technical, operating, and regulatory topics, and all of the questions and answers—both right and wrong—are available in the public domain. Furthermore, the governments of many countries—notably, the United States—have effectively outsourced the job of testing.

In the United States, volunteer examiners now administer the examinations. Volunteer-examiner coordinators arrange for testing sessions at convenient places and times (**Figure 1**). Upon successful completion of an exam by an applicant, the coordinators forward the required data to the Federal Communications Commission, which then issues licenses, with call signs—to identify each licensee and his or her location of license using a prefix and a suffix. In the United States, three classes of license now exist, each conveying a set of privileges, including permitted bands, modes, and power levels. Passing a more advanced exam entitles the licensee to more privileges.

The US amateur-licensing process no longer requires knowledge of Morse code for any class of license. This requirement has historically been a major impediment for many technically skilled individuals who were interested in ham radio but who could not or would not conquer Morse code. Ironically, the portions of the bands reserved for CW (continuous-wave) operation are busier than ever, as new licensees discover that narrow-band modes are more effective for weak-signal work than are wider-bandwidth modes, such as SSB (single-sideband) voice.

Many amateurs make contacts using voice modes, primarily SSB mode on HF and FM on VHF and UHF. The signal-processing capabilities of a sound-card-equipped PC that connects to an HF SSB or a VHF FM transceiver have driven the emergence of new modes. Even a modestly equipped PC has sufficient speed to generate and decode the FSK signals for conventional radio teletype. Experimenters have created modulation schemes and accompanying protocols, complete with forward-

Figure 1 A group of prospective amateurs meets at a license-examination testing session.

Figure 2 Yaesu's FTDX-5000 HF transceiver offers the highest receiver performance currently available.

Figure 3 The Elecraft K3 HF transceiver delivers high performance in a small package.

error correction, which enable direct keyboard-to-keyboard contacts even with low power and small antennas. The variety of FSK and PSK signals being used create unusual buzzing and chirping sounds when traveling to a speaker, and computers easily demodulate them and turn them into legible text. Some ingenious hams even use the PC's signal-processing capabilities to emulate the signals that World War II-vintage mechanical text-to-radio systems, such as Hellschreiber, generated.

Some hams also engage in transmission of full-motion video signals—usually on VHF or UHF bands, on which sufficient bandwidth is available. Others transmit still pictures on HF, using voice-bandwidth signals and a PC. Data networks have also evolved using various systems, including TCP/IP.

21ST CENTURY EQUIPMENT

Licensed amateurs can transmit in bands in the LF, MF, HF, VHF, UHF, and microwave bands. With a good antenna, amateurs' equipment can achieve worldwide communications on many of these bands.

Most amateurs buy their equipment from stores. Years ago, the best-known brands were mostly US companies, such as EF Johnson and Heathkit and the now-defunct Collins, Hallicrafters, and Hammarlund. Today, the most popular brands are mostly Japanese companies, including Icom, Kenwood, Yaesu, and Alinco (**Figure 2**). A few US manufacturers, such as Elecraft and FlexRadio, have entered the market in the past decade (**Figure 3**), and the first Chinese-made transceivers are beginning to appear, from manufacturers such as Wouxun.

The technology used in ham equipment has evolved significantly. Most high-performance HF/VHF transceivers now use digital-signal-processing technology for at least some of the modulation, demodulation, and filtering functions. A careful partitioning of both analog- and digital-signal processing achieves the best performance, and today's radios offer excellent sensitivity and 100-dB dynamic range, with digital-signal-processing-enabled selectivity. Although most radios still maintain the traditional format of a front panel with a large knob to control the frequency and lots of other buttons and knobs, some newer SDRs (software-defined radios), such as those from FlexRadio, abandon this tradition in favor of keyboard and mouse operation; they have no front-panel controls (**Figure 4**).

Handheld VHF FM transceivers have evolved to include multiband operation, embedded GPS, spectrum-analyzer displays to show signals on adjacent frequencies, and even Bluetooth. None have yet reached the level of sophistication of smartphones, but touchscreen-driven radios and Internet connectivity cannot be far off. Speaking of smartphones, hundreds of ham-radio apps are available for these devices, ranging from license-prep courses to satellite tracking to remote-station control.

However, not all hams buy their equipment off the shelf. Some prefer to build their own equipment. Ham operators have always been enthusiastic tinkerers, often building their equipment from discarded pieces of consumer electronics they find in their neighborhoods. Many hams understand concepts such as intermodulation distortion and phase noise, for example, because they have heard the effects of these signal imperfections, and they understand what happens when a nominally linear power amplifier enters hard compression.

Home-brewed radios can range from extremely simple transmitters and receivers to true state-of-the-art SDR systems. At the low end, one creative ham disassembled a compact fluorescent light bulb and discovered a high-speed, high-voltage switching transistor and assorted capacitors and inductors. By adding a 3.579-MHz TV color-burst quartz crystal, which sits conveniently in the middle of the 80m amateur band, he was able to construct a 1.5W CW transmitter from the parts (**Reference 2**).

Simple receivers are also easy to construct.

Figure 4 FlexRadio Systems' Flex-5000A software-defined radio has no front-panel controls at all.

Ham operator Charles Kitchin has developed a series of superregenerative receivers that are easy to build and that work surprisingly well (**Reference 3**).

The work of the High-Performance Software-Defined Radio Organization is at the cutting edge of radio design. This group has collaboratively developed a series of modules that use the latest high-performance components, including the RF amplifiers, mixers, ADCs, DACs, processors, and memory. For example, the Mercury receiver module enables direct sampling of the 0- to 65-MHz spectrum, using a 130M-sample/sec, 16-bit ADC and an FPGA to undertake digital downconversion. Open-source software performs all of the signal-processing and control functions, and the hardware also supports third-party software (**Figure 5**).

An engineer interested in developing his own SDR radio can build or buy an RF front-end/quadrature downconverter and connect it to the audio input of a PC and buy or write appropriate software for the demodulation and detection functions. Connecting the baseband in-phase and quadrature outputs of the radio to the left and the right inputs of the PC completes all of the hardware work. Some hams have constructed SDR front ends in the form factors of USB memory sticks and draw their power from those sockets.

For those more inclined toward classic analog-radio design, OpenQRP is an interesting project. "QRP" is a ham abbreviation for low-power transmitter (**Figure 6**). The creator of the group, Steve Elliott, call sign K1EL, has developed an open-source hardware and software design for a simple low-power CW transceiver. He uses an Atmel microprocessor in the popular Arduino prototyping platform for the human interface and various control functions and provides a PCB and complete kit of parts. Elliott documented his trial-and-error design as it evolved, and his blog serves as an excellent tutorial on radio design (**Reference 4**).

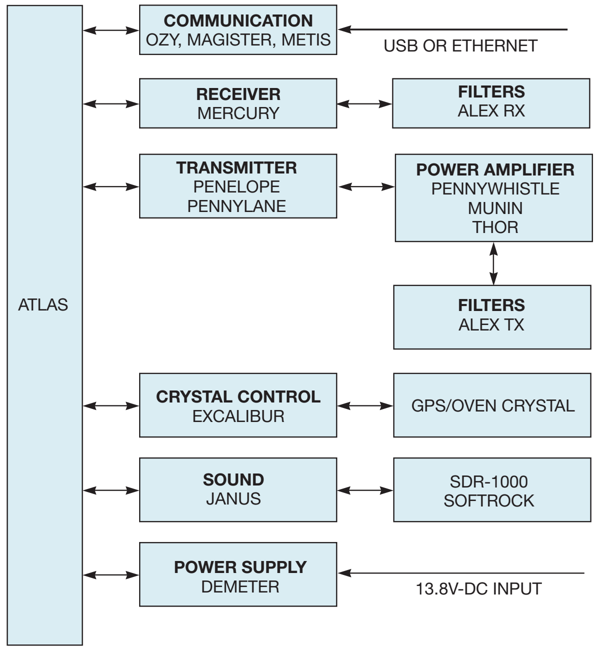

Figure 5 The OpenHPSDR provides a modular design for its open-source, collaborative software-defined radio.

THE STATE OF THE ART

Some segments of the ham-radio hobby allow you to impress your engineering friends, and maybe even your non-engineering friends. When you tell people you are into ham radio, they often ask, "How far can you reach with that?" The answer is complicated, and you may be able to give them some impressive answers. For nontechnical types, one answer I like to give is that, from my home in New England, my longest-distance contact for many years was Texas—the *long* way around. One morning about 20 years ago, I was operating on the 15m, 21-MHz band and had aimed my directional-beam antenna at Europe. A friend in Texas called in and said that he could hear me only when he pointed his antenna toward the Pacific. We tried various things and concluded that we were indeed talking to each other the long way around. HF propagation exhibits interesting behaviors at different times of day and season, and long-path contacts are relatively common.

Hams also experiment with other interesting and unusual terrestrial-propagation modes in the microwave region. In 2010, a group of French and Swiss amateurs took advantage of the evaporative duct—a horizontal layer in the lower atmosphere about 10 to 20m above the ocean's surface in which radio signals are guided, or ducted, and in which they experience less attenuation than they otherwise would. The amateurs used this duct to establish two-way SSB voice contacts between Cape Verde and Portugal at frequencies of 5.7 and 10 GHz—a distance of 2700 km, or nearly 1700 miles. Transmitter power was 15 to 25W, and the antennas were small—approximately 1m-diameter dishes.

A few years ago, Nobel Prize-winning astrophysicist Joe Taylor, call sign K1JT, developed the WSJT (weak-signal Joe Taylor) suite of protocols and modulation schemes for various types of VHF/UHF communications. Under normal circumstances, VHF and UHF signals can have path lengths of only a few tens or hundreds of miles long, depending on terrain, antenna gain, and power. WSJT changes that scenario.

One version of the protocol targets use in the RF-reflecting paths of ionized meteor trails, which last only a fraction of a second. It transmits a 30-sec-long sequence of four-tone FSK at a speed roughly equivalent to 100 words per minute, or 441 baud, in an effort to get enough bits over the short-lived path to enable an exchange of call signs and signal reports. Stations take turns

Figure 6 This low-cost, low-power continuous-wave transceiver uses a classic analog radio with a flexible programmable-control interface.

FOR MORE INFORMATION

Alinco
www.alinco.com

ARRL
www.arrl.org

Atmel
www.atmel.com

Elecraft
www.elecraft.com

Federal Communications Commission
www.fcc.gov

FlexRadio Systems
www.flex-radio.com

High-Performance SDR Organization
www.openhpsdr.org

Icom America
www.icomamerica.com

Kenwood
www.kenwoodusa.com

OpenQRP
http://openqrp.org

Wouxun
www.wouxun.com

WSJT
physics.princeton.edu/pulsar/K1JT

Yaesu
www.yaesu.com

transmitting and receiving, exchanging certain details to verify that each end of the path has successfully detected and decoded signals. Although the US military has for many years used meteor scatter, the mode generally requires huge antennas and high power to succeed. Taylor's system brings meteor-scatter communications to owners of relatively small stations.

Another WSJT mode is for earth-to-moon-to-earth, or "moon-bounce," communications, which uses the moon as a passive, and not very efficient, reflector. Signals at 144 MHz bouncing off the moon return to Earth about 2.5 sec later and approximately 250 dB weaker than when they left (**Figure 7**). That figure is not an error; the path loss is 250 dB.

Hams have for decades been bouncing signals off the moon, but only those with full-power transmitters, very sensitive receivers, and huge antennas could accomplish it using the traditional CW or SSB voice modes. Assuming a transmitter power of 1000W, or 60 dBm, and antenna gain of 20 dBi at both the transmitter and the receiver, the received signal is –150 dBm. A high-performance receiver can detect this weak signal in a narrow bandwidth. Amateurs have occasionally used the well-known 1000-foot radio-astronomy-dish antenna at Arecibo, Puerto Rico, for moon-bounce experiments. In the amateur band at 432 MHz, the dish has approximately 60 dB of gain and enables two-way contacts with simple stations on both SSB and CW modes.

Figure 7 A two-way contact through moon bounce uses free WSJT software.

Taylor's WSJT moon-bounce system uses a nearly one-minute-long sequence of 65-tone FSK modulation, with a considerable amount of built-in coding and error correction. Fortunately, the coding and decoding are well within the processing capabilities of a modern PC, which can decode signals 24 to 28 dB below the noise in a 2.4-kHz bandwidth. Stations with simple 100W transmitters and antennas no bigger than TV antennas now routinely make contact with stations many thousands of miles away, as long as both are able to "see" the moon.

Radio amateurs have also used other satellites besides the moon for communication. Over the years, amateurs have designed, constructed, and launched more than 100 satellites, which usually carry one or more beacons; telemetry channels for various housekeeping functions and student-experiment payloads; and one or more transponders, which use one amateur band for the uplink and another for the downlink. ARISSat (Amateur Radio on the International Space Station Satellite)-1 was launched during a spacewalk by two cosmonauts. Many astronauts and cosmonauts have held amateur-radio licenses. The ARRL (American Radio Relay League) ARISS program frequently arranges demonstration contacts between astronauts aboard the ISS and school groups. The ARRL has been the national association for hams for almost 100 years. It publishes a range of books on virtually every facet of the hobby, along with study guides and manuals.

Ham radio can add a new dimension to a hobby you may already pursue. Some hams combine orienteering with radio-direction finding in "fox hunts." The organizers hide a series of small radio transmitters in a designated area covering a few square miles, and the competitors must use a portable radio and directional antenna to locate each of the "foxes." The combination of technical skill and running ability makes for a competitive sport. Another activity combines mountain hiking with the ham-radio hobby. Hikers carry lightweight, battery-powered radios and portable antennas to take advantage of the excellent signal propagation possible from high elevations. Both operators who get on the air from many summits and those who contact them can win awards in this sport. In addition, many sailors get their ham licenses and install amateur equipment on their boats for recreation and as emergency backups if all other onboard radio systems fail.

For those who are active in their communities, amateur-radio groups often coordinate with local and regional public-safety agencies to provide emergency communications when all else fails. Although most wired- and wireless-communications systems rely on infrastructure that may not survive natural or manmade disasters, a ham operator needs only a radio, a battery, and a piece of wire to get on the air. **EDN**

REFERENCES

1 Part 97, Title 47, Federal Communications Commission, Sept 7, 2006, pg 587, http://1.usa.gov/oDDViH .

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3 Kitchin, Charles, "A Short Wave Regenerative Receiver Project," http://bit.ly/qm9UHu.

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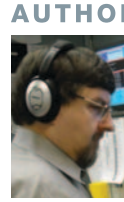

Doug Grant received his first ham-radio license from the FCC in 1967 and his bachelor's degree in electrical engineering from Lowell Technological Institute (now the University of Massachusetts—Lowell). He has more than 30 years' experience in the semiconductor industry, mostly at Analog Devices, where he worked in engineering; marketing; and product-line management for analog, mixed-signal, RF, and wireless products. He has logged close to 500,000 contacts with other radio hams in every country in the world. Grant is now an independent consultant specializing in semiconductor and wireless technologies.