Modes
3

United States Amateur Radio operators are encouraged by the Federal Communications Commission (FCC) to explore, investigate and experiment, with wide latitude. The government wants hams to try new things, test new ideas and push the capabilities of two-way radio-frequency (RF) communications. In this chapter, written by Brian Battles, WS1O, you'll learn basic information about the most popular amateur operating modes. You'll see what each one is used for and its advantages and disadvantages, and you'll get a general idea of the resources needed to try each one. Details of how radio signals are created and how those signals are made to carry information is explained in later chapters of this book. This is an introduction; the other chapters of this *Handbook*, the *ARRL Operating Manual*, *QST*, *QEX* and a whole Amateur Radio publishing industry cover the continuously evolving realm of Amateur Radio modes.

WHAT IS A MODE?

In Amateur Radio, a mode is considered to be any modulation technique that permits two-way communication with another station using an identical or compatible system to receive and demodulate it. If that sounds confusing, just think of a simple analogy, such as the way we use money in modern society: A certain amount of American dollars can be used to purchase an item that may also be purchased with an equivalent amount in Japanese yen. The dollar and the yen, however, are not directly compatible—you can't simply exchange them one for one. Yet they are both forms of payment for goods and services.

This is typical of most ham radio modes. You can talk over an FM repeater, but a person with a CW receiver who tunes to your frequency won't hear a thing you say. FM and CW aren't compatible. Most Amateur Radio operating modes are incompatible with each other, and each has advantages and disadvantages that make it worthwhile to select the best mode for the intended communication. Because its information is transmitted by varying the carrier frequency substantially, an FM signal uses a relatively large amount of RF bandwidth. On a relatively wide band such as 2 m (144-148 MHz, 4 MHz wide), many hams use narrow-bandwidth FM (NBFM). NBFM requires about 15-20 kHz of spectrum for each conversation (hams call them "QSOs"). Several such FM

Rick Castaldo, KD1BR, keeps in touch with his friends using 80-meter SSB.

signals would easily use up all of a narrow band such as 30 m (10.1-10.15 MHz, 0.05 MHz wide), and few conversations could take place at the same time. Other modes, such as single-sideband suppressed-carrier amplitude modulation (SSBSCAM, or SSB) and continuous wave (CW), require much less bandwidth. Here's the trade-off: while FM has enhanced audio fidelity and relatively little background noise, SSB and CW permit many more simultaneous QSOs in any given range of frequencies.

CW is the perfect mode for weak-signal work. John Shew, N4QQ, uses CW to operate EME (moonbounce) during the 1993 AMSAT Space Symposium.

The radio amateur has a variety of frequencies to select from when attempting to establish two-way communications. At the low end are the *medium frequencies* (MF), specifically the 160-m band (1.8-2.0 MHz). Then there are the *high frequency* (HF) or "shortwave" bands (80-10 m, or 3.5-29.7 MHz). The next steps up are the *very high frequency* (VHF) bands (6-1.25 m, or 50-225 MHz). Above these are the *ultra high frequency* (UHF) bands (70-23 cm, or 420-2450 MHz). Above all these are the *super high frequency* (SHF), *extremely high frequency* (EHF) and other segments, more simply referred to as *microwaves* (2900-250,000 MHz). The band you choose affects your signal's range (see the chapter on **Propagation**). But the mode you select is also important, for many reasons.

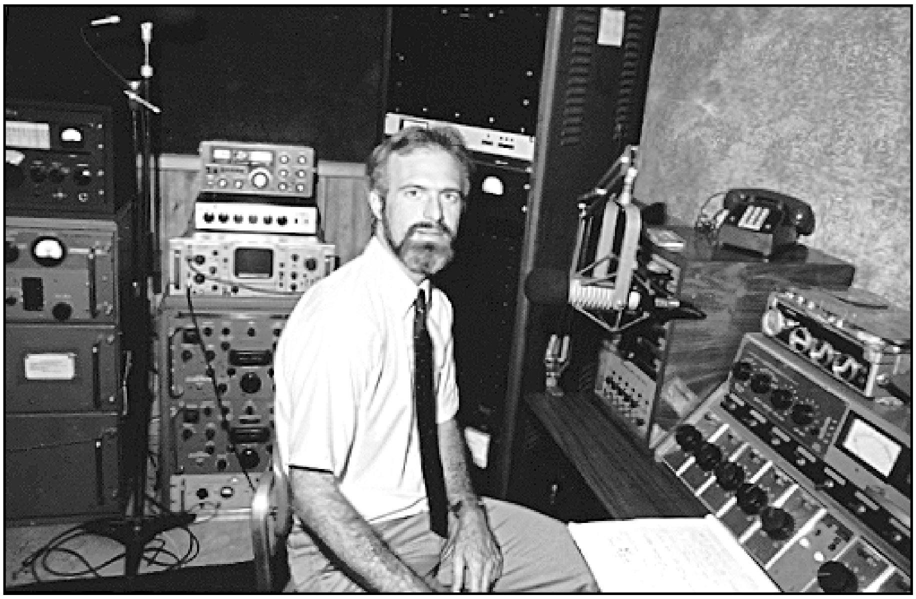
The key to successful Amateur Radio communications is *signal-to-noise ratio (S/N)*. This means you can communicate with anyone if your signals are loud enough to be heard through any noise present. Sometimes the noise wins; there's always *some* noise present on any radio frequency. Similarly, there's *some* propagation available to any desired location. The propagation path may not be sufficient to help conduct a weak signal halfway around the world, but theoretically, if you transmitted enough power, if there were absolutely no noise, you could contact almost anyone in the world at any time propagation conditions permitted your signal to reach its destination. The challenge in radio communications is to work within the practical constraints of your license privileges, budget, physical capabilities and atmospheric conditions to maximize your chances of being heard. If the S/N at the receiving end is sufficient, you will be heard. If the noise level is too great, you won't get anywhere.

Every portion of the radio-frequency spectrum exhibits its own unique characteristics of propagation and noise. For example, the MF or lower-frequency HF amateur bands are in a range that is particularly subject to noise. Frequencies below 5 MHz exhibit ever-present random atmospheric noise from storms, and the background of "hash" generated by man-made electrical gadgets, appliances and machinery is often very loud. If you live in an urban environment, it can be difficult to hear anyone most of the time, especially in the summer, when thunderstorms rage throughout your hemisphere. On the other hand, radio amateurs fortunate enough to live in rural settings far from factories, congested housing and other sources of noise can enjoy good reception on 160 m, especially in the winter, when thunderstorm activity is lowest.

In addition to considering the noise and propagation conditions on the various bands, an Amateur Radio operator must intelligently select the *mode* of transmission most likely to succeed. The factors of concern are (1) What modes can your transmitter produce? (2) What mode is the intended recipient using? (3) What mode will provide the receiving station with the best S/N?

The first is easiest to determine—just look in the manual or at your rig's front panel controls. The second may be more of a mystery. Unless you have some means of predicting the mode the other station is using, you must make an educated guess. The third requires an understanding of what each mode is best suited to accomplish and how to take advantage of its characteristics.

Let's examine factors (2) and (3). To make communications convenient, hams have established standard operating techniques that make it easier to choose a mode. For example, most amateur



Sounding like a broadcaster from radio's Golden Age, Paul Courson, WA3VJB, operates classic AM equipment from his well-equipped shack in West Friendship, Maryland. The setup doesn't just look like a broadcast station, it's used in Paul's work in commercial radio production. ***(photo courtesy of WA3VJB)***

voice communications on the 160, 80 and 40-m bands (1.8-7.3 MHz) are conducted via lower sideband (LSB), while upper sideband (USB) is the normal mode on 20, 17, 15, 12 and 10 m (14-28 MHz). On 2 m (144-148 MHz) and 1.25 m (222-225 MHz), the predominant mode is frequency modulation (FM) for voice and data communications. Above 420 MHz there is a mixture of FM and SSB voice communications, fast-scan amateur television (ATV), CW and experimental modes.

There are exceptions to these "rules." Data communications, such as radio-teletype (RTTY) and packet, are operated almost entirely on LSB at HF; DXing (long-distance communication) on VHF and UHF is mainly conducted using USB and Morse code; 10-m repeaters use FM. Aside from such exceptions, however, you can normally assume that stations operating voice on 20 m are likely to be using USB, a 2-m repeater is almost certainly using FM, and a packet station on 30 m will be running LSB. You should set your transceiver accordingly.

Once you know what modes are used by most operators on a given frequency, what frequency and mode should you select to have the best chance of establishing contact? You won't be heard unless your signal significantly exceeds the noise at the receiving end.

There are five main categories of communications in Amateur Radio: Radiotelegraph (Morse code), radiotelephone (voice), radioteletype (Baudot and ASCII RTTY and AMTOR), digital (packet, PacTOR, CLOVER, G-TOR) and image (SSTV, FSTV and fax). Let's look at the main Amateur Radio operating modes and compare their uses and characteristics.

CW

CW *(continuous wave)* is the oldest mode of ham transmission in use today. It consists of a plain, unmodulated RF signal (or "carrier") which is transmitted by the closure of a manual key or an electronic keyer circuit (sometimes called "on-off keying"). CW conveys intelligence through the International Morse code. (This is a variation on the American Morse code used by commercial telegraphers on wired lines in the late 19th century.)

The Sounds of Amateur Radio

Listen to a sample CW transmission.

AM

Amplitude modulation was the earliest technique used to transmit the human voice over radio. It was the dominant 'phone mode until the late 1940s and 1950s, when single sideband (SSB) came along. AM uses a full carrier with two modulated sidebands, and takes up a fair amount of bandwidth. In practice, two SSB signals or eight CW signals could be transmitted within the bandwidth used by one AM signal.

Morse Code: A Language, Not a Mode

Digital signals are those that can be represented accurately in terms of integer numbers. Morse code has been called the most basic form of digital radio communication. It involves nothing more than three elements: a short tone, a long tone and a space. In digital perspective, these could be represented by the numerals 0, 1 and 2. If all we can do is send separate elements, we are limited to three possible pieces of information. (In practice, there would actually be only two definite expressions, the 0 and 1, or short tone and long tone. A space by itself would be the same as no signal at all.)

Mixing and matching the tones and spaces created a system to denote letters of the alphabet, the digits 0-9 and a few punctuation marks. As a result, no individual character requires more than six elements to be unique and clear.

Language expressed in nothing but long and short tones (dahs and dits) has been in use since before Samuel F. B. Morse devised the American Morse system of telegraphy. In prehistoric times, it was discovered that a prearranged method of sending signals could use a small set of such symbols, yet be a potentially powerful means of conveying complex information. The arrangement of the signals (long/short, loud/soft, bright/dim, single/double, on/off) could be used to signify much more than just two alphabetic or numeric symbols. Morse and his colleagues developed a standard code that took advantage of the frequency with which certain English letters are used in language, and made efficient use of the way our ears and minds work. Learning Morse code is as easy as learning about 40 words in a foreign language. With practice, a "speaker" of Morse code can decipher a string of long and short tones and spaces at almost half the speed of everyday spoken English conversation.

Now that we have a language, we need a means to transmit and receive it at two separate locations. Wired telegraphy was the earliest means, but the invention of wireless radio transmissions less than 50 years later made it a simple matter of turning the transmitter on and off in a particular sequence to produce a corresponding sound at the receiving end. The first equipment used to create such radio signals were spark-gap transmitters. Spark transmitters sent an electromagnetically noisy pulse to a resonant antenna system where the pulse essentially reverberated until its energy was either radiated or dissipated in the resistance of the circuit. During the reverberation, the amplitude gradually decreased, so the result is a damped wave—a wave with changing strength. The part that was radiated became an electromagnetic field. The field was strong enough for a sensitive, specially designed antenna and receiver to respond to the electromagnetic bursts by rendering an audible sound in a headset or other transducer. As experiments continued, it wasn't long before the vacuum tube was perfected. By using a tube in a tuned electrical circuit, a transmitter could generate an almost-pure, constant unmodulated radio signal on a specific frequency. The signal generated by the tube was smoother and occupied much less space on the electromagnetic spectrum.

So how did the term *continuous wave* (*CW*) come about? Many beginning hams mistakenly think that it somehow means the transmitter is emitting a constant RF signal. But how could this be? Wouldn't this mean that each press of a code key actually breaks the circuit, rather than closes it? Of course, that's backwards. A code key closes the circuit when it's pressed (or squeezed, in the case of a paddle). No, the transmitted carrier is called *continuous* because it's not damped as were the spark signals; it's continuous in the sense that the RF sent when the key is pressed is transmitted as a single radio-frequency wave of continuous strength. CW is the simplest mode to implement in a radio. You can learn more about the principles of CW in the **Modulation Sources** chapter.

Because it's less spectrum efficient, it has been reduced to a "curiosity" on the air. There are many antique wireless enthusiasts who derive great joy from the warm, rich sound of a strong AM signal, especially when generated by a properly adjusted and maintained vintage transmitter. AM operators use specific frequencies on almost every amateur band, and most polite hams respect the rights of AMers to operate, just as AM fans avoid transmitting on portions of the bands generally used for SSB, CW, amateur television and digital modes.

FM offers clear, reliable voice communication. This is especially critical during public-service activities. Using FM portable transceivers and directional antennas, hams operate from the Command HQ tent at the Big Sur International Marathon.

ANGLE MODULATION: FM AND PM

FM is by far the most popular mode of Amateur Radio communication. The majority of newcomers to the hobby use FM transceivers to operate on VHF and UHF frequencies; the most popular activity is voice operation via 2-m FM repeaters. In fact, many amateurs who get their start on the air using 2-m FM and repeaters are unfortunately never exposed to other kinds of operation; they miss the pleasure of using other modes and bands. Considering that it's mainly limited to local contacts, the 2-m band offers reliable communication quality over a reasonably long range. Most VHF and UHF repeaters use FM, a great deal of direct, nonrepeater (simplex) traffic is conducted using FM, and there's an FM segment on the 10-m band (29.2-29.8). Above 30 MHz, virtually all amateur packet radio is conducted using FM transmissions. Repeater operation typically permits hams to use hand-held and mobile transceivers to make clear contacts over ranges of 100 miles or more. FM is a quiet mode, because the technique of angle modulation greatly minimizes the effects of static and noise. The trade-off is that a rather strong signal is needed at the receiver to produce the "quieting" effect that distinguishes FM communications.

Frequency modulation and its sibling, phase modulation, is accurately known as *angle modulation* because the frequency or the phase of a transmitted signal's carrier can be shifted to provide an "FM" signal. Amateurs use a form of FM called narrowband FM, which is about 3-20 kHz wide. This is just enough to afford decent voice communication. Commercial FM broadcast stations (88-108 MHz in the US) use wideband FM with 75-kHz deviation and 200-kHz channel spacing, which permits transmitted audio frequencies in the range of 50-12,000 Hz.

The Sounds of Amateur Radio

Listen to a sample FM transmission.

Table 3-1

Equipment Requirements for Amateur Radio Operating Modes

Mode	*Typical activity*	*Radio(s)*	*Antenna(s)*	*Other*
CW, HF	Ragchewing, contesting, DXing, traffic handling	CW transmitter/ receiver, Transceiver, single or multiband	Ranges from simple fixed wire antennas to tower-mounted rotatable, multi-element Yagis and phased arrays	Antenna tuner (optional) Tower (optional) Rotator (for Yagis) Amplifier (optional) CW key, paddles or keyer
CW, VHF/UHF	Ragchewing, contesting, DXing, satellites	All-mode transceiver	Omnidirectional vertical; long, extended Yagi ("boomer"), quagi or helix (depending on the application)	Tower or roof-mount for antenna desirable, Rotator (for Yagis) Key or paddle and keyer
SSB, HF	Ragchewing, contesting, DXing, traffic handling	SSB transceiver	Ranges from simple wire antennas up to tower-mounted, rotatable, multi-element Yagis and phased arrays	Antenna tuner (optional) Tower (optional) Rotator (for beams) Amplifier (optional)
SSB, VHF/UHF	Ragchewing, contesting, DXing satellites	All-mode transceiver	Omnidirectional vertical, long, extended Yagi ("boomer"), quagi or helix (depending on the application)	Tower or roof-mount for antenna desirable since DX is mostly line of sight Rotator (for Yagis)
AM, HF	Ragchewing	AM or multimode transceiver	Fixed wire or beam antennas	Antenna tuner (optional) Tower (optional) Amplifier (optional) Microphone
FM, HF	Ragchewing, repeaters	Multimode transceiver	Omnidirectional vertical or beam	Antenna tuner (optional) Tower (optional) Amplifier (optional) Microphone
FM, VHF/UHF	Ragchewing, repeaters, contesting	FM or multimode transceiver	Omnidirectional vertical or Yagi	Tower (optional) Amplifier (optional)
Digital	Ragchewing, message handling, data networking, satellites	HF or VHF/UHF transceiver	Omnidirectional or directional	Amplifier (optional) TNC or multimode processor (optional) Computer or terminal
Image	Ragchewing	HF SSB transceiver or UHF video transceiver	Omnidirectional or directional	Amplifier (optional) TV camera or image scanner Computer (for SSTV and fax) Demodulator (for SSTV and fax)

SSB

Suppressed-carrier single sideband, what we call "single sideband" is an AM signal from which the carrier and one sideband have been removed. The receiving station picks up the SSB signal, adds a carrier, and converts the RF signal back into voice.

Operators who enjoy making long-distance contacts on the VHF and UHF bands find that SSB is a better choice than FM. Even though there are many more VHF/UHF transceivers on the market that offer only FM, SSB is useful because it's much easier to copy a weak sideband signal than a weak FM transmission. The signal strength needed to quiet an FM receiver is relatively high. With low signal-to-noise ratios, it's nearly impossible to make out the other operator's voice. In conditions where weak signals are common, SSB can provide intelligible audio through a background of considerable noise.

The Sounds of Amateur Radio — **Listen to a sample SSB transmission.**

DIGITAL MODES

Technically, any means of communication based on a simple "black-and-white" value can be considered a digital mode, because it can be expressed with simple whole numbers. A CW transmission can be viewed as a mixture of "on/off" signals, to which we could assign the values 1 and 0. Conversely, a series of 1s and 0s, in the proper order, could signify a Morse code message. In fact, many devices use this technique to encode and decode Morse code communication automatically.

In addition to simply turning a signal on and off, there are other ways to designate those digital 1s and 0s, or changes in *state*. Frequency shift keying (FSK) uses the principle of switching between two frequencies, which are used to designate the *mark* and *space* (on and off state, or digital 1 or 0). FSK is achieved by using a control circuit to switch a transmitted carrier up and down to the mark and space frequencies. We can achieve the same result by modulating an SSB transceiver with high- and low-pitched audio signals producing the functional equivalent of true FSK.

The next step toward smooth, effective Amateur Radio communications makes use of machines, specifically, electronic digital computer processing. Fortunately, the FCC permits certain kinds of amateur digital communications because they help provide error-free communications even in difficult conditions.

RTTY

Before there was radio, there was *teletype* (abbreviated *TTY*), a system of sending printed text by typing on a terminal that was connected by wires to a similar machine. The military began connecting mechanical teletype machines to HF radios during World War II. This was the birth of *radioteletype*, or *RTTY*. After some experimentation with simple on-off keying, the designers switched to FSK, which proved effective.

The Sounds of Amateur Radio — **Listen to a sample RTTY transmission.**

In the days before personal computers, enterprising hams obtained inexpensive surplus TTY machines and modified them to provide output signals that could be fed into an SSB transceiver's microphone input. The resulting signals fit within the bandwidth permitted for voice transmissions. A typical modern RTTY installation consists of three parts: a computer, a communications processor and an FSK or SSB transceiver.

In basic radioteletype (RTTY, pronounced **RIT-ee**), the operator types a continuous string of characters on the computer. A terminal program sends the characters through the serial port to the communications processor, which translates the characters into the appropriate mark/space signals as either control signals for an FSK transceiver (or audio tones for the audio input of an SSB transceiver). At the receiving station, the transceiver audio is translated by the communications processor into characters, which are sent to the computer screen via the serial port and terminal program. Amateur Radio operators use several kinds of RTTY.

Baudot (named after French engineer Émile Baudot [1845-1903], pronounced **baw-DOE**), is a method of exchanging alphanumeric characters over wires and radio links. Baudot is sometimes referred to as International Teletype Alphabet 2 (ITA2). It produces letters, numbers and a limited number of punctuation symbols with a five-bit code. Because five bits per character permit a limited number (32) of symbols, the alphabet is sent in capital (upper-case) letters. Baudot RTTY is the most widely used form of amateur RTTY on the HF bands.

ASCII (an acronym for the *A*merican *S*tandard *C*ode for *I*nformation *I*nterchange, and pronounced **ASK-ee**) is a form of RTTY that transmits seven bits per symbol. ASCII is the same code used on most modern computers. It contains the entire upper- and lower-case alphabet, punctuation and some special symbols.

AMTOR

The Sounds of Amateur Radio — **Listen to an AMTOR QSO in progress.**

In a standard RTTY transmission, only one station transmits, while the other receives. Characters may be printed incorrectly if the S/N is inadequate. Atmospheric static, fading or noise bursts can garble incoming characters. A partial solution to this challenge is a form of RTTY called *AMTOR* (*Am*ateur *T*eleprinting *O*ver *R*adio), which uses a computer processor to maintain a virtually error-free communications link. Instead of one station transmitting while the other passively receives, both stations maintain a link by exchanging transmissions. The sending station sends short bursts of data and the receiving station sends shorter acknowledgment (ACK) bursts between them. Characters are sent in groups of three. The receiving station checks each character, looking for a 4:3 bit ratio. If the ratio is correct for each of the three characters, they are displayed on the receiving terminal and the receiving station sends an ACK, telling the transmitting station to continue. If errors exist, the receiving station sends a negative acknowledgment (NAK) signal, which commands the transmitting station to resend the incorrectly received group.

Because AMTOR runs a continuous validity check on the characters exchanged, it's more reliable than "plain" RTTY, which can produce lots of incorrect text. AMTOR is well suited to traffic handling and passing messages when accuracy is worth a slight trade-off in speed. A disadvantage of AMTOR is that both stations must "hear" each other well, or the communication is reduced to a lengthy exchange of poorly received character groups and NAKs.

Packet

Packet radio is an error-free mode that uses the complete ASCII character set and supports the transfer of binary data. It is called "packet" because data is not sent as a single, continuous string of characters, but rather transmitted in small bursts, or *packets*. Each packet contains not only the data to be transferred, but also *overhead* information used to route the packets and reassemble them into their original continuous whole. The overhead includes data that identifies the sending and receiving stations, enabling the packet transmission to reach the proper destination. It also provides the FCC-required station identification of the sender.

When two packet stations are exchanging data, they are said to be *connected*. One station sends a packet and then waits a specified amount of time for a reply. The receiving station checks the packet for errors and sends an ACK if the packet is error-free. If not, the receiving station does nothing. When the waiting time

The Sounds of Amateur Radio — **Listen to a sample packet transmission.**

PACTOR is becoming the digital HF mode of choice for many hams. This dedicated PACTOR controller by PacComm also supports Baudot, AMTOR and CW. Many amateurs who once used AMTOR and packet on the bands below 30 MHz have switched to PACTOR for its more robust capabilities.

This suitcase houses a complete portable PACTOR station: transceiver, PACTOR controller, wire antenna and cables, all in one convenient package. Its owner, Joe Mehaffey, K4IHP, of Atlanta, Georgia, connects it to his laptop computer to operate mobile or from almost anywhere he pleases. He even used it to maintain a regular schedule with ham family members and neighbors while traveling around the Australian countryside. *(photo by K4IHP)*

expires, the originating station retransmits the packet on the assumption that it did not arrive error-free. Packet stations communicate directly in many cases. If the path is too long to support a direct connection, however, packet relays known as *nodes* or *digipeaters* are used.

Packet radio stations are able to communicate with each other because they conform to a standard format, or protocol, described as AX.25. This is a specification derived from a similar protocol, X.25, used by commercial packet networks. AX.25 version 2.0 was approved by the ARRL Board of Directors in 1984; it is the general amateur packet radio protocol currently authorized by the FCC.

Packet data rates are limited to a maximum of 300 bit/s within the Amateur Radio bands below 28 MHz. Even at this relatively slow rate, noise and interference makes efficient packet communication difficult on the HF bands. Unless conditions are good at both ends of the path, packets must be repeated many times before they arrive error-free.

Above 28 MHz, data rates are not so limited. Most VHF packet users operate their systems at 1200 bit/s using 2-m FM. However, networks have been established that use much higher data rates—9600 bit/s and beyond—to link nodes and packet bulletin board systems over a wide area. The most popular networking system is NET/ROM, but there are several contenders such as TexNet, ROSE and TCP/IP. Through these systems the packet-radio network has become accessible to amateurs throughout the nation and the world.

APRS

APRS (Automatic Position Reporting System) uses the unconnected packet radio mode to graphically indicate the position of moving and stationary objects on maps displayed on a computer monitor. Unconnected packets are used to permit all stations to receive each transmitted APRS packet on a one-to-all basis rather than the one-to-one basis required by connected packets.

Virtually all VHF APRS activity occurs on 2 meters, specifically on 144.39 MHz, which is recognized as *the* APRS operating channel in the United States and Canada. Like most other 2-meter packet operations, APRS operates at 1200 bit/s.

The standard configuration for packet radio hardware (radio-to-TNC-to-computer) also applies to APRS until you add a GPS receiver to the mix. You don't need a GPS receiver for a stationary APRS installation (nor do you need a computer for a mobile or tracker APRS installation). In these cases, an extra port or special cable is not necessary. It is necessary, however, when you desire both a computer and a GPS receiver in the same installation.

One way of accomplishing this is by using a TNC or computer that has an extra serial port for a GPS receiver connection. Alternatively, you can use a hardware single port switch (HSP) cable to connect a TNC and GPS receiver to the same serial port of your computer. The HSP cable is available from a number of sources including TNC manufacturers Kantronics, MFJ and PacComm.

Whichever GPS connection you use, make sure that you configure the APRS software so it is aware that a GPS receiver is part of the hardware configuration and how the GPS receiver connection is accomplished.

For additional information see the book, *APRS Tracks, Maps and Mobiles* by Stan Horzepa, WA1LOU, published by ARRL.

PACTOR

Two German hams, Hans-Peter Helfert, DL6MAA, and Ulrich Strate, DF4KV, worked together to find a solution to the problems of HF data communication. The result of their effort is a blend of the best parts of packet radio and AMTOR: *PACTOR*, and now *PACTOR II.*

Helfert and Strate liked AMTOR because it's a simple system that works well with marginal signal-to-noise levels. However, they disliked its inadequate error-correction capabilities, its slow effective maximum data rate (less than 35 bauds) and its use of the five-bit Baudot code character set (all upper-case letters). To make up for the deficiencies of AMTOR, Helfert and Strate devised a new system based on AMTOR that adopted some features of packet radio.

Advantages of PACTOR include:

- An error-correction algorithm called *Memory ARQ*, a method for reconstructing an original block of data by adding together the broken pieces of that block as it's repeated until the block is whole.
- Data-compression techniques (Huffman coding) that can increase the data transfer rate by up to 400% over uncompressed data.
- Compatibility with ASCII and binary data transfers.
- Automatic adjustment of its data rate to compensate for changes in radio conditions.
- Mark or space polarity is inconsequential because it is frequency-shift independent.
- Tolerates interference well, while maintaining the communication link.
- It uses unique addresses (the complete call sign of a station is its PACTOR address).
- Fast, reliable changes of transmission direction and end of transmission confirmation at both ends of a connection.

Like packet and AMTOR, PACTOR is a two-way affair: A transmitting station sends data and a receiving station sends back electronic acknowledgment of each burst of characters. Unlike packet or AMTOR, however, PACTOR dynamically adapts to conditions. Rather than relying on each transmission to provide a solid block of clear characters, PACTOR can accept a series of imperfect or incomplete data segments and "intelligently" attempt to reassemble them into a solid group. In this way, the number of transmissions is reduced because the receiving station may be able to "make out" enough detail from two or three successive bursts to provide an errorless segment of data.

The Sounds of Amateur Radio

Listen to a PACTOR QSO.

G-TOR

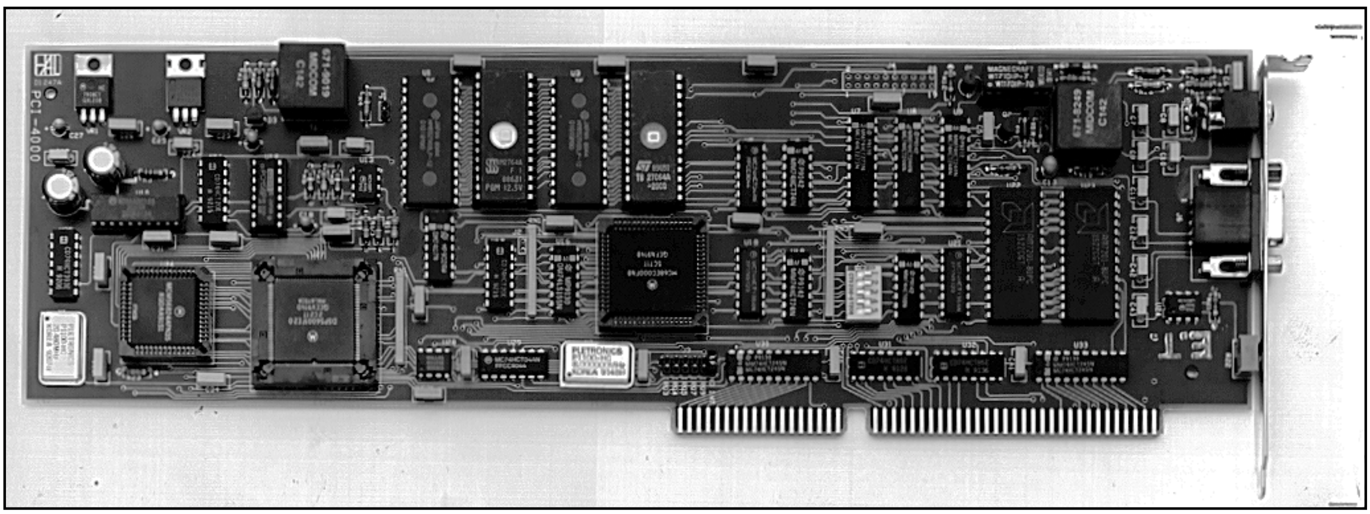
G-TOR was developed by Kantronics with twin goals: to provide greater throughput on HF channels than AMTOR and PACTOR and to be compatible with existing multimode TNCs. To increase throughput, G-TOR uses Huffman encoding to compress data, Golay forward error correction, a cyclic redundancy check to detect errors, data interleaving and automatic repeat requests to replace data that cannot be corrected. Golay encoding and interleaving work together to provide forward error correction that is effective even when long bursts of bits are corrupted. Headquarters operators have seen G-TOR provide twice the throughput of PACTOR and four times that of AMTOR under difficult conditions. More tests are needed, however. We simply don't have enough data yet to know for sure which technique is best.

The Sounds of Amateur Radio **Listen to a G-TOR QSO.**

CLOVER

No matter which digital mode you use—packet, AMTOR, PACTOR or RTTY—data communications on the low bands can be a struggle because of the nature of HF. When HF conditions are perfect, almost anything works, but how often are HF conditions "perfect"? Under the less-than-perfect conditions typically encountered, digital modes begin to fail. It used to be that as conditions deteriorated, all that was left was Morse code. But now there's *CLOVER*. It's a rather complex system invented for the purpose of relaying files and text on HF bands at higher speeds than packet, with faster throughput and versatile self-adjusting parameters. Developed by Ray Petit, W7GHM, and HAL Communications Corp president Bill Henry, K9GWT, CLOVER is named for the cloverleaf waveform it produces when displayed on a monitor scope. CLOVER offers improved data communication in the HF spectrum by using a high-speed, bandwidth-efficient modem and an error-correction protocol designed to counteract changing propagation conditions.

HAL Communications implemented CLOVER in a hardware/software system called PCI-4000/PC-CLOVER, for IBM-compatible computers (with 80286 CPUs or better). The user plugs a PCI-4000 board into one PC expansion slot and installs the *PC-CLOVER* software on the computer's disk drive,



Bill Henry, K9GWT, and Ray Petit, W7GHM, are the fathers of CLOVER, an extraordinarily powerful mode of digital communication. It's an adaptive, error-correcting mode that can pass information over long-distance radio links under severe conditions of poor propagation. This is the original CLOVER adapter, the HAL PCI 4000, a one-slot add-on board for IBM-compatible personal computers.

connects the CLOVER card to an HF transceiver, and is ready to go on the air.

On-air experience and tests indicate that CLOVER-II can reliably pass error-corrected data on HF at rates of 10-70 bytes/sec. (80 to 560 bits/sec.) Under average conditions, throughput is 20 to 40 bytes/sec. (160 to 320 bits/sec.)—2 to 10 times faster than AMTOR, Pactor, or AX.25 HF packet. While CLOVER-II with its 500-Hz wide spectra is preferred for Amateur Radio use, CLOVER-2000, the commercial version, has four times greater throughput—up to 2000 bits/sec. This waveform uses 8 tones spaced 250 Hz apart, a symbol rate of 62.5 baud, and has a characteristic spectrum from 500 to 2500 Hz. CLOVER-2000 is directly compatible with all HF SSB equipment.

The CLOVER system includes an "AUTO-ARQ" mode that provides a three-pronged attack against the problems caused by HF data signal distortion. This forward-error-correction will correct as many as 31 bytes of erroneous data for every 188 bytes of transmitted data, without requiring repeat transmissions. (AMTOR, PACTOR and packet correct errors only by retransmitting data.) When erroneous data exceeds 31 of 188 transmitted bytes, only the damaged data blocks are repeated. (AMTOR and PACTOR repeat all the data of a transmitted pulse, even for one character error.)

The CLOVER modem samples the characteristics of each received block of data (the signal-to-noise ratio, frequency offset and phase dispersion) to determine the current operating conditions. With this information, CLOVER optimizes the other station's transmitting parameters to match the measured conditions. (AMTOR and packet have no adaptive capabilities, and PACTOR uses an adaptive algorithm.)

AUTO-ARQ is available in three flavors, or "bias" settings, for three types of band conditions. For average HF conditions, the "normal" bias setting offers a good balance between error correction, data rate and throughput. For extreme HF conditions, the "robust" or "fast" bias settings are available. The robust bias setting provides the greatest degree of error correction, but to achieve this, throughput is decreased. Robust bias is recommended for fixed-frequency operation (below 7 MHz) where maintaining a connection over an unstable path is more important than the amount of data throughput. For ideal conditions (stable paths at frequencies near the MUF), the fast bias setting provides reduced error correction, greater data rates and maximum data throughput.

HAL Communications has four DSP modems that support CLOVER emissions. The P38 and DXP-38 are low cost and designed specifically for Amateur Radio use. These modems use the TMS320C25 DSP engine and a 68EC000 control processor. The PCI-4000 and DSP-4100 use the DSP-56001/2 IC and are intended primarily for commercial applications. The P38 and PCI-400 are PC ISA bus compatible plug-in circuit boards. Firmware for the on-board processors is loaded via the PC ISA Bus. The DXP-38 and DSP-4100 are cabinet modems that operate via a serial I/O connection. Firmware for these modems is stored in on-board Flash memory. Firmware updates are free and may be uploaded from the HAL web page as required. The PCI-4000/2K and DSP-4100/2K are special versions of the commercial modems that include the CLOVER-2000 waveforms. The same command, control and status report language is used in all four modems. Full details for third-party software authors are provided in a series of HAL Engineering documents, available from the HAL web page (**www.halcomm.com**).

There are many advantages and unique features in a CLOVER system. For example, a CLOVER ARQ link is always bidirectional. Like AX.25 packet radio, CLOVER does not require special "OVER" commands to be sent to change channel direction. Information may flow in either direction at any time. Further, adaptive modulation control is independent for each direction. Strong noise at one site in an ARQ link may reduce data flow to that receiver but will not impede data flow in the other direction. CLOVER sends 8 bit data at all times. Special data parsing and reconstruction algorithms are not required. Any 8-bit file in the PC can be sent error free via CLOVER, be it an executable program, a binary data file, image file, or digital audio file.

PSK31

Despite its limited character set and lack of error correction, Baudot RTTY remains popular for conversational QSOs, roundtables and nets. Baudot RTTY was designed to work with equipment that does not meet today's standards for stability and selectivity. In the beginning, decoding and printing of Baudot signals was done in mechanical machines. Why do hams continue to use this second-only-to-CW oldest digital mode in the computer age?

There's a big difference between digital mode users who are interested in moving blocks of data from one point to another and those who only want to make two-way conversational contacts. If you're sending data over a network, you'll need speed—lots of it on the node-to-node connections. For a two-way contact you only need enough speed to keep up with your typing. Transferred data needs to be error-free, and if that adds some delays, no problem. By contrast, two-way contacts should have minimal system-imposed delays so that data exchange seems *conversational* to the users.

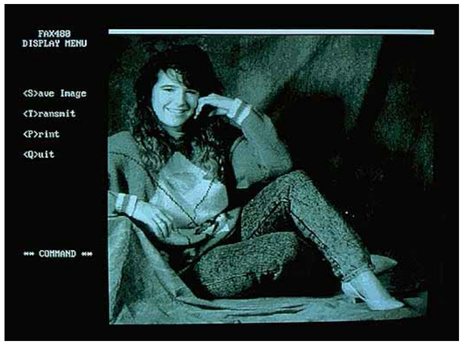
The error-correcting digital modes aren't designed for the "typical" ham QSO. They're great for transferring data, but not so great for conversations—especially when more than two stations are involved.

Peter Martinez, G3PLX, who brought us AMTOR, has developed a new mode that is designed for today's radio amateur using current ham gear to make QSOs with other amateurs. This mode is called PSK31. The PSK derives from the fact that signals use phase-shift keying. The 31 comes from the 31.25 baud rate.

In addition to your transceiver and antenna, you only need a computer with a Windows operating system and a 16-bit Soundblaster card (or compatible) to receive and transmit PSK31. A May 1999 *QST* article by Steve Ford, WB8IMY, explains in easy-to-understand language what you need to know to get in on the fun.

Additional information and software is available for free download over the Web. In addition to Windows software, you'll find versions for DOS, Linux and Macintosh. You'll also find software that does not rely on a particular operating system. You can even join an e-mail reflector to keep up with the latest developments. Point your Web browser to: **http://aintel.bi.ehu.es/psk31.html** for information and links to downloads. You may want to use a Web search engine to find other pages.

PSK31 is still in its infancy, and support for it is still under development. For that reason, it makes sense to watch the pages of *QST*, and to follow developments by visiting key Web pages.



Hams can say "I'll fax you" with ease, by using a home computer with the right hardware and software. Ralph Taggart, WB8DQT, of Mason, Michigan, transmitted this picture of his daughter Jennifer with a system that doubles as a slow-scan TV adapter. *(photo by WB8DQT)*

The Sounds of Amateur Radio — **Listen to a PSK31 QSO.**

IMAGE—FSTV, SSTV AND FAX

Amateur television (ATV) comes in two main categories: fast-scan TV (FSTV) and slow-scan TV (SSTV). ATV allows hams to send television pictures over the airwaves. SSTV originated earlier; it is a technique used to send color or black-and-white still pictures over HF, using bandwidth comparable to that used by SSB voice. Because of the large amount of information required to transmit a video image, the bandwidth restrictions for HF operation limit the mode to still pictures. FSTV, on the other hand, is used on the UHF bands, where the FCC permits hams to use much broader bandwidths. Therefore, a UHF FSTV picture can be a real-time moving picture.

Many amateur TV experimenters use home camcorders to supply the input to their FSTV transmitters. Watching a received FSTV signal looks almost the same as a commercial TV broadcast. In fact, some FSTV enthusiasts outfit their stations with "professional" video and processing equipment, such as cameras, monitors, switchers, special-effects devices and computers to control and manipulate images. There are numerous FSTV repeaters around the US.

Fax is an additional form of image communications. Fax is an abbreviation for *facsimile*, a form of transmission that sends a visual "photocopy" of a two-dimensional image, such as a piece of paper, a photograph or a diagram. The first fax machines were mechanical devices with paper wrapped around a rotating drum, or scanned by a moving light source. The light and dark spots on the paper (that is, blank space and typewritten characters) were converted to electrical impulses. These impulses were sent along wires to a receiving device that converted the impulses back into an image on paper.

Modern amateur faxes are sent using PCs and special software. The images may be almost any computer file format. Images are often created by using a device called a scanner to convert a printed image into a digital format. The software converts the image into audio tones that are sent via the transmitter for decoding at the receiving end. The receiving station can display the faxed image on a computer monitor screen or printer. Fax images can also be "captured" as they are received and saved to a disk file for later access (for example viewing, printing, resending, modification). When a fax transmission begins, the receiving station must be tuned in and listening so that it can receive and decode the synchronization data sent at the beginning of the fax. Without the sync data, the receiving station can't properly interpret the image. This presents a challenge: In voice, Morse code, RTTY, packet or ATV, the operator may identify his or her station using that mode. Faxing is different: The FCC doesn't accept a faxed station identification as a fulfillment of the legal requirement to identify at least once every 10 minutes during a transmission, and interrupting a fax transmission to send a Morse code or voice identification causes the transmitting and receiving stations to lose synchronization. Because faxes can take a long time to transmit, new operators must learn what size file can be faxed in the span of 10 minutes before the transmission must be interrupted to send the required station identification.

The Sounds of Amateur Radio

Listen to a sample FAX transmission.

SPREAD SPECTRUM

Spread spectrum remains largely an experimental mode. It's limited to certain frequencies and methods of implementation, and requires equipment and designs that are on the edge of radio technology. Advanced amateur and commercial development, however, may lead to wider use of this technique of conserving limited radio spectrum. You can find more information in Chapter 12.

Glossary

ACK—An abbreviation for "acknowledgment." AMTOR and PACTOR stations exchange ACKs to verify that information has been received without errors.

ACSSB—Amplitude Compandored Single Sideband. A narrow-bandwidth, low-noise AM mode designed to compete with narrow-bandwidth FM in the Land Mobile Radio Service.

AM—Amplitude modulation. Full AM transmissions use a full carrier with two modulated sidebands, however, SSB and ACSSB are both AM modes.

AMTOR—Amateur Teleprinting Over Radio. A popular method of digital communication on the HF bands.

APRS—Automatic Postion Reporting System. A method that uses the unconnected packet radio mode to graphically indicate the position of moving and stationary objects on maps displayed on a computer monitor.

ASCII—American Standard Code for Information Interchange. A standard method of encoding data so that it can be understood by many computers.

AX.25—The Amateur Radio version of the CCITT X.25 packet protocol (x.25 is used for computer communications over telephone lines).

Bit—A binary digit, 0 or 1, mark or space.

Connect—To establish a data communications link between two packet stations.

CW—Continuous wave. A transmission consisting of an unmodulated carrier.

Digipeater—Digital repeater. A device that receives, temporarily stores, and then retransmits packet radio transmission directed specifically to it.

DXing—Operation to contact far-distant stations (foreign countries on HF, beyond the radio horizon on VHF and higher bands).

FM—Frequency modulation. A form of modulation where the RF carrier shifts frequency according to the amplitude of the modulating audio signal.

FSK—Frequency shift keying. Modulating a transmitter by using data signals to shift the carrier frequency. Commonly used for digital transmissions.

NAK—An abbreviation for "non-acknowledgment." AMTOR and PACTOR stations exchange NAKs to request retransmission of data (due to errors).

Node—A junction point in a packet network where data is relayed to other destinations. A node can support more than one user at a time and operate on several different frequencies simultaneously.

RTTY—Radioteletype. A method of sending text information using shifting MARK/SPACE signals or audio tones.

SSB—A form of amplitude modulation (AM) in which the carrier and one sideband are removed.

TNC (terminal node controller)—Software or hardware that processes packets.