By Joe Taylor, K1JT

WSJT: New Software for VHF Meteor-Scatter Communication

Interplanetary dust particles are plunging into Earth's atmosphere continuously. With this revolutionary software you can communicate over distances up to 1400 miles by bouncing signals off the ionized trails of these tiny meteors.

In February 2000 I started playing with meteor scatter on the 2- and 6-meter bands, using the relatively new computer-assisted high speed CW technique (HSCW). I had done some meteor and ionospheric scatter work in an earlier hamming life, more than 40 years ago.[1] My long-dormant interest in Amateur Radio having been warmly rekindled, I was anxious to see what advantages modern equipment and techniques might bring to this fascinating and always-available communication mode for VHF DX.

I quickly learned that the high-speed CW mode of carrying out meteor-scatter QSOs can be very effective. The mode was entertainingly described by Shelby Ennis, W8WN, in a recent *QST* article.[2] HSCW makes it possible to use the very brief "pings" of signals reflected from the ionized trails of meteors entering the Earth's atmosphere some 100 km above the surface. On the 50 and 144 MHz bands these pings can be received at almost any time from a moderately well equipped station at a distance of 500 to 1100 miles (800 to 1800 km). The pings typically last no more than a few tenths of a second at 144 MHz, so they are useless for voice communication or normal-speed CW. Indeed, single-sideband operators who get on during the peaks of major meteor showers call them "the abominable pings," and in order to make QSOs they wait patiently for the much less frequent "blue whizzers" whose stronger ionization can support two-meter SSB exchanges for a few seconds or longer. Outside the major showers, blue whizzers are so rare that they, too, are essentially useless for communication unless you are extremely lucky or willing to run in unattended "beacon" mode. As a result, SSB meteor-scatter contacts are virtually nonexistent on 2 meters except near the peaks of major showers.

On the other hand, pings from meteor trails with "underdense" ionization are nearly always available in usable numbers. Even 100-W, single-Yagi stations at suitable distances can usually hear several pings from each other in a 10 to 20 minute period. At typical HSCW speeds around 8000 letters per minute, a ping lasting 0.1 second contains about 13 characters—just about enough for your call, the other station's call, and perhaps a signal report. With coordinated timing, good frequency calibration, and some diligence, operators who take the time to learn the technique can easily complete QSOs this way. It's a fascinating way to work a bunch of new states, VUCC grid locators, or (if you live in Europe) DXCC entities. It can also work wonders for fattening your multiplier total in a VHF contest. You do not need an EME-class station, and best of all, you don't need to wait for a meteor shower or for one of those all-too-elusive band openings that usually happen when you had to be out of town.

Alas, all too few stations in North America have cared to put the effort into learning the HSCW technique for working meteor scatter. Our European friends have put us to shame in this respect; many hundreds of amateurs over there use the technique regularly. In our own hemisphere, HSCW meteor scatter has attracted surprisingly few converts. A North American High Speed Meteor Scatter Contest has been run for each of the past four years, and I've had great fun taking part in the 2000 and 2001 events. The total number of participants, however, has been under two dozen in any given year—and it seems that these include nearly all of the North American hams who have been active and HSCW-capable in those years.

Having learned International Morse as a youngster and never having lost my proficiency, I love CW as a mode of communication. But I also appreciate the progress that modern digital methods have brought to our hobby. Motivated in part by a desire to make VHF meteor-scatter communication accessible and attractive to a much larger number of fellow hams, and in part by a simple desire to show that it could be done, in April 2001 I set out to design a digital encoding scheme and software package to enable amateur QSOs using the brief pings from underdense meteor trails. The result has led to a computer program called *WSJT* (for "Weak Signal Communication, by K1JT") that implements a signal protocol called FSK441. The mode works so well that it has been rapidly embraced by the VHF fraternities in Europe and North America, and is now making inroads in Africa and the South Pacific, as well.

If your station is capable of weak signal SSB work on the 6 meter or 2 meter bands—say, if you have 100 W or more

[1]Notes appear on page 41.

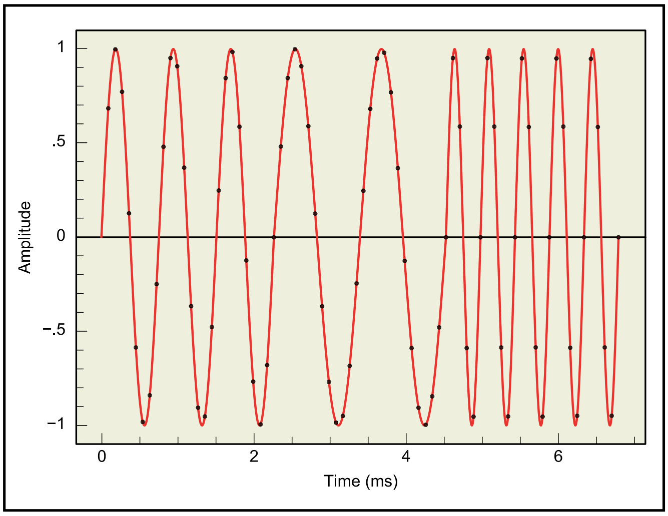

Figure 1—Audio waveform corresponding to the letter C in an FSK441 transmission. Each tone lasts for exactly 25 samples (filled circles) at the 11025 Hz sampling rate, or about 2.3 ms. Each character requires three tone intervals. The code for the letter C is 103, which means that the transmitted tones are at the frequencies 1323, 882 and 2205 Hz.

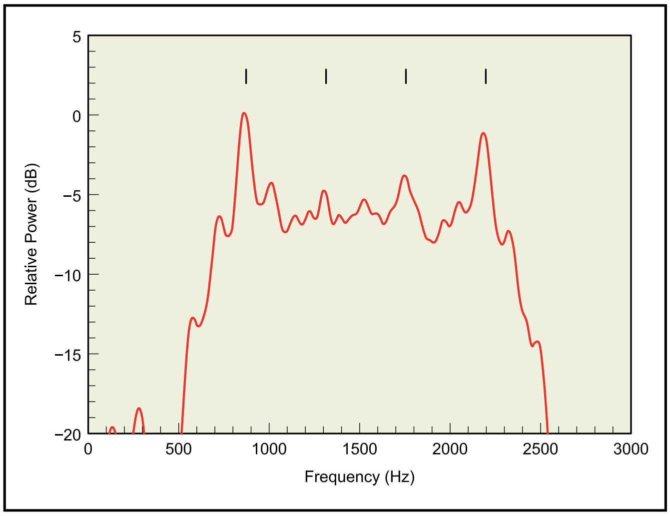

Figure 2—Computed spectrum of the FSK441 message "W8WN 27 K1JT 2727." The frequencies of the four basic tones are indicated by the tick marks above the spectrum. Note that nearly all of the transmitted power falls in the range 660–2425 Hz.

to a modest Yagi up at least 40 feet—then with the help of *WSJT* you should be able to work similarly equipped stations in the 500-1100 mile range at nearly any time of the day or year. (On the minimum end of the scale, *WSJT* QSOs have been made with as little as 10 W, and I have worked N4KZ rather easily at 610 miles when he was using an 80-meter loop antenna on 6 meters.) With a higher antenna and more power, QSOs out to 1300 or 1400 miles become possible. A few QSOs have already been made with *WSJT* on 222 MHz, as well, and contacts on 432 MHz might be possible near the peak of a major meteor shower.

What Do I Need?

Like a number of other digital and quasi-digital communication modes that have recently become popular on the amateur bands, such as PSK31, MFSK16 and Hellschreiber, *WSJT* requires an SSB transceiver, a computer running the *Windows* operating system, and a soundcard interfaced to the radio's "microphone in" and "speaker out" ports. A 75 MHz Pentium-class computer is a minimum, and you will be happier with a faster CPU, especially if you want to use other programs (such as a Web browser) when running *WSJT*. Your computer should have at least 24 MB of RAM, 40 MB of free disk space, and a monitor with 800 × 600 or higher resolution. Microsoft *Windows* 95, 98, NT, 2000 and XP have all been used successfully. You will, of course, need a station capable of weak signal work on one or more VHF bands.

The *WSJT* program is available for download free of charge at the Web site **pulsar.princeton.edu/~joe/K1JT** and at the European mirror site **www.vhfdx.de/WSJT**. Download the file *WSJT100.ZIP* for Version 1.00, or a similar file name with a higher version number, if one exists. Unzip the distribution file into a convenient directory such as C:\TEMP and then run SETUP.EXE in that directory to install *WSJT* to a permanent location of your choice. The default installation directory on most computers will be C:\Program Files\WSJT.

You will need a simple computer-to-radio interface like those required for such modes as PSK31, MFSK16, and Hellschreiber. The DTR or RTS line of one of the computer's serial communication (COM) ports is used to key your transmitter's push-to-talk (PTT) line. Connections are also required between the transceiver audio output and computer sound card input, and vice versa. Station accessories that accomplish these things are easy to build[3] and are available commercially from a number of sources advertising in *QST*. You will need a method of synchronizing your computer clock with UTC to an accuracy around one second or better. I heartily recommend a free software utility[4] called *Dimension 4*, which synchronizes your computer clock with atomic time standards at national timekeeping laboratories whenever you are connected to the Internet.

Sometime during the beta-test phase of developing *WSJT*, when I was getting swamped with requests for enhancements, Andy Flowers, K0SM, took pity on me and volunteered to help flesh out the online instructions I had written. With that collaborative effort as a start, further work at my end led to the presently available 13-page *User's Guide and Reference Manual*. If you plan to give *WSJT* and VHF meteor scatter a try, I urge you to download the *User's Guide,* print it out, and read it carefully. Although many have shown that it is possible to install *WSJT* and learn to use it by trial and error, the manual should definitely be read by anyone serious about getting the most from *WSJT*.

How Does It Work?

The encoding scheme used in *WSJT* was designed to make the best use of signals just a few decibels above the receiver noise, exhibiting rapid fading and Doppler shifts up to 100 Hz, and typically lasting from 20 to a few hundred milliseconds. The Doppler shifts and effective path-length variations make any sort of phase-shift keying (for example, a system analogous to PSK31) a poor candidate for this kind of signal. Large and rapid signal strength variations make on-off keying difficult to decode reliably. In addition, such modulation is inefficient in spectral usage at high speeds, and is very prone to errors caused by atmospheric noise. After considering many possible encoding schemes and testing several of them under real meteor-scatter conditions (thanks to the patient and tireless early morning efforts of Shelby, W8WN, who has seldom refused my request for a schedule!) in early June I decided on a scheme that uses four-tone frequency shift keying at a rate of 441 baud. The adopted scheme has been given the technical name FSK441, although most people seem to be calling it simply "the *WSJT* mode."

In a normal FSK441 message, each character is encoded as three audio-frequency tones sent sequentially. Each tone can have one of four possible frequencies, so the maximum number of encodable characters is 4 × 4 × 4 = 64. For reasons described below, the four sequences that have the same tone sent three times in succession are reserved for a special purpose; in addition, the 15 remaining sequences that begin with the highest frequency tone are not used. This leaves 45 character codes available for general use. For the sake of consistency, and because I intended for *WSJT* also to implement the weak signal mode called PUA43, designed by Bob Larkin, W7PUA, I chose to use the same 43-character "alphabet" that is incorporated in that mode. This character set includes 26 letters, 10 digits, the space character, and the six special characters: . , ? / # $. Two available character codes remain undefined in FSK441.

Digital computers use binary arithmetic, and the basic unit of information is given the contracted name "bit" for "binary digit." When expressed in numerical terms, a bit can have the value 0 or 1. Since the FSK441 scheme uses four basic tones, base-four notation is the most convenient way of describing its code. For want of a better term, I call the digits of the base-four code "dits," rather than "bits." Each character in the FSK441 alphabet is described by a sequence of three dits, whose numerical values fall in the range 0 to 3. The full coding scheme of FSK441 is presented using this notation in Table 1. Three-digit numbers represent the three-tone sequences corresponding to each character. Tones 0 through 3 correspond to the audio frequencies 882, 1323, 1764 and 2205 Hz. Since the modulation rate is specified as 441 baud, or 441 dits per second, the character transmission rate is 441/3 = 147 characters per second. At this speed a ping lasting 0.1 seconds can convey a very respectable 15 characters of text.

The timing of FSK441 is such that each dit of each character consists of exactly two full cycles of the audio tone at 882 Hz, three cycles at 1323 Hz, four at 1764 Hz, or five at 2205 Hz. *WSJT* runs the computer sound card at a sampling rate of 11025 Hz and therefore each dit, 1/441 of a second long, requires exactly 25 samples for its representation in the digitized waveform. Each generated tone blends into the next one in a phase- and amplitude-continuous manner. An example of the generated signal is presented in Figure 1, which shows the audio waveform corresponding to the letter "C" (code 103; see Table 1). An FSK441 transmission contains no dead spaces between tones or between characters; the typical short messages exchanged in meteor scatter QSOs are sent repeatedly and continuously, usually for 30 seconds at a time. Different tones do not overlap in time, so there is little opportunity for even a poorly adjusted transmitter to produce intermodulation products. For all of these reasons, the audio signal used to generate FSK441 signals is spectrally clean and largely confined to the range 660-2425 Hz, thereby making very effective use of the audio bandwidth of a modern SSB transceiver. In a well-designed and well-adjusted transmitter, the resulting RF spectrum will be similarly clean, and it will remain so even if Class C power amplifiers (or poorly designed solid state amplifiers driven into their limiting regions) are used. An example audio frequency spectrum is shown in Figure 2, computed for the message "W8WN 27 K1JT 2727." The four individual tones can be seen in the spectrum, as well as the sidebands produced by their keying pattern in this particular message. Tones 0 and 3 happen to be used more frequently than tones 1 and 2 in this message, so their spectral peaks are proportionally higher in the average spectrum.

Table 1
FSK441 Character Codes

Character	*Tones*	*Character*	*Tones*
1	001	H	120
2	002	I	121
3	003	J	122
41	010	K	123
5	011	L	130
6	012	M	131
7	013	N	132
8	020	O	133
9	021	P	200
.	022	Q	201
,	023	R	202
?	030	S	203
/	031	T	210
#	032	U	211
space	033	V	212
$	100	W	213
A	101	X	220
B	102	Y	221
C	103	0	223
D	110	E	230
F	112	Z	231
G	113		

WSJT has another highly effective ploy in its bag of tricks, based on the use of the reserved character codes 000, 111, 222 and 333. Originally I identified these four codes with the ASCII characters +, *, % and @, but I recognized that if a message were composed of any one of these characters sent repeatedly, with no intervening spaces, the transmitter would send a pure tone: an unmodulated carrier at the frequency of the suppressed SSB carrier plus that of the appropriate audio tone. I decided to define such transmissions as having the meaning of the most frequently used short messages in high-speed meteor scatter QSOs, namely R26, R27, RRR and 73. Because these shorthand messages are transmitted as single tones, they have very narrow bandwidths upon reception, even after allowing for the vagaries of propagation. They are therefore easy to recognize, both by ear and by the software. The narrow bandwidth means that a suitable DSP algorithm can dig the signals out of the noise very effectively, even if they are significantly weaker than the weakest decodable multi-tone messages. Single-tone messages have proven to be very effective and reliable, except where co-channel QRM is a severe problem. When pings are few and weak, they can speed up the average time to complete a QSO by a factor of two or more.

Decoding the Pings

The computer algorithm for decoding a received FSK441 message must be able to detect pings, carry out two stages of synchronization on the signals within the pings, and finally translate a sequence of measured frequencies back into a text message. The code that finds pings and determines their length starts by measuring the received power in the full receiver passband, smoothed and sampled at 20 ms intervals. When the signal exceeds the background level by more than a specified threshold, a ping is said to have started. When the power has dropped to at least 1 dB below the threshold, the ping is said to have ended. Pings with deep fading may be interpreted as several closely spaced pings.

The synchronization required for message decoding occurs in two stages. The program first identifies the starting points of the sequences of 25 consecutive waveform samples that convey each transmitted tone. This task is tractable because within properly phased 25-sample intervals, FSK441 signals always consist of a single tone. The decoding software therefore needs to align things so that a mixture of tones is not found in any such 25-sample sequence. The result of this process is a series of measurements of the received audio tone frequencies that reproduce the sequence generated at the transmitter. In practice, the software also needs to account for some frequency offset between transmitter and receiver, perhaps up to 200 Hz or so. Having made its best estimate of the frequency error, the program identifies each received tone with one of the four nominal FSK441 frequencies and labels it with a dit value in the range 0–3, as defined earlier.

The second necessary synchronizing step is to establish which dits in an arbitrary sequence are the *leading* members of the three-dit sequences defining charac-

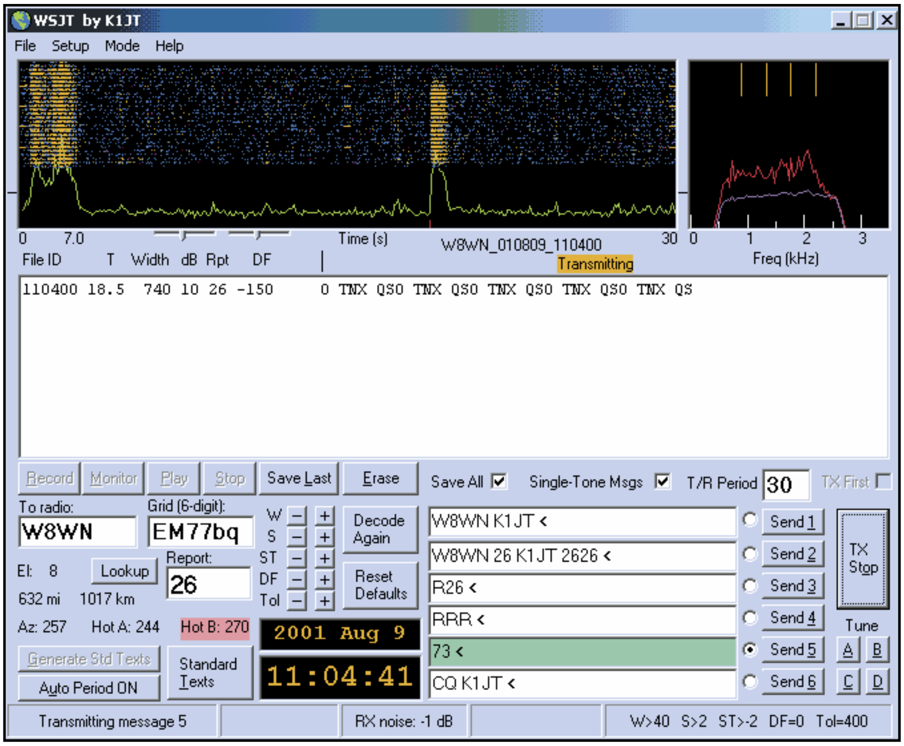

Figure 3—This screen-capture photo shows the main *WSJT* screen during a meteor scatter QSO with W8WN. Thunderstorms were present to the west of K1JT at the time, explaining the two static crashes near the beginning of the displayed 30-second recording as well as the noisier-than usual baseline of receiver background noise (the green line). The signal about 18 seconds into the record is a ping from an underdense meteor trail, and the message it conveyed is displayed in the central text box.

ters in the message. For reasons of transmission efficiency, no special synchronizing information is embedded in an FSK441 message. Instead, the proper synchronization is established from the message content itself, making use of the facts that (a) three-dit sequences starting with "3" are never used, and (b) the "space" character is coded as 033, as shown in Table 1. Messages sent by *WSJT* always contain at least one trailing space—the software inserts one, if you do not include it explicitly—and most messages will include additional spaces to improve readability. Other characters may have dits with value 3 in the second or third positions, but never in the first. Therefore, to properly synchronize a received signal the decoding algorithm examines the sequence of measured dit values, skipping through the time series in steps of three, and selects as the properly synchronized starting point a dit numbered N in the sequence such that none of the dits N, N+3, N+6, N+9, ... has the value 3. Under the conditions specified above, such a dit will necessarily be the leading one of an FSK441 character code.

After synchronization has been accomplished, message decoding is a snap. The sequences of dit values are converted from base-four notation into the computer's native binary arithmetic, and the numerical codes are converted to characters by means of a lookup table.

Two other subtleties of the decoding software are worth mentioning here. As you will quickly learn from listening to an FSK441 transmission, the audio waveform has a distinctive and easily recognizable "burbling" sound that is largely independent of the exact message content. This character can be described in terms of modulation of the signal power in each of the four tone frequencies, at the 441 Hz keying rate and its harmonics. The software readily detects this modulation; its absence implies that the signal being examined is *not* an FSK441 signal and that it may be safely rejected as interference or noise.

Single-tone messages are transmitted as pure carriers, and their effective bandwidths upon reception are essentially equal to the inverse of the duration of the ping. Even an extremely short ping of 20 ms duration will exhibit a bandwidth of only 50 Hz, far less than the modulated widths of the individual tones in a multitone message. Consequently, a different and much more sensitive detection method is appropriate. The spectrum of a ping suspected of carrying a single-tone message is examined with a spectral resolution of about 40 Hz, leading to very high sensitivity and an excellent ability to avoid spurious decodings.

Normal Operation

Figure 3 shows a screen-capture image of *WSJT* in operation at my station. At the top of the form are two graphical areas. The larger one displays a "waterfall" spectrogram in which time runs left to right and audio frequency increases upward. The signal displayed here is a 30 second recording from a QSO with W8WN; it includes two strong static crashes near the beginning, followed by a moderately strong ping about 18.5 seconds into the record. The green line at the bottom of this plot area represents the power in the full receiver passband, sampled every 0.1 second. The vertical displacement of each point on the green curve is proportional to the total power in all of the waterfall pixels directly above it, on a dB scale.

The smaller graphical window at the right displays two spectral plots, also on a dB scale. The purple line graphs the spectrum of audio-frequency noise, averaged over the full 30 seconds; in the absence of any strong signal, it effectively illustrates the receiver's passband shape. The red line displays the spectrum of the strongest detected ping. Yellow tick marks at the top of this plot area (and also at the left, center, and right of the larger area) indicate the nominal frequencies of the four FSK441 tones. The 441-baud modulation broadens out the pure tones so that their widths begin to approach their spacing, thereby creating an approximately flat transmitted spectrum for most messages. (Note, however, that local peaks may still exist in the spectrum, as illustrated in Figure 2.) In the red curve of Figure 3 you can just about recognize the peaks corresponding to the four basic tones. Each tone has been shifted slightly to the left, relative to the yellow tick marks, because of a small frequency offset between transmitter and receiver.

The large text box in the middle of the *WSJT* screen displays decoded text from any pings detected in the receiving interval. One line of text appears for each validated ping. Information in the text line in Figure 3 shows that the recording interval began at 11:04:00 UTC and that a ping was detected 18.5 seconds into the interval. The ping was 740 ms long, and peaked 10 dB above the noise. According to the somewhat arbitrary criteria coded into *WSJT* (which are made to be roughly equivalent to the operator-judged signal reports sent in high-speed CW meteor scatter work), such a signal rates a "26" signal report. The next number shows that the program estimates W8WN to have been transmitting at a frequency offset by –150 Hz relative to my receiver's frequency. Finally the decoded message is shown, with Shelby thanking me for another fine 2-meter meteor-scatter ragchew over our 640-mile path.

You may have noticed that the two

ping-like signals near the start of the 30-second receiving interval did not produce any decoded text. In the green-line plot and even in the waterfall spectrogram, these signals look very similar to the real ping later in the recording. However, they would not have sounded the same. As described earlier, the *WSJT* program has been taught how to recognize the "burbling" characteristic sound of an FSK441 signal. In the present instance the program would have examined the two early pulses, decided that they did not "smell quite right," and properly rejected them as noise.

A few additional comments on the decoded text in Figure 3 may be helpful. At 147 characters per second, a 740 ms ping should contain more than 100 characters. All displayed messages are truncated to 40 characters, however. Since the actual messages transmitted by *WSJT* are limited to a maximum of 28 characters, even the longest ones can be displayed to their full extent, perhaps with some repetition. Under some circumstances, *WSJT* gains additional sensitivity by detecting the repetition pattern of a message and averaging over all the cycles contained in the length of a received ping. This process is most useful for weak pings whose duration is 0.2 seconds or longer, and it can be especially effective on 6 meters where ping lengths are greater. When the program has taken advantage of message averaging, an asterisk is appended to the line of decoded text.

You can control the behavior of *WSJT* by selecting items from the four menus at the top of the screen and using the controls and text boxes in the lower part of the form. As one example, the "Options" item on the "Setup" menu causes the screen shown in Figure 4 to be displayed. This form permits the entry of various station parameters that typically do not change very often. I will not describe the functions of the on-screen controls any further here; you can readily guess the purpose of many of them from the labels visible in Figures 3 and 4, and they are described in full detail in the downloadable *User's Guide and Reference Manual*.

Standard Procedures

Meteor scatter is not a communication mode well suited to ragchewing! QSOs can be completed much more easily if you adhere to a set of standard procedures that have evolved from HSCW and other earlier techniques. A standard message format and message sequence helps the process considerably. *WSJT* generates standard messages automatically, as illustrated in the text boxes at the lower right of Figure 3. The formats of the messages are designed for efficient transfer of the most essential information: the exchange of both call signs, a signal report or other information, and acknowledgments of same. Timed message sequences are a must, and *WSJT* defaults to 30 second transmitting and receiving periods. Although other intervals can be selected, it helps to minimize QRM from nearby stations if everyone adheres to one standard. According to the procedures used by common consent in North America, the westernmost station transmits first in each minute.

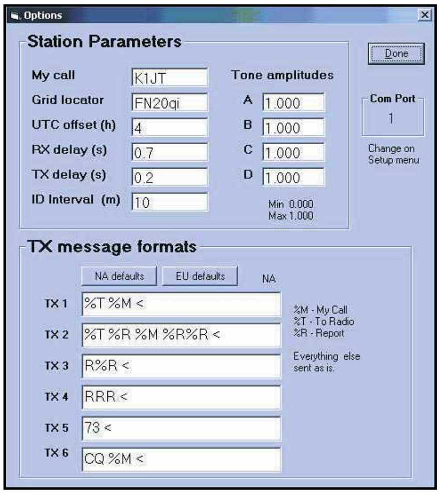

Figure 4—The "Options" screen of *WSJT*, called up from an item on the "Setup" menu. Use this screen to set a number of station parameters, typically ones that do not change frequently. Amplitudes of the four FSK441 tones can be set individually, if desired, to correct for certain transmitter idiosyncrasies. Programmable templates are available for establishing the format of standard messages, and default standards are provided for both North American and European conventions.

At the start of a QSO you should send the other station's call and your own call alternately. Then, as the QSO proceeds…

1. If you have received less than both calls from the other station, send both calls.

2. If you have received both calls, send both calls and a signal report.

3. If you have received both calls and a report, send R plus signal report.

4. If you have received R plus signal report, send RRR.

5. If you have received RRR—that is, a definite acknowledgment of all of your information—your QSO is officially complete. However, the other station may not know this, so it is conventional to send 73 (or some other conversational information) to signify that you are done.

Signal reports are conventionally sent as two-digit numbers chosen from non-overlapping ranges. The first digit characterizes the lengths of pings being received, on a 1-5 scale, and the second estimates their strength on a 6-9 scale. The most common signal reports are "26" for weak pings and "27" for stronger ones, but under good conditions reports such as "38" and higher are sometimes used. Whatever signal report you decide to send to your QSO partner, it is important that you do not change it, even if stronger pings should come along later in the contact. You never know when pings will successfully convey fragments of your message to the other end of your path, and you want your received information to be consistent.

Slightly different standard procedures have been adopted for high-speed meteor-scatter in Europe. You will undoubtedly find it useful to seek out and read additional information on current practices available on the Internet. Some good starting places are listed in the sidebar entitled "Meteor Scatter Resources."

The 6- and 2-meter calling frequencies in common use for *WSJT* in North America are 50.270 and 144.140 MHz. Typical practice for calling CQ is to send something like CQ U5 K1JT or CQ D9 K1JT, indicating that you will listen for replies up 5 kHz or down 9 kHz from your transmitting frequency, and will respond on that frequency. However, the easiest way to initiate a QSO is to post a one-line invitation on a Web page known as "Ping Jockey Central" (see sidebar). Someone at a suitable range from you will

Meteor Scatter Resources

For additional reading on the history and astrophysics of amateur meteor-scatter communications, as well as operating hints and details concerning practices in current use, the following references and Internet addresses are recommended.

1. The classic papers on amateur meteor-scatter communications are the two by Walter F. Bain, W4LTU: "VHF Meteor Scatter Propagation," Apr 1957 *QST*, p 20, and "VHF Propagation by Meteor-Trail Ionization," May 1974 *QST*, p 41. The second one is reprinted in the ARRL publication *Beyond Line of Sight.*

2. Many additional papers, unpublished hints, and extremely useful bits of information can be found on the Web pages **www.qsl.net/w8wn/hscw/hscw.html** and **www.meteorscatter.net/hsms.htm**, and links contained therein.

3. A number of highly useful explanatory files are bundled with a freely available program called *MS-Soft*, by OH5IY, available at **www.sci.fi/~oh5iy**.

4. At least two subscriber reflectors are devoted to meteor scatter communications. Their addresses are **hsms@qth.net** (primarily used in North America) and **meteor-scatter@qth.net** (primarily in Europe).

5. Meteor scatter schedules can be made in near real time by posting a message on the Web page known as Ping Jockey Central at **www.pingjockey.net/cgi-bin/pingtalk**.

likely reply to such a posting, suggesting a specific frequency, and your QSO can begin. The ranges of frequencies now being used for *WSJT* in North America are 50.270-50.300 and 144.100-144.150.

Increasing Levels of Activity

Version 0.82 of *WSJT* was first made available to a group of about 20 volunteer beta-testers, nearly all of them HSCW veterans, on June 20, 2001. A majority of this group started making QSOs immediately, and they helped me to polish some of the program's rough edges and root out some bugs. An open beta release of Version 0.92 was announced on July 7, and within two more weeks the program was being widely used and discussed on VHF- and meteor-scatter Internet reflectors and DX clusters in both America and Europe. Release of a stable and more polished Version 1.0 of *WSJT* was announced on August 26. Since that time the installation package has been downloaded more than 1700 times from my own Web site, and more than 3000 times from the European mirror site.

I have made more than 150 contacts with *WSJT* myself, including 45 "initials" (first contacts with a new call sign). These QSOs include 19 states and 38 Maidenhead grid locators on 2 meters, and they do not include stations within 500 miles of me. Most of my contacts were made with a 160 W brick and an 11 element Yagi at 45 feet. Many other stations have been far more successful; for example, K0PW told me recently that in three months he had worked 73 initials and 30 states on 2 meters, using *WSJT*. I have counted more than 120 North American hams that are actively using the mode now, and additional calls are showing up every week. In Europe the activity levels appear to be substantially higher: I have heard estimates suggesting that at least 500 amateurs there are using *WSJT*, representing more than 50 DXCC entities. These numbers include extra activity centered around the Perseids meteor shower, which peaked on August 12, and it is likely that similar increases will occur near the peaks of the remaining members of the "big four" of the annual meteor showers: the Leonids around November 18, Geminids around December 13, and Quadrantids around January 3.

Another indicator of the growing interest in *WSJT* is its significant presence in the September 2001 VHF QSO Party, the first major North American VHF contest since the release of the program. I have no idea how many QSOs and multipliers were made using the mode during the contest, but I suspect the answer must be at least in the hundreds. I saw plenty of efforts to make *WSJT* schedules in advance of the contest period, and in the East, at least, the larger mountaintop "super stations" were involved. Without really trying very hard, I made 18 meteor scatter contacts during the contest, 17 of them being multipliers I would not otherwise have worked. These were not the quickest QSOs made during the contest, but they were not unreasonably long either. The median time to complete a QSO was 5 minutes on 6 meters and 13 minutes on 2 meters.

Looking Ahead

On a time-available basis, I hope to make further improvements in *WSJT*'s decoding algorithms and its convenience of use. Even more interesting, from a technical point of view, will be the incorporation of the extreme weak-signal mode known as PUA43. Unlike FSK441, PUA43 is designed for signals that are more or less constant in amplitude but buried deep below the level of the receiver noise. Even though quite inaudible, such signals can convey a slow but steady stream of information that is decodable by using DSP integration techniques. W7PUA and his collaborators have demonstrated the impressive capabilities of the PUA43 mode by making EME (moonbounce) contacts with 150 W and single Yagis on 2 meters, and with 5 W and 10 foot dishes on 1296 MHz. To my knowledge, the PUA43 mode is presently available only in software written for the elegant home-brewed DSP-10 2-meter transceiver,[6] also designed by W7PUA. I hope to incorporate the mode into *WSJT*, as well, thereby making its capabilities available to amateurs using a much wider range of equipment.

As a sort of enticement for things to come, let me quote some numbers comparing the theoretical sensitivities and transmission rates of modes being discussed here, as well as the more familiar CW and SSB. In a typical transceiver's 2.5 kHz bandwidth, an SSB signal needs to be 4-6 dB above the noise to be copyable. Normal speech rates are two or three words per second; when one is sending call signs by voice as part of a minimal QSO, this means about three or four letters per second. In the same receiver bandpass, FSK441 signals can be copied at about 2 dB above the noise, and the special single-tone messages used in *WSJT* are copied down to 4 or 5 dB *below* the noise. The FSK441 transmission rate is a hefty 147 characters per second, but of course the useful throughput depends on the availability of meteors. Morse code at 20 WPM can be copied if it is about 6 dB below the noise in a 2.5 kHz bandwidth. (Note that such a signal would be about 1 dB *above* the noise in a 500 kHz bandwidth.) At 20 WPM, the throughput of CW is about 1.7 characters per second.

Amateurs customarily think of CW as being the most effective mode for weak signal communication, and the numbers just quoted seem to bear this out. However, please take note that a one-minute PUA43 transmission, containing 28 characters sent at 0.5 characters per second, can be copied all the way down to *some 27 dB below the receiver noise*. Post-detection averaging can yield nearly another 6 dB improvement in half an hour of alternating one-minute intervals of transmission and reception. The slower transmission rate, and even more importantly the coherent detection of the narrow band signal over 2-second intervals, accounts for the very substantial increase in signal to noise ratio.

PUA43 is a highly effective mode for VHF/UHF tropospheric propagation, in addition to EME. Because it works well with weak but steady signals, it nicely complements the short-ping capabilities of FSK441. With both PUA43 and FSK441 in its bag of tricks, the modest VHF station described earlier should be able to work out to 500 miles or so at any time with tropospheric propagation and the PUA43 mode, and from there out to 1100 miles and beyond by using FSK441 and meteor scatter. If you are within those distances of central New Jersey, I look forward to working you with one of these modes soon!

Joe Taylor was first licensed as KN2ITP in 1954, and has since held the Amateur Radio call signs K2ITP, WA1LXQ, W1HFV, VK2BJX and K1JT. Trained in the academic fields of physics and astronomy, he was Professor of Astronomy at the University of Massachusetts from 1969 to 1981 and since then has been Professor of Physics at Princeton University. His research specialty is radio astronomy, and he was awarded the Nobel Prize in Physics in 1993 for discovery of the first orbiting pulsar. He currently serves as Dean of the Faculty at Princeton and chases DX from 160 meters through the microwave bands. You can contact Joe at 272 Hartley Ave, Princeton, NJ 08540-5656; **k1jt@arrl.net**.

Notes

[1]Joe Taylor, K2ITP, "Working Ionospheric Scatter on 50 MHz," Dec 1958 *QST*, p 28.

[2]Shelby Ennis, W8WN, "Utilizing the Constant Bombardment of Cosmic Debris for Routine Communication," Nov 2000 *QST*, p 28.

[3]Steve Ford, WB8IMY, "PSK31 2000," May 2000 *QST*, p 42.

[4]Download the computer clock utility *Dimension 4* from **www.thinkman.com/dimension4**.

[5]The *WSJT* home page is at **pulsar.princeton.edu/~joe/K1JT**.

[6]Bob Larkin, W7PUA, "The DSP-10: An All-Mode 2-Meter Transceiver Using a DSP IF and PC-Controlled Front Panel," Sept 1999 *QST*, p 33, Oct 1999 *QST*, p 34, and Nov 1999 *QST*, p 42.