WSJT
Version 3.0

User's Guide
and
Reference Manual

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by

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WSJT 1

Introduction

WSJT is the name of a computer program. It stands for "Weak Signal communications, by K1JT." The program currently offers three operating modes: **FSK441**, **JT44**, and the **EME Echo** mode.

FSK441 is designed for high speed meteor scatter communication using the brief "pings" of signals reflected from the ionized trails of meteors about 100 km above the earth's surface. Such pings are typically a few dB above the receiver noise and may last from ten to a few hundred milliseconds. By using these brief pings, FSK441 facilitates QSOs in the range 500 to 1400 miles (800 to 2200 km) in the amateur 2-meter and other VHF and UHF bands.

JT44 is designed for communications with very weak signals of roughly constant strength. The program is able to work at levels 10–15 dB or more below the weakest intelligible CW signals, and this makes JT44 ideal for tropospheric scatter and Earth-Moon-Earth (EME) communications. Smaller stations are able to complete EME QSOs much more readily with JT44 than with more traditional communication modes.

EME Echo mode facilitates testing station performance by measuring your echoes from the moon. It also provides tools for measuring sun noise, antenna temperature, and similar quantities relative to a chosen reference level, and for predicting the strength of your lunar echoes.

System Requirements

WSJT is designed for computers running the Microsoft Windows operating system, including the variants Windows 95, 98, 98/SE, ME, NT, 2000, and XP. Minimum hardware requirements include a 75 MHz Pentium or equivalent CPU, 24 MB of RAM, 40 MB of free disk space, a monitor with 800 x 600 or higher resolution, and a Windows compatible sound card. Recent versions of Windows may require more memory, and a faster CPU may be desirable if you run other programs while using WSJT. You will need a simple computer-to-radio interface like those required for other sound card modes such as PSK31. The DTR or RTS line of a serial communication (COM) port is used to key the push-to-talk (PTT) line of the transmitter. Connections must be made between the transceiver audio output and computer sound card input, and vice versa. Station accessories that accomplish these things are easy to build and available commercially from a number of sources.

Both FSK441 and JT44 require time synchronization between the transmitting and receiving stations. You will need a method of setting your computer clock to an accuracy of one second or better, and keeping it set. Many operators use an internet clock-setting program, while others use a GPS receiver. You may choose to set the computer clock manually to WWV or another broadcast time

service, but this procedure can be cumbersome and you will have to watch it carefully. Computer clocks tend to drift. Do not set your clock to UTC at the beginning of an EME or meteor-scatter schedule and expect it to be accurate half an hour later!

Installation

WSJT is available for free download at `pulsar.princeton.edu/~joe/K1JT` and at the European mirror site `www.vhfdx.de`. Download the file `WSJT300.EXE`, or a similar file name with a higher version number, if one exists. Execute this file install WSJT to a permanent location of your choice. If you have obtained the program on a CD-ROM, place the disk in the proper drive, and run the program `WSJT300.EXE` to install WSJT.

If you discover that an update to WSJT has been released and you wish to upgrade to the new version, download the appropriate update file. It will be named something like `UPD301.EXE` (signifying an upgrade to version 3.0.1), and will be a much shorter file than the full installation package. Execute the file to install the upgrade. Typically, the installation process will copy new versions of the files `WSJT.EXE` and `WSJT1.DLL` (and possibly one or two other files) over your existing copies. Be sure that they are installed in the same directory that you previously used to install WSJT.

Initial Setup

Connect the appropriate interface cables between the computer and your radio. If you need help with details of the hardware interface, refer to one of many available descriptions of the station setups for other sound card modes—for example, WB8IMY's article on PSK31 in QST for May 2000.

To start the WSJT program, double-click its Windows desktop icon or select it from the Windows "Start" menu. When first launched, WSJT will start in FSK441 mode. (To be sure you are in FSK441 mode, you may press function key **F7**.) You should then go through the following steps, in sequence.

Station Parameters

Select **Setup | Options** and enter your callsign in the **My call** text box and your 6-digit Maidenhead grid locator in the **Grid locator** box. If you keep your computer clock on local time, enter the correct **UTC offset** in hours. If your location is east of Greenwich, the offset should be negative. Depending on details of your station's T/R switching mechanism, you may want to enter values of a few tenths of a second or more for **RX delay**, **TX delay**, or both, to avoid hot-switching your antenna relay or recording switching transients on receive. To enable periodic station identification in FSK441 mode, enter the desired

interval in minutes under **ID interval**. To activate this feature you must also provide an audio file named `ID.WAV` in the installation directory, containing the desired announcement. It can be a voice or CW recording, or indeed any recording of your choice. Automatic station identification is presently implemented only in FSK441 mode.

Click **NA Defaults** to select FSK441 message templates based on customary practices in North America, or **EU Defaults** for European-style messages. You may edit the templates if you prefer a slightly different message format, but be aware that large changes could have the effect of confusing your QSO partner. This selection has no effect on the default messages in JT44 mode, which are the same worldwide. Click on **Done** to dismiss the **Options** screen and return to the main screen.

T/R Switching

Select menu item **Setup | Set COM Port** and enter the number of the COM port you wish to use. Entering "0" will disable automatic PTT switching, which you might choose to do if you will use VOX control. Next you should indicate on the **Setup** menu whether you wish to use the **DTR** or **RTS** line for PTT control. Note that you can both "check" and "uncheck" items on this menu. If you do not know whether your interface is wired for DTR or RTS, try checking both. If you are making your own interface for PTT control, note that the standard 9-pin serial port connector uses pin 4 for DTR, pin 7 for RTS, and pin 5 for ground. A very simple controller interface is given in the following diagram, in which the transistor is a 2N4401 (or almost any other general purpose NPN transistor):

DTR
Pin 4/Yellow on DB9

1K

PTT

GND
Pin 5/Green on DB9

Radio GND
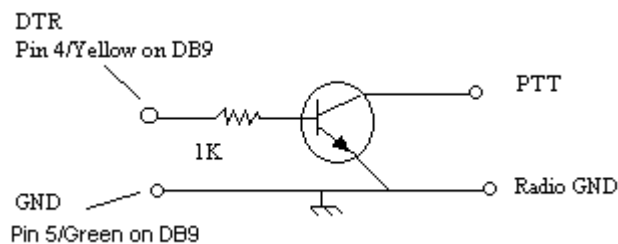
Click one of the four **Tune** buttons labeled **A**, **B**, **C**, or **D** to be sure that T/R switching works — i.e., that the PTT line of your radio is keyed. Each tune button causes one of the four FSK441 audio tones to be sent to your radio via the sound card output. Be aware that all transmissions with WSJT are intended to produce full-amplitude, key-down carriers with 100% duty cycle.   For comparison, the on-off keying of CW yields roughly a 50% duty cycle. If a high duty cycle for a 30-second transmission will overstress your final amplifier, reduce power accordingly. Click **TX Stop** to stop transmitting.

RX Audio Level

The next step is to adjust the receiver audio level and the sound card audio gain. If your radio provides a way to control the Automatic Gain Control (AGC), turn it off or to its "fast" position. It may also help to turn down the RF gain control and turn off the noise blanker. You will probably want to experiment with the noise blanker later; with many radios, WSJT signals are not adversely affected by the noise blanker, but in other cases meteor-scatter pings can be severely clipped. Most noise blankers should be usable and effective in JT44 mode.

TX messages   Receive Parameters
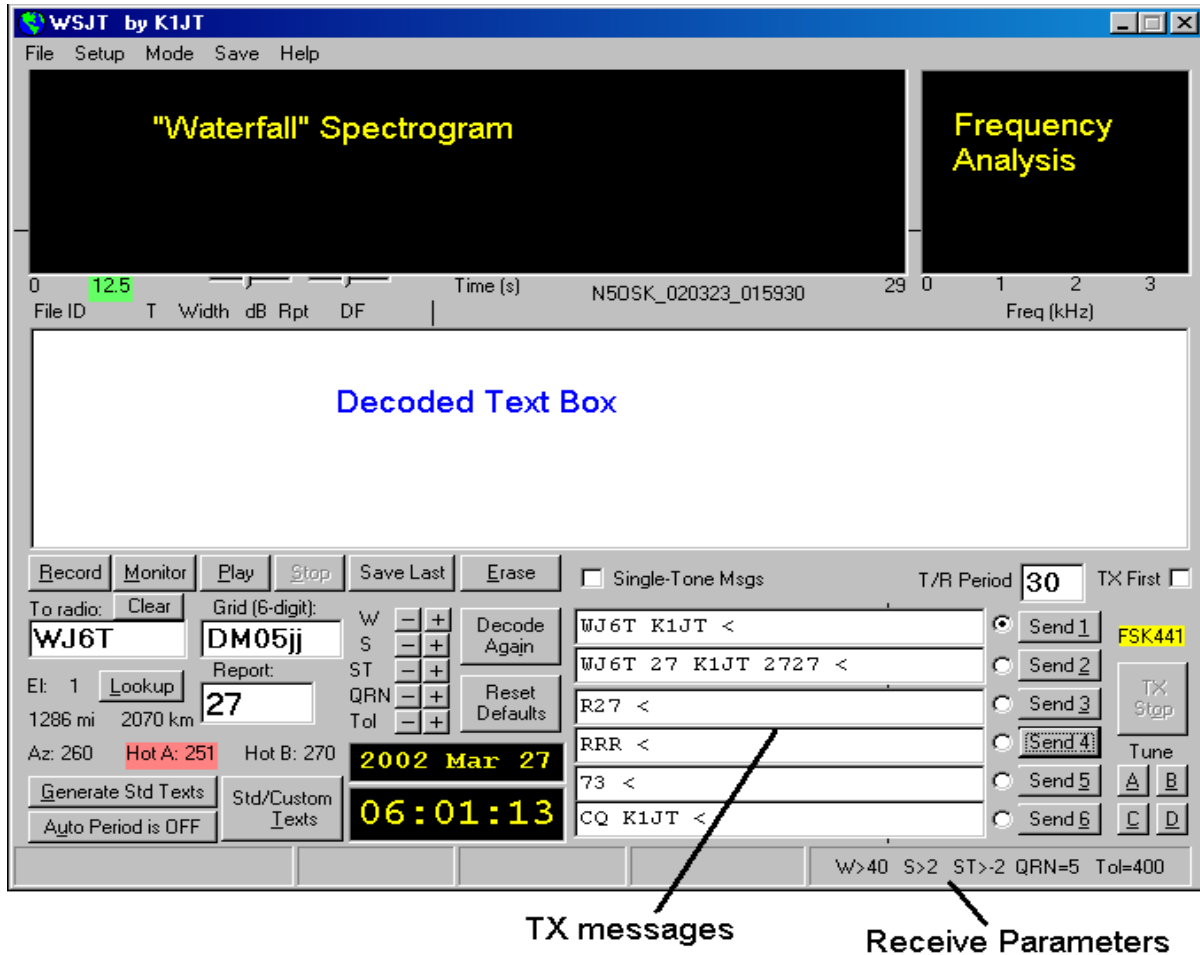
With WSJT running in FSK441 mode and the receiver tuned to a clear frequency, click **Record** to start a receiving period. In the first panel of the status bar at the bottom of the WSJT screen you should see an entry of the form "File: callsign_yymmdd_hhmmss". The callsign part of this long file name comes from the **To radio** text box, while "yymmdd" and "hhmmss" represent the current date and time. In the second panel of the status bar you should see "File Position: n s", where "n" is an integer counting off the seconds of recording to the named file. After recording a few seconds of audio, click **Stop**. A third message should appear in the middle panel of the status bar saying "RX Noise: x dB". This

message describes the level of received noise as digitized by the sound card, expressed in dB relative to the optimum level.

A jagged green line should appear in the large plot area, along with a two-dimensional waterfall-style spectrogram. The green line is a graph of received noise power (vertical axis) during the time you were recording (horizontal axis). The waterfall plot is a time vs. frequency spectrogram of the received audio. If you see no green line and no spectrogram, there's probably no receiver noise (or not enough noise) going into the sound card.

Adjust the receiver audio gain and/or the computer's "line in" volume control and repeat the short recordings until you establish a noise level close to 0 dB. The value is not overly critical: ± 2 or 3 dB from the nominal 0 dB should be fine. The computer's sound mixer can be called up from the **Setup** menu and may present you with several adjustable sliders as volume controls. You may have to try them all to find the right one. You may also want to experiment with using the "microphone in" connector instead of "line in" for interfacing to the receiver. Be sure that any sound card special effects such as tone controls and "3-D Sound" are turned off.

When the recording level is properly adjusted the wavy green line will appear below the waterfall spectrogram and approximately aligned with the short horizontal tick marks just outside the edges of the plot area. WSJT displays a message if the receiver audio level is extremely low or there is no audio at all. If this occurs, check to make sure your cables are connected and that you have selected the correct audio input channel on the Windows sound mixer.

You may find the optimum mixer settings for WSJT to be different from those of other programs you use. If you intend to switch often between different programs, you may have to readjust the controls for each program. There are free utility programs (such as "QuickMix") that will store your mixer settings and allow you to switch them easily when you change programs.

TX Audio Level

The WSJT modes use audio frequency shift keying to send information. FSK441 uses 4 audio tones to drive the transmitter, JT44 uses 44 tones, and EME Echo mode uses a large number of possible frequencies. When you are transmitting in any of these modes, each tone should produce nearly the same output power.

With the program in FSK441 mode, tune your radio to a clear frequency (or better yet, use a dummy load) and click the four **Tune** buttons **A**, **B**, **C**, and **D** in order. These actions will cause the transmission of pure tones at 882, 1323, 1764, and 2205 Hz, respectively, relative to the radio's suppressed carrier frequency. Check the transmitter power output (or the final amplifier current, or some other relative indicator) while transmitting each tone. Variations of 10% or

even 20% among the four tones are acceptable, but 50% differences will significantly deteriorate the readability of your signal under marginal conditions. In a properly adjusted transmitter the power output should be constant and independent of the mode and message content.

Unlike the situation with PSK31, it is not necessary to reduce audio gain in the transmitter to preserve linearity and minimize distortion. Indeed, turning *up* the audio gain may be all that's required to equalize your transmitted power in the four FSK441 tones. Activating the speech processor may also help to level your transmitted spectrum. Such simple measures should be tried before resorting to the individual adjustment of tone amplitudes described next.

A means is provided on the **Setup | Options** screen to set amplitudes of the four FSK441 tones separately. Relative numerical values may be entered to scale the generated amplitudes as desired. Note that the numerical values should fall in the range 0.0 to 1.0 and that they represent voltage amplitude, not power. If, for example, you find that tone D produces twice the power output of all the other tones, you should reduce the numerical amplitude of tone D to 0.707 (the square root of 0.5) to compensate. The amplitude settings have no effect in the JT44 or EME Echo modes.

Frequency Readout

By convention WSJT is used with each station configured to transmit and receive the upper sideband. For scheduling and other purposes, the frequency of operation is stated as that of the suppressed carrier, or more simply, the frequency displayed on the dial. Note, however, that the dial readings of many radios are not calibrated as accurately as might be desired. Before operating, you should do your best to assure that you are transmitting and receiving within 100 or 200 Hz of the desired frequency.

The easiest way to do this is to feed a small sample of transmitter output to a well-calibrated frequency counter. The counter reading will be the frequency of the audio tone added to that of the suppressed carrier. After setting up the test equipment, click one of the **Tune** buttons to transmit a single tone. For example, tune your radio to 144150.000 kHz USB and press the **A** button to activate the transmitter and generate an audio tone of 882 Hz. The frequency counter should read 144150.882 kHz. If the counter reads higher (or lower) than this amount and you trust its calibration, you will need to compensate by tuning your radio lower (or higher) by the same amount every time you operate.

Many inexpensive counters will not read to the nearest Hz when measuring frequencies in the VHF range. Note, however, that an accuracy of about 100 Hz is more than adequate for any of the WSJT modes. In the example given above, suppose you set your radio to 144150.000 kHz USB and send an 882 Hz tone, and your counter reads 144150.4 kHz. Adjust the tuning dial until the counter

reads 144150.9 kHz, which is close enough to the nominal frequency of 144150.882 kHz. Say the dial then reads 144150.475 kHz. You would conclude that the radio's calibration is 475 Hz low. Every time you run a schedule with another station you should remember to set the dial frequency higher than the schedule frequency by that amount.

Amplifier Requirements

At any instant an FSK441, JT44, or EME Echo transmission consists of a single-frequency sine wave. There is no "key up" time during a transmission, and one tone changes to the next one in a phase-continuous manner. As a result, WSJT does not require a high degree of linearity in your power amplifier. As with the traditional two-frequency FSK systems used for RTTY, the signal characteristics present no opportunities for generating inter-modulation products. This means that you may send an FSK441, JT44, or EME Echo signal through a class C or other highly nonlinear amplifier if you wish, without creating unwanted sidebands or splatter. (Do not use a voice ID recording if you use a nonlinear amplifier, however.) Keep in mind that if full amplitude transmissions lasting for 30 seconds will overheat your final amplifier, you should reduce power.

Operating in FSK441 Mode

Receiving FSK441

WSJT displays a received signal graphically at the end of each recording period. The green-line graph of signal strength vs. time represents power (proportional to the square of the receiver output voltage) smoothed over 0.1 s intervals. Pings appear on this plot as upward-going spikes above the grassy baseline. Full scale (to the top of the plot area) represents a signal 30 dB above the fluctuations in receiver noise power.
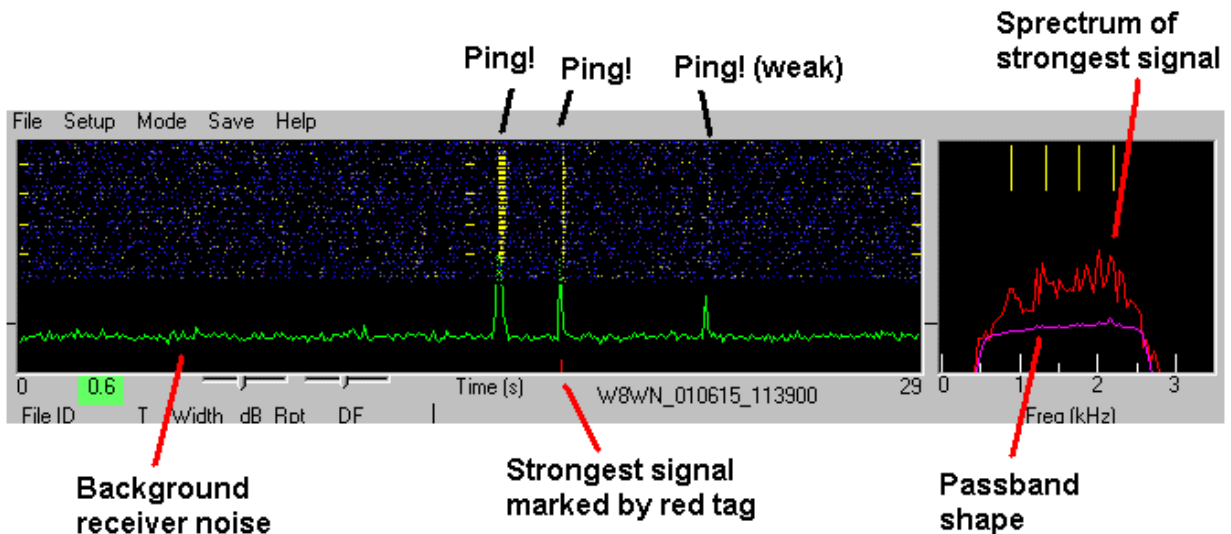
Recordings of receiver noise in FSK441 mode also produce a purple curve in the small plot area at the upper right, along with four yellow tick marks above the curve. The purple line illustrates the average spectrum of received noise and therefore (in the absence of signal) represents your receiver's passband shape, including the effects of IF and audio filters and the sound card interface. The vertical scale is in dB, with the length of the yellow tick marks equal to 10 dB. The tick marks at the top of the window denote the frequencies of the four tones used by FSK441, namely 882, 1323, 1764, and 2205 Hz. Ideally, your receiver passband shape should be approximately flat—that is, the purple curve should be nearly horizontal on the graph—from about 600 to 2500 Hz. If this is not the case with your receiver, WSJT will do its best to compensate automatically.

A red curve may also appear in the smaller plot area. Its meaning is similar to that of the purple curve, except that it represents the spectrum of the strongest ping-like signal found by the decoding algorithm. There will be no red curve if no ping was detected. A small red tick mark will appear along the bottom edge of the large plot area to identify the signal region whose spectrum has been plotted in red.

Decoded Text

Decoded text from received signals appears in the white text box near the center of the screen. As an example, a QSO between K1JT and K0SM might produce lines of text like the following:

```
FileID    T Width dB Rpt    DF     |

154000 15.0 260    8  26  -21      K1JT 27 K0SM 2727          *
154100 17.2  40    2  16  195      R3 1#
154500  6.7 100    5  26  -21 RRR                            3
```

The first number on each line shows the start time of the recording in hhmmss format. The second number shows the time of a detected ping relative to the beginning of the file, in seconds. The third and fourth numbers give the duration of the ping in milliseconds and its peak strength in dB, measured as (S+N)/N. Column five suggests an appropriate signal report, and column six displays a quantity called DF that measures the apparent frequency offset of the received signal, in Hz. If one of the specially encoded single-tone messages has been detected, it is listed next: R26, R27, RRR, or 73. The decoded text from a multi-tone message comes last.

In the example above you can see that the first ping contained two callsigns and a "27" signal report. The ping occurred at 15:40:15.0 UTC. It lasted 260 ms, peaked at 8 dB above the noise, and was received 21 Hz lower than the

expected frequency. The signal received at 15:41:17.2 was a noise burst that triggered the decoder. It is very short and contains no useful information. You will soon learn to recognize such signals as QRN, rather than an actual meteor ping, when you hear them. Even when they are very brief, legitimate FSK441 signals have a distinct "burbling" sound that is clearly different from the sound of a static crash. Single-tone pings are easy to recognize by ear, as well. WSJT is adept at distinguishing these different sounds, and will suppress text output from most non-FSK441 signals. Occasionally the program will be fooled, however, by birdies or QRN. With experience you will gain skill in making the necessary distinctions yourself.

The ping at 15:45:06.7 was decoded as a single-tone "Roger" message. Notice that the RRR appears in a separate column to the left of any multi-tone messages.

WSJT attempts to detect the inherently repetitive pattern of all multi-tone transmissions. If the length of the periodic message is recognized, the program will average over the available repetitions to improve copy. When this happens you will see an asterisk (*) at the far right after the decoded text, as shown in the example above. Single-tone decodings are accompanied by a number in the same column, indicating the relative reliability of the detection on a 1–3 scale.

The frequency resolution used in decoding multi-tone messages is about 43 Hz, so reported frequency differences of about this magnitude are not significant. WSJT will correctly receive FSK441 signals that are mistuned by 200 Hz or even more, but retuning the receiver (or using the RIT) so as to reduce DF to something smaller than 100 Hz is nevertheless desirable. It is best to keep your transmitter frequency constant, to avoid confusing your QSO partner.

Mouse-Pick Feature

When the mouse pointer is moved inside the spectrogram area its horizontal location is displayed numerically at the bottom left of the plot, in seconds. Clicking the left mouse button inside the graphical area forces the program to attempt decoding of whatever signal is present at that particular time. Clicking the right mouse button will do the same thing, but with the message-averaging feature disabled. When you are attempting to decode a marginal ping, try clicking with each button at several slightly different starting locations. Clicking with the mouse is also useful for decoding steady signals that fail to trigger the ping detector automatically.

Final Preparation for a QSO

Enter the desired length of the transmit and receive periods in seconds in the **T/R Period** box on the main screen. Thirty (30) second periods have become standard in most places, but other values can be used. Check the **TX first** box if

you wish to transmit during the first sequence. In North American meteor-scatter work it is conventional for the westernmost station to transmit first in the T/R sequence; other regions may use different conventions. Enter the other station's callsign in the **To radio** text box and click on **Generate Std Texts** to create a sequence of the most commonly used messages. You may edit the messages, if desired, and you can also compose custom messages. To do so, toggle the **Standard/Custom Texts** button and then edit any of the six text boxes provided. WSJT will save your custom messages and restore them the next time you run the program.

If you click on the button labeled **Lookup**, WSJT will attempt to find the specified callsign in a database file CALLSIGN.TXT in the installation directory. This file contains grid locators (and possibly other information) for each listed call. An example file has been included with the program distribution, but you will probably want to adapt it to your own region and extend it over time. (Edit the file using Windows Notepad or another ASCII text editor, following the formats already present.) If the callsign in **To radio** is found in the database file, the program will copy the grid locator into the adjacent text box and use it to compute the distance and bearing to the other station. If the **Lookup** request fails and you know the other station's grid locator, you can enter it by hand. The full six-digit grid locator is preferable, but the four-digit locator followed by a space will suffice with reduced accuracy.

In addition to the great circle azimuth bearing, the program will list the takeoff elevation for reflections from meteor trails at 100 km height, and the azimuths of statistical "hot spots" on either side of the direct path. The hot spots are the directions that provide the best geometry for reflections between the two specified locations, assuming random meteor directions. The hot spot highlighted in red is the most favorable one at the present time of day. Keep in mind that during meteor showers the directions of meteor paths are anything but random. Under those conditions the highlighted hot spot is not necessarily the better one.

Standard QSO Procedure

Completing contacts with WSJT is much more efficient if you follow standard operating procedures. Seek out and read carefully some of the relevant information on high-speed meteor scatter practices available on the web, for example at the URLs www.qsl.net/w8wn/hscw/hscw.html and www.meteorscatter.net/hsms.htm.

Very briefly stated, the standard North American message sequence for a minimal meteor-scatter contact goes as follows:

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 your 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 — the QSO is officially complete. However, the other station may not know this, so it is conventional to send 73s (or some other conversational information) to signify that you are done.

When you are ready to start an automated sequence of reception and transmission periods, either to start a schedule or to call or answer a CQ, click on the circle next to the desired TX message and toggle **Auto Period On**.

How WSJT Decodes an FSK441 Signal

When each receive period is finished, all pings above the stated thresholds of width **W** and strength **S** will be selected and decoded automatically. A separate strength threshold, **ST**, is provided for pings carrying single-tone messages. All three parameters can be set to their default values **W**=40 ms, **S**=2 dB, and **ST**= –2 dB by clicking the **Reset Defaults** button. Adjustments can be made at any time by clicking on the + and – buttons next to the parameter labels. The flowchart below presents a simplified schematic description of the process used by WSJT to decode an FSK441 signal.
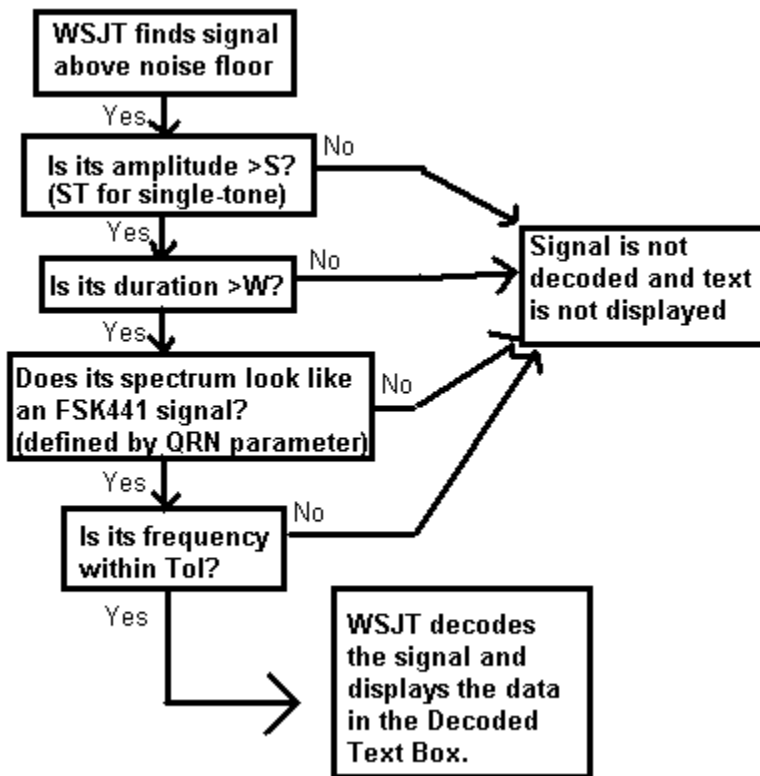
Ping widths are measured and reported by WSJT in 20 ms increments. Note that at the FSK441 transmission speed of 147 characters per second, a 20 ms ping contains only about three characters. Nevertheless, it is not unusual to see WSJT correctly decode three or four characters from a 20 ms ping only 1 or 2 dB above the noise.

Single-tone messages are shorthand notations for certain frequently used parts of meteor-scatter QSOs. Because of the narrower bandwidth that can be used in the decoder, they can be decoded at levels 6 dB and more below those required for multi-tone messages. Setting the ST limit at –2 dB seems to be about right for most conditions, and keeps the probability of false single-tone decodes quite low. It is wise, however, to gain some experience listening to WSJT's single-tone messages before blindly accepting their decodings. After doing so you may decide to set the **ST** threshold to lower values when you have reached the relevant part of a meteor-scatter QSO and you know the other station's frequency offset, DF.

WSJT employs a QRN filter to distinguish between impulsive interference and legitimate FSK441 signals. The **QRN** parameter can be set at levels from 1 to 10, with the default value being 5. In a noisy environment, such as when your antenna is pointed toward a distant thunderstorm, static crashes can fool the decoder into displaying garbage text. Setting the **QRN** value higher will help to filter out this garbage. However, a higher **QRN** value makes the program less sensitive to weak or slightly mistuned signals. In a very quiet environment, **QRN**=3 may be a logical choice.

WSJT attempts to compensate for relative mistuning between the transmitting and receiving stations. However, mistuning by more than about 200 Hz will generally cause the decoding accuracy to deteriorate. For every decoded ping the program lists its best estimate of frequency offset in the DF column. The accuracy of these estimates is approximately ±22 Hz for multi-tone FSK441 signals, and somewhat better for single-tone pings. Within these tolerances, you should see consistent numbers in the DF column during a QSO that is producing usable signals.

If DF lies outside the range ±100 Hz, it will probably help to retune your receiver to compensate. For example, if you see DF values for correctly decoded text at –280 Hz, or if you observe that the red spectral curve for a strong ping seems to be displaced significantly to the left and the ping has *not* decoded properly, tune your receiver lower in frequency by the appropriate amount. Do this with the RIT control, or by using split T/R mode if your radio has such a feature. In general you will want your transmitted frequency to remain constant, since your QSO partner will be trying to tune in your own signal at the same time. You do not want to confuse him/her by moving your frequency around!

Note that if the relative tuning of transmitter and receiver is offset by an amount approaching 441 Hz, the FSK441 inter-tone spacing, a peculiar situation can arise in which DF is reported to be close to zero and yet decoding fails. Such a circumstance will be recognizable by the evident displacement of the red spectral curve to the right or left, so that a whole tone seems to be missing near the low or high end of the spectrum. Retune the receiver to bring the received FSK441 spectrum for subsequent pings into proper registration.

You can narrow the range of frequencies to be searched by reducing the value of **Tol** (for "tolerance") from its default maximum value of 400 Hz. If you have clearly identified the frequency at which you are receiving your QSO partner, setting **Tol** to a lower value such as 100 Hz may significantly reduce any on-screen gibberish from falsely decoded noise bursts. In such a circumstance it is often safe to reduce the other threshold parameters to smaller values, say **W**=20 ms, **S**=1 dB, **ST**=–5 dB, to finish your QSO. You have effectively "locked onto" your partner's signal.

After adjustments have been made to one or more of the decoding parameters, clicking **Decode Again** will trigger reprocessing of the entire received file. As always, right- or left-clicking with the mouse pointer on a particular signal feature with trigger decoding of the signal under the pointer.

Whatever values are selected for the threshold limits for pings, you are likely to see some errors in the decoded messages, especially near the beginnings and ends of pings where the signal fades up from and back into the noise. Of course, comparable errors occur with CW or any other mode of communication when signals are marginal. Unlike some digital modes that require high accuracy and therefore employ error-correcting schemes, the design criteria for FSK441 willingly relax accuracy requirements in order to gain speed. The necessary accuracy is achieved by means of repetition and operator skill.

On-Screen Controls

Auto Period ON/OFF toggles on and off the timed sequencing of transmit and receive periods. During a schedule, you and your partner alternate so that only one station is transmitting at any time. The duration of each RX or TX interval is set by the **T/R Period** parameter.

Brightness adjusts the brightness of the waterfall spectrogram. Click **Decode Again** to see the effect of a change.

Contrast adjusts the contrast of the waterfall spectrogram. Click **Decode Again** to see the effect of a change.

Decode Again causes the last recorded or opened file to be decoded once more, perhaps after one or more decoding or display parameters have been changed.

Erase will delete all information in the decoded text box and the graphical areas.

Generate Std Texts will create standard messages used in FSK441 QSOs by using information in the message templates and the **My call**, **To radio**, and **Report** text boxes. The standard format of the messages is slightly different depending upon your IARU region (see **NA Defaults** and **EU Defaults** under the **Setup | Options** menu item.) This button will also reset the TX message number to 1 and the **Tol** parameter to 400 Hz.

Lookup causes the program to search the callsign data base for the entry in the **To radio** box. If that callsign is found, the station's grid locator will be retrieved and used to calculate distance and azimuth.

Monitor causes WSJT to make a series of recordings, perhaps to monitor a calling frequency or to copy two other stations engaged in a QSO. Recording is continuous except for small gaps between the timed receiving periods. Decoded text will be displayed in the usual way after each recording is finished.

Play. This control plays a recorded file through the sound card speaker output. It functions much like the "Play" button on a cassette recorder.

QRN. Setting the **QRN** parameter to higher values will help to suppress false decodings caused by atmospheric noise, but will also make the program less sensitive to weak or slightly mistuned signals. The default value is 5.

Record. This button starts a recording of audio from the radio. The program will record for the time entered in the **T/R Period** box or until you press the **Stop** button. If **Auto Period On** is set, recording will stop at the end of the present T/R interval. When a recording in finished, it will be plotted and decoded. This control works much like the "Record" button on a cassette recorder.

Reset Defaults will reset the decoding parameters **W**, **S**, **ST**, **QRN,** and **Tol** to their default values.

S sets the minimum increase in signal that will be accepted as a multi-tone ping. If **S** is set at 2 dB, WSJT will attempt to decode signals that are 2 dB or more above the noise floor and last longer than the limit set by the **W** parameter. Setting **S** to a lower value will trigger the decoding of weaker signals, but will probably also display more false signals. Adjustments are made with the + and – buttons. You can see the current settings in the status bar at the bottom right of the WSJT screen.

Save Last. Clicking this button will prevent the most recently recorded file from being deleted at the start of the next recording. (See also the menu items **Save | Save Decoded** and **Save | Save all**.)

Send 1 – 6. Pressing these buttons activates the transmitter. The specified message will be sent until the end of the present TX sequence or, if **Auto Period** is **Off**, for the duration listed in the **T/R Period** box. The background in the TX message box becomes colored to remind the operator which message is being transmitted. Yellow backgrounds denote multi-tone messages, while light blue backgrounds indicate single-tone messages.

Single-Tone Messages. Check this box to enable the transmission of single-tone shorthand messages for R26, R27, RRR, and 73. The single-tone messages are very effective for completing QSOs when pings are weak and infrequent and QRM is not a problem.

ST sets the minimum strength of a single-tone signal that WSJT will attempt to decode. It works in much the same way as the parameter **S** for multi-tone signals, and allows even weaker signals to be successfully decoded. The current value of **ST** is displayed in the status bar at the bottom right of the WSJT form.

Standard Texts / Custom Texts permits you to toggle between two sets of TX messages. The standard texts are those most commonly used in meteor-scatter QSOs; custom texts can be used to store other messages such as grid locator or contest information. Custom messages will be saved when you exit WSJT and restored when you next start the program.

Stop terminates a **Record**, **Monitor**, or **Play** operation. It functions much like the "Stop" button on a cassette recorder.

Tol sets the bandwidth or "tolerance" of a software filter. WSJT will not present decodings for signals it judges to be mistuned by more than this number of Hz. By default **Tol** is set to its maximum value, 400 Hz, and you should normally leave it there until the frequency offset of the other station has been determined. When DF has been established and reduced to a small value by retuning the receiver, you may decrease the value of **Tol** to reduce the probability of false decodings. The current value of **Tol** is displayed in the status bar at the bottom right of the WSJT form.

Tune A, B, C, D. These buttons cause steady tones to be generated at one of the four standard FSK441 frequencies. Use them to adjust your transmit audio level, tune your amplifier, adjust your automatic level control (ALC) setting, etc.

TX First should be checked if you wish to transmit during the first period of the timed T/R sequence. Uncheck it if your schedule partner is transmitting in the first period. In North America the convention for meteor-scatter work is for the westernmost station to transmit first. In the rest of the world, the easternmost station usually transmits first.

TX Stop will interrupt a transmission in progress. It will not toggle **Auto Period Off**, however. To prevent another transmission from starting, press TX Stop and then toggle **Auto Period Off**.

W sets the minimum width of impulsive signals that will be considered for message decoding. Use the **+** and **–** buttons to adjust the value of **W**. You can see the current setting in the status bar at the bottom right of the screen

Text Boxes

Decoded Text. This box is the large area in the center of the program window. It displays decoded text and other useful information, allocating one line per ping. A scrollbar appears if the number of lines exceeds the window height. You cannot edit text in this window. However you can highlight text, copy it to the Windows clipboard by typing CTRL-C, and then paste it elsewhere by using CTRL-V.

Grid. After a successful **Lookup**, this box will display the six-digit grid locator of the callsign in the **To radio** box. You may also enter a grid locator manually. If only four digits of the locator are known, add a space.

Report. Enter the signal report you wish to send to the other station, then click on **Generate Std Texts** to create the standard messages. In FSK441, as well as in HSCW, operators use a two-number reporting system in which the first digit (1–5) denotes ping duration and the second (6–9) represents signal strength. Be aware that **Generate Std Texts** resets the active Tx message to #1 and **Tol** to 400 Hz.

Status Bar. This strip along the bottom of the program window provides panels for displaying useful information such as file name, file position, RX audio level, and decoding parameters.

To radio should contain the callsign of the station being called or worked. Text entered in this box will become the first part of the file name when a recording begins.

T/R Period sets the length of automatic transmitting and receiving intervals, in seconds.
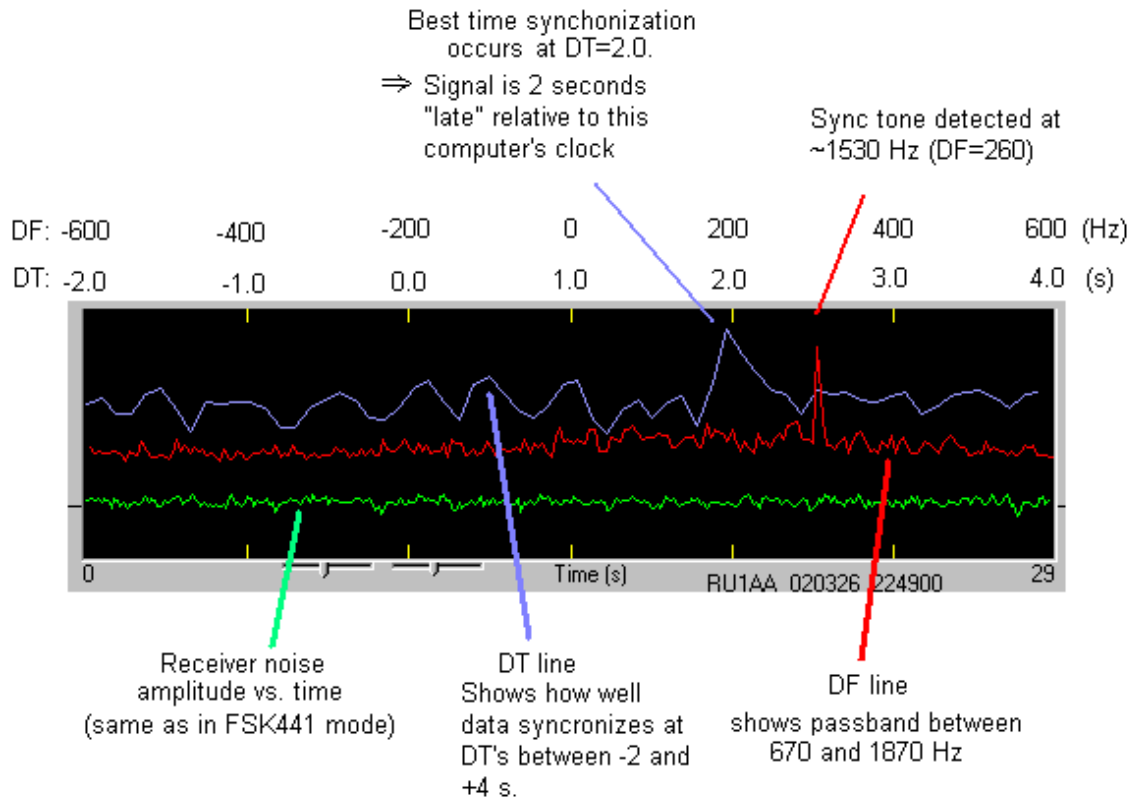
Operating in JT44 Mode

How JT44 Works

The JT44 message format involves 135 intervals of data transmission, each about 0.186 sec in length. Of these, 69 intervals carry a synchronizing tone at 1270.5 Hz. The other 66 intervals carry a 22-character message, repeated three times. Each of 43 supported characters is assigned a unique tone in the frequency range 1302.8 to 1755.0 Hz. Proper message transfer requires synchronization between transmitter and receiver, and for this purpose it is desirable to have your computer's clock set to UTC with an accuracy of one second or better.

SPECTRAL ANALYSIS OF A JT44 TRANSMISSION

" W5SNX W0VD   "
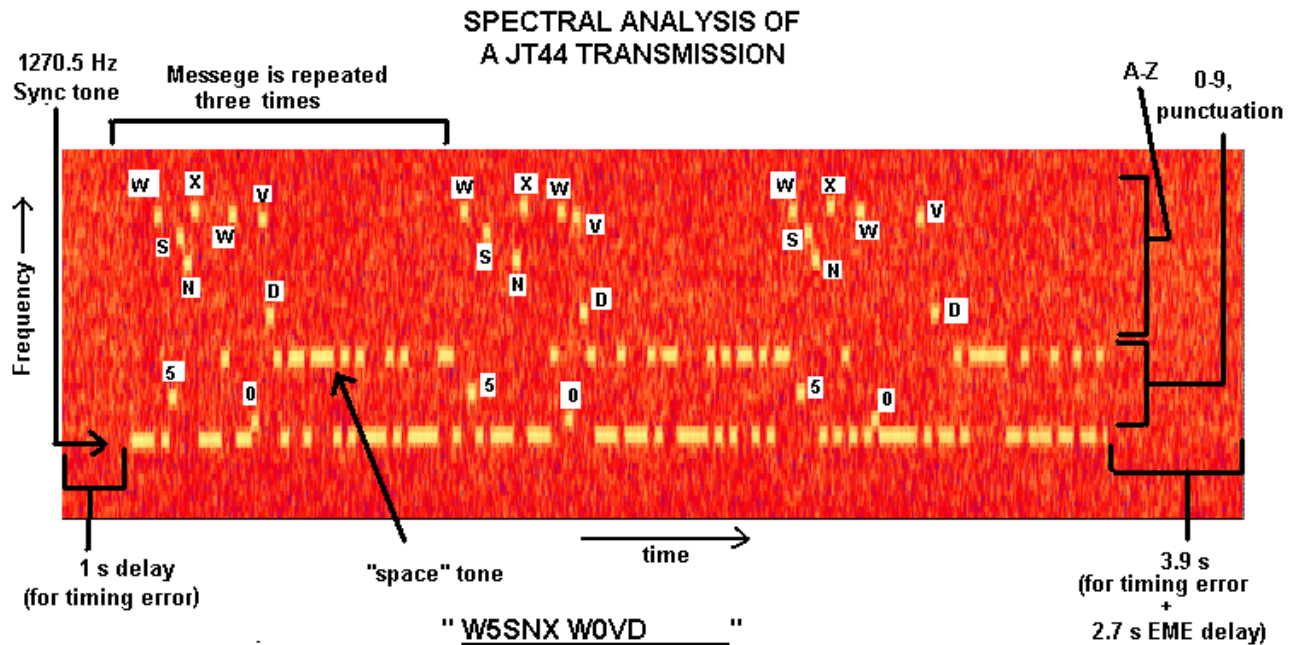
The figure above shows a time vs. frequency spectrogram of a strong JT44 signal (about +10 dB S/N in a 2500 Hz bandwidth). Transmit audio starts 1.0 second into the TX interval and lasts for 135 intervals, or about 25.08 seconds. The final 3.92 seconds (minus necessary relay switching time, etc.) of the transmit period may in future be used for station identification in voice or CW, but this feature has not yet been implemented. The idle time also serves to accommodate EME propagation delays and possible offsets between your computer's clock and that of your QSO partner.

When WSJT finishes a recording, it analyzes the file for a sync tone. It looks for the best S/N ratio of a tone with the prescribed on-off pattern, as illustrated in the spectrogram above (see also Appendix A). For this search the program scans a ±600 Hz frequency range and time offsets from –2.0 to +4.0 seconds. Graphical

details on the attempts at time and frequency synchronization are presented in the display area at the top of the program window, as illustrated below.

Best time synchonization occurs at DT=2.0.
⇒ Signal is 2 seconds "late" relative to this computer's clock

Sync tone detected at ~1530 Hz (DF=260)

| DF: | -600 | -400 | -200 | 0 | 200 | 400 | 600 (Hz) |
| DT: | -2.0 | -1.0 | 0.0 | 1.0 | 2.0 | 3.0 | 4.0 (s) |

0   Time (s)   RU1AA 020326 224900   29

Receiver noise amplitude vs. time (same as in FSK441 mode)

DT line
Shows how well data syncronizes at DT's between -2 and +4 s.

DF line
shows passband between 670 and 1870 Hz

Once WSJT has determined the frequency and time offsets DF and DT, it attempts to recover the 22-character message. On average, single letters in the message will have poorer signal-to-noise ratio than that of the sync tone by 6.8 dB. This is because much less time is spent sending each particular letter, and therefore less signal energy is present at any particular character's frequency. However, averaging the received character-tone spectra over many 30-second reception periods can make up that loss. For such incoherent averaging, each doubling of the number of periods adds 1.5 dB in S/N. Four periods gets you 3 dB improvement, 16 periods gets 6 dB, and so on. If the signal strength is fairly steady and the sync-tone remains detectable, you can get good copy of any message in a maximum of 15 to 20 minutes.

The cost of using half of the transmission time for the sync tone is 1.5 dB, and this seems to be a very good compromise in practice. It means that transmissions can be synchronized at the receive end even when the S/N is –28 or –29 dB relative to the background noise in a 2500 Hz bandwidth. Note that, by comparison, the minimum CW signal strength that can be copied is about –11 dB relative to same noise level, or equivalently +6 dB in a 50 Hz bandwidth.

21

JT44 can present solid copy with signal levels well below those required for conventional CW.
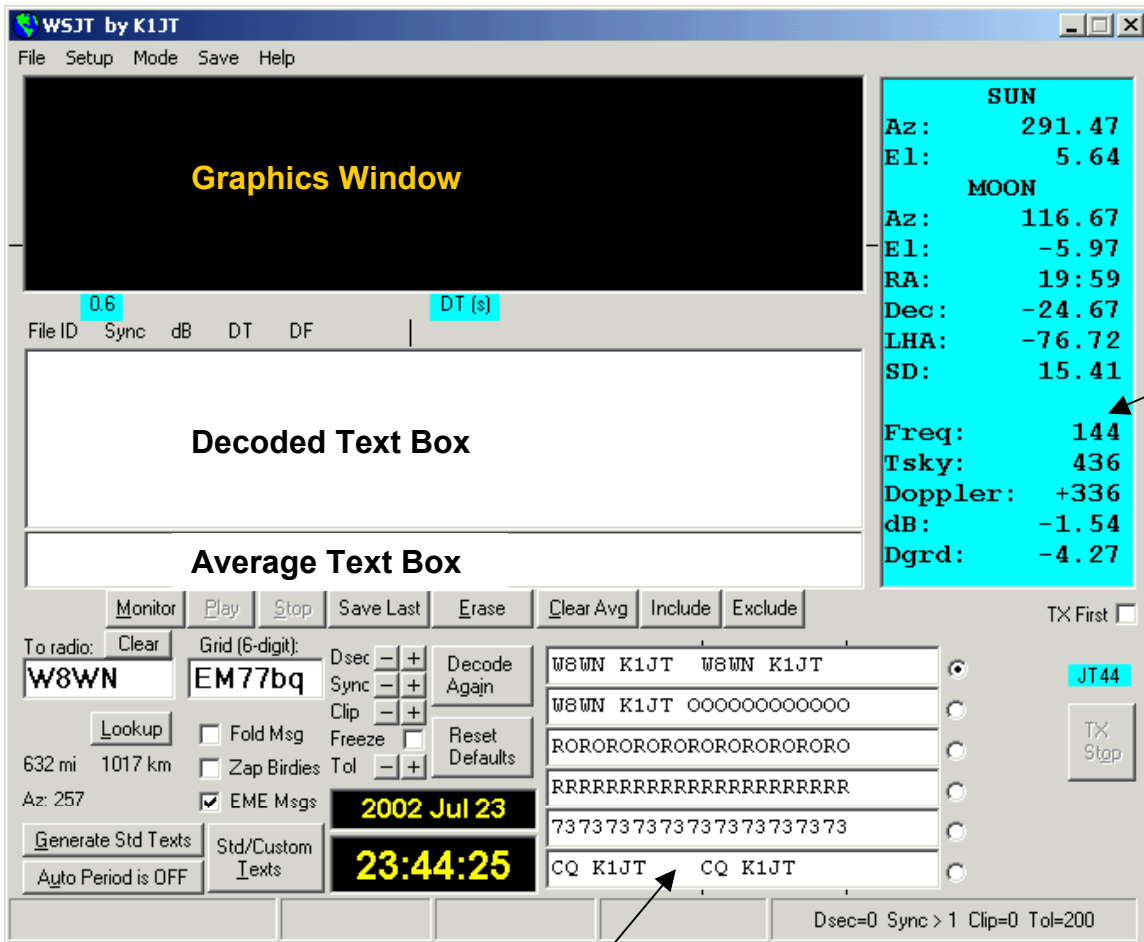
Receiving JT44

JT44 transmissions cannot be decoded unless the transmitter and receiver are synchronized. As a consequence, the only means provided for initiating a transmission or reception interval is by triggering **Auto Period On**. Just as in FSK441 mode, WSJT analyzes a recorded JT44 signal after a receiving sequence has been completed. A graphical display is presented and the decoded text, if any, is displayed in text boxes near the center of the screen.

To monitor both the first half and second half of each minute for JT44 signals, click the **Monitor** command. WSJT will accumulate separate average messages for the first and second transmitting sequence, so that you can "read the mail" and follow the progress of someone else's QSO. To monitor just one side of a

contact you may also check **Setup | TX Mute** (or use shortcut **F3)** and then toggle **Auto period On**. The effect is as if you were in a QSO with another station, except that you will not actually transmit.

Decoded Text

JT44 provides two separate boxes for decoded text. The larger one displays a line of new information after each receive cycle. A typical line produced by a relatively "strong" signal—i.e., one just above the threshold of audibility—might look like the following:

```
FileID Sync  dB   DT    DF        |

194300   3  -16 -0.2  12     *    K0SM K1JT   K0SM K1JT
```

The File ID column displays the UTC start time of the reception interval, in this case 19:43:00. These six digits also serve as the trailing portion of the name of the wave file stored on disk.   The numerical parameter labeled "Sync" provides a measure of confidence that the message has been properly synchronized, on a nonlinear 0 to 10 scale.   Values of 1 or above usually indicate valid synchronization. Next comes a measure of the signal strength, measured in dB relative to the noise in the full receiver passband, typically about 2500 Hz. DT measures the time offset of a received message relative to your computer's clock. If both station's clocks are accurately set, DT should be approximately 0.0 s for terrestrial QSOs and +2.5 s for EME QSOs. Finally, the parameter DF presents a measure of the frequency offset of the received signal relative to your own radio's dial setting, in Hz.   In normal operation WSJT searches for the synchronizing signal over a frequency range –600 to +600 Hz and time delays from –2.0 to +4.0 s.

Most JT44 operation involves signals that are very weak.   The weakest synchronizable signals will not produce good copy on a single transmission; for steady levels between about –24 and –29 dB, the program will generally be able to achieve synchronization but may correctly decode no more than a few characters in the message.   For each transmission that is above the user-settable "Sync" threshold (default **S**=1), WSJT accumulates an "average message" and displays it in the smaller text box near center screen. Each message included in the average is marked with an asterisk (*) after the DF column.   In this way, WSJT can build up the message from a number of successive reception intervals.

The illustration on the next page shows text received by GM4JJJ during a 144 MHz EME QSO with K1JT. Notice that none of the four reception periods gave usable copy, but averaging them together reproduced the message perfectly.

Information from the latest recording is displayed in the graphical display, while all of the text output is accumulated in the main text box.
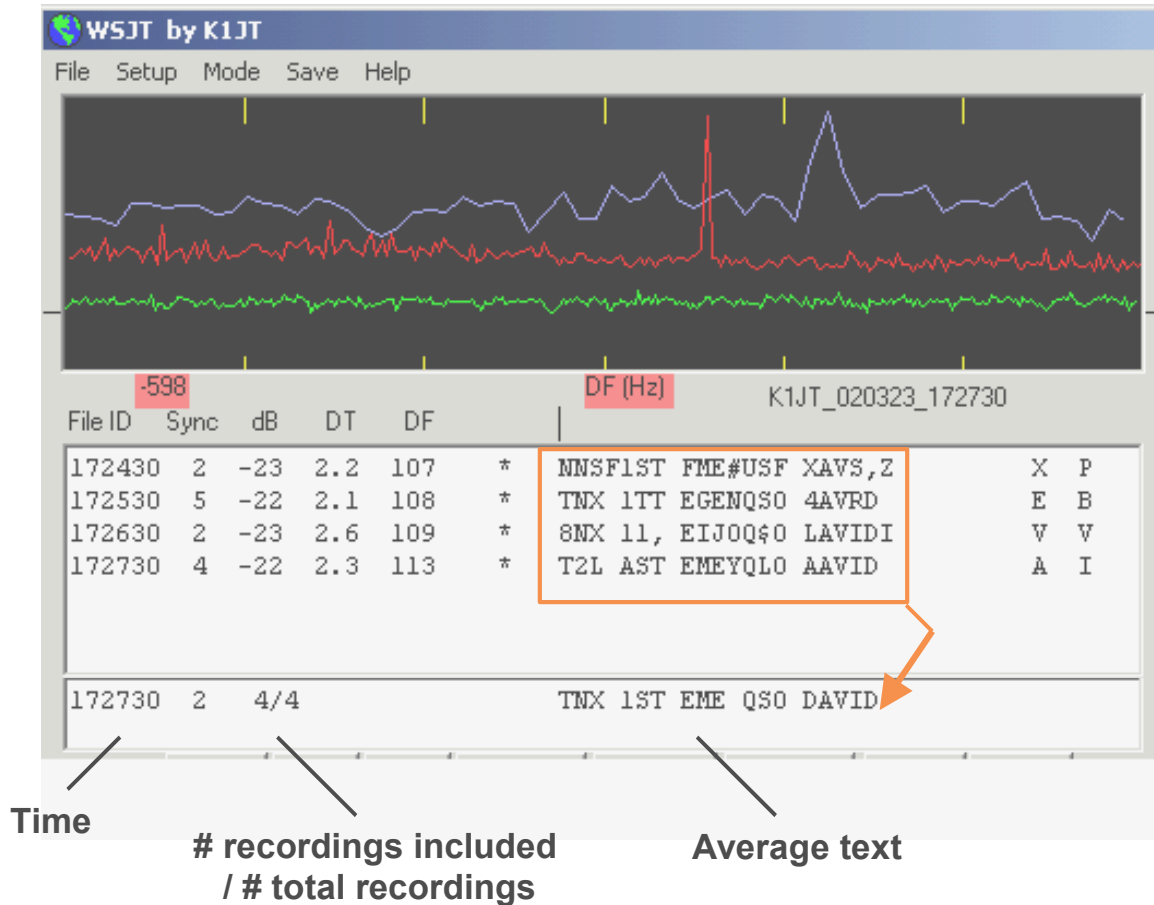
Sometimes a signal will fade below the synchronizing threshold or interference will cause the program to find an incorrect DF or DT. If you are sure the program made an error you can press the **Exclude** button to remove the most recent recording from the accumulating average. Similarly, the **Include** button will include the latest file in the average even if it failed to exceed the Sync threshold.

In addition to message averaging over a number of receive periods, WSJT offers several forms of averaging within each period. Three extra characters at the far right accompany each decoded JT44 message. These characters represent the average of the odd, even, and "last N" characters of the message, where N is the number of repeated characters at the trailing end of standard message #2. Messages with repetitive content (see "Message Formats" below for examples) can gain up to 5.4 dB in signal-to-noise ratio by such intra-message averaging. In addition, by checking the box labeled **Fold Msg** or clicking on the **Fold** button you can instruct the program to average the first and second 11-character of the 22-character message. This procedure can yield 1.5 dB in added sensitivity for exactly repeated 11-character messages.
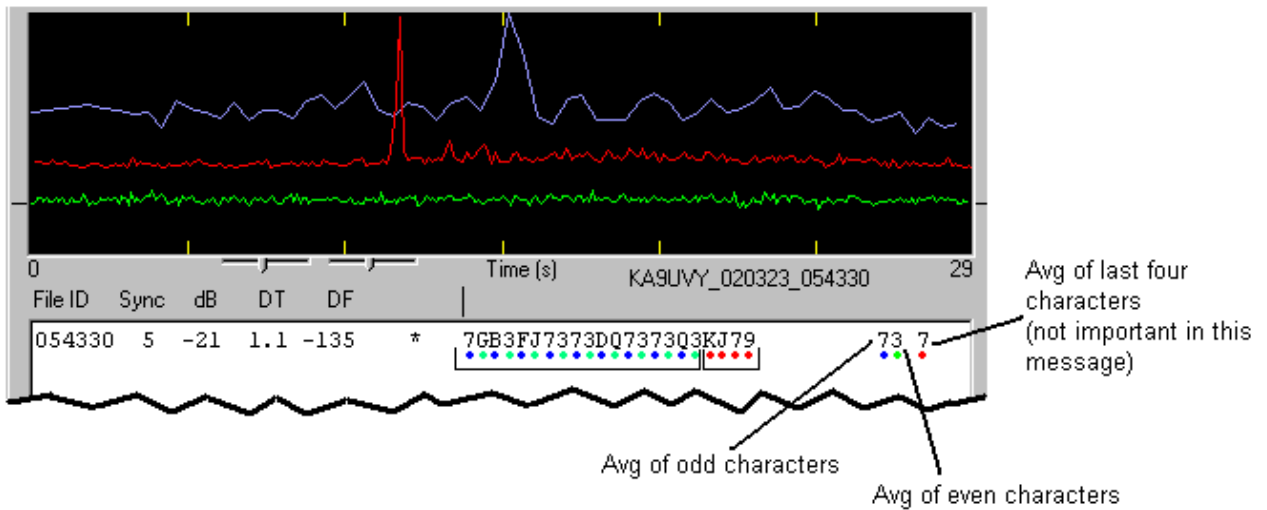
Birdies

Birdies are undesired low-power RF signals that can appear as steady carriers, drifting carriers, pulsing signals, or warbly noise spread over a narrow spectral region. Computers and computer monitors can be sources of birdies, as can handheld electronic games, coffee makers, and even your own transceiver. No matter where you choose to operate, you will probably find birdies. When choosing a schedule frequency, it helps to listen first to ensure that the frequency is clear of birdies.

Because of its long-term signal averaging techniques, the JT44 mode can detect birdies that are impossible to hear. Birdies may appear as spikes in the red graphical display, thus giving the false impression of a detected sync tone. (In general they will not, however, be accompanied by a peak in the blue curve.) Trying to make a JT44 QSO on a frequency close to one or more birdies can cause the program to confuse the sync tone and the birdie or to decode the birdie as spurious text. Although it is best to operate on clear frequencies, it is sometimes impossible to evade a birdie that appears in the middle of a QSO. The following illustration is an example of what can happen if a birdie appears in the passband together with a valid JT44 signal.

Many possible DF's!

Many possible DT's

Strong signal, but program is unable to synchronize
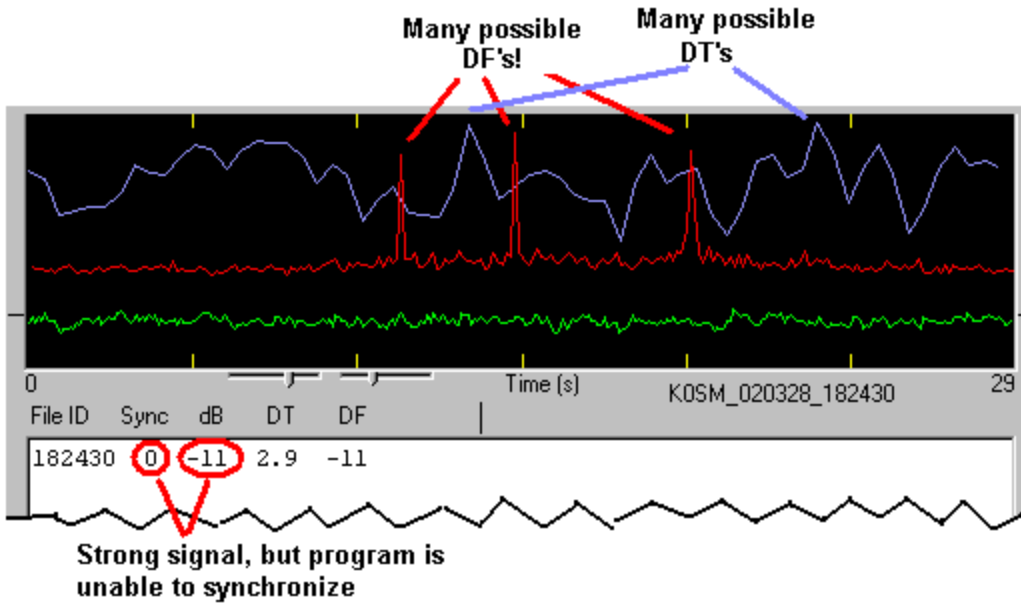
In the figure above, the red curve shows birdies at DF = −150 and DF = −11, while the valid sync tone is at DF = +201 Hz. The program chose the signal at DF = −11 because it was the strongest. Notice that the program had trouble finding the proper DT for this signal, since a carrier with slightly wavering amplitude may fit the pseudo-random timing pattern equally well at many DT's, creating a jagged blue line with many peaks. Although the signal is relatively strong, the program was unable to find an acceptable sync value (Sync=0), and no text was displayed.

Birdies ignored

Correct Sync tone detected
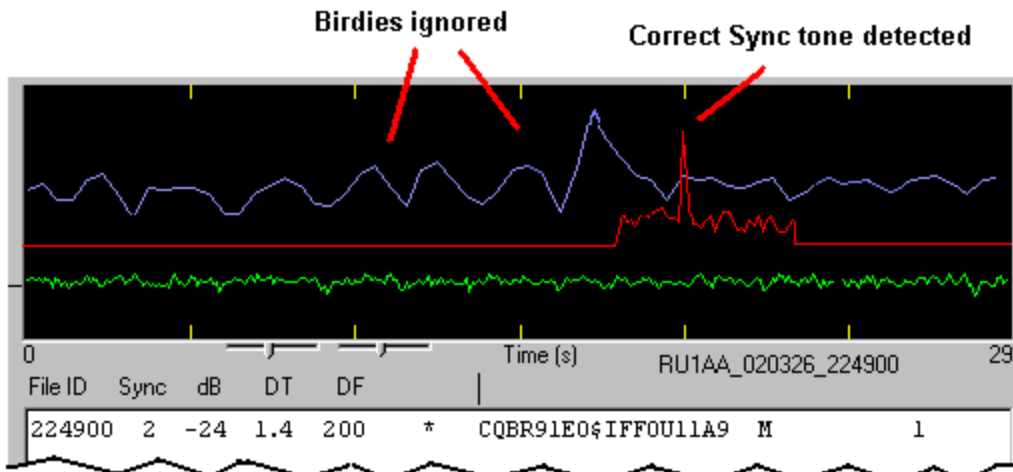
Once the program detects a JT44 signal so that you see some recognizable text, you may click with the mouse on the appropriate spike in the red curve and then

check **Freeze**. Subsequently, WSJT will search a smaller range of frequencies around the selected DF. The range to be searched is determined by the **Tol** parameter. The illustration above shows a recording similar to the one in the previous figure, but this time **Freeze** was checked and **Tol** set to 100 Hz. Notice that birdies outside of the 100 Hz window have been ignored. The Sync value has increased to 2 (usually enough to signify good synchronization) and some text is displayed: RU1AA was calling CQ off the moon in this example. You may set the **Tol** parameter as low as 25 Hz, but keep in mind that EME Doppler shifts change slowly and some radios drift gradually over time.

It can also be helpful to check a box labeled **Zap Birdies**. By doing so you will instruct the decoder to ignore narrow-bandwidth signals that remain on during the JT44 sync-tone intervals. In many instances this can improve your copy of a JT44 signal in the presence of birdies falling in the signal passband, which extends upward from the sync tone by 485 Hz. The birdies will still appear in the displayed red curve, so you can keep track of them.

Standard Message Formats

Transmit and receive periods in JT44 mode are always 30 seconds long, starting on UTC half-minutes. Messages are 22 characters in length. If you enter a message shorter than 22 characters, the remainder will be filled with spaces; if you enter more than 22 characters, only the first 22 will be sent. Because of the tight synchronization requirements of JT44, you cannot change messages while transmitting. However, at any time you may pre-select the next message that will be sent. You may edit messages at any time, except for the one actually being transmitted.

WSJT supports two standard message formats in JT44 mode. Either format is valid for a QSO, regardless of the mode of propagation. Indeed, many other possible formats would also be perfectly valid. It is helpful, however, to adopt some standards to be used for making QSOs under marginal conditions, and it's important that you use them correctly to exchange the necessary information. For a valid QSO, both stations must receive complete callsigns, a piece of information (grid locator, signal report, etc.), and a "Roger". You can switch between the two standard message formats by checking or unchecking the **EME Msgs** box and then clicking the **Generate Std Texts** button. Notice that the repetitive content of the standard messages allows the program usefully to average the "odd", "even", and "last N" characters, as well as the first and second halves of the message, as possible aids for message decoding.

1. `K0SM K1JT FN20`
2. `K0SM K1JT FN20 RRRRRRR`
3. `RRRRRRRRRRRRRRRRRRRRRRR`
4. `7373737373737373737373`
5. `(empty, user defined)`
6. `CQ K1JT    CQ K1JT`

EME: ("EME Msgs" checked)

1. `K0SM K1JT  K0SM K1JT`
2. `K0SM K1JT OOOOOOOOOOOO`
3. `ROROROROROROROROROROROR`
4. `RRRRRRRRRRRRRRRRRRRRRRR`
5. `7373737373737373737373`
6. `CQ K1JT    CQ K1JT`

Practical Operating Hints

The secret of successful JT44 communication is making sure that frequency and time synchronization can be achieved. Be sure that you know your frequency calibration well enough to be within a few hundred Hz of the intended frequency. On EME paths the receiving operator should adjust RIT to account for the expected Doppler shift, especially on frequency bands higher than 144 MHz. Be sure to keep your Windows clock set to within one second or better. For terrestrial QSOs the outer limit for combined clock errors that will still provide good copy at both ends is ±2.0 seconds. (For example, if each station has a 1.1 second setting error and they are in opposite directions, synchronizing attempts in at least one direction will surely fail.) You should aim to have WSJT display values of DT in the range –1.0 to +1.0 seconds for terrestrial contacts. The EME path adds about 2.5 seconds of propagation delay, and since the maximum DT allowed by WSJT is 4.0 s, the outer limit for acceptable clock offsets is reduced from 2.0 to about 1.5 s. You should aim to have DT in the range 1.7 to 3.3 seconds for EME QSOs, with absolute outer limits of 1.0 to 4.0 seconds.

Solar and Lunar Data

The box at the upper right of the screen in JT44 and EME Echo mode presents useful data for tracking the moon, measuring sun noise, tuning your receiver, and evaluating EME path loss at the present time. Coordinates of the sun are given as Azimuth and Elevation (**Az** and **El**), in degrees. The same quantities are presented for the moon, as well as right ascension (**RA**), declination (**Dec**), and

local hour angle (**LHA**); all are in degrees except for **RA**, which is given in hours and minutes. The moon's semi-diameter (**SD**) is given in arc minutes.

Doppler shift for the band in use is given in Hz. Since the two-way Doppler depends on the other station's location as well as your own, the **Doppler** field is blanked out if the **Grid** box is empty. In EME Echo mode, the listed **Doppler** is your own self-echo number, and the **Grid** box is simply ignored. **Tsky** is the galactic background temperature in the direction of the moon, scaled to the operating frequency. The parameter labeled **dB** is the additional signal loss for the moon's present distance, relative to perigee. **Dgrd** is an estimate of the total signal degradation in dB, relative to the best possible time when the moon is simultaneously at perigee and in a "cold" part of the sky.

On-Screen Controls

Auto Period ON/OFF toggles the timed T/R sequencing on and off. During a schedule, you and your partner alternate so that only one station is transmitting at any time. If you choose only to listen, disable the transmitter by toggling **F3** or by checking the **Setup | TX mute** menu item.

Clear Avg. Clicking this button erases text in the smaller text box and clears the average message accumulators. Use this command when the other station has started to send a new message, or when the average contains no useful information.

Clip is set by default to zero. If you increase its value to 1, 2, or 3, the program will apply "soft," "moderate," or "hard" clipping to the signal before attempting to decode the message. Use this feature to reduce the effect of static crashes, meteor pings, or other brief signal or noise enhancements. Under some conditions clipping can recover the program's ability to synchronize on a weak residual JT44 signal.

Decode Again causes the last open file to be decoded once more, perhaps after parameters have been changed or **Clear Avg** has been executed.

Dsec is a clock offset parameter, measured in seconds with 0.5 s increments. Its value (displayed in the status-bar panel at the lower right) is added to the time kept by Windows to establish the UTC displayed and used by WSJT. You can use it to make small clock adjustments when necessary. In general, however, it is best to keep the computer clock set accurately and **Dsec** set to zero.

EME Msgs. Checking this box will change the standard message formats to ones like those generally used in CW EME communication. Many operators will be more comfortable using this style of message, although it can require an additional exchange to complete the QSO. After checking or unchecking this box, press **Generate Std Texts** to create the desired messages.

Erase deletes all information in the decoded text box and the graphical display area. Information in the average text box will be retained, however.

Exclude will remove the most recent recording from the average message. Use this option when you are sure that the program has synchronized incorrectly and you wish to avoid contaminating the average message with bad data.

Fold. Click this button to decode the most recent recording as an 11-character message. The average message will also be presented in folded form. You can revert to the full 22 character, unfolded message (if the **Fold Msg** box is unchecked) by pressing **Decode Again**.

Fold Msg. Check this box to gain an average of 1.5 dB in sensitivity for a JT44 message that is identical in its first 11 and last 11 characters.

Freeze. Check this box when the DF of the other station has been clearly established and you want WSJT to search only frequencies near that value in subsequent receive periods. The target DF is set by clicking on the red curve with the mouse, and the extent of the search range is determined by the adjustable **Tol** parameter.

Generate Std Texts triggers generation of the standard messages used in JT44 mode. The messages will use the information you have entered in the **My call** and **To radio** text boxes. This button will also reset the TX message number to 1 and the **Tol** parameter to 200 Hz. The standard format of the messages can be changed by first checking or unchecking the **EME Msgs** box.

Include will add the most recent recording to the accumulating average message if the signal level was greater than –32 dB, even if the Sync value is below the threshold determined by the **S** parameter.

Lookup causes the program to search the CALLSIGN.TXT file for the callsign in the **To radio** box. If the callsign is found, the station's grid locator will be retrieved and the distance and great circle azimuth bearing will be displayed.

Play. This control plays the most recently processed file through the sound card output port. It functions much like the "Play" button on a cassette recorder.

Reset Defaults will reset the parameters **S, Clip,** and **Tol** to their default values.

S sets the "Sync" threshold for the JT44 decoder. The higher this value is set, the less chance of the decoder incorrectly interpreting a signal. Higher values will not allow very weak signals to be decoded. The default value is 1.

Save Last. Clicking this button will prevent the most recently recorded file from being deleted at the start of the next recording. (See also the menu items **Save | Save Decoded** and **Save | Save all**.)

Standard/Custom Texts permits you to toggle between two distinct sets of TX messages. The standard texts are those most commonly used in JT44 QSOs; custom texts can be used to store other messages such as name or contest information. Custom messages will be saved when you exit WSJT and restored when you next start the program.

Stop will stop a recording in progress. It functions much like the "Stop" button on a cassette recorder.

Tol sets the range of frequency offsets that WSJT will search to find the synchronizing tone. **Tol** is active only when the **Freeze** box is checked. When the correct offset has been established and set by clicking on the red curve with the mouse, you may decrease the value of **Tol** to reduce the probability of false decodings. The range of **Tol** is adjustable from 25 to 200 Hz.

TX First should be checked if you wish to transmit during the first 30 seconds of each minute. Uncheck it if your schedule partner is transmitting in the first period.

TX Stop will interrupt a transmission in progress. It will not toggle **Auto Period Off**, however. To prevent another transmission from starting, press **TX Stop** and toggle **Auto Period Off**. Once you stop a JT44 transmission you cannot start it again, because time synchronization would be lost.

Zap Birdies. Check this box if you have problems with persistent narrow-band interference in the first 500 Hz above a received JT44 sync tone. It will be most useful if you have already selected the correct sync tone frequency and checked the **Freeze** box.

Text Boxes

Average Text. This box contains the average text from all previous receive periods (or since **Clear Avg** was last pressed). It displays the time of the last file included, the number of files included/received, and the program's best estimate of the received message.

Decoded Text. This box is the larger text area near the center of the WSJT form. Each line displays the start time of the receive period, the "Sync" value for that recording, the relative strength of the signal in dB, the time offset DT of the received signal relative to your computer's clock, the frequency offset DF of the signal, and the decoded text. At the end of the decoded text there may appear intra-message averages for the "odd", "even", and "last N" characters of the message. You cannot edit text in this window, but you can copy it onto the

Windows clipboad by highlighting it and typing CTRL-C. You can then paste it elsewhere by using CTRL-V.

Grid. After a successful **Lookup**, this box will display the six-digit grid locator of the callsign in the **To radio** box. You may also enter a grid locator manually. If only four digits of the locator are known, add a space.

Status Bar. This strip along the bottom of the program screen is used to display useful information such as file name, file position, RX audio level, and the decoding parameters.

To radio should contain the callsign of the station being called or worked. Text entered in this box becomes the first part of the file name when a recording starts.

Operating in EME Echo Mode

How EME Echo Mode Works

EME Echo mode is designed to help evaluate the performance of your station for moonbounce communications. Activate it from the **Mode** menu or by hitting function key **F9**. Most of the familiar WSJT controls will disappear from the screen, leaving just a few that are essential for controlling Echo mode. If your station is operational in the FSK441 and JT44 modes and you have provided the proper signal levels, all you need to do for an echo test is to start WSJT, hit **F9** to switch to EME Echo mode, aim your antenna at the moon, pick a clear frequency, and toggle **Auto Period On**. The program will then start cycling through the following loop:

1. Transmit a fixed tone for 2.0 s
2. Wait about 0.5 s for the start of your return echo
3. Record the received signal for 2.0 s
4. Analyze, average, and plot the results
5. Repeat from step 1

The loop cycle time is 6 seconds, so the transmitter duty cycle is only 2/6 or 33%. Your transmitter will think it is loafing, in comparison with FSK441 or JT44, although your T/R relays will get a good workout! At the start of each transmission the frequency of the transmitted tone will be randomly offset around a nominal value of 1500 Hz. A number in the text box labeled **Dither (Hz)** controls the magnitude of the offset. The computed spectrum of each recording is shifted by the offset amount before being accumulated into the average. This procedure is very effective in minimizing the effect of birdies in the receiver passband. In the average spectrum, a fixed-frequency birdie will be smeared out over a wide range, while the desired signal remains sharply defined.

Two curves are plotted in the graphical area during each pass through the 6-second loop. Each curve represents the spectrum of received power over a 400 Hz range, centered on the expected echo frequency. The blue curve is a reference spectrum that you can use to be sure you have chosen a birdie-free passband. It is aligned so as to remove the Doppler shift computed at the start of the run, but the alignment is not subsequently adjusted for changes in Doppler or for the programmed dithering of the transmitted frequency. Stable birdies will therefore stay fixed in the blue curve, making them easy to recognize. The red curve displays the desired echo signal, with each computed spectrum adjusted to correct for changing Doppler and for the programmed frequency dithering. Your echo should appear as a narrow spike near the middle of the red curve, close to DF = 0.

In addition to the graphical display, lines will appear in the WSJT text window in the following form:

```
 N   Level  Sig       DF   Width   Q
32    0.8  -31.7     3.6    1.3    4
33    0.6  -31.5     3.6    1.3    5
. . .
```
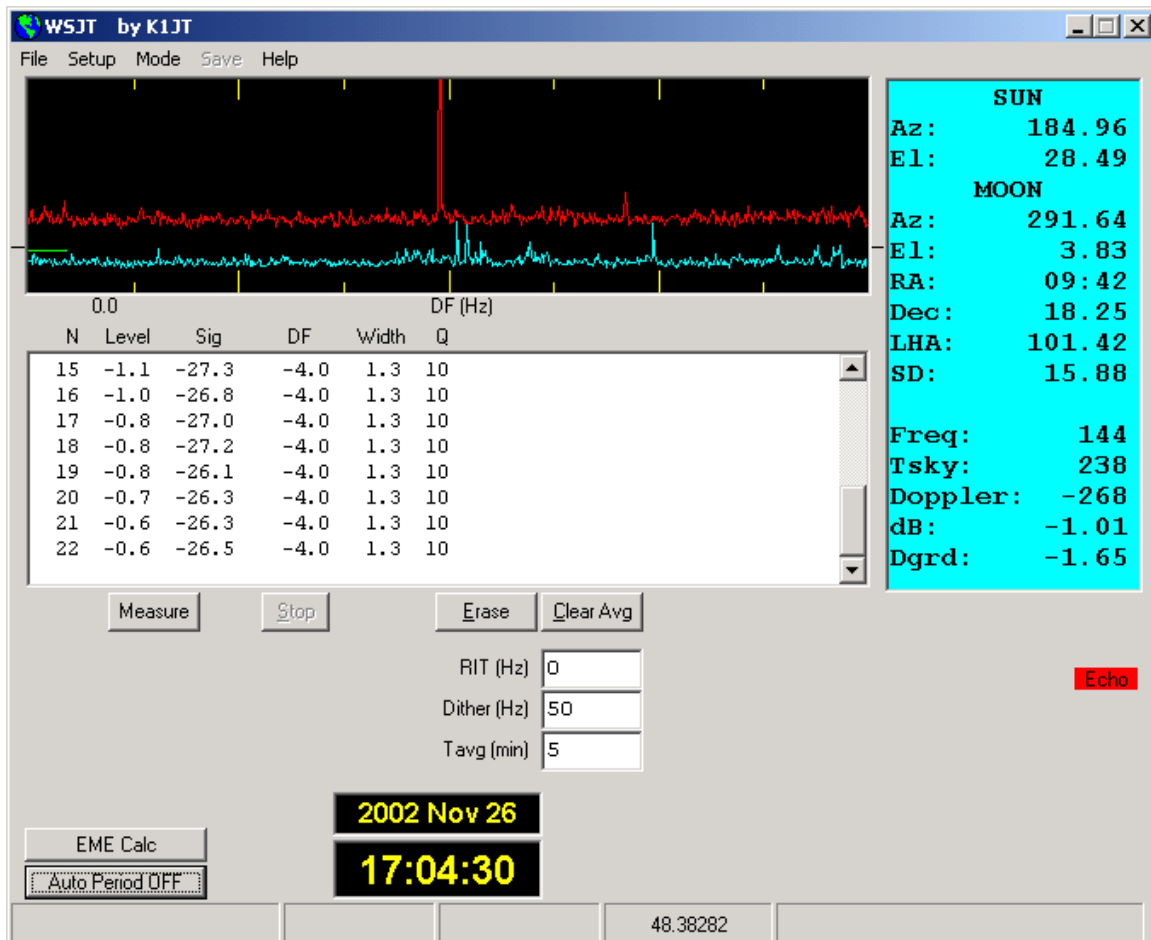
Information in the text box gives the number N of completed echo cycles, the average level of receiver background noise in dB, the average signal strength in dB, the measured frequency offset of the detected echo in Hz (after correction for the expected Doppler shift), the spectral width of the echo in Hz, and a relative quality indicator for the echo detection, on a 0–10 scale. Background noise level is given relative to the optimum "zero dB" level for WSJT in all modes. Signal strength is measured in the same units as used for FSK441 and JT44, that is, in dB relative to the noise power in a 2500 Hz bandwidth. Q = 0 means that an echo detection has not been achieved, or is very unreliable—in which case the values of DF and Width are probably meaningless, and Sig is an upper limit. Larger values of Q imply increasingly significant echo measurements.

By default WSJT will assume that your receiver and transmitter are tuned to the same frequency. An on-screen box labeled **RIT (Hz)** is provided so that you can inform the program of any offset receiver tuning, for example to accommodate a large Doppler shift. Suppose you are running a test on 23 cm and the predicted Doppler shift at the start of the run is –1400 Hz. In that case the 1500 Hz (nominal) transmitted audio tone would be detected at 100 Hz, probably well below the low-frequency cutoff in your receiver's passband. Use your transceiver's RIT control to offset the receiver tuning by the predicted Doppler shift or a nearby rounded value, and enter this offset in the RIT box before starting the echo measurement. The program will track subsequent changes in the Doppler shift up to about 800 Hz, if necessary, without any further adjustments. Your echo should appear near the center of the red curve, as usual. You won't need to use the RIT feature on 6 or 2 meters, where Doppler shifts are much smaller and echoes always fall within the receiver's SSB passband.

EME Echo mode uses the calculated Doppler shift to align received spectra so that the echo should appear at DF = 0. Offsets of a few Hz are to be expected, but the frequency of a valid echo should be well defined and stable. If you click **Clear Avg** to start a new measurement, the echo signal should build up again at the same DF. To be absolutely sure that you are seeing you own echo, try offsetting your receiver frequency by a known amount, say 50 Hz, with the RIT. The echo should then shift by 50 Hz in the opposite direction.

Echo Sensitivity

If you can hear your own EME echoes, you should see a large spike in the red curve within ten seconds after toggling **Auto Period On**. If your echoes are 15 to 20 dB below the audible threshold you should see a significant spike on the red curve within a few minutes. To give you a better example of what to expect, consider the parameters of the K1JT station. On 2 meters I run up to 400 Watts to a 17.6 dBd antenna (4 x 9 el yagis) aimed at the horizon. I cannot hear my own CW echoes with this system. However, when the moon is in my elevation window at 0 to 10 degrees I can easily detect my echoes at any time of the

month using WSJT in EME Echo mode. Indeed, under good conditions I can turn off the PA and use my FT-847 barefoot, delivering 35 W to the antenna, and still detect my echoes rather easily. The EME Echo mode can detect signals down to about –38 dB in five minutes.

The spectral analysis carried out in EME Echo mode provides a frequency resolution and detection bandwidth of 0.67 Hz. If your transmitter or receiver has short-term frequency stability much worse than this value, so that an oscillator in the system drifts or wobbles by more than about 1 Hz in a few seconds, your echo sensitivity will be degraded. Most modern radios have no difficulty in meeting this standard on the 6 and 2 meter bands, but the higher UHF and microwave bands may be more problematic with some equipment.

The "Measure" Sub-Mode

A button labeled **Measure** activates a utility for measuring relative noise power from your receiver. Click the **Measure** button and your system will record audio for one second, compute the level of the noise power, and display the result in units of dB relative to the nominal "zero dB" level. The program will repeat this cycle every 2 seconds, plotting the results as a green line in the graphical screen area and writing summary data in the large text box. If the cumulative file DECODED.CUM has been activated from the **File** menu, the data will be written into that file as well, tagged with the Modified Julian Date on which you made the measurements.
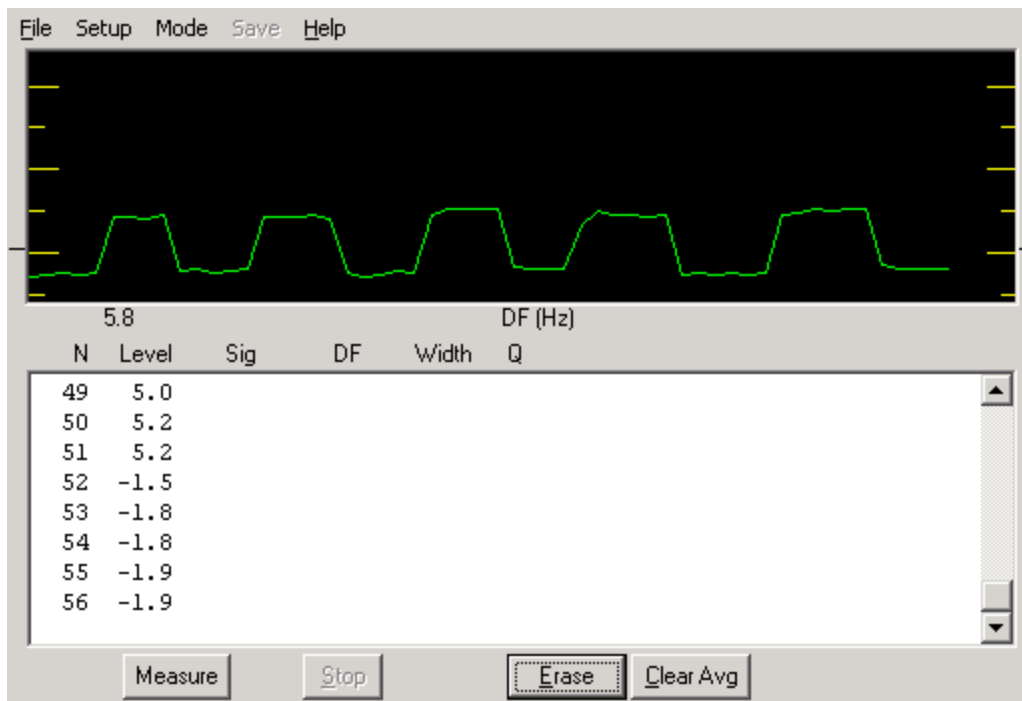
You can use this mode to measure sun noise, antenna temperature, ground noise, preamp gain, and a host of other useful quantities, relative to a chosen reference level. Be sure to disable the receiver AGC if you intend to use the mode for quantitative measurements. It would also be wise to take some test data (for example, using a calibrated attenuator) to confirm that the reported dB readings are reliable in your system as configured.

The screen image on the previous page was made by running **Measure** mode for about two minutes while switching the preamp in the station receiver on and off five times. The yellow tick marks at the sides appear at 5 and 10 dB intervals. You can see that in this test the indicated preamp gain is about 7 dB.

EME Calc

Clicking the button labeled **EME Calc** at the lower left of the screen will pop up a simple utility program for predicting the strength of your echoes from the moon (see illustration on next page). Enter the requested quantities for your station and press **Compute;** if you enter parameters for a DX station as well, you will see the maximum strengths for both station's self-echoes and for each of your signals at the other location. Clicking **Now** will enter the frequency of the active band as specified on the **Setup | Options** page, and the sky background temperature at that frequency. You can **Save** a set of parameters to a file, and **Load** the saved parameter set (or another one) at some later time.

It's important to note that the echo strengths specified are maximum values. They assume that everything is working right, Faraday rotation is cooperating, if relevant, and that the parameters you have specified are reliable. There are many reasons why your actual echo strength at a given time may be less than the predicted strength, and very few reasons why it might (briefly) be slightly greater.

EME Calculator   by K1JT

	A: Home station	Freq (MHz)	B: DX station
TX power (W)	500		50
TX feedline loss (dB)	1.7	Load	1.7
RX noise figure (dB)	0.8		0.8
RX feedline loss (dB)	0.4	Save	0.4
Antenna gain (dBi)	19.7		19.7
Ground gain (dB)	0.0		3.0
Sidelobe noise (K)	150		150
Tsky (K)	361	144	361

		Compute	
dB Moon (dB)	-0.4		-0.4
DGRD (dB)	-1.7		-1.7
Tr (K)	79.0		79.0
Tsys (K)	590.0		590.0

	Echo A	Rx B	Echo B	Rx A
S/N in 2500 Hz BW (dB)	-20.4	-27.4	-24.4	-17.4
S/N in 50 Hz BW (dB)	-3.4	-10.4	-7.4	-0.4

Menus

File |

Open allows you to read back a previously recorded file stored on disk. The file must be a standard wave file recorded in 8-bit monaural format with 11025 Hz sampling.

Delete files in RxWav will cause WSJT to delete all *.WAV files in the RxWav subdirectory. You will be asked for confirmation before the deletions are carried out.

Save text in file DECODED.CUM will cause all decoded text to be appended to a file named `DECODED.CUM` in the WSJT installation directory. If the file is not already present, the program will create it.

Delete file DECODED.CUM will delete the cumulative text file so that you can start it afresh.

Exit will terminate the program.

Setup |

Options

My call. Enter your callsign in this box.

Grid locator. Enter your 6-digit grid locator.

UTC offset. If your computer clock is not set to UTC, use this option to offset the WSJT clock by the appropriate number of hours. If you are east of Greenwich, enter a negative value.

RX delay will enforce a specified minimum delay between the end of a transmission and the start of the next recording. The usual purpose is to avoid dropouts and spikes created by amplifier switching transients. **RX delay** has no effect in EME Echo mode, where a fixed 0.5 s delay is used.

TX delay enforces a specified minimum delay between activation of the PTT line and the start of the first audio tone sent to the transmitter. This delay can protect antenna relays and mast-mounted pre-amplifiers from transmitted RF during the changeover time. **TX delay** has no effect in EME Echo mode, where a fixed 0.5 s delay is used.

ID Interval sets the time between automatic station identifications in FSK441 mode. To use this feature you must provide an audio file named ID.WAV in the WSJT installation directory. The file may identify your station using any desired mode, e.g., voice or CW. A CW identification should be recorded as a keyed sidetone, preferably at about 440 Hz. A value of zero disables the automatic identification. Automatic station identification is not currently available in JT44 mode.

Options

Station Parameters

		FSK441 amplitudes
My call	K1JT	
Grid locator	FN20qi	A 1.000
UTC offset (h)	5	B 1.000
RX delay (s)	0.2	C 1.000
TX delay (s)	0.4	D 1.000
ID Interval (m)	10	Min 0.000 Max 1.000

Done

Com Port
1
Change on
Setup menu

Audio Output
○ Left
○ Right
◉ Both

FSK441 message templates

NA defaults   EU defaults   NA

Freq MHz
144

TX 1	%T %M <
TX 2	%T %R %M %R%R <
TX 3	R%R <
TX 4	RRR <
TX 5	73 <
TX 6	CQ %M <

%M - My Call
%T - To Radio
%R - Report

Everything
else sent as is.

NA/EU Defaults. These buttons establish the default style templates used to create messages when you push the **Generate Std Texts** button in FSK441 mode.   Different meteor scatter operating procedures are used in different IARU regions, and WSJT has been programmed to create standard messages automatically for both North American and European operators. Users in other parts of the world should decide collectively what format they wish to use. The standard templates may be edited, for example to automatically append "/P" or another suffix or prefix to a callsign, or to properly format a contest exchange.   For example, if G4FDX in Indiana changes the template for message TX1 to read "%T W9/%M" before working K1JT, when he presses **Generate Std Texts** the message "K1JT W9/G4FDX" will appear in the box for TX message 1.

FSK441 Amplitudes. If necessary, use these boxes to adjust the relative strength of each FSK441 tone. See the section on "Setting the TX Audio Level" for more information. Level adjustment of different tones is not currently supported in JT44 mode.

Audio output. You may select which stereo channel carries the TX audio from the sound card to the radio: check **Left**, **Right**, or **Both**.

Freq MHz. Enter the nominal frequency in MHz of the band you are operating. The entry is used for computing Doppler shifts and sky background temperatures when operating in JT44 or EME Echo mode.

Set COM port allows you to select which COM port will activate T/R switching. Enter the number of the desired port. If you do not want the computer to control T/R switching, enter "0".

DTR, RTS. These are the names of two signal lines in the serial port. You may select either or both of them to activate your station's T/R switching sequence.

Adjust RX/TX Volume controls. Clicking on these menu items will cause the sound mixer volume controls to be displayed for adjustment.

Alternate graphical pointer. The mouse pointer in FSK441 mode becomes a "crosshairs" pointer when placed over the graphical area. If this item is checked, the pointer will remain an "arrow".

Alternate PTT Logic. Check this item to select slightly different program logic for controlling your T/R switching via the COM port. A few combinations of hardware and operating system drivers seem to work better with this option.

Tx Mute. Check this item (shortcut **F3**) to prevent making actual transmissions. Use together with **Auto Period On** to monitor one side of a QSO.

Enter new "To radio" callsign. Choose this item (shortcut **F4**) to clear the **To radio** and **Grid** boxes in preparation for typing new entries.

Mode |

WSJT currently supports three signaling modes: FSK441, JT44, and EME Echo mode. Use this menu (or the shortcut keys **F7**, **F8**, and **F9**) to switch between modes.

Save |

> **Save Decoded.** Checking this item will cause any files that produce decoded text to be saved in subdirectory `RxWav` under your main WSJT installation directory.

> **Save All.** Checking this item will cause all recorded files to be saved in subdirectory `RxWav` under your main WSJT installation directory.

Help |

> **Help** displays a brief message urging you to download and read the WSJT *User's Guide and Reference Manual* (the manual you are reading now).

> **About WSJT** displays version and copyright information. On some Windows installations the "System Info" button will also display information about your computer and its operating system.

> **Which message should I send?** Choosing this item (or using its shortcut **F5)** will pop up a text box with reminders about the standard message exchanges used for minimal QSOs with FSK441 and JT44.

Appendix A: Specifications of the Signal Protocols

FSK441

FSK441 uses four-tone frequency shift keying at 441 baud. The frequencies of the audio tones are 882, 1323, 1764, and 2205 Hz. Each encoded character uses three tone intervals and therefore requires 3/441 seconds (approximately 2.3 ms) for transmission. FSK441 accommodates an alphabet of 43 characters, the same ones used in the PUA43 system developed by Robert Larkin, W7PUA.

Character encoding is defined in the table reproduced below. The four tones have been labeled 0 – 3 for the tones 882 through 2205 Hz, in increasing order. As an example, the letter "T" has the code 210 and is transmitted by sending sequentially the tones at 1764, 1323, and 882 Hz. Note that the character <space> is encoded as 033, and that three-tone sequences starting with the highest frequency tone (number 3) are not used. It follows that if transmitted messages always include at least one space, a decoding algorithm can establish proper synchronization from the message content itself, with zero overhead. This encoding strategy is one of the secrets of the high efficiency of FSK441 for meteor scatter communications.

<u>FSK441 character codes</u>

1	001		H	120
2	002		I	121
3	003		J	122
4	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			

The four possible "single-tone" character codes, namely 000, 111, 222, and 333, are reserved for special use as shorthand messages. When sent repeatedly, these reserved characters generate pure single-frequency carriers. Their pings are easily recognized by the human ear and also by appropriate software. The shorthand messages are defined to mean "R26", "R27", "RRR", and "73", respectively, for the four tones. These messages are frequently used in meteor scatter QSOs, after callsigns have been exchanged.

JT44

JT44 uses 44-tone frequency shift keying at $11025/2048 \approx 5.38$ baud. All transmitted messages contain 135 data intervals, each 2048 audio samples long. Sixty-nine of the intervals carry a synchronizing tone at frequency $118*11025/1024 \approx 1270.5$ Hz. The remaining 66 intervals carry a 22-character message, repeated three times. Each character is represented by a tone at frequency $11025*(N+121)/1024$, where N is an integer in the range 0 to 42. Permissible characters include the digits `0-9`, letters `A-Z`, and special characters `.,/#?$` and `<space>`.

JT44 requires time synchronization. Transmit and receive periods are nominally 30 seconds each, starting on UTC half-minutes. Transmitted audio begins 1.0 seconds into the TX interval and lasts for 135 x 2048 samples at the 11025 Hz sound card sampling rate, approximately 25.08 seconds. The final 3.92 seconds of the transmit period (minus any time reserved for T/R switching and transient recovery) may in future be used for station identification. The idle time also serves to accommodate EME propagation delays of approximately 2.5 seconds, as well as clock errors up to about one second.

The 69 sync-tone intervals and 66 character-tone intervals are interleaved according to a pseudo-random pattern having the desirable property that its auto-correlation function has a single spike at zero lag and falls to low values elsewhere. Detecting and aligning with this sync-tone pattern is one of the principal "secrets" of JT44, allowing the software to accommodate relatively large frequency and time errors. The program can synchronize reliably with frequency errors up to ±600 Hz and time offsets from –2.0 to +4.0 seconds. The range of permissible time offsets was made asymmetrical so as to easily accommodate EME delays.

Frequencies assigned to the sync tone and the 43 character tones are listed in the following table.

Frequencies of JT44 tones

```
 N Char  Freq (Hz)
 -------------------
   <sync>  1270.5
 0    0    1302.8
 1    1    1313.5
 2    2    1324.3
 3    3    1335.1
 4    4    1345.8
 5    5    1356.6
 6    6    1367.4
 7    7    1378.1
 8    8    1388.9
 9    9    1399.7
10    .    1410.4
11    ,    1421.2
12 <space> 1432.0
13    /    1442.7
14    #    1453.5
15    ?    1464.3
16    $    1475.0
17    A    1485.8
18    B    1496.6
19    C    1507.3
20    D    1518.1
21    E    1528.9
22    F    1539.6
23    G    1550.4
24    H    1561.2
25    I    1571.9
26    J    1582.7
27    K    1593.5
28    L    1604.2
29    M    1615.0
30    N    1625.8
31    O    1636.5
32    P    1647.3
33    Q    1658.1
34    R    1668.8
35    S    1679.6
36    T    1690.4
37    U    1701.1
38    V    1711.9
39    W    1722.7
40    X    1733.4
41    Y    1744.2
42    Z    1755.0
```

The pseudo-random sequence that assigns each of the 135 transmission intervals to carry either synchronizing or data information is reproduced below. Each "1" in the sequence represents a sync tone, and each "0" a data tone.

```
Interval #     1=sync, 0=character tone                          .

   1-20:  1 1 1 0 1 0 0 0 0 1 1 1 0 0 1 1 0 0 0 0
  21-40:  1 0 0 1 0 0 0 1 0 1 0 1 1 1 0 1 0 1 1 1
  41-60:  1 0 0 1 0 0 1 0 1 1 1 0 0 1 1 1 0 0 0 0
  61-80:  0 0 1 1 1 0 1 1 1 0 1 0 0 1 1 1 1 0 1 0
 81-100:  1 0 0 1 0 1 0 0 0 0 0 0 1 0 1 0 1 0 1 0
101-120:  1 1 1 1 1 0 1 0 1 1 0 1 0 0 0 0 0 1 1 0
121-135:  1 1 1 0 1 1 0 1 1 0 1 0 1 1 0
```

For the sake of sensitivity comparison, the following table lists the approximate minimum signal levels required for intelligible JT44 signals and for ordinary CW copied by ear in a 50 Hz bandwidth. Signal levels are reported in two ways: signal to noise ratio (S/N) in a 50 Hz bandwidth and S/N in a 2500 Hz bandwidth, the latter being the quantity reported by WSJT. These two measures differ by 10*log(2500/50) = 17.0 dB.

Type of Signal	S/N in 50 Hz Bandwidth (dB)	Reported WSJT level (dB)
Minimum intelligible 12 WPM CW signal	+5.0	-12.0
JT44 random message	-6.1	-23.1
JT44 random message after 4 minutes	-9.1	-26.1
JT44 ROROROROROROROROROROR message	-11.3	-28.3
JT44 Random message after 16 minutes	-12.1	-29.1
JT44 limit for synchronization	-12.9	-29.9

The signal-averaging features of JT44 rely on the signal level being more or less steady in amplitude. Significant QSB can reduce the advantage of JT44 over CW, because a good CW operator will copy on the peaks. Your mileage may vary for other reasons, as well.

EME Echo Mode

Because it uses a very narrow detection bandwidth of 0.67 Hz, EME Echo mode can detect signals much weaker than those required for JT44 communications. The threshold signal level for detection of echoes with Q=1 is given by

$$Sig = -29.4 - 5 \log_{10} N,$$

where N is the number of echo cycles. (If N is larger than 10T$_{avg}$, where T$_{avg}$ is the specified averaging time in minutes, replace N by 10T$_{avg}$.) This equation means that you should be able to detect echoes down to about –34 dB in one minute (N=10) and –38 dB in five minutes (N=50).

Appendix B: Astronomical Calculations

WSJT carries out a number of astronomical calculations to provide tracking data for the sun and moon, path losses and Doppler shifts for EME signals, sky background temperatures, etc. You may find it useful to know something about the nature and accuracy of these calculations.

The state of the art for establishing three-dimensional locations of the sun, moon, and planets at a specified time is embodied in a numerical model of the solar system maintained at the Jet Propulsion Laboratory. The model has been numerically integrated to produce tabular data that can be interpolated with very high accuracy. For example, the celestial coordinates of the moon or a planet can be determined at a specified time to within about 0.0000003 degrees. Although the ephemeris tables and interpolation routines could easily be incorporated into WSJT, the accuracy provided would be overkill for our desired purposes. Instead, WSJT uses closed-form calculations based on a limited number of harmonic terms that have been fit to the high-accuracy data.

The precise algorithms used for solar and lunar positions were developed by Van Flandern and Pulkkinen (*Astrophysical Journal Supplement Series,* 44, 391–411, 1979). Series expansions from this paper yield accuracies of about 0.02 and 0.04 deg for the sun and moon positions, respectively, and they will remain almost this good for nearly a thousand years. At this level of accuracy the effects of nutation and aberration can be ignored, as can most of the smaller planetary perturbations. (Perturbations involving the Moon, Jupiter, Saturn, and Uranus are included, however.) Ephemeris Time and Universal Time are taken as equivalent, and the time steps associated with leap seconds are ignored. These and all other approximations employed are consistent with the specified accuracy level.

The coordinates displayed for the sun are geocentric. Since the moon is much closer its diurnal parallax is significant, and therefore topocentric coordinates are

given for your specified location. For both sun and moon, the listed elevation is the apparent position of the center of the disk, corrected for atmospheric refraction.

To improve the accuracy of predicted Doppler shifts of EME signals, a larger number of terms was used in the series expansion for lunar distance. WSJT properly accounts for the oblateness of the Earth when establishing locations relative to the Earth's center. Final accuracy of the Doppler shifts computed by WSJT is better than 1 Hz at 144 MHz, and this has been confirmed by direct comparison with a calculation based on the JPL ephemeris.

The sky background temperatures reported by WSJT are derived from the all-sky 408 MHz map of Haslam et al. (*Astronomy and Astrophysics Supplement Series, 47, 1, 1982)*, scaled by frequency to the (–2.6) power. This map has angular resolution of about 1 degree, and of course most amateur EME antennas have much broader beamwidths than this. Your antenna will therefore smooth out the hot spots considerably, and the observed extremes of sky temperature will be less. Unless you understand your sidelobes and ground reflections extremely well, it is unlikely that more accurate sky temperatures would be of much practical use.

Appendix C: Availability of Source Code

All significant calculations carried out in WSJT are written in the ancient but honorable language of Fortran.   As a means of documenting and preserving the algorithms used for encoding and decoding FSK441 and JT44 signals, a package of source code has been prepared and placed on the WSJT web site. This package may be of interest to others who want to delve into the signal processing that lies at the core of WSJT, or perhaps wish to port WSJT to another platform such as Linux. [Note: if language in this Appendix seems rather arcane, it's possible that playing with the WSJT source code is not for you!]

The source code is packaged as a tarfile and can be downloaded from the URL `pulsar.Princeton.edu/~joe/K1JT/wsjt.tar`.   The file contains the Fortran routines used to generate and decode FSK441 and JT44 signals, as well as a suite of programs for testing the algorithms with simulated signals and example scripts for compiling and executing the programs. To use the package under Linux—or under Windows, assuming that you have the program `tar.exe` and the Compaq Visual Fortran compiler, which is driven by `df.exe`—proceed as follows:

Extract the source code from the tarfile:

```
% tar xf wsjt.tar
```

Compile the programs testfsk441 and testjt44:

```
% compile
```

Small changes in the `compile` script may be necessary if you have a different Fortran compiler.

The test programs are set up to generate FSK441 or JT44 messages with specified content and signal characteristics. The generated signals will be embedded in random gaussian noise so that they will be similar to real FSK441 or JT44 signals received on the air. You can set such things as signal strength, ping duration, DF, and DT, as well as the message being sent.

For example, to run the `testfsk441` program so as to generate a brief ping of duration 140 ms and signal strength +2 dB, carrying the message "W8WN K1JT", type the following command:

```
% testfsk441 "W8WN K1JT" 140 2
```

which should produce the following output:

```
 00099   5.0  100  2 16   22      JT W8WN K1JT W8W$
```

This is the line of text that would be displayed by WSJT in its scrolling text box if the program had recorded the file you just generated. The generated file will have been saved under the name 00099.wav. You can open the file from the WSJT "File | Open" menu and it will be decoded in the usual way. You can also play it back so as to hear the generated ping. Experienced FSK441 operators will swear that it sounds like a real signal recorded from a meteor ping.

If you wish to experiment with the single-tone messages for R26, R27, RRR, or 73, set the command-line message field respectively to "++", "**", "%%", or "@@".

To test the JT44 algorithms you can type something like the following at the command line:

```
% testjt44 "RU1AA K1JT OOOOOOOOOOO" 0 0 -25 10
```

This will generate a series of 10 files with the message "RUA11 K1JT OOOOOOOOOOO" at DT=0, DF=0, and signal level –25 dB, and should produce the following output:

```
 000001  4  -25 -1.0   -1    *   RUSYAAK8 TMOKJTR79OZOT         AO O
 000002  3  -25 -1.0    0    *   OU,1A K1/RMO5.OQAAO4OR         OO O
 000003  2  -25 -1.0    0    *   #O1AA #MJTUOSGN$ OOR6O         OO O
 000004  3  -24 -1.0    0    *   .U1Y2 #QJL4OO,96OO 2?J          O O
 000005  4  -25 -1.0    0    *   RZK5I K1TT#Z,2KQ2OOO$O         OO O
```

```
000006  2  -24  -1.0    0    *    CV5SANHVITW FOOBOOR0OG              OO O
000007  3  -25  -1.0    0    *    RU1?C 01K4 O2OEO#OOO,/              OO O
000008  3  -23  -1.0    0    *    RURA7AVAST6Q6NOI$ETSSW             6A O
000009  3  -25  -1.0   -1    *    R,V$M KYU #GOO8OO?CLOB             OO O
000010  4  -25  -1.0    0    *    ZUVTU#K1JT 2OPOOOOHOOJ             OO O
```

Again, these are the same lines as those displayed in the WSJT scrolling text window if the identical files were recorded in real time. The files are saved with names `00001.wav` through `00010.wav`, and you can play with them from within WSJT, as described above.

After the preceding run, if you type

```
% cat decoded.txt
```

you will see the accumulating JT44 "average message" as it would be displayed (one line at a time) in the JT44 average text window:

```
000001  1   1/1                  RUSYAAK8 TMOKJTR79OZOT
000002  1   2/2                  RUIYA K1UTMO5.OOD#OOOR
000003  1   3/3                  RU1AA K1ATKO5.OODOOOOO
000004  1   4/4                  RU1YA K1JTKO5.OOOOOOOO
000005  1   5/5                  RU1AA K1JTKOSOWQOOOOOO
000006  1   6/6                  RU1SA K1JT OFOOOOOOOOO
000007  1   7/7                  RU1SA K1JT OOOOOOOOOOO
000008  1   8/8                  RU1AA K1JT OOOOOOOOOOO
000009  1   9/9                  RU1AA K1JT OOOOOOOOOOO
000010  1  10/10                 RU1AA K1JT OOOOOOOOOOO
```

Note that although the generated signal is very weak and was not decoded well in any of the individual 30-second transmissions, the average builds up quickly to the correct message.

Appendix D. Possible Future Developments

WSJT seems always to be a work in progress. Plans for its future development are of course subject to change, but for reasons made evident by the graph on the following page there are several possibilities among my current favorites. The diagram shows minimum usable signal levels for a number of different communication modes, plotted as a function of character transmission rate. Signal levels are specified using the WSJT convention of dB relative to noise power in a 2500 Hz bandwidth. The dashed line labeled "theoretical limit" makes it clear that higher transmission rates require stronger signals, in direct proportion. This follows because the higher rates require larger bandwidths, which accept proportionally larger noise powers.

Morse code is inefficient as a signaling protocol because on average each character requires about 12.7 key-down "dit" intervals. This inefficiency exacts an 11 dB S/N penalty, and it's for this reason that frequency-sensitive digital modes can do much better. The graph shows that FSK441 is better than 6000 LPM high-speed CW by about 8 dB, even while achieving 1.5 times better throughput. For 2000 LPM the corresponding numbers are 3 dB and 4.5 times, respectively. Near the middle of the transmission rate scale, the graph shows that 12 WPM Morse can be copied down to about –12 dB signal level, but JT44 reaches –23 dB for the same transmission rate. By using its averaging algorithms (which amount to incoherent integration), JT44 can get down to about –29 dB. EME Echo mode, most sensitive of all, starts out around –30 dB and gets down to –38 dB within a few minutes.

From this discussion, two interesting possibilities suggest themselves for future WSJT development. If coherent averaging could be used in a JT44-like mode, rather than incoherent, it should be possible to gain nearly 3 dB over the present system in 4 minutes of averaging, because the averaging slope would increase from 1.5 to 3 dB per octave. At higher transmission rates there is a significant coverage gap around 10–50 characters per second. Two "phantom modes" tentatively called JT6M and FSK110 are indicated there; these modes presently exist only on paper, but their implementation might be a real boon for efficient meteor scatter work on the 6-meter band. FSK441 was primarily designed for 2 meters, where random meteor pings generally last for only about 100 ms. However, ping duration scales as wavelength squared, so at 6 meters a significantly slower transmission rate is still enough to permit callsigns and a signal report to be transmitted in a single ping. The FSK110 and JT6M modes should be able to do this with sensitivity gains of about 6 dB and 13 dB, respectively, over FSK441.