Using WSPR Mode in WSJT7

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Quick Start: If you are already familiar with the JT65 mode in WSJT, here's a quick summary of operational differences between the WSPR QSO mode and JT65.

1. WSPR uses 2-minute T/R sequences rather than 1-minute.

2. The structured messages are slightly different. Callsigns enclosed in <…> brackets are sent as hash codes (see below); signal reports use an S1 to S9 scale, with S1 corresponding to S/N = –30 dB on the WSJT scale, S2 –27 dB, ..., up to S9 = –6 dB. A variety of "canned" and "partly canned" messages are offered, as well as free text messages up to 8 characters. See Table 1 and remaining text for details.

3. Right-click on the Tx6 message box to pop up a list of templates for special messages. Click on a desired message and edit it as needed, replacing any lower-case text with appropriate words or numbers. Click OK to copy the result into Tx6. Hit Shift+F2 for a reminder about permissible words in special messages. Be careful to stay within the specified message format.

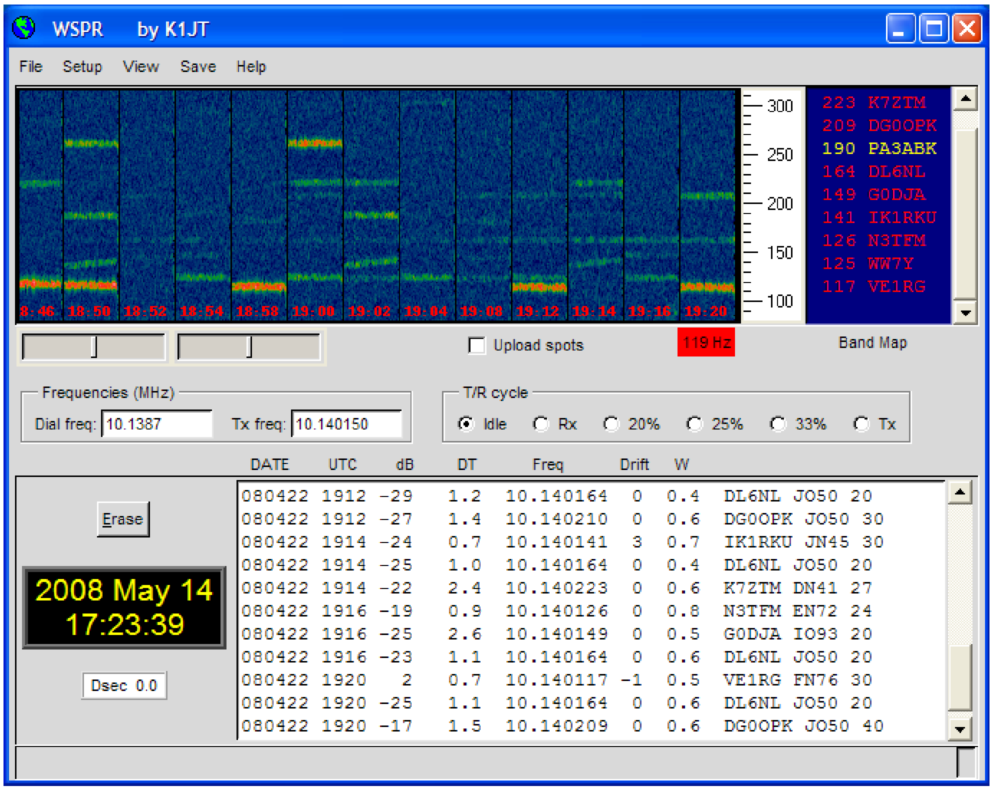
4. As in JT65, double-click on a callsign in the decoded text box to transfer it to "To Radio" and create standard messages with the appropriate signal report. Double-right-click to do the same thing and also switch "Auto" on.

Be sure to read the rest of this document as you start to make WSPR mode QSOs! Please send comments and suggestions to k1jt@arrl.net.

Background: WSPR mode was created in March 2008. The name is pronounced "whisper," which seems appropriate for a mode designed for extremely weak signals; it is an acronym for "Weak Signal Propagation Reporter," and has come to be used for both the protocol and a computer program that implements it. The protocol was developed for beacon-like signals originating from QRP transmitters on the LF, MF, and HF bands, but also with an eye toward its possible use for making QSOs with very weak signals. WSPR uses structured messages with a high degree of compression, strong forward error correction, an embedded sync vector for establishing accurate time and frequency offsets between transmitter and receiver, and 4-tone frequency shift keying at 1.46 baud. Transmissions last for slightly less than 2 minutes. Total bandwidth is about 6 Hz, so WSPR signals are about 1/60 the bandwidth of JT65B signals and 1/4 the bandwidth of 20 wpm CW. Dozens of WSPR signals can fit into a few hundred Hz of spectrum, with few collisions. The screen shot on the next page shows the WSPR program in use on a 200-Hz segment of the amateur 30 m band.

The WSPR program transmits during a specified fraction of available 2-minute slots, and receives in the rest; a typical "transmitting percentage" is 25%. Messages consist of callsign, grid locator, and transmitter power in dBm; on the HF bands, most operators have been using power levels of

100 mW to 5 W. As you can see in the screen shot below, WSPR signals can be decoded with signal-to-noise ratios as low as –29 dB in the standard reference bandwidth of 2500 Hz. As in JT65, strong forward error correction guarantees that messages are almost always received exactly as transmitted, or not at all.



WSPR Mode in WSJT: The WSPR protocol has now been extended to include message types useful for making 2-way contacts.   Capabilities for such QSOs have been built into WSJT Version 7.   The new message types are illustrated by templates and examples in Table 1, on the next page. Upper-case letters and numerals are conveyed exactly as shown in the templates. Lower-case items are replaced by appropriate parameter values, for example `call=K1JT`, `grid=FN20`, `rpt=S1` to `S9`, `name=VICTORIA`, `wx=SNOW`, `freetext=CUL JACK`, and so on, as shown in the examples.

WSPR messages may contain one full callsign and one “hash-coded” callsign. The transmission of hash codes is indicated by angle brackets surrounding the call, as in `<K1JT>`; the brackets appear in displays of both transmitted and received messages. Since hashing is a many-to-one mapping, the process is not reversible. However, if a full callsign has been decoded in a previous transmission, the decoder may assume that matching hash codes usually imply matching callsigns. With a 15-bit hash code, the chances of misidentification are very small, especially within the confines of a particular QSO.

Table 1. Templates and examples of WSPR messages.

Template	Example of usage
CQ call grid	CQ K1JT FN20
CQ p/call	CQ PJ4/K1JT
<call1> call2	<K1JT> W6CQZ
DE call grid	DE W6CQZ CM87
DE p/call	DE PJ4/K1JT
call1 <call2> rpt	W6CQZ <K1JT> S4
QRZ call	QRZ K1JT
p/call rpt	PJ4/W6CQZ S4
call1 <call2> R rpt	K1JT <W6CQZ> R S3
p/call R rpt	PJ4/K1JT R S3
<call1> call2 RRR	<W6CQZ> K1JT RRR
call1 <call2> RRR	W6CQZ <K1JT> RRR
DE p/call RRR	DE PJ4/K1JT RRR
73 DE call grid	73 DE W6CQZ CM87
73 DE p/call	73 DE PJ4/K1JT
TNX name 73 GL	TNX VICTORIA 73 GL
OP name 73 GL	OP HARRY 73 GL
pwr W DIPOLE	5 W DIPOLE
pwr W VERTICAL	10 W VERTICAL
pwr W gain DBD	1 W 0 DBD
pwr W gain DBD 73 GL	1500 W 21 DBD 73 GL
PSE QSY freq KHZ	PSE QSY 1811 KHZ
WX wx temp F/C wind	WX SNOW -5 C CALM
freetext	CUL JACK

A minimal QSO using WSPR mode might look like the following sequence of messages:

1.	CQ K1JT FN20	
2.		<K1JT> W6CQZ
3.	W6CQZ <K1JT> S4	
4.		K1JT <W6CQZ> R S3
5.	<W6CQZ> K1JT RRR	
6.		TNX JOE 73 GL

A third-party operator listening to this QSO from the beginning would copy everything just as the participating stations do. Even if only one of the QSO partners can be copied at the third station, both callsigns will be received in full. If the third-party operator tunes into the middle of a QSO, so that his decoder cannot yet identify one of the hashed callsigns, it will produce something like

W6CQZ <...> S4

instead of the full message. He must then stay tuned to determine the identity of the missing callsign. There will be no ambiguities for the QSO partners themselves. Full callsigns are always decoded (or already available, in the case of one's own call) before their hash codes are needed.

Signal report `S1` corresponds to –30 dB on the WSJT scale, `S2` = –27 dB, `S3` = –24 dB, etc., up to `S9` = –6 dB. On this scale, the threshold for signal audibility is around `S5` to `S6`. The placeholder `"p/"` stands for an add-on prefix or suffix in compound callsigns like `ZB2/DF2ZC` or `DH7FB/P`. Information conveying the prefix or suffix replaces the information that would otherwise carry a grid locator or hashed callsign.

The lower-case items `"pwr"`, `"gain"`, `"temp"`, and `"freq"` in Table 1 stand for numbers. A 2m EME station might send the message

```
1500 W 21 DBD
```

to inform his QSO partner about his equipment. Similarly, a QRP HF station might send

```
1 W 0 DBD
```

or

```
5 W DIPOLE
```

If an operator finishes a QSO on 80 m and wants to try 160 m next, he might send

```
PSE QSY 1811 KHZ
```

Weather reports can be conveyed by setting `"wx"` to `CLEAR, CLOUDY, RAIN,` or `SNOW`; `"temp"` should be set to a value such as `76 F` or `-5 C`; `"wind"` should be be set to `CALM, BREEZES,` or `WINDY`. Names may contain up to nine letters, and `"freetext"` may contain any combination of eight or fewer letters, numerals, spaces, and the punctuation marks `+ . / ?` . Space has been reserved in the WSPR protocol for many more "canned" or "partly canned" messages like those in the final group of templates, after some on-the-air experience has been gained.

The screen shot on the next page shows WSJT making a (simulated) WSPR-mode QSO. Notice the extremely narrow bandwidth of the signal on the waterfall spectrogram. The signal illustrated here is nearly 10 dB below audible threshold.

Protocol Specifications: Basic specifications of the WSPR protocol are presented in Table 2. For comparison, specs for the JT65 mode are also shown. The WSPR message payload is 50 bits per transmission; most messages use 28 bits for a standard callsign and 15 bits for a hash-coded callsign or grid locator. The remaining 7 bits convey signal reports, acknowledgments, power levels, and special message types. Special messages can use the first 43 bits for any dedicated purpose. The WSPR protocol uses continuous-phase 4-tone FSK with tone spacing and keying rate equal to 12000/8192 = 1.46 Hz. Each transmission contains (50+K-1) × 2 = 162 channel symbols, and each symbol conveys both a data bit (MSB) and a synchronizing bit (LSB). Transmissions last for 162*8192/12000 = 110.6 s.

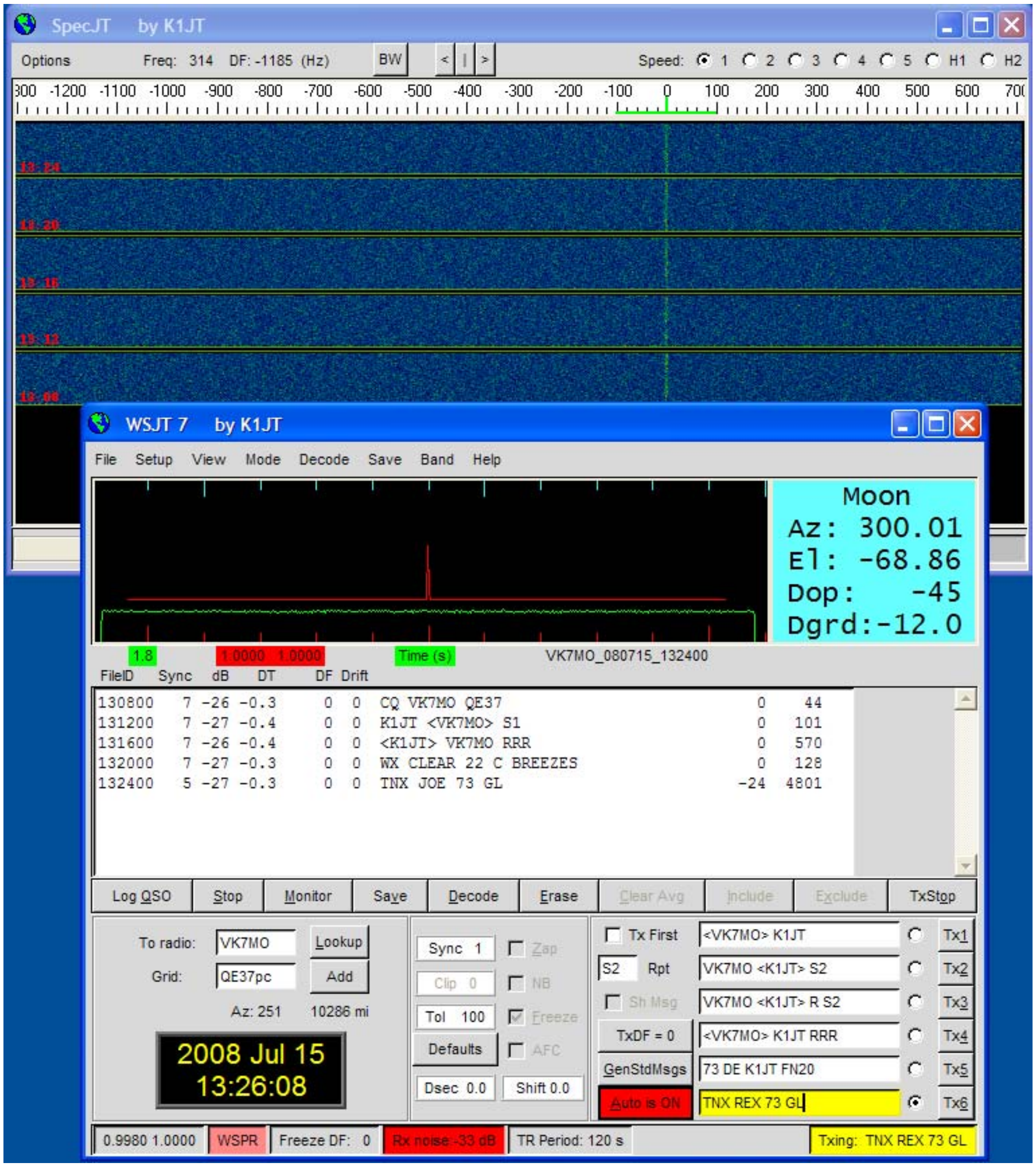


Table 2. Basic specifications for the JT65 and WSPR protocols.

	WSPR	JT65
Message length (bits)	50	72
Forward error correction	Convolutional, K=32, r=1/2	RS (63,12)
Channel symbols	162	126
Sync vector (bits)	162	126
Modulation	4-FSK	65-FSK
Keying rate (baud)	1.46	2.69
Transmission length (s)	110.6	46.8
Occupied bandwidth (Hz)	5.9	355

Sensitivity: A sensitivity comparison of WSPR mode and other weak signal communication modes is presented in Table 3. The assumed conditions are additive white Gaussian noise, no fading, and Doppler spreading less than 1 Hz. WSPR will be effective over any propagation path that provides S/N exceeding –29 dB in reference bandwidth 2500 Hz, with Doppler spreading less than about 1 Hz. Such paths should include most LF, MF, and HF paths of interest to amateurs.

Table 3. Approximate sensitivity comparisons for CW, JT65B, and WSPR.

	Threshold S/N (dB)
CW (best human operators)	–18
JT65B (KV decoder)	–24
JT65B (Average of 3 transmissions, KV decoder)	–27
JT65B (Deep search)	–28
WSPR	–29
WSPR (Average of 3 transmissions)	–32

Although designed primarily for use at LF, MF, and HF, the WSPR mode has also been tested on 144 MHz EME. It works well on that path; however, it has some obvious disadvantages when compared with JT65 for general EME use. Two-minute T/R sequences imply that QSOs take twice as long; moreover, two-minute transmissions at 100% duty cycle put greater thermal stress on high power amplifiers. I do not expect WSPR to be effective (in its present form) at 432 MHz and higher, because of too much Doppler broadening at those frequencies. Another potential mode that retains one-minute T/R sequences and achieves nearly the same performance as WSPR is presently under study.

WSPR and WSJT are available for free download on the WSJT Home Page, `physics.princeton.edu/pulsar/K1JT/.` These programs are all open-source, licensed under the Gnu General Public License. They can be used under Windows, Linux, FreeBSD, and OS/X. Contributions to the programs by other interested amateurs are encouraged. Source code is maintained in an open repository at `developer.berlios.de/projects/wsjt/.`

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