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WSPRing Around the World

You'd be astonished at what you can do these days with just a few watts.

Joe Taylor, K1JT, and Bruce Walker, W1BW

Amateur Radio would be much less interesting if our communication channels were always predictable and reliable. In fact, we often don't know where in the world our signals may be copied. If vagaries of the ionosphere and MF and HF propagation fascinate you, you'll surely enjoy using WSPR and its associated Web site, **WSPRnet.org**.

WSPR (pronounced "whisper") is an acronym for "Weak Signal Propagation Reporter." With a computer program of this name and a standard SSB transceiver, you can participate in a worldwide network of low power stations exchanging beacon-like transmissions to probe potential propagation paths. Most participating stations transmit as well as receive, although short wave listener (SWL) activity is also common. In principle, and with the propagation gods willing, everyone can copy and be copied by everyone else who is currently active with WSPR on the same band.

When a global picture of all these connections becomes available, things get especially interesting — and that's the purpose of WSPRnet. Most stations using WSPR are configured to automatically upload their reception reports to a central database at **WSPRnet.org**, in real time. By pointing your browser to WSPRnet you can get nearly instantaneous reports of where and at what signal strength you're being received, and view the results plotted on a world map.

In today's ham jargon, WSPR is another *sound card mode*. Its setup requirements are similar to those o2f, say, PSK31. WSPR transmits and receives, but it does not support normal types of on-the-air conversation. Instead, it sends and receives specially coded, beacon-like transmissions aimed at establishing whether particular propagation paths are open. Transmissions convey a call sign, station location, and power level using a compressed data format with strong forward error correction (FEC) and narrow-band, four-tone frequency-shift-keying (FSK). The FEC greatly improves chances of copy and reduces errors to an extremely low rate. The signal bandwidth is only 6 Hz, which together with randomized time-sharing assures that dozens of WSPR signals can fit into a tiny 200 Hz segment of each amateur band. The WSPR protocol is effective at signal-to-noise ratios as low as –28 dB in a 2500 Hz bandwidth, some 10 to 15 dB below the threshold of audibility. On most bands, typical WSPR power levels are 5 W or less — sometimes a *lot* less. You will be amazed to discover that these very low power signals can be copied in distant corners of the world.

WSPR Operation

WSPR software can be freely downloaded from **www.physics.princeton.edu/pulsar/K1JT/**. Packaged installation files are available for *Windows* and *Linux*; the program can also be compiled for *Macintosh*, *FreeBSD* and other operating systems. *WSPR* is "open source" software, and its source code is maintained in a public repository at **developer.berlios.de/projects/wsjt/**.

As with all sound card modes, WSPR requires audio connections between your computer and radio transceiver. Briefly stated, sound card audio out goes to the transceiver's audio in, and the radio's audio out goes to sound card in. You can use VOX control for TR switching; if you prefer hard-keyed switching you'll need a serial port or USB-to-serial adapter. A serial connection can also provide handy CAT control of most modern transceivers. If you use other data modes such as PSK31, you probably have the necessary connections already in place. If not, you'll find sound card interfaces available from a number of *QST* advertisers. Your SSB transceiver should be set to use upper sideband.

Even though FCC rules require you to be present at your station to operate WSPR, the operation itself is largely automated. Time-synchronized transmissions last for slightly less than two minutes, nominally starting one second into an even UTC minute. Reception and transmission intervals alternate in a pseudo-random fashion such that on average, a specified percentage (typically 20 to 25%)

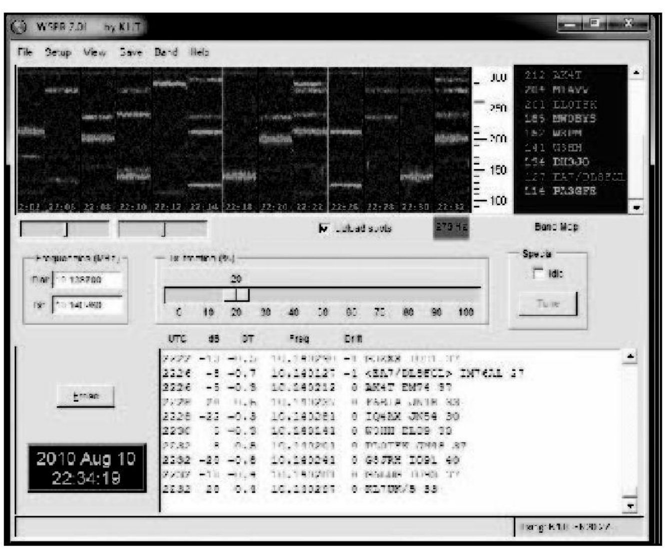

Figure 1 — Typical appearance of the main screen during WSPR operation.

Figure 2 — The WSPRnet home page.

of the two minute intervals are used for transmitting. It's important for your computer's clock to be accurate to within a second or so. Conventional operating frequencies for WSPR are summarized in Table 1. Many additional details of WSPR operation, including step-by-step startup instructions, are given in the *WSPR 2.0 User's Guide,* which — thanks to a number of bilingual users — is now available in English, French, German, Italian, Japanese, Polish, Portuguese and Russian at **www.physics.princeton.edu/pulsar/K1JT/wspr.html**.

In normal operation the main *WSPR* screen looks something like Figure 1. At the end of each two minute reception interval the software decoder looks for all detectable *WSPR* signals in a 200 Hz passband and displays the results in a waterfall spectrogram, a scrolling text window, and a scrolling Band Map. The spectrogram covers a frequency range of about 220 Hz; the last three digits of the received frequency, in Hz, are displayed on the vertical scale at right. Time runs from left to right in the spectrogram, the full width spanning about half an hour. On a typical computer screen each two-minute interval corresponds to a strip about 1 cm wide in the spectrogram. The times of your own transmissions are denoted by thin green vertical lines. For example, at the time Figure 1 was made, transmissions had been made at 2204, 2216 and 2224 UTC.

Each decoded WSPR signal produces text showing the UTC, signal-to-noise ratio in dB (in a 2500 Hz reference bandwidth), time offset DT in seconds, frequency in MHz, drift rate in Hz/minute, and the decoded message. Time offsets greater than about ±2 seconds indicate a significant clock error at transmitter or receiver, or possibly both. Apparent frequency drifts greater than ±1 Hz per minute can usually be traced to the transmitter, and should be corrected if possible. (Of course, receiver drift can also contribute to measured drifts, but this condition is easily recognized because nearly all signals will appear to drift by the same amount.) Good frequency stability is essential to WSPR's remarkable sensitivity, because the software filters used for decoding are only about 1.5 Hz wide.

WSPRnet

The **WSPRnet.org** Web site is written and maintained by Bruce, W1BW. It provides a central repository for WSPR reception reports ("spots") and offers a simple user interface for querying the database, a mapping facility, and many other handy features. By default, the worldwide map shows all WSPR stations reporting or decoded over the past hour, and illustrates the open propagation paths between them. The map can be zoomed and panned, and you can set various criteria to determine exactly which spots are included. The WSPRnet site also offers band-by-band counts of stations reporting in the past hour, a chat facility for brief communications between operators, an interface to the historical database back to March 2008, and a number of statistical summaries of the data. An example of the *WSPRnet* home page is shown in Figure 2. This particular screen capture, taken in August 2010, mentions that the WSPR database contains more than 32 million spots. Recently an average of 300 to 500 stations, scattered around the world, have been submitting roughly 50,000 to 100,000 WSPR reports each day.

Figure 3 is a typical example of the WSPRnet world map, in this case for the 30 meter band. You can specify selection criteria that limit the map to a particular band, a longer or shorter time interval, or spots involving a particular call sign. You can click on a call sign to see what other stations are hearing and being heard by that station. Red labels on the map indicate stations (or SWLs) operating in receive-only mode.

WSPR Protocol and Software

The WSPR protocol was originally named MEPT_JT, which stood for "Manned Experimental Propagation Tests, by K1JT." The "Manned" part of the name was a reminder that under FCC rules a transmitting station (with a few very specific exceptions) must always be attended. In current practice, everybody just calls the mode WSPR.

The WSPR protocol is designed to do just one thing, and do it very well. Messages normally consist of a standard call sign, a four character grid locator and the power level in dBm (decibels relative to 1 milliwatt). This information is compressed into 50 binary digits and then encoded using a convolutional code with constraint length $K = 32$ and rate

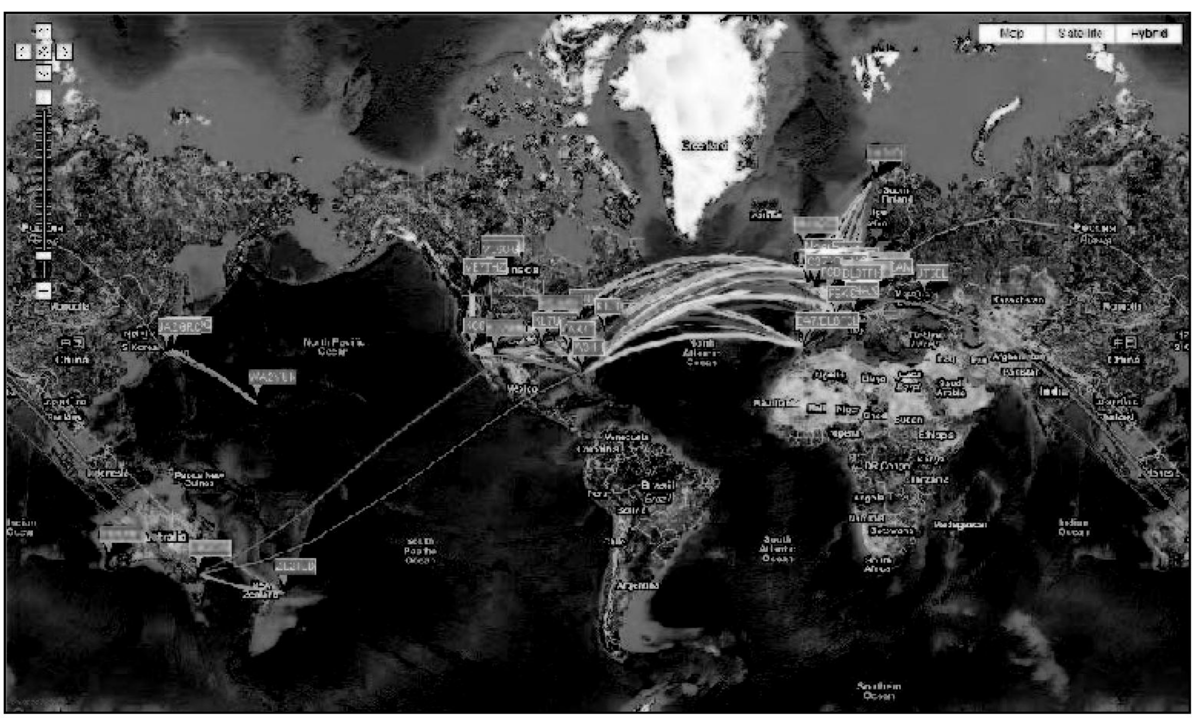

Figure 3 — The WSPRnet global map of spots posted on 30 meters over a typical one-hour period.

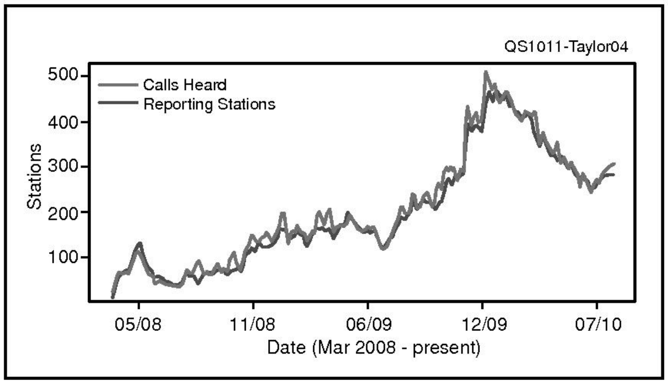

Figure 4 — Seven-day moving average of the number of stations participating, per day, from early 2008 through mid-2010.

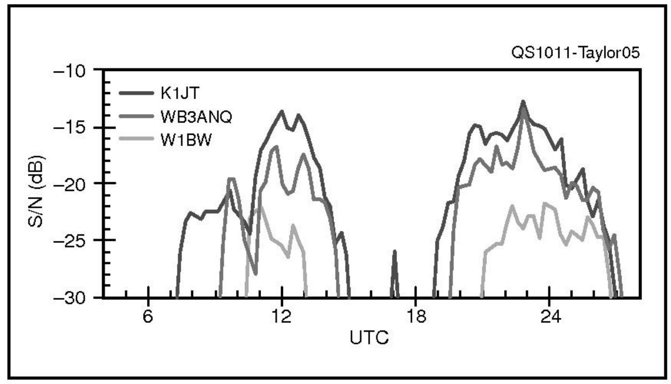

Figure 5 — Average S/N reported by VK6DI (Western Australia) for K1JT, WB3ANQ and W1BW (all in northeast USA) during March and April 2009 on the 30 meter band, plotted vs time of day.

Table 1

Conventional Frequencies for WSPR Activity

Band (meters)	*Dial Frequency (MHz)*	*Actual Transmitting Frequency (MHz)*
160	1.836.600	1.838.000 – 1.838.200
80	3.592.600	3.594.000 – 3.594.200
40	7.038.600	7.040 000 – 7.040 200
30	10.138.700	10.140.100 – 10.140.300
20	14.095.600	14.097.000 – 14.097.200
17	18.104.600	18.106.000 – 18.106.200
15	21.094.600	21.096.000 – 21.926.200
12	24.924.600	24.926.000 – 24.926.200
10	28.124.600	28.126.000 – 28.126.200
6	50.293.000	50.294.400 – 50.294.600

$r = ½$. Each of the resulting 162 bits is used as the most significant bit of a 2 bit "channel symbol" to be transmitted using 4 tone frequency shift keying at 1.46 baud. The least significant bit is defined by a pseudo-random sequence known to the software at both transmitter and receiver and used to establish accurate synchronization of time and frequency.

Convolutional codes with long constraint lengths have the important advantage that undetected decoding errors are rare. These codes are too complex to be decoded with the well-known and highly efficient Viterbi algorithm, so the WSPR decoder uses the so-called "sequential" algorithm, instead. Full details of the WSPR protocol and its implementation in the WSPR program will be published elsewhere. WSPR is licensed under the GNU General Public License and its source code is freely available to anyone.

Propagation Studies

The WSPRnet database represents a rich source of experimental data for propagation studies. To provide a simple example, we queried the database to give us all spots of K1JT, WB3ANQ, and W1BW posted by VK6DI on the 30 meter band. It happens that all four of these stations were running WSPR more or less around the clock between March 20 and April 12, 2009. VK6DI was a receive-only station; K1JT mostly ran 5 W, WB3ANQ 1 W and W1BW 100 mW. All stations used simple dipole antennas. Figure 5 shows the signal-to-noise ratios reported by VK6DI for each US station, sorted by time of day (in 15 minute intervals) and then averaged over the three week period. As expected, the 5 W signals from K1JT typically start a little sooner and are somewhat stronger than the lower power signals from WB3ANQ and W1BW, but otherwise the data for all three stations are remarkably consistent. At this low point of the sunspot cycle, each station enjoyed both short-path and long-path propagation on 30 meters from northeast US to Western Australia, on most days — even at the 100 mW power level. In fact, WSPR signals from both WB3ANQ and W1BW of less than 10 mW were also decoded by VK6DI, nearly halfway around the world. You can surely think of many other fascinating ways to explore propagation phenomena by using the WSPRnet database.

Conclusion

Radio Amateurs keep finding new ways to challenge the frontiers of wireless communication, exploring the wonders of the electromagnetic spectrum and the extraordinarily wide range of interactions between electromagnetic waves and the terrestrial environment. Conceived with just-for-fun, hobbyist motivations, WSPR has helped to bring some recent technical advances from the professional and scientific world into Amateur Radio, thereby providing educational benefits to the nation and the world as well as many hours of enjoyment for technically minded experimenters. We hope you'll enjoy playing with WSPR as much as we have, and at the same time will add to your knowledge and understanding of radio propagation and modern communication techniques.

Many people have contributed to the development of WSPR and WSPRnet — indeed, too many to list here — but we especially wish to thank VA3DB and G4KLA, who have worked tirelessly to help ensure portability of *WSPR* to the *GNU/Linux*, *FreeBSD*, and *OS X* operating systems, and G4ZOD and OZ1PIF, who have spent countless hours helping us to identify and eliminate bugs in the software.

Joe Taylor is an ARRL member first licensed as KN2ITP in 1954, and has since held call signs K2ITP, WA1LXQ, W1HFV, VK2BJX and K1JT. He was Professor of Astronomy at the University of Massachusetts from 1969 to 1981 and since then has been Professor of Physics at Princeton University. He was awarded the Nobel Prize in Physics in 1993 for discovery of the first orbiting pulsar. He chases DX from 160 meters through the microwave bands. Joe can be reached at 272 Hartley Ave, Princeton, NJ 08540, or **k1jt@arrl.net**.

Bruce Walker is an ARRL member licensed since 1991 and has held the call signs N1IKV, WT1M and W1BW. He holds a degree in physics from MIT, and has spent most of his career involved in high performance scientific computing, currently with the Broad Institute in Cambridge, Massachusetts. His primary radio interests are currently very low power (QRPp) operation on HF and software-defined radios (SDRs). You can reach Bruce at 667 Belknap Rd, Framingham, MA 01701-2843, or **bruce@w1bw.org**.