

# HF Time of Arrival Project

Joe Taylor, K1JT

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This progress report describes recent work on a project outlined on the [AA6E](#) web site. Martin Ewing (AA6E) and I have been conducting experiments to determine whether locating a transmitter by measuring differences in a signal's time-of-arrival (TOA) at different receivers can be feasible, with useful accuracy, using standard amateur radio equipment. Our tests are based on time-tagged digital recordings of over-the-air radio signals. We introduce narrow, attenuated 1 PPS pulses from a GPS receiver, in parallel with the normal receiving antenna, at the receiver input. The receiver's audio output typically contains a signal plus audible clicks from the 1 PPS pulses. This audio is digitized and recorded by a computer configured as for running [WSPR](#). If recordings of the same signal are made simultaneously at a number of stations, they can be collected, synchronized by using the 1 PPS ticks, and then cross correlated to obtain differential time-of-arrival information. In principle, with three or more receiving stations this approach provides enough information to determine the location of the transmitter. More receivers is better, and ideally they should be spread out over the geographical region of interest. That's why we have solicited volunteers who might be interested in participating in the experiments.

## Test Observations of WWV and WWVH

We've made some tools that can help you make interesting single-station test measurements as a warm-up, to establish that your setup is properly configured. The goal of the test is to measure the propagation delay (and thus the approximate distance) from WWV (Fort Collins, Colorado, Maidenhead locator DN70Iq) and/or WWVH (Kauai, Hawaii, BL01cx) to your own station. The test software is a command-line program called 'wwv'. You can download the Windows executable from <http://www.physics.princeton.edu/pulsar/K1JT/wwv.exe>. The program can also be compiled for other platforms such as Linux, FreeBSD, and OS X, using a subset of the tools required for compiling WSPR.

Here's how to conduct your warm-up observations:

1. Connect the 1 PPS pulse through a suitable attenuator to your receiver's antenna jack, in parallel with the receiving antenna. The attenuator can be a simple resistive divider, but you'll probably need to make some adjustments to get the level right. Tune to a WWV frequency in AM mode, and make sure that you can easily hear the 1 PPS pulses on top of the WWV signal.
2. Disconnect the antenna so that you hear only the 1 PPS pulses and background noise. Make the 1 PPS pulses strong enough to be heard clearly, but not so strong that they are clipped or pump the receiver AGC. The noise blanker should be OFF.
3. Open a command-prompt window, CD to the WSPR installation directory, and enter the command

```
C:\Radio\WSPR> type fmt.ini
```

```
Linux command: cat fmt.ini
```

to make sure that a file named `fmt.ini` exists. If you have been running WSPR in this directory and have executed at least one band-change command with CAT enabled, `fmt.ini` will contain the command to change the frequency of your radio, the device number used by WSPR for audio input, and (if you have the latest WSPR v3.0) your callsign and grid locator. With earlier versions of WSPR the callsign and locator will not be present, so you'll need to add them by editing the file with a text editor such as Windows Notepad. My `fmt.ini` file looks like this (the first line is long, and shown here as two lines):

```
rigctl -m 214 -r COM1 -s 4800 -C data_bits=8 -C stop_bits=2
-C serial_handshake=Hardware F 1836590
1
K1JT
FN20qi
```

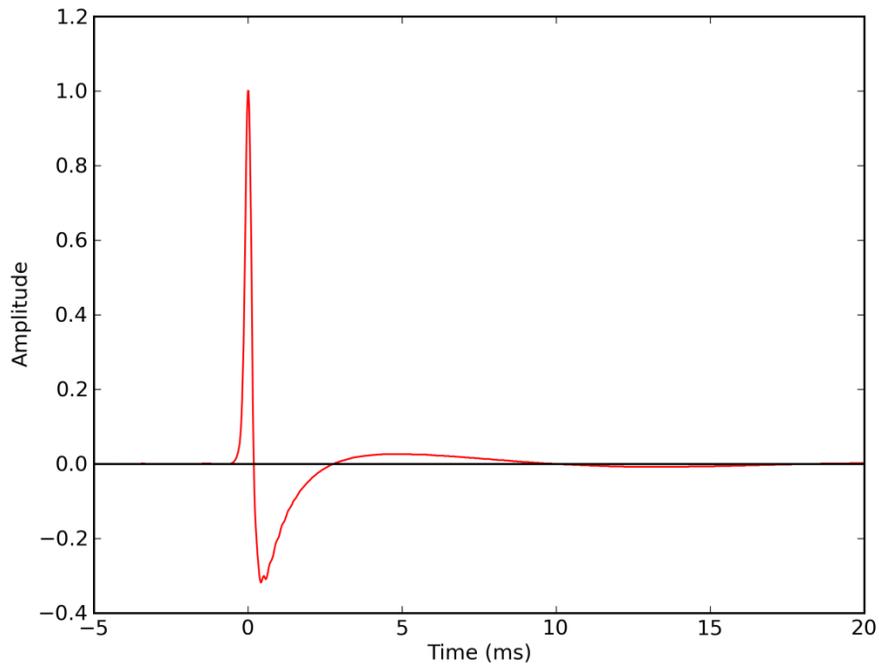
If you do not wish to use CAT control, replace the long first line in `fmt.ini` with the single word `none`.

4. Your first measurement should be a calibration run to determine the precise shape of the 1 PPS pulse after it passes through your receiver. Enter the command

```
C:\Radio\WSPR> wvv cal 60
```

to make a 60-second recording of audible 1 PPS clicks from your HF receiver. The program uses the nominal sample rate 48000 Hz. The soundcard's sample clock may not be very accurate, so at the end of the minute the true sample rate is determined from the spacing of the 1 PPS pulses. A typical measured rate will be something like 47999.609 Hz, and this number is saved by the program for future use. The recorded data are then resampled at 48000.000 Hz, the new data averaged over intervals of exactly 48000 samples, and the resulting average pulse profile — the so-called “impulse response” of your receiver — saved on disk as file `prof_1pps.dat`. This profile can be examined with a graphing program, or imported into a spreadsheet for plotting. For convenience, a shortened version of the profile (excluding most of the featureless baseline) is saved as file `short_1pps.dat`. The calibration profile is Fourier transformed and averaged in 100-Hz intervals to produce complex calibration data in the frequency domain. This information is saved for later use in file `cal.dat`.

With a Trimble Thunderbolt GPS receiver and a TS-2000 receiver in AM mode, my calibration profile `short_1pps.dat` looks like Figure 1 on the next page. Your 1 PPS profile will probably have a somewhat different shape, depending on details of your receiver passband.



**Fig. 1** – The average 1 PPS pulse as measured at K1JT, using a TS-2000 in AM mode.

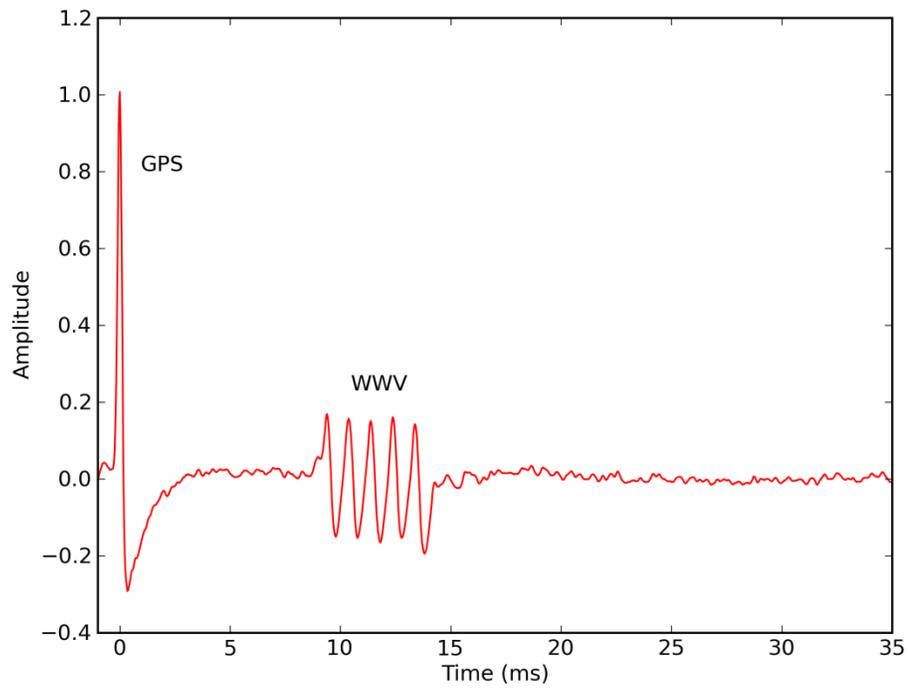
5. Now you're ready to reconnect the receiving antenna and make calibrated measurements of propagation time from WWV or WWVH to your station. You can specify the observing frequency in kHz; to observe at 10 MHz, the command is

```
C:\Radio\WSPR> wwv 10000
```

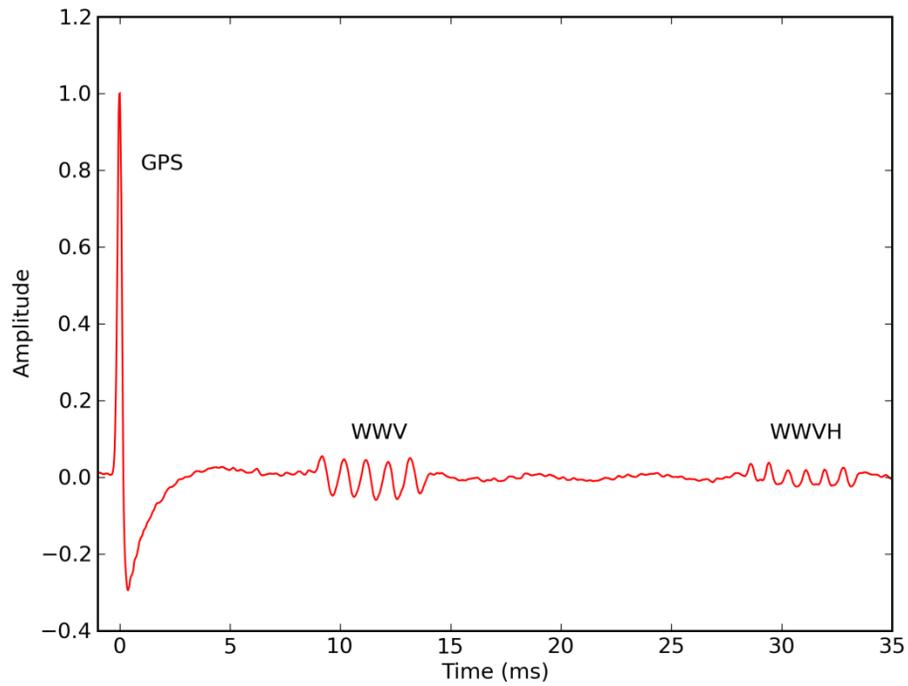
To cycle automatically through all WWV frequencies, 2.5, 5, 10, 15, and 20 MHz, using CAT control of your radio, use the command

```
C:\Radio\WSPR> wwv all
```

Measurements will be one minute long. At the end of each minute the program resamples the data at 48000 Hz and computes an average one-second profile, as described above. The profiles should now contain the 1 PPS pulse and also the WWV “tick” — five cycles of a 1000-Hz sine wave for WWV, or six cycles at 1200 Hz for WWVH — delayed by the propagation time. Expanded views of two such profiles are shown in Figures 2 and 3, on the next page. During normal observations, the most recent of these profiles is available as disk file `prof.dat` and a shortened version as `short.dat`.



**Fig. 2** – Average profile for a one-minute observation of GPS pulses and WWV. Local time was 10 PM, and the frequency was 2.5 MHz.



**Fig. 3** – Average profile for a one-minute observation at 10 MHz, 10 PM local time.

After calibrating the data and aligning the GPS pulse at  $t=0$ , the program attempts to find the WWV and WWVH ticks. When successful, it measures their delays with respect to the GPS pulse and displays the results on screen and also to an accumulating disk file `delay.dat`. Typical results look like this (with column headings added):

Date	UTC	Nday	Freq	dB	Delay	WWV
20110216	002201	47.0159	2500	0.8	8.77	1
20110216	002301	47.0166	5000	10.7	8.85	1
20110216	002401	47.0173	10000	6.9	9.54	1
20110216	002501	47.0180	15000	9.0	8.90	1
20110216	002701	47.0194	2500	4.7	8.71	1
20110216	002801	47.0201	5000	9.4	9.85	1
20110216	002901	47.0208	10000	14.0	9.46	1
20110216	003001	47.0214	15000	10.9	8.88	1
20110216	003301	47.0235	5000	11.0	9.88	1
20110216	003301	47.0235	5000	4.1	8.92	1

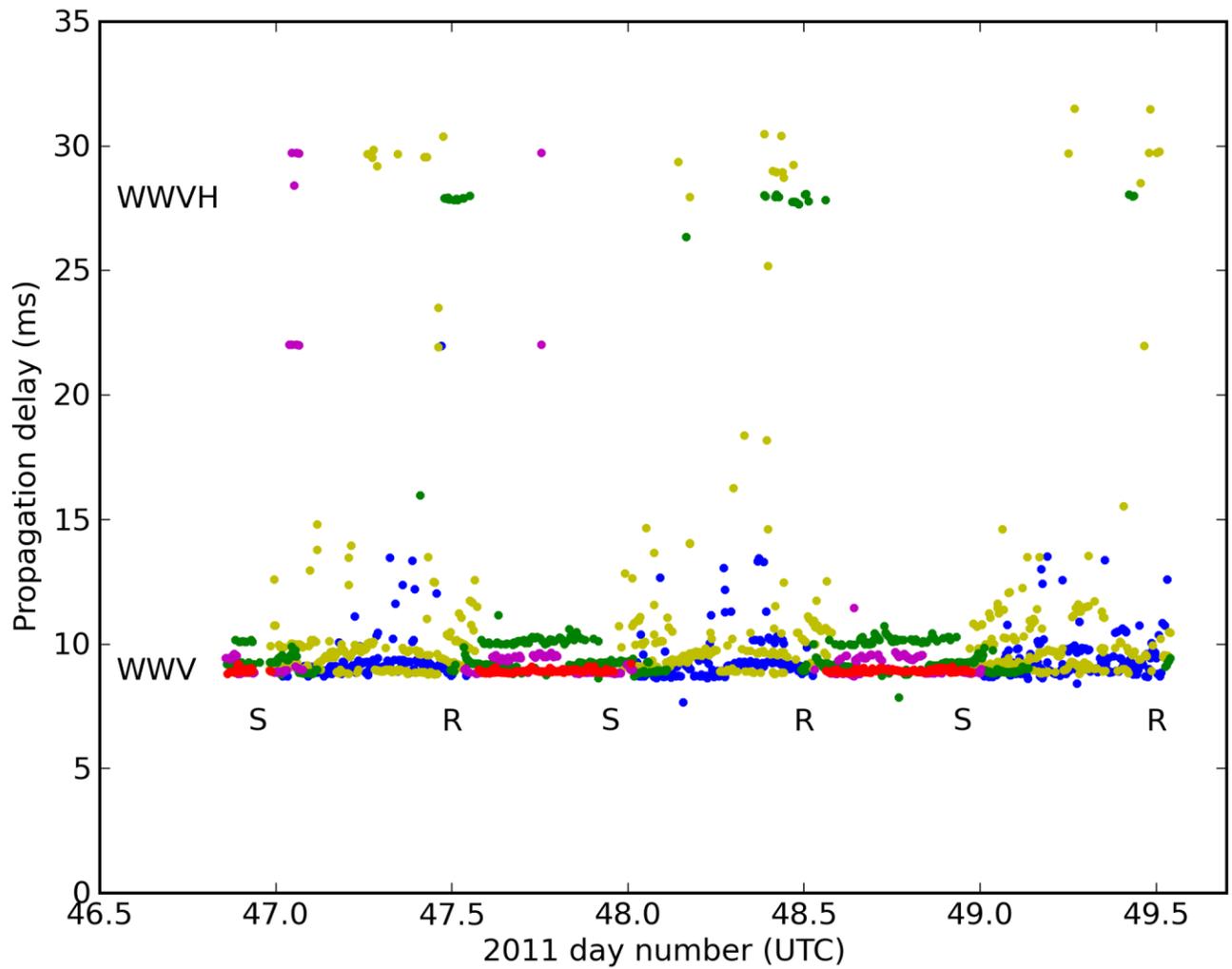
“Nday” is the time in days since January 0, 2011. Numbers labeled “dB” indicate strength of the recovered WWV tick relative to a fixed cutoff level. Depending on levels of noise and QRM, measurements with strengths less than a few dB may be unreliable. Delays are given in milliseconds, and the column headed “WWV” contains 1 for WWV, 2 for WWVH.

You can use a plotting program or import your data into a spreadsheet to examine the delay measurements graphically. Figure 4 shows results obtained at K1JT over a recent three-day period, using a vertical scale large enough to show results for both WWV and WWVH. The minimum possible delays (great-circle distances divided by the speed of light) are 8.55 and 26.89 ms, respectively. Some delay measurements around 22–23 ms (and a few others in this plot) are probably spurious. I have not yet identified their cause.

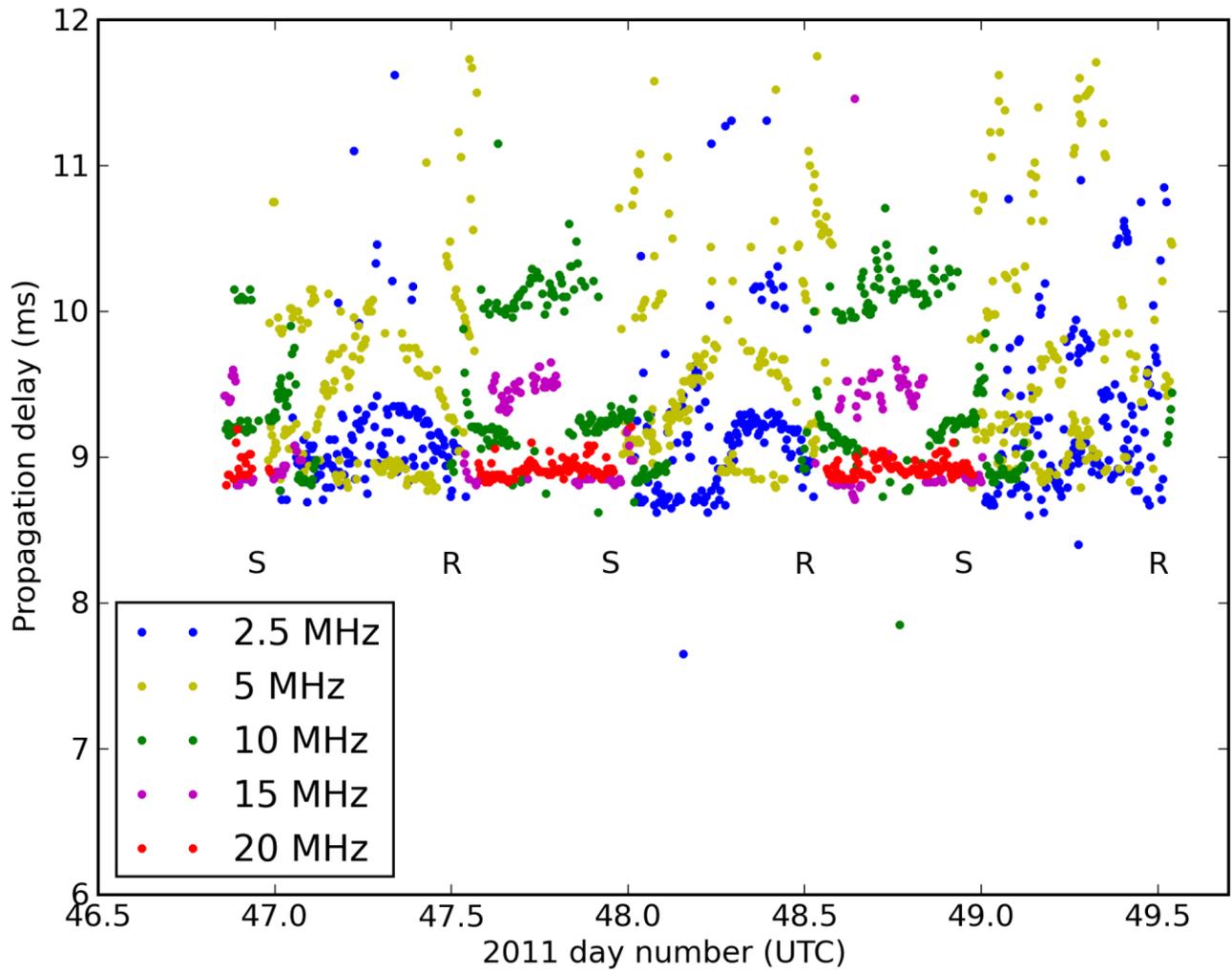
Figure 5 shows the WWV measurements with an expanded vertical scale. Here you can see direct evidence of the multiple propagation paths open at different frequencies, at various times of the day. For example, the 20 MHz signal is available only in the daytime. With single-hop propagation and reflection high in the  $F_2$  layer, it always has a delay close to 8.9 ms. The smallest measured propagation delays are about 8.7 ms, just slightly more than the minimum for the great-circle distance. The longest delays correspond to multi-hop propagation and are several milliseconds greater.

### Next Steps

After having made satisfactory measurements of the WWV propagation times, you’ll be ready to participate in a multi-station experiment aimed at determining how well we can establish the location of a transmitter, when treating that location as unknown. For this purpose we’ll want to select one or more reliable signals that many of us can receive. One possibility is a suitably located shortwave broadcast (or perhaps standard AM broadcast) station. Other suggestions for reliable and predictable test signals would be welcome!



**Figure 4:** Propagation delays from WWV and WWVH to K1JT on February 16-18, 2011. Great-circle distances correspond to delays of 8.55 and 26.89 ms, respectively. See Figure 5 for the color legend; times of sun rise (R) and set (S) are indicated.



**Figure 5:** Measured propagation delays from WWV to K1JT on February 16-18, 2011. The great-circle distance corresponds to a delay of 8.55 ms. Times of sun rise (R) and set (S) are indicated.