**Accurate Frequency Measurements**

**with your WSPR Setup**

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# Introduction

The popular program ***WSPR***, “Weak Signal Propagation Reporter,” has drawn new attention to the importance of frequency accuracy and stability in weak-signal amateur radio communications. Appendix C of the [WSPR 2.0 User’s Guide](http://www.physics.princeton.edu/pulsar/K1JT/WSPR_2.0_User.pdf) explains how to calibrate your modern transceiver so that you can know your own frequency and measure the frequency of other over-the-air signals with accuracies better than one Hertz. Using ***FMT*** — a package of new software tools described below — you can adapt these techniques to make measurements for other purposes, including the ARRL’s Frequency Measuring Test. The next running of this friendly competition is November 10-11, 2010 — less than two weeks away, as I write. Measurements made with your standard ***WSPR*** setup can be good enough to put you in the top tier of contestants in the Frequency Measuring Test. You will need a transceiver set up for using ***WSPR,*** including CAT control. With this technique you won’t need a GPS receiver, rubidium oscillator, high-accuracy frequency counter, or any other expensive laboratory-grade equipment.

The ***FMT*** tools go a long way toward automating the calibration of your radio and making frequency measurements with it. However, obtaining good results still requires you to think carefully about what you are doing, and why. These instructions should help to set you off on the right path.

# Software Installation

The ***FMT*** software is packaged with the latest WSPR release, which can be downloaded from <http://www.physics.princeton.edu/pulsar/K1JT/WSPR2.11_r22xx.EXE>. (Windows) or [http://www.physics.princeton.edu/pulsar/K1JT/wspr\_2.11r22xx.deb](http://www.physics.princeton.edu/pulsar/K1JT/wspr_2.11r22xx.deb%20) (Ubuntu or other Debian-based Linux). Install the program in the usual way for your operating system. If you are using Vista or Windows 7, I recommend installing to a directory such as C:\Radio\WSPR rather than the default location C:\Program Files\WSPR.

**Calibrating Your Radio**

The ***FMT*** software tools are driven from the command line. (If you’re not comfortable working from the command line, you’ll have a bit more to learn. If you must have a GUI-driven program, you might need to look elsewhere.) Verify that WSPR 2.11 works correctly and is properly configured for your soundcard and for CAT control of your radio. Execute at least one band-change command within WSPR, to be sure that your radio obeys CAT commands correctly. ***WSPR 2.11*** will create a file fmt.ini containing parameters that fmt needs for CAT control and access to your soundcard.

Open a command-prompt window and cd to the directory where you installed WSPR 2.11. Verify that the executable programs fmt, fmtave, fcal and fmeasure are present by entering each program name at the command prompt. Messages in response to these commands give simple guides to the required command syntax:

C:\Radio\wspr> fmt

Usage: fmt <kHz> <0|1> <offset> <range> <tsec> <call>

Example: fmt 10000 1 1500 100 30 WWV

C:\Radio\wspr> fmtave

Usage: fmtave <infile>

Example: fmtave fma.all

C:\Radio\wspr> fcal

Usage: fcal <infile>

Example: fcal fmtave.out

C:\Radio\wspr> fmeasure

Usage: fmeasure <infile>

Example: fmeasure fmtave.out

Program fmt requires six parameters after the program name — a nominal frequency in kHz, a flag (0 or 1) to indicate whether this is a calibration measurement, the desired offset in Hz, search range in Hz above and below the nominal offset, specified duration of measurement, in seconds, and callsign. For example, to make a 30-second calibration measurement of the WWV 10 MHz signal, offsetting your receiver so that the WWV carrier provides an expected beat note of 1500 Hz and searching over a range ± 100 Hz from that audio frequency, use the command:

C:\Radio\wspr> fmt 10000 1 1500 100 30 WWV

In response to this command, program fmt will set the radio’s dial to 9.998500 MHz and acquire audio for 30 seconds. The audio signal is then analyzed in overlapping segments about 6 s long, spaced by about 3 s. For each segment the program prints a line similar to those in the following table:

UTC Freq CAL Offset fMeas DF Level S/N Call

(kHz) ? (Hz) (Hz) (Hz) (dB) (dB)

------------------------------------------------------------------

15:34:44 10000 1 1500 1516.339 16.339 5.3 44.5 WWV

15:34:47 10000 1 1500 1516.491 16.491 9.1 46.3 WWV

15:34:49 10000 1 1500 1516.493 16.493 8.4 48.0 WWV

15:34:52 10000 1 1500 1516.317 16.317 6.7 42.3 WWV

15:34:55 10000 1 1500 1516.302 16.302 6.7 44.5 WWV

15:34:58 10000 1 1500 1516.500 16.500 7.2 40.5 WWV

15:35:00 10000 1 1500 1515.917 15.917 4.4 41.3 WWV

15:35:03 10000 1 1500 1515.745 15.745 5.2 40.8 WWV

15:35:06 10000 1 1500 1516.523 16.523 6.6 41.0 WWV

15:35:09 10000 1 1500 1516.423 16.423 5.4 43.2 WWV

Here fMeas is the observed frequency of the beat note and DF = fMeas - Offset is the measured dial error at 10 MHz. Output from fmt also appears (without column headings) in the file fmt.out — which is started afresh at each program invocation — and in fmt.all, where it accumulates until you explicitly delete the file.

As described in Appendix C of the [WSPR 2.0 User’s Guide](http://www.physics.princeton.edu/pulsar/K1JT/WSPR_2.0_User.pdf), to calibrate your radio you should make a number of measurements like this example, over a range of frequencies. This process can be automated by executing a batch file similar to the following one, which I call gocal.bat:

C:\Radio\wspr> type gocal.bat

fmt 660 1 1500 100 30 WFAN

fmt 880 1 1500 100 30 WCBS

fmt 1210 1 1500 100 30 WPHT

fmt 2500 1 1500 100 30 WWV

fmt 3330 1 1500 100 30 CHU

fmt 5000 1 1500 100 30 WWV

fmt 7850 1 1500 100 30 CHU

fmt 10000 1 1500 100 30 WWV

fmt 14670 1 1500 100 30 CHU

fmt 15000 1 1500 100 30 WWV

fmt 20000 1 1500 100 30 WWV

In Linux the name of the script is simply gocal (without the extension), but the contents are the same. Executing the batch file causes calibration sequences to be run for each of a number of stations whose frequency calibration you have good reason to trust. For this example I used local AM broadcast stations WFAN (660), WCBS (880), WPHT (1210), and the standard-frequency transmissions of WWV and CHU. Use gocal as a template and make your own batch file using stations you can receive well at the relevant time of day. You don’t need as many calibration stations as shown in the example, but be sure to use enough to cover a range of frequencies from the AM broadcast band up through at least 10 MHz.

After typing gocal at the command prompt you should see the output from fmt for each line in the file, and the measurements will accumulate in fmt.all. Here’s an abbreviated copy of fmt.all obtained by executing gocal.bat at my station one afternoon (the column headings were added by hand):

UTC Freq CAL Offset fMeas DF Level S/N Call

(kHz) ? (Hz) (Hz) (Hz) (dB) (dB)

------------------------------------------------------------------

15:41:51 660 1 1500 1503.103 3.103 1.5 54.4 WFAN

15:41:54 660 1 1500 1503.103 3.103 1.7 54.1 WFAN

15:41:56 660 1 1500 1503.103 3.103 2.1 53.6 WFAN

...

15:42:22 880 1 1500 1503.459 3.459 1.8 56.4 WCBS

15:42:25 880 1 1500 1503.460 3.460 2.6 55.5 WCBS

15:42:27 880 1 1500 1503.459 3.459 1.5 56.6 WCBS

...

15:42:53 1210 1 1500 1503.850 3.850 1.0 56.6 WPHT

15:42:56 1210 1 1500 1503.851 3.851 -0.8 58.4 WPHT

15:42:58 1210 1 1500 1503.849 3.849 0.5 57.2 WPHT

...

15:43:23 2500 1 1500 1559.336 59.336 -4.1 9.7 WWV \*

15:43:26 2500 1 1500 1403.312 -96.688 -3.9 7.8 WWV \*

15:43:28 2500 1 1500 1418.310 -81.690 -4.1 8.1 WWV \*

...

15:43:54 3330 1 1500 1506.960 6.960 1.4 65.2 CHU

15:43:57 3330 1 1500 1506.961 6.961 0.5 65.7 CHU

15:43:59 3330 1 1500 1506.960 6.960 0.1 65.7 CHU

...

15:44:25 5000 1 1500 1509.350 9.350 0.7 27.5 WWV

15:44:28 5000 1 1500 1509.345 9.345 0.5 27.4 WWV

15:44:30 5000 1 1500 1509.342 9.342 0.9 28.5 WWV

...

15:44:55 7850 1 1500 1513.547 13.547 17.1 58.6 CHU

15:44:58 7850 1 1500 1513.550 13.550 15.5 60.0 CHU

15:45:00 7850 1 1500 1513.556 13.556 17.1 58.4 CHU

...

15:45:26 10000 1 1500 1516.681 16.681 6.7 46.2 WWV

15:45:29 10000 1 1500 1516.656 16.656 4.8 42.8 WWV

15:45:31 10000 1 1500 1516.789 16.789 6.6 49.0 WWV

...

15:45:57 14670 1 1500 1523.601 23.601 -3.4 28.6 CHU

15:46:00 14670 1 1500 1523.066 23.066 -3.4 31.0 CHU

15:46:02 14670 1 1500 1523.660 23.660 -3.5 30.3 CHU

...

15:46:27 15000 1 1500 1523.940 23.940 5.1 49.2 WWV

15:46:30 15000 1 1500 1523.818 23.818 4.5 53.1 WWV

15:46:32 15000 1 1500 1523.832 23.832 1.7 50.5 WWV

...

15:46:58 20000 1 1500 1530.897 30.897 22.3 35.6 WWV

15:47:01 20000 1 1500 1530.793 30.793 22.1 33.4 WWV

15:47:03 20000 1 1500 1530.779 30.779 22.1 36.9 WWV

...

Notice that the DF measurements for a particular station usually agree to within a few tenths of a Hz. In addition, they generally increase (or decrease) in proportion to the station frequency. In mid-afternoon I can’t hear WWV at 2.5 MHz, so those table entries are garbage in this particular example; they should be deleted from the file before further processing. A rough guide to potentially questionable entries is provided by the S/N measurement, and an asterisk at the end flags any line with S/N < 20 dB. You must learn to recognize and remove spurious measurements from the table.

Use Windows notepad (or your favorite text editor) to delete any bad lines from fmt.all. After this is done, run program fmtave on it to average all valid measurements for each calibration station. Your screen should look something like the output reproduced on the next page. The same output (without column headings) will appear in file fmtave.out. In this table N is the number of valid measurements at each frequency, and rms is the root-mean-square scatter of individual measurements of DF about the quoted average.

C:\Radio\wspr> fmtave fmt.all

Freq DF CAL N rms UTC Call

(kHz) (Hz) ? (Hz)

---------------------------------------------------

0.660 3.103 1 10 0.00 15:41:51 WFAN

0.880 3.459 1 10 0.00 15:42:22 WCBS

1.210 3.850 1 10 0.00 15:42:53 WPHT

3.330 6.960 1 10 0.00 15:43:54 CHU

5.000 9.343 1 10 0.00 15:44:25 WWV

7.850 13.559 1 10 0.02 15:44:55 CHU

10.000 16.772 1 10 0.11 15:45:26 WWV

14.670 23.245 1 10 0.25 15:45:57 CHU

15.000 23.824 1 10 0.05 15:46:27 WWV

20.000 30.834 1 10 0.07 15:46:58 WWV

Your next step is to fit a straight-line calibration function to the sequence of measurement pairs (Freq, DF) appearing in fmtave.out. As described in Appendix C of the [WSPR 2.0 User’s Guide](http://www.physics.princeton.edu/pulsar/K1JT/WSPR_2.0_User.pdf), you can do this by executing the program fcal, passing it the name of the file containing your averaged calibration measurements:

C:\Radio\wspr> fcal fmtave.out

C:\Users\joe\wsjt\wspr>fcal fmtave.out

Freq DF Meas Freq Resid Call

(MHz) (Hz) (MHz) (Hz)

------------------------------------------------

0.660 3.103 0.660003103 -0.036 WCBS

0.880 3.459 0.880003459 0.004 WPHT

1.210 3.850 1.210003850 -0.080 CHU

3.330 6.960 3.330006960 -0.019 WWV

5.000 9.343 5.000009343 -0.038 CHU

7.850 13.559 7.850013559 0.078 WWV

10.000 16.772 10.000016772 0.199 CHU

14.670 23.245 14.670023245 -0.045 WWV

15.000 23.824 15.000023824 0.059 WWV

20.000 30.834 20.000030834 -0.123

A: 2.19 Hz B: 1.4384 ppm StdDev: 0.097 Hz

err: 0.05 0.0047

Column 3 of this table gives the frequency of each calibrating station, according to your uncalibrated radio; column 4 is the difference between your *corrected* measurement and the nominal station frequency — in other words, the residual dial error, in Hz, after applying your radio’s calibration function. The last two lines of output give the intercept A and slope B of the straight-line calibration function, and the estimated uncertainties of A and B. (These are the constants that should be entered on the Setup | Advanced screen of ***WSPR***. They are written into file fcal.out, and you can enter them automatically, the next time you start ***WSPR***, by clicking on “Read A and B from fcal.out” on the Setup | Advanced screen.) The calibration constants will also be used in the final step of making ***FMT*** measurements.

**Suggested Procedure for the ARRL Frequency Measuring Test**

The November 2010 Frequency Measuring test extends over seven 15-minute intervals, each providing a different test signal. W8SKE will transmit an unmodulated carrier on about 7055 and 3575 kHz, K5CM on 3578 and 1844, WA6ZTY on 7097, and W6OQI on 7067 and 3567. See <http://www.arrl.org/files/file/W1AW/Other%20FMT%20files/FMT.pdf> for more important details.

To avoid the possibility of typing errors at crucial times, I recommend preparing batch files with names equal to the starting UTC of each test segment. For example, my first file for the November 2010 FMT will be named 0230.bat (or simply 0230 in Linux) and will contain this single command line:

fmt 7055 0 1500 1000 180 W8SKE

Typing 0230 at the command prompt will run fmt for three minutes, producing 64 frequency measurements of the strongest signal found between 7054 and 7056 kHz. Similar batch files should be prepared for each of the other test signals.

My overall recipe for measurements in the FMT thus involves the following steps:

1. Delete or rename any existing file fmt.all.
2. Run your batch file gocal, as described above.
3. Use batch files to run program fmt during the three key-down minutes in each of the seven 15-minute intervals.
4. Run gocal again.
5. Make a backup copy of fmt.all, naming it something like fmt.all.nov2010.

Running gocal both before and after your test measurements lets you see whether your radio’s calibration constants are stable. You should turn your radio on and leave it on for at least 24 hours before the test, to minimize any possible thermal drift.

After making your backup file copy — step 5 above — your measurement tasks are complete!

**Analyzing your Data**

So… now it’s time to analyze your data. To provide an example for this last step, I edited one line in the file fmtave.out described above, changing

5.000 9.343 1 10 0.00 15:44:25 WWV

to

5.000 9.343 0 10 0.00 15:44:25 WWV

so that the WWV signal at 5 MHz will be treated as an unknown frequency, rather than a frequency calibrator. (Your own measurements made during the Frequency Measuring Test will already have created lines in file fmtave.out indicating that they are to be treated as unknown frequencies.) Your final step is now a simple one:

C:\Users\joe\wsjt\wspr>fmeasure fmtave.out

Freq DF A+B\*f Corrected

(MHz) (Hz) (Hz) (MHz)

----------------------------------------

5.000 9.343 9.381 4.999999962

This output will also saved in file fmeasure.out. Column 3 is the interpolated value of your radio’s dial error at the frequency of the test signal. Column 4 is what you’ve been waiting for: your best estimate of the true frequency of the test signal. In this case, the one “unknown” frequency was measured to be 4.999999962 MHz — just 38 milliHertz below the correct value 5.000000000 MHz.