ARRL FMT Technique with FlexRadio 6000 Series Radios

(Flex 6000 Series FMT Technique, V1.02.docx)

Ron Panetta, WB2WGH

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Credits

Thanks to the following contributors to this document:

Steve Hicks	N5AC	FlexRadio
Mike Walker	VA3MW	FlexRadio

Any suggestions and/or corrections to this document can be sent to the author, Ron Panetta, WB2WGH, whose E-mail address is good on QRZ.COM.

Background (Yes, you can skip this section if you don't care 😊)

The following extract is a Flex Community post by Steve, N5AC, VP Engineering/CTO and the full thread is available at https://community.flexradio.com/flexradio/topics/arrl-fmt-tonight-getting-the-most-accurate-frequency. Based on this original post, information gleaned from post responses and other sources, I've pulled together this "how to" guide in hopes that it will eliminate some of the stumbling blocks I encountered.

> The FLEX-6000 radios are well suited to perform in the challenge, but there's some important information you should know before having a go at it. I apologize in advance that this will not be a complete "how to" guide and I hope that some others may be able to answer questions on what I've written as they arise. I've been meaning to post this for several weeks and just haven't had the time.
>
> In a direct sampling radio like the FLEX-6000, there is a Direct Digital Synthesizer (DDS) or Numerically Controlled Oscillator (NCO) performing the tuning of receivers in the digital domain. In the FLEX-6000, there is a complex set of DDSs and mixers that control the final output frequency of the radio. We've not previously exposed how all this works in the radio and so the opaqueness of this part of the radio makes competing in the FMT hard. So this post will provide enough information to get a much more accurate measurement for those that are interested. The capabilities here were developed for a government customer of ours and have been shown to get frequency results within a few hundred microHertz (yes, microHertz). It is important to point out that doppler shift in the ionosphere and other considerations will affect your on-air accuracy, but the FLEX-6000 should get you closer that any other amateur radio I know of.
>
> Note that for best results, you will need to have a FLEX-6500 or FLEX-6700 with either the on-board GPS option or a 10MHz reference that is derived from a GPS locked oscillator (or cesium, rubidium, hydrogen maser, etc). A FLEX-6300 will simply not have the same level of accuracy, but you can have a go after using the WWV calibration built into the radio. Incidentally, if you are using a FLEX-6500 or 6700 that is locked to a reference, ensure that you have your frequency offset setting set to ZERO.
>
> THEORY
> When a DDS is tuned, it is supplied with a frequency tuning word (FTW). The frequency tuning word is limited to a set number of bits and most of ours in the radio are 30-32 bits. Every frequency cannot be represented with 32 bits, of course, and the error in any given DDS can be calculated by taking the sampling radio divided by 2^<# of bits>. In our case, this would be 245,760,000 / 2^32 = 57.22mHz (millihertz). This means that the radio can be off as much as 57mHz at any time. Some changes were made a few months ago that limit this to +/- 28.61mHz (SmartSDR v1.10.9 and later). In addition, a new API command was added that will actually report the error for both the receiver and transmitter:

http://wiki.flexradio.com/index.php?title=TCP/IP_slice#GET_ERROR

So you can tune a receiver and then connect to the radio using the API and request the error. Then you can use available software to measure the audio frequency of a tone in your passband and make the adjustment provided by the get_error command. Details on using the API are beyond the scope of this quick posting so you'll have to look around to get that information. The short version is that you find your radio's IP address, use a telnet client to telnet to it and then issue the get_error command after you've tuned your slice receiver.

I hope this helps someone use the FLEX-6000 in the FMT and I'd be glad to answer questions as I have time. Again, our military customers use this to get within a couple hundred microHertz so you should be able to do very well in the FMT by applying this information.

Flex Radio Time Base Background Information

The Flex 6000 series supports 3 time base frequency references

- External 10 MHz reference via the rear panel “10 MHz Input” jack
- The internal GPSDO option
- The internal TXCO

For those not familiar with GPS Disciplined Oscillators (GPSDO), they are leverage GPS signals to generate a very accurate 10MHz time base reference when powered without interruption. They consist of a small GPS receiver which disciplines an internal oscillator (typically an OCXO) and generates a 10MHz reference output (some produce a sine wave and some produce a square wave). A small GPS satellite antenna provides GPS signals to the GPSDO and must have good sky visibility to maximize the number of satellites in view (and accuracy of the 10MHz reference). They are far more accurate than internal crystal time base references.

FlexRadio offers a GPSDO option for some of its radios. If you already have an accurate 10MHz time base (e.g., from a GPSDO), some Flex radios support an external 10MHz time base via the rear panel “10 MHz Input” jack.

The following table summarizes the accuracy of various time base sources:

Type	Description	Accuracy per year (approx.)	Error[1] (Hz) at 10MHz
XO	Crystal oscillator	1×10^{-4}	1000
TXCO	Temperature Compensated crystal oscillator	2×10^{-6}	20
OCXO	Oven controlled crystal oscillator	1×10^{-8}	0.1
Rb OCXO	Rubidium disciplined oscillator	5×10^{-11}	0.0005
GPSDO	GPS disciplined oscillator	5×10^{-12}	0.00005
Cesium	Cesium atomic clock	$>1 \times 10^{-11}$	<0.0001

Notes:

[1] Error a function aging and many other factors

Most Flex users likely use the internal crystal time base for a reference frequency standard. A calibration process is also provided to determine a correction factor for that internal timebase. Per the FLEX 6000 Hardware Reference Manual:

15.1 FREQUENCY CALIBRATION

The FLEX-6000 incorporates high-quality low phase noise TCXOs and OCXOs for frequency accuracy and stability. However, oscillators undergo a slow gradual change of frequency with time, known as aging and may require periodic frequency calibration using a known frequency standard.

The FLEX-6000 *without* an installed GPSDO can be calibrated by the user utilizing the automated routine provided in the SmartSDR for Windows client software. Before running this calibration routine, allow for the radio to temperature stabilize for at least 30 minutes before calibrating the frequency. The calibration routine will temporarily use Slice A and ANT-1 to receive over the air signals from a known frequency source, such as WWV or CHU. Also, refrain from frequency calibrating the radio in extremely high, low or fluctuating ambient temperatures as this will introduce error into the calibration process. Please refer to the SmartSDR for Windows Software User's Guide for detailed frequency calibration instructions.

Per the FLEX 6000 Hardware Reference Manual the following extract provides insight into the radio's specifications for the external time base reference input:

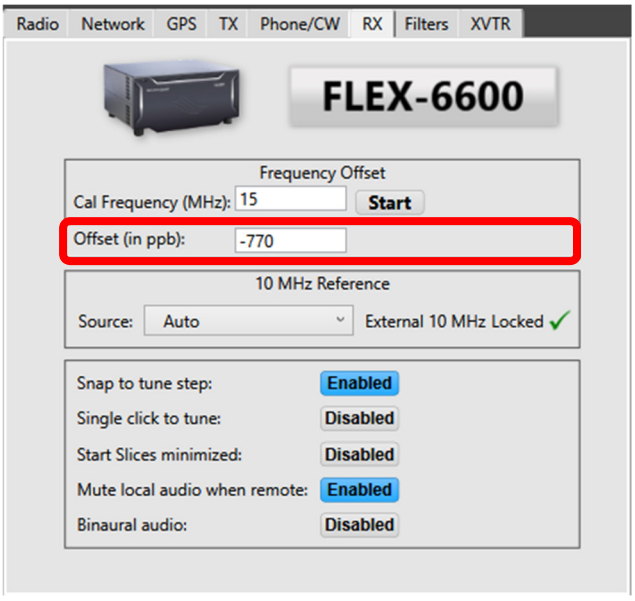
10MHZ REFERENCE CLOCK INPUT

The external reference clock input is used to synchronize the radio's master oscillator. Requires a 1.0v p-p minimum to 3.3v p-p maximum (4dBm min - +15dBm max), sine or square wave signal.

Different Flex architectures handle time base selection differently. Per insight from Flex:

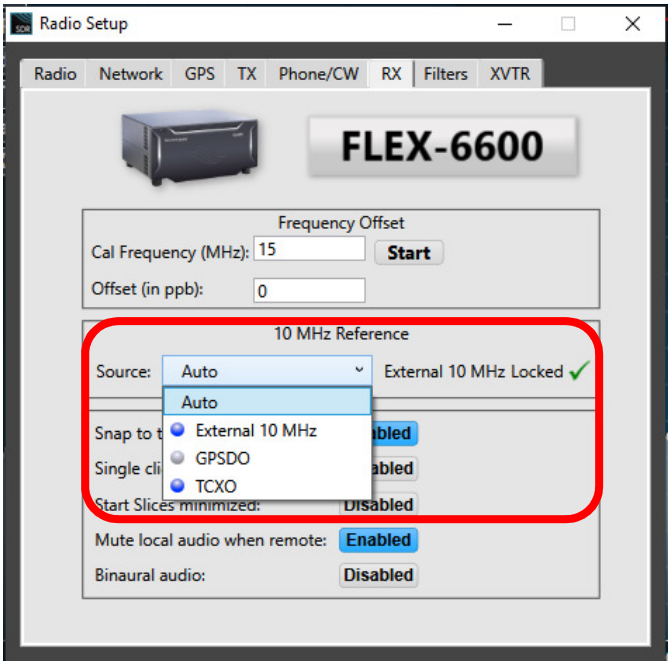
FLEX-6300, 6500 & 6700	The radio software samples the external clock input first, then the optional GPSDO (if present), then the internal oscillator (FLEX-6500: TCXO, FLEX-6700/6700R: OCXO). Once an active source is found, the radio software stops looking for any other clock source. If the external source is lost, the radio will look for an active internal oscillator, but it will not look for any other oscillator signal until the radio is powered off and re-started. ***I - The external signal is only sampled at initial startup of the radio software. It is necessary to make the external signal available on the rear panel connector before the radio is powered up. Otherwise, the signal will not be used.***
FLEX-6400, 6400M, 6600 & 6600M	Constantly search and use a priority scheme to decide which reference to use

The correction ("Offset (in ppb)") can be observed with SmartSDR, via "Settings" -> "Radio Setup"-> "RX" per the screen snapshot below.



Note, when using a GPSDO, internal or external, the "Offset" should be set to zero unlike this particular screen snapshot

One can confirm the available time base references and also determine the time base in use. In SmartSDR, this is done via "Settings" -> "Radio Setup"-> "RX" per the screen snapshot below. The Maestro can also be used via (Menu -> Radio):



Configuring the Radio

Time Base Reference

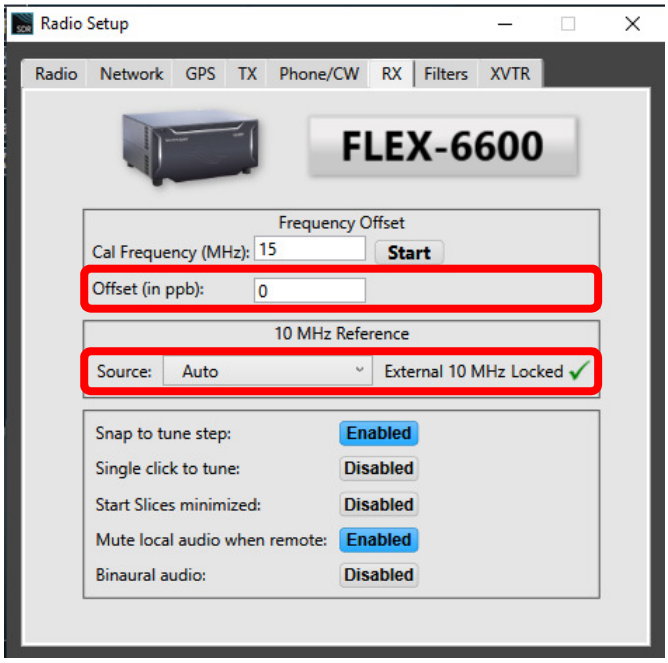
Follow the appropriate process depending on your time base reference.

Internal OCXO/TCXO

1. Perform a time base calibration per your radio's calibration process in the hardware reference manual or extract in the section above.

Internal GPSDO

1. Install the GPSDO per the Flex provided documentation
2. Set the time base error to zero (0) and verify the internal time base is selected:



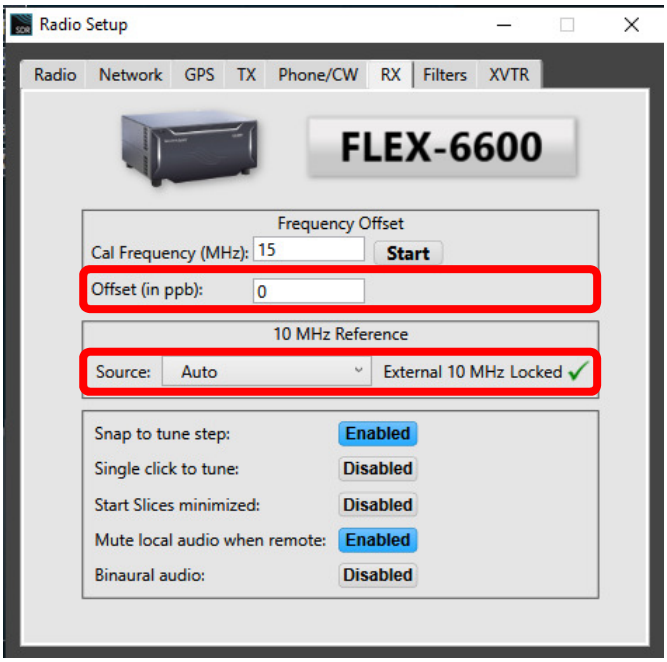
Note, in my case I am using an external reference so the screen snapshot does not reflect an internal timebase

External GPSDO

1. Verify your time base reference meets your radio's specifications per the Flex provided documentation. For example:

10MHZ REFERENCE CLOCK INPUT
The external reference clock input is used to synchronize the radio's master oscillator. Requires a 1.0v p-p minimum to 3.3v p-p maximum (4dBm min - +15dBm max), sine or square wave signal.

2. Set the time base error to zero (0) and verify the internal time base is selected:



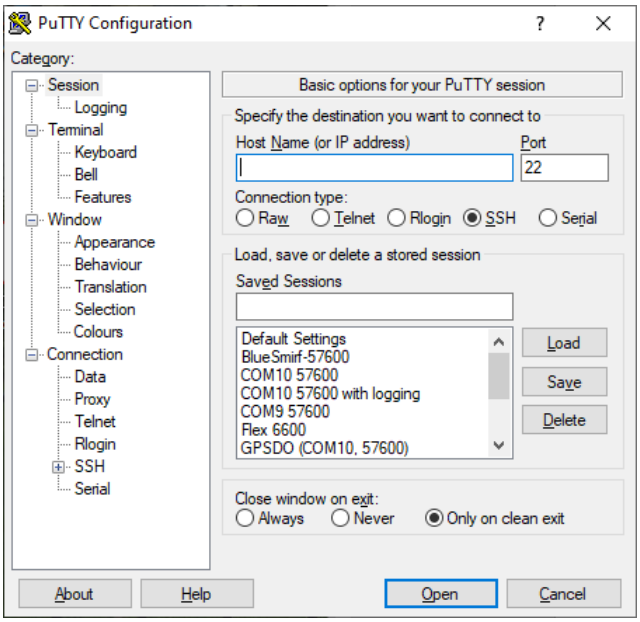
Configuring Putty to Obtain Flex Frequency Error on Selected Radios

Flex SDR frequency errors can be queried and used to correct measured frequencies on certain Flex radios. If you have a radio with this feature, this section provides insight in obtaining that error. If you do not have a radio with this feature, ignore this section.

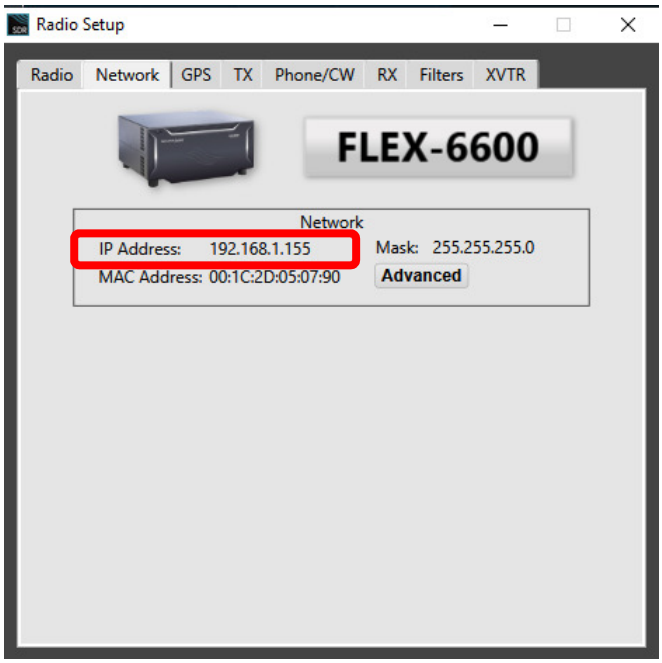
Radio	SDR Frequency Error Query
6300, 6400, 6400M	Not implemented. Although the "get_error" command may execute and return values, those values will invalid
6500, 6600, 6600M, 6700	Implemented and returns correct error information

You can optionally correct for SDR errors associated with the slice in question per the info above. To do that, query the radio's error registers. This can be performed via telnet to the radio's IP address and query it for the error correction. This section will provide insight into configuring Putty (http://putty.org/).

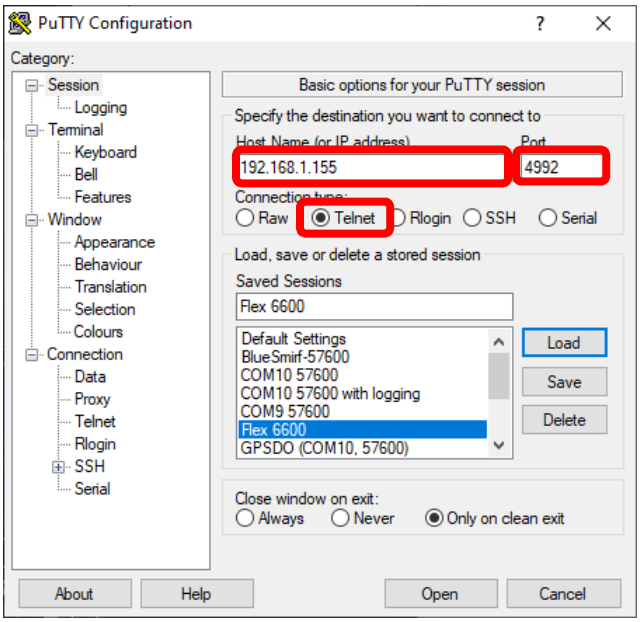
1. Download and install Putty
2. Open Putty



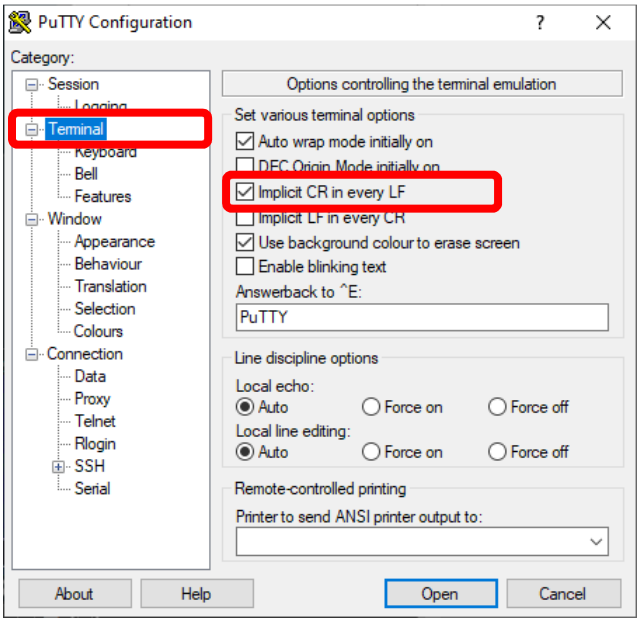
3. Determine your radio's IP address via SmartSDR ("Settings" -> "Radio Setup"-> "Network") or Maestro (Menu -> Radio):



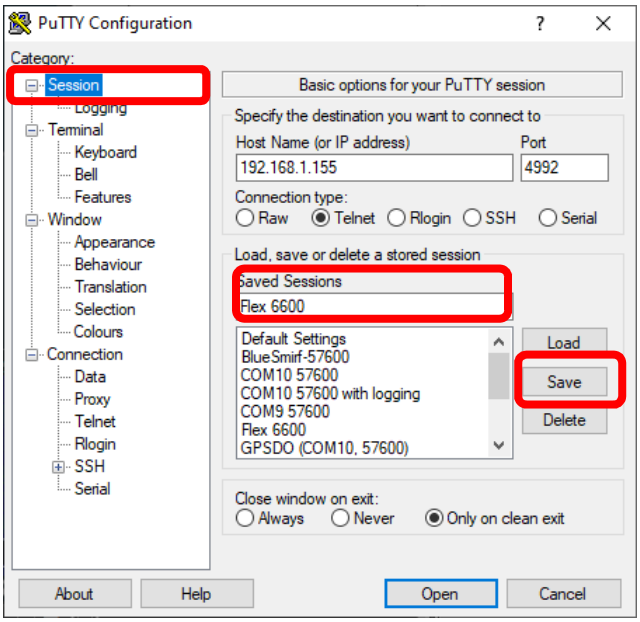
4. Enter the IP address, change the connection type to Telnet and enter 4992 for the port



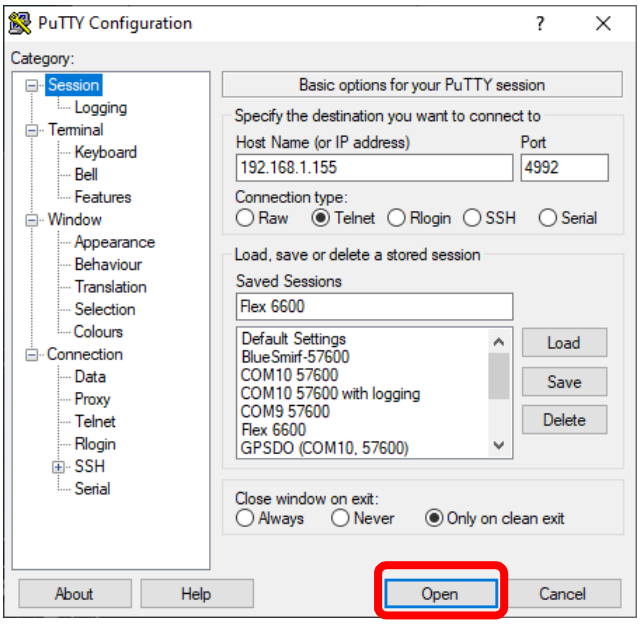
5. Click “Terminal” in the left side “Category” and check “Implicit CR in every LF”:



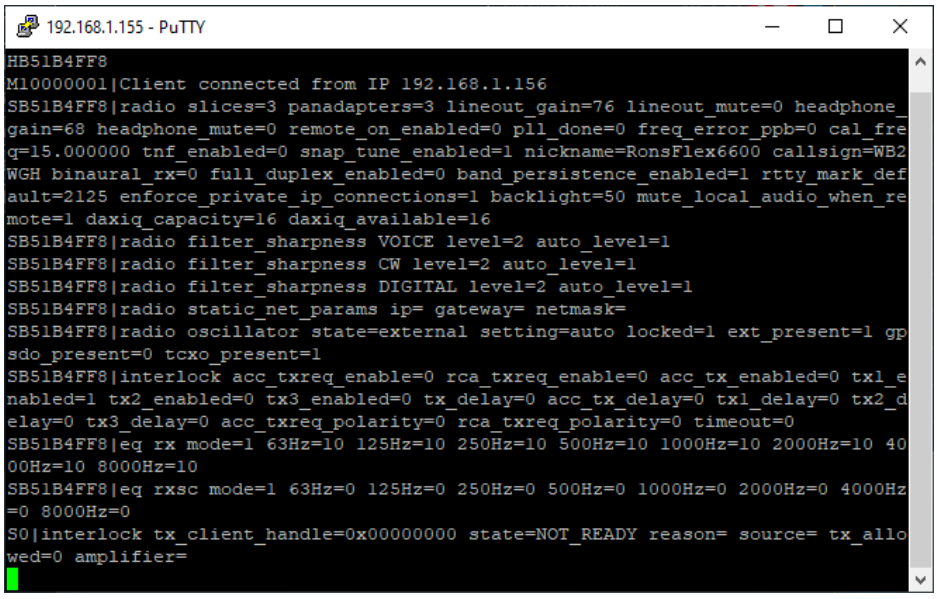
6. Click “Session”, enter a name in “Saved Sessions” and click “Save” to save the configuration:



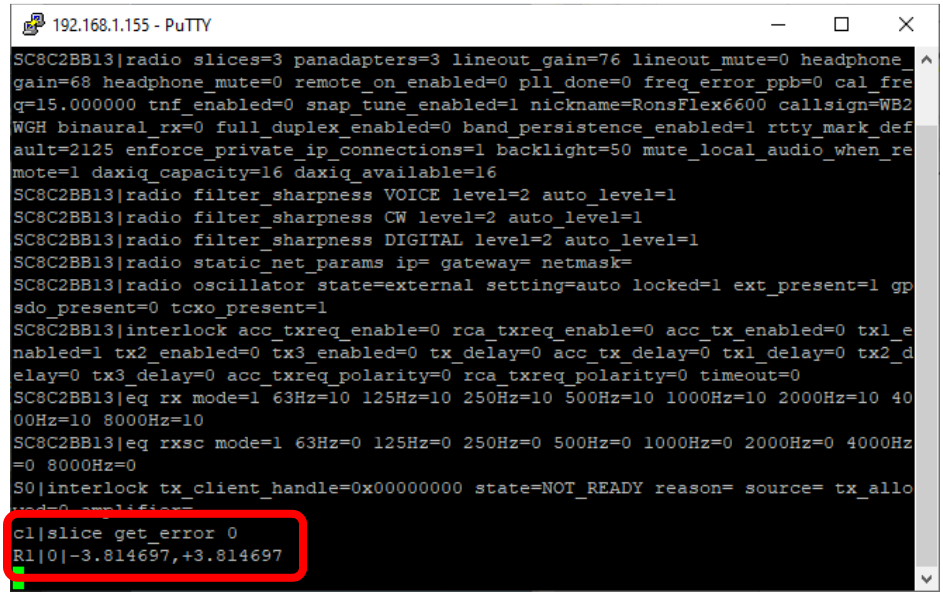
7. Open a slice on your radio and ensure that is slice “A”.
8. Click “Open” in the Putty window:

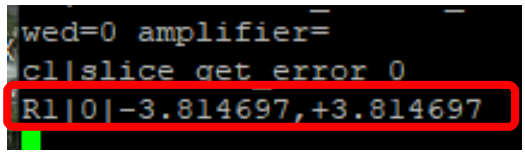


9. You should see a window like this:



10. Enter the following command in the window “c1|slice get_error 0”. Note the Flex is not very tolerant of typos 😊. You should see a response like this:





11. Make note of the 2 values returned:
    a. RX error (in milliHertz) = -3.814697
    b. TX error (in milliHertz) = +3.914697
12. Any change of frequency of the slice OR the panadapter will change these numbers. If you have WSJT setup to control the rig, it may tune somewhere and tune back, etc. In other words, this

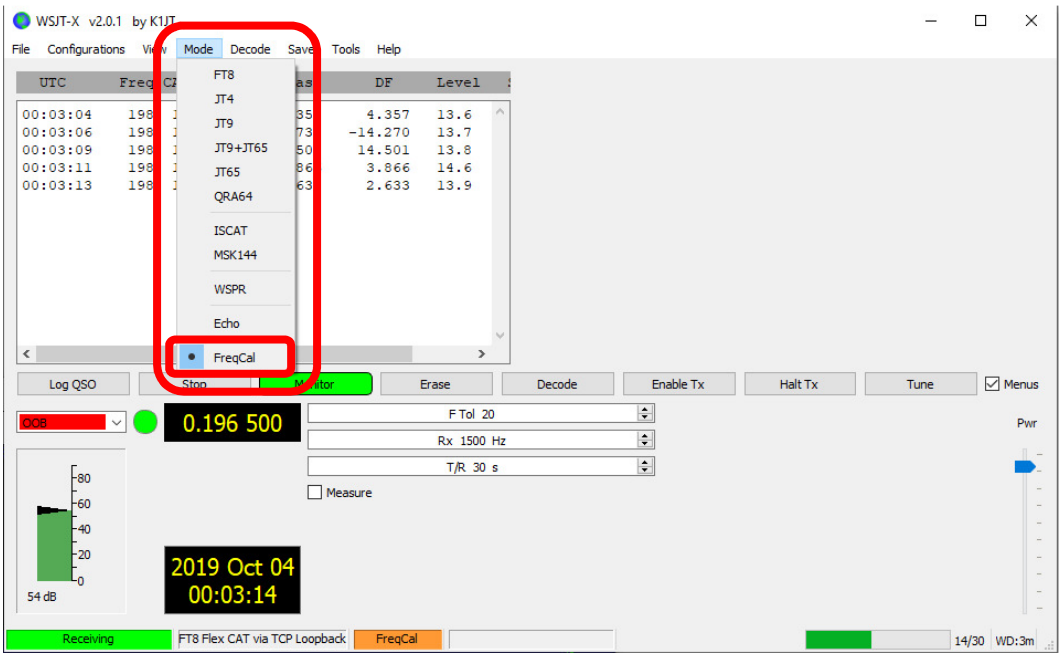
step needs to be performed AFTER everything is setup and the receiver is tuned to ensure that the correct frequency error is retrieved.

Configure SmartSDR

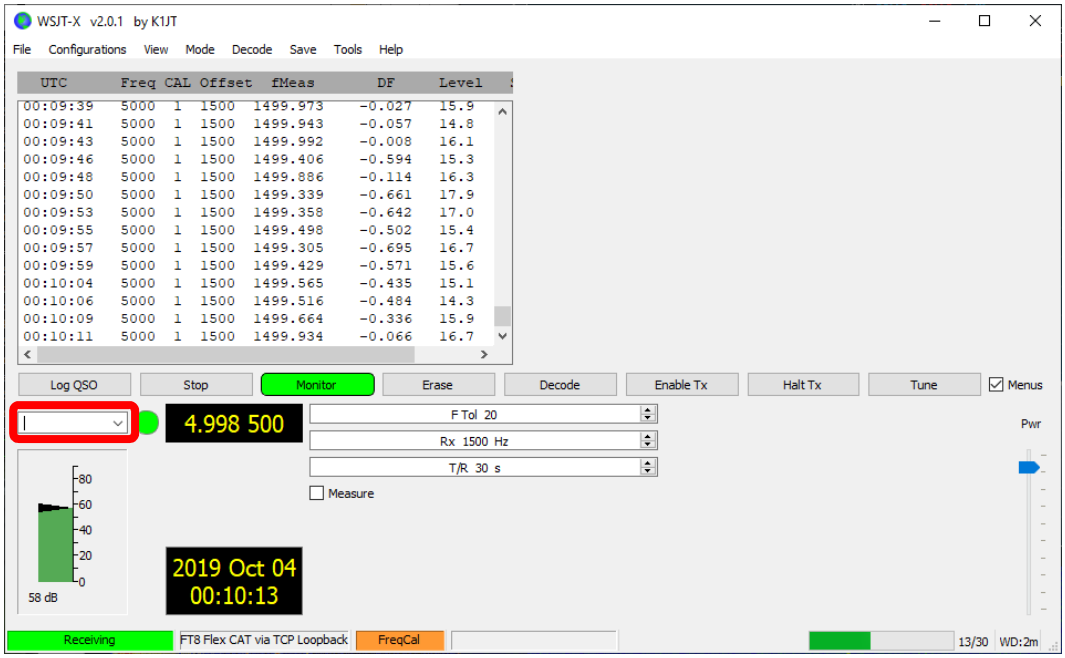
1. Start SmartSDR and ensure SmartCAT and SmartDAX are running to facilitate WSJT access and control.
2. Set the slice (slice A is used here) for USB and an upper bandwidth limit of 2.1KHz (must be at lease 1.5KHz)

Configure WSJT-X

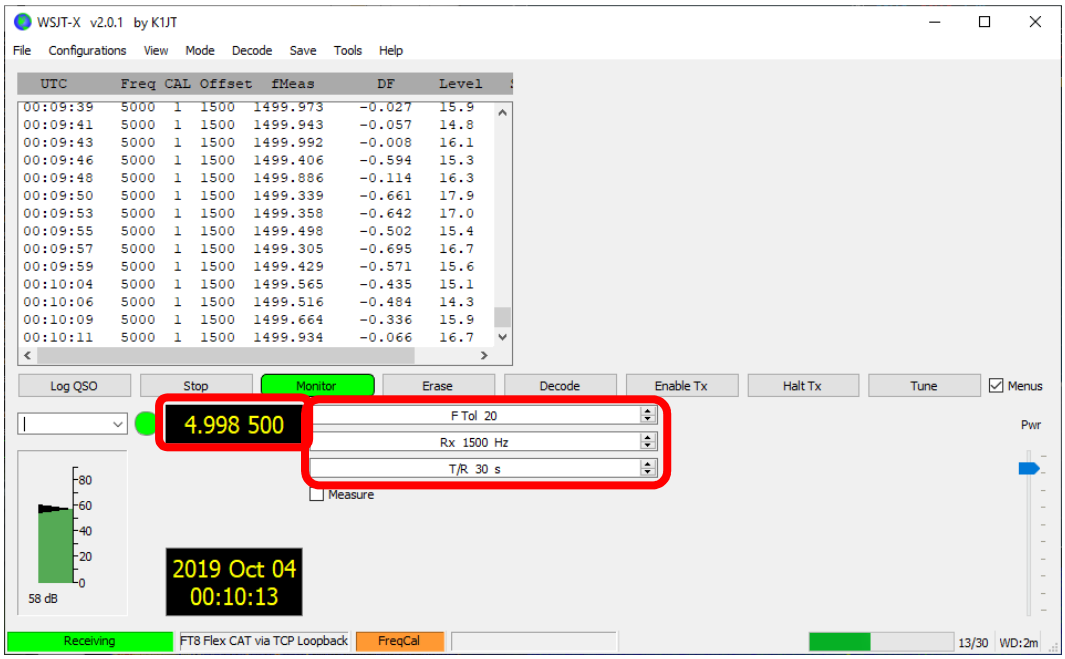
1. Download and configure WSJT to communicate with your Flex. There are several documents that detail the process. Here is one example.
2. Start WSJT-X and set the “Mode” to “FreqCal”

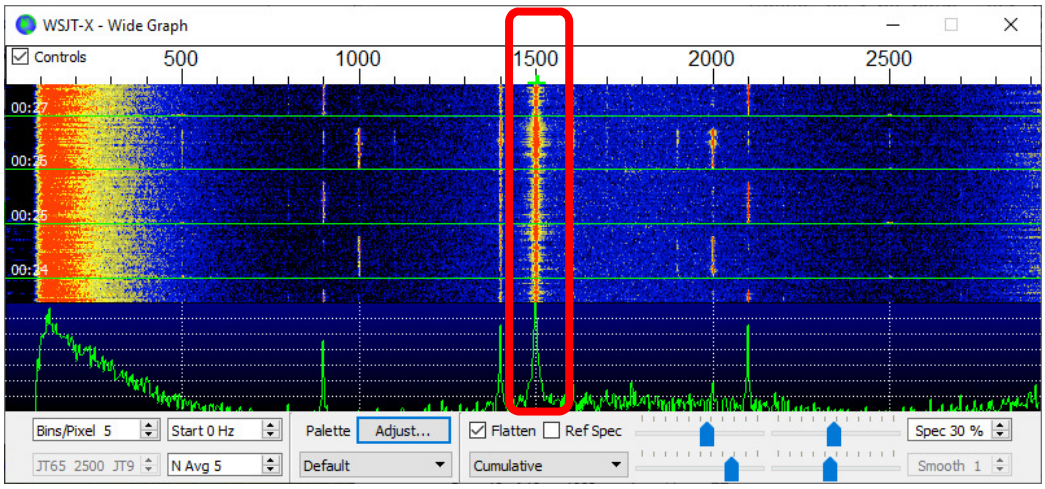


3. Select a test station in the frequency selector pulldown. I suggest selecting a station other than 10MHz WWV as I have noticed internal RF coupling between the 10MHz time base reference signal and the received signal when tuned to 10MHz.



4. Note some subtle elements in the WSJT-X window:
    a. The 3 stacked pull downs.
        i. The “F Tol” pulldown defaults to 20Hz and that is the frequency tolerance for the tuned frequency. Need more info!
        ii. The “Rx” window will default to 1500 Hz and reflects the audio tone WSJT-X will monitor. You will notice that WSJT-X decrements the tuned frequency by this amount to generate an audio tone at that frequency from the carrier in question.
        iii. The “T/R” pulldown defaults to 30 seconds. Need more info!



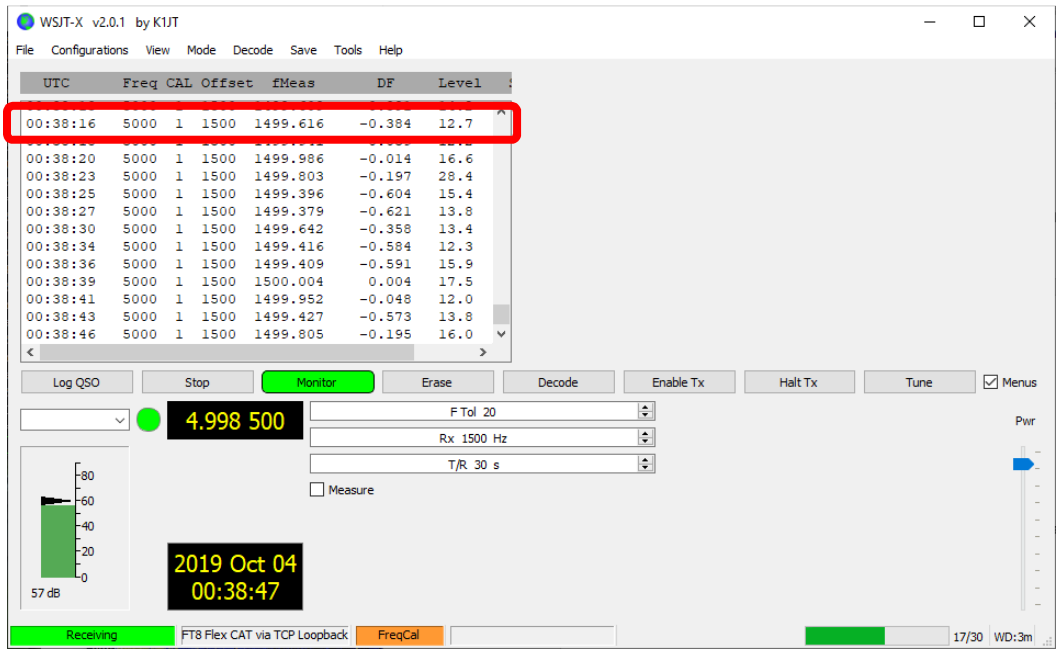


5. WSJT should be properly configured at this time. You can select an alternate frequency (as required by the ARRL Frequency Measurement Test, by selecting the frequency in the SmartSDR slice. **Remember to tune 1500Hz low!**
6. After the final frequency tuning, resample the internal FlexRadio error values (c1|slice get_error 0) via Putty for the current error value.

Sample Frequency Test Calculation

One data point

1. Extract one data sample from the WSJT-X window.



2. Calculate the carrier frequency as follows:

Actual Frequency = SliceFrequency + WSJT_Offset – (Flex_RX_Error/1000)

Using the values in this article:

- SliceFrequency = 4,998,500 Hz
- WSJT_Offset = 1,499.616 Hz
- Flex_RX_Error = -3.814697 milliHz

Actual Frequency = 4,998,500 + 1,499.616 – (-3.814697/1000)
Actual Frequency = 4,999,999.6198147

3.

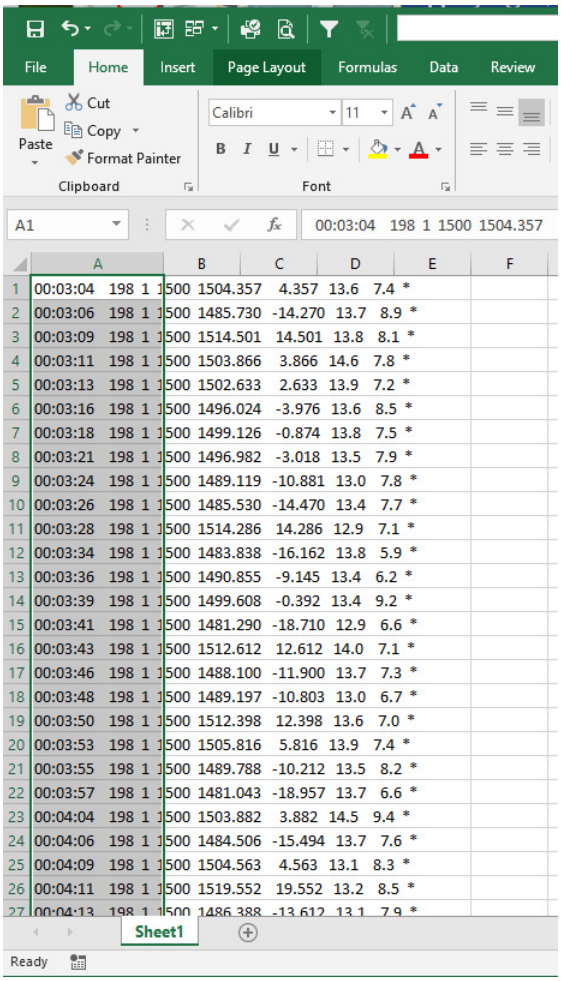
Averaging Multiple Data Points

For averaging multiple data points, one can use a spreadsheet (e.g., Excel, OpenOfficeCalc, LibreOffice Calc, etc). Excel will be used in this example.

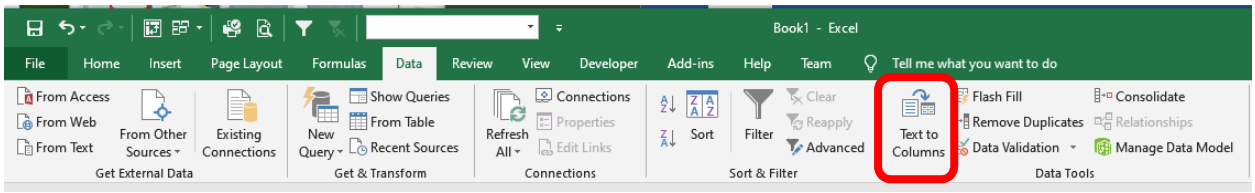
1. In the WSJT-X window, select (CRTL/A) and copy (CRTL/C) the data points. One must be quick and enter the two commands between WSJT-X refreshes. Following is a subset of the data

```
00:03:04   198  1  1500  1504.357    4.357  13.6   7.4  *
00:03:06   198  1  1500  1485.730  -14.270  13.7   8.9  *
00:03:09   198  1  1500  1514.501   14.501  13.8   8.1  *
00:03:11   198  1  1500  1503.866    3.866  14.6   7.8  *
00:03:13   198  1  1500  1502.633    2.633  13.9   7.2  *
00:03:16   198  1  1500  1496.024   -3.976  13.6   8.5  *
00:03:18   198  1  1500  1499.126   -0.874  13.8   7.5  *
00:03:21   198  1  1500  1496.982   -3.018  13.5   7.9  *
00:03:24   198  1  1500  1489.119  -10.881  13.0   7.8  *
00:03:26   198  1  1500  1485.530  -14.470  13.4   7.7  *
00:03:28   198  1  1500  1514.286   14.286  12.9   7.1  *
00:03:34   198  1  1500  1483.838  -16.162  13.8   5.9  *
00:03:36   198  1  1500  1490.855   -9.145  13.4   6.2  *
00:03:39   198  1  1500  1499.608   -0.392  13.4   9.2  *
00:03:41   198  1  1500  1481.290  -18.710  12.9   6.6  *
00:03:43   198  1  1500  1512.612   12.612  14.0   7.1  *
00:03:46   198  1  1500  1488.100  -11.900  13.7   7.3  *
00:03:48   198  1  1500  1489.197  -10.803  13.0   6.7  *
```

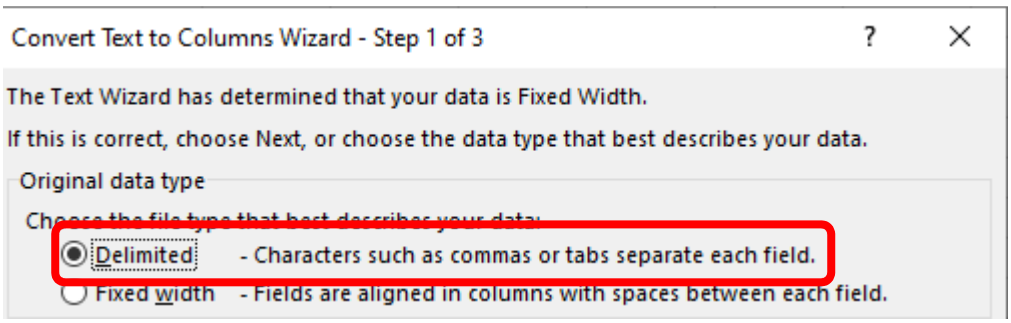
2. Import the data into Excel
    a. Open Excel
    b. Create a new blank spreadsheet
    c. Position the active cell at A1
    d. Paste the WSJT-X data



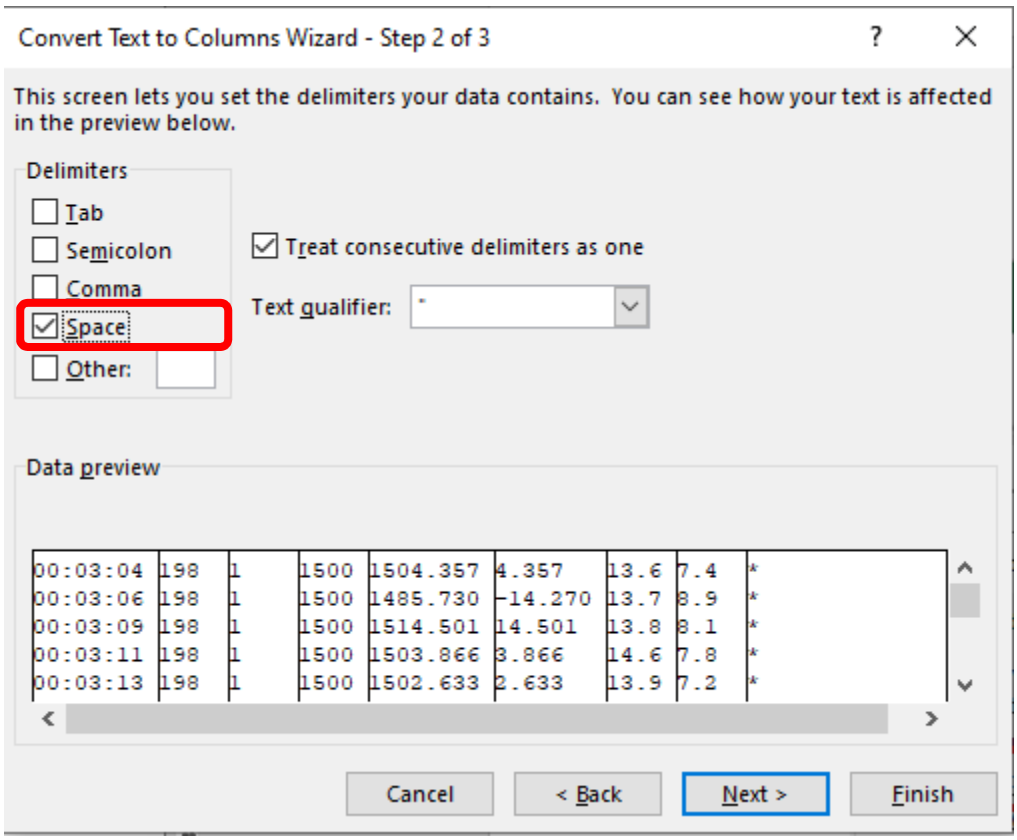
e. While column A is highlighted go to “Data” => “Text to Columns”



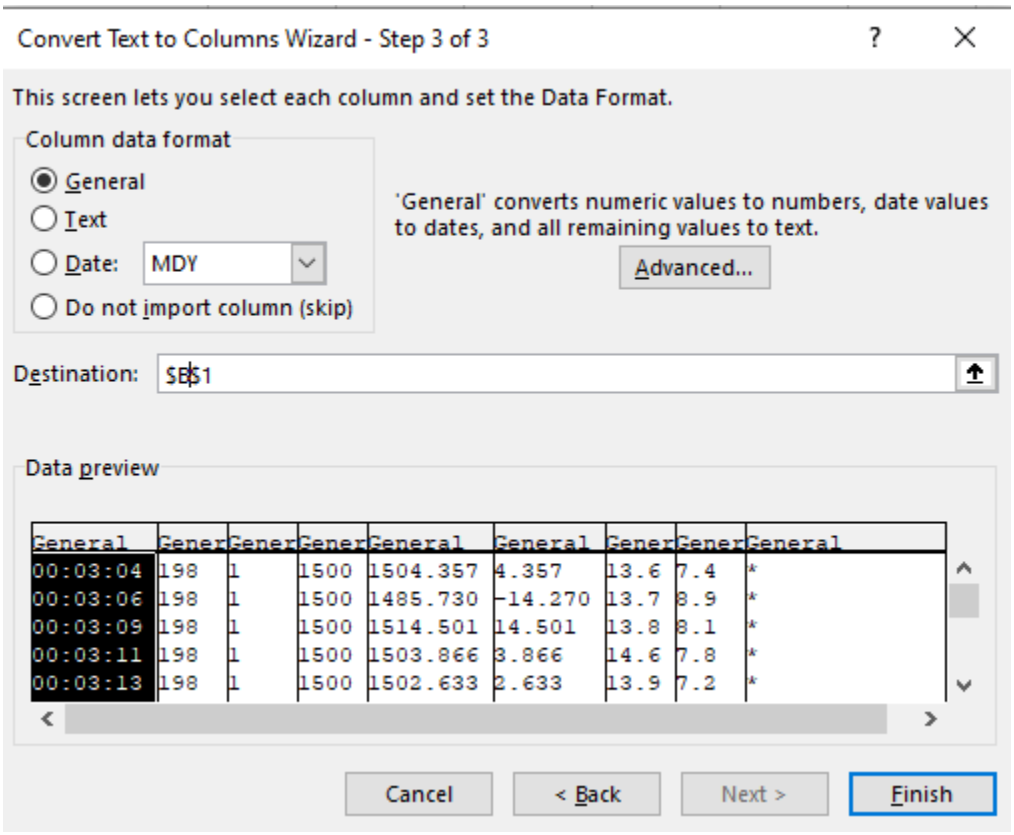
f. Change the data type to “Delimited” and click “Next”



g. Change the delimiter to “Space” and click “Next”



h. Optionally change the “Destination” from “A1” to “B1” and click “Finish”. Changing the destination preserves the original imported data rather than over writing it.

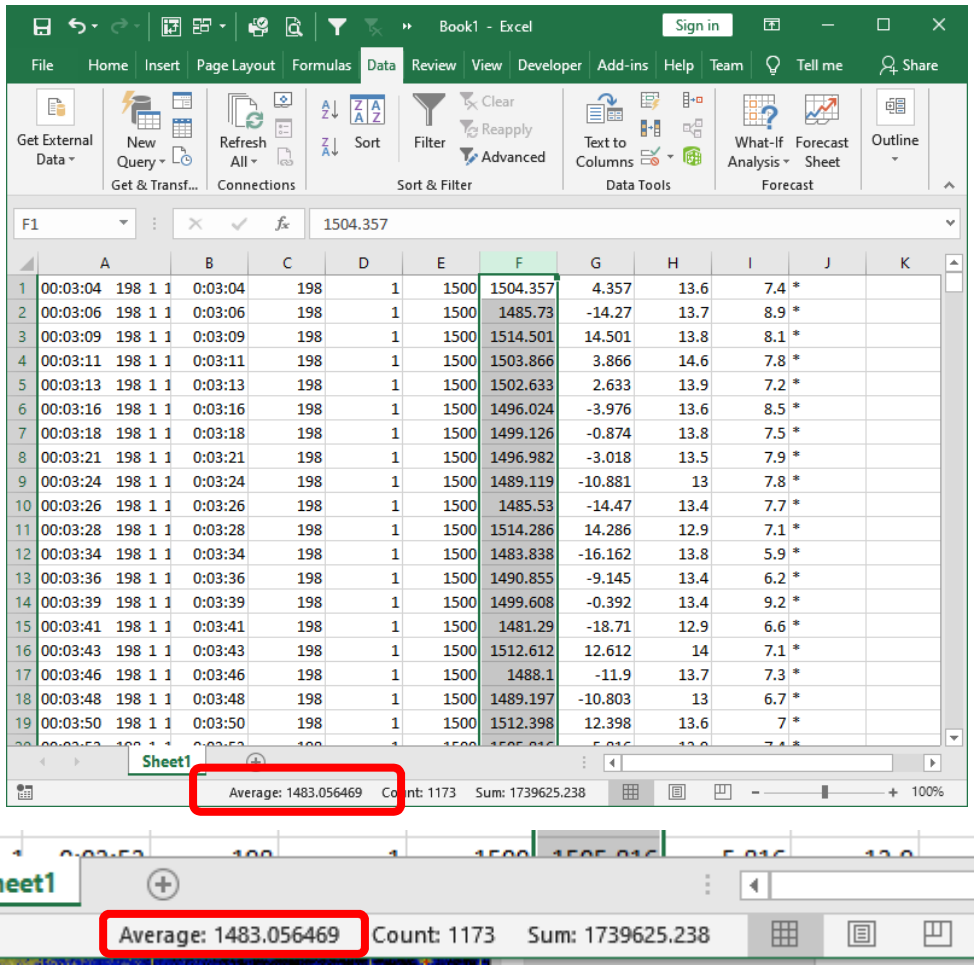


i. You should have something that resembles the following:

	A	B	C	D	E	F	G	H	I	J
1	00:03:04 198 1 1	0:03:04	198	1	1500	1504.357	4.357	13.6	7.4	*
2	00:03:06 198 1 1	0:03:06	198	1	1500	1485.73	-14.27	13.7	8.9	*
3	00:03:09 198 1 1	0:03:09	198	1	1500	1514.501	14.501	13.8	8.1	*
4	00:03:11 198 1 1	0:03:11	198	1	1500	1503.866	3.866	14.6	7.8	*
5	00:03:13 198 1 1	0:03:13	198	1	1500	1502.633	2.633	13.9	7.2	*
6	00:03:16 198 1 1	0:03:16	198	1	1500	1496.024	-3.976	13.6	8.5	*
7	00:03:18 198 1 1	0:03:18	198	1	1500	1499.126	-0.874	13.8	7.5	*
8	00:03:21 198 1 1	0:03:21	198	1	1500	1496.982	-3.018	13.5	7.9	*
9	00:03:24 198 1 1	0:03:24	198	1	1500	1489.119	-10.881	13	7.8	*
10	00:03:26 198 1 1	0:03:26	198	1	1500	1485.53	-14.47	13.4	7.7	*
11	00:03:28 198 1 1	0:03:28	198	1	1500	1514.286	14.286	12.9	7.1	*
12	00:03:34 198 1 1	0:03:34	198	1	1500	1483.838	-16.162	13.8	5.9	*
13	00:03:36 198 1 1	0:03:36	198	1	1500	1490.855	-9.145	13.4	6.2	*
14	00:03:39 198 1 1	0:03:39	198	1	1500	1499.608	-0.392	13.4	9.2	*
15	00:03:41 198 1 1	0:03:41	198	1	1500	1481.29	-18.71	12.9	6.6	*
16	00:03:43 198 1 1	0:03:43	198	1	1500	1512.612	12.612	14	7.1	*
17	00:03:46 198 1 1	0:03:46	198	1	1500	1488.1	-11.9	13.7	7.3	*
18	00:03:48 198 1 1	0:03:48	198	1	1500	1489.197	-10.803	13	6.7	*
19	00:03:50 198 1 1	0:03:50	198	1	1500	1512.398	12.398	13.6	7	*
20	00:03:53 198 1 1	0:03:53	198	1	1500	1505.816	5.816	13.9	7.4	*
21	00:03:55 198 1 1	0:03:55	198	1	1500	1489.788	-10.212	13.5	8.2	*
22	00:03:57 198 1 1	0:03:57	198	1	1500	1481.043	-18.957	13.7	6.6	*
23	00:04:04 198 1 1	0:04:04	198	1	1500	1503.882	3.882	14.5	9.4	*
24	00:04:06 198 1 1	0:04:06	198	1	1500	1484.506	-15.494	13.7	7.6	*
25	00:04:09 198 1 1	0:04:09	198	1	1500	1504.563	4.563	13.1	8.3	*

j. Highlight column “F” the “fMeas” column and you should have something that resembles the following. Note the “Average” on the lower portion of the window. In this case, the average is 1,483.056469 Hz. If “Average” does not appear on your Excel

window, right click in that portion of the window and enable “Average”. For more information , Google “View summary data on the status bar”.



k. Use this average in the calculation described above in “One Data Point” calculation.

Measurement Notes

1. The WSJT-X measured frequency is sometimes impacted by the PCs resource utilization (CPU, disk, etc). Minimize any multitasking on the PC.

Optimizations

Filtering data based on S/N

Incorporation of fldigi guidance

TBD