NACT TUTORIAL 5
CRYSTAL CHARACTERIZATION & MATCHING

Applies to: NAT and NACT MODES

Prerequisites: Tutorials 0, 1, 2 and 3 (or 3T)

This tutorial takes you through the steps to test, grade, and sort a batch of crystals to select one or more groups of crystals for use in a crystal filter. The sample filter used here is the 6-crystal filter used in the PHSNA Measurement Receiver designed by Jerry Haigwood, W5JH, and implemented and kitted by Jim Giammanco, N5IB (https://groups.yahoo.com/neo/groups/PHSNA/files/Measurement%20Receiver/). The principles demonstrated in this tutorial could be applied to most any other crystal filter design. The object of this tutorial is to analyze a batch of 30 crystals to identify the six crystals with the minimum series resonant frequency variations or "spread". If we are lucky, we will be able to identify more than one group of crystals with acceptable frequency spreads. The crystals used here were ordered as 3.2768 MHz and are all marked "3.27" (Mouser Part no. 520-HCA327-17X).

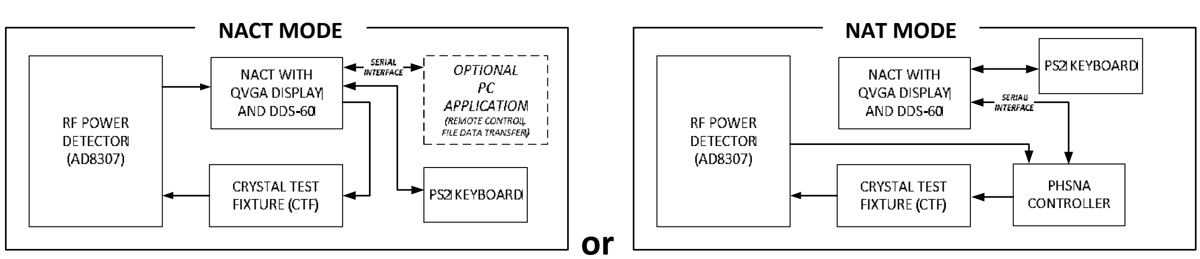
The requirements for this tutorial are:

- NAT running firmware Version 3.0 or later.
- Logarithmic RF Power Meter such as the RF Power meter designed by W7ZOI and W7PUA used by the PHSNA.
- PS2 Keyboard
- Crystal Test Fixture (CTF)
- The batch of crystals to be characterized.
- SD Card

To operate in NAT mode you will also need the following:

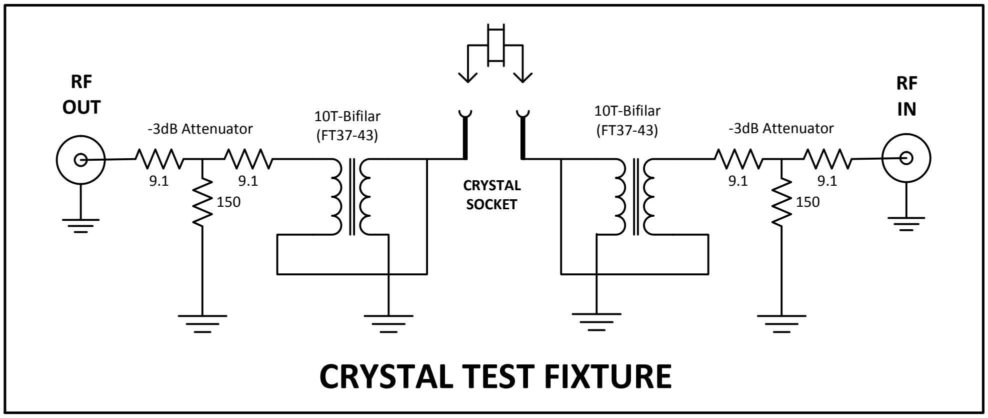
- PHSNA Arduino UNO/NANO based controller.

You will also need all interconnecting cables and power sources.

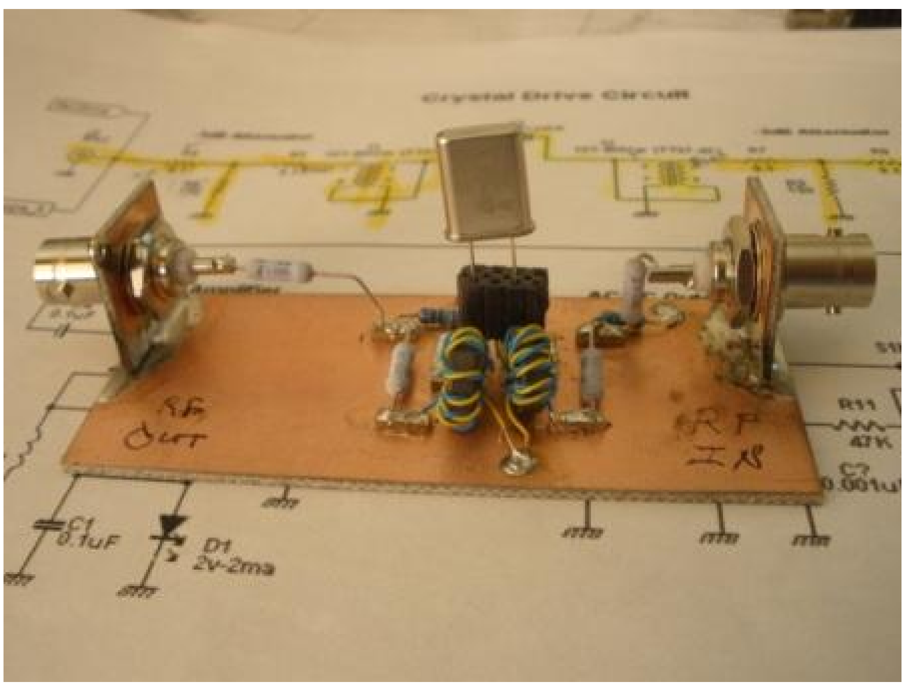


Crystal Test Fixture (CTF)

The crystal test fixture used for this tutorial is based on the Crystal Drive Circuit designed by Jim Kortge, K8IQY (http://www.k8iqy.com/testequipment/pvxo/pvxopage.htm). There are certainly many other CTF designs that could be used.



I built my CTF on a small copper-clad board using some Manhattan-style construction. The CTF circuit is symmetrical so the RF IN and RF OUT connector assignments are completely arbitrary.



Crystal Identification

For this tutorial we are going to characterize a batch of 30 crystals. Each data set is individually recorded and is the result of a single frequency sweep with the associated crystal plugged into the CTF. Each data set consists of seven, comma-separated, fields and is terminated by a Carriage Return. Numeric values are recorded as ASCII decimal digits and may contain a fractional part. Each data set contains the following information:

- Data set/crystal ID.
- Series resonance frequency in Hz.
- -3dB bandwidth in Hz.
- Rs - Series resistance in ohms to two decimal places
- Cm - Motional capacitance in picofarads to four decimal places
- Lm – Motional inductance in millihenries to two decimal places
- Q – Quality factor as an integer

The first field in each data set is a unique identifier consisting of the XTAL PREFIX (from page two of the PLX data sheet) concatenated with the scan or plot number. It is imperative that you be able to identify the individual crystals and can associate each one with its data set. One method would be to mark each crystal with an identification number associated with its data set. I prefer to not mark the crystals and, instead, load them into egg cartons and process them in a specific order so a crystal's location in the egg carton(s) identifies the associated data set ID.

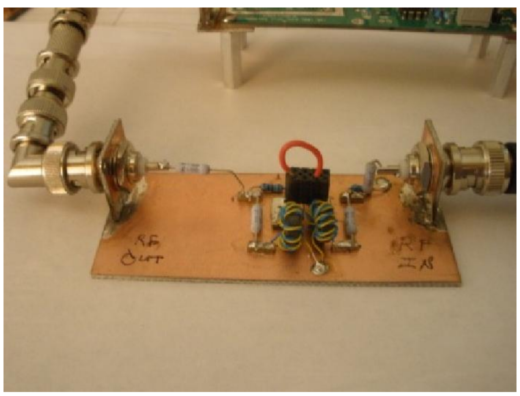
There are three basic parts to crystal characterization:

1. CTF calibration
2. Data collection
3. Data sorting and matching.

This tutorial presents each of the basic parts as a separate sequence of steps.

Crystal Test Fixture Calibration

1. Connect the CTF RF IN connector to the DDS output and the RF OUT to the RF Power Meter input.
2. Install a jumper in the crystal socket to short the two pins together.



3. Power on all components.
4. Create a PLX data sheet as follows:
    a. Press Scroll Lock to enter Command mode.
    b. Press F3 to display the data entry form

c. Set up the F3 PLX data sheet to cover a frequency range of 1 MHz surrounding the frequency of interest (3.2768 MHz in this case). The exact frequencies and frequency increments are not critical since we are just calibrating the CTF.
Enter the following on the form:

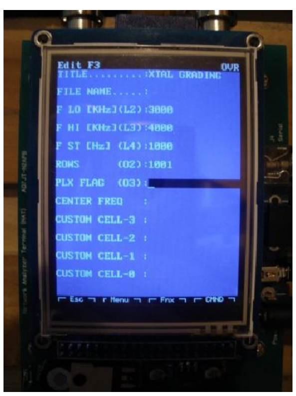
page one:

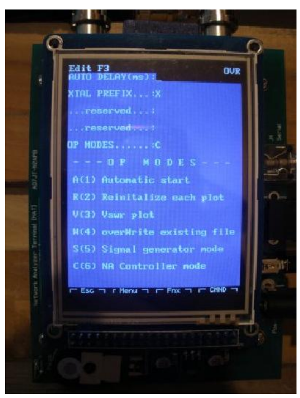
TITLE – XTAL GRADING
FILE NAME – leave blank for now
FREQ LO – 3000
FREQ HI – 4000
FREQ ST – 1000
leave the rest of page one blank and press Page Down to display page two

page two:

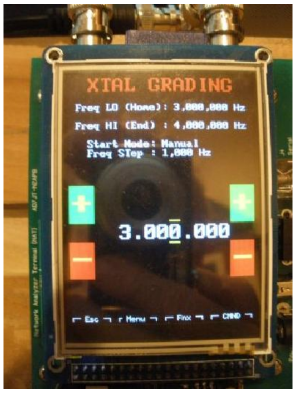
AUTO DELAY(ms) – leave blank
XTAL PREFIX – X
OP MODES – C (if NACT mode, blank otherwise)

5. Press Enter to save the data sheet to EEPROM.

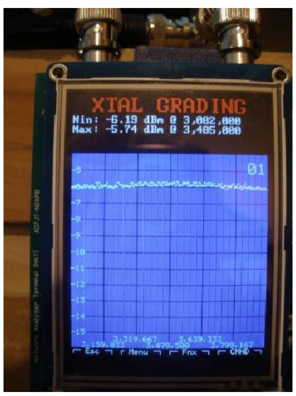




6. Press F3 to activate the data sheet.



7. Press the Space bar to start the frequency scan. After the scan, the results will be plotted. This relatively straight line illustrates the insertion loss for the CTF which is mainly due to the two -3dB attenuators.



8. Press Ctrl-C to capture the calibration data in the calibration buffer and EEPROM. The calibrated data will then be plotted as a straight line at 0.00 dBm.

9. Press Escape twice and F3 to restart the PLX data sheet.

10. Press the Space bar to calibrate and replot the data. Note that the variation from a straight line at 0.00 dBm is due to noise in our test setup and should be much less than one dBm. This variation will not significantly affect our crystal characterization.

11. Remove the jumper from the crystal socket.

Crystal Data Collection

1. Install the first crystal in the CTF crystal socket.
2. Press Escape to return to Terminal mode and press Scroll Lock and F3 to edit the PLX data sheet. Change entries on page one as follows:

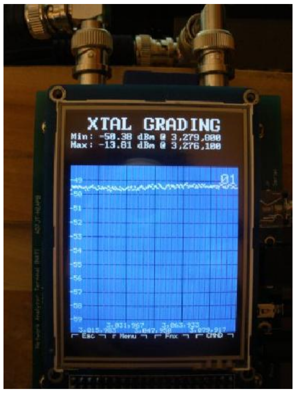
   FREQ LO – 3000
   FREQ HI – 3500
   FREQ ST – 100

   If you are using crystals for a different frequency, adjust the FREQ LO and FREQ HI values accordingly.

   Page two of the PLX data sheet remains the same as set in the calibration process (step 4c).

3. After FREQ ST is entered, pressing the down arrow will cause the ROWS field to be computed and filled in (5001 in this case). Note that this is too many points to all be plotted but that's OK. Press Enter to save the changes.

4. Press F3 to activate the PLX data sheet and the Space bar to run a scan.



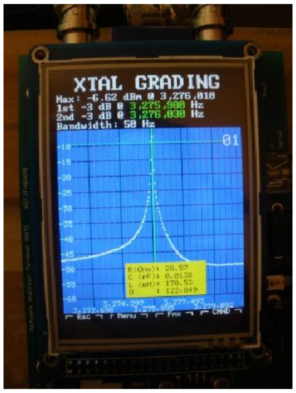
The plot is uninteresting but the Max value frequency (3,276,100) is all we are after here. This is what this scan predicts is the series resonant frequency of this crystal. However, the FREQ ST value of 100 is way too coarse to locate the frequency with sufficient accuracy but it gives us a starting point for the next step.

5. Edit the F3 PLX data sheet as follows:

   a. Use the Home key to clear FREQ LO and FREQ HI.
   b. Set FREQ ST to 10.
   c. Set the ROWS to 1001.
   d. Set CENTER FREQ to the frequency of the maximum found in step 13 (3276.100 in this case).
   e. Press the down arrow to have the firmware compute and fill in FREQ LO and FREQ HI.

   f. Press Enter to save the changes.

6. Press F3 to activate the PLX data sheet and press the Space bar to run a scan.



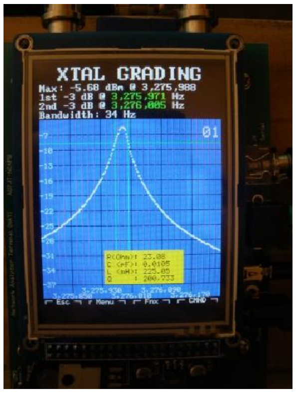
   Note the Max frequency for this scan (3,276.010).

7. Edit the F3 PLX data sheet as follows:

   a. Use the Home key to clear FREQ LO and FREQ HI.
   b. Set FREQ ST to 1.
   c. Set the ROWS to 481.
   d. Set CENTER FREQ to the frequency of the maximum found in step 6 (3276.010 in this case).
   e. Press the down arrow to have the firmware compute and fill in FREQ LO and FREQ HI.

   f. Press Enter to save the changes.

8. Press F3 to activate the PLX data sheet and press the Space bar to run a scan.

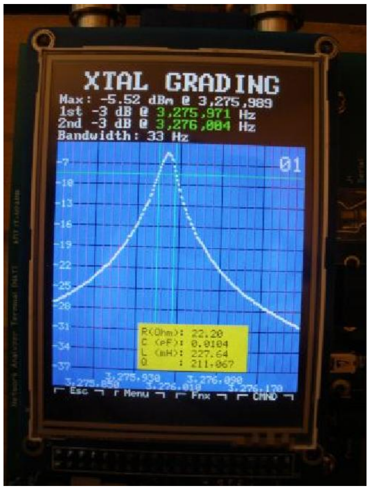


The band pass curve should now be pretty much centered in the plot area. Now we are ready to start characterizing our batch of crystals. Note that we have setup our frequency range based on a single crystal. If you find crystals too far outside this frequency range, you may want to adjust the center frequency to accommodate them and then restart the characterization process.

9. Edit the PLX data sheet by setting the FILE NAME field to "X.CSV" on page. You may also want to enable overwriting an existing file (W op mode) to make it easier to restart if your characterization process in interrupted (to, for example, change the center frequency).

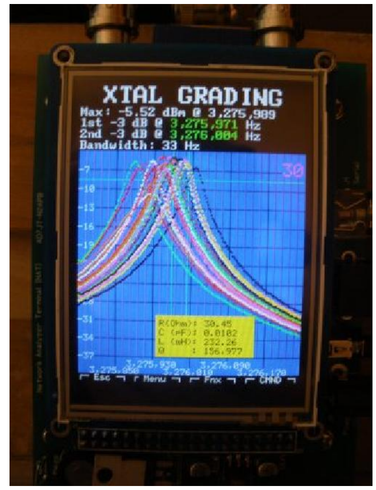
10. With the first crystal still in the CTF, press F3 to activate the PLX data sheet.

11. Press the Space bar to run the scan and record the data.



After the first pass

After pass 15 (half done)



After pass 30 (all done)

12. After the BEEP, replace the crystal in the CTF with the next crystal in the batch.
13. Perform steps 11 and 12 for every crystal in the batch. Note that the information in the yellow box is for the last frequency scan. The information at the top of the display (Max, 1st, 2nd, and Bandwidth) are always for the first scan which is used to scale and render the basic plot screen.
14. The combined plot gives a visual indication of how varied some of the crystal parameters are. My batch of 30 seems to be pretty good. Even though the crystal I chose to set up the sweep parameters was at the high end of the frequency range, the range is so limited; all the crystals could be plotted. I should get several usable groups of six crystals out of this batch.
15. Press Escape to close the data file and go to Terminal mode. The pertinent data is now contained in the SD card file X.CSV.

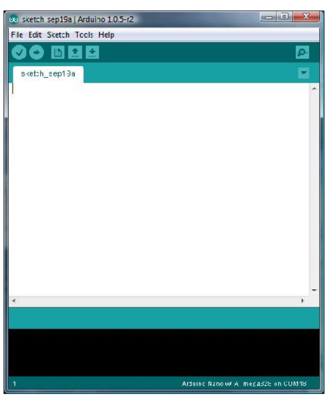
Data Sorting and Matching

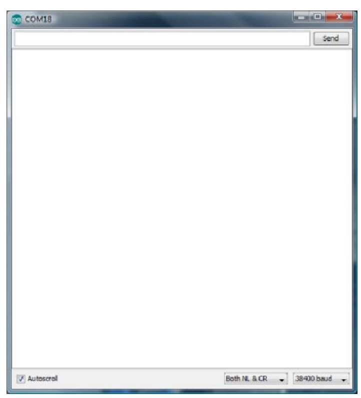
Now we want to sort the data and find the six crystals with the smallest spread of serial resonance frequencies. To do this we will enter the data in an Excel spreadsheet. We have a few options for transferring data from the SD card to a PC:

- List the data with a DOS TYPE command and hand key it into a spread sheet (not my favorite option).
- Plug the SD card into a PC with an SD card connector and open the X.CSV file in a spread sheet.
- Use the DOS UP Load File command (UPLF X.CSV) to transfer the data to a terminal emulator running on the PC and cut and paste the data into a spread sheet.

We will use the last option and will use the Arduino Serial Monitor for the terminal emulator.

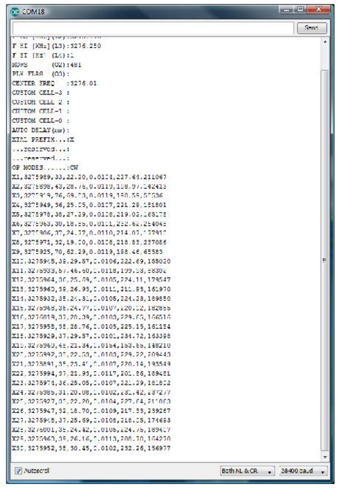
1. Connect the NACT serial interface to a port on the PC.
2. Start the Arduino environment (IDE).
3. If necessary, use the Tools -> Serial Port to select the port the NACT serial interface is on.
4. Start the Arduino Serial Monitor (Ctrl+Shift+M); it is not necessary to load a sketch. Make sure the NACT serial interface baud rate and the terminal emulator baud rates are the same (I am using 38400 bps here).

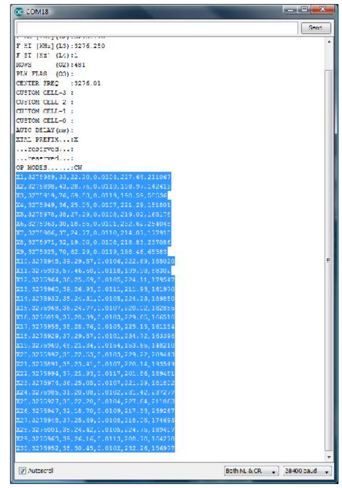




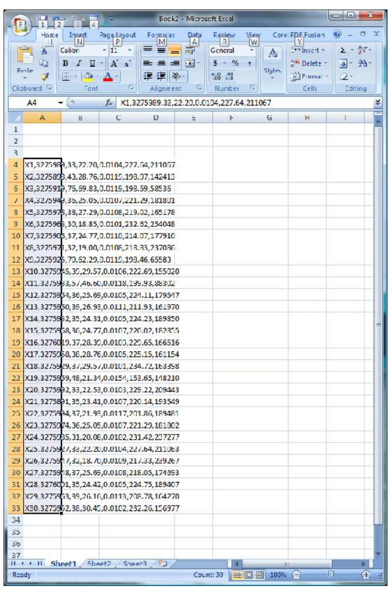
5. With the NACT in Terminal mode, press and release Scroll Lock and press Escape to enter DOS mode.

6. Enter “UPLF X.CSV” on the prompt line and press Enter to execute the command. The total contents of the X.CSV file will be displayed in the Serial Monitor window. We are only interested in the data rows so select them by highlighting them in the Serial Monitor window and press Ctrl-C to copy them to the clipboard.

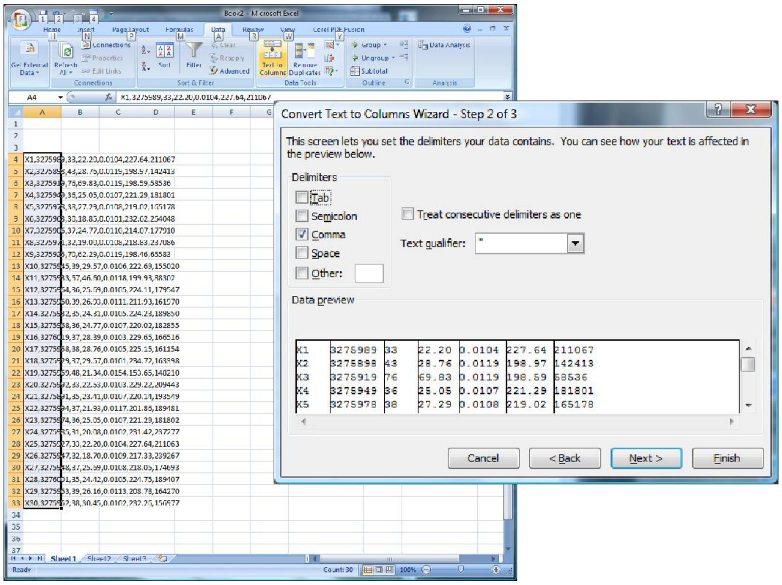




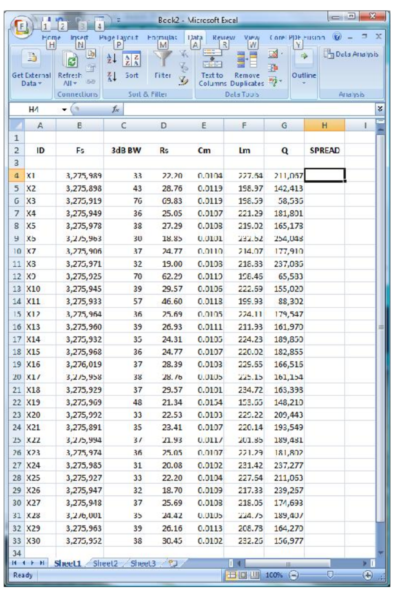
7. Open Excel with a blank spread sheet and paste the data rows to the first column starting at row 4.



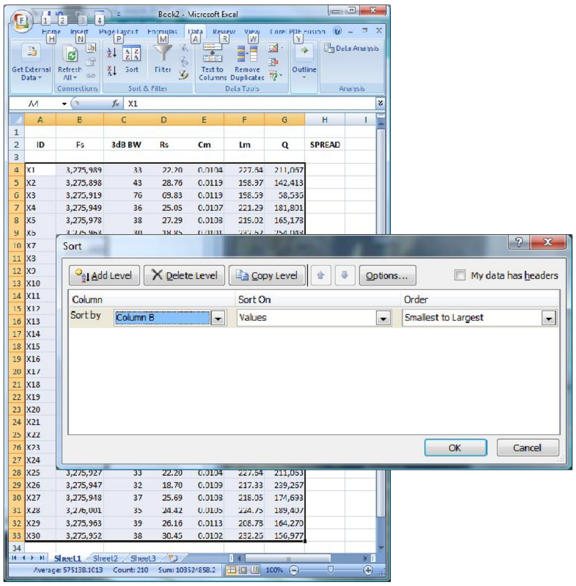
8. With the data selected, convert the data rows to columns using Excel's Convert Text to Columns Wizard. At the first step select "Delimited" and at the second step select Comma as the delimiter and click the Finish button.

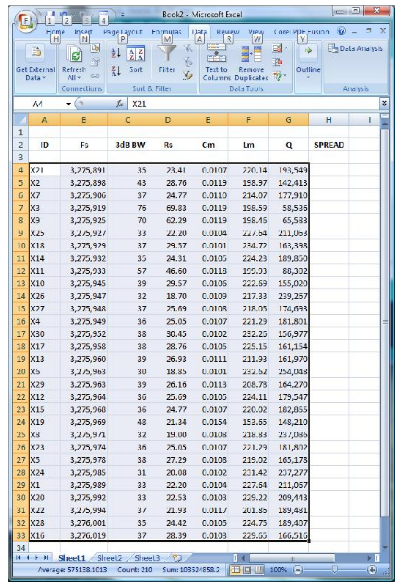


9. Observe the data is now in columns. If desired, add column headings and do whatever data formatting you want (fixed number of decimal digits, thousands separator, etc.).

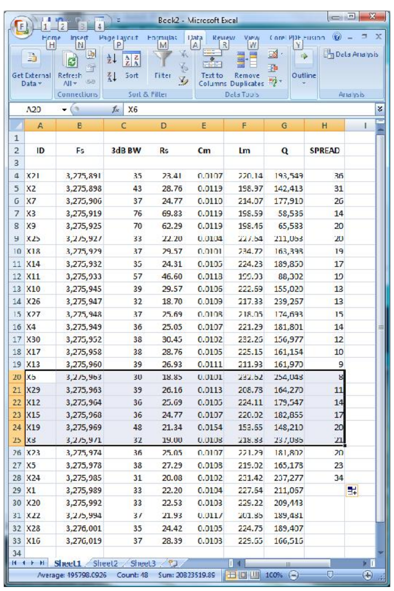


10. Select the data rows and Use the Data -> Sort function to sort the data rows in order of increasing serial resonance frequency (column B).



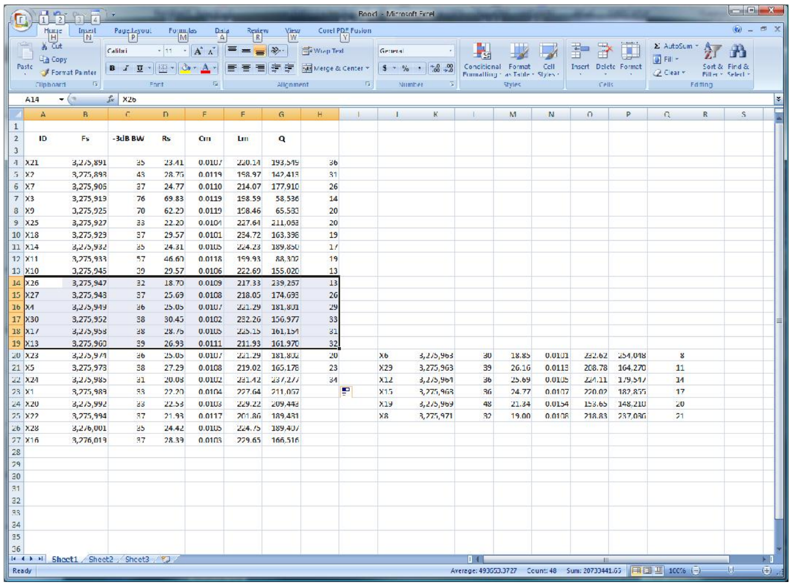


11. In the column I labeled “SPREAD” (H) enter a formula that computes the frequency difference between this row and one five rows down (e.g., H4 = B9-B4). This will give the frequency spread for each row and the next five rows.



12. The best group of six crystals for my Measurement Receiver crystal filter is the group of six crystals starting on row 20: X6, X29, X12, X15, X19 and X8. This group of crystals has a frequency spread of only 8 Hz!

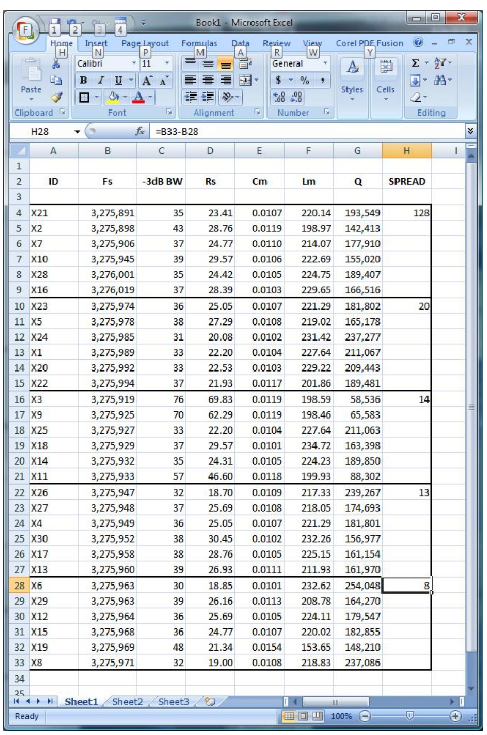
13. To find other usable groups of crystals, remove the six best from the list, redo the SPREAD equation and look for the next lowest frequency spread.



ID	Fs	-3dB BW	Rs	Cm	Lm	Q	
X21	3,275,891	35	23.41	0.0107	220.14	193,549	36
X2	3,275,898	43	28.76	0.0119	198.97	142,413	31
X7	3,275,906	37	24.77	0.0110	214.07	177,910	26
X3	3,275,919	76	69.83	0.0119	198.59	58,536	14
X9	3,275,925	70	62.29	0.0119	198.46	65,583	20
X25	3,275,927	33	22.20	0.0104	227.64	211,063	20
X18	3,275,929	37	29.57	0.0101	234.72	163,398	19
X14	3,275,932	35	24.31	0.0105	224.23	189,850	17
X11	3,275,933	57	46.60	0.0118	199.93	88,302	19
X10	3,275,945	39	29.57	0.0106	222.69	155,020	13
X26	3,275,947	32	18.70	0.0109	217.33	239,267	13
X27	3,275,948	37	25.69	0.0108	218.05	174,693	26
X4	3,275,949	36	25.05	0.0107	221.29	181,801	29
X30	3,275,952	38	30.45	0.0102	232.26	156,977	33
X17	3,275,958	38	28.76	0.0105	225.15	161,154	31
X13	3,275,960	39	26.93	0.0111	211.93	161,970	32
X23	3,275,974	36	25.05	0.0107	221.29	181,802	20
X5	3,275,978	38	27.29	0.0108	219.02	165,178	23
X24	3,275,985	31	20.08	0.0102	231.42	237,277	34
X1	3,275,989	33	22.20	0.0104	227.64	211,067	
X20	3,275,992	33	22.53	0.0103	229.22	209,443	
X22	3,275,994	37	21.93	0.0117	201.86	189,431	
X28	3,276,001	35	24.42	0.0105	224.75	189,407	
X16	3,276,019	37	28.39	0.0103	229.65	166,516	

X6	3,275,963	30	18.85	0.0101	232.62	254,048	8
X29	3,275,963	39	26.16	0.0113	208.78	164,270	11
X12	3,275,964	36	25.69	0.0105	224.11	179,547	14
X15	3,275,968	36	24.77	0.0107	220.02	182,855	17
X19	3,275,969	48	21.34	0.0154	153.65	148,210	20
X8	3,275,971	32	19.00	0.0108	218.83	237,086	21

14. This time we have a group with a frequency spread of 13 Hz. Still not too bad. If you want, continue this process until all five groups of six crystals are identified and ordered by frequency spreads. In my crystal collection there are four groups of six crystals with frequency spreads of 20 Hz or less.



ID	Fs	-3dB BW	Rs	Cm	Lm	Q	SPREAD
X21	3,275,891	35	23.41	0.0107	220.14	193,549	128
X2	3,275,898	43	28.76	0.0119	198.97	142,413	
X7	3,275,906	37	24.77	0.0110	214.07	177,910	
X10	3,275,945	39	29.57	0.0106	222.69	155,020	
X28	3,276,001	35	24.42	0.0105	224.75	189,407	
X16	3,276,019	37	28.39	0.0103	229.65	166,516	
X23	3,275,974	36	25.05	0.0107	221.29	181,802	20
X5	3,275,978	38	27.29	0.0108	219.02	165,178	
X24	3,275,985	31	20.08	0.0102	231.42	237,277	
X1	3,275,989	33	22.20	0.0104	227.64	211,067	
X20	3,275,992	33	22.53	0.0103	229.22	209,443	
X22	3,275,994	37	21.93	0.0117	201.86	189,481	
X3	3,275,919	76	69.83	0.0119	198.59	58,536	14
X9	3,275,925	70	62.29	0.0119	198.46	65,583	
X25	3,275,927	33	22.20	0.0104	227.64	211,063	
X18	3,275,929	37	29.57	0.0101	234.72	163,398	
X14	3,275,932	35	24.31	0.0105	224.23	189,850	
X11	3,275,933	57	46.60	0.0118	199.93	88,302	
X26	3,275,947	32	18.70	0.0109	217.33	239,267	13
X27	3,275,948	37	25.69	0.0108	218.05	174,693	
X4	3,275,949	36	25.05	0.0107	221.29	181,801	
X30	3,275,952	38	30.45	0.0102	232.26	156,977	
X17	3,275,958	38	28.76	0.0105	225.15	161,154	
X13	3,275,960	39	26.93	0.0111	211.93	161,970	
X6	3,275,963	30	18.85	0.0101	232.62	254,048	8
X29	3,275,963	39	26.16	0.0113	208.78	164,270	
X12	3,275,964	36	25.69	0.0105	224.11	179,547	
X15	3,275,968	36	24.77	0.0107	220.02	182,855	
X19	3,275,969	48	21.34	0.0154	153.65	148,210	
X8	3,275,971	32	19.00	0.0108	218.83	237,086	