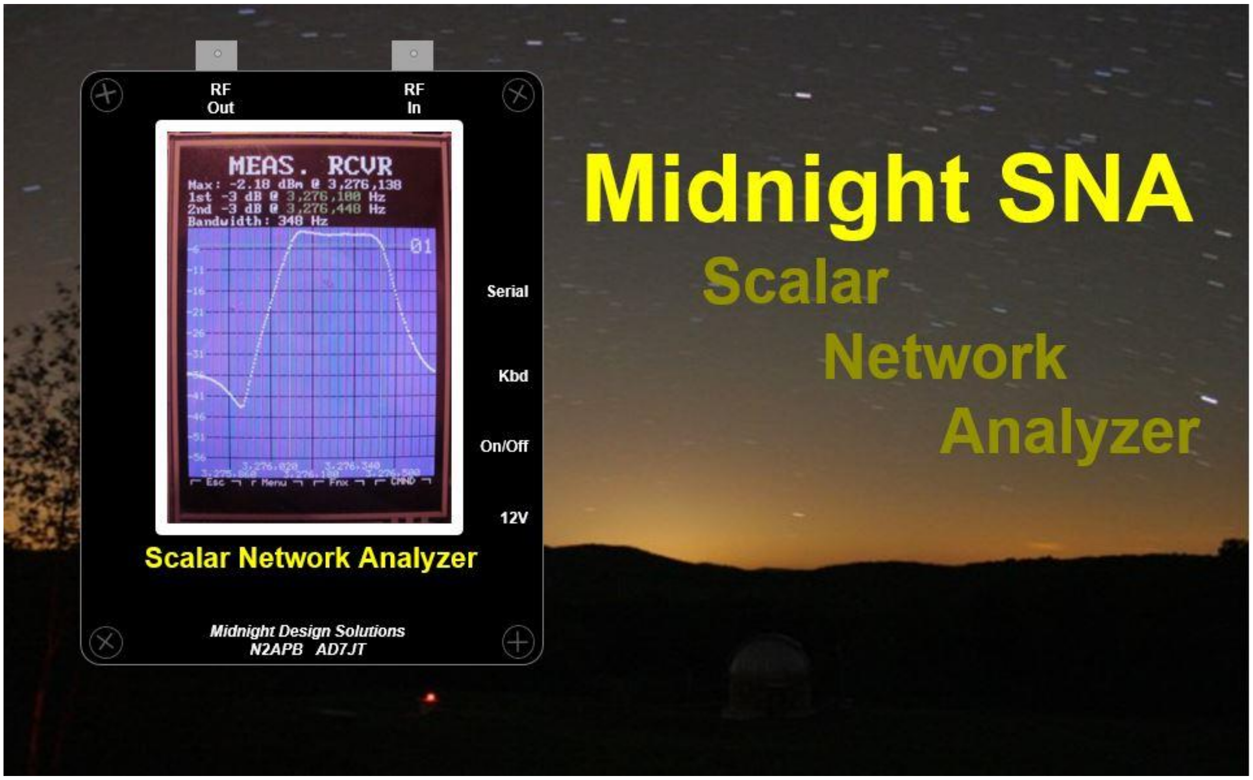


Tutorial M5 - Testing & Grading Crystals

By Dave Collins AD7JT
10 May 2015

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 filter used as an example here is a 6-crystal filter with a target -3dB band pass of 400 Hz and a center frequency of about 3.277 Hz. As a rule of thumb, the series resonant frequency spread should be less than 10% of the target filter band pass. We will need six crystals with a frequency spread of less than 40 Hz. A batch of 30 crystals are sorted to find the six with the narrowest series resonant frequency spread.

CONTENTS

1. APPLIES TO

All Midnight SNA units running V4.00 firmware or later.

2. PREREQUESITES

The MSNA must be calibrated per Tutorial M1.

3. ADDITIONAL REQUIREMENTS

In addition to the MSNA, the following will be needed to complete this tutorial:

1. Two short lengths of 50-ohm coax to connect RF OUT and RF IN to the device under test (DUT).
2. Crystal test fixture to match impedances and reduce drive to the crystal being tested.
3. A PC running Windows and Excel or the equivalent.

   and

   A USB to serial adapter interface and a terminal emulation application capable of transferring text files from the serial interface to mass storage (e.g., the HDD).

   or

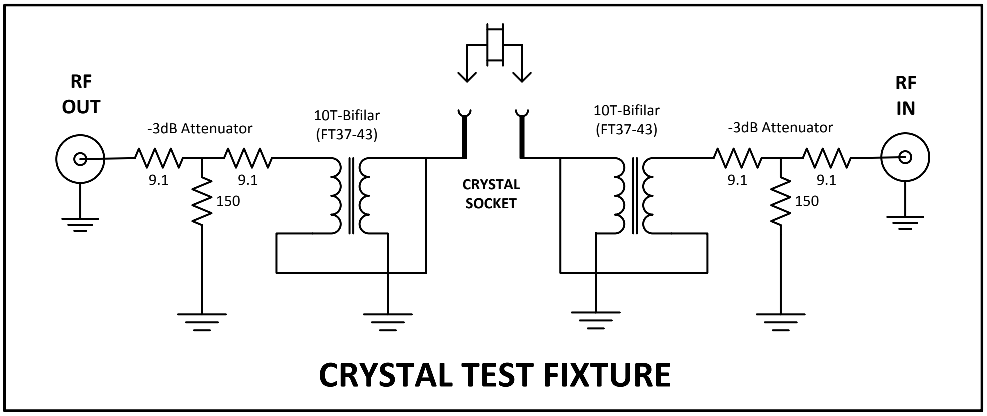
   An SD card reader.

4. CRYSTAL TEST FIXTURE (CTF)

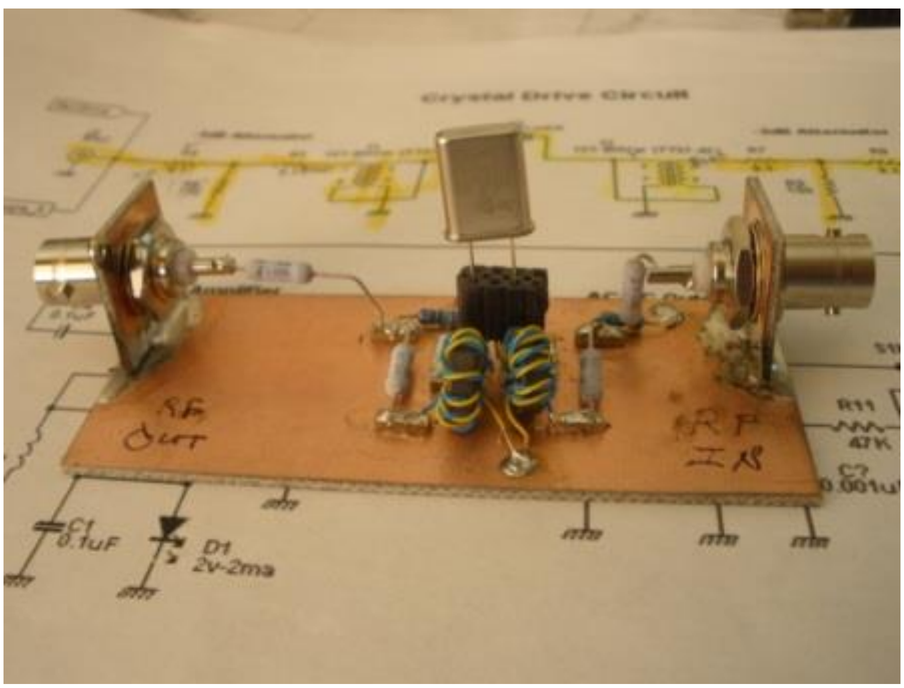
The following describes a CTF that may be used for this tutorial. This CTF is based on the Crystal Drive Circuit designed by Jim Kortge, K8IQY, details can be found online at:

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.



5. CRYSTAL IDENTIFICATION

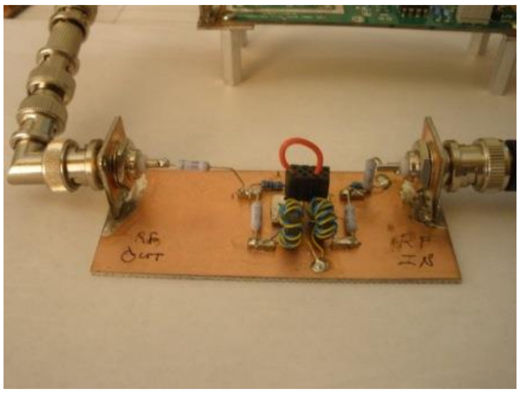
For this tutorial we are going to characterize a batch of 30 crystals. Each data set is individually recorded and is the result of a single frequency sweep with the associated crystal plugged into the CTF. Each data set consists of seven, comma-separated, fields and is terminated by a Carriage Return.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

1. Data set/crystal ID.
2. Series resonance frequency in Hz.
3. -3dB bandwidth in Hz.
4. Rs - Series resistance in ohms to two decimal places
5. Cm - Motional capacitance in picofarads to four decimal places
6. Lm – Motional inductance in millihenries to two decimal places
7. 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 macro 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.

6. PART 1 - CRYSTAL TEST FIXTURE CALIBRATION

1. Connect the CTF to the MSNA RF OUT and RF IN connectors with the two short coax cables.
2. Install a jumper in the crystal socket to short the two pins together.



3. Power on all components.
4. Press ALT-C to clear the calibration data buffer and EEPROM area.
5. Press SCROLL-LOCK > R to edit the roll-off power level.
6. Edit the roll-off power level and set it to 3.
7. Press ENTER to save the roll-off power level
8. Create a macro data sheet as follows:
    a. Press SCROLL-LOCK > F_3 to display the data entry form
    b. Set up the F_3 macro data sheet to cover a frequency range of about 1 MHz surrounding the frequency of interest (3.277 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:

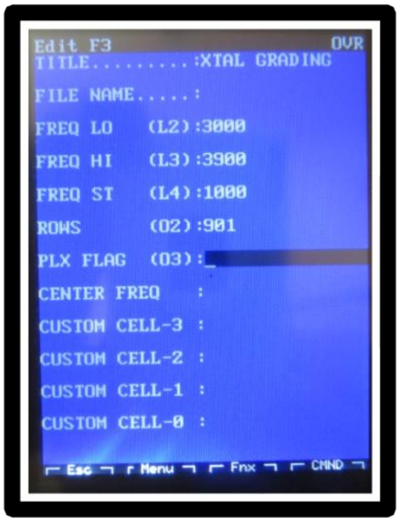
       TITLE .... **XTAL GRADING**
       FILE NAME .... leave blank for now
       FREQ LO **3000**
       FREQ HI **3900**
       FREQ ST.................. **1000**
       ROWS **901**
       leave the rest of page one blank and press PAGE DOWN to display page two

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

page two:

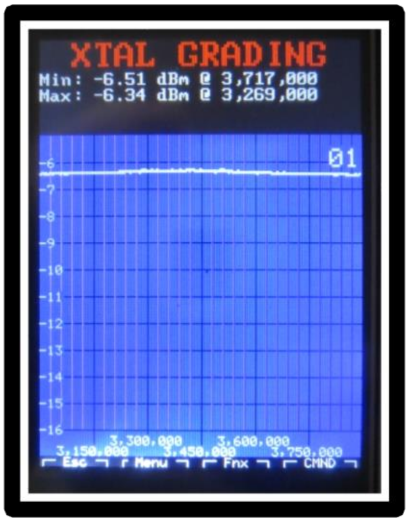
XTAL PREFIX .... **X**
leave the rest of page two blank.

c. Press ENTER to save the data sheet to EEPROM and return to Terminal mode.

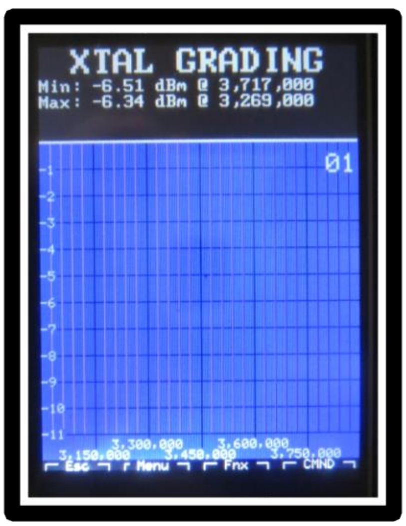


9. Press F3 to start the macro.

10. Press the SPACE bar to run the frequency scan. After the scan, the results will be plotted. This relatively straight line shows the insertion loss for the CTF which is mainly due to the two 3dB attenuators.

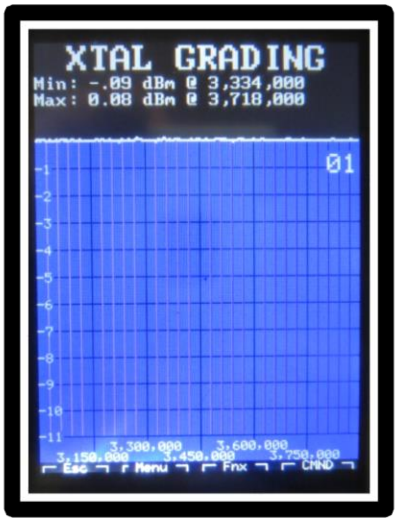


11. Press CONTROL-C to capture the calibration data in the calibration buffer and EEPROM. The calibrated data will then be plotted as a straight line at 0.00 dBm.



12. Press ESCAPE twice and then press F3 to restart the macro.

13. Press the SPACE bar to record and plot 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.



14. Press ESCAPE to terminate the macro and return to Terminal mode.

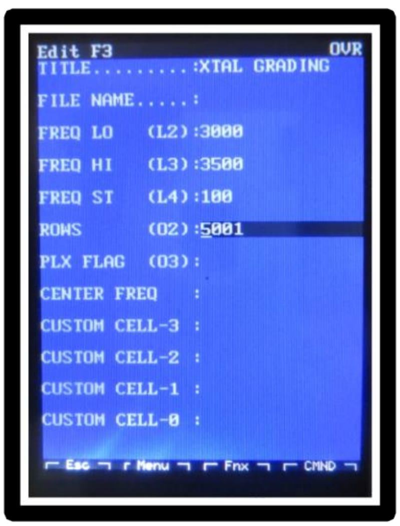
15. Remove the jumper from the crystal socket.

7. CRYSTAL DATA COLLECTION

1. Install the first crystal in the CTF crystal socket.
2. Press SCROLL-LOCK > F_3 to edit the macro data sheet. Change entries on page one as follows in the order shown:

   ROWS...........................blank (select and press HOME)
   FREQ LO......................**3000**
   FREQ HI.......................**3500**
   FREQ ST.......................**100**
   leave the rest of page one the same as set in the calibration process (step 8c).

   After FREQ ST is entered, 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.

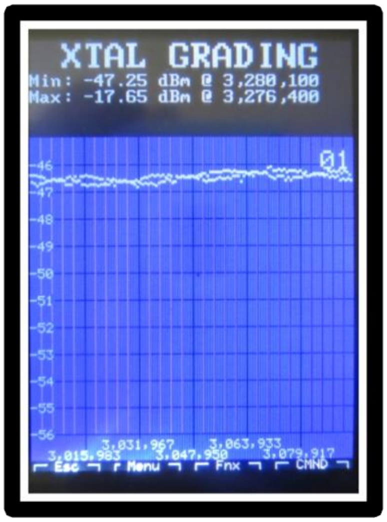
   

   If you are using crystals of a different frequency, adjust the FREQ LO and FREQ HI values accordingly.

   Page two of the macro data sheet remains the same as set in the calibration process (step 8c).

3. Press ENTER to save the changes and return to Terminal mode.

4. Press F_3 to start the macro and press the SPACE bar to run a scan.

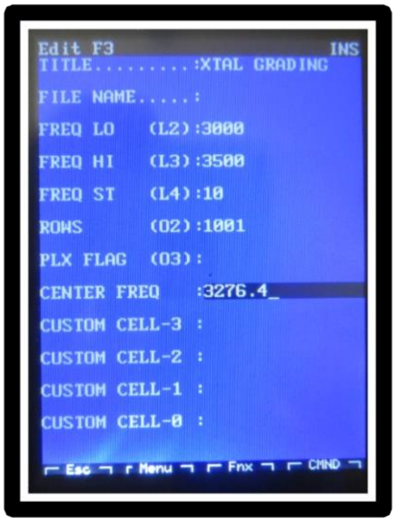


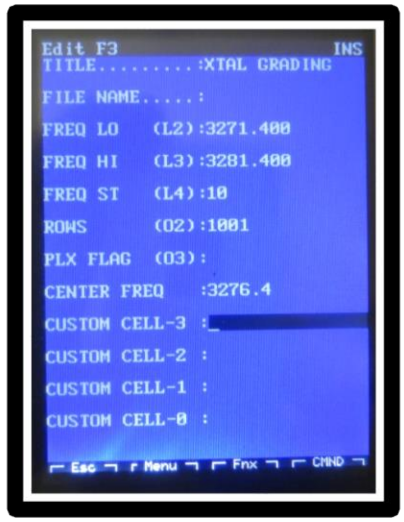
This plot is uninteresting but the Max value frequency (3,276,400) is all we are after here. This is what this scan predicts is the series resonant frequency of this crystal. However, the FREQ ST value of 100 is way too coarse to locate the frequency with sufficient accuracy but it gives us a starting point for the next step.

5. Press ESCAPE to stop the macro and return to Terminal mode.
6. Press SCROLL-LOCK > F_3 then edit the macro data sheet as follows in the order shown:

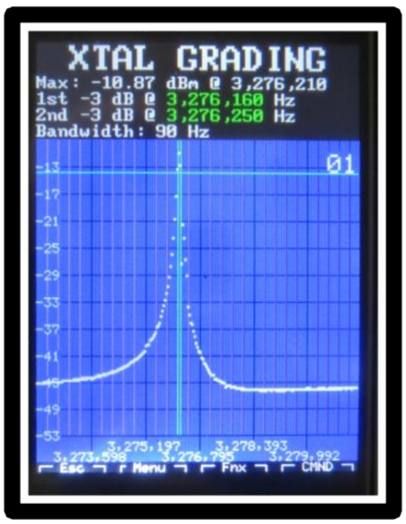
FREQ ST....................**10**
ROWS........................**1001**
CENTER FREQ ....the Max frequency from step 4 (**3276.4** in this case).

Press the DOWN AROW to have the firmware compute and fill in FREQ LO and FREQ HI.





7. Press ENTER to save the changes and return to Terminal mode.
8. Press F3 to start the macro and press the Space bar to run a scan.



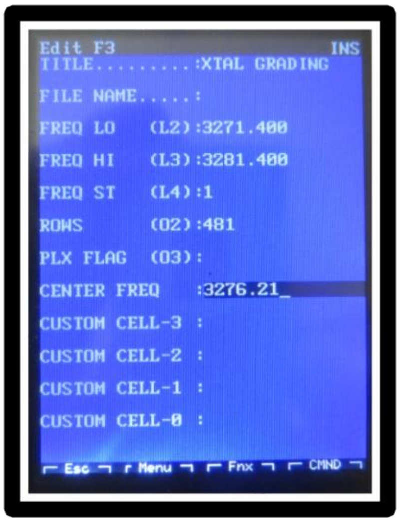
Note the Max frequency for this scan (3,276,210).

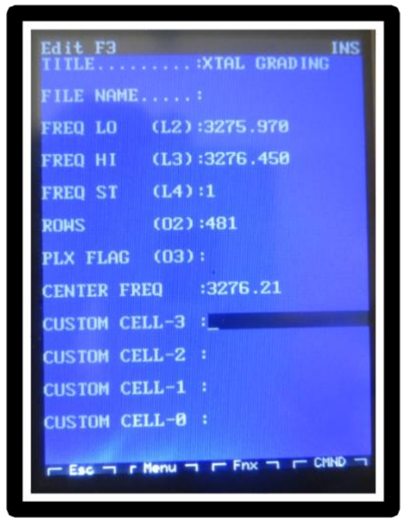
9. Press ESCAPE to terminate the macro and return to Terminal mode.

10. Press SCROLL-LOCK > F_3 then edit the macro data sheet as follows in the order shown:

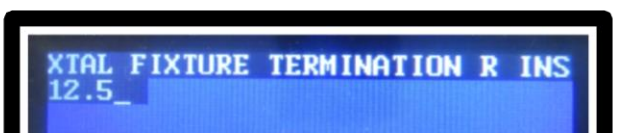
    FREQ ST....................**1**
    ROWS........................**481**
    CENTER FREQ ....the Max frequency from step 8 (**3276.21** in this case).

    Press the down arrow to have the firmware compute and fill in FREQ LO and FREQ HI.

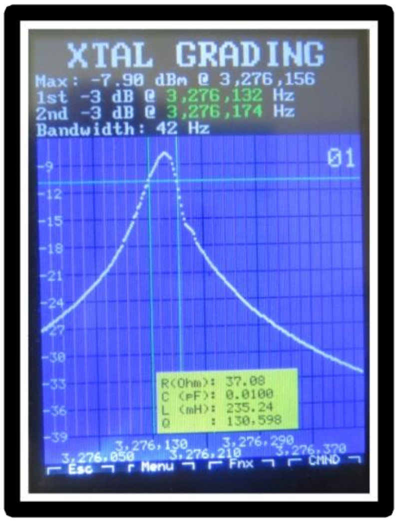




11. Press ENTER to save the changes and return to Terminal mode.
12. Enter SCROLL-LOCK > X to edit the CTF termination resistance.
13. Enter 12.5 and press ENTER to save it and return to Terminal mode.



14. Press F_3 to start the macro and press SPACE to run a scan.



The band pass curve should 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.

a. Press SCROLL-LOCK > F_3 then edit the macro data sheet as follows:

   FILE NAME ....**X.CSV**

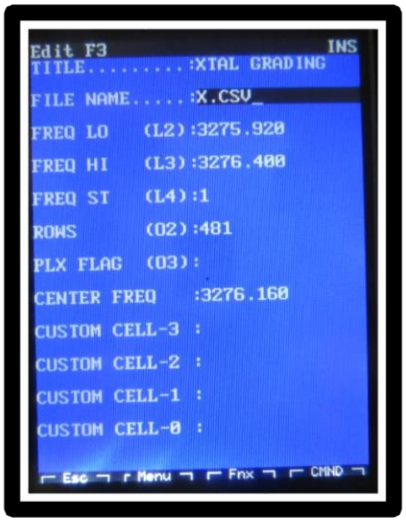
   leave the rest of the page unchanged

b. Press PAGE DOWN to edit page two and add the following:

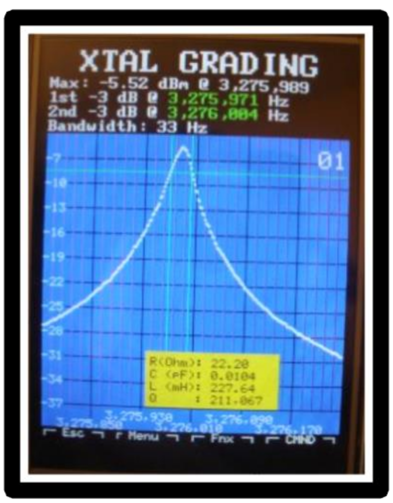
   OP MODES ....**W**

   leave the rest of the page unchanged

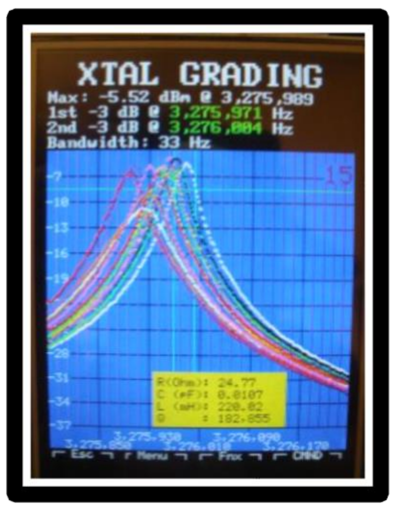
c. Press ENTER to save the changes and return to Terminal mode.



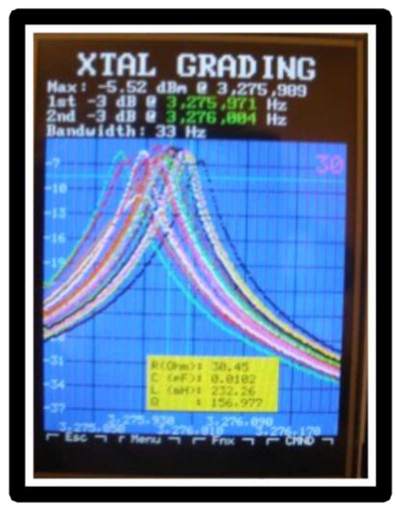
15. With the first crystal still in the CTF, press F_3 to start the macro.
16. Press SPACE to run the scan and record the data.
17. After the BEEP, replace the crystal in the CTF with the next crystal in the batch.
18. Perform steps 16 and 17 for every crystal in the batch. Note that the information 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.



After the first pass



After pass 15 (half done)



After pass 30 (all done)

19. 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.

20. Press ESCAPE to close the data file and return to Terminal mode. The pertinent data is now contained in the SD card file X.CSV.

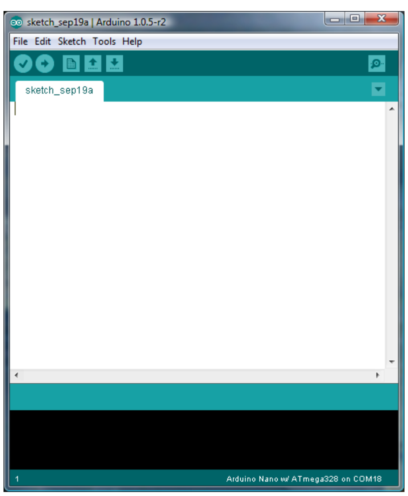
8. DATA SORTING AND MATCHING

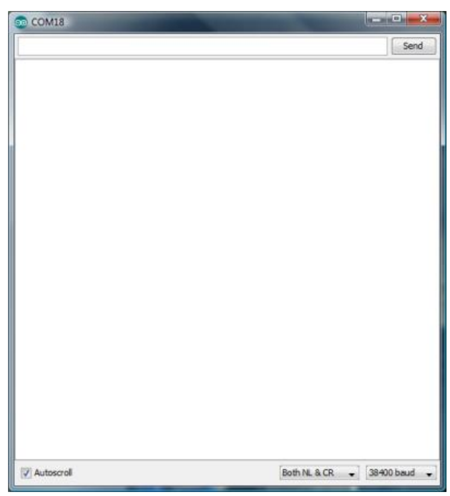
Now we want to sort the data and find the six crystals with the smallest spread of serial resonance frequencies. To do this we will enter the data in an Excel spread-sheet. We have a few options for transferring data from the SD card to a PC:

1. List the data with a DOS TYPE command and hand key it into a spread sheet (not my favorite option).
2. Plug the SD card into a PC with an SD card reader and open the X.CSV file in a spread sheet.
3. 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 (my favorite option).

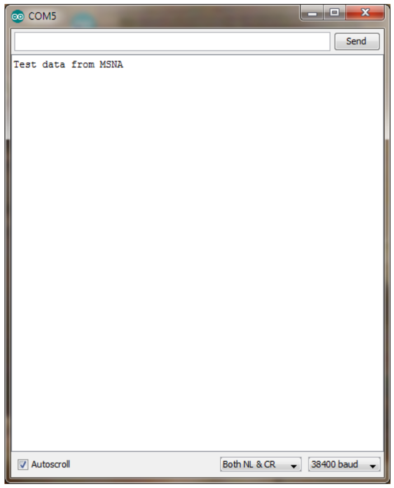
We will use the last option and will use the Arduino Serial Monitor for the terminal emulator.

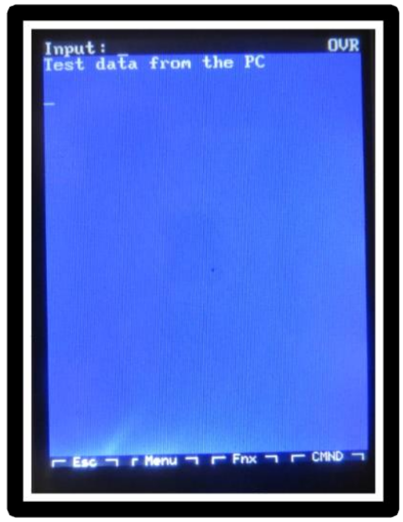
1. Connect the MSNA serial interface to a port on the PC.
2. Start the Arduino environment (IDE).
3. If necessary, use the Tools > Serial Port to select the port the MSNA serial interface is on.
4. Start the Arduino Serial Monitor (Ctrl+Shift+M); it is not necessary to load a sketch. Make sure the MSNA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



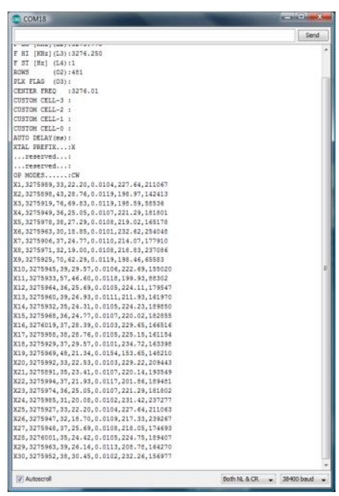


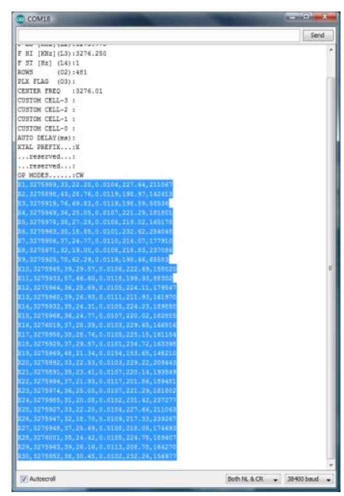
5. Test the connection with the MSNA in terminal mode, anything typed on the input line will be received and displayed by the terminal emulator. Similarly, anything typed on the input line of the terminal emulator will be displayed by the MSNA.



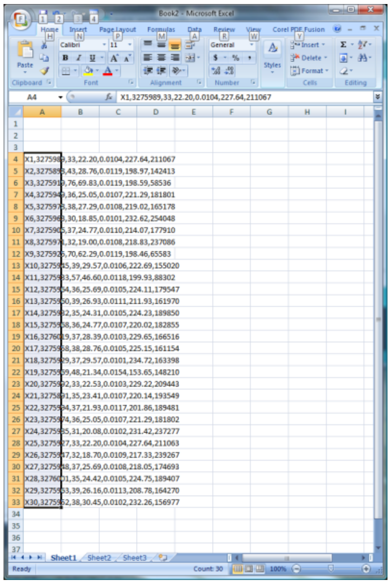


6. With the MSNA in Terminal mode, press and release SCROLL-LOCK and press ESCAPE to enter DOS mode.
7. Enter "**UPLF X.CSV**" on the prompt line and press ENTER to execute the UPLF command.
8. Press ESCAPE to exit DOS mode and return to Terminal mode.
9. The total contents of the X.CSV file will be displayed in the terminal emulator 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.

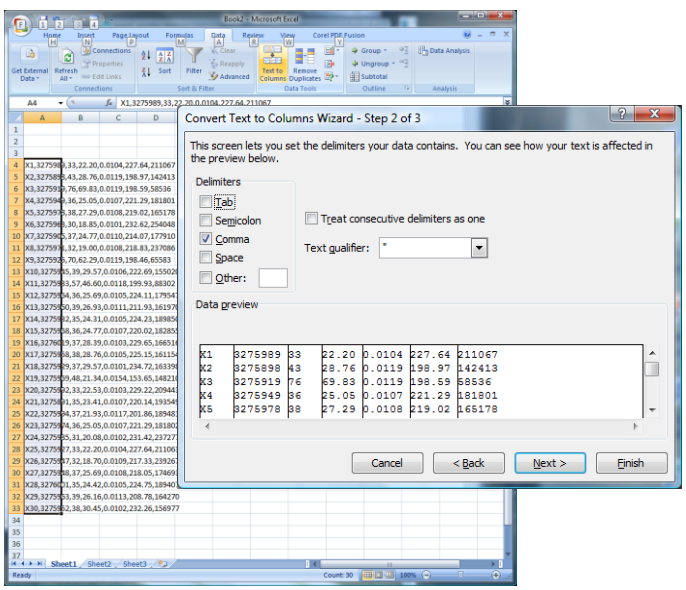




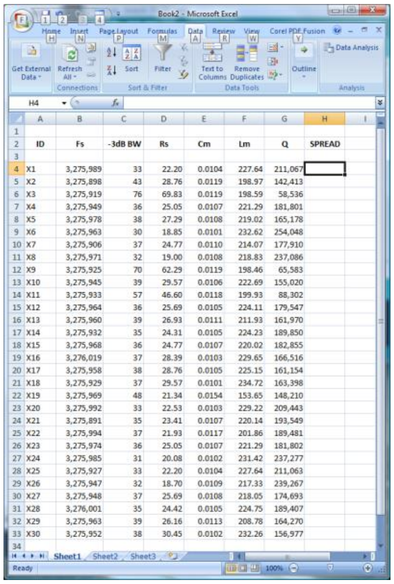
10. Open Excel with a blank spread sheet and paste the data rows to the first column starting at row 4.



11. 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.

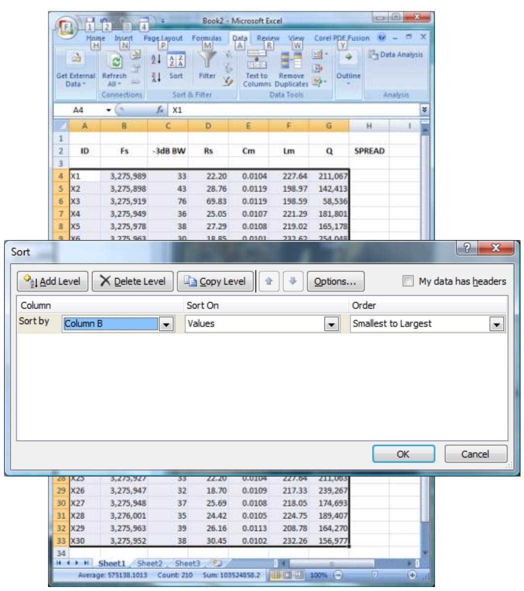


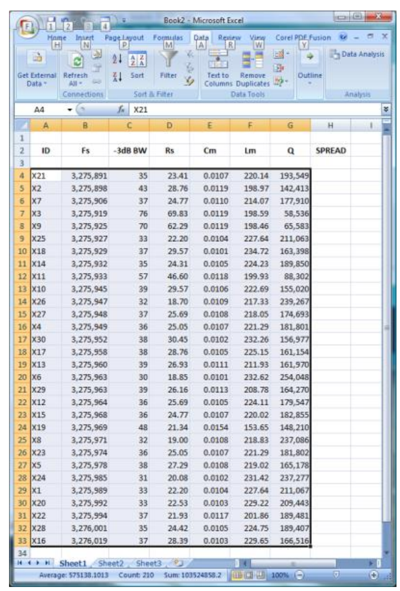
12. Observe the data is now in columns. If desired, add column headings and do whatever data formatting you want (fixed number of decimal digits, thousands separator, etc.).



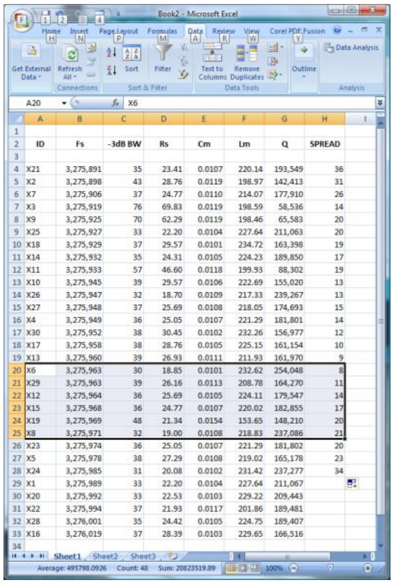
13. Visually scan the data and eliminate any data rows that do not meet your basic criteria. For example, you might want to eliminate all crystals with a Q less than 150,000. Here we left the table intact.

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





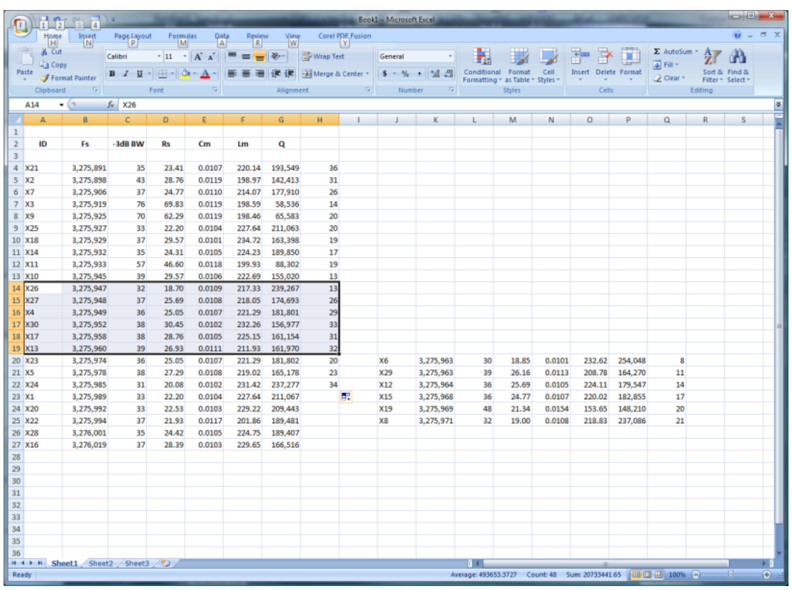
15. In the column I labeled “SPREAD” (H) enter a formula that computes the frequency difference between this row and one five rows down (e.g., H4 = B9-B4). This will give the frequency spread for each row and the next five rows.



ID	Fs	-3dB BW	Rs	Cm	Lm	Q	SPREAD
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	15
X4	3,275,949	36	25.05	0.0107	221.29	181,801	14
X30	3,275,952	38	30.45	0.0102	232.26	156,977	12
X17	3,275,958	38	28.76	0.0105	225.15	161,154	10
X13	3,275,960	39	26.93	0.0111	211.93	161,970	9
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
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	189,481	
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	

16. 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!

17. To find other usable groups of crystals, remove the six best from the list, recalculate (F9) and look for the next lowest frequency spread.



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X21	3,275,891	35	23.41	0.0107	220.14	193,549	36
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X9	3,275,925	70	62.29	0.0119	198.46	65,583	20
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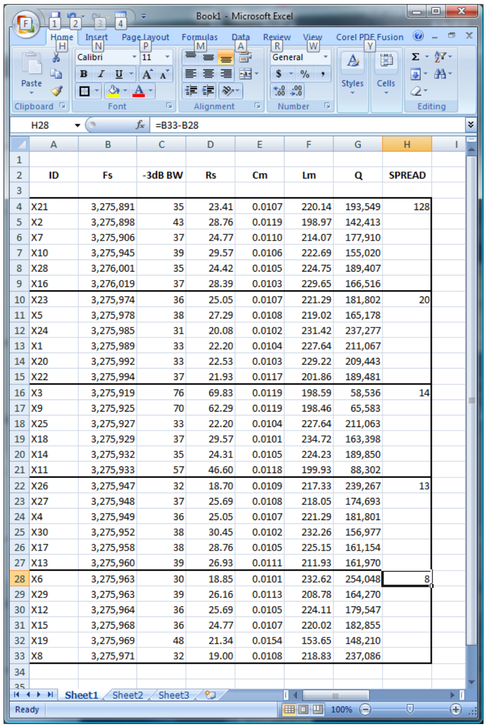
X18	3,275,929	37	29.57	0.0101	234.72	163,398	19
X14	3,275,932	35	24.31	0.0105	224.23	189,850	17
X11	3,275,933	57	46.60	0.0118	199.93	88,302	19
X10	3,275,945	39	29.57	0.0106	222.69	155,020	13
X26	3,275,947	32	18.70	0.0109	217.33	239,267	13
X27	3,275,948	37	25.69	0.0108	218.05	174,693	26
X4	3,275,949	36	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	189,481	
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

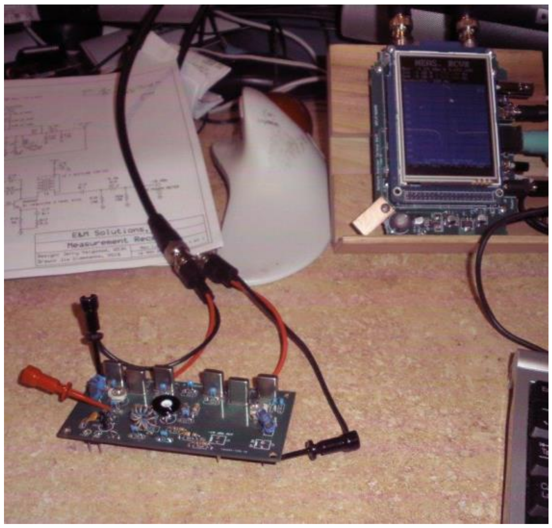
18. This time we have a group with a frequency spread of 13 Hz. Still not too bad. If you want, continue this process until all five groups of six crystals are identified and ordered by frequency spreads. In my crystal collection there are four groups of six crystals with frequency spreads of 20 Hz or less. The fifth group has a frequency spread of 128 and does not qualify for this application.

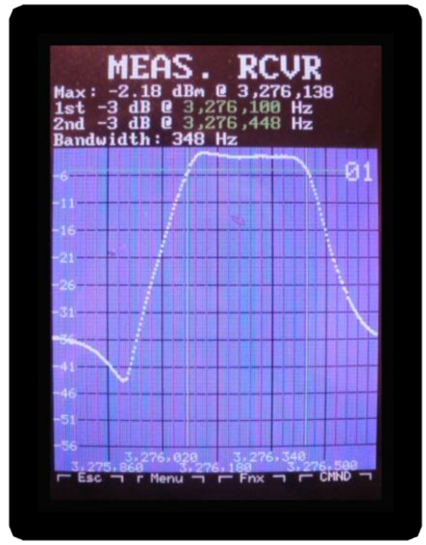


ID	Fs	-3dB BW	Rs	Cm	Lm	Q	SPREAD
X21	3,275,891	35	23.41	0.0107	220.14	193,549	128
X2	3,275,898	43	28.76	0.0119	198.97	142,413	
X7	3,275,906	37	24.77	0.0110	214.07	177,910	
X10	3,275,945	39	29.57	0.0106	222.69	155,020	
X28	3,276,001	35	24.42	0.0105	224.75	189,407	
X16	3,276,019	37	28.39	0.0103	229.65	166,516	
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	

9. RESULTS

The six crystals with an 8 Hz frequency spread were used in a lattice filter with the following results:





Test setup Resulting plot