

# PRECISION FREQUENCY MEASUREMENT, TRANSCEIVER CALIBRATION, AND THE FREQUENCY MEASURING TEST

George, K1IG  
K1IG@arrrl.net

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# ARRL FREQUENCY MEASURING TEST

- Began in 1931
- Twice a year — April and November
- Measure frequencies over the air
- Goal is 1 Hz or better accuracy — measure and report to the nearest 0.01 Hz
- 100 - 130 participants worldwide



# MINIMUM SETUP?





WHAT YOU NEED

# WHAT YOU NEED



Rig

# WHAT YOU NEED



Rig



Computer

# WHAT YOU NEED



Rig

Audio Cable



Computer



# WHAT YOU NEED



These Three Things and Some Free Software  
Get You Measuring Within 1 Hz



# THREE STEP PROCESS

1. Load software and set it up
2. Calibrate your computer
3. Calibrate your rig

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1. Load software and set it up
2. Calibrate your computer
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Total Time = One Hour

# FREE SOFTWARE

## **Windows**

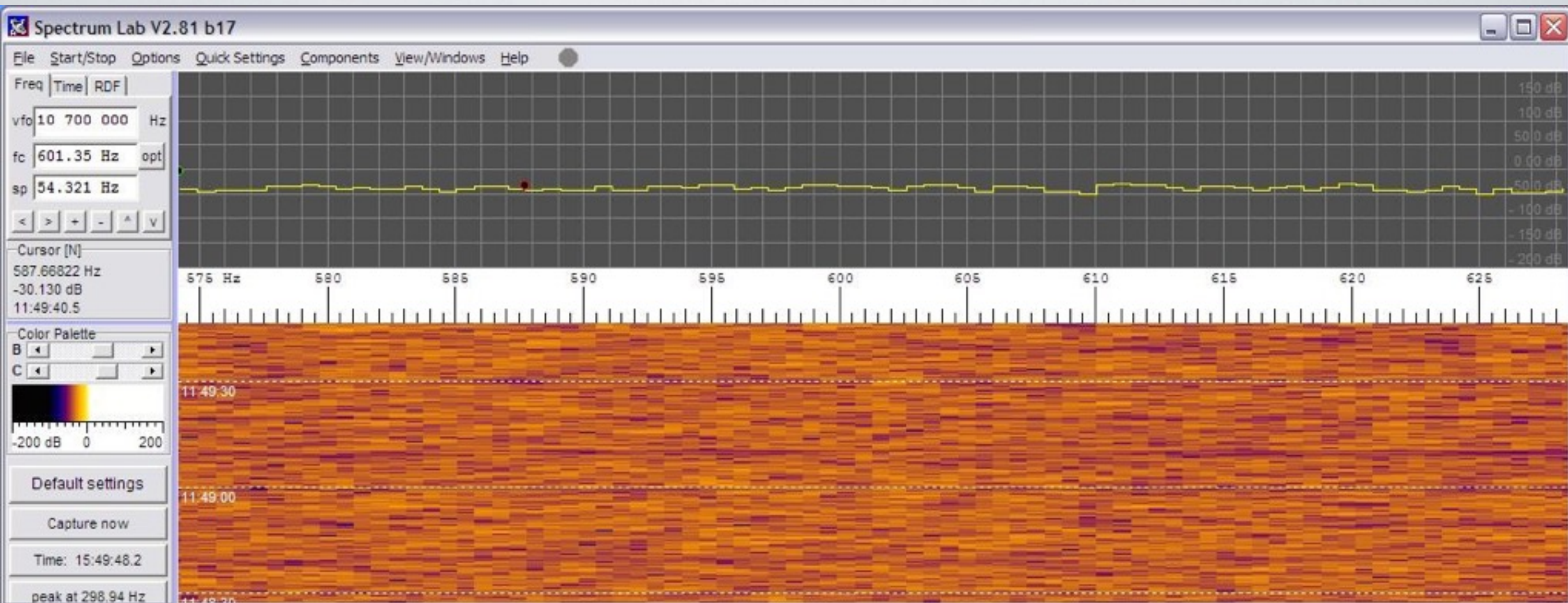
- Spectrum Lab
  - <http://www.qsl.net/dl4yhf/spectral.html>
- Installation tutorial at:
  - <http://www.ve2azx.net/technical/FMT/SpecLabInfo.pdf>

## **Mac/Linux/Windows**

- Fldigi
  - <http://www.w1hkj.com/Fldigi.html>
  - Download, installation and help files on main webpage
- WSPR
  - <http://physics.princeton.edu/pulsar/K1JT/wspr.html>
  - [http://physics.princeton.edu/pulsar/K1JT/FMT\\_User.pdf](http://physics.princeton.edu/pulsar/K1JT/FMT_User.pdf)



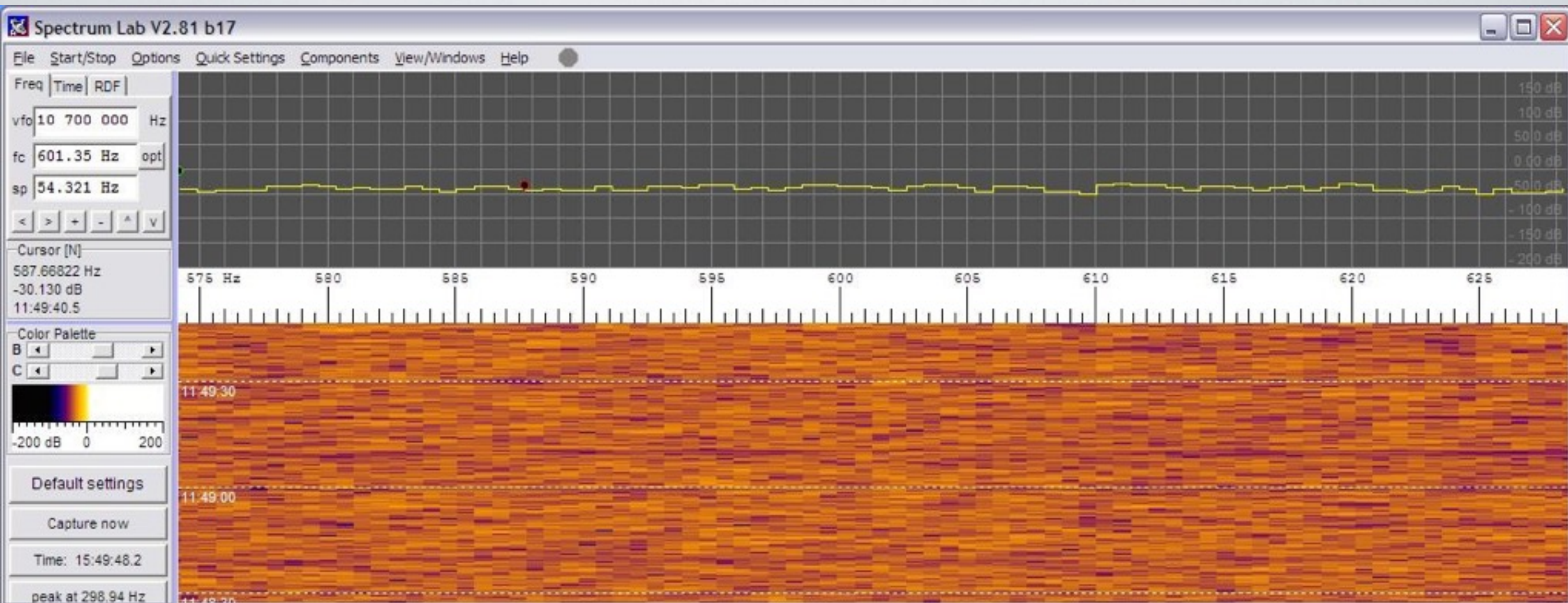
# SPECTRUM LAB



- Very versatile and accurate
- Will run in Linux/Wine or Mac/Parallels at reduced capability

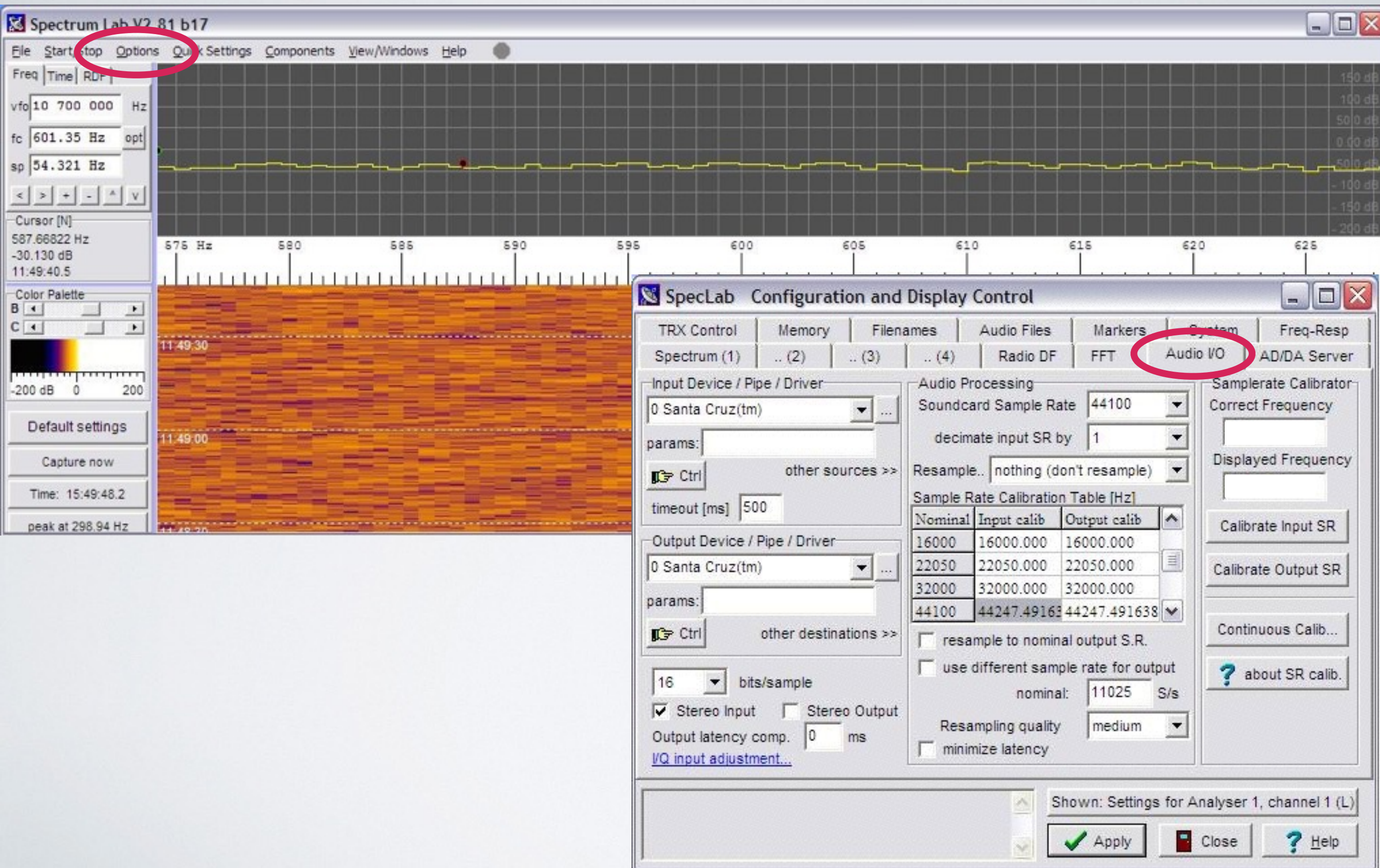


# SPECTRUM LAB SETUP





# SPECTRUM LAB SETUP





# SPECTRUM LAB SETUP

The screenshot shows the Spectrum Lab V2.81 b17 interface. The main window displays a frequency spectrum plot with a yellow line representing the signal. The x-axis is labeled 'Hz' and ranges from 575 to 625. The y-axis is labeled 'dB' and ranges from -200 to 150. The left sidebar contains various controls, including a 'vfo' field set to 10 700 000 Hz, a 'fc' field set to 601.35 Hz, and a 'sp' field set to 54.321 Hz. The 'Cursor [N]' section shows a frequency of 587.66822 Hz and a level of -30.130 dB. The 'Color Palette' section shows a color bar with a scale from -200 dB to 200 dB. The 'Configuration and Display Control' dialog box is open, showing the 'Audio I/O' tab. The 'Input Device / Pipe / Driver' is set to '0 Santa Cruz(tm)'. The 'Output Device / Pipe / Driver' is also set to '0 Santa Cruz(tm)'. The 'Audio Processing' section shows a 'Soundcard Sample Rate' of 44100 and a 'decimate input SR by' of 1. The 'Sample Rate Calibration Table [Hz]' is displayed with columns for 'Nominal', 'Input calib', and 'Output calib'. The 'Resampling quality' is set to 'medium'. The 'System' tab is also visible, showing 'Audio I/O' and 'AD/DA Server' options. A red circle highlights the 'Audio I/O' tab in the dialog box. An arrow points from the text 'Select sound card' to the 'Input Device / Pipe / Driver' dropdown menu.

Spectrum Lab V2.81 b17

File Start Stop Options Quick Settings Components View/Windows Help

Freq Time RDP

vfo 10 700 000 Hz

fc 601.35 Hz opt

sp 54.321 Hz

Cursor [N]

587.66822 Hz

-30.130 dB

11:49:40.5

Color Palette

B

C

-200 dB 0 200

Default settings

Capture now

Time: 15:49:48.2

peak at 298.94 Hz

SpecLab Configuration and Display Control

TRX Control Memory Filenames Audio Files Markers System Freq-Resp

Spectrum (1) .. (2) .. (3) .. (4) Radio DF FFT **Audio I/O** AD/DA Server

Input Device / Pipe / Driver

0 Santa Cruz(tm)

params:

Ctrl other sources >>

timeout [ms] 500

Output Device / Pipe / Driver

0 Santa Cruz(tm)

params:

Ctrl other destinations >>

16 bits/sample

☒ Stereo Input ☐ Stereo Output

Output latency comp. 0 ms

[I/Q input adjustment...](#)

Audio Processing

Soundcard Sample Rate 44100

decimate input SR by 1

Resample.. nothing (don't resample)

Sample Rate Calibration Table [Hz]

Nominal	Input calib	Output calib
16000	16000.000	16000.000
22050	22050.000	22050.000
32000	32000.000	32000.000
44100	44247.49163	44247.491638

☐ resample to nominal output S.R.

☐ use different sample rate for output

nominal: 11025 S/s

Resampling quality medium

☐ minimize latency

Samplerate Calibrator

Correct Frequency

Displayed Frequency

Calibrate Input SR

Calibrate Output SR

Continuous Calib...

? about SR calib.

Shown: Settings for Analyser 1, channel 1 (L)

Apply Close Help

Select sound card



# SPECTRUM LAB SETUP

The main Spectrum Lab window displays a frequency spectrum plot with a yellow line representing the signal. The x-axis ranges from 575 Hz to 625 Hz, and the y-axis ranges from -200 dB to 150 dB. The left sidebar contains various controls including VFO, Fc, Sp, Cursor, and Color Palette. The top menu bar includes File, Start, Stop, Options, Quick Settings, Components, View/Windows, and Help. The 'Quick Settings' menu is circled in red.

The 'SpecLab Configuration and Display Control' dialog box is open, showing the 'Audio I/O' tab. The 'Input Device / Pipe / Driver' is set to '0 Santa Cruz(tm)'. The 'Audio Processing' section shows 'Soundcard Sample Rate' set to 44100. The 'Sample Rate Calibration Table [Hz]' is visible, with the 44100 row highlighted. The 'Output Device / Pipe / Driver' is also set to '0 Santa Cruz(tm)'. The 'Audio I/O' tab is circled in red.

Annotations with arrows point to the 'Input Device / Pipe / Driver' dropdown and the 'Soundcard Sample Rate' dropdown, with the following text:

- Select sound card
- Set Sample Rate to 44100

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Buttons at the bottom of the dialog include Apply, Close, and Help. The status bar at the bottom indicates 'Shown: Settings for Analyser 1, channel 1 (L)'.



# SPECTRUM LAB SETUP

Spectrum Lab V2.81 b17

File Start Stop Options Quick Settings Components View/Windows Help

Freq | Time | RDP

vfo 10 700 000 Hz

fc 601.35 Hz opt

sp 54.321 Hz

Cursor [N]  
587.66822 Hz  
-30.130 dB  
11:49:40.5

Color Palette  
B  
C

Default settings  
Capture now  
Time: 15:49:48.2  
peak at 298.94 Hz

SpecLab Configuration and Display Control

TRX Control Memory Filenames Audio Files Markers System Freq-Resp

Spectrum (1) .. (2) .. (3) .. (4) Radio DF FFT **Audio I/O** AD/DA Server

Input Device / Pipe / Driver  
0 Santa Cruz(tm)

params:  
Ctrl other sources >>

timeout [ms] 500

Output Device / Pipe / Driver  
0 Santa Cruz(tm)

params:  
Ctrl other destinations >>

16 bits/sample  
☒ Stereo Input ☐ Stereo Output  
Output latency comp. 0 ms  
[I/Q input adjustment...](#)

Audio Processing  
Soundcard Sample Rate 44100  
decimate input SR by 1  
Resample.. nothing (don't resample)  
Sample Rate Calibration Table [Hz]

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☐ resample to nominal output S.R.  
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nominal: 11025 S/s  
Resampling quality medium  
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Samplerate Calibrator  
Correct Frequency  
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Calibrate Input SR  
Calibrate Output SR  
Continuous Calib...  
? about SR calib.

Shown: Settings for Analyser 1, channel 1 (L)

Apply Close Help

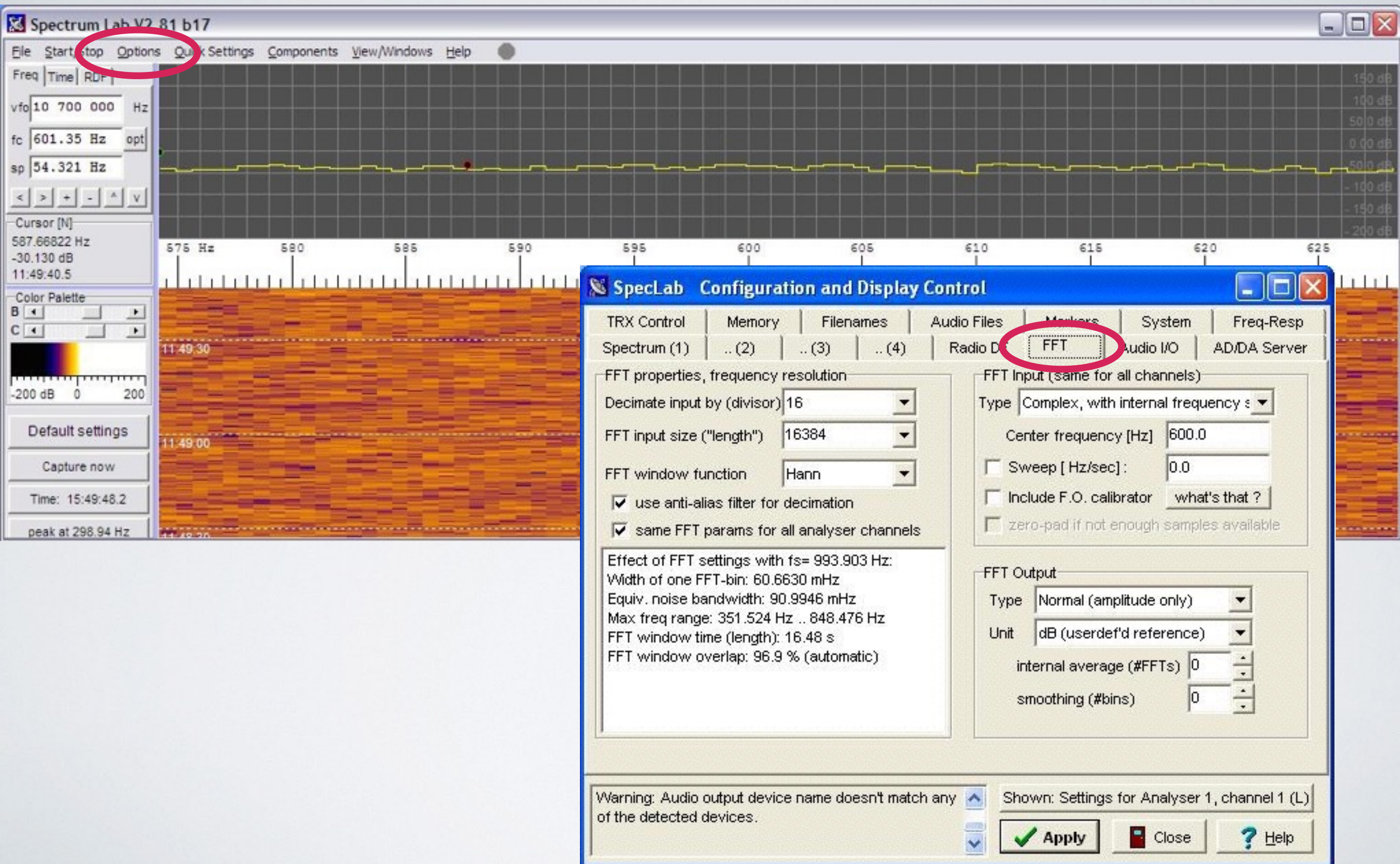
Select sound card

Set Sample Rate to 44100

Hit Apply

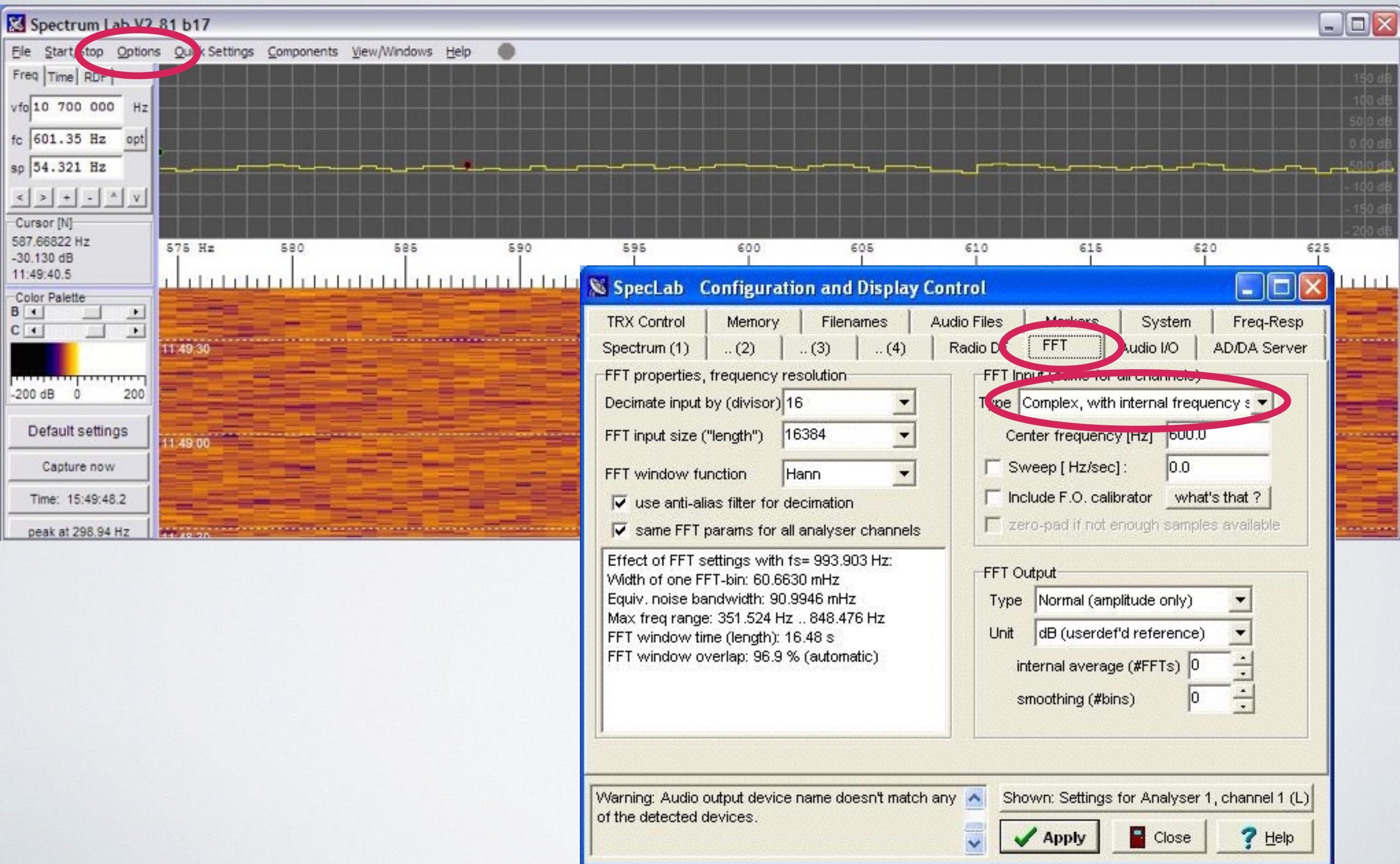


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Spectrum (1) .. (2) .. (3) .. (4) Radio D FFT Audio I/O AD/DA Server

FFT properties, frequency resolution

Decimate input by (divisor) 16

FFT input size ("length") 16384

FFT window function Hann

☒ use anti-alias filter for decimation

☒ same FFT params for all analyser channels

Effect of FFT settings with fs= 993.903 Hz:  
Width of one FFT-bin: 60.6630 mHz  
Equiv. noise bandwidth: 90.9946 mHz  
Max. freq range: 351.524 Hz .. 848.476 Hz  
FFT window time (length): 16.48 s  
FFT window overlap: 96.9 % (automatic)

FFT Input (same for all channels)

Type Complex, with internal frequency s

Center frequency [Hz] 600.0

☐ Sweep [Hz/sec]: 0.0

☐ Include F.O. calibrator what's that ?

☐ zero-pad if not enough samples available

FFT Output

Type Normal (amplitude only)

Unit dB (userdef'd reference)

internal average (#FFTs) 0

smoothing (#bins) 0

Warning: Audio output device name doesn't match any of the detected devices.

Shown: Settings for Analyser 1, channel 1 (L)

Apply Close Help

Try these settings. If the display freezes, reduce them. Accuracy will suffer.



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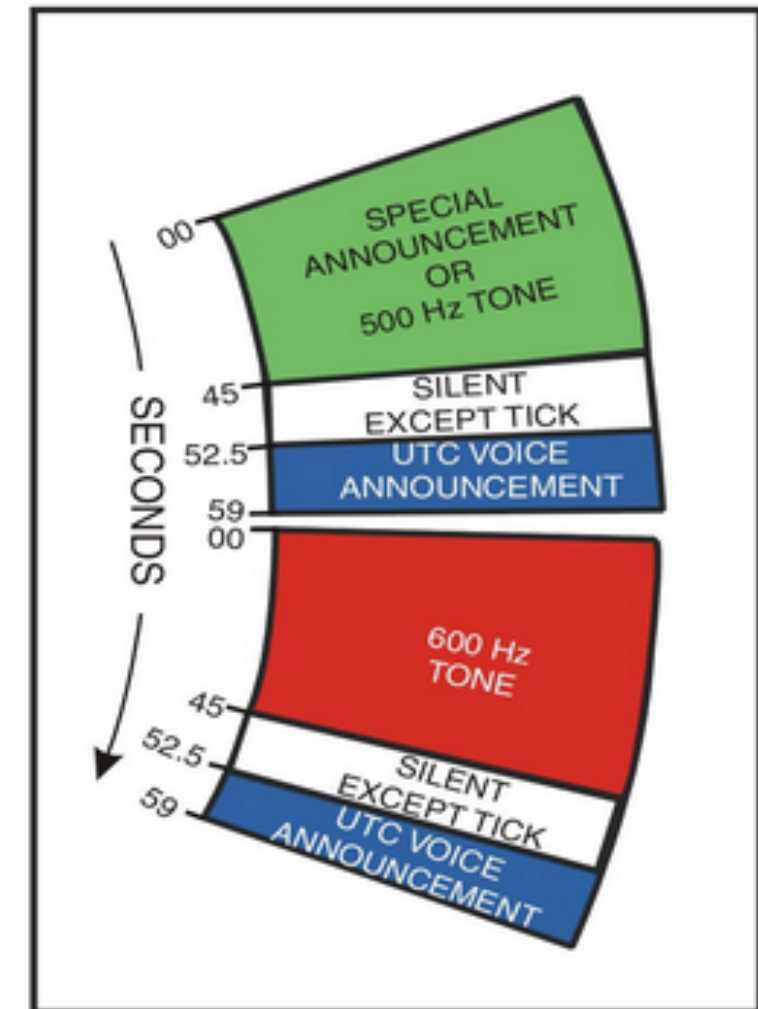
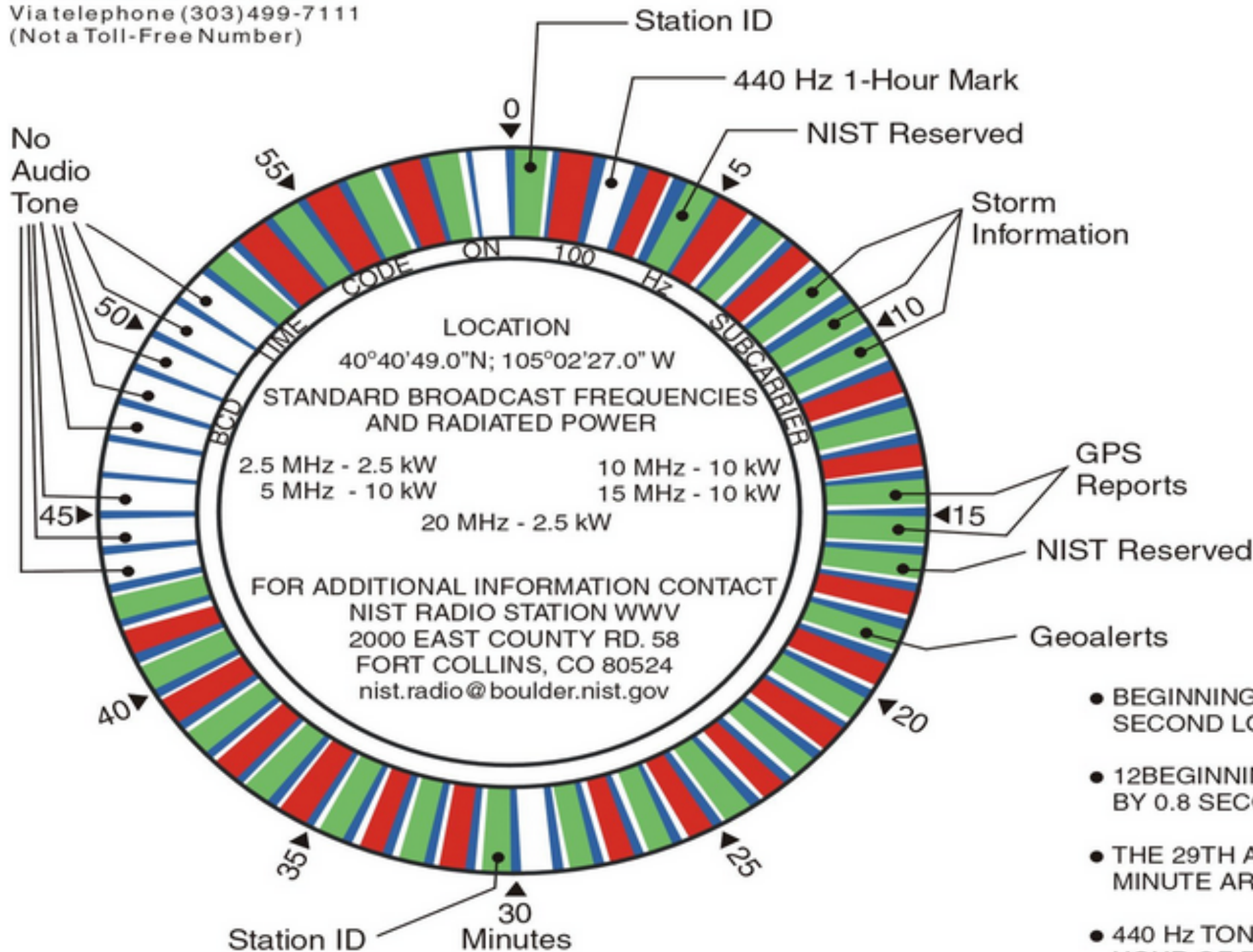


# WWV

## WWV

### Broadcast Format

Via telephone (303) 499-7111  
(Not a Toll-Free Number)



- BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8 SECOND LONG, 1500 Hz TONE.
- 12 BEGINNING OF EACH MINUTE IDENTIFIED BY 0.8 SECOND LONG, 1000 Hz TONE.
- THE 29TH AND 59TH SECOND PULSES OF EACH MINUTE ARE OMITTED.
- 440 Hz TONE IS OMITTED DURING FIRST HOUR OF EACH DAY.

# COMPUTER CALIBRATION

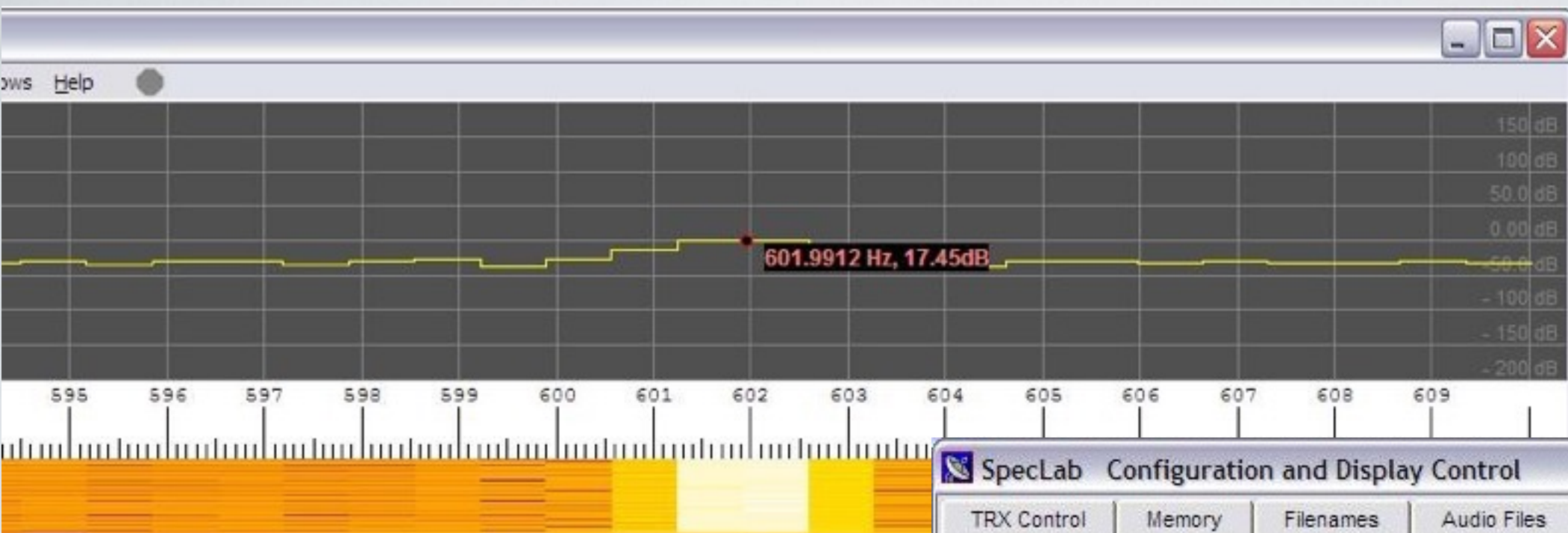


- 2-3 hour warm-up
- Tune to any WWV in AM mode
- Measure frequency during 600 Hz tone
- Apply correction

**Avoid sunrise/sunset times  
(WWV Doppler)**

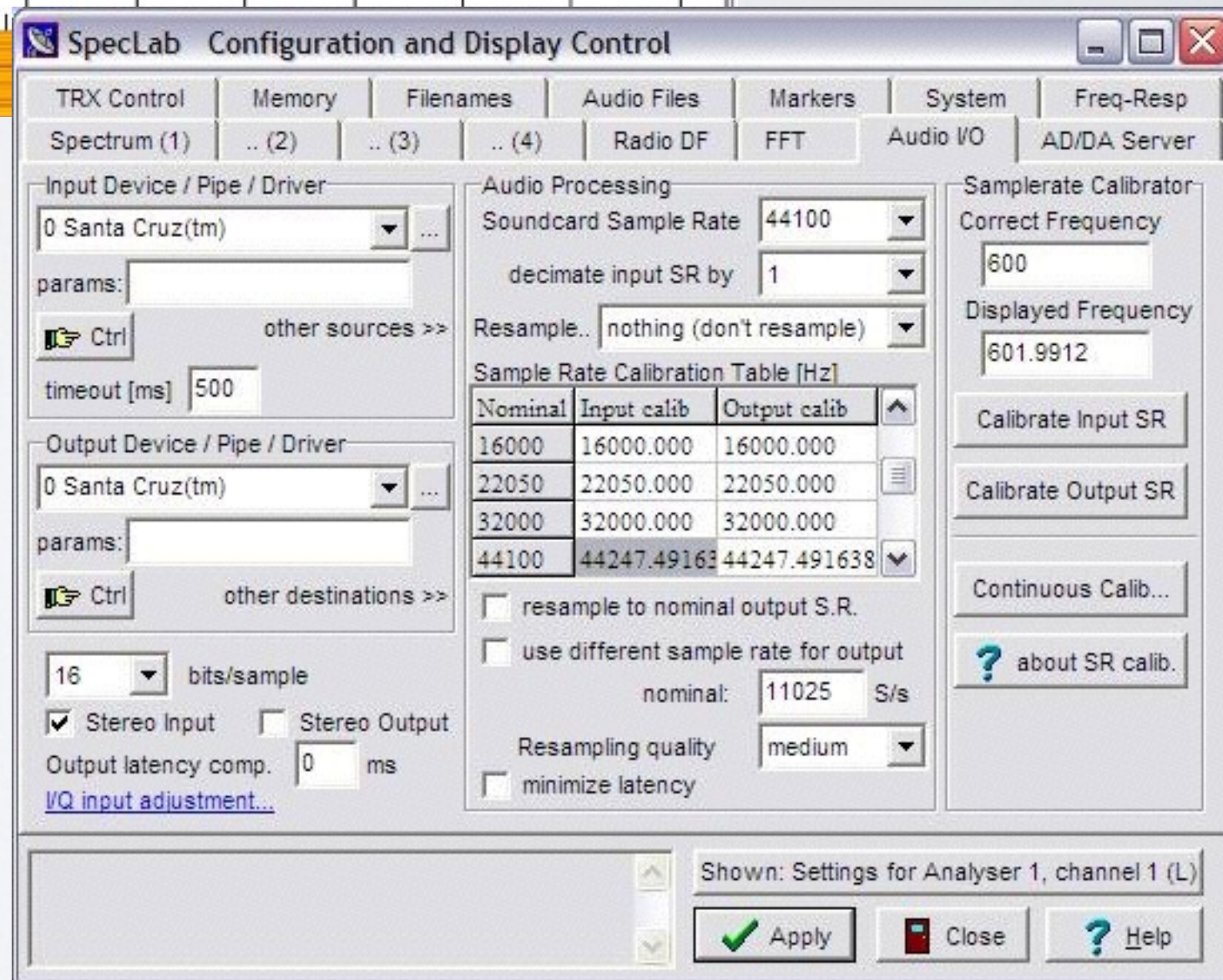


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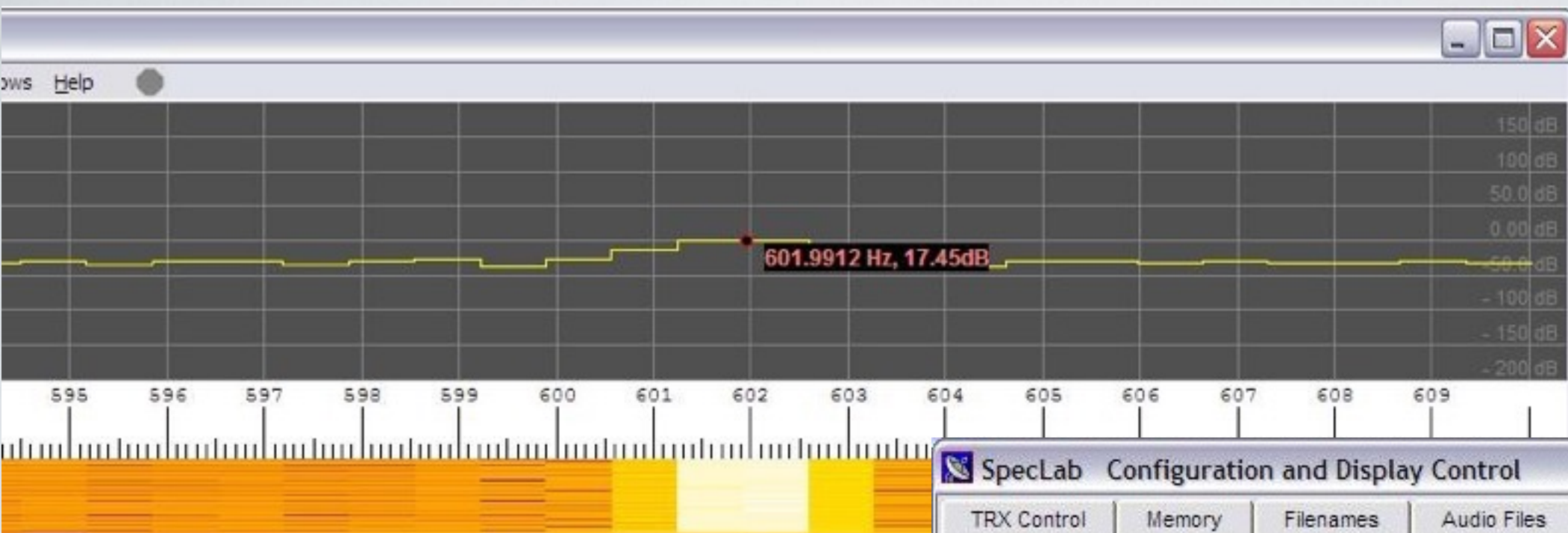
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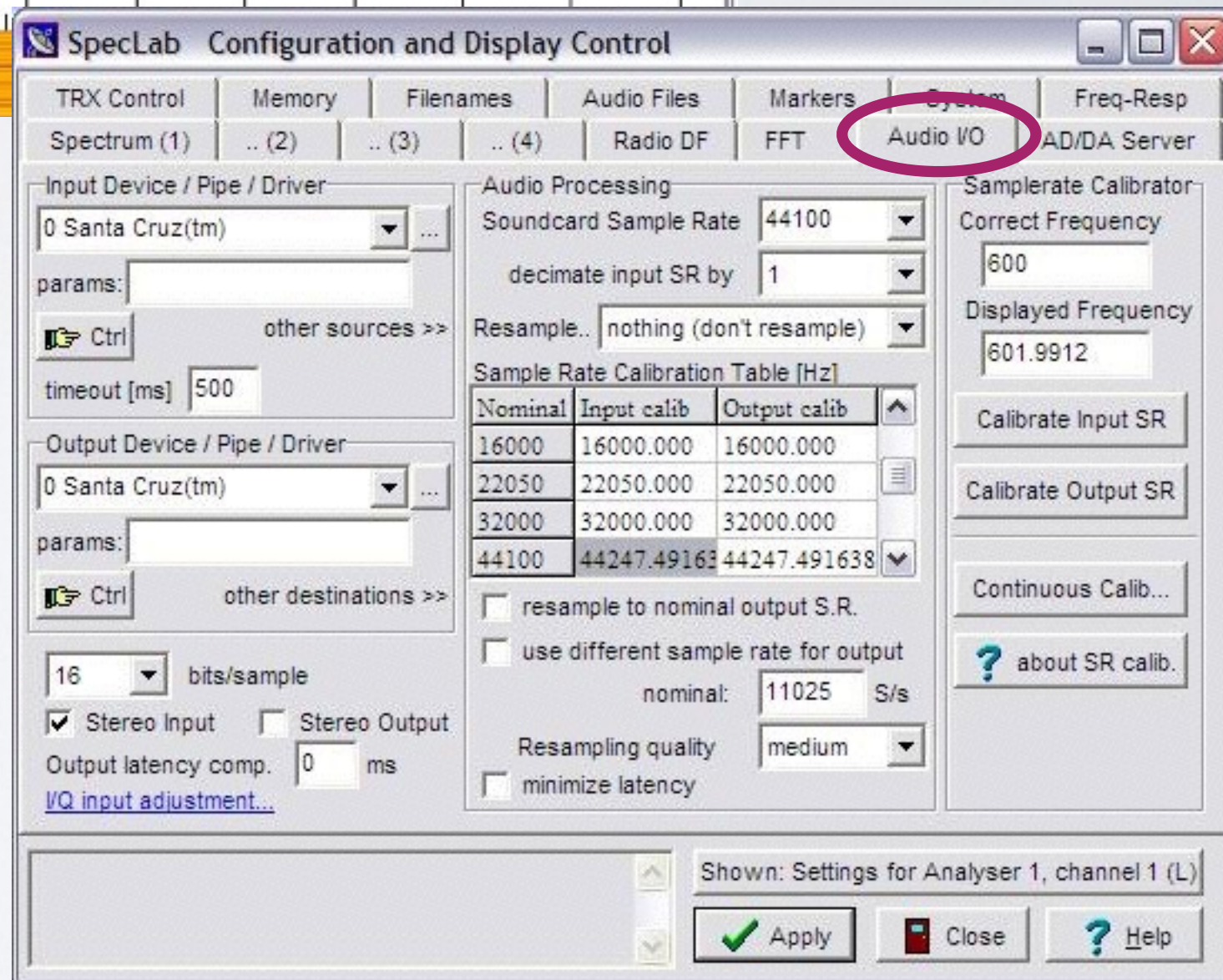


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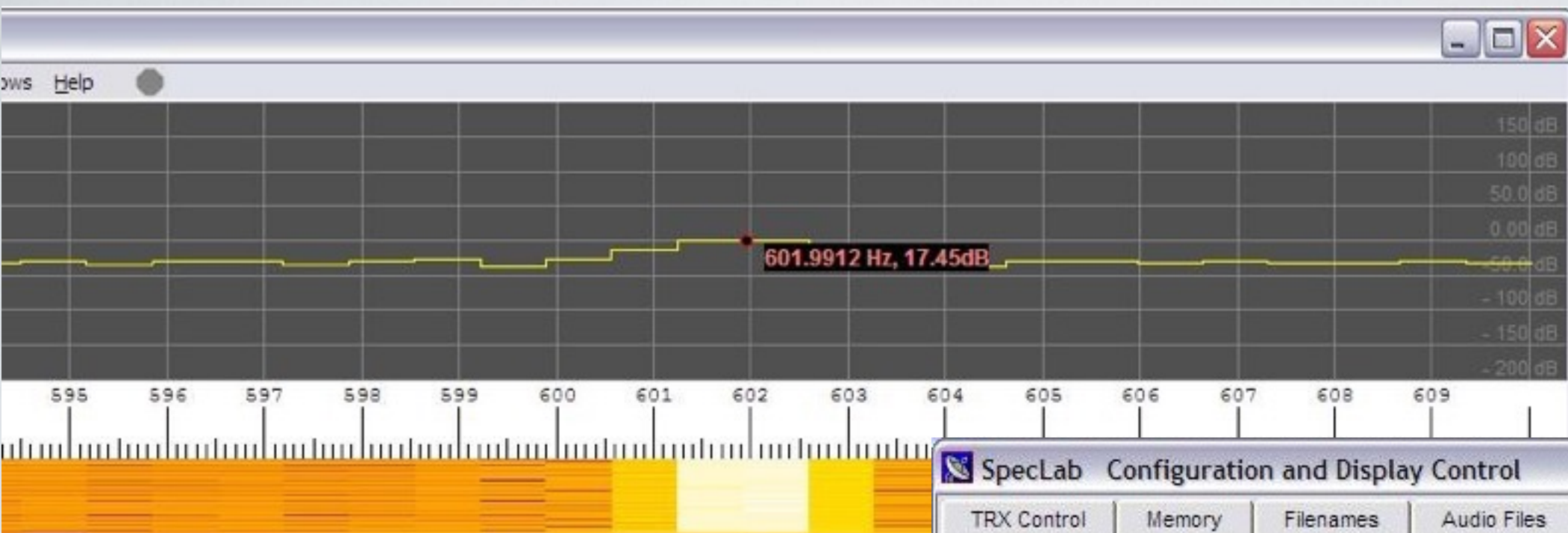
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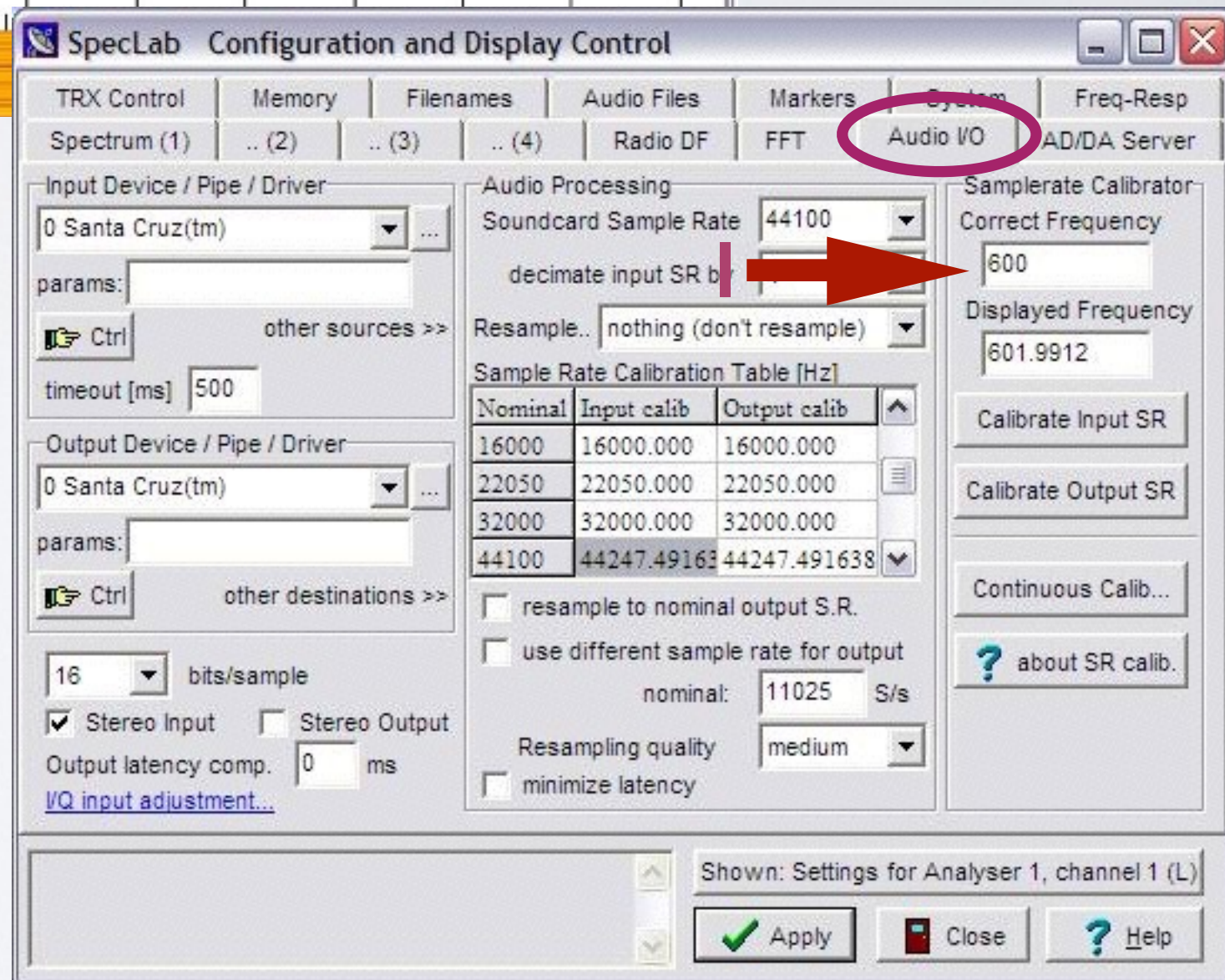


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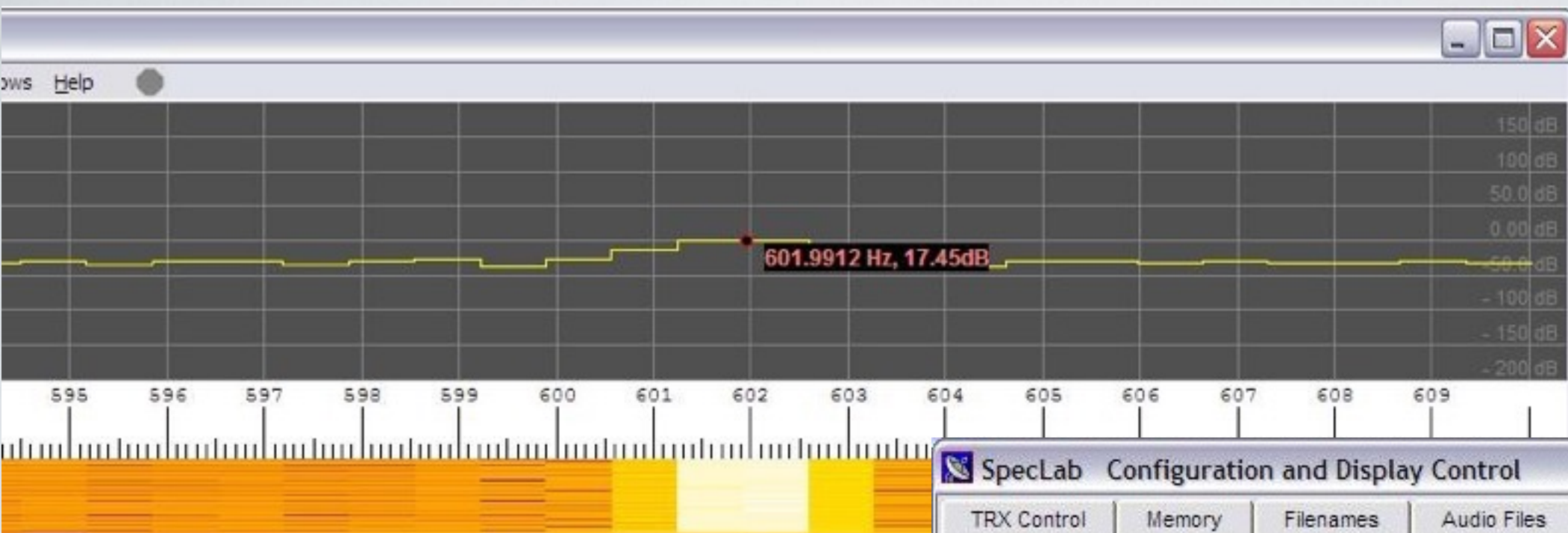
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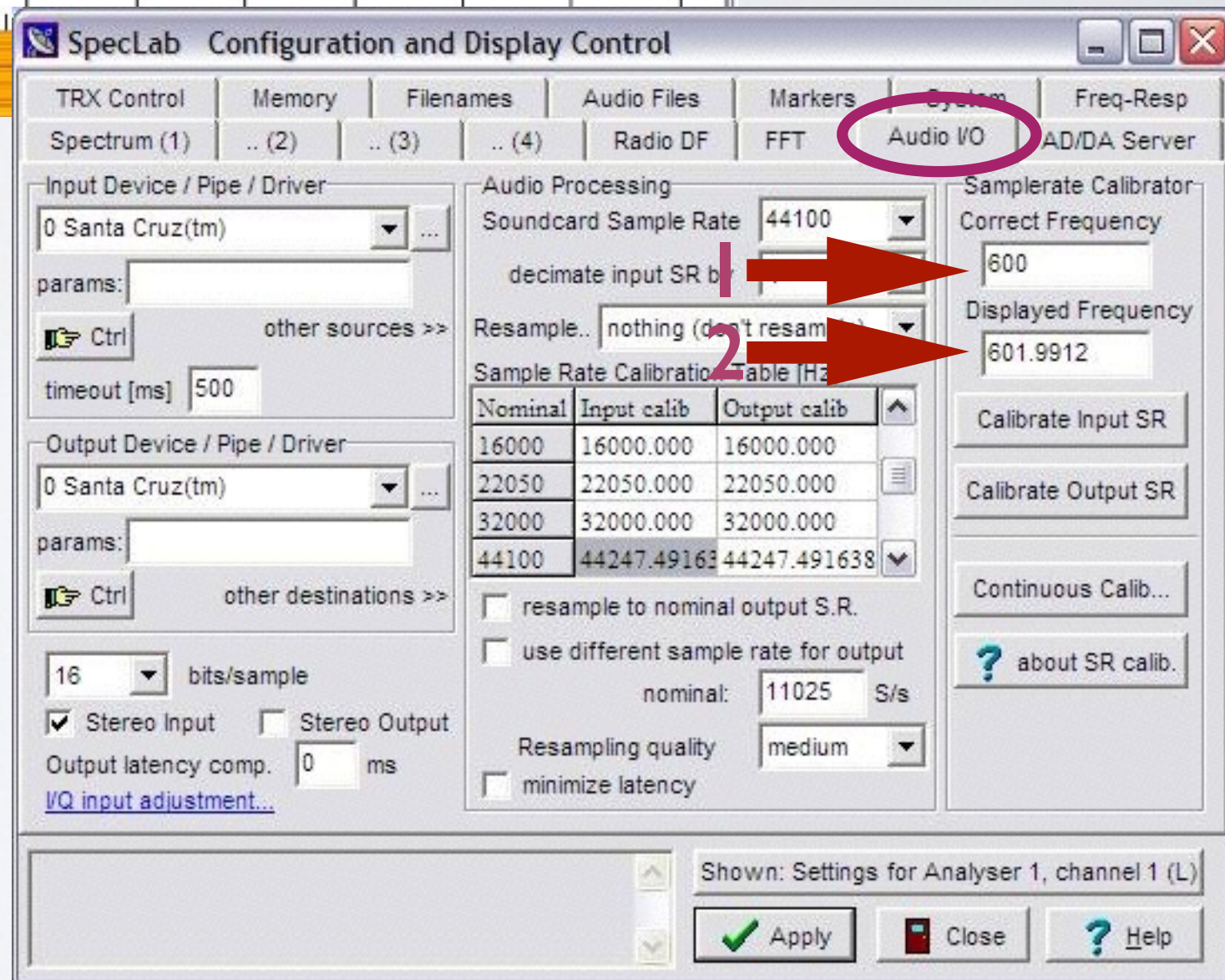


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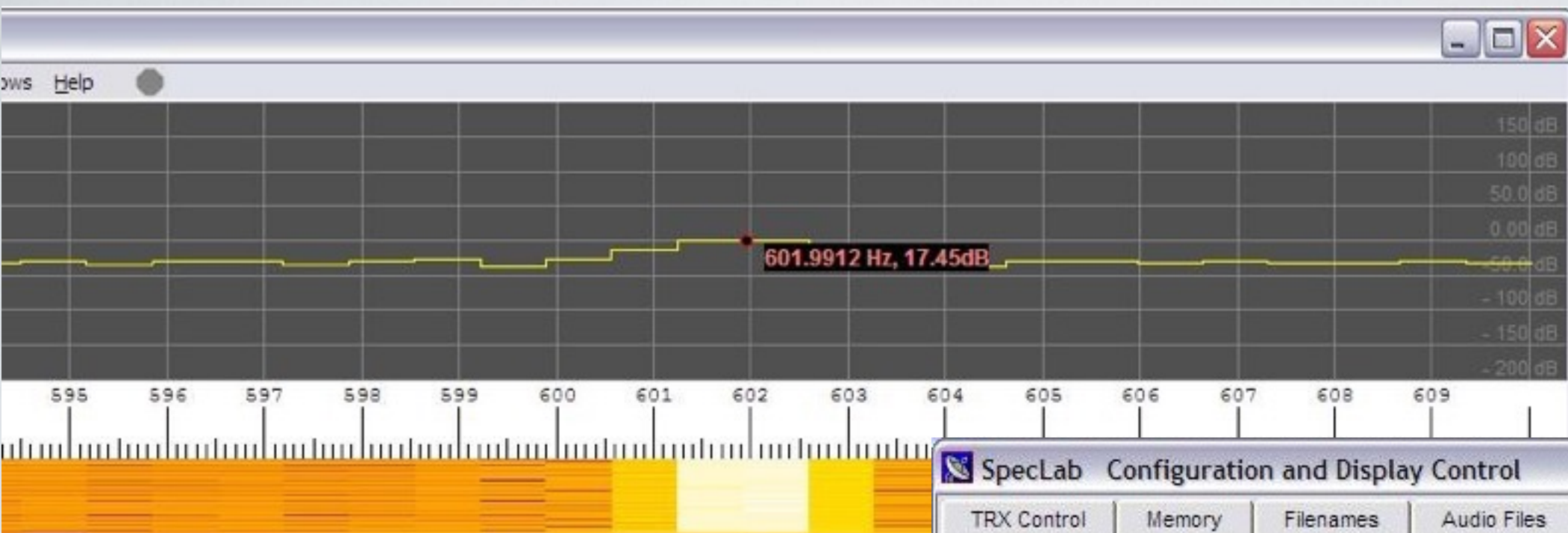
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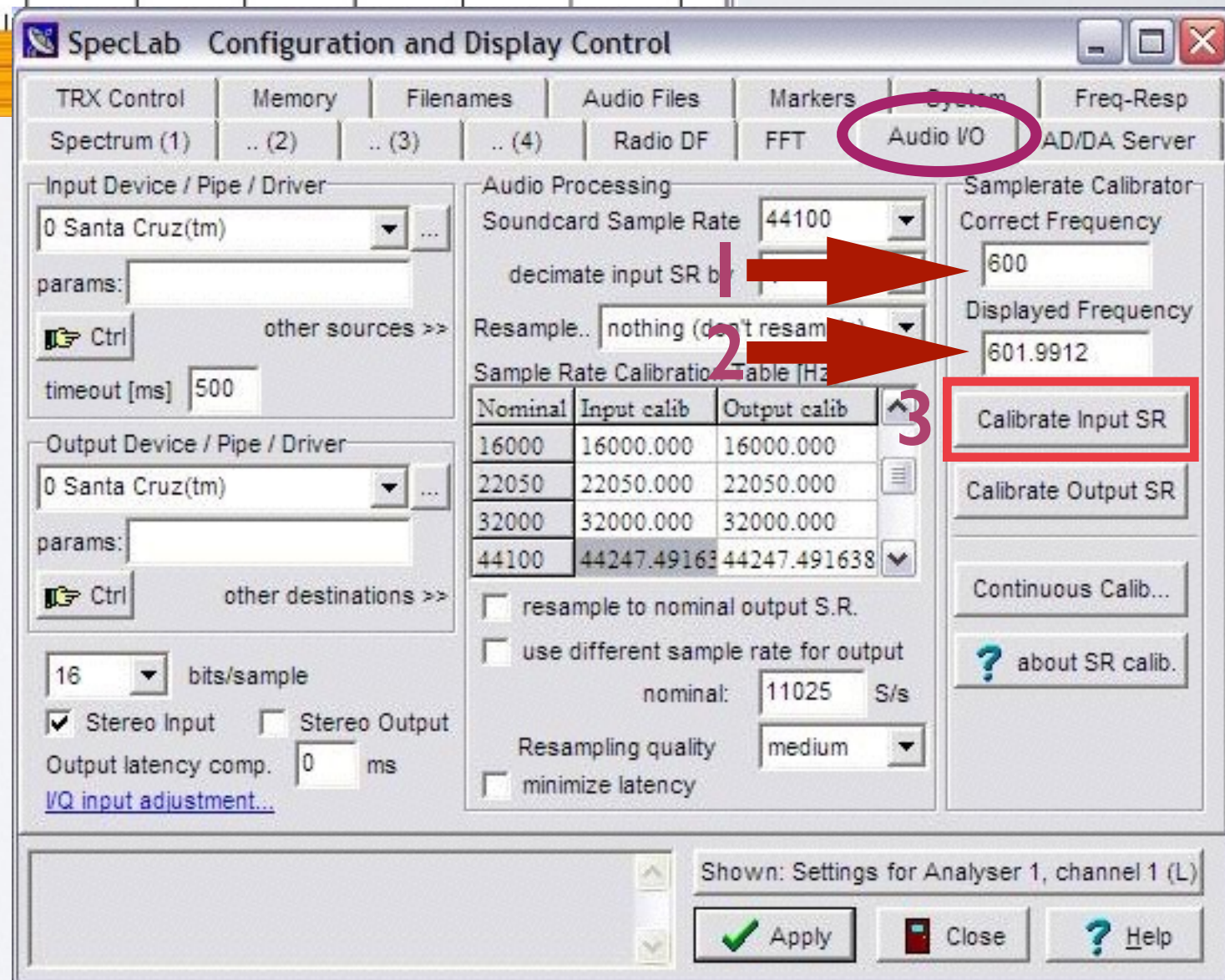


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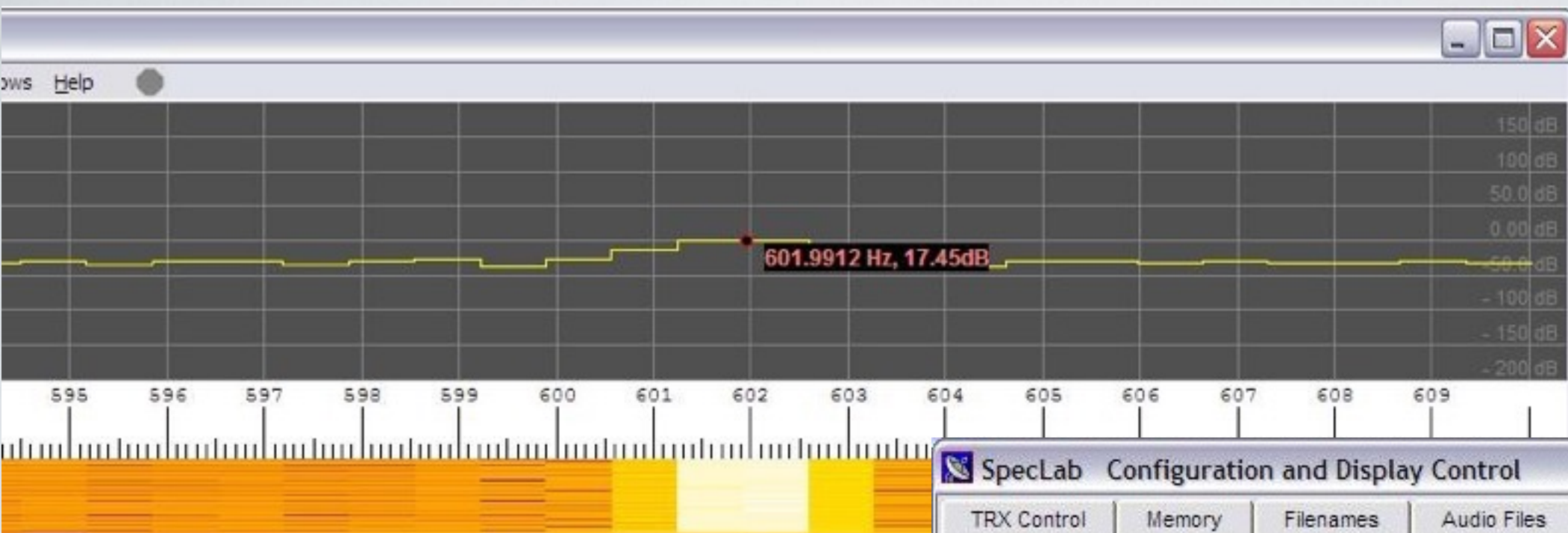
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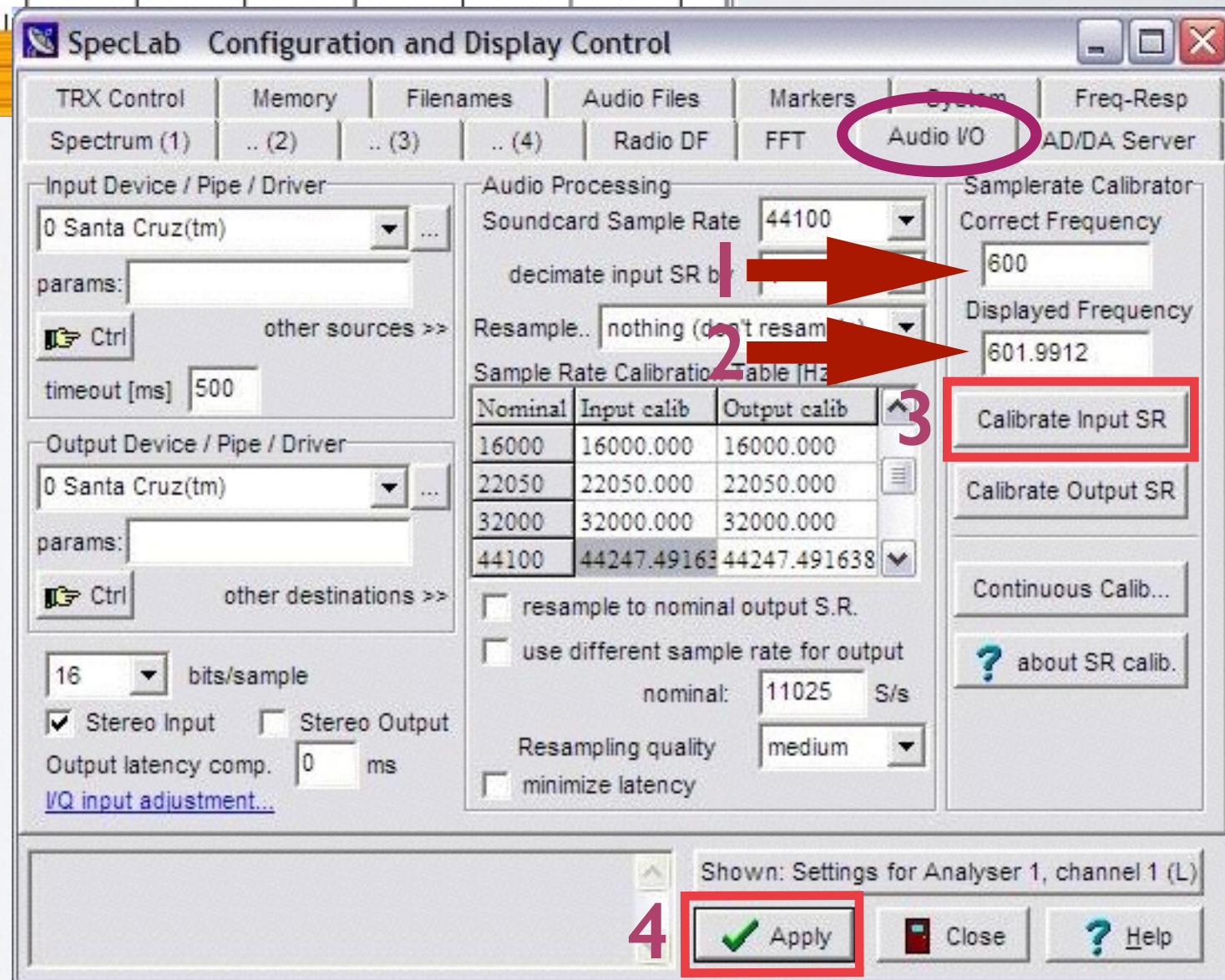


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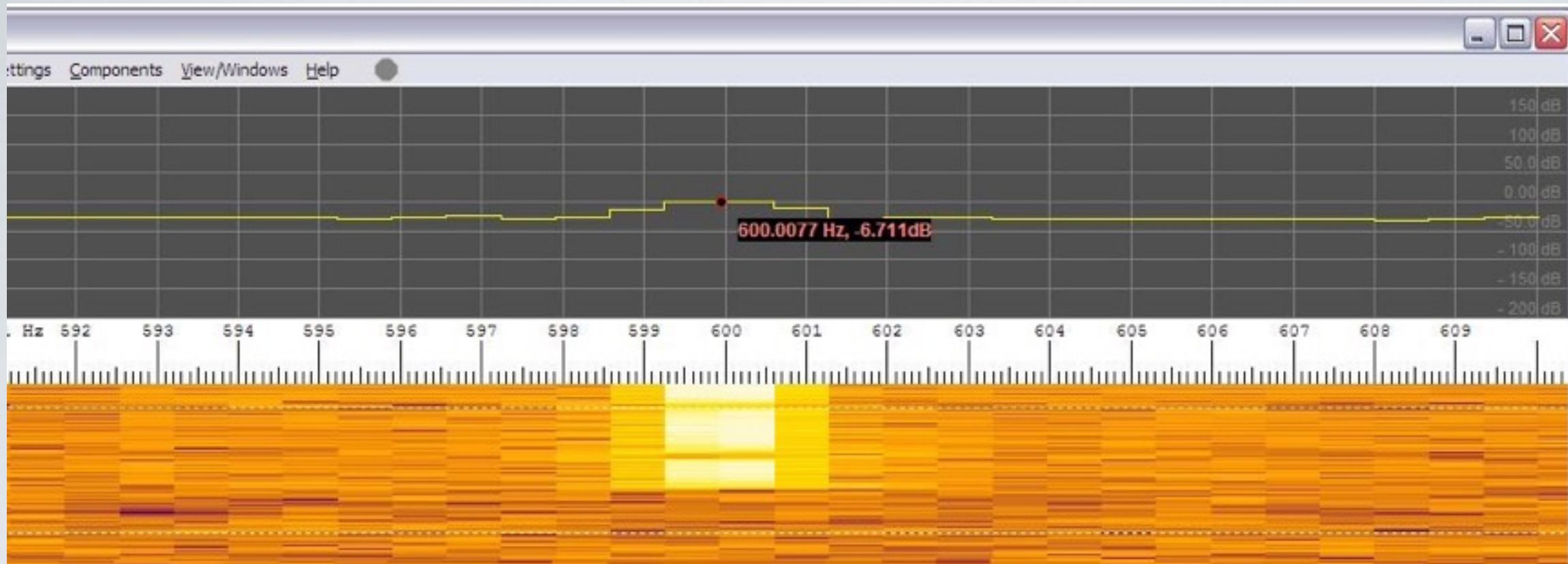
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# COMPUTER CALIBRATION



After calibration, we're within 0.0023 Hz

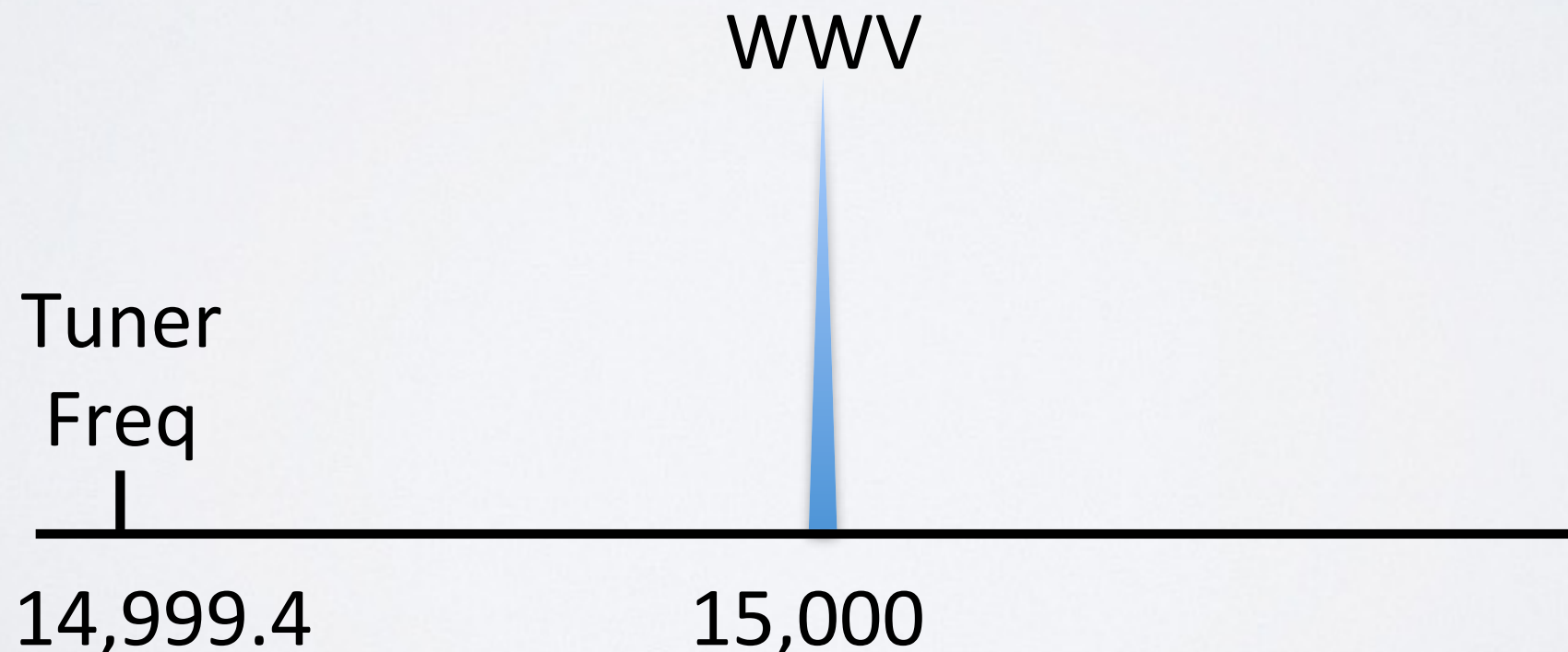
# RIG CALIBRATION

1. Set rig to USB
2. Tune to 15 MHz WWV
3. Re-tune to 14,999.400 KHz = WWV - 600 Hz
4. Measure the frequency of the carrier
5. Adjust your rig (if possible) to center the carrier at 600 Hz — consult manual



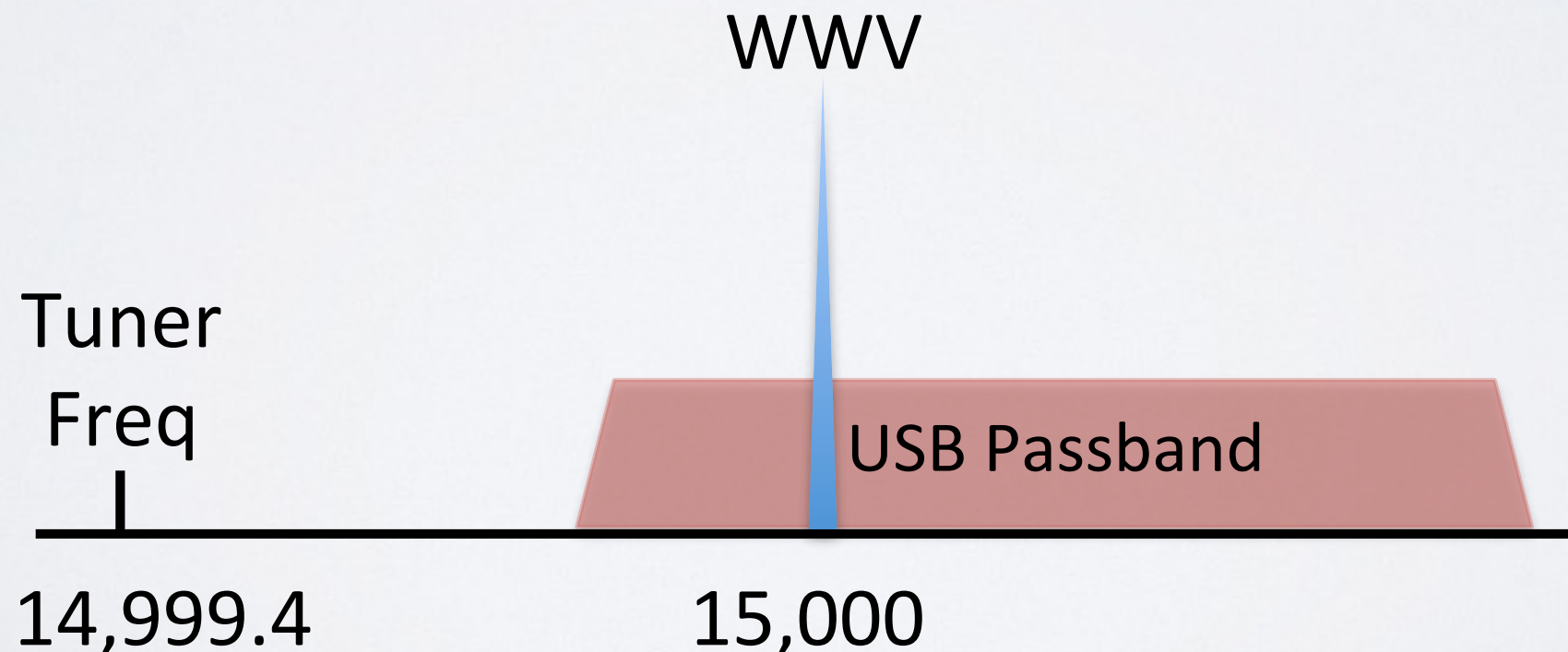
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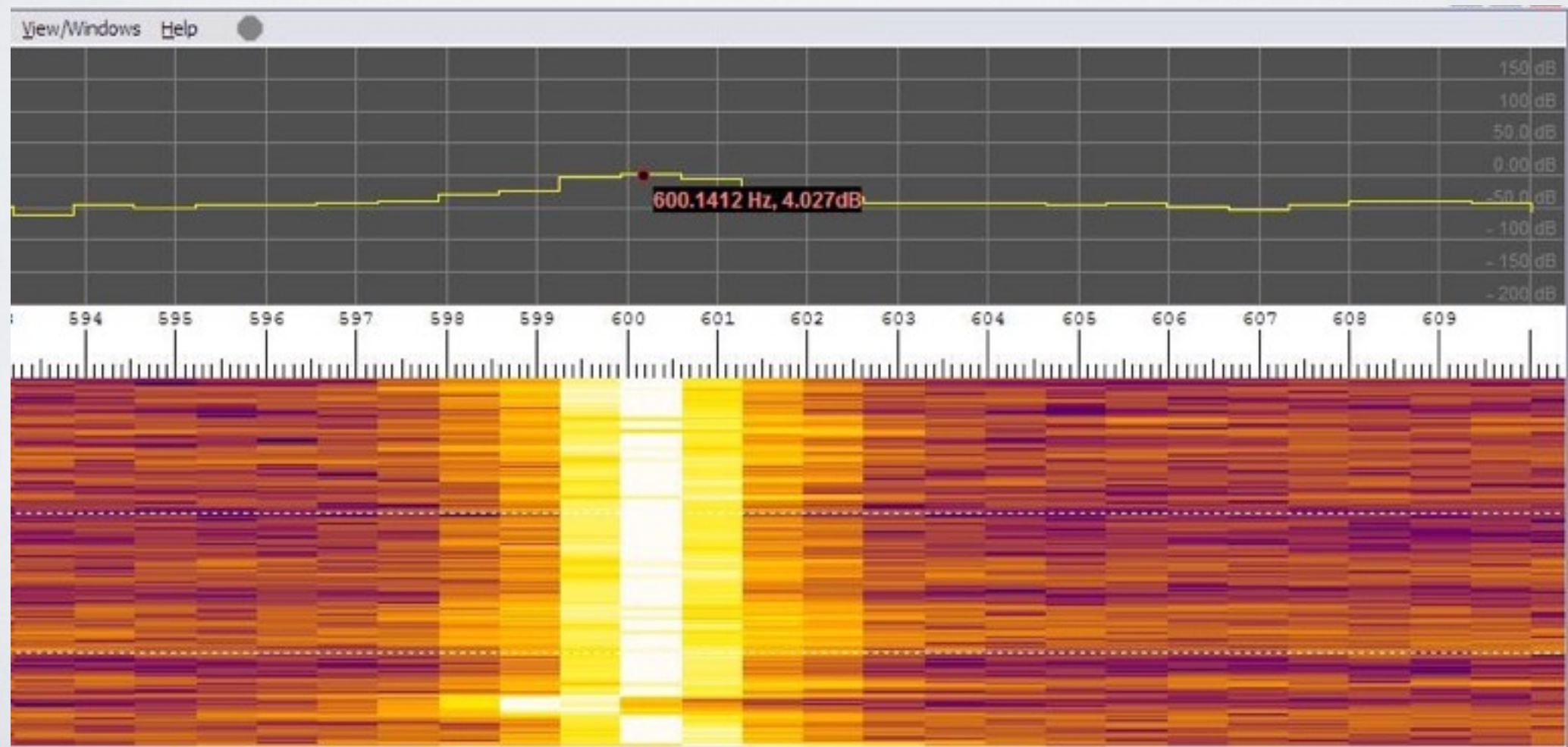
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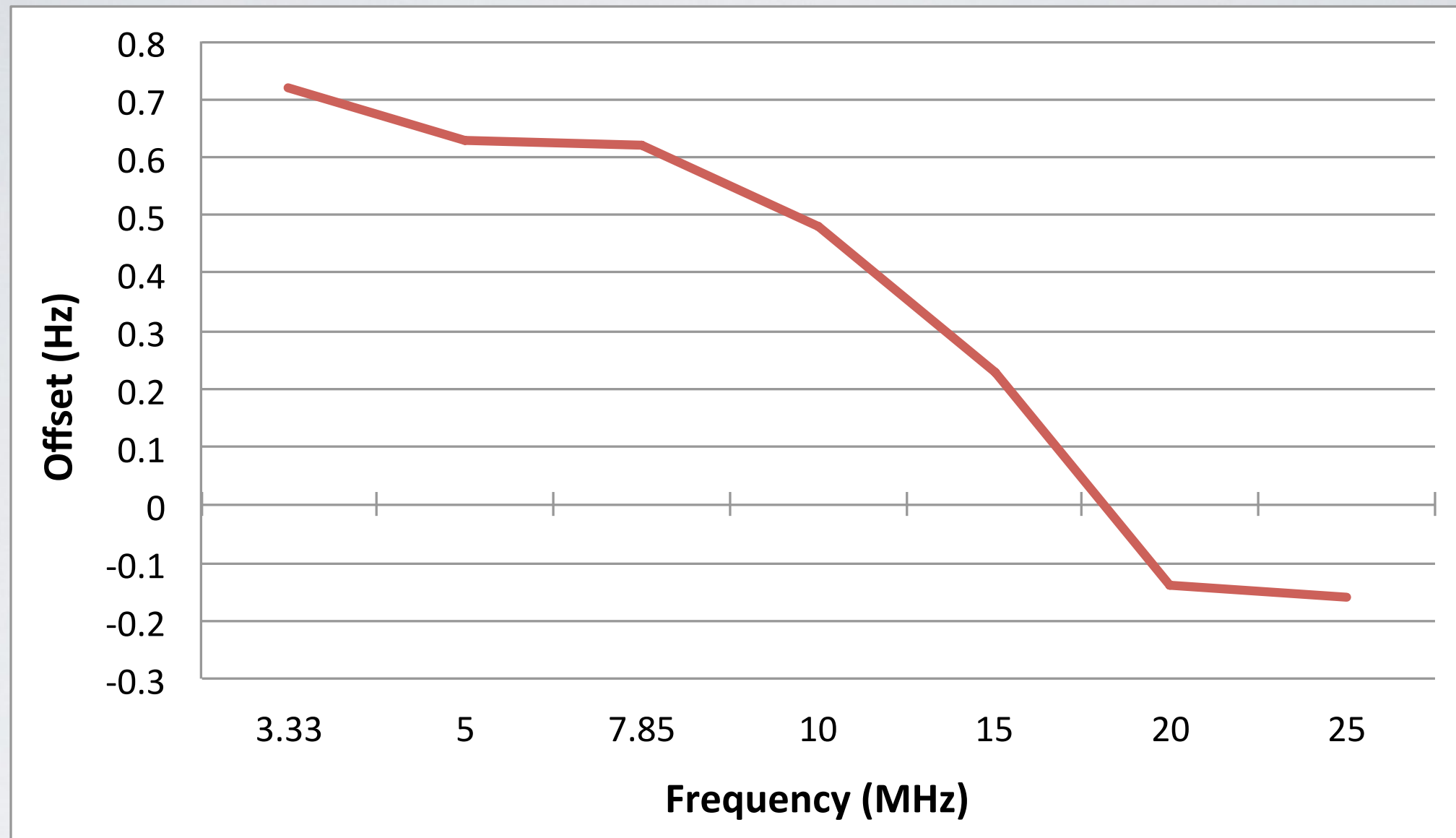


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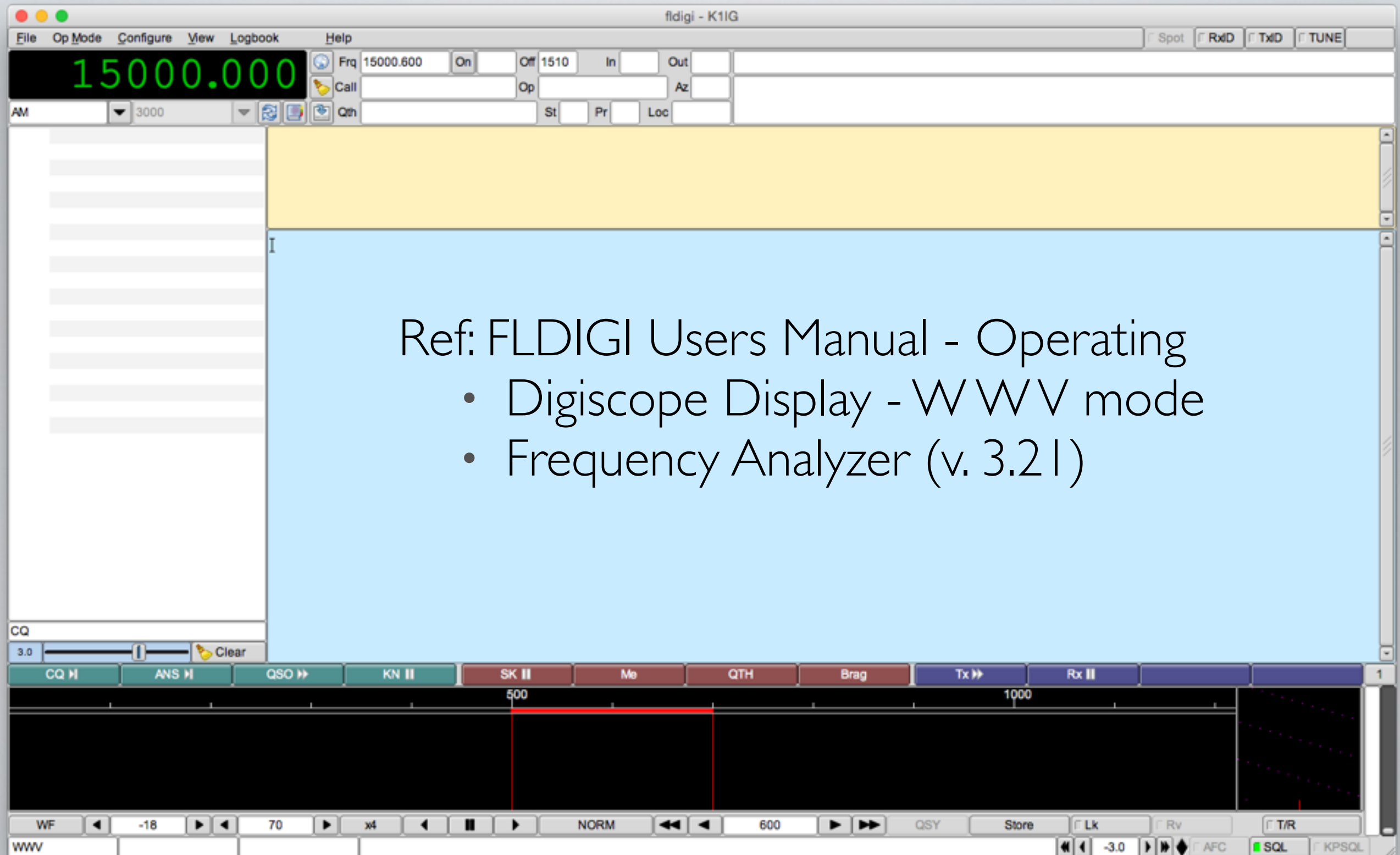
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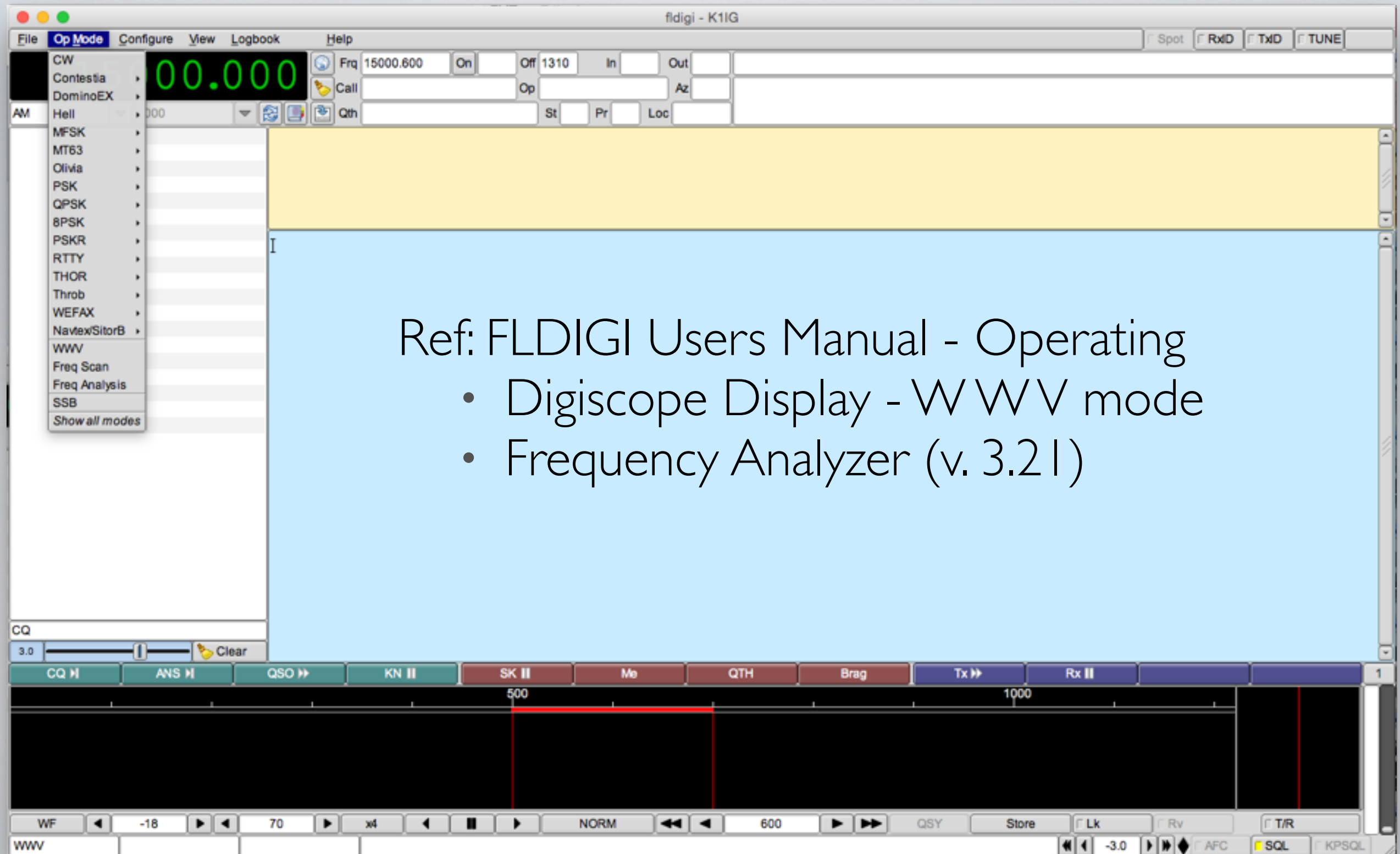
- Measure all WWV and CHU frequencies (-600 Hz)
- Make a correction chart based on WWV and CHU measurements



# FLDIGI

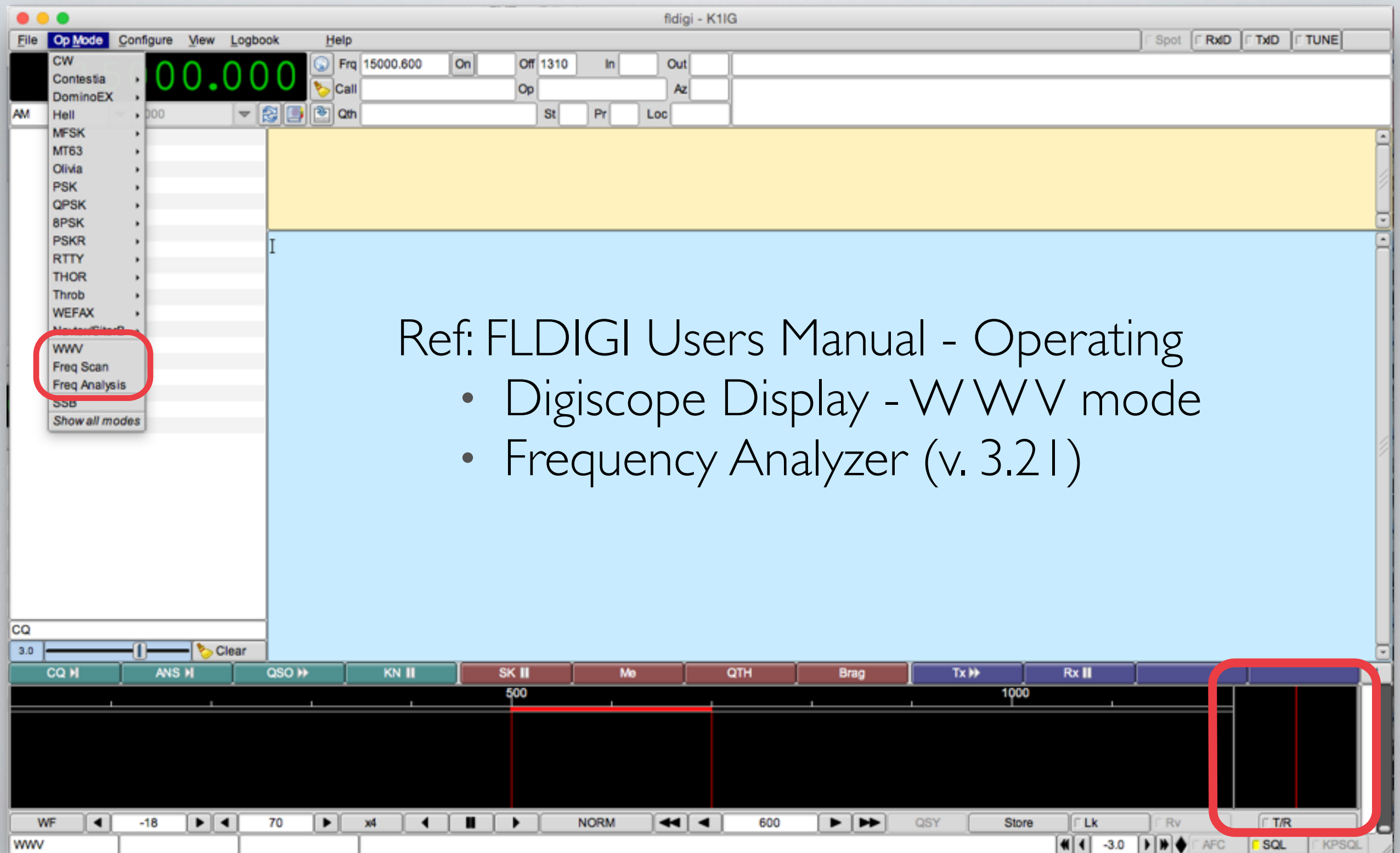


# FLDIGI





# FLDIGI



# FLDIGI SETUP

## Computer Calibration — Part I

1. Select Op Mode - W W V
2. Select View - Floating Scope
3. Select Configure - Sound Card



# FLDIGI SETUP

## Computer Calibration — Part I

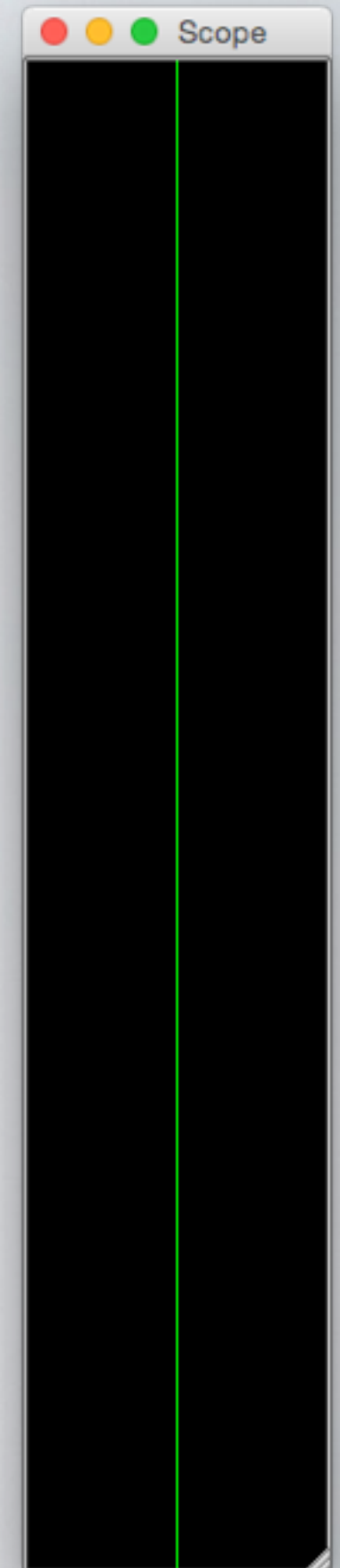
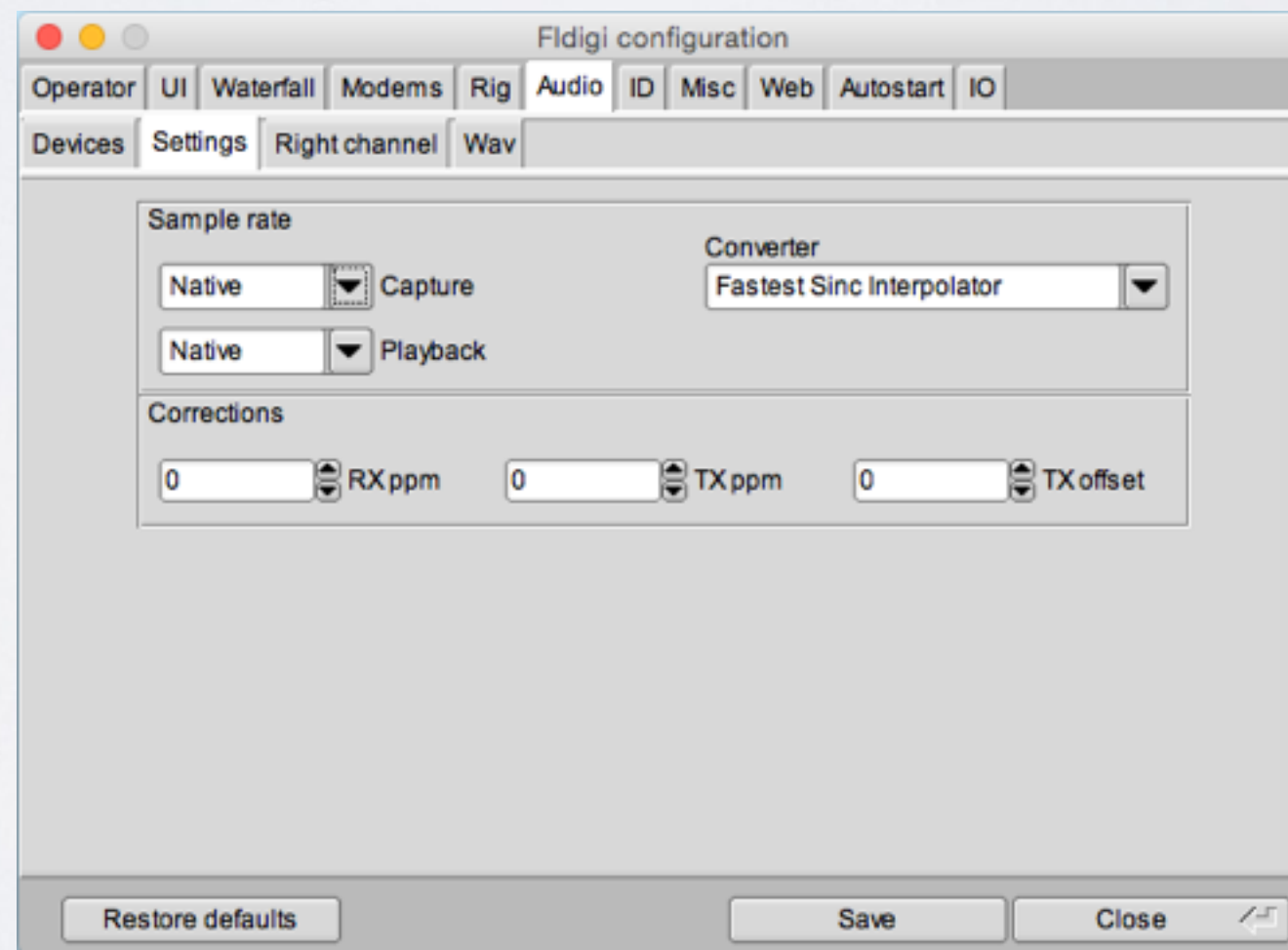
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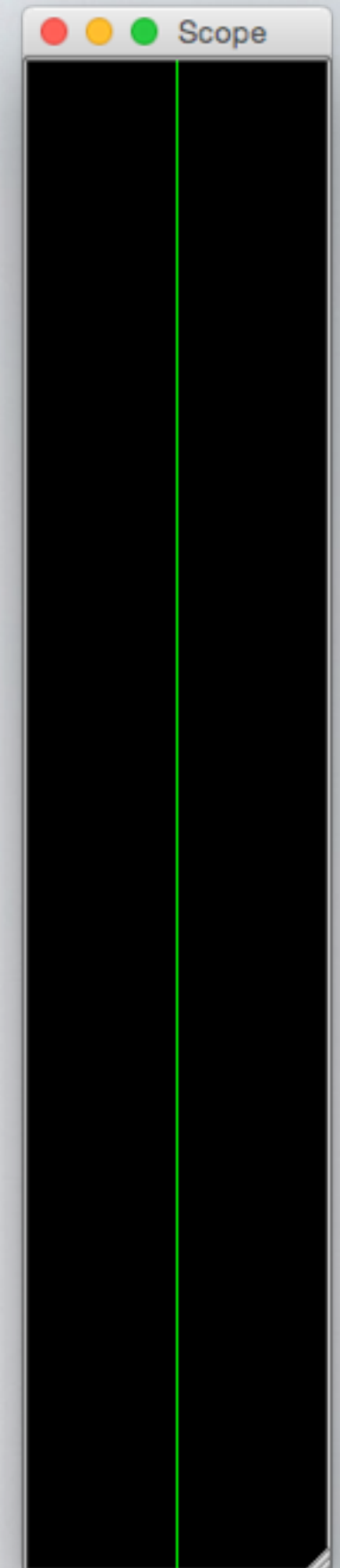
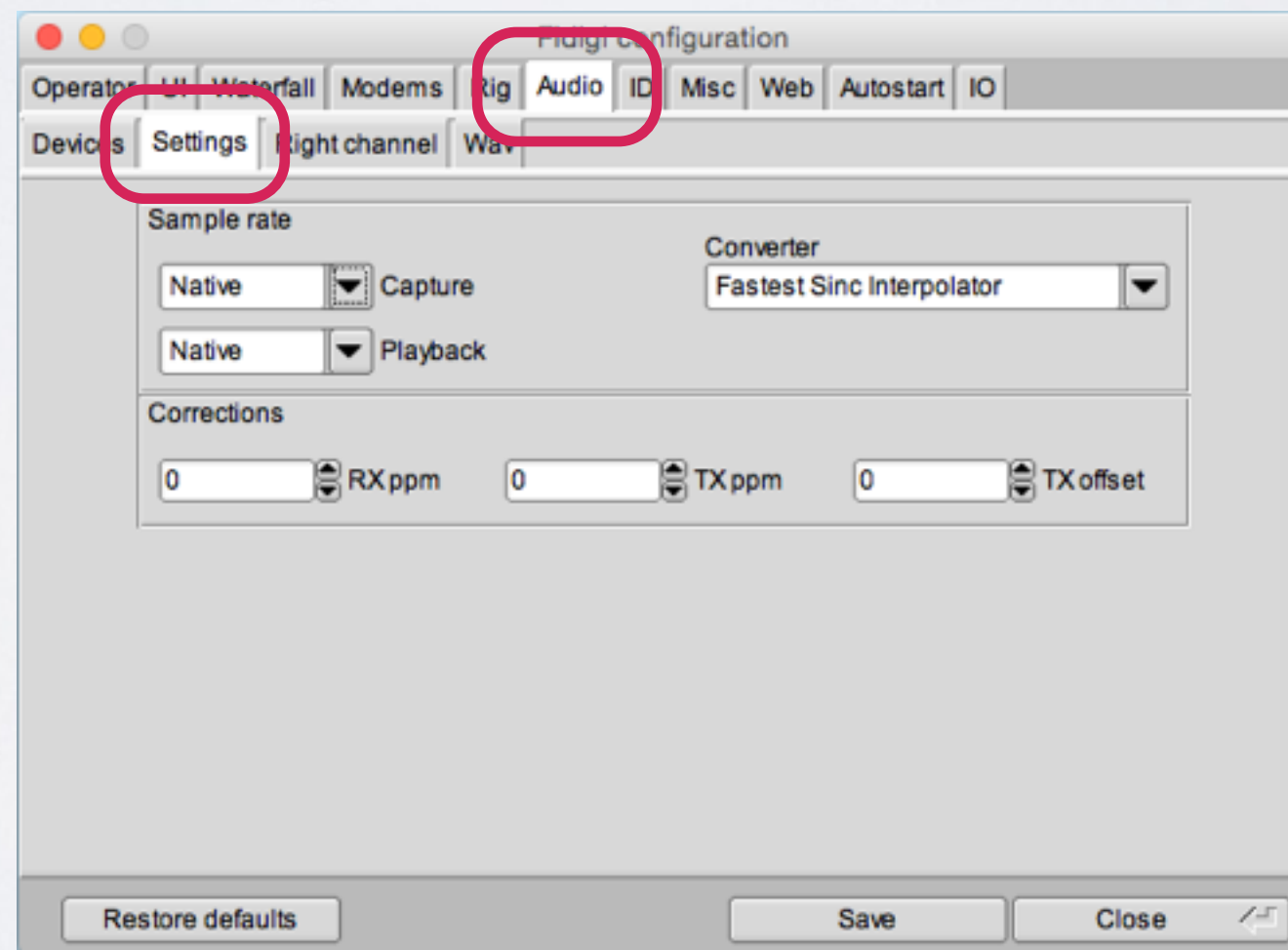




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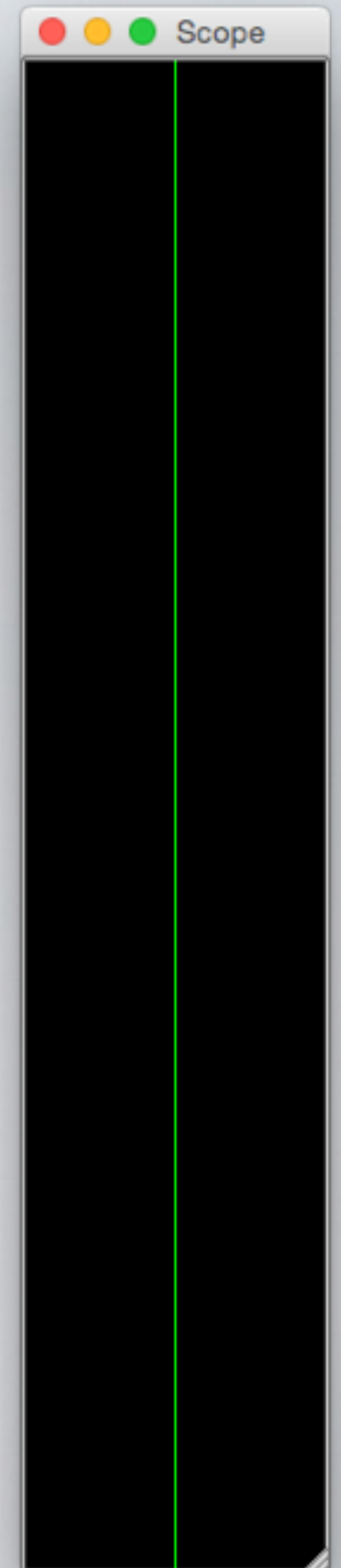
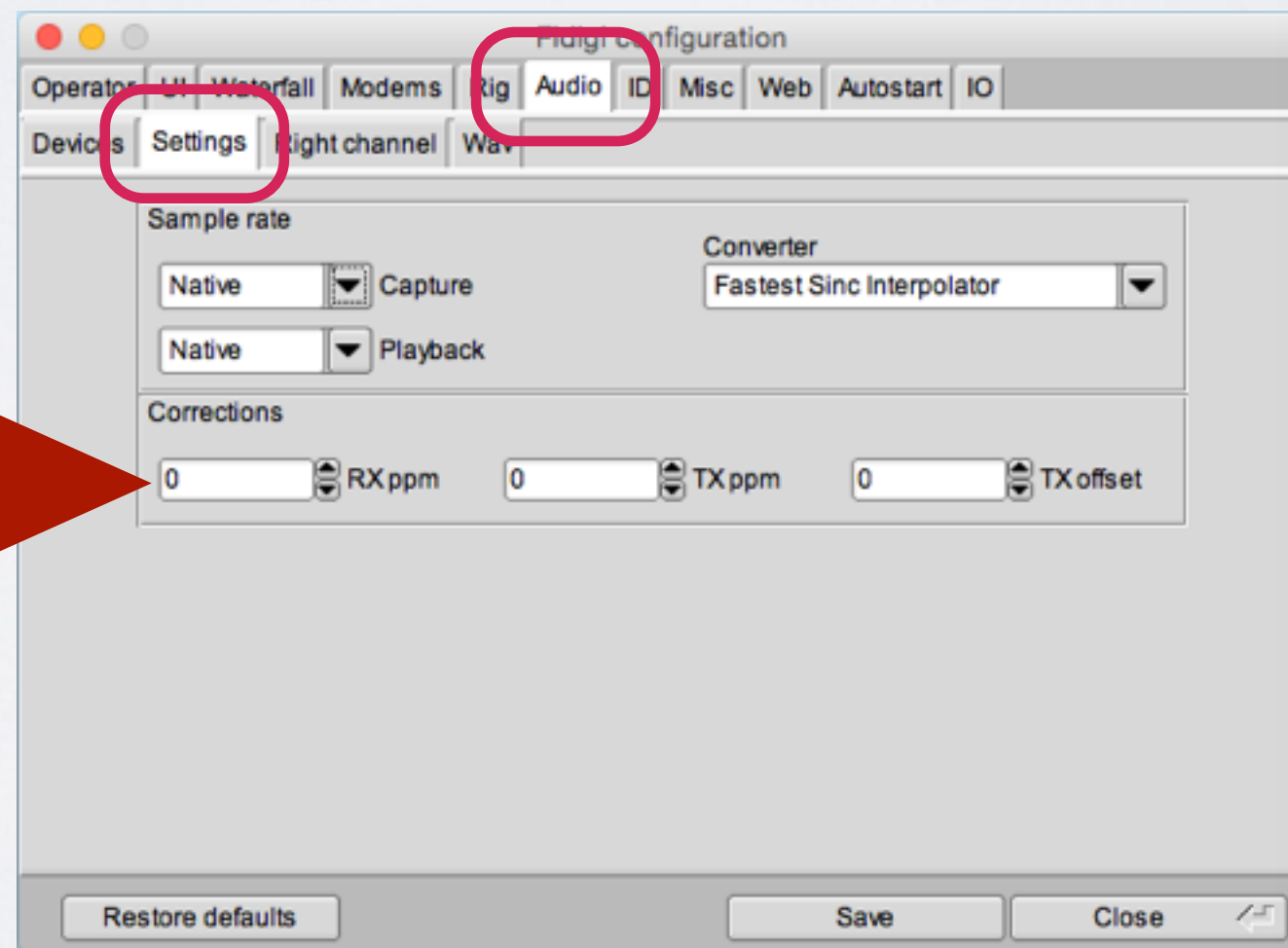
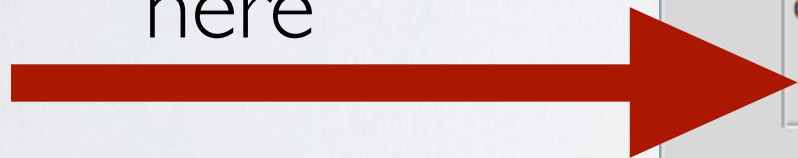


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Make  
corrections  
here

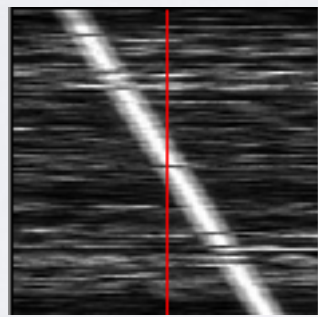




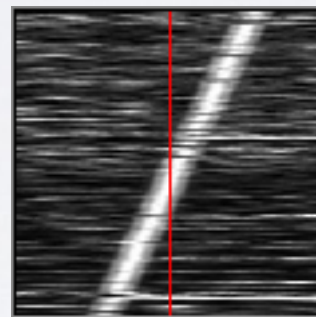
# FLDIGI SETUP

## Computer Calibration — Part II

1. Set Rig to AM — tune to any WWV
2. Apply “RX ppm” corrections to make the scope line vertical

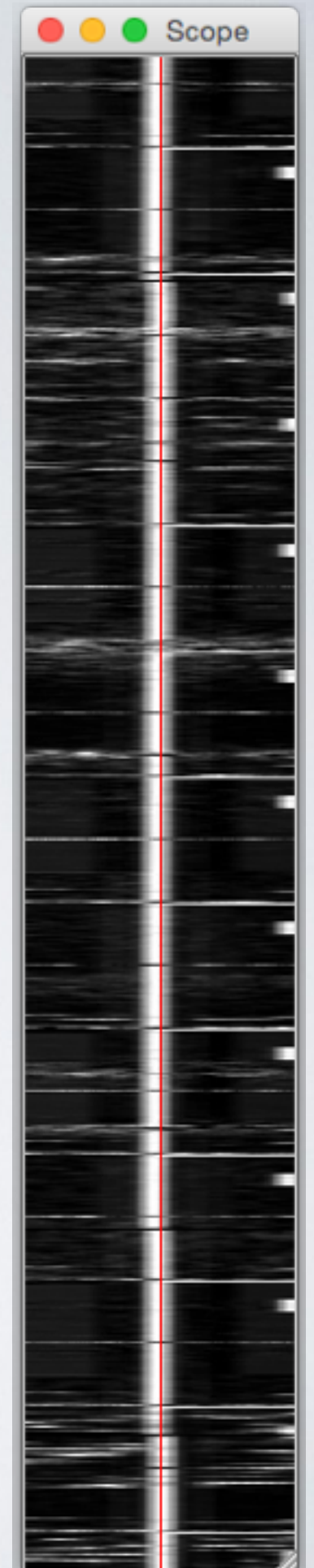


-1000 ppm



+1000 ppm

Ref: FLDIGI Users Manual  
Digiscope Display — WWV Mode



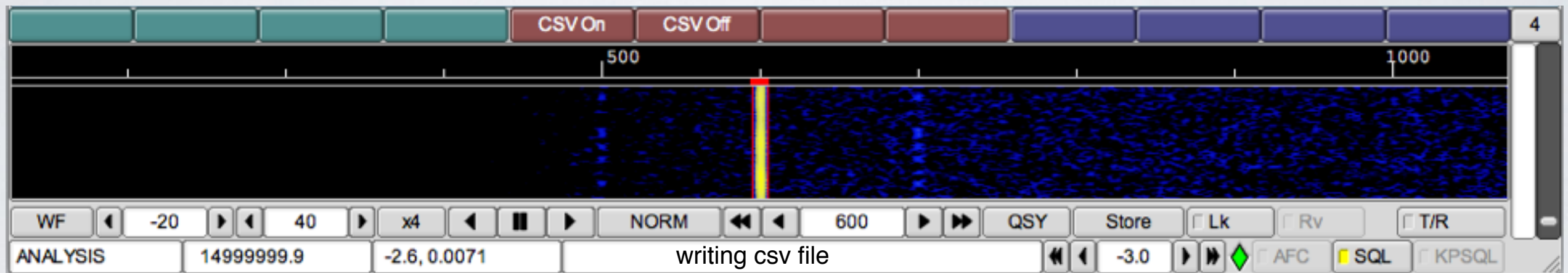
# FLDIGI RIG CALIBRATION

1. Set Rig to USB — tune to W W V - 600 Hz
2. Select Op Mode - Freq Analysis
3. Adjust rig so waterfall is exactly at 600 Hz



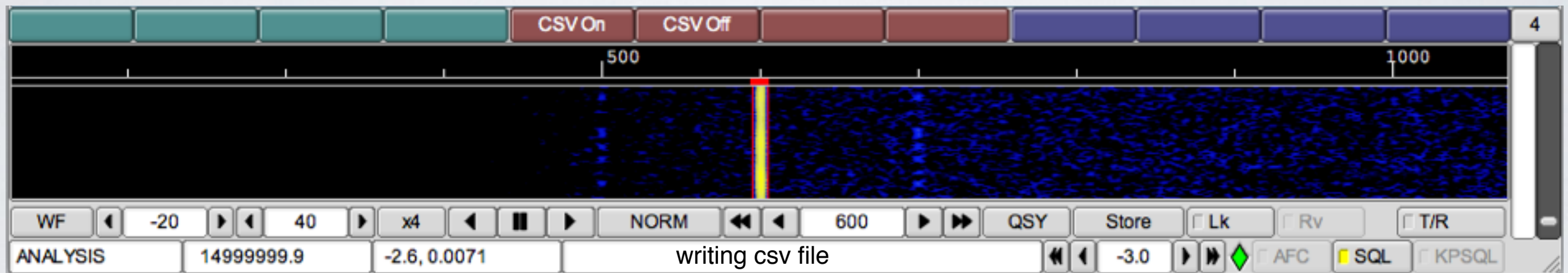
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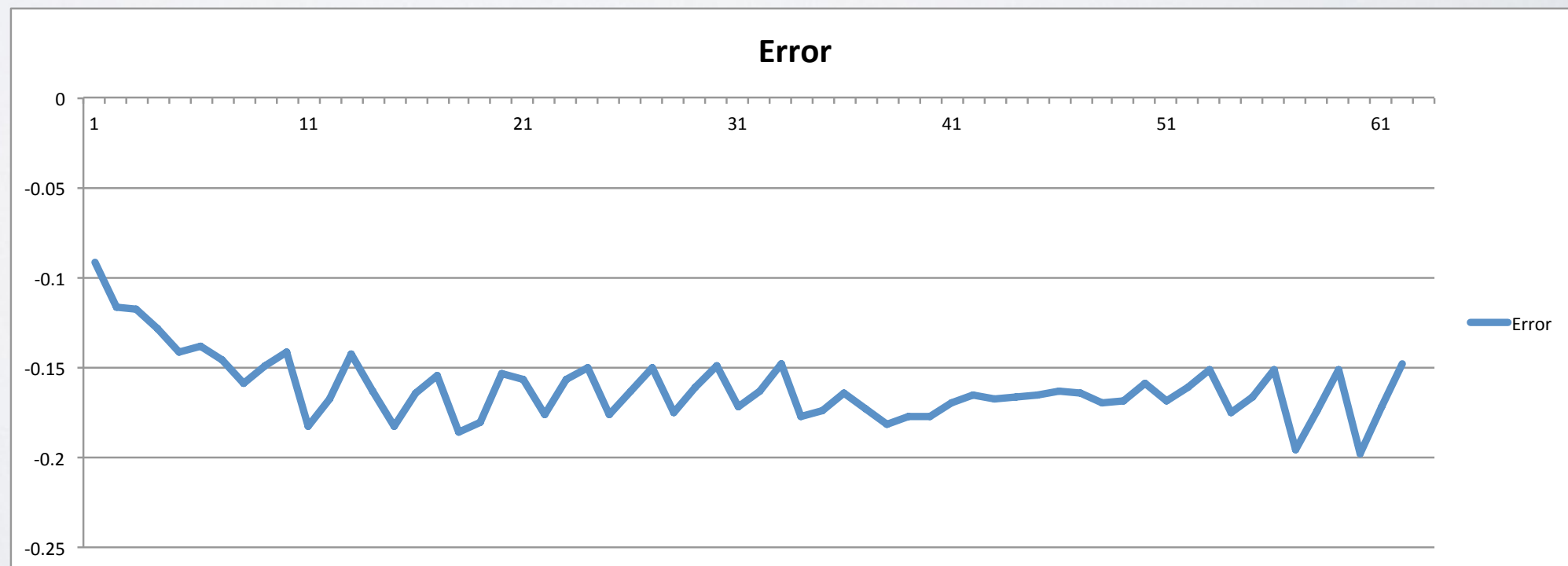


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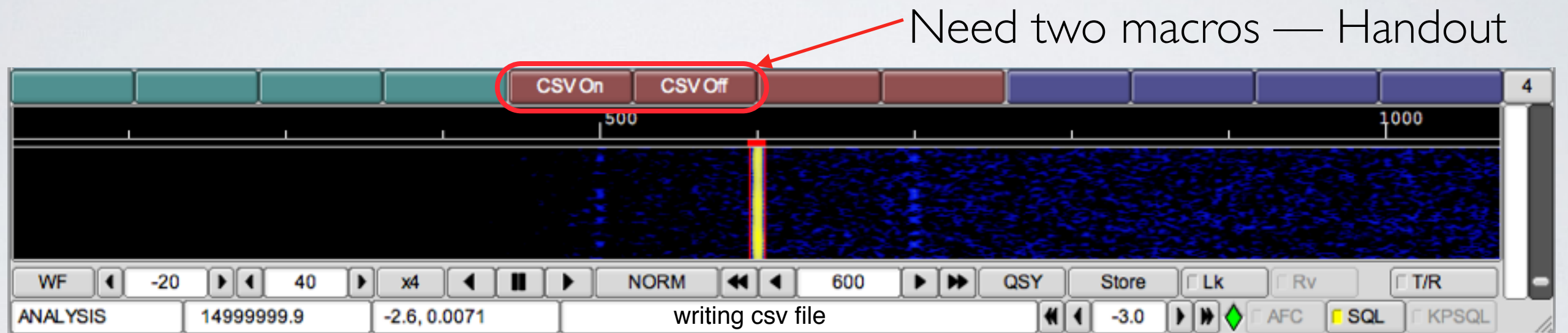
You'll get a data file that you can import into a spreadsheet



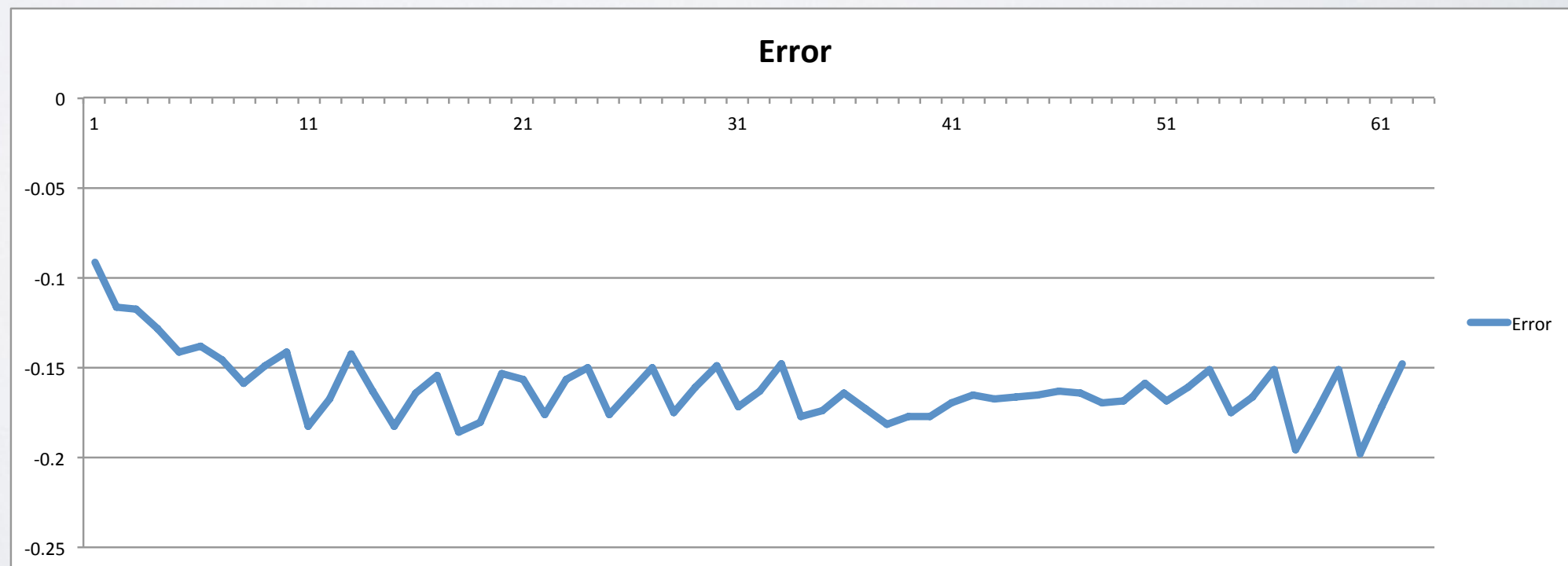


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# SMARTPHONE RIG CAL



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- Smartphones are surprisingly accurate, but need good signals

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- Look for “Piano Tuning” or “Guitar Tuning” in your app store - several free apps give 0.1 Hz readout



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- Hams have successfully participated in the FMT with Android tablets





# FREQUENCY MEASURING

Tune below frequency so sidetone is about 600 Hz

Broadcast Frequency = 9,980 KHz

# FREQUENCY MEASURING

Tune below frequency so sidetone is about 600 Hz





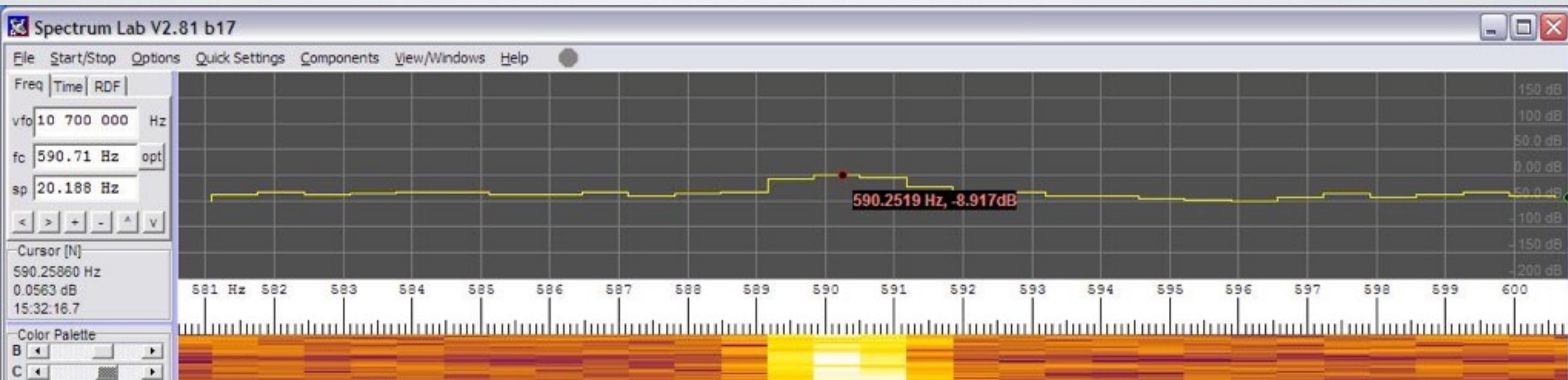
# FREQUENCY MEASURING

Tune below frequency so sidetone is about 600 Hz



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Tune below frequency so sidetone is about 600 Hz



Offset error = +0.141 Hz, so offset is subtracted



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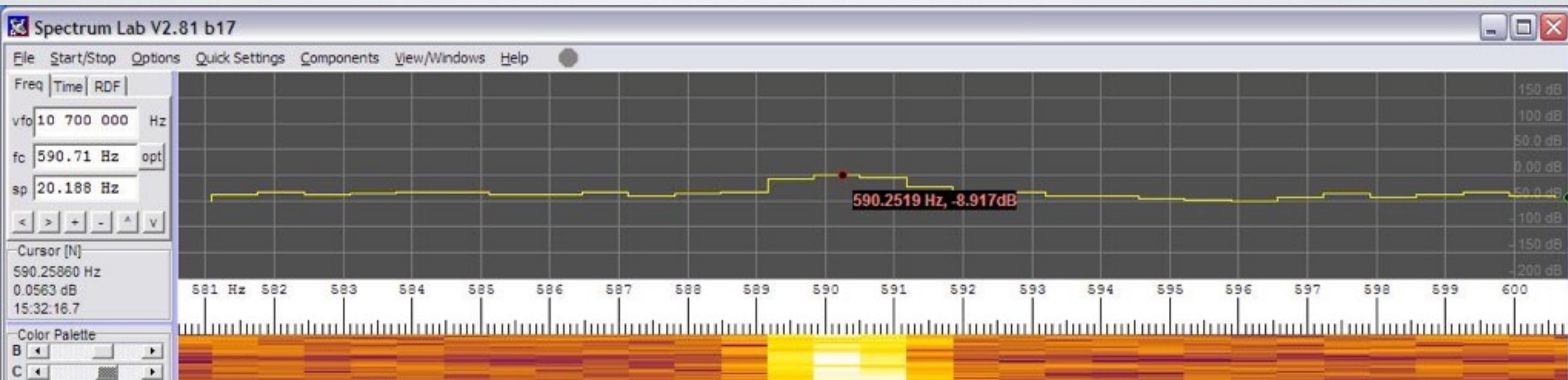


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$$\text{Tuner} + \text{Spectrum Lab} \pm \text{Offset} = \text{Frequency}$$

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Tune below frequency so sidetone is about 600 Hz



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$$\text{Tuner} + \text{Spectrum Lab} \pm \text{Offset} = \text{Frequency}$$

$$9,979,400 + 590.252 - 0.141 = 9,979,990.111 \text{ Hz}$$



# FREQUENCY MEASURING TEST

Test announcement in QST and:

<http://www.arrl.org/frequency-measuring-test>

Data entry page and previous results are at:

<http://www.b4h.net/fmt/>

Test Format (three frequencies):

- 5 minute call-up
- 2 minute test (carrier or tone)
- 1 minute sign-off

Go to designated website and enter data to nearest .01 Hz

**Perform calibrations before and after the test!**


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**ARRL** The national association for  
AMATEUR RADIO

**April 2015 Frequency Measurement Test**  
**Results**

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**April 9, 2015**

**Actual Radio Frequencies (Hz):**

	80m	40m	20m
K5CM	3,598,437.38	7,055,633.92	
WA6ZTY			14,121,570.83

**Note:** The requirement to be included in the *green box* was changed to +/- 1.5 Hz for 20 meters due to calibration issues at the transmitter that were discovered after the FMT. These issues have been corrected and will not be a problem in subsequent FMTs.

**K5CM/WA6ZTY All (<=1/1.5 Hz):**  
AA6LK, AB2UW, AB4RS, AC2DE, AF9A, AG2M, K1GGI, K2LYV, K3JQ, K3KO, K4BYN, K4KJQ, K4TRH, K5CM, K5RKS, K6APW/7, K6IQL, K6LU, K6OQK, K7HIL, K7KMQ, K9KK, KB2MN, KB8W, KC9DOA, KD2BD, KG6HSQ, KI5EE, KJ8S, KK6JTL, KM6QX, KU4PY, N0EXM, N3CRT, N3FG, N3IZN, N4AU, N5DM, N6SKM, N7EP, N8OB, NR5ON, NY7T, VE2IQ, W0CZ, W0HBK, W1KU, W2FD, W3JW, W3SA, W4JLE, W5LAC, W6BM, W6IHG, W6OQI, W7PUA, W8IMA, WA1ABI, WA4FJC, WA6RZW, WB0LXZ, WB3AKD, WB4ALM, WB6BNQ, WB8TFV

**K5CM 80 (<=1 Hz):**  
AA0CL, AA6LK, AB2UW, AB4RS, AC2DE, AD3Y, AF9A, AG2M, K1GGI, K2LYV, K3JQ, K3KO, K4BYN, K4KJQ, K4TRH, K5CM, K5RKS, K6APW/7, K6IQL, K6LU, K6OQK, K7HIL, K7KMQ, K9KK, KB2MN, KB8W, KC2LNC, KC2SYK, KC9DOA, KD2BD, KD5MMM, KG0HY, KG6HSQ, KI5EE, KJ8S, KK6JTL, KK6KFQ, KM6QX, KN1H, KU4PY, N0EXM, N3CRT, N3FG, N3IZN, N4AU, N5DM, N5LUL, N6SKM, N7EP, N8OB, N8SBE, N9CIF, NR5ON, NY7T, VE2IQ, W0CZ, W0HBK, W0PHD, W1KU, W2FD, W3FAY, W3JW, W3SA, W4JLE, W5AJ, W5LAC, W5TV, W6BM, W6IHG, W6OQI, W7KPZ, W7PUA, W8IMA, W9ZB, WA1ABI, WA1N, WA4FJC, WA6RZW, WA6ZTY, WB0LXZ, WB0OE, WB3AKD, WB4ALM, WB6BNQ, WB6HYD, WB8TFV, WC8J, WX4TW

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Actuals to nearest 0.01 Hz

# TECHNIQUES FOR THE TRULY SERIOUS



# TECHNIQUES FOR THE TRULY **FANATICAL\***

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- Record the test as a WAV file and play it back on other computers for analysis
- Feed a 10 MHz GPSDO (GPS Disciplined Oscillator) signal into your receiver and computer for nanosecond accuracy
- Warm up receiver for 48 hours in a temperature controlled blanket



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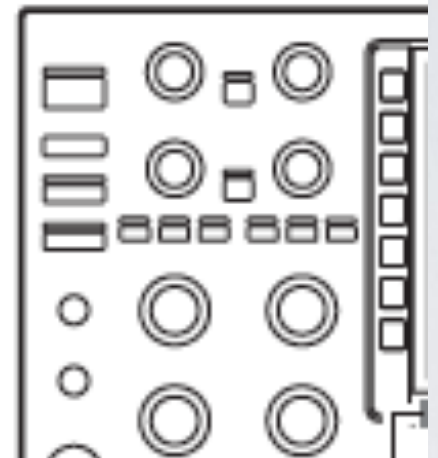
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\* No guarantee of accuracy improvement

# RIG CALIBRATION

## ■ Calibration the Frequency (approximate)

A very accurate frequency counter is required to calibrate the frequency of the transceiver. However, a rough check may be performed by receiving radio station WWV, WWVH, or other standard frequency signals.

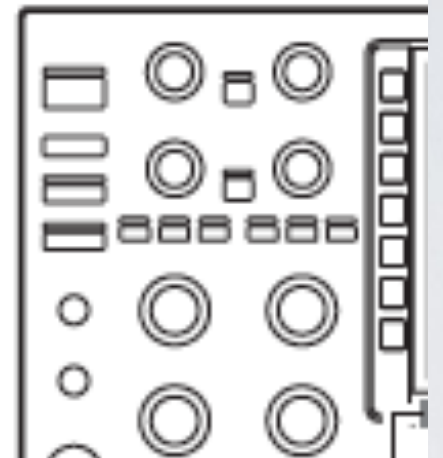




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**EXACT!**