# BeamformX Reference Manual

Version 3

May 6, 2017

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OptiNav, Inc.

# Contents

# Introduction

BeamformX is an acoustic beamforming code from OptiNav, Inc. It runs with the Signal Interface Group (SIG) ACAM 100 microphone array. If offers real time processing and post processing. It outputs beamforming images, videos, raw array data for post processing, quantitative spectra for selected parts of the scene, and source point tracking tables.

# Requirements

BeamformX requires Windows 7, 8 or 10 running on a computer that supports at least 4 parallel threads and has at least 4 GB of memory. A fast computer is preferred because the CPU speed limits the real time beamforming frame rate. The computer must have 64-bit Java, as well as SIG CCM software. Live data requires an ACAM 100 connected by USB.

# Quick Start Guide

Run the software installer from http://www.signalinterface.com/ftp.html. While you are there, also download the ACAM 100 Acoustical Camera User Manual. Download the latest version of BeamformX from http://www.optinav.info/ftp.html and place it in any convenient location on the computer. This document is written for BeamformX Version 3, May 6, 2017. Install 64-bit Java if it is not already installed.

Connect the ACAM 100 to the computer by USB and look for a blinking red light on the array controller. If the light does not blink, consult "Appendix A. Troubleshooting" in the ACAM 100 manual.

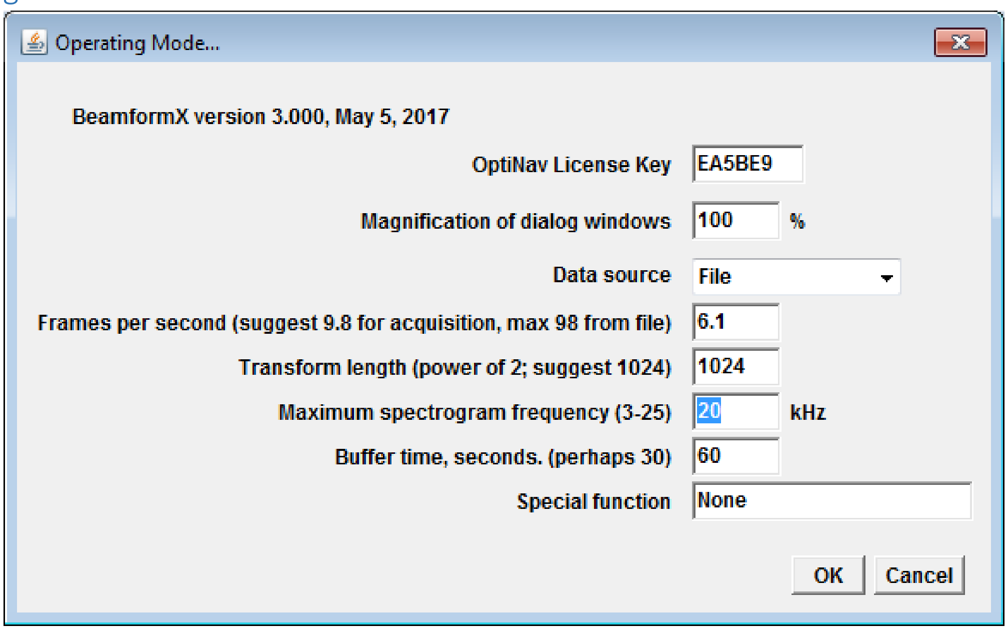
Run BeamformX. You should see the "Operating Mode" dialog. If the size of the dialog is inappropriate, change the value in "Magnification of dialog windows". Enter the OptiNav License Key for BeamformX. Choose "Connected array" for Data source. If this option not shown, then the red light is probably not blinking. Fix this problem and rerun BeamformX. Click OK. You should see at least the Control, Display, Spectrum, and Spectrogram windows. Arrange them as desired. Except for the Control Dialog, the other windows can be resized by dragging the corners. The sizes can also be changed using Control/Settings/Magnification of Display, Spectrogram, and Spectrum.

Press “Control/Camera” and set the “Field of View Magnification factor” to 1.5 and the “Undistortion factor” to 1.2. If you know the Camera pan, tilt, and resolution values, enter these in the dialog and press OK. Create some sound in the field of view of the array. You should see a Beamforming spot on the Display. Experiment with the Freq and Min and Max sliders. Click Pause and Resume to see what these do. Create an ROI on an interesting feature in the Spectrogram to examine it and press Resume to continue. Experiment with the focus distance setting, *z*, in meters at the lower left of the Control dialog and “Decay time”. To exit BeamformX, close the Control or the Display window.

# Reference

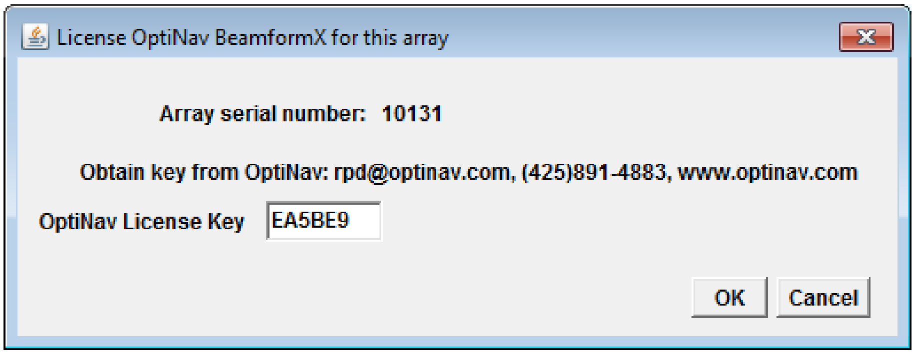
The user interface of BeamformX is designed to be mostly self-explanatory, but some of the features require discussion. The following is intended to document every part of the program, arranged by the structure of the user interface. Please direct any questions or suggestions to Bob Dougherty, OptiNav, Inc., rpd@optinav.com, (425) 891-4883.

## Operating Mode




### OptiNav License Key

The key from OptiNav, Inc. that is required to run BeamformX. It is paired to the array serial number. If the entered license key is not correct, you may see a dialog giving the serial number. Obtain the license key and enter it.




## Magnification of dialog windows

This controls the size dialog windows for the current run and the size of this startup window for the next run.

## Data source

The choices are “Connected array” and “File”. If the no array is correctly installed and set up, then the only choice is “File”. This refers to a binary (.bin) log file that was previously created by BeamformX. The file format is simple and open.

## Frames per second

This is a request for the rate (*fps*) at which BeamformX will update the Spectrum and Spectrogram and attempt to update the Display and the Peak list.  Some Display and Peak list updates may be skipped if the computer cannot perform the beamforming fast enough.  Faster computers and lower frame rates increase the likelihood that no updates will be skipped. “Settings/Wait for beamforming” and “Settings/slow motion playback factor” can also be used to prevent skipping. Note that the optical video camera has a maximum rate of 30 fps, so higher rate choices will cause some optical images to be reused. For most applications, 9.8 fps is a reasonable choice.

Not all values of the frame rate *fps* are feasible. BeamformX makes a choice based on the dialog input and the transform length, as discussed below.

## Transform length

This setting (*TL*) determines the narrowband analysis bandwidth:

$$\Delta f = \frac{50{,}000\ \frac{\text{samples}}{\text{sec}}}{TL}$$

It also determines the feasible values of fps because each frame contains a whole number of data blocks of *TL* sample each. Specifically, $fps = \frac{\Delta f}{N}$, where *N* is a whole number. For example, if *N* = 1024, then $\Delta f$ = 48.82 Hz, and the feasible values of fps are 48.82, 24.41, 16.27, 12.2, 9.76, 8.13, 6.97, 6.10, …..

The block length, $\frac{1}{\Delta f} = \frac{TL}{50{,}000}$ sec, is the (horizontal) time step of the Spectrogram. The (vertical) frequency step of the Spectrogram is $\Delta f$.

*TL* must be a power of 2. The smallest allowed value is 8 and the largest is the sampling rate (50,000 samples per second) divided by the frame rate. While collecting data from a connected array, the largest value of TL is 4096. The larger values are possible while post processing from a file.

The recommend value of *N* for most cases is 1024. Choosing *N* = 2048 or 4096 makes more frequency choices available, which may be helpful for low frequency beamforming, but also makes the Spectrogram window very tall and narrow. The Spectrogram window can be trimmed as described below.

Selecting "Settings/Beamforming bandwidth/Engine Order" enters a mode that scales by the frequency by the RPM/60 in order to identify tones created by rotating machinery such as automobile engines. In typical applications of this mode, the value of TL used during the post processing should be chosen to be very large, such as 16,384, so that the different engine order components will appear in distinct frequency bins. When acquiring data for this type of analysis, the value of fps should be given a small value, such as 3, so that the large TL value is can be selected during the post processing. The value of TL during the data capture is not important in this case, since the large value will be selected during post processing.

### Maximum spectrogram frequency

Set this to a value smaller than 25 kHz to reduce the height of Spectrogram window. This may be desirable if the Spectrogram is unreasonably tall and narrow and the high frequency portion of the Spectrogram is not needed.

For Engine Order analysis, as discussed above, the Maximum spectrogram frequency should usually be set to the minimum, 3 kHz, since the large TL means that the Spectrogram potentially has many lines.

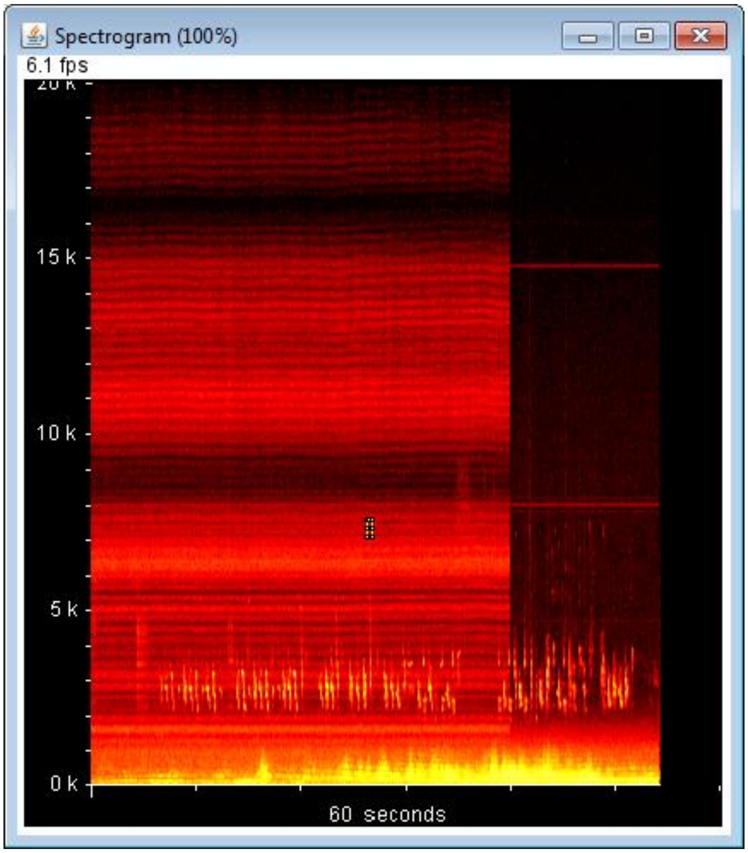
### Buffer time, seconds

This is a request for the temporal (horizontal) extent of the Spectrogram. This is the duration of a ring buffer that can be used to repeatedly examine a portion of the data when acquisition is paused. If the requested time, together with the block length, $\frac{TL}{50,000}$, would cause the Spectrogram to have more the 512 columns, then a smaller buffer time is used.

### Special function

BeamformX has certain special capabilities that are accessed by entering the appropriate key words in the Special function box.

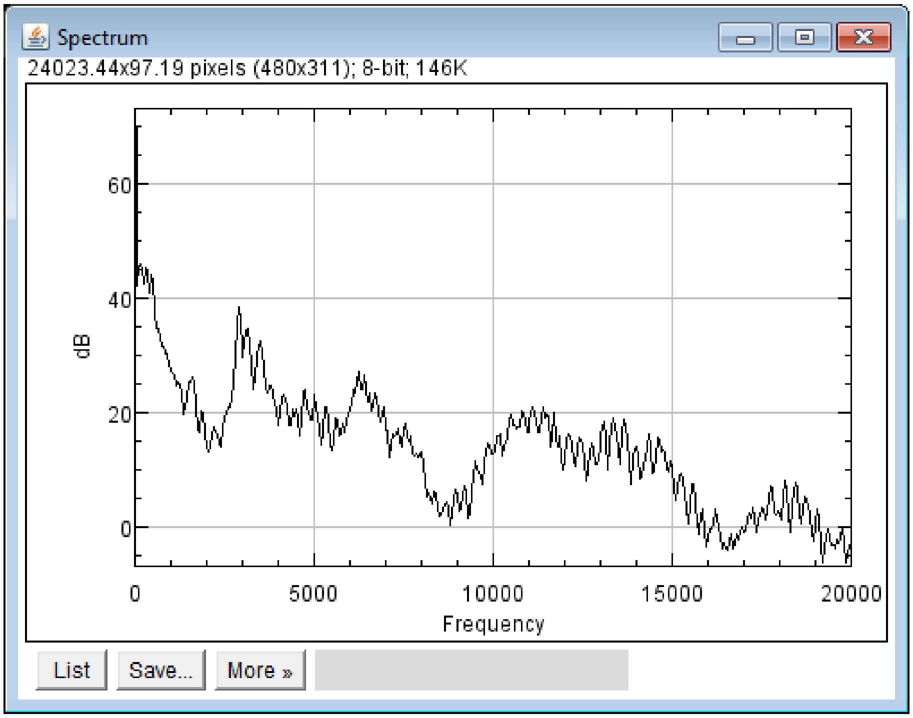
## Spectrogram




This gives a spectrogram for the last few seconds of data. It scrolls continuously if data input is not paused. Creating a Region of Interest (ROI) on the Spectrogram causes input to pause, if it is not paused already, and updates the Display using the frequency and time ranges selected in the ROI. The time range becomes the new "Decay time" (see Control/Settings). The frequency range is redefined from the user input to one of three bandwidth choices: Narrowband, 1/12 octave band, or 1/3 octave band (see Settings/Beamforming bandwidth). The ROI can be nudged horizontally or vertically by using the arrow keys on the keyboard. When using the arrow keys, it is important to wait for the Display to update before another key press. This can take a significant time if the Decay time is long, since a lot of data has to be processed from scratch. Pressing the arrow keys too rapidly causes unexpected movements of the ROI because BeamformX is unable to keep up with the requests and gets lost.

The data for the Spectrogram is usually a single microphone (see "Settings/microphone for spectrum and sound"). Alternatively, if an ROI is present in the Display, then the Spectrogram gives analysis of the focused point at the center of the ROI. The method of focusing depends on the checkbox "Settings/Active focusing".

## Spectrum




The Spectrum shows the narrowband spectrum from the selected microphone or center of the ROI on the Display. It represents either the latest data, for the live case, or the time of the ROI in the Spectrogram for the paused case. Exponential averaging is applied, using the time constant given in "Control/Settings/Decay time". The Sound Pressure Level shown is integrated over the narrowband bandwidth, $\Delta f$, and given in dB re. 20 $\mu$Pa. (See Operating Mode.) The levels are A-weighted if "Control/Settings/A-weighting" is selected.

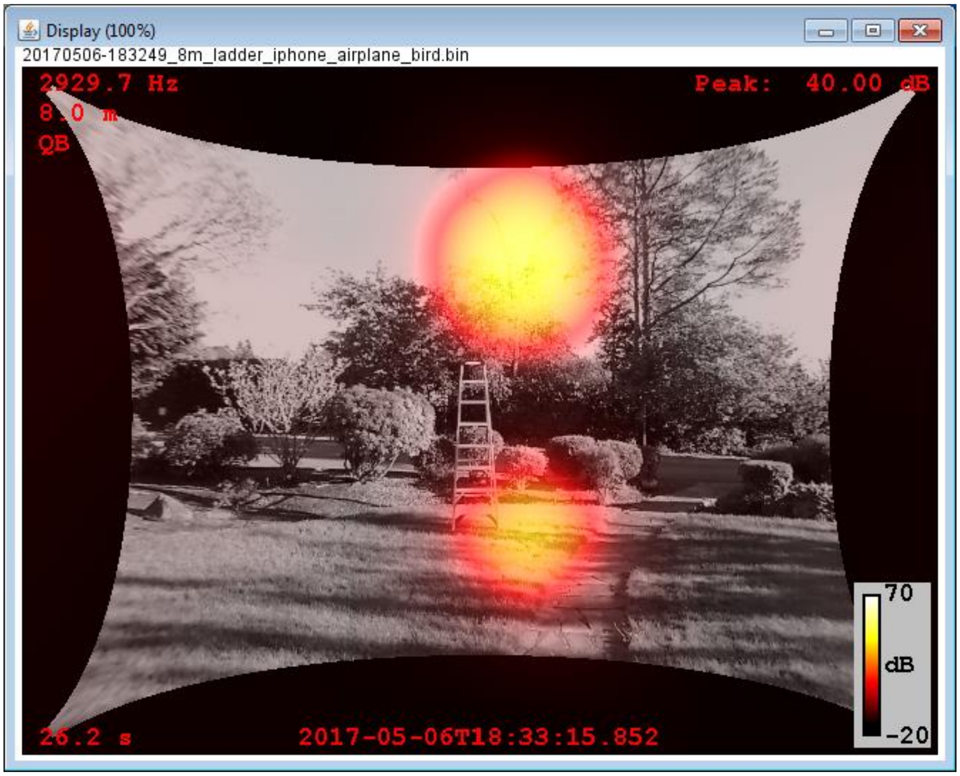
The levels, and the A-weighting, are approximate. The array microphones were calibrated by SIG with a precision calibrator when the array was assembled, but no further measures have been taken to ensure calibration accuracy.

The buttons on the bottom of the Spectrum can be used to list the spectrum, copy the values to the system clipboard, save the spectrum as a text files, and other functions. The dB scale limits are controlled by the Min and Max sliders on Control. The frequency extent is set in "Settings/Upper frequency of spectrum (also limits RPM tracking)". The scales can also be adjusted using the menu under the More button, but changes made to the ranges with the More button are not retained when some of the other adjustment in BeamformX are made.

One feature of the More button below the spectral displays is the option to make a high resolution plot for publication. The line plot utility in BeamformX is derived from the ImageJ package.

Clicking on the main panel of the Spectrum causes the beamforming analysis center frequency to shift to the clicked frequency, but unlike creating an ROI on the Spectrogram, does not pause the input if it is running. This is a quick way to choose a spectral peak frequency for study.

## Display

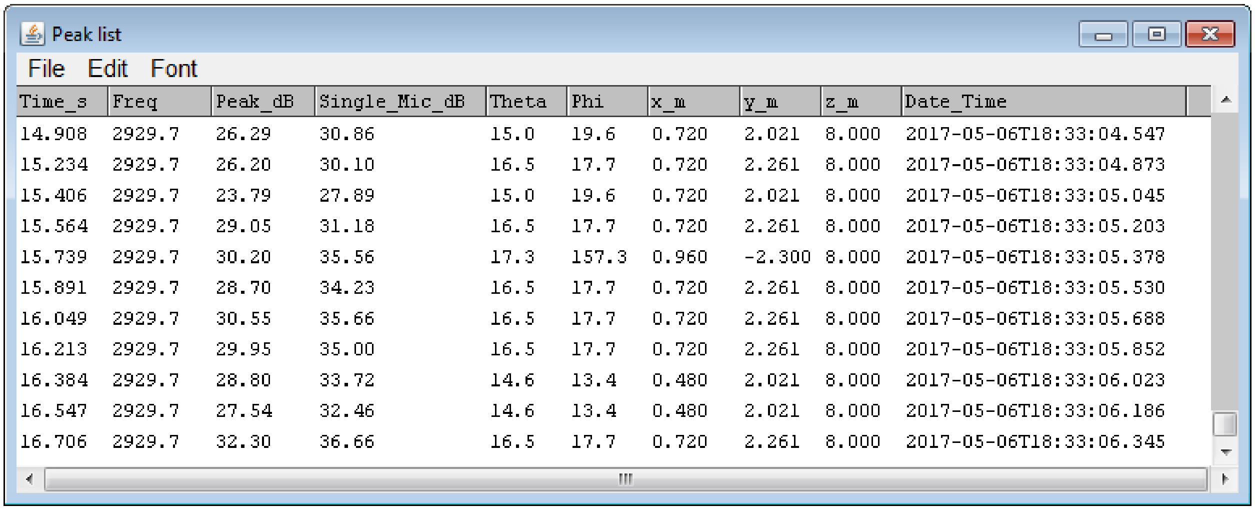



The Display gives the beamform map. The center frequency is shown at the upper left, along with the focus distance, *z*, and the notation QB represents Quantitative Beamforming, which is a version of Functional Beamforming. The legend of the color scale shown in the lower right corner. Optional notations include the time from the start of data at the lower left, the date and time at the bottom, and the peak SPL at the upper right. The portion of the map that is covered by the optical video camera shows a black and white camera image that has been adjusted to correct for optical distortion. The area of the map outside the optical image has a black background.

Creating an ROI on the Display, in addition to affecting the peak and integral values, causes the Spectrum and the Spectrogram to display values that are focused to the center of the ROI. If mute is not selected, the audio output also reflects the ROI.

See the discussion of “Limit to ROI”, “Inhibit ROIs” and “Partitioning ROIs” for other actions of ROIs.

## Peak list



Peak list
File Edit Font

| Time_s | Freq | Peak_dB | Single_Mic_dB | Theta | Phi | x_m | y_m | z_m | Date_Time |
|---|---|---|---|---|---|---|---|---|---|
| 14.908 | 2929.7 | 26.29 | 30.86 | 15.0 | 19.6 | 0.720 | 2.021 | 8.000 | 2017-05-06T18:33:04.547 |
| 15.234 | 2929.7 | 26.20 | 30.10 | 16.5 | 17.7 | 0.720 | 2.261 | 8.000 | 2017-05-06T18:33:04.873 |
| 15.406 | 2929.7 | 23.79 | 27.89 | 15.0 | 19.6 | 0.720 | 2.021 | 8.000 | 2017-05-06T18:33:05.045 |
| 15.564 | 2929.7 | 29.05 | 31.18 | 16.5 | 17.7 | 0.720 | 2.261 | 8.000 | 2017-05-06T18:33:05.203 |
| 15.739 | 2929.7 | 30.20 | 35.56 | 17.3 | 157.3 | 0.960 | -2.300 | 8.000 | 2017-05-06T18:33:05.378 |
| 15.891 | 2929.7 | 28.70 | 34.23 | 16.5 | 17.7 | 0.720 | 2.261 | 8.000 | 2017-05-06T18:33:05.530 |
| 16.049 | 2929.7 | 30.55 | 35.66 | 16.5 | 17.7 | 0.720 | 2.261 | 8.000 | 2017-05-06T18:33:05.688 |
| 16.213 | 2929.7 | 29.95 | 35.00 | 16.5 | 17.7 | 0.720 | 2.261 | 8.000 | 2017-05-06T18:33:05.852 |
| 16.384 | 2929.7 | 28.80 | 33.72 | 14.6 | 13.4 | 0.480 | 2.021 | 8.000 | 2017-05-06T18:33:06.023 |
| 16.547 | 2929.7 | 27.54 | 32.46 | 14.6 | 13.4 | 0.480 | 2.021 | 8.000 | 2017-05-06T18:33:06.186 |
| 16.706 | 2929.7 | 32.30 | 36.66 | 16.5 | 17.7 | 0.720 | 2.261 | 8.000 | 2017-05-06T18:33:06.345 |

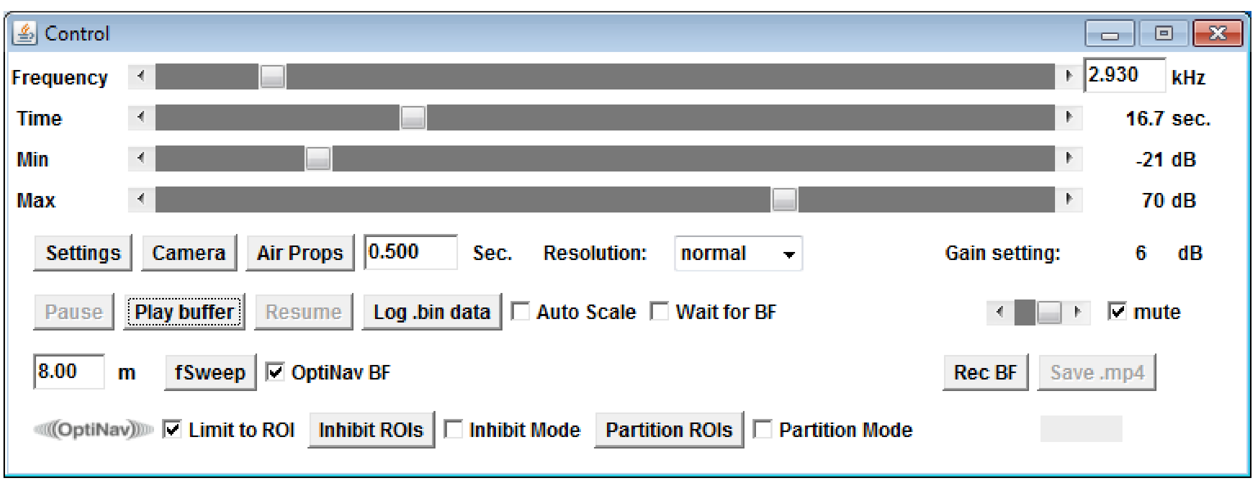
The Peak list, if shown, gives statistics concerning the peak value in the beamform map. The 3D coordinates in meters assume that the focus distance, *z*, is set correctly.

Each time the display is updated, a row is added to the Peak list. By examining the times listed, it is possible to determine whether frames have been skipped due to insufficient CPU resources for the frame rate.

Using the File menu, it is possible to export the Peak list as a test file for a spreadsheet or for input to another program, such as a 3D tracking application.

In Partitioning mode, the Peak list is replaced by the "Partition Results" table.

## Control




In the standard (not Engine Order) mode, the Control dialog has five sliders, three text boxes, five checkboxes, eleven buttons, one choice dialog, a progress bar, and some ancillary text items. Six of the buttons, ROIs, Settings, Camera, Air Props, fSweep, Inhibit ROIs, and Partitioning bring up additional dialogs.  Choosing "Engine Order" in Settings/Beamforming bandwidth adds an additional text box, RPM, and an additional checkbox, Track RPM, to the Control dialog.

## Control sliders

### *Freq*

This sets the center frequency of the analysis band used for the beamforming Display. It does not pause the input, but does cause a recomputation of the Display if the input is paused. The center frequency is the FFT frequency for the narrowband case, and the geometric mean of the upper and lower band limits for the proportional band cases, 1/3 and 1/12 octave band.

### *Time*

This pauses the input, adjusts the time of the ROI in the Spectrogram, and prompts a recomputation of the Display.

### *Min and Max*

These set the minimum and maximum dB levels for the Spectrum and the Spectrogram. If Auto Scale is not selected, then they also set the minimum and maximum levels of the color scale of the Display. If Auto Scale is selected, then Min is becomes the lowest allowed level of the color scale of the Display. Sources below this level are not shown in the Display. Max has no effect on the Display if Auto Scale is selected.

### *Gain*

The short slider near the lower right corner of Control sets the gain of the audio output. When it is adjusted, the selected dB gain value (-80 to +6) is displayed in the text box above the slider. In addition to affecting the computer speaker output, the Gain value is applied to the sound track of output MPEG 4 videos. This can be useful in the common case that the video sound would otherwise be too loud.

## Control checkboxes

### *Auto Scale*

If Auto Scale is selected, then the Display sets the top color to the level of the highest beamforming result. The bottom color is set lower than the top color by the amount set in the Auto Scale slider. If Auto Scale is not selected, then the top color and the bottom color for Display are set to the Max and Min slider settings, respectively. This makes the Display color scale absolute. The dynamic range of the OptiNav Beamforming algorithm in BeamformX version 3 is high enough that Auto Scale is generally not required. It is usually effective to leave Auto Scale unselected and adjust the Min setting to be higher than the apparent noise floor in the Display.

### *Wait for BF*

In playing from the Spectrogram buffer or from a binary Log file (.bin), Wait for Beamforming causes the processing to slow down, if necessary, to enable the beamforming to complete for each frame. This causes all of the times to appear in the tabular results and the recorded beamforming results stack. Can give odd stuttering sounds from the computer speaker if Mute is deselected because the playback stops and starts. Has no effect with live data.

### *OptiNav BF*

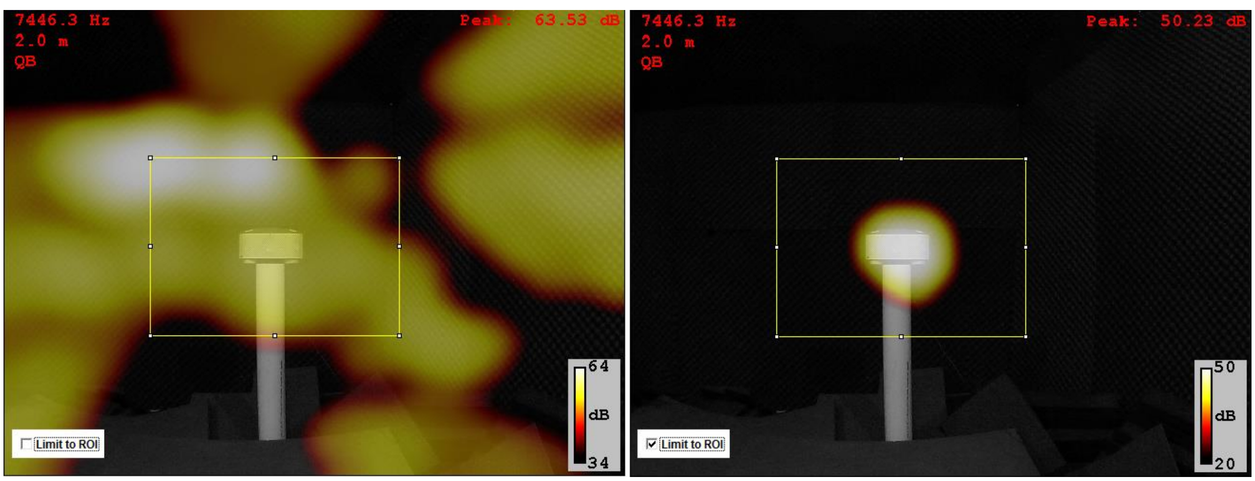
This selects the OptiNav beamforming algorithm known as Quantitative Beamforming. This method, a special case Functional Beamforming, is protected in part by a patent application and in part by trade secrets. It excels in terms of resolution, speed, dynamic range, and level accuracy. Deselecting OptiNav BF chooses the conventional Frequency Domain Beamforming (FDBF) algorithm. FDBF can have serious difficulties with sidelobes for sources both inside and outside the beamform map, potentially leading to incorrect conclusions regarding the sound sources. OptiNav BF should always be selected. Many of the features of BeamformX do not function if OptiNav BF is not selected.

### *Limit to ROI*

If the Display has an ROI (Region of Interest, created by clicking and dragging in the Display with the mouse) and OptiNav BF is selected, then selecting Limit to ROI causes the algorithm to exclude sources that are not inside the ROI. This is a powerful way to examine the source distribution within a certain region while blocking interference from outside the region.

In the example shown below, the sound sources are the loundspeaker in the center of the image and a more-powerful loudspeaker out of view behind the phased array. The single microphone SPL in the analysis band was 76.39 dB. In the image on the left, there is an ROI around the loudspeaker, but Limit to ROI is not checked. Despite its high dynamic range capability, OptiNav BF is unable to locate the loudspeaker source in this case, and, instead, shows sidelobes and/or multiple reflections from the interfering source at a level of 63.53 dB. Choosing Limit to ROI removes the interference and shows the loudspeaker at 50.23 dB, or 26.16 below the single microphone level. The SNR is -26.15 dB.

If the Display Window does not have an active ROI, then “Limit to ROI” has no effect because, in that case, the ROI is taken to be the entire window, so no sources are excluded.




### *Inhibit Mode*

This checkbox turns on or off Inhibit Mode. The effect of Inhibit Mode is to suppress any sources that are located within Inhibit ROIs. This is similar to the effect of “Limit to ROI”, but more selective. In “Limit to ROI”, any source that is not within the active ROI of the image is suppressed. In “Inhibit Mode”, the suppression applies to particular sources that are associated with one or more Inhibit ROIs. The button “Inhibit ROIs” bring up a dialog that is used to create these ROIs. This process is described in the paragraph for that button.

### *Partition Mode*

This checkbox turns on or off Partition Mode. This mode, like “Inhibit Mode”, requires one or more special ROIs. They are created with the “Partition ROIs” dialog. The ROIs are arranged so as to contain acoustic sources of interest. When Partition Mode is selected, each of the Partition ROIs operates independently to exclude sources that are not within the particular ROI. The highest source level within the ROI is found and used to color the entire ROI in the Display. The resulting levels are listed by ROI in the table “Partition Results” if the Peak Table is active as determined in the Settings dialog. If a frequency sweep (see fSweep) is performed in Partition Mode, then, in addition to the tabular results, a plot showing the spectra for the various sources is produced. By naming the ROIs in the Partition ROIs dialog, the curves in the plot can be designated descriptively in the legend. The names also appear in the heading of the table.

### Mute

This mutes the computer speaker, and is selected by default to prevent feedback. Feedback can also be reduced by decreasing the Gain, creating an ROI on the Display, and, of course, playing non-live data from the Spectrogram buffer or a .bin file.

## Control textboxes

### *Sec.*

The time constant for the exponential filter for the Spectrum and the Display, in seconds. Set it to a short time to follow rapidly changing sources or a longer time for stationary sources to give better stability and possibly resolution and dynamic range.

### *m*

The focus distance, *z*, in meters.

### *RPM*

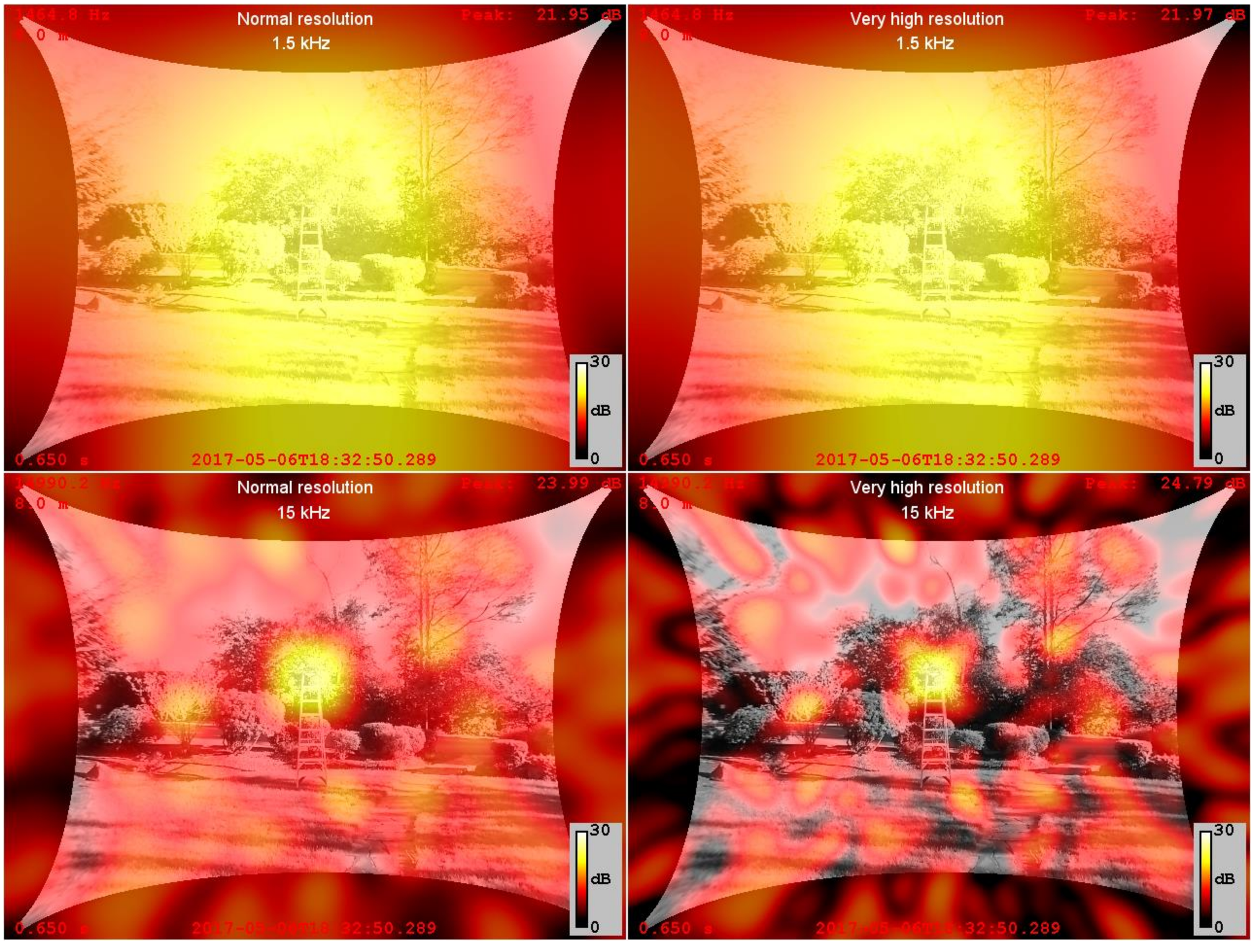
This textbox is only shown if “Settings/Beamforming bandwidth” is set to “Engine Order.” The RPM entered is used to replace the frequency scales with $Engine\ Order = \frac{Frequency,Hz}{\frac{RPM}{60}}$. No special order analysis is performed; it is important to analyze steady intervals of data for which the RPM is known so that it can be entered correctly.

## Control choice dialog

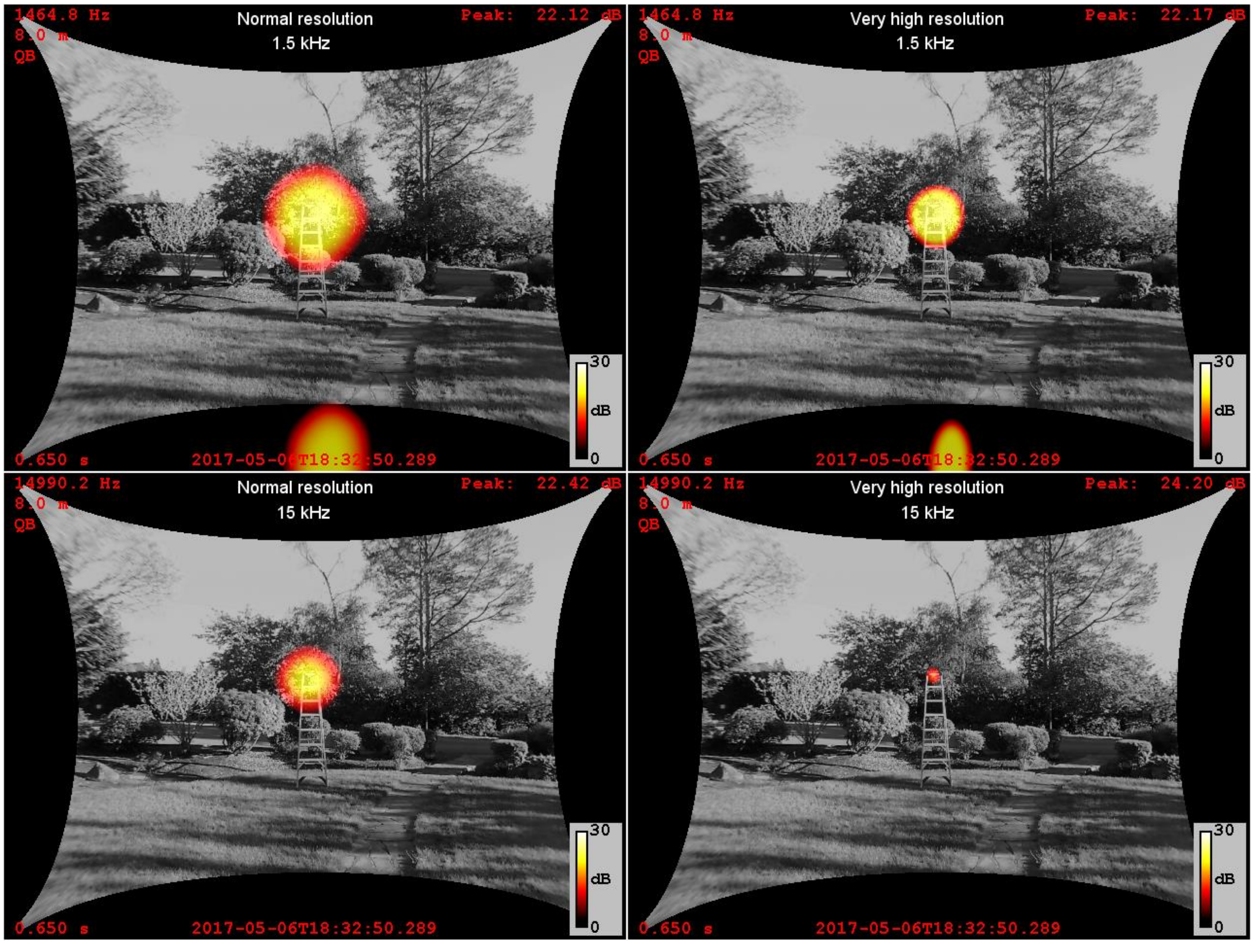
### *Resolution*

In conventional beamforming (FDBF), the size of the spots in the Display representing small sources depends on the frequency. Lower frequency gives larger spots. In OptiNav BF, size of the spots for compact sources is much less sensitive to frequency, but does depend on the Resolution choice: low, normal, high, or very high. A higher resolution setting gives smaller spots, but requires slightly more computer time because the beamforming is performed using a finer internal grid. The very high resolution setting is disabled during live array operation because it may be too slow to keep up. The progress bar in the lower right corner of the Control dialog is active for the high and very high resolution settings so that it is clear that something is happening during the computation.

Examples of the effect of frequency and the resolution choice are given the following two images, first FDBF and second Quantitative (OptiNav) beamforming. The data and the other settings are the same for the two images. An iPhone with a white noise app was placed on top of the ladder to act as the sound source. This comparison between FDBF and QB illustrates the reason for the suggestion that OptiNav beamforming should always be used.

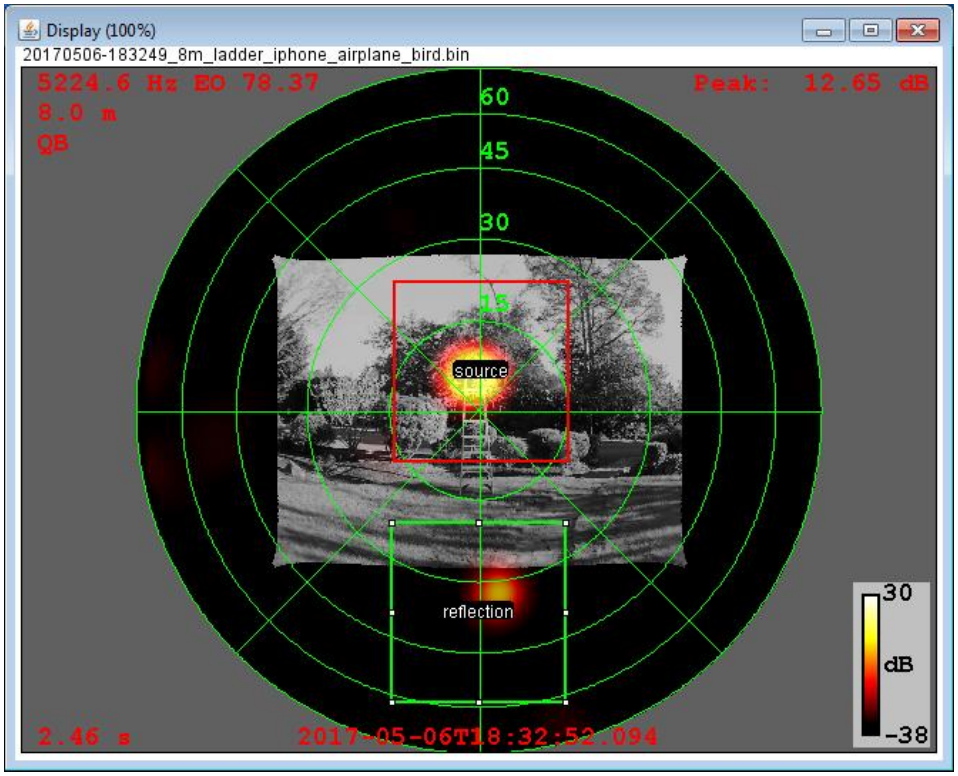



Effect of frequency and the Resolution choice for conventional beamforming (no OptiNav BF).

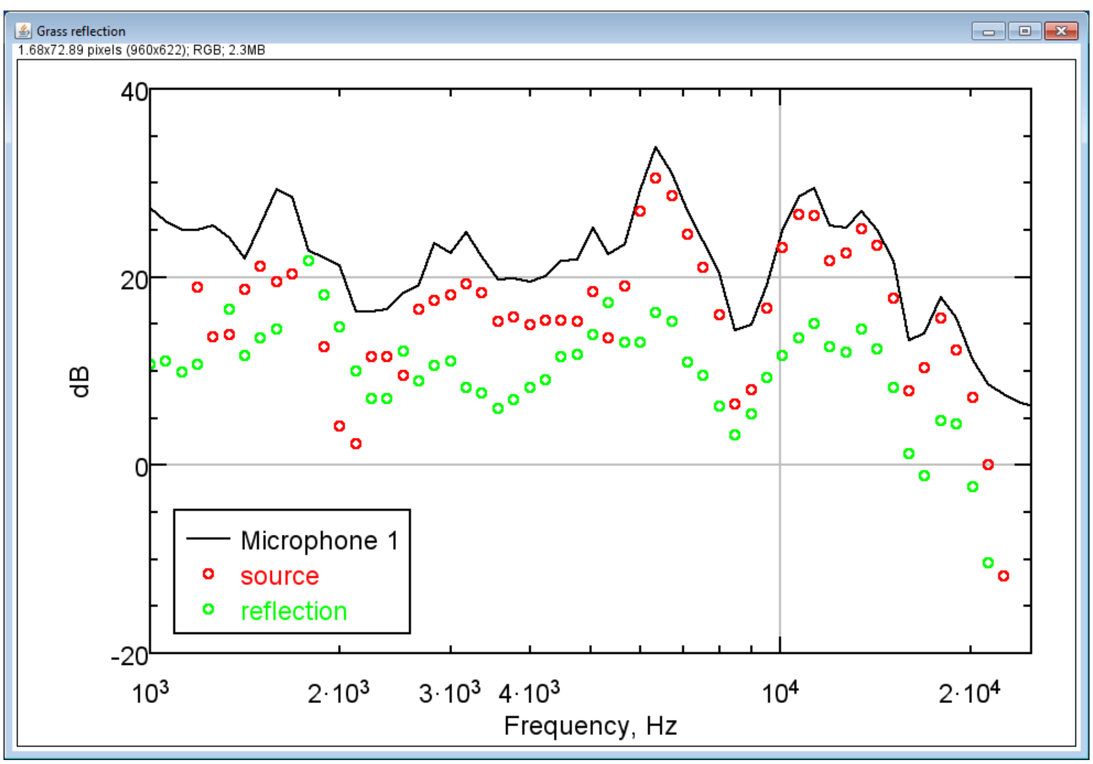



Effect of frequency and the Resolution choice for Quantitative Beamforming (OptiNav BF).

The spot at the bottom of the images for 1.5 kHz represents reflection by the grass. The reflection is not seen at 15 kHz because it is too weak in relation to the direct source to be seen at the same time in these images, but applying “Limit to ROI”, “Inhibit ROIs” or “Partition ROIs” can reveal the reflection at 15 kHz. Its level is 10.4 dB, which is 12 dB lower than the direct source at 22.4 dB. See the discussion of these options. Using two Partition ROIs as shown below, the spectra of the direct and reflected sounds can be found from a frequency sweep

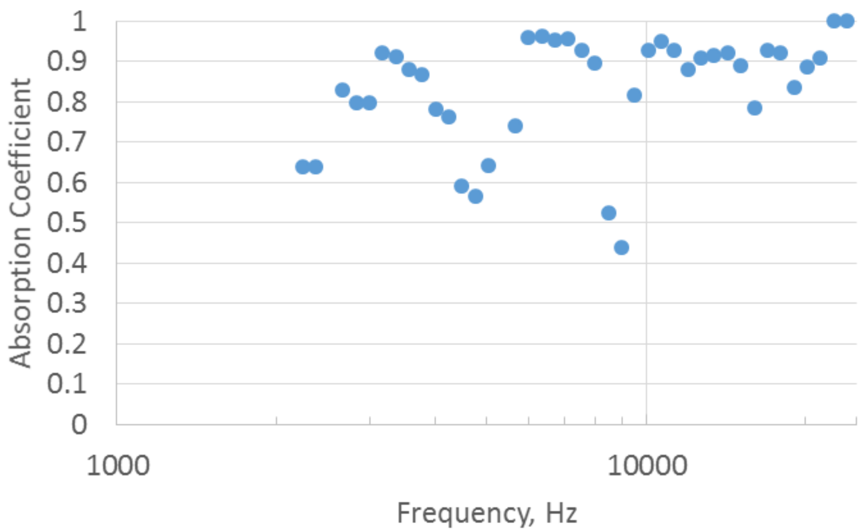



Partition ROIs for measuring absorption coefficient of grass.




Source and reflection spectra in grass reflection data.

Exporting the Partition Results table to a spreadsheet and converting to the absorption coefficient gives the following. Extending this lower frequency would require a more robust sound source than an iPhone.

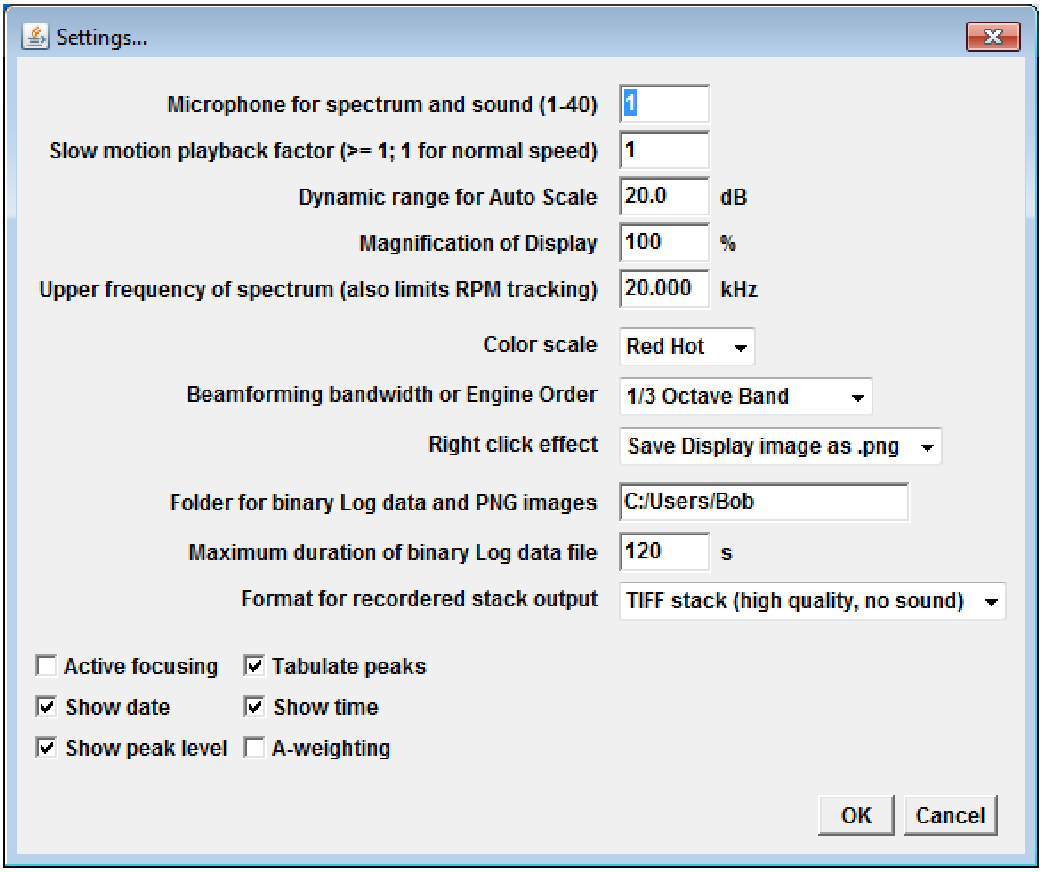



Derived absorption coefficient of grass.

## Control buttons

### *Settings*

This brings up the Settings dialog:




Settings dialog.

## Microphone for spectrum and sound (1-40)

Since all of the microphones are so close together, changing this this should not produce big changes. It can be useful for identifying problem microphones. Some of them have more 15 kHz camera noise than others. As noted elsewhere, making an ROI on the Display overrides this for the spectrum and the audio output.

## Slow motion playback factor

This causes playback from the Spectrogram buffer to take place at slower than real speed. Combined with a high frame rate (see Operating Mode), which requires a short transform length (also see Operating Mode), this can be used to make a video that temporally separates echo images from an impulsive source in a large reverberant space. It can also be used to create high speed video of rapidly moving sources, at least the acoustic channel of the video. The optical part is limited by the 30 Hz frame rate of the video camera.

## *Dynamic range for Auto Scale*

This sets the range of dB levels covered by the color scale if the Auto Scale checkbox is selected in the Control dialog. A small setting, such as 3 dB, shows only the loudest sources. Increasing the setting can reveal weaker sources, up to a limit that depends on the situation. See “Limit to ROI” and “Inhibit ROIs” for ways to find still weaker sources.

### Magnification of Display

Control the size this window. The size can also be adjusted by dragging the corners of the window.

### Upper frequency of spectrum

Limits the range of frequency shown in the Spectrum.  Also limits the frequency range used for tracking RPM in Engine Order mode.

### Color scale

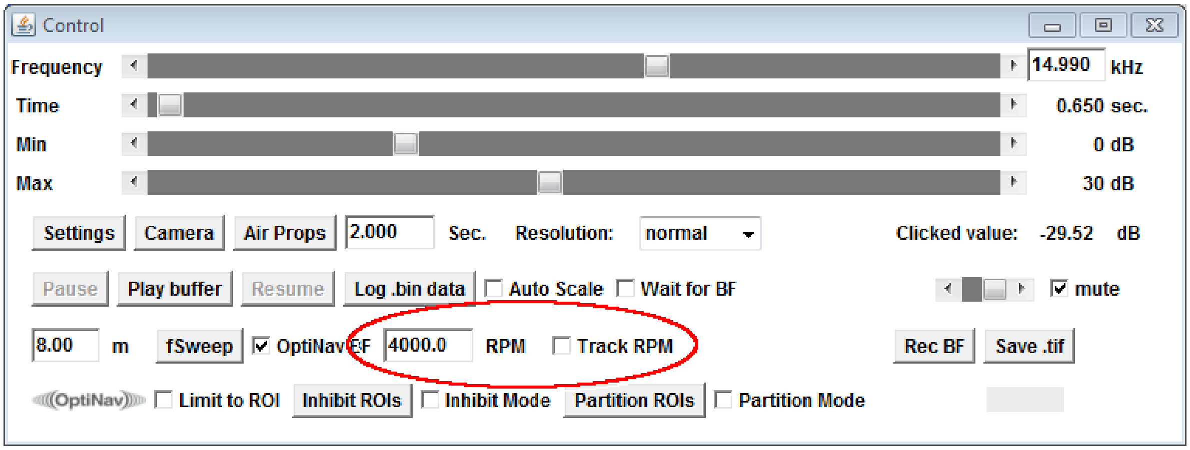
The choices for the color contour maps are Red Hot, Rainbow, and Fire. The preferred map is Red Hot because it translates correctly when rendered in grayscale and should be suitable for colorblind viewers. Rainbow is more colorful.

### Beamforming bandwidth

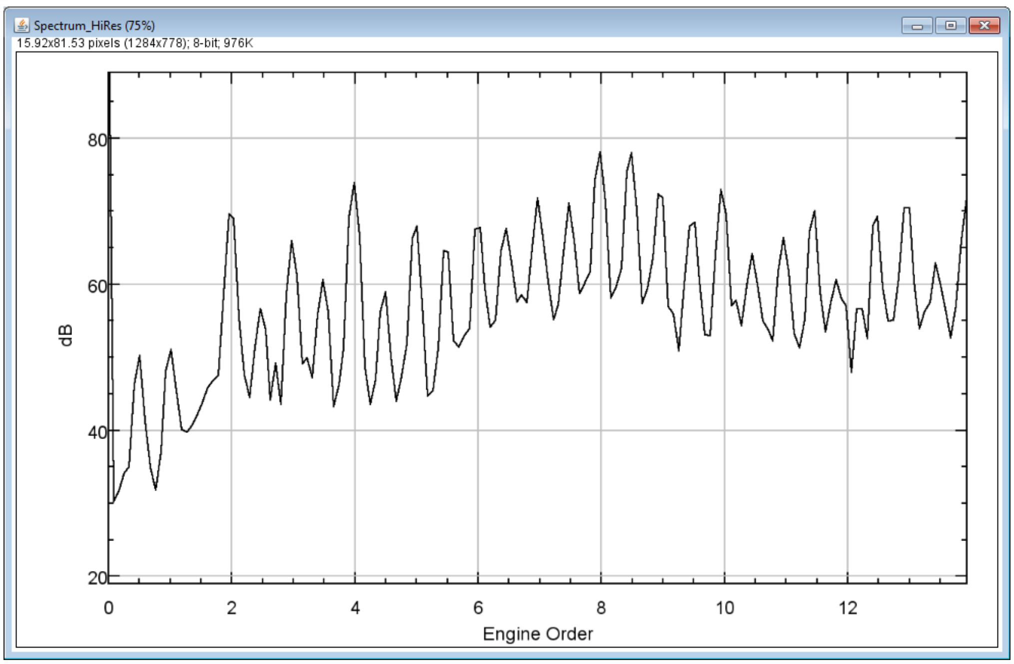
The choices are narrowband, 1/12 Octave Band, 1/3 Octave Band, and Engine Order.  The beamforming levels shown in the Display and the text tables are integrated over the selected band. The narrowband bandwidth is $\Delta f = \frac{50{,}000\,\frac{\text{samples}}{\text{sec}}}{TL}$, where TL is the transform length that is specified in the Operating Mode dialog at startup. Wider bands usually give better beamforming results because more information is available to the algorithm, so 1/3 OB is often preferred when searching for sources. A disadvantage of 1/3 OB is that broadband sources far from the center of the image can be artificially extended in the radial direction.

When the frequency is specified directly using the Freq slider or text box or by clicking on the Spectrum or the Spectrogram, the selected frequency is the center of the 1/12 or 1/3 OB. When performing a frequency sweep (see Control/fSweep), the preferred 1/12 or 1/3 octave bands are used.

Choosing Engine Order for the Beamforming Bandwidth adds the RPM text box and the Track RPM checkbox to the Control dialog. The entered RPM is used to replace the frequency axis of the spectral plots by engine order, and RPM and engine order columns are added to the tabular output. Checking Track RPM causes BeamformX adjust the RPM to try to make spectral peaks occur at engine orders 0.5, 1,  1.5, 2, 2.5, … $\frac{f_{max}}{\left(\frac{RPM}{60}\right)}$, where $f_{max}$ is the Upper frequency of the spectrum entered in Setting. The process is the collect from an engine runup test while pausing at a an RPM that is known, at least approximately. While post processing the data, set the time to the interval where the RPM is known, enter this into the RPM box, and select “Track RPM.” Stepping through preceding or following times, the RPM should adjust to follow the data. The transform length should be set high enough that the different engine orders are in separate narrowband frequency bins.

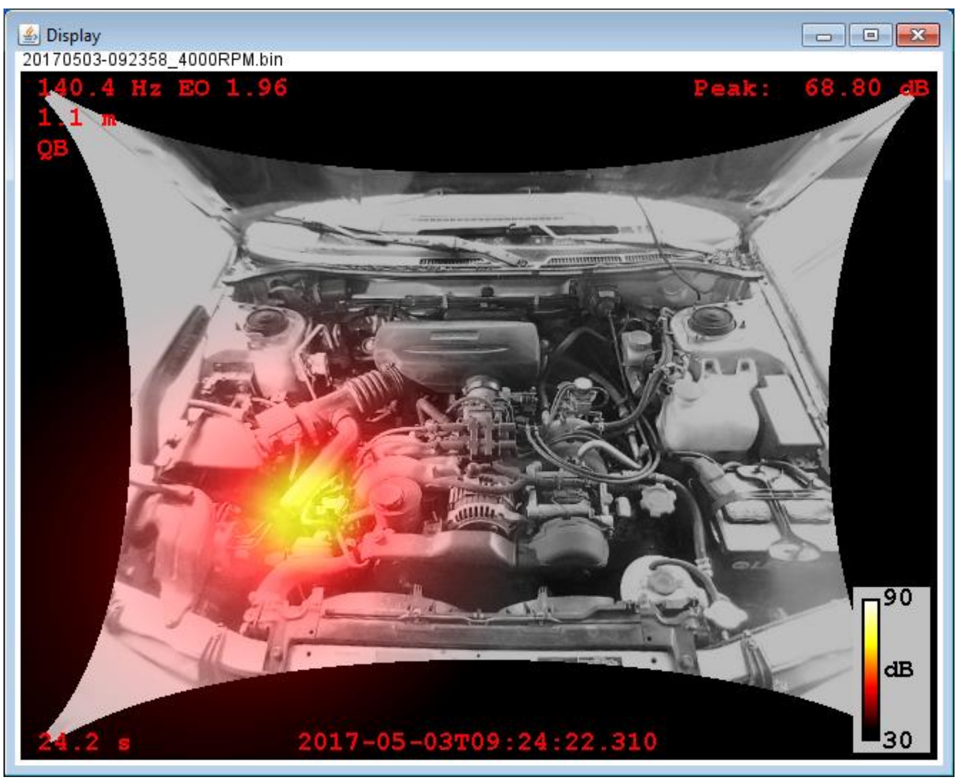



Control dialog with “Settings/beamforming bandwidth or engine order” set to “Engine Order”.




Engine order spectrum from an automobile engine. “Transform length (power of 2 suggest 1024)” set to 8,192 at startup. “Settings/beamforming bandwidth or engine order” set to “Engine Order”. “Settings/Upper frequency of spectrum (also limits RPM tracking)” set to 1 kHz.

Setup for automobile engine order test.




Automobile engine at 4304.6 RPM, engine order 2 (140.4 Hz).

## Right click effect

The choices are “Save Display image as .png” and “Start/stop binary recording”. If the Display window is the front window (the most recently clicked upon), then issuing a right click event with the mouse will cause a still image of the Display to be saved or start or stop binary recording of a Log file. The destination folder (see below) must be set for still images to be saved. If the destination folder is not set and the "Start/stop binary recording" option is used, the BeamformX will prompt for a destination before starting the recording.

### Folder for binary Log data and PNG images

This is the destination folder for .png images from right clicks and the default folder for binary recording files. If this folder is specified, then starting binary recording with a right click or by pressing "Control/Log .bin data" will immediately create a file in that folder with a name like 20160922-085234.bin (encodes the date and time) and start recording. If destination folder is not specified, or is invalid, then BeamformX will prompt for the destination file before starting the recording. Recording stops when the time limit is reached (see below) or when it is stopped manually with another right click or by pressing "Control/Stop log".

### Maximum duration of binary Log data file

Recording stops automatically when this time limit is reached.

### Format for recorded stack output

If a stack of images has been created using "Control/Rec BF", then it can be output as an "MPEG4 video with sound", a "TIFF stack (high quality, no sound)", or an "MPEG4 video with no sound" according to this choice. The button in the lower right corner of the Control dialog performs the output; its label changes according to the format choice.

### Active focusing

Controls the algorithm used for focusing the array to the center of the ROI in the display for selective listening. Choosing the Active focusing invokes an array signal processing scheme that attempts to isolate a signal from the ROI center that is incoherent with other sounds reaching the array. This can improve the results if there is, in fact, a source preset. If there is not source at the center of the ROI, then Active focusing can create strange clicking sounds. Deselecting Active focusing gives straightforward delay and sum processing, which is less dramatic more predictable than active focusing.

### Tabulate peaks

Shows the Peak list window or Roi integrals window.

### Show time, peak level

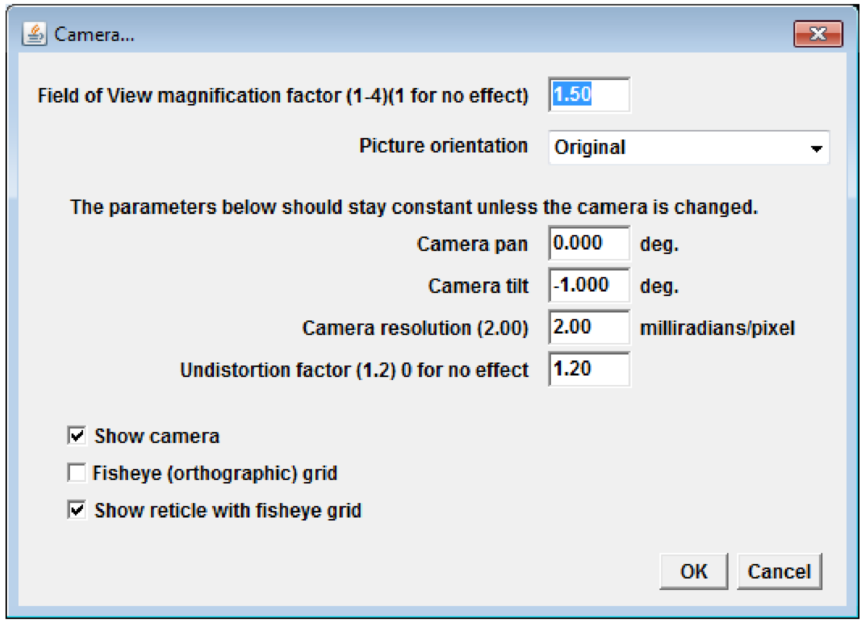
Enable these labels in the Display.

### A-weighting

Applies A-weighting to the Spectrum and the Display results. An extrapolation of the A-weighting formula is applied for frequencies above 20 kHz.

### *Camera*

This brings up the Camera dialog. The first two items on the dialog, "Field of View magnification factor" and "Picture orientation" can be used to change the Display according to the requirements of the current task. The remaining parameters, Camera pan, tilt, resolution, and undistortion factor, should only be adjusted for a new array or when the camera is changed.

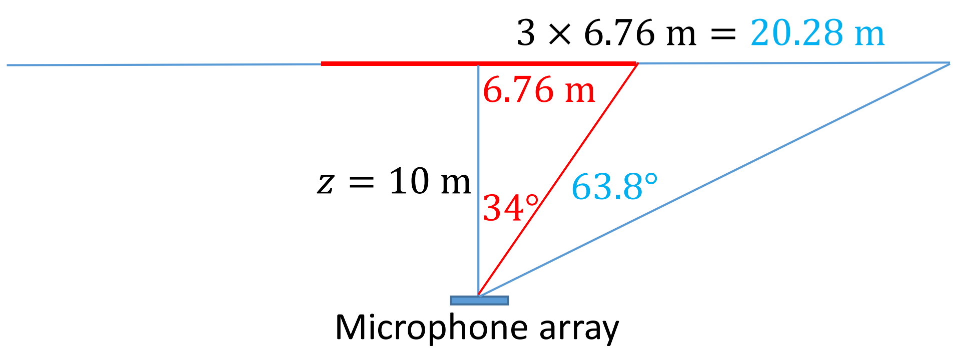



Camera dialog.

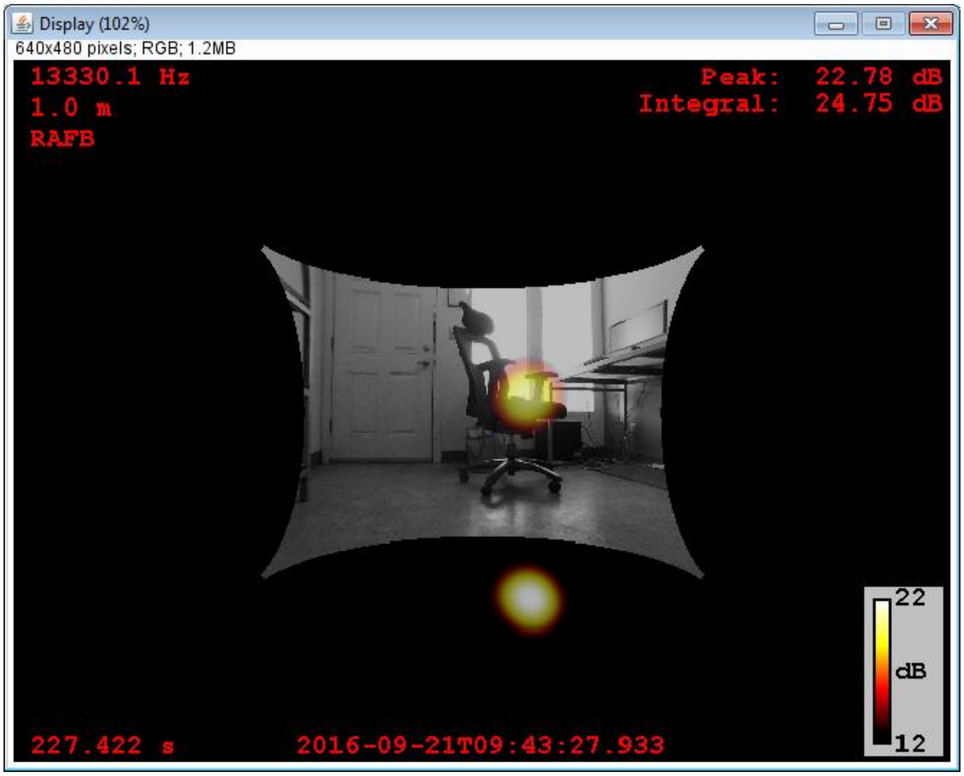
## Field of View magnification factor

This is a linear scale factor that is applied the lateral extent of the beamform map shown in the Display. Increasing this value increases the acoustic field of view. Values larger than about 1 cause the acoustic field of view to be larger than the optical camera's field of view. The optical image is padded with black where necessary. This factor does not change the size of the Display in pixels, but changes the spatial extent that each pixel represents.

As an example, suppose the field of view of the optical camera is 68°, so the half angle of the FOV is 34°, as shown below in red. With $z = 10\ \mathrm{m}$, this gives a spatial half-FOV of 6.76 m (shown in blue). Setting the "Field of View magnification factor" to 3 expands the spatial half-FOV for the acoustic image to 20.28 m. The angular half-FOV is then 63.8°, so the full FOV of the acoustic map is 128.6°. In the sample image, setting the "Field of View magnification factor" to 3 reveals the source reflected in the floor that may not have been visible otherwise.




**"Field of View magnification factor" = 1 (red) and 3 (blue)**




**“Field of View magnification factor” = 3**

## Picture orientation

The choices are “Original”, “Flip horizontal”, “Flip vertical”, and “Flip horizontal and vertical”. At present, there are no 90° options.

## Camera pan and tilt

Angles that represent the mismatch between the optical axis of the camera and the z-axis of the array coordinate system. Adjust these so that the acoustic image of a small, high frequency, source near the center of the Display coincides with the optical image of the source. Once these are set correctly for a given array, it should not be necessary to change them.

## Camera resolution

This value specifies the resolution in milliradians per pixel, for a point near the center of the image. The focal length of the camera in pixels is 1000 times the reciprocal of this value. The value refers to the case that the “Field of View magnification factor” is set to 1. It can be determined using optical measurements alone, but it can also be set so that when an acoustic source is moved a long distance across the field of view, parallel to the array, the optical and acoustic images track at the same speed. Before determining this parameter, it is best to set the “Undistortion factor” as described below. Once the Camera resolution is determined, it should not need to be changed unless the camera is changed or the video resolution of the camera is changed. BeamformX does not presently include a way to change the video resolution of the camera. (Changing the “Field of View magnification factor” scales the video image before showing it on the Display, but does not change the resolution of the image coming from the camera.)

### Undistortion factor

This factor compensates for optical distortion (usually barrel distortion) of the video camera. It should be set so that straight lines, such as edges of doors and walls, in the real world appear as straight lines in the image. Lines that are far from the center of the image and parallel to an edge are the most sensitive to distortion, so these should be used to set the parameter. Once it is correctly set, this parameter should not need to change. Set to 0 for no effect. Nominal ACAM 100 value = 1.2.

The undistortion algorithm cannot correct for a fisheye lens. A future version of BeamformX will deal with fisheye lenses. Setting “Field of View magnification factor” a large value such as 3 covers almost as large an angular sector as a fisheye lens with the acoustic information.

### Show camera

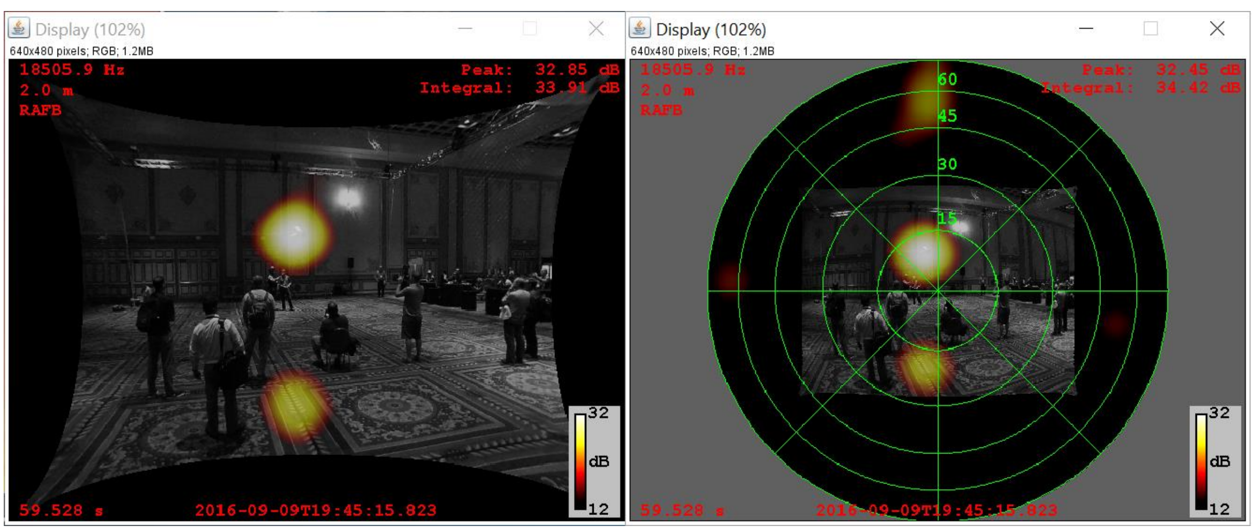
Deselecting this checkbox removes the optical image from the Display.

### Fisheye (orthographic) grid

This selects a very wide (180°) beamforming grid with a fisheye perspective such that the radius from the center of the image is proportional to the sine of the angle between the ray representing the grid point and the central axis of the array. Since the optical camera does not have a fisheye lens, the optical image covers only a portion of the fisheye Display. The beamforming grid is still a plane parallel to the array, separated from the array by a distance z, but, in this case, it is an infinite plane. One interesting use of this grid outdoors is to point the array straight up and set z to perhaps 6 meters (might as well be infinity). The resulting plot looks similar to a radar image, showing things like aircraft in the sky. If the aircraft are far from the overhead direction, then they show as spots on the perimeter of the circular display.

### Show reticle with fisheye grid

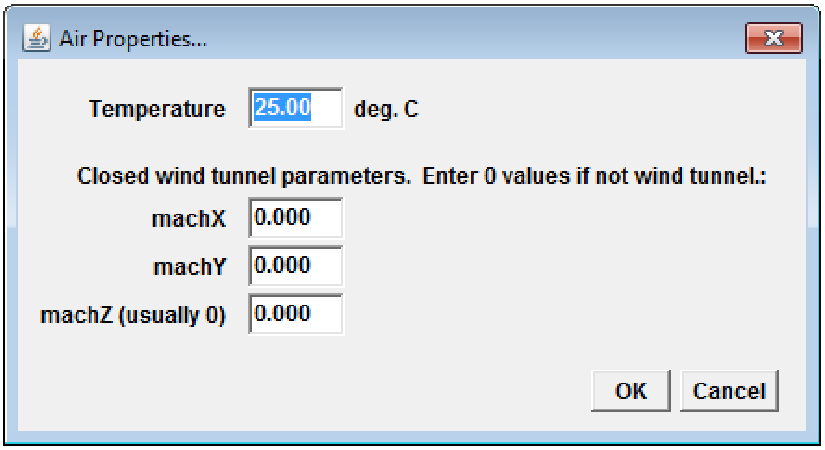
The fisheye grid normally has green reference circles and radial lines for angle orientation. Deselecting this checkbox removes the reticle. The checkbox has no effect if the fisheye grid is not selected.




**Regular (gnomonical) and fisheye (orthographic) displays.**

### *Air Props*

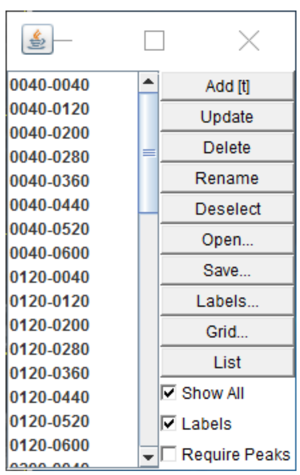
Properties of the medium affecting the acoustic propagation for beamforming.




It may be sufficient to leave the Temperature set to 25° C unless it is drastically different, since it has a small effect on the beamforming. The wind tunnel Mach number components make use of the analytical Green's function for uniform flow. Experiment with the signs to make sure the correction moves the source spots in the expected direction (upstream).

### *ROIs*

Brings up the non-modal ROIs dialog.




The list of ROIs at the left is initially empty. To add and ROI, use the mouse to create an ROI containing an interesting region on the Display and click Add [t]. Repeat the process to add more ROIs more potential source regions. Checking Show All causes all of the ROIs to be, well, shown in the Display. They can be labeled or not depending on the Labels checkbox. To update an ROI, select it in the list, press Update, and change it in the Display. Delete, Rename, and Deselect should be self-explanatory. To save a single ROI, select it and choose Save… To save several ROIs, shift-click to select them and use Save… In this case, they are save in a .zip file. The saves ROIs can be read back in using Open… The Grid button creates a grid of many ROIs covering the display. List gives information about the ROIs. The effect of Require Peaks is discussed with the ROI Mode checkbox.

The ROIs dialog, like many parts of the BeamformX GUI, is derived from the ImageJ graphics package written by Wayne Rasband and others.

### *Pause, Play Buffer, and Resume*

These buttons control whether the Spectrum, the Display, and the computer speaker are active and whether the data comes from the input source (the connected microphone array or the binary Log file) or the Spectrogram buffer.

#### Pause

Causes the input to stop and the playback time to stop moving. In the case of a connected array, data that arrives during the paused state is lost.

When running from a Log file, Pause interrupts the reading from the file so that the data that that has been read into the Spectrogram buffer from inside the file history can be analyzed.

#### Play Buffer

Causes the playback time to start advancing within the Spectrogram buffer. The button is only enabled when input is paused, and pressing it does not cause input to resume.

#### Resume

Causes the input from the Log file or the connected microphone array to resume and the playback time to resume moving.

### *Log .bin data*

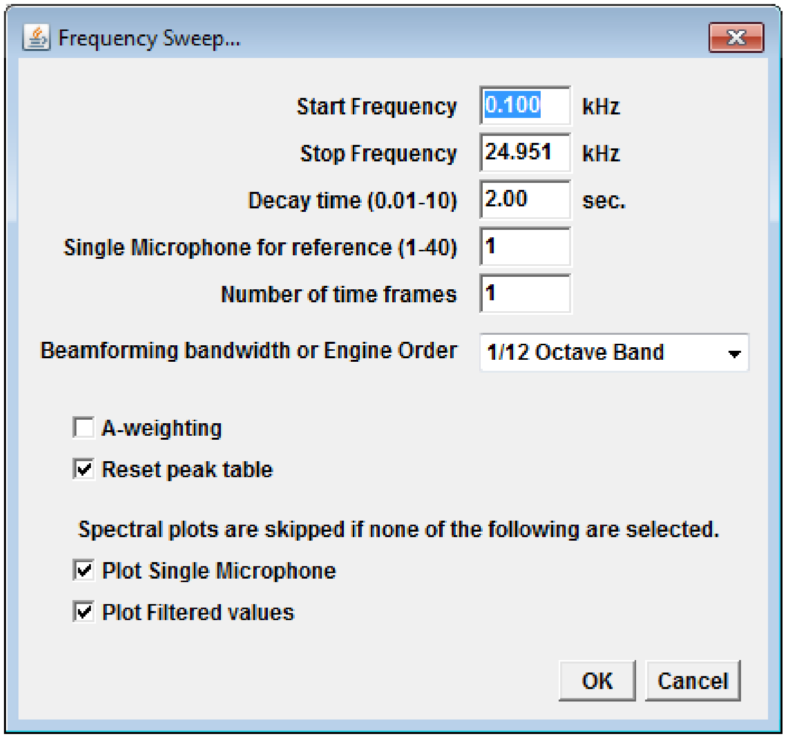
Starts writing all of the data from the microphone array, acoustic and optical, to a binary Log file (.bin). If a valid folder is entered into "Settings/ Folder for binary Log data and PNG images", then the file is created automatically with a name like name like 20160922-085234.bin and writing starts immediately. If a valid folder is not specified, then the user is prompted for the name of the Log file. Writing stops automatically and the file is closed when the time limit given in "Settings/ Maximum duration of binary Log data file" is reached or when the button "Stop log" is pressed. (The label for "Log .bin data" changes to "Stop log" while data is being written.)

It is possible to Log .bin data into a new file while reading data from an old file. This gives a way to edit Log files into smaller parts.

The .bin file format is open. The file begins an ASCII number giving the number of bytes in an XML header. Next comes the header. This contains important setting parameters including values that define the block sizes of the binary data. The binary data follows, alternating between acoustical data from the microphones and pixel data describing frames from the video camera. The details will be provided in a separate document.

### *fSweep*

This pauses the system and brings up the Frequency Sweep dialog.




The Start and Stop Frequency parameters control the range of the frequency sweep. The "Number of time frames" parameter controls how many times the sweep is repeated for successive times. The optional results to plot are the Single Microphone level and the Peak. The other parameters are duplicated from the Settings dialog for convenience. Pressing OK performs the frequency sweep and returns a plot of the results. If the individual beamforming plots are required, select "Rec BF" before pressing fSweep.

The checkbox Reset peak table causes the new frequency sweep results to be separated from previous values in the table.

In previous versions of BeamformX, the peak result was limited to the ROI, if any. Starting with Version 3, the peak represents the entire Display unless "Limit to ROI" is selected or "Partition Mode" is selected. These functions use powerful algorithms to find weak sources in the ROIs to the exclusion of sources outside the ROIs. In "Partition Mode" the fSweep dialog has slightly different options from the case of the normal mode. The "integral" results in previous versions of BeamformX are not supplied in Version 3.

### *Rec BF*

This causes the successive Display results to be accumulated in a stack ("Recording") of images. The stack can subsequently be examined or exported using "Save .mp4" or "Save .tiff" according to the choice in "Settings/Format for recorded stack output." The .mp4 videos can optionally have sound, and the volume of the sound is affected by the Gain setting on the Control dialog.

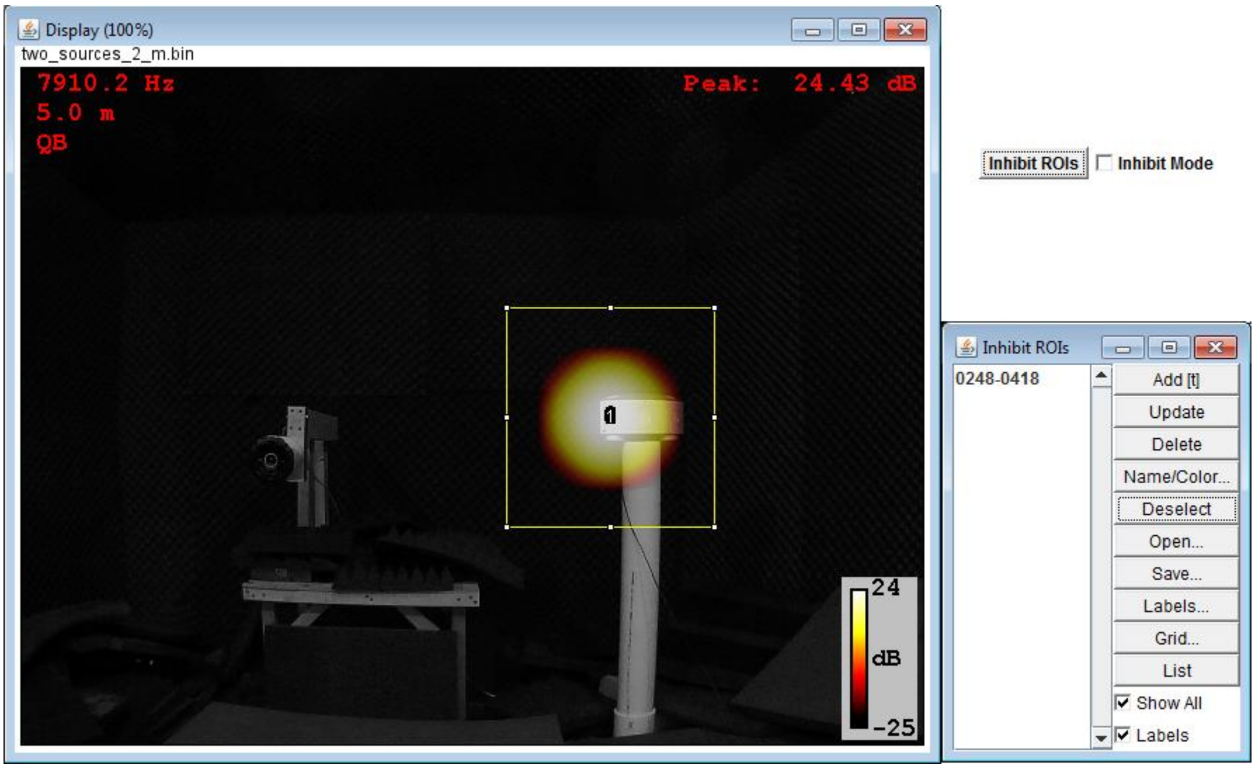
The number of slices in the stack is limited by computer memory. Each slice requires 1.2 MB. The use of Rec BF should be limited to when it is really needed. The stack can, and should, be cleared by closing it when it is no longer needed. Be careful not to accidentally close the Display, as this exits BeamformX.

### *Save .mp4 or Save .tiff*

Writes the Recording stack and possibly sound to a file with the format selected in "Settings/Recorded stack output".

### *Inhibit ROIs*

The Inhibit ROIs dialog is used to create and maintain a list of ROIs that suppress sources in the corresponding locations if the Inhibit Mode checkbox is selected. Suppose the Display includes a strong source that may be interfering imaging the sources of interest. Create an ROI that contains the strong source, press the Inhibit ROIs button to bring up the dialog, and press Add [t].



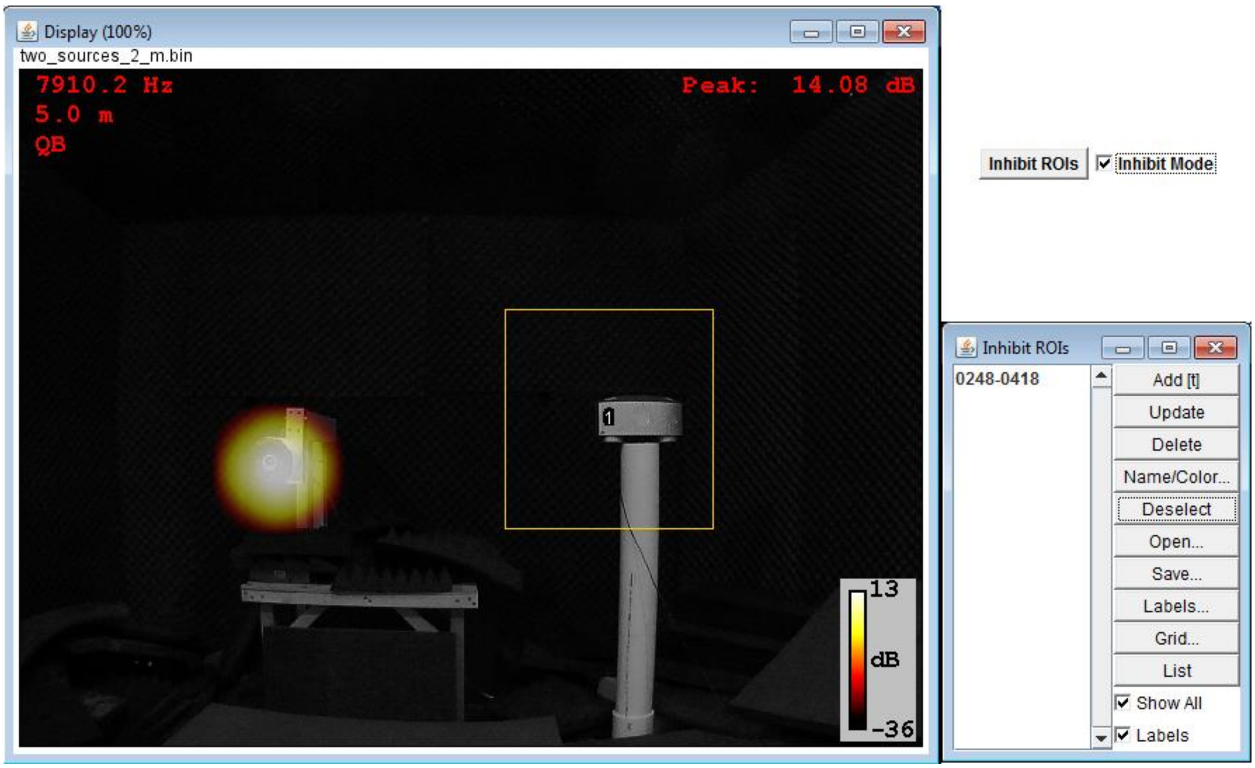

The ROI appears on the list in the Inhibit ROIs dialog with a name derived from its coordinates (0248-0418 in this case). Selecting "Inhibit Mode" in the Control dialog causes the inhibit ROI to become active, suppressing the source inside it and thereby revealing the weaker source. Be sure that "Limit to ROI" is not selected. It may help to click once on the Display to remove the creation ROI to avoid confusing it with the ROI that is saved in the Inhibit ROI dialog.

In the example, the stronger source is 24.43 dB and the weak source is 14.08 dB. In principle, the beamforming should have been able to see the weaker source at 10.35 down from the stronger source at same time, given the 50 dB Auto Scale setting. Sometimes this works, but not in this case. The inhibit ROI aids the algorithm in finding weaker sources.

To experiment with the inhibit ROI, it is possible to select it by clicking on in the list in the Inhibit ROIs dialog and then drag it around on the Display so that it either covers a given source or not. The source should appear and disappear.

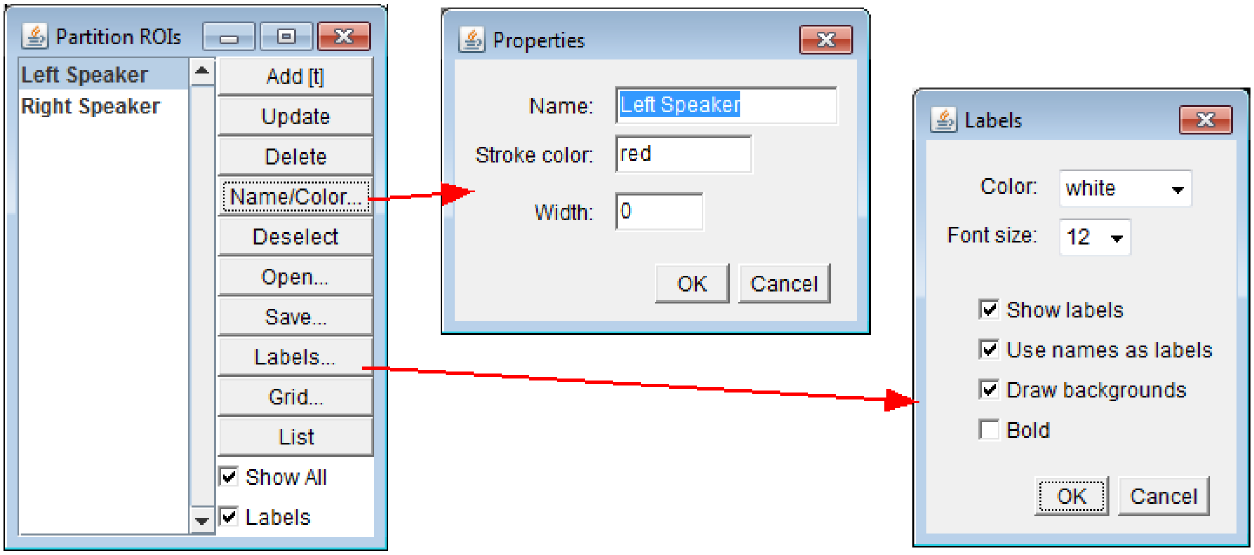
It is possible to add any number of inhibit ROIs to the Inhibit ROI dialog so that multiple sources are suppressed.  It is also possible to make the inhibit ROIs large so that a single inhibit source suppresses more than one source. The buttons on the Inhibit ROI dialog can be used to rename the ROIs, save one or all them, read in saved ROI or groups of ROIs (in an RoiSet.zip files) There are several other functions for controlling ROIs. The ROI management functions are derived from ROI Manager in the ImageJ graphics package by Wayne Rasband and others.

The effect of the “Limit to ROI” checkbox is equivalent to surrounding a given ROI with inhibit ROIs that cover every part of the image outside the ROI.



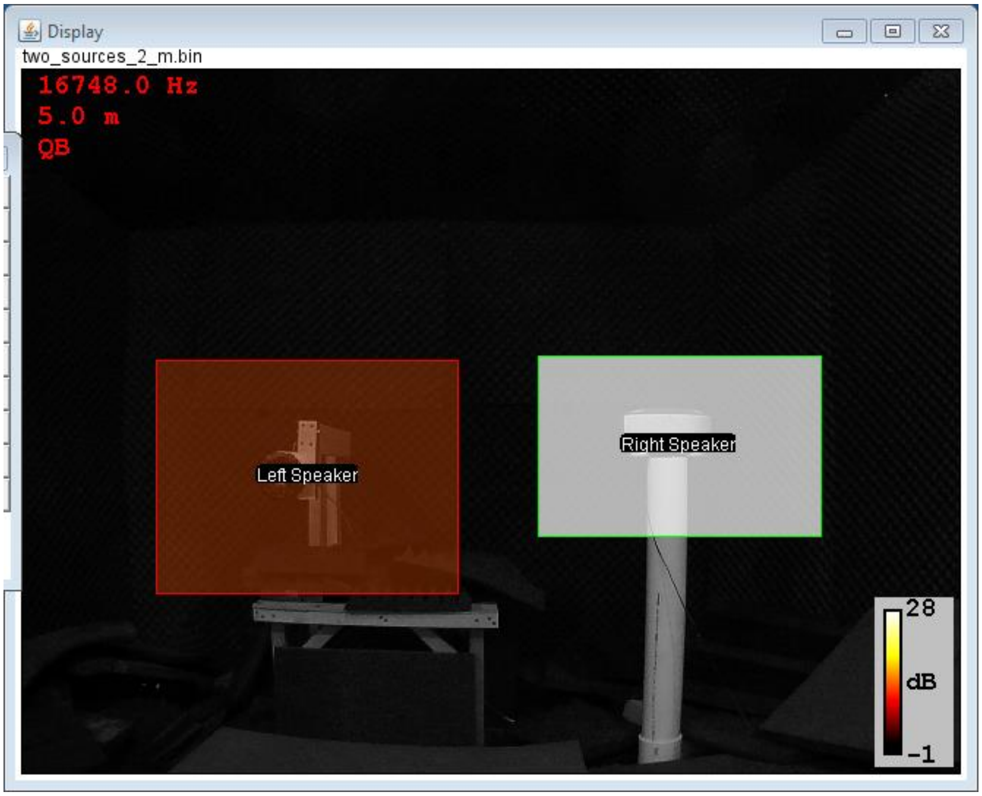

## *Partition ROIs*

The Partition ROIs dialog is very similar to the Inhibit ROIs dialog.  Use it create several ROIs in parts of the Display that potentially contain sources. As the ROIs are added, they are assigned different border colors to aid in distinguishing results in the plots from frequency sweeps.  The dialog buttons can be used to change the colors or names of the partition ROIs, if desired.  To cause the names to appear on the Display and the tabular and plot results, use “Partition ROIs/Labels…” Make sure that “Limit to ROI” is not selected, unless the function is being used deliberately with a large ROI. Choosing “Partition Mode” causes the partition ROIs to be shown as uniform colors representing the highest beamforming level found in each ROI. During the calculation, the “Limit to ROI” function is applied to each partition ROI in turn, so weak sources should be found automatically. Using fSweep to perform a frequency sweep gives separate spectra for the individual partition ROIs.

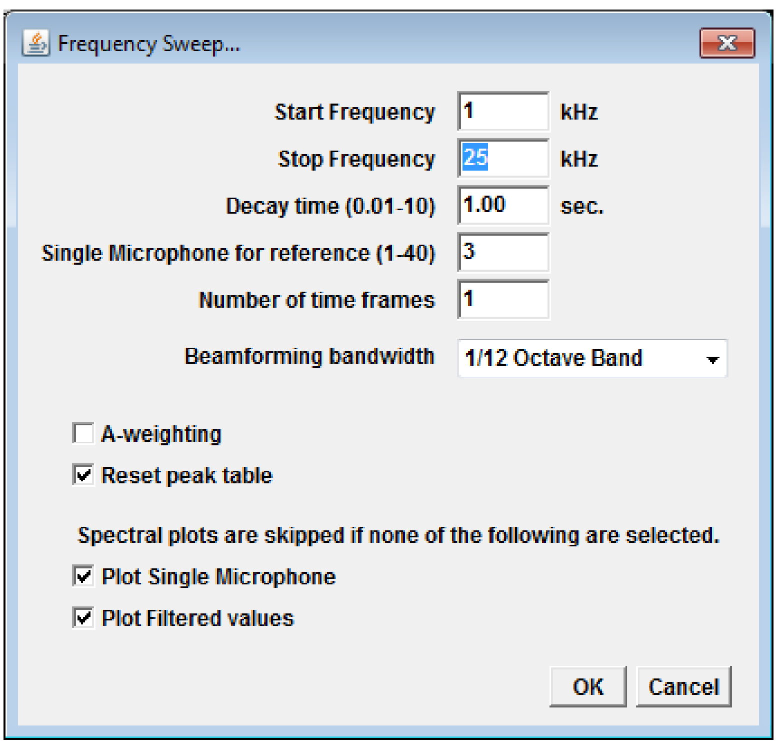



Use of the Partition ROIs dialog.

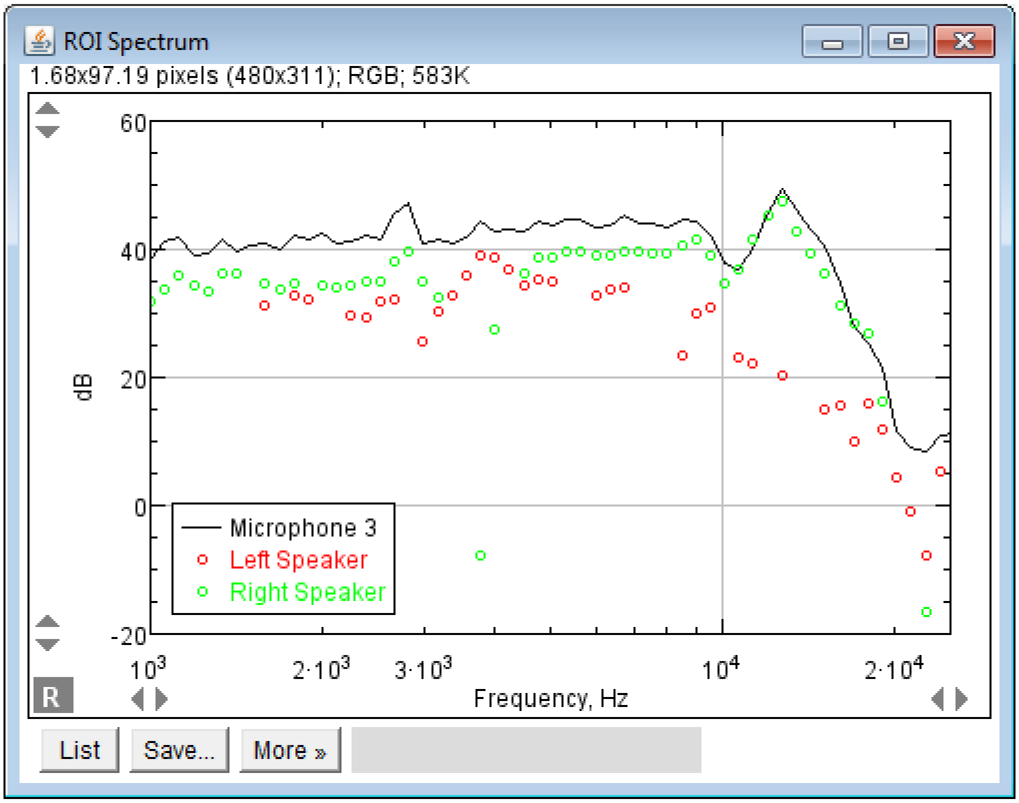

Display with partitions set up.




Display after selecting Partition mode.




Frequency sweep dialog (fSweep) in Partition ROIs mode.




Plot resulting from fSweep in Partition ROIs mode, after using More/Set Range… to adjust the scales.