LOW-FREQUENCY

ACOUSTICS TOOLBOX

USER'S GUIDE

v1.6

Dr Adam J. Hill

a.hill@derby.ac.uk

WWW.ADAMJHILL.COM

Entertainment Engineering Group (WWW.UODLIVE.COM)

Department of Electronics, Computing and Mathematics

College of Engineering & Technology

University of Derby, United Kingdom

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Disclaimer

This software is part of ongoing research, therefore no guarantees can be made for an error-free piece of software. Be sure to validate all results if using the toolbox to aid research.

Toolbox overview

The Low-Frequency Acoustics Toolbox (Low-FAT) is an easy to use piece of software which allows for acoustic simulations of non-rectangular topologies. The modeling technique utilized is a finite-difference time-domain (FDTD) method, which is generally most accurate and efficient for investigating low-frequency acoustics. Boundary conditions are treated as perfectly rigid with frequency-independent absorption. Any number of sources can be placed within the space (limited by the number of pressure grid points). By default, sources are omnidirectional point sources. Dipole or cardioid polar patterns are possible as well.

Any number of listening points can be placed within the acoustical space (limited by the number of pressure grid points), placed automatically in a grid or manually by the user. Each listening point records the pressure response during the simulation which can be used later for data analysis. The option also exists to record the full pressure grid response across the entire simulation, which allows for detailed animations to be generated post-simulation.

Further options include time/frequency domain analysis as well as bespoke tone burst analysis and auralization. The full features of this toolbox are described within this user's guide.

Under no circumstances may this toolbox be used in commercial/for-profit applications. However, you are most welcome to use the program to support research, although formal acknowledgement is expected.

Feel free to email Adam Hill (a.hill@derby.ac.uk) regarding any found bugs (there are most likely some lurking within the code!) or to request additional features.

Enjoy using the toolbox. Hopefully it will be of use to your research/interests and contribute to your knowledge and understanding of low-frequency acoustics!

System requirements

The Low-Frequency Acoustics Toolbox was written entirely in MATLAB R2016b running on a Microsoft Windows 10 (64-bit) PC. There are no guarantees of compatibility with Apple or Linux operating systems. The software requires the MATLAB Compiler Runtime (MCR), which will be automatically installed if your PC currently doesn't have the MCR. Toolbox processing time depends on system capabilities and the maximum simulation size/time/resolution is governed by the amount of available memory to the MCR.

Installation

Download the 32- or 64-bit installation ZIP folders from my website (www.adamjhill.com/downloads) and extract the contents. The installer application which will take you through the full installation process.

Once installed, you can launch the application from Program Files > University of Derby > LowFAT > application > LowFAT.exe or from a shortcut on your desktop (if you choose that option during installation).

Graphical user interface (GUI) layout

The Low-Frequency Acoustics Toolbox is laid out in an easy to use graphical user interface (GUI). The software operates from a home screen (as shown in Figure 1). All functions of the toolbox can be accessed from this screen.

On the left of the screen there are a number of pushbuttons that allow the user to access various features of the toolbox. Users are only allowed to select features that are available, depending on the current state of the acoustic model being designed.

The box on the right of the screen gives an overview of the current state of the model, including information on the acoustic space, sound sources, measurement points, simulation time and specific room shape and layout.
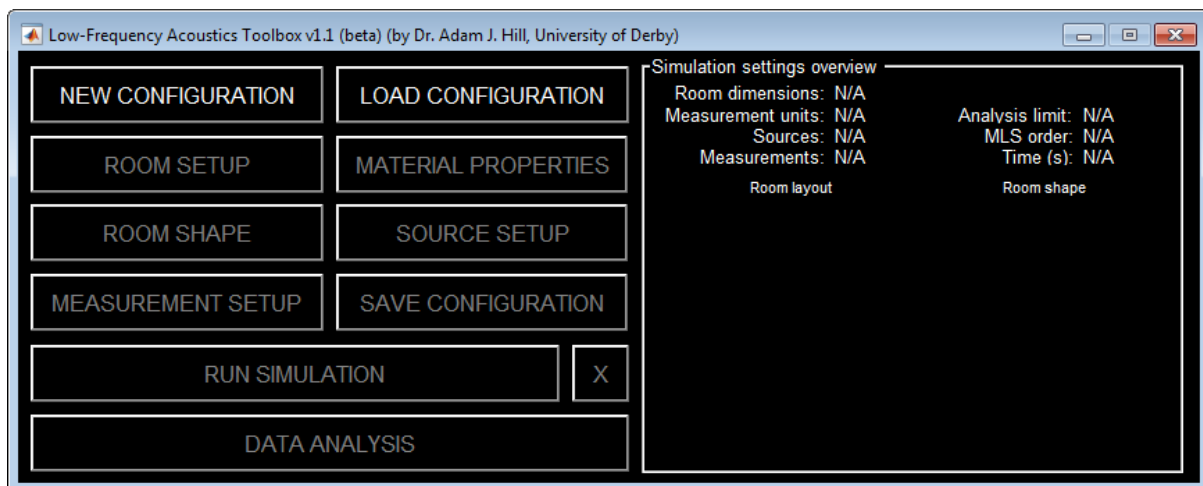

Figure 1 – Home screen for LowFAT

The features accessible from the home screen are as follows:

New configuration

On clicking this button, users are asked if they wish to wipe all current data to begin a new configuration. Selecting YES clears all data and resets the software. Selecting NO results to the home screen without making any changes.

Load configuration

On clicking this button, users are able to load previously saved configurations. If the file format isn't a valid LowFAT configuration file (saved in.mat format), the user will see an error message and will be returned to the home screen without making any changes.

Once a configuration file has been successfully loaded, the user will be asking if they wish to load a simulation data file as well. Again, if the file isn't in the appropriate format, an error message will be shown and the user will be returned to the home screen without any changes being made.

Room setup

The room setup menu allows users to set the basic configuration of the acoustic space, including rectangular dimensions, measurement units and upper frequency analysis limit.

This option is only available until the sources and/or measurement points have been set. Users need to be sure that they fully define the room before placing sources and measurement points for this reason.

Material properties

The material properties setup menu allows users to define the absorption coefficients for all room boundaries and obstacle surfaces. Users have the choice of manually defining the absorption coefficients or choosing from a list of pre-defined materials. All absorption coefficients are set to 0.1 (10% absorption) as default.

Room shape

The room shape menu allows users to fine-tune the shape of the pressure point grid used within the FDTD simulation. This is accomplished by using a cookie cutter-like approach to shaping the space.

Source setup

The source setup menu allows users to precisely define how many sources are to be included in the simulation and set each source's position, polar response, orientation, frequency response, polarity and electronic delay.

This option is only available once the room has been defined.

Measurement setup

The measurement setup menu allows users to precisely define how many measurement locations are to be included in the simulation and set each measurement point's exact location in space, either automatically or manually.

This option is only available once the room has been defined.

Save configuration

The save configuration button allows users to save the configuration file for later use.

This option is only available if the room, sources and measurement points have been successfully defined.

Run simulation

The run simulation button gives the user the option of what data to record during the simulation and where to automatically save the data to on disk.

This option is only available if the room, sources and measurement points have been successfully defined.

X

This serves as a cancel button during simulation runtime. If a simulation is canceled, no data will be saved. This option is only available when a simulation is currently running.

Data analysis

This button launches the data analysis function that accompanies the toolbox. Within this function, users are able to analyze a range of aspects of the saved data including time + frequency domain analysis, data visualization + animations and monaural auralizations.

This option is only available once a simulation has been successfully completed or if a data file has been loaded along with a configuration file.

New configuration

To begin a new configuration, simply click the NEW CONFIGURATION button, as seen on the toolbox's home screen (Figure 1). This option is always available.

If there is existing model data in the toolbox, clicking the new configuration button will prompt the user to decide whether they'd like to proceed with the new configuration (which will clear all existing data in the toolbox).

Once clicked (and confirmed, if necessary), the toolbox will be reset so that the only options now available are NEW CONFIGURATION, LOAD CONFIGRATION and ROOM SETUP.

Load configuration

To use an existing configuration (saved during a previous session), click the LOAD CONFIGURATION button, as seen on the toolbox's home screen (Figure 1). This option is always available.

If there is existing model data in the toolbox, clicking the load configuration button will prompt the user to decide whether they'd like to proceed with loading the configuration (which will clear all existing data in the toolbox).

The user will then be prompted to select the configuration file (always .mat format). If the file is a correct LowFAT configuration file, then the loading will be successful and the relevant options will become available. If the file is in the incorrect format, an error will be displayed and the loading operation will be terminated.

Once successfully loaded, users will have the option to load in a data file for use with the data analysis function. The data files are also stored using the .mat format. If an incorrectly formatted file is chosen an error will be displayed and no data will be loaded.

Room setup

Selecting the ROOM SETUP button from the toolbox's home screen opens a menu which appears as shown in Figure 2.

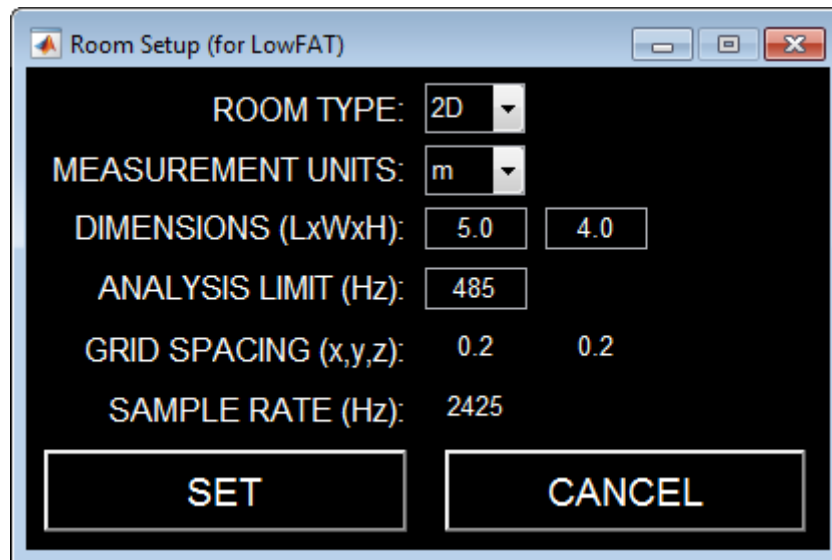**Figure 2 – Room setup menu with default settings**

The options within this menu are as follows:

Room type

Determines how many dimensions the FDTD model will contain.

2D   =   two-dimensional acoustic model

3D   =   three-dimensional acoustic model

Measurement units

Determines what units to use in building/analyzing the model.

m   =   meters

ft   =   feet

Dimensions

Defines the rectangular dimensions of the acoustic space being modeled (expressed in the units as defined by MEASUREMENT UNITS).

L   =   length
W   =   width
H   =   height   (only visible if creating a 3D model)

Analysis limit

Defines the upper frequency limit (Hz) for simulation accuracy. This is defined by requiring at least ten pressure grid points per wavelength.

If a user enters too high a frequency (which will cause the computer to run out of memory), the software will automatically revert to the highest possible analysis frequency.

Grid spacing

This setting is not directly definable by the user. It is automatically calculated based on the room dimensions and the required analysis limit. The software ensures that the grid points will fit evenly into the defined space.

Sample rate

This setting is not directly definable by the user. It is automatically calculated based on the required analysis limit and is expressed in Hz.

Set

Pressing this button applies the currently displayed room settings to the model and closes the room setup menu, returning to the home screen.
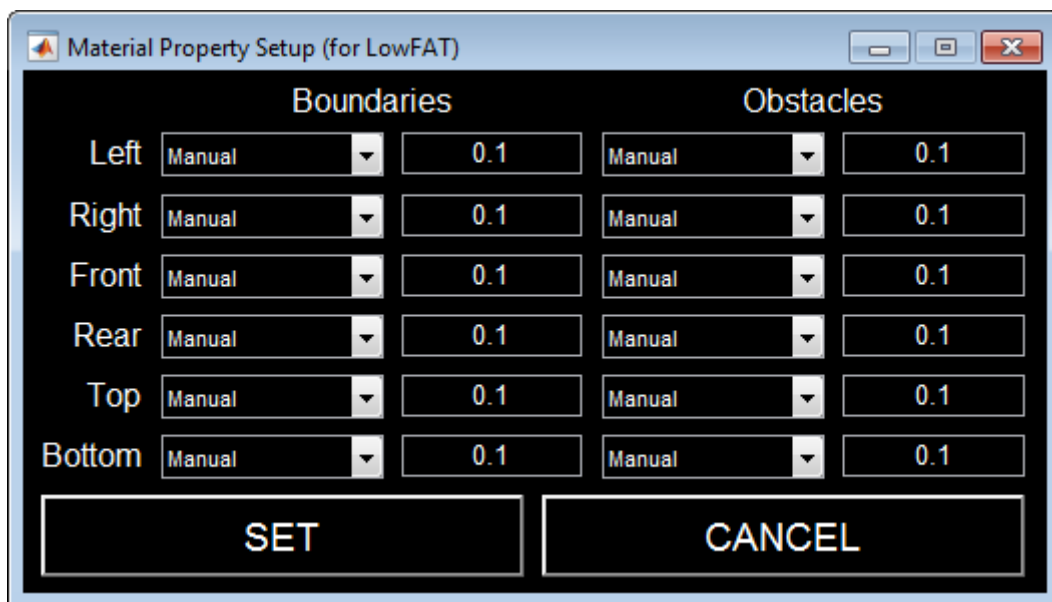
There is no option to undo applying room settings once this button is clicked, so be sure that the settings are correct!

Cancel

Pressing this button exits the room setup menu and returns to the home screen without applying any changes to the current model. All settings defined in the room settings menu will be lost.

Material properties

Selecting the MATERIAL PROPERTIES button from the toolbox's home screen opens a menu which appears as shown in Figure 3. This option is only available once ROOM SETUP has been completed.

Figure 3 – Material property setup menu with default settings

This menu allows the user to define the material or specific absorption coefficient for each surface in the room. This is split into boundaries (primary room walls) and obstacles (objects places within the space).

The setting default to 0.1 for each absorption coefficient with the drop down menu set to manual mode (allowing the user to manually enter the absorption coefficient). Alternatively, users can select one of a number of materials available in any of the drop down menus. When this is done, the absorption coefficient will be updated in the adjacent box and the edit box won't be editable. To edit the coefficient, simply re-select the manual option in the relevant drop down menu.

Room shape

Selecting the ROOM SHAPE button from the toolbox's home screen opens a menu which appears as shown in Figure 4. This option is only available once ROOM SETUP has been completed.

Figure 4 – Room shape menu with default settings

The options within this menu are as follows:

Selection shape

This menu allows users to choose what cookie cutter shape they'd like to use for shaping the model.

For 2D topologies, the available shapes are:

- o Box
- o Diagonal
- o Curve

For 3D topologies, the available shapes are:

- o Box
- o Diagonal (XY, XZ or YZ)
- o Pyramid
- o Curve (XY, XZ or YZ)
- o Dome

Lower coordinate

This coordinate (as entered over the three edit boxes) is expressed in the chosen measurement unit (meters or feet) and defines the point closest to the origin of the room coordinate system to begin the pressure grid point selection.

The chosen selection shape will be highlighted (in yellow) between the lower coordinate and the upper coordinate.

Upper coordinate

This coordinate (as entered over the three edit boxes) is expressed in the chosen measurement units (meters or feet) and defines the point furthest from the origin of the room coordinate system to end the pressure grid point selection.

The chosen selection shape will be highlighted (in yellow) between the lower coordinate and the upper coordinate.

Selection classification

A user may choose whether the selected (yellow) points will be considered inside or outside the modeled space when the selection is applied with the apply selection button.

Invert selection

Pressing this button changes all selected (yellow) points within the box (or cube) defined by the lower + upper coordinates to white and the white points to yellow, thus inverting the current selection.

Flip left/right

This flips the currently selected shape along the x-axis (left to right).

Flip front/back

This flips the currently selected shape along the y-axis (front to back).

Flip up/down

This flips the currently selected shape along the z-axis (top to bottom). This button is only active when using a 3D topology.

Plot rotation

This is a toggle button that enables/disables plot rotation. When this is selected, a user can click and drag the current room shape plot to inspect it from different angles. Right-clicking on the plot brings up some useful options for various viewpoints. Double clicking on the plot will restore the default view.

Apply selection

This button commits the current selection of points to either inside or outside the modeled space (depending on the selection classification setting).

Any change made with this button can be undone by clicking the undo button.

Undo

This button allows users to undo the previous apply selection click and reverts to the previous room shape. The undo function only has a memory of one previous room shape.

Set room shape

Pressing this button applies the currently displayed room shape to the model and closes the room shape menu, returning to the home screen.

Cancel

Pressing this button exits the room shape menu and returns to the home screen without applying any changes to the current model. All changes made in the room shape menu will be lost.

Source setup

Selecting the SOURCE SETUP button from the toolbox's home screen opens a menu which appears as shown in Figure 5. This option is only available once ROOM SETUP has been completed.

Figure 5 – Source setup menu with default settings

The options within this menu are as follows:

of sources

The user can define how many sources are to be included in the model (must be greater than zero and less than the total number of pressure grid points).

Changes to the number of sources will be reflected in the source table below.

MLS order

The Low-Frequency Acoustics Toolbox operates using maximum length sequences (MLS) to determine the impulse responses at all the measurement points in the model. Users can select which order of MLS signal they wish to use. The higher the order, the longer the signal (and simulation time). MLS signals are automatically played twice to avoid any onset/offset distortion.

Time

This is the total simulation time which is automatically calculated based on the chosen MLS signal. This is not a variable that the user can edit.

It's recommended that MLS order is chosen so that the resulting simulation time is greater than twice the reverberation time of the room. 11th or 12th order MLS is usually a good starting point.

Keep in mind that MLS order also dictates FFT resolution (higher resolution for longer MLS signals) in the data analysis section.

Source table

This is where a user can adjust the key settings for each source in the model. The editable settings are:

x = source location in the x-dimension (m or ft)

y = source location in the y-dimension (m or ft)

z = source location in the z-dimension (m or ft)
(only available if using a 3D model)

Pattern = polar response of the source
(choice of omnidirectional, dipole or cardioid)

Rotation = if source pattern is dipole or cardioid, then this setting controls the orientation of the source (adjustable in 15 degree increments). 0 degree indicates that the source is facing directly along the x-axis. Rotation is counter-clockwise.

Polarity rev? = if checked, the source's polarity will be reversed

Delay = electronic delay applied to the source (in ms)

SPL = sound power level of the source (in dB)

Sub FR? = If checked, a generic subwoofer frequency response is applied to the source. If left unchecked, the source will exhibit a flat response (although this will be limited to the upper frequency limit of the model).

All positional changes applied within the source table will be automatically reflected in the Room Layout plot directly to the right of the table.

Set sources

Pressing this button applies the currently displayed source setup to the model and closes the source setup menu, returning to the home screen.

The changes in the source setup will be reflected on the right-hand side of the home screen (in the room layout plot and the settings overview).

Cancel

Pressing this button exits the source setup menu and returns to the home screen without applying any changes to the current model. All changes made in the source setup menu will be lost.

Measurement setup

Selecting the MEASUREMENT SETUP button from the toolbox's home screen opens a menu which appears as shown in Figure 6. This option is only available once ROOM SETUP has been completed.

Figure 6 – Measurement setup menu with default settings

The options within this menu are as follows:

of measurement points

The user can define how many measurement points are to be included in the model (must be greater than zero and less than the total number of pressure grid points).

Changes to the number of measurement points will be reflected in the measurement point table below.

Point placement mode

Automatic = a rectangular grid over the horizontal plane is automatically generated based on the number of measurement points and the automatic placement options

Manual   =   the user can manually define the measurement point locations by using the measurement point table

Points per row

Number of points per row in the automatically generated measurement point grid. Rows run along the y-dimension.

Grid front/back limits

Defines the beginning and end locations of the automatically generated grid along the y-dimension (in the measurement units of the model, meters or feet). Defaults to span the full width of the space.

Grid left/right limits

Defines the beginning and end locations of the automatically generated grid along the x-dimension (in the measurement units of the model, meters or feet). Defaults to span the full length of the space.

Grid height

Defines the height of the automatically generated grid. Only available when using a 3D acoustic model.

Measurement point table

This is where a user can adjust the key settings for each measurement point in the model (only available if the point selection mode is set to manual). The editable settings are:

x   =   measurement point location in the x-dimension (m or ft)

y   =   measurement point location in the y-dimension (m or ft)

z   =   measurement point location in the z-dimension (m or ft)
                (only available if using a 3D model)

Set points

Pressing this button applies the currently displayed measurement setup to the model and closes the measurement setup menu, returning to the home screen.

The changes in the measurement setup will be reflected on the right-hand side of the home screen (in the room layout plot and the settings overview).

Cancel

Pressing this button exits the measurement setup menu and returns to the home screen without applying any changes to the current model. All changes made in the measurement setup menu will be lost.

Save configuration

Once a user has completed the room, source and measurement setup, the save configuration option will become available.

Clicking this button will open a prompt for the user to identify where on the disk to save the configuration file (in .mat format) and what to name it.

Saving a configuration allows a user to exit the toolbox and the recommence work at a later date. The configuration file is also needed if a user plans to analyze saved data generated with that configuration.

Run simulation

Selecting the RUN SIMULTION button from the toolbox's home screen opens a menu which appears as shown in Figure 7. This option is only available once ROOM SETUP, SOURCE SETUP and MEASUREMENT SETUP has been completed.
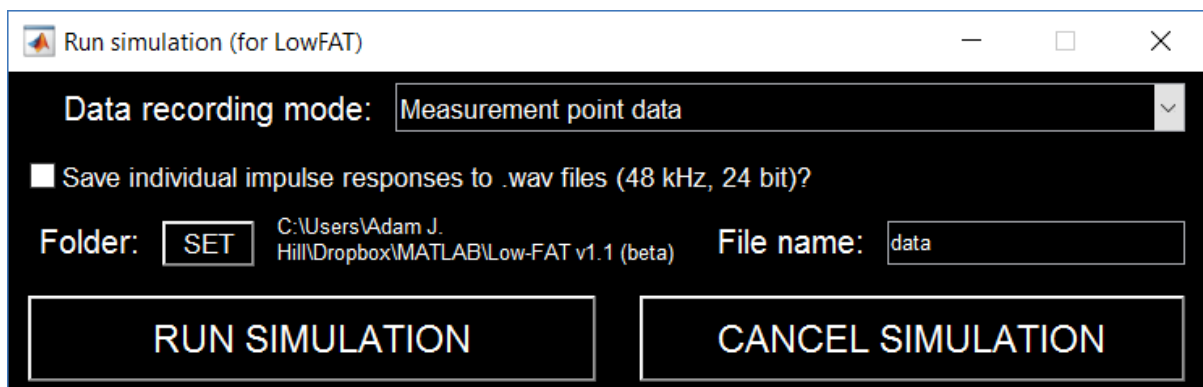

Figure 7 – Run simulation menu with default settings

The options within this menu are as follows:

Data recording mode

Within this menu, users can decide which pieces of data are automatically saved during the simulation runtime.

Options include:

Measurement point data

Sound pressure vs. time is recorded over the entire simulation at the measurement points only.

Measurement point data and full grid data

Sound pressure vs. time is recorded over the entire simulation at the measurement points. The full sound pressure data over all grid points in the model is also recorded over the entire simulation. This option is useful if a user wants to create animations in 2D or 3D format.

This option is likely to cause the simulation to run slower than usual and requires significant memory. If this option is selected and the computer doesn't have the required memory, an error will be displayed and the recording mode will revert back to measurement point data only. It is common for data files using this option to exceed 1 GB when using a 3D acoustic model.

Save individual impulse responses

Tick this box to save the impulse response for each measurement point in the model as a .wav file (48 kHz sampling rate, 24 bit depth). The output files will be labeled as IR_(x, y).wav where x indicates the row number (along the x-dimension) and y indicates the seat number (along the y-dimension). The IR files will be saved to the directory specified by the folder setting.

Folder

Click this button to choose a folder on the computer to automatically save the data to.

File name

A user can define the file name for the automatically generated data file. This defaults to "data", but please keep in mind that if this is not changed, any existing file in the current folder named "data" will be overwritten. There is no need to add the ".mat" extension in the file name.

Run simulation

Clicking this button triggers the start of the simulation and automatically returns the user to the home screen.

When back on the home screen, the RUN SIMULTION button will be RED and a progress text will appear to indicate progress through the simulation.

To cancel the simulation, simply click the X button on the home screen.

Once the simulation is complete (or cancelled), the RUN SIMULTION button will turn black again and the progress text will disappear.

If the simulation has successfully completed, the DATA ANALYSIS option will become available and the data from the simulation will have been automatically saved.

Cancel simulation

Pressing this button exits the run simulation menu and returns to the home screen without running the simulation. All changes made in the run simulation menu will be lost.

Data analysis

Selecting the DATA ANALYSIS button from the toolbox's home screen opens a menu which appears as shown in Figure 8. This option is only available once a simulation has been successfully completed or a data file has been loaded.

Figure 8 – Data analysis menu with default settings

The screen shot shown in Figure 8 is using data from an example 3D model with dimensions 5 m x 4 m x 3 m (0.1 absorption coefficient for all surfaces), an analysis limit of 594 Hz (resulting in 20 cm grid point spacing), 1 omnidirectional source located at (0.4 m, 0.4 m, 0.4 m), a 64-point measurement point grid with a height of 1.6 m, which has been modelled using a 13th order MLS.

The options within this menu are as follows:

Source settings

The source settings available are dictated by the source type chosen:

o Impulse response

This is the impulse response that is calculated directly from the MLS used and measured during the simulation.

This is the default source type.

o Gaussian pulse

This source generates a Gaussian pulse which has a peak centered at the halfway point of the signal's duration.

Settings include:

- Amplitude

  Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

- Duration

  Length (in seconds) of the source signal.

- Center frequency

  Center frequency of the Gaussian pulse (in Hz).

- Fractional bandwidth (BW)

  Bandwidth of the Gaussian pulse (fraction of the center frequency, so 0.5 = 50% of the center frequency)

- Sinusoid

  This source generates a pure tone sinusoidal signal.

  Settings include:

  - Amplitude

    Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

  - Duration

    Length (in seconds) of the source signal.

  - Frequency

    Frequency of the sinusoid (in Hz).

- Sine sweep

  This source generates a logarithmic sine sweep.

  Settings include:

  - Amplitude

    Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

  - Duration

    Length (in seconds) of the sine sweep.

  - Frequency

    Frequency range of the sweep (in Hz).

o   Tone burst

This source generates a tone burst signal.

Settings include:

- Amplitude

  Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

- Duration

  Length (in seconds) of the source signal.

- Frequency

  Frequency of the tone burst carrier frequency (in Hz).

- Cycles/reps

  Number of cycles of the carrier frequency per tone burst and number of repetitions of the tone burst.

o   Tone burst sweep

This source generates a tone burst sweep. Analysis options are limited for this type of signal.

Settings include:

- Amplitude

  Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

- Duration

  Length (in seconds) of the source signal.

- ▪ Frequency

  Frequency of the tone burst carrier frequency (in Hz).

- ▪ Cycles/reps

  Number of cycles of the carrier frequency per tone burst and number of repetitions of the tone burst.

- ▪ Freq. step

  Frequency spacing between adjacent tone bursts in the sweep (in Hz).

o White noise

  This source generates a white noise signal.

  Settings include:

  - ▪ Amplitude

    Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

  - ▪ Duration

    Length (in seconds) of the source signal.

o Pink noise

  This source generates a pink noise signal.

  Settings include:

  - ▪ Amplitude

    Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

  - ▪ Duration

    Length (in seconds) of the source signal.

o   Audio file

This source option allows the user to load in an audio file (.wav, .mp3, .flac, .m4a, .mp4, .ogg). The software automatically converts any stereo files in mono, which is required for running through the data analysis methods.

Settings include:

▪   Amplitude

Level of the source with reference to the impulse response measurement from the simulation (0 dB = no change).

▪   Duration

Length (in seconds) of the source signal (not editable).

Preview source

Clicking this button plays back the raw source signal as defined by the source settings above.

Options

The options available are dictated by the source type chosen as well as what data was saved during the simulation.
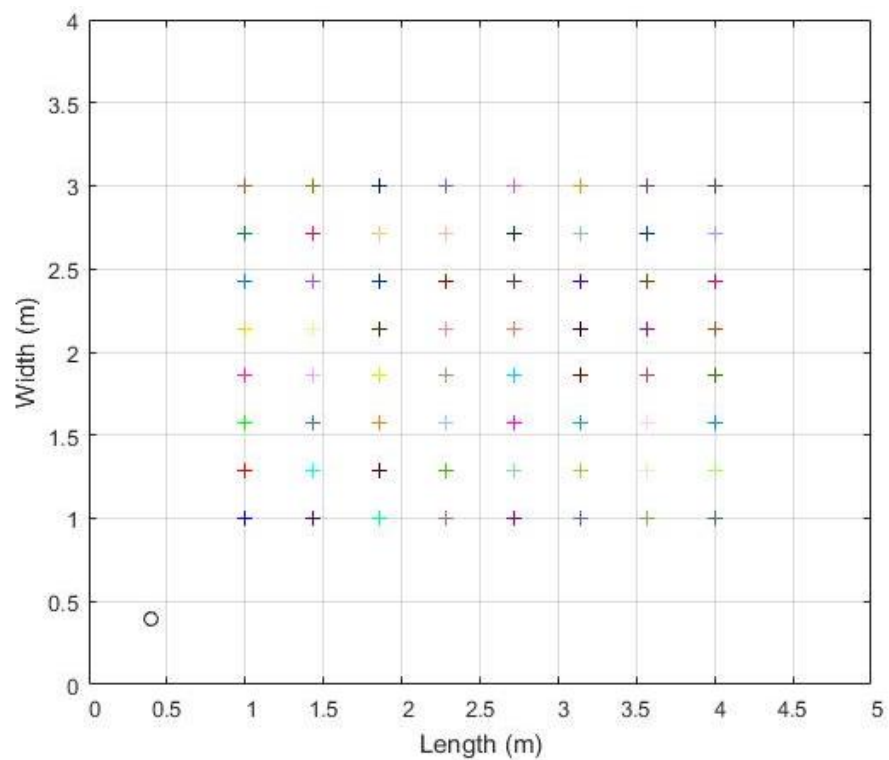
The full list of options is as follows:

o   Room layout

Plots a birds-eye view of the room layout. Sources and measurements are indicated by circles and colored crosses, respectively.

This plotting option is available for all source signals and saved data.

An example room layout plot is shown below (based on the configuration as detailed at the beginning of this section):
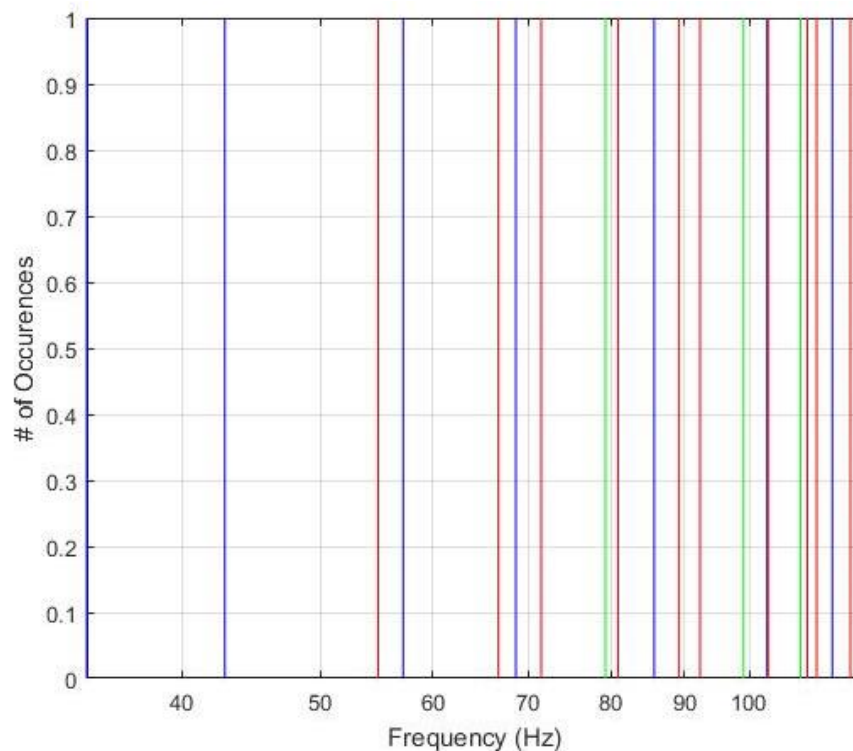
o   Modal distribution

Plots the mathematically-predicted modal frequencies. The plot is color-coded, where blue, red and green represent axial, tangential and oblique modes, respectively. Oblique modes are only plotted for 3D configurations. Users can define the frequency range to be plotted.

This plotting option is available for all source signals and saved data. The predicted modes are only accurate for completely rectangular topologies.

An example modal distribution plot is shown below (based on the configuration as detailed at the beginning of this section):
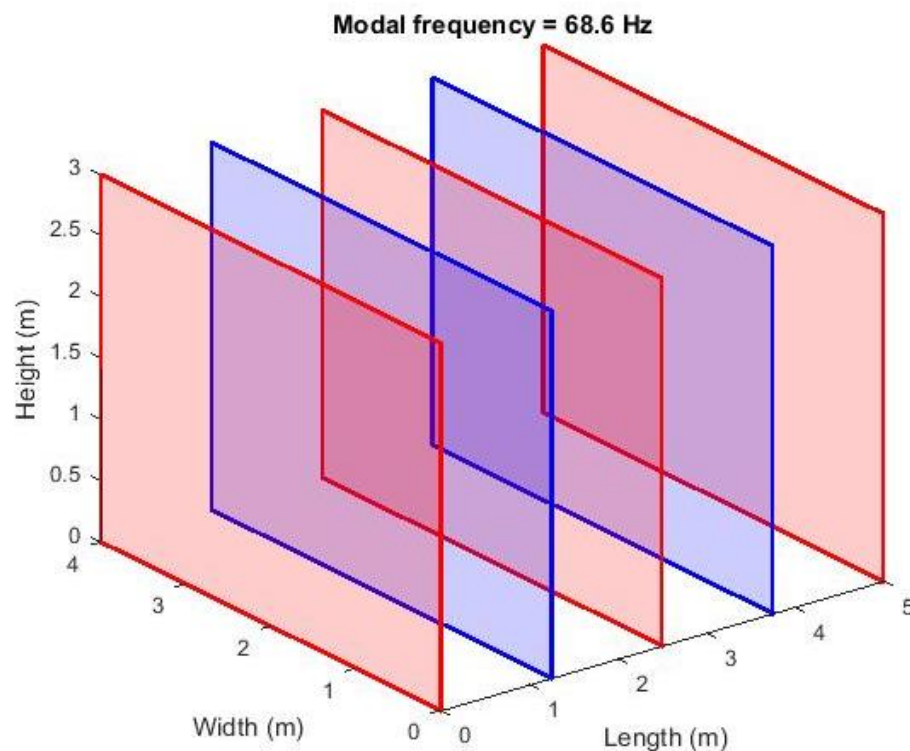
o   Modal layout

Plots the spatial distribution of the mathematically-predicted modal frequencies. The plot is color-coded, where blue points/lines/planes represent nodes (zero sound pressure) and red points/lines/planes represent anti-nodes (sound pressure maximum).

Users can define the mode to be visualized by inputting the modal indices (Nx, Ny, Nz). Nz is only active for 3D configurations. The theoretical modal frequency for the visualization is displayed above the plot.

This plotting option is available for all source signals and saved data. The predicted modal spatial layouts are only accurate for completely rectangular topologies.

An example modal layout plot is shown below (based on the configuration as detailed at the beginning of this section):
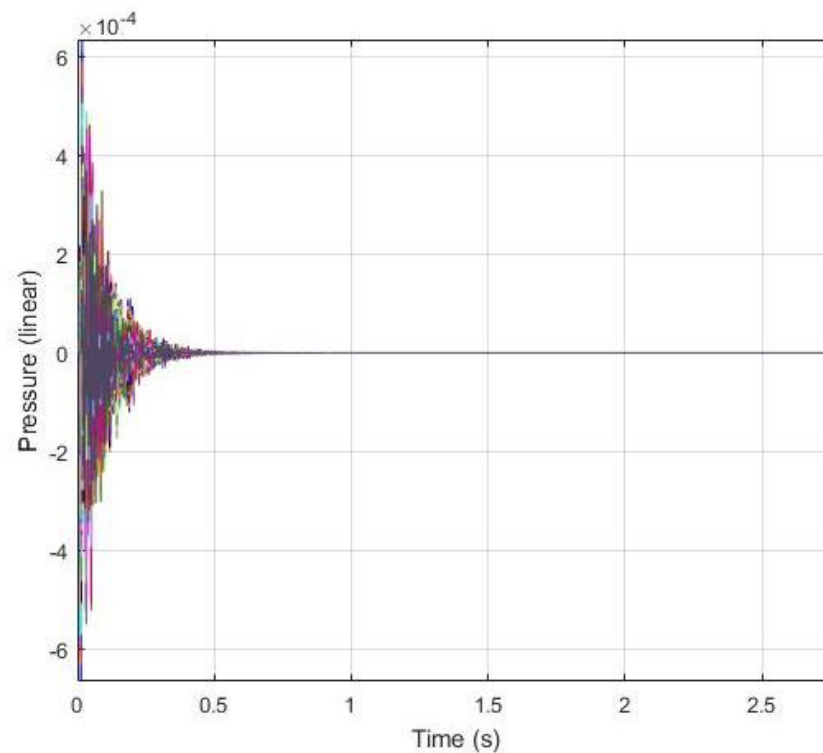
o Signal vs. time

This plotting option displays the simulated data in terms of time vs. amplitude.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the time range plotted and the amplitude scale (linear).

An example time domain plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):
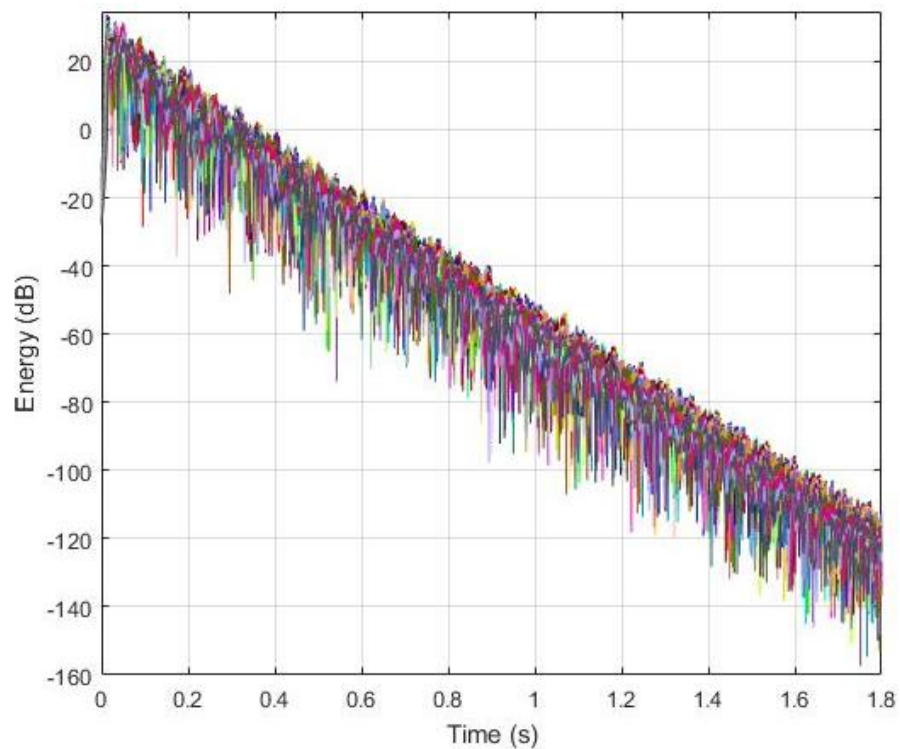
o   Energy time curve (ETC)

This plotting option displays the energy time curve (ETC) of the simulated data.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the time range plotted and the amplitude scale (dB).

An example ETC plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):
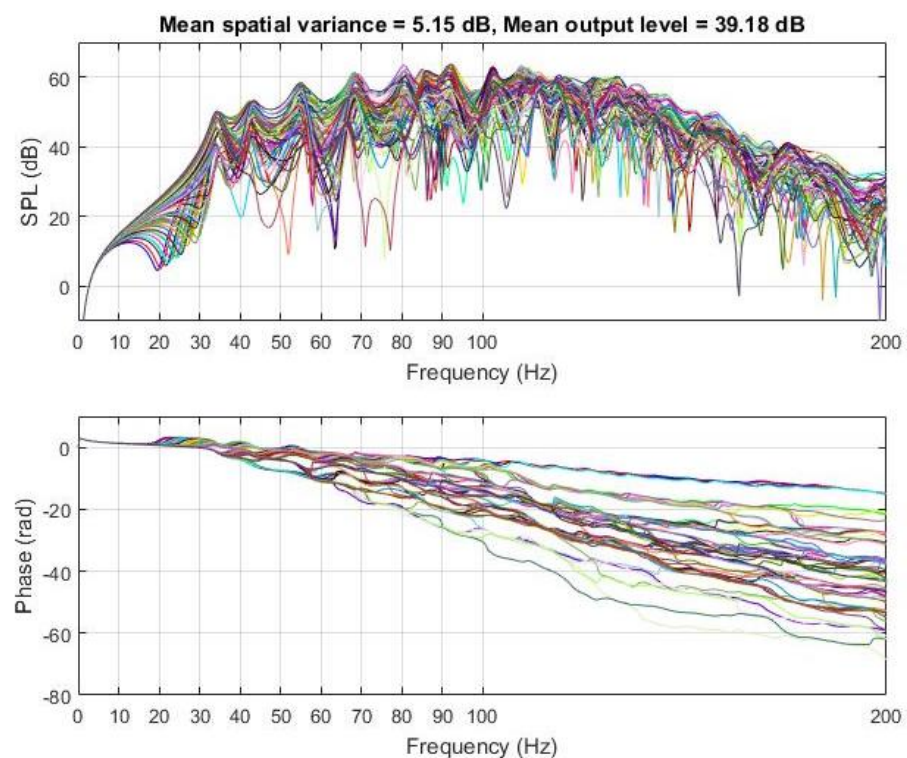
o Complex frequency response

This plotting option displays the complex frequency response (magnitude and phase) of the simulated data.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the frequency range plotted and the amplitude scale (dB or radians). An additional option includes the ability to overlay the theoretical modal frequencies as colored vertical lines using the tick boxes underneath the plotting area. Octave smoothing can be controlled vie the smoothing box.

Mean spatial variance (how much the magnitude response varies, on average, from point to point in the measurement grid) and mean output level (average recorded level over all measurement points) are both automatically calculated and displayed above the plots.

An example complex frequency response plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):
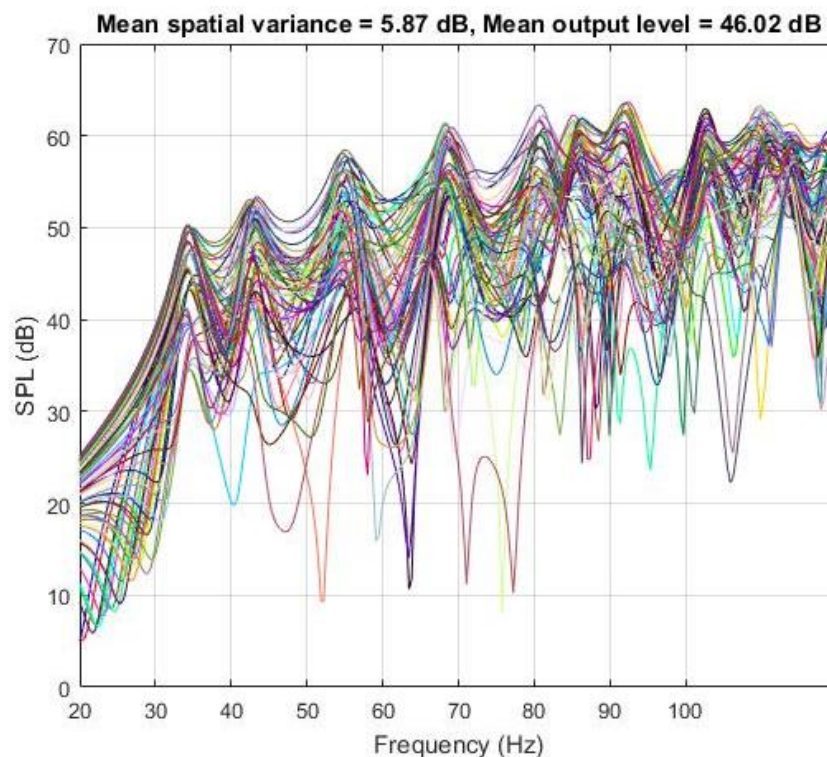
o   Magnitude response

This plotting option displays the magnitude response of the simulated data.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the frequency range plotted and the amplitude scale (dB). An additional option includes the ability to overlay the theoretical modal frequencies as colored vertical lines using the tick boxes underneath the plotting area. Octave smoothing can be controlled vie the smoothing box.

Mean spatial variance (how much the magnitude response varies, on average, from point to point in the measurement grid) and mean output level (average recorded level over all measurement points) are both automatically calculated and displayed above the plots.

An example magnitude response plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):
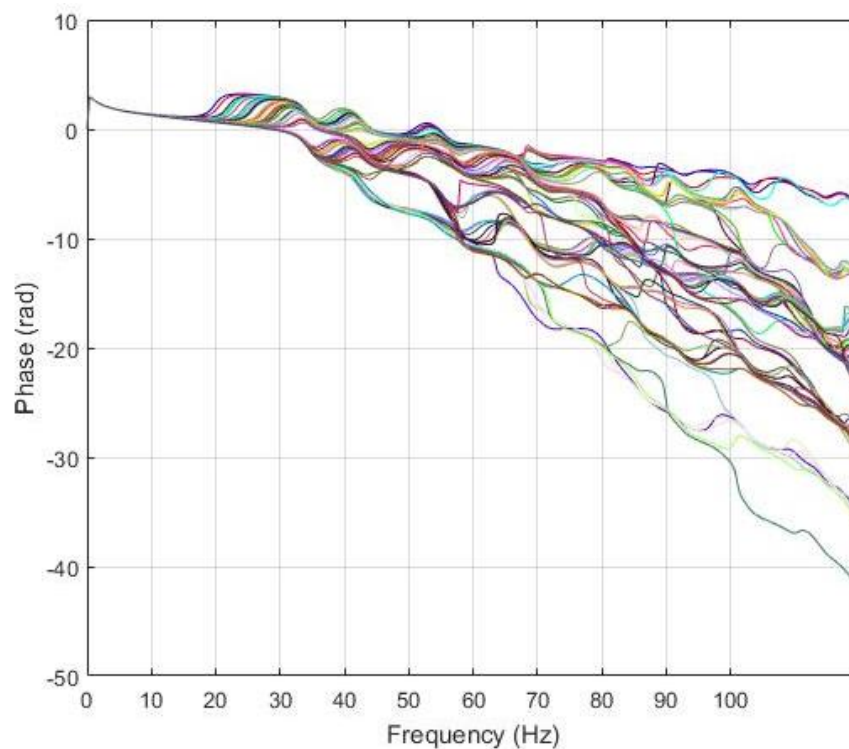
o Phase response

This plotting option displays the phase response of the simulated data.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the frequency range plotted and the phase scale (radians). An additional option includes the ability to overlay the theoretical modal frequencies as colored vertical lines using the tick boxes underneath the plotting area.

An example phase response plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):
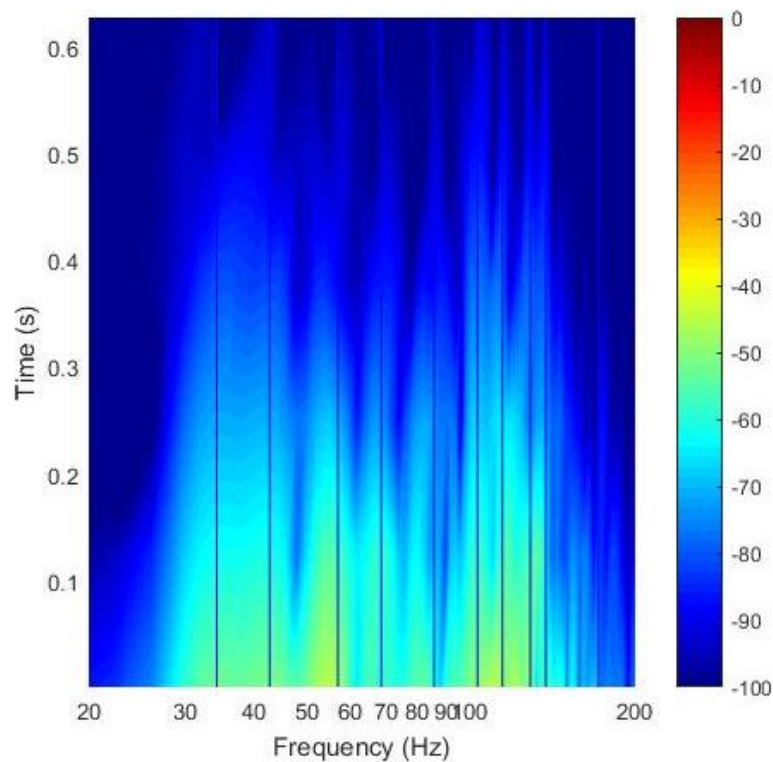
o Spectrogram

This plotting option displays a spectrogram of the simulated data.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot the average spectrogram calculated over all measurement points.

Users have the option to adjust the frequency range plotted and the amplitude scale (dB). An additional option includes the ability to overlay the theoretical modal frequencies as colored vertical lines using the tick boxes underneath the plotting area.

An example spectrogram is shown below with point (5, 5) plotted, and theoretical axial modes overlaid (based on the configuration as detailed at the beginning of this section):
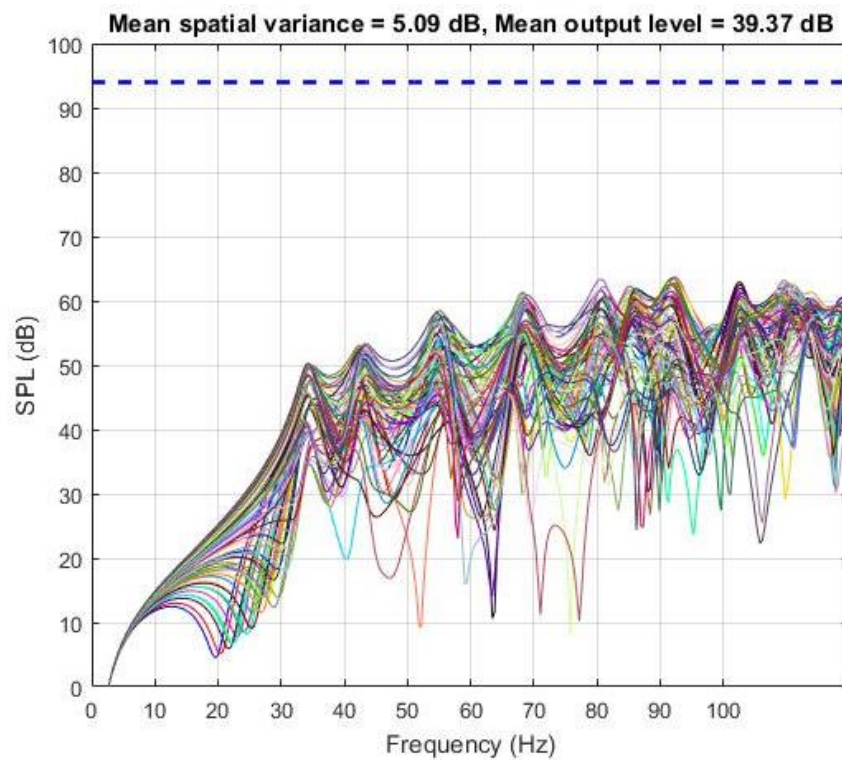
o Input vs. output (magnitude response)

This plotting option displays the magnitude response of the simulated data with the magnitude response of the raw source signal overlaid as a thick blue dotted line.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the frequency range plotted and the amplitude scale (dB). An additional option includes the ability to overlay the theoretical modal frequencies as colored vertical lines using the tick boxes underneath the plotting area. Octave smoothing can be controlled vie the smoothing box.

Mean spatial variance (how much the magnitude response varies, on average, from point to point in the measurement grid) and mean output level (average recorded level over all measurement points) are both automatically calculated and displayed above the plots.

An example input vs. output (magnitude response) plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):

Mean spatial variance = 5.09 dB, Mean output level = 39.37 dB

o   Input vs. output (signal vs. time)

This plotting option displays the simulated data in terms of time vs. amplitude along with the raw source signal's time response plotted as a thick blue dotted line.

Users have the option to select which measurement point to plot via the point selection menu. Alternatively, users can plot all points together or the average calculated over all measurement points.

Users have the option to adjust the time range plotted and the amplitude scale (linear).

An example input vs. output (signal vs. time) plot is shown below with all measurement points plotted (based on the configuration as detailed at the beginning of this section):

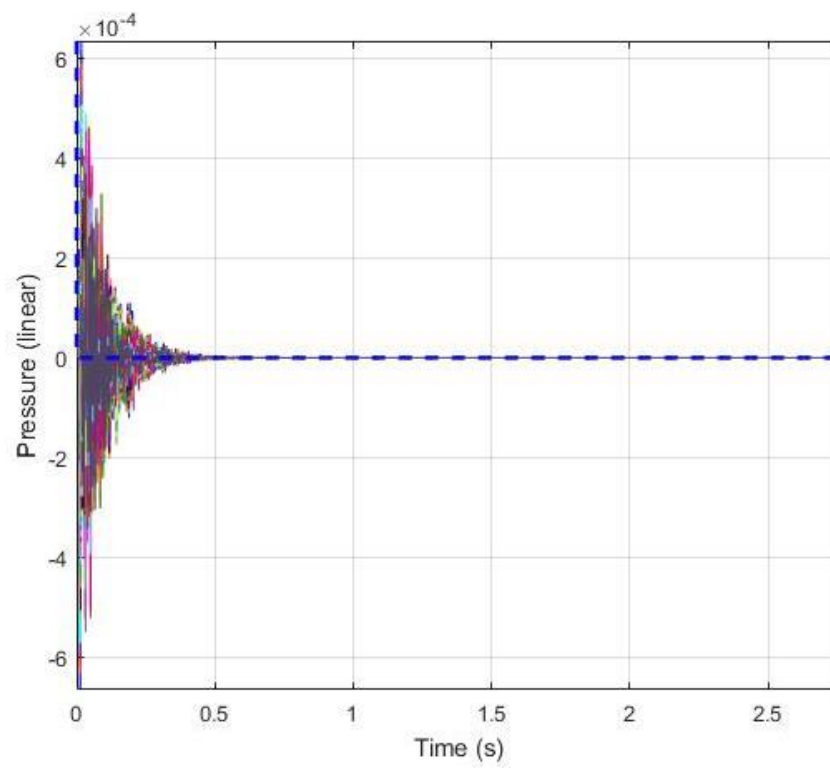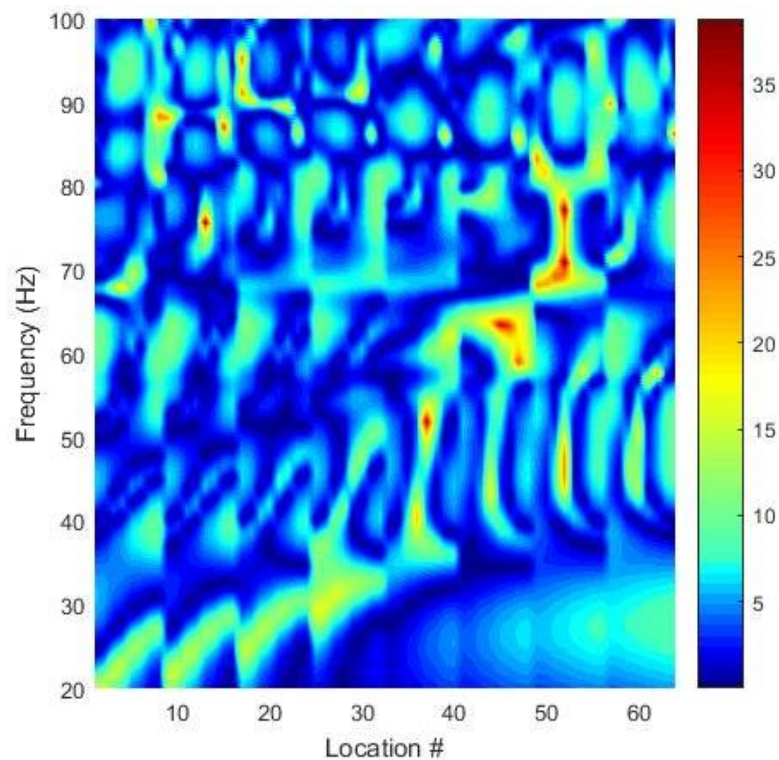o Magnitude deviation (vs. frequency)

This plotting option displays the magnitude deviation vs. frequency for each measurement point. The measurement points are plotted horizontally in terms of location number, beginning with the first point in the first row and progressing through each row until all points have been addressed.

Magnitude deviation in this instance is calculated by calculating the mean magnitude response over all locations for each frequency bin and then calculating how far off the mean response an individual measurement point's magnitude response is (in dB), calculated for each frequency bin individually.

Users have the option to adjust the frequency range plotted.

An example magnitude deviation (vs. frequency) plot is shown below (based on the configuration as detailed at the beginning of this section):

o Magnitude deviation (overall)

This plotting option displays the magnitude deviation as a birds-eye view of the measurement grid. The measurement points are plotted in terms of location coordinate, which is directly in line with the room layout plot.

Magnitude deviation in this instance is calculated by calculating the standard deviation from the mean room magnitude response for each measurement point.

Users have the option to adjust the frequency range plotted.

An example magnitude deviation (overall) plot is shown below (based on the configuration as detailed at the beginning of this section):
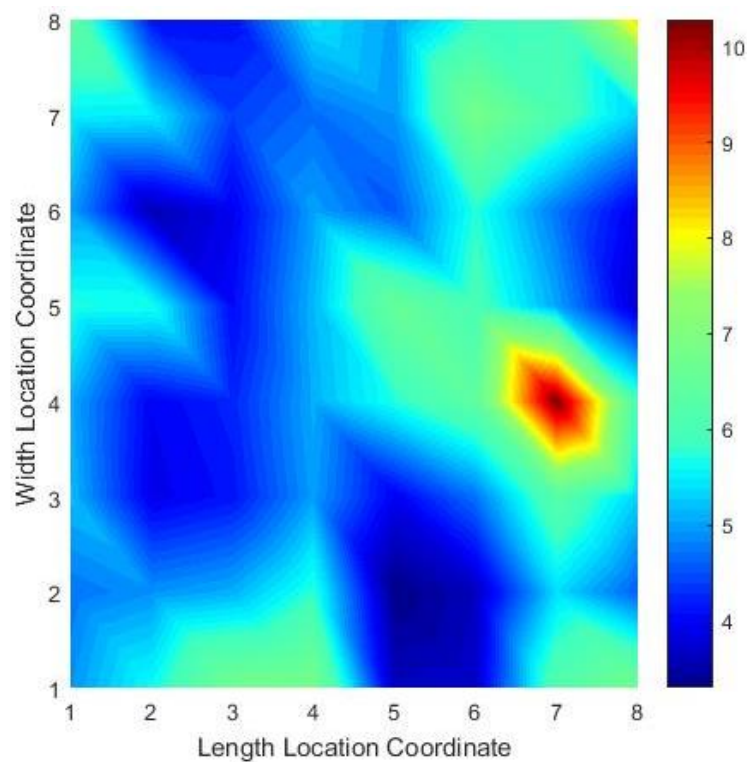
o   Tone bursts (comparison)

This plotting option allows users to compare tone burst measurements (time domain) at up to four measurement points. Additionally, users can inspect the tone burst time response for the raw source signal. Plots are displayed as time (s) vs. amplitude (linear).

The specific tone burst to be plotted can be selected from the drop down menus in the lower right hand corner of each plot. Each tone burst measurement can be played back by pressing the button with the ">" label in the lower right hand corner of each plot. Users have the option to adjust the time range plotted.

Example tone bursts (comparison) plots are shown below when dealing with a tone burst source signal with a carrier frequency of 50 Hz, 15 cycles per burst and 3 burst repetitions (based on the configuration as detailed at the beginning of this section):

o Tone burst (mean error vs. frequency)

This plotting option is only available with a tone burst sweep source signal. The plot shows the mean average error vs. frequency for each measurement location. Each measurement's amplitude envelope (for each tone burst frequency in the sweep) is compared to the raw source signal's envelope and the mean absolute error (MAE) is calculated.

The measurement points are plotted horizontally in terms of location number, beginning with the first point in the first row and progressing through each row until all points have been addressed.

An example tone burst (mean error vs. frequency) plot is shown below when dealing with a tone burst sweep from 20 – 120 Hz (steps of 5 Hz) with 15 cycles per burst and 3 burst repetitions (based on the configuration as detailed at the beginning of this section):
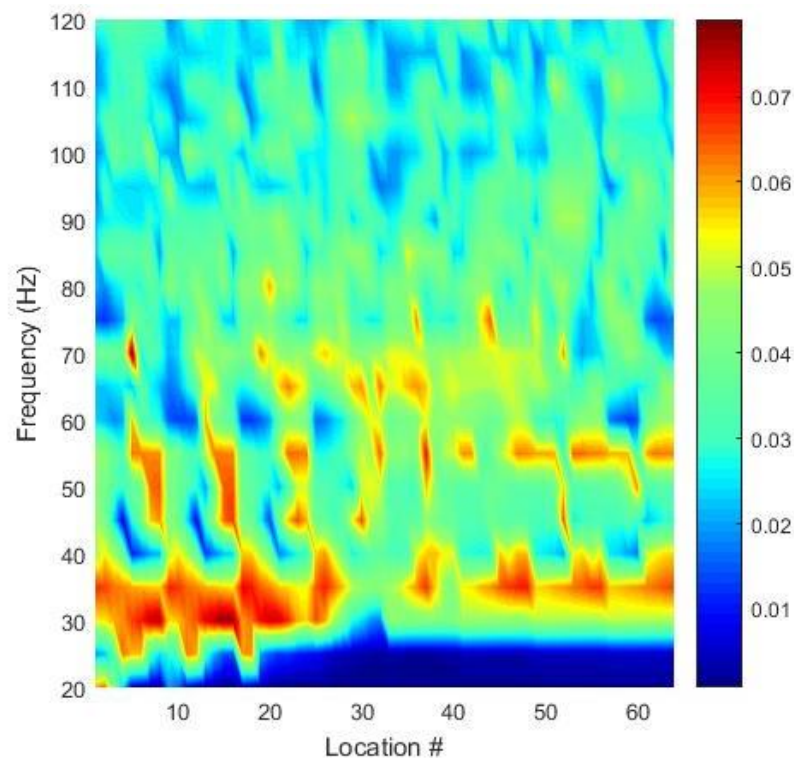
o   Tone burst (overall mean error)

This plotting option is only available with a tone burst sweep source signal. The plot shows the mean average error for each measurement location (average over the frequency range of the sweep). Each measurement's amplitude envelope is compared to the raw source signal's envelope and the mean absolute error (MAE) is calculated.

The measurement points are plotted in terms of location coordinate, which is directly in line with the room layout plot.

An example tone burst (overall mean error) plot is shown below when dealing with a tone burst sweep from 20 – 120 Hz (steps of 5 Hz) with 15 cycles per burst and 3 burst repetitions (based on the configuration as detailed at the beginning of this section):
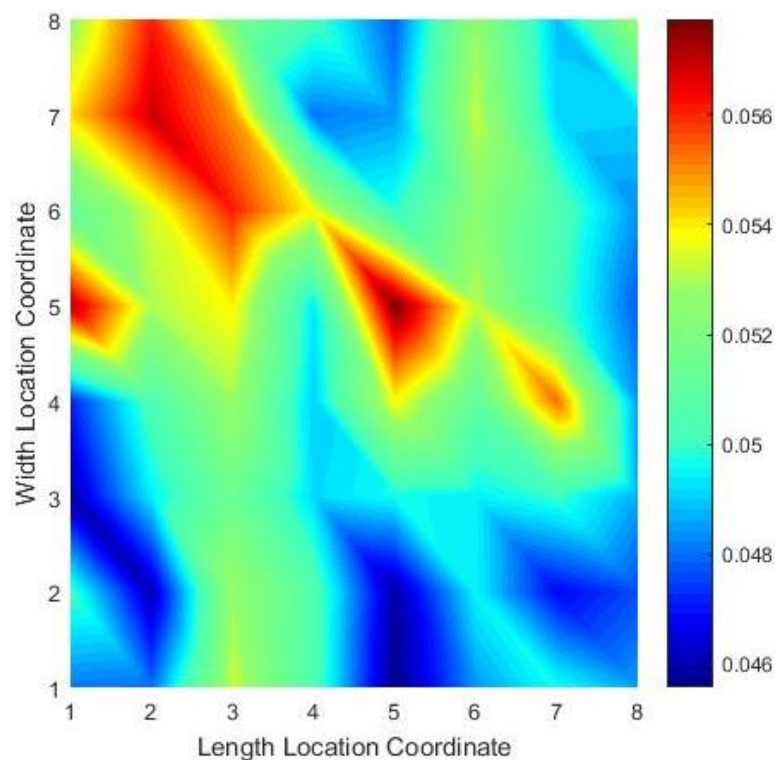
o   Sound distribution 2D (sound pressure level)

This plotting option is only available when the full grid data is saved in the simulation. This option plots the sound distribution due to the source signal as a 2D plot.

Users can define the SPL (dB) range used for the color scale as well as the time step to plot. The averaging window defaults to 0 s, indicating no time averaging. If a user desires a time averaged plot, the averaging value can be set to any value between zero and the length of the signal under analysis. If the model is 3D, the user can define the vertical slice to plot.

An example sound distribution 2D (sound pressure level) plot is shown below when dealing with a 34 Hz sinusoid source signal, inspecting the final time step in the simulation (based on the configuration as detailed at the beginning of this section):
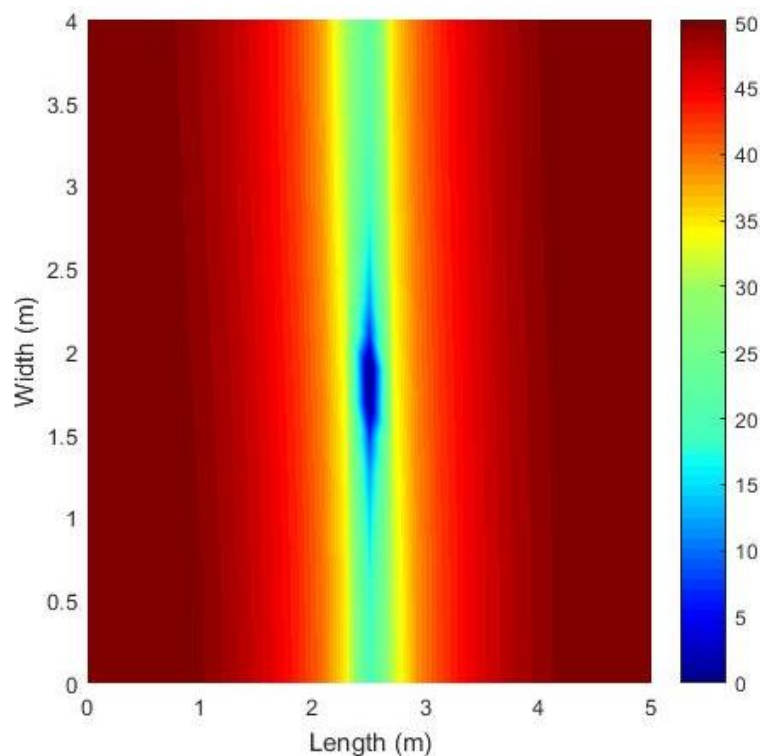
o   Sound distribution 2D (sound pressure)

This plotting option is only available when the full grid data is saved in the simulation. This option plots the sound distribution due to the source signal as a 2D plot.

Users can define the sound pressure (linear) range used for the color scale as well as the time step to plot. The averaging window defaults to 0 s, indicating no time averaging. If a user desires a time averaged plot, the averaging value can be set to any value between zero and the length of the signal under analysis. If the model is 3D, the user can define the vertical slice to plot.

An example sound distribution 2D (sound pressure) plot is shown below when dealing with a 34 Hz sinusoid source signal, inspecting the final time step in the simulation (based on the configuration as detailed at the beginning of this section):

o   Sound distribution 3D (source pressure level)

This plotting option is only available when the full grid data is saved in the simulation. This option plots the sound distribution due to the source signal as a 3D plot.

Users can define the SPL (dB) range used for the color scale as well as the time step to plot. The averaging window defaults to 0 s, indicating no time averaging. If a user desires a time averaged plot, the averaging value can be set to any value between zero and the length of the signal under analysis.

An example sound distribution 3D (sound pressure level) plot is shown below when dealing with a 34 Hz sinusoid source signal, inspecting the final time step in the simulation (based on the configuration as detailed at the beginning of this section):
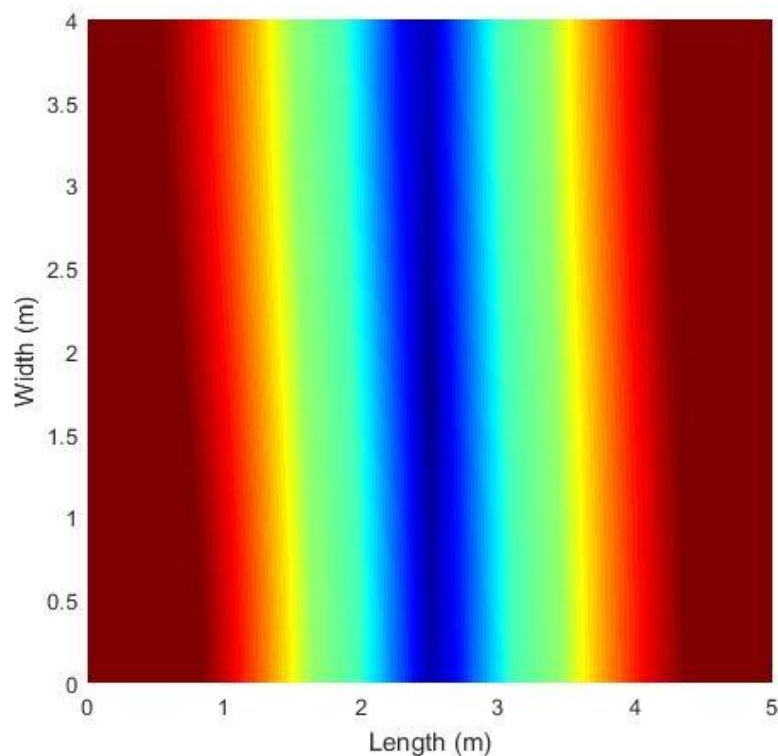
o Sound distribution 3D (sound pressure)

This plotting option is only available when the full grid data is saved in the simulation. This option plots the sound distribution due to the source signal as a 3D plot.

Users can define the sound pressure (linear) range used for the color scale as well as the time step to plot. The averaging window defaults to 0 s, indicating no time averaging. If a user desires a time averaged plot, the averaging value can be set to any value between zero and the length of the signal under analysis.

An example sound distribution 3D (sound pressure) plot is shown below when dealing with a 34 Hz sinusoid source signal, inspecting the final time step in the simulation (based on the configuration as detailed at the beginning of this section):
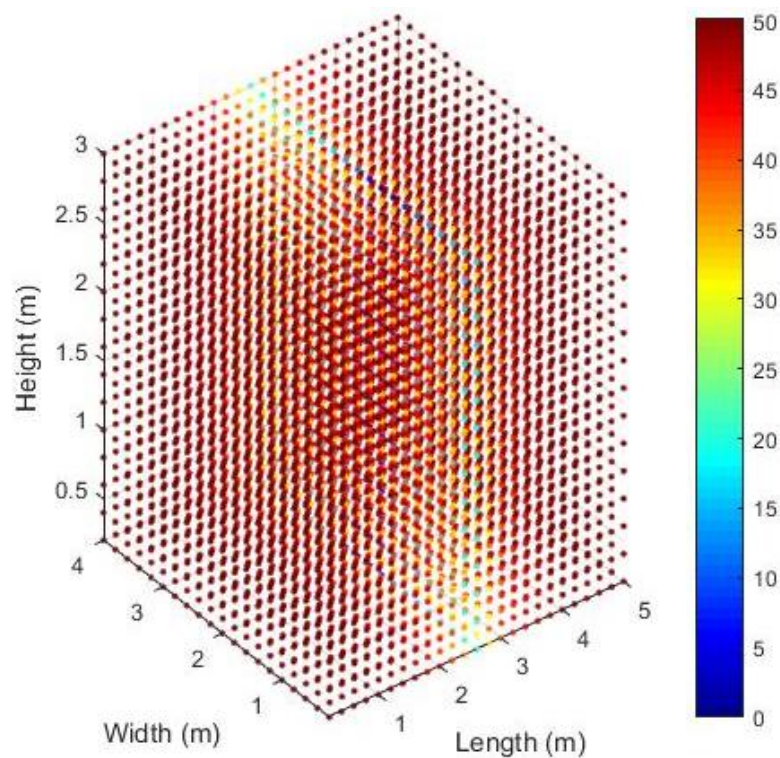

o Animation 2D (sound pressure level)

This plotting option is only available when the full grid data is saved in the simulation. This option creates an animation of the sound distribution over time due to the source signal as a 2D plot.

Users can define the SPL (dB) range used for the color scale as well as the time range to animate. If the model is 3D, the user can define the vertical slice to plot.

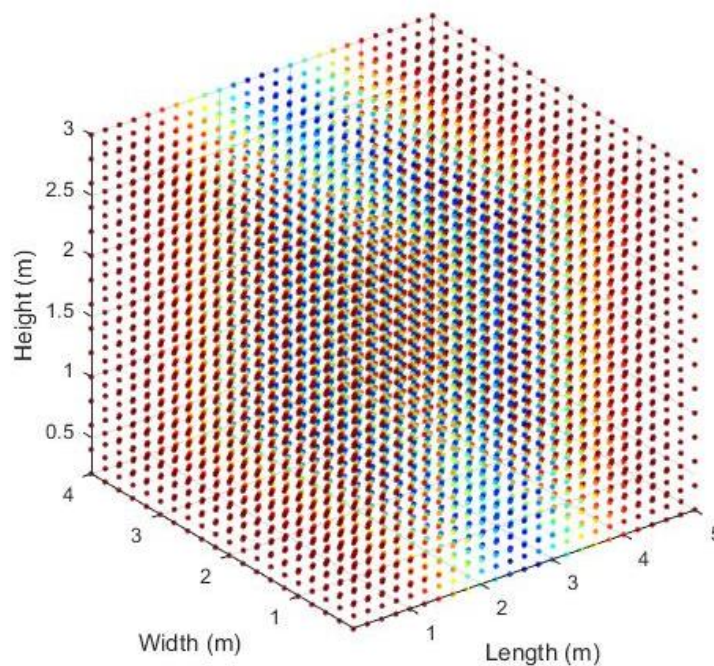Animations can be run with the green ">" button and stopped with the red "x" button.

o Animation 2D (sound pressure)

This plotting option is only available when the full grid data is saved in the simulation. This option creates an animation of the sound distribution over time due to the source signal as a 2D plot.

Users can define the sound pressure (linear) range used for the color scale as well as the time range to animate. If the model is 3D, the user can define the vertical slice to plot.

Animations can be run with the green ">" button and stopped with the red "x" button.

o Animation 3D (source pressure level)

This plotting option is only available when the full grid data is saved in the simulation. This option creates an animation of the sound distribution over time due to the source signal as a 3D plot.

Users can define the SPL (dB) range used for the color scale as well as the time range to animate.

Animations can be run with the green ">" button and stopped with the red "x" button.

o Animation 3D (sound pressure)

This plotting option is only available when the full grid data is saved in the simulation. This option creates an animation of the sound distribution over time due to the source signal as a 3D plot.

Users can define the sound pressure (linear) range used for the color scale as well as the time range to animate.

Animations can be run with the green ">" button and stopped with the red "x" button.

Auralization

Pressing the AURALIZATION button sends the data analysis function in auralization mode. This is indicated by the button turning green.

In auralization mode, users will see the room layout plot. Click any of the measurement points on the plot (indicated by colored crosses) to auralize the source signal at that location.

As an auralization is playing back, the button will turn yellow. It will return to green once playback is complete.

To exit auralization mode, simply click the AURALIZATION button again, which will turn it back to black.

Plotting

There are three options within the plotting section:

o **Save plot/animation**

This button allows the user to save the current plot or animation to file. The user will be prompted to choose a file name and location for saving.

Note that animations take a long time to save. Please be patient! Also, the animation files are as uncompressed .avi. These files will be very large, so make sure you have enough disk space before saving.

o **Edit colors**

This button allows the user to alter the colors on each measurement point.

The points can be set to the same user-defined color, by choosing the ALL option.

The points can be individually altered by choosing the INDIVIDUAL option.

The point colors can be reset to the toolbox defaults by clicking the RESET option.

o **Invert BG color**

This button will switch the background and text colors in the toolbox from black to white. This is often useful if users are creating plots to be used in publications or presentations.

Exit analysis

Clicking this button exits the data analysis function and returns the user to the home screen. Any unsaved plots or animations will be lost when this button is clicked.

References

Toolbox development

- Hill, A.J.; M.O.J. Hawksford. "Visualization and analysis tools for low frequency propagation in a generalized 3D acoustic space." Journal of the Audio Engineering Society, vol. 59, no. 5, pp. 321-337. May, 2011.

- Hill, A.J.; M.O.J. Hawksford. "Visualization and analysis tools for low frequency propagation in a generalized 3D acoustic space." 127th AES Convention, New York, USA. October, 2009.

- Hill, A.J.; M.O.J. Hawksford. "Seeing through the darkness: Visualizing low frequency behavior in small rooms." Proc. IOA - Reproduced Sound 25, Brighton, UK. November, 2009.

FDTD equations

- Olesen, S.K. "Low frequency room simulation using finite difference equations." AES Convention 102. March 1997.

- Celestinos, A.; S. Birkedal Nielsen. "Multi-source low frequency room simulation using finite difference time domain approximations." AES Convention 117. October, 2004.

- Tolan, J.G.; J.B. Schneider. "Locally conformal method for acoustic finite difference time-domain modelling of rigid surfaces." 140th Meeting of the ASA. July 27, 2003.

Polar pattern control

- Olson, H.F. "Gradient Loudspeakers." JAES Volume 21, Issue 2, pp. 86-93. March, 1973.

Record of updates

v1.6

o Fixed issue with data files overwriting. Now it should be impossible to accidentally overwrite data files.

o Option added to magnitude and phase response plotting where you can now overlay the average response across all the individual responses.

o Fixed issue with source delay displaying in seconds rather than milliseconds in the source setup menu.

o Fixed all averaging to exclude responses consisting of NaN values (which occur when a measurement point is accidentally placed outside the simulation space). Similar issue fixed when calculating spatial variance and mean output level.

o Fixed measurement point placement to avoid points at the extremes of the simulation space accidentally being located beyond the set boundaries (causing a simulation error).

o Improved functionality for configuration files saved in feet. There have been various issues found by users (thanks Daisuke!) when trying to save a file in feet and then re-loading. Hopefully the problem has been solved, but there many be some lingering bugs.

o Fixed MLS order setting box in source setup menu to ensure to generated time is correct (should be twice the expected MLS length – $2^m – 1$).

v1.5

o Added plotting option to limit the time frame for signal analysis. This will allow for easier analysis of acoustic response over time as the simulation progresses.

o Color generation for measurement point analysis updated so that measurement point rows are represented in the same color group for easier analysis.

o Added time averaging feature to sound distribution plots in the data analysis section to allow for clearer analysis of spatial data.

o Added green ">" button for sound distribution plots which allows user to set all parameters before plotting (as opposed to automatic plotting, which can be time consuming due to the convolution process).

o Fixed issues with room shaping in feet.

o Fixed issue with loading a configuration or data file from a folder other than where the software is installed.

v1.4

o Corrected issue with defining source and measurement locations in feet.

o Updated final pressure distribution and animation plots to correctly display room dimensions when using feet as units, as well as correctly displaying the data.

o Addressed issues with automatic user input checks for the data analysis functions when using feet as units. The discovered issues have now been corrected.

o Adjusted size of room dimensions text box in the simulation settings overview section, to avoid larger dimensions being cut off.

v1.3

o New smoothing function written, which operates significantly faster than the original function (now based on approximate spectral smoothing, rather than fractional octave bank filtering).

o Smoothing function made available for phase response plots.

o Phase now plotted in degrees rather than radians.

o Error messages now contain full details.

o Spectrogram scaling corrected. Smoothing option added.

o Magnitude deviation rage controls added for MD analysis functions. Smoothing option added.

o Fixed issue with incorrect saving of sound pressure distribution animations.

v1.2

o Corrected issue with sound pressure animations in 2D topologies (software was incorrectly plotting SPL instead of sound pressure).

o Changed all sound pressure distribution plotting and animation functions so that the true sound pressure is represented, rather than displaying the absolute value of the pressure.

o Built in error catching into each function, so that users are now made aware when something has gone wrong in the software (and basic details of the error encountered).

v1.1

o Fixed bug where source signals longer than impulse responses were causing software crashes when asked to plot SPL distributions and create animations. A similar issue was resolved when saving animations.

o Fixed issue with aliasing at high-frequencies by implementing a lowpass filter at one-fifth the model sampling rate.

- o The auralization crossover was corrected so that the crossover point is now correctly set to the upper frequency limit of the model.
- o Source signal amplitude is now allowed to be greater than 0 dB.
- o Progress bars have been added for all convolution and saving operations within the data analysis function of the toolbox.
- o Error due to sound sources being placed on the far edge of a dimension fixed.
- o Absorption settings removed from room settings menu, so that users can adjust absorption after setting the room dimensions.
- o Background color changed for the 32-bit version to avoid invisible buttons.
- o Option added in the run simulation menu to allow for automatic saving of individual measurement point impulse responses to 48 kHz, 24 bit .wav files.
- o Measurement settings menu fixed for 3D models, so that default measurement point height is automatically set to the vertical dimension's midpoint.
- o Frequency response plots corrected so that the x axis scales are logarithmic.
- o Option added to frequency plots to allow for octave band smoothing.