

Sound Intensity Measurement with the Online Analysis Module (ATP 08)

Introduction

The term "sound intensity" refers to the energy flow in space, i.e. the amount of energy passing through a unit area normal to the direction of the radiated sound per unit of time. Unlike the sound pressure level, sound intensity is thus a vector quantity, which has a magnitude and a direction. Therefore, the sound intensity is very well suited for the localization of sound sources. Physically, sound intensity is "energy per time and area", which is the same as "power per area", and is measured in watts per square meter (W/m^2).

Sound intensity can be calculated as the product of sound pressure p and sound particle velocity u . To measure the parameters required for the calculation, two types of sensors are available: The first type are the PU probes produced by Microflown Technologies, which measure the sound pressure p and the sound particle velocity u directly. The velocity sensor consists of two very thin wires located closely to each other, which are heated by an electric current. The temperature difference of these wires caused by the sound particle velocity – involving a variation of the electric resistance of the wires – delivers the measurement signal for the sound particle velocity. To measure the sound pressure level, a microphone is integrated into the probe.

The other type are pressure gradient sensors, also called PP probes, where the sound pressure p is measured at two different locations in the sound field by means of two microphones installed close to each other. From these two sound pressure values, the pressure gradient can be determined by means of linear approximation, and from it, the sound particle velocity can be calculated via integration. The two microphones of the PP probe, mounted oppositely, are separated by a spacer. The length of this spacer affects the frequency range that can be measured. The shorter the spacer, the higher is the upper frequency limit, and the longer the spacer, the lower is the lower frequency limit. The microphone pair used must meet the highest standards regarding the identical measurement of the phase of the sound wave. For the measurement, the axis through the microphone pair is oriented so that it corresponds to the normal vector of the measurement area.

The ArtemiS Online Analysis Module (ATP 08) supports both types of probes.

Preparations in the HEAD Sensor Explorer

In the HEAD Sensor Explorer, first the probe to be used must be entered as a new sensor. This can be done either in a new or in an already existing sensor list. In the opened sensor list, a folder must be selected or a new folder must be created, where the new sensor can then be inserted.

For a PU probe, select the sensor type "PU Probe", and for a PP probe with two microphones, select the sensor type "Int. Probe (2 Mic)". In the field "Number of Sensors" you can only select "1 Axis" for the

PP probe, while the PU probe allows you to choose between "1 Axis" and "3 Axis" types. After confirming the sensor type by clicking on "Next", a window with a parameter table for entering data for the selected sensor type will open. For the PP probe, this table provides two columns, one for each of the two microphones. Here you can enter, for example, the sensitivity of the two microphones directly via the keyboard. When selecting a one-dimensional PU probe, the first column lists the parameters for the pressure sensor, and the second column those for the velocity sensors (see figure 1). For a three-dimensional probe, the table is expanded accordingly.

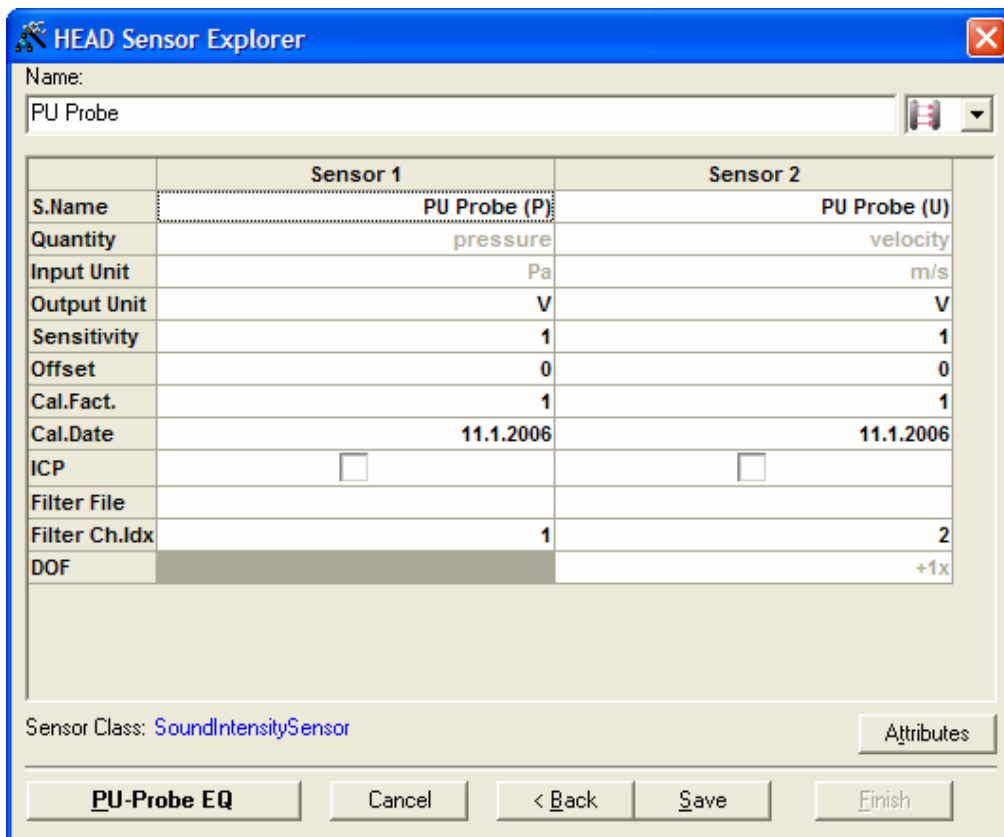


Figure 1: Parameter table in the HEAD Sensor Explorer

For the correct measurement with a PU probe, specifying only the sensitivity is not sufficient. To equalize a PU probe correctly, either click into the "Filter File" field to load a user-defined equalization curve, or click on the "PU-Probe EQ" button. This button will open the *HEAD Sensor Equalizer* window, where data from the calibration documents provided by Microflown Technologies can be entered (see figure 2). On the first tab, the information regarding the microphone used must be entered, and on the second tab those for the velocity sensor. Before doing that, you must first specify in the "Options" field (lower left), whether it is a calibration with two ("Type 1") or three cut-off frequencies ("Type 2"). The number of cut-off frequencies can be found in the calibration documents. In the right half of the window, the equalization curve can be monitored. Click on the "Preview" button to start a preview of the area specified in the lower right.

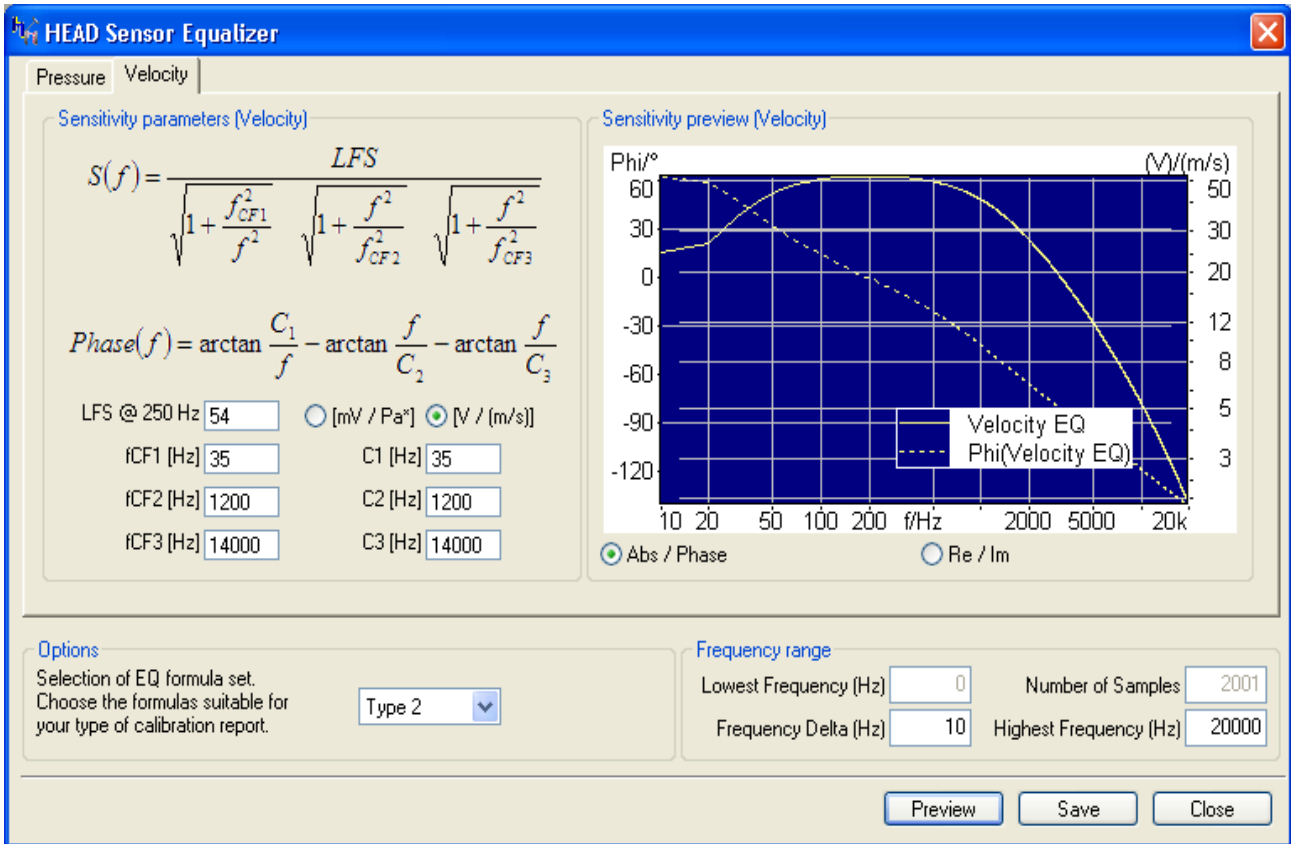


Figure 2: HEAD Sensor Equalizer

Clicking on "Save" saves the data in a separate two-channel EQU file, "Close" closes the dialog. All required data for the PU probe, such as the sensitivity, the equalization and the units, have automatically been entered in the parameter table.

To quit the parameter table for the PP or PU probe, click on "Finish", and after saving the sensor list, the necessary preparations in the HEAD Sensor Explorer are finished.

Measuring Sound Intensity in the ArtemiS Online Analysis Module (ATP 08)

To perform a sound intensity measurement, first the measurement probe must be connected to a suitable frontend, which in turn must be connected to a computer. After that the Online Analyzer can be started in ArtemiS . Depending on the individual configuration, the Analyzer either starts immediately or after selecting the current frontend. Once the frontend is configured correctly, you can start with the settings in the channel list. Press the [F11] key to open the channel list. In this list, the sensor defined in the HEAD Sensor Explorer can be connected to the desired channels. To make sure that the sound intensity is calculated correctly and the DOF-Information is saved, it is important to take care of the correct order of the channels and the correct referencing. In the window area labeled "Details" the first channel must be entered as the reference channel for the second channel of the probe (see figure 3). For a three dimensional probe the first channel has to be referenced to the channels 3 and 4, too.

Channels:										Details:		
	On	Name	Sensor	S.Name	Range	FE Range(50%)	SamplingRate	ICP	Coupling	DOF	SQuadriga.In2	
In1	<input checked="" type="checkbox"/>	In1		PU Probe (P)	+/-7.471 Pa	-36 dB[V]	44.1 kHz	<input type="checkbox"/>	AC		Calculator	
In2	<input checked="" type="checkbox"/>	In2		U Probe (U)	+/-0.075 m/s	+4 dB[V]	44.1 kHz	<input type="checkbox"/>	AC + 1X		Ref. Ch. In1	
In3	<input type="checkbox"/>	In3		<no sensor>	+/-1.418 V	-6 dB[V]	44.1 kHz	<input type="checkbox"/>			Window Hanning	
In4	<input type="checkbox"/>	In4		<no sensor>	+/-1.418 V	-6 dB[V]	44.1 kHz	<input type="checkbox"/>			Extended	
PlnL	<input type="checkbox"/>	PlnL		<no sensor>	0 .. 1000 Hz						Sensor	
PlnR	<input type="checkbox"/>	PlnR		<no sensor>	0 .. 1000 Hz						S.Name PU Probe (U)	
											Quantity velocity	

Figure 3: Channel list in the Online Analyzer

Pressing the [F12] key opens a window where the analysis results to be saved can be selected ("Save Analysis"). If only the result of the sound intensity measurement is of interest, all other analysis functions can be disabled, as shown in figure 4.

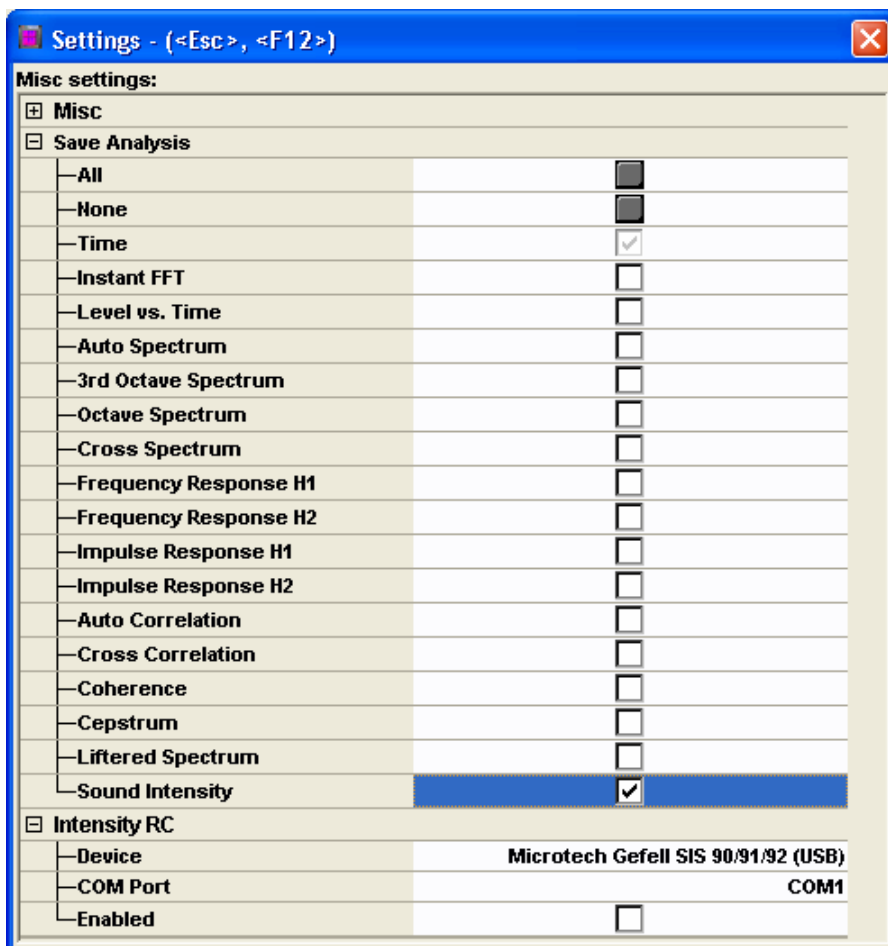


Figure 4: Selection of analysis results to be saved by the Online Analyzer

Further below in this window, the remote control option for certain measurement probes can be activated. To ensure a correct communication between computer and probe, it is also necessary to specify the probe type ("Device") and the connection port used ("COM Port"). In the current version, the

Online Analyzer supports the remote control functions of the following PP probes: Microtech Gefell SIS 90/91/92 and G.R.A.S. 50 AI-B. To close the selection window, press the [Esc] key.

Depending on the probe type used (PU or PP), the measured quantities will differ. The PU probe measures the sound pressure level and the sound particle velocity, whereas the PP probe measures the sound pressure level at two different locations. This means, of course, that the algorithms used to calculate the sound intensity in each case are different as well. The calculation algorithm can be selected in the main window of the Online Analyzer in the area "Settings" -> "Sound Intensity" -> "Method". For a PU probe, "Press. Velocity" must be selected, for a PP probe, select "Press. Gradient".

For the PU probe, in addition to the calculation method, the resolution of the sound intensity analysis can be selected as well in the selection box "View". For the "Press. Gradient" method, in addition to the resolution, also the current atmospheric pressure, the temperature and the length of the spacer between the two microphones must be entered (see figure 5). Only if these values are specified correctly, will the calculation algorithm of the Online Analyzer work correctly.

Analyzer settings:	
<input checked="" type="checkbox"/>	StartTrigger
<input checked="" type="checkbox"/>	StopTrigger
<input type="checkbox"/>	Averaging
<input type="checkbox"/>	Type
<input type="checkbox"/>	Manual Stop
<input type="checkbox"/>	Repetitions
<input type="checkbox"/>	Duration [s]
<input checked="" type="checkbox"/>	Calculation
<input type="checkbox"/>	Trans. Window
<input type="checkbox"/>	Exp. Window
<input checked="" type="checkbox"/>	Liftered Spectrum
<input type="checkbox"/>	Sound Intensity
<input type="checkbox"/>	Method
<input type="checkbox"/>	Amb. Press. [mbar]
<input type="checkbox"/>	Amb. Temp. [°C]
<input type="checkbox"/>	Mic. Distance [cm]
<input type="checkbox"/>	View
<input checked="" type="checkbox"/>	Files

Figure 5: Settings for the sound intensity calculation

Furthermore, you can also select an "Averaging" function in the Settings. It can be used to smooth the diagram curve if it is very unsteady. In the "Repetitions" field, the number of blocks used for averaging is entered. If this number is set to "-1", an unlimited number of repetitions is included in the averaging. After selecting "Sound Intensity" in the selection box above the diagram (see figure 6), the correct channel for the display must be selected. For the application of a PP probe, this is the first channel, for which the second channel in the channel list was entered as the reference channel. The selection of the channel to be displayed is done in the selection box to the left of the diagram. Pressing the [Space] key starts the measurement.

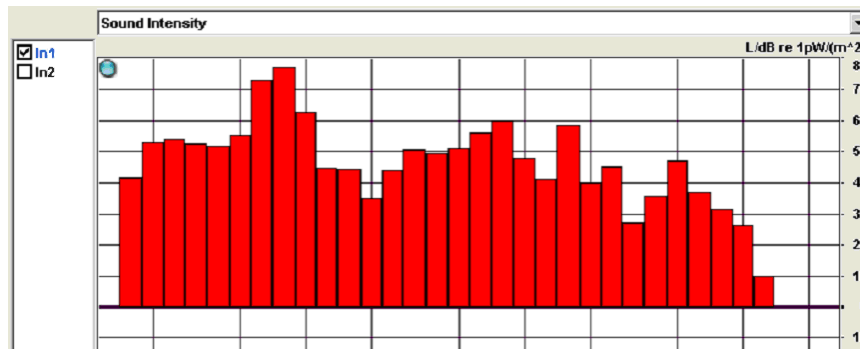


Figure 6: Diagram area of the Online Analyzer with sound intensity curve

If the displayed values are unusually small, this can be caused by a missing or wrong reference value for the calculation of the intensity level with the unit "dB". This reference value is 1 pW/m^2 and can be set in ArtemiS in the "Options" -> "Settings" -> "Miscellaneous" menu. Click into the upper left field of the "Reference Values" table with the right mouse button, and select "New" from the context menu. In the newly inserted line, you can enter the unit " W/m^2 " and the reference value " $1\text{e-}12$ " (see figure 7). Now the sound intensity will be converted to "dB" with the correct reference value.

Reference values		
	Unit	Ref. val.
1	Pa	2e-005
2	W	1e-012
3	%	100
4	$\text{m}(\text{s}^2)$	1e-006
5	$\text{W}(\text{m}^2)$	1e-012

Figure 7: Setting the reference value in ArtemiS

Application Example

In the following example, the sound power level of a laser printer in stand-by mode is determined using the sound intensity method. For this purpose, five measurement areas around the printer (forming a cube) are defined (figure 8), and the sound intensity of each area is determined. The sound power level of the laser printer can then be calculated by adding up the partial sound intensities multiplied with the measurement area.

The sound intensity is a vector quantity, i.e. the sign of the sound intensity indicates the direction of the sound flow. A positive sign means that sound passes the measurement area in the direction away from the measurement object; a negative sign means that sound enters the measurement area from the outside. If there is an interfering stationary noise in the background, it would radiate into the measurement area from one side (negative sign) and leave it on the other side (positive sign). By adding up the correctly signed partial sound intensities, in order to determine the sound power level, the interference noise would thus be eliminated from the calculation. However, this is only possible as long as the interference only consists of stationary sound signals.



Figure 8: Printer with indicated partial measurement areas

In this example, the measurement of the sound intensity is made with a PU probe from Microflow. With this probe, the five partial measurement areas around the printer are scanned typically using a back and forth pattern, both in horizontal and vertical direction. The size of each partial area is 0.2 m².

In order to measure the sound intensity correctly, the calculation method must be specified correctly in the Online Analyzer settings, and the other configurable parameters must also be set in accordance with the measurement situation. The following describes how changing some of the parameters affect the measurement result. Figure 9 shows a screenshot of the Online Analyzer window with the configurable parameters.

Analyzer settings:	
<input type="checkbox"/> StartTrigger	
└ Mode	FreeRun
<input type="checkbox"/> StopTrigger	
└ Mode	Repetitions
<input type="checkbox"/> Averaging	
└ Type	Freq. Domain Lin.
└ Manual Stop	<input type="checkbox"/>
└ Repetitions	400
└ Duration [s]	74.3039
<input type="checkbox"/> Calculation	
└ FFT Size	8192
└ Overlap [%]	67
└ Window	Hanning
└ Spect. Weight.	None
└ Band Row	B
└ Trans. Window	
└ Exp. Window	
<input checked="" type="checkbox"/> Liftered Spectrum	
<input type="checkbox"/> Sound Intensity	
└ Method	Press. Gradient
└ Amb. Press. [mbar]	1013.2

Figure 9: Analyzer Settings

In the menu item *Calculation*, the FFT window size (*FFT Size*), the window overlapping (*Overlap*), the window function (*Window*) and the spectral weighting (*Spect. Weight.*) for the calculation are specified. To ensure a sufficient number of samples in the individual third-octave bands, the FFT window size should not be made too small. For a sampling rate of 44.1 kHz and an FFT window size of 8192 samples, the resulting frequency resolution is about 5.4 Hz. If the sound intensity is displayed in third octaves, only one sample per third octave band is available for frequencies below 50 Hz. This should be taken into account in the interpretation of the measurement results. If, as shown in the screenshot, a Hanning window is used, it is recommended to use an overlap of at least 67% in order to compensate for the temporal weighting effects of the Hanning function¹. A spectral weighting is normally not used for the display of the sound intensity.

In the menu item *Averaging*, various averaging methods are available. For measuring the sound intensity, the most commonly used settings are "Freq. Domain Lin." and "Freq. Domain Exp.". For example, to localize noise sources and noise sinks, the exponential averaging in the frequency domain is suitable, whereas the linear averaging is used for the measurement of averaged sound intensity spectra. The number of blocks used for the linear averaging is specified in the *Repetition* field. It must be chosen sufficiently high, so possible outliers are eliminated by the averaging process. The number is high enough if the levels of the intensity spectrum vary only slightly towards the end of the measurement.

The *Start Trigger Mode* is set to "FreeRun", and the *Stop Trigger Mode* is set to "Repetitions". That way, the analysis starts as soon as the [Space] key is pressed and stops automatically as soon as the number of blocks entered under *Averaging Repetitions* has been analyzed. The required measurement duration as well as additional measurement regulations are compiled in the ISO 9614 standard.

The measurement of the sound intensity for the five partial measurement areas of the laser printer was performed with the settings shown in figure 9 and saved. As soon as an analysis result has been saved in the Online Analyzer, it appears automatically in the "Analysis Pool for Files" of the active ArtemiS project. Figure 10 shows the project for the sound intensity measurement of the laser printer.

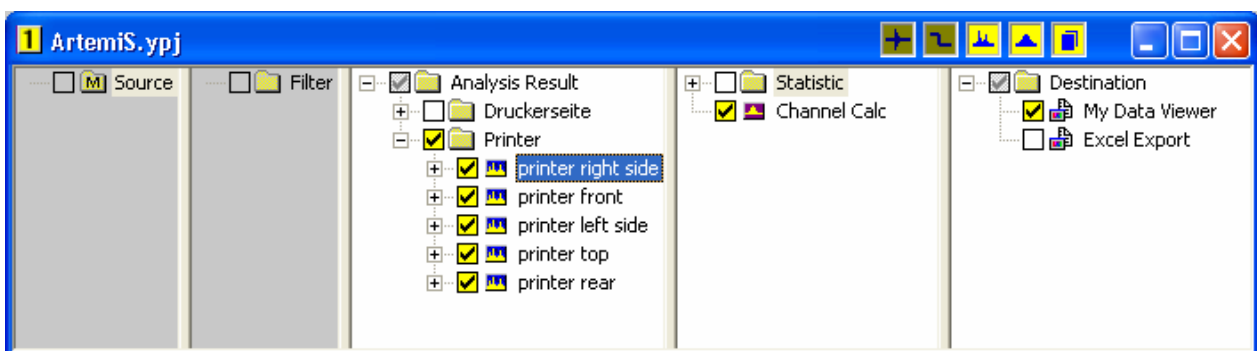


Figure 10: ArtemiS project with sound intensity measurements in the "Analysis Pool for Files"

¹ For a fixed number of iterations the measurement time will decrease because of the overlapping windows. However, the displayed time (duration [s]) remains the same for all overlapping values because this time indication relates to the saved time signal and not to the actual measurement time. The saved time signal is artificially generated by placing the single windows one after another. By this means, the length of the saved time signal is independent of the degree of overlap.

To calculate a sound power spectrum from the five measured partial intensities, the *Channel Calc* function in the *Statistics Pool* can be used. Figure 11 shows the required script.

First, the size of the partial measurement areas is defined in the script. Since in our example all partial areas have the same size, only one value must be specified here.

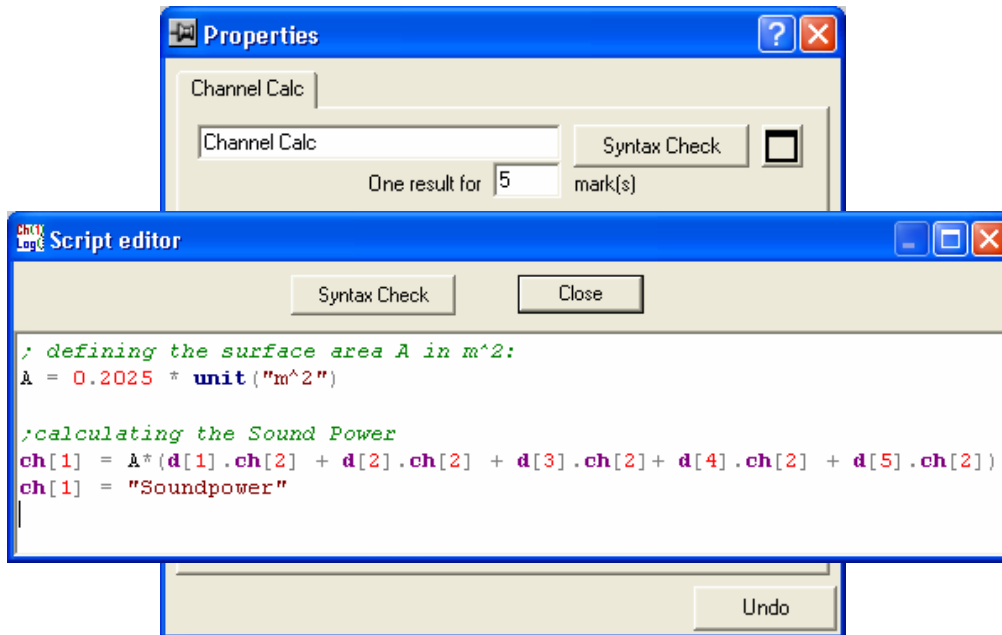


Figure 11: Script Editor of the *Channel Calc* function for calculating the sound power level

In the next step, the individual sound intensities are multiplied with the area and added up. From the two-channel file saved by the Online Analyzer, only the second channel is needed. The script shown creates a one-channel file, which is calculated only from the second channel of each of the five data sets. "d[1].ch[2]" stands for the second channel of the first data set, which was activated for the calculation in the "Analysis Pool for Files". The instruction "ch[1] = "Soundpowerlevel"" changes the channel name to "Soundpowerlevel".

Figure 12 shows the sound power spectrum of the laser printer. The diagram only shows the frequency range between 50 and 10000 Hz, because with the measurement setup used and the selected Analyzer settings, only data in this range were measured correctly. The sound power spectrum shows that the laser printer emits broadband noise and has a tonal component at 200 Hz.

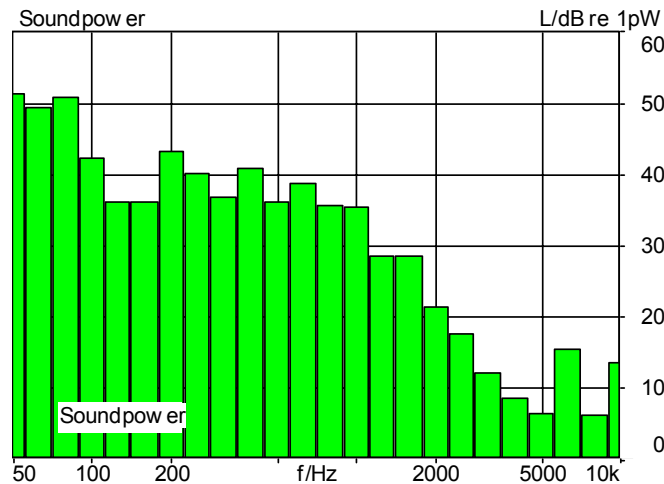


Figure 12: Sound power spectrum of the laser printer

Note

In order to use the features presented in this application note you will need the ArtemiS Basic version (Code 4600), the ArtemiS Online Analysis Module, ATP 08 (Code 4608), and the ArtemiS Calculation Module, ATP 14 (Code 4614).

Do you have any questions or remarks? Please write to: Application-Notes@HEAD-acoustics.de. We look forward to receiving your response!

Appendix

Phase Calibration of a PP Probe

In order to carry out the phase calibration, the measurement probe, frontend, ArtemiS equipped with at least the extended filter ATP 09 (Code 4609), and a sound intensity calibrator are required. The sound intensity calibrator is shipped with a microphone coupler, a pistonphone and a sound source. To calibrate the probe, a sensor list with a corresponding sensor must already be defined (see section "Preparations in the HEAD Sensor Explorer"). After a sound intensity probe has been selected as a sensor in the Online Analyzer, first a level calibration of the microphones must be performed. To do so, open the calibration dialog in the Online Analyzer with the keyboard shortcut [Shift]+[F11]. For the level calibration, you can use the microphone coupler and the pistonphone that came with the sound intensity calibrator. To perform the level calibration, insert the microphones into the ports 1 and 2 of the coupler as well as the pistonphone. For a correct calibration, the sound level of the pistonphone must be entered in the calibration dialog of the Online Analyzer. Note that the pistonphone cannot achieve its nominal sound level (the value printed on the pistonphone) while it is installed in the coupler. The correct level to be entered can be found in the documentation sheet of the sound intensity calibrator.

After the successful level calibration, the phase calibration can be started. To do so, leave the microphones in the coupler and replace the pistonphone by the sound source. The phase calibration requires several steps:

- measuring the transfer function between the two microphones,
- smoothing the transfer function curve and
- adding the smoothed filter function to the sensor properties.

Since the levels of the microphones have been calibrated in the previous step, the measured transfer function represents the phase difference between the microphones. Before the measurement, open the Settings dialog of the Online Analyzer ([F12] key) and make sure that under *Save Analysis* only the *Frequency Response H1* analysis is selected. Saving other analysis results is not necessary for the phase calibration. Furthermore, in the *Analyzer Settings* under *Averaging*, at least 200 repetitions must be specified in order to achieve a sufficiently long averaging time (see figure A.1). Afterwards, the measurement can be performed and the transfer function can be saved.

Analyzer settings:	
<input type="checkbox"/> StartTrigger	
Mode	FreeRun
<input type="checkbox"/> StopTrigger	
Mode	Repetitions
<input type="checkbox"/> Averaging	
Type	Freq. Domain Lin.
Manual Stop	<input type="checkbox"/>
Repetitions	200
Duration [s]	18.576
<input type="checkbox"/> Calculation	
FFT Size	4096
Overlap [%]	0
Window	Hanning
Spect. Weight.	None
Band Row	B

Figure A.1: Analyzer Settings for measuring the transfer function

Sound sources used for sound intensity calibration usually have an upper frequency limit of 5 to 6 kHz. Above 5 kHz, the measured transfer function does not deliver meaningful results. If frequencies above 5 kHz are to be measured in sound intensity measurements later, the transfer function of this higher frequency range must be corrected manually before using it for phase calibration. This correction, however, only sets the absolute value and phase to zero and thus does not deliver an actual calibration. Generally the phase matching of intensity probes microphones is very good, so that phase calibration is only necessary at lower frequencies. Only in the lower frequency range do phase differences need to be taken in account.

The correction can be done with ArtemiS as follows:

First, open a project in ArtemiS and insert a new filter array into the Filter Pool. Now open the *Properties* dialog of the FIR filter (see figure A.2) and click on the button with the three dots to load the

measured transfer function as a filter. Then click on the *Edit* button to open a diagram where you can edit the transfer function. In this case, this can most easily be done with the *Edit numerical* function, which can be invoked by a click into the diagram with the right mouse button. With the entries shown in figure A.3, the curve above 5 kHz can be corrected manually.

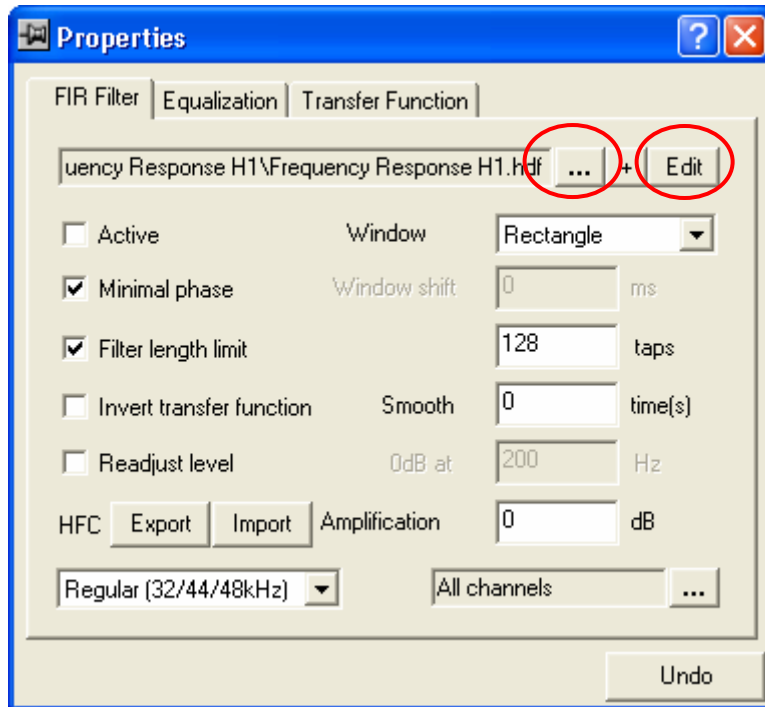


Figure A.2: Properties dialog of the FIR filter with selected transfer function H1

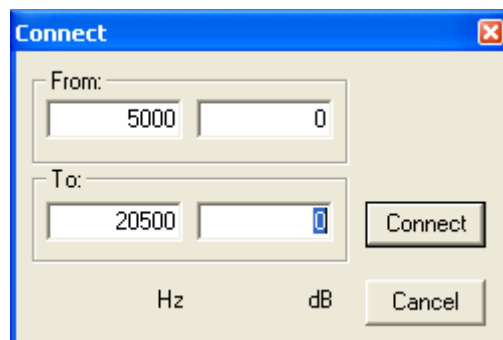


Figure A.3: Numeric entries for correcting the curve

In addition to the absolute value of the transfer function, the phase above 5 kHz must be corrected as well. Click on a unit of the Y axis to open a selection box, where you can select the phase angle in degrees to be displayed (see figure A4). As soon as the display has been switched, you can set the phase angle above 5 kHz to zero as well, using the same numerical entry method as described above.

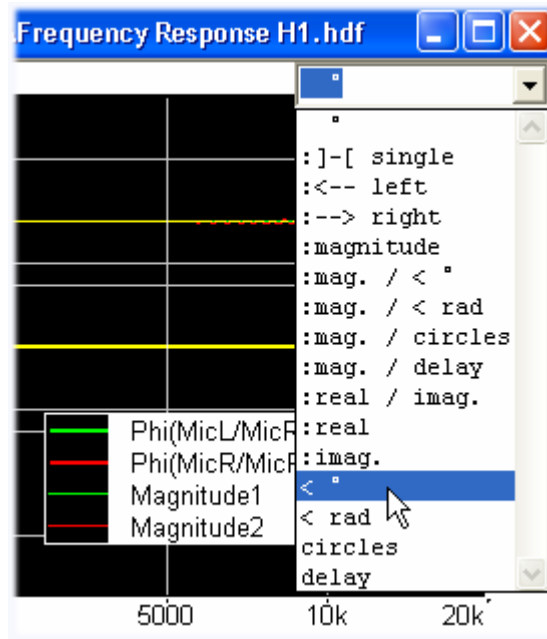


Figure A.4: Selecting the phase angle in degrees for display in the editing diagram

Since only the first channel is needed for the phase correction, it is sufficient to correct only the first channel of the absolute value and the phase as described above. After closing the editing diagram, the correction is saved.

The corrected filter can now be assigned to the sound intensity probe in the Sensor Explorer or in the Online Analyzer and can be used for the following measurements.

A double click on a sound intensity sensor in the Sensor Explorer opens the *Properties* dialog. Select the filter created above for the second microphone. The selection box can be opened by clicking into the *Filter File* field. Because the phase corrections are stored in the first filter channel, the *Filter Channel Index* field must be set to 1. With this setting, the first channel of the filter file is used for correction. Figure A.5 shows an example for the *Properties* dialog of a sound intensity probe. Saving the sensor list saves the current sensor settings.

A PP probe configured this way is correctly calibrated regarding both level and phase values and can therefore be used for the measurement of sound intensities.

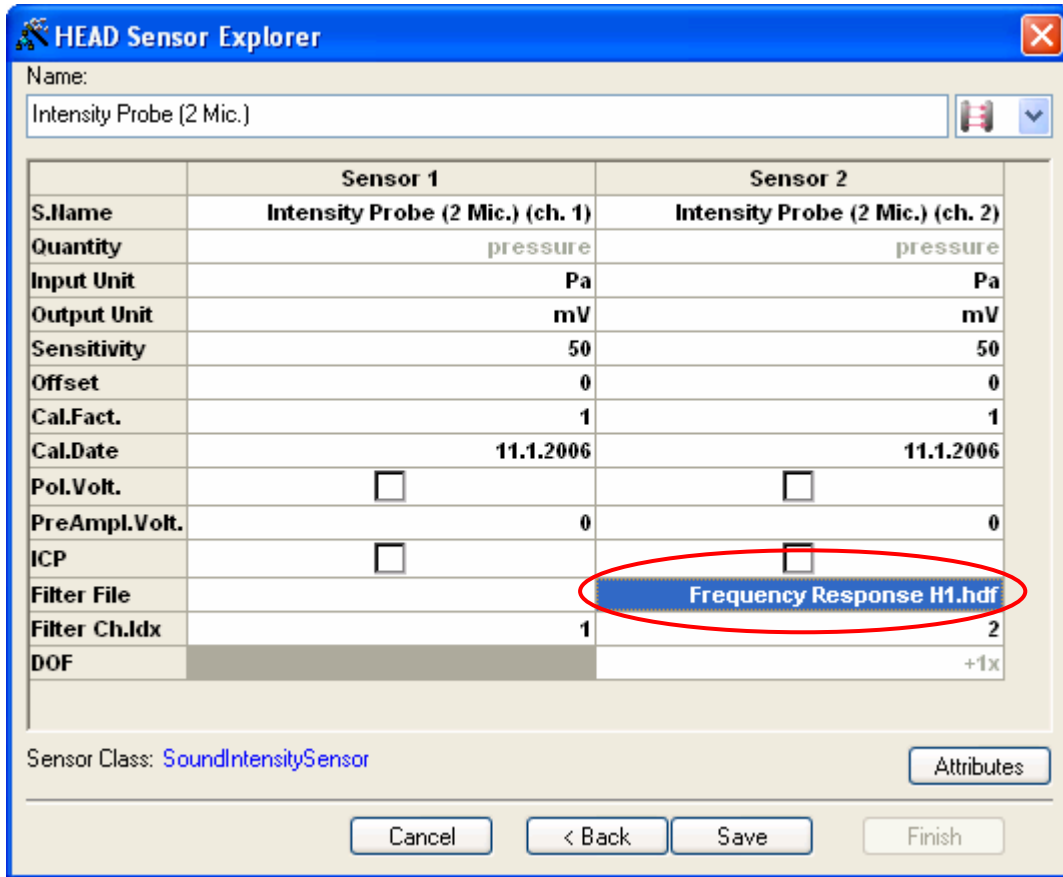


Figure A.5: Properties dialog of the sound intensity probe in the Sensor Explorer