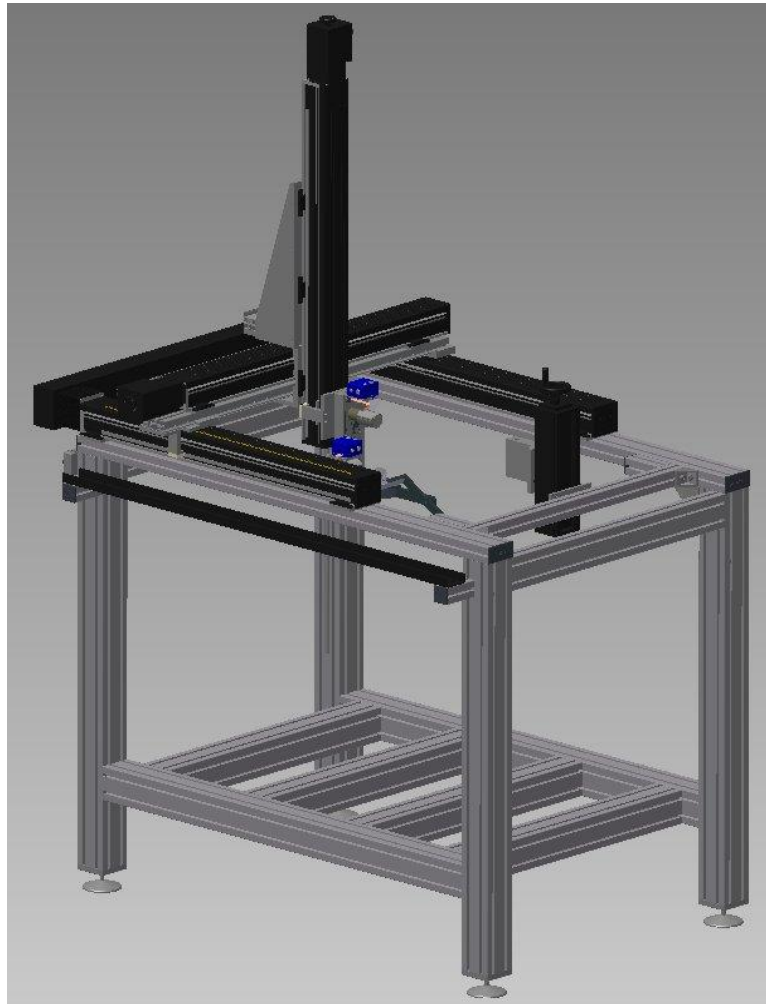


Ultrasound Test Tank Systems



UMS Post Processing: User Guide

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INTRODUCTION

This manual describes the Post Processing Engine (PPE) that is part of the UMS software. All data post processing is handled within PPE, regardless of whether the data to be processed is a single data trace or the results of a two dimensional (2D) scan. A flowchart describing the basic operation of PPE can be found in Figure 1.

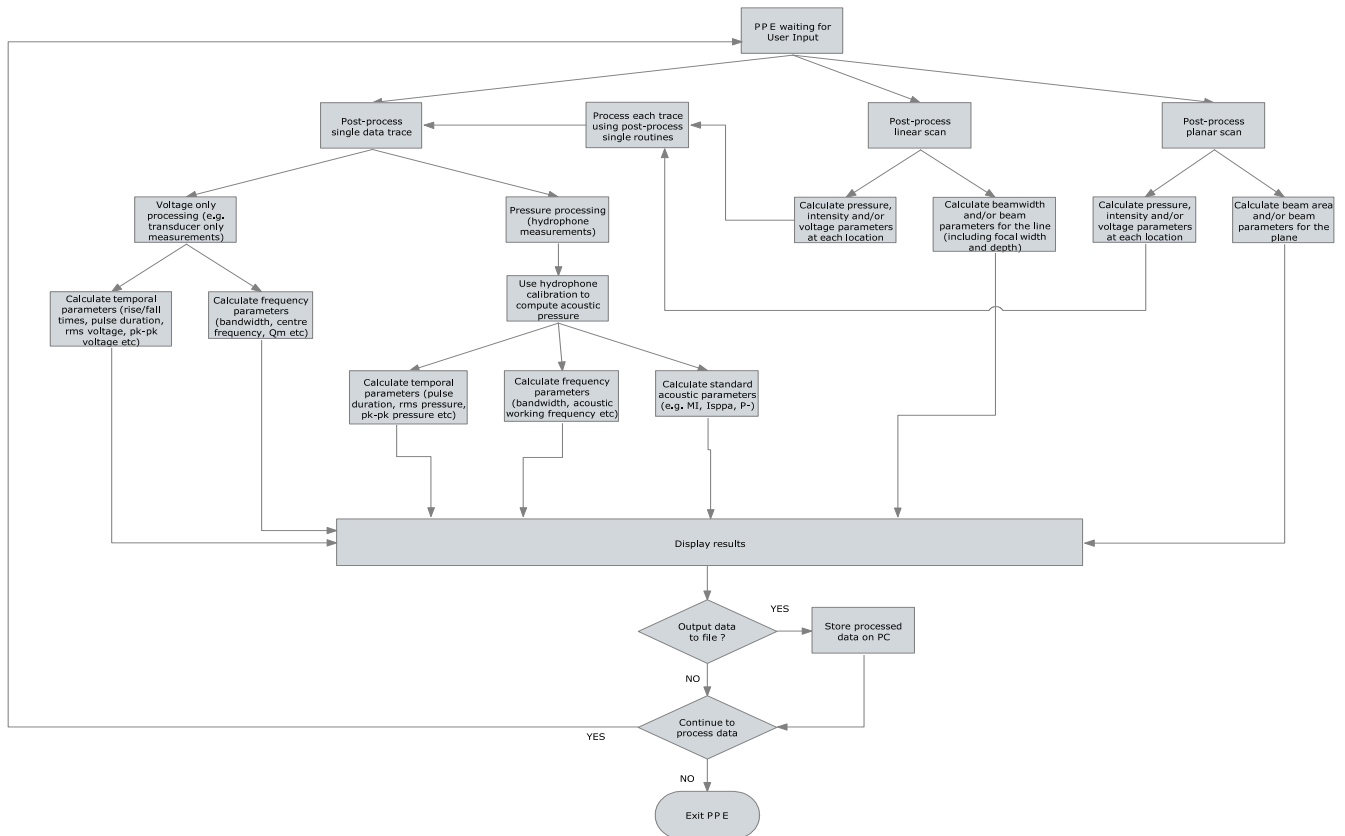


Figure 1 - Flowchart describing operation of PPE

Through out this manual, whenever a front panel control is referred to it will be identified thus:

<**Finish**> a control labeled "Finish" on the front panel

<**File**→**Open**> the "Open" item from within the "File" menu on the front panel

,or,

<**Voltage Parameters**→**RMS Voltage**> the "RMS Voltage" control from within the "Voltage Parameters" cluster on the front panel

FILE NAME CONVENTION

There are a large number of data files that are created by UMS and PPE and some standard file naming conventions have been implemented to assist users.

Raw data

Raw data files produced by UMS will have the file names consistent with one of the following.

Type of Measurement	File name
Single waveform	{STUB}.txt
Part of a linear scan	{STUB}{axis}{numeric}.txt
Part of a planar scan	{STUB}{axis}{numeric}{axis}{numeric}.txt

Where:

{STUB} is the file name stub supplied by the user at the time of acquisition

{axis} is alphabetic block identifying the axis used to conduct the scan. Possible values for this block are [X, Y, Z, Theta, Abt_X, Abt_Y] although not all these axes may be implemented. Arbitrary scans (linear scan type only) use the character [A] as an {axis} identifier

{numeric} is a three digit, zero-padded, number showing the integer index of the point within the scan.

Processed data

If a raw waveform has been processed through PPE without the use of hydrophone data the file name will gain an additional suffix of {_voltage}. Processed voltage waveforms also contain voltage spectrum information

Example: TESTX001.txt becomes TESTX001_voltage.txt

If a raw waveform has been processed through PPE with hydrophone data the file name will gain an additional suffix of {_pressure}. Processed pressure waveforms also contain pressure spectrum information

Example: TESTX001.txt becomes TESTX001_pressure.txt

Whenever a raw waveform has been processed through PPE an additional file containing spectral bandwidth as well as voltage and/or pressure waveform parameters will be produced. This file will have a {_params} suffix.

Example: TESTX001_params.txt

All processed linear scans, or linear profiles extracted as a row or column from within a planar scan, will be stored in a file with the `{_profile}` suffix. Processed planar data sets will be stored with a `{_map}` suffix.

THE PPE USER INTERFACE

The initial data entry screen

When the PPE application is loaded, the user is presented with the following front panel (see Figure 2). The tab panel at the top of the page initially shows just 4 options, but additional tabs may appear as the user selects additional options within the software.

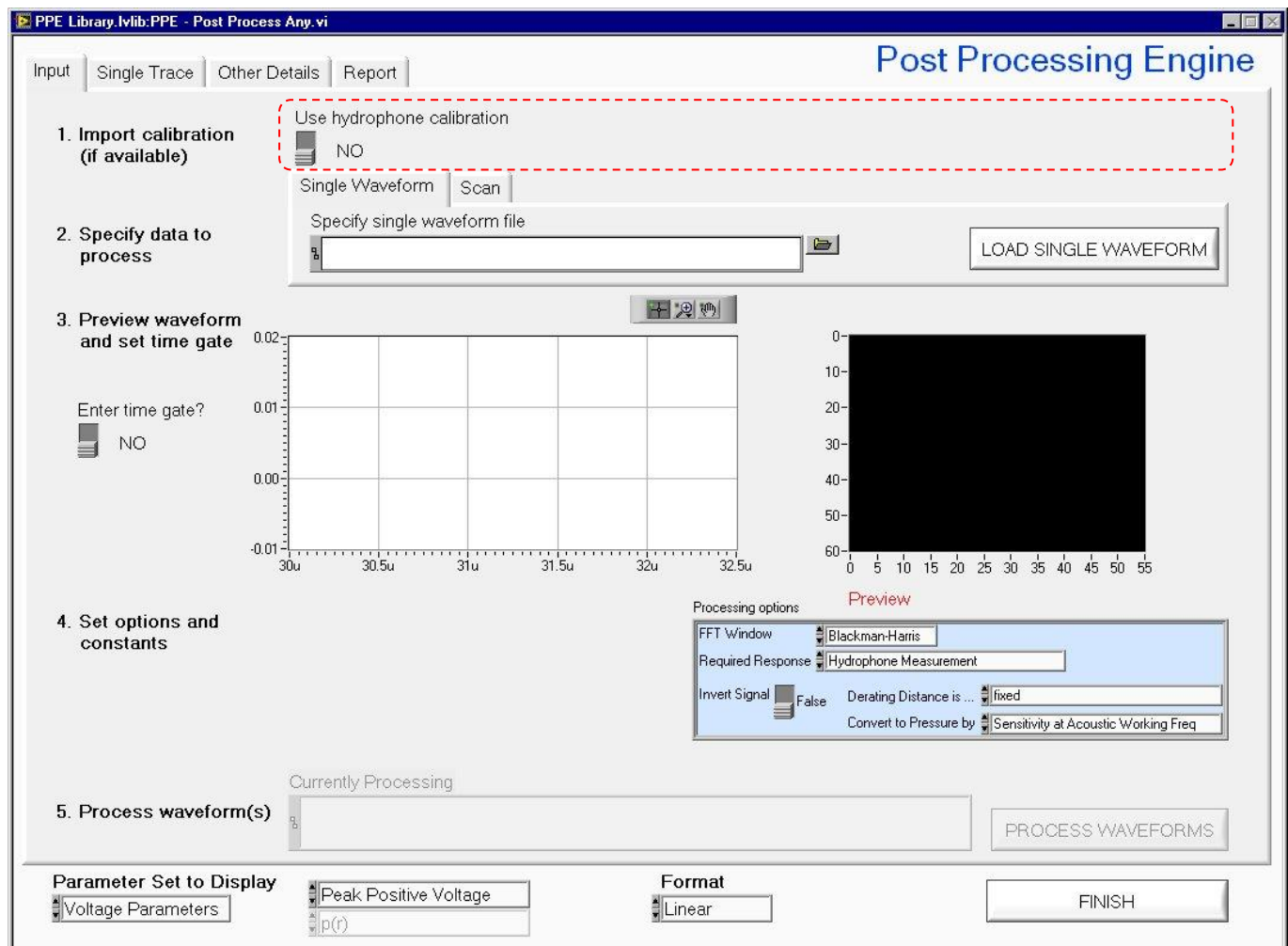


Figure 2 - Initial front panel display

All data processing follows the same basic steps (listed 1-4 on the front panel). These steps should be performed in numerical order and are as follows:

1. Import calibration (if available)
 - Before any data can be processed, PPE needs to be told whether a calibrated hydrophone was used to acquire the data. This is done by toggling the <Use Hydrophone Calibration> switch. When <Use Hydrophone Calibration> has the value YES other the user will be presented with drop-down selector allowing the relevant hydrophone system to be selected. The <Load Hydrophone Data> button should then be pressed to load the data. These additional controls will appear within the area marked by the red dashed line.

NB. A red dashed line is used throughout this manual to indicate features relating to the calculation of acoustic parameters that are only displayed if **<Use Hydrophone Calibration>** has the value **YES**.

2. Specify data to process

- To select a single waveform simply click the file selector button to the right of the **<Specify single waveform file>** and use the dialog that appears to select a raw waveform (i.e. without a **_voltage** or **_pressure** suffix) to process. This data is then loaded into PPE with the **<LOAD SINGLE WAVEFORM>** button.
- To select a scan, the **<Scan>** tab must first be clicked to enable the display of the **<Specify scan specification file>**. As with single waveforms, the file selector button and its associated dialog box is used to choose the scan specification file that was automatically created by UMS when a scan was requested. This data is then loaded into PPE with the **<LOAD SCAN SPECIFICATION>** button.

3. Preview waveform and set time gate

- Once a **<LOAD ...>** button has been pressed (Step 2), a waveform will be displayed in the preview graph on the front panel. For scans, this waveform is a representative waveform taken from the middle of the scan. By toggling the **<Enter time gate?>** switch the user can activate cursors on the preview graph. These can be dragged to appropriate positions to discard portions at the start and end of the waveform (e.g. for example in NDT to remove the front surface and rear surface reflections from a metal plate when looking to detect internal flaws)
- If the data loaded in the previous stage was a scan specification file, a preview of the Voltage Squared Integral profile stored automatically by UMS during the scan will also be visible.

4. Set options and constants

- The final stage before processing data is to specify some additional constants. The **<Processing options>** pane is always visible, but if the user is going to **<Use Hydrophone Calibration>** then an additional **<Acoustic Constants>** pane will also be visible. The contents of the **<Acoustic Constants>** pane are used in the calculation of various medical ultrasonic output parameters, but the names of the constants are self-explanatory.
- The **<Processing options>** pane contains a number of features that need further explanation.
 - In order to calculate the spectral properties of a waveform it needs to undergo a Fast Fourier Transform. To prevent spectral leakage errors

the use of a windowing function is highly recommended and thus the user should select an **<FFT Window>** from the available list. If no window is required select **<FFT Window→Rectangular >**.

- When calculating transducer spectral responses, a pulse/echo measurement will show a much sharper spectral peak than a transducer is measured with a hydrophone. This is because a pulse/echo measurement applies the frequency response of the transducer on both the output and receive operations. To display the transmit-only response of a transducer tested via a pulse/echo measurement, the square root of the spectrum should be used. The **<Required Response>** selector allows the user to specify whether the transducer was measured with a hydrophone or in pulse/echo mode. If in pulse/echo mode there is a choice of displaying the pulse/echo response or the transmit-only response (in which case the square root correction is applied).
- Toggling the **<Invert Signal>** allows the user to correct for devices that output a positive voltage corresponds to a negative pressure. Failure to correct the signal so that a positive voltage corresponds to a positive pressure will lead to an incorrect evaluation of negative pressure and hence MI
- Many acoustic output parameters require measured values to be attenuated to account for the difference in acoustic loss of tissue vs water. Within the **<Acoustic Constants>** pane there is a control called **<Derating Distance (mm)>** but the way that this value is used may vary. Three options are provided by the **<Derating distance is ...>** selector:
 1. **<Derating distance is ...> fixed.** The value of **<Acoustic Constants→Derating Distance (mm)>** is used for all data being processed
 2. **<Derating distance is ...> offset relative to start position.** The value of **<Acoustic Constants→Derating Distance (mm)>** is used to specify the distance between the transducer and the measurement point with the smallest Z co-ordinates (Z_0). All subsequent measurement points at Z co-ordinates (Z_n) have their de-rating distance calculated according to $(Z_n - Z_0 + \text{<Derating Distance (mm)>})$. This function is most useful when user wishes to scan in an axial direction to find the spatial maxima of a de-rated quantity.
 3. **<Derating distance is ...> derived from start time of pulse.** If the acoustic signal leaves the transducer face at the instant the oscilloscope of UMS is triggered, PPE will derive a derating distance

from the arrival time of the acoustic signal and the acoustic velocity in water (corrected for measured temperature in water).

- Within IEC 62127 – part 1, there are two possible methods to convert a hydrophone voltage signal to acoustic pressure. The first simply scales the measured voltage signal by the hydrophone sensitivity at the measured acoustic working frequency. The second option uses Fourier Transform techniques to deconvolve the hydrophone response in the frequency domain and then transform back to a time domain signal. The **<Convert to Pressure by>** selector allows the user to select between these two options

5. Process waveform(s)

- Clicking the **<PROCESS WAVEFORMS>** button will start data processing. The preview graph will be updated to show each raw waveform as it is processed and the **<Currently Processing>** text box will display the relevant filename of waveform.
- For large data sets it may take PPE several minutes to process all the data
- An additional button **<ABORT PROCESSING>** will appear. If clicked, this button will abort the data import and processing operations.

Processed data – single waveforms

If a single waveform only has been processed, then PPE will display the single trace page (see Figure 3). Within this page are graphs displaying the **<Waveform>** (i.e. pressure or voltage) with its associated **<Frequency Spectrum>**. Please note that pressure waveforms obtained via a deconvolution process may be different in shape to the raw voltage waveforms.

Underneath the **<Waveform>** is a cluster containing **<Voltage Waveform Parameters>**. If hydrophone data was used during processing, an additional **<Acoustic Parameters>** cluster will also be visible. An analysis of **<Spectral Bandwidth>** can be found beneath the **<Frequency Spectrum>** graph. Please note that the frequency spectrum and its associated parameters are of the processed waveform (i.e. pressure or voltage) and not of the raw waveform. Thus if deconvolution has been used, the spectrum displayed relates to the deconvolved waveform.

The **<Format>** selector at the bottom middle of this page can be used to change the **<Frequency Spectrum>** display between linear and logarithmic (dB) units.

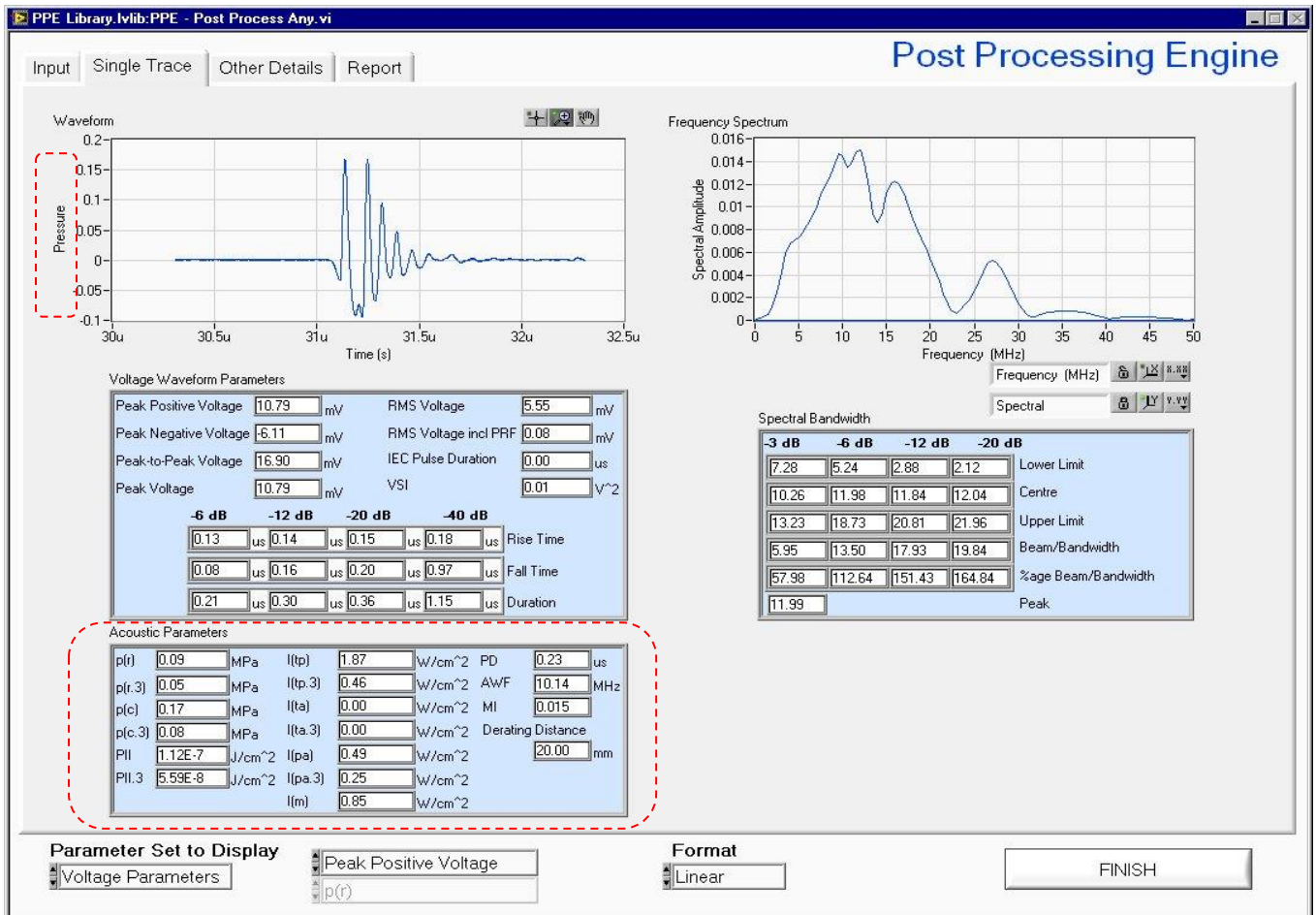


Figure 3 - Single trace analysis page

Processed data – linear scans

Following successful processing of a linear scan, PPE will display the line scan analysis page (an example of which can be found in Figure 4). The line graph displays the profile of the quantity displayed in the **<Parameter Set to Display>** controls. If hydrophone data was used during processing, the left hand **<Parameter Set to Display>** selector will allow a choice of either Voltage or Acoustic parameters, otherwise the Acoustic parameters option will not be enabled. If the first **<Parameter Set to Display>** selector is set to Voltage Parameters, the upper right hand **<Parameter Set to Display>** selector can be set to display profiles of any parameter from the **<Voltage Waveform Parameters>** cluster (except the Rise/Fall Times and duration). Changing first **<Parameter Set to Display>** to Acoustic Parameters with disable the upper right selector and enable the lower in right selector. This then enables the user to display a profile of any of the **<Acoustic Parameters>**.

The software will automatically attempt to calculate the beam widths at a range of threshold levels relative to the peak. If the profile does not pass below the specified threshold level (e.g. the profile does not fall below the -20dB down point) then the system will display NaN in the relevant section of the **<Linear Scan Analysis>** cluster.

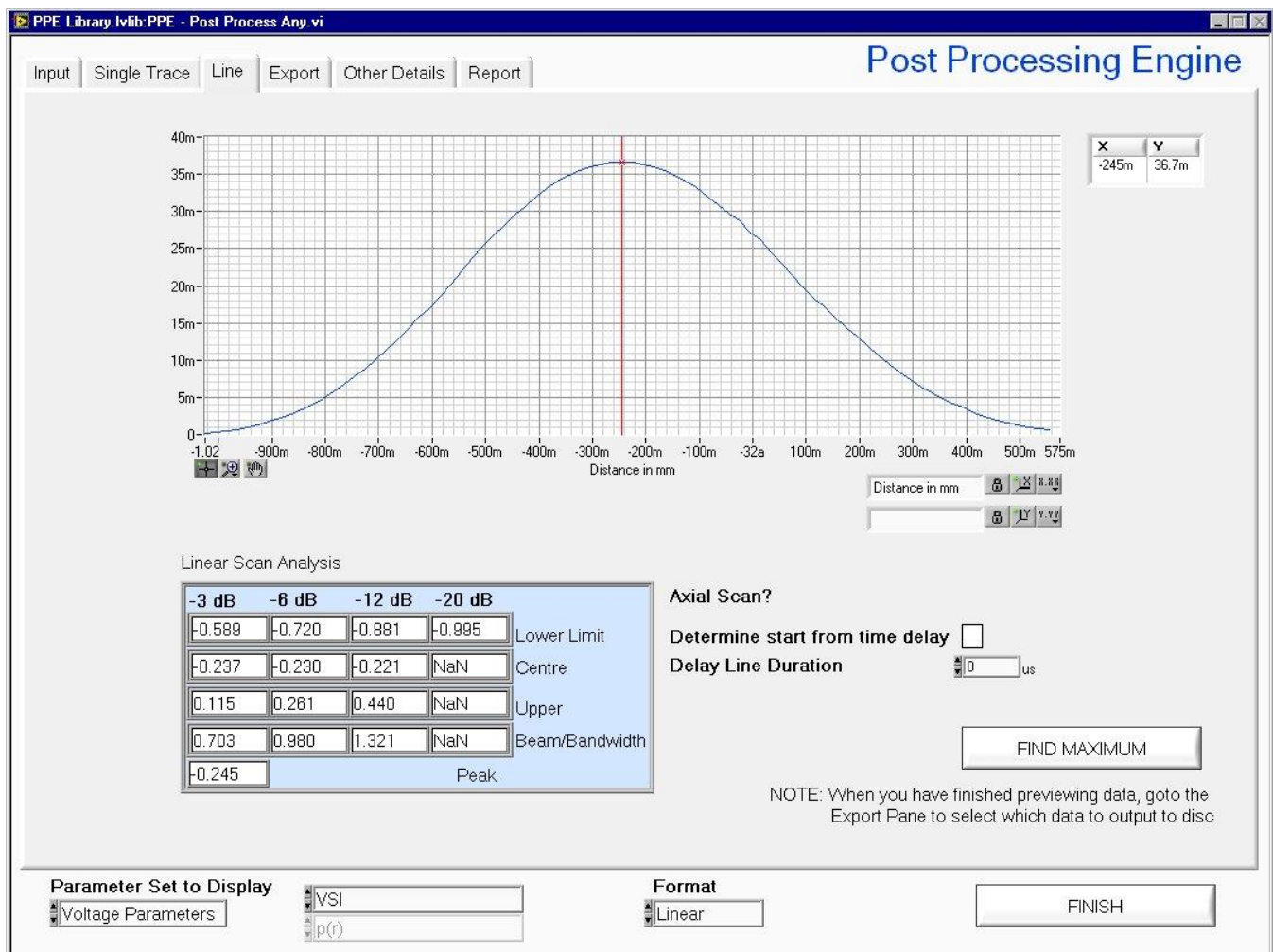


Figure 4 – Linear scan analysis page

The mouse can be used to move the red cursor on the graph to a data point of the users choosing. Whenever this is done the **<Single Trace>** page (see Figure 3) will be populated with the data trace and spectrum from that point in the scan. Furthermore, the **<Other Details>** page (see Figure 7) will be updated to indicate further information (e.g. measurement co-ordinate, water temperature, date/time) relating to that data point.

If the processed scan was conducted along the acoustic axis of the transducer, it is often desirable to have distance co-ordinates expressed in terms of distance from the transducers (rather than in system co-ordinates which is the default option). Clicking the **<Determine start from time delay>** checkbox instructs PPE to calculate the starting position of the scan from the time of propagation to the first point (in conjunction with the acoustic velocity derived from the temperature of the water). As with the calculation of de-rating distance, this calculation can be subject to error if there is a delay between the instant at which the oscilloscope is triggered and the instant at which the acoustic signal leaves the front face of the transducer. If this is the case (for example due to a delay line or acoustic lens on the transducer) then PPE can apply the temporal correction specified in **<Delay Line Duration>** to compensate for this offset.

The **<FIND MAXIMUM>** button can be used to re-position the cursor at the position of the peak of the graph.

If the user wishes to save any of the line profiles that have been displayed to disc, the user should click the tab labeled **<Export>** and follow the instructions contained within "Exporting processed data" section of this manual.

Processed data – planar scans

Upon successful processing of a planar scan, PPE will display the planar scan analysis page (see Figure 5). An intensity map representation of the data set is shown in the top left corner. As with Linear scans, the **<Parameter Set to Display>** selectors allow the user to choose which of the available parameters is displayed. The **<Format>** selector at the bottom middle of this page can be used to change the data display between linear and logarithmic (dB) units.

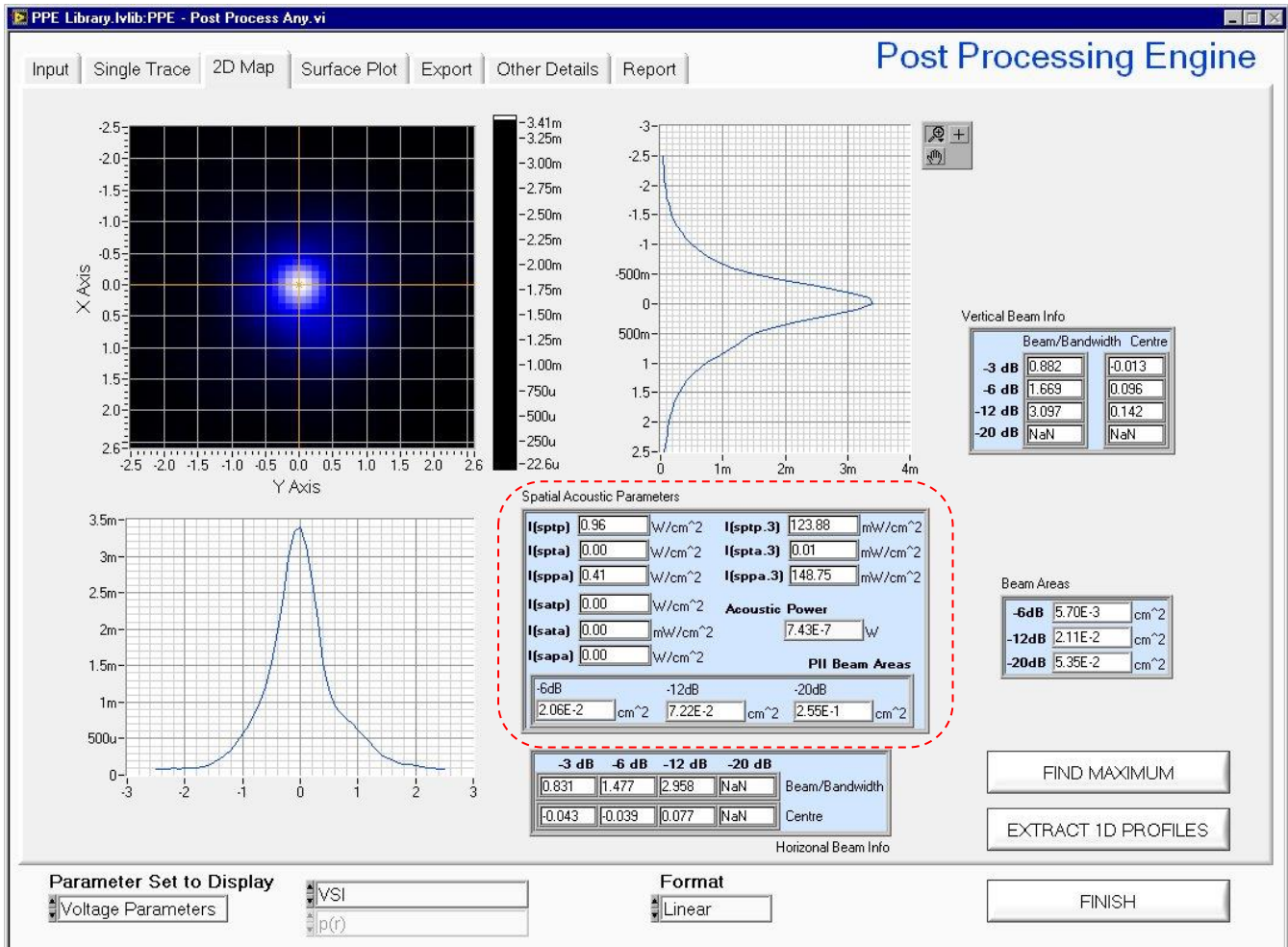


Figure 5 – Planar scan analysis page

The intensity plot has an orange cross-hair cursor on it. The field profile underneath the vertical arm of the cross hair is shown in a graph to the left of the intensity plot and the analysis of this profile is shown in the **<Vertical Beam Info>** cluster. Similar data for the horizontal arm of the crosshair cursor is shown in the lower graph with beamwidth analysis shown in the **<Horizontal Beam Info>** cluster. As the cursor is moved around, these graphs and clusters will be updated to reflect the data under the cursor. As with the analysis of linear scans, the waveform data relating to the point under the centre of the cross hair, is automatically loaded into the **<Single Trace>** page and additional information is updated into the **<Other Details>** page.

The **<FIND MAXIMUM>** button can be used to re-position the cursor at the position of the peak of the graph.

The calculation of **<Beam Areas>** is done by counting the number of data points that exceed the threshold level (e.g. -6dB down on peak) and then multiplying this value by the relevant spatial increments used in the acquisition of the scan. No geometric assumptions (e.g. circularity) are used in the calculation of these values.

If hydrophone data was used during processing, the **<Spatial Acoustic Parameters>** cluster will be visible. Within this cluster **<P11 Beam Areas>** are explicitly shown since it is the P11 area that is used in the calculation of the spatial average intensity parameters (see Section Derived spatial peak acoustic intensity parameters later in this manual).

If the user wishes to save any of the line profiles (e.g. a row or column of data), simply move the cursor to the required row/column and click the **<EXTRACT 1D PROFILES>** button. These profiles are stored in the same directory as the source data, using the filename stub from the scan specification file, with the file suffixes `{_Horizontal_profile}` and `{Vertical_profile}`. Additionally the beamwidths associated with these extracted linear profiles are store in files with `{_Horizontal_params}` and `{Vertical_params}` suffixes.

To store 2D data sets, the user should click the tab labeled **<Export>** and follow the instructions contained within "Exporting processed data" section of this manual.

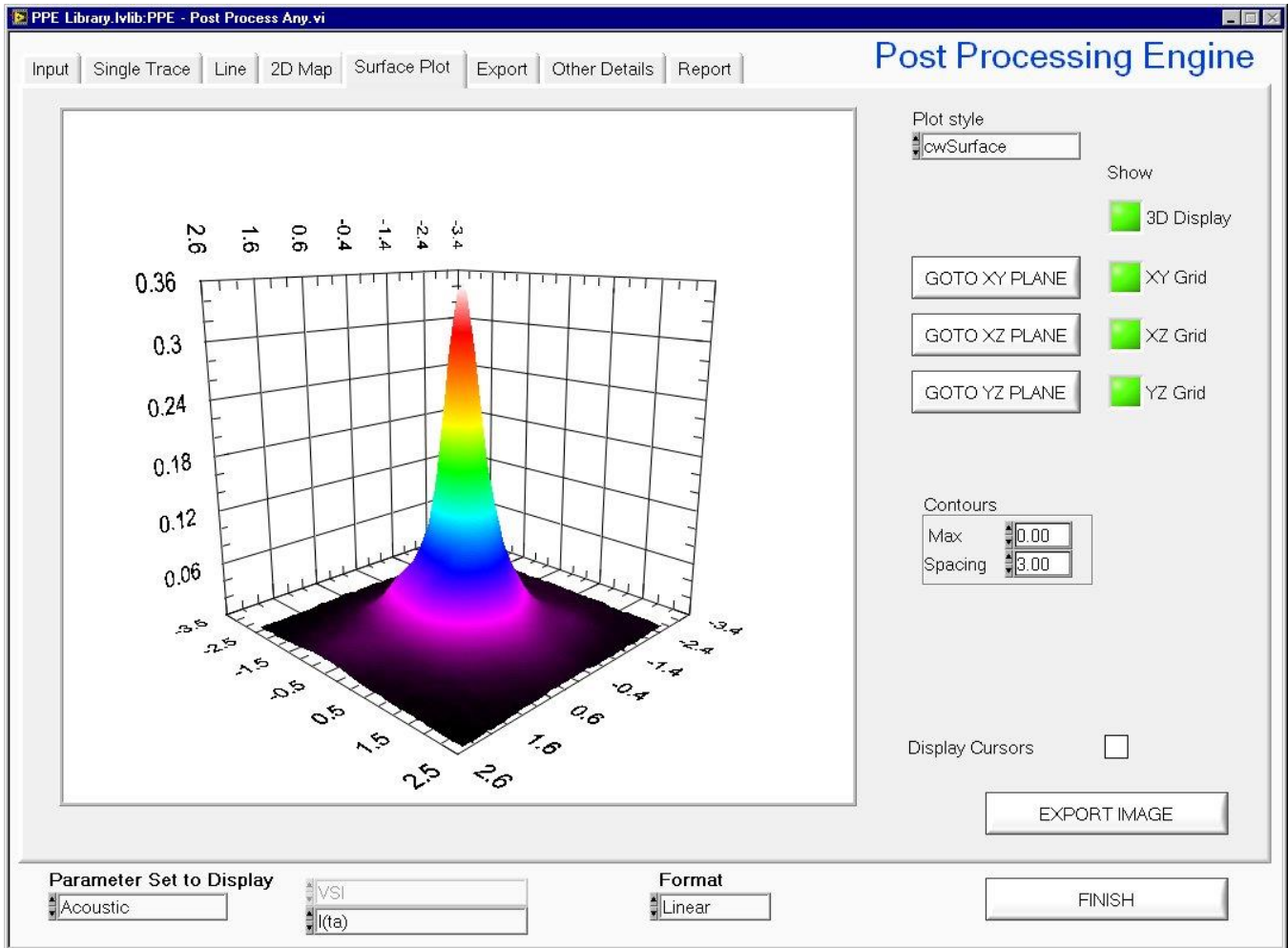


Figure 6 – Surface plot display page

Planar scan data can also be displayed as a 3D Surface plot (see Figure 6). The **<Plot Style>** selector allows the user to choose a preferred display format.

If **<Plot Style>** is set to either “cwContourLine” or “cwSurfaceContour” then it is best to choose a logarithmic data format with the **<Format>** selector at the bottom middle of this page. Additionally, the **<Contours>** cluster is used to modify the contour line spacing for these plot types. Logarithmic data is automatically normalized to the peak value within the plot, therefore **<Contours→Max>** should normally be set at 0 (dB). The **<Contours→Spacing>** control specifies the increment between contour lines and should be a positive value. Therefore for contours drawn at 0, -6dB, -12dB ... etc, **<Contours→Spacing>** should be set at 6 (dB).

The **<Display Cursors>** function is also enabled when using either of the two Contour styles listed above. Setting a cross in the **<Display Cursors>** box, whilst in either of these styles will activate cursors on the Surface/Contour plot. It is important to remember that these cursors represent a position in 3D space. Therefore when **<3D Display>** is off, it is the point where the cursor touches the projection onto the base plane (and not the position of the black

cross on the cursors) that represents the points used to calculate the **<Cursor Measurements>**.

Clicking and dragging the mouse within the graph area allows the user to change the viewing angle of the plot, and using the mouse wheel allows the user to zoom in/zoom out on the surface plot. Clicking any one of the buttons labeled **<GOTO XY PLANE>**, **<GOTO XY PLANE>** or **<GOTO YZ PLANE>** will change the viewing angle to a pre-defined position. Please note that when using **<GOTO XY PLANE>**, that it is still a view of a 3D surface and thus the amount of zoom in and out will affect the perspective of the image. Toggling the **<3D Display>** switch to its un-illuminated state will render a genuine projection onto the base plane that is free of perspective artifacts.

If the **<EXPORT IMAGE>** button is pressed, the user will be presented with a dialogue box so that a filename can be selected. This file will be a JPEG image representation of the currently displayed surface/contour plot.

Other measurement details

Whenever the waveform data within the **<Single Trace>** page is altered (e.g. by changing the cursor position in the linear and planar scan analysis pages) the measurement information with the **<Other Details>** page is also updated. An example of the type of data displayed can be found in Figure 7. The data on this page was automatically stored by UMS at the time of acquisition and cannot be user edited.

It is useful to note that the file location of the currently loaded waveform can be found in the **<Currently Displayed Filename>** control. This filename may then be of use when preparing a measurement report (see the “Generating a measurement report” section of this manual).

The screenshot shows the 'Post Processing Engine' software interface with the 'Other Details' page selected. The interface is divided into several sections:

- Position:** X: -0.00, Y: 0.002, Z: 0. Abt_X: 0, Abt_Y: 0, Theta: 0.
- Absolute position:** User: Paul, Date: 31/03/2010 11:58, Water Temperature: 17.2 degC, Water Treatment: De-ionised, de-gassed, Acoustic Path Length: 375-420 mm, Source Signal Type: Toneburst, # Cycles: 1, Target-Reflector Type: None, Source Signal Amplitude: 10V pk-pk, Calibration Frequency: 18 MHz, # Averages: 32, Cable Type: RG58, 1.5m, Terminating Impedance: 50 Ohms, Supply Voltage: 28 V dc, Comments: (empty).
- Device Type:** Transducer.
- Hydrophone:** Hydrophone SN: PA1093, Hydrophone Type: Needle, Hydrophone Diameter: 0.2 mm.
- Transducer:** Transducer SN: Imasonic1, Transducer Type: PZT - Unfocussed, Transducer Diameter: 10, Transducer ROC: 0, Nominal Frequency: 0.
- Other Parameters:** Preamplifier SN, DC Coupler SN, Booster Amp SN, Attenuator SN, RFB SN, Power Meter SN, Signal Amp/Comp SN, Optics System SN (all n/a). Comments: (empty).
- Currently Displayed Filename:** G:\Calibration\Imasonic\NewData310310\2DY025X025_pressure.txt.
- Signal Generator:** Model: HP3314A, Serial Number: 12345, Description: Function generator.
- Signal Amplifier:** Model: n/a, Serial Number: n/a, Description: n/a.
- DAQ Device / Analyser:** Model: Waverunner 62Xi, Serial Number: n/a123456, Description: Digital sampling.
- Parameter Set to Display:** Acoustic, VSI, I(ta).
- Format:** Linear.
- FINISH** button.

Figure 7 – Other measurement details page

Exporting processed data

Export of parameters calculated as a result of processing a scan is done on the **<Export>** page of PPE. An example of this page can be found in Figure 8. Data is saved to disc by putting a check mark in the relevant boxes of the **<Export>** page and then pressing the **<EXPORT SELECTED DATA>** button. The option to export Acoustic profiles and maps is only available if hydrophone data was used during data processing.

All data is saved in the directory that was the source for the original waveform data. If the most recently processed scan was linear then files will be stored with a {_profile} suffix. Processed 2D data from planar scans will be stored in a file with a {_map} suffix.

For convenience, **<SELECT ALL>** and **<CLEAR ALL>** buttons are available, to check or uncheck all boxes respectively.

The screenshot shows the 'Export' tab of the 'Post Processing Engine' software. The interface is divided into several sections:

- Navigation Tabs:** Input, Single Trace, Line, 2D Map, Surface Plot, **Export**, Other Details, Report.
- Section Headers:**
 - Voltage profiles/maps to export
 - Acoustic profiles/maps to export (highlighted with a red dashed border)
- Checkboxes for Selection:**
 - Voltage profiles:** Peak Positive Voltage, Peak Negative Voltage, Peak-to-Peak Voltage, Peak Voltage, RMS Voltage, RMS Voltage incl PRF, IEC Pulse Duration, VSI.
 - Acoustic profiles:** p(r), p(r.3), p(c), p(c.3), PII, PII.3, I(tp), I(tp.3), I(ta), I(ta.3), I(pa), I(pa.3), I(m), PD, Derating Distance, AWF, MI.
- Action Buttons:** SELECT ALL, CLEAR ALL, EXPORT SELECTED DATA.
- Bottom Panel:**
 - Parameter Set to Display: Acoustic
 - Format: Linear
 - FINISH button

Figure 8 – Data export page

Generating a measurement report

PPE also contains the facility to automatically generate measurement reports in PDF format. This facility is accessed on the **<Report>** page (see Figure 9). The first stage of reporting is to provide a **<Report Filename>** and to select a **<Certificate Type>**. If **<Certificate Type>** is set to "Transducer (Pulse/Echo)" then the front page of the certificate will contain data about the **<Target Reflector Type>** from the **<Other Details>** page. Alternatively if **<Certificate Type>** is set to "Transducer (w/Hydrophone)" then the front page of the certificate will contain data relating to the hydrophone system used to undertake the measurement. The **<Company Name>** and **<Company Address>** fields should either be filled in with appropriate data or left blank.

All Measurement reports must contain a voltage or pressure waveform in the **<Time Trace>** control. The file selector button associated with this control will therefore only allow you to select files with a {_voltage} or {_pressure} suffix. The frequency domain representation of this waveform will be displayed on the certificate if the **<Spectrum>** check box is selected. The **<Use dB?>** and **<Maximum Frequency>** controls can be used to format the appearance of the spectral graph on the measurement report. If a pressure waveform is the chosen **<Time Trace>** the **<Pulse Intensity Integral>** checkbox will become available for user selection.

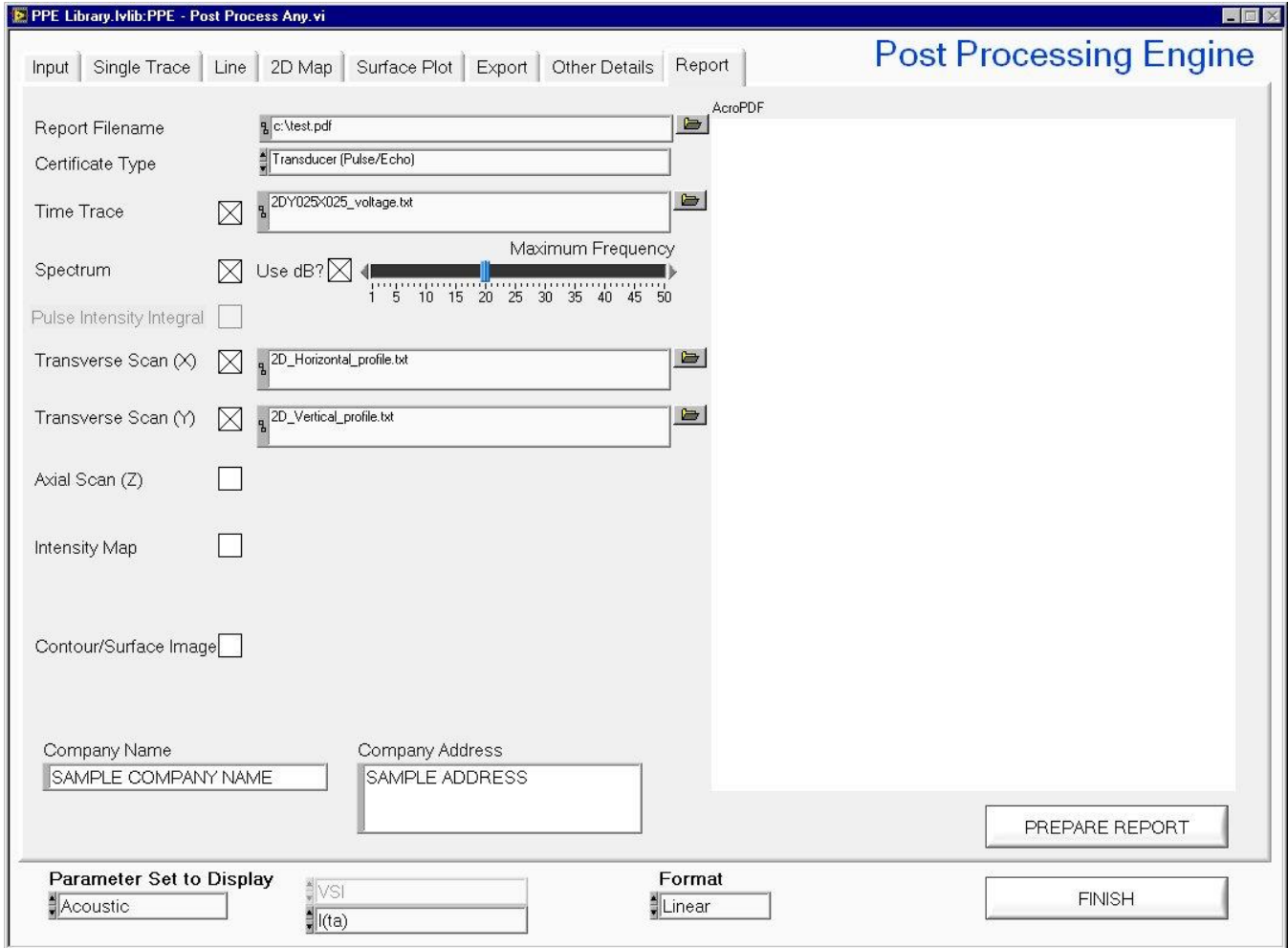


Figure 9 – Measurement report generation page

To include graphs of the X-axis profile of a transducer, the **<Transverse Scan (X)>** checkbox should be marked and the file selector alongside will appear. This file selector will only select files that have a {_profile} suffix (e.g. following data export from a linear scan, or extracted 1D profiles from a linear scan). The same process is used with **<Transverse Scan (Y)>** and **<Axial Scan (Z)>** controls for the other two axes.

Display of 2D data sets is achieved by placing a check mark in the **<Intensity Map>** control. The file selector that appears alongside will only select files that have a {_map} suffix. It is also possible to include a JPEG image that had been exported from the **<Surface Plot>** page. Simply place a check mark in the **<Contour/Surface Image>** control and use the file selector to navigate to the appropriate image file.

Clicking the **<PREPARE REPORT>** button will load in the relevant data files, extract data, prepare graphs and write a PDF file to the location specified in the **<Report Filename>** control. A copy of the PDF certificate will also be displayed in the preview window on the right.

THEORETICAL BASIS FOR ACOUSTIC CALCULATIONS

The description of pressure and intensity parameters is taken from definitions specified in IEC 62127-Part 1 and UD2-2003. Definition of de-rated acoustic parameters and Mechanical Index (MI) is taken from UD 2-2003 and IEC 62359. Please note that PPE calculates many of its acoustic parameters on the assumption that the source system is in not in an auto-scanning mode. It is also assumed that any plane scan is orthogonal to the acoustic axis. The complexity of many scanned systems is such that PPE cannot have *a priori* knowledge of the scanning configuration and thus cannot be programmed to deal with these cases. It may be possible to customize PPE for a specific customer's requirements, but the user should contact one of the applications engineers at Precision Acoustics Ltd if this is required.

Primary pressure parameters

Considering an arbitrary continuous pressure waveform expressed as $p(t)$ (or a digitized acoustic pressure waveform as acquired by UMS as $p(\Delta t)$), the peak compressional pressure, p_c , and peak rarefactional pressure, p_r , and peak-to-peak acoustic pressures are defined as

$$\begin{aligned} p_c &= \max[p(\Delta t)] \\ p_r &= \min[p(\Delta t)] , \\ p_{pkpk} &= p_c - p_r \end{aligned} \quad \text{Equation 1}$$

and the pulse-pressure-squared integral, p_i , is defined as

$$p_i = \int_{-\infty}^{\infty} [p(t)]^2 . dt . \quad \text{Equation 2}$$

Equation A-2 assumes that $p(t)$ is a continuous function of t , but UMS acquires discrete (digitised) data, $p(\Delta t)$, and therefore Equation 2 must be expressed in its discrete form, specifically

$$p_i = \frac{1}{f_s} \sum_{n=0}^{N-1} [p(\Delta t)]^2 , \quad \text{Equation 3}$$

where f_s is the sampling frequency, and N is the number of samples acquired.

It is now possible to define the pulse duration from the pulse-pressure-squared integral. If 2 times, t_1 and t_2 , are defined such that

$$t_1 = \frac{n_1}{f_s} \text{ and } t_2 = \frac{n_2}{f_s}$$

where indices n_1 and n_2 are determined from

$$\frac{1}{f_s} \sum_{n=0}^{n_1-1} [p(\Delta t)]^2 < 0.1 p_i \leq \frac{1}{f_s} \sum_{n=0}^{n_1} [p(\Delta t)]^2$$

and

$$\frac{1}{f_s} \sum_{n=0}^{n_2} [p(\Delta t)]^2 \leq 0.9 p_i < \frac{1}{f_s} \sum_{n=0}^{n_2+1} [p(\Delta t)]^2,$$

then the pulse duration t_d , is given by

$$t_d = 1.25(t_2 - t_1). \quad \text{Equation 4}$$

Having determined the pulse duration, the pulse acoustic pressure, p_p is thus defined

$$p_p = \left(\frac{p_i}{t_d} \right)^{\frac{1}{2}}. \quad \text{Equation 5}$$

The rms acoustic pressure, p_{rms} , is also derived from the pulse–pressure–squared integral, and is defined as

$$p_{rms} = (p_i \cdot PRF)^{\frac{1}{2}}, \quad \text{Equation 6}$$

where PRF is the Pulse Repetition Frequency.

Spatial peak pressure parameters

Having derived the primary pressure parameters, it is now necessary to quantify how these parameters vary as a function of measurement location. Particular interest is paid to finding the spatial peak value of one or more primary pressure parameters. By way of an example, many measurement standards (including IEC61157 and UD 2-2003) require that certain spatial peak of parameters to be quantified. Since we are concerned with spatial variations in both the x and y directions, all previously derived quantities will now be expressed in the form $p_+(x,y)$, $p_i(x,y)$ etc. Firstly we shall define the spatial peak acoustic pressure, p_{sp} .

$$p_{sp} = \max[p(x, y)], \quad \text{Equation 7}$$

The spatial peak pulse acoustic pressure, p_{spp} is defined as

$$p_{spp} = \max[p_p(x, y)] \quad \text{Equation 8}$$

where $p_p(x,y)$ is the larger of p_+ and $|p_-|$. The spatial peak rms acoustic pressure, p_{spr} is defined as

$$p_{spr} = \max[p_r(x, y)]. \quad \text{Equation 9}$$

Derived acoustic intensity parameters

Acoustic Intensity cannot be directly measured with a hydrophone, and thus in order to derive Intensity parameters from measured values of pressure, it is necessary to make certain assumptions. Beissner (1982) has prepared a detailed discussion of the effect of such approximations. Using the approximation that the acoustic radiation is behaving like a plane wave (as discussed in IEC 61157) various intensity parameters are defined as follows.

Pulse intensity integral, PII, is defined as

$$PII = \frac{1}{f_s \rho c} \sum_{n=0}^{N-1} [p(\Delta t)]^2 \quad \text{Equation 10}$$

Temporal Peak Intensity, I_{tp} , is given by

$$I_{tp} = \frac{p_p^2}{\rho c} \quad \text{Equation 11}$$

where ρ is the density of water, and c is the velocity of sound in water. The pulse average intensity, I_{pa} , is defined as

$$I_{pa} = \frac{PII}{t_d} \quad \text{Equation 12}$$

whilst the temporal average intensity, I_{ta} , is calculated using the equation

$$I_{ta} = PII \times PRF . \quad \text{Equation 13}$$

Derived spatial peak acoustic intensity parameters

Spatial peak intensities are calculated by finding the spatial maximum of the relevant intensity parameter. Thus Spatial Peak Temporal Peak Intensity, I_{SPTP} , is defined

$$I_{SPTP} = \max[I_{TP}(x, y)]. \quad \text{Equation 14}$$

Similar definitions hold for Spatial Peak Pulse Average Intensity, I_{SPPA} ,

$$I_{SPPA} = \max[I_{PA}(x, y)] \quad \text{Equation 15}$$

and Spatial Peak Temporal Average Intensity, I_{SPTA}

$$I_{SPTA} = \max[I_{TA}(x, y)] \quad \text{Equation 16}$$

Derived spatial average acoustic intensity parameters

Spatial average intensities are found by spatially integrating the relevant intensity parameter and then dividing this integral by the beam area for that parameter. To find beam area it is first necessary to determine the spatial peak value of the intensity parameter in question and then setting a threshold level below that (typically -6dB). The beam area, A , is then found by counting all points whose intensity exceeds this threshold level and then multiplying by the incremental area associated with each point.

Thus Spatial Average Temporal Peak Intensity, I_{SATP} , is defined

$$I_{SATP} = \frac{\int I_{TP} dA}{A} . \quad \text{Equation 17}$$

Similar definitions hold for Spatial Average Pulse Average Intensity, I_{SAPA} ,

$$I_{SAPA} = \frac{\int I_{PA} dA}{A} \quad \text{Equation 18}$$

and Spatial Average Temporal Average Intensity, I_{SATA}

$$I_{SATA} = \frac{\int I_{TA} dA}{A} \quad \text{Equation 19}$$

Other ancillary parameters

The acoustic working frequency, f_{awf} , is calculated according to the relationship

$$f_{awf} = \frac{f_1 + f_2}{2} , \quad \text{Equation 20}$$

where f_1 and f_2 are the frequencies at which the frequency spectrum first becomes 3dB lower than the maximum spectral amplitude.

Speed of sound in water

As can be seen from Equations 13 to 15, all of the calculated acoustic intensity parameters are dependent upon an accurate value for the speed of sound in water. Since the speed of sound in water is a function of temperature, it is necessary to account for this variation. Bilaniuk and Wong (1993) have devised an empirical method of calculating the speed of sound in pure water. Since the relevant measurement standards (such as IEC 61102) require the use of de-ionised (or distilled), de-gassed water, it will be assumed that the medium in which measurements are conducted is "pure" water, and will thus obey the empirical relationship described by Bilaniuk and Wong(1993).

Output de-rating

UD 2-2003 and IEC 62359 define a method of correcting acoustic measurements made in water in an attempt to account for the ultrasonic attenuation of tissue that would be encountered between the source of the ultrasound and a given particular location in the tissue. This process is often referred to as “output de-rating”. Within these standards, the average attenuation is assumed to be 0.3 dB/MHz/cm along the acoustic beam axis in the body. The multiplicative method to de-rate acoustic pressure parameters is

$$P_{derated} = P \times 10^{(-0.05 \times 0.3 \times f_{awf} z)}, \quad \text{Equation 21}$$

whilst intensity parameters are de-rated with

$$I_{derated} = I \times 10^{(-0.1 \times 0.3 \times f_{awf} z)}. \quad \text{Equation 22}$$

Within equations 21 and 22, z denotes the distance from the source to the measurement point. It is common practice to use the de-rating factor as an additional subscript to indicate when a parameter has been de-rated, thus $p_{r,3}$ is the peak rarefactional pressure derated by 0.3 dB/cm/MHz

Mechanical index

UD 2-2003 and IEC 62359 also define the Mechanical Index (MI) as

$$MI = \frac{P_{r,derated}(z_{sp})}{\sqrt{f_{awf}}}, \quad \text{Equation 23}$$

where $p_{r,derated}(z_{sp})$ is the de-rated peak rarefactional pressure at the point of the beam axis where the de-rated pulse intensity integral is a maximum.

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APPLICATIONS AND TECHNICAL SUPPORT

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