BSA Flow Software

Installation & User's guide

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1. General

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1.3 Laser safety

All equipment using lasers must be labeled with the safety information. Dantec FiberFlow and FlowLite systems use class III and class IV lasers whose beams are safety hazards. Please read the laser safety sections of the documentation for the laser and LDA optics carefully. Furthermore, you must instigate appropriate laser safety measures and abide by local laser safety legislation. Use protective eye wear when the laser is running.

Danger laser light

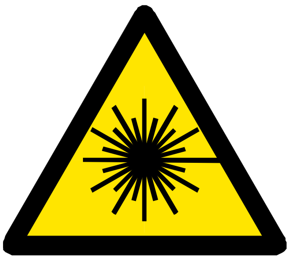
Laser light is a safety hazard and may harm eyes and skin. Do not aim a laser beam at anybody. Do not stare into a laser beam. Do not wear watches, jewellery or other blank objects during alignment and use of the laser. Avoid reflections into eyes. Avoid accidental exposure to specular beam reflections. Avoid all reflections when using a high-power laser. Screen laser beams and reflections whenever possible. Follow your local safety regulations. You must wear appropriate laser safety goggles during laser alignment and operation.

During alignment, run the laser at low power whenever possible.

Since this document is concerned with the BSA Flow Software, there is no direct instructions in this document regarding laser use. Therefore, before connecting any laser to the system, you must consult the laser safety section of the laser instruction manual.

Precautions

As general precautions to avoid eye damage, carefully shield any reflections so that they do not exit from the measurement area.



2. Introduction

Congratulations with your BSA Flow Software. BSA Flow Software packages are running on Windows NT® 4.0 or Windows 2000®. In combination with Dantec Measurement Technology's BSA processors, and FiberFlow or FlowLite optical systems, it provides an integrated, flexible and easy-to-use system for all LDA fluids experiments.

Several man-years have been devoted to the development of this software. The result is a leading-edge package with a range of innovative features, including:

- end-results on-line
- project explorer
- wizards
- visual system configuration
- integrated measurement interface.

The software makes full use of the facilities available in Windows:

- Takes advantage of the 32-bit multi-threading /multi-tasking capabilities in 32-bit Windows
- Tabulated dialogues, activity bars, detachable toolbars etc. simplify use of the system
- Screen-layout is flexible, with moveable, resizable frames and windows
- Context menus throughout the program simplify operation by identifying relevant options.

2.1 Products covered in this manual

2.1.1 BSA Flow Software (main package)

The main package takes care of communication with hardware, acquisition of data or import of data and statistical processing of data. It includes wizards for setting up the processors, traverse and traverse mesh. Results can be presented in lists and histograms.

2.1.2 Cyclic phenomena add-on

As the name implies, this add-on is used in connection with cyclic phenomena, occurring e.g. in rotating machinery or wave tanks. Data containing synchronisation information from e.g. an encoder is sorted according to the phase angle, and statistical quantities are computed for each user-defined phase angle interval.

2.1.3 Spectrum & correlation add-on

The Spectrum part of this add-on is typically used to analyse periodicity of flow velocity fluctuations. If the velocity fluctuations contain periodicity, this will show up as a peak in the spectrum function.

The correlation part can be used to determine the integral time scale of the velocity fluctuations, which is useful for setting up the time between samples to ensure statistically independent samples for calculation of moments.

2.1.4 Advanced graphics add-on

This add-on includes the 2D plot and vector plot. 2D plots are used for presentation of many types of data, e.g. time series, velocity profiles to mention a few.

The vector plot is used to present 2- or 3-component velocity measurements as vectors, according to the traverse position.

2.1.5 Advanced traverse add-on

This add-on includes a generic traverse driver which is used to communicate via an RS232 line with another computer controlling a third party traverse. Up to 6 physical traverse axes can be controlled with the generic traverse driver.

It also allows coordinate transformation between a logical and a physical coordinate system through an external look-up table.

2.2 Products supported by the software

2.2.1 Processors supported by BSA Flow Software (main package)

The BSA Flow Software (main package) supports the following processors:

- 62N20 BSA F 50 Flow Processor with one or more velocity channels
- 62N40 BSA F 60 Flow Processor with one or more velocity channels
- 62N30 BSA F 70 Flow Processor with one or more velocity channels
- 62N50 BSA F 80 Flow Processor with one or more velocity channels
- 62N25 BSA P50 Flow and Particle Processor with one or more velocity channels
- 62N45 BSA P60 Flow and Particle Processor with one or more velocity channels
- 62N35 BSA P70 Flow and Particle Processor with one or more velocity channels
- 62N55 BSA P80 Flow and Particle Processor with one or more velocity channels
- 62N560 Synchronisation Option for BSA F50, F60, F80, P50, P60, P80.
- National Instruments GPIB interface boards AT-GPIB, PCI-GPIB, PCMCIA-GPIB, etc. using Windows 95/98/NT driver software

2.2.2 Other equipment supported by BSA Flow Software

- Lightweight Traverse systems
- 57G15 Traverse Interface
- ISEL/Techno/Charlierobot traverse systems using RS232 based controller
- Third party traverse systems can be controlled using the Generic Traverse Driver
- Encoders

2.3 Where to find documentation

It is assumed that the reader is familiar with Windows.

2.3.1 Getting started

Chapter 3 includes descriptions of the following:

- installation of the software and hardware
- cable connections

2.3.2 Detailed user guide

Chapter 4 gives a detailed overview of the user interface and gives an overview of the windows and menus.

If further includes procedures for

- aquiring data step by step
- re-analysing existing data
- re-acquisition of data

Chapter 5 describes the property editor.

Chapter 6 describes use of options and add-ons. Your system may include some or all of these.

2.3.3 Reference information

Chapter 7 includes reference information such as general LDA and PDA theories and descriptions of the data analysis algorithms used in the software.

2.3.4 Trouble shooting

Chapter 8 provides instructions on how to check connections from hardware to software.

2.3.5 On-line help

The software is prepared for addition of on-line help, but this is not implemented at present.

2.4 General nomenclature

The following nomenclature is used throughout this manual and the User's Guide:

processor	BSA processor
software	the BSA Flow Software
PC	the PC connected to the LDA system, on which the BSA Flow software is installed

2.5 Conventions

- ***Warning, Caution*** and ***Note*** are three different ways of highlighting important matters:
- ***Warnings*** are used when improper operation may result in risks for you or other people in the room.
- ***Cautions*** are used when improper operation may result in risks for the apparatus.
- ***Notes*** are used when improper operation may result in an unreliable function of the apparatus.

2.6 File naming conventions

2.6.1 Project and sample files

The entire system configuration including acquired data for each experiment is stored in a so-called Project file. Project files have the filename extension LDA. The sample files or sample projects are identical to project files and therefore also have the filename extension LDA.

2.6.2 Templates

Complete experiment setups or parts of it (branches) can be stored as templates to facilitate re-use in new projects.

Two template types are available: Project Templates and Templates.

Project templates include the total experimental setup. Project templates have the filename extension LDP.

Templates include parts of an experimental setup. Template files have the filename extension LDT.

2.6.3 Export files

Exported data files are given the filename extension TXT, irrespective of the chosen file format.

Graphics can be exported in four different formats. Depending on the selection the filename extension is EMF, BMP, JPG or TIF.

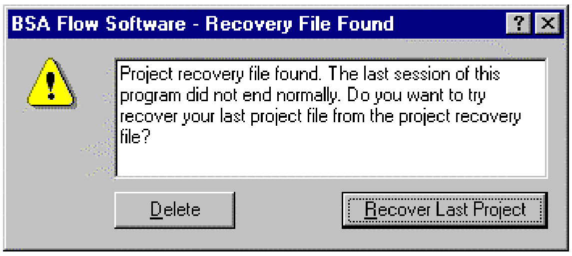
2.7 Data security

To provide the highest possible level of data security, i.e. to avoid unnecessary losses of acquired data, the software has the so-called project recovery feature.

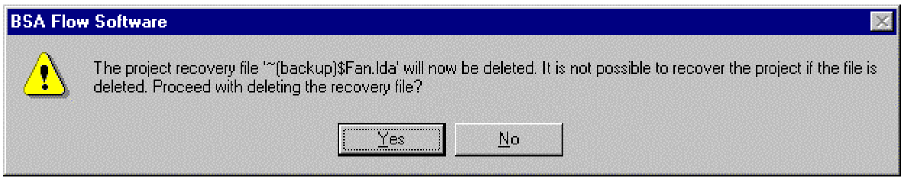
During data acquisition a mirror project file is generated in the WINDOWS\TEMP directory. Should the program or the Windows operating system crash before the current project could be terminated and all data stored, the mirror project file can be recovered.

In the case of normal termination of the program, the mirror file is deleted automatically.

After a crash has occurred, the following window will appear upon program startup:



This gives the user the possibility to recover saved data or delete them. Should the ‘Delete’ button accidentally be pressed, another warning will appear:



3. Installation

The software requires Windows NT 4.0 Service Pack 3 or later versions, or Windows 2000. You can check your Windows version by double clicking the System icon under Control Panel. The version no. is shown under the General tab.

To install the software, the user must log in with administrator privileges. After installation, normal user privileges suffice for using the software.

3.1 General

3.1.1 PC requirements

Minimum configuration

- Pentium PC, 400 MHz
- 128 MB RAM
- Fast and large hard disk with a sizeable free storage space for data storage
- 17 inch monitor with at least 1024×768 resolution and 256 colours or more
- Windows NT 4.0 or Windows 2000

Slots required

Hardware	Slot type	Comments
62N series BSA processor	PCI	For Ethernet adapter included with the BSA
57N series BSA processor and/or 57G15 Traverse interface	ISA (AT) or PCI	For GPIB interface board
Analog input to 57N series BSA processor	ISA (AT) or PCI	For A/D board
58N series FVA or PDA processor	ISA (AT)	For 58G130 FVA/PDA interface
Analog input to 58N series FVA or PDA processor	ISA (AT) or PCI	For A/D board
Lightweight traverse: manual control unit	PCI	For I/O board

Additional required items for 57Nxx BSA processors or for 57G15 Traverse Interface

- National Instruments GPIB interface board, such as AT-GPIB/TNT p-n-p or PCI-GPIB/TNT communication board. A Plug & Play card is strongly recommended.

Note	*To get plug-and-play under Windows NT with the AT-GPIB/TNT p-n-p board, a driver called PnP ISA Enabler Driver (from the NT installation CD) must be installed first.*

- Installation software for communications driver from National Instruments.

Additional required items for 58Nxx FVA or PDA processors

- 58G130 FVA/PDA interface

3.1.2 Memory and disk space requirements

The amount of memory required changes dynamically when the software is running, and typically increases when data is being acquired and decreases when the same data has been stored. The amount of memory occupied depends on which drivers and programs are loaded. Typically the program occupies about 10 MB of RAM, but high data rates and projects with many objects may require much more. You can monitor how much memory is available by running some of Windows' system tools.

Data is stored in a temporary file in the Windows/temp directory till the project is saved.

Note	*The Windows/Temp directory and the BSA Flow/Projects directories must both have enough free space to hold the required amount of data*

Most objects can save data, and they will do this as default. To check whether an object saves data or not, right-click the object's icon, select Properties and see if the Save data in the current project is ticked.

***Saving disk space**:* *You can save disk space by not saving data from all objects. By re-running the objects you can always reconstruct the results.*

As a guideline to the required disk space for data files some examples of file sizes are given below.

1-component measurements	1 position	10 positions	100 positions	comment
1 sample	43 kB	46 kB	72 kB	with histogram only
1000 samples	83 kB	370 kB	3.2 MB	with histogram only
10000 samples	367 kB	3.2 MB	31.6 MB	with histogram only
100000 samples	3.2 MB			with histogram only
100000 samples	6.3 MB			with histogram and cyclic phenomena, 180 phase bins

2-component measurements	1 position	10 positions	100 positions	comment
1 sample	61 kB			with hardware coincidence and histogram
1000 samples	125 kB	699 kB	6.4 MB	with hardware coincidence and histogram
10000 samples	682 kB	6.4 MB		with hardware coincidence and histogram
10000 samples	900 kB	8.2 MB		with hardware and software coincidence and histogram (50% software coincidence rate)

It is generally recommended to avoid file sizes above 100 MB since very large files slow down the system performance with a risk of a crash of the operating system.

If more data is required, it is therefore recommended to split the experiment into several smaller projects, each resulting in files smaller than 100 MB.

Checking the load of the PC

If you are in doubt whether the operating system is being loaded too heavily, you can run the Windows Task Manager (Press CTRL-Alt-Delete and select Task Manager) to see how the memory usage (in kB) and the CPU usage (in %).

If memory usage approaches the available amount of physical memory (RAM) there is a high risk of a system crash. The remedy is to reduce the file size.

CPU usage will often be 100% during short intervals, but if it is permanently 100%, the system is overloaded. A possible remedy is to disable as many objects as possible during acquisition (see chapter 4 and 5 for details).

3.1.2.1 Directory structure

The BSA Flow Software's extensive use of database technology means that you do not need to concern yourself with data files and their locations. However, to back-up your data it is useful to know the default file structure.

When BSA Flow Software is installed, it will create the directories BSA Flow Software under C:\Program Files\Dantec\ for the program files (BSAFlow.exe, .dll, and others).

Data will be stored at the following locations:

Windows NT: Project files:

Winnt\Profiles\<user ID>\Personal\My Flow Projects

Import, Export and template files: in subfolders to the above.

Windows 2000: Project files:

Documents and Settings \<user ID>\My Documents\ My Flow Projects

Import, Export and template files: in subfolders to the above.

3.1.2.2 Compatibility with BURSTware, FLOware and SIZEware

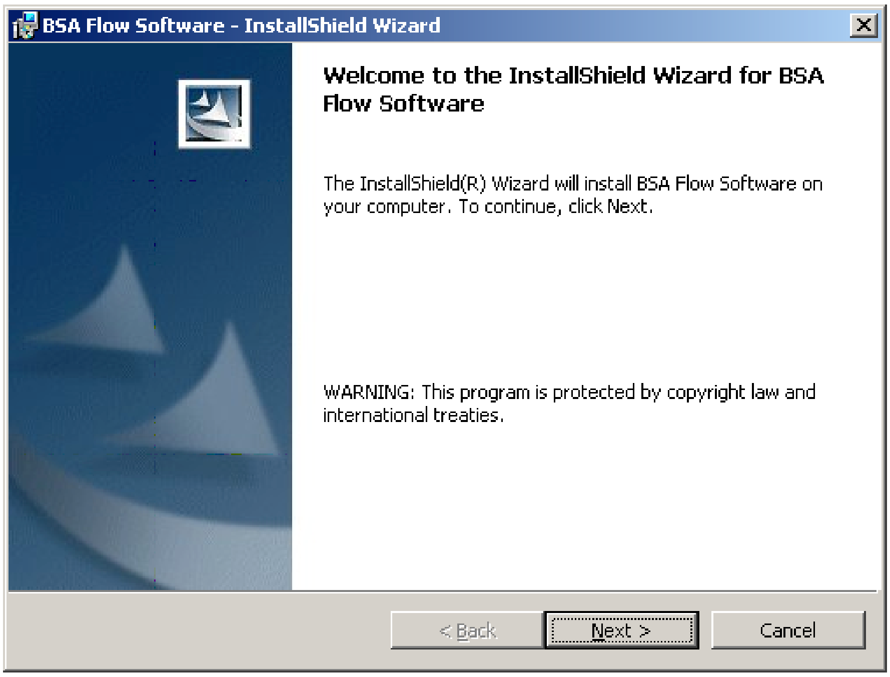
Old velocity files from BURSTware or FLOware, and size files from SIZEware can be imported in the BSA Flow software for analysis and presentation. Please see the chapter "re-analysing existing data" in this manual for further details.

3.2 Installing software

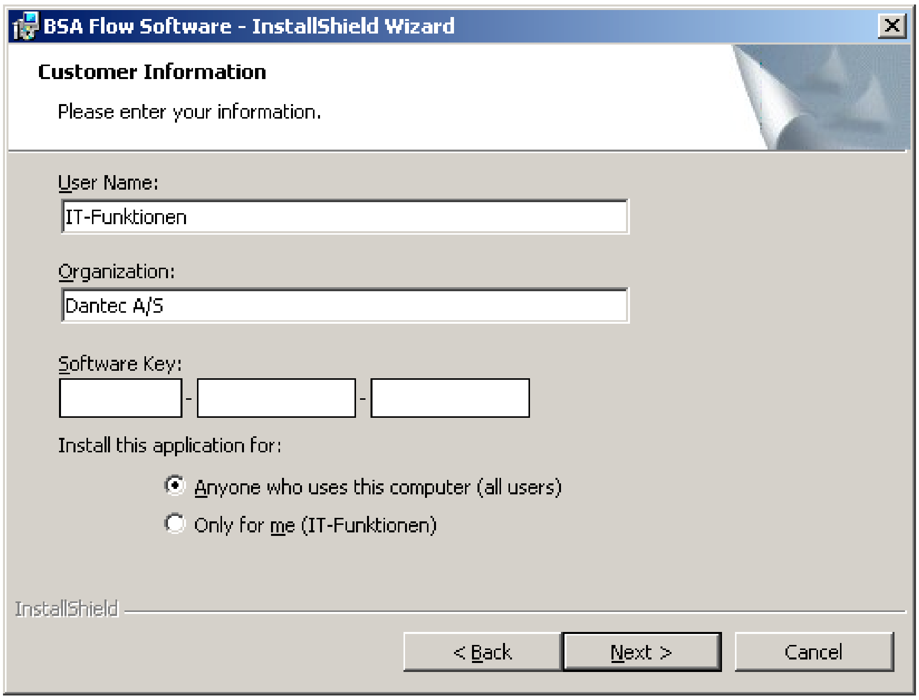
The BSA Flow software serves as the centralised interface for control of the BSA Processor and other equipment in the system and supports data analysis and presentation features. The minimum configuration of the BSA Flow software comprises the main software package. One or more options may be added for further functionality.

Recommendation	*Make a backup of your old data prior to the installation of the new software.*

To install the BSA Flow Software, insert the CD-ROM into the CD-ROM drive of the PC. If your PC supports the autostart feature, you will get the following screen display:

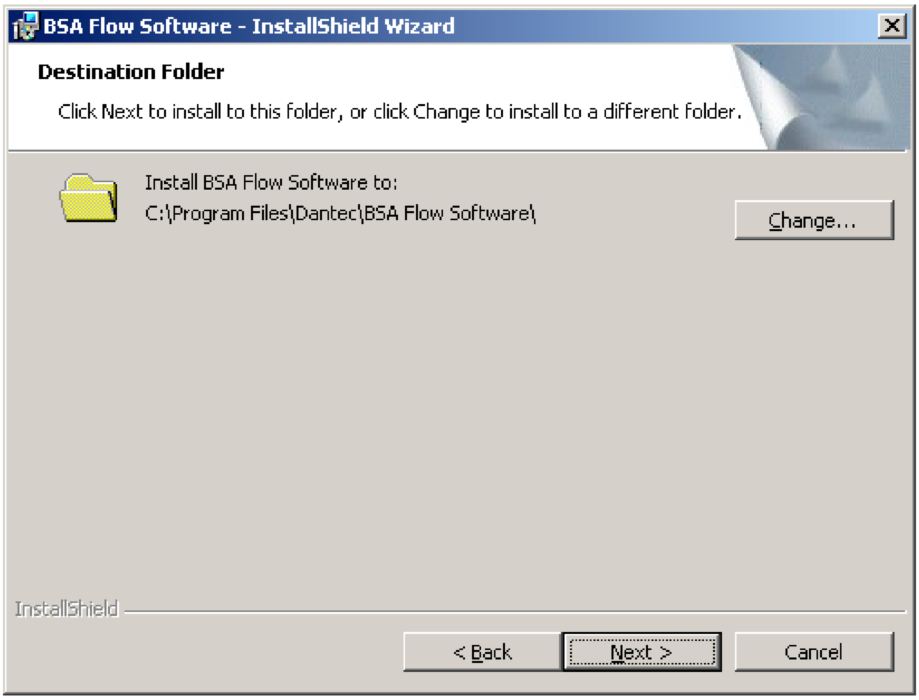


Follow the instructions of the InstalledShield Wizard. After having accepted the terms in the licence agreement and read information about the software, you will get the following screen:

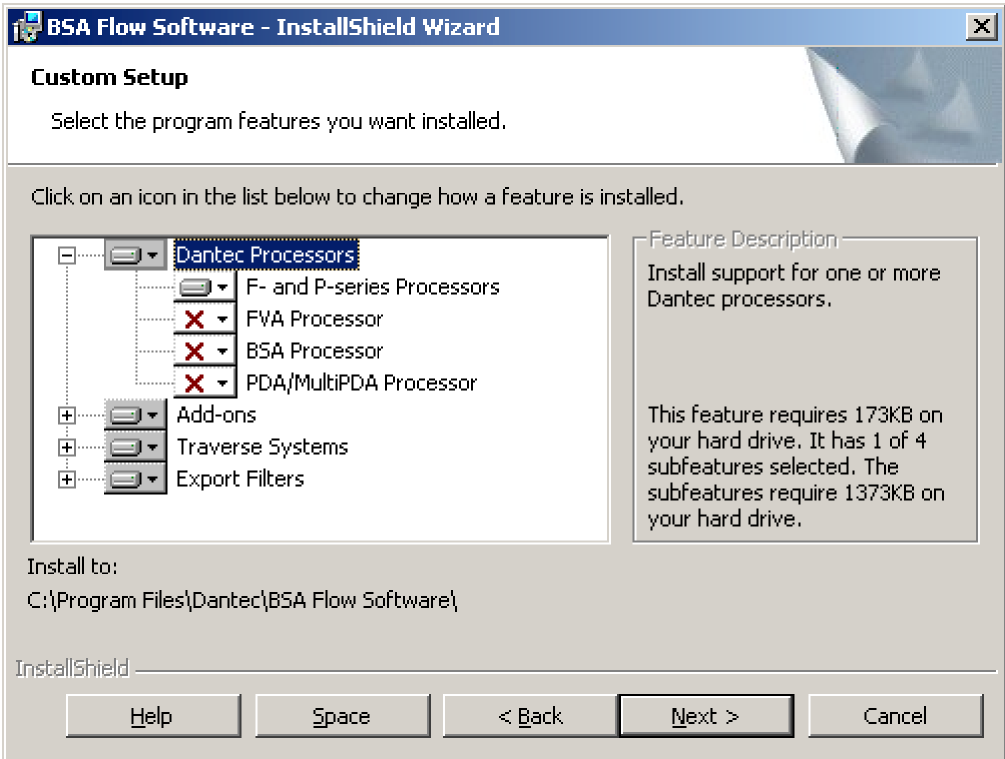


Fill the blank and your dungle code (software key). Select the user authorisation and click on next.

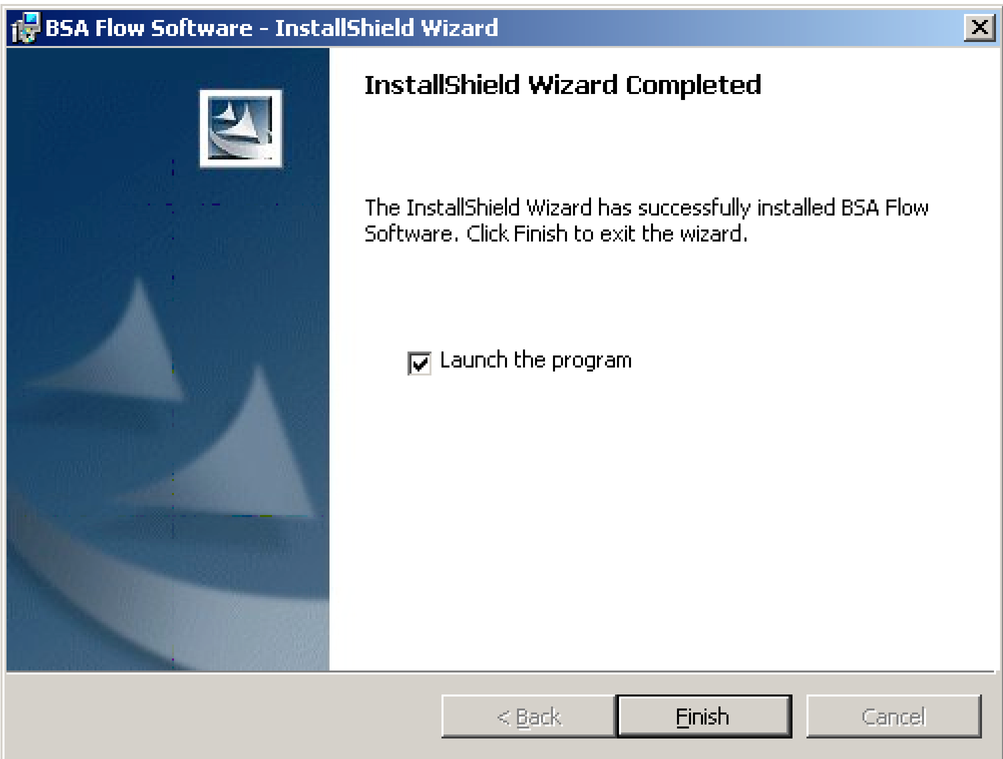
You have the possibility to define the disk and directory where you want to install the software:



The following screen allows you to configure your system. Click on the icon of each object to install it. This object has to be supported by your dongle.



The installation will be finished when you will get the following screen:



If you do not get the above screen displays, please execute the SETUP.EXE file in the CD's root directory. This will start the installation program. You will be asked for the hardware key (dongle) password during the installation. This is shown on a page supplied with the software.

It is recommended that you follow the guidelines in the installation routine. In particular, it is recommended that you install the file in the default directory path.

C:\Program Files\Dantec\BSA Flow Software\

Data belonging to a particular experiment are stored in *Projects*. Sample projects are included and can be used to get acquainted with the software's features, before you move on to acquisition of data.

3.2.1 Installing the Ethernet board

The BSA comes with a 3Com Etherlink 10/100 Mbps PCI Network Interface Card for the PC, and a peer-to-peer Ethernet cable. Please install this according to the Quick Guide supplied with the card.

Caution	*Do not use the peer-to-peer Ethernet cable to connect to a network, since the pin connections are different for point-to-point and normal network connection.*

3.2.2 Setting up IP Address and Subnet Mask

3.2.2.1 Configuration Selector Settings

The BSA Processor is equipped with a Configuration Selector switch on the rear panel. This switch can be used to configure the processor to a number of predefined network settings like IP address and subnet mask, see list. When the switch is turned and after the processor is restarted, the processor will adapt to the selected settings. In some cases the processor will need extra time to restart when the switch position is altered.

Version 1.00

Selection	IP Address	Subnet Mask	Comment
0	10.10.100.100	255.255.0.0	System defaults.
1	10.10.100.101	255.255.0.0	
2	10.10.100.102	255.255.0.0	
3	10.10.100.103	255.255.0.0	
4			Not used.
5			Not used.
6			Not used.
7	192.168.255.254	255.0.0.0	FlowMap processor.
8	10.10.100.34	255.255.0.0	
9	10.10.100.30	255.255.0.0	
10	0.0.0.0	255.0.0.0	DHCP Server support.
11			Not used.
13	10.10.100.100	255.255.0.0	Reset to system defaults (set IP address to default).
14			Reset to system defaults (keep IP address).

15			Not used.

Version 2.00

Selec tion	IP Address	Subnet Mask	Comment
0	10.10.100.100	255.0.0.0	System defaults.
1	10.10.100.101	255.0.0.0	.
2	10.10.100.102	255.0.0.0	.
3	10.10.100.103	255.0.0.0	.
4	.	.	Not used.
5	.	.	Not used.
6	.	.	Not used.
7	192.168.255.254	255.0.0.0	FlowMap processor.
8	10.10.100.34	255.0.0.0	.
9	10.10.100.30	255.0.0.0	.
10	0.0.0.0	255.0.0.0	DHCP Server support.
11	.	.	Not used.
12	#.#.#.#	#.#.#.#	User defined in Configuration Service.
13	10.10.100.100	255.0.0.0	Reset to system defaults (set IP address to default).
14	.	.	Reset to system defaults (keep IP address).
15	.	.	Not used.

3.2.2.2 Peer-to-peer connection

It is recommended that systems running with the BSA Processor runs peer-to-peer with the application PC. This is primarily because of performance and service considerations. When the processor and computer is connected peer-to-peer the two parts have to have nearly the same IP address and subnet masks. Valid combinations for the application PC are:

Version 1.00	Version 2.00
10.10.x.x 255.255.0.0	10.x.x.x 255.0.0.0

3.2.2.3 Configuration Service

Another way to change the IP address, subnet mask and processor name is to use the advanced Configuration Service installed in the processor. This service can be reached using an existing network connection or by a serial null-modem cable connection.

When using a network connection, communication can be established using the Telnet utility. In the case of a serial connection the program HyperTerminal can be used. Both programs are found in standard installations of Windows. A quick way to use the Configuration Service is to launch communication from the Connection page in the Device Configuration.

3.2.3 Installing a GPIB board (for 57N series BSA and for 57G15 traverse interface)

Components

The GPIB communication package is described by the suppliers packing list but comprises at least the following items

- PCI-GPIB/TNT (or other) IEEE 488.2 communications board manufactured by National Instruments - a Plug & Play card is strongly recommended
- GPIB communications cable of proper quality, length not exceeding 4 m
- Installation software for communications driver from National Instruments, which suits the Windows version.
- Installation and User's Guide documentation.

Caution	*It is crucial that you use a communication cable of approved quality and length which satisfies the specifications for GPIB (IEEE 488.2) communications.* *Although communication between your PC and the processor may appear to be operating with a non-standard cable the reliability of transmission can be significantly reduced.*

3.2.3.1 Configuring the GPIB driver

Install the PCI-GPIB driver software and additional programs by following the installation procedure given in the installation guide.

The instructions below are based on the *National Instruments* NI-488.2M Software for the PCI-GPIB board.

For your information, please find enclosed some screen dumps of one sample set-up.

You will find the GPIB set-up in the control panel under "GPIB”

Figure 3-1 Control Panel in Windows NT.

Double-click the GPIB icon to get into the GPIB Configuration menu:

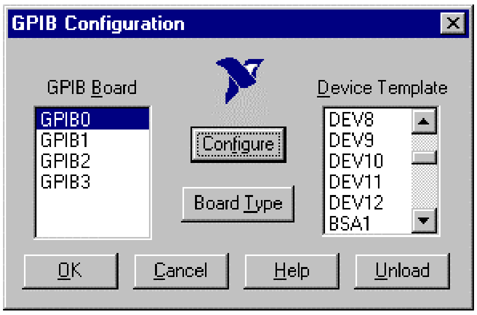


Figure 3-2 GPIB configuration menu

Select GPIB0 and click on Configure, which brings you to the next menu. This will look like the upper left part of the next figure. Click on the Software button to expand to the menu below.

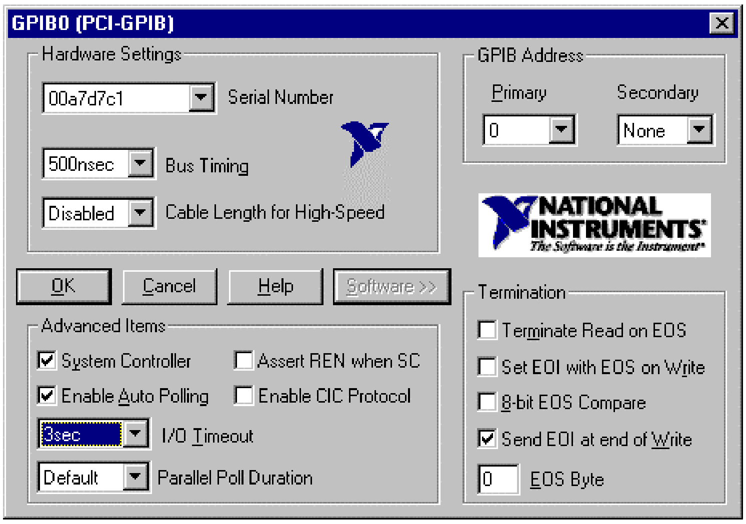


Figure 3-3 Menu for configuration of the GPIB board

The serial number of your board is different from the one indicated above. It is found by the driver software itself. Do not modify it.

It is recommended to set the I/O Timeout to 3 seconds as shown, rather than the default 10 seconds value. This will give faster feedback to you if there is a communication problem.

Click OK to get back to this menu:

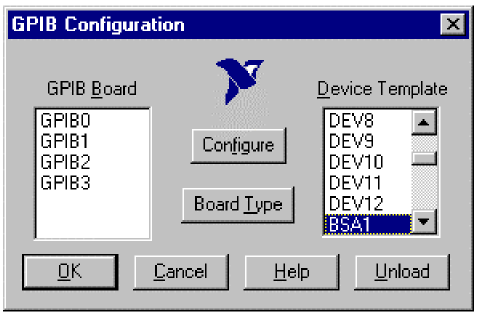


Figure 3-4 Menu for configuration of the GPIB devices

In the Device Template list, select DEV10 and click the Configure button.

This opens the following menu. The title bar will display DEV10 Settings till you modify the Name field. Change the name to 57G15. Set the other parameters as shown on the figure.

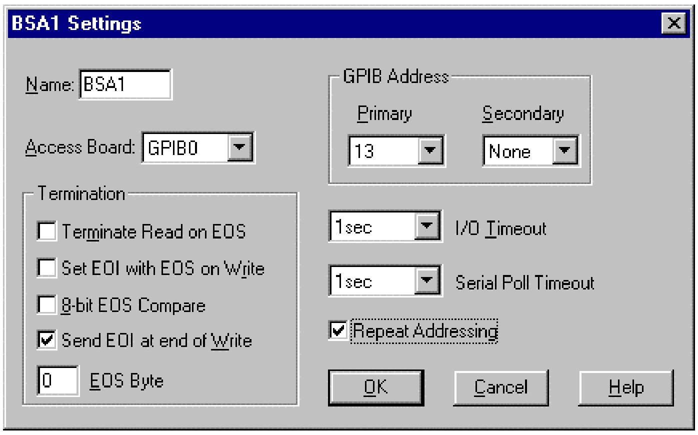


Figure 3-5 Menu for settings of a GPIB device

Click the OK button, which brings you to a prompt for restarting the NI-488.2M software:

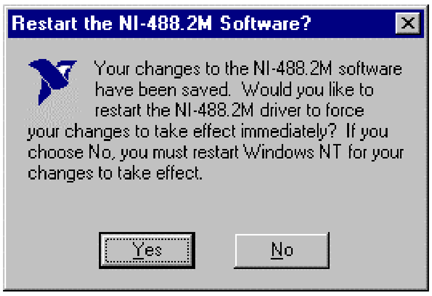


Figure 3-6Prompt for restarting the GPIB driver

Click the Yes button.

To activate the driver, it is necessary to run a diagnostics program. You will find this in the directory holding the GPIB driver software.

Run the Diagnostic.exe program. This will bring up the following window:

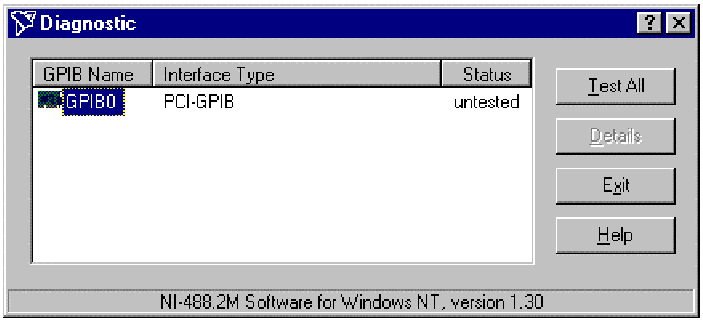


Figure 3-7 Diagnostic window before test

Click the Test All button. After a few seconds, the window changes to:

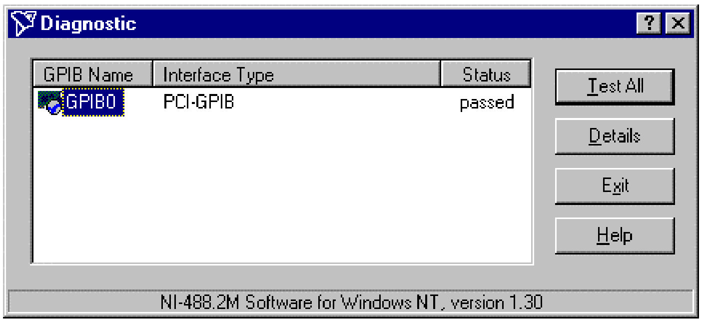


Figure 3-8 Diagnostic window after test

Click the Exit button and the GPIB installation is complete.

3.2.4 Installing the FVA/PDA interface board (for 58N series FVA and PDA processors

The 58G130 PDA Interface Board is designed for use with computers with an ISA 16-bit or EISA 32-bit bus. This bus must be fully compatible with an IBM PC/AT bus.

Caution	*Make sure that the computer is disconnected from the power supply before opening and installing the interface board.*

The 58G130 FVA/PDA Interface Board has an on-board buffer with 4 MByte of DRAM which allows for acquisition of more than 250.000 samples at up to 150 kHz data rate. During acquisition data is stored in this memory and transferred to the computer by means of 16 bit I/O-operations. The buffer management is controlled by software.

Address switches

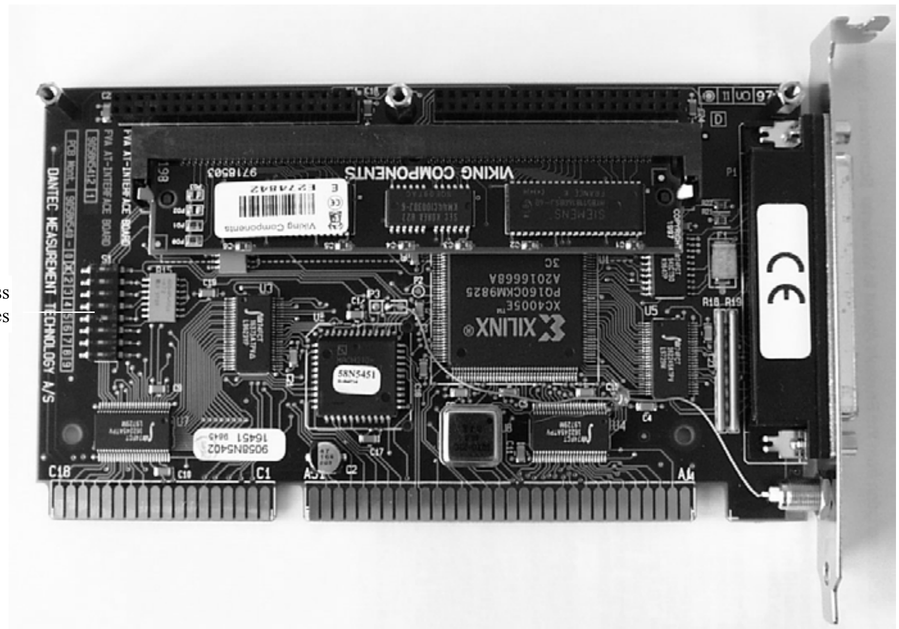


Figure 3-9 58G130 FVA/PDA Interface board

It is important that all boards installed in the PC use different addresses.

The 58G130 PDA Interface Board can be used with an address in the range 200 to 3F0 (hex). If required, it is possible to change the address of the 58G130 PDA Interface Board. The available address range and the according switch settings are listed in Table 3-1. The switch socket on the interface board contains eight switches. Only switches 1 to 5 are used to define the board address. Switches 6, 7 and 8 are not used. It is recommended to leave those in “Off”-position.

Switch					**Address**	**Switch**					**Address**
1	**2**	**3**	**4**	**5**	**Hex**	**1**	**2**	**3**	**4**	**5**	**Hex**
0	0	0	0	0	200	0	0	0	0	1	300
1	0	0	0	0	210	1	0	0	0	1	310
0	1	0	0	0	220	0	1	0	0	1	320
1	1	0	0	0	230	1	1	0	0	1	330
0	0	1	0	0	240	0	0	1	0	1	340
1	0	1	0	0	250	1	0	1	0	1	350
0	1	1	0	0	260	0	1	1	0	1	360
1	1	1	0	0	270	1	1	1	0	1	370
0	0	0	1	0	280	0	0	0	1	1	380
1	0	0	1	0	290	1	0	0	1	1	390
0	1	0	1	0	2A0	0	1	0	1	1	3A0
1	1	0	1	0	2B0	1	1	0	1	1	3B0
0	0	1	1	0	2C0	0	0	1	1	1	3C0
1	0	1	1	0	2D0	1	0	1	1	1	3D0
0	1	1	1	0	2E0	0	1	1	1	1	3E0
1	1	1	1	0	2F0	1	1	1	1	1	3F0

Table 3-1. 58G130 board addresses and switch settings (0 = off; 1 = on).

3.2.5 Installing Lightweight traverse systems

The Lightweight Traverse system requires a serial (COM) port in the PC.

3.2.5.1 Installing the manual control unit

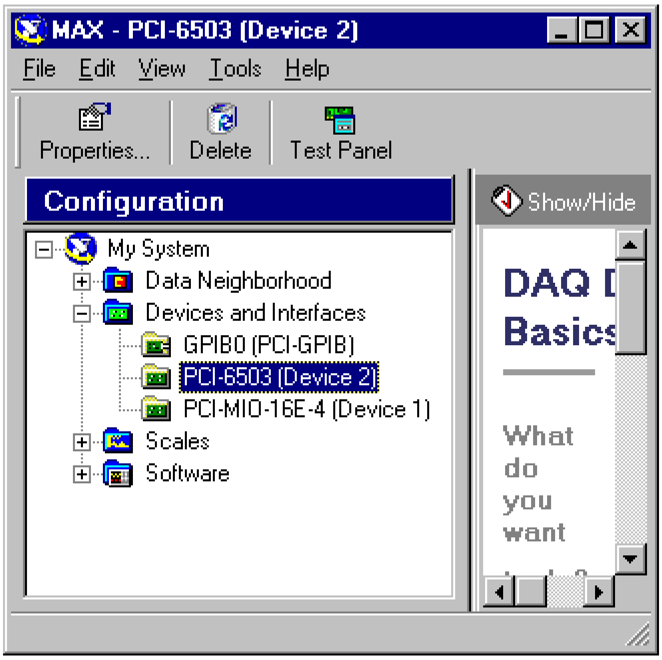
The manual control unit consists of:

- a digital I/O board, National Instruments model 6503, requiring a PCI slot in the PC,
- an additional rear panel with a short ribbon cable attached,
- and a hand box with four switches for +/-X, +/-Y, +/-Z movements and High/Low speed selection.

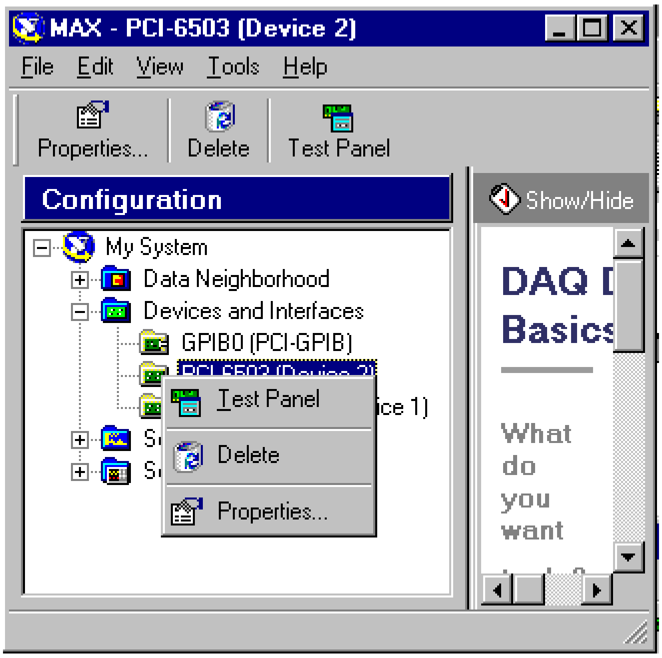
With the PC and traverse controller switched off,

- insert the digital I/O board in a free PCI slot in the PC.
- Mount the additional rear panel next to it and
- connect the ribbon cable to the digital I/O board.
- Connect the handbox to the rear panel.

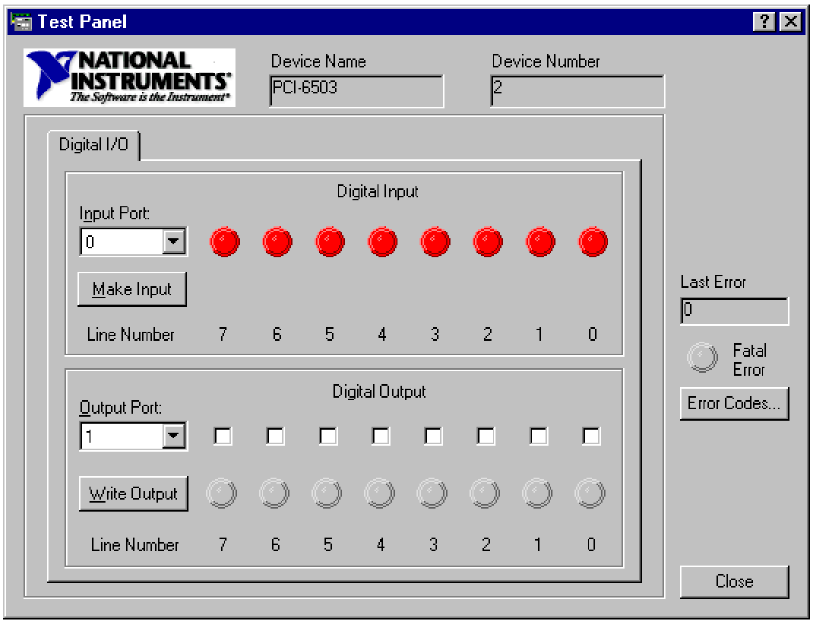
- Switch the PC on and install the National Instruments driver on the PC
- Restart the PC and double click the Measurement&Automation icon on the desktop. This opens a window similar to the one shown below.



- Click the + button next to Devices and Interfaces. This will display the installed National Instruments boards. In this example, two additional boards are installed.
- Write down the device no. of the PCI-6503 board, in this example it is 2. You will need this information for configuring BSA Flow Software correctly.
- Right-click on the PCI-6503 icon, and select Test Panel



- This brings up the following window:



- Activate the four switches in turn. This should affect the digital inputs 0 through 6.
- Close the Measurement&Automation window.
- This concludes the installation and test of the manual control unit.
- Operation from BSA Flow software is described in chapter 4.

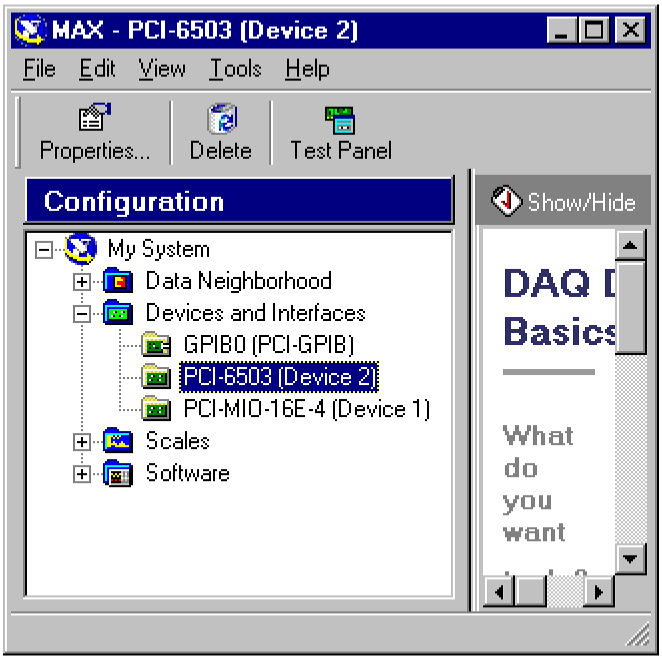
3.2.6 Installing 57G15 Traverse interface

The 57G15 traverse interface requires a GPIB interface in the PC.

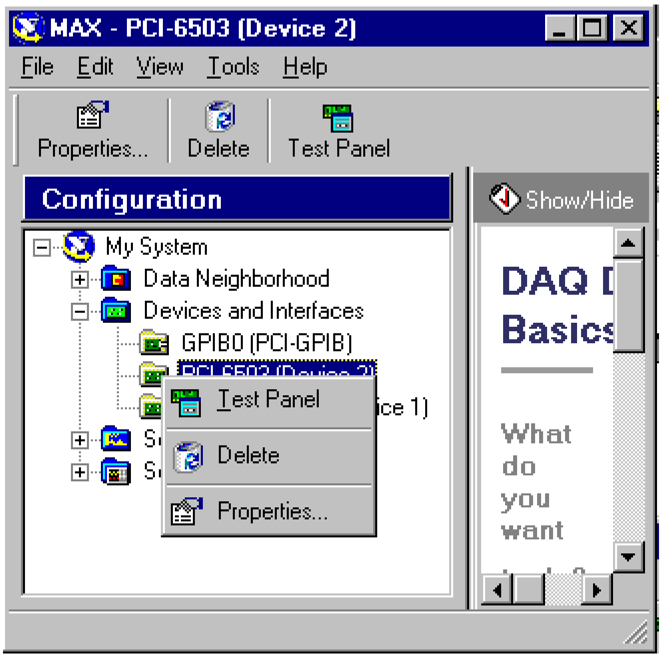
Remember to rename GPIB device 10 to 57G15, see section 3.2.3.

3.3 Lightweight traverse with handbox

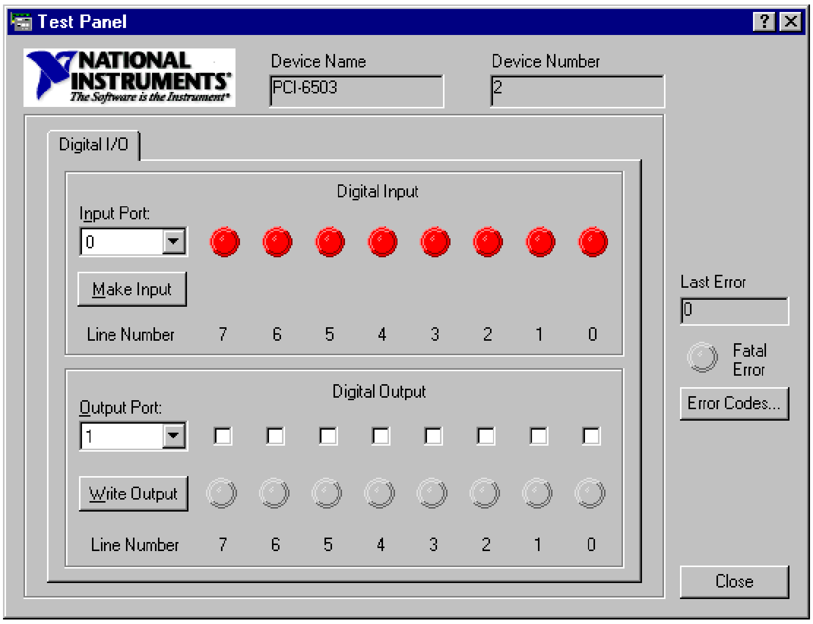
- Switch the PC on and install the National Instruments driver on the PC
- Restart the PC and double click the Measurement&Automation icon on the desktop. This opens a window similar to the one shown below.



- Click the + button next to Devices and Interfaces. This will display the installed National Instruments boards. In this example, two additional boards are installed.
- Write down the device no. of the PCI-6503 board, in this example it is 2. You will need this information for configuring BSA Flow Software correctly.
- Right-click on the PCI-6503 icon, and select Test Panel



- This bring up the following window:



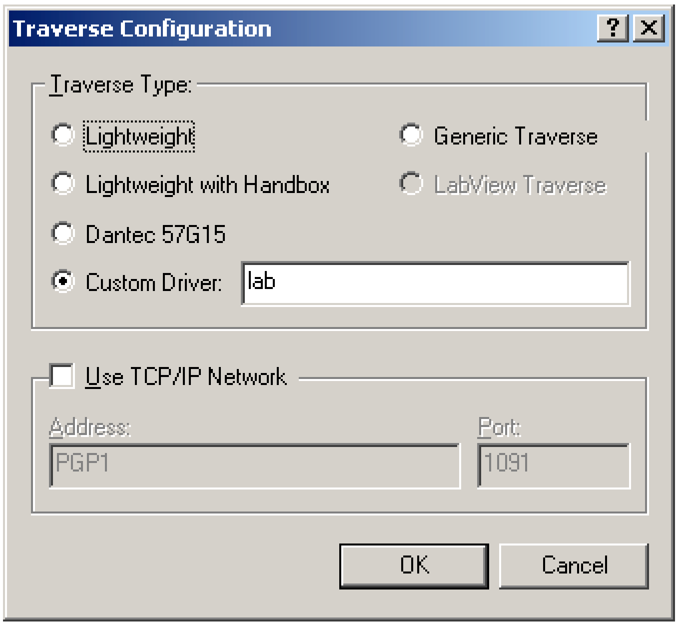
- Activate the four switches in turn. This should affect the digital inputs 0 through 6.
- Close the Measurement&Automation window.
- From the Windows Control Panel, open the Dantec Device Configuration
- Follow the procedure in *section 4.7.2 configuring an LDA or PDA system*. When you come to the Traverse Configuration window,

3.4 Custom configuration

If you need to modify some of the traverse properties, e.g. calibration factor, sign, COM port or other, you can save the configuration and make it the default configuration.

The procedure is:

- make the required changes to the traverse properties,
- right-click the Traverse Server
- select Save and specify a name for the traverse, for example lab. It will be saved with the name lab.cfg.
- Close BSA Flow Software
- Open Dantec Device Configuration from the Control Panel
- Click on Traverse – click on Properties
- Select Custom Driver and write lab in the box:



- Next time you define a project in BSA Flow Software, the traverse properties will be those defined in the lab.cfg file.

3.5 Third party traverse system

To control a third party traverse system you will need the Advanced Traverse Add-on. This is described in chapter 6.4.

4. The user interface

The user interface enables the user to control the set-up of all instrumentation in the LDA or PDA system, data acquisition as well as data analysis options, making LDA or PDA experiments straightforward and flexible.

The user interface uses standard Windows NT conventions. Most of the elements seen on the display can be moved and resized by the mouse. Right-clicking opens context menus.

Besides the standard Windows menus and toolbars, the user interface consists of four panes:

- the project explorer, for visualising the whole sequence of data handling from source to end-result.
- the property editor, where the parameter values of selected objects are set up
- the workspace, showing LDA and PDA system configuration and data presentation views (lists, plots). The workspace is different for LDA and PDA.
- the message window providing system status information.

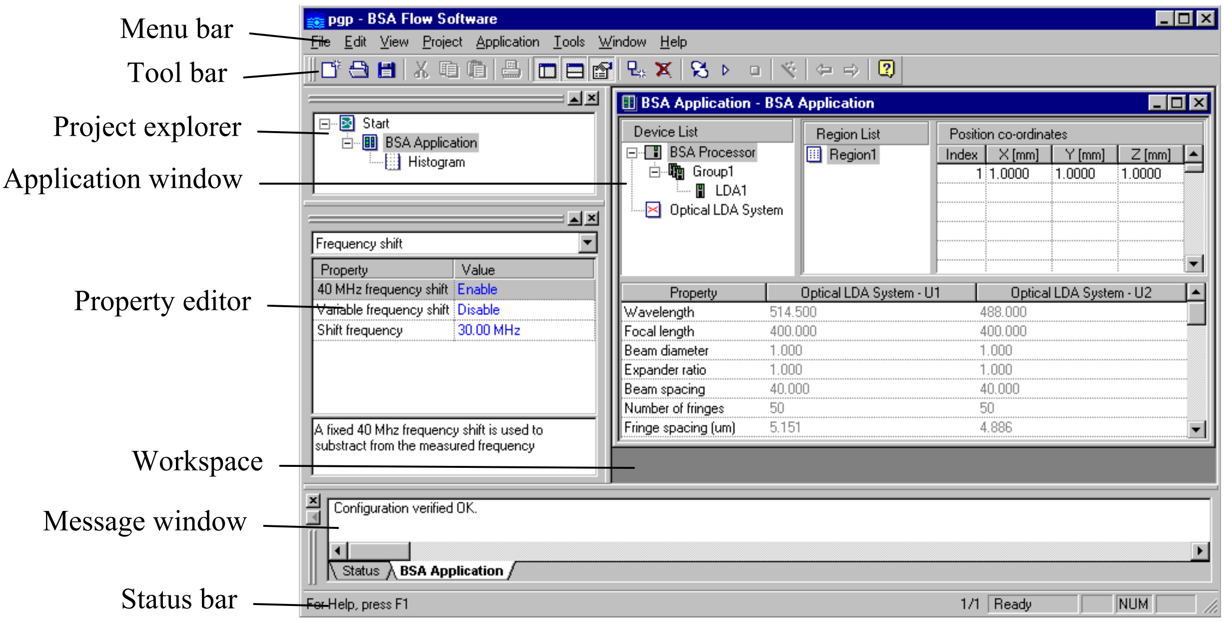


Figure 4-1 The main elements of the user interface (62N series BSA processors)

The different windows in the workspace are selected either by clicking on them or by clicking on their icon in the project explorer.

The Property editor displays the properties for the currently selected icon in the Project explorer.

If an icon in the Device list of the BSA Application window is selected, the properties of the selected icon are displayed in the Property editor.

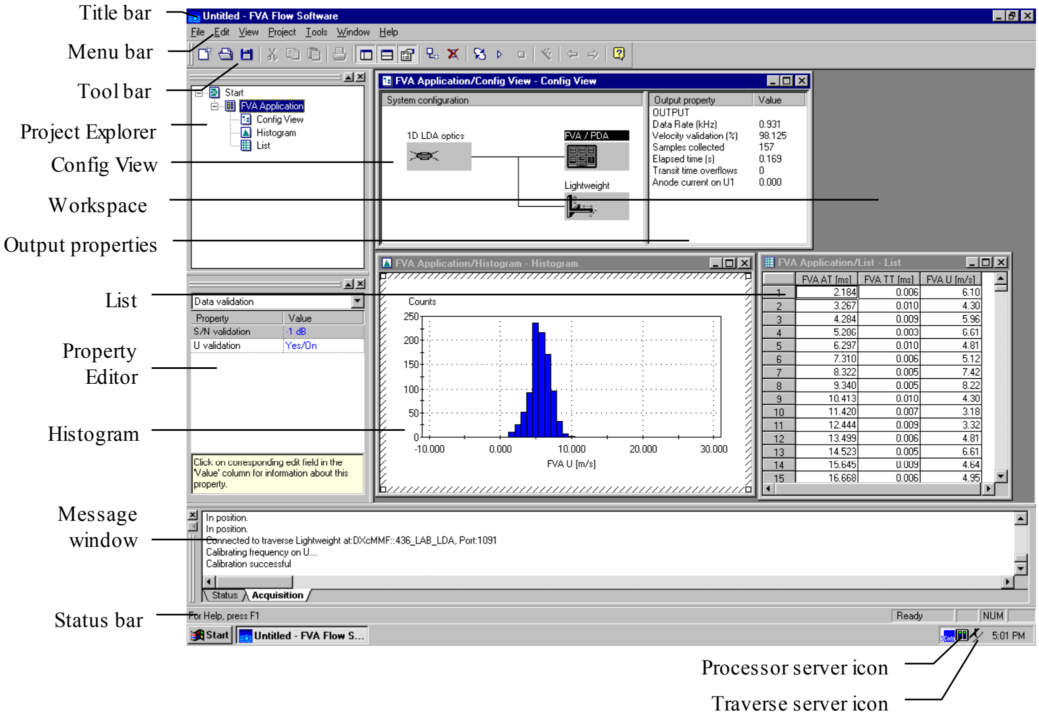


Figure 4-2 The main elements of the user interface (57Nseries BSA and 58N series FVA/PDA processors)

4.1 Project explorer

Before beginning a measurement procedure, the user can define a sequence of data acquisition, analysis and display options leading to the required end-result. The end-result is updated on-line during measurement, providing immediate feedback on measurement quality.

Analysis sequences for the experiment are visually presented by *the project explorer*. The project explorer consists of linked object icons that provide intuitive traceability as well as an experimental log.

Objects are events which generate or present data. The objects are visualised as icons in a hierarchical structure, the *project tree*, and selected from context-sensitive dialogs. Examples of objects are:

- data sources (signal processors or imported data)
- statistical calculations
- spectrum or correlation calculations
- sorting cyclic data into phase angles
- phase averaging
- data plots
- data lists
- data export

Object are described in detail in chapter 5.

The data is stored in a database and can be further analysed, by adding objects to or deleting objects from an existing data analysis sequence.

When a new object is added to an existing one, it is called a *child object*. The existing object is called the *parent object*. An object and its child objects is called a *branch*. Branches or complete project trees can be saved as *templates*, see section 4.1.5.

4.1.1 A project tree example

The figure below shows an example of an analysis sequence as visualised in the project explorer.

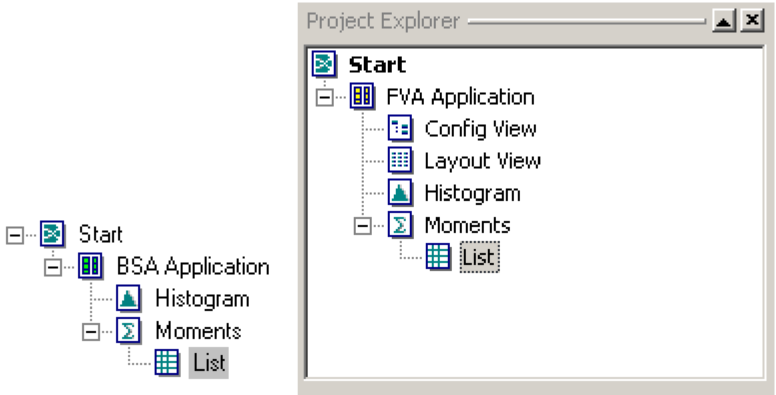


Figure 4-3 A typical project tree for velocity profile measurement

The project tree in Figure 4-3 includes what would typically be required for a velocity profile measurement. The output from this during a measurement would be:

- on-line velocity histograms for the current traverse position
- an on-line updated spreadheet list of traverse positions and the mean, RMS, skewness and flatness of velocities in each position.

If you have the Advanced Graphics add-on to the BSA Flow software, it is possible to add a Profile Plot which can be updated on-line. This add-on also includes vector plot, which can display the two-dimensional mean velocities as a vector map for 2D or 3D data.

4.1.2 Guidelines for objects

- The project explorer always starts with a Start icon.
- The child object to the Start icon is always a data source, either BSA F/P Application, BSA Application, FVA Application, PDA Application or Import velocity files.
- BSA F/P Application includes set-up of the hardware and traverse mesh. It is possible to define different regions each with its own set of properties for processors, traverse, optics etc. The traverse mesh always includes at least one position. When acquisition is launched, the traverse will move to this position.
- BSA Application, FVA Application and PDA Application must be followed by Config View, which provides access to the hardware and optics settings. If a traverse mesh is to be used, it should also be followed by a Layout View, which controls the layout of traverse regions and positions.

- The Traverse Mesh is used to define measurement position meshes, and if required regions with different hardware settings. Each region can have its own set of properties for processors, traverse, optics etc.
- Analysis and display objects must be added to the data source object.
- A Histogram object is often added directly to the data source object, to get an on-line visualisation of the distribution of velocity samples in the current position.
- Numerical output to the monitor is generated by adding a List object.

List can display:

- the individual velocity samples if added to a data source object, before or after coordinate transformation
- moments of the velocity distribution if added to a Moments object
- Spectrum or correlation function values if added to Spectrum or Correlation object

Data can be manually exported from lists by right clicking on the List object and selecting Export... from the context sensitive menu.

Data can be automatically exported from a data source by adding an Export object to the project tree.

4.1.3 Adding objects

Objects can be added to a parent object by:

- Right mouse clicking on an object
- Clicking on an object and clicking the New object button in the toolbar

In both cases, a dialog like this opens:

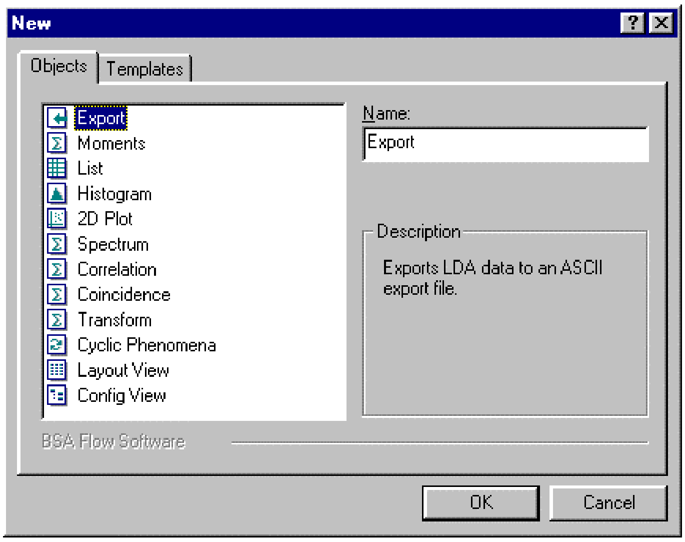


Figure 4-4 Dialog for adding objects to the BSA Application object (some if the items in the list require add-ons)

You can enter a more descriptive name for the object before adding it to the project, or you can edit the name in the project explorer. The name can at any time be changed using the Rename command in the context menu for the object in the project explorer. A short description of the object is also shown in the New Object dialog. For templates this description is the same as the one you entered in the Save As Template dialog and the name of the template is the same name as the one you used when saving the template.

The items in the list depend on the active object. If the active object exposes an output format that another object can understand this object can be placed after the active object. Some of the object do not expose any output formats and they cannot have any child objects attached. Most of these object are plot objects like Histogram, 2D Plot, Vector Plot etc. Other objects like Layout View and Config view attached to the BSA Application object, and the Export object, do not own an output format either, they will also be the last in their branch.

You can attach more child-objects to one parent object, as long as the rules above are applied.

See section 4.1.5 for details about templates.

4.1.4 Deleting objects

Objects are deleted by

1. clicking the object to be deleted, *and*
2. clicking the Delete object button in the tool bar, *or*
3. pressing the CTRL + Del keys on the keyboard

You will always be prompted before the delete action is performed. All child objects to the deleted object will also be deleted.

4.1.5 Disabling / enabling objects

Objects are desabled or enbled by

1. Right-clicking the object to be desabled or enbled, and
2. Selecting the disable or enable button

In desabling an object, you vill reduce the work load of your PC. The properties of this object will not be available while this object is disabled. When you enable an object, you will have to re-run this object.

4.1.6 Templates

Templates automate typical tasks, and allow you to customise your work, like templates in a word processing program.

Two types of templates are available:

- LDA Project Templates (.ldp)
- LDA Templates (.ldt)

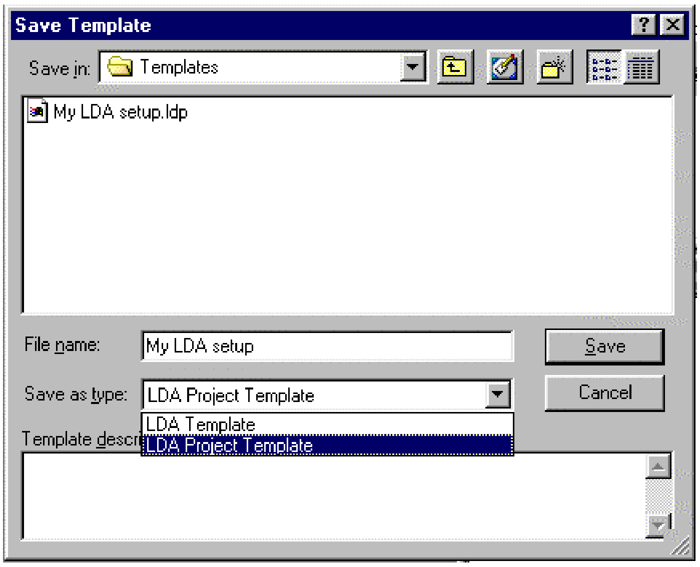
These Templates are avalaible for PDA and LDA systems.

4.1.6.1 LDA and PDA Project templates

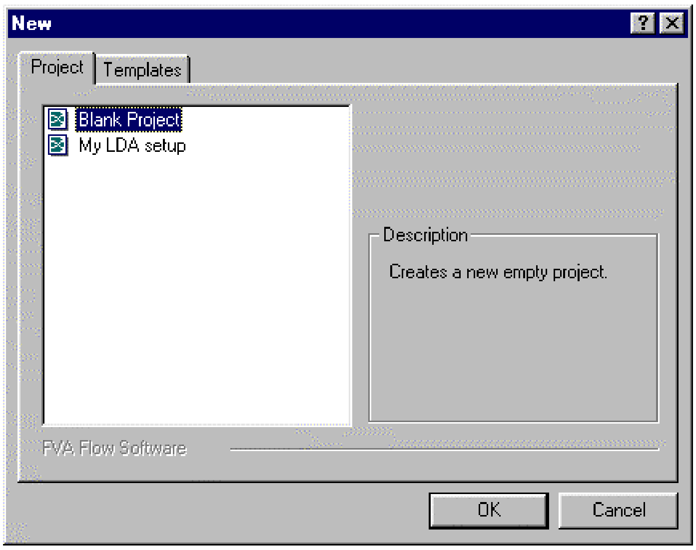
LDA and PDA Project Templates can e.g. include the BSA Application object, which you may always wish to start with.

To make a project template, you must do the following:

Define the project tree, right-click on the BSA Application, and select Save as Template. In the Save template dialog, type in the File name, e.g. My LDA setup, and select LDA Project Template as file type:



Next time you select File - New, your project template will appear in the list under the Project tab:



4.1.6.2 LDA and PDA templates

The entire project tree, a branch or a single object can be saved as a template. Templates are added to a project tree as described in section 4.1.3, by selecting the Templates tab instead of the default Object tab. This opens the dialog with a list of the templates you have defined, instead of the list of objects.

Templates can only be added to the project if the first object in the template understands the output format of the active object in the project explorer. This means, that if you save a template for an entire project starting at the BSA Application object, the template can only be attached when the active object is the Start object. It is therefore a good idea to name the template using the first object in it.

You can customise a complete measurement set-up, including:

- your preferred screen layout
- hardware configuration, position mesh
- data analysis and presentation
- data export

and save it as a template.

New similar experiments can thus be defined very quickly.

For example, a template for boundary-layer measurements could consist of:

- BSA Application, defining the optics and hardware set-up and the traverse mesh
- Histogram view of raw velocity components
- Transform object for coordinate transformation of the raw velocity components
- Histogram view of the transformed components
- Moments calculation
- 2D velocity profile plot (requires Advanced Graphics add-on)

With such a template, you can see

- on-line histograms of raw and transformed velocity components in the actual mesh position, and
- on-line build-up of the velocity profile plot.

Templates could also be defined for more specific tasks, e.g.

- coordinate transformation of raw velocity components, or
- a preferred screen layout for display of lists, histograms etc.

4.2 Property editor

Properties are user-controllable parameters associated with hardware or objects. The property editor is used to view and modify properties.

Most objects have associated properties (Start does not).

An object's properties are displayed, when the object is selected in the project explorer.

The property editor has a field in the top in which different sub-sets of properties can be selected by clicking on the drop down symbol . In the example below, the Lightweight icon has been selected in the Config view, and the subset Lightweight channel 1 selected from the drop down list. The list of properties consists of a Property column and a Value column. Some fields in the value column have a drop down list associated. The drop down symbol appears if you click in the Value field. In the example below, the value field of the Calibration factor pulse/mm property is selected, and the drop down list has been opened.

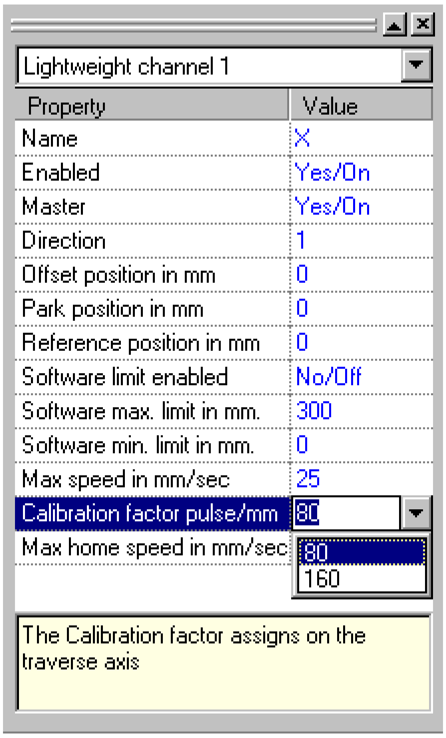


Figure 4-5 the properties of Lightweight - Lightweight channel 1

Histogram objects with more than one velocity channel have individual properties for each graph.

BSA Application objects have individual properties for each piece of hardware (optics, processors, traverse etc.).

The properties of the individual objects are described in chapter 5 and 6.

4.3 The tool bar

Most of the tool buttons on the tool bar are familiar to the Windows user.

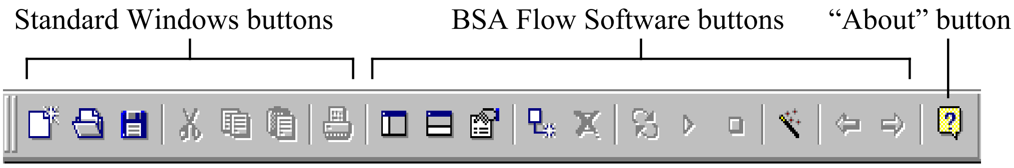


Figure 4-6. The tool bar buttons A brief explanation of each of the BSA Flow Software buttons is given below. A detailed description is given in Chapter 4.

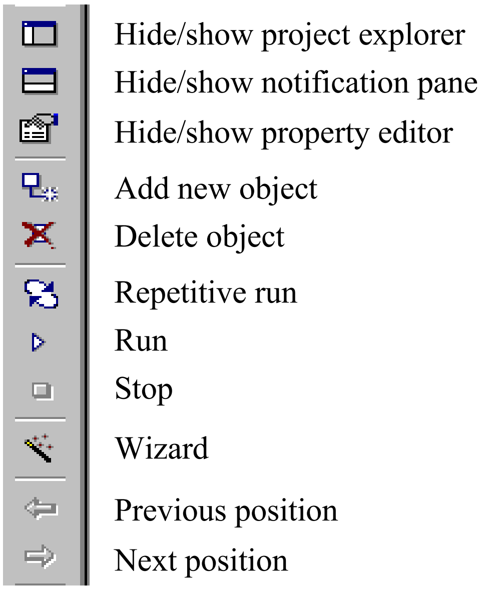


Figure 4-7. Function of the BSA Flow Software buttons

4.4 Menu bar

The menu bar contains the following choices:

Figure 4-8 The menu bar

4.4.1 File menu

File is the menu which allows opening and saving of files.

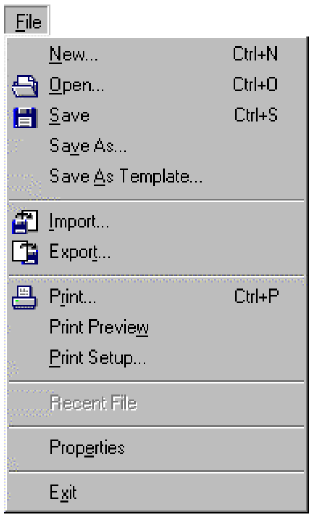


Figure 4-9 the File menu

Most of the choices in the drop down list are well known to Windows users and will not be explained here.

Save As... Save As opens the standard save as dialog which allows you to save a project with a new name.

Save As Template... Save As Template opens the save as dialog which allows you to save an object or a branch of object as a template for later use.

Templates are used to save parts of or whole projects including analysis sequences and screen layouts for re-use in other projects. A branch of a project tree (see section 4.1) or a complete project tree can be saved. Please refer to section 4.1.5 for details.

The name of the template is later used to identify the template, it is therefore a good idea to select an understandable name for the template. In the Save As Template dialog you can enter a description to the template. This description can be read in the New Template dialog, see section 4.1.3.

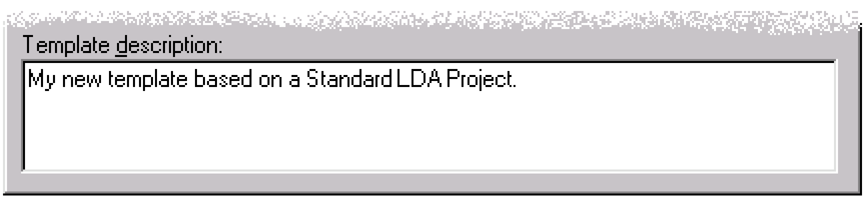


Figure 4-10 Save As Template dialog.

Import Import is reserved for future use.

Export Export is used to export from plots and lists when one of them is active in the workspace.

When a list is active the columns can be exported in four different ASCII formats.

- Formatted text (Space delimitted)
- Text (Tab delimitted)
- CSV (Comma delimitted)
- TecPlot (Tab delimitted)

When a plot (Histogram, 2D plot, Vector plot etc.) is active the plot can be exported as a graphic file in the following formats

- Windows Enhanced Metafile (EMF)
- Windows Bitmap (BMP)
- JPEG Bitmap (JPG)
- TIFF Bitmap (TIF)

All the graphic formats are well known Windows formats. The Enhanced Metafile format is a vector format that is useful when the graph needs to be rescaled after it has been exported. The smallest export files can be generated using the JPEG format which is commonly used when presenting plots on the internet.

Properties

This choice opens a dialog with two tabs: General and Summary.

General contains information about the type, size and location of the project.

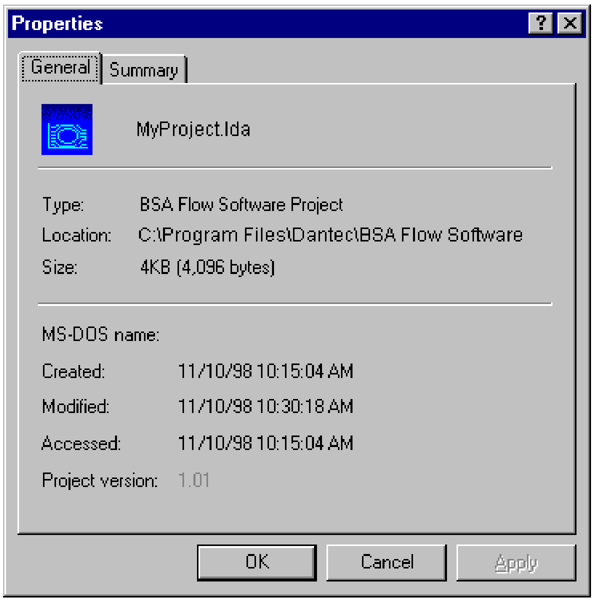


Figure 4-11 the Properties - General dialog

Summary is where you can add title, subject, author, comments and keywords to a project file. You can then use the Windows explorer to see this information by right-mouse clicking on a file in the file list. This means, that you can search in this information without opening the file itself.

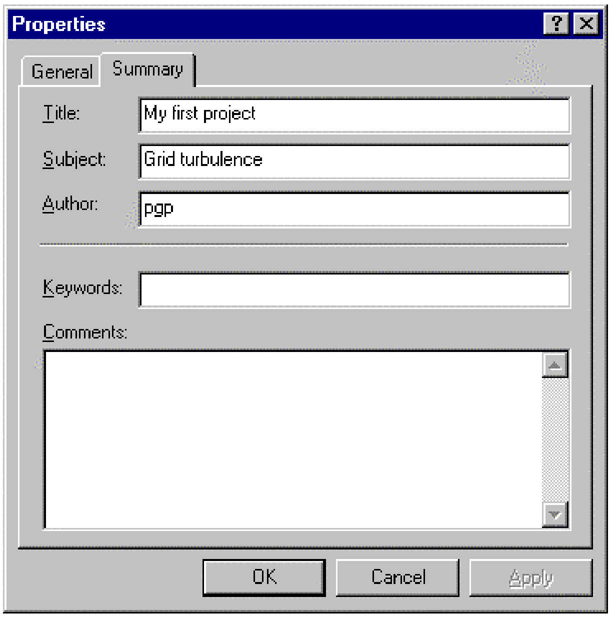


Figure 4-12 the Properties - Summary dialog

Exit Exit terminates the program.

4.4.2 Edit menu

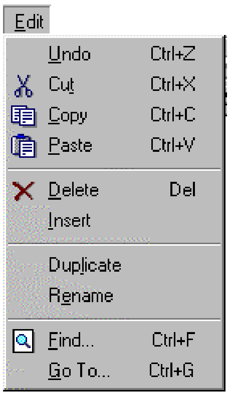


Figure 4-13 the Edit menu

The edit menu is self explanatory.

4.4.3 View menu

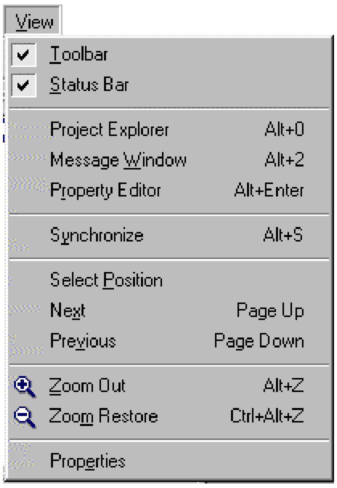


Figure 4-14 The View menu

The View menu controls which elements are displayed on the screen.

You can hide or show the following elements (please refer to the beginning of this chapter)

- The Toolbar
- The Status Bar
- The Project Explorer
- The Message Window
- The Property Editor

The last three can also be hidden or shown using tool buttons, see section 4.3.

Synchronize Used to ensure that the object (in the project explorer) corresponding to the highlighted view (in the workspace) is selected. If this synchronize is not selected, the object highlighted in the project explorer remains the same irrespective of which view is selected in the workspace.

Select position Opens the following dialog:

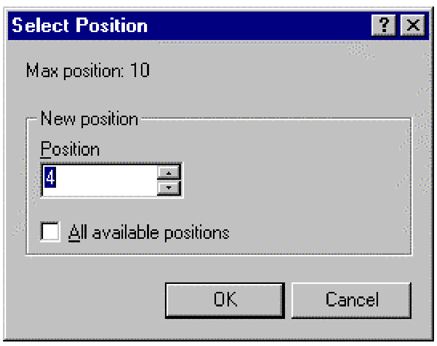


Figure 4-15 The Select Position dialog

This is used to specify the position, from which the object should display data. If All available positions is ticked, the view will update display data from all positions sequentially. This is useful during acquisition, in order to monitor the data quality.

If All available positions is *not* ticked, a position number must be specified.

The number refers to the order in which data was acquired. The number corresponds to the line number of the layout view. For off-line analysis of data, it is often practical to select a single position at a time.

This command can only be activated from objects representing data from a single position (i.e. *not* Moments and child objects of Moments).

Previous & Next Previous is used to change to the previous position in a traverse mesh and Next to the next position. If only one position (single point measurement) is present the command has no effect. If the selected object represents data from many positions (e.g. moments, profile plots), these commands can not be activated.

Zoom Out If a plot (Histogram, 2D plot, Vector plot etc.) is active in the workspace and the plot is zoomed in, the plot can be zoomed one step out using this command.

Zoom Restore If a plot is repeatedly zoomed in, this function can be used to zoom out to the original scale.

Properties shows the Object Properties dialog for the active object in the project explorer. It has General and Summary tabs with similar functions as described under the File menu.

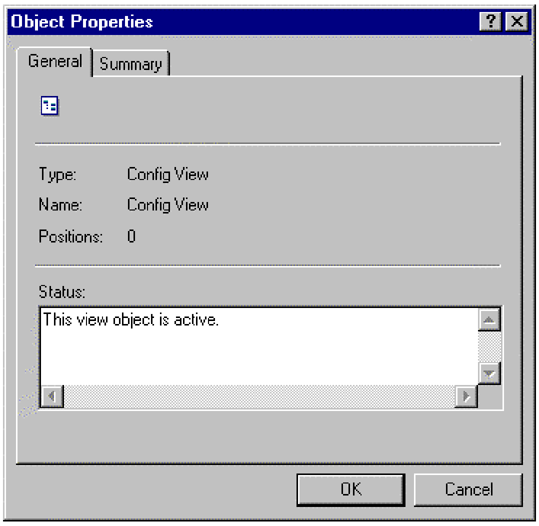


Figure 4-16 The Object Properties - General dialog

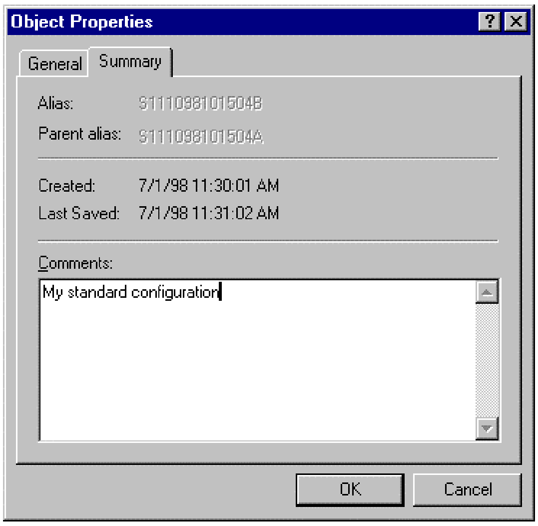


Figure 4-17 The Object Properties- Summary dialog

4.4.4 Project menu

This menu is used to run or stop data acquisition or import of data. It also allows the user to recalculate the objects in the project. Repetitive is useful when setting the system up: for the current position it will run all objects repetitively, without storing data to disk.

To optimise e.g. the PM high voltage, you can set a value, run repetitively and watch validation and data rate values in the processor output properties. Then stop acquisition, change the setting and run repetitive again.

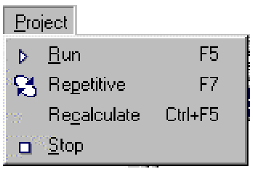


Figure 4-18 The Project menu

4.4.5 Tools menu

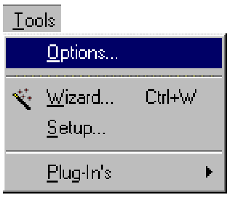


Figure 4-19 The Tools menu

Options

With the Options you get a dialog with five tabs, the first of which is General:

General

The General tab shows general properties and user information.

Note	*It is recommended that all the general options are enabled.*

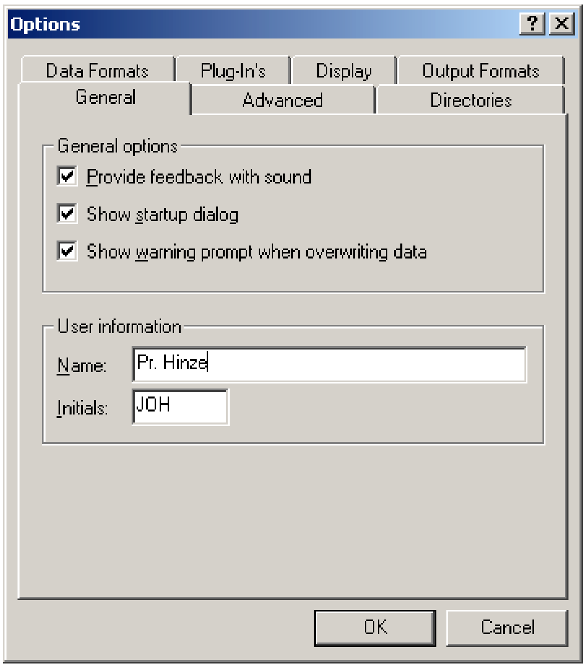


Figure 4-20 The Tools - Options - General dialog

If Provide feedback with sound is checked, the PC will beep e.g. when data collection is started and completed.

With Show startup dialog checked, one of the following dialogs is shown when you start the software:

Figure 4-21 The Startup dialogs

The Startup dialog is a quick way to get access to existing projects or create a new project.

If Show warning prompt when overwriting data is checked the Data Overwrite Warning dialog is displayed every time an experiment is about to overwrite original data. In the Data Overwrite Warning dialog you can choose to skip this dialog the next time by unchecking Show this at next run; this is however not recommended.

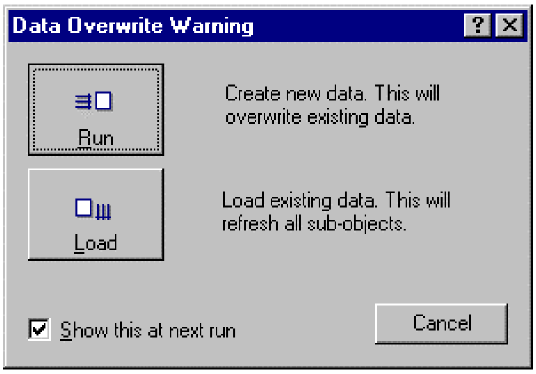


Figure 4-22 The Data Overwrite Warning dialog

The user information is stored along with the project.

Advanced

The Advanced tab gives the following choices:

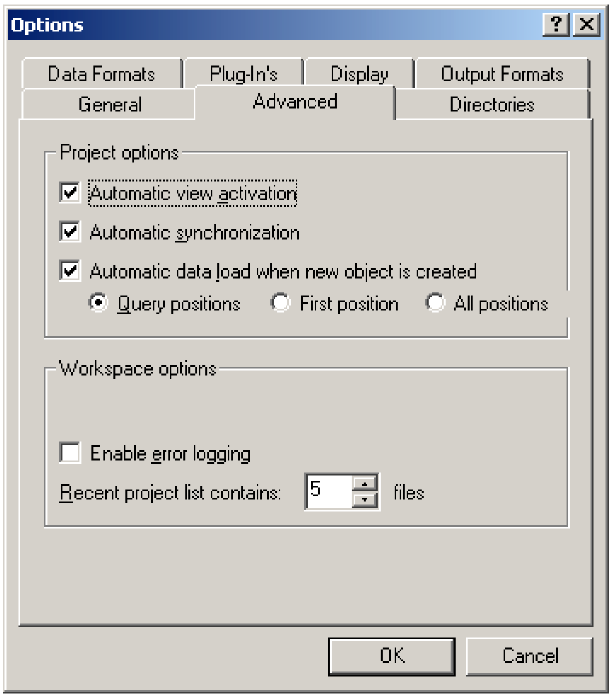


Figure 4-23 The Tools - Options - Advanced dialog.

When Automatic view activation is checked, the windows in the workspace will be activated when the corresponding object is selected in the project explorer. This provides a quick way of finding data belonging to a specific object in the project explorer.

When Automatic Synchronization is checked, a click on a window in the workspace will highlight the corresponding object in the Project Explorer, and vice versa.

Note	*By using the keybord shortcut Ctrl+Tab you can toggle between the windows in the workspace.*

When Enable error logging is checked, all internal error messages are logged to a file. The name of the file is "ErrorLog.txt" and it is placed in the Common directory.

Directories

The Directories tab opens the dialog in which default directories for different file types are specified:

- Projects
- Templates
- Import files
- Export files

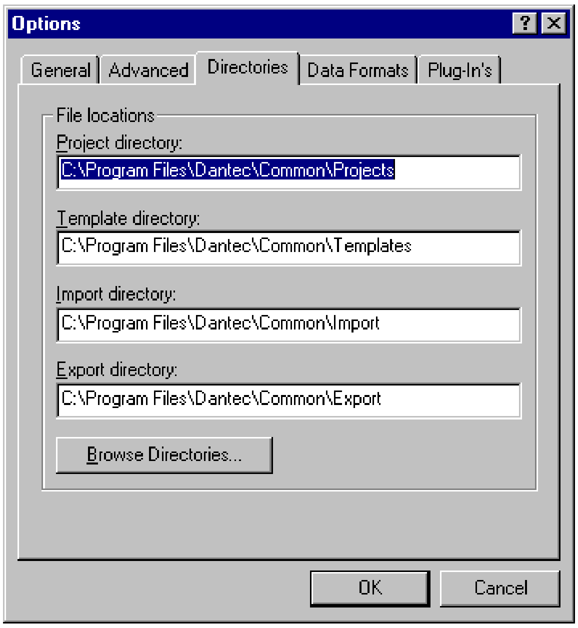


Figure 4-24 The Tools - Options - Directories dialog

Each of the directories can be changed by selecting Browse Directories.

It is recommended that you keep your Project files together on your disk. By doing so in the Project Directory, the files will be easier to find.

Note	*Changing the Template Directory means that all your templates must be moved. The software will only include templates located in the directory pointed to by the Template Directory. See section 4.1.5 for more information about templates.*

Data Formats

The Data Formats tab allows the user to change the unit name and format of the unit for certain data types. Here it is possible to define how the data will be presented throughout the program. You can also choose your favourite unit, e.g. you can change from ft to mm (only avalaible for 62N series BSA processors).
The checkbox Display velocity as frequency below the list allows to work in frequency or in velocity units as defined in the list.

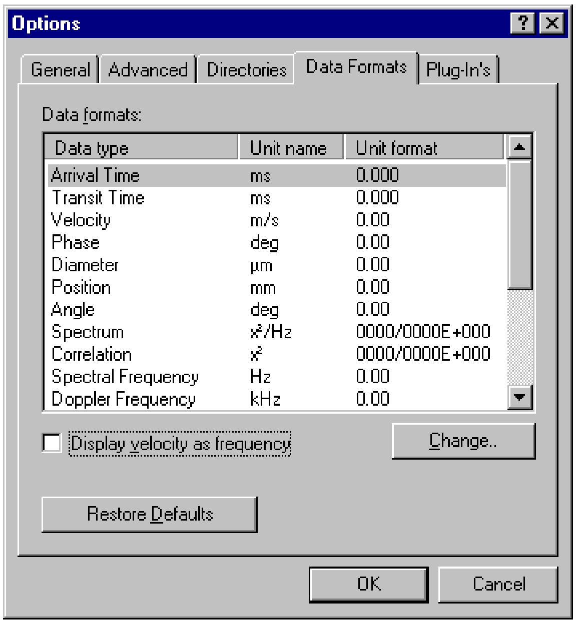


Figure 4-25 The Tools - Options - Data Formats dialog.

The Data Format list show corresponding settings for Data Type, Unit Name and Unit Format. The unit name defines how the data values are scaled and the unit format how the scaled values are displayed in data lists, data export etc. in the software. The unit format is an example of how the value is displayed.

A set of default settings can be applied by clicking the Restore Defaults button.

The possible unit formats are:

- Integer
- Floating Point
- Exponential
- Significant Digits

Use the Integer unit format with caution, the data format display will be converted from floating point notation to integer with loss of precision.

If your unit format is Floating Point you can choose between three formats. Floating point presents values with a precision given in decimal points. You can select a precision between 0 - 15 decimals.

If your values lie in a range far from 0 you can select the Exponential unit format. Like the Floating Point format, this will present the value with 0 - 15 decimals, but it will add an additional offset given by a exponential factor. All the values will be presented with a exponential factor.

The fourth format, Significant Digits, combines the two previous formats. By specifying the number of significant digits in the range 0 - 15 the value will be formatted using decimal point and if needed exponential factor. Compared to the two previous formats values may be presented both with and without an exponential factor. This means, that the values can look very different in format, but they will always have the correct number of significant digits corresponding to the selected precision.

If the Change button is clicked, the following menu appears:

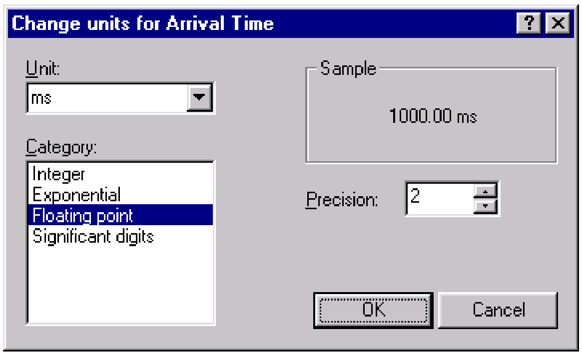


Figure 4-26 In this example, arrival time values are displayed as a floating point value in ms with 2 decimal digits precision.

This dialog can be used to convert from metric to imperial units, and to set number of digits displayed in numerical values.

The changed units will take effect after you rerun your project.

Note	*If you want to change the format in a List you should select the Format command for the context menu of the list. The unit formats are an overall formatting and should not be used to format list locally.*

Plug-Ins

The Plug-In's tab provides a way to add plug-in modules and tools to the software.

By default a processor server module (BSA Server module orPD Server Module), and Traverse Server module are included in the Tools list. You can add as many tools as you like. For example, you can add your word processing program or a spreadsheet program so that you can switch to these from within the software.

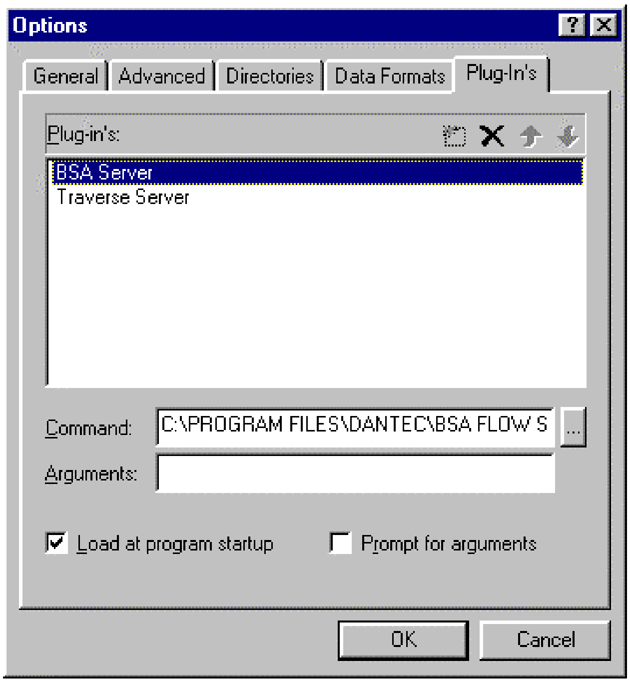


Figure 4-27 The Tools - Options - Plug-In's dialog

Furthermore the tools will be automatically loaded if Load at program statup is checked. Prompt for arguments should be checked if you want to enter a new argument each time you load a tool.

The Plug-In's added to the list will be placed in the Tools-Plug-In's- menu. From there each tool can be quickly loaded, see below.

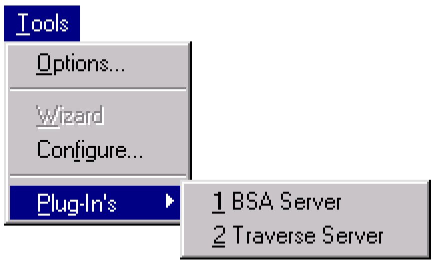


Figure 4-28 the Tools - Plug-In's menu

By default the BSA Server or FVA Server and the Traverse Server are placed in the list. BSA Server or FVA Server is responsible for communication with the processor. Traverse server is responsible for communication with the traverse. A server must be open if communication with the related hardware is required. i.e. when acquiring data. For off-line analysis of data the servers may or may not be open. The Tools - Plug-In's menu is used to open the servers. The servers can be closed by right-clicking on the server icon and selecting close from the context sensitive menu.

Display

The Dispaly menu allows the user to define the font and color used for the plots and lists

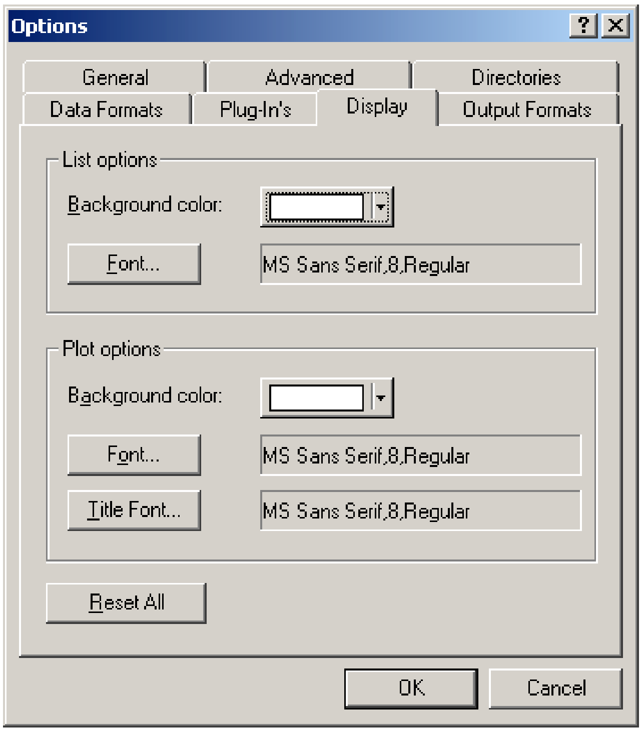


Figure 4-29: the Tools: Display mesnu

Output format

The Output format tab opens the dialog in which footer text used for the plots can be defined. To add some further information about the measurment, click on the narrow (see Figure 4-30 and Figure 4-31).

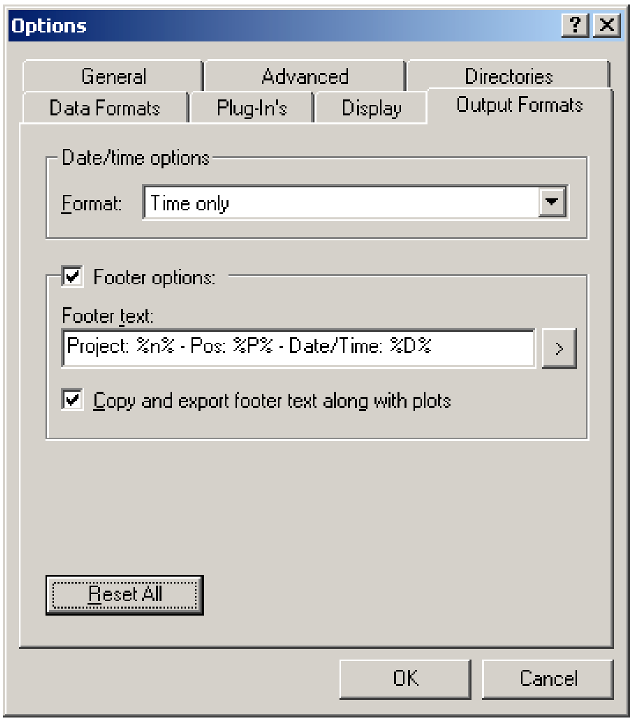


Figure 4-30 The Tools: Output formats

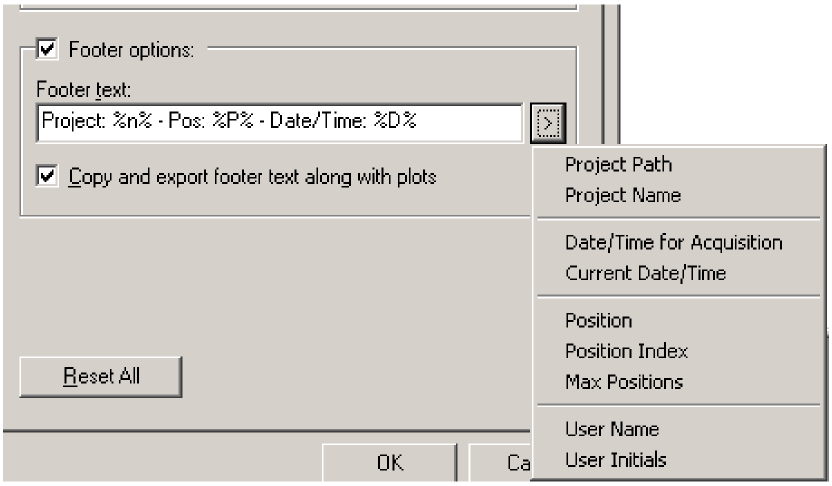


Figure 4-31:The Tools: Output formats. Add some further informations

4.4.6 Window menu

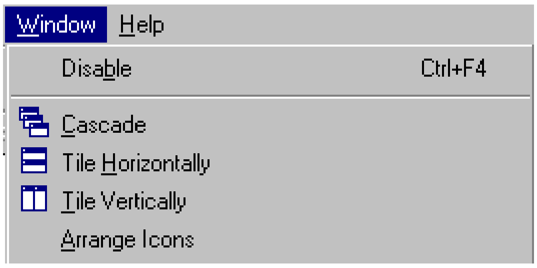


Figure 4-32 TheWindow menu

This menu has the same functionality as in other Windows programs. It arranges the windows in the workspace.

4.4.7 Help menu

Figure 4-33 The Help menu

There is no on-line help in BSA Flow Software, so selection of “Contents” will prompt the user to search for a non-existing help file.

Software Key... is used to modify the software key that is used with the dongle for access to the software, if e.g. you have typed an incorrect key during installation, or you have purchased new add-ons. Each dongle has an individual software key associated with it, which defines which add-ons are enabled.

Dantec on the Web allows you to access Dantec’s web-site, using an internet browser.

About BSA Flow Software... provides information about the version and build no. of the software, the software key, the dongle serial number, and which options are enabled. Dantec requires this information connection with trouble shooting.

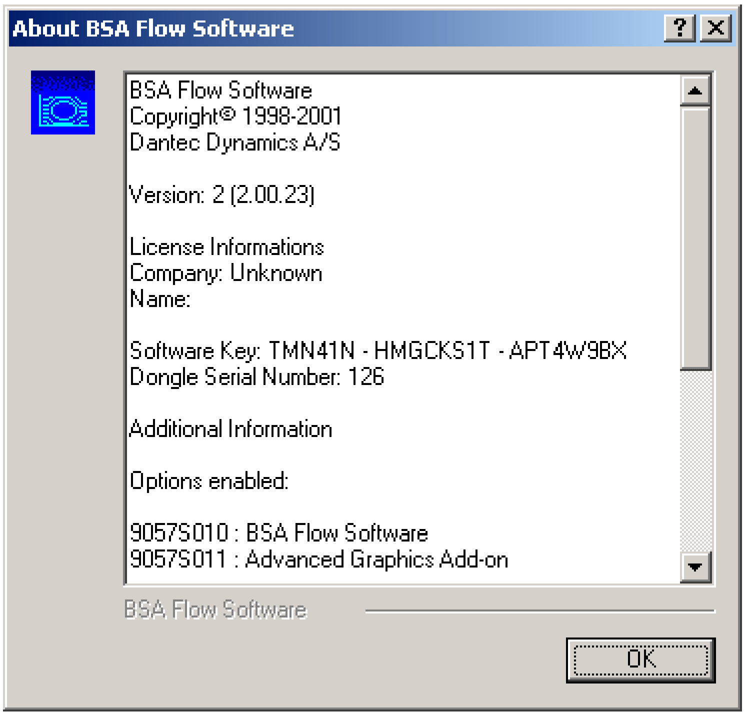
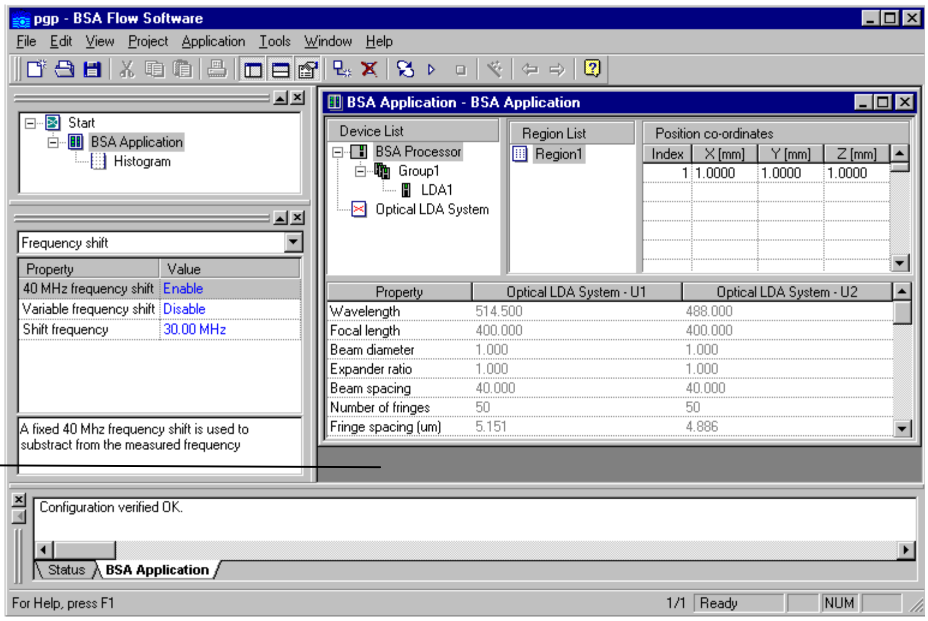


Figure 4-34 The About dialog

4.5 Workspace

Workspace



The workspace is the “output window” of the software, where data is presented in the form of lists or graphs. It is also where the BSA Application are displayed.

The workspace is similar to the desktop of Windows:

- it can hold multiple windows,
- a windows is selected by clicking on it
- a window can be maximised, minimised and closed by clicking buttons in the upper right corner of it

A window can be activated

- by clicking on it, or
- by clicking on the corresponding object in the project explorer

4.6 Message window

The Message window constitutes an output window to the user. The message window can have many sections whereas the most common sections are as in Figure 4-35:

- Status
- Acquisition

Figure 4-35 Message window showing context menu and the two standard sections: Status and Acquisition.

The section acts as an information output to the user, where the user can keep track of the progress during acquisition and/or state of the program.

You can at any time clear a section for information from the message window context menu. Some information has additional help attached which can be opened by double clicking on the message or by selecting “Go to Help” from the context menu.

4.7 Set-up and data acquisition, 62N series BSA based LDA and PDA systems

4.7.1 Cable connections

The BSA power requirement is 100-240 VAC, 3.5-1.5 A, 50-60 Hz.

Warning	*Make sure that the BSA and the PC are properly connected to ground. Switch off the processor before connecting cables to it. Do not hold the photo-multipliers by hand when the high voltage is switched on.*

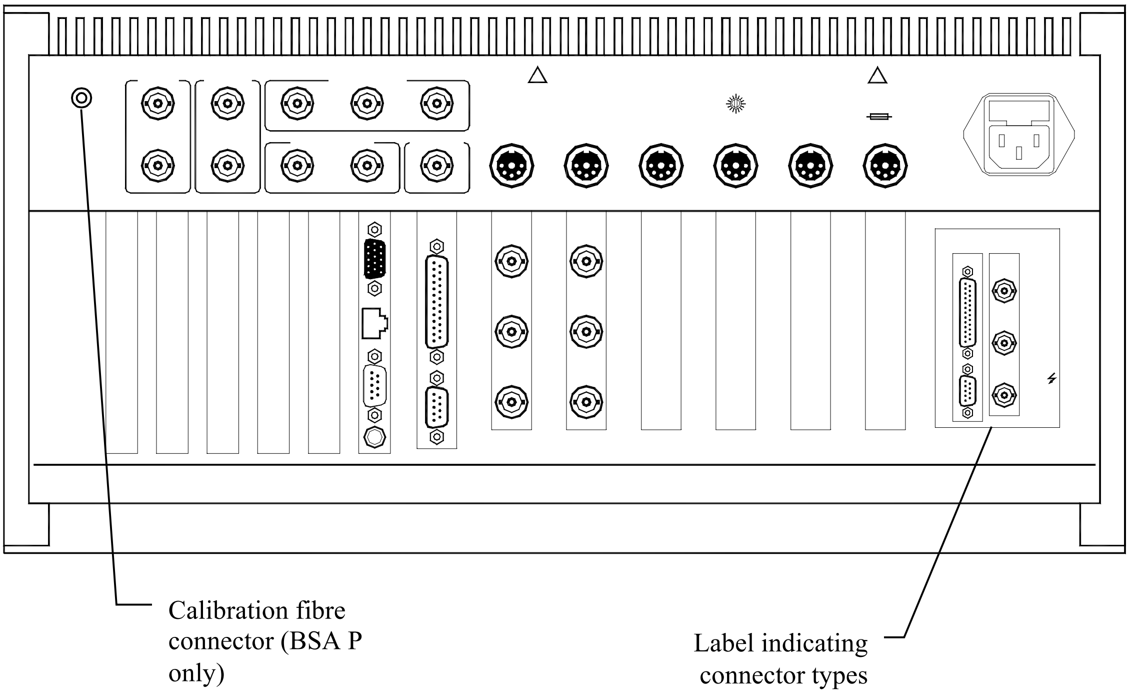


Figure 4-36 The rear panel of a BSA F processor, 2 channels configuration

4.7.1.1 PM and Bragg cell connections

Warning	*Switch off the processor before connecting cables to it.* *Do not hold the photo-multipliers by hand when the high voltage is switched on.*

The number of channel and the way to connect depend on the system configuration. The following table gives the different configurations:

Configuration	1 PM aux.	2 PM aux.	3 PM aux.	4 PM aux.	5 PM aux.
LDA 1D	U1				
LDA 2D	U1	U2			
LDA 3D	U1	U2	U3		
PDA fiber 1D	U1	U2	U3		
PDA fiber 2D	U1	U2	U3	V	
PDA fiber 3D	U1	U2	U3	V	W
PDA dual 2D	U1	U2	V2	V1	
PDA dual 3D	U1	U2	V2	V1	W

- Connect the 57X08 photomultiplier to connectors High Voltage, PM Aux. and PM In. Each velocity channel has its PM Aux connector in the upper half of the rear panel, and three connectors in an input module in the lower half. A label at the right hand side of the rear panel indicates the connector names.
- Connect the Bragg cell to the connector Bragg Cell 40 MHz in the upper left. If your optical system requires a different Bragg dell drive frequency, the connector Bragg Cell Var. can be used. This output does not include DC supply to the Bragg cell amplifier, which must be supplied from elsewhere.

4.7.1.2 PC connection

- Mount the Ethernet card supplied with the BSA in a free slot in the PC, and install its driver.
- Connect the supplied point-to-point Ethernet cable between the RJ42 connector and the Ethernet network interface card in the PC.

4.7.1.3 Shutter and optical fibre connection (for PDA only)

For a BSA P processor (PDA processor):

- Connect the BNC cable between shutter connector on the detector unit and the connector Programmable output 2 on the processor.
- Connect the calibration optical fibre between the Cal. Input on the detector unit and the Calibration Fibre Connector on the processor.

Caution	*The optical fibre must not be folded or twisted. It will be damaged. .*

4.7.1.4 Synchronisation input/output connections

Use of these connections requires the Synchronisation Option for the BSA F/P50, F/P60, F/P 70 or F/P 80. TTL level or differential signals can be connected or are supplied from to these.

The user can specify which connectors are used for what from the Processor - Advanced property list under in the property editor. The different types of inputs and outputs are described in Chapter 5.

Inputs can be mapped to BNC connectors marked Programmable Inputs 1-3, or to the 25-pin D-Sub connector marked S1.

Outputs can be directed to BNC connectors marked Programmable Outputs 1 - 2 or to the 25-pin D-Sub connector marked S1.

Caution	*The BNC connector Programmable Output 2 is **not TTL level**, but includes 12 V DC. If TTL level input on auxiliary equipment is connected to this connector, it may be damaged.*

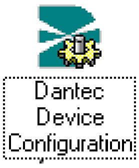
Encoder signals
Connect the once-per-revolution (or "reset pulse") signal to the connector defined as the Sync 1 or Encoder reset input under the processor properties. See chapter 5 for details about the set-up of synchronisation inputs.

If you want to use angle stamping (See the "Cyclic phenomena" section of the User's guide for details):
Connect the encoder pulse signal (N pulses per revolution) to the connector defined as the Sync 2 or Encoder input under the processor properties.

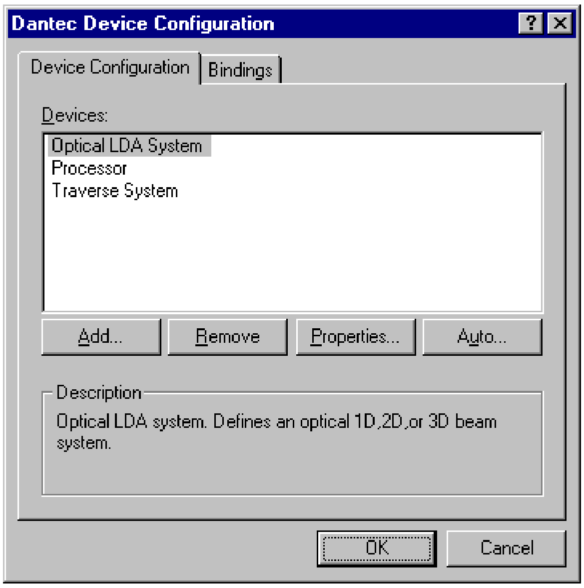
4.7.2 Configuring an LDA or PDA system procedure

After installation of the Ethernet card and the BSA Flow Software:
1. Go to "Start", "Settings", "Control Panel"
2. Open "Network Dial-up Connections"
3. Right mouse click on Local Area Connection, open "Properties"
4. Click on TCP/IP, then "Properties", click on "Use following IP address"
5. Enter: IP address 10.10.100.25 Subnet mask 255.255.0.0
6. Click "OK" and you may need to restart the computer.
7. Turn on the BSA processor and wait for the "ready" light to come on.
8. Open "Control panel" and click on the Dantec Device Configuration Icon.
9. A "wizard" may run and fail to find the BSA processor, click on OK and click on "Add", then "Processor", "OK".
10. Click on processor, then properties, set TCP/IP to 10.10.100.100
11. Click on "information", "update", processor should then be found and connected.
12. Click on "optics", set-up either LDA or PDA optical system and optical configuration can then be set.
13. BSA software can now be run.

After installation of the BSA Flow software and interfaces, a system configuration must be defined in the PC. The is done from the Windows Control Panel by double clicking on the Dantec Device Configuration icon:



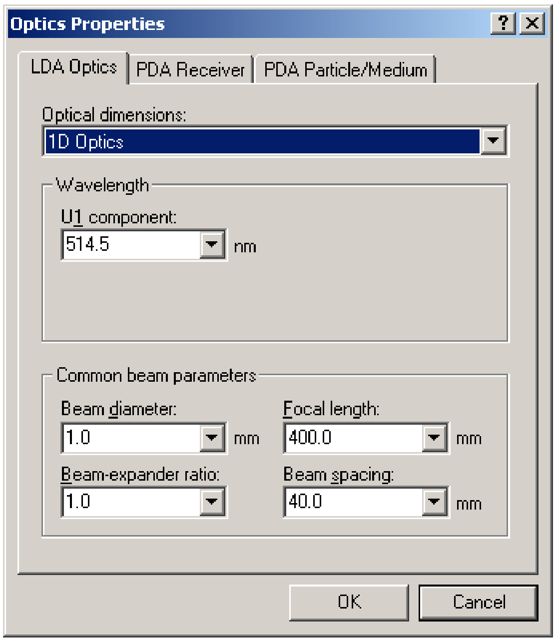
This opens the following window:



4.7.2.1 LDA and PDA transmitting optics

The minimum configuration consists of a Processor and an Optical LDA System or Optical PDA System. More devices, e.g. a traverse system, can be added using the Add button.

Click on the Optical LDA System or Optical PDA System in the Devices list, and click on Properties. This opens the following window (the PDA tabs appear only with the Particle Sizing add-on installed):

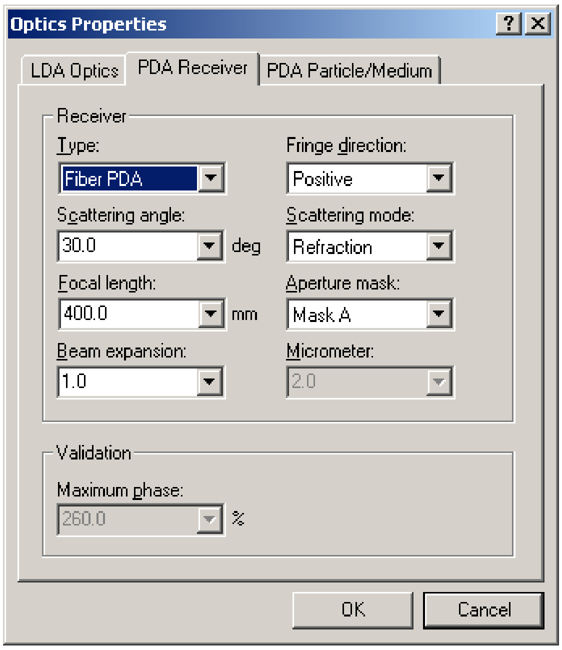


For now, select 1D Optics even if your optical system is 2D or 3D. Later on, when you are familiar with the software, you can revert to the Dantec Device Configuration utility and configure according to your equipment.

Type or select from the drop down lists the appropriate beam parameters of your system. Click OK if you are using a LDA system and skip the PDA receiving optics part or click on PDA Receiver if you have a PDA system.

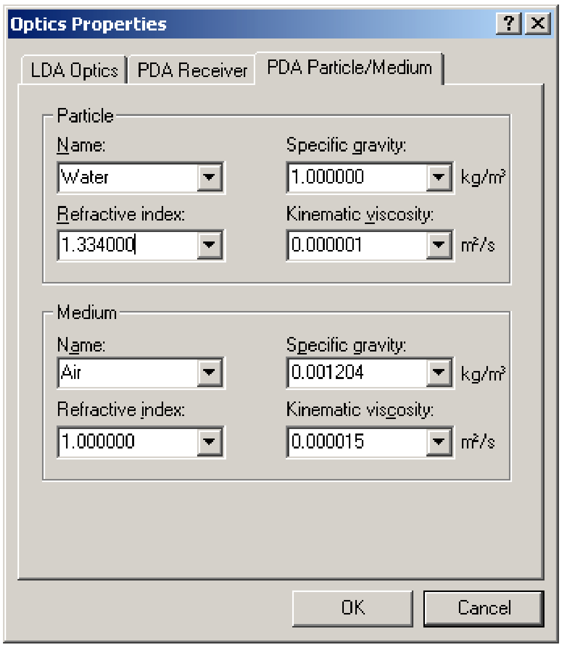
4.7.2.2 PDA receiving optics

For the PDA, select the PDA Receiver from the Optics properties. This opens the following window:



Select the receiver type and type or select the appropriate parameter values. Further details are given in chapter 5.7.

Click on PDA Particle/Medium from the Optics properties and type or select the parameters of the following window. The default setting is water droplets in air.

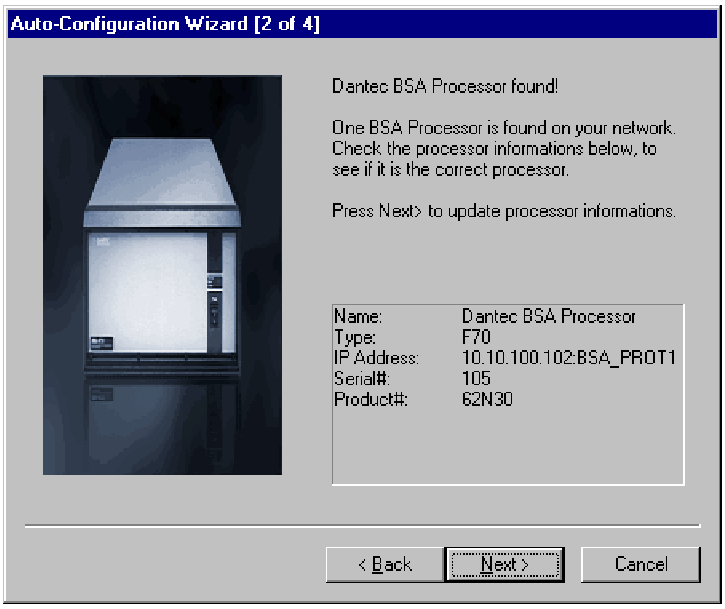


Click on OK.

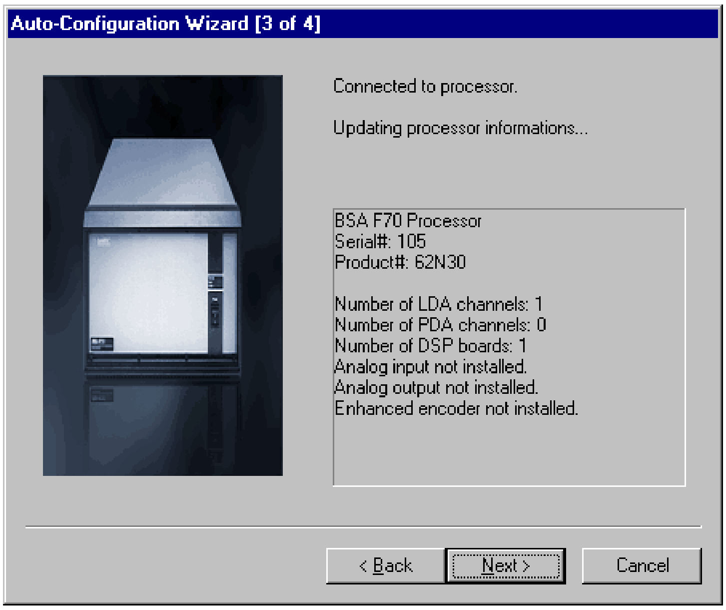
4.7.2.3 BSA

Now select Processor, and click the Auto button. This starts the Auto-configuration wizard, which guides you through the procedure for establishing a connection between the BSA and the PC.

In the second step of the wizard, you should obtain a window similar to this:

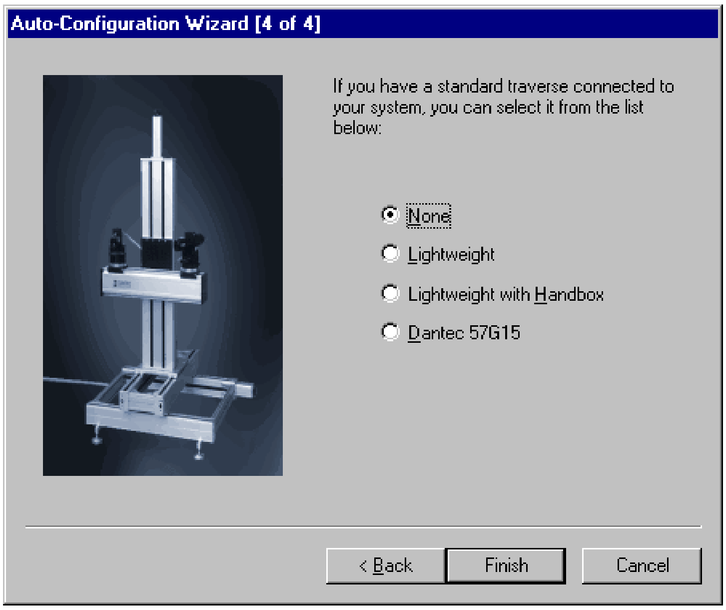


In the third step, the software connects to the processor to detect the number of channels and installed options, e.g. like this:



4.7.2.4 Lightweight Traverse

In the final step, you can define the traverse system to be used:



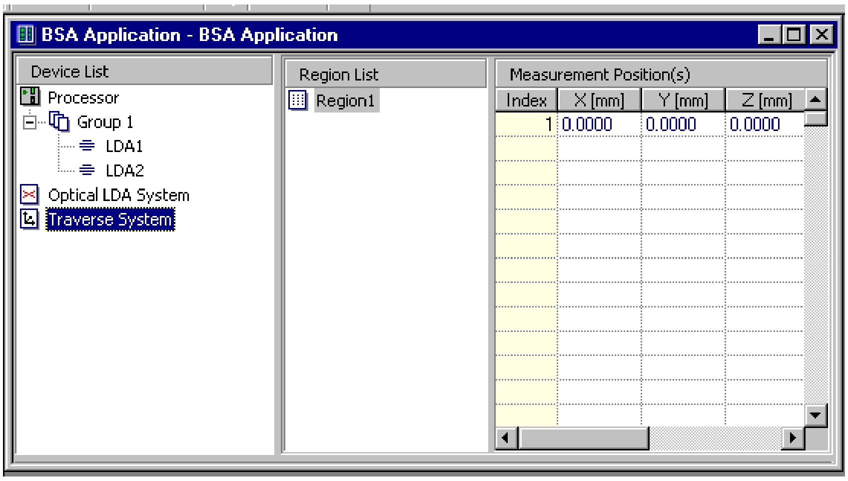
Click Lightweight, and click finish to complete the wizard.

Note	*Another way to find a processor connected to the application computer, is to use the Find (Search in Windows 2000) Dantec Dynamics Processor(s) placed in the windows Start/Find menu. This dialog will list information for the found processor(s), including name, type and IP address. After the IP address is found, it can be set in the Device Configuration for the processor.*

Start BSA Flow Software.

Open a new project.

Insert a BSA Application after the start icon.

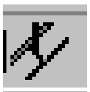


Click on the Traverse system icon.

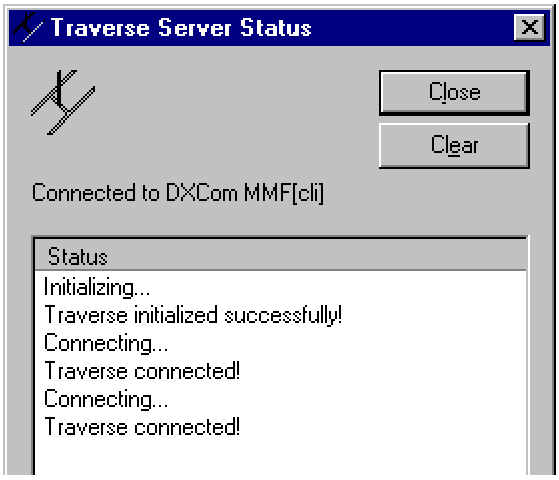
Right-click on the Traverse System icon and select Connect to traverse.

In the property editor, select the correct COM port, usually COM1 or COM2.

Check that connection is established by right-clicking on the traverse server icon in the lower left corner:

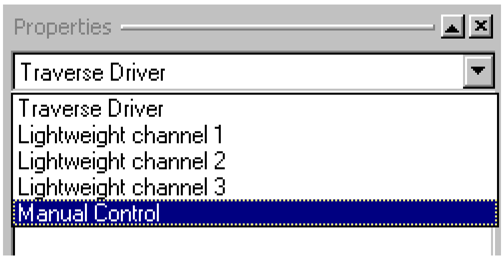


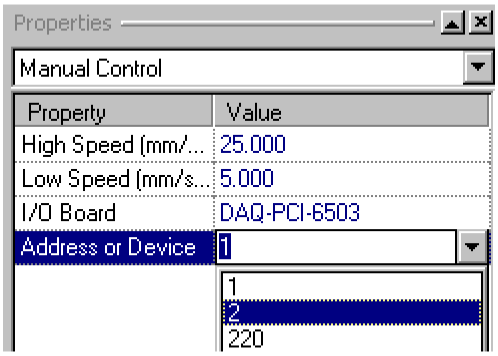
If connection succeeded you will get a message similar to this:

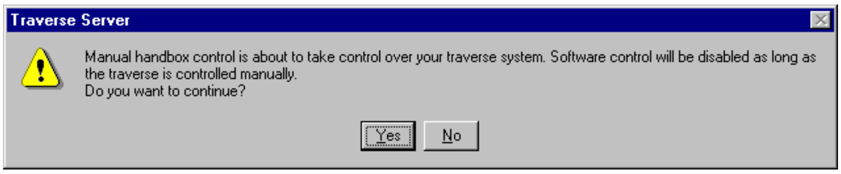


4.7.2.5 Lightweight Traverse with handbox

- Follow instructions in section 4.7.2.4, and select Lightweight with Handbox instead of Lightweight
- Continue through the procedure in section 4.7.2.4.
- In the Traverse properties, select the Manual Control

- 

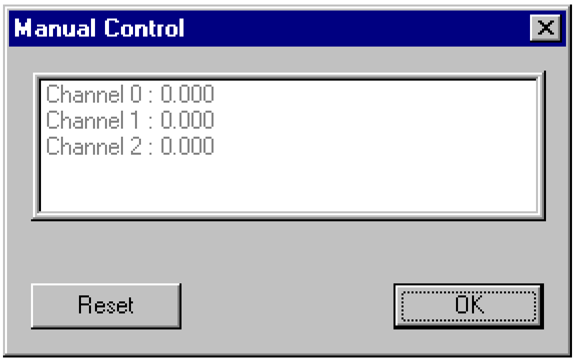
- In the properties of the Manual Control, select the correct I/O Board (DAQ-PCI-6503) and Address or Device, in our example it is 2.
- 

- Check that the traverse server is connected correctly, as described in section 4.7.2.4. You are now ready to test the manual control unit.
- Right-click on the traverse server, select Manual Control. This gives you the following message:
- 

- *NB: if the device address is incorrect , you will get the following message instead:*
- 

- *Click OK, and you get another message:*
- 

- *Click OK again and go back to the manual control properties to select the correct Device or Address.*
- Right-click the Traverse server again, select Manual control, click on Yes, and you will get the Traverse Server message shown above.
- Click on Yes, and the following appears:

* 

You can now move the traverse using the manual control. The position is updated after the movement. Clicking on the Reset will set the current position to 0.000 on all axes.

4.7.2.6 57G15 Traverse interface

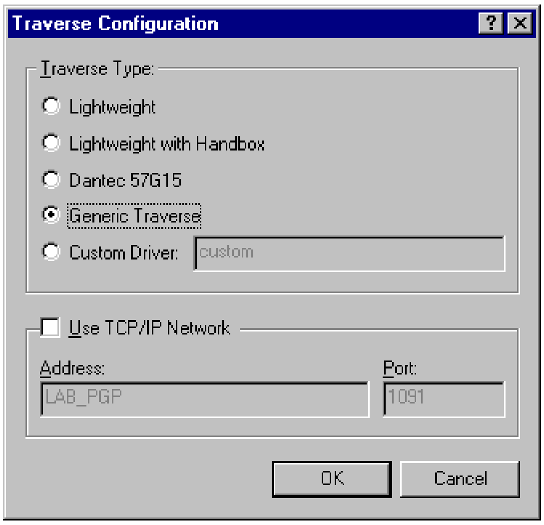
In Auto-Configuration Wizard (4 of 4), see section 4.7.2.4, select Dantec 57G15 and click Finish.

4.7.2.7 Third party traverse system

The Advanced Traverse Add-on is required for this.

Open the Dantec Device Configuration from the Windows Control Panel.

Click on traverse – properties



select Generic Traverse.

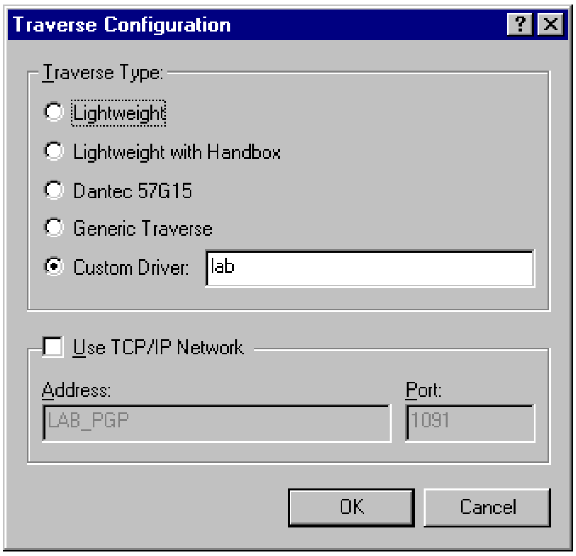
For further details on using the Advanced Traverse Add-on, please consult chapter 6.

4.7.2.8 Changing the default properties of the traverse

If you need to modify some of the traverse properties, e.g. calibration factor, sign, COM port or other, you can save the configuration and make it the default configuration.

The procedure is:

- make the required changes to the traverse properties,
- right-click the Traverse Server

- select Save and specify a name for the traverse, for example lab. It will be saved with the name lab.cfg.
- Close BSA Flow Software
- Open Dantec Device Configuration from the Control Panel
- Click on Traverse – click on Properties
- Select Custom Driver and write lab in the box:
- 

- Next time you define a project in BSA Flow Software, the traverse properties will be those defined in the lab.cfg file.

4.7.3 Data acquisition, LDA, step-by-step procedure

The description below is for a 1 channel LDA system.

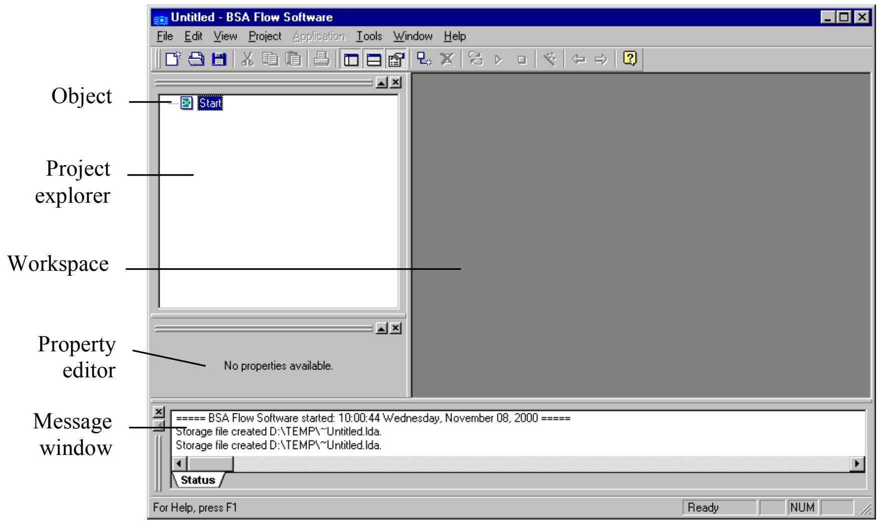
Assumptions:

- optics and the traverse system have been configured
- 40 MHz Bragg cell is used
- all cable connections have been made
- the BSA Flow Software has found the BSA
- the measurement volume is located at a point in the flow
- the laser is running
- particles are present in the flow

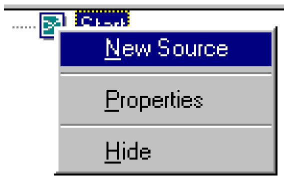
1. Double click the BSA Flow icon on the desktop.

2. Click New project in the dialog box that appears

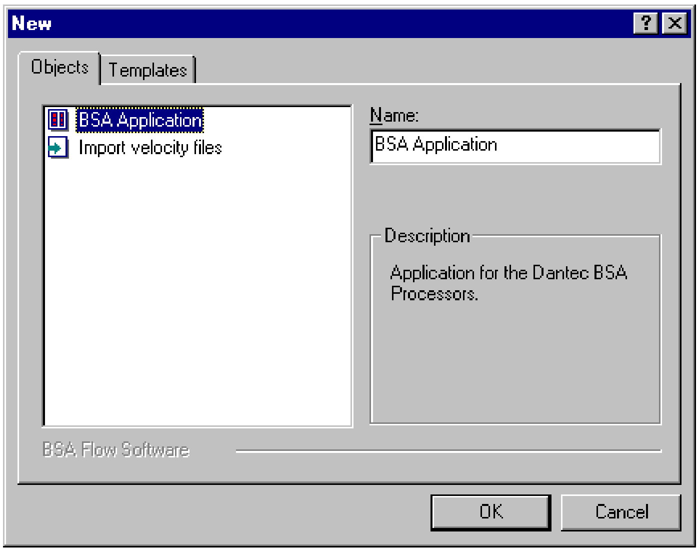
3. In the New window that appears, select Blank Project, and click the OK button. This opens a window like this:



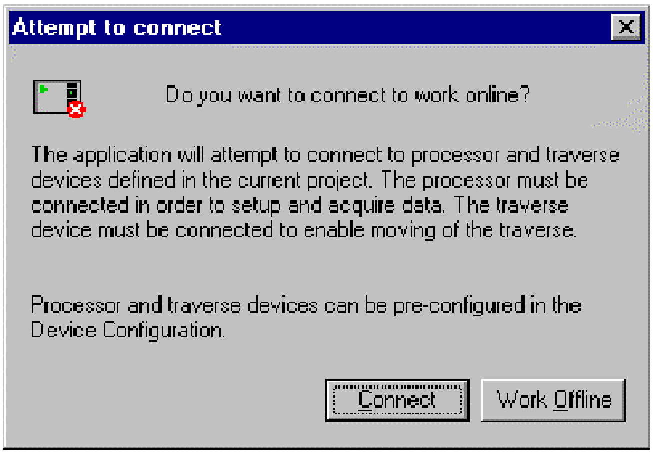
4. In the Project Explorer pane at the top left, right-click on the Start icon, and the following appears:



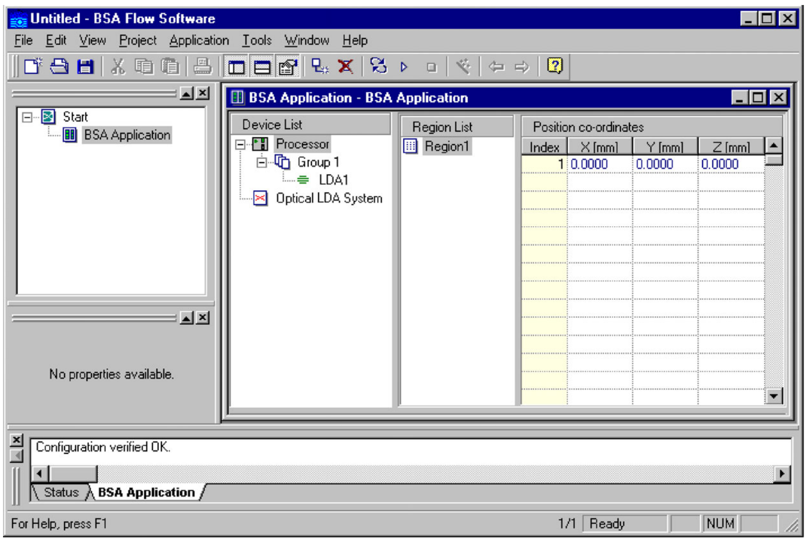
5. Click New Source, and the following appears:



6. Select the BSA Application and click OK. This brings up the following dialog:

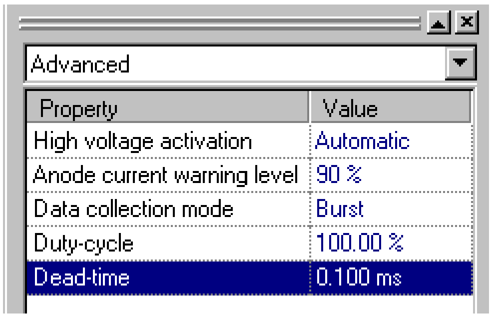


7. Click Connect. The software now connects to the BSA, and an icon named BSA Application appears in the Project Explorer. In the Workspace a window with the same name appears.



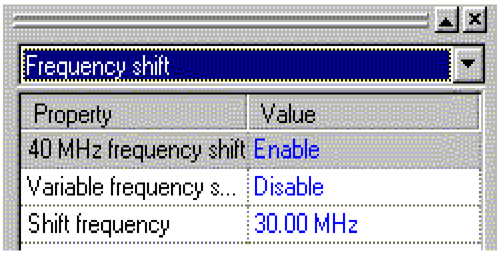
8. In the BSA Application window, a tree structure including icons Processor, Group 1, LDA 1 and Optical LDA System appear.
Clicking on one of the icons will display its properties in the Property editor pane..
If your processor has more than one velocity channel, the Device List will display all channels (LDA1, LDA2, LDA3).
For this exercise, delete the extra channels by right-clicking on them and selecting Delete in the dialog that appears.

9. Processor properties are common for all velocity channels in the processor. In the property editor, select the Advanced list. Keep the default settings as shown below.



To change a setting, click in the Value field for the property and select the proper value from the pop up list, or type it in.

10. In a similar manner, check in the Frequency Shift list that you have the following settings:



11. Group 1 properties are used to set up acquisition stop criteria (no. of samples and acquisition time) and for systems with more than one velocity channel, coincidence filtering parameters and properties common for all coincident velocity channels.
Establish the following (default) settings:

Coincidence group

Property	Value
Max. samples	2000
Max. acquisition time	10.00 s
Filter method	Overlapped
Burst window	0.010 ms
Scope zoom	400 %
Invalid data	Excluded
Encoder data	Excluded
High voltage	Off

Stop criteria for data acquisition of this group

When there is only one velocity channel in the group, the Filter method and Burst window properties are not used.

12. LDA 1 properties are specific to velocity channel 1.
Select the Advanced list. For standard Dantec optical systems, the properties should be the following (default):

Advanced

Property	Value
Anode current limit	1500 µA
Frequency shift	Fixed
Frequency shift direction	Up
External shift frequency	30000.00 kHz

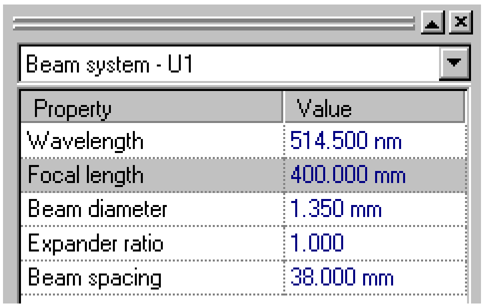
13. Select the Range and gain list.

Range and gain

Property	Value
Center frequency	0.000 m/s
Bandwidth	37.656 m/s
Record length mode	Fixed
Record length	128
Maximum record length	128
High voltage level	1000 V
Signal gain	26 dB
Burst detector SNR level	0 dB
Level validation ratio	4

Set Center frequency and Bandwidth to values corresponding to the velocity range in the flow. Keep the default values of the other properties in the list.

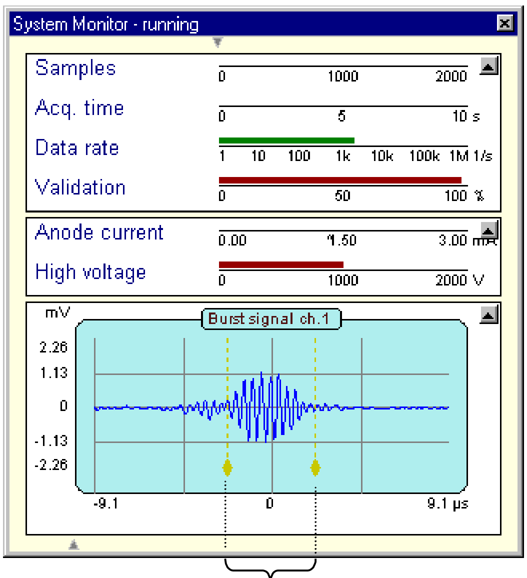
14. Optical LDA System properties include the number of velocity components, wavelength and other optical parameters.



The optical parameters that you defined in the Dantec System Configuration will appear in the list. If necessary, you can modify them.

Note	*The software computes the effective beam spacing at the front lens as* Beam Spacing *multiplied by* Expander Ratio*.* *To get correct optical parameters, set the expander ratio to 1, and the beam spacing to the one at the front lens.* *In the* Beam diameter *field, enter the beam diameter at the front lens, i.e. the beam diameter before beam expander(s) multiplied with the total beam expansion.*

15. To monitor the Doppler signals, right click on Processor, Group 1 or LDA 1 in the BSA Application window, and select System Monitor from the list. An "always on top" window appears. After a short delay, an oscilloscope-like display will appear in this window. This shows a number of samples of the filtered Doppler bursts.
In addition to the oscilloscope display it includes panes showing acquisition parameters and the photo-multiplier anode current. The three panes can be collapsed individually by clicking on the button in their upper right corner.



Record interval

The two yellow vertical dotted lines in the Burst signal display indicate the record length that is passed to the FFT processor to determine the Doppler frequency.

Recognising a good Doppler burst requires some experience. The validation rate a good indicator. You can see the validation rate in the System monitor window.

Optimise data rate and validation by adjusting the high voltage, gain settings and record length settings under the Range and gain properties. The record interval should be shorter than or equal to the length of the displayed bursts, as in the shown example.

Avoid overloading the photomultipliers. With 57X08 type photomulitpliers, the processor's built-in protection circuit will reduce the PM high voltage in case of excessive PM anode current, but it is recommended to avoid overload situations.
In case of measurements between the blades of an impeller the PM current will be high when an impeller blade passes through the measurement volume, and this will overload the PM current for a short period, which is acceptable. However, if possible, it is recommended to establish a laser shutter system which blocks the laser beams during passages of solid surfaces through the measurement volume

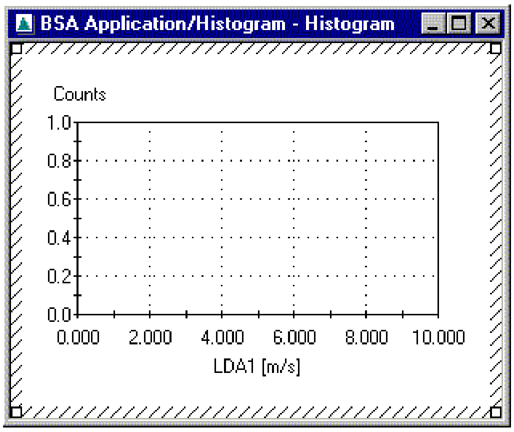
The burst signal can be triggered by the channel that is displayed, by another velocity channel, or it can be free running. The trigger channel can be controlled from the Range and gain list under the LDA 1 properties.

The scaling of the X axis depends on the Scope zoom property belonging to the Group 1, and on the Record length property in the Range and gain list belonging to LDA1.
If Scope zoom is set to 400 %, and Record length is set to 32, a total of 128 samples are displayed (400 % of 32 samples). The maximum is 1024 samples, so if record length is set to 1024, Scope Zoom values greater than 100% will not add additional samples to the display.

16. The System monitor window requires some of the PC's resources.

It is recommended to close the Doppler monitor pane if you are running experiments with high data rates.

17. Before taking data, a result display should be defined. To display a velocity distribution histogram, right-click on the BSA Application icon in the project explorer and select New. Select Histogram from the dialog. A new window appears in the workspace.



The axes will automatically rescale when you start acquiring data.

18. To start acquisition, click on BSA Application in the project explorer, and click on the Run button  in the tool bar (or press the F5 button on the keyboard).

19. The histogram will be updated during the measurement. With 2000 samples selected, all data is usually sent in a single block, so the histogram updates once only. The update rate depends on the data rate. With high data rates and a large number of samples, you will see several updates during an acquisition.

20. When the acquisition is completed, the "Run" button is clear again. If the System monitor is open, either the Samples or Acquisition bar graph is at full scale.
Under the menu "Tools - Options - General" you can select "Feedback with sound". With this option active, you will hear a beep from the PC when acquisition is completed.

21. You have now completed data acquisition in a single point. To save the data, click the Save button in the toolbar (or select File-Save in the menu bar), and give the project file a name. It will be stored in the Projects folder.

22. You can add further processing objects, data lists or graphs by right mouse clicking on the BSA Application icon in the project explorer and selecting "new" from the dialog that appears.

23. To save time when new objects have been added, you can run those objects alone by clicking on the highest level object you want to run, and then click the "Run" button or press F5 on the keyboard. This will run the object and it's child objects.

4.7.4 Data acquisition, PDA, step-by-step procedure

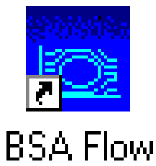
The description below is for a 1D channel PDA system.

Assumptions:

- optics and the traverse system have been configured
- 40 MHz Bragg cell is used

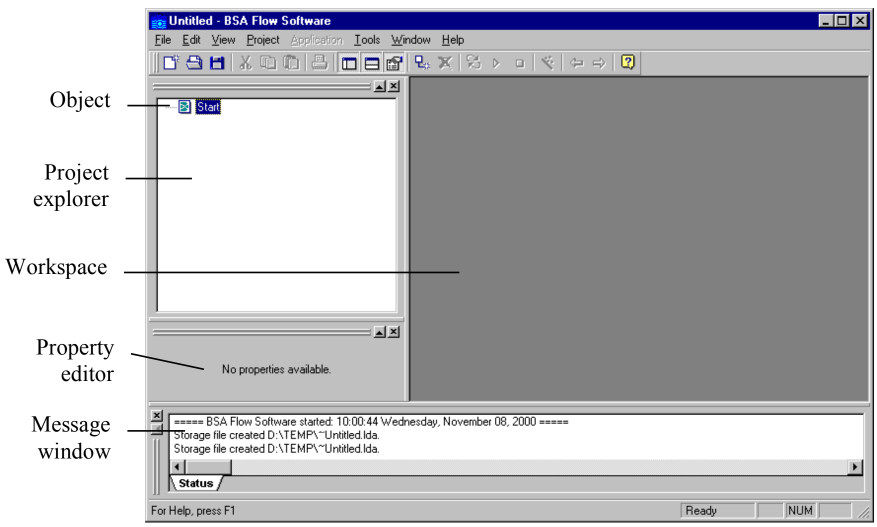
- all cable connections have been made
- the BSA Flow Software has found the BSA
- the measurement volume is located at a point in the flow
- the laser is running
- particles are present in the flow
- the transmitting optics and receiving optics are precisely aligned

1. Double click the BSA Flow icon on the desktop

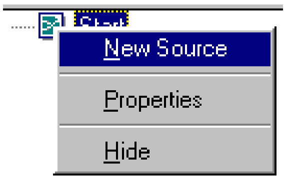


2. Click New project in the dialog box that appears

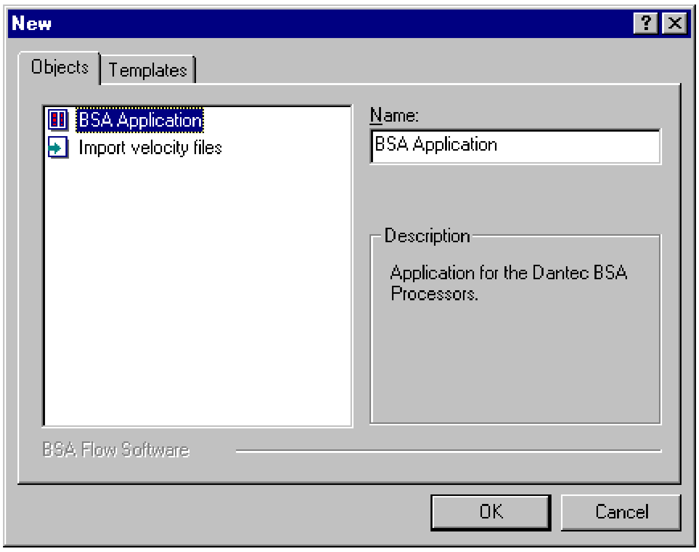
3. In the New window that appears, select Blank Project, and click the OK button. This opens a window like this:



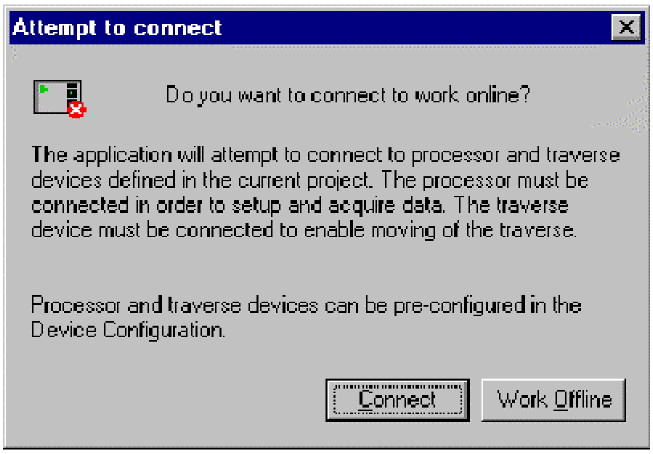
4. In the Project Explorer pane at the top left, right-click on the Start icon, and the following appears:



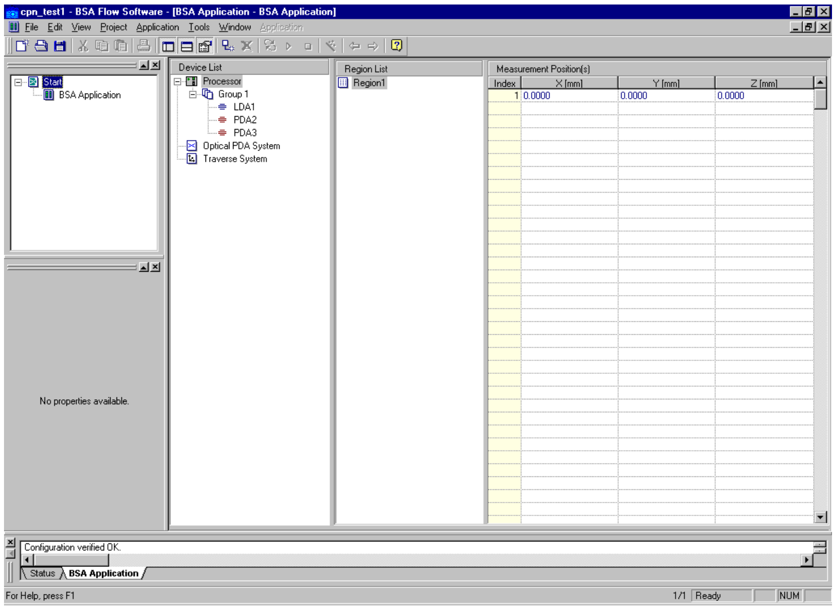
5. Click New Source, and the following appears:



6. Select the BSA Application and click OK. This brings up the following dialog:

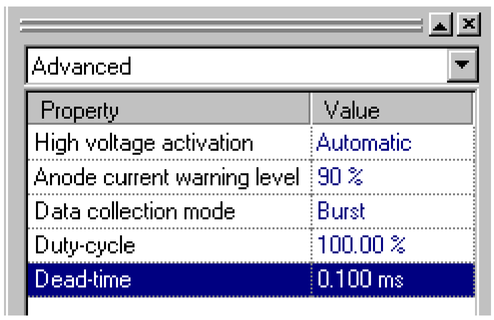


7. Click Connect. The software now connects to the BSA, and an icon named BSA Application appears in the Project Explorer. In the Workspace a window with the same name appears.



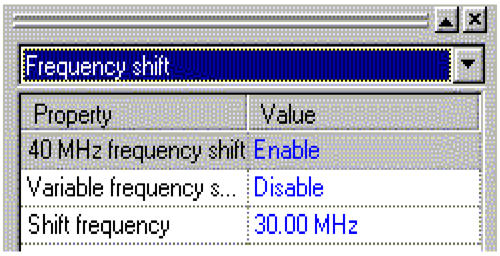
In the BSA Application window, a tree structure including icons Processor, Group 1, LDA 1, PDA 2, PDA 3 and Optical PDA System appear. Clicking on one of the icons will display its properties in the Property editor pane.

8. Processor properties are common for all velocity and size channels in the processor. In the property editor, select the Advanced list. Keep the default settings as shown below.

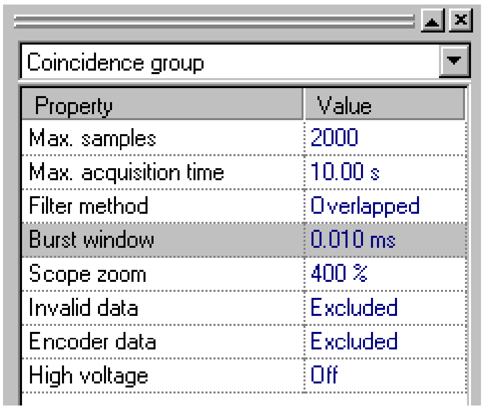


To change a setting, click in the Value field for the property and select the proper value from the pop up list, or type it in.

9. In a similar manner, check in the Frequency Shift list that you have the following settings:



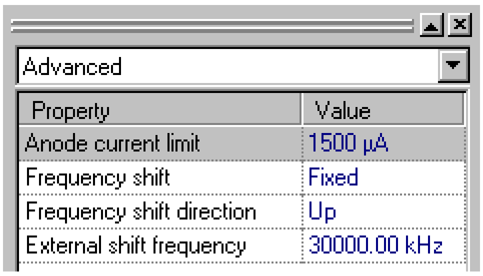
10. Group 1 properties are used to set up acquisition stop criteria (no. of samples and acquisition time) and for systems with more than one velocity channel, coincidence filtering parameters and properties common for all coincident velocity channels.
Establish the following (default) settings:



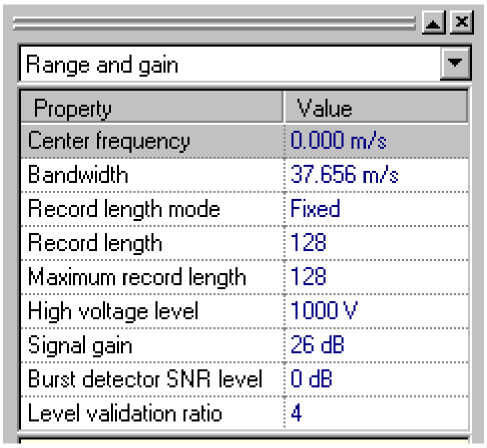
Stop criteria for data acquisition of this group

When there is only one velocity channel in the group, the Filter method and Burst window properties are not used.

11. LDA 1 properties are specific to velocity channel 1.
Select the Advanced list. For standard Dantec optical systems, the properties should be the following (default):

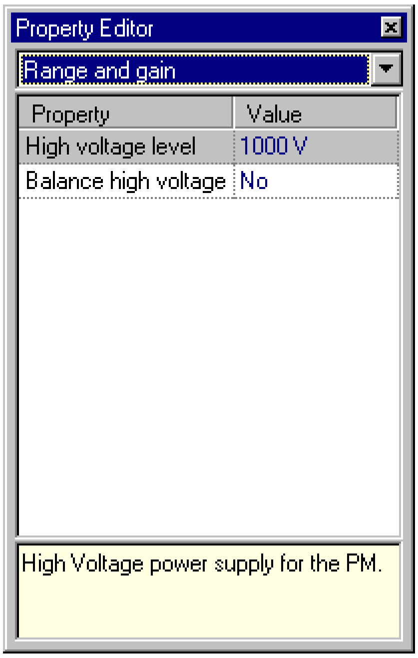


12. Select the Range and gain list.

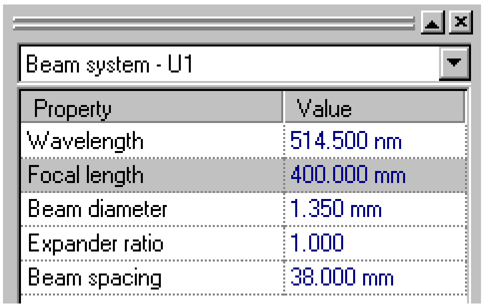


Set Center frequency and Bandwidth to values corresponding to the velocity range in the flow. Keep the default values of the other properties in the list.

13. PDA 2 and PDA 3 properties are specific to size measurement: channel 2 and 3 for a 1D PDA.
Select the Range and gain. The default values should be the following:



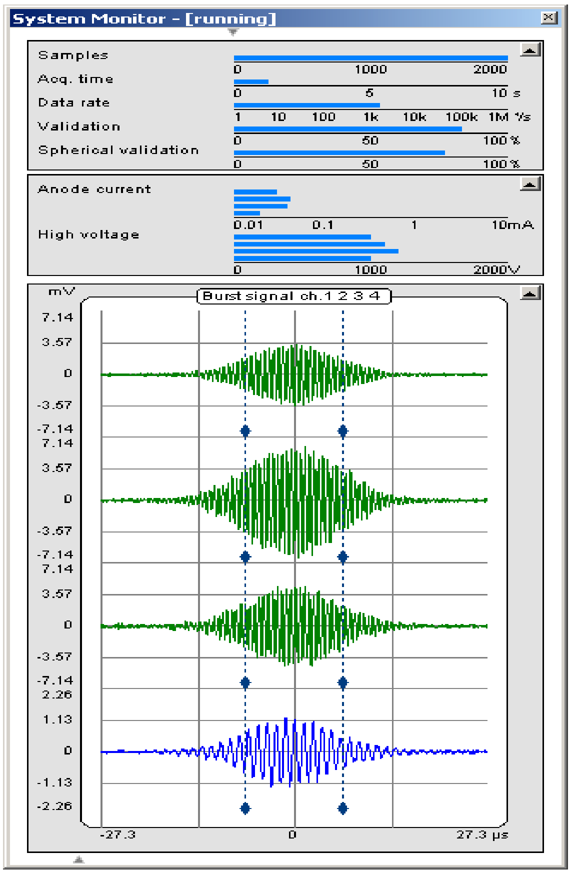
15. Optical PDA properties include Beam system 1, particle properties and medium properties.



The optical parameters that you defined in the Dantec System Configuration will appear in the list. If necessary, you can modify them.

Note	*The software computes the effective beam spacing at the front lens as* Beam Spacing *multiplied by* Expander Ratio. *To get correct optical parameters, set the expander ratio to 1, and the beam spacing to the one at the front lens. In the* Beam diameter *field, enter the beam diameter at the front lens, i.e. the beam diameter before beam expander(s) multiplied with the total beam expansion.*

24. To monitor the Doppler signals, right click on Processor, Group 1, LDA 1 PDA 2 or PDA 3 in the BSA Application window, and select System Monitor from the list. An "always on top" window appears. After a short delay, an oscilloscope-like display will appear in this window. This shows a number of samples of the filtered Doppler bursts. The number of channels depends on the optical configuration (1,2,3D LDA or PDA)
In addition to the oscilloscope display it includes panes showing acquisition parameters and the photo-multiplier anode current. The three panes can be collapsed individually by clicking on the button in their upper right corner.



The two yellow vertical dotted lines in the Burst signal display indicate the record length that is passed to the FFT processor to determine the Doppler frequency.

Recognising a good Doppler burst requires some experience. The validation rate a good indicator. You can see the validation rate in the System monitor window.

Optimise data rate and validation by adjusting the high voltage, gain settings and record length settings under the Range and gain properties or the Quick calibration. The record interval should be shorter than or equal to the length of the displayed bursts, as in the shown example.

Avoid overloading the photomultipliers. With 57X08 type photomulitpliers, the processor's built-in protection circuit will reduce the PM high voltage in case of excessive PM anode current, but it is recommended to avoid overload situations.
In case of measurements between the blades of an impeller the PM current will be high when an impeller blade passes through the measurement volume, and this will overload the PM current for a short period, which is acceptable. However, if possible, it is recommended to establish a laser shutter system which blocks the laser beams during passages of solid surfaces through the measurement volume

The burst signal can be triggered by the channel that is displayed, by another velocity channel, or it can be free running. The trigger channel can be controlled from the Range and gain list under the LDA 1 properties.

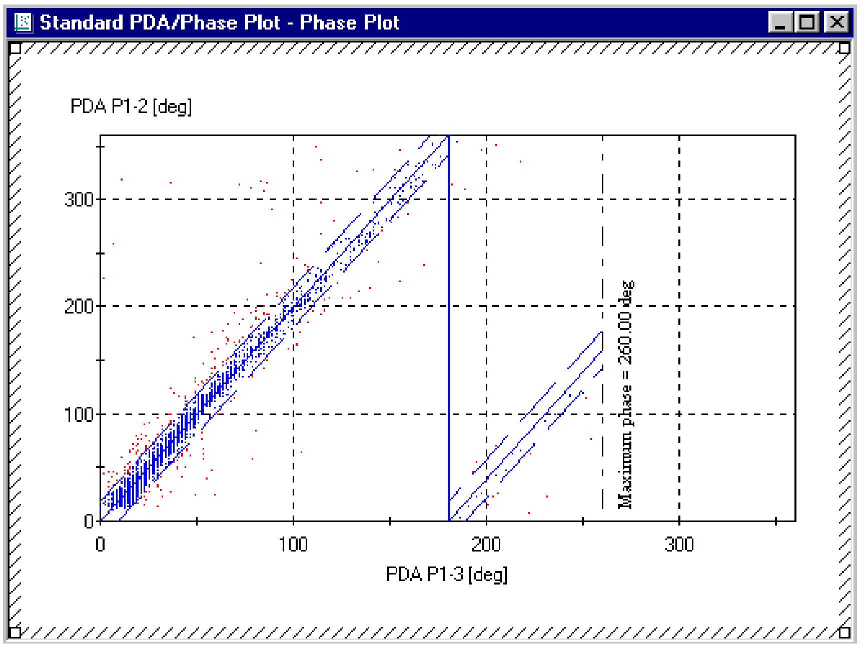
The scaling of the X axis depends on the Scope zoom property belonging to the Group 1, and on the Record length property in the Range and gain

list belonging to LDA1.
If Scope zoom is set to 400 %, and Record length is set to 32, a total of 128 samples are displayed (400 % of 32 samples). The maximum is 1024 samples, so if record length is set to 1024, Scope Zoom values greater than 100% will not add additional samples to the display.

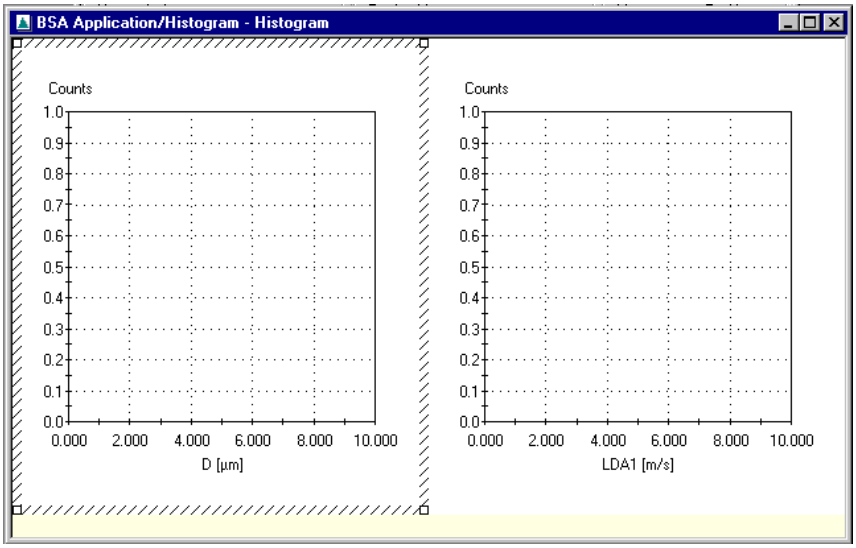
The System monitor window requires some of the PC's resources.

It is recommended to close the Doppler monitor pane if you are running experiments with high data rates.

25. Before taking data, you should open the phase plot graph to check the alignment of the receiving optics with the transmitting optics Right-click on BSA application in the project explorer, click on New and select phase plot. During a measurement, the following graph appears:



26. To display a velocity and a diameter distribution histograms, right-click on the BSA Application icon in the project explorer and select New. Select Histogram from the dialog. A new window appears in the workspace.



The axes will automatically rescale when you start acquiring data.

27. To start acquisition, click on BSA Application in the project explorer, and click on the Run button  in the tool bar (or press the F5 button on the keyboard).

28. The histogram will be updated during the measurement. With 2000 samples selected, all data is usually sent in a single block, so the histogram updates once only. The update rate depends on the data rate. With high data rates and a large number of samples, you will see several updates during an acquisition.

29. When the acquisition is completed, the "Run" button is clear again. If the System monitor is open, either the Samples or Acquisition bar graph is at full scale.
Under the menu "Tools - Options - General" you can select "Feedback with sound". With this option active, you will hear a beep from the PC when acquisition is completed.

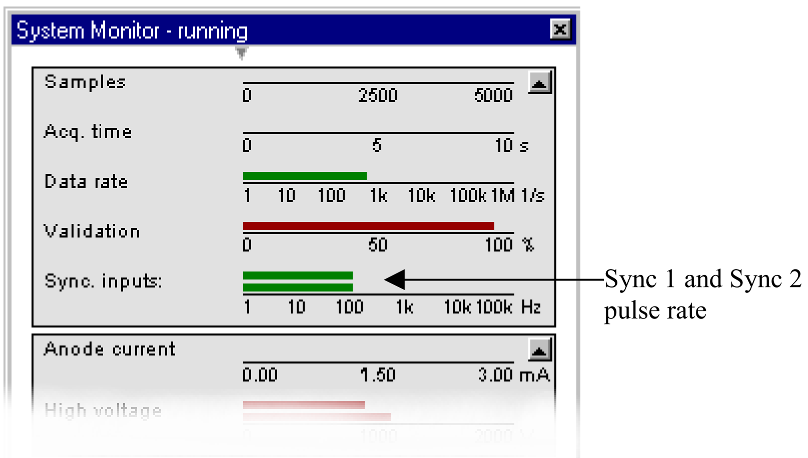
30. You have now completed data acquisition in a single point. To save the data, click the Save button in the toolbar (or select File-Save in the menu bar), and give the project file a name. It will be stored in the Projects folder.

31. You can add further processing objects, data lists or graphs by right mouse clicking on the BSA Application icon in the project explorer and selecting "new" from the dialog that appears.

32. To save time when new objects have been added, you can run those objects alone by clicking on the highest level object you want to run, and then click the "Run" button or press F5 on the keyboard. This will run the object and it's child objects.

4.7.5 Checking for encoder pulses

If an encoder is connected to the SYNC1 or SYNC2, open the System Monitor window. A bar graph will show the arrival rate of the SYNC pulses:



4.7.6 Data rate requirements

Below are some recommendations. For a detailed description, please consult the Reference guide chapter.

Mean and RMS velocity

If you are looking for average quantities such as mean and RMS velocity, the data rate is not critical, but you should aquire sufficient samples for reliable statistics. This usually means 1000 - 2000 samples per position, but depends on the flow characteristics.

To avoid statistical bias, you can use the Controlled Dead Time mode, with the Dead Time interval set to at least 2 times the integral time scale of the flow. Alternatively, you can use burst mode and select Transit Time Weighting in the Moments object.

Time series, spectrum and correlation functions

For this type of results where the dynamics of fluctuations is investigated, the data rate should obviously be high. If you expect a dominant frequency in a spectrum, the data rate should ideally be around 2 π times the frequency you are looking for since the spectrum will fall off at a frequency of mean data rate/2 π. If you cannot achieve such data rate, the optical system must be optimised in terms of laser power, receiving optics aperture, and use of forward scatter if possible. Changing from back scatter to forward scatter typically increases the data rate by at least an order of magnitude.

4.8 Set-up and data acquisition, 57N series BSA based LDA systems

4.8.1 Cable connections

4.8.1.1 PM and Bragg cell connections

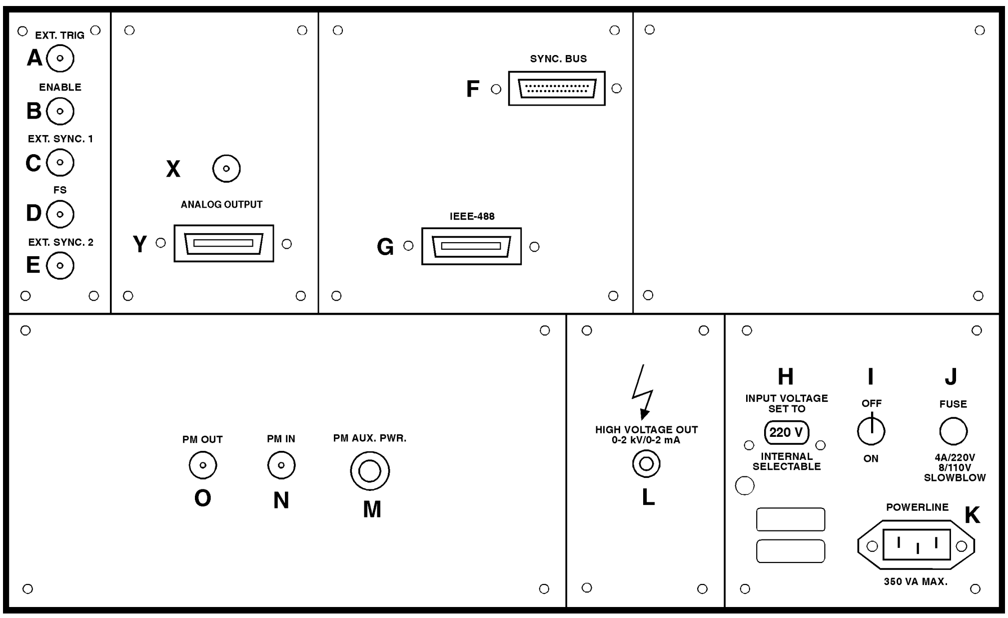


Figure 4-37 The rear panel of a 57N BSA or BSA enhanced

- Connect the 57X08 photomultiplier to connectors L (High voltage out), M (PM Aux. Pwr.) and N (PM in)
- Connect the Bragg cell to the D connector (FS)

4.8.1.2 PC connection

- Connect the GPIB cable between connector G (IEEE-488) and the GPIB interface board in the PC
- If more BSAs are used, they must be connected in “Daisy-chain”, e.g. PC to BSA1, BSA1 to BSA2, etc.

4.8.1.3 Synchronisation input/output connections

BSA synchronisation

If two or three BSAs are used, and coincident data are required:

- Connect the F connectors to each other in “Daisy-chain”, using the synchronisation cable supplied with the BSA.

Encoder signals

TTL level encoder signals can be connected to the BSA.

- Connect the once-per-revolution signal to the C connector (Ext. sync 1). *If more BSAs are used, the C connectors must all be connected to this signal.*
- Connect the encoder pulse signal to the E connector (Ext. sync 2). This signal needs only to be connected to one BSA, as it is passed on to the other BSAs through the synchronisation cable mentioned above.

Gating signal

The burst detector (and hence data acquisition) can be controlled by a TTL signal connected to the B connector (Enable). When the signal is high, the burst detector is enabled.

4.8.1.4 Front panel connections

There are four connectors on the front panel. Please refer to the BSA manual for details.

It is often useful to monitor the PM signal after amplification and filtering:

- Connect an oscilloscope to the “Doppler” connector.

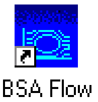
4.8.1.5 Analog input

Please refer to chapter 6.

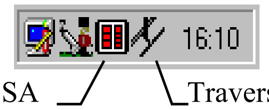
4.8.2 Configuring an LDA system

For clarity, the setup of a 1-channel LDA system without traverse is described below. Once you are familiar with this, it is simple to change the configuration to more channels and to include a traverse system. Chapter 5 gives a detailed description of the software elements.

Double click the BSA Flow icon on the desktop.



This will start server programs which take care of communication with the processor(s) and traverse system (if any). In the lower right hand corner of the desktop this is indicated by icons:



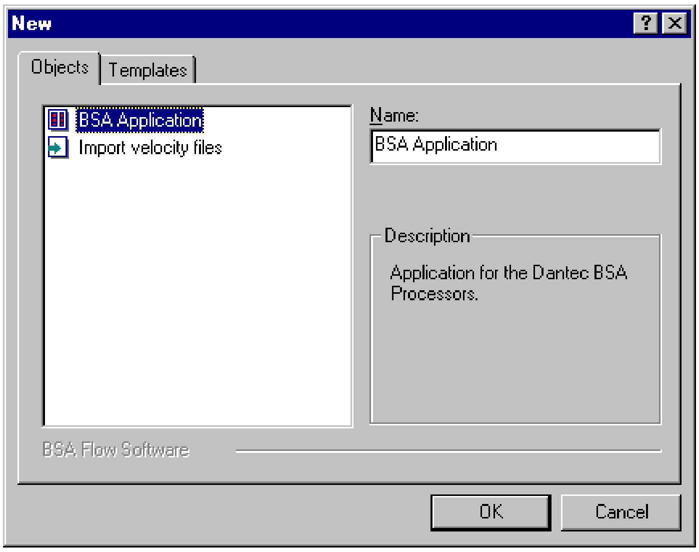
BSA server   Traverse server

Click New project in the dialog box that appears

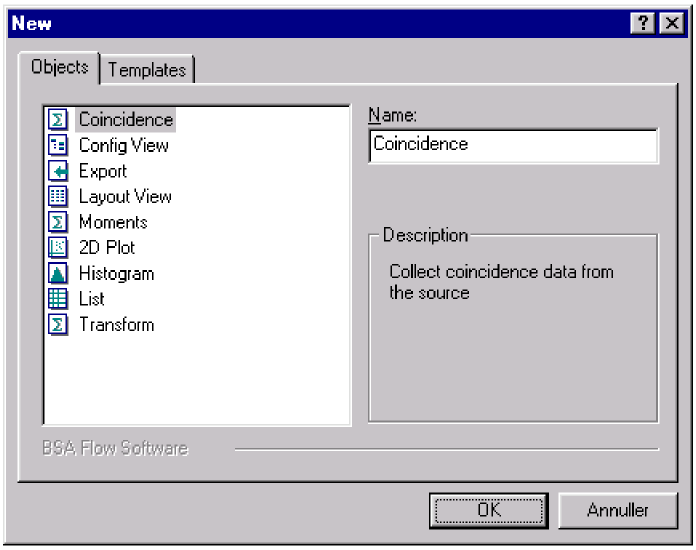
In the New window that appears, select Blank Project, and click the OK button.

In the Project Explorer pane at the top left, a Start icon appears, Click on it with the right mouse button, and the following appears:

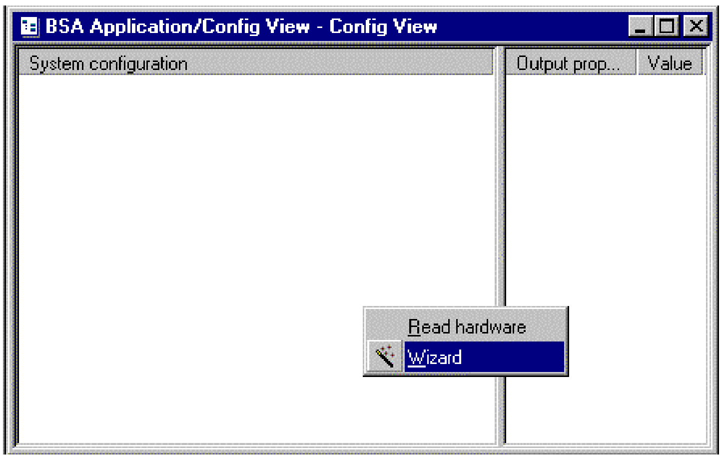
Click New Source, and the following appears:



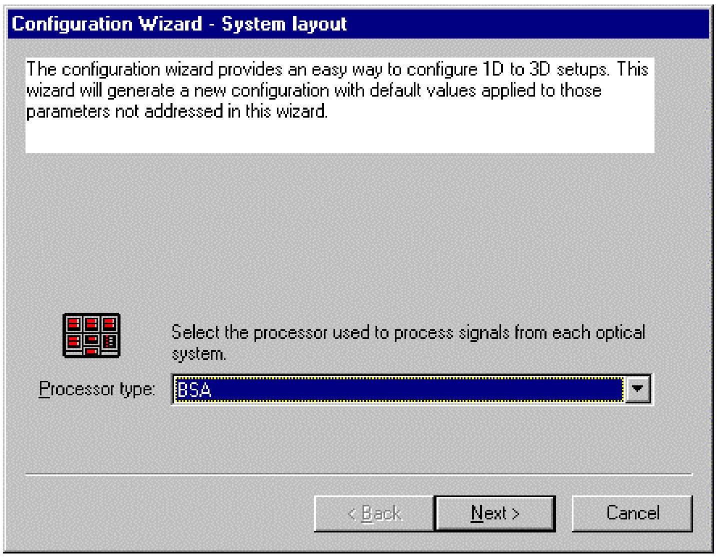
Select the BSA Application and click OK. In the Project Explorer an icon named BSA Application appears. Click on it with the right mouse button, and the following appears



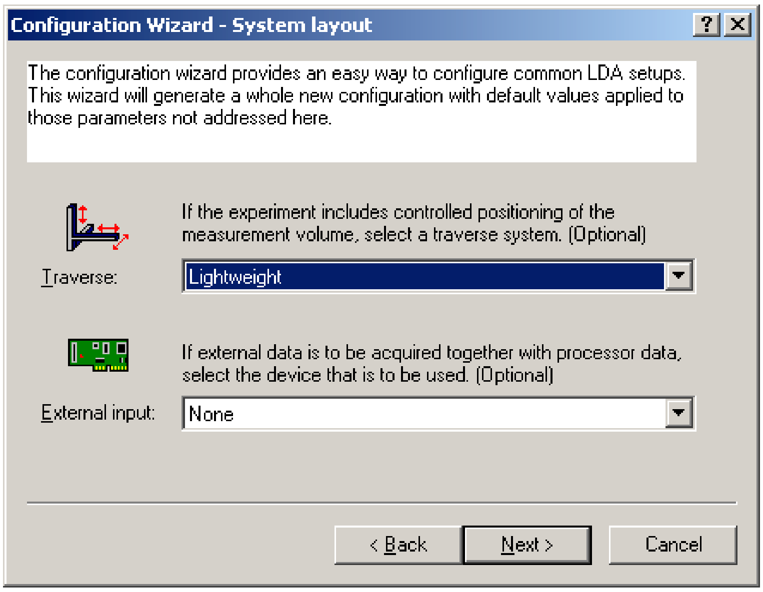
Double-click Config or click Config and then OK, and a blank window named Config view appears in the Workspace at the right hand side of the display. Right-mouse-click in the Config view window and the following appears:



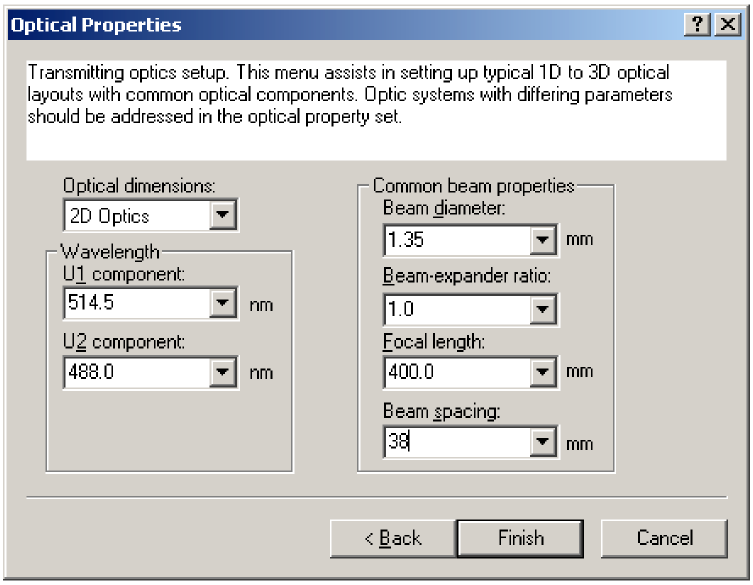
Click the wizard button to see this:



Select BSA in and click Next to see the following dialog box:

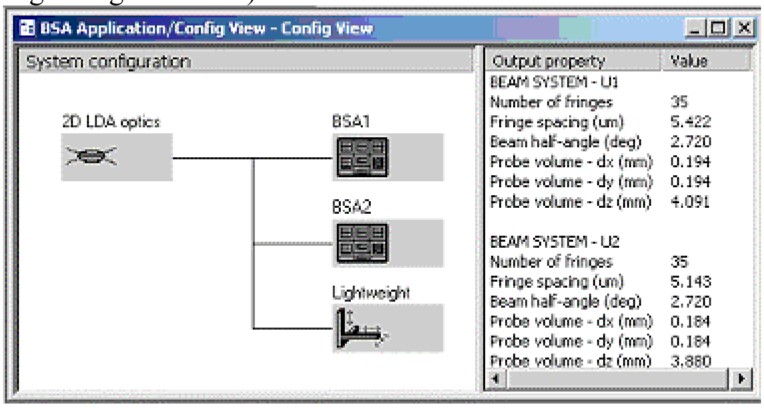


In the Traverse and External Input fields, select the appropriate items. click Next



Fill in the optical parameters of the LDA optics. Click “Finish”.

The “Config view” now looks like this (shown for 2-channel system with Lightweight traverse):

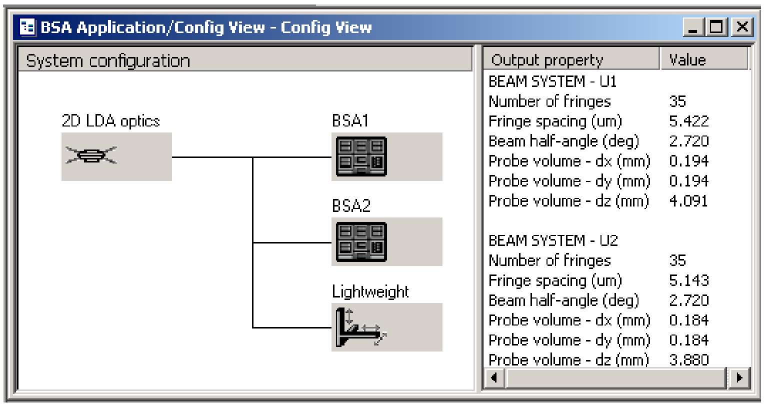


4.8.3 Data acquisition, LDA, step-by-step procedure

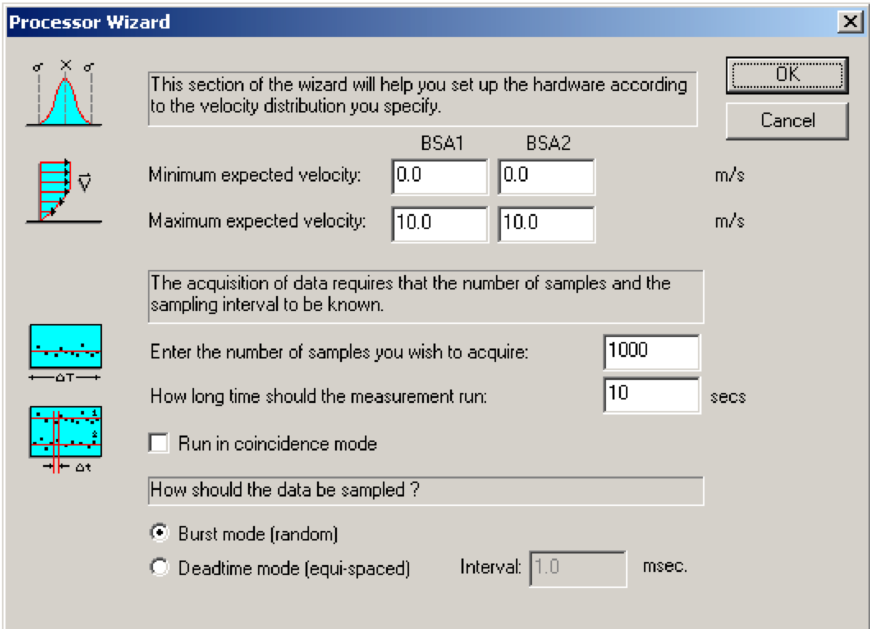
Assumptions:

- optics and the traverse system have been configured
- 40 MHz Bragg cell is used
- all cable connections have been made
- the BSA Flow Software has found the BSA
- the measurement volume is located at a point in the flow
- the laser is running
- particles are present in the flow
- the transmitting optics and receiving optics are precisely aligned

1. Configure your LDA system according to the previous section, so that you have a Config View window similar to this:

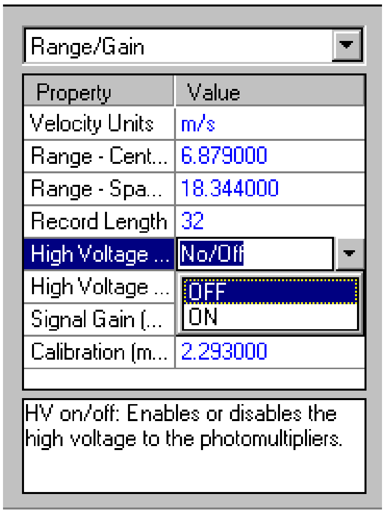


2. Click on one of the BSA icons, and click the "Wizard" button in the tool bar, or click the right mouse button on the BSA icon, and select Wizard to see this:



3. Insert the expected min. and max. velocities. This will set the BSA's Center frequency and Span values to the nearest suitable values. Fill in the two fields "Enter the number of samples you wish to acquire" and "How long time should the measurement run" e.g with the values shown above. Under the question "How should the data be sampled?", select "Burst mode (random)".

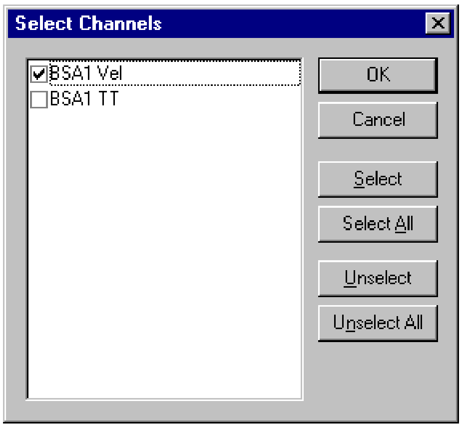
4. In the “Config view” window, click the BSA1 icon. In the property list, click the arrow down at the right hand side of the top field. Select “Range/Gain” from the drop down list.



5. In the “Value” column, set the High Voltage and Signal Gain to the values you normally use (usually around 1000V and 30 dB).
Repeat this for other BSAs if applicable.

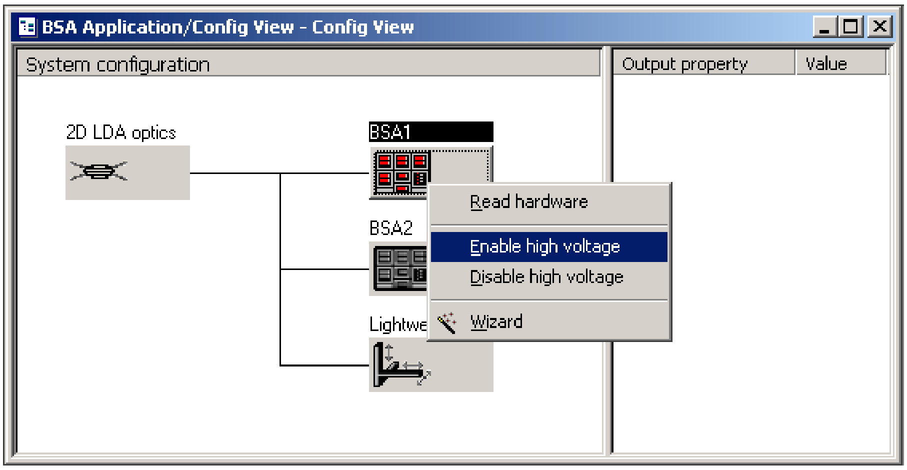
6. In the project explorer, right-mouse-click the “BSA Application” icon to add a new object (see step 6.) From the list, select “Histogram”. A window titled “BSA Application/Histogram - Histogram” appears.

7. Right-click in the histogram window, and click the Configure button in the window, to see this:

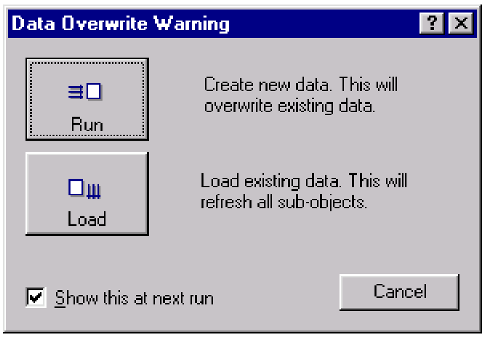


If you are running a 1D configuration, Select BSA1 Vel and click OK.
If you are running a 2D configuration, Select BSA1 Vel and BSA2 Vel and click OK.

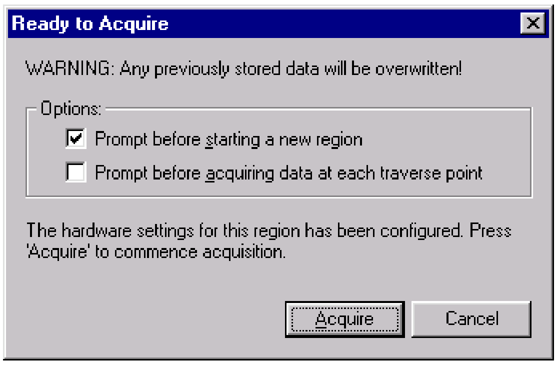
8. Right-click on one of the BSA icons in the Config View window, and select Enable high voltage from the drop down list



9. You are now ready to start acquisition of data. When the laser, the flow and the seeding is in operation, go to the Project explorer, click the BSA Application and click the Run button. First the Data Overwrite Warning prompt dialog is displayed.



10. After selecting Run, communication to the hardware is starting and after a short time, the following message appears:



11. Click OK, and acquisition will begin. In the “Config view”, the background of the output properties at the right hand side will be grey, and the output properties will be updated during the measurement. Another indication of acquisition in process is that the “Run” button is dimmed.
The histogram will be updated during the measurement. With 1000 samples selected, all data is usually sent in a single block, so the histogram updates once only. The update rate depends on the data rate. With high data rates and a large number of samples, you will see several updates during an acquisition.
When the acquisition is completed, the background of the output properties window returns to white and the “Run” button is clear again. Under the menu “Tools - Options - General” you can select “Feedback with sound”. With this option active, you will hear a beep from the PC when acquisition is completed.

12. You have now completed data acquisition in a single point. To save the data, click the Save button in the toolbar, and give the project file a name. It will be stored in the Projects folder.

13. You can add further processing objects, data lists or graphs by right mouse clicking on the “BSA Application” icon in the project explorer and selecting “new” from the dialog that appears. Please consult chapter 5 for details about the objects.

14. To save time when new objects have been added, you can run those objects alone by clicking on the highest level object you want to run, and then click the “Run” button or press F5 on the keyboard. This will run the object and it’s child objects.

4.8.4 Lightweight traverse

With the PC and the traverse controller switched off:

- Connect the RS232C connector of the traverse controller to a serial port of the PC. The BSA Application in the software is used to select which COM port is used with the traverse.

Caution	***Please make sure to connect the cable end marked “interface” to the traverse controller, and the cable end marked “PC” to the PC.***

Connect the motor cables between the traverse controller’s Stepping Motor Output connectors to the motors. BSA Flow Software considers channel 1 to be the left-most plug-in unit in the traverse controller.
Connect the emergency stop (if available) to the connector “Not-Aus” on the rear panel of the controller.

4.8.5 Lightweight traverse with handbox

Connect the handbox to the connector on the rear panel of the PC.

Connect motor cables from the traverse

4.8.6 57G15 Traverse Interface

Connect the GPIB cable from the Traverse Interface to the GPIB board in the PC. If other GPIB devices are used, they must be connected in daisy-chain.

4.9 Set-up and data acquisition, 58N series FVA based LDA systems

4.9.1 Cable connections

4.9.1.1 PM and Bragg cell connections

- Connect the 57X08 photomultiplier to connectors L_1 (High voltage out, channel U), M (Photo-multiplier auxiliary power output, channel U) and X (Photo-multiplier signal input, channel U)
- Connect the braggcell to the U connector (Bragg cell driver 1).

4.9.1.2 PC connection

- Connect the interface cable between connector S (Computer interface) and the 58G130 FVA/PDA interface board in the PC

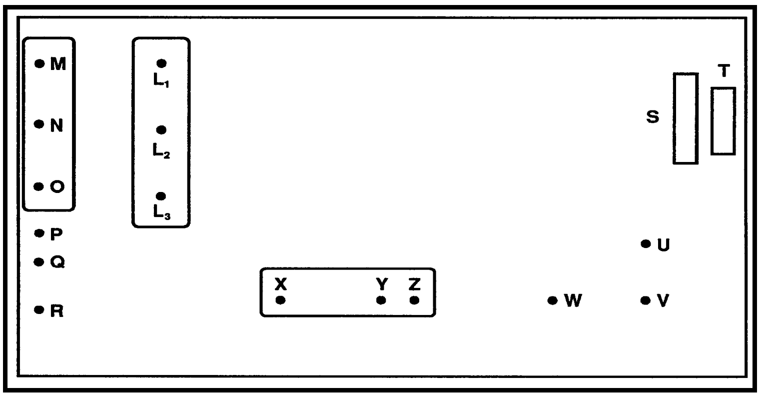


Figure 4-38 Rear panel lamps, switches and connectors of a Flow Velocity Analyzer.

Legend

L_1) High voltage output, channel U*.

L_2) High voltage output, channel V*.

L_3) High voltage output, channel W*.

M) Photo-multiplier auxiliary power output, channel U*.

N) Photo-multiplier auxiliary power output, channel V*.

O) Photo-multiplier auxiliary power output, channel W*.

P) Voltage selector.

Q) Fuse.

R) Power line connector.

S) Computer interface.

T) Encoder input.

U) Bragg cell driver 1 (output).

V) Bragg cell driver 2 (output).

W) Burst detector inhibit input.

X) Photo-multiplier signal input, channel U*****.

Y) Photo-multiplier signal input, channel V*****.

Z) Photo-multiplier signal input, channel W*****.

* The Photo-multiplier auxiliary power output, channels U, V and W, the Photo-multiplier signal input, channels U, V and W, and the High voltage output, channel U, use different cables in one sheath for connection to the photo-multiplier. Do not force the cable plugs to fit the connectors. The plugs are of different types and will mate only with their respective connectors.

4.9.1.3 Synchronisation input connections

The FVA signal processor is equipped with an encoder input connector T. This input is usually used when measuring on rotating machinery. The socket and pin connections are shown in Figure 4-39.

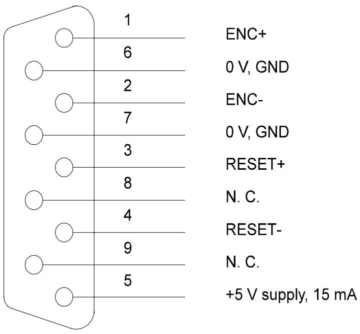


Figure 4-39: Pin assignment of the encoder socket.

The connector offers differential input for two encoder signals, ENC and reset. ENC should give a number of pulses per revolution while reset should give only one pulse per revolution. In both cases the rising edge is used and the pulses must be minimum 1 μs wide. Both inputs need not be used at the same time. If the encoder has a TTL or CMOS type output rather than differential, make an adapter as shown in Figure 4-40.

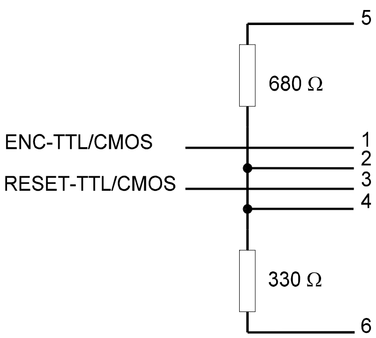


Figure 4-40: Adapter diagram.

4.9.1.4 Front panel connections

- Connect an oscilloscope to the "Doppler monitor output, channel U" connector (B). This allows monitoring of the filtered and amplified photomultiplier signal.

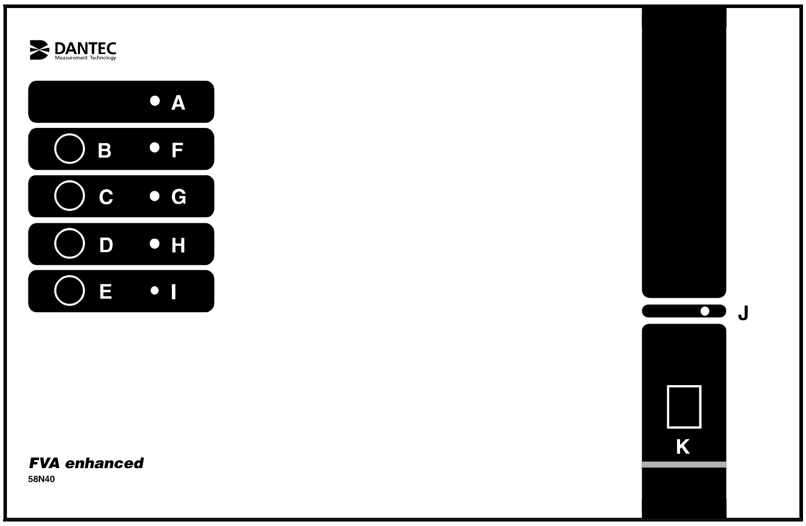


Figure 4-41 Front panel lamps, switches and connectors, 58N40 FVA enhanced.

Legend

A) High voltage on lamp.

B) Doppler monitor output, channel U.

C) Doppler monitor output, channel V.

D) Doppler monitor output, channel W.

E) Burst detector envelope monitor output.

F) Photo-multiplier overload lamp.

G) Photo-multiplier overload lamp.

H) Photo-multiplier overload lamp.

I) Burst detected lamp.

J) Power on lamp.

K) Power on/off switch.

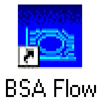
4.9.1.5 Analog input

Please refer to chapter 6.6.

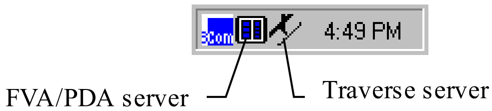
4.9.2 Configuring an LDA system

A step-by-step guide to a one component measurement is provided below. It is assumed that your LDA system is set up to measure in a point in the flow where you know the approximate mean velocity. If you have a 57G15 traverse controller or a lightweight traverse controller, do not switch it on yet.

1. Double click the BSA Flow icon on the desktop.



2. This will start server programs which take care of communication with the processor(s) and traverse system (if any). In the lower right hand corner of the desktop this is indicated by icons:

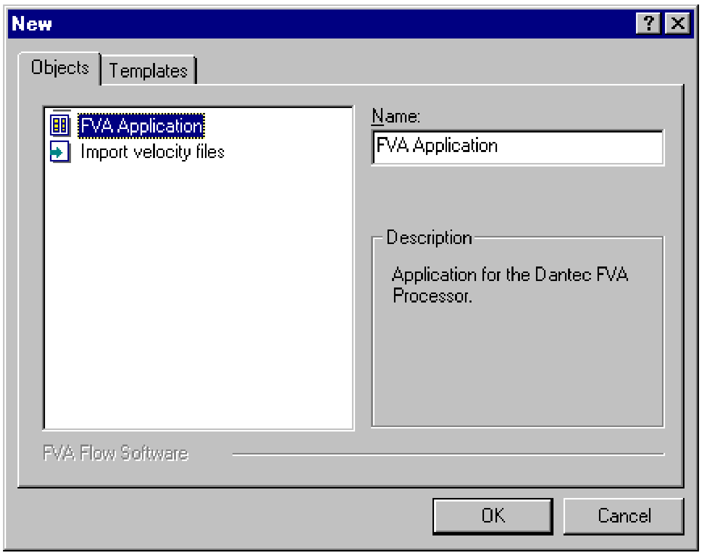


3. Click New project in the dialog box that appears

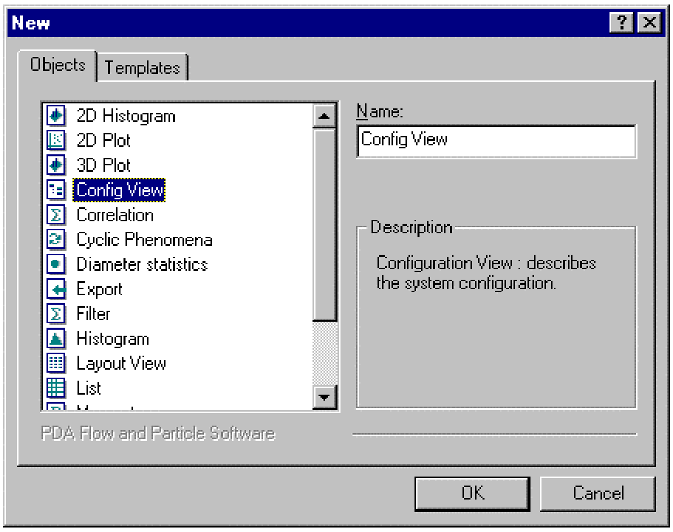
4. In the New window that appears, select Blank Project, and click the OK button.

5. In the Project Explorer pane at the top left, a Start icon appears, Click on it with the right mouse button, and the following appears:

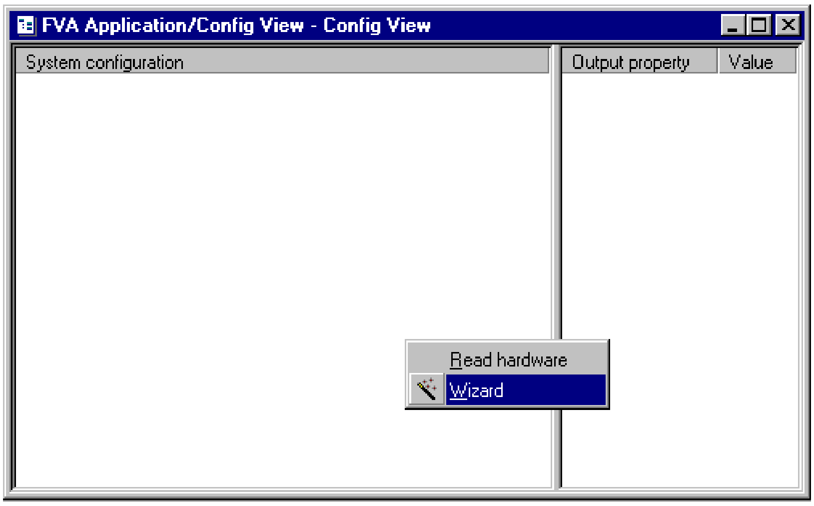
6. Click New Source, and the following appears (for PDA processor, PDA Application will appear instead of FVA Application):



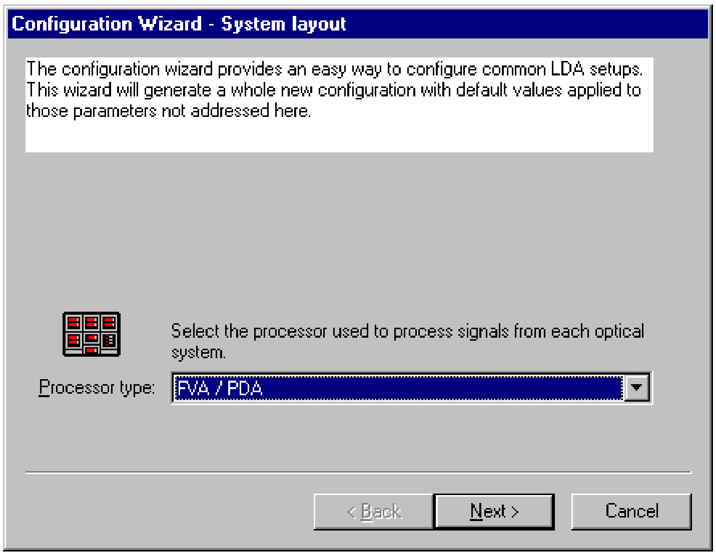
7. Select the FVA Application or PDA Application and click OK. In the Project Explorer an icon named FVA Application or PDA Application appears. Click on it with the right mouse button, and the following appears:



8. Double-click Config or click Config and then OK, and a blank window named Config view appears in the Workspace at the right hand side of the display. Right-mouse-click in the Config view window and the following appears:

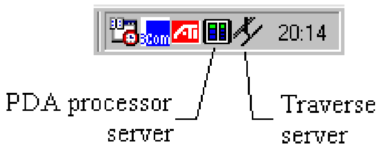


9. Click the wizard button to see this:

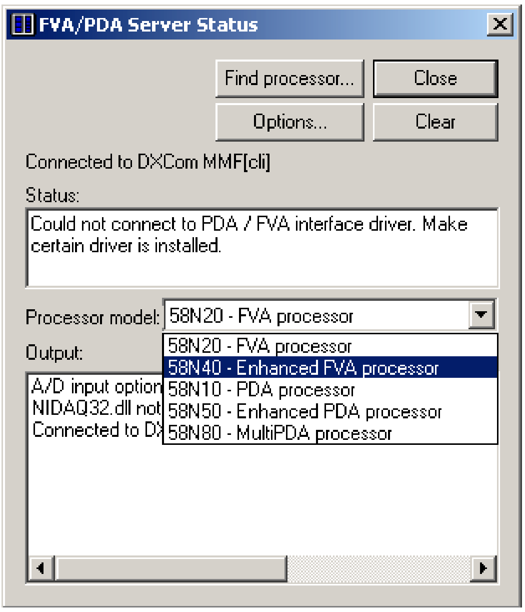


10. Select FVA/PDA.

11. To specify the type of FVA processor you are using, right mouse click on the PDA server icon in the lower right hand corner of the desktop.

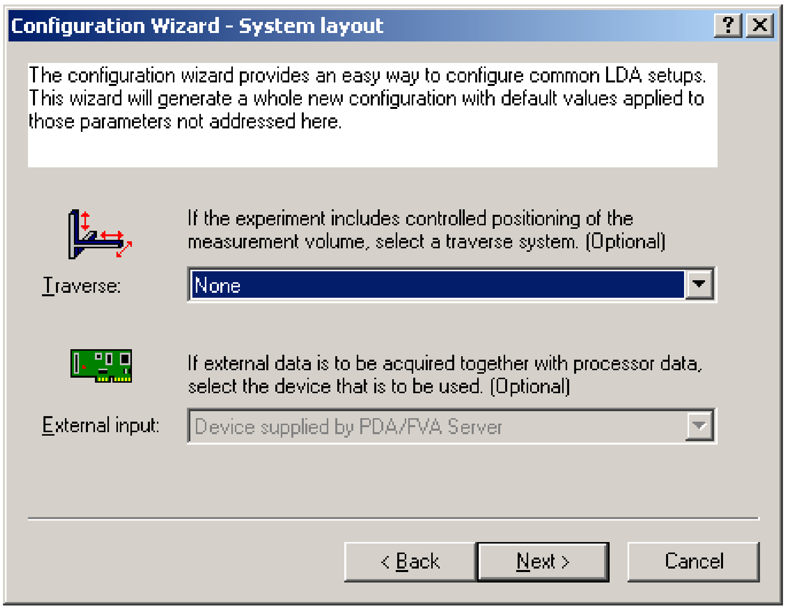


12. In the FVA/PDA Server Status window select your processor type from the processor model pull-down list and click on Close.

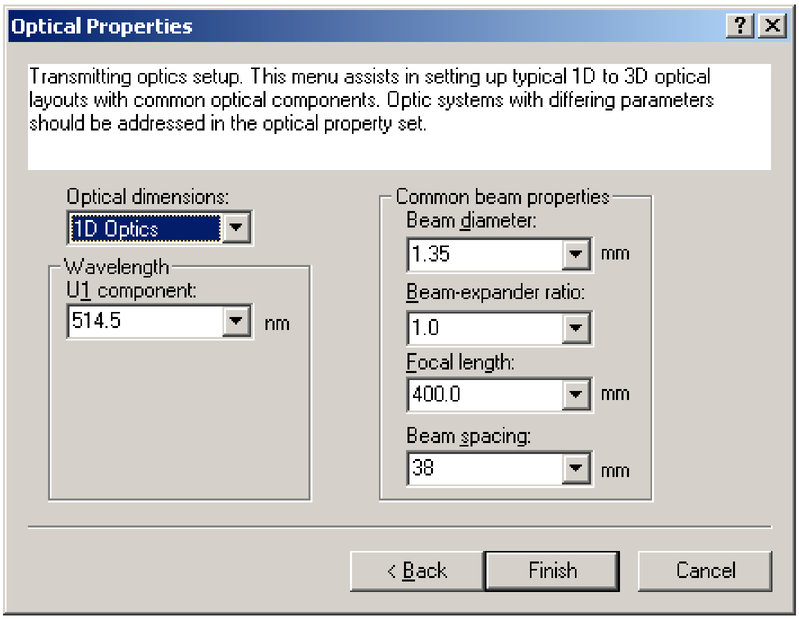


Click “Next”

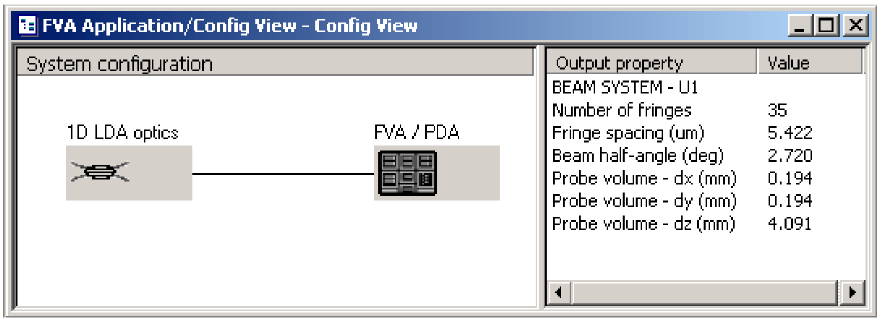
13. For the beginning do not select a traverse system, even if you have one installed with your system.



14.click Next to see the following dialog box:



15.Select 1D Optics for now, and fill in the optical parameters of your transmitting optics. Click the finish button, and the Config View window looks like this:



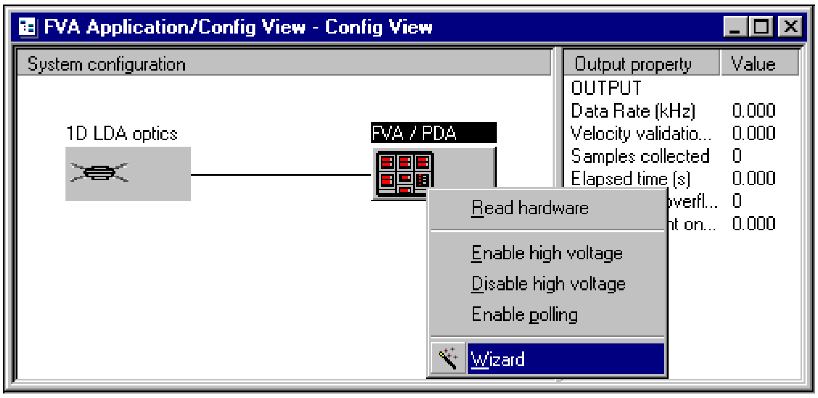
16.You have now completed the set-up of the LDA system

4.9.3 Data acquisition, LDA, step by step

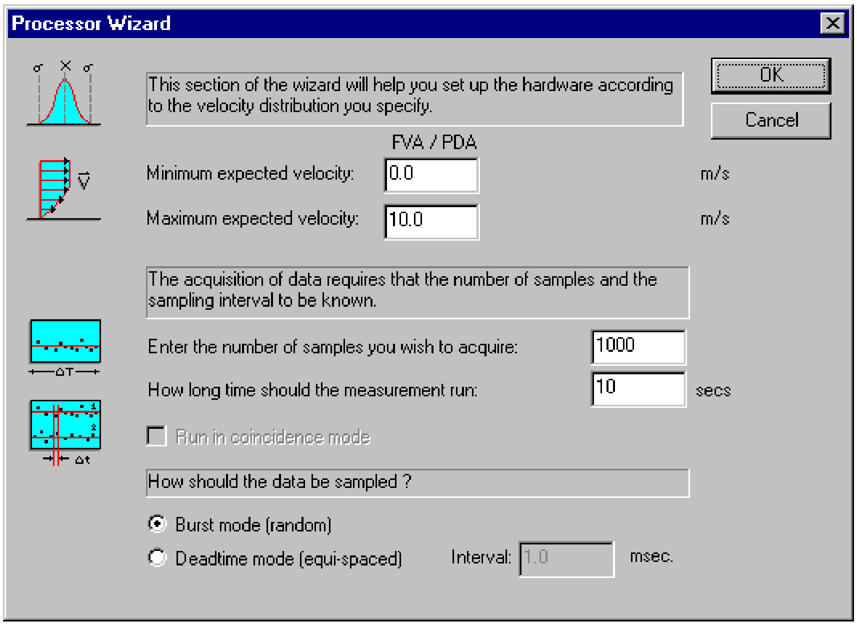
Assumptions:

- optics and the traverse system have been configured
- 40 MHz Bragg cell is used
- all cable connections have been made
- the BSA Flow Software has found the BSA
- the measurement volume is located at a point in the flow
- the laser is running
- particles are present in the flow
- the transmitting optics and receiving optics are precisely aligned

1. Configure your LDA or PDA system according to the previous section
2. Click on the FVA/PDA icon, and click the “Wizard” button in the tool bar, or click the right mouse button on the FVA icon, to see this:

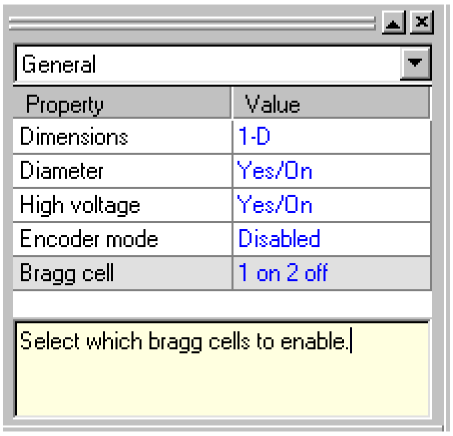


3. Select Wizard to see this:



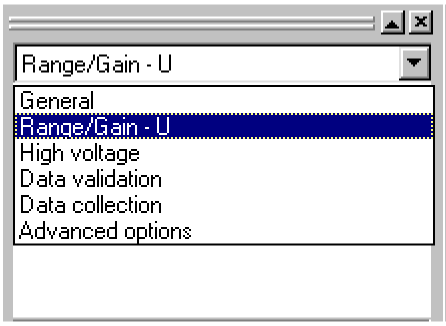
4. Insert the expected minimum and maximum velocities. This will set the processor's frequency bandwidth to the nearest suitable value. Fill in the two fields Enter the number of samples you wish to acquire and How long time should the measurement run e.g with the values shown above. Under the question How should the data be sampled?, select Burst mode (random). Click OK to return to the Config View.

5. In the Config View window, click the FVA/PDA icon. In the property list you will see the General properties:

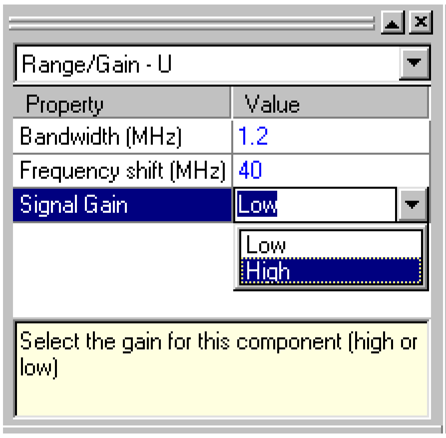


Choose the settings as shown above.

6. Click on the “Down” arrow on the right-hand side of the General field. Select Range/Gain - U from the pull-down list.

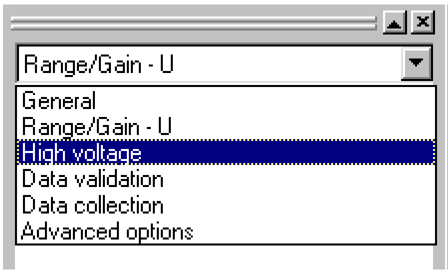


7. The Bandwidth has been set automatically by the Processor Wizard.

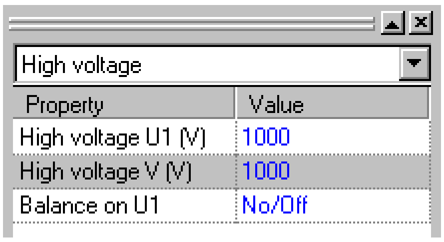


Depending on particle size and available laser power, it might be necessary to set the signal gain to “High”.

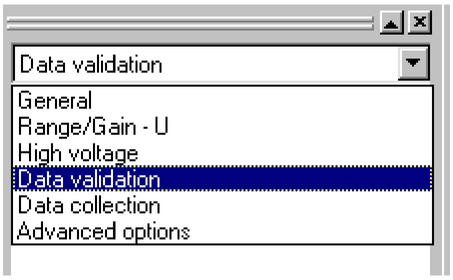
8. Select “High voltage” from the pull-down list.



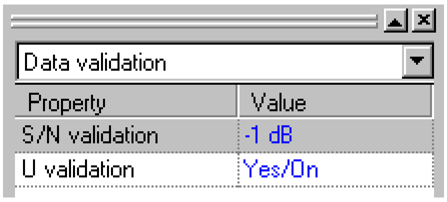
9. Set the high voltage to the value you normally use. If you have no reference knowledge regarding the high voltage level, start with 1000 V.



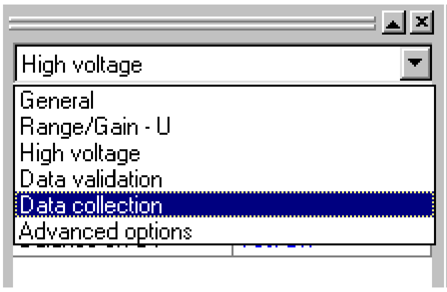
10. Select “Data validation” from the pull-down list.



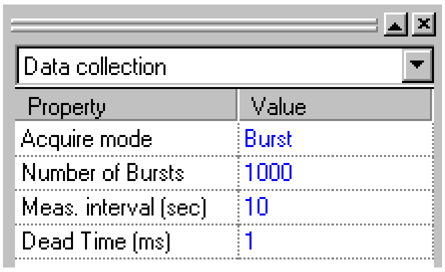
11. Set the signal-to-noise (S/N) validation limit to -1dB. Set the U validation to Yes/On.



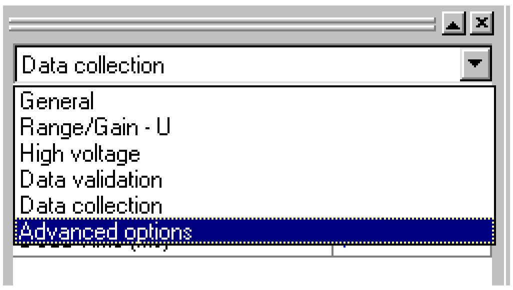
12. Select “Data collection” from the pull-down list.



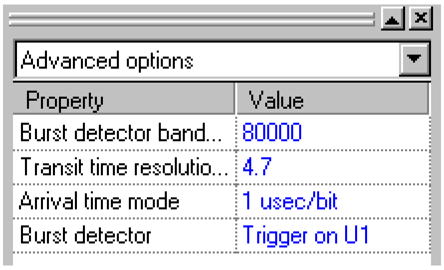
13. All the settings have been made automatically by the “Processor Wizard”.



14. Select “Advanced options” from the pull-down list.

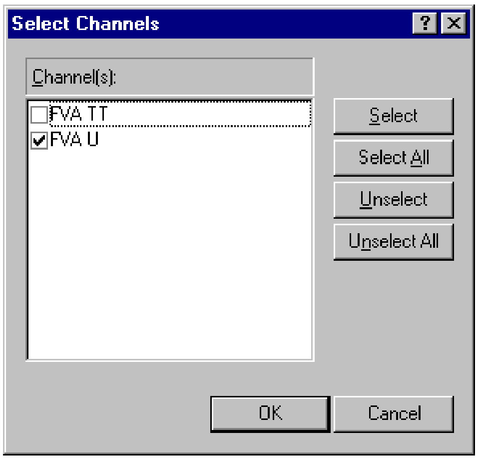


15. Use the default settings as shown below.



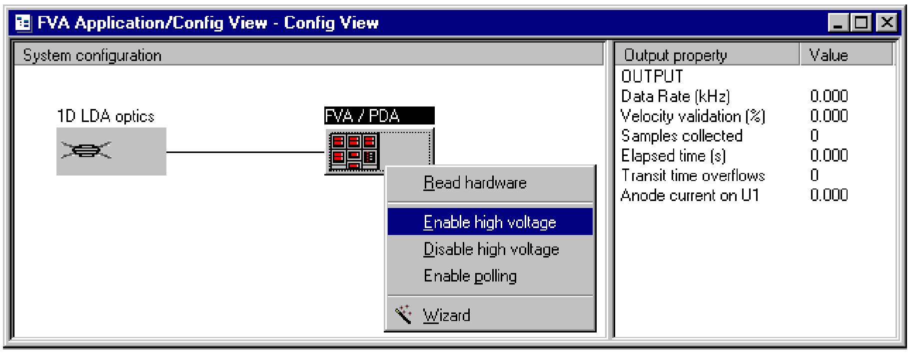
16. In the project explorer, right-mouse-click the FVA Application icon to add a new object (see step 7.) From the list, select Histogram. A window titled FVA Application/Histogram - Histogram appears.

17. Right mouse click in the window that appears, and click the Setup button in the window, to see this:

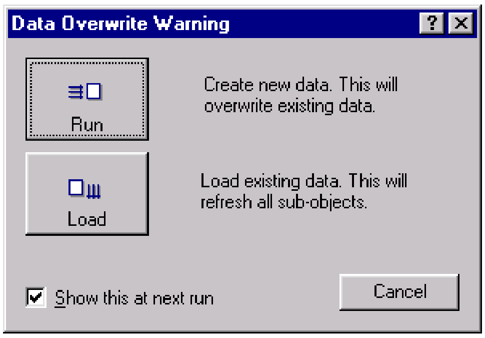


In the dialog box, select FVA U and click OK.

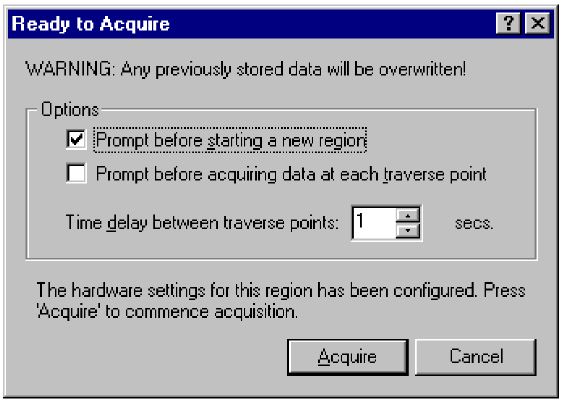
18. Right-click on the FVA/PDA icon in the Config View window, and select Enable high voltage from the drop down list



19. You are now ready to start acquisition of data. When the laser, the flow and the seeding is in operation, go to the Project explorer, click the Standard LDA and click the Repetitive Run or Run button. First the Data Overwrite Warning prompt dialog is displayed.



20. After selecting Run, communication with the hardware is starting and after a short time, the following message appears:



21. Click Acquire to start data acquisition. The automatic calibration routine will be performed prior to data acquisition. In the Config view, the background of the output properties at the right hand side will be grey, and the output properties will be updated during the measurement. Another indication of acquisition in process is that the Run button is dimmed.

22. The histogram will be updated during the measurement. With 1000 samples selected, all data is usually sent in a single block, so the histogram updates once only. The update rate depends on the data rate. With high data rates and a large number of samples, you will see several updates during an acquisition.

23. When the acquisition is completed, the background of the output properties window returns to white, and the Run button is clear again. Under the menu Tools - Options - General you can select Feedback with sound. With this option active, you will hear a beep from the PC when acquisition is completed.

24. You have now completed data acquisition in a single point. To save the data, click the Save button in the toolbar, and give the project file a name. It will be stored in the Projects folder.

25. You can add further processing objects, data lists or graphs by right mouse clicking on the Std. LDA icon in the project explorer and selecting New from the dialog that appears.

26. To save time when new objects have been added, you can run those objects alone by clicking on the highest level object you want to run, and then click the Run button or press F5 on the keyboard. This will run the object and it's child objects.

    You can hide the Message window from the context menu or you can hide or show it from the Software menu, see section 4.4.3.

4.10 Set- up and data acquisition, 58N series PDA based PDA systems

4.10.1 Cable connections

Caution	*Before proceeding with the installation of the 58N80 MultiPDA signal processor, ensure that the Voltage Selector on the signal processor's back panel (Figure 4-) is set to the line voltage of the wall outlet. The selector can be switched between 110 V and 220 V using a screwdriver.* *Always turn the power to the 58N80 MultiPDA signal processor OFF before connecting or disconnecting a photo-multiplier.* *Do not hold the photo-multipliers by hand when the high voltage is switched on.*

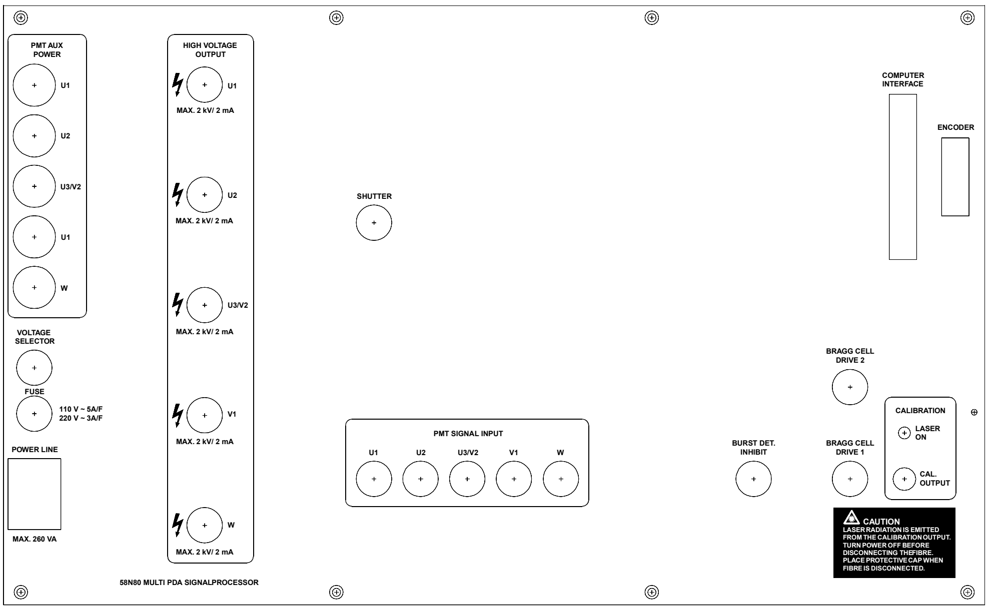


Figure 4-: The back panel of the 58N80 MultiPDA signal processor.

4.10.1.1 PM and Bragg cell connections

Photo-multipliers

Three connections are made for each of five possible photo-multipliers installed in the *Detector Unit*:

- <u>PMT Auxiliary Power:</u> provides ±12 V for the pre-amplifier.
- <u>PMT Signal Input:</u> receives the Doppler signal (DC anode current).
- <u>High Voltage Output:</u> gives a cathode voltage for the PMT. If no connection is made to one or more of the high voltage supplies, that supply will shut down automatically.

Each photomultiplier is electrically connected to the socket on the back panel of the detector unit (Figure 4-42 PMT signal output, High voltage input, and PMT auxiliary power). Each connector is identified by a label as in the following example.

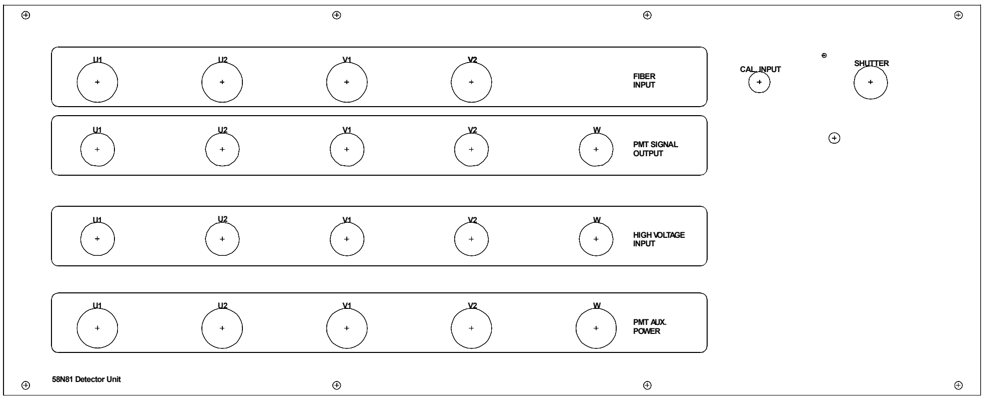


Figure 4-42: Back panel of the 58N81 DualPDA Detector Unit.

- Connect the braggcell to the Bragg cell drive 1 connector.

Bragg cell drives

Bragg cell drive 1 provides +12 V, 300 mA and 40 MHz, 900 mV_{pp}, 50 W for the *60X40* and *60X41* transmitters. Bragg cell drive 2 has the same characteristics as the Bragg cell drive 1 output. It is intended for driving a second Bragg cell in 3D configurations using the older non-fibre *55X* series transmitting optics.

Burst detector inhibit

The burst detector inhibit input is normally left open. The burst detector will trigger normally when the input is left open or held at a TTL-high level. The burst detector will stop triggering if the input is forced to a TTL-low level. When the burst detector mode is set to ‘external trigger’ the measurements are gated from this input. In this mode the integration time depends on the pulse length (the time interval where the burst detector inhibit is pulled high). The levels are TTL levels.

4.10.1.2 PC connection

Computer interface The computer interface socket connects the 58N-- signal processor to the 58G130 PDA Interface Board in the computer. The special cable required is a part of the interface kit. Standard length is 2 m, longer cables can be supplied on request.

Caution	*Before connecting the cable ensure that the 58N-- PDA signal processor and the computer are properly grounded. Connect the units to the same outlet, because different outlets can be at different ground potentials*

4.10.1.3 Shutter and optical fiber connection

Calibration output The calibration output connects to a fibre that transmits a calibration signal to the *PDA Detector Unit*.

Danger	*Laser radiation is emitted from the calibration output. Turn the power*
Laser light	*to the 58N--PDA signal processor OFF before disconnecting the optical fibre. Place the protective cap on the output when the fibre is disconnected.*
	The wavelength of the diode laser in the 58N-- PDA signal processor is 670 nm and the maximum radiated power is 100 µW.
	To avoid eye damage never look into the output should it be left open. Do not disconnect the distal end of the fibre from the receiving optics, before disconnecting the proximal end of the fibre from the calibration output.

Shutter This is a driver output for the shutter in the *58N--PDA Detector Unit*.

4.10.1.4 Synchronisation input connections

Encoder input The *58N--PDA* signal processor is equipped with an encoder input. This input is usually used when measuring on rotating machinery. The socket and pin connections are shown in Figure 4-43.

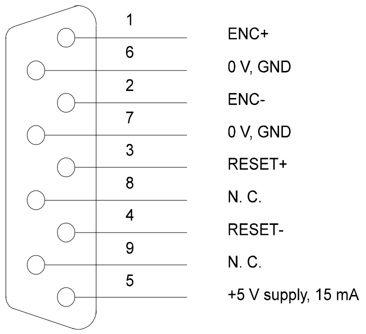


Figure 4-43: Pin assignment of the encoder socket.

The connector offers differential input for two encoder signals, ENC and reset. ENC should give a number of pulses per revolution while reset should give only one pulse per revolution. In both cases the rising edge is used and the pulses must be minimum 1 μs wide. Both inputs need not be used at the same time. If the encoder has a TTL or CMOS type output rather than differential, make an adapter as shown in Figure 4-44.

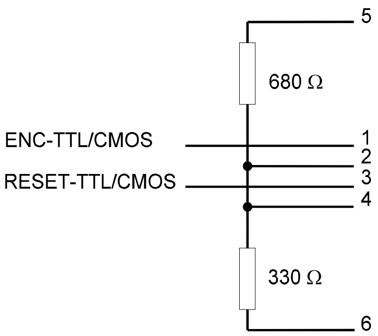


*Figure 4-44***.** *Adapter diagram.*

Voltage selector and fuses

Sets the *58N80 MultiPDA* signal processor for 110 V (100 to 120 V) or for 220 V (200 to 240 V) operation. For 110 V operation a 5 A fast blow fuse is used, and for 220 V operation a 3 A fast blow fuse is used.

Caution	*Make sure that the voltage setting of the selector corresponds to that of the electric power outlet.*

Power line

Standard mains power inlet: single phase plus safety ground connection, max. 260 VA.

4.10.1.5 Front panel connections

The front panel of the *58N80 MultiPDA* signal processor is shown in Figure 4-45.

Figure 4-45: The front panel of the 58N80 MultiPDA signal processor.

Monitor

The Doppler monitor outputs for the PMT channels *U1*, *U2*, *V1*, *V2* and *W* (Figure 4-45) are indicated along with the envelope monitor output for the burst detector.

The Doppler monitor output signals are to be connected to an oscilloscope to facilitate proper setting of the PMT high voltages and alignment of the PDA receiving optics (see 4.10.3 Data acquisition, PDA, step by step).

Burst detector

At this output the detected envelope of the *U1* signal is present. Burst detection is based on a three-level scheme (Figure 4-46). More details are given in **3.1.5 Burst detection (electronics)** in the ***DualPDA or PDA Reference Guide***.

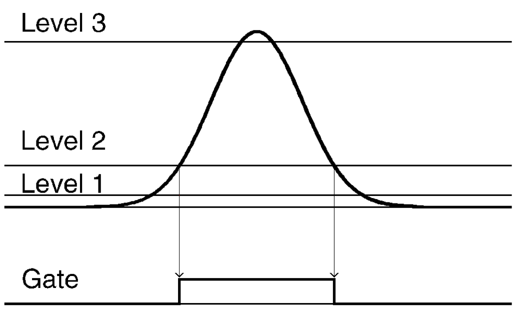


Figure 4-46: The burst detector levels.

PM overload

Red light emitting diodes to the right of the monitor outputs (Figure 4-45) shine if the circuits limiting the average anode current of each PMT to 100 µA are activated. The high voltage will be reduced automatically, preventing damage to the photo-multipliers, but the overload condition is associated with inaccurate phase measurements jeopardizing the accuracy of the diameter estimates. This inaccuracy is a consequence of delays in the PMTs being dependent on the high voltage.

These delays are measured and compensated for during normal working conditions; however, the compensation is not correct if the conditions, i.e. high voltage, change.

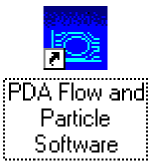
4.10.1.6 Analog input

Please refer to chapter 6.6.

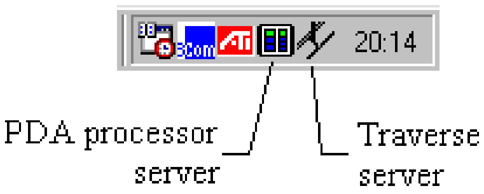
4.10.2 Configuring a PDA system

A step-by-step guide to a one component measurement is provided below. It is assumed that your PDA system is set up to measure in a point in the flow where you know the approximate mean velocity. For simplicity, it is recommended to start with a 1D configuration, even if you have a 2D or 3D PDA system available. If you have a 57G15 traverse controller or a lightweight traverse controller, do not switch the traverse on yet.

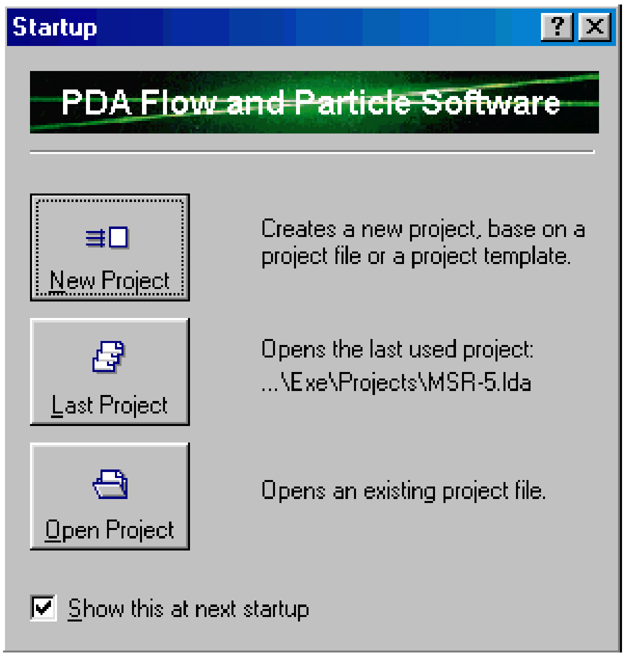
1. Double click the PDA software icon on the desktop.

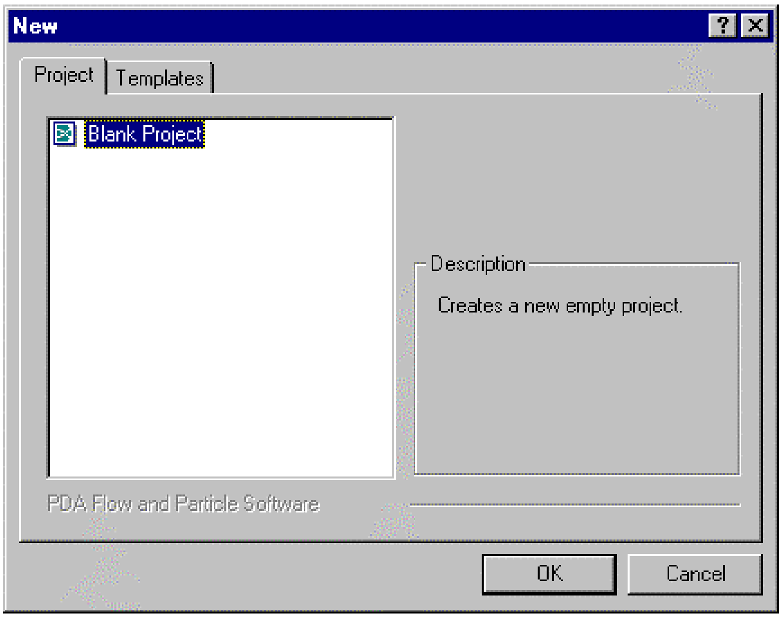
   This will start server programs which takes care of communication with the PDA processor and traverse system (if any). In the lower right hand corner of the desktop this is indicated by icons:

2. Click “New project” in the dialog box that appears

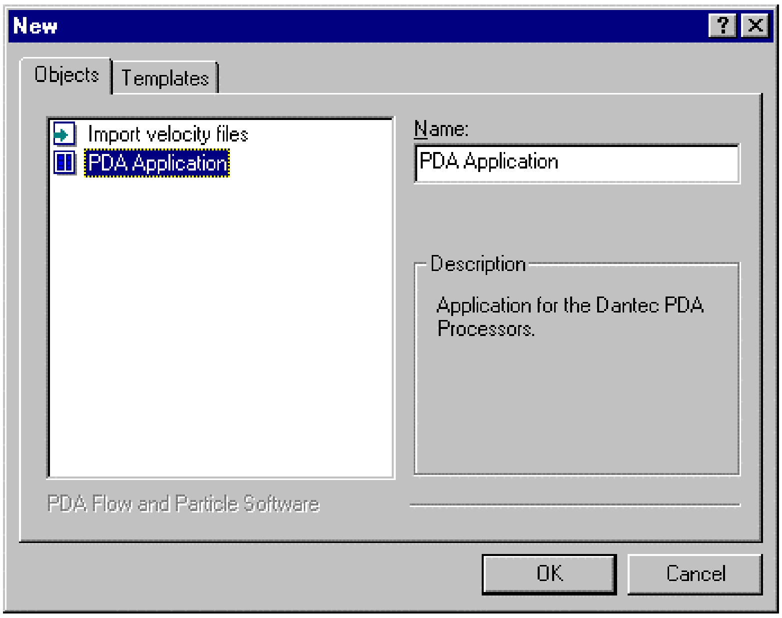


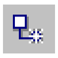
3. In the “New” window that appears, select “Blank Project”, and click the OK button.

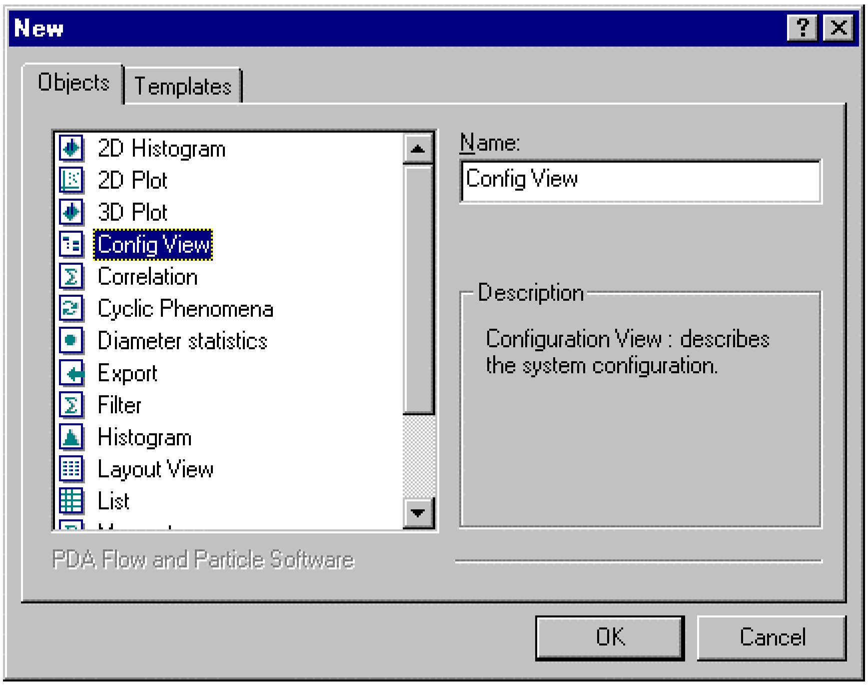


4. In the Project Explorer pane at the top left, a “Start” icon appears, Click on it with the right mouse button, and the following appears:

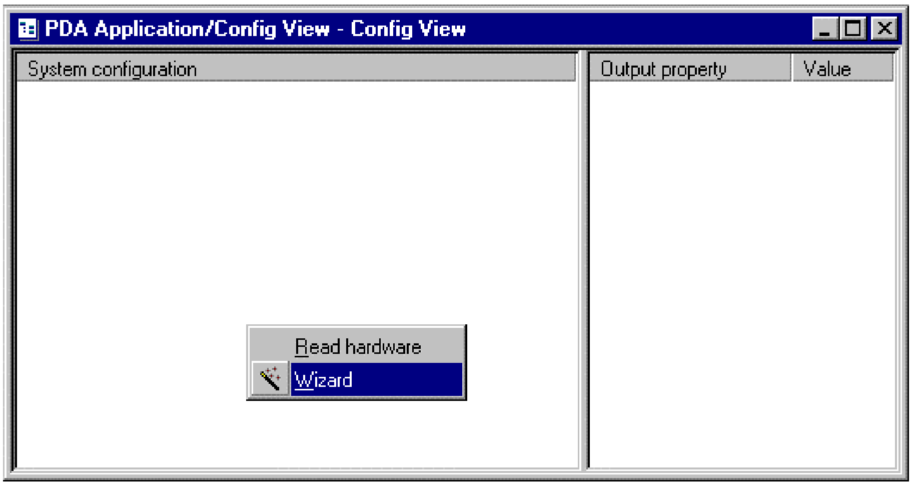
5. Click “New Source”, and the following appears:



6. Select the PDA Application and click OK. In the Project Explorer an icon named PDA Application appears. Click on the “New object” icon  in the tool bar and the following appears:

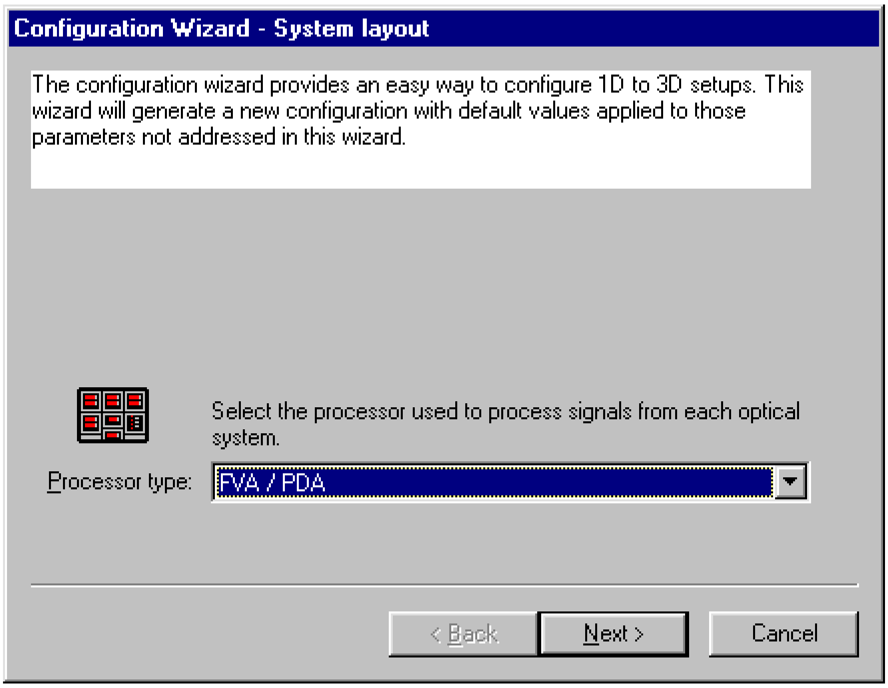


7. Double-click “Config View” or click “Config View” and then “OK”, and a blank window named “Config View” appears in the Workspace at the right hand side of the display. Right-mouse-click in the “Config View” window and the following appears:

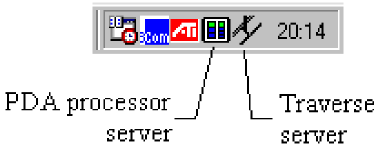


Click on the Wizard button.

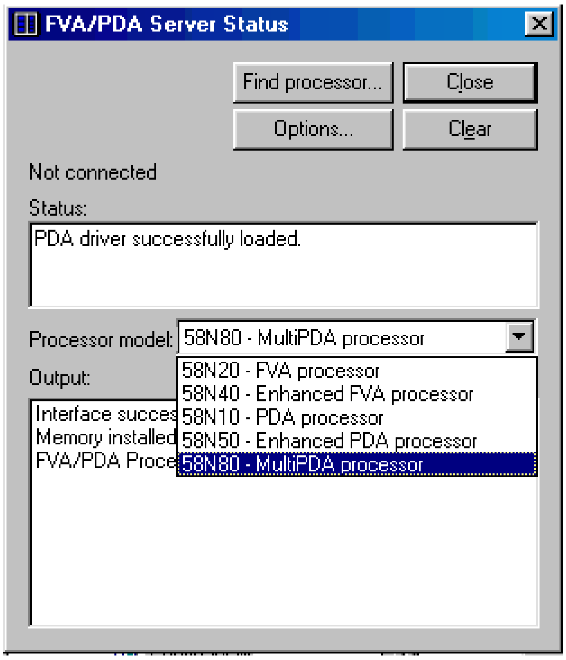
8. Select FVA / PDA as processor type.



To specify the type of PDA processor you are using, right mouse click on the PDA server icon in the lower right hand corner of the desktop.

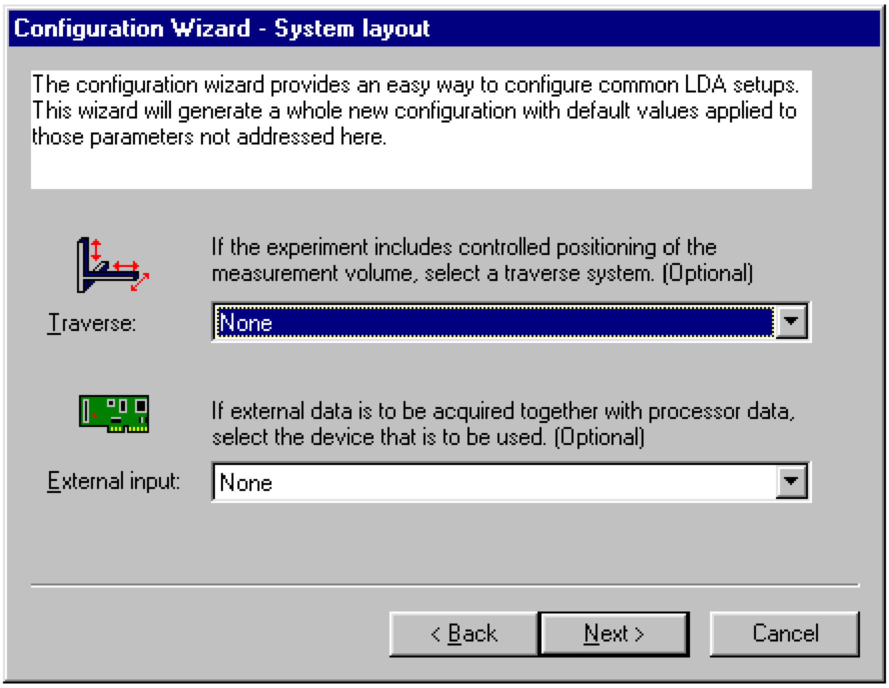


In the FVA/PDA Server Status window select your processor type from the processor model pull-down list and click on Close.



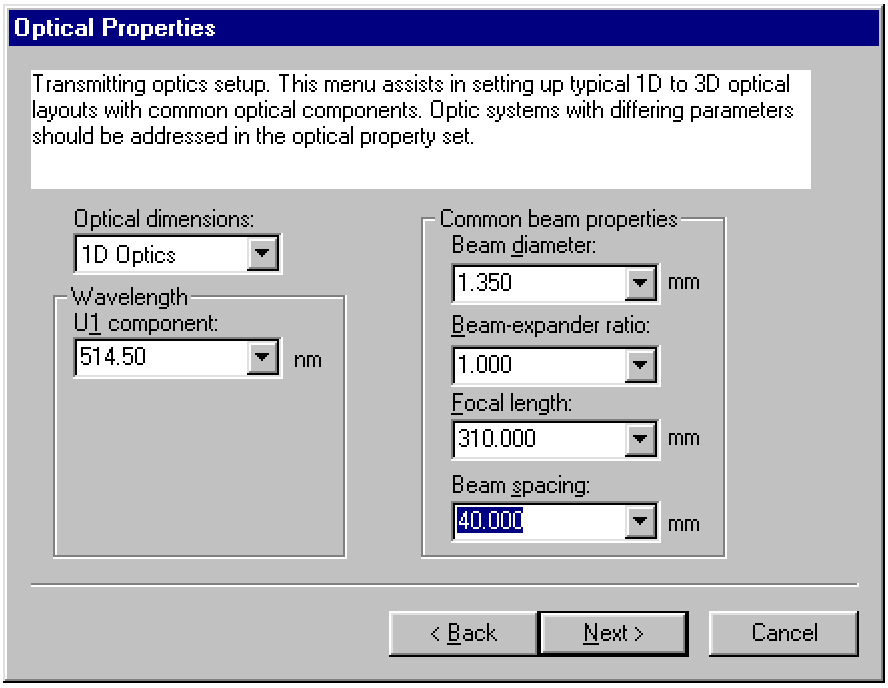
Click “Next”:

9. For the beginning do not select a traverse system, even if you have one installed with your PDA.



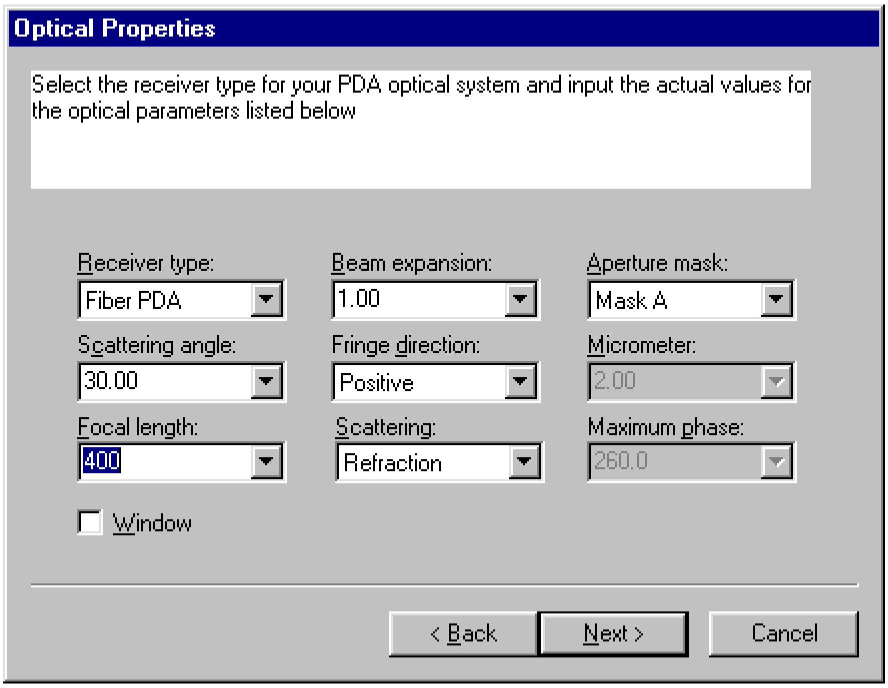
Click “Next”.

10. Select "1D Optics" and enter the appropriate parameter values corresponding to the setup you are working with.



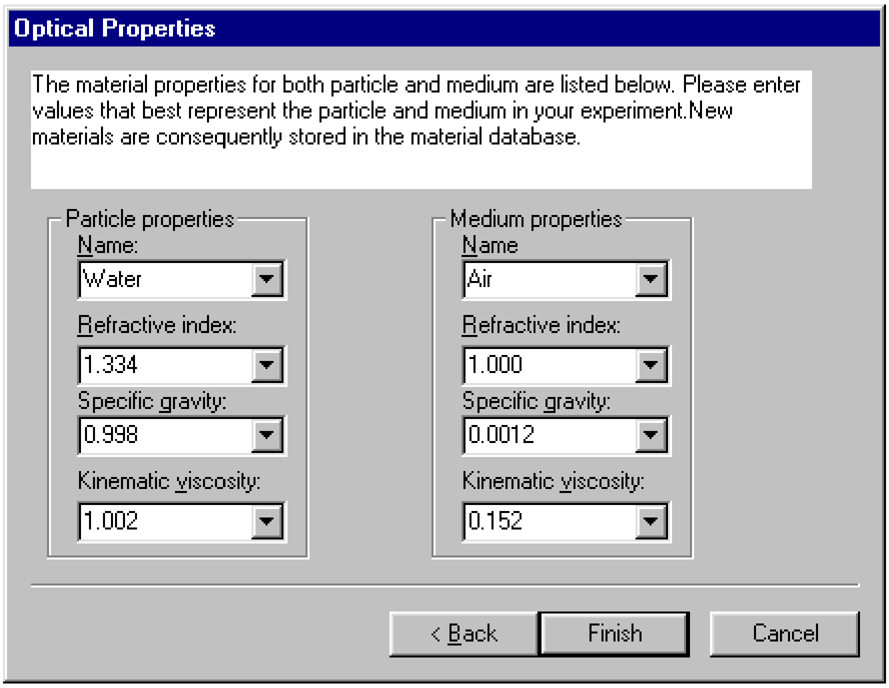
Click "Next".

11. Select the receiver type and enter the appropriate parameter values.



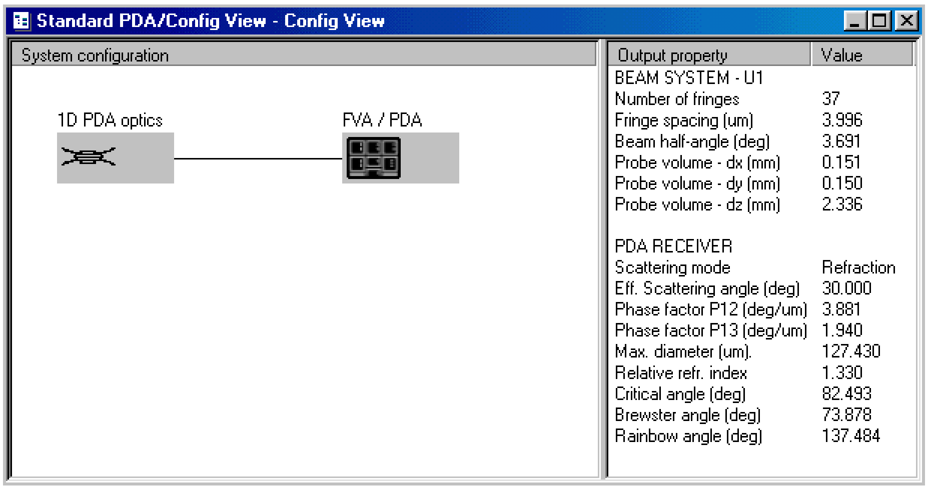
Click "Next".

12. Select and enter the properties of the particle and medium materials. The default setting is water droplets in air.



Click “Finish”.

The “Config View” now looks like this:

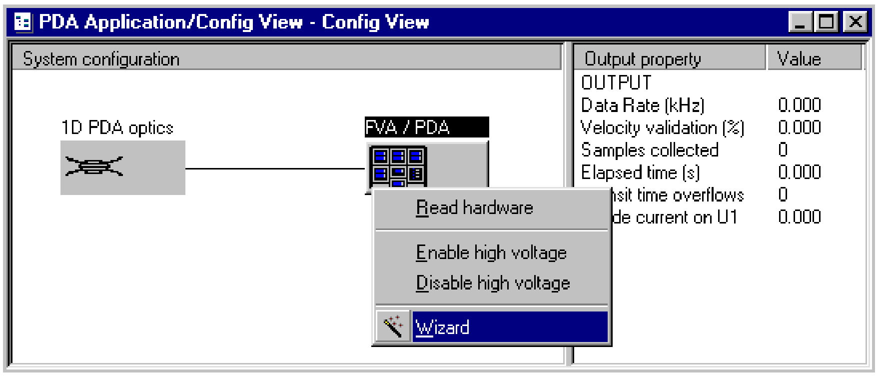


4.10.3 Data acquisition, PDA, step by step

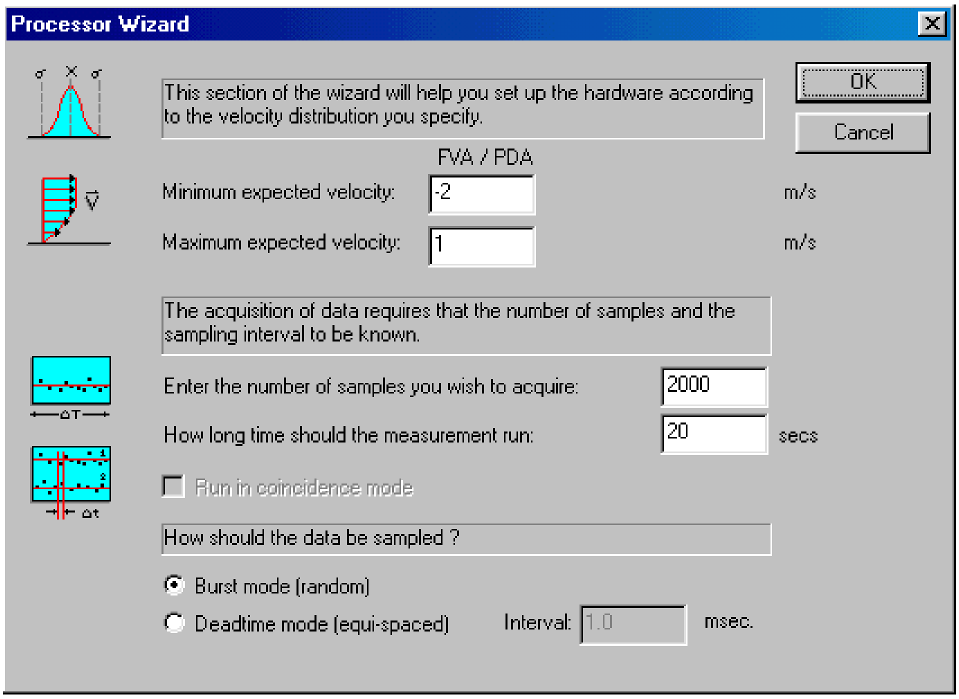
Assumptions:

- optics and the traverse system have been configured
- 40 MHz Bragg cell is used
- all cable connections have been made
- the BSA Flow Software has found the BSA
- the measurement volume is located at a point in the flow
- the laser is running
- particles are present in the flow
- the transmitting optics and receiving optics are precisely aligned

1. Click on the FVA/PDA icon, and click the "Wizard" button in the tool bar, or click the right mouse button on the FVA/PDA icon, to see this:

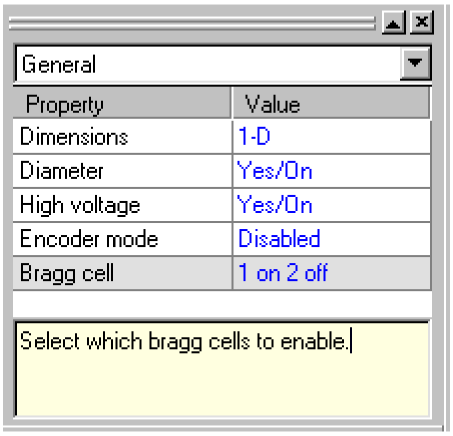


2. Select Wizard to get the processor wizard.



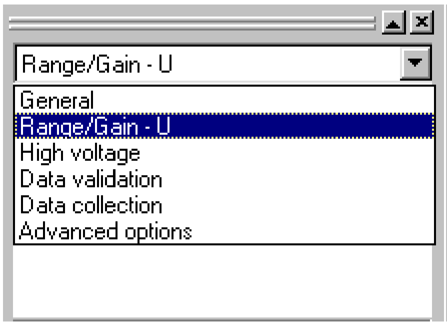
3. Insert the expected minimum and maximum velocities. This will set the processor's frequency bandwidth to the nearest suitable value. Fill in the two fields "Enter the number of samples you wish to acquire" and "How long time should the measurement run" e.g with the values shown above. Under the question "How should the data be sampled?", select "Burst mode (random)". Click "OK" to return to the "Config View".

4. In the "Config View" window, click the FVA/PDA icon. In the property list you will see the "General" properties.

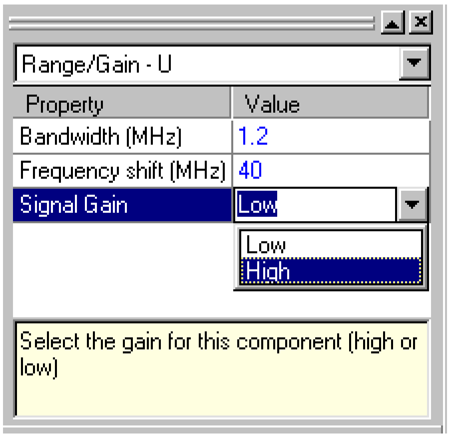


Chose the settings as shown above.

5. Click on the "Down" arrow on the right-hand side of the "General" field. Select "Range/Gain - U" from the pull-down list.

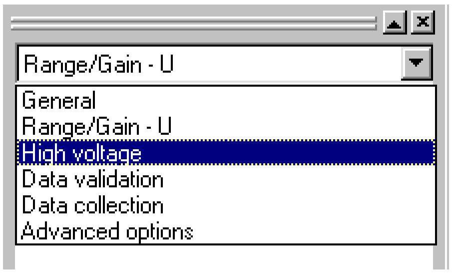


6. The Bandwidth has been set automatically by the “Processor Wizard”.

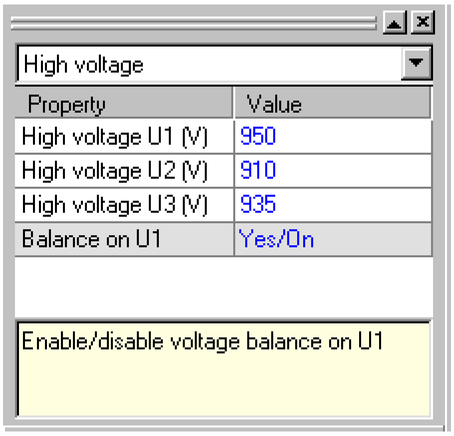


Depending on particle size and available laser power, it might be necessary to set the signal gain to “High”.

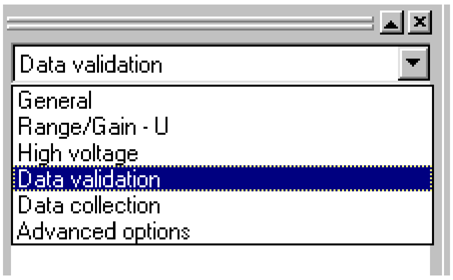
7. Select “High voltage” from the pull-down list.



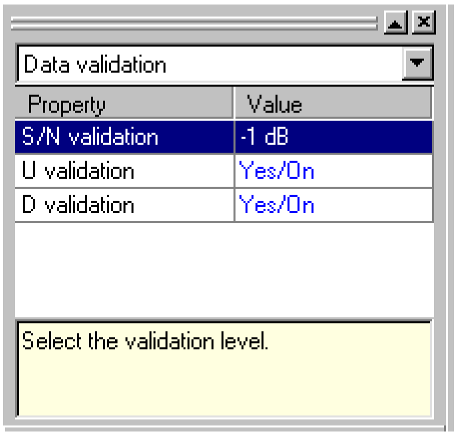
8. Set the high voltages to the values you normally use. If you have no reference knowledge regarding the high voltage level, start with 800 V for each channel.



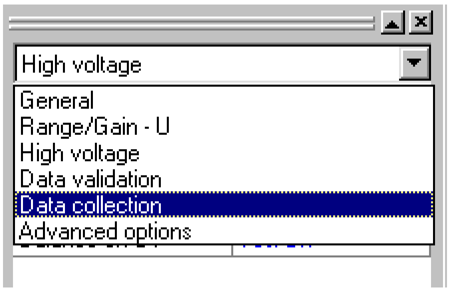
9. Select “Data validation” from the pull-down list.



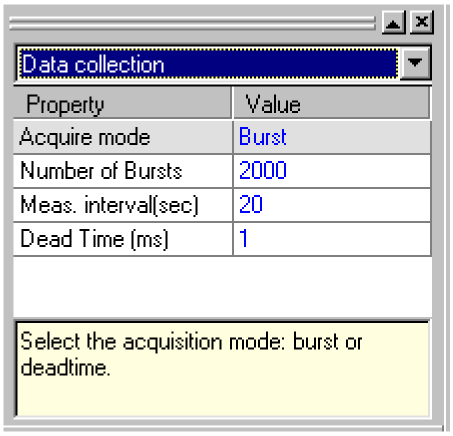
10. Set the signal-to-noise (S/N) validation limit to -1dB. Enable both, the velocity and diameter validation.



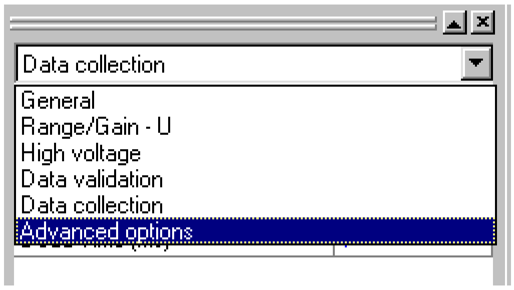
11. Select “Data collection” from the pull-down list.



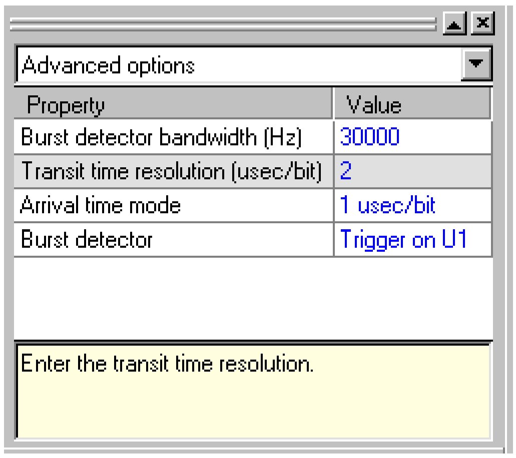
12. All the settings have been made automatically by the “Processor Wizard”.



13. Select “Advanced options” from the pull-down list.



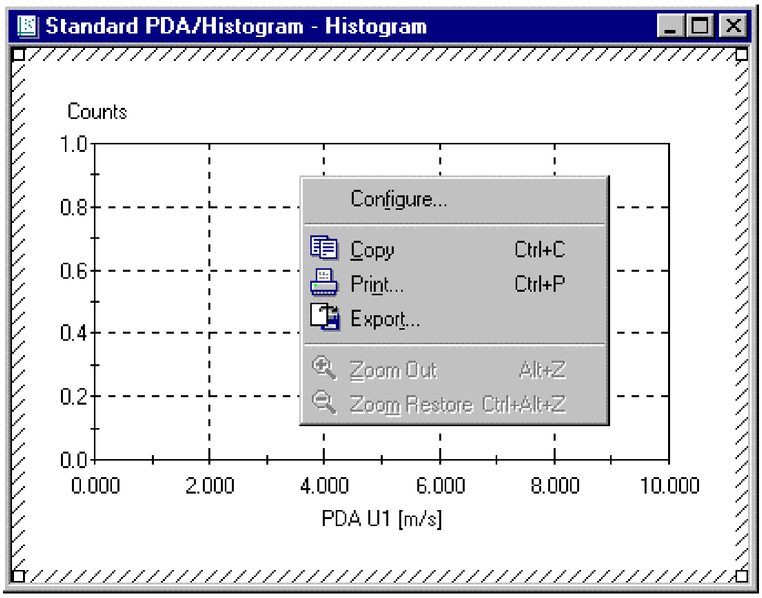
14. Use the default settings as shown below.



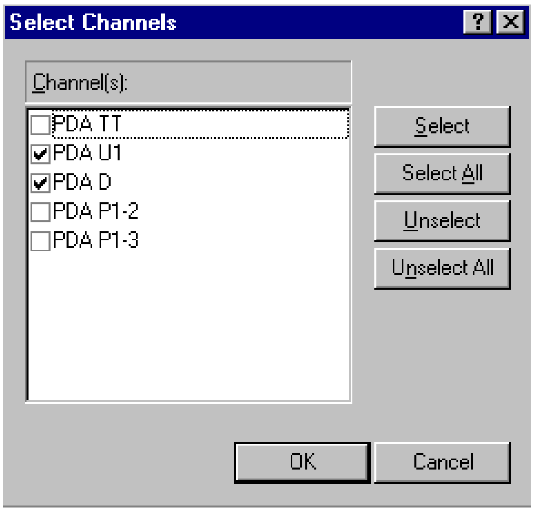
15. Click on the “1D PDA optics” icon in the “Config View” and you will get the optical properties in the property editor. They don’t have to be modified now because they have been set by the “Configuration Wizard”.

16. In the project explorer, click the PDA Application icon and then click the “New object” icon in the tool bar to add a new object (see step 6.). From the list, select “Histogram”. A window titled “PDA Application/Histogram - Histogram” appears, with the X-axis scaled to a default range.

17. Right mouse click in the window that appears, and click the “Configure” button in the window.

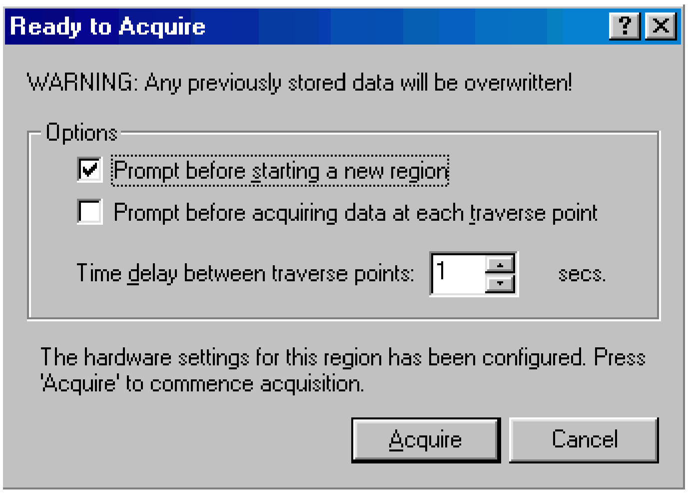


Select the channels PDA U1 and PDA D.



Click “OK”.

18. You are now ready to start acquisition of data. When the laser and the particle flow is in operation, go to the Project explorer, click the PDA Application and click the “Repetitive Run” or the “Run” button. Communication to the signal processor is starting, followed by the Data Overwrite Warning prompt.



Click “Acquire” to start data acquisition.

19. The automatic calibration routine will be performed prior to data acquisition. In the “Config View”, the background of the output properties at the right hand side will be grey, and the output properties will be updated during the measurement. Another indication of acquisition in process is that the “Run” button is dimmed.

20. The histogram will be updated during the measurement. With 1000 samples selected, all data is usually sent in a single block, so the histogram updates once only. The update rate depends on the data rate. With high data rates and a large number of samples, you will see several updates during an acquisition.

21. When the acquisition is completed, the background of the output properties window returns to white, and the “Run” button is clear again. Under the menu “Tools - Options - General” you can select “Feedback with sound”. With this option active, you will hear a beep from the PC when acquisition is completed.

22. You have now completed data acquisition in a single point. To save the data, click the Save button in the toolbar, and give the project file a name. It will be stored in the Projects folder.

23. You can add further processing objects, data lists or graphs by right mouse clicking on the PDA Application icon in the project explorer and selecting “new” from the dialog that appears.

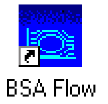
24. To save time when new objects have been added, you can run those objects alone by clicking on the highest level object you want to run, and then click the “Run” button or press F5 on the keyboard. This will run the object and it’s child objects.

4.11 How to load existing data

In this section you will get acquainted with the user interface by analysing sample data distributed along with the software.

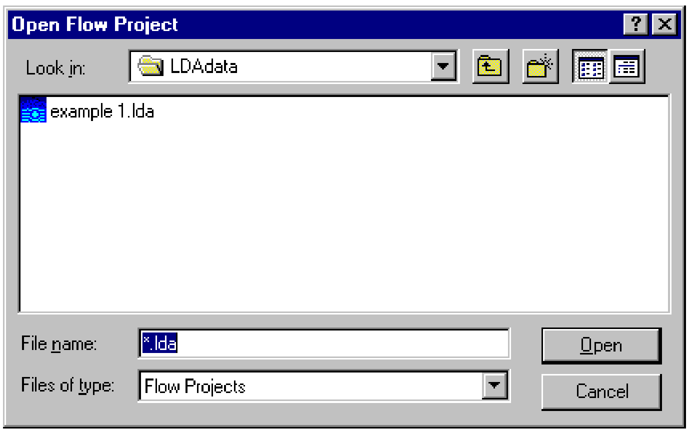
You can either read the sample data directly from the CD-ROM or copy it to a directory on your hard disk. The procedure below assumes that sample data is located in folder named Samples.

1. Double click the BSA Flow icon on the desktop.



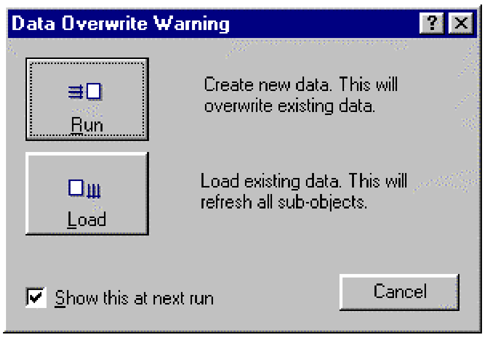
2. Click Open Project in the dialog box that appears.

3. In the Open window that appears, double-click the Samples folder. (The contents of this folder may differ from the list below).



4. Open a file in the list. The program will now open the workspace as it was saved .
5. In the project explorer, click on the BSA Application icon.

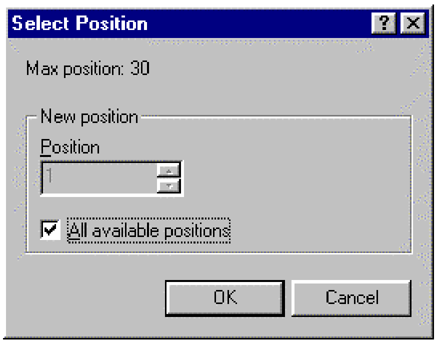
6. In the toolbar, click on the Run button. A Data Overwrite Warning appears:



Click Load.

7. The software now loads the data from disk and updates the objects in the project.

8. Click on the histogram window. It displays the histogram of the last position.
To select another position, right-click the Histogram object in the project explorer, and click Select position in the drop-down menu.



Unselect All available positions and type in the number of the position you want to get a histogram from (according to it's number in the list in the mesh). This will update the histogram with data from that position.

In the tool bar, there are buttons for "Previous position" and "Next position". This will display the histogram from the previous position (in the same order as shown in the measurement positions table in the BSA Application window).

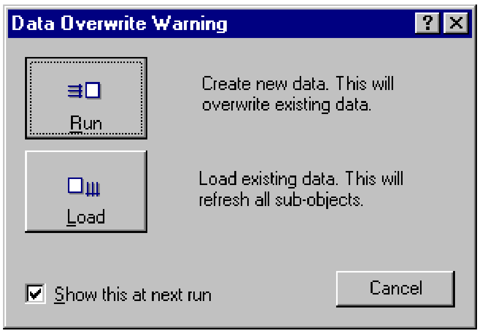
9. All views representing data from a single position can be updated as described above (lists, histograms, spectrum or correlation graphs, time series graphs, etc.)

10. New objects can be added to existing objects by clicking the “new object” button in the toolbar, or by right-mouse-clicking on an existing object. The prerequisite is that it is meaningful to add an object. It is not possible to add new objects to graph or list objects.

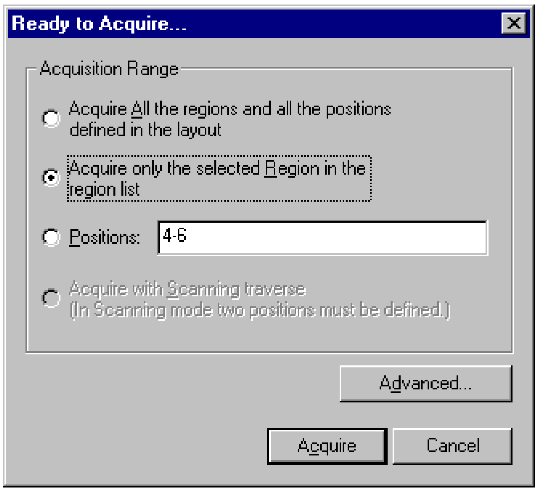
4.12 How to re-acquire data

4.12.1 With same settings

In Project Explorer, select BSA Application. Click the Run button. The Data Overwrite Warning appears:



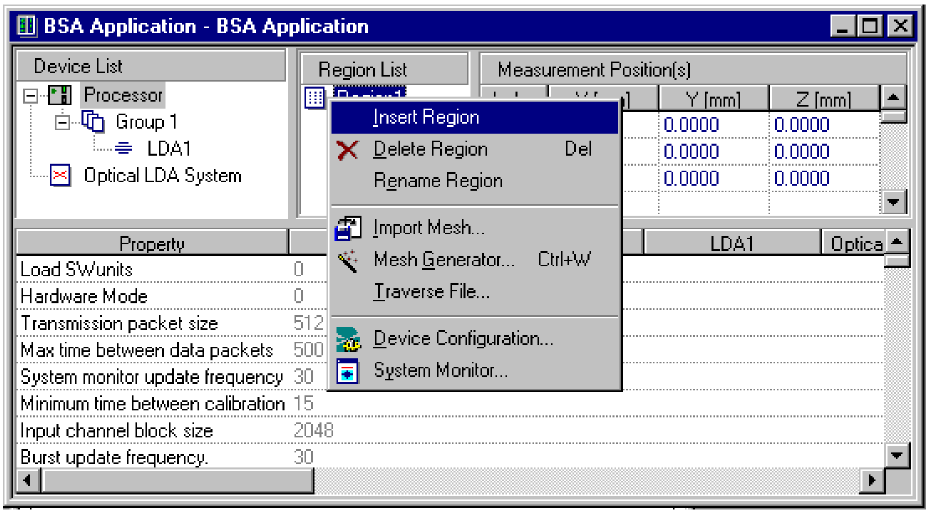
Click Run. In the Ready to acquire window that appears, choose the proper acquisition range (all regions, selected region or specified positions), and click Acquire.



If you have graph or lists views as child objects, these will only display the new points during acquisition. To see all points, you must select the BSA Application in the Project Explorer, and load data from there.

4.12.2 Point(s) with new settings

If you need to modify settings, e.g. the processor velocity range, you must add a new region: in BSA Application: right-click in the Region List, and select Insert Region:

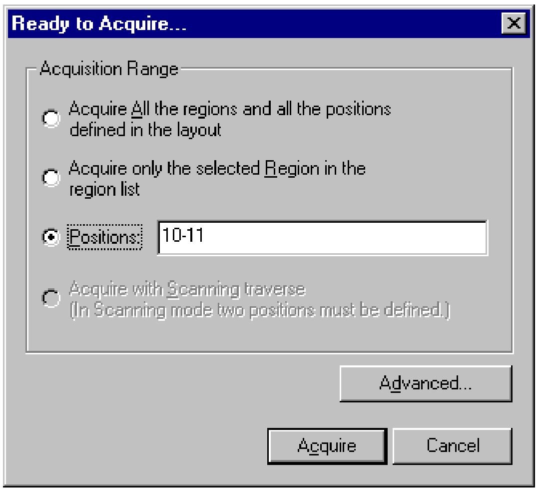


Define the positions that you want to acquire data in, either by typing the positions in, or using the Mesh Generator.
Click on the new region, and click on the Run button. This brings up the Data Overwrite warning. Proceed as described above.
If you have graph or lists views as child objects, these will only display the new points during acquisition. To see all points, you must select the BSA Application in the Project Explorer, and load data from there.

4.13 How to add new data to a project

In BSA Application, add the new positions to the position co-ordinates list.

Click the Run button. Click Run in the Data Overwrite Warning window. In the Ready to Acquire… window, select the Positions option, and specify the indices of the new positions:



Click Acquire.

If a complete new region was added, choose accordingly in the above dialog box.

5. Project explorer objects

This chapter describes the properties of objects available with the basic BSA software and the Particle Size Add-on.

Properties associated with other add-ons are described under the relevant add-on in chapter 6.

5.1 Accessing properties

The access to properties is different for the BSA F/P processors and for other processors.

With the BSA F/P processors, all properties are accessed from the BSA Application window:

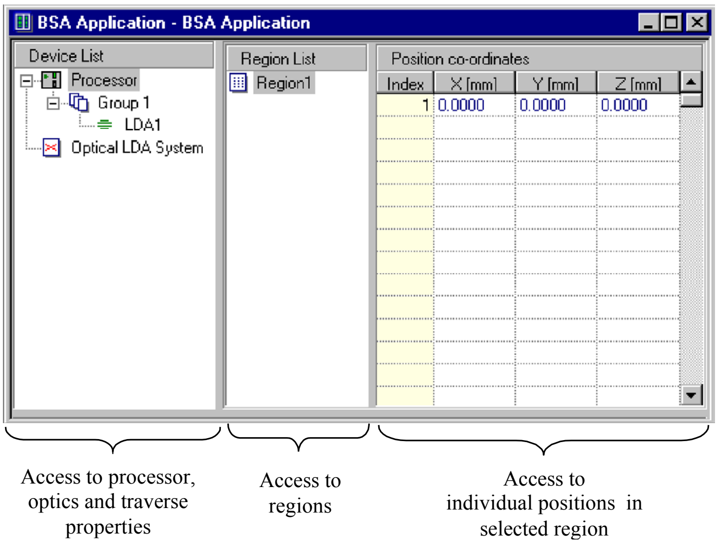


Figure 5-1 Access to properties from BSA F/P processors

When clicking on one of the icons in this window, the associated properties will be shown in the Property Editor.

With earlier processors (57N series BSA, 58N series FVA and PDA), access is via two windows: the Config View (for processor, optics and traverse properties), and the Layout view (for Regions and individual positions in a region):

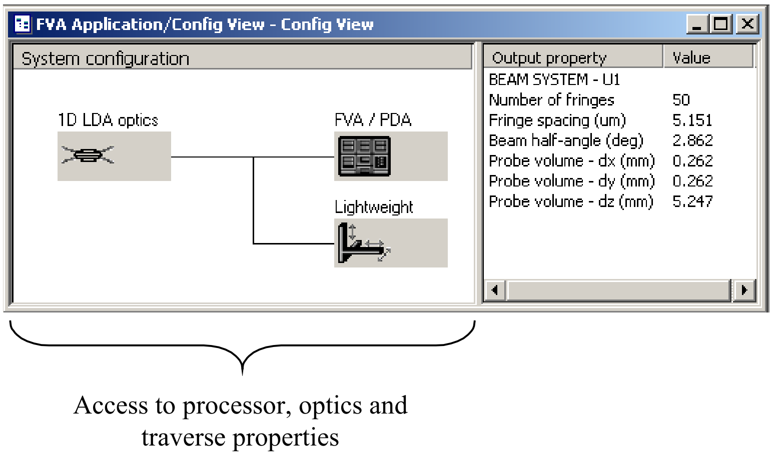


Figure 5-2 Access to hardware preperties from BSA, FVA and PDA processors

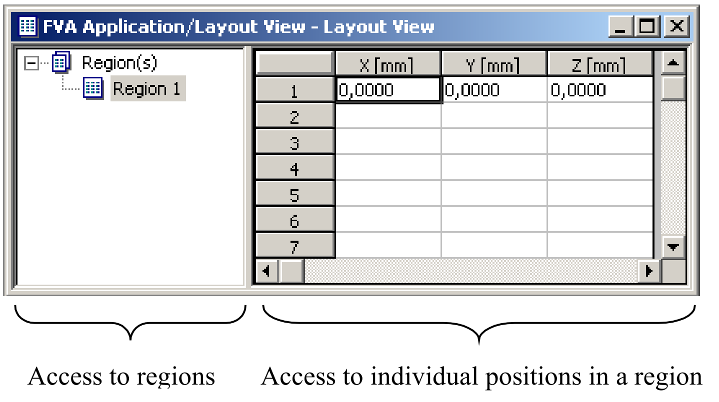


Figure 5-3 Access to Regions and individual positions in a region from BSA, FVA and PDA processors

The processor properties depend on the processor model. Optics and traverse parameters are identical for all processors (PDA optics properties apply only to BSA P and to PDA processors).

5.1.1 Accessing properties from BSA F/P Application

For processor set-up, please refer to section 5.4.
For LDA optics set-up, please refer to section 5.7.
For PDA optics set-up, please refer to section 5.8.
For traverse set-up, please refer to section 5.9.

5.1.2 Accessing properties from BSA Application

For processor set-up, please refer to section 5.5.
For LDA optics set-up, please refer to section 5.7.
For traverse set-up, please refer to section 5.9.

5.1.3 Accessing properties from FVA Application

For processor set-up, please refer to section 5.6.
For LDA optics set-up, please refer to section 5.7.
For traverse set-up, please refer to section 5.9.

5.1.4 Accessing properties from PDA Application

For processor set-up, please refer to section 5.6.
For PDA optics set-up, please refer to section 5.8.
For traverse set-up, please refer to section 5.9.

5.2 Start

The first object in a project is the Start object. The start object is the root of a project and is linked to one or more underlying source objects. Right mouse clicking on the Start icon gives you a list of possible source objects.

The example below shows two:

- BSA Application (see section 5.4 or Import velocity files (see section 5.3).

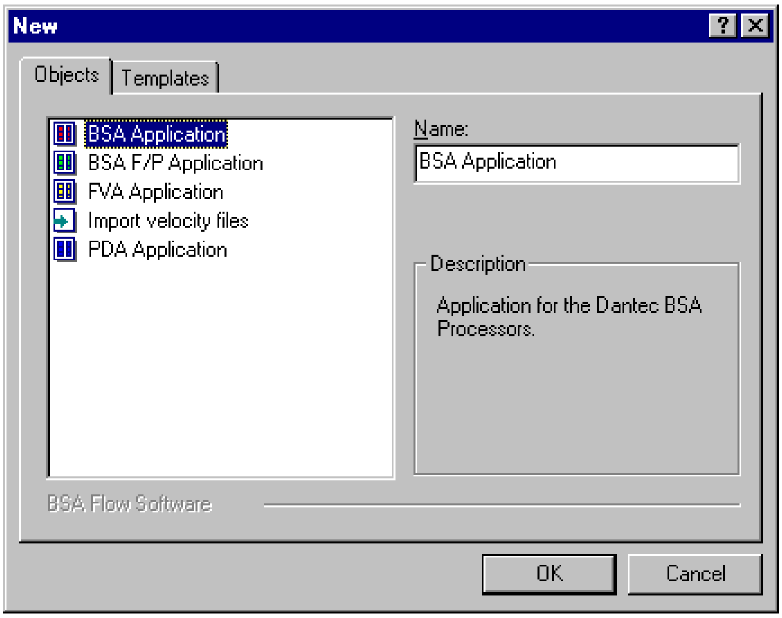


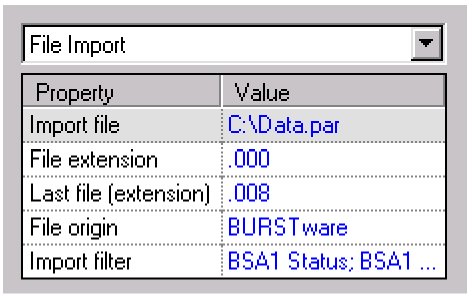
Figure 5-4 Dialog when right mouse clicking on the start icon.

5.3 Import velocity files

The Import velocity files object is used to import data from Burstware, Floware or Sizeware. The object looks for *velocity data files* associated with a parameter file, e.g Data.par as in the example below.

For the file naming conventions used in Burstware, Floware or Sizeware, please refer to the user's guides for these products.

Example properties are shown below:



File Import

Property	Value
Import file	C:\Data.par
File extension	.000
Last file (extension)	.008
File origin	BURSTware
Import filter	BSA1 Status; BSA1 ...

Figure 5-5 File Import properties

The three upper lines specify the path, the first and the last file to import.

The Import file property looks for files with the .par extension to import. To browse, click once on the Value field next to Import file, and click the browse button ... that appears. You can then find the relevant file as when you search for a file with the Windows explorer.

File extension specifies the first file to import, if the .par file selected is for a measurement with multiple positions. Burstware automatically generates file extensions for the individual positions .000, .001, ... .00a, ...00z, 010, ...ZZZ.

If you are interested in a single position among many, specify the data file's extension for that position in the File extension line.

If you are interested in all positions (typically for velocity profile and vector plots), specify .ZZZ as the Last file (extension).

If you are only interested in the file specified in the File extension line, leave the Last file (extension) blank.

The File origin line informs about the type of data is has found at the specified location. It can be either Burstware, Floware or Sizeware.

The Import filter line lists the data types available in the file(s) to import. You can select all or parts of the list to import. For example, if the files contain data from a two channel measurement, you can select data from one of the channels only if you wish. This is specified by tick marks in the drop down list accessed from the value field.

It is recommended always to include the Status from all processor channels.

5.4 BSA F/P Processor properties

The BSA Application controls hardware communication and data acquisition, and the measurement positions, the traverse mesh. The left hand part of the window controls the hardware settings. The properties of the hardware are displayed in the Property editor upon selection of the hardware in the Device list. These properties are explained in section 5.4 to 5.9.2. The generation of measurement positions, and the linking between these and hardware settings takes place in the right hand part of the window. This is described in section 5.9.7 to 5.9.8.3.

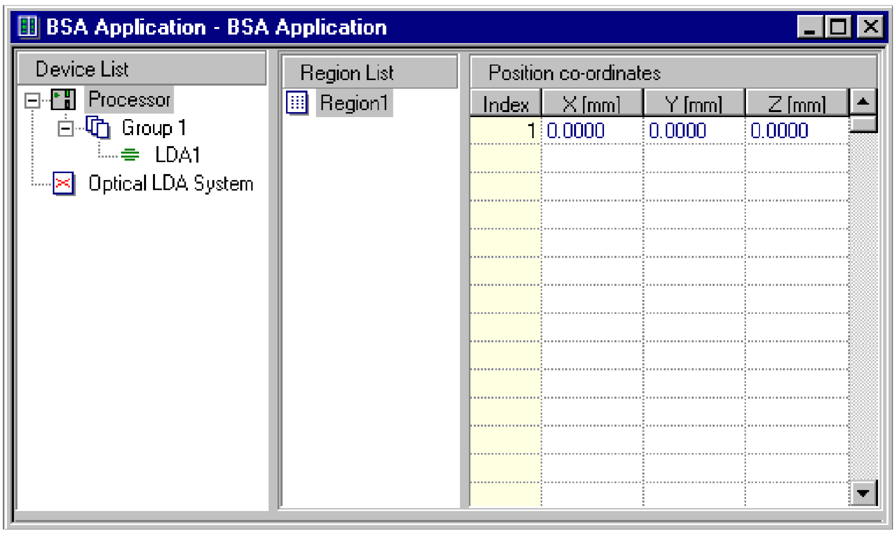


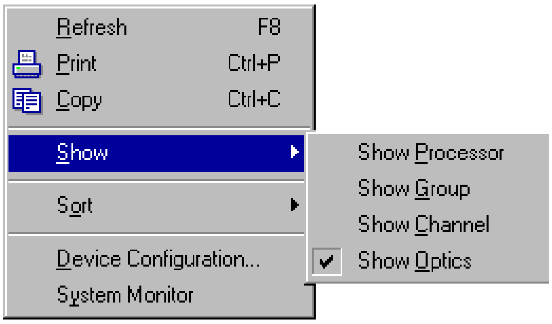
Figure 5-6 The BSA Application window for a 1D LDA system

Click on the Processor icon in the BSA Application window to see the user-controllable processor properties in the property editor.

The processor properties are divided into three levels:

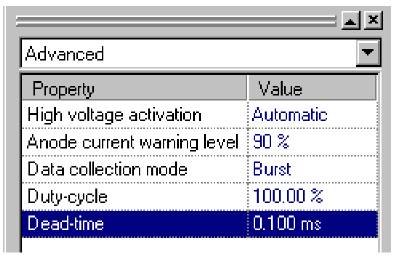
- Processor include properties common to all velocity channels
- Group comprises properties common to coincident velocity channels
- LDA1, LDA2, PDA1, PDA2 etc. set up properties, which are specific to each channel.

To get an overview of all current properties for hardware, look at the bottom of the BSA Application window. You can select which properties to show here by right-clicking in that part of the window and selecting Show. You may have to drag the BSA Application window larger to see the property listing.



Select Processor, Group and Channel to see all BSA properties. You can only select one at a time, so the procedure must be repeated for each item to show.

5.4.1 Advanced



- High voltage activation can be Automatic or Manual. In the former case, the photo-multiplier high voltage is switched on when the System monitor is active or when data acquisition (in repetitive mode or normal acquisition) is taking place. Automatic is recommended.

- Anode current warning level can be set from 50% to 150%. The setting determines at what level the System monitor indicates a warning about the photo-multiplier anode current. A protection circuit reduces the photo-multiplier high voltage if the *mean* anode current exceeds 100% of the Anode current limit (defined under LDA1). The *peak* anode current can exceed this limit during short intervals, hence the warning level can be set to exceed 100%.

- Data collection mode: can be Burst, Continuous, Dead Time or External. In most cases, Burst or Dead Time mode is used. Briefly explained, Burst mode is used when high temporal resolution is required, e.g. if the required result is auto-correlation or turbulence spectrum data, or in connection with rotating machinery.
  Dead Time can used to avoid over-sampling the velocity information, and thereby eliminate velocity bias. It is typically used when the required result is the moments of the velocity distribution (mean, RMS, skewness and flatness). It has the additional advantage of reducing the data file size, compared to the other modes.
  Please consult chapter 8 for more information on how to use the different modes.

  Burst is used when the photo-detector signal consists of discrete bursts from seeding particles, and when a high data rate is required. There is one measurement per detected burst, producing arrival time, transit time and velocity information.

  Continuous mode is used if the Doppler signals appear as quasi-continuous signals. This is typically the case when measuring the velocity of a solid surface. In continuous mode, the burst detector is not used, and the photo-detector signal is processed continuously. Several measurements can be taken during each burst. Auto-adaptive record length is not applicable in this mode.

  In Dead time mode, the time axis is divided into intervals. In each interval, only the first Doppler burst is processed. The interval is specified in the Dead-time property.

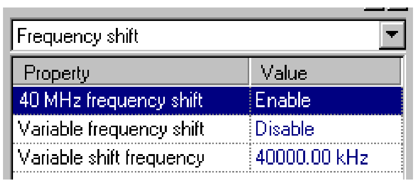
  In the External (trigger) mode it is possible to use an external burst detector. The external device is connected at the rear panel to the connector specified in the Sync. Input Signals list under the Burst detector signal property. TTL levels are used.

- Duty cycle is only applicable to Continuous mode. The duty cycle is defined as the percentage of records transferred to FFT processing. It is used in experiments with a very high data rate to prevent an input buffer overflow. Possible values are shown in the drop down list.

- Dead-time is only applicable to the Dead Time data collection mode and defines the length of the time interval, from which to process the first burst.

- Calibration mode (only available with Particle Size add-on).

5.4.2 Frequency shift



These properties control the signals on the Bragg cell connectors at the rear panel of the BSA. These can be used individually or in combination.

Note	The 40 MHz output includes DC supply compatible with Dantec Bragg cells. The Var. output only supplies an AC signal.

The connector 40 MHz is used with LDA optics using 40 MHz optical frequency shift, such as most Dantec FiberFlow and FlowLite systems, and in dual-Bragg cell systems with one cell operating at 40 MHz.
The connector Var. is used with LDA optics using other drive frequencies to the Bragg cell, and in dual-Bragg cell systems with the first Bragg cell operating at 40 MHz.

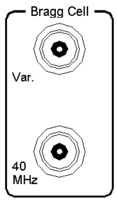


Figure 5-7 The Bragg cell connectors on the BSA rear panel

- 40 MHz frequency shift: The value can be Enable (default) or Disable.
  Enable activates the BNC connector named Bragg cell 40 MHz.
  Disable disconnects the 40 MHz signal from the connector.

- Variable frequency shift directs a Bragg cell driver signal to the BNC connector named Bragg cell Var. The drive frequency is defined by the property Shift frequency.

- Variable shift frequency defines the frequency of the driver signal at the Bragg cell Var. connector.

5.4.3 Synchronisation Inputs and Outputs

The BSA has a number of input and output connectors for synchronisation and handshake with external equipment. The software controls the routing of these signals to/from the connectors on the rear panel through the Sync. Input Signals and Sync. Output Signals properties.

Note	The BSA F50 processor requires the 62N560 Synchronisation option to make use of these inputs and outputs

The synchronisation input connectors are the three BNC connectors named Programmable Input 1, 2 and 3, and the 25-pin D-sub connector underneath these as shown on the figures below.
The Optional Input connector is reserved for future extensions of functionality.

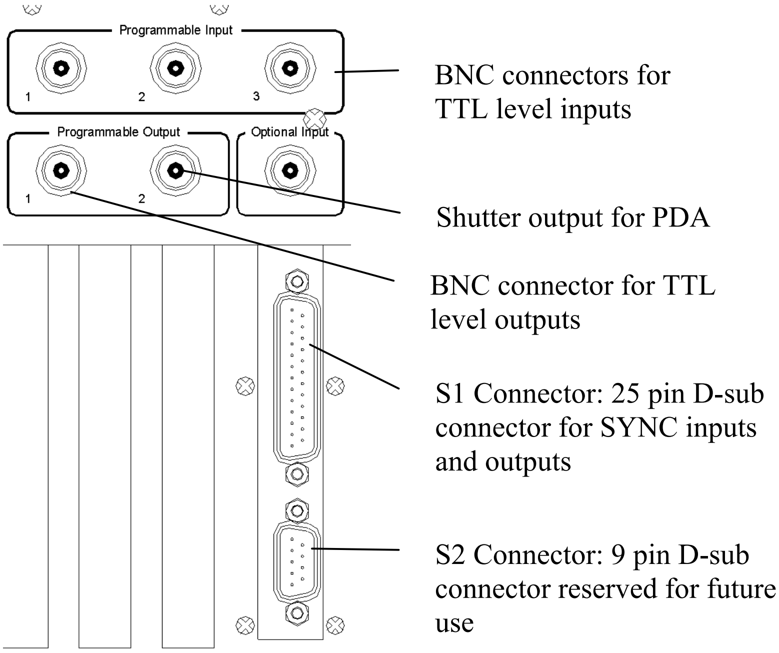


Figure 5-8 The synchronisation input connectors on the BSA

The pin numbering of S1 and assignments are shown in Figure 5-9 and Table 5-1. Please note that some of the pins are assigned to Sync outputs which are described in the next section.

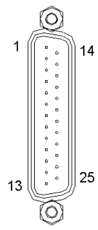


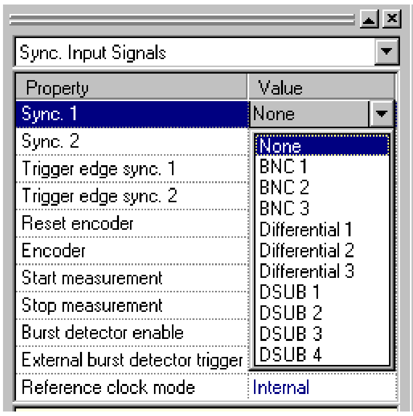
Figure 5-9 Pin numbering on the S1 connector

Pin	Signal	Pin	Signal
1	Out 1	14	Ground
2	Out 2	15	Ground
3	Out 3	16	Ground
4	DSUB 1	17	Ground
5	DSUB 2	18	Ground
6	DSUB 3	19	Ground
7	DSUB 4	20	Ground
8	Differential 1 -	21	Ground
9	Differential 1 +	22	Ground
10	Differential 2 -	23	Ground
11	Differential 2 +	24	Ground
12	Differential 3 -	25	+ 5 Volt
13	Differential 3 +		

Table 5-1 Pin assignments on the S1 connector

Please refer to the technical data of the 62Nxx BSA regarding signal levels etc.

5.4.4 Sync. Input Signals properties



- Sync 1 signal is used with cyclic events to mark the beginning of a cycle or revolution. Thus it should be generated once per cycle. The reset pulse from an angular encoder can be connected to this input. This signal is used in the Cyclic Phenomena add-on software to scale angle or phase information.
- Sync 2 signal is used for encoder pulses. This signal is connected to a counter, which is read when a Doppler burst is detected. The counter is reset whenever a Sync 1 pulse is received. The counter reading is used to relate the velocity measurements to the angular position of the encoder. In the Cyclic phenomena add-on, data can be sorted according to the angular position for plotting e.g. velocity vs. angle. The angular resolution is defined by the number of encoder pulses per revolution or per cycle.
  If the angular speed is constant, the Sync 1 signal combined with the

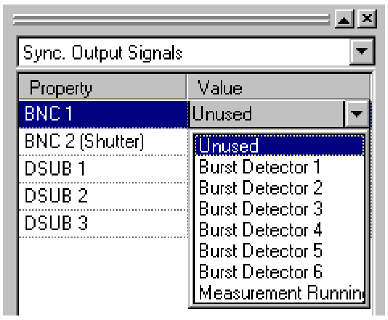
BSA's clock provide better angular resolution.

- Trigger edge sync. 1: can take the values Positive or Negative. Determines whether the SYNC 1 input triggers on a positive going or negative going edge of a trigger pulse.
- Trigger edge sync. 2: see above
- Reset encoder: used for once-per-revolution encoder pulses
- Encoder: used for encoder pulses.
- Start measurement: trigger input, will start data acquisition and hence the BSA's arrival time counter on the rising edge of a TTL pulse
- Stop measurement: trigger input, will stop data acquisition on the falling edge of a TTL pulse.

Note	*The same TTL signal can be used to start and stop the measurement, if both* Start measurement *and* Stop measurement *are connected to it.*

- Burst detector enable: this can be used as a gate signal to enable measurements only during the time that this signal is high (TTL level). The difference between this input and the start/stop inputs is that start/stop starts and stops the arrival time counter, whereas the Burst detector enable just enables or disables detection of bursts, while the arrival time counter keeps counting.
- External burst detector trigger: can be used in connection with third-party burst detector circuits.
- Reference clock mode: can be Internal or External. Default is Internal. If two or more BSA boxes are used together, one of them should have this property set to internal, and the BNC connector "10 MHz Ref Out" from this unit should be connected to the "10 MHz Ref In" on the other BSA(s), which should have this property set to External.

5.4.5 Sync. Output Signals properties



Two types of TTL signals can be mapped to the connectors "Programmable Output 1" or "S1":
A Burst Detector signal from one of the velocity channels, or a Measurement Running signal.
The Burst Detector signal is a TTL signal which is high for the duration of the burst. It is delayed by approx. 8 ms to the photo-multiplier signal.
The measurement running signal is a TTL signal which is high during acquisition. This can be used for gating external equipment during LDA data acquisition.

The connector "Programmable Output 2" is called BNC 2(Shutter) in the software. It is used to control the shutter in PDA receiving optics.

5.4.6 Group properties

Coincidence group

Property	Value
Max. samples	2000
Max. acquisition time	10.00 s
Filter method	Overlapped
Burst window	0.010 ms
Scope zoom	400 %
Encoder data	Excluded
High voltage	Off

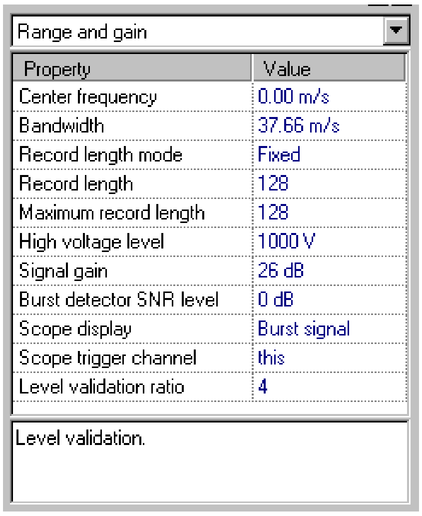
Coincident data from velocity channels are obtained by placing those channels in a common group. The group properties are common for all channels in that group. If coincident data are *not* required, the channels can be placed in separate groups. It is possible to perform subsequent coincidence filtering of data from separate groups by adding a Coincidence object to a project, see section 5.10.

- Max. samples: stop criterion for data acquisition for the selected coincidence group.
- Max. acquisition time: stop criterion for data acquisition for the selected coincidence group.

  Acquisition stops when one of the two criteria is fulfilled.
- Filter method: Can be Overlapped or Windowing. This determines how coincidence filtering is done.
  Overlapped requires that bursts partly overlap.
  Windowing requires that bursts are detected within a time window defined by the Burst window property. This setting may be useful when measuring through curved window surfaces, where burst overlap may not be possible. With a PDA system, channel LDA1, PDA2 and PDA3 are always running in Overlaping mode. The Windowing option can be used only in case of 2D or 3D PDA systems.
- Burst window: defines the time window for coincidence filtering by the Windowing method.
- Scope zoom: determines the scaling of the Doppler monitor time axis. Values can be typed in or chosen from the list. The highest possible value is 3200%.
- Encoder data can be Excluded or Included. Must be Included when the SYNC input signals property Encoder is connected to a rear panel connector.
- High Voltage can be set Off or On. Default is Off.
  If automatic high voltage activation has been selected under the Processor – Advanced properties, this property can be left Off.
  If manual high voltage activation was chosen, the photo-multiplier high voltage is switched on or off using this property.
  If different groups are defined, high voltage must be activated individually in each group.

5.4.7 LDA 1, 2, .. properties

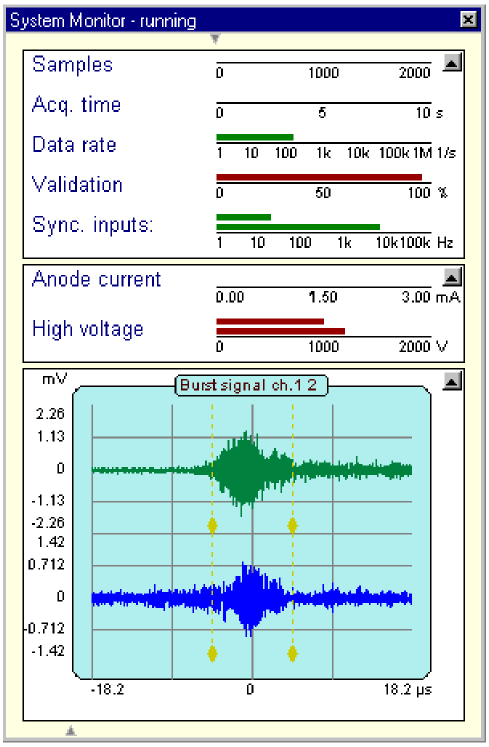
5.4.7.1 Range and gain



- Center frequency is used to set the center of the required velocity range. It should be set according to the estimated mean velocity in the flow. You can type a value or select one from the list. If you type a value, the software will select the nearest possible value of the processor. The unit can be m/s, ft/s or ft/min. This, and the format of the figures, is specified from the Tools - Options – Data formats menu. Under the list of data types, a check box Display velocity as frequency must be checked if the Doppler frequency should be shown instead of velocity.
- Bandwidth: the width of the velocity range around the center frequency. Units are the same as for the center frequency. Bandwidth should be set according to the expected range of fluctuations in flow velocity. If in doubt, set a large bandwidth to begin width, define a histogram and make an acquisition. Zoom in to proper center frequency and bandwidth afterwards.
- Record length mode: can be Auto-adaptive (BSA F70 only) or Fixed. In auto-adaptive mode, the processor will adapt the record length individually to each burst, within the limits specified by the Record length and Maximum record length values.
  In Fixed mode, the Minimum record length value is always used.
  To estimate the required record length, use the Doppler monitor display.
- Record length: sets the number of samples of the shortest record length in Auto-adaptive mode, or the applied record length in Fixed mode.
- Maximum record length: sets the number of samples of the longest record length in Auto-adaptive mode. Not used in Fixed mode.
- High voltage level: sets the high voltage to the photo-multiplier. The recommended starting level is around 1000 V. Depending on the seeding, the laser power, the LDA optics and the position of the measurement volume in the flow, the optimum may be higher or lower. Optimisation should take both this property and the Signal gain into account. The criterion may be the validation rate or the data rate or some compromise between them, depending on the application. The validation rate and data rate are displayed in the System monitor window.

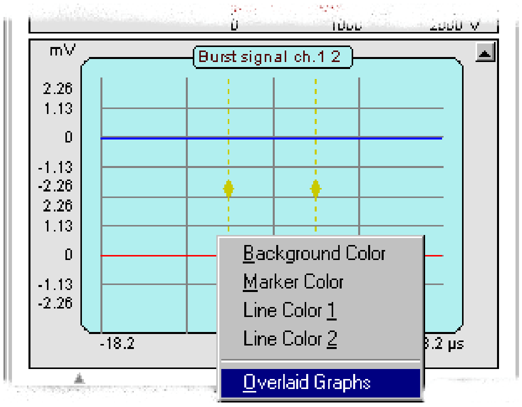
- Signal gain: sets the gain of the photo-multiplier signal amplifier. Recommended starting level is around 24 dB. Should be optimised together with the high voltage as described above.
- Burst detector SNR level: sets the SNR threshold level of the SNR based burst detector. The default value is 0 dB. High values will reject more noisy bursts, leading to higher validation and lower data rate, and vice versa.
- Scope display: Can be Burst signal or Off.
- Scope trigger channel: Value can be Free run, this, or 1 to 6 (velocity channels).
The Doppler monitor is digitally triggered at the center of a burst except in free run.
In normal operation, the trigger channel should be set to this.
If dependency between velocity channels is investigated (e.g. to check coincidence), the trigger channel could be another velocity channel.
Free run can be used to get an impression of the data rate or background noise.
- Level validation ratio: (BSA F70 and P70 only): Level validation looks at the ratio between the two highest peaks in the burst spectrum. If the ratio is higher than the specified value, the burst is validated, otherwise it is rejected.

5.4.7.2 System monitor



The system monitor window is opened by right-clicking on the BSA Application icon in the project explorer, or by right-clicking anywhere in the BSA Application window, and selecting System monitor from the drop down list. The example above is for a 2-channel setup with encoder signals connected to SYNC1 and SYNC2.

The System monitor window displays bar graphs of acquisition parameters such as elapsed acquisition time, number of acquired samples, data rate, validation and synchronisation pulse rate, when the SYNC1 and SYNC2 inputs are defined.
It also shows an oscilloscope-like display of the Doppler signal. The purpose of this is to monitor the Doppler bursts during set-up and optimisation of the processor, optics and seeding, and to get an estimate of the required record length.

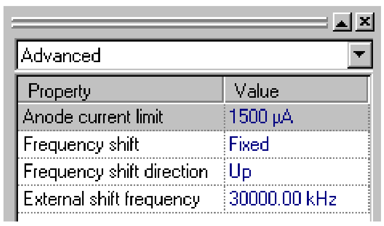


The colour(s) of the signal traces can be modified by right-clicking in the burst signal window. The traces can be overlaid from the same dialog.

The System monitor display evidently requires some resources of the PC, which is not critical in low to medium data rate cases (data rate up to some kHz).

In applications with high data rates, it is recommended to switch the System monitor off to free as many system resources in the PC as possible.

5.4.7.3 Advanced



Advanced

Property	Value
Anode current limit	1500 µA
Frequency shift	Fixed
Frequency shift direction	Up
External shift frequency	30000.00 kHz

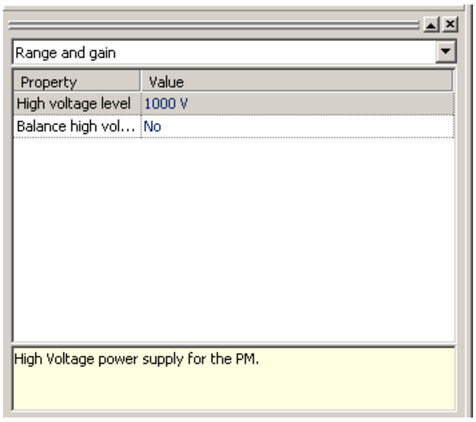
- Anode current limit: to protect the photo-multiplier tube e.g. when approaching walls, the BSA includes a current limiter circuit which reduces the high voltage if the photo-multiplier anode current exceeds the set limit. For Dantec standard photo-multipliers 57X08 and those used in FlowLite optical systems, the limit should be set to 1500 µA. For other photo-multipliers, please consult the suppliers' technical specifications.
- Frequency shift: can be Off, Fixed, Variable or Manual.
  Off is used for unshifted optical systems, or if the "raw" signal frequency including the shift frequency is to be measured.
  Fixed is used with LDA optical systems using 40 MHz Braggcell such as most Dantec systems.
  Variable is used when the BSA processor property Variable frequency shift is enabled.

Manual is used to specify the frequency shift when third party frequency shift equipment is used, if this is not driven by the BSA's Bragg cell outputs.

- Frequency shift direction: the normal value is Up. In this case, a positive flow velocity will produce a photo-multiplier signal frequency higher than the shift frequency.
  Down is used if the optical system is set up to reduce the signal frequency by an amount corresponding to the shift frequency. This is typically the case if the velocities are so high that they would produce out-of-range signal frequencies for the processor, if Up was chosen.
- External shift frequency is used to specify the effective frequency shift when using third party frequency shift equipment.

5.4.8 PDA 1,2 properties

5.4.8.1 Range and gain



- High voltage level: sets the high voltage to the photo-multiplier. The recommended starting level is around 1000 V. Depending on the size of the particles, the laser power, the PDA optics and the position of the measurement volume in the flow, the optimum may be higher or lower. Optimisation should take both this property and the Signal gain into account. The criterion may be the validation rate or the data rate or some compromise between them, depending on the application. The validation rate and data rate are displayed in the System monitor window.
- It frequently occurs that two photomultipliers of the same type require different high voltage levels to generate the same signal amplitude. This is due to sensitivity variations. Once the high voltage levels for all PMs have been set accordingly, the Balance can be enabled to maintain the ratio.

5.5 BSA Processor properties

Click on the BSA icon in the Config view to see the user-controllable BSA properties in the property editor.

For details about BSA properties, please refer to the BSA Installation and User's guide, chapter 4: Front panel operation.

At the right hand side of the Config view window, the BSA's *output properties* are displayed. As the name indicates, these are read from the BSA and cannot be edited. Please see the next section for details of the output properties.

The BSA properties are organised in four groups for clarity:

- Range/Gain include the most frequently used properties, such as the center frequency, the span, the photomultiplier high voltage and gain settings
- Timing/Triggering sets up the clock and coincidence modes of the BSAs
- Data collection/Buffering sets up stop criteria for data collection, and the output buffer mode is specified here
- Advanced options include pedestal attenuation setting, oversize reject , PM current limit and other properties which are seldom modified.

5.5.1 Optimisation of BSA property settings

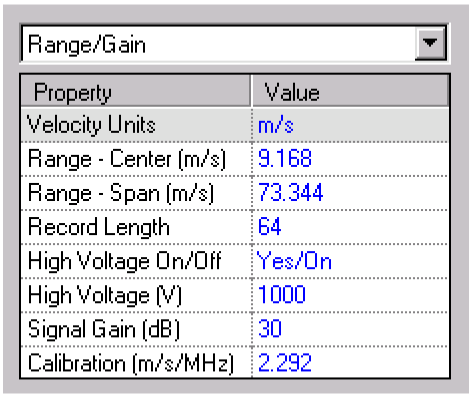
The main parameters to optimise are normally the validation and the data rate. With BSAs with active front panel these are displayed on the front panel.

In the software, these values are shown in the BSA output properties window during acquisition.

Note	*You can get continuously updated BSA output properties without acquiring data by running in Repetitive acquisition mode.* *This is done by clicking on the Repetitive button in the tool bar.*

After optimisation it is recommended to disable polling, since polling slows the software down due to frequent communication with the hardware.

5.5.2 Range/gain


Range/Gain

Property	Value
Velocity Units	m/s
Range - Center (m/s)	9.168
Range - Span (m/s)	73.344
Record Length	64
High Voltage On/Off	Yes/On
High Voltage (V)	1000
Signal Gain (dB)	30
Calibration (m/s/MHz)	2.292

Figure 5-10 The BSA Range/Gain properties

- Velocity units can be m/s or Hz
- Range - Center: type in or select from drop-down list in the Value field
- Range - Span: type in or select from drop-down list in the Value field

A quick way to set up the center frequency and span is to use the processor wizard (see section **Error! Reference source not found.**).

Note:	*If the processor wizard is used to modify a property, all the properties defined in the wizard are transferred to the BSAs. If e.g. the measurement time has been set to 10 seconds in the property editor, and the processor wizard is activated to modify something else, and has a different value of the measurement time, value from the wizard will override the value from the property editor*

Manual selection can be done either by selecting a value from the drop-down list or by typing a value. In the latter case, the nearest available setting is selected by the software.

- Record Length: legal values 8, 16, 32 and 64, type in or select from drop-down list in the Value field.

Note	*The record interval is displayed in the BSA output properties. It depends on the* Record length *and the* Span *settings. It must be set to match the shortest burst lengths. Please check this by connecting the monitor output of the BSA to an oscilloscope (see section 3.6).* *The validation will normally have an optimum when the record length is well matched to the burst duration.* *For more details, please refer to the BSA Installation and User's guide, chapter 4.*

- High Voltage On/Off controls the high voltage to the photomultipliers.

Note	*High voltage for all BSAs can be switched on or off by right-clicking on one of the BSA icons in the* Config view *and selecting from the dialog that appears*

- High Voltage: type in or select from drop-down list in the Value field. The high voltage setting should be optimised to the seeding and optics configuration. A good starting point (for Dantec's model 57X08 photomultipliers) is 1000 V. Too high setting gives noise resulting in low validation. Too low setting may give high validation, but less than optimum data rate because bursts from small seeding particles will not be detected.
- Signal Gain: type in or select from drop-down list in the Value field. Signal gain should be optimised to the seeding and optics configuration. Usually 25 to 35 dB is used with 57X08 Photomultipliers.

Note	*Optimisation of high voltage and gain is a trial and error process. The parameters to optimise are:* *data rate* *validation* *These are displayed in Output properties part of the* Config view *window. To get continuous updating of the data rate and validation, enable polling (right-click on the BSA icon, select enable polling)* *There is some trade-off between data rate and validation, so the best setting depends on the application:* *If temporal resolution is important, data rate may be the highest priority.* *If high accuracy is important, validation should be the highest priority.*

- Calibration refers to the calibration factor for the beam system connected to the BSA. The calibration factor can be conveniently defined and set up using the Configuration wizard - Optical parameters (see section **Error! Reference source not found.**).

5.5.3 Timing/triggering

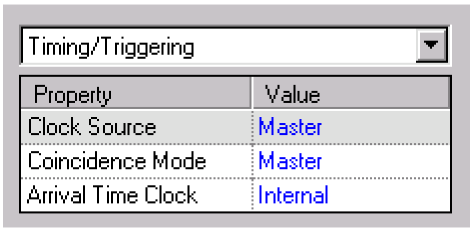


Figure 5-11 The BSA Timing/Triggering properties

The Timing/Triggering properties are used to set up the clock and coincidence modes of the BSAs. For details about these, please consult the BSA Installation and User's Guide, chapter 6.

Note	*It is important that the timing/triggering set-up has been completed before any acquisition is attempted. Incorrect settings may mean that no data is acquired.*

Recommended settings

If a 1 channel configuration has been defined in the Config view, the BSA wizard send the following set-up to the BSA:

1 channel configuration

Clock Source	Private
Coincidence Mode	Private
Arrival Time Clock	Internal

If a 2- or 3-channel configuration has been defined in the Config view, and the Coincidence check box is ticked, the BSA wizard send the following set-up to the BSA:

2 or 3 channel configuration	**BSA1**	**BSA2**	**BSA3**
Clock Source	Master	Slave	Slave
Coincidence Mode	Master	Master	Master
Arrival Time Clock	Internal	Internal	Internal

Clock source

If coincident data from two or more BSAs is required, one of the BSAs has to be set to clock source master, and the other(s) to slave.

If you have a combination of master and slave BSAs, it is recommended that the master BSA is used as channel 1 (GPIB address 13), because the BSA wizard assumes that the first channel can be set to clock source master. Slave BSAs cannot be set to clock source master.

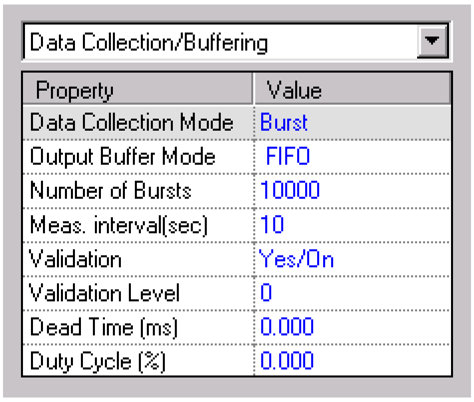
If coincidence is not required, all BSAs can be set to private.

Coincidence Mode:In 1 channel configuration it must be set to private.
In 2- or 3-channel configurations, there must be at least one master, but all BSAs can be set to coincidence master as well.

Note	*For correct function of hardware coincidence, the record interval of the BSAs must be identical.*

Arrival time clock This is set to internal in most situations. If an encoder is used in rotating machinery, external clock can be used, but in most cases internal clock is better. Please consult chapter 6 for details.

5.5.4 Data collection/Buffering


Data Collection/Buffering

Property	Value
Data Collection Mode	Burst
Output Buffer Mode	FIFO
Number of Bursts	10000
Meas. interval(sec)	10
Validation	Yes/On
Validation Level	0
Dead Time (ms)	0.000
Duty Cycle (%)	0.000

Figure 5-12 The BSA Data Collection/Buffering properties

Data collection mode

Can be Burst, Continuous, Controlled Dead Time or External Trigger.

In most cases, Burst or Controlled Dead Time mode is used. Please consult chapter 8 for more information on when to use which of the two modes.

Continuous mode is mainly used if the LDA system is measuring the velocity of a solid surface, which produces quasi-continuous signals.

Please consult the BSA Installation and User's Guide for details about the External Trigger.

Output Buffer Mode

Can be One-shot or FIFO (First In First Out).

FIFO is recommended, because it allows continuous updating of the data rate and validation display in the Config view's BSA output properties window. FIFO may cause loss of some data in extreme cases with very high data rates, but the data will not be corrupted.

In One-shot mode, there is no data loss, but there is no updating of the BSA ouput properties window till after completion of the data acquisition. The BSA writes data to its output buffer, and data transfer to the PC takes place, when the requested number of samples have been acquired.

The max. possible number of samples in One-shot mode is limited by the BSA output buffer length, which depends on the BSA model:

BSA model	Output buffer size (each sample includes velocity, transit time and arrival time*)
57N20 BSA enhanced master 57N21 BSA enhanced master 57N35 BSA enhanced slave	131070
57N11 BSA master 57N26 BSA slave	43690
57N10 BSA 57N25 BSA slave	10922

* In continuous data collection mode, transit time information is not available.

Note	*BSAs model 57N10 and 57N25 cannot be set to One-Shot mode with BSA Flow Software*

In FIFO mode, data is read into the BSA Output buffer and out to the PC at the same time. Therefore, very long records of flow data can be taken, provided the read-out is faster than the read-in rate. If read-in is faster than read-out, out buffer overflow conditions will appear, and the BSA will stop masuring till there is room available in the output buffer again. This causes “holes” in the time series, but the arrival time information is correct after an output buffer overflow condition.

Number of Bursts

One of the stop criteria for data collection. (The other one is Meas. interval). For moments (see chapter 8) the required number of bursts is typically in the order of 1000 to 2000, depending on the flow and required confidence level.

For spectrum and/or correlation measurements, the number of bursts is typically more than 10000. The effect of increasing the number of bursts is clearly seen when a 2D Plot of a spectrum is updated during acquisition: the scatter of the spectral function at high frequencies becomes smaller as the number of processed blocks increases.

Meas. Interval (sec)

The longest acquisition time per measurement position. Acquisition stops when either the Number of Bursts or the Meas. Interval criterion is fulfilled.

Validation If set to Yes/On, only validated samples will contribute to the number of bursts count and be stored.

If set to No/Off, all samples (validated and non-validated) will contribute to the number of bursts count and be stored.

Validation Level This property is normally set to 0. If the BSA includes the variable validation option, the validation criteria can be changed using this property. Please consult the "BSA Installation & User's guide - Variable spectral level validation option" chapter for proper settings.

Dead time (ms) If the Data Collection Mode is set to Controlled Dead Time, the dead time interval is defined by this property. See chapter 8 for instruction about proper settings.

Duty cycle (%) If the Data Collection Mode is set to Continuous, the duty cycle is defined by this property. Please consult the BSA Installation & User's guide, chapter 4 for details.

5.5.5 Advanced options

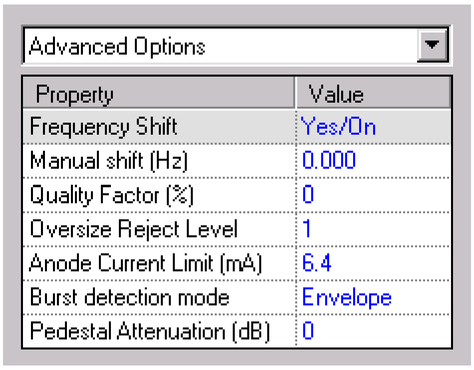


Figure 5-13 The BSA Advanced Options properties

Frequency Shift If the BSA includes a built-in frequency shift unit, frequency shift can be switched on or off by this property. With Frequency Shift on, the Range - Center property can be set to negative values, 0 or positive values (see section 5.5.2). With frequency shift off, only positive Range - Center values can be set.

Manual shift (Hz) If an external frequency shift device is used, this property is used to inform the software about the frequency shift. The Frequency Shift property should then be set to No/Off.

Some LDA systems include a downmixer mixing the signal frequency down from e.g. 40 MHz. The input to the software must be the effective frequency shift.

Example:

An LDA system with Dantec's 55N10 Frequency Shifter is used. The shift frequency of the frequency shifter is set to 1 MHz. Depending of the sign convention, the input to the software should be either 1000000 (Hz) or -1000000 (Hz).

Quality Factor (%) Please consult the BSA Installation & User's guide, chapter 4, for details.

Oversize Reject Level Please consult the BSA Installation & User's guide, chapter 4, for details.

Anode Current Limit (mA) To protect the photomultiplier tube e.g. when approaching walls, the BSA includes a current limiter circuit which reduces the high voltage if the photomultiplier anode current exceeds the set limit.

Recent Dantec LDA systems use model 57X08 Photomultipliers. For these, the limit should be set to 1.6 mA.

Older Dantec LDA systems may use model 55X08 Photomultipliers. For these, the limit should be set to 0.1 mA.

Burst detection mode Please consult the BSA Installation & User's guide, chapter 4, for details.

Pedestal Attenuation (dB) Please consult the BSA Installation & User's guide, chapter 4, for details.

5.5.6 BSA output properties

Output property	Value
BSA1	
Data Rate (kHz)	0.111
Validation (%)	34
Samples collected	1000
Elapsed time (s)	9.128
Anode Limiter	No/Off
Record interval (us)	5.333

Figure 5-14 The BSA output properties

The BSA output properties are displayed at the right hand side of the Config view window, when a BSA icon is selected.

It provides information about the data acquisition conditions. During acquisition, all the listed properties except Record interval (us) are updated.

If the BSA is not equipped with the Active Front Panel, the Output property window is useful for optimisation of the BSA settings. When loading existing data files, it shows the acquisition conditions at the end of each acquisition. In the example above, the stop criteria were Number of bursts: 1000, and Meas. Interval: 20 seconds, and the acquisition stopped when the Number of bursts criterion was satisfied.

The Record interval (us) property is important for optimisation of the record interval to the burst duration. It should be closely matched to the shortest bursts. The burst duration can be estimated either by looking at the BSA monitor output signal on an oscilloscope, by making a Histogram of the Transit Time, or by making a List with BSA Application or FVA Application as the parent object.

The Validation (%) will reach an optimum, when there is a good match between the burst duration and the Record interval (us).

5.6 FVA/PDA Processors properties

Click on the FVA/PDA icon in the Config view to see the user-controllable FVA/PDA properties in the property editor.

For information about the principles of the FVA, please refer to the manuals supplied with the processor.

At the right hand side of the Config view window, the FVA/PDA's *output properties* are displayed. As the name indicates, these are read from the FVA/PDA and cannot be edited. Please see the next section for details of the output properties.

The FVA/PDA processor properties are organised in six groups for clarity:

- General contains number of channels, high voltage on/off, encoder mode, Bragg cell control and A/D input. For PDA processors, the diameter measurement can be enabled.
- Range/Gain includes the frequency bandwidth and gain settings
- High voltage includes the photomultiplier high voltage setting for all channels

- Data validation determines validation criteria and minimum SNR
- Data collection sets up stop criteria for data collection
- Advanced options specify burst detection mode and timer characteristics

5.6.1 Optimisation of FVA/PDA property settings

The main parameters to optimise are normally the validation and the data rate. In the software, these values are shown in the FVA/PDA output properties window during acquisition.

Note	*You can get continuously updated FVA/PDA output properties without acquiring data by running in Repetitive acquisition mode.* *This is done by clicking on the Repetitive button in the tool bar.*

5.6.2 General

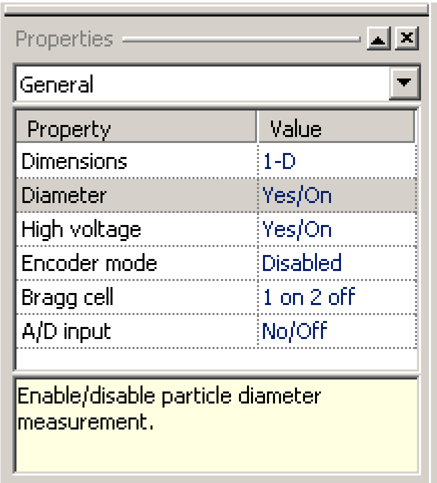


Figure 5-15 The PDA processor General properties

Dimensions

The Dimensions setting should be chosen to be smaller or equal to the number of dimensions of the FVA project, i.e. in a 3D FVA project it is possible to acquire only 1D or 2D data even if a 3D FVA system is installed.

Diameter

The Particle Diameter measurement is only avalaible with PDA processors.It can be enabled or disabled.

High voltage

The High voltage supply to all photomultipliers can be enabled or disabled. It is recommended to disable the high voltage during alignment procedures, when e.g. a solid surface is brought into the measurement volume.

Encoder mode

The Encoder mode can be Disabled, Use arrival time, or Use encoder.

If the experiment produces a once-per-revolution pulse only, set this property to Use arrival time.

If it produces both a once-per-revolution pulse and a number of encoder pulses, set the property to Use encoder pulses.

Bragg cell

Bragg cell specifies whether Bragg cell output channel 1 or 2 of the FVA processor is activated.

A/D input

This setting is described in chapter 6.6.

5.6.3 Range/Gain

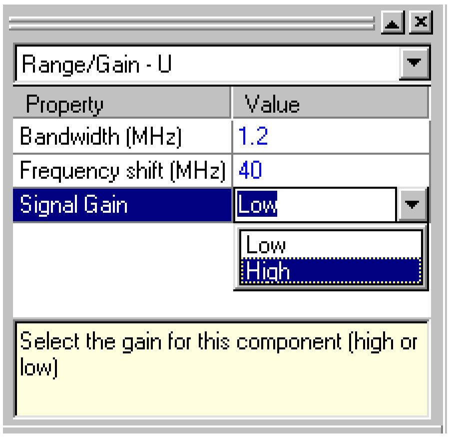


Figure 5-16: The FVA/PDA processor Range/Gain properties

Bandwidth The Bandwidth property allows to select one of the six frequency bandwidth settings of the FVA processor.

Frequency shift The value of Frequency shift has to be set to the shift frequency which is used in the transmitting optics.

Signal Gain Signal gain can be Low or High. High gain is 10dB above Low gain.

5.6.4 High voltage

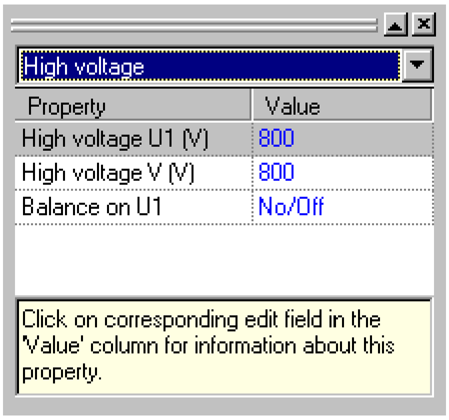


Figure 5-17: The High voltage properties

The high voltage can be set to any value between 0 and 2000 Volt individually for every photomultiplier. It frequently occurs that two photomultipliers of the same type require different high voltage levels to generate the same signal amplitude. This is due to sensitivity variations. Once the high voltage levels for all PMs have been set accordingly, the Balance can be enabled to maintain the ratio.

5.6.5 Data validation

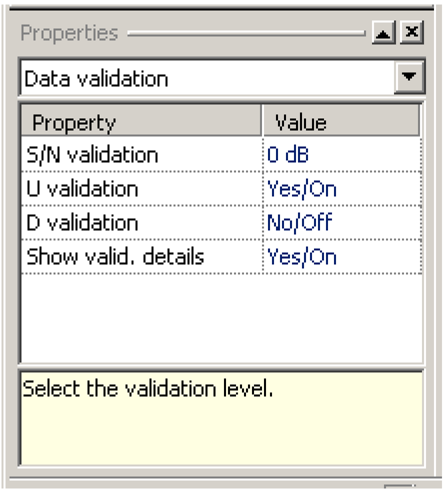


Figure 5-18: The Data validation properties

S/N validation

The Signal-to-Noise ratio validation rejection level can be set to any value between -6 dB and +3 dB. Signals having a signal-to -noise ratio below the validation level will be rejected.

As a rule of thumb, use a validation level of -3 dB with a "high" number of fringes (more than 24), 0 dB is suitable for a "medium" number of fringes (between 12 and 24), while +2 dB is required with a "low" number of fringes (less than 12) to avoid false measurements.

U, V, W validation

The signal-to-noise validation can be enabled or disabled for every velocity channel individually.

D validation

Only avalaible with PDA processor. The Diameter validation comprises signal-to-noise validation on all diameter signal channels (i.e. U1, U2 and U3 for FiberPDA and U1, U2, V1 and V2 for DualPDA) and sphericity check (i.e. comparison of measured phase differences: U1-U2 vs. U1-U3 for FiberPDA and U1-U2 vs. V1-V2 for DualPDA). The diameter validation is always enabled and rejected measurements will be marked accordingly (status information). By setting the D validation to No/Off or Yes/On one can decide to store all measurements or to store only measurements that have passed the diameter validation.

Please note that if the D validation is set to Yes/On, measurements which do not fulfill the sphericity check will not be displayed in the phase plot.

Show valid. details

Only avalaible with PDA processors. If the display of validation details is enabled, the percentage of consistency, range and level errors for each velocity channel and the range and level error for each diameter/phase channel is displayed in the output properties (see chapter 5.6.8).

5.6.6 Data collection

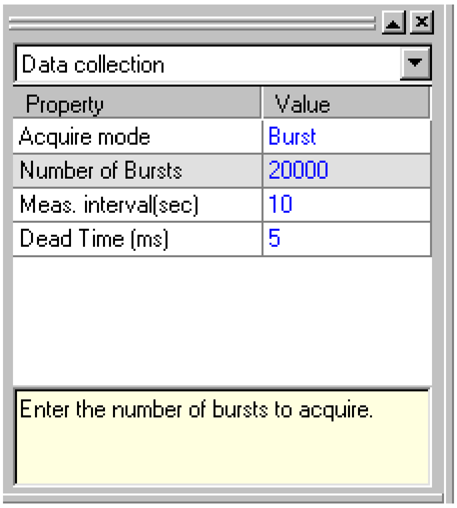


Figure 5-19: The Data Collection properties

Acquire mode,

Dead time

Data acquisition can be performed in Burst mode or Dead Time mode. In most cases Burst mode is used. Dead Time mode is recommended if statistically independent samples have to be acquired in applications with a very high seeding particle concentration. The dead time interval can be set to any particular value in Milliseconds. Setting the dead time to twice the integral time scale of the flow, which can be estimated from a previous measurement in Burst mode, will ensure statistically independent samples.

Number of bursts,

Meas. interval

Number of bursts and measurement interval are the two stop criteria for data collection.

For a sufficient statistical certainty in moments processing, the required number of bursts is typically in the order of 1000 to 2000, depending on the flow and required confidence level.

For spectrum and/or correlation measurements, the number of bursts is typically more than 10000. The effect of increasing the number of bursts is clearly seen when a 2D Plot of a spectrum is updated during acquisition: the scatter of the spectral function at high frequencies becomes smaller as the number of processed blocks increases.

5.6.7 Advanced options

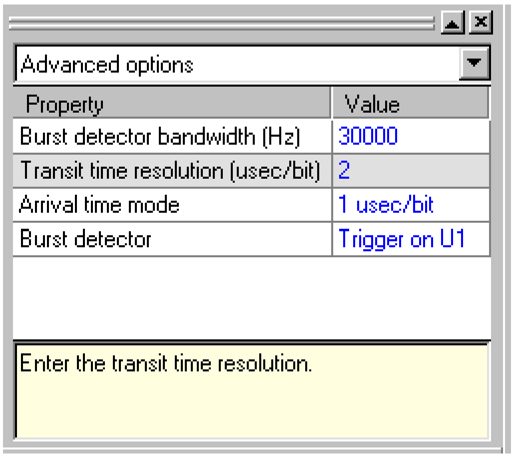


Figure 5-20. The Advanced Options properties

Burst detector bandwidth

The burst detector bandwidth is reset automatically when the U bandwidth is changed. The burst detector bandwidth should correspond to the inverse of the average particle transit time.

The default value, which is set automatically, is based on a calculated minimum residence time which is determined from the measurement volume size and the maximum velocity for the selected frequency bandwidth.

Transit time resolution

The value of the transit time resolution is the current transit time clock rate in microseconds per bit. The transit time is contained in an eight-bit register that can be incremented at a rate from 0.1 to 65535 µsec/bit. The transit time resolution changes automatically when the frequency bandwidth or the measurement volume size is changed. The selected default value can be changed if desired.

Arrival time mode

The arrival time clock mode can be set to "1 µsec/bit" or "10* TT" (ten times the transit time clock). The arrival time value is contained in a 24-bit register that can be set to increment at a rate of 1 MHz (1 µsec/bit) or ten times the transit time clock rate. The counter works in modulo 2^{24}, i.e. 0 to 16777215. The arrival time counter overflows when the register accumulates more than 2^{24}. When this occurs, 2^{24} is added to the arrival time count in the computer. For this to work properly, however, the maximum allowable delay between two particle arrivals is $2^{24} \times$ (*Arrival time resolution*). Thus if the time between two particle arrivals can be more than 16.7 s, the 1 µs resolution should not be selected.

Burst detector The burst detector mode can be one of the four selections described below:

- Trigger on U: This is the default burst detector mode. The burst detector is triggered by the squared envelope from the *U1* signal. The trigger levels are illustrated in Figure 5-21. Level 2 determines the start and stop of the measurement. The envelope must exceed level 3 to validate the burst, and it must be below level 1 between bursts. Applying a TTL low level to the burst detector inhibit connector (BNC chassis connector) on the rear panel of the FVA processor disables burst detection. If left open or held at TTL high level, detection is enabled. This allows conditional sampling using an external trigger source. When triggering on *U1*, the inhibit line inhibits when data can be collected.
- Internal trigger at 800 Hz: In this mode the processor is continuously triggered internally at a rate of 800 Hz rather than from the burst detector acting on the *U1* envelope signal.
- Internal trigger at 26 kHz: In this mode the processor is continuously triggered internally at a rate of 26 kHz rather than from the burst detector acting on the *U1* envelope signal.

Note	*The* Internal trigger at 800 Hz *and* Internal trigger at 26 kHz *triggering modes should be used for near-continuous signals, where the signal amplitude does not change significantly — for example, when the input signal is a function generator or a signal with little amplitude modulation. The burst detector inhibit line is disabled in these two modes.*

- External Trigger: In this mode the burst detector inhibit input completely controls burst detection, i.e. the burst detector is by-passed. The TTL level voltage should be held high during the integration time interval (*gate*) shown in Figure 5-21. The BNC connector BURST DET. INHIBIT on the rear panel of the signal processor functions as gate input.

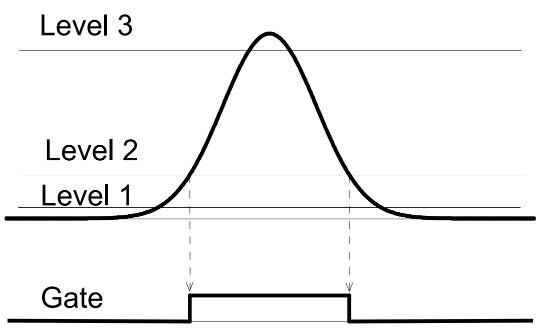


Figure 5-21: Burst detection trigger levels.

5.6.8 FVA/PDA output properties

Output property	Value
OUTPUT	
Valid. Data Rate (kHz)	0.004
Velocity validation (%)	100.000
Diameter validation (%)	82.566
Attempted samples	304
Validated samples	251
Elapsed time (s)	60.000
Transit time overflows	0
U1 Anode current (uA)	7.281
U2 Anode current (uA)	6.789
U3 Anode current (uA)	7.680
Validation details:	
U consistency (%)	0.000
U range (%)	0.000
U level (%)	0.000
U12 range (%)	10.855
U12 level (%)	5.263
U23 range (%)	0.000
U23 level (%)	8.224
U31 range (%)	1.316
U31 level (%)	2.632

Figure 5-22: The FVA/PDA processor output properties

The FVA/PDA processor output properties are displayed at the right hand side of the Config View window, when the FVA/PDA processor icon is selected. It provides information about the data acquisition conditions. During acquisition, all the listed properties are updated.

When loading existing data files, it shows the acquisition conditions at the end of each acquisition. In the example above, the stop criteria were Number of bursts: 2000, and Meas. Interval: 10 seconds, and the acquisition stopped when the Number of bursts criterion was satisfied.

Data rate The displayed Data Rate (kHz) is the rate of validated samples per time.

Velocity validation The Velocity validation (%) displays the percentage of acquired samples that fulfill the minimum signal-to-noise criterion.

Samples collected This is the total number of validated and acquired samples.

Elapsed time This is the total experiment time.

Transit time overflows The transit time overflow monitor displays how many samples are detected with a transit time counter overflow. This can be used to improve the accuracy of residence time (or transit time) weighted statistics.

The transit time counter is an 8-bit counter which counts clock pulses with a pre-set tick interval, the *transit time resolution*. If this resolution is too fine, the transit time counter frequently overflows meaning the transit time will be underestimated. As the measured transit time is used to determine the weighting factor for each velocity sample when doing velocity bias correction by the transit time weighting method, such an overflow will deteriorate the velocity statistics accuracy.

Transit time overflow is therefore an indication that you should increase the tick interval. Too long an interval, however, will also reduce the accurracy of the measurements. The ideal interval duration would be that which is just sufficient to make the transit time overflow counts zero.

Anode current These are the measured anode currents (in µA) from the photomultiplier tubes. The anode currents can be used to balance the photomultiplier high voltages if no oscilloscope is available for this purpose.

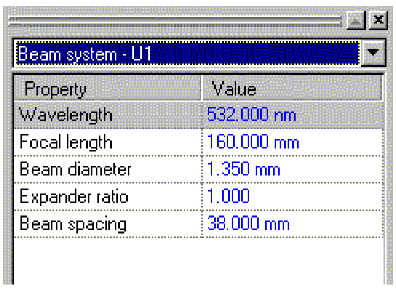
Validation details The display of validation details (only for PDA processor) can be enabled or disabled in the validation setup menu.

Consistency errors indicate a mismatch between velocity measurements based on the short and the long delay. High consistency error levels usually indicate malfunctioning hardware.

Range errors are caused by too narrow frequency bandwidth or size range settings.

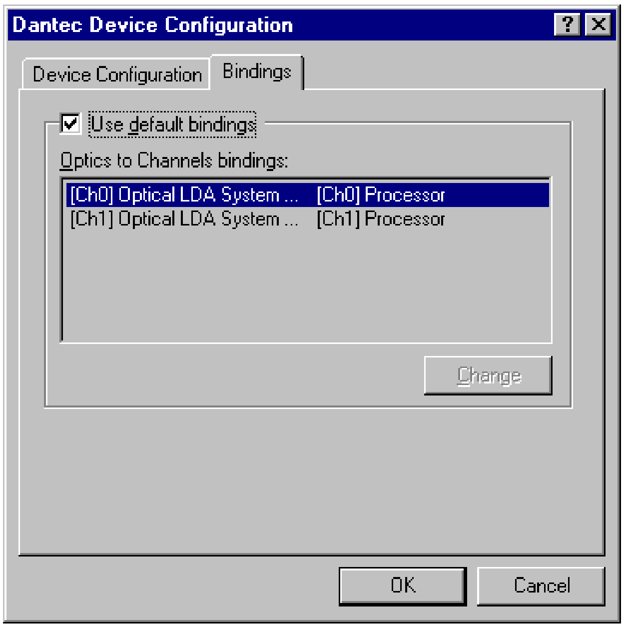
Level errors indicate insufficient signal-to-noise ratio. This can be caused by e.g. poor measurement conditions or poor optical alignment.

5.7 Optical LDA System properties



The software supports up to three beam systems each representing a measured velocity component. Each beam system has a set of properties as shown.
The beam systems should be associated with velocity channels in the processor.
With BSA F/P processors, the default is that Beam system U1 is associated

with velocity channel LDA1, etc. If you want a different relationship between optics and processor channels, start the Dantec Device Configuration (right-click in the BSA Application window or start it from the Windows Control Panel), and select the Bindings tab:



Uncheck the Use default bindings box to change the bindings.

With BSA, FVA and PDA processors, the Beam System properties refer to the PM input, e.g. Beam System U1 refers to the optics properties of the optics and PM connected to PM input 1.

Based on the parameters specified below, the software computes the measurement volume dimensions and the fringe spacing. These can be seen in the lower part of the BSA Application window, when Show - Show Optics is checked in the context menu (right-click in the lower part of the window).

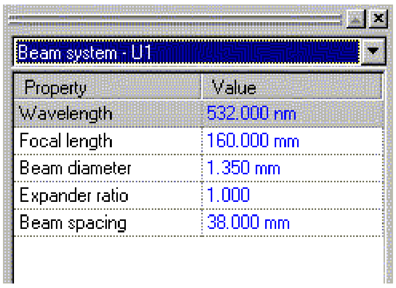
Note	*The software computes the effective beam spacing at the front lens as Beam Spacing multiplied by Expander Ratio.* *To get correct optical parameters, set the expander ratio to 1, and the beam spacing to the one at the front lens.* *In the Beam diameter field, enter the beam diameter at the front lens, i.e. the beam diameter before beam expander(s) multiplied with the total beam expansion.*

- Wavelength: the wavelength of the laser line used, in nm.
  The most common wavelengths used for LDA are:
  476.5 nm: “violet” or dark blue line of an Argon-Ion laser
  488 nm: blue line of an Argon-Ion laser
  514.5 nm: green line of an Argon-Ion laser
  532 nm: green line of a frequency doubled Nd:YAG laser
  632.8 nm: red line of a Helium-Neon laser
- Focal length: the focal length of the front lens of the transmitting optics. Used for calculation of the fringe spacing in and dimensions of the measurement volume.

- Beam diameter: the diameter of the laser beam at the exit of the optics (*before front lens and beam expander*). Used for calculation of the dimensions of the measuring volume.
- Expander ratio: Should be set to 1 if no beam expander is used. The beam diameter is multiplied by the expander ratio to find the resulting beam diameter at the exit of the beam expander or entry to the front lens. Used for calculation of the fringe spacing in and dimensions of the measurement volume.
- Beam spacing: the spacing between the beams in the selected beam system, *before the beam expander.* This figure is multiplied by the expander ratio to find the resulting beam spacing at the exit of the beam expander or entry to the front lens. Used for calculation of the fringe spacing in and dimensions of the measurement volume.

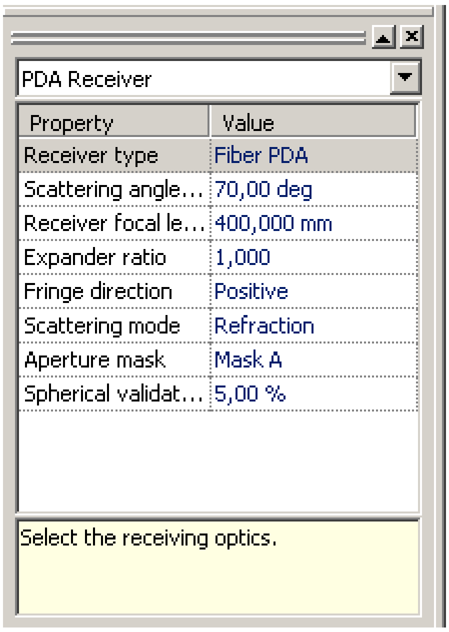
5.8 Optical PDA System properties

5.8.1 PDA beam system



The Beam system is the same as in the LDA configuration. See the below part Optical LAD System properties.

5.8.2 PDA Receiver



- Receiver type: This list contains all Dantec receivers – ClassicPDA, FiberPDA and DualPDA
- Scattering angle: The scattering angle is measured relative to the direct forward scatter direction, i.e. positioning the receiver directly opposite to the transmitter would correspond to a scattering angle of 0 degrees.
- Receiver focal length: the focal length of the front lens of the receiving optics. Used for calculation of the fringe spacing in and dimensions of the measurement volume.
- Expander ratio: Should be set to 1 if no beam expander is used. The beam diameter is multiplied by the expander ratio to find the resulting beam diameter at the exit of the beam expander or entry to the front lens. Used for calculation of the fringe spacing in and dimensions of the measurement volume.
- Fringe direction: the Fringe direction setting describes the direction of fringe motion (in the beam intersection volume – see 7.3.2.1 Main flow direction and fringes direction) relative to the receiving optics orientation, i.e. whether the fringes move in the direction from receiving aperture U1 towards U2 or from U2 towards U1.

  The fringe direction setting affects the sign of the phase factors but not the Doppler frequency. Therefore, the direction of fringe motion affects the measurement of diameter but not the velocity measurement.

  For the ClassicPDA and the FiberPDA the fringe direction can be positive or negative (see Figure 5-23).

  For the DualPDA there are four different possible combinations, because the fringe direction must also be considered for the V component. The fringe direction setting can be U+/V+, U+/V-, U-/V+ or U-/V- (see Figure 5-24).

  The user will check the fringe direction in using the phase plot (see paragraph 5.15) with the spherical validation off. If the fringe direction is incorrect, the phase of the detected particles will be outside the tolerance band (spherical validation)

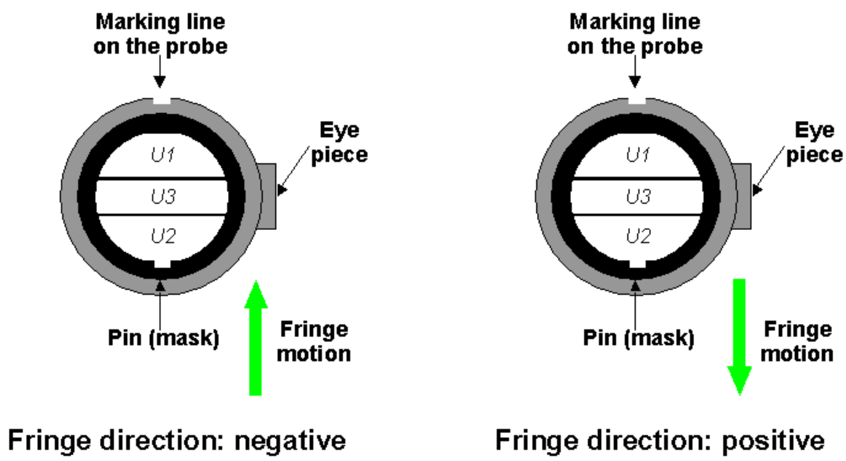


Figure 5-23. Fringe direction settings for the FiberPDA (front view).

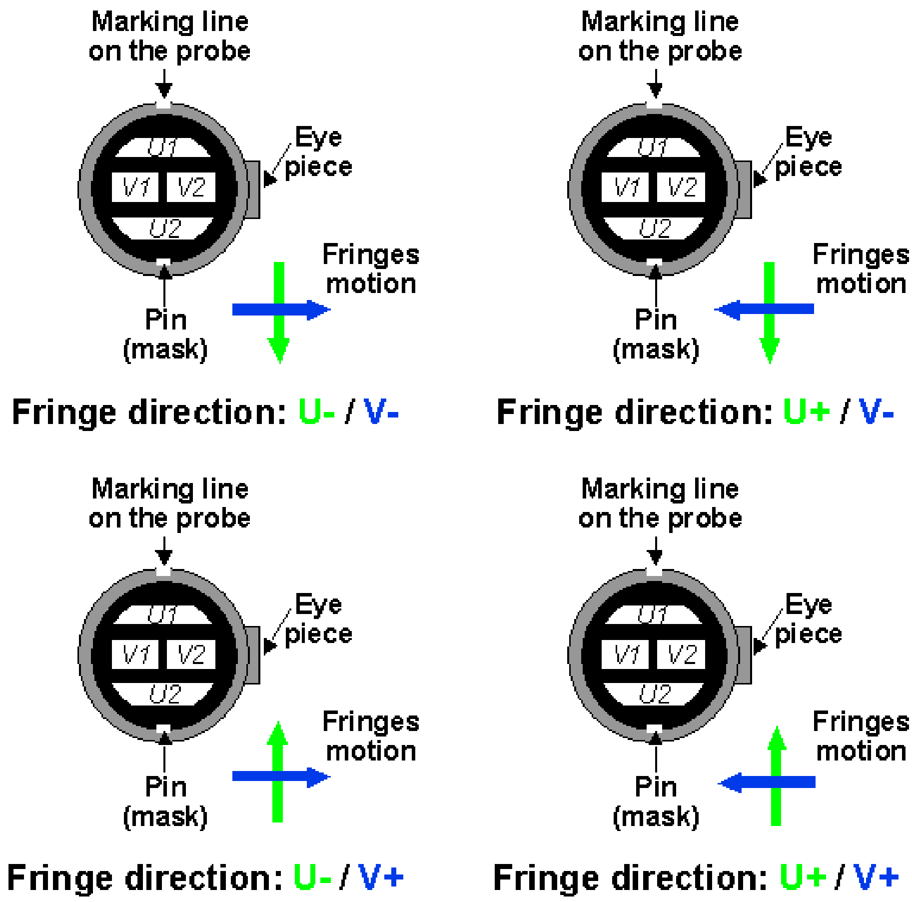


Figure 5-24: Fringe direction settings for the DualPDA (front view).

- Scattering mode: Scattering can be Reflection, Refraction or 2nd order Refraction (see PDA Installation and User's Guide)
- Aperture mask: The Aperture mask field is active for FiberPDA and DualPDA only. Select the mask that you have mounted in your receiving probe. A mask (with large apertures) is for small particles, B mask (with medium apertures) is for medium particles and C mask (with small apertures) is for large particles (Figure 5-25 and Figure 5-26)

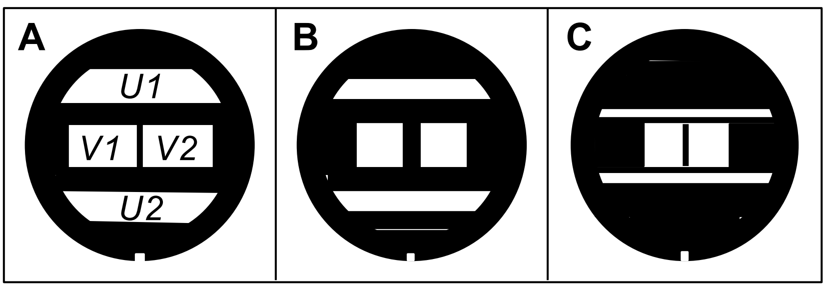


Figure 5-25: Masks for Dual PDA receiving probe

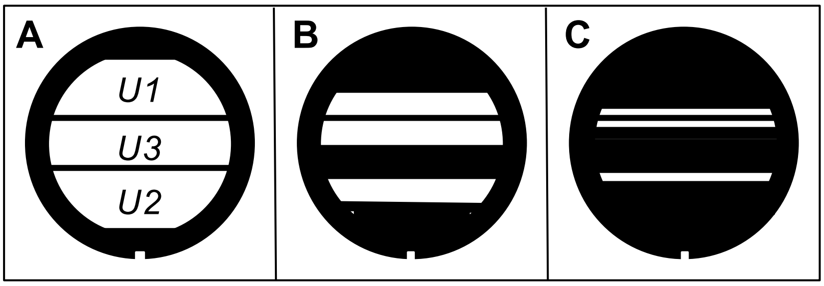


Figure 5-26: Masks for Fiber PDA receiving probe

- Spherical validation: This field defines the width of the tolerance band of the phase difference between detectors (see phase plot description). This width is given in percent of size range.

5.9 Traverse properties

5.9.1 Lightweight traverse properties

The following applies, when the Lightweight Traverse has been selected in the Dantec system configuration.

The traverse properties are accessed by clicking on the traverse icon in the BSA Application. In the property editor, the box on top includes the following choices, when Lightweight Traverse has been selected:

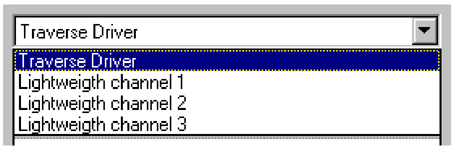


Figure 5-27 The Traverse Driver list of choices

Selection of Traverse Driver displays the following:

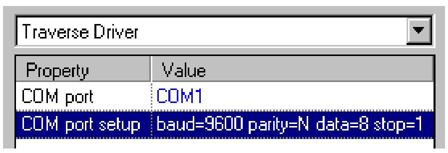


Figure 5-28 The Traverse Driver properties

In the value fields, select the settings that correspond with the COM port used for connection to the traverse.

Up to three axes can be configured. Lightweight channel 1 refers to the axis connected to the first slot (from left) in the traverse controller.

For each channel, the properties are:

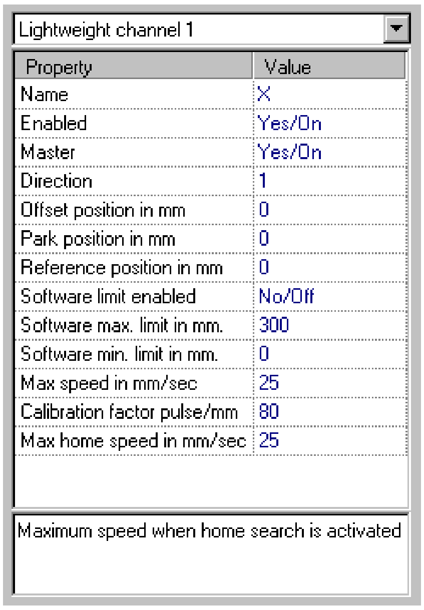


Figure 5-29 The Lightweight channel properties.

Name:

Used to assign the name X, Y or Z to an axis. The default assignment is channel 1 is X, channel 2 is Y and channel 3 is Z.

Two physical axes cannot have the same name.

Enabled:

Only the channels which are physically present in the traverse controller should be enabled.

Master:

Should always be set to Yes/On. Reserved for future use.

Direction of channel:

1 means positive away from the motor, -1 positive towards the motor. In a standard 3 axis Lightweight Traverse, setting the vertical axis to -1 yields a right hand coordinate system.

Offset position in mm:

The traverse coordinate of a datum point (see section 5.9.3)

Park position in mm:

If the Park button in the traverse dialog is clicked, the traverse moves to the Park position.

Reference position in mm:

The traverse coordinate of the laboratory origin (see section 5.9.3).

Software limitation enabled:

Activates software limits of movements for the axis.

Software max. limit in mm.:

Self explanatory.

Software min. limit in mm.:

Self explanatory.

Max. speed in mm/sec:

The highest allowed speed of traverse movement, based on the calibration factor property.

Calibration factor pulse/mm:

Hardware specific, given as the number of (encoder or stepmotor) pulses per mm movement of the axis. On the Ligtweight traverse it is indicated on a label on the motor. In most systems it is either 80 or 160.

Max. home speed in mm/sec:

The highest allowed speed of movement, when the Home button in the traverse wizard is clicked.

5.9.2 Lightweight traverse Manual Control properties

The Lightweight Traverse can be configured for use with a manual control box.

To use a manual control box together with a Lightweight Traverse, the following hardware is necessary:

digital I/O board prepared for manual control box.

manual control box with 5 meter cable.

The digital I/O board is mounted in an empty slot inside the computer and the manual control box is connected through the cable.

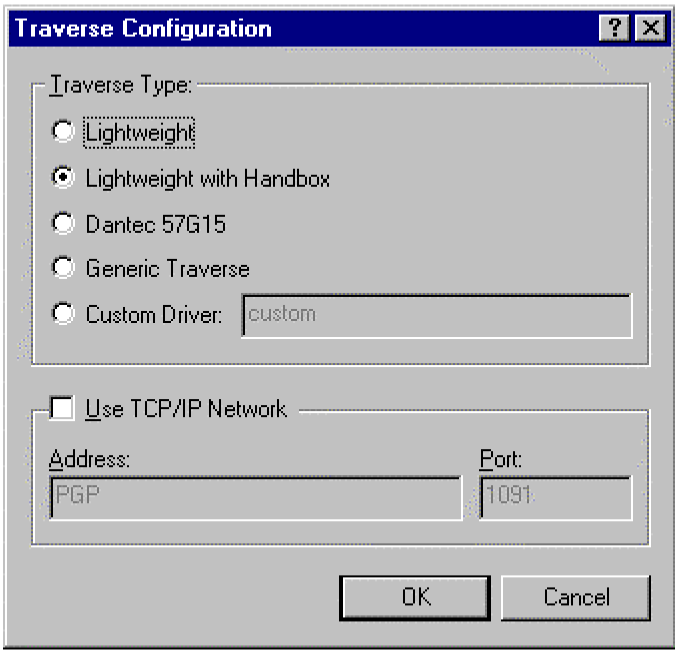


Figure 5-30 Selecting Lightweight Traverse with handbox in the Dantec Device Configuration.

The configuration of the software is done by selecting Lightweight with Handbox in the Dantec Device Configuration under Traverse - Properties.

In the property editor, a Manual Control list id added to the traverse properties:

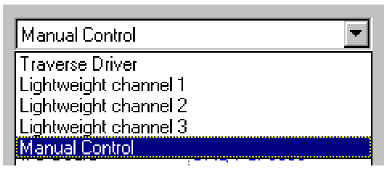


Figure 5-31 Traverse properties drop down list

Two types of handbox interface are available:

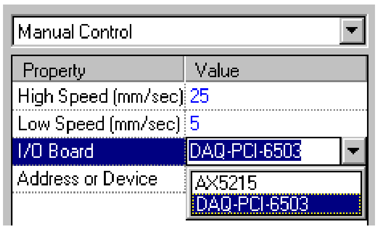


Figure 5-32 I/O Board type

Older systems use an AXIOM 5215 board.

Note	*AXIOM boards cannot be used under Windows NT. An upgrade kit is available.*

Recent systems use a National Instuments DAQ-PCI-6503 board.

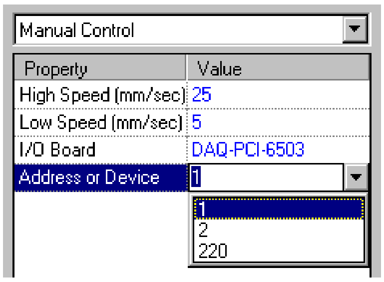


Figure 5-33 I/O Board Address or Device

The address of the AXIOM board must correspond with the hardware address switch setting. The factory default is 220.

Caution	*Incorrect address setting for the AXIOM board may lead to uncontrolled traverse movements*

The switch settings on the AXIOM I/O board as delivered (0=ON, 1=OFF):

Base address 10001000 = 220 Hexadecimal

Jumper J1: DIS1 jumper mounted

Jumper J2: DIS2 jumper mounted

Jumper J3: X jumper mounted

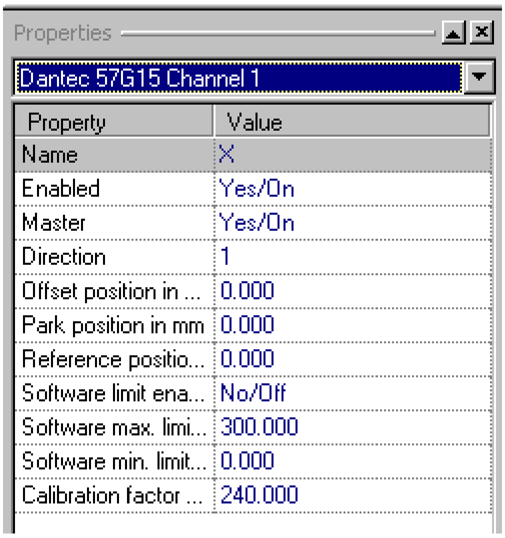
Jumper J1, J2 and J3 must never be changed. The base address can be changed if necessary because of other boards using the same address.

The default address of the National Instruments is 1, but the driver can handle two boards in which case the address may be 1 or 2.

The handbox has a switch for high or low speed. These speeds are specified from the property list.

5.9.3 57G15 Traverse properties

The following properties are available when the Dantec 57G15 was selected in the Dantec System configuration or in the Configuration wizard.



Up to 4 channels are supported. The channel is selected in the list in top of the property editor.

The properties are identical to those of the Lightweight Traverse. Please see section 5.9 for details.

Dantec 57H series traverse units have a calibration factor of 240 pulses/mm.

5.9.4 Generic Traverse properties

These properties are used with third-party traverse systems, or Dantec traverse systems with 4 to 6 axes

Up to 6 axes are supported. Please see the Advanced Traverse Add-on section of chapter 6.

5.9.5 Traverse properties: adjusting the traverse position reading to laboratory coordinates

When setting up the traverse properties, a relationship between two coordinate systems must be established:

- the laboratory coordinate system,

and

- the traverse coordinate system.

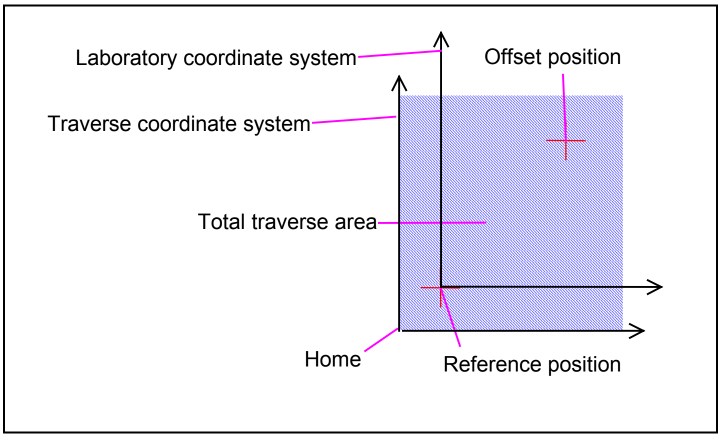


Figure 5-34 The traverse range and the laboratory coordinate system, (only two coordinates shown for clarity)

The traverse axes are assumed parallel with the laboratory coordinates, but they may have opposite sign conventions on one or more axes. This is dealt with by the Direction property as explained under the traverse properties.

Initially, the software only knows the traverse coordinate system. Therefore, some known position in the laboratory coordinate system, a *datum point*, must be used to relate the laboratory coordinates to the traverse coordinates. The datum point must be within the traverse range, and it must be possible to accurately position the LDA measuring volume at this point.

If the datum point *is* the laboratory origin, initialisation is simply done by moving the LDA measuring volume to the datum point, and resetting the traverse coordinates by clicking the Reset button in the Traverse Wizard. However, in practise the datum point may be different from the laboratory origin. The software therefore operates with two properties: Reference position and Offset position.

Reference position is the laboratory origin's coordinates in the traverse coordinate system. It can be outside or within the traverse range.

Offset position is the datum point's coordinates in the traverse coordinate system. It must be within the traverse range.

Both of these must be known to initialise the traverse coordinates. If they coincide it suffices to input the traverse coordinates of the position in the Reference position value field.

The laboratory coordinate system usually refers to symmetry planes or boundaries of a flow rig, e.g. center line, wall, center of turntable, or to a well defined part of an object around which the flow is investigated, e.g. the corner of an object, the center of a circular, cylindrical or spherical object, etc.

5.9.5.1 Traverse coordinates of a datum point

To establish the traverse coordinates of a datum point , use the traverse wizard (right-click on the traverse icon in the BSA Application):

1. Move the traverse to its home position, click Reset if the position display does not show (0,0,0)
2. Move the traverse to the datum point using the X, Y and Z position fields and up/down arrows. See below for recommended methods to determine whether the measuring volume is in position.
3. When the measuring volume is at the datum point, read the current traverse position from the traverse wizard position display, and type these coordinates into the Offset position in mm field of the traverse properties (one traverse axis at a time).
4. Knowing the Offset position's laboratory coordinates, the Reference position in mm's traverse coordinates can be calculated. Type these into the Reference position in mm field of the traverse properties.
5. Click Reset. The position display should now display the laboratory coordinates of the datum point, and the initialisation procedure is complete.

5.9.5.2 Methods to determine whether the LDA measuring volume is in position

Note	*For all the below procedures, it is important to protect the photomultiplier tubes. Run the laser at low power and make sure that the PM current limit property of the processor has been correctly set.If the PM current saturates, reduce the PM high voltage.*

The main difficulty is normally to determine whether the measurement volume's longest dimension is centered correctly. The below methods can be used for this. The pinhole/power meter method is good for determination of all three coordinates.

Pinhole/power meter method

A precise method is to mount a pinhole matched to the diameter of the measuring volume within the flow rig, and accurately measure its position relative to the laboratory origin. The LDA measuring volume must then be moved to the position where maximum light power from all beams pass through the pinhole. This method is highly repeatable, if a power meter is used to measure the power of the beams after the pinhole.

Window surface/photomultiplier current method

Another often used method is to use a window surface as the reference for the LDA measuring volume: if there is a window between the LDA optics and the flow, and the LDA measuring volume can be traversed to the window position, the detected Doppler signal from the wall or the PM anode current will reach a maximum, when the center of the measuring volume is at the surface of the window.

Model surface/photomultiplier current method

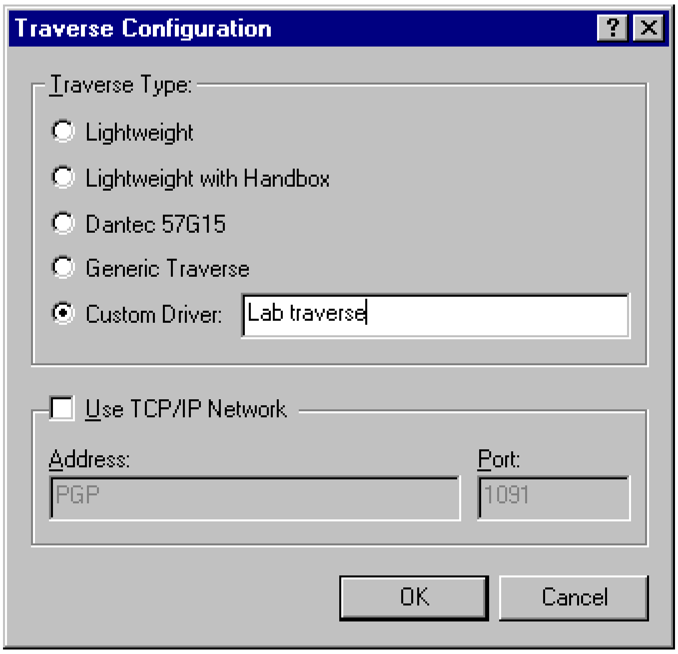
Similar to the window surface method, but if the surface is not transparent, stronger reflections occur, and it may be necessary to reduce the PM high voltage more. The automatic protection of the PM may further reduce the high voltage. In this case, reduce the laser power if possible until the PM current is below the allowed limit.

5.9.6 Saving traverse properties for use in other projects

To ensure that new projects use the traverse properties that you have defined, it is necessary to perform the steps below.

The template function supports the properties of the Lightweight, Lwhandbox and Generic traverse systems, but if you define new projects without aplying a template, the traverse properties will be the system default values.

To save traverse settings in such a way that they are automatically used in future projects, you must right-click the traverse server icon  and select Save... This opens a dialog in which you can rename the traverse server to any name that you wish, e.g. Lab Traverse.
In the Dantec Device Configuration, select Custom Driver, and type in the name you gave the traverse:



If you forget the name, you can search it in Windows Explorer in the \Dantec\Common folder, by looking for files with .cfg extension.

Once you have redefined the traverse in the Dantec Device Configuration, the new settings will apply for all new projects.

5.9.7 Traverse dialog

Right-click the traverse icon in the Region List to activate the traverse dialog. The description below is valid when a handbox (if available) is not activated.

Note	*If 57G15 is used, be aware that if the traverse is moved using the manual control box, it will move back to the last position defined by the software, when switching the manual control off. If Reset is clicked first,the position display of the traverse wizard is reset to 0,0,0, and the traverse will not move when switching to software control.* *If the PC is remotely located, and the manual control is used to initialise the traverse position, this should be done before starting the software, or the Reset button should be clicked before switching to software control*

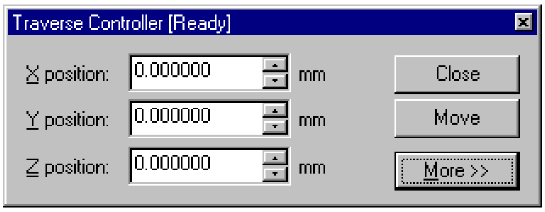


Figure 5-35 The Traverse dialog

The X, Y and Z position fields show the actual position.

Move moves the traverse to the typed in position. During movement, this button is called Stop, allowing to stop the movement.

You can expand the dialog by clicking the More >> button:

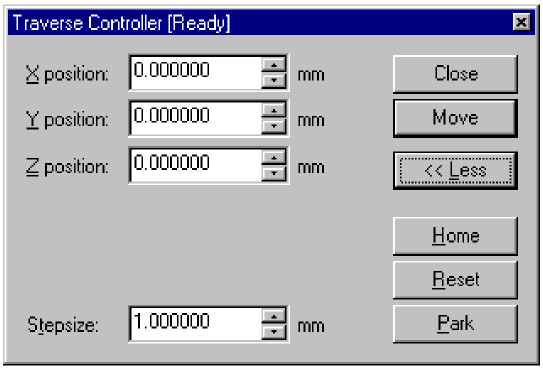


Figure 5-36 The expanded Traverse dialog

Home moves the traverse to its home position. For the Lightweight traverse, this is towards the motor. For the 57G15 it is opposite.

Reset resets the traverse origin position. It sets the traverse coordinates to 0, if Reference position and Offset position properties are 0.
If the Reference position and/or Offset position properties are not 0, the traverse coordinates are reset to the sum.

Park moves the traverse to the Park position defined in the properties.

Close closes the dialog.

5.9.8 Traverse Mesh generator

A traverse mesh wizard can be opened by right-clicking in the Region list. This can quickly generate cartesian or cylindrical meshes with equidistant steps along each axis. The positions are generated in the order that gives the shortest travel, i.e. “meander” type movement as shown in the Traverse motion figure at the lower right hand corner of the Mesh Generator window.

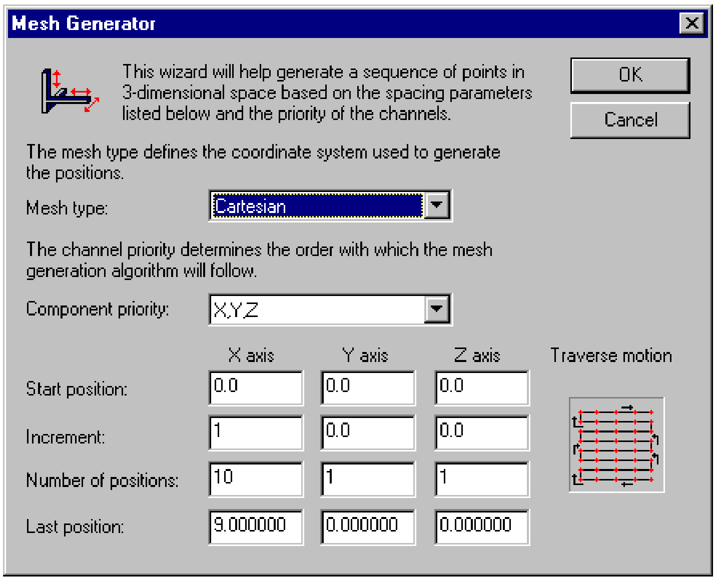


Figure 5-37 The mesh generator window, cartesisan mesh.

Meshes can be generated externally and imported as ASCII files or via the clipboard.

5.9.8.1 Cartesian mesh

Component priority governs the order in which the axes are moved.

If Component priority X,Y,Z is selected, the Z axis moves through its range, then the Y axis moves one step, the Z axis moves back through its range, the Y axis moves a step and so forth. When the Z and Y ranges are completed, the X axis moves one step and the Z and Y axis repeat the sequence described above till the X range has been completed.

The Start position, Increment etc. are self explanatory. There is no upper limit to the number of positions, but large numbers require much RAM or virtual memory.

5.9.8.2 Cylindrical mesh

In case of Cylindrical mesh type, the the R and Theta axes are assumed to be in the plane defined by the traverse controller's first two channels. The cylindrical coordinates are converted to X, Y, Z coordinates which are shown in the Layout view.

Example:

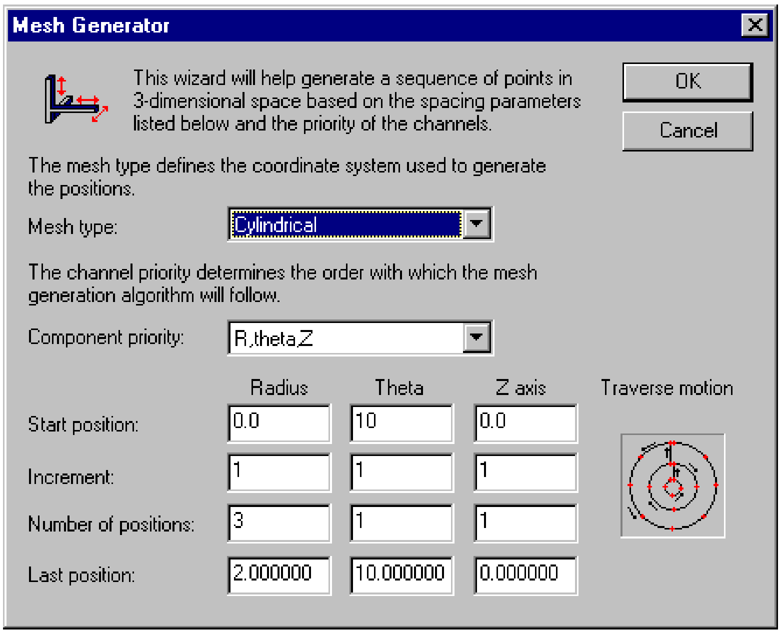
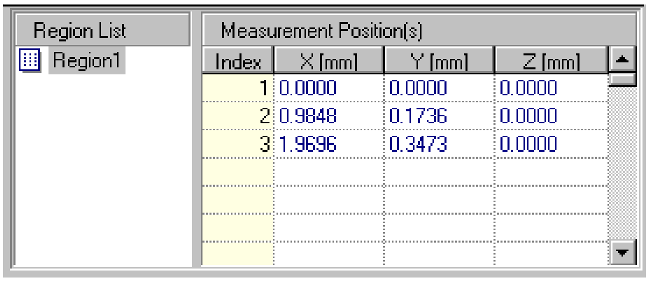


Figure 5-38 The Mesh Generator dialog, Cylindrical mesh.

Resulting Measurement Position(s) table:



Region List: Region1

Measurement Position(s)

Index	X [mm]	Y [mm]	Z [mm]
1	0.0000	0.0000	0.0000
2	0.9848	0.1736	0.0000
3	1.9696	0.3473	0.0000

Figure 5-39 Region List and Measurement Position(s) table

If the component priority is changed to Theta, R, Z, the trajectory changes to the following pattern:

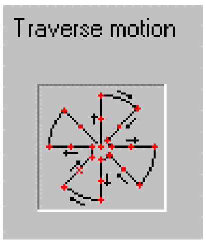


Figure 5-40 Motion pattern, Cylindrical mesh

5.9.8.3 Regions

Regions are used to adapt hardware settings to local conditions.

Consider a wake flow measurement:

In the free stream, there may be a high mean velocity and a very low turbulence level, whereas in the wake, the mean velocity can be low and the turbulence level high.

If a “free stream” and a “wake” region are defined, the LDA 1,2.. properties Center frequency and Bandwidth properties can be set such that the processor resolution is optimally exploited in both regions.

Near a wall, it might be useful to reduce the PM high voltage setting, so a near wall region could be defined to handle this.

The number of processor channels and traverse channels and are fixed for a project file, but any other property can be changed from one region to another.

Each region’s traverse mesh may be identical to another region’s, or different. This means that experiment conditions could be changed, and the same mesh used again within the same project file, to keep related data in a single file.

In the BSA Application's table of positions, each position has an associated line number, like in a spreadsheet. If several regions are used, the first line number in the second region is 1 higher than the last line number in the first region. The line number is used as the index, when graphs or lists from single positions are shown (right click on the graph object, select position, etc.).

Default is a single region. To define more regions, you can either:

- right click on Region 1 (or another region), and select Insert region,

or

- right click on Region 1 (or another region), and select Duplicate

The Duplicate function is recommended, because it duplicates all properties, so that only the ones to be modified need to be touched afterwards.

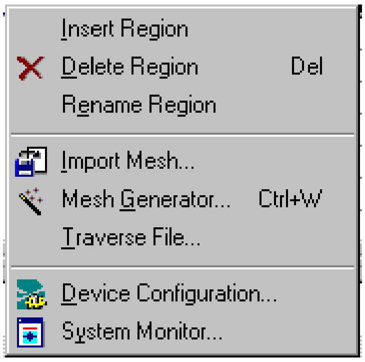
A region can be deleted by right clicking on its icon, and selecting Delete.

A region can be renamed either by right clicking on its icon, and selecting Rename, or by clicking on its icon and overwriting the name.

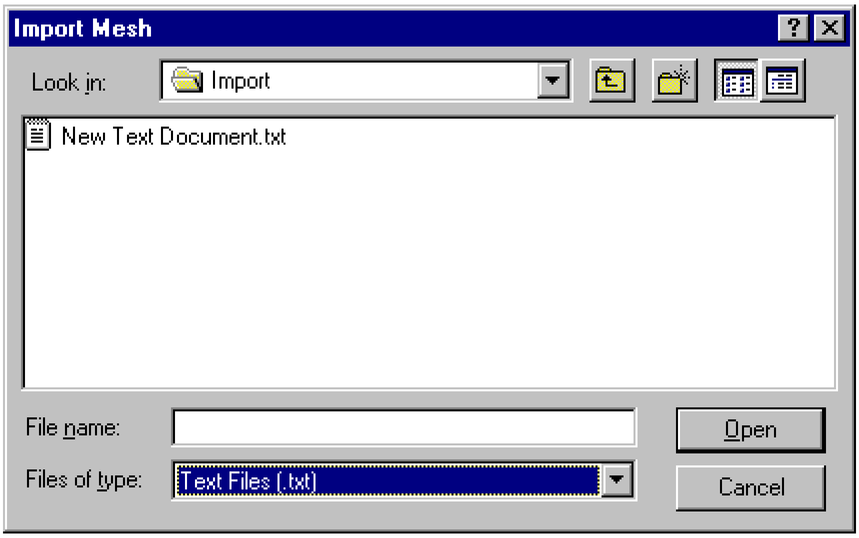
5.9.8.4 Importing traverse positions

Traverse positions can be imported via the Windows clipboard (by Copy and Paste commands), or from ASCII (.txt) files or Burstware traverse files (.trv) by right clicking on a region in the region list.

Select Import Mesh from the dialog:



Select a file from the Import Mesh window that appears:



ASCII files should contain three columns representing X, Y and Z coordinates in the unit defined under Tools -Options - Data formats (default is mm), separated by tab or semicolon (;).

5.10 Coincidence

Due to different sensitivity of the various receivers, a seeding particle passing through the outskirts of the measuring volume may sometimes generate a velocity sample on one channel, without simultaneously generating a sample on the other(s).
Most calculations involving two or more velocity components require that the velocity samples in question are coincident (i.e. simultaneous). Consider coordinate transformation as an example: Calculating an orthogonal velocity sample with components u, v and w from "skew" components u_1, u_2 and u_3 obviously require that the latter are simultaneous. Otherwise the calculated (orthogonal) velocity sample would have no meaning, since it could not be related to any specific point in time. Similar considerations apply when calculating cross-moments (Reynolds stresses).

Note	*the 62N BSA can be set up to provide coincident data by placing velocity channels in the same group. This is hereafter referred to as* **hardware coincidence**. *If velocity channels are placed in separate groups,* **software coincidence** *can be applied by adding a Coincidence object as described in this section.*

Coincidence filtering is a child of a data source object. Possible parent objects are BSA F/P Application, BSA Application, FVA Application, PDA Application and Import velocity files as shown in Figure 5-41.

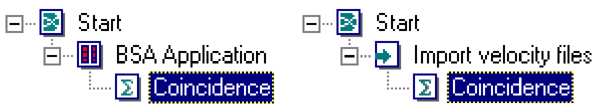


Figure 5-41 Data-sources for coincidence filtering.

If Import velocity files is used as data-source, arrival time must be available and included in the import operation for the coincidence object to work.

The property editor of this object contains two properties:

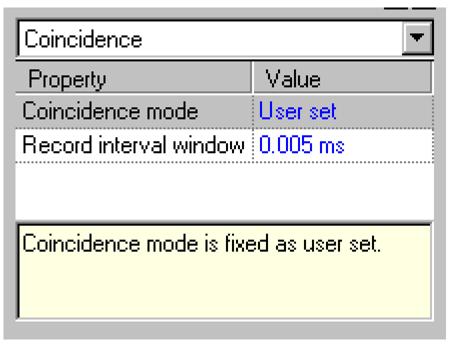


Figure 5-42 Property editor of the coincidence object.

The property Record interval window describes the largest acceptable time difference between velocity samples in the velocity channels. If the arrival times differ by more than this, the samples are not considered coincident, and the software will attempt to find a better match.

The property Coincidence mode is always User set. The user must manually enter the Record interval window. An appropriate value is the measurement volume diameter divided by the highest velocity present in the flow.

5.11 Transform

The object Transform will perform a coordinate transformation of the measured velocity-components based on a transformation matrix provided by the user. The velocity-samples used must be coincident.

It is possible to apply more than one transform. For example, with 3D optics it may be practical to have a fundamental transform for the optical system, followed by one ore more transforms referring to the pan and tilt position of the optics. In this way, only the pan or tilt-related transform needs to be modified if the orientation of the optics is changed.

With BSA F/P processors with velocity channels in the same group, and with FVA and PDA processors, velocity samples are coincident.

With BSA processors, a Coincidence-object should be applied prior to the Transform object.

Note	*It is possible to create the Transform-object as a direct child-object of a data-source object (BSA Application or Import Velocity file). This should only be attempted if you are sure that velocity-samples supplied by the data-source are indeed coincident, since coordinate transform is otherwise impossible, and an error message will be generated.*

Normally coordinate transformation is used, when limited optical access or other physical restraints have forced velocities to be measured along directions not coinciding with the coordinate directions otherwise used in the model and in calculations. In such cases orthogonal velocity-components u, v and w can be calculated from "skew" components u_1, u_2 and u_3 according to the matrix calculation:

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

By default velocity component u_1 is assumed to come from the first processor channel, u_2 from the second and u_3 from the third. Using BSA processors for example it will be assumed by default that LDA1 supplies u_1, LDA2 supplies u_2 and LDA3 supplies u_3, but if necessary this can be changed editing the general properties of the transform object:

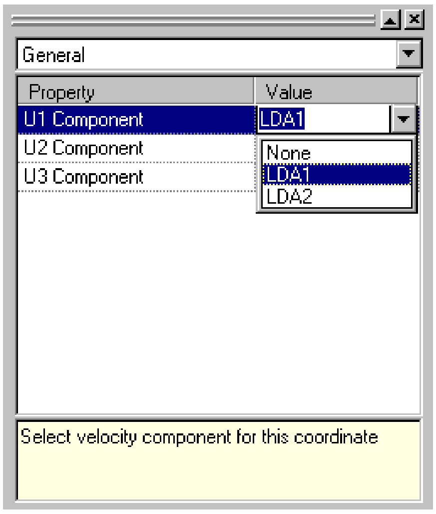
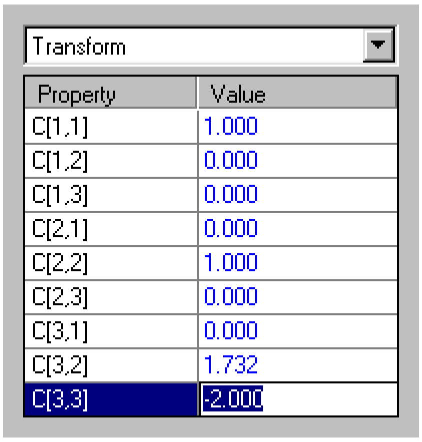


Figure 5-43 General properties of the transform object.

In the examples in Figure 5-43 there are two input channels. The property value None can be used if you wish to make coordinate transformation of 2-dimensional velocity measurements.

Finally the transformation matrix needs to be defined, using the Transform properties of the Transform object:



$$\Leftrightarrow \begin{Bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{Bmatrix} = \begin{Bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 1.732 & -2.000 \end{Bmatrix}$$

Figure 5-44 Defining the transformation matrix.

The example in Figure 5-44 corresponds to the geometry shown in Figure 5-45, where a 2D-probe connected to BSA2 and BSA1 measure the velocity components u_1 and u_2, while a 1D-probe connected to BSA3 measure the velocity component u_3.

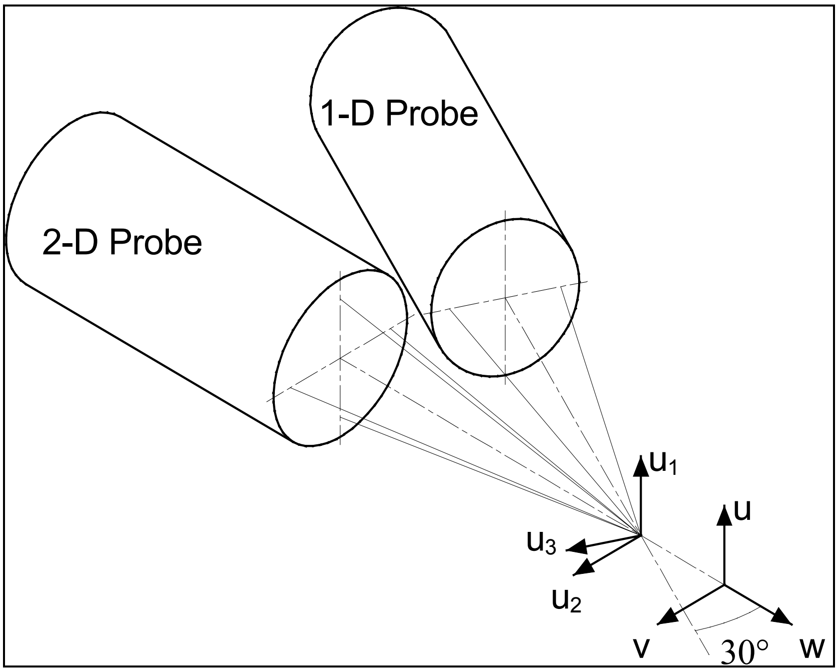


Figure 5-45 Possible geometry of a 3D LDA system.

Velocities u_1 and u_2 correspond directly to the ortogonal velocities u and v, but due to restricted optical access the third component w cannot be measured directly, but must be calculated from u_2 and u_3. With an angle of α between the two probes, and u_3 lying in the v-w-plane, the w-component can be calculated from u_2 and u_3:

$$w = \frac{u_2}{\tan\alpha} - \frac{u_3}{\sin\alpha}$$

– in the matrix-formulation including all velocity-components and with α=30° inserted this yields:

$$\underline{\underline{C}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & \dfrac{1}{\tan\alpha} & \dfrac{-1}{\sin\alpha} \end{bmatrix} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 1.000 & 0.000 \\ 0.000 & 1.732 & -2.000 \end{bmatrix}$$

– corresponding to the values shown in Figure 5-44.

An alternative geometry of a 3D LDA system is presented in Figure 5-46:

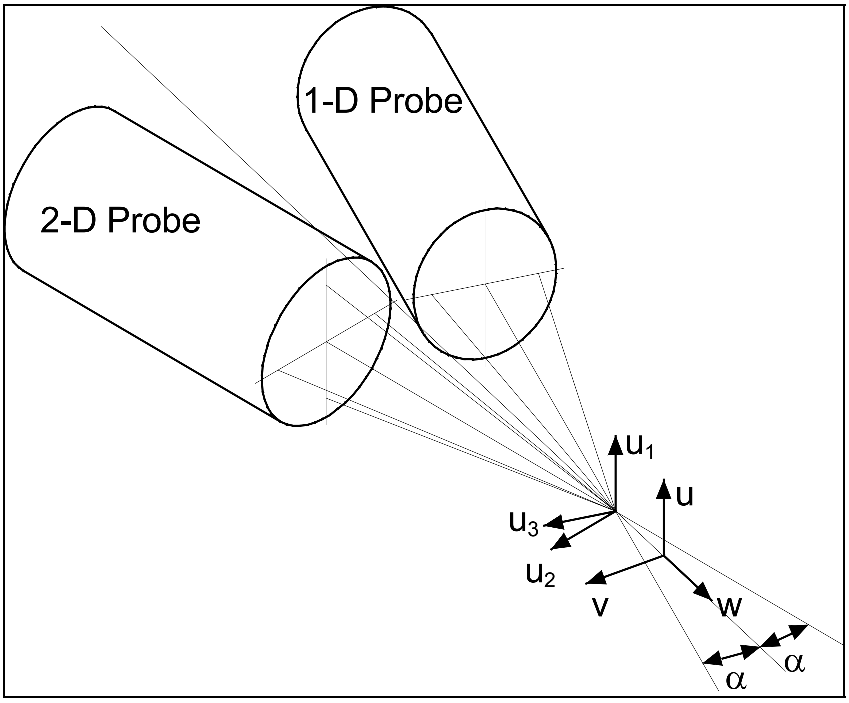


Figure 5-46 Alternative geometry of a 3D LDA system.

– the 2D-probe still measures the velocity components u_1 and u_2, while the 1D-probe measures the velocity component u_3.

The optical axes of both probes still lie in the v-w plane, and u_1 still correspond to the desired vertical velocity component u exactly, but horisontal velocity-components are now measured differently:

In the example in Figure 5-45, only the 1D probe measured off-axis, while the 2D probe was aligned with the optical axis parallel to the w-direction, yielding u_2=v. In the example in Figure 5-46, both probes measure off-axis, being aligned symmetrically on either side of the w-axis, requiring a somewhat different transformation matrix.
Assuming that both probes has an off-axis angle of α=15º this becomes:

$$\underline{\underline{C}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \dfrac{1}{2\cos\alpha} & \dfrac{1}{2\cos\alpha} \\ 0 & \dfrac{1}{2\sin\alpha} & \dfrac{-1}{2\sin\alpha} \end{bmatrix} = \begin{bmatrix} 1.000 & 0.000 & 0.000 \\ 0.000 & 0.518 & 0.518 \\ 0.000 & 1.932 & -1.932 \end{bmatrix}$$

5.12 Histogram

The Histogram object will produce a histogram of a selected quantity, usually a velocity as shown in Figure 5-47. Possible parent objects are Import velocity files, BSA F/P Application, BSA Application, FVA Application, PDA Application, Coincidence and Transform.

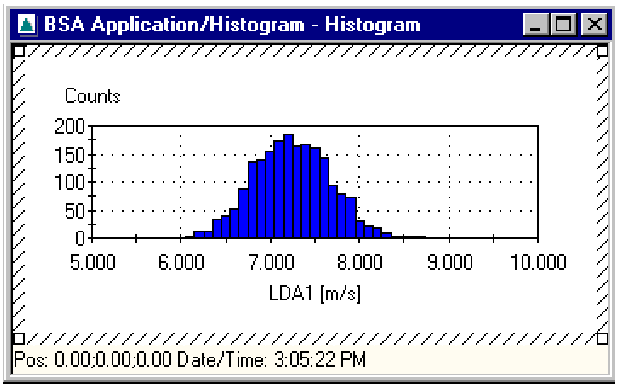


Figure 5-47 Histogram.

Once the histogram has been created, the quantity shown can be changed by right-clicking the histogram window and selecting Configure in the resulting context menu. This will open a dialog like the ones shown in Figure 5-48.

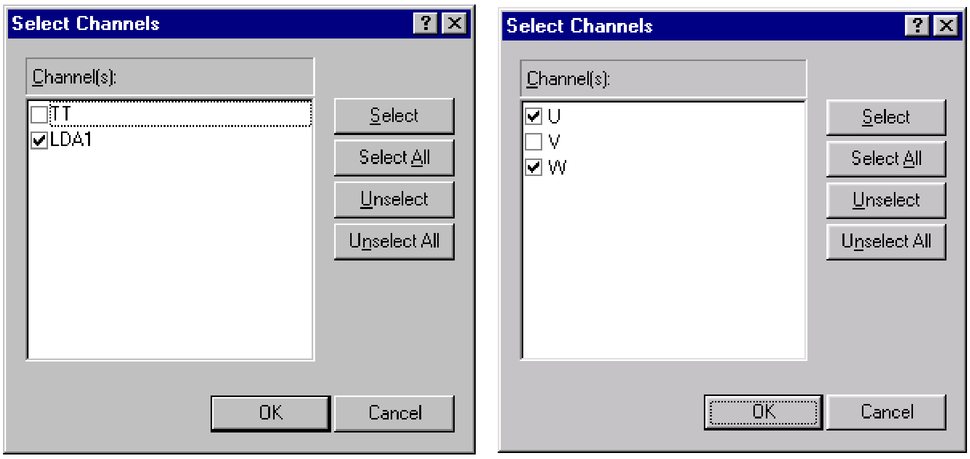


Figure 5-48 Possible inputs to the Histogram depend on the parent object.

Possible inputs to the Histogram object depend on the parent object: If Transform is the parent object the calculated velocity-components u, v and w can be selected, and otherwise velocities from the processor channels are possible, (FVA, BSA, PDA or LDA type data). Transit Time TT will normally be an option also, except when importing BURSTware or FLOware data, where this information may not be available.

Note that the histogram window may contain several histograms simultaneously if multiple inputs are selected in the dialogs in Figure 5-48.

5.12.1 Property group 'Data'

The Data properties define how many bins are used in the histogram, how the results are displayed (Count, Percentage or Cumulative) and whether the mean, RMS or 3xRMS is marked in the histogram.

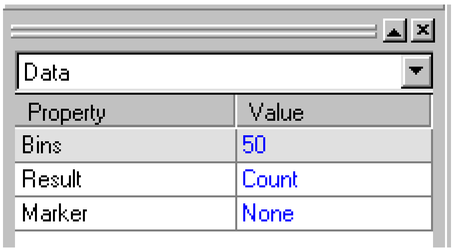


Figure 5-49. Data properties of the histogram object.

Bin

The property Bin determine the number of bins created between XMin and Xmax. If the number of bins is too low, the resulting histogram will appear coarse, while too many bins may result in very few or even no samples within each bin, so that the distribution of samples cannot be recognized properly.

Result

The property Result can be set to Count, Percentage or Cumulative, and define the Y-Axis of the histogram. Count and Percentage look similar, but show either the total number of samples within each bin, or the percentage of all samples. Cumulative is different, since it will show the cumulative percentage of velocity samples lower than or equal to the value on the X-axis.

Marker

The property Show Marker can be set to None, Mean, RMS or 3xRMS, and provides the option of showing a marker in the histogram. The marker is a dotted vertical line indicating the Mean value, Mean+RMS or Mean+3xRMS.

5.12.2 Property group ‘Scale’

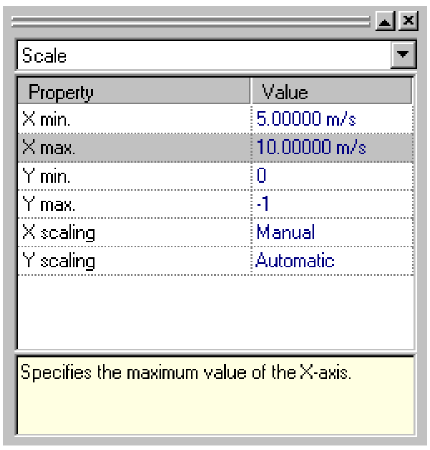


Figure 5-50. Scale properties of the histogram object

X min., X max. These properties determine the minimum and maximum values on the X-, and Y-

Y min., Y max. axis respectively. If the properties X scaling and Y scaling are set to Automatic, the minimum and maximum values will be adjusted automatically to match the data shown.

X scaling, Y scaling These properties can be either Automatic or Manual, with Automatic being the default setting. When scaling is set to Automatic, the minimum and maximum values of the axis in question will be automatically adjusted according to the data, while Manual scaling, means that the user specifies minimum and maximum-values manually.

The default setting Automatic ensures that all samples are included in the initial plot, while subsequently the user can zoom in on areas of specific interest by switching to manual scaling. Whenever the user changes a minimum or maximum value manually, the scaling of the corresponding axis will switch to Manual.

5.12.3 Property group 'Display'

The display options define the graph colours, the text font to be used for labelling and whether a grid is shown in the plot area or not. Furthermore, a 3D effect of the histogram can be defined with the other parameters in the display options group.

The histogram can be oriented vertially or horizontally. A title can be applied.

Note	*The font and font size of titles and text on axes can be globally defined for all graph objects in the Tools-Options dialog under the Display tab.*

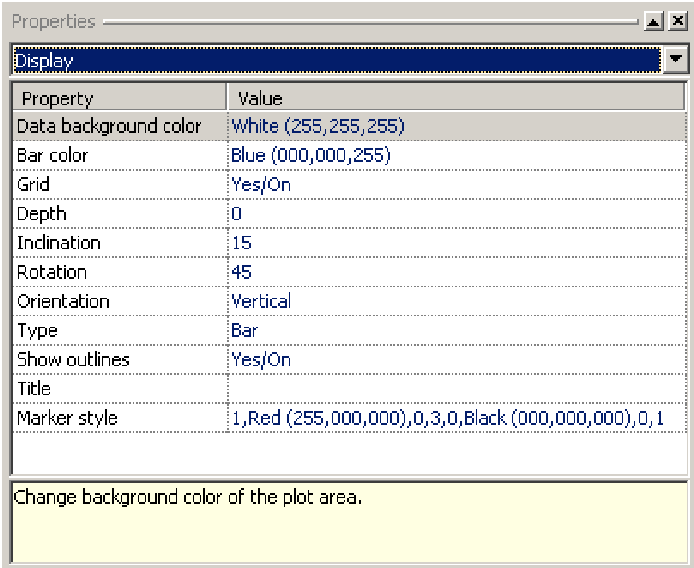


Figure 5-51. Display options of the histogram object.

5.13 Moments

The Moments object is used to calculate moments (One-Time statistics), such as mean and RMS on the basis of velocity samples. Possible parent objects are Import velocity files, BSA Application, Coincidence and Transform. If Transform is the parent object, moments are calculated on the basis of orthogonal velocities u, v and w, and otherwise calculations are performed on the basis of velocities from LDA1, LDA2 and LDA3.

The formulas used are shown in Table 5-2, using u and v as inputs:

Mean	$\overline{u} = \sum_{i=0}^{N-1} \eta_i u_i$	(Output)
Variance	$\sigma^2 = \sum_{i=0}^{N-1} \eta_i \left(u_i - \overline{u}\right)^2$	(Not Output)
RMS	$\sigma = \sqrt{\sigma^2}$	(Output)
Skewness	$S = \frac{1}{\sigma^3} \sum_{i=0}^{N-1} \eta_i \left(u_i - \overline{u}\right)^3$	(Output)
Flatness	$F = \frac{1}{\sigma^4} \sum_{i=0}^{N-1} \eta_i \left(u_i - \overline{u}\right)^4$	(Output)
Cross-Moments	$\overline{uv} - \overline{u}\,\overline{v} = \sum_{i=0}^{N-1} \eta_i \left(u_i - \overline{u}\right)\left(v_i - \overline{v}\right)$	(Output)

Table 5-2: Formulas for estimating moments.

The weighting factor η_i can be set to either

$$\eta_i = \frac{1}{N} \qquad \text{(Arithmetic weighting)}$$

or

$$\eta_i = \frac{t_i}{\sum_{j=0}^{N-1} t_j} \qquad \text{(Transit time weighting).}$$

–where N is the number of velocity samples, and t_i is the transit time of the i'th seeding particle passing the LDA measuring volume. (Transit Time is sometimes referred to as residence time).

Arithmetic weighting should only be used if the velocity-samples are independent, meaning that the time between samples exceeds twice the integral timescale of the flow. If this is violated, mean-velocity will be biased towards higher velocities, and higher order moments will be affected as well. In such cases transit time weighting should be used instead: This takes somewhat longer to compute, but results are bias-free.

Which weighting-scheme to use is selected in the property editor of the Moments object (See Figure 5-52).

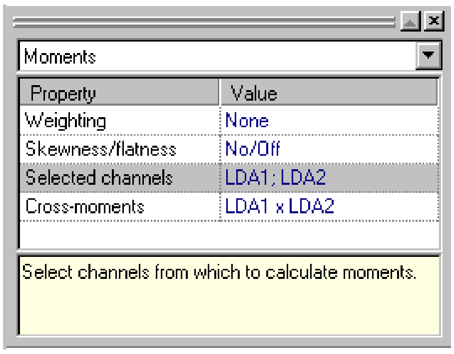


Figure 5-52 Properties of the moments object.

The property Weighting can be set to either None or Transit Time. The former correspond to arithmetic weighting, while the latter mean that transit time weighting is used.

The property Skewness/flatness determine whether or not the higher order moments Skewness and Flatness are included in the calculation, simply by setting this property to Yes/On or No/Off. (Skewness is sometimes referred to as Kurtosis).

The property Selected channels determine which velocity components are included in the calculation: Left-Click the Value-field and then click the  button to activate the dialog Select Channels shown in Figure 5-53:

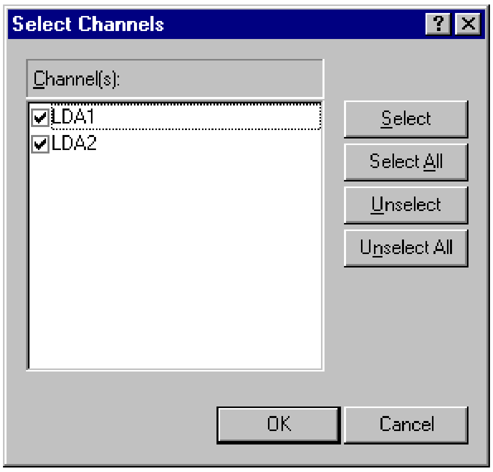


Figure 5-53 Selecting inputs for the moment calculation.

In this example two velocity components are available, and both are included in the moments-calculation. In Figure 5-53 the options are LDA1, and LDA2, but if the parent object had been Transform, it would have been U and V – the names usually used for orthogonal velocity components.

Finally the Moment-property Cross-moments is used to determine, which velocity components are used for the calculation of cross-moments: Left-Click the Value-field and then click the ... button to activate the dialog Select Cross-Moments shown in Figure 5-54.

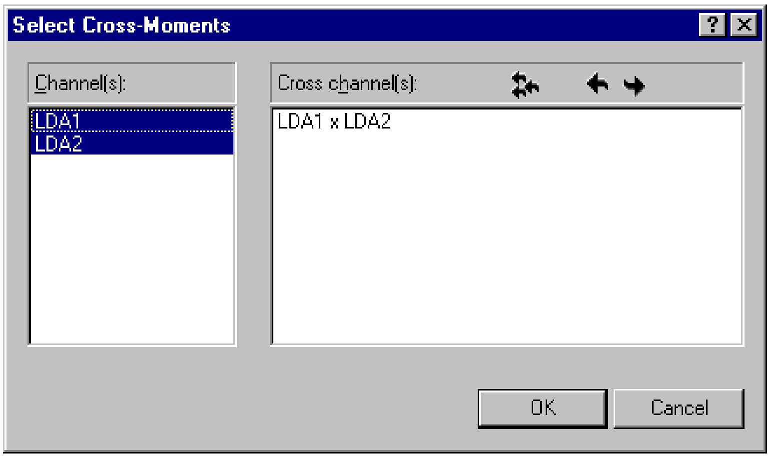


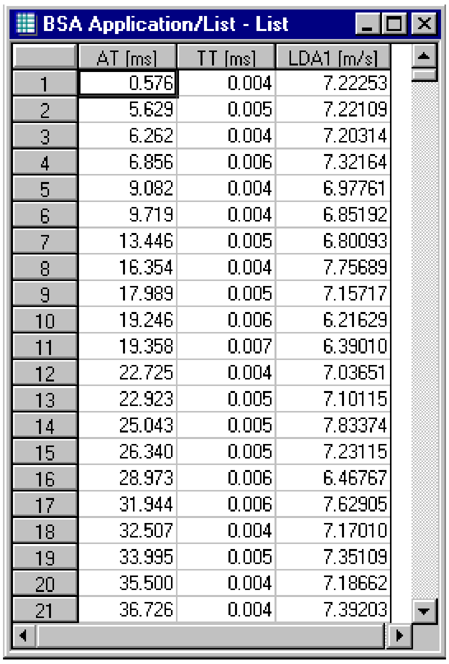
Figure 5-54 Selecting input for calculation of cross-moments.

In this example only one pair of velocity-components are chosen, but any of the three combinations 1-2, 1-3 or 2-3 are possible. Again velocities from LDA1 and LDA2 are shown, but orthogonal velocity components U and V would have been available instead, if the parent object had been Transform.

5.14 List

Apart from the Histogram, all of the objects described so far are used to acquire or process data, but none of them provide any output.
Results can be presented either as graphics, using routines supplied in the “Advanced Graphics Add-On”, or numerically using the List object.

List is thus a general purpose object, which can be a child of any object supplying data, and these data are presented in a spreadsheet-like manner on the screen. (See Figure 5-55).

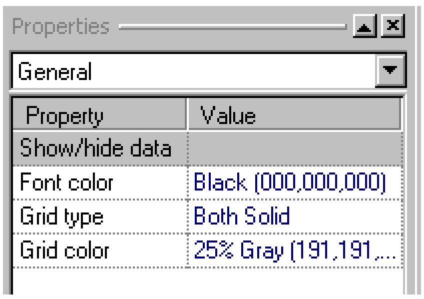


	AT [ms]	TT [ms]	LDA1 [m/s]
1	0.576	0.004	7.22253
2	5.629	0.005	7.22109
3	6.262	0.004	7.20314
4	6.856	0.006	7.32164
5	9.082	0.004	6.97761
6	9.719	0.004	6.85192
7	13.446	0.005	6.80093
8	16.354	0.004	7.75689
9	17.989	0.005	7.15717
10	19.246	0.006	6.21629
11	19.358	0.007	6.39010
12	22.725	0.004	7.03651
13	22.923	0.005	7.10115
14	25.043	0.005	7.83374
15	26.340	0.005	7.23115
16	28.973	0.006	6.46767
17	31.944	0.006	7.62905
18	32.507	0.004	7.17010
19	33.995	0.005	7.35109
20	35.500	0.004	7.18662
21	36.726	0.004	7.39203

Figure 5-55 List output of 1D velocity data.

Height and width of rows and columns can be modified with the mouse, dragging cell-boundaries of column titles and row numbers.

The actual contents of the list depend on the parent object. In Figure 5-55 the parent object was an import object with one-dimensional BSA data, and consequently the raw velocity-samples are shown including measured velocity, transit time (TT) and arrival time (AT) from LDA1. If the parent object had been Transform, velocities U, V and W would have been shown.



Property	Value
Show/hide data	
Font color	Black (000,000,000)
Grid type	Both Solid
Grid color	25% Gray (191,191,...

Figure 5-56 Properties of the list object.

The remaining properties of the List object shown in Figure 5-56 determine fonts and grids used in the on-screen list-display.

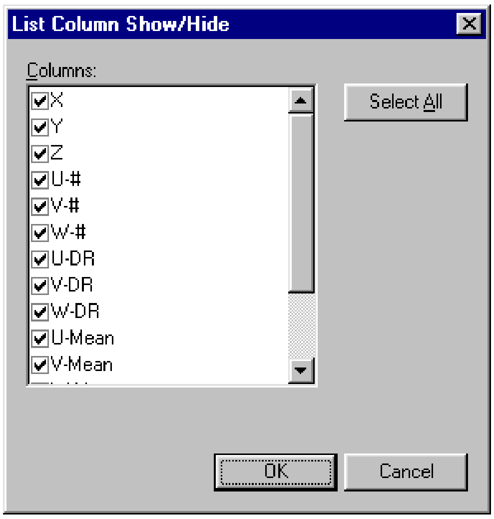


Figure 5-57 Properties of Column Show/Hide dialog

Columns can be hidden by using the Column Show/Hide dialog which is accessed by clicking in the Show/hide data field in the Property Editor.

Further facilities of the List-object can be reached through a context-menu activated by right-clicking the mouse inside the List-display:

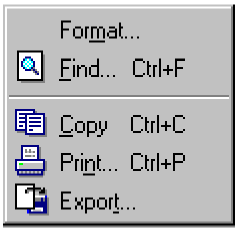


Figure 5-58 Context menu of the list object.

Selecting Format in the context-menu will bring up the Format-dialog shown in Figure 5-59:

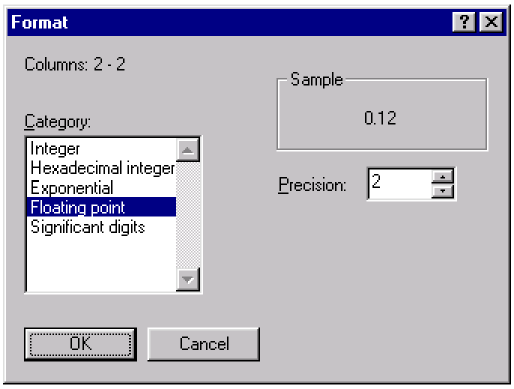


Figure 5-59 Formatting values in the selected columns of the list.

The Format dialog will format the output of the column you clicked. For example you may find it useful to increase the number of decimals used in the output of transit times, since especially in fast flows, transit times will in general be very small, and may show up as zero in the default output format. If you select several columns prior to activating the context-menu, you can apply the same formatting to all these columns simultaneously.

The next selection in the context menu is Find, which will bring up the Find dialog shown in Figure 5-60:

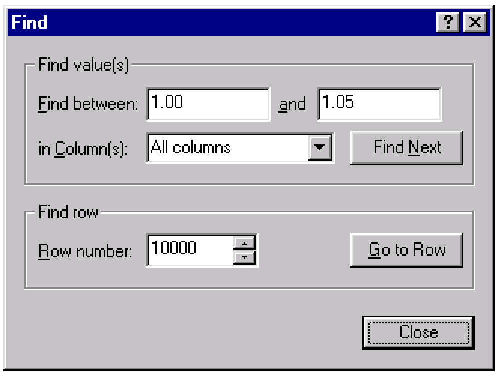


Figure 5-60 Find is used to search the list, either by value or by row number.

The Find-facility is especially useful for locating specific information in large lists: You can look for cells fulfilling specific criteria regarding value and also instruct the software to search a specified column only. Peak-finding might be an example: If you have a large dataset, where the majority of values lie between 0 and 20, except for a peak-value somewhere, which may be in the order of 100, instruct the Find-routine to locate cells with values above 50. If the list you are searching contain raw samples, this might be an erroneous measurement, which you wish to investigate closer, or if the data comes from a spectrum-calculation, you might want to know the exact frequency, at which the peak occurs.

The next two entries in the context menu are Print and Copy, which will print the list on the printer, or copy it to the clipboard, from where you may paste it into a spreadsheet, a word-processing program or something else.

The last entry in the context menu is Export, which will open up the Export File dialog shown in Figure 5-61.

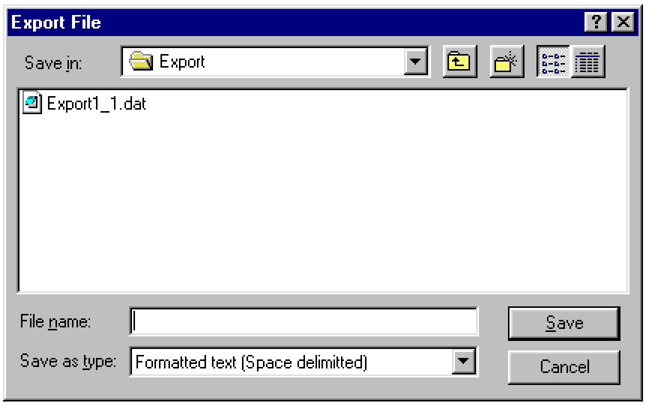


Figure 5-61 Exporting list-data through the context menu.

The contents of the list will be exported to a file specified by the user. In the dialog the user can select the drive and folder in which to save the exported data, and also specify filename and file-format. The design of this dialog corresponds to normal Windows standard.

5.15 Phase Plot

This object is only available in PDA configuration (size add-on).

The phase plot mainly serves as a tool during system setup. It is used to facilitate proper optical alignment and to ensure correct setting of all parameters affecting the particle size measurement. During data acquisition the phase plot allows to continuously monitor measurement quality.

The phase plot is a 2D plot displaying the relationship between two measured phase differences. The phase plot for a FiberPDA differs slightly from that of a DualPDA. For a FiberPDA the phase plot displays the measured phase difference between detector U1 and U2 as a function of the phase difference between detector U1 and U3. For a DualPDA the phase U1-U2 is shown as a function of phase V1-V2.

A typical phase plot for a FiberPDA is shown in Figure 5-62. The displayed phases are measured phase differences which are corrected by the phase offset determined during phase calibration. The diagonal continuous line represents the theoretical relationship between the two phase differences for perfectly spherical particles. To account for a finite accuracy of the system, a certain deviation from the ideal line has to be tolerated. Therefore, a tolerance band, indicated by the two dashed lines, is defined. The width of this tolerance band can be set by the user by changing the value of the parameter *Sph. validation* in the PDA Receiver menu.

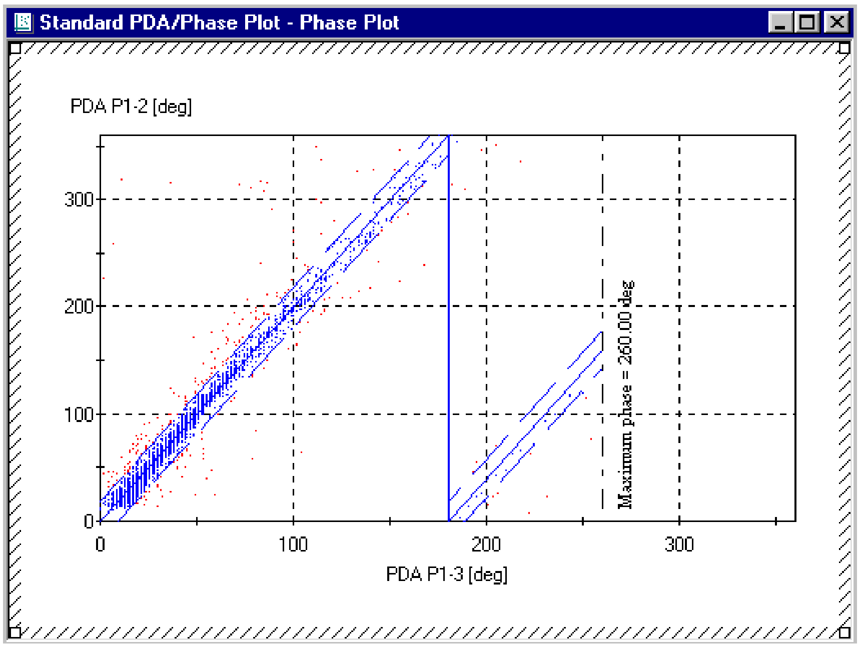


Figure 5-62: FiberPDA phase plot.

Every single measurement is displayed in the phase plot as a colored dot. Validated samples (samples inside the tolerance band) are displayed as blue dots. Rejected samples (samples outside the tolerance band) are indicated by red dots.

Note	*If the* D validation *is set to* Yes/On, *measurements which do not fulfill the sphericity check (red dots) will not be displayed in the phase plot.*

With optimized optical alignment and correct parameter settings, a cloud of dots will build up centered around the continuous line and mostly within the tolerance band. Poor alignment or e.g. wrong setting of the fringe direction will be indicated in the phase plot by a more or less significant deviation of the data points from the theoretical line.

The phase plot also provides some information about the sphericity of the measured particles. Whereas the FiberPDA has only a rather limited ability to detect non-sphericities, the DualPDA is significantly more sensitive to distinguish deformed droplets. This is due to the different detector arrangements.

For the FiberPDA (and ClassicPDA) the maximum phase difference between detectors U1 and U3 is set to a default value of 260 degrees. This is due to signal visibility reasons. For the DualPDA the maximum phase of the planar PDA (V1-V2) can be set to any value between 0 and 360 degrees.

5.16 Diameter statistics

This object is only available with a PDA configuration (size add-on).

The diameter statistics object provides a more advanced statistical analysis of the measured particle diameters. The results can be output graphically, in tabular form or exported. Possible child objects are List, Export and all graph types from the advanced graphics add-on.

As an example, a list output is shown in Figure 5-63 and a profile plot taken in a water spray is given in Figure 5-64.

Standard PDA/Diameter statistics/List - List

	X [mm]	Y	Z	Counts	D10 [um]	D20 [um]	D30 [um]	D32 [um]	Dv0.1 [um]	Dv0.5 [um]	Dv0.9 [um]	Span	Concentr	U Flux	V Flux
1	-3.00	0.00	0.00	1E+004	24.23	35.05	45.67	77.52	46.51	102.58	122.97	0.745	2526.33	0.05	0.01
2	-2.80	0.00	0.00	1E+004	26.21	37.35	47.91	78.84	47.79	102.58	122.97	0.733	2426.56	0.06	0.01
3	-2.60	0.00	0.00	1E+004	23.91	35.52	46.37	79.04	47.79	103.86	122.97	0.724	2214.36	0.06	0.01
4	-2.40	0.00	0.00	1E+004	22.03	31.97	41.65	70.71	41.41	94.94	121.70	0.846	3536.09	0.05	0.01
5	-2.20	0.00	0.00	1E+004	20.86	29.16	37.81	63.60	37.59	87.29	120.42	0.949	4726.52	0.05	0.01
6	-2.00	0.00	0.00	1E+004	17.97	25.01	32.85	56.65	31.22	78.37	121.70	1.15	7038.65	0.03	0.01
7	-1.80	0.00	0.00	1E+004	14.93	20.75	27.53	48.44	27.40	65.63	112.78	1.3	11426.13	0.02	0.00
8	-1.60	0.00	0.00	1E+004	12.88	17.72	23.55	41.58	23.57	52.88	111.50	1.66	13102.48	0.02	0.00

Figure 5-63: List output from the diameter statistics object.

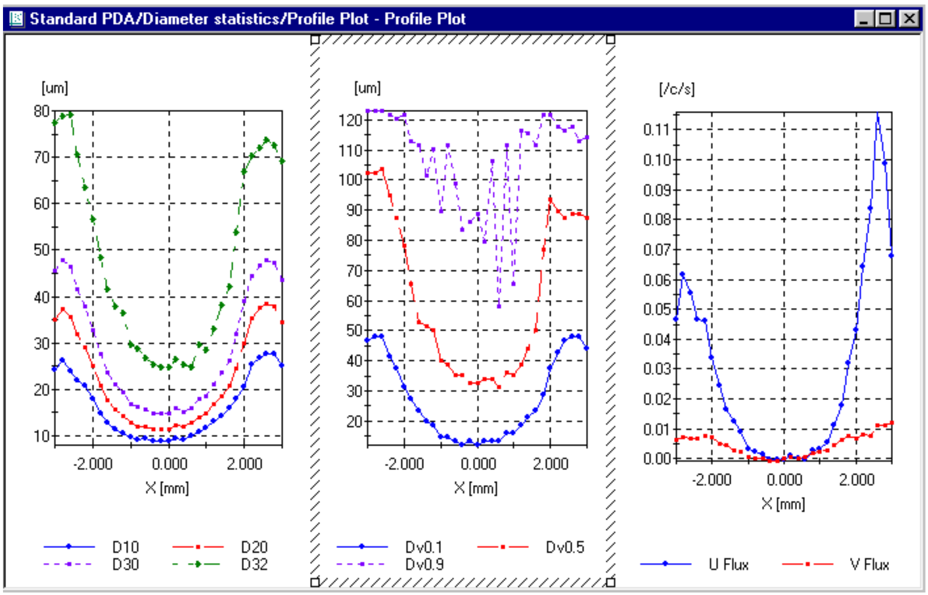
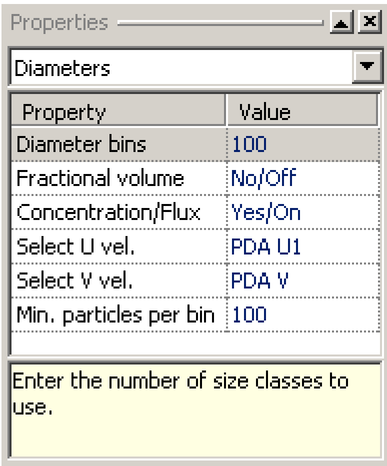


Figure 5-64: Profile plot showing diameter moments and measured volume fluxes.

The property list of the diameter statistics object is shown below.


Properties

Diameters

Property	Value
Diameter bins	100
Fractional volume	No/Off
Concentration/Flux	Yes/On
Select U vel.	PDA U1
Select V vel.	PDA V
Min. particles per bin	100

Enter the number of size classes to use.

Figure 5-65: Property list of the diameter statistics object.

The number of diameter bins the analysis is based on, can be defined by the user. The computation and output of the fractional volumes, concentration and fluxes can be enabled or disabled, as requested.

The output quantities of the diameter statistics object are listed below:

Output quantity	Description
D10	Mean diameter
D20	Area mean diameter
D30	Volume mean diameter
D32	Sauter mean diameter (SMD)
D43	De Broukere mean diameter
Dv0.1	10% fractional volume diameter: 10% of the total particle volume is contained in particles smaller than this diameter.
Dv0.5	50% fractional volume diameter (Volume median diameter)
Dv0.9	90% fractional volume diameter
Span	Describes the width of the size distribution
Concentration	The average number of particles per unit volume (particles/cm^3)
U Flux	The volume flux of particle material in the direction of the U velocity component through a reference area per unit of time ($cm^3/cm^2/s$)
V Flux	The volume flux of particle material in the direction of the V velocity component through a reference area per unit of time ($cm^3/cm^2/s$)

Table 5-3: Description of diameter statistics moments.

The definition of all the mean diameters, flux and concentration are given in the chapter 7.5: Data analysis.

5.17 Export

Like the List object Export is a general purpose object which can be used to export data from any object supplying data. Consequently any data that can be listed can also be exported.

The main difference between exporting from a list, and by adding an export object is, that the Export object can export to multiple files e.g. one per position, and this is done on the fly, whereas exporting from a list requires manual interaction for each file to be exported.

The property editor of the Export object is shown in Figure 5-66:

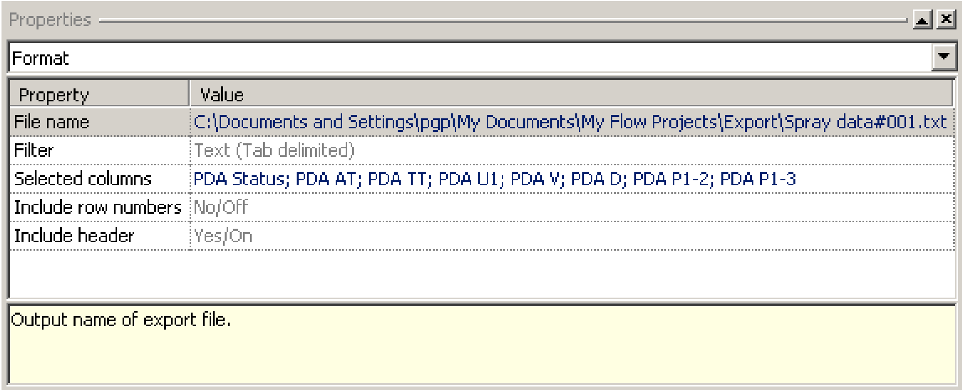


Figure 5-66 Properties of the Export object

5.17.1 File name

Modifying the property File name is done in a dialog shown in Figure 5-67.

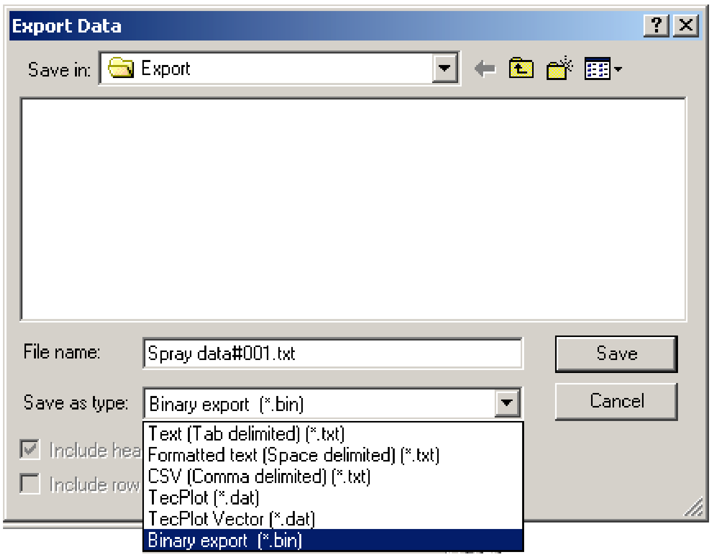


Figure 5-67 File Name dialog

Please see the next section for information about the different file types.

The Export object adds a number to the name of each exported file. In the example in Figure 5-66, the project file name that we export from is called Spray data.lda. The export file names will be Spray data#001.txt, Spray data #002.txt, etc., where the #001 is the first position, #002 is the second, etc.

If more export objects are added to the same project file, the export file names will be Spray data2#001 etc.

5.17.2 Filter

The property Filter displays the format of the exported ASCII file as chosen in the File Name dialog.:

- Text (Tab delimited)
- Formatted text (Space delimited)
- CSV (Comma delimited)

- TecPlot: includes header information required for import into TecPlot
- TecPlot Vector: arranges data in the order required by TecPlot for vector plots. This should only be used when exporting moment data.
- Binary Export is a compact binary export format included with the Binary Export add-on. Please refer to chapter 6 for details about this.

5.17.3 Selected columns

The property Selected columns determine which data is included in the export, and allows the user to arrange columns in a different order. It will bring up the dialog shown in Figure 5-68:

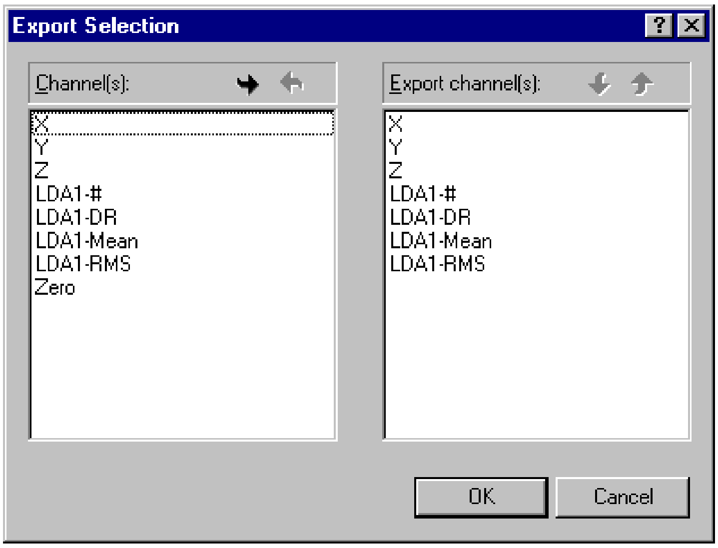


Figure 5-68 Selecting the data to be exported

The actual data available depend on the parent-object of the export-object itself. In the example in Figure 5-68, the parent object was Moments from a 1-Dimensional LDA.

A "Zero"-column is available to fill in blank columns in the exported data. This will facilitate importing data into programs requiring a specific format. For example a blank could be filled in if the receiving program requires coordinates X, Y and Z, and you have only X, and Y available.

The Export object will export data with the format defined under Tools - Options - Data formats.

5.17.4 Include row numbers

The property Include row numbers is used to determine whether or not a sequential numbering of the exported data should be included. By default this property is set to No/Off.

5.17.5 Include header

Additional header information is added to the exported files if the Include header is Yes/On. For each exported file the traverse position and the project name is included in the header. Note that if this is not selected ASCII-export does not include any header information other than the column names.

5.18 Filter

The filter object allows to define a subrange of a dataset and to perform further analysis on this subrange only. An example is data acquired between the blades of an impeller. The blade passages may produce data, which should be removed. This could be done by adding a filter object to the cyclic phenomena object to remove data from within certain phase angles or velocity data, which fall outside the range of fluid velocities to be expected. The filter object can be a parent object or a child object.

Note	*Several filter objects can be applied to the same data, filtering one parameter in each. For example, if you wish to filter the velocity ranges of two velocity components, you can apply two filters and filter one component in each.*

The properties of the filter object are shown below:

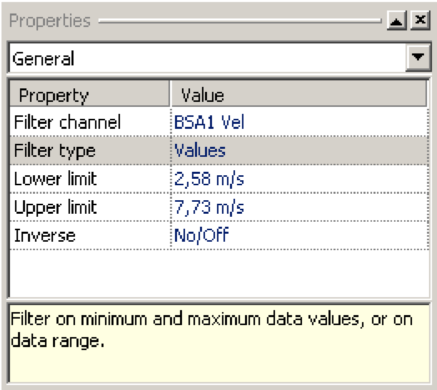


Figure 5-69. Properties of the filter object.

Filter channel selects the quantity being subject to the filtering function. The selection of quantities depends on the general configuration of the project and where in a project the filter is applied. A typical example of a selection of available filter channels is shown below:

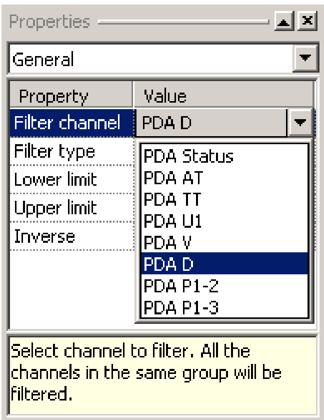


Figure 5-70. The filter channel drop-down list

The desired filter range is specified by the lower and upper limit. The limits have to be entered in the units that are defined for the selected filter channel.

Filter type can be either Values or Range.

Values mean that the filter will apply to the value of the selected quantity, in the above example PDA D.

Range means that the filter will apply to the sample indices in the range Lower limit to Upper limit. For example if Lower limit is 100 and Upper limit is 200, only the samples # 100 to 200 will be passed through the filter.

Inverse applies the filter to values outside the specified Lower limit and Upper limit.

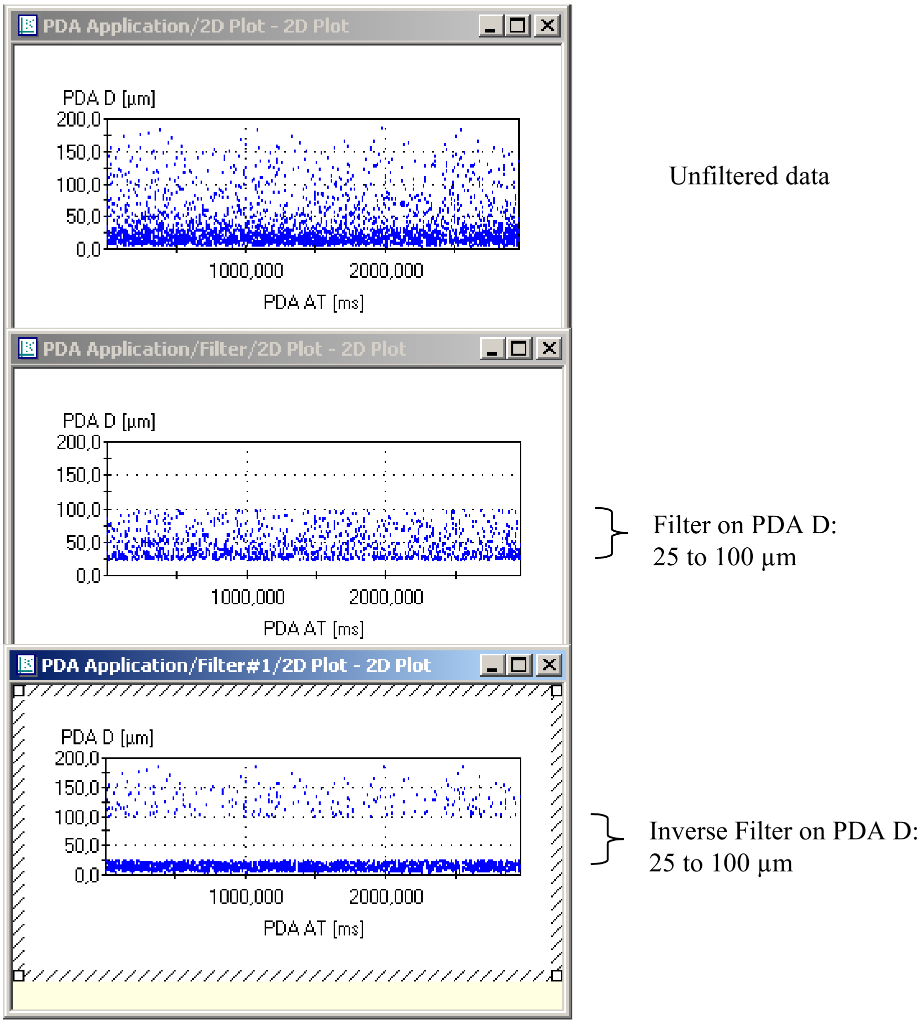


Figure 5-71 Filter and Inverse filter applied to PDA D data

In the above example, filters could also have been applied to the PDA AT corresponding to a filter along the X axis of the plots. Filtering on range would also affect the X axis, since the sample index increases with arrival time.

6. Options and add-ons

This chapter includes descriptions of various options and add-ons for the system, except the size add-on which is described in the chapter 5. They are not an integrated part of the basic software package, but are bought separately including documentation, which can be inserted here.

6.0 Installing an add-on

Add-ons are included on the CD containing BSA Flow Software. Before installing an add-on, you must install the basic BSA Flow software package as described in chapter 3.

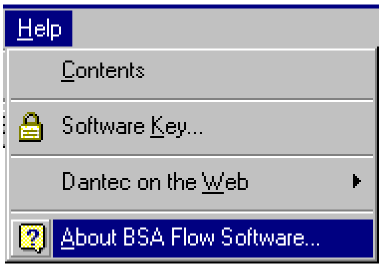
To install an add-on, insert the CD-ROM in you PC and install the add-on as described in chapter 3.

If you do not have autostart on your PC, use Windows Explorer to browse the CD-ROM. Open the folder Software\AddOn v1.50. This contains a number of sub-folders, including Cyclic Phenomena, Advanced Graphics, etc. Open the one corresponding with the add-on you wish to install, and double-click on the Setup.exe file in it. This will launch the installation program, guiding you through the installation of your add-on.

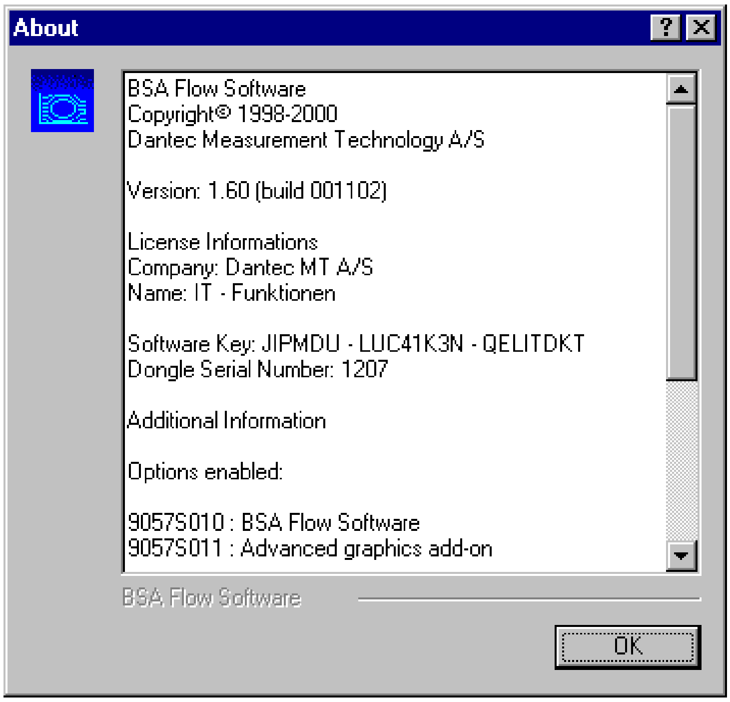
Softwarekey

The BSA Flow software and the add-ons are dongle-protected, and during the installation of your add-on you will be asked to enter a softwarekey. Apart from matching your dongle, the softwarekey also determines which add-ons you will be allowed to install.

When ordering an add-on, you may be asked to supply the old softwarekey and the corresponding serial-number of your dongle. This information is needed to generate a new softwarekey matching your existing dongle, but allowing you to install the new add-on. The information can be found in the About dialog of your existing BSA Flow Software along with information about add-ons and options already installed:



⇒



6.1 Cyclic Phenomena add-on

As the name implies the cyclic phenomena add-on is used for analysing cyclic phenomena. In some flows, such as vortex shedding behind an obstacle, the cyclic behaviour may be an intrinsic property of the flow itself, but such cases are not covered here.
This add-on is designed to handle flows, where the cyclic behaviour stems from some measurable external influence, such as the movement of a piston, the opening and closing of a valve, or the rotation of a turbine-impeller.

Reset-Pulse (mandatory)

To handle such cases, the cyclic phenomena add-on require a Reset-pulse to be sent to the processor once per cycle (for example when the piston reaches top dead centre, when the valve opens, or once per revolution of the turbine impeller). Assuming constant angular velocity between Reset-pulses, this allows the cycle phase angle of each sample to be resolved based on the arrival time of the sample.

The Reset-pulses may be taken from a shaft encoder mounted on a turbine-shaft, or on the camshaft of an engine. A simple sensor detecting top dead centre can also be used, or the signal can be taken directly from an electronic valve-controller.

Encoder-Pulses (optional)

If a shaft encoder is used, you may send encoder-pulses to the processor also, and use these instead of the arrival time to resolve the phase of each velocity sample. In most cases this will be less accurate than time-based phase-resolving, but it may be useful if for example the angular velocity is not constant in the time between Reset-pulses.

Hardware connections

Reset pulse and encoder pulses, if used, must be connected to the Synchronisation Inputs on the BSA rear panel. In the Processor properties, the connectors must be mapped to the relevant function, as described in chapter 5.

6.1.1 Cyclic Phenomena object

When the add-on is installed, the cyclic phenomena object will appear in the list of options, when you create a new object (See Figure 6.1-1).

Required input

The Cyclic Phenomena object can be created as a child of any object which beyond sample values supplies reset information marking each cycle, and a time-stamp or angle-stamp for each sample.

The status codes (shown in Table 6.1-1) are required to distinguish normal data samples from other events such as Reset-pulses. As well as normal samples, these events must be time-stamped to allow phase-sorting, and this can be done using either internal or external clock. While internal clock time-stamps data samples with arrival time, external clock is used when phase-sorting is to be done on the basis of encoder-pulses. In the latter case data samples are time-stamped with an encoder pulse count representing rotational position of the shaft encoder.

Processor Type	Sample ID	Reset-Pulse ID
BSA	(Blank)	Sync1

Table 6.1-1 Status codes distinguish samples and reset pulses.

If the data recorded contain no reset-pulses you will get an error message trying to run the cyclic phenomena object.

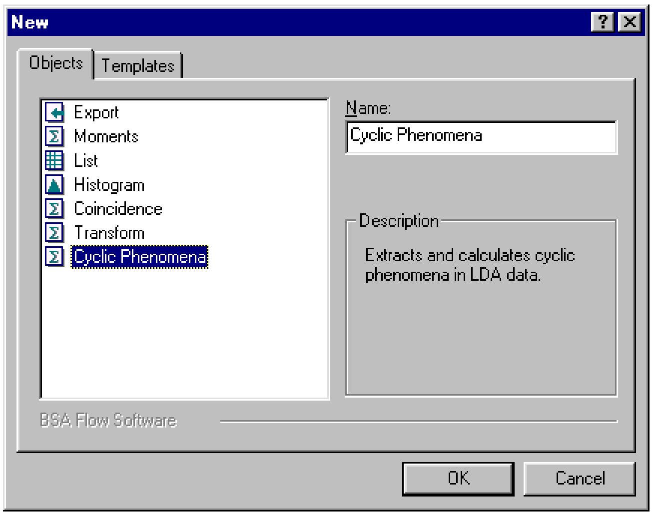


Figure 6.1-1 Cyclic phenomena in the list of possible new objects.

2D- / 3D data	data from the BSA processors share one common arrival time (or encoder pulse count), so a Cyclic Phenomena object can handle data from all channels
A/D-Data	In most cases, data samples will represent measured velocities, but the Cyclic Phenomena object can also assist in analysing say pressure or temperature, if data from an A/D-board is used as input along with velocity samples from an BSA processor. This requires the Analog Input Option.

6.1.2 Properties of the Cyclic phenomena object

The properties of the Cyclic Phenomena object is shown in Figure 6.1-2:

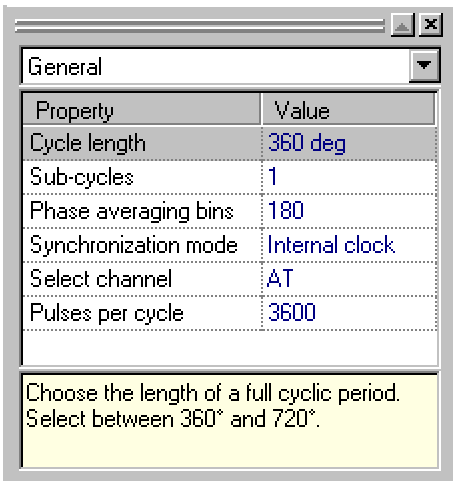


Figure 6.1-2 Properties of the Cyclic Phenomena object

Cycle length

The property Cycle length can be set to either 360 deg or 720 deg, with 360 deg as default. It determines whether the time between two Reset-pulses should be interpreted as 360° or 720°, the latter being relevant for example in four stroke engines, where one full cycle correspond to two revolutions of the crankshaft.

Note: *Please note that* Cycle length = 720 deg *does not accept two reset-pulses within each cycle, even if a full cycle correspond to two revolutions of the crankshaft: There is no way to tell, which reset-pulse indicates the start of a cycle, and which one is a "halfway marker". Instead the shaft encoder should be connected to the camshaft, or a 2:1 gearing mounted between the crankshaft and the encoder, to yield only one reset pulse per cycle.*

Sub-cycles

The property Sub-cycles is an integer with the default value 1. It is typically used for measurements on propellers and the like, where the number of sub-cycles correspond to the number of blades on the propeller. In the example in Figure 6.1-2 the 7 blades are merged into one, with a resulting full cycle length of 360°/7 = 51.4°.

Phase averaging bins

The property Phase averaging bins determines the number of angle bins used for phase averaging. After phase sorting of the samples, mean and rms values are also calculated within each angle bin. Which value to enter here depends on the experiment itself: To get good resolution it is desirable to have many narrow bins, but if the angle bins are too narrow, there may be very few samples within each of them and consequently the calculated mean and rms for each bin will not be very reliable. Assuming that the samples are evenly distributed over the full cycle, the appropriate number of bins will in general increase with the total number of samples taken.

Note: *Please note that the number of bins always relate to the full cycle even if it is divided in sub-cycles: In the example in Figure 6.1-2 120 bins distributed over a full cycle of 360° yield angle bins, that are each 3° wide. However the full cycle is divided in 7 sub-cycles of 51.4°, and the actual width of the* *angle bins is adjusted to 3.025° to produce an integer number of bins within the sub-cycle.*

Synchronisation mode

The property Synchronisation mode is a read only property indicating whether phase sorting is done on the basis of arrival time or encoder pulses. The property is set automatically according to the incoming data samples. Internal clock mean that arrival time is used, while Encoder count means that phase sorting is done based on encoder pulses.

Select channel

The property Select channel is used when measurements are performed in 2- or 3-D, and coincidence filtering has not been performed prior to phase sorting. In this case 2 or 3 LDA-channels are connected yielding not only several velocity samples, but also several arrival times and status codes. The property Select channel determine which samples are to be phase sorted. If you want to phase sort all the samples, you must either create a separate cyclic object for each of them, or perform coincidence filtering first to get samples that share common arrival times and status codes.

Pulses pr. cycle

The property Pulses pr. cycle is relevant only when Encoder count is used (i.e. when phase sorting is done on the basis of encoder pulses rather than arrival time). The property indicates the length of a full cycle measured in pulses (i.e. the number of pulses per revolution of the shaft encoder).

6.1.3 Output from the Cyclic phenomena object

The Cyclic phenomena object is a processing object identified by the Σ-icon in the project explorer, and like all processing objects it performs calculations, but does not itself present the results. To see the results you can create a List-object as a child of the Cyclic phenomena object. (See Figure 6.1-3)

Pump/SubCycle/List - List

	AT [ms]	Time [ms]	Angle [deg]	BSA1 Vel [m/s]	Angle Bin [deg]	Counts	BSA1 Vel-Mean	BSA1 Vel-RMS
6	104231,56	0,000	0,000	-1,021	18,151	12001	0,059	0,056
7	327349,74	0,000	0,000	-1,103	21,176	4282	0,127	0,203
8	286330,27	0,000	0,000	-0,879	24,202	644	-0,771	0,519
9	121000,75	0,001	0,012	-1,739	27,227	704	-0,956	0,595
10	221934,80	0,002	0,024	-1,398	30,252	645	-1,041	0,605
11	218939,05	0,002	0,024	-1,526	33,277	642	-1,074	0,654
12	118087,51	0,003	0,036	-1,291	36,303	651	-1,163	0,698
13	48739,82	0,004	0,048	-1,520	39,328	641	-1,157	0,747
14	214196,80	0,004	0,048	-0,265	42,353	596	-1,306	0,721
15	45887,96	0,008	0,084	-0,981	45,378	608	-1,347	0,633
16	34347,16	0,008	0,090	-1,242	48,403	584	-1,454	0,533
17	254469,72	0,009	0,096	-0,527	51,429	513	-1,424	0,561
18	151996,05	0,009	0,096	2,544				

Figure 6.1-3 Output from the Cyclic phenomena object

The first four columns in Figure 6.1-3 show the results of phase sorting, while the last four columns show the results of phase averaging.

Time- / Encoder-Based In Figure 6.1-3 phase sorting has been done on the basis of arrival time, but it might as well have been done on the basis of encoder pulses. In the latter case the two first columns would contain encoder pulse counts representing a total count (Arrival Pulse, or AP) and a count since last recorded reset pulse (i.e. how far into current cycle).

AT

The arrival time shown here is relative to the first Reset-pulse received, and consequently does not correspond to the arrival times you will see, if you create a list of the raw data. In the example used here, the first Reset-Pulse arrived 0.576 ms after the experiment was started, and consequently all the arrival times shown are 0.576 ms lower than the ones you would find looking at a list of raw velocity samples.

Time

The Time shown in Figure 6.1-3 is relative to the latest Reset-Pulse received, and consequently indicates the time within each cycle.
Phase sorting is done based on this value.

Angle

The column labelled Angle contains estimated phase angles.
When phase sorting is done on the basis of arrival time, phase angles are estimated from the time within the cycle and the duration of the current cycle (i.e. the time between the previous and the following reset-pulse).
If phase sorting is done using encoder pulses, phase angles are estimated from the number of pulses since last reset, and the cycle length specified in the property Pulses pr. Cycle.

Note *Please note that phase angles estimated from arrival times do not necessarily correspond to the angular position of a rotating shaft unless this shaft moves with constant velocity so there is absolute linearity between time and position. In some cases, such as a rotating impeller in a turbine,* *constant velocity is a reasonable assumption, but in other cases, such as the crankshaft in a four-stroke engine, the velocity can vary significantly within each cycle even if the duration of the cycle is constant. If knowledge of the angular position is important and linearity cannot be assumed, you should phase sort on the basis of encoder pulses rather than arrival time.*

Velocity

The fourth column contains the phase-sorted samples. In the example in Figure 6.1-3, the samples come from LDA1. Obviously velocity samples may also come from a different processor, and the column will then be labelled accordingly.
With 2- or 3-dimensional measurements coordinate transformation can be performed prior to phase sorting, and the resulting orthogonal velocities U, V and W will then be shown in separate columns. Coordinate transformation requires coincidence filtering, and whenever coincidence filtering is performed prior to phase sorting you will get more than one column of output data containing the phase sorted coincident samples.

Angle Bin

The last columns relate to the phase averaged data. Phase averaging is done by sorting velocity samples into angle bins, and calculating mean and rms of all the velocity samples, that fall within the same bin. The column labelled Angle Bin identify these bins by their upper limit: For example, the last one shown in Figure 6.1-3 has Angle Bin = 51.429, indicating that the results are based on velocity samples with phase angles in the range 48.403° to 51.429° (48.403° being the upper limit of the previous angle bin).

Counts

The column labelled Counts contains the number of samples that fell in each bin, and is relevant in estimating the accuracy of the calculated mean- and RMS-values. If either of the angle bins contain too few samples to yield reliable mean- and RMS-values, you will have to increase the bin width by reducing the total number of bins.

Mean and RMS

The last columns contain the calculated Mean-velocities and RMS-values for each of the angle bins. In the example in Figure 6.1-3 the samples come from LDA1, but they may also come from a different processor, or be labelled U, V or W, if coincidence filtering and coordinate transformation has been performed prior to phase sorting.
Again coincidence filtering prior to phase sorting will yield mean- and RMS-values for all of the samples (velocities) available.

6.1.4 Presenting results

To present your results, you can either use the advanced graphics add-on, or you can export the results storing them in a file, and then use your own or third party software to make a presentation based on the data in the file.

Figure 6.1-4 show some of the presentations that can be made using the advanced graphics add-on:

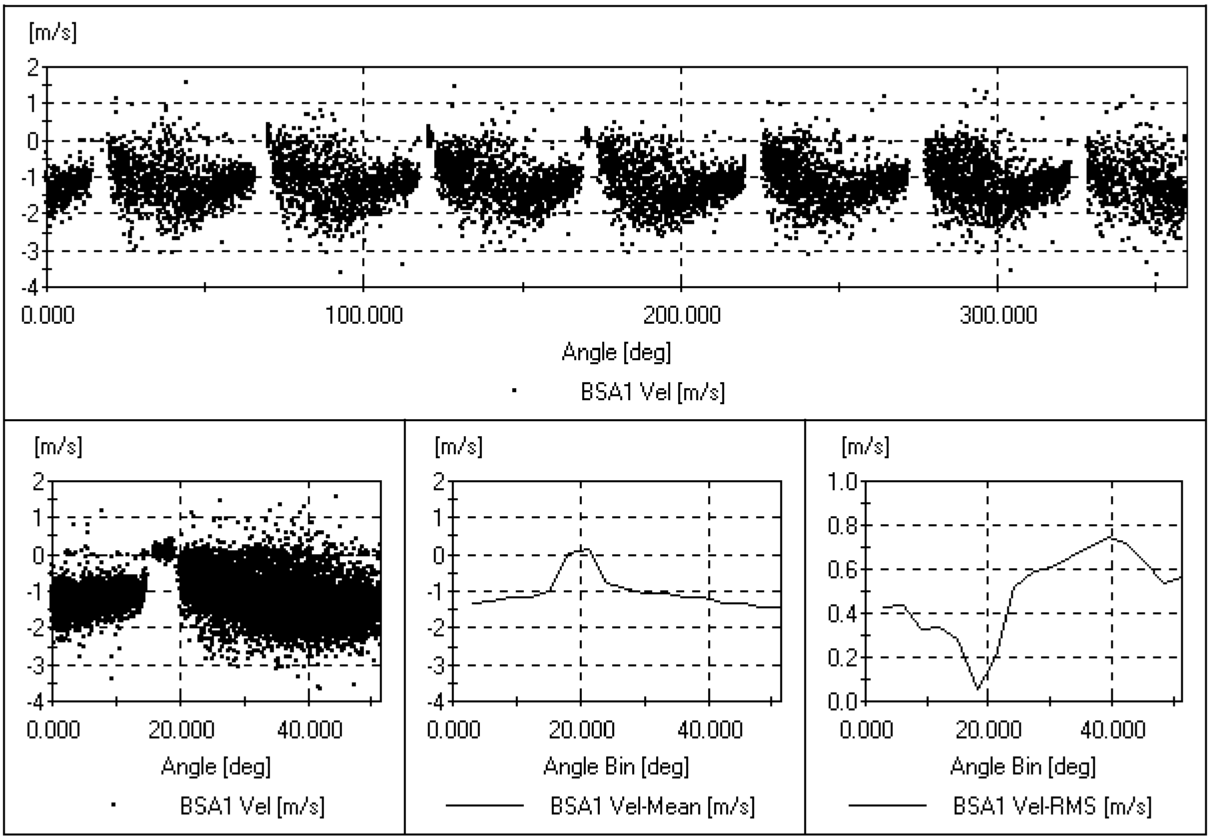


Figure 6.1-4 Phase sorting and phase averaging:
Upper: Phase sorting the full cycle indicate the presence of 7 subcycles.
Lower left: Phase sorting with 7 subcycles merged into one.
Lower center: Phase averaging within angle bins yield mean velocities.
Lower right: Phase averaging within angle bins yield rms values.

Figure 6.1-4 illustrate phase sorting and phase averaging performed on cyclic data from measurements in a pump.
The upper figure show the results of phase sorting the full cycle, and 7 subcycles are clearly visible corresponding to the number of blades.
The three lower figures show phase sorting and phase averaging performed with Subcycles = 7: The leftmost figure shows all the velocity samples merged into a single subcycle, and the other two show the corresponding mean-velocities and rms-values calculated within 17 angle bins each approximately 3° wide.

6.2 Spectrum & Correlation add-on

The Spectrum & Correlation add-on will allow you to estimate autospectral density functions as well as autocorrelation functions on the basis of your measured data.

When the add-on is installed, three new objects, Spectrum, Advanced Spectrum and Correlation, will appear in the list of options, when you create a new object (See Figure 6.2-1).

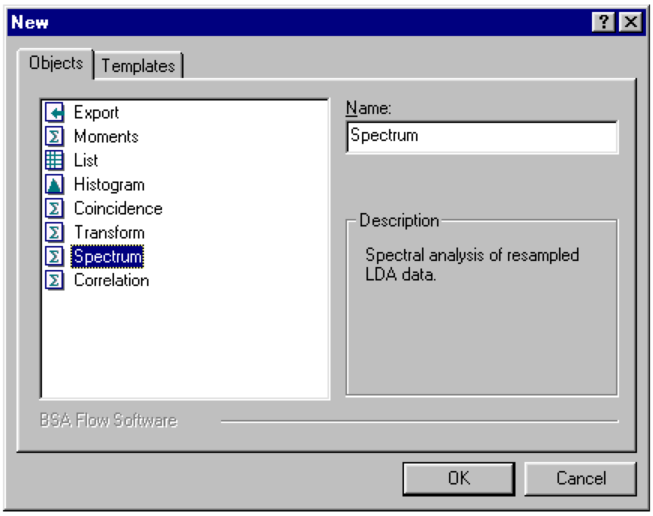


Figure 6.2-1 Spectrum and Correlation in the list of possible new objects

Required input

The only input required for the calculation of correlations and spectra is data samples including arrival time. The data can be raw velocity samples from the LDA processor(s), or they can be coordinate transformed into velocity samples U, V and W.
As long as arrival time information is available for each and every data sample, correlations and spectra can be calculated.

2D- / 3D- data

The correlation and spectrum objects can handle only one arrival time. If you wish to process data from different velocity channels by a single spectrum/correlation object, you can either use hardware coincidence (the velocity channels are in the same group) or software coincidence by a coincidence object.

6.2.1 Spectrum object

The spectrum object will estimate power spectral density from the raw data-samples using FFT-techniques, to obtain results as quickly as possible.

The FFT-approach require samples that are equally spaced in time, and to achieve this, sample/hold and resampling of the raw data is done prior to the actual FFT-analysis, with the resampling frequency determined as twice the desired maximum frequency of the calculated spectrum.

6.2.1.1 Properties of the Spectrum object

The properties of the spectrum object is shown in Figure 6.2-2.

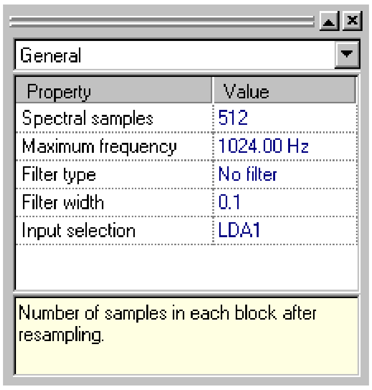


Figure 6.2-2 Properties of the spectrum object

Spectral samples

The property Spectral samples determines the number of discrete frequencies at which the power spectral density should be estimated. The FFT-technique used require this number to be an integer power of 2, and consequently the user has to choose among a limited number of possible values: 32, 64, 128, ... , 65536. If a different value is entered, the nearest higher power of two will automatically be selected.

Maximum frequency

The property Maximum frequency determines the highest frequency at which the power spectral density should be estimated. In the example in Figure 6.2-2 4096 spectral samples are calculated with a maximum frequency of 40960 Hz. This yields spectral samples at 10 Hz, 20 Hz, 30 Hz, ... , 40960 Hz.

Note:	*Please be aware that energy contained at frequencies above the selected maximum may distort results due to aliasing. To avoid this make sure to select a maximum frequency high enough that no significant energy is contained at higher frequencies.*

On the other hand a maximum frequency significantly above the mean datarate of the raw samples will not yield reliable results either.

Particle rate filter

In fact the random seeding particle arrivals combined with the sample-and-hold technique used act as a first order low-pass filter with cut-off frequency at $\dot{n}/2\pi$, where $\dot{n}$ is the mean datarate (See Figure 6.2-3). This so-called particle rate filter will attenuate the high-frequency components of the signal (i.e. the measured velocity) with f^{-1} above the cut-off frequency, and consequently the power spectrum estimate will be attenuated with f^{-2}.

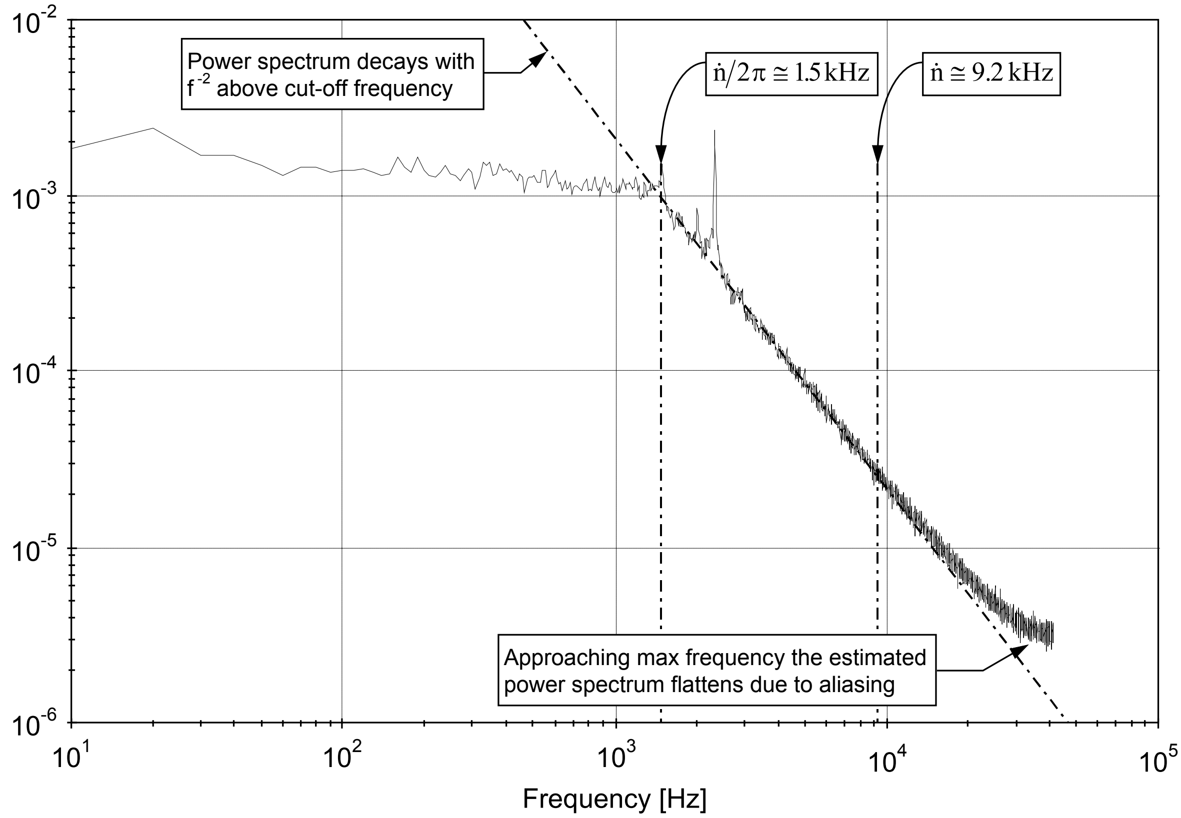


Figure 6.2-3 The 'Sample-and-hold' technique act as a low-pass-filter attenuating the spectrum.

If you are investigating turbulence this presents a pitfall, since the decay of spectral power with f^{-2} can easily be confused with the inertial subrange, which according to the Kolmogorov spectrum law decays with $f^{-5/3}$.
In this case you must carefully check your datarate to verify that the spectral decay found does indeed represent the physics of your flow, rather than particle rate filtering of the true velocities.

Investigating peaks in the power spectrum is not affected quite as much by the particle rate filter: Although the peak value will be reduced above the cut-off frequency, so will spectral values at neighbouring frequencies, and the peak itself is still easily recognised as seen in Figure 6.2-3, showing a peak at about 2.3 kHz. Above all, the frequency at which the peak occurs is not affected by the particle rate filter at all.

The problem of particle rate filtering stems from the fact that LDA as such yield random velocity-samples instead of a continuous signal, and consequently the problem cannot be avoided. With a sufficiently high datarate the problem will however be small, and you should thus always aim at the highest possible datarate in your experiment.

Aliasing

Finally the effect of aliasing can be seen clearly in Figure 6.2-3: Energy contained at frequencies above the maximum frequency is aliased into the range investigated, causing the estimated spectrum to flatten out as it approaches the maximum frequency selected. In this particular example only very little energy was present above the maximum frequency, and below approximately 20 kHz aliasing can thus be ignored completely.

Noise floor

The effect of aliasing described above can easily be confused with the noise floor of your measurement, but the true noise floor will itself be damped by the particle rate filter, and consequently may not be recognised at all.
A suspected noise floor must thus be verified by checking the datarate.

Blocking

Using the FFT-approach to estimate spectra, the raw samples need only cover a time-span corresponding to half the reciprocal of the desired frequency resolution. If more samples are available several “raw” estimates will be calculated, and the final spectrum estimate is the average of all these “raw” estimates.
Since the raw samples are divided in consecutive blocks of equal duration, this approach is referred to as blocking, and the accuracy of the estimated autospectral density function increases with the number of blocks.

The duration of each block and the number of blocks is determined as:

$$T_b = \frac{N_{est}}{2 \cdot f_{max}} \qquad N_b \le \frac{T_{tot}}{T_b}$$

-where T_b is the duration of the block, N_{est} is the number of spectral estimates, f_{max} is the desired maximum frequency, N_b is the number of blocks, and T_{tot} is the total duration of the experiment.
(The number of blocks is rounded towards the nearest lower integer value).

To get as many blocks as possible within the limited duration of the experiment, short blocks are desirable. Unfortunately the frequency-resolution Δf of the calculated spectrum is inversely proportional with the duration T_b of the blocks, so the settings chosen will be a compromise between resolution and accuracy:

$$\Delta f = \frac{f_{max}}{N_{est}} = \frac{1}{2 \cdot T_b}$$

There is a lower limit to the duration of each block, since obviously it must contain a reasonable amount of raw data, in order to get meaningful results: It is thus required that each block should contain at least 16 raw samples.

Upon completion of the spectrum-calculation the number of blocks included is shown in the notification pane at the bottom of the screen (Select the Status-tab if several tabs are available).
The message 0 blocks processed indicate that the software was unable to perform the calculation requested due to insufficient data. This may happen if the maximum frequency and number of samples requested yield a block length that is either too short or too long. If the block length is too short, there may not be 16 raw samples within each block as required, and obviously the longest block allowed correspond to the duration of the experiment itself, treating the whole experiment as one single block.

Filter type

If the necessary resolution and maximum frequency combined with the duration of the experiment yields a very limited number of blocks, the calculated spectrum-estimates may not be very accurate. The problem will show as a noisy spectrum with relatively large differences between estimates at neighbouring frequencies, and to mitigate this you can use a filter to smooth the calculated spectrum. (In the context of spectra filtering is sometimes referred to as frequency smoothing). The filter will replace each spectral estimate with a weighted average of raw estimates calculated at neighbouring frequencies. A multitude of filters exist, but they differ mainly in subtle differences in the weighting schemes used, and only a limited number is supported by the spectrum object. The property Filter type may thus be selected as No filter, Box, Hanning or Papoulis, where the default value No filter obviously mean that no filtering is performed.

Filters are implemented using FFT-techniques to reduce calculation time:

1. Switch to time-domain performing a Fourier transform of the spectrum.
2. Apply a so-called Lag-window to the resulting correlation estimate.
3. Fourier transform back to the frequency-domain.

The Lag-window multiplies each correlation estimate with a factor $w(\tau)$ depending on the lag-time τ of the estimate in question. This factor is one for a lag-time of zero, and then decreases until it reaches zero. The various filters differ only in the way the factor varies in between:

Box:

$$w(\tau) = \begin{cases} 1 & \text{for } \tau \le T \\ 0 & \text{otherwise} \end{cases}$$

Hanning:

$$w(\tau) = \begin{cases} \frac{1}{2}\left[\cos\left(\frac{\tau}{T}\pi\right) + 1\right] & \text{for } \tau \le T \\ 0 & \text{otherwise} \end{cases}$$

Papoulis:

$$w(\tau) = \begin{cases} \frac{1}{\pi}\sin\left(\frac{\tau}{T}\pi\right) + \left(1 - \frac{\tau}{T}\right)\cos\left(\frac{\tau}{T}\pi\right) & \text{for } \tau \le T \\ 0 & \text{otherwise} \end{cases}$$

In the Box-window (also known as a Top-hat window) the weighting factor does not decrease gradually as with most other window-functions. Instead it jumps from 1 to 0 at a threshold lag T, determined by the Filter width W:

$T = W \cdot \tau_{max}$

-where τ_{max} is the maximum lag-time of the correlation estimate calculated by Fourier-transformation of the original spectrum.

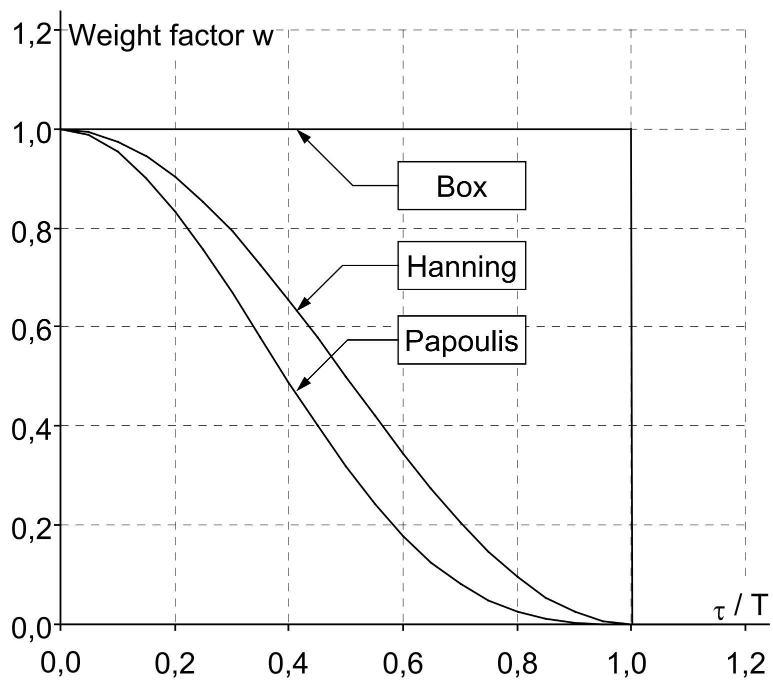


Figure 6.2-4 Weighting factors used for filtering

Filter width

The property Filter width determines when the lag-window reaches zero and should be set to a value between 0 and 1. The value relates to the maximum lag-time of the correlation estimate calculated by Fourier-transformation of the spectrum: Filter width = 1.0 means that the lag-window reaches zero at the maximum lag-time, Filter width = 0.5 means that it reaches zero at half the maximum lag, and so on. Filter width = 0.0 is not allowed, since this would produce correlation and spectrum estimates equal zero for all lags and frequencies.

In general large filter widths will smooth the spectrum less than small widths, and the Box filter with Filter width = 1.0 actually correspond to no filter at all. Depending on the quality of the raw data, the number of spectral estimates and the maximum frequency selected, there is also a lower limit for the filter width, but no general values can be given;
In most cases a filter width in the range 0.1 → 1.0 will work fine, and sometimes even a filter width of 0.01 may be OK.

Peak smearing

Please be aware that filtering will smooth true peaks as well as noise peaks in the spectrum. Any peak will be broadened, and its height reduced, and in severe cases a true peak may not even be recognised after filtering. (See Figure 6.2-5).
It is therefore strongly recommended that you take a look at the spectrum calculated without filters before you decide whether or not to use a filter.
If you are in doubt as to whether or not a peak in the calculated spectrum is a noise peak, try increasing and/or decreasing the maximum frequency somewhat. Noise peaks are random by nature, and even such slight changes will affect them considerably. A true peak on the other hand should remain more or less unaffected.

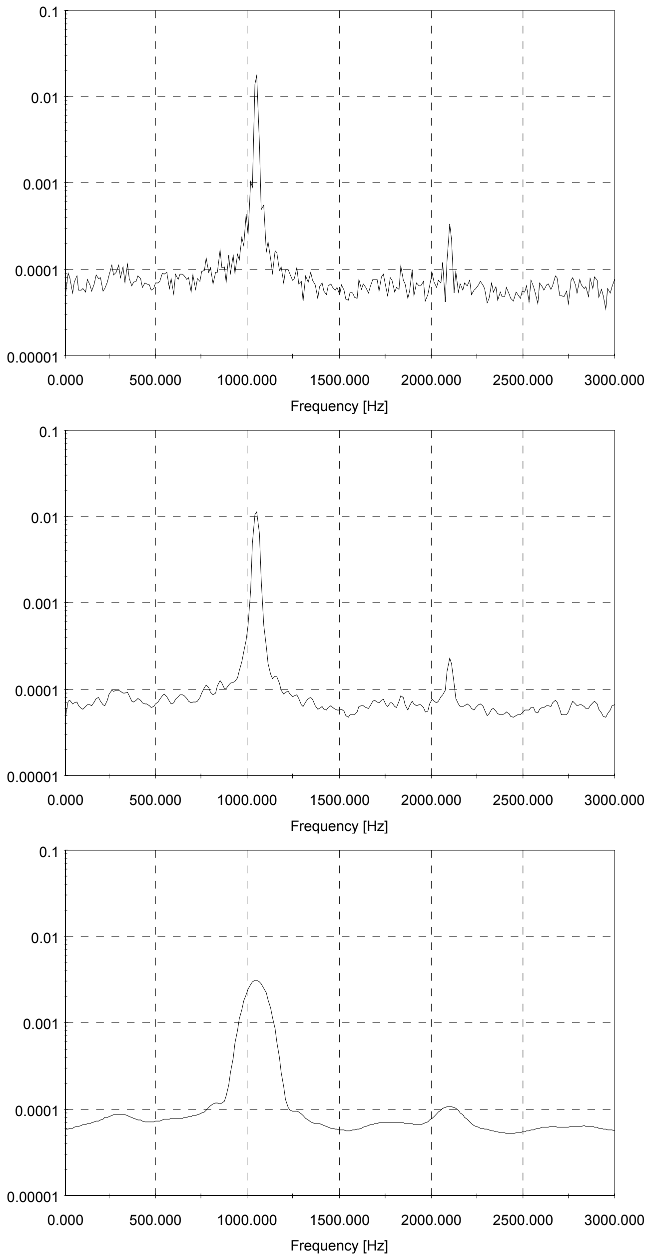


Figure 6.2-5 Filtering a spectrum:
Top: Raw spectrum
Middle: Papoulis / Width 1.0 (Smoothed spectrum)
Bottom: Papoulis / Width 0.2 (Smeared spectrum)
(Graphs made using the Advanced Graphics add-on)

Input selection

The property Input selection is used to select the data for which a spectrum estimate should be calculated. Clicking in the value field will bring up the Select Channels dialog in which the source-data is selected.
Please remember that the spectrum object cannot handle more than one arrival time. Multiple inputs (for example LDA1, LDA2 <u>and</u> LDA3) are thus allowed only if they share a common arrival time (i.e. if coincidence filtering has been performed prior to spectrum calculation).
If several arrival times are available, only one velocity may be selected, and the software will then automatically use the corresponding arrival time.

6.2.1.2 Output from the Spectrum object

The Spectrum object is a processing object as identified by the Σ-icon in the project explorer, and like all processing objects it performs calculations, but does not itself present the results. To see the results you can create a List-object as a child of the Spectrum object. (See Figure 6.2-6)

BSA Application/Spectrum/List - ...

	Frequency [Hz]	Spectrum [LDA1] [x^2/Hz]
1	2.00	0.001472
2	4.00	0.0008416
3	6.00	0.0005247
4	8.00	0.0009965
5	10.00	0.0006659
6	12.00	0.0004993
7	14.00	0.0004965
8	16.00	0.0004905
9	18.00	0.0004812
10	20.00	0.0006176

Figure 6.2-6 Output from the Spectrum object

The minimum output from the spectrum object is two columns as shown in Figure 6.2-6, but if several inputs sharing a common arrival time have been selected, more columns will be included, corresponding to several spectra estimated at the same discrete frequencies.

Frequency

The first column of the output from the Spectrum object identifies the discrete frequencies at which power spectral densities have been estimated. Each of the data samples entering this object is time-stamped with an arrival time measured in seconds, yielding frequencies measured in Hz.

Spectrum

The remaining output columns from the Spectrum object contain the estimated power spectral densities at each of the discrete frequencies in the first column. In the example in Figure 6.2-6 only one spectrum was calculated, but more may be included.

Units

Because input to the spectrum calculation can be (Doppler) frequency or velocity, there is no fixed unit on the estimated spectral values, and instead the data-source is indicated in the column header, to help distinguish when multiple outputs are produced.
If spectra are calculated from a quantity with the unit [u], the resulting estimate of power spectral density will have the unit [u^2/s].
If for example power spectral density is calculated from measured velocity with the unit [m/s], the resulting spectral unit will be [$(m/s)^2$/s] = [m^2/s].

6.2.1.3 Presenting results from the Spectrum object

To present your results, you can either use the advanced graphics add-on, or you can create an export object storing the results in a file, and then use your own or third party software to make a presentation based on the data in the file.

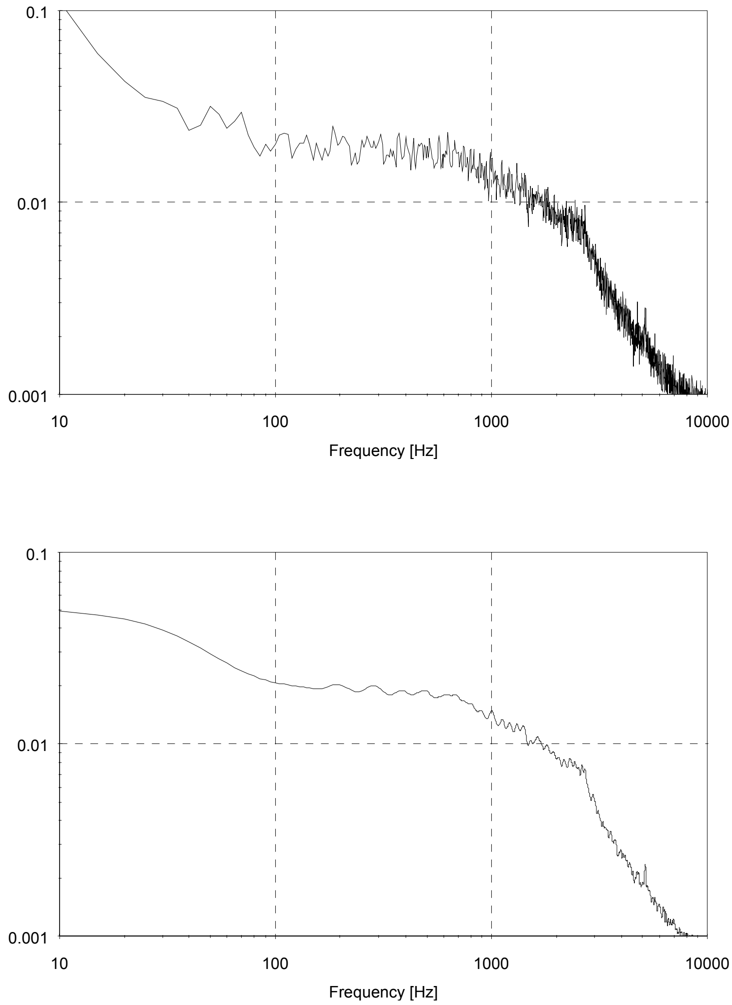


Figure 6.2-7 Turbulence spectrum calculated with the Spectrum object.
Upper: Raw spectrum.
Lower: Smoothed with a Hanning filter (Filter width 0.2).
(-Results presented using the Advanced graphics add-on).

6.2.2 Advanced Spectrum object

The Advanced spectrum object is similar to the Spectrum object, but uses a refined signal reconstruction method.

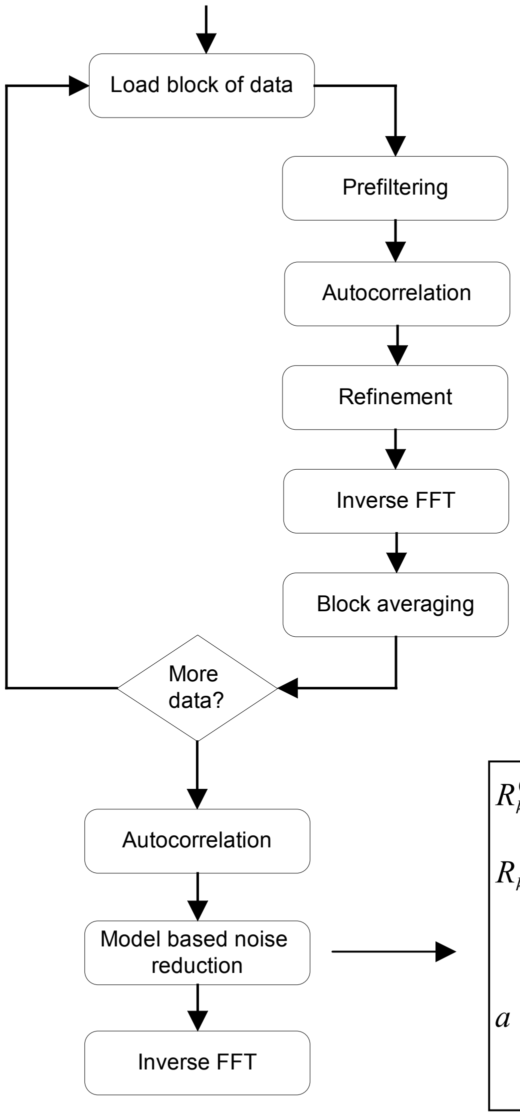
Comparisons with hot-wire measurements have shown that the Advanced Spectrum processing method produces spectra which resemble spectra measured with a hot-wire anemometer better than spectra calculated with the Spectrum object.

Spectra from the Spectrum object fall off from a frequency of [mean data rate/2π], due to the particle rate filter effect, as explained in the previous section.

Spectra from Advanced Spectrum typically start falling off at a higher frequency, and the spectral density is lower at low frequencies.

The Advanced Spectrum calculation produces spectra with more variance than Spectrum. To get smooth looking results, more samples are required, typically more than 100.000 samples. This requires a powerful PC with a large memory, min. 128 MB, preferably more.

The algorithm consists of four parts: resampling of the randomly distributed data, spectral processing, block averaging, and noise reduction. The routine is illustrated in more detail below:



$$R_k = \begin{cases} R_k & k = 0 \\ \left[(2c+1)R_k - c\left(R_{k-1} + R_{k+1}\right)\right] & k \neq 0 \end{cases}$$

$$c = \frac{e^{-\dot{n}\Delta\tau}}{\left(e^{-\dot{n}\Delta\tau} - 1\right)^2}$$

$$R_k^{(M)} = ae^{-b|k|^c}$$

$$R_k = \begin{cases} R_0^{(M)} & k = 0 \\ R_k & k \neq 0 \end{cases}$$

$$a = \frac{\sum_{k=1}^{K} \frac{1}{\sqrt{k}} R_k e^{-bk^c}}{\sum_{k=1}^{K} \frac{1}{\sqrt{k}} e^{-2bk^c}}$$

6.2.2.1 Properties of the Advanced Spectrum object

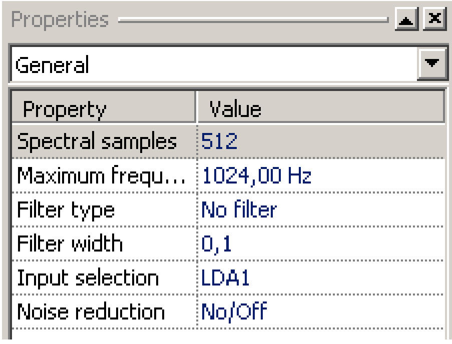


Figure 6.2-8 Properties of the Advanced Spectrum object

The properties are identical to those of the Spectrum object, except for “Noise reduction”.

Note	*It is recommended to keep Noise reduction Off during acquisition, and to switch it On when running off-line.*

For the remaining properties, please refer to section 6.2.1.1.

6.2.2.2 Output from the Advanced Spectrum object

Please refer to section 6.2.1.2

6.2.2.3 Presenting results from the Advanced Spectrum object

Please refer to section 6.2.1.3

6.2.2.4 Background information and references

The Advanced Spectrum add-on is based on a new algorithm, the Refined Sample and Hold algorithm.

With this algorithm, turbulence spectra can be correctly estimated to frequencies above the mean data rate, without sacrificing computing speed. The upper frequency limit is thus 10-20 times higher than that of the traditional sample-and-hold technique. One advantage of this is that correct spectra can be obtained without excessive seeding of the flow. Two papers presenting the theory and an experimental verification of the algorithm were presented at the 10th International Symposium on Applications of Laser Techniques to Fluid Mechanics in Lisbon, Portugal, July 2000. See http://in3.dem.ist.utl.pt/downloads/lxlaser2000/pdf/03_2.pdf and http://in3.dem.ist.utl.pt/downloads/lxlaser2000/pdf/03_5.pdf.

In a comparison made at the 1998 Lisbon Conference on laser anemometry, two algorithms stood out as producing better results than other ones: the refined sample an hold technique and the improved Slot Correlation technique. The latter gives slightly lower variance of the spectrum, but is much slower than the refined sample and hold technique, and is therefore not practical for on-line processing purposes.

To evaluate the new algorithm, comparisons were made with spectra obtained by constant temperature anemometry (CTA), generally accepted as the reference measurement method for turbulence spectra, and with the traditional sample-and-hold algorithm used in the Spectrum Add-on currently available for Dantec's BSA Flow Software. The measurements were taken at the same location in the wake of a cylinder in a wind tunnel producing vortex shedding at a frequency of 1 kHz.

Effect of data rate

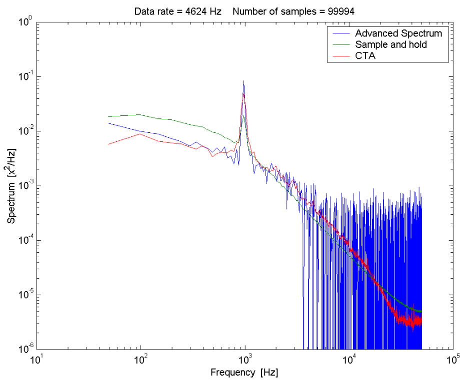


Figure 6.2-9 Data rate 4.6 kHz, 100k samples

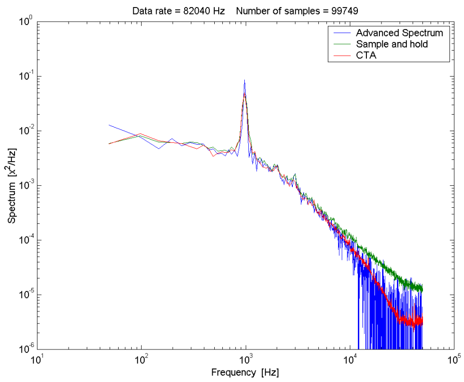


Figure 6.2-10 Data rate 82 kHz, 100k samples

Figure 6.2-9 and Figure 6.2-10 show how data rate affects the results. The red curve is the "correct spectrum" obtained by CTA. The green and blue curves are the spectra obtained from LDA data using sample and hold and refined sample and hold, respectively.

Figure 6.2-9 shows that sample and hold overestimates low frequencies and falls off with a slope of 1 decade per decade from a frequency of approx. 1 kHz. Adrian an Yao (1987) reported that the cut-off frequency is equal to the data rate divided by 2π, which corresponds well with the graphs. They recommended that data rates of 20 times the highest frequency of interest should be used for S&H, or more than 100 kHz for the present example.

The figure also shows that the refined sample and hold spectrum corresponds well with the CTA spectrum up to 3 kHz, at which point noise becomes dominant.

Figure 6.2-10 shows results from the experiment repeated with the highest seeding rate that could be produced in the wind tunnel. All three curves agree well up to about 6 kHz. Above this frequency, sample and hold overestimates the spectral density, whereas the refined sample and hold agrees with the CTA except for larger variance.

Effect of sample size

The variance of the refined sample and hold is closely related to the sample size, as can be seen in Figure 6.2-11 and Figure 6.2-12.

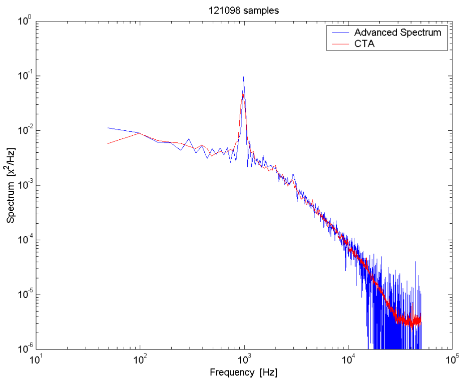


Figure 6.2-11: Data rate 75 kHz, 121k samples

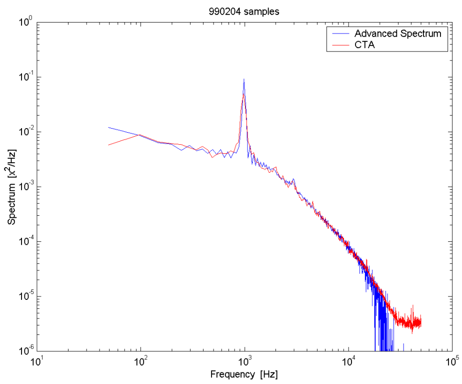


Figure 6.2-12: Data rate 75 kHz, 1M samples

For clarity only the CTA and refined sample and hold curves are shown here, since the sample and hold curves are, in both cases, virtually identical to the one shown in Figure 6.2-10

Figure 6.2-12 shows that by increasing the sample size from 120k to 1M, the variance of the spectrum is reduced, and the CTA and LDA spectra are practically identical up to 20 kHz. Above that frequency the LDA spectral values are lower than the CTA values. This may be due to particle lag rather than the data processing method.

Conclusion

The Advanced Spectrum Add-on to Dantec's BSA Flow Software is relatively insensitive to data rate and produces correct spectral estimates up to a frequency corresponding to the data rate. This is a dramatic improvement over traditional sample and hold which requires 10-20 times higher data rates.

The variance of the spectrum from the Advanced Spectrum Add-on is higher than the one obtained using sample and hold, but can be reduced by increasing the sample size.

6.2.3 Correlation object

Using FFT-techniques to obtain results as quickly as possible the correlation object will estimate the time autocorrelation function on the basis of raw data-samples.

The FFT-approach require samples that are equally spaced in time, and to achieve this, sample/hold and resampling of the raw data is done prior to the actual FFT-analysis, with the resampling frequency determined from the number of correlation samples requested, and from the desired maximum lag-time.

6.2.3.1 Properties of the Correlation object

The properties of the correlation object is shown in Figure 0-1.

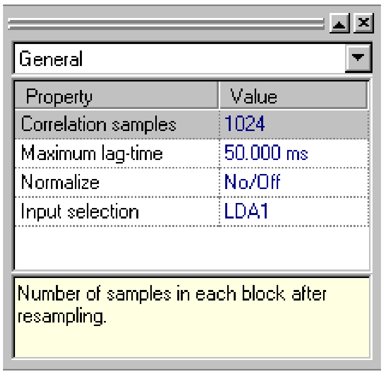


Figure 0-1 Properties of the correlation object

Correlation samples

The property Correlation samples determine the number of discrete lag-times at which the autocorrelation function should be estimated.
The FFT-technique used require this number to be an integer power of 2, and consequently the user has to choose among a limited number of possible values: 32, 64, 128, ... , 65536. If a different value is entered, the nearest higher power of two will automatically be selected.

Maximum lag-time

The property Maximum lag-time determines the largest lag-time at which the autocorrelation function should be estimated. In the example in Figure 0-1 1024 correlation samples are calculated with a maximum lag-time of 10.24 ms, yielding correlation estimates at 0 µS, 10 µS, 20 µS, ... , 10.24 ms.

Blocking

Using the FFT-approach to estimate correlations, the raw samples need only cover a time-span corresponding to the desired maximum lag-time. If more samples are available several “raw” estimates will be calculated, and the final correlation estimate is the average of all these “raw” estimates.
Since the raw samples are divided in consecutive blocks of equal duration, this approach is referred to as blocking, and the accuracy of the final autocorrelation function increases with the number of blocks.

The duration T_b of each block equals the desired maximum lag-time τ_{max}, and consequently the number of blocks N_b can be determined from the total duration T_{tot} of the experiment:

$$T_b = \tau_{max} \qquad N_b \leq T_{tot} / \tau_{max}$$

-where N_b is rounded to the nearest lower integer value.

To get as many blocks as possible within the limited duration of the experiment, short blocks are desirable, but there is a lower limit.

First of all each block must contain a reasonable amount of raw data in order to get meaningful results: It is thus required that each block contain at least 16 raw samples. Normally the number of blocks included in the calculation will increase as the maximum lag-time decreases, but since blocks including less than 16 raw samples are excluded, the total number of blocks will decrease, when you approach this limit.

Furthermore you must be aware that within each block only very limited information is available regarding the larger lag-times; -In fact only a single sample pair (the very first and the very last sample) truly provides information regarding correlation at the desired maximum lag-time. Consequently you should always select a maximum time-lag considerably larger than the highest lag-time of any real interest:

To get reasonable results in turbulent flows the maximum lag-time should thus be at least 10 times the integral time-scale τ_I, and preferably even higher; A maximum time-lag of 50 or even a 100 times τ_I is not excessive, provided it does not reduce the number of blocks too much.

Similarly the maximum time-lag should be at least 10 times the period if you wish to estimate the autocorrelation of a cyclic flow.

Please be aware that the correlation is actually calculated as the inverse Fourier transform of a spectrum estimate, which in turn has been calculated using the FFT-techniques described in section 0.
Consequently aliasing may distort correlation-estimates if the flow contains significant turbulent energy above the resampling frequency; Prior to FFT the raw data is resampled with a resampling frequency determined from the desired number of correlation estimates, and the desired maximum lag-time:

$$f_{res} = \frac{N_{est}}{\tau_{max}} = \frac{1}{\Delta\tau}$$

-where f_{res} is the resampling frequency, N_{est} is the number of correlation estimates, τ_{max} is the desired maximum lag-time, and $\Delta\tau$ is the lag-time resolution achieved. In other words aliasing may distort the estimated autocorrelation function if the lag-time resolution is too coarse.

Note:	*In order to avoid aliasing the maximum lag-time can in principle be reduced and/or the number of correlation estimates increased to produce arbitrarily high resampling frequencies. You should be aware however that apart from an increase in the calculation time a resampling frequency significantly above the mean datarate of the raw samples has almost no effect on the correlation estimate as shown in Figure 0-2.*

Three different correlation estimates have been calculated, all with the same maximum lag-time, but with the number of correlation estimates selected to produce resampling frequencies of half, equal and twice the mean datarate respectively. This corresponds to the lag-time resolution being double, equal and half the average time between the raw samples.

All correlation estimates in Figure 0-2 have been calculated up to a maximum lag-time of 40 ms, but only the first 1 ms is shown.

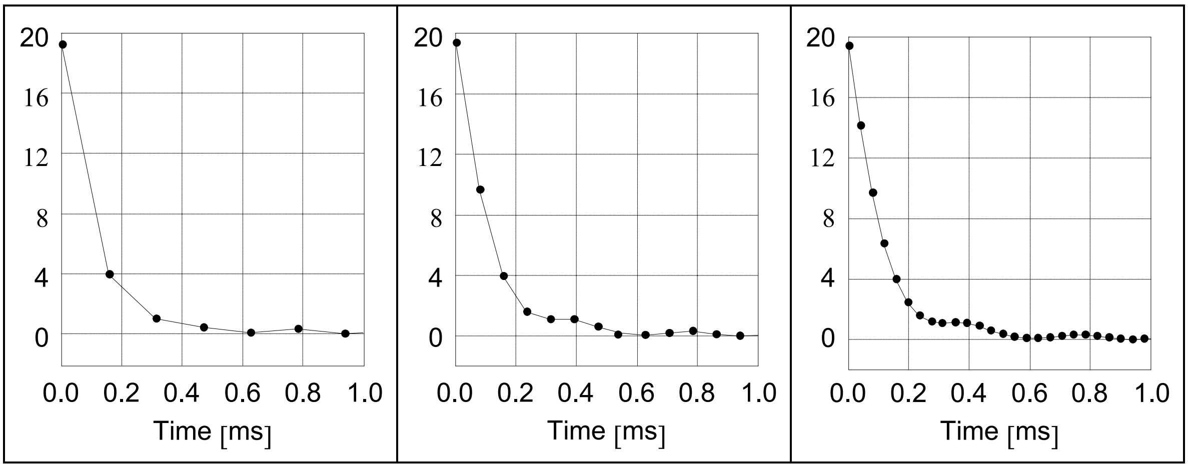


Figure 0-2: *Autocorrelation estimated with varying lag-time resolutions:*
Left: Resolution about double the mean time between raw samples.
Middle: Resolution about equal to the mean time between raw samples.
Right: Resolution about half the mean time between raw samples.
(Results presented using the Advanced graphics add-on).

From the left-hand correlation estimate to the middle one the resampling frequency has been increased from about half to equal the mean datarate, by doubling the number of correlation samples, and details that were missed with the low resampling frequency are now seen clearly. In the right-hand correlation estimate, the number of correlation samples has been doubled once more, thereby doubling the resampling frequency also, but this time no new details are revealed in the calculated correlation estimate. This does not necessarily mean that the true correlation does not contain finer details, but with the data available they cannot be resolved.

Since seeding particles pass the LDA measuring volume with random intervals, they produce velocity samples with random intervals also, and consequently some of these samples will be closer together than the mean time between samples. This means that using a lag-time resolution finer than the average time between samples may improve results, but resampling at a frequency more than 5-10 times the mean datarate yield precious little new information, while increasing calculation time dramatically.

Upon completion of the correlation-calculation, the number of blocks included is shown in the notification pane at the bottom of the screen (Select the Status-tab if several tabs are available).
The message 0 blocks processed indicate that the software was unable to perform the calculation requested due to insufficient data. This may happen if the maximum lag-time requested yield a block length that is either too short or too long. If the block length is too short, there may not be 16 raw samples within each block as required, and obviously the longest block allowed correspond to the duration of the experiment itself, treating the whole experiment as one single block.

Normalize

The property Normalize is used to determine whether or not the estimated autocorrelation function should be normalized. By default this property is set to No/Off, but changing it to Yes/On the estimate will be normalized to give the correlation coefficient instead of the correlation itself.

By definition the autocorrelation at lag-time zero should equal the variance of the measured quantity, and the correlation coefficient $\rho(\tau)$ is defined as the correlation $R(\tau)$ divided by the variance V:

$$\rho(\tau) = \frac{R(\tau)}{V}$$

In practice the estimated correlation at lag-time zero never matches the variance exactly, and to avoid problems with this, the correlation coefficient is estimated by dividing all correlation estimates with the value estimated at lag-time zero:

$$\rho(\tau) \cong \frac{R(\tau)}{R(0)} \quad \Rightarrow \quad \rho(0) \equiv 1$$

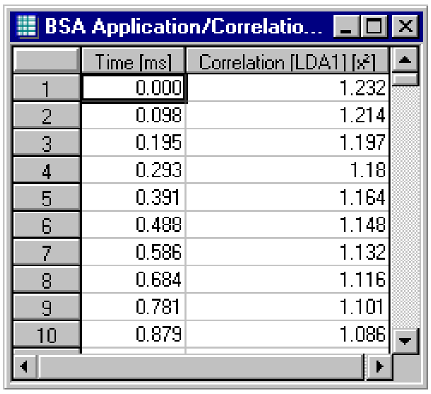
-This ensures that the correlation coefficient at lag-time zero equals one.

Input selection

The property Input selection is used to select the data for which a correlation estimate should be calculated. Clicking in the value field will bring up the Select Channels dialogue in which the source-data is selected. Please remember that the correlation object cannot handle more than one arrival time. Multiple inputs (for example LDA1, LDA2 and LDA3) are thus allowed only if they share a common arrival time (i.e. if coincidence filtering has been performed prior to correlation calculation).
If several arrival times are available, only one velocity may be selected, and the software will then automatically use the corresponding arrival time.

6.2.3.2 Output from the Correlation object

The Correlation object is a processing object as identified by the Σ-icon in the project explorer, and like all processing objects it performs calculations, but does not itself present the results. To see the results you can create a List-object as a child of the Spectrum object. (See Figure 0-3)


BSA Application/Correlatio...

	Time [ms]	Correlation [LDA1] [s^2]
1	0.000	1.232
2	0.098	1.214
3	0.195	1.197
4	0.293	1.18
5	0.391	1.164
6	0.488	1.148
7	0.586	1.132
8	0.684	1.116
9	0.781	1.101
10	0.879	1.086

Figure 0-3 Output from the Correlation object

The minimum output from the correlation object is two columns as shown in Figure 0-3, but if several inputs sharing a common arrival time have been selected, more columns will be included, corresponding to several correlations estimated at the same discrete lag-times.

Time

The first column of the output from the Correlation object identify the discrete lag-times at which the autocorrelation function has been estimated. By default lag-times are shown in ms, but units can be changed in the options dialog (Click *Tools>Options>Data Formats*).

Correlation

The remaining output columns from the Correlation object contain the estimated autocorrelations at each of the discrete lag-times in the first column. In the example in Figure 0-3 only one spectrum was calculated, but more may be included.

Units

Because input to the spectrum calculation can be (Doppler) frequency or velocity, there is no fixed unit on the estimated correlation values, and instead the data-source is indicated in the column header, to help distinguish when multiple outputs are produced.
If the estimated autocorrelation functions are normalized, the results will be dimensionless, but otherwise calculating correlation from a quantity with the unit [u], will yield a correlation estimate with the unit [u^2].
If for example the source data is velocity with the unit [m/s], the resulting correlation estimate will have the unit [$(m/s)^2$] = [m^2/s^2].

6.2.3.3 Presenting results from the Correlation object

To present your results, you can either use the advanced graphics add-on, or you can create an export object storing the results in a file, and then use your own or third party software to make a presentation based on the data in the file.

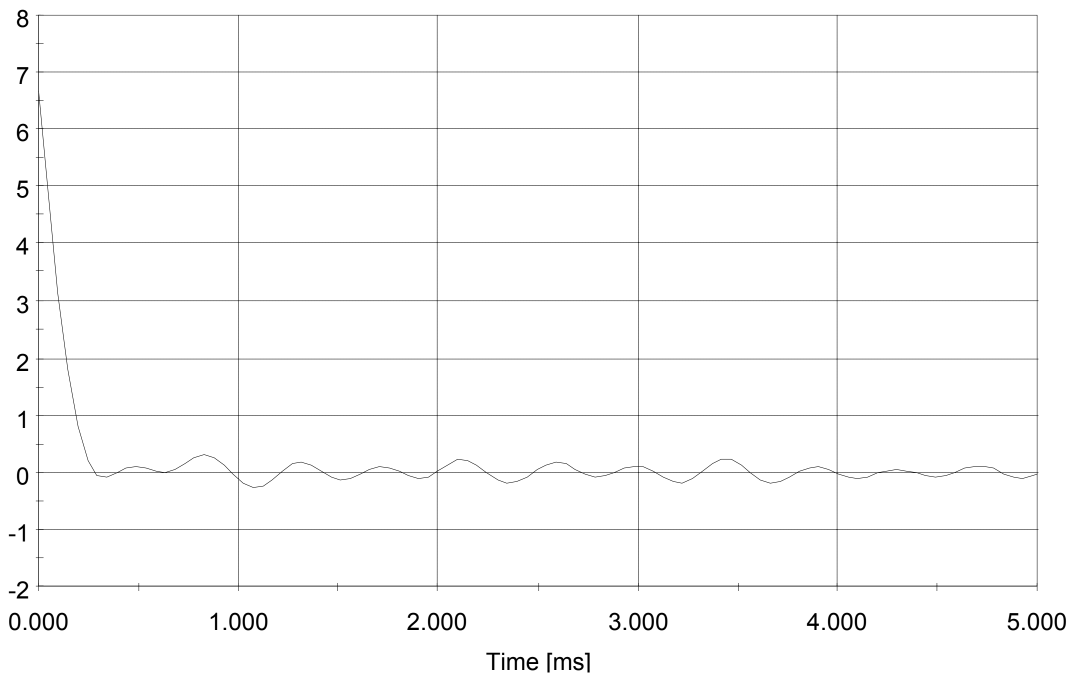


Figure 0-4 Autocorrelation function corresponding to the spectrum in Figure 6.2-3. (Presented using the Advanced Graphics Add-On.).

6.3 Advanced Graphics Add-On

The main software package is designed primarily for data acquisition, and offers only very limited data presentation capabilities.
Histograms are included to assist the user in properly setting up the system, but beyond that, the main software package offers no means of graphically presenting the results.

The latter is the topic addressed by the Advanced Graphics Add-On, offering a number of new objects, that can be used to present raw samples as well as calculated quantities.

When the Advanced Graphics Add-On is installed, five new objects may appear in the list of options when you create a new object:

- 2D Plot
- 2D Histogram
- 3D Plot
- Profile plot
- Vector plot

Required input

While the 2D Plot, 2D Histogram and 3D Plot can be the child of any object supplying data, Profile plot and Vector plot display statistical mean values and thus can only be child to the Moments object. Furthermore, the Vector plot requires at least two measured velocity components.

Within these limits anything can be plotted: From the main software package you can create time-history plots of the raw PDA-samples, or present mean- and rms-values varying in different measuring positions.

From the cyclic phenomena Add-On you can plot phase-sorted and/or -averaged data, and obviously the Spectrum and Correlation Add-On will yield data, that can be presented graphically as correlations and spectra.

All of this is based on LDA-data, but if the A/D-Option is installed, you will also be able to create plots showing pressure, temperature or something else, and obviously any other quantity derived from this (mean, rms, phase average, correlation, etc.).

Zooming and Panning

To have a closer look at some details in a plot, you can temporarily zoom in on an area of a plot, and pan this area left, right up and down. You can also read values from a plot with a simple mouse-click. This as well as Zooming and Panning is described in more detail in section 6.3.7.

Exporting plots

Any plot (including histograms) can be exported to other documents.
This is done using copy and paste via the Clipboard, or by exporting to a graphic image file.
Exporting plots is described in more detail in section 6.3.8.

6.3.1 Scaling and display options

The five graphics objects of the Advanced Graphics add-on have slightly different property groups where graphics-related parameters are assigned. The property groups Scale and Display, however, are contained in each of the five objects.

6.3.1.1 Property group 'Scale'

The scaling properties of the graphics objects differ slightly between 2D graphics and 3D graphics. Examples of both are shown in Figure 6.3-1 and Figure 6.3-2. Please note that the 2D Histogram is also a 3D graphics presentation.

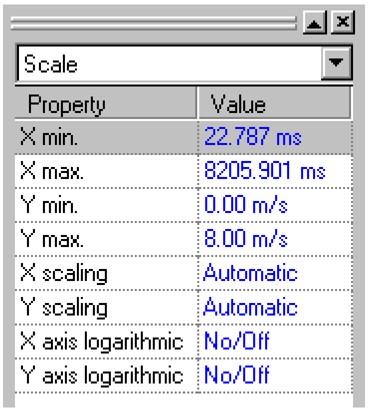


Figure 6.3-1 Scale properties for 2D graphics.

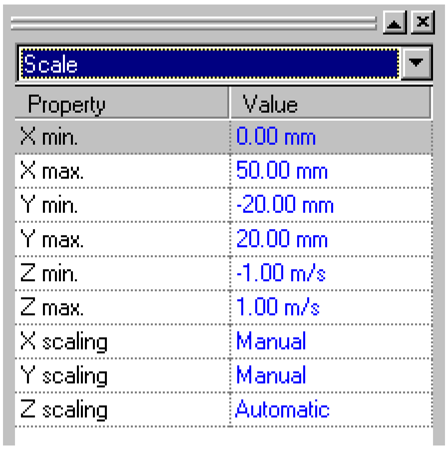


Figure 6.3-2. Scale properties for 3D graphics.

XMin, XMax, YMin, YMax, ZMin, ZMax

These properties determine the minimum and maximum values on the X-, Y- and Z-axis respectively. If the properties X Scaling, Y Scaling and Z Scaling are set to Automatic, the minimum and maximum values will be adjusted automatically to match the data shown.

X Scaling, Y Scaling, Z Scaling

These properties can be either Automatic or Manual, with Automatic being the default setting. When scaling is set to Automatic, the minimum and maximum values of the axis in question will be automatically adjusted according to the data, while Manual scaling, means that the user specifies minimum and maximum-values manually.

The default setting Automatic ensures that <u>all</u> samples are included in the initial plot, while subsequently the user can zoom in on areas of specific interest by switching to manual scaling. Whenever the user changes a minimum or maximum value manually, the scaling of the corresponding axis will switch to Manual.

XAxisLogarithmic & YAxisLogarithmic

These properties can be either Yes/On or No/Off, with No/Off being the default setting. As the name implies, these properties determines whether the corresponding axis should be logarithmic or linear.

Only positive values can be plotted on a logarithmic axis, and consequently negative values will be ignored.

The Vector Plot does not have these properties.

6.3.1.2 Property group ‘Display’

Also the display options differ slightly between the various graphics objects. The display options mainly define the graph colors, the text font to be used for labelling and the linestyle for the data curves.

2D Plot and Profile plot allow more than one data curve to be shown in one graph. Therefore, each data curve can be assigned an individual style (see Figure 6.3-3)

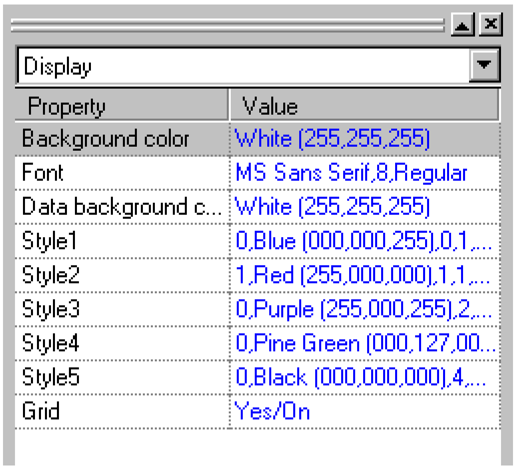


Figure 6.3-3. Display options for the 2D Plot.

Font

Clicking the right-hand side of the Value field for the Font property will bring up a dialog, where you can modify Font Type, Font Style and Font Size used in the plot for axis labels and so on.

BackgroundColor & PlotBackgroundColor

These two properties determine the background colour used around and inside the plot itself, respectively. Again you press the right-hand side of the value field to bring up a palette of colours to choose from.

Style 1…5

The last five properties in the Advanced Properties Group, determine how the data samples are presented in the plot.

Provided they share some common X-value (such as arrival time), multiple data-sets can be presented in the same plot, and to distinguish them, different colours, linestyles and markers are used for each.

For the first 5 data-sets, the user can modify these settings by clicking the right-hand side of the value field to bring up a dialog like the one shown in Figure 6.3-3. For data-sets beyond the fifth, the system will assign varying colours, linestyles and markers automatically, without any user influence.

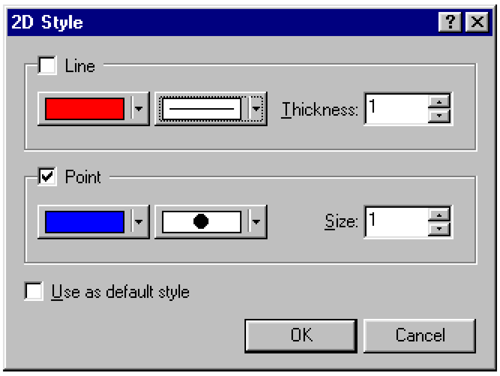


Figure 6.3-4. Modifying the plot style.

If you check the Line box the data-samples will be connected with lines of colour, linestyle and thickness corresponding to the user selections made.

If you check the Point box each sample will be shown with a marker of colour, type and size corresponding to user the selections made.

Finally checking the box Use as default style, will change the default settings of the style in question to correspond to the selections just made. This way you need not make the same changes over and over, if you have some preferred settings.

Plot Template

If your preferred settings involve more than colours and linestyles, you can save an entire plot as a template including all property settings. Templates are described in more details elsewhere in the manual.

None of the changes will take effect until you press OK, while pressing Cancel will ignore the changes, and close the dialog.

6.3.2 2D Plot

The 2D Plot is a point-based plot, presenting results from measurements and/or calculations performed in a single point. If measurements are made in a traverse mesh, you can step through the different measuring positions, but the results must be viewed one at a time unless you create multiple 2D Plots, each showing data from a different measuring point.

This may seem a limitation, but it also makes the 2D Plot one of the most versatile plot types, since you can freely determine which data to show on both the horizontal and the vertical axis of the plot. In the other plot types (Profile and Vector Plot) one or even both of the axes must correspond to a traverse axis X, Y or Z. With the 2D Plot the only limitation is that data on the horizontal axis must be somehow related to the data on the vertical axis: For example it is not possible to show velocity samples from one LDA-channel as a function of arrival times from another LDA-channel. (Obviously this makes no sense anyway so this is not really a limitation).

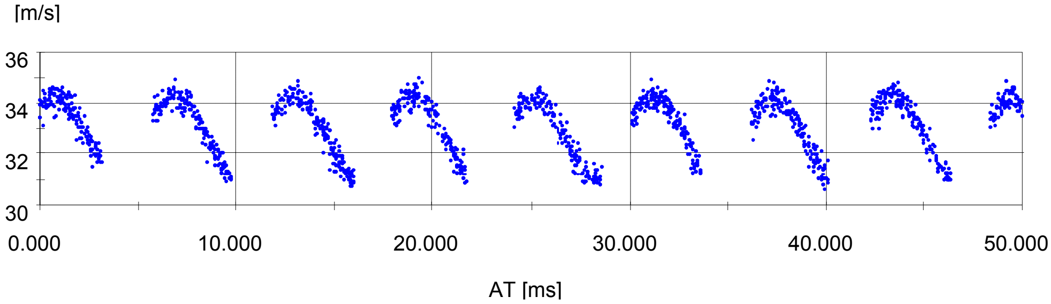


Figure 6.3-5 2D Plot showing the time-history of velocity samples from a periodic flow.

Figure 6.3-5 shows an example of a 2D Plot, where velocity samples from a periodic flow are shown as a function of their arrival time.
All other figures shown in section 6.3.2 of this text, refer to this example.

6.3.2.1 Configuring the 2D Plot

The configuration of a 2D Plot is used to determine which data to plot. To configure a 2D Plot, you simply select the plot, and then right-click inside the plot window. This will bring up a configuration dialog similar to Figure 6.3-6 showing the data available for plotting.

Note	*If data is not yet available (i.e. measurements have not yet been performed), you will get an error message trying to configure the plot unless system setup has progressed so far that the type of data can be predicted.*

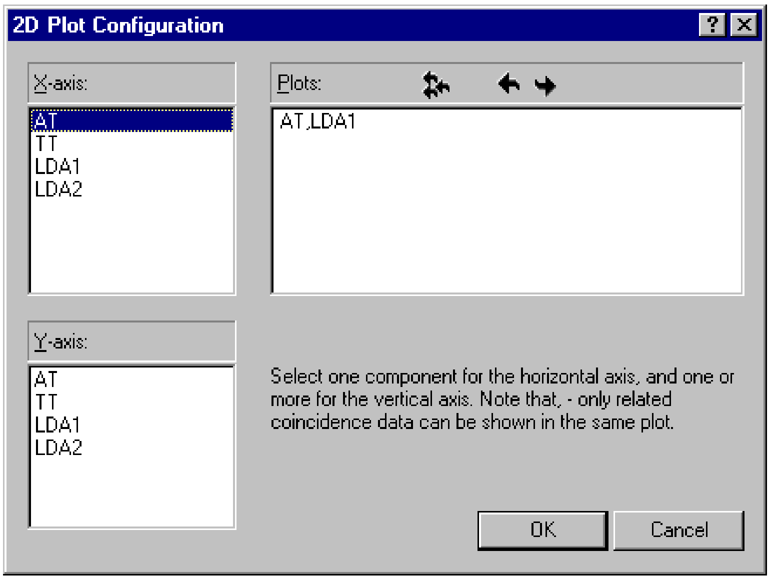


Figure 6.3-6 Configuration determines the contents of the 2D Plot.

To create a plot, select data for the horizontal axis from the X-axis field, then select data for the vertical axis from the Y-axis field, and finally press the right-hand arrow ( ) above the Plots field to add the new plot.

Each plot can have only one parameter on the X-axis, but several parameters on the Y-axis.

A single plot window may contain several individual plots. Since they share a common parent object in the project tree, the same data is available for all plots, but different subsets of the complete dataset can be chosen for each of the individual plots, and consequently they need not be related to each other.

The plots defined appear as a list in the Plots field, occupying one line each. The leftmost parameter on each line identifies data for the X-axis, while the rest of the line identifies data for the Y-axis.

Existing plots cannot be reconfigured, but they can be removed by selecting them in the Plots field, and pressing the left-hand arrow ( ).
The symbol with multiple left-hand arrows ( ) above the Plots field will delete all plots from the plot window.

Performing 2- or 3-dimensional measurements with the velocity channels in separate groups will also produce 2 or 3 individual arrival times, and creating a 2D Plot to present the samples directly, you will have to make 2 or 3 individual plots within the plot window, since the samples are not related to each other.

In the example used here, coincidence filtering is performed prior to the 2D Plot, and consequently all velocity samples are related through a common arrival time. This allows the different samples to be shown in the same plot, instead of several individual plots within the same plot window.

6.3.2.2 Stepping through a traverse mesh

As explained earlier the 2D Plot is a point-based plot, presenting results from measurements and/or calculations performed in a single point.
If measurements are made in a traverse mesh, you can step through the different measuring positions, to investigate the results one point at a time.

To do this you must select the 2D Plot object in the project tree, and then press the left or right-arrows in the toolbar to step backward or forward in the sequence of measuring points. This will step through measuring positions in the sequence they were measured.

To jump quickly to a specific measuring position, you can also right-click the 2D Plot object in the project tree, and then click Select Position in the context menu that appears. This will open a dialog similar to the one shown in Figure 6.3-7.

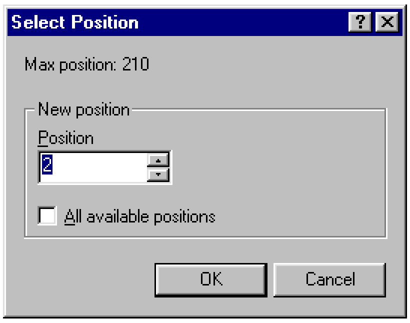


Figure 6.3-7 Selecting a measuring point as data source for the 2D Plot.

The position number shown correspond to the sequence number of the measuring point in the Layout View, and to navigate between the different measuring positions, it is recommended, to keep the Layout View open and visible in a part of the workspace, while jumping from one measuring point to another.

If the checkbox All available positions is checked, you will no longer be able to manually select the measuring position. Instead the system will sequentially show results from all available positions. This can be useful during data acquisition, where it will allow the plot to be automatically updated as measurements progress.

6.3.3 2D Histogram

The 2D Histogram is also a point-based plot presenting results from measurements and/or calculations performed in a single point. If measurements are made in a traverse mesh, you can step through the different measuring positions, but the results must be viewed one at a time unless you create multiple 2D Histograms, each showing data from a different measuring point.

As the name implies, it is a histogram-type graph displaying the distribution of two measured or calculated quantities simultaneously in a 3D graph. As an example, **Figure 6.3-8** shows a BSA1velocity-BSA2 velocity histogram.

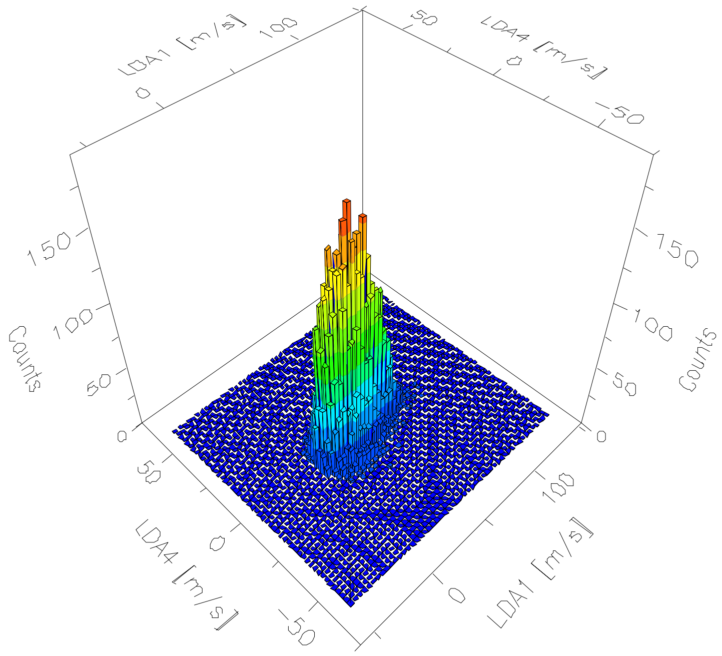


Figure 6.3-8. *2D velocity-velocity histogram*

6.3.3.1 Configuring the 2D Histogram

The configuration of a 2D Histogram is used to determine which data to plot. To configure a 2D Histogram, you simply select the histogram, and then right-click inside the histogram window. This will bring up a configuration dialog similar to Figure 6.3-6, showing the data available for plotting.

Note	*If data is not yet available (i.e. measurements have not yet been performed), you will get an error message trying to configure the plot unless system setup has progressed so far that the type of data can be predicted.*

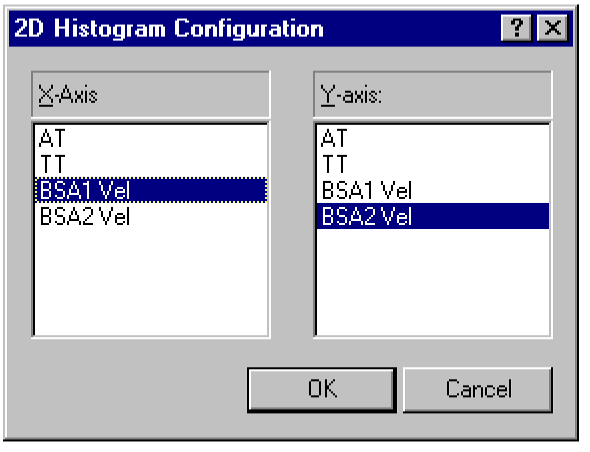


Figure 6.3-9. *Configuration determines the contents of the 2D Histogram.*

To configure a histogram, select one data source from the X-axis field and the second data source from the Y-axis field and click OK. To update the graph you have to click the Run button or press F5.

The third axis can not be configured freely. For the third axis you can choose between Counts and Percentage by assigning the parameter Result in the Data group (see Figure 6.3-10).

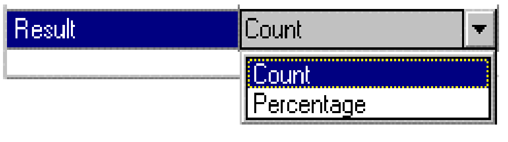


Figure 6.3-10. The histogram information can be displayed as counts or percentage.

6.3.3.2 Property group ‘Data’

The Data properties comprise the number of bins for each displayed data channel and the chart type selection.

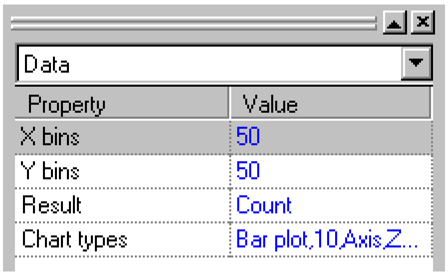


Figure 6.3-11. Data properties for the 2D Histogram.

The default setting for chart type is ‘Bar plot’. To select a different chart type double-click on the right-hand side of the value field. This will bring up the setup window for chart type selection. You can select between ‘Contour plot’, ‘Bar plot’ and ‘Surface plot’ (see *Figure 6.3-12*).

The contour plot is a 2D graph showing the counts or percentage information as colour coding.

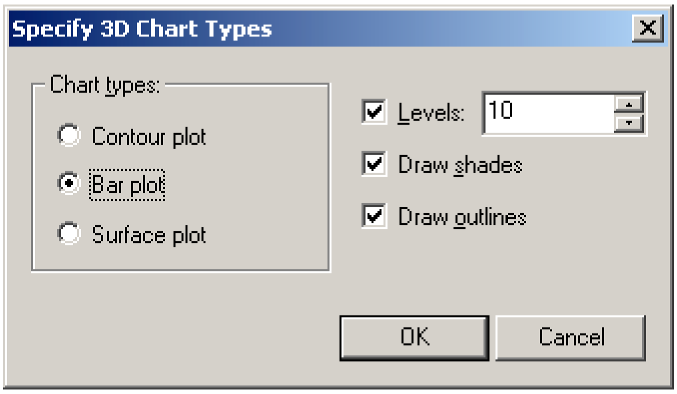


Figure 6.3-12. The choice of three different chart types

If you check the ‘Zones’-box in the bar plot and surface plot setup windows, the counts or percentage information will also be displayed with colour coding.

The number of zones is user-defined. Checking the ‘Show legend’-box will add the legend to the histogram window.

6.3.4 3D Plot

The 3D Plot is also a point-based plot, presenting results from measurements and/or calculations performed in a single point. If measurements are made in a traverse mesh, you can step through the different measuring positions, but the results must be viewed one at a time unless you create multiple 3D Plots, each showing data from a different measuring point.

The 3D Plot is very similar to the 2D Histogram, with the only difference that in the 3D Plot all three axes can be configured freely by the user. As an example, **Figure 6.3-13** the velocity profile across a jet. Similar to the 2D Histogram, the legend can be shown which always refers to the quantity displayed on the third (vertical) axis.

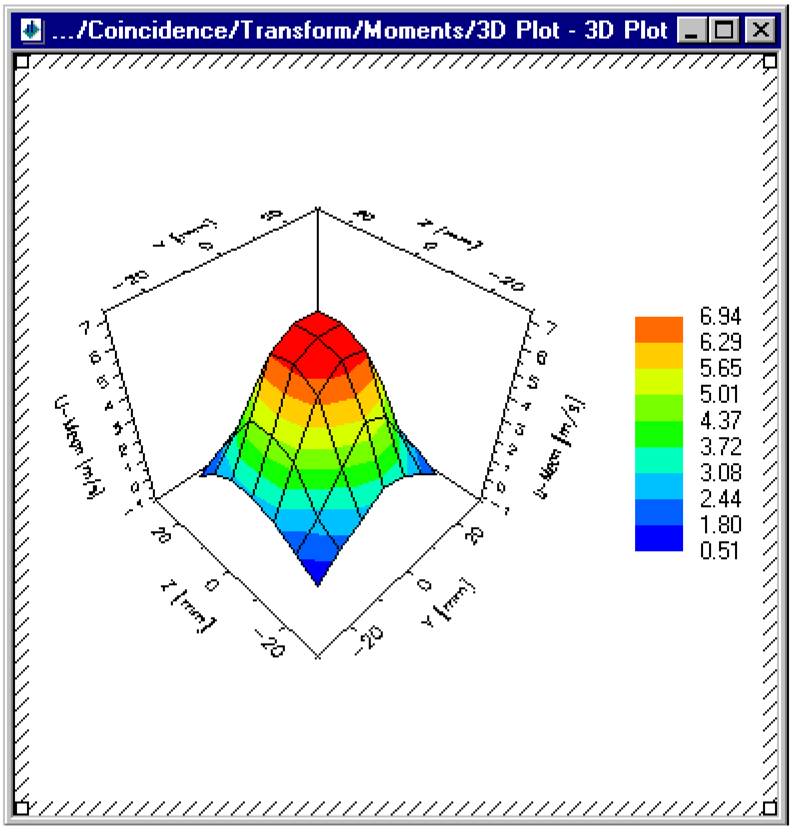


Figure 6.3-13. *3D Plot showing the the main velocity component of a jet flow as a function of the position in a cross section.*

6.3.4.1 Configuring the 3D Plot

The configuration of a 3D Plot is used to determine which data to plot. To configure a 3D Plot, you simply select the plot, and then right-click inside the plot window. This will bring up a configuration dialog similar to Figure 6.3-6, showing the data available for plotting.

Note	*If data is not yet available (i.e. measurements have not yet been performed), you will get an error message trying to configure the plot unless system setup has progressed so far that the type of data can be predicted.*

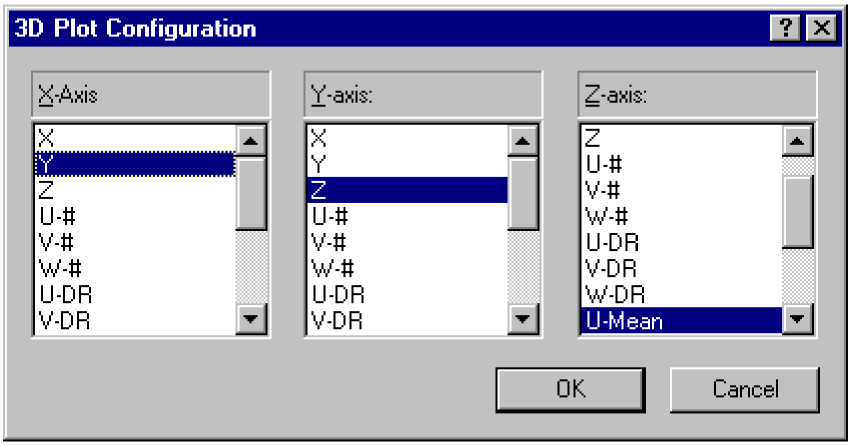


Figure 6.3-14. *Configuration determines the contents of the 3D Plot..*

To configure a 3D Plot, select one data source from the X-axis field, the second data source from the Y-axis field and the third data source from the Z-axis field and click OK. To update the graph you have to click the Run button or press F5.

6.3.4.2 Property group 'Data'

The Data options properties are similar to those in the 2D Histogram. Please see section **6.3.3.2** for details.

6.3.5 Profile Plot

While the 2D Plot is a point-based plot, showing results from measuring positions one at a time, the Profile Plot gathers results from several measuring points, and is thus available only when measurements are performed in a traverse mesh. It has a Moments object as parent.

The Profile Plot shows variations in some calculated quantity such as mean- or rms-value along a line parallel to one of the traverse axes X, Y or Z. The horizontal axis must thus correspond to a traverse axis, while the calculated quantities are shown on the vertical axis of the Profile Plot.

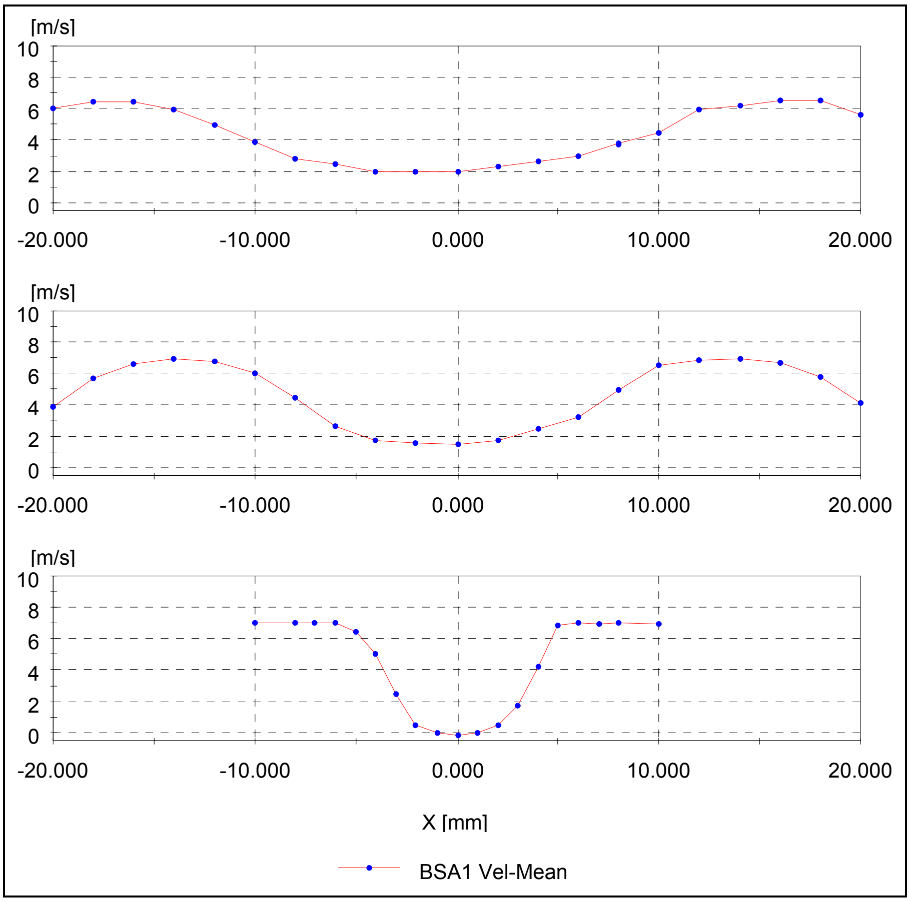


Figure 6.3-15 Profile Plots of mean velocities downstream of an obstacle.

Figure 6.3-15 shows examples of Profile Plots, where the mean velocity is calculated and shown in different positions downstream of an obstacle. All other figures shown in section 6.3.3 of this text, refers to this example.

6.3.5.1 Configuring the Profile Plot

The configuration of a Profile Plot is used to determine which data to plot. To configure a Profile Plot, you simply select the plot, and then right-click inside the plot window. This will bring up a configuration dialog similar to Figure 6.3-16, showing the data available for plotting.

Note	If data is not yet available (i.e. measurements have not yet been performed), you will get an error message trying to configure the plot unless system setup has progressed so far that the type of data can be predicted.

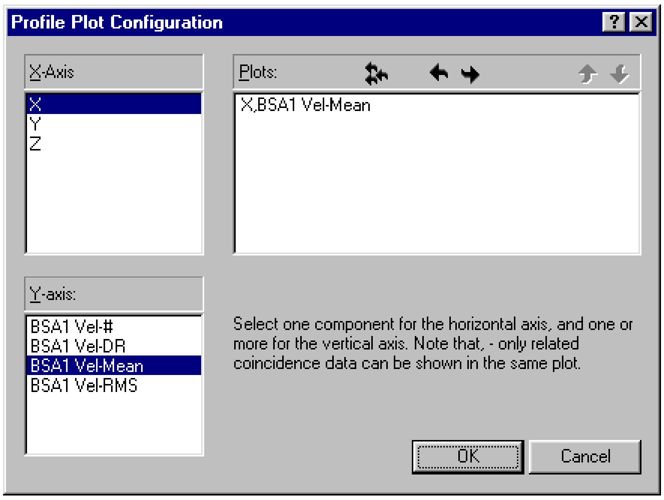


Figure 6.3-16 The configuration dialog determines the contents of the Profile Plot.

To define a plot, select data for the horizontal axis from the X-axis field, then select data for the vertical axis from the Y-axis field, and finally press the right-hand arrow ( ) above the Plots field to add the new plot.

As explained earlier, the horizontal axis must correspond to one of the traverse axes, X, Y or Z, and correspondingly these are the only options available.

While only one parameter can be shown on the horizontal axis, several parameters can be selected for the vertical axis. This allows for example the presentation of both mean- and rms-values in the same plot.

A single plot window may contain several individual plots, and the plots defined appear as a list in the Plots field, occupying one line each.
The leftmost parameter on each line identify the varying point coordinate shown on the horizontal axis, while the rest of the line identify quantities to be presented on the vertical axis.

Existing plots cannot be reconfigured, but they can be removed by selecting them in the Plots field, and pressing the left-hand arrow ( ).
The symbol with multiple left-hand arrows ( ) above the Plots field will delete all plots from the plot window.

6.3.5.2 Property group 'Data'

The property group Profile shown in Figure 6.3-17 contains the properties that are specific for the plot type Profile Plot.

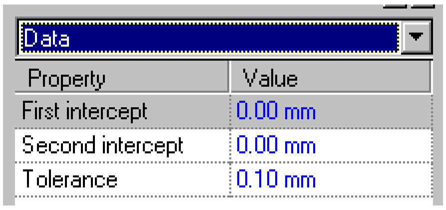


Figure 6.3-17 Data properties of the Profile Plot.

First & Second Intercept

As explained earlier, the Profile Plot shows variations in some calculated quantity along a line parallel to a traverse axis, X, Y or Z, chosen in the configuration of the plot.

This means that the measuring points included in the plot should be identical on all but one of the three position coordinates. In the uppermost Profile Plot in Figure 6.3-15 for example, the measuring positions included have X-coordinates varying from X = -20 mm to X = 20 mm, but they all have coordinates Y = 50 mm and Z = 0 mm corresponding to the intercept values shown in Figure 6.3-17.

The exact meaning of the intercept values depend on which coordinate is allowed to vary, and is shown in Table 6.3-1:

Coordinate shown on the horizontal axis	Intercepts	
	First =	Second =
X	Y-Coordinate	Z-Coordinate
Y	X-Coordinate	Z-Coordinate
Z	X-Coordinate	Y-Coordinate

Table 6.3-1 Interpreting intercept values of the Profile Plot.

Both intercepts have the default value zero, and you will probably have to change them in order to get the Profile Plot desired.

Tolerance

Ideally the measuring points included in a Profile Plot should be exactly identical on all but one of their position coordinates.
For practical purposes however, they need only be identical within a certain tolerance band as specified by the property Tolerance.

In the example used here, the X-coordinate is allowed to vary, while the other coordinates must be Y = 50 ± 0.1 mm, and Z = 0 ± 0.1 mm respectively.

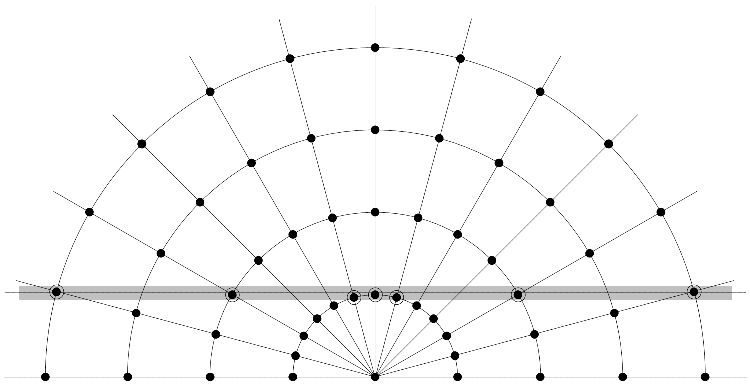


Figure 6.3-18 Using a tolerance band to create a Profile Plot from measuring points that are not exactly aligned.

With a conventional cartesian traverse mesh, the default tolerance value of 0.1 mm will normally be sufficient, but with other types of traverse meshes, you may wish to increase it as illustrated in Figure 6.3-18.

6.3.6 Vector Plot

Like the Profile Plot, the Vector Plot gathers results from multiple measuring points, and is thus available only when measurements are performed in a traverse mesh.

Unlike the Profile Plot however, the Vector Plot presents results in a plane rather than along a line, and thus requires that both the horizontal and the vertical axes of the plot correspond to two of the traverse axes X, Y or Z.

Since furthermore the Vector Plot shows mean velocities only, it is the least versatile of the plot types offered by the Advanced Graphics Add-On, but at the same time unique in its ability to give an overview of the overall behaviour of the flow measured.

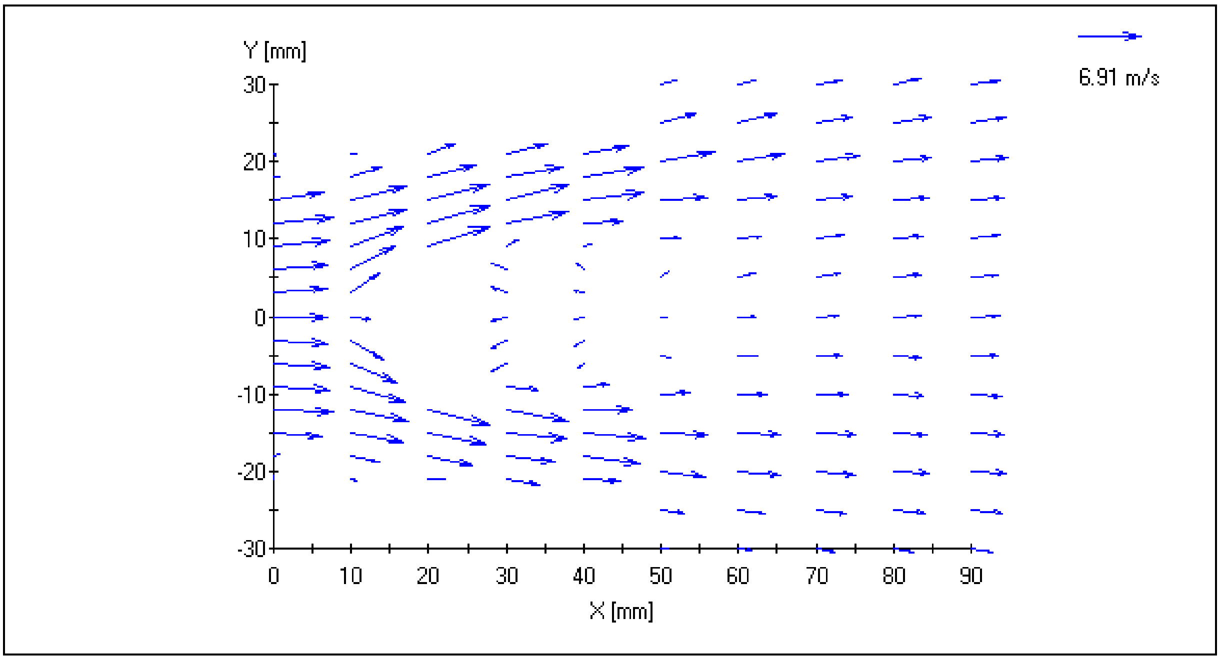


Figure 6.3-19 Vector Plot showing mean velocities downstream of an obstacle.

Figure 6.3-19 shows an example of a Vector Plot, showing mean velocities in a large area of the flow around an circular cylinder located with it's axis in position (x,y) = (20,0) mm. The reversing flow for x < 40 mm suggests the presence of vortices behind the cylinder, and it appears that the reattachment point lies at between x = 40 and X = 50 mm, y = 0.

All other figures shown in section 0 of this text, refers to this example.

6.3.6.1 Property group 'Data'

The property group Data shown in Figure 6.3-20 contain the properties that are specific for the plot type Vector Plot.

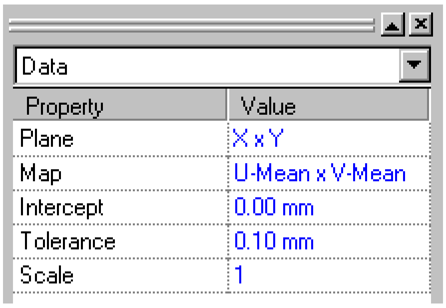


Figure 6.3-20 Properties of the Vector Plot.

Plane

As explained earlier, the Vector Plot shows mean velocities in a plane parallel to two of the traverse axes. The property Plane determines which of the two traverse axes to use. Right-clicking in the right-hand side of the value-field will present a drop-down list with possible options.

Map

The vectors in the plot are shown in the plane investigated, and for this to make any sense it is important that the velocity components shown are indeed parallel to the traverse axes chosen.

By default it is assumed that the first mean velocity component supplied by the moments object (in this example BSA1 Vel-Mean) is parallel to the X-axis of the traverse, and similarly that the second component is parallel to the Y-axis and so on.
If this assumption does not hold, the Map property is used to specify the velocity-components that are parallel to the traverse axes chosen.

If the velocities measured are not parallel to any of the traverse axes, your project tree must include the objects Coincidence and Transform prior to the Moments object, in order to perform coordinate transformation and get velocity-components U, V and W, that are indeed parallel to the traverse axes X, Y and Z.

Intercept

Within a certain tolerance band, all the measuring positions included in a Vector Plot must share a common coordinate on one of the three position coordinates. This common value is specified by the property Intercept.

Plane	X × Y, Y × X	X × Z, Z × X	Y × Z, Z × Y
Intercept =	Z-Coordinate	Y-Coordinate	X-Coordinate

Table 6.3-2 Interpreting intercept values of the Vector Plot

Intercept has the default value zero, and you may have to change it in order to get the Vector Plot desired.

Tolerance

Ideally the measuring points included in a Vector Plot should be exactly identical on one of their position coordinates.
For practical purposes however, they need only be identical within a certain tolerance band as specified by the property Tolerance.

In the example used here, the X- and Y-coordinates differ, while all measuring points included in the Vector Plot must have Z = 0 ± 0.1 mm.

With a conventional cartesian traverse mesh, the default tolerance value of 0.1 mm will normally be sufficient, but you may wish to increase it with other types of traverse meshes, such as the one shown in Figure 6.3-18, where you might imagine the chosen plane extending into or out of the paper.

Scale

If the default vectors shown are either too long or too short, the property Scale can be used to increase or reduce their lengths.

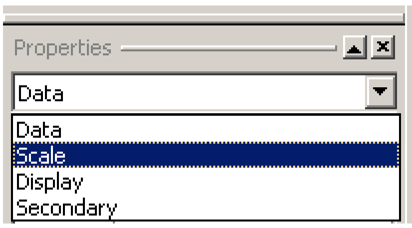
In the example used here, the default vectors were too long, so the scale property was changed to 0.1 reducing the vector lengths to a tenth.

Reference Vector

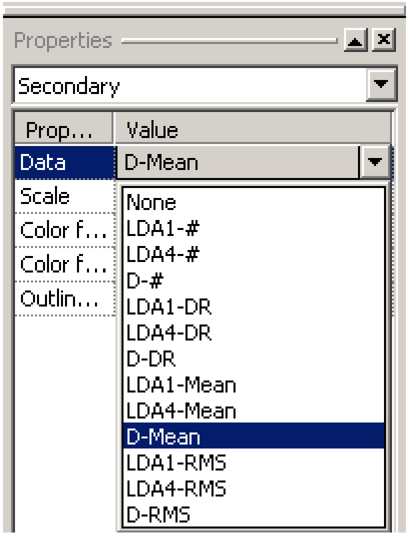
Note the reference vector labelled 6.91 m/s in the upper right-hand corner of Figure 6.3-19. This does not represent an actual velocity, but serves as a scale for the interpretation of the vector lengths shown.
The reference vector has a fixed length and is thus not affected when you change the Scale property. Instead the accompanying velocity is adjusted. In the example used here, the scale vector was labelled 3.45 m/s by default, but changing the scale factor from 1.0 to 0.5 increased the value to 6.91 m/s as shown.

6.3.6.2 Property group "secondary data"

The property group Vector Plot allows you to add some secondary datas to the Vector Plot.



These secondary datas can be selected from the data list:



The scale, colors and outline properties can be defined by the user as for the other plot.

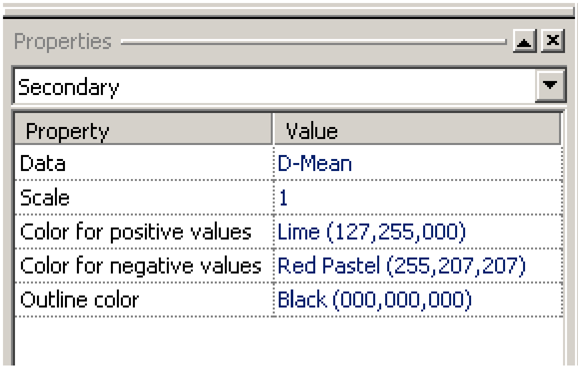


Figure 6.3-21 shows a velocity vector plot with diameters (circles).

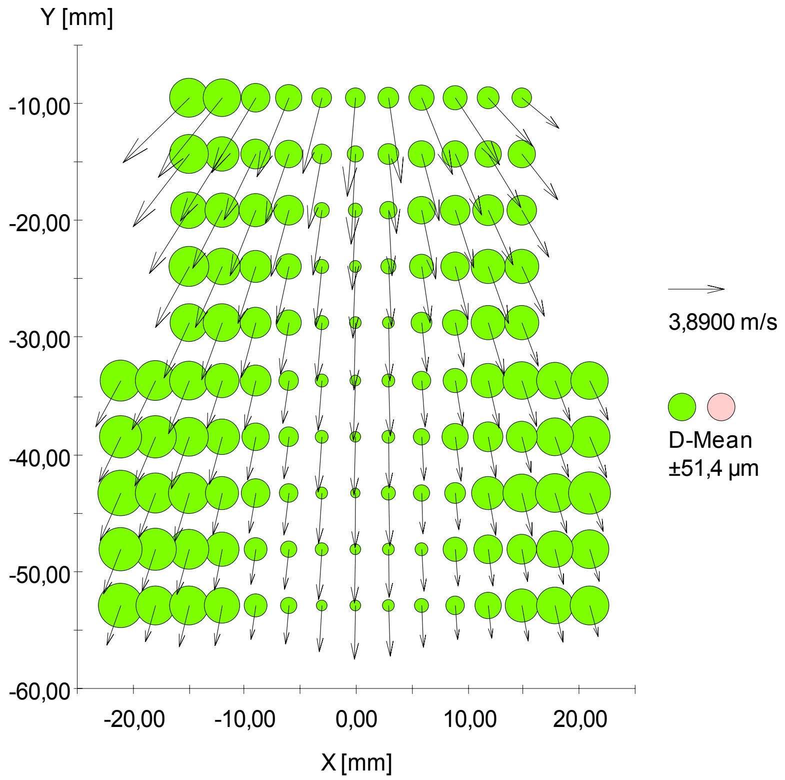


Figure 6.3-21: vector plot with secondary data.

6.3.7 Zooming & Panning in a plot

If you want to investigate details in a plot, you can zoom in on the area of interest.

Permanent zoom

Using the property editor is one way of doing this by increasing minimum-values and/or reducing maximum-values on the horizontal and/or the vertical axis of the plot. Although very accurate, this approach require that you enter four new boundary limits for the plot, and switching back to the full view requires you to change all four limit-values once more. Consequently this approach is only recommended, if you wish to zoom in permanently on a specific area of your plot.

Temporary zoom

If you wish to temporarily zoom in on a specific area, and do not require the limit-values to be so accurately defined, a different approach can be used: Simply press the Ctrl- or the Shift-key on your keyboard, and hold it down while selecting a rectangular area in your plot using the mouse. The area is selected by pressing the left mouse button in a corner of the intended zoom-area, and then drag the mouse to the opposite corner. When you release the left-hand mouse button in the opposite corner, the system will zoom in on the area selected.

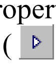
Zooming out

You can zoom in repeatedly going into still finer details of your plot, and zooming out again can either return you to the full view or to the previous level of magnification: Right-click inside the magnified plot, and select either Zoom Out or Zoom Restore from the context menu that appears. Alternatively you can use the corresponding keyboard shortcuts Alt-Z or Ctrl-Alt-Z to respectively zoom out one level, or return to the full view.

Panning

Whether or not you have zoomed in on a plot, you can pan up, down, left or right, using the arrow-keys on the keyboard. Pressing the up or down-arrow will shift the plot up or down in steps of 20% of the current plot height, and similarly pressing the left or right-arrow keys will shift the plot left or right in steps of 20% of the current plot width.

Restoring a plot

If you loose track of your plot having used several zooms and pans, you can always return to the settings in the property editor by running the plot object: Select the plot and press the run-key () on the toolbar, or use the shortcut key F5. Right-clicking the plot object in the project explorer and selecting Run from the resulting context menu has the same effect.

Reading values

The Advanced Graphics Add-On can also help you reading numerical values in a plot: Left-click the mouse while pointing somewhere within the plot area. The coordinates of the current cursor position will then be read out in the status bar in the lower right-hand corner of the screen.

Please be aware that within the Windows operating system, the position of the mouse cursor is measured in screen-pixels. This limits the resolution achievable when reading values in a plot, and to improve the accuracy of the reading, you may wish to maximise the plot to fill the entire workspace.

6.3.8 Exporting plots

All of the previous text in section 6.3 of this document relates to plots on the screen, but they remain an integral part of the BSA Flow Software.
This section describes how you can export the plots, so they can be used in a report or presentation to document your results.

Prints will be scaled to fit the paper selected, while exporting plots to a file or to the clipboard, will yield exact copies of what you see on the screen.

6.3.8.1 Copying a plot to the Clipboard

Using the Clipboard is the traditional way of sharing information between different applications on the Windows platform:

1. Select the plot that you wish to copy by clicking either the plot window in the workspace, or the plot-icon in the project explorer.
2. Copy the selected plot to the clipboard in one of the following ways:
   - Click the Copy-button () in the toolbar, or…
   - Select Copy from the Edit menu, or…
   - Use the keyboard shortcut Ctrl-C, or…
   - Right-click the plot-window in the workspace, or the plot-icon in the project explorer, and select Copy from the context menu that appears.

Either way the selected plot will be copied to the clipboard in two formats: Bitmap and Enhanced Metafile. Other Windows applications can now import the plot from the clipboard in either of the formats supplied.

6.3.8.2 Printing a plot

Printing a plot can also be considered an export, since a plot printed on paper is no longer an integral part of the BSA Flow Software.

1. Select the plot that you wish to print by clicking either the plot window in the workspace, or the plot-icon in the project explorer.
2. Send the selected plot to the printer in one of the following ways:
   - Click the Print-button () in the toolbar, or…
   - Select Print from the File menu, or…
   - Use the keyboard shortcut Ctrl-P, or…
   - Right-click the plot-window in the workspace, or the plot-icon in the project explorer, and select Print from the context menu that appears.

Provided a printer is included in your Windows installation, you will get a print dialog similar to the one shown in Figure 6.3-22, where you may be able to select the number of copies to print, which printer to use and which settings to use on the selected printer.

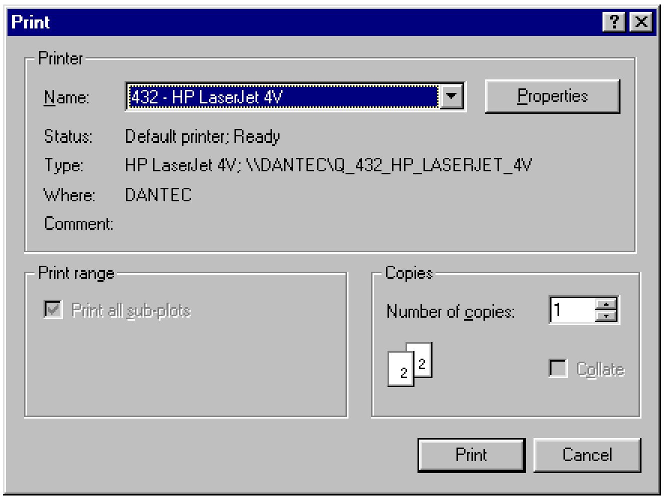


Figure 6.3-22 Preparing to print a plot.

6.3.8.3 Exporting a plot to a file

The clipboard is intended only for temporary storage, and instead you can make a true export, storing the plot in a (permanent) graphic image file:

1. Select the plot that you wish to export by clicking either the plot window in the workspace, or the plot-icon in the project explorer.
2. Export the selected plot in one of the following ways:
   - Select Export from the File menu, or…
   - Right-click the plot-window in the workspace, or the plot-icon in the project explorer, and select Export from the resulting context menu.

This will bring up an export dialog like the one shown in Figure 6.3-23.

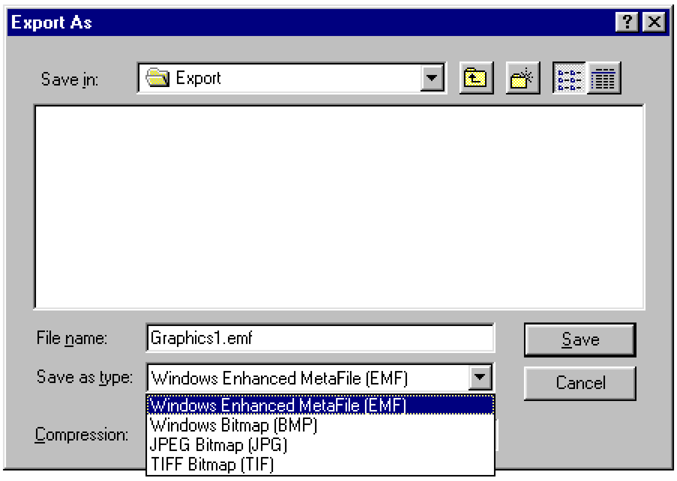


Figure 6.3-23 Exporting a plot to a file.

In this dialog you determine the drive and directory in which you want to store the plot, along with the filename and file format desired.

Four formats are supported, Enhanced Metafile being a vector-based graphics format, while the others are bitmap types.

While JPEG and Metafile are fixed formats, the Windows and TIFF bitmap formats can be compressed or uncompressed as selected in the Compression-field.)

6.4 Advanced traverse add-on

The advanced traverse add-on comprises additional traversing control features which can be useful in the following situations:

In combination with the standard Lightweight traverse driver:

- Logical measuring and traverse position co-ordinates are different. The user can move the traverse independently in up to 3 directions, specified in the external traverse file.

In combination with the standard 57G15 traverse driver:

- Logical measuring and traverse position co-ordinates are different. The user can move the traverse independently in up to 4 directions, specified in the external traverse file.

In combination with the Generic traverse driver:

- The user can write his own traverse controller using the Generic Traverse driver supporting up to 3 directions without the use of the external traverse file.
- Logical measuring and traverse position co-ordinates are different. The user can move the traverse independently in up to 6 directions, specified in the external traverse file.

Control of third party traverse systems is established by using the Generic traverse driver. With this driver the user can use any programming language with access to the serial port interface. The user’s traverse controlling program can be placed on a separate computer, running a different operating system, or it can be operated on the same PC the software is running on. In the latter case at least two serial ports have to be available in the PC. If the traverse is also connected to a serial port, the PC requires at minimum three serial ports.

6.4.1 Generic Traverse Driver

6.4.1.1 Properties

The Traverse Driver properties mainly specify the COM-port settings and configuration. In addition, a command string can be specified. This command string is used to send information to the traverse controller.

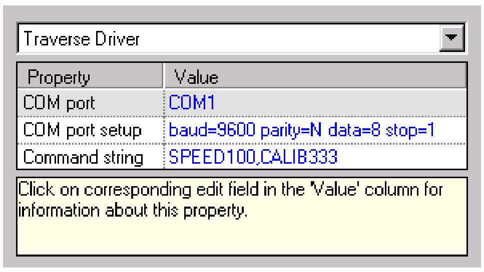


Figure 6.4-1: Common serial COM-port properties, including command string for initialisation of the traverse..

The property section for each Generic traverse channel is very similar to the Lightweight channel properties.

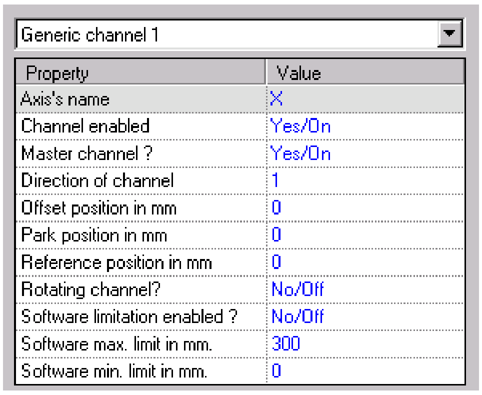


Figure 6.4-2: Generic traverse channel properties, similar to the Lightweight channel settings..

6.4.1.2 The Protocol

The protocol contains the following commands.

Command	**Send**	**Receive**	**Comment**
Initialize	#INIT:string&	#INIT:error&	Sends an initialisation string to the traverse controller. The initialisation string is user defined and can be used by the user for setting specific settings to the traverse. string = Initialisation string (max. 128 characters).
Move	#MOVE:X,Y,Z&	#MOVE:error&	Sends a move command to the traverse controller including the new traverse positions. Positions X, Y, Z are all in um.; meaning 1000*mm.
Read	#READ&	#READ:error;X,Y,Z&	Sends a command to read the current traverse position. Positions X, Y, Z are all in um.; meaning 1000*mm. If error the positions should be set to 0.
Stop	#STOP&	#STOP:error&	Sends a stop command to the traverse controller. Stops the traverse (if possible).
Reset	#RESET&	#RESET:error&	Resets the current position as home.
Home	#HOME&	#HOME:error&	Moves to home position.

error = error code (see Table 6.4-2)

Table 6.4-1: Generic driver protocol specifying the command set.

Code	Meaning
0	No error.
1	Generic user error, failed to understand input message. The string returned from the controller to the driver could not be understand. The string must follow the protocol described in Table 6.4-2) Table 6.4-1.
2	Generic user error, return code out of range. User supplies error return codes must be larger than 100.
3	Generic user error, failed to understand command response. The command received is not among the one described in Table 6.4-2) Table 6.4-1.
4	Generic user error, failed to understand extension response. The command extension, e.g. for the READ command, must follow the protocol described in Table 6.4-2) Table 6.4-1.
5	Generic user error, failed to read position. The position formatting in READ could not be read.
>100	Error, error codes supplied by user.

Table 6.4-2: User error return codes.

6.4.1.3 How It Works

Most of the commands are called when the traverse is not moving, this is controlled from this driver, and can be explained as synchronous. However two commands MOVE and HOME are asynchronous.

Synchronous call

The traverse is not moving and you want to reset the current position to the new reference position. You make the command RESET and the traverse driver will wait for the controller to answer. If the traverse is moving the command will not be executed from the driver and the controller will not get the command at all. All synchronous calls must be answered right away, otherwise a time-out (default 5 sec.) will occur in the driver.

Asynchronous call

When you want to move the traverse you send the MOVE command to the driver and the driver will send the command to the controller if the traverse is not already moving. The controller should not respond to this command until the traverse stops. In the meantime the controller can be called with either a STOP command or a READ command. The STOP and READ commands are synchronous, and the controller must answer these command right away, see Figure 6.4-3. In some cases the controller controls a traverse which cannot request positions while moving, in this case the READ command is answered with the starting position until it stops.

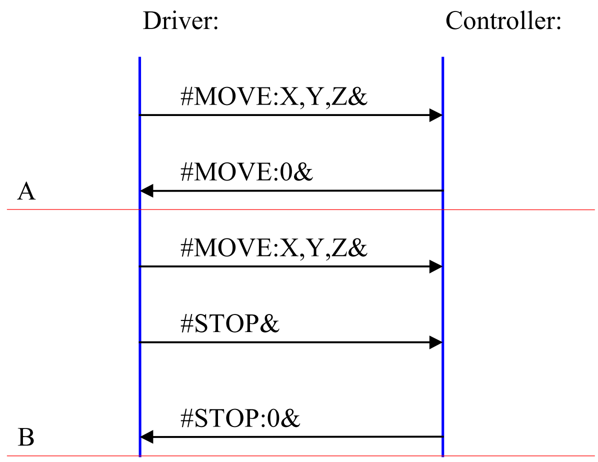


Figure 6.4-3: Asynchronous timing examples.

In Example A in Figure 6.4-3 a normal MOVE command is send from the driver to the controller, when the traverse is in position the controller sends back a MOVE in return. In Example B Figure the driver sends a MOVE command, the driver then sends a synchronous STOP command and the controller must respond this with a STOP in return. Note that the controller does not need to send a MOVE in return in example B when STOP is called.

6.4.1.4 How to Use the Initialisation String

The initialisation string can be used to send information to the traverse controller. The generic traverse protocol is small and precise and will fulfill most users demands. Users who want more control or use different traverses can save a initialisation string along with a BSA Flow Software project, telling how to control the traverse for that particular project. The user must format the string in a way that they can unpack in the controller. E.g. if the traverse should use a particular speed during the current project the initialisation string could look like this: "SPEED:1000".

6.4.1.5 How to write a Controller

The controller is a piece of software on a remote computer controlling the actual traverse system. The two computers must both have a free RS232 port installed. Set the communication ports on both computers to the following settings:

Baud Rate	9600
Data Bits	8
Parity	None
Stop Bits	1
Flow Control	None

Table 6.4-3: RS232 Port Settings for Generic Driver.

The two computers must be connected using a serial null-modem cable. The remote computer running the controller software can be any type of machine running any kind of operating system (OS) supporting RS232 communication.
Typically the RS232 communication is event driven. Whenever data is arriving to the port the OS is informed. The controller software can be notified using events or messages depending on the architecture chosen. The protocol is designed so that the & character can be used as end character in the incoming data flow.

It is important that the controller answers the commands send from the driver using the right protocol. If the driver cannot understand the incoming answer it fails (see error code 1-5).

If the controller needs to make time consuming operations, it must answer the incoming command before stating this. In this case the controller can choose to ignore incoming commands by answering them quickly.

6.4.1.6 Examples

Example 1
The user needs to change settings in his program every time the traverse is used, in this example max. speed set to 100 and a calibration constant to 333. He can use the initialisation string to set the settings from time to time, saved in the project.

SendToSerialPort("#INIT:SPEED100,CALIB333&")
IF (ReceivedFromSerialPort() == "#INIT:0&") -> OK

Example 2
When the application wants to move to a position the co-ordinates are scaled from mm, used in the application, to µm used in traverse communication.

x = 2.34594, y = 0.145, z = 2.5 (mm)

SendToSerialPort("#MOVE:2346,145,2500&")
IF (ReceivedFromSerialPort() == "#MOVE:0&") -> OK

We loose precision on the x co-ordinate, but it has no relevance.

Example 3
Reading the position can be done by calling
SendToSerialPort("#READ&")

IF (ReceivedFromSerialPort() == "#READ:0&") -> OK

Other errors e>100 can be found by examining the return string.

6.4.2 Use of External Traverse files

The External Traverse file can be enabled in the Region(s) menu in the region list.

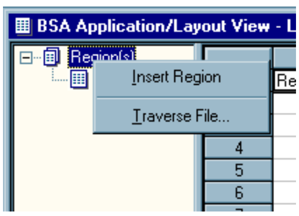


Figure 6.4-4: Traverse File option in the Region(s) menu list.

The external traverse file acts as a transformation matrix between the three axis logical coordinate system (as specified in the Layout View) and the physical coordinate system (as generated by the used traversing gear), which may comprise up to six traversing axes.

When an external traverse file is used, the advanced traverse add-on works with two coordinate systems:

- X, Y, Z logical measuring position coordinates
- A, B, C, D, E, F traverse position coordinates

The mesh of logical measuring positions can be generated with the Layout View Mesh Wizard. The logican traverse mesh may comprise one or more regions.

The physical traverse position coordinates are located in a look-up table (the external traverse file) in ASCII format. Each coordinate is placed in a column each separated by Tab, Comma or Space. The reference between the logical traverse mesh and the external traverse file is given by the traverse position index, i.e. the traverse position index in the layout view table corresponds to the line number in the external traverse file. As an example the coordinates of a five axis system are given below:

A	B	C	D	E
1000	2500	0	-1000	20000
1000	3000	1000	-1100	20000
1000	3500	2000	-1200	20000
1000	4000	3000	-1300	30000

Table 6.4-4: An example for a five axis external traverse file.

Please note that the coordinate values must be entered in **micrometers (μm)** and that the external traverse file shall only contain the position coordinates, i.e. the first line in the above example (A B C D E) shall not be in the file.

The table can be generated by the user in e.g. MS Excel or similar, and exported as ASCII.

The number of positions in the measuring coordinate system and the traverse coordinate system must be the same, otherwise a warning message will be displayed.

The look-up table is not enabled by default. The user must enable this option and specify the path to the external traverse coordinate file. The file path is stored along with the measurement project.

6.5 57N36 BSA Analog Input Option and 57N38 BSA Analog Input Kit

This chapter describes the analog input option to 57Nxx BSA processors.

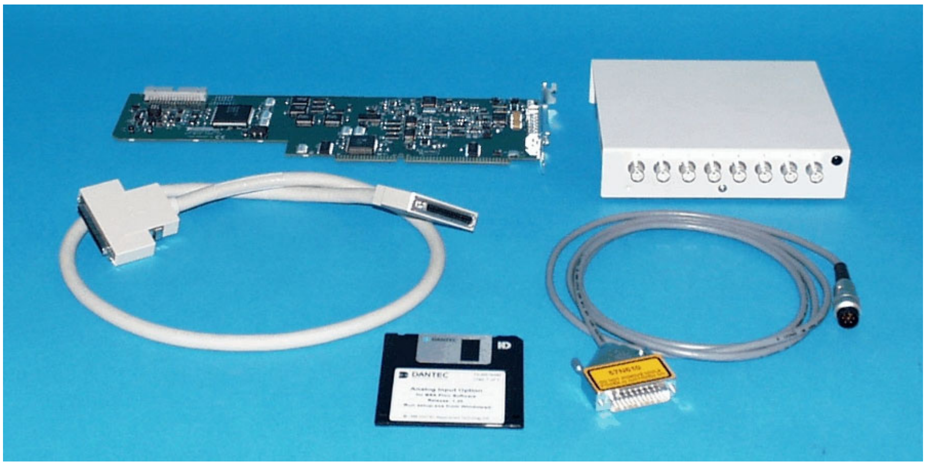


Figure 6.5-1 57N36 BSA analog input option parts

The Analog Input Option will allow you to sample analog signals, while simultaneously acquiring LDA-data. Beyond the additional software modules for the BSA Flow Software, this requires an A/D-board with driver software, and a connector box with cables connecting to the PC, and to the LDA-processor(s) for synchronisation.

The 57N36 BSA Analog Input option includes a National Instruments AT-MIO-16E-10 A/D board.

The 57N38 BSA Analog Input kit does not include the A/D board. The kit can be used with the following types of National Instruments A/D boards:

- AT-MIO-16E-1
- AT-MIO-16E-10
- PCI-MIO-16E-1
- PCI-MIO-16E-4

6.5.1 Installation

Installing the Analog Input option involves both software and hardware:

1. Install the software Add-On for the BSA Flow Software.
2. Install the NI-DAQ® driver software for the A/D-Board.
3. Install the A/D-board in your PC.
4. Test and configure the A/D-board as necessary.
5. Connect the A/D-board and the connector box.
6. Connect the SyncBus of the Master BSA processor to the connector box.
7. Connect your analog signal(s) to the input(s) on the connector box.

Please refer to the hardware-manual supplied by the manufacturer regarding installation and configuration of the A/D-board (steps 2-4 above).

Caution	To avoid accidental damage to your equipment, please make sure that both PC and processors are properly grounded and switched off while connecting or disconnecting (steps 5-7 above).

6.5.2 Hardware connections

All hardware connections relating to analog inputs go through the A/D connector box depicted in Figure 6.5-2. As the name implies, the connector box performs no signal conditioning, but simply transfers in- and out-going signals directly to and from the A/D-board via the 68-pin connector shown at the bottom of the figure.

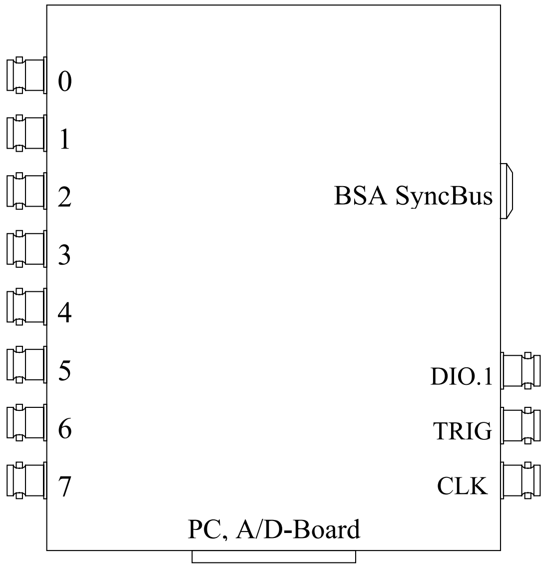


Figure 6.5-2 Hardware connections on the A/D-connector box.

Analog inputs

Up to 8 analog signals can be sampled on the input connectors labelled 0-7. The A/D-board used support multiple signal types, but internally the connector box is wired for RSE (Referenced Single Ended), where all signals share a common ground. Using any of the other signal types (NRSE or DIFF) thus require hardware modifications. Please refer to the hardware manual supplied by the manufacturer for further information on this subject.

Signal Levels

The A/D-board used support both unipolar and bipolar signals:

Unipolar: 0-10 V
Bipolar: ±5 V

An on-board amplifier can be used to amplify weak signals prior to the A/D-conversion, while signals beyond the limits stated above will be clipped. (Please refer to the hardware manual supplied by the manufacturer for information on the maximum voltages that the hardware can sustain).

Synchronisation

Synchronisation of A/D-data with the LDA-data is performed via a cable connecting the BSA SyncBus to the connector box.

Note	Synchronisation of A/D- and LDA-data require the BSA clock signal to be available on the BSA SyncBus connector. This is accomplished by running one of the BSA's as master clock, while the other BSA's in a 2- or 3-D measurement must be run as clock slaves.
Caution ☞	Electronics inside the cable connector may be damaged if the system is on power when connecting or disconnecting the cables between the connector box, the PC and the BSA's. Consequently the PC and the BSA's should always be switched off when connecting or disconnecting these cables!
Grounding	Furthermore you should ensure proper grounding of both the PC and the BSA's, since otherwise there is a potential risk of damaging your equipment even if it is switched off while connecting or disconnecting the cables!

Note

Please note that sampling of the analog signals are not triggered by the LDA-bursts themselves. A burst detection signal is available on the BSA SyncBus, but using this would trigger an A/D-sample on all LDA-bursts including the ones that subsequently fail to pass burst validation in the processor (i.e. an A/D-sample could be triggered by noise!). Normally such invalid LDA-bursts are not transferred from the processor to the PC, but once triggered, the A/D-board will always take a sample.
Consequently this approach would yield more A/D-data than LDA-data, and since the A/D-board does not time-stamp the A/D-data, it would be impossible to distinguish valid and invalid A/D-data.
The only solution would be to transfer both valid and invalid bursts from the processor to the PC, and beyond a dramatic increase in the amount of data to be stored, it would also reduce the valid datarate achievable, since invalid data would occupy a lot of the available data transfer time.

Burst-triggered sampling of the A/D-input would also require that the acquisition of LDA-data was performed in dead-time mode:
Due to the random timing of particle arrivals in the measuring volume, two valid LDA-bursts may come so quickly after one another, that A/D-conversion of the first analog sample is still in progress, when the second LDA-burst triggers a new A/D-sample. The A/D-board cannot take a new sample while A/D-conversion of the previous sample is in progress, and consequently A/D-data would be missing.
The only solution would be to run the LDA-processor(s) in dead-time mode, with a dead-time corresponding to the A/D-conversion time. Since all analog inputs share the same A/D-converter through a multiplexer, the dead-time required would increase with the number of analog channels in use.

Instead a different approach is used:
The A/D-board is set to sample the analog inputs at a sample rate adjustable by the user, and triggered to start sampling at the same time as the LDA-processor(s). Using the 1 MHz BSA clock from the SyncBus as source clock, each A/D-sample can then be assigned an arrival time.

To merge the velocity data and analog data, a Coincidence object must be made.

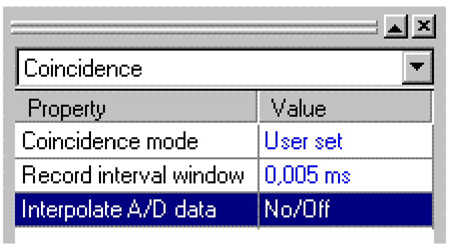


Figure 6.5-3 The Interpolate A/D data property of the Coincidence object

There are two ways of merging the data using the coincidence object:

1. Simple coincidence filtering (Interpolate A/D data off). If the coincidence window is narrow and the a/d sampling rate low, this will reject many data. By widening the coincidence window a higher proportion of the data will pass, but the velocity data may not stem from the same particle passage (in case of 2D or 3D LDA)

2. Linear interpolation of the analog data (Interpolate A/D data on): for each velocity arrival time, linear interpolation, based on the arrival times, between the preceding and succeeding analog samples is performed. If the a/d sampling rate is significantly higher than the Nyquist frequency, this will give accurate analog values. This method has the advantage of *not* rejecting many velocity samples.

6.5.3 Software set-up

Once A/D-hardware as well as software has been installed, acquisition of A/D-data can be included in your experiment set-up via the configuration wizard shown in Figure 6.5-4.

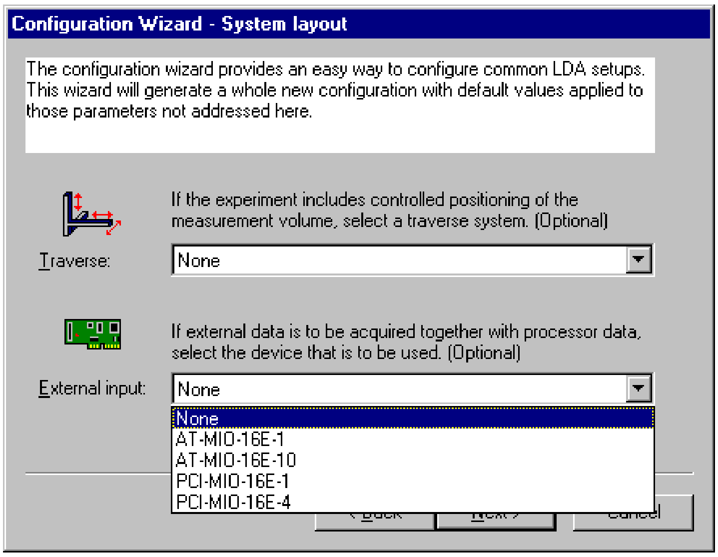


Figure 6.5-4 Enabling the A/D-board in the configuration wizard

Having defined the A/D-device as part of your experiment set-up, the configuration wizard is completed as usual defining laser wavelengths, lens focal lengths and so on. Once the configuration wizard is finished, the A/D-board will appear as an icon in the Config View as shown in Figure 6.5-5.

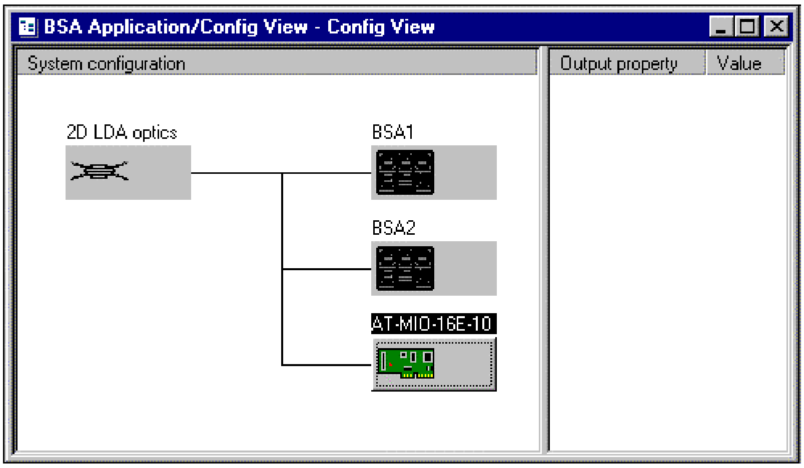


Figure 6.5-5 A/D-icon appearing in the configuration view

6.5.4 General properties of the A/D-device

The settings of the A/D-board are accessed by clicking the A/D-icon in the configuration view. This will bring up the Board configuration properties in the property editor as shown in Figure 6.5-6. The properties shown here are common for all analog channels, while properties that are specific for each individual channel can be accessed via the drop down list.
The channel specific properties are described on page 6.56.5-10 ff.

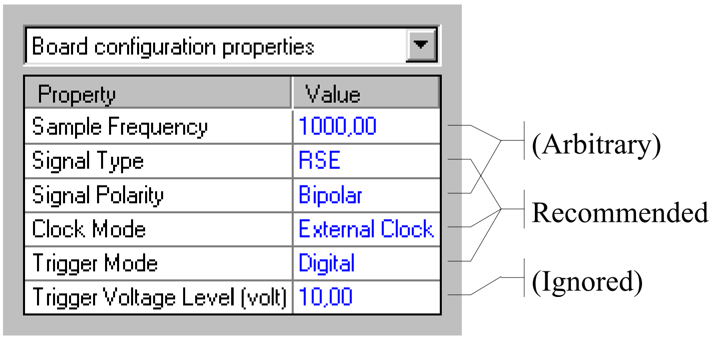


Figure 6.5-6 Recommended settings of the general A/D-properties.

The properties shown in Figure 6.5-6 represent the recommended settings: While Sample Frequency and Signal Polarity can be chosen freely, Signal Type, Clock Mode and Trigger Mode should be RSE, External Clock and Digital respectively.
With these settings the property Trigger Voltage Level is not used, and consequently the value will be ignored.

Sample Frequency

The property Sample Frequency determines the sampling frequency used for acquisition of analog data. Sampling frequency is measured in Hz, based on the assumption that the clock base frequency is 1 MHz.

If you wish to monitor a slowly varying signal, you can set the sampling frequency freely according to the expected behaviour of the signal (i.e. fulfilling the Nyquist sampling criterion on the incoming analog signal).

If you wish to obtain A/D-data that are coincident with LDA-samples, you must select a sampling frequency somewhat higher than the mean datarate of

LDA-samples to account for the random timing of seeding particles passing the LDA measurement volume. In most cases an A/D sampling frequency of 2-3 times the mean datarate of LDA-samples will be sufficient.

Note

Please note that this will produce 2-3 times more A/D-data than LDA-data, and you may encounter problems with loss of A/D-data due to A/D buffer overflow. The size of the A/D buffer is determined from the number of LDA-samples requested, since prior to the experiment the software can't tell what the mean datarate of the LDA-samples will be, and consequently can't predict the actual number of A/D-samples taken while collecting LDA-data.

To avoid this problem, you can request a number of LDA-samples 2-3 times higher than what you actually want, and then limit the duration of the measurement, so it will stop acquiring data due to time-out.

Example

Imagine an experiment, where you want approximately 2000 LDA samples, and wish to acquire A/D-data at twice the mean datarate to ensure a reasonable degree of coincidence despite the random timing of the LDA-samples. From a preliminary experiment you know that the mean datarate is approximately 500 Hz, and consequently you set the A/D sampling frequency at 1 kHz. Setting up the system to acquire exactly 2000 LDA samples will produce LDA and A/D-buffers capable of holding 2048 samples, which is sufficient for the LDA data, but obviously too small for the A/D data: About halfway through your experiment the A/D-buffer will overflow, and the remaining analog samples will be lost.

To avoid this you should request 4000 LDA samples, but limit the duration of the measurement to maximum 4 seconds. This will yield LDA and A/D buffers capable of holding 4096 samples. The time-out after 4 seconds combined with the mean LDA datarate of approximately 500 Hz yields about 2000 LDA samples as desired, while in the same period of time the A/D sampling rate of 1 kHz produces 4000 A/D-samples, but now without buffer overflow.

To get the best possible degree of coincidence between LDA and A/D-samples you might be tempted to sample the analog signal(s) at a frequency significantly above the mean datarate of LDA samples, but please be aware that this will increase the memory requirements of the PC dramatically, and consequently this should be done only if it is truly necessary.

Signal Type

The property Signal Type can be set to one of the following:

- RSE (Referenced Single-ended).
  An analog input configured in RSE mode connects one analog input line to the positive input of the on-board amplifier, while the negative input of the amplifier is internally tied to analog input ground.
- NRSE (Non-referenced single-ended).
  An analog input configured in NRSE mode connects one analog input line to the positive input of the on-board amplifier, while the negative input of the amplifier connects to an external ground reference.
- DIFF (Differential).
  An analog input configured in DIFF mode uses two analog input lines. One line connects to the positive input of the on-board amplifier, while the other line connects to the negative input.

Please refer to hardware documentation supplied by the manufacturer for further information on the different signal types.

Recommended Signal Type	By default the Connector Box is wired for Referenced Single-Ended (RSE), and using any of the other signal types (DIFF or NRSE) thus require hardware modifications. Please refer to the hardware documentation from National Instruments if you wish to use any signal type other than RSE

Ground-loop errors

Using the RSE signal type is simple, but involves the risk of ground-loop errors, if the signal connected at the analog input comes from an external sensor with its own ground level. A difference in ground-potential between the external sensor and the connector box may cause a significant electrical current to run in the ground wire connecting the sensor with the connector box. Due to the resistance of the wire itself, this will cause a voltage difference between the two ends of the wire, and this will produce offset errors in the measured analog signal.

To avoid ground-loop errors please make sure that sensor ground and connector box ground are properly tied together, or better still, ensure that the sensor connected does not have its own ground level, but rather shares the same ground level as the rest of your equipment (i.e. has the same power supply).

Signal Polarity

The property Signal Polarity determines the polarity of the incoming signals: Unipolar always have positive voltages, while Bipolar signals may have negative as well as positive voltages.

- Unipolar (0-10 Volt).
- Bipolar (±5 Volt).

In both cases the span between minimum and maximum voltage is fixed at 10 Volts, and to exploit this properly an on-board amplifier can be used to amplify weak signals prior to the A/D-conversion. Signals beyond the limits stated above will be clipped. (Please refer to the hardware manual supplied by the manufacturer for information on the maximum voltages that the hardware can sustain).

Clock Mode

The property Clock Mode determines the base clock source used to control the sampling frequency, and two options are available:

- On-board.
- External (Recommended).

Recommended Clock Mode	In general it is recommended to select external clock and use the Sync-cable supplied to transfer the BSA Master Clock from the BSA SyncBus to the A/D-board via the connector box. This ensures that the arrival times assigned to the A/D-samples are truly comparable to the arrival times of the LDA-samples.

Using the on-board clock is a possible alternative: The on-board clock runs at 1 MHz like the BSA clock, so resulting A/D arrival times should be comparable to the LDA arrival times, but in this case the A/D-board and the BSA’s will be running on two separate clocks, that are not synchronised. Consequently there may be a phase difference between the two clocks, and especially in long experiments slight deviations from the nominal 1 MHz clock frequency may cause the two clocks to drift relative to each other.

It is possible to select external clock, and use something other than the BSA master clock to control the A/D sampling, but this is not recommended, since it will become very difficult to predict and interpret the results:

The sampling frequency and the A/D arrival times are generated based on the assumption, that the base clock frequency is 1 MHz. This assumption will be fulfilled if the on-board clock is used, or if the BSA Master Clock from the BSA SyncBus is used as external clock, but cannot be guaranteed otherwise.
Consequently using an external clock other than the BSA Master Clock may yield true sampling frequencies and A/D arrival times differing significantly from the values indicated by the software!

Warning ☞	If necessary the external clock source must be supplied at the CLK-input on the connector box. Inside the box this input is connected in parallel with one of the pins in the BSA SyncBus connector, and consequently you should never connect both the BSA Sync cable and an external clock at the CLK input since this may damage your equipment!

Trigger Mode

The property Trigger Mode specifies the conditions that will trigger the start of A/D-sampling with the specified sampling frequency.
Three possibilities are available:

- Software.
- Digital.
- Analog.

Software triggering is the easiest, and does not require any hardware connections at all. Sampling of the analog signals is simply started via a software command, when the experiment is started. Unfortunately the resulting A/D-samples are not synchronised with the LDA-samples, since delays in the communication between the PC and the BSA(s), cause the A/D-board to start sampling before the BSA(s) starts collecting LDA-data.

Recommended Trigger Mode	To synchronise A/D- and LDA-samples, it is recommended that you use digital triggering, where the master BSA issues a start signal on the SyncBus to start all BSA's simultaneously. Through the Sync cable this signal is also transferred to the A/D-board via the connector box.

With digital triggering you may also trigger the start of A/D-sampling with an external signal connected to the TRIG input on the connector box.

With digital triggering the signal supplied at the TRIG input should be a TTL signal, but with analog triggering you can trigger the start of A/D-sampling at any voltage level within the range determined by the property Signal Polarity.
The analog trigger level is specified by the property Trigger Voltage Level.

Warning ☞	Whether external triggering is digital or analog, it must be connected to the TRIG-input on the connector box. Inside the box this input is connected in parallel with one of the pins in the BSA SyncBus connector, and consequently you should never connect both the BSA Sync cable and an external trigger at the TRIG input since this may damage your equipment!

Trigger Voltage Level

The last of the general A/D-properties Trigger Voltage Level is relevant only when the property Trigger Mode is set to Analog.

It determines the voltage level that the signal connected to the TRIG input on the connector box should reach before the A/D-sampling starts. Once started, the A/D-board will continue sampling the analog signal(s) until the BSA's stop acquiring LDA-data.

6.5.5 Channel properties of the A/D-device

As with the general properties of the A/D-board, channel specific settings are accessed by clicking the A/D-icon in the configuration view. This will bring up the Board configuration properties shown in Figure 6.5-6, and from the drop down list you can get access to channel specific properties like the ones shown in Figure 6.5-7.

channel 0 properties

Property	Value
Channel name	0
Channel Enable	Yes/On
Gain Factor	1.000
Type	Voltage
Max input voltage	10.000
Min input voltage	0.000
C0	0.000
C1	1.000
C2	0.000
C3	0.000
C4	0.000
C5	0.000
C6	0.000

Figure 6.5-7 Properties of each A/D-channel

Channel name

The property Channel name is an arbitrary name, by which A/D-data from the channel in question will be referenced elsewhere in the program.
By default the channel name corresponds to the A/D-channel number, but any text can be entered here. For example the name Temp could be used for an analog input coming from a temperature sensor.

Channel Enable

The property Channel Enable determines whether or not A/D-samples should be collected from the analog input in question. Up to 8 analog channels can be sampled, but obviously only the inputs where a signal is actually connected is of any interest, and the others should be disabled.

Gain Factor

Depending on the Signal Polarity selected in the Board configuration properties, the input signal(s) are supposed to be within the interval 0-10 Volts (Unipolar) or ±5 Volts (Bipolar).
While signals exceeding these limits will be clipped, weaker signals can be amplified prior to the A/D-conversion, and the property Gain Factor controls this amplification.
For each of the analog input channels the Gain Factor can thus be set to

1, 2, 5, 10, 20, 50 or 100.

Type

The property Type determines the unit applied to A/D-data and whether or not to use polynomial conversion:

Name	Unit	Conversion
Voltage	[V]	No
Temperature	[°C]	Yes
Pressure	[kPa]	Yes
Position	[mm]	Yes
Angle	[deg]	Yes
Velocity	[m/s]	Yes

A polynomial conversion routine is supplied to enable linearisation of the output from non-linear sensors. By default the property Type is set to Voltage, meaning that no conversion is performed, and that the resulting A/D-values are voltages measured at the input of the A/D-converter. (Amplification is included, since this happens prior to the A/D-conversion).

Units

If you wish to use other units than the ones shown above, this can be accomplished using conversion routines built into the BSA Flow Software (Select Tools>Options>Data Formats, select the Data Type you wish to change, and press the Change button. In the following dialog select a new unit from the drop down list with available units).

Please note however, that the built-in conversion succeeds the polynomial conversion of the analog input, and thus assumes the input to have the above-mentioned units.
If for example you have a non-linear temperature sensor connected to an analog input, and you wish temperature samples to be recorded in °F, you should still set polynomial coefficients so the polynomial conversion yields a linearised output representing temperature measured in the default unit °C, and then let the built in routines convert this to °F as desired.

Min/Max input voltage

The properties Min and Max input voltage determines the voltage range in which the polynomial conversion algorithm is valid. (Again the voltage limits apply after signal amplification, since the gain factor is applied prior to A/D-conversion, and the polynomial conversion is applied after).

Input voltages above Max will be clipped to produce the same output as Max input voltage, and likewise Input voltages below Min will be clipped to produce the same output as the Min input voltage.

C0, C1, ..., C6

The last properties C0 - C6 defines the conversion polynomial.
Assuming that the input signal comes from a non-linear temperature sensor the voltage V can be converted to temperature T according to:

$$T = C_0 + C_1V + C_2V^2 + C_3V^3 + C_4V^4 + C_5V^5 + C_6V^6$$

–where the polynomial coefficients must be supplied by the user.

By default C_1 is 1.0 and the other coefficients are zero, corresponding to no conversion at all.

6.5.6 Output from the A/D-device

The A/D-device is a data source included in the Standard LDA object just like a LDA processor, and the rest of the program treats A/D-samples no different than any other data. This becomes apparent when you make a list showing the results of your experiment (see Figure 6.5-8):

The first three columns form a group of data originating from the data source BSA1, the next three form another group of data originating from BSA2, and finally the last two columns form a group of data originating from the A/D-board.

In a three-dimensional measurement a group of data originating from BSA3 would also have been present, while in a one-dimensional measurement only the group originating from BSA1 would have been present.

Standard LDA/List - List

	BSA1 Vel [m/s]	BSA1 TT [ms]	BSA1 AT [ms]	BSA2 Vel [m/s]	BSA2 TT [ms]	BSA2 AT [ms]	A/D AT [ms]	A/D 0 [V]
1	20,067	0,002	0,826	-0,588	0,001	0,112	0,000	0,215
2	21,335	0,002	2,750	-1,137	0,001	1,361	1,000	0,186
3	23,343	0,002	4,197	-0,847	0,001	2,056	2,000	0,151
4	21,375	0,002	4,738	-0,565	0,001	3,525	3,000	0,115
5	20,776	0,002	4,780	-0,595	0,001	3,842	4,000	0,078
6	19,202	0,002	7,473	-0,939	0,001	5,314	5,000	0,039
7	20,820	0,001	10,102	-1,160	0,001	6,641	6,000	-0,002
8	21,291	0,002	10,473	-0,489	0,001	7,764	7,000	-0,039
9	19,407	0,002	10,796	-0,901	0,001	8,116	8,000	-0,078
10	22,454	0,002	12,803	-0,901	0,001	8,561	9,000	-0,115
11	24,940	0,002	13,137	-0,649	0,001	11,236	10,000	-0,154
12	20,788	0,002	13,766	-0,733	0,001	12,053	11,000	-0,186

Figure 6.5-8 Output from the A/D-device

A/D AT

The first column of the A/D-group contain the arrival times assigned to the A/D-samples. The arrival times are not really measured, but since the analog input(s) are sampled at a fixed and known frequency, it is easy to determine the time at which each sample was taken.

In the example in Figure 6.5-8 only one of the analog input channels were enabled. If more analog inputs had been sampled, additional columns would have been added, but since they are all sampled with the same frequency, they would share a common arrival time.

A/D 0

The remaining columns contain the actual analog samples.
In the example in Figure 6.5-8 only one of the analog input channels were enabled, but sampling more of the analog inputs would simply have added additional columns.

By default the channel name corresponds to the analog channel number, and in the example in Figure 6.5-8 this was left unchanged, leading to the column header A/D 0, since channel 0 was used for the analog input. Supplying a different channel name, such as 'Temp' would have produced the column header A/D Temp.

In the example in Figure 6.5-8 the property Type was left at the default value Analog, disabling the polynomial conversion of analog values, and yielding the unit [V] corresponding to the voltage measured at the input of the A/D-converter.

Selecting a different Type, such as Temperature would have enabled the polynomial conversion, and produced the unit [C] instead.

Finally it should be noted that the Gain Factor was set at 1 in the example in Figure 6.5-8. The voltages measured appear to be very small, and with the signal type Bipolar allowing voltages in the range ±5V, improved accuracy would have been obtained using a Gain factor of 10

6.5.7 Further processing

Once acquired A/D-data is treated no different than any other type of data, and consequently any processing available for LDA-data can be performed on A/D-data as well.

This is illustrated in Figure 6.5-9 and Figure 6.5-10 where a spectrum is calculated on the basis of a sampled sinusoidal input.

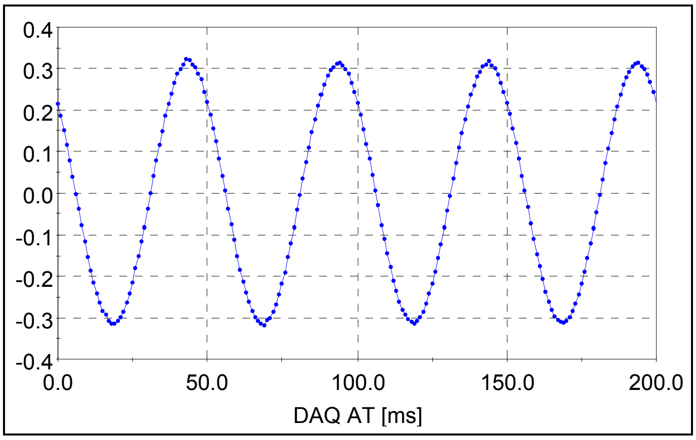


Figure 6.5-9 Sampling a sinusoidal analog input.

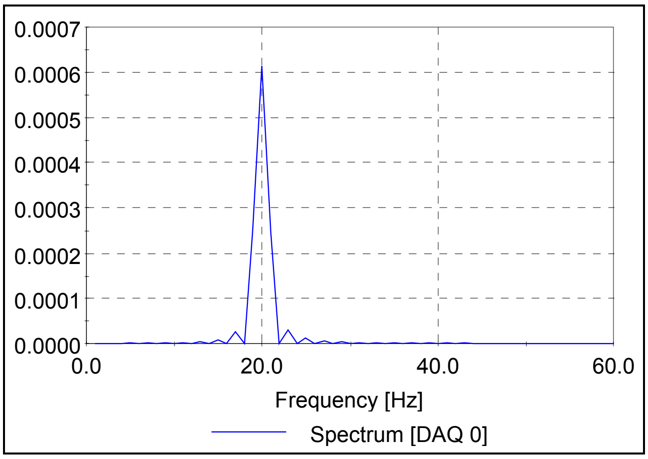


Figure 6.5-10 Spectrum calculated from A/D-data using the Spectrum and Correlation Add-On.

(Both figures have been generated using the Advanced Graphics Add-On).

6.6 FVA/PDA Analog Input

This chapter describes the analog input to 58Nxx FVA and PDA processors.

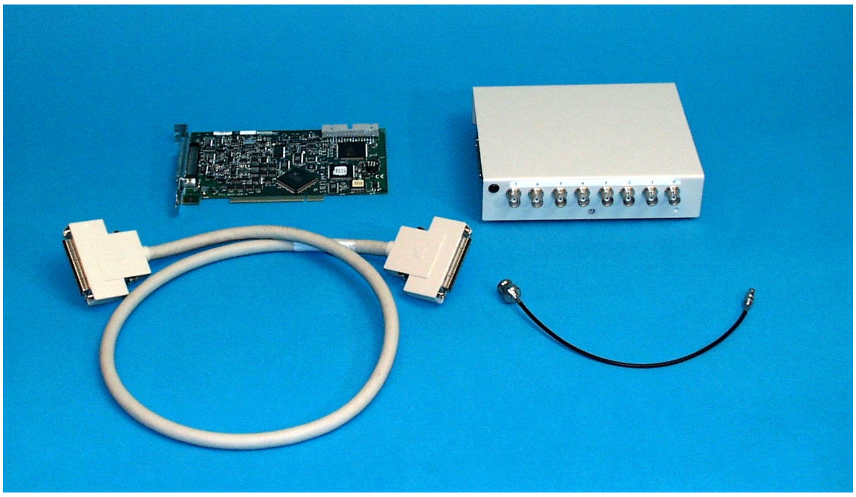


Figure 6.6-1 58N30 BSA analog input option parts

The FVA/PDA Analog Input Option will allow you to sample analog input signals, while simultaneously acquiring LDA- or PDA-data. Beyond the additional software module for the BSA Flow, this requires an A/D-board with driver software, and a connector box with cables connecting to the PC for synchronisation.

The 58N30 FVA Analog Input option includes:

- National Instruments PCI-MIO-16E-1 A/D board (requires a half length PCI slot in the PC)
- a BNC connector box
- cables for connection between the BNC connector box and the PC

The 58N31 FVA/PDA Analog Input kit does not include the A/D board.

The FVA/PDA Analog input kit comprises:

- a BNC connector box
- cables for connection between the BNC connector box and the PC

The kit can be used with the following types of National Instruments A/D boards:

- AT-MIO-16E-1 (requires a full length AT-slot in the PC)
- PCI-MIO-16E-1 (requires a half length PCI slot in the PC)

The required software is included on the CD-ROM with the BSA Flow Software.

The software controls the set-up of the a/d board and a fifth order linearisation polynomium for each channel.

To acquire analog data using FVA Flow Software or PDA Flow and Particle Software, the SYNC output on the FVA/PDA interface should be connected to the Clock input on the BNC connector box.

6.6.1 Installation

Installing the Analog Input option involves both software and hardware:

1. Install the NI-DAQ® driver software for the A/D-Board.
2. Install the A/D-board (PCI-MIO-16-E1) in your PC.
3. Test and configure the A/D-board as necessary.
4. Connect the A/D-board and the connector box.
5. Connect the synchronisation signal cable from the 58G130 FVA/PDA interface board to the CLOCK input of the connector box.
6. Connect your analog signal(s) to the input(s) on the connector box.

Please refer to the hardware manual supplied by the manufacturer regarding installation and configuration of the A/D-board (steps 2-4 above).

Caution

To avoid accidental damage to your equipment, please make sure that both PC and processors are properly grounded and switched off while connecting or disconnecting (steps 5-7 above).

6.6.2 Hardware connections

All hardware connections relating to analog inputs go through the A/D connector box depicted in Figure 6.6-2. The connector box performs no signal conditioning, but simply transfers in-going signals directly to the A/D-board via the 68-pin connector shown at the bottom of the figure.

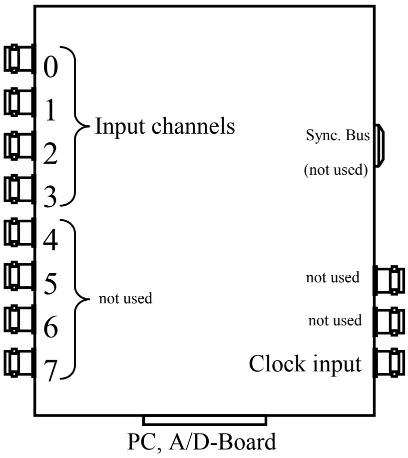


Figure 6.6-2: Hardware connections on the A/D-connector box.

Analog inputs

The analog input signals have to be connected via BNC cables to the connector box.

Synchronisation

A/D-data is automatically synchronised with the LDA/PDA-data because sampling of the analog data is triggered by the LDA/PDA bursts.

6.6.3 Software set-up

General software support of analog input is controlled by the dongle. If A/D-support is enabled, the "General" property list of the processor will include the parameter “A/D input”. This parameter can be set to “Yes/On” or “No/Off” as shown in Figure 6.6-3

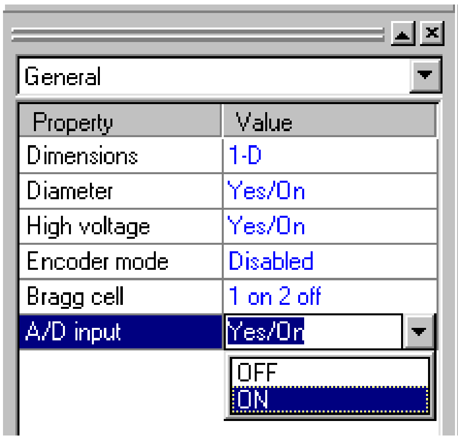


Figure 6.6-3: A/D input parameter

6.6.4 General properties of the A/D-device

If the A/D input parameter has been set to “Yes/On”, the settings of the A/D-board are accessible through the processor’s property list. The basic A/D configuration properties in the property editor are shown in Figure 6.6-4. The properties shown here are common for all analog channels, while properties that are specific for each individual channel can be accessed via the drop down list.

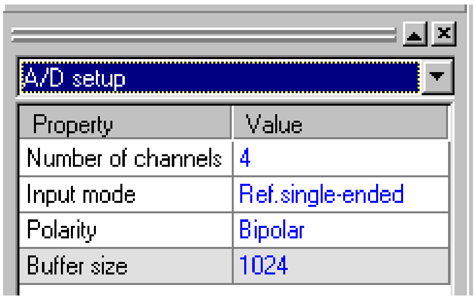


Figure 6.6-4: Basic A/D configuration properties

Number of channels

The maximum number of analog signal channels is four. The number of trigger pulses provided by the FVA/PDA interface board limits this. Although the connector box has 8 input connectors (0 – 7), only four connectors (0 – 3) are supported, because the FVA/PDA interface board generates four trigger pulses only.

The analog channels are automatically coincident and synchronised to the LDA/PDA data. Due to the timing sequence of the trigger pulses, there will be a delay of 1 microsecond between the analog channels.

Input mode

The property Signal Type can be set to one of the following:

- RSE (Referenced Single-ended).
  An analog input configured in RSE mode connects one analog input line to the positive input of the on-board amplifier, while the negative input of the amplifier is internally tied to analog input ground.
- NRSE (Non-referenced single-ended).
  An analog input configured in NRSE mode connects one analog input line to the positive input of the on-board amplifier, while the negative input of the amplifier connects to an external ground reference.
- DIFF (Differential).
  An analog input configured in DIFF mode uses two analog input lines. One line connects to the positive input of the on-board amplifier, while the other line connects to the negative input.

Please refer to hardware documentation supplied by the manufacturer for further information on the different signal types.

Recommended Signal Type	By default the Connector Box is wired for Referenced Single-Ended (RSE), and using any of the other signal types (DIFF or NRSE) thus require hardware modifications. Please refer to the hardware documentation from National Instruments if you wish to use any signal type other than RSE

Ground-loop errors

Using the RSE signal type is simple, but involves the risk of ground-loop errors, if the signal connected at the analog input comes from an external sensor with its own ground level. A difference in ground-potential between the external sensor and the connector box may cause a significant electrical current to run in the ground wire connecting the sensor with the connector box. Due to the resistance of the wire itself, this will cause a voltage difference between the two ends of the wire, and this will produce offset errors in the measured analog signal.

To avoid ground-loop errors please make sure that the sensor connected does not have its own ground level, but rather shares the same ground level as the rest of your equipment (i.e. has the same power supply).

Polarity

The A/D-board used supports both unipolar and bipolar signals:

Unipolar: 0-10 V
Bipolar: ±5 V

An on-board amplifier can be used to amplify weak signals prior to the A/D-conversion, while signals beyond the limits stated above will be clipped. (Please refer to the hardware manual supplied by the manufacturer for information on the maximum voltages that the hardware can sustain).

Buffer size

To allow for variable data rates the user must select an efficient double buffer size. The buffer size can range from 256 up to 8192 in steps of power-of-2. This is due to the operating characteristics of the driver software. The data update rate is directly related to how long it takes to fill half of the buffer, otherwise the software waits. Small buffer sizes are to be used for low data rates, where regular frequent updates are required. Larger buffer sizes are required for higher data rates to ensure for adequate buffering of the input stream. Failure to follow this guideline will result in possible data overflow or data loss. Maximum tolerable data rates for different buffer sizes are listed in Table 6.6-1.

Maximum sustainable input rate	**Buffer size**

5 kHz	256
8 kHz	512
15 kHz	1024
20 kHz	2048
30 kHz	4096
45 kHz	8192

Table 6.6-1: Maximum input rates for different buffer sizes.

6.6.5 Channel properties of the A/D-device

Some parameters can be set specifically for each analog input channel. The channel specific properties are listed in Figure 6.6-5.

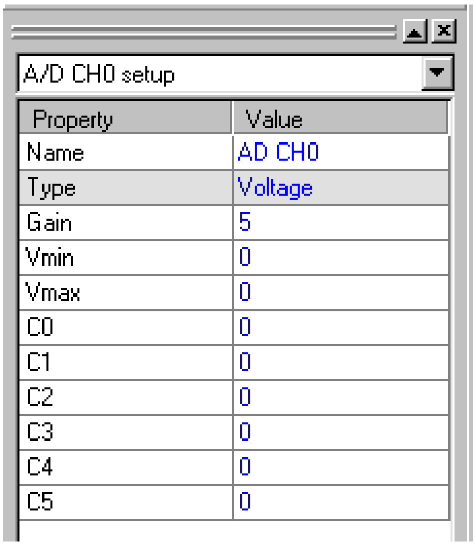


Figure 6.6-5: Properties of one analog input channel

Channel name

The property Channel name is an arbitrary name, by which A/D-data from the channel in question will be referenced elsewhere in the program.
By default the channel name corresponds to the A/D-channel number, but any text can be entered here. For example the name Temperature could be used for an analog input coming from a temperature sensor.

Type

The property Type determines the unit applied to A/D-data and whether or not to use polynomial conversion:

Name	Unit	Conversion
Voltage	[V]	No
Temperature	[°C]	Yes
Pressure	[kPa]	Yes
Position	[mm]	Yes
Angle	[deg]	Yes
Velocity	[m/s]	Yes

A polynomial conversion routine is supplied to enable linearisation of the output from non-linear sensors. By default the property Type is set to Voltage, meaning that no conversion is performed and that the resulting A/D-values are voltages measured at the input of the A/D-converter. (Amplification is included, since this happens prior to the A/D-conversion).

Units

If you wish to use other units than the ones shown above, this can be accomplished using conversion routines built into the FVA Flow Software (Select Tools>Options>Data Formats, select the Data Type you wish to change, and press the Change button. In the following dialog select a new unit from the drop down list with available units).

Gain factor

Depending on the Signal Polarity selected in the Board configuration

properties, the input signal(s) are supposed to be within the interval
0-10 Volts (Unipolar) or ±5 Volts (Bipolar).
While signals exceeding these limits will be clipped, weaker signals can be amplified prior to the A/D-conversion, and the property Gain Factor controls this amplification.
For each of the analog input channels the Gain Factor can thus be set to

1, 2, 5 or 10

Vmin, Vmax

The properties Vmin and Vmax determine the voltage range in which the polynomial conversion algorithm is valid. (Again, the voltage limits apply after signal amplification, since the gain factor is applied prior to A/D-conversion, and the polynomial conversion is applied after).

Input voltages above Vmax will be clipped to produce the same output as Max input voltage, and likewise Input voltages below Min will be clipped to produce the same output as the Min input voltage.

C0, C1, …, C5

The properties C0 – C5 define the conversion polynomial.
Assuming that the input signal comes from a non-linear temperature sensor the voltage V can be converted to temperature T according to:

$$T = C_0 + C_1V + C_2V^2 + C_3V^3 + C_4V^4 + C_5V^5$$

– where the polynomial coefficients must be supplied by the user.

By default C_1 is 1.0 and the other coefficients are zero, corresponding to no conversion at all.

6.6.6 Display and further processing of analog data

The A/D-channels are treated like any other data sources in the FVA/PDA software. Analog data can be listed (see **Error! Reference source not found.**), displayed graphically, filtered, averaged and exported. An analog data channel can also be used as a filter criterion. It is possible, for example, to process and evaluate only data that are associated with a certain temperature or pressure range.

FVA Application/List - List

	FVA AT [ms]	FVA TT [ms]	FVA U1 [m/s]	FVA V [m/s]	AD CH0 [V]
1	4,141	0,017	6,32	1,30	0,215
2	4,157	0,006	8,64	1,64	0,215
3	4,965	0,008	7,92	1,82	0,220
4	5,581	0,006	8,84	2,14	0,222
5	7,147	0,032	7,04	1,99	0,232
6	10,686	0,017	7,22	1,99	0,254
7	14,569	0,042	3,14	0,96	0,276
8	14,705	0,010	5,27	2,14	0,278
9	21,207	0,021	8,84	1,13	0,317
10	23,260	0,021	9,20	2,14	0,330
11	25,055	0,038	10,10	2,14	0,337
12	26,848	0,015	8,84	0,96	0,347

Figure 6.6-6 List output including data from the A/D-device

Acquired A/D-data is treated no different than any other type of data, and consequently any processing available for FVA/PDA-data can be performed on A/D-data as well.

This is illustrated in Figure 6.6-7 and Figure 6.6-8, where a spectrum is calculated on the basis of a sampled sinusoidal input.

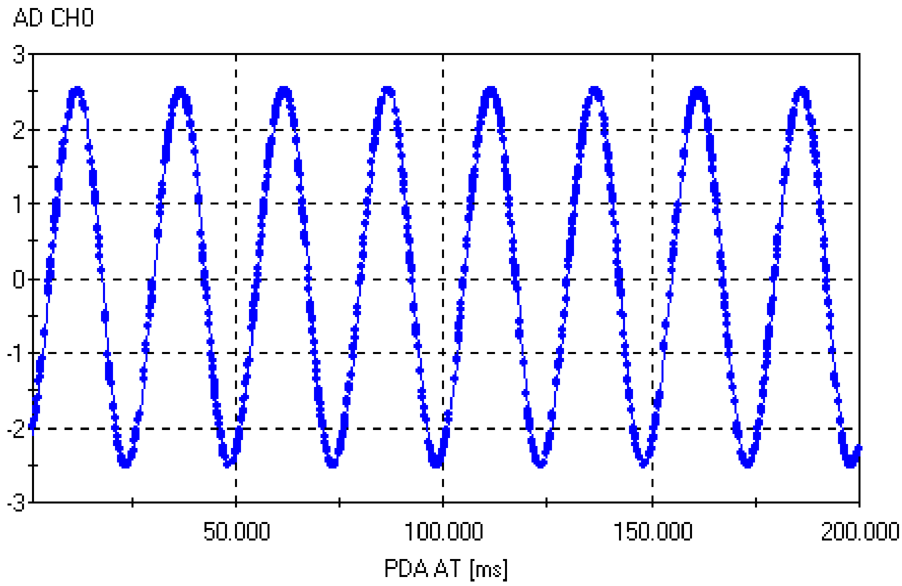


Figure 6.6-7. Sinusoidal analog input signal

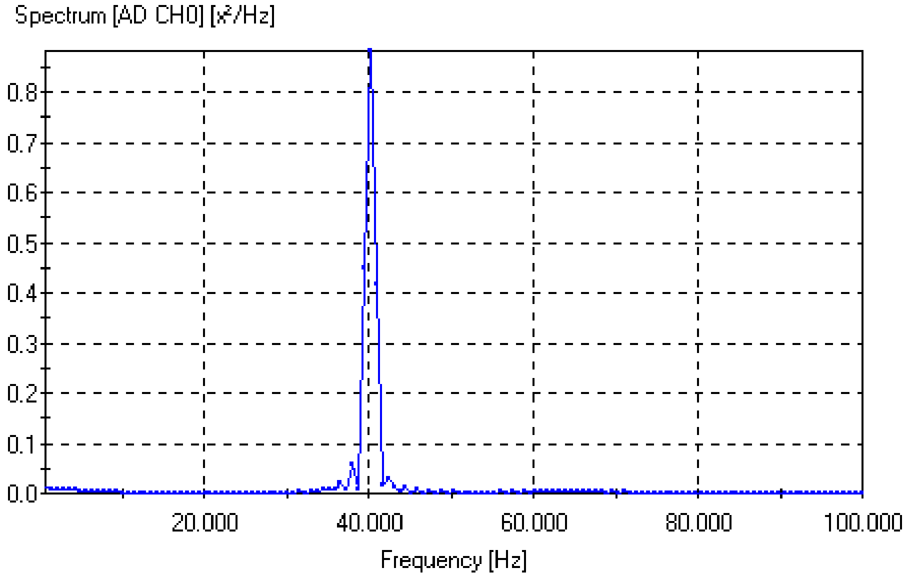
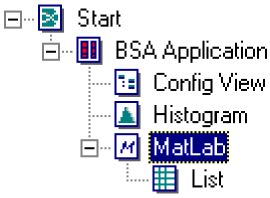


Figure 6.6-8. Spectrum calculated from A/D-data using the Spectrum and Correlation Add-On.

(Both Figure 6.6-7 and 8 have been generated using the Advanced Graphics Add-On).

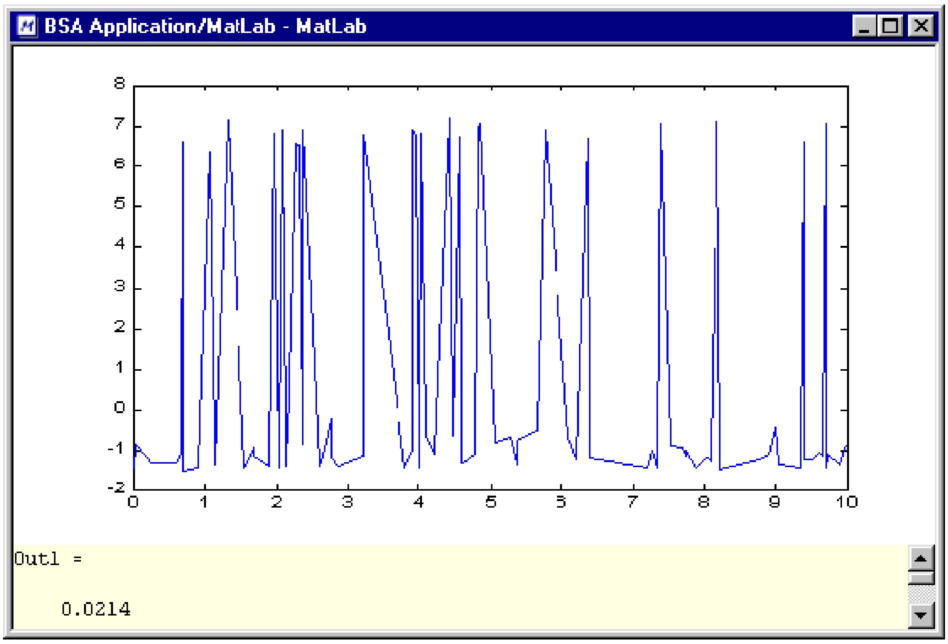
6.7 MatLab Link add-on

Please read the MatLabReadme.txt file for installation instructions.



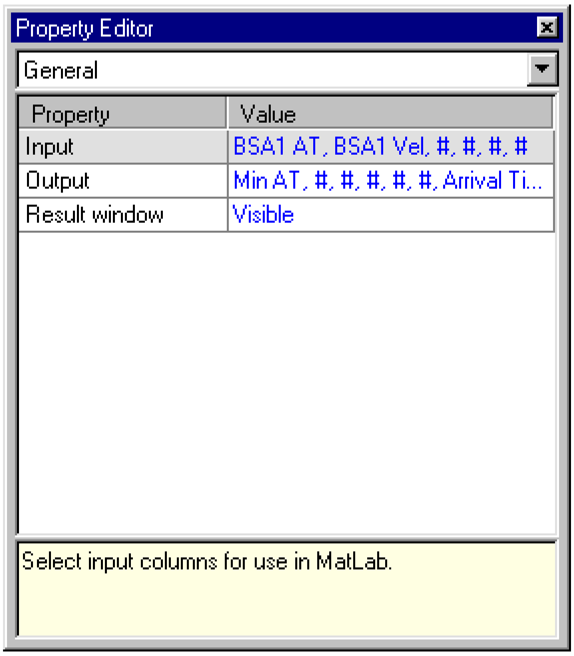
The MatLab Integration Object can be placed after all objects returning data as output. The MatLab Integration Object can be used to make calculations and returning data back to the Dantec Flow Software, and it can be used to display figures generated from within MatLab. All the manipulations are made using MatLab scripts.

When defining a plot using MatLab script the plot displayed in Figure 1 (default) will be returned and display in the MatLab integration Object within the Dantec Flow Software. The figure will be displayed as vector graphics and scaled to fit the size of the window. Axis, titles etc. must be provided using the MatLab script.



Output from MatLab engine can optionally be displayed in the bottom of the window.

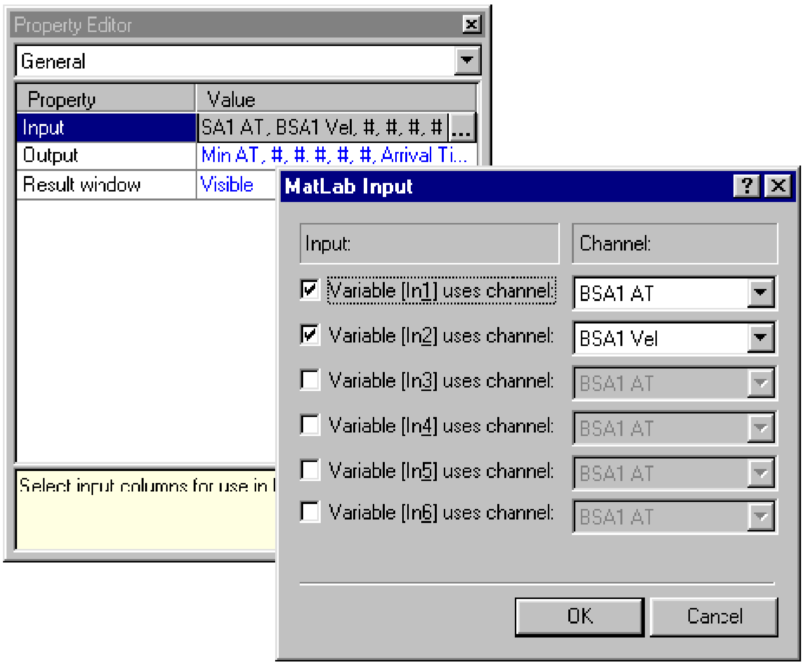
6.7.1 Properties



Three properties are defined for the MatLab Integration Object:

6.7.1.1 Input

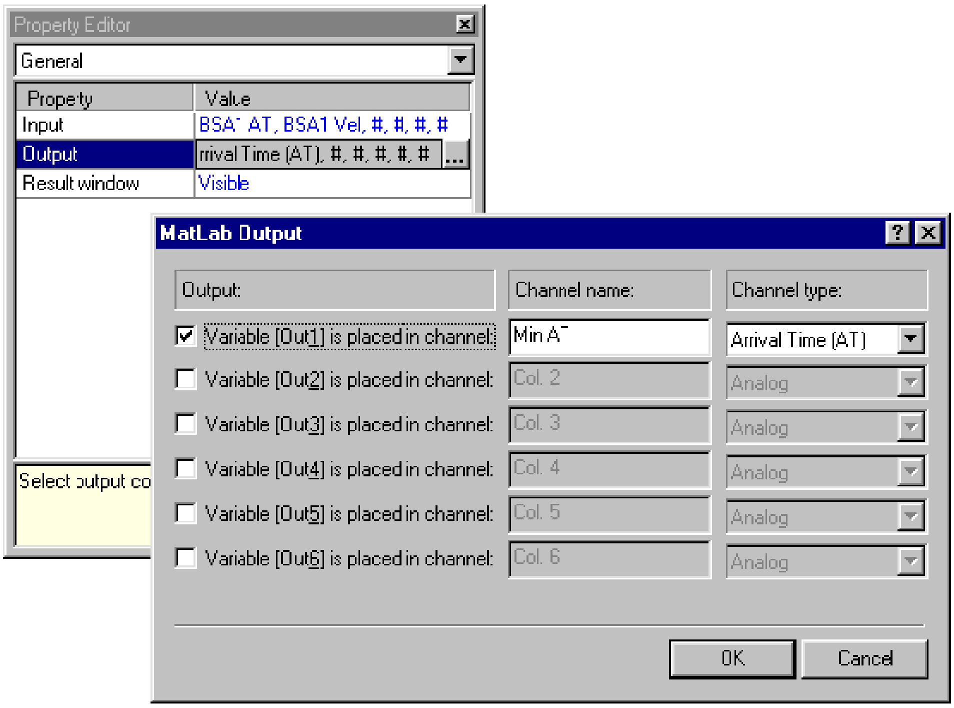
Defines the input columns to use with MatLab. Each input column will be named In1, In2 etc. and the MatLab script must refer to these names for column data. Up to 6 input columns can be used with the MatLab Integration Object.

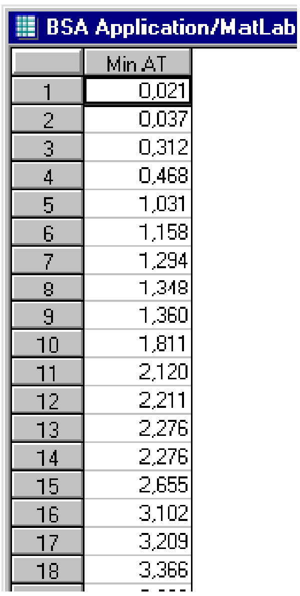


Select the variable and input columns to use.

6.7.1.2 Output

Specifies the optional output from MatLab. Each output column must be called Out1, Out2 etc. for the Dantec Flow Software to understand the data columns as output. These can be send to optional underlying objects.





6.7.2 Result window

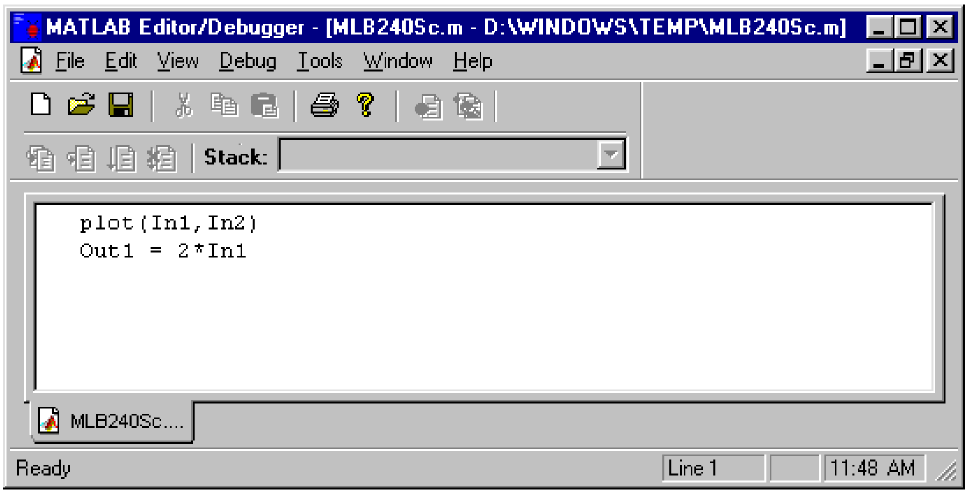
Hides and displays the window showing informations and error messages send from the MatLab engine.

6.7.3 Script

For running the script right-click in the MatLab window (remember to activate the MatLab object in the Project Tree)

The figure can be copied, send to a printer and exported as a graphics file.

Write the MatLab script commands in the MATLAB Editor. Before the script can be run it must be saved from within the editor.



Ex. In1 and In2 are defined as input variables and Out1 is defined as output.

6.8 Binary export add-on

The BSA Flow Software offers binary export of data. The binary format is more compact than the ASCII export formats. The export can be initiated either from the Export Object or from the List export command.

6.8.1 Structure of Binary File

The overall structure of the binary file is displayed in Figure 1. The first part of the binary file contains a file header of 518 bytes, please see Table 1. This describes the contents and origin of the binary file. Following the file header a number of data blocks each representing a data column is placed. Each of these blocks begins with a data header of 154 bytes. This header describes the format and size of the data.

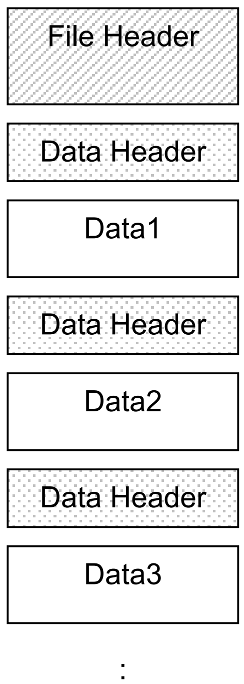


Figure 1 Overall binary file structure.

Offset	Bytes	Field description
000H	6	Binary export signature "DXEX\0\0", ASCII string.
006H	2	Version number.
008H	4	Size of this file header.
00CH	16	Traverse x-position, ASCII string.
01CH	16	Traverse y-position, ASCII string.
02CH	16	Traverse z-position, ASCII string.
03CH	12	Reserved.
048H	128	Project name, ASCII string.
0C8H	16	User name, ASCII string.
0D8H	64	Time stamp, ASCII string.
118H	64	Reserved.
158H	2	Number of data arrays.
15AH	128	Reserved.
1DAH	32	Reserved.
1FAH	12	Reserved.

Table 1 Format of Binary Export file header.

Offset	Bytes	Field description
000H	2	Version.
002H	4	Size of this data header.
006H	64	Name of data array.
046H	4	Reserved.
04AH	4	Data type: 0 = double precision 1 = float precision 2 = integer
04EH	4	Data size. 8 = double precision 4 = float precision 4 = integer
052H	4	Data count.
056H	4	Reserved.
05AH	16	Reserved.
070H	16	Reserved.

086H	32	Reserved.

Table 2 Format of Binary Export data header.

6.8.2 Data

Data is placed immediately after the data header. The size of the data block is given by: Data size * Data count. Data is saved in double presition, floating point or integer format given by the Data type value, see Table 3.

Data type	Data size	Data formats
0	8 bytes	Double precision floating point
1	4 bytes	Floating point
2	4 bytes	Integer

Table 3 Data formats.

6.8.3 C Headers

The header structures for C/C++ can be found in the “DXExportHeader.h" file included in the samples directory on the CD-rom.

6.8.4 Programming Examples

A sample program for the binary export is placed on the CD-rom. In the samples directory a tool is also included for converting a binary export file to an ASCII file.

```
//Ex1: Open and read file header information
int main(int argc, char* argv[])
{
	char id[6] = {0};	// binary export file id
	short version = 0;	// file header version
	long size = 0;	// file header size

	printf("Open and read file header information\n");

	char filename[256] = {0};
	strcpy(filename,argv[1]);

	int fh = _open(filename,_O_RDONLY|_O_BINARY);
	if (fh==-1) exit(1);

	// reading file header id
	_lseek(fh,0x000,SEEK_SET);
```

```
    _read(fh,id,sizeof(id));

    // reading file header version
    _lseek(fh,0x006,SEEK_SET);
    _read(fh,&version,sizeof(version));

    // reading file header size
    _lseek(fh,0x008,SEEK_SET);
    _read(fh,&size,sizeof(size));

    _close(fh);

    printf("id = %s, version %d, header size %d\n",id,version,size);

    return 0;
}



//Ex2: Read first data array header
int main(int argc, char* argv[])
{
    long size = 0;  // file header size
    char name[64] = {0};// data array name
    long datasize = 0;   // data size = sizeof(double)
    long datacount = 0;  // number of data samples

    printf("Open and read first data header information\n");

    char filename[256] = {0};
    strcpy(filename,argv[1]);

    int fh = _open(filename,_O_RDONLY|_O_BINARY);
    if (fh==-1) exit(1);

    // reading file header size
    _lseek(fh,0x008,SEEK_SET);
    _read(fh,&size,sizeof(size));

    // reading data array name
    _lseek(fh,size + 0x006,SEEK_SET);
    _read(fh,name,sizeof(name));

    // reading data size
    _lseek(fh,size + 0x04E,SEEK_SET);
    _read(fh,&datasize,sizeof(datasize));
```

```
	// reading number of data samples
	_lseek(fh,size + 0x052,SEEK_SET);
	_read(fh,&datacount,sizeof(datacount));

	_close(fh);

	printf("%s data block size = %d\n",name,datasize*datacount);

	return 0;
}
```

```
//Ex3: Read last data array block
int main(int argc, char* argv[])
{
	long fsize = 0; // file header size
	long dsize = 0; // file header size
	short arrays = 0;    // number of data arrays
	char name[64] = {0};// data array name
	long datasize = 0;   // data size = sizeof(double)
	long datacount = 0;  // number of data samples
	long pos = 0;        // pointer to last data header

	printf("Open and read last data array block\n");

	char filename[256] = {0};
	strcpy(filename,argv[1]);

	int fh = _open(filename,_O_RDONLY|_O_BINARY);
	if (fh==-1) exit(1);

	// reading file header size
	_lseek(fh,0x008,SEEK_SET);
	_read(fh,&fsize,sizeof(fsize));

	// reading number of data arrays
	_lseek(fh,0x158,SEEK_SET);
	_read(fh,&arrays,sizeof(arrays));

	// reading data header size
	_lseek(fh,fsize + 0x002,SEEK_SET);
	_read(fh,&dsize,sizeof(dsize));

	// calculating distance to last data header
	pos = fsize;
```

```
for (int i=0;i<arrays-1;i++)
{
      // reading data size
      _lseek(fh,pos + 0x04E,SEEK_SET);
      _read(fh,&datasize,sizeof(datasize));

      // reading number of data samples
      _lseek(fh,pos + 0x052,SEEK_SET);
      _read(fh,&datacount,sizeof(datacount));

      pos += dsize + datasize*datacount;
}

// reading data array name
_lseek(fh,pos + 0x006,SEEK_SET);
_read(fh,name,sizeof(name));

// reading data size
_lseek(fh,pos + 0x04E,SEEK_SET);
_read(fh,&datasize,sizeof(datasize));

// reading number of data samples
_lseek(fh,pos + 0x052,SEEK_SET);
_read(fh,&datacount,sizeof(datacount));

printf("%s data block size = %d\n",name,datasize*datacount);

// reading data type
_lseek(fh,pos + 0x04A,SEEK_SET);
_read(fh,&datatype,sizeof(datatype));

if (datatype==0)
{
      double* data = new double[datasize*datacount];
      // reading data samples
      _lseek(fh,pos + dsize,SEEK_SET);
      _read(fh,data,datasize*datacount);
      printf("first element in last data block %f\n",data[0]);
      delete [] data;
}
else if (datatype==1)
{
      float* data = new float[datasize*datacount];
      // reading data samples
      _lseek(fh,pos + dsize,SEEK_SET);
      _read(fh,data,datasize*datacount);
      printf("first element in last data block %f\n",data[0]);
```

```
            delete [] data;
      }
      else if (datatype==2)
      {
            int* data = new int[datasize*datacount];
            // reading data samples
            _lseek(fh,pos + dsize,SEEK_SET);
            _read(fh,data,datasize*datacount);
            printf("first element in last data block %f\n",data[0]);
            delete [] data;
      }

      _close(fh);

      return 0;
}
```

7. Reference guide

7.1 Theory of Laser Anemometry

7.1.1 Summary

The development of continuous wave gas lasers has made it possible to use the Doppler effect in an optical non-intrusive method for measuring the velocity of gases, liquids and solids.

The method is called Laser Doppler Anemometry or LDA, and this document provide some background information on the technique.

7.1.2 Background

Laser anemometers are non-contact optical instruments for the investigation of fluid flow structures in gases and liquids. The instruments owe their existence to the invention of the gas laser in the early sixties. Some earlier attempts to measure fluid velocities by optical methods had been made, but it was not until the advent of laser light with its unique properties of spatial and temporal coherence that it became possible to design an efficient optical anemometer. From the very beginning Dantec has participated actively in this exciting development, and today Dantec offers the most comprehensive line of commercial laser anemometer equipment available.

7.1.3 Characteristics of laser anemometry

Laser anemometers offer unique advantages in comparison with other fluid flow instrumentation:

- Non-contact optical measurement.
  Laser anemometers probe the flow with focused laser beams and can sense the velocity without disturbing the flow in the measuring volume. The only necessary conditions are a transparent medium with a suitable concentration of tracer particles (or seeding) and optical access to the flow through windows, or via a submerged optical probe. In the latter case the submerged probe will of course to some extent disturb the flow, but since the measurement take place some distance away from the probe itself, this disturbance can normally be ignored.
- No calibration - no drift.
  The laser anemometer has a unique intrinsic response to fluid velocity - absolute linearity. The measurement is based on the stability and linearity of optical electromagnetic waves, which for most practical purposes can be considered unaffected by other physical parameters such as temperature and pressure.
- Well-defined directional response.
  The quantity measured by the laser Doppler method is the projection of the velocity vector on the measuring direction defined by the optical system (a true cosine response).The angular response is thus unambiguously defined.
- High spatial and temporal resolution.
  The optics of the laser anemometer is able to define a very small measuring volume and thus provides good spatial resolution and allows local measurement of Eulerian velocity. The small measuring volume in combination with fast signal processing electronics also permits high bandwidth, time-resolved

measurements of fluctuating velocities, providing excellent temporal resolution. Usually the temporal resolution is limited by the concentration of seeding rather than the measuring equipment itself.

- Multi-component bi-directional measurements.
  Combinations of laser anemometer systems with component separation based on color, polarization or frequency shift allow one-, two- or three-component LDA systems to be put together based on common optical modules. Acousto-optical frequency shift allows measurement of reversing flow velocities.

Together these properties of laser anemometers certainly constitute a very attractive description of a measuring instrument. As is often the case however, optimization of the performance of a system with respect to certain parameters may influence other performance characteristics negatively. As a matter of fact, some of the compromise decisions which have to be made when selecting and setting up a laser anemometer system can be traced back to the famous uncertainty principle of wave theory, which describes the impossibility of attaining complete information of both spatial and temporal location of a wave train simultaneously.

In the following we describe the principles of Laser Doppler measurements and mention some of the consequences of the results of the theory on practical measurements.

7.1.4 Principles of LDA

7.1.4.1 Laser beam

The special properties of the gas laser, making it so well suited for the measurement of many mechanical properties, are the spatial and temporal coherence. At all cross sections along the laser beam, the intensity has a Gaussian distribution, and the width of the beam is usually defined by the edge-intensity being $1/e^2$=13% of the core-intensity. At one point the cross section attains its smallest value, and the laser beam is uniquely described by the size and position of this so-called beam waist.

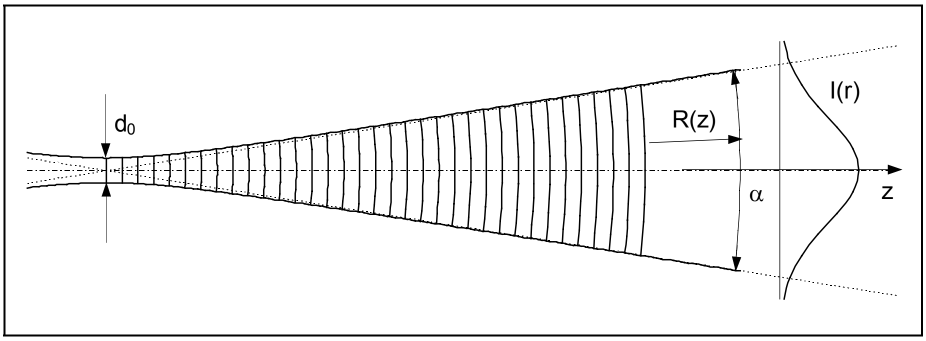


Figure 7-1 Laser beam with Gaussian intensity distribution.

With a known wavelength λ of the laser light, the laser beam is uniquely described by the size d_0 and position of the beam waist as shown in 7-23.

With z describing the distance from the beam waist, the following formulas apply:

Beam divergence $\alpha = \dfrac{4\lambda}{\pi d_0}$

Beam diameter $d(z) = d_0 \sqrt{1 + \left(\dfrac{4\lambda z}{\pi d_0^2}\right)^2} \quad \rightarrow \alpha z \textit{ for } z \rightarrow \infty$ (7-1)

Wave front radius $R(z) = z\left[1 + \left(\dfrac{\pi d_0^2}{4\lambda z}\right)^2\right] \quad \begin{cases} \rightarrow \infty \textit{ for } z \rightarrow 0 \\ \rightarrow z \textit{ for } z \rightarrow \infty \end{cases}$

The beam divergence α is much smaller than indicated in 7-23, and visually the laser beam appear to be straight and of constant thickness. It is important however to understand, that this is not the case, since measurements should take place in the beam waist to get optimal performance of any LDA-equipment. This is due to the wave fronts being straight in the beam waist, and curved elsewhere, and will be explained in more detail later. For now you should just note that the wave front radius approach infinity for z approaching zero, meaning that the wave fronts are approximately straight in the immediate vicinity of the beam waist. This means that the theory of plane waves can be used here, greatly simplifying calculations.

7.1.4.2 Doppler effect

As indicated by the name Laser Doppler Anemometry, the Doppler effect plays an important role in LDA, since the technique is based on Doppler shift of the light reflected (and/or refracted) from a moving seeding particle.

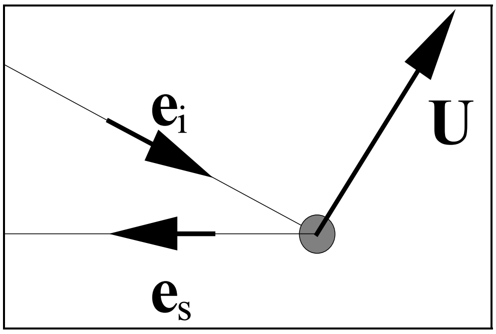


Figure 7-2 Light scattering from a moving seeding particle.

The principle is illustrated in Figure 7-2 above, where the vector **U** represent the particle velocity, and the unit vectors $\mathbf{e}_i$ and $\mathbf{e}_s$ describe the direction of incoming and scattered light respectively. According to the Lorenz-Mie scattering theory, the light is scattered in all directions at once, but we consider only the light reflected in the direction of the receiver.

The incoming light has the velocity c and the frequency f_i, but due to the particle movement, the seeding particle "sees" a different frequency f_p, which is scattered towards the receiver. From the receivers point of view, the seeding particle act as a moving transmitter, and the movement introduce additional Doppler-shift in the frequency of the light reaching the receiver.

Using Doppler-theory, the frequency of the light reaching the receiver can be calculated as:

$$f_s = f_i \frac{1-\mathbf{e}_i \cdot (\mathbf{U}/c)}{1-\mathbf{e}_s \cdot (\mathbf{U}/c)} \tag{7-2}$$

Even for supersonic flows the seeding particle velocity $|\mathbf{U}|$ is much lower than the speed of light, meaning that $|\mathbf{U}/c| \ll 1$.
Taking advantage of this, the above expression can be linearized to:

$$f_s \cong f_i\left[1+\frac{\mathbf{U}}{c}\cdot(\mathbf{e}_s-\mathbf{e}_i)\right] = f_i + \frac{f_i}{c}\mathbf{U}\cdot(\mathbf{e}_s-\mathbf{e}_i) = f_i + \Delta f \tag{7-3}$$

With the particle velocity **U** being the only unknown parameter, in principle the particle velocity can be determined from measurements of the Doppler shift Δf.

Intersecting beams

In practice this frequency change can only be measured directly for very high particle velocities (Fabry - Perot interferometer). More commonly the light scattered from two intersecting laser beams is mixed as illustrated in Figure 7-3.

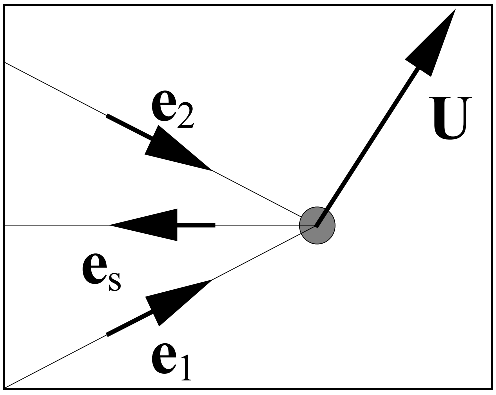


Figure 7-3 Scattering of two incoming laser beams.

In this way both incoming laser beams are scattered towards the receiver, but with slightly different frequencies due to the different angles of the two laser beams.

$$\begin{aligned} f_{s,1} &= f_1\left[1+\frac{\mathbf{U}}{c}\cdot(\mathbf{e}_s-\mathbf{e}_1)\right] \\ f_{s,2} &= f_2\left[1+\frac{\mathbf{U}}{c}\cdot(\mathbf{e}_s-\mathbf{e}_2)\right] \end{aligned} \tag{7-4}$$

Doppler frequency

When two wave trains of slightly different frequency are super-imposed, we get the well-known phenomenon of a beat frequency due to the two waves intermittently interfering with each other constructively and destructively. The beat frequency correspond to the difference between the two wave-frequencies, and since the two incoming waves originate from the same laser, they also have the same frequency, $f_1=f_2=f_I$, where subscript I refer to incident light:

$$
\begin{aligned}
f_D &= f_{s,2} - f_{s,1} \\
&= f_2\left[1+\frac{\mathbf{U}}{c}\cdot(\mathbf{e}_s-\mathbf{e}_2)\right] - f_1\left[1+\frac{\mathbf{U}}{c}\cdot(\mathbf{e}_s-\mathbf{e}_1)\right] \\
&= f_I\left[\frac{\mathbf{U}}{c}\cdot(\mathbf{e}_1-\mathbf{e}_2)\right] \\
&= \frac{f_I}{c}\left[|\mathbf{e}_1-\mathbf{e}_2|\cdot|\mathbf{U}|\cdot\cos(\varphi)\right] \\
&= \frac{1}{\lambda}\cdot 2\sin(\theta/2)\cdot u_x = \frac{2\sin(\theta/2)}{\lambda}u_x
\end{aligned}
\tag{7-5}
$$

-Where θ is the angle between the incoming laser beams and φ is the angle between the velocity vector **U** and the direction of measurement.

Note that the unit vector $\mathbf{e}_s$ has dropped out of the calculation, meaning that the position of the receiver has no direct influence on the frequency measured. (According to the Lorenz-Mie light scattering theory, the position of the receiver will however have considerable influence on signal strength).

The beat-frequency, also called the Doppler-frequency f_D, is much lower than the frequency of the light itself, and it can be measured as fluctuations in the intensity of the light reflected from the seeding particle. As shown in Equation (7-5) the Doppler-frequency is directly proportional to the x-component of the particle velocity, and the velocity can thus be calculated directly from f_D:

$$
u_x = \frac{\lambda}{2\sin(\theta/2)}f_D \tag{7-6}
$$

7.1.4.3 The fringe model

Although the above description of LDA is accurate, it may be intuitively difficult to quantify. To handle this, the fringe model is commonly used in LDA as a reasonably simple visualisation producing the correct results.

Interference fringes

When two coherent laser beams intersect, they will interfere in the volume of intersection. If the beams intersect in their respective beam waists, the wave fronts are approximately plane, and consequently the interference produce parallel planes of light and darkness as shown in Figure 7-4.

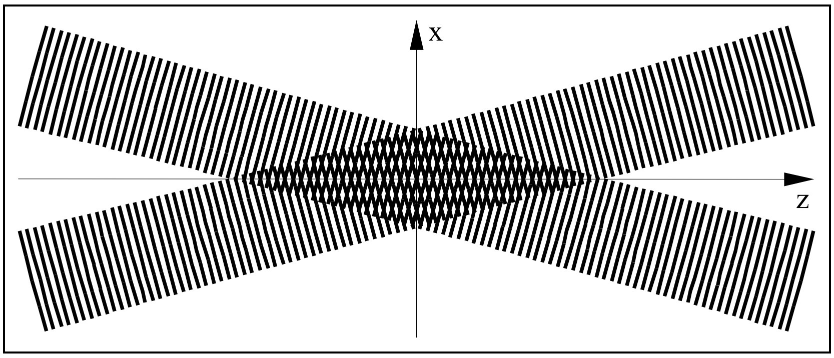


Figure 7-4 Fringes form where two coherent laser beams cross.

The interference planes are known as fringes, and the distance δ_f between them depend on the wavelength and the angle between the incident beams:

$$\delta_f = \frac{\lambda}{2\sin(\theta/2)} \tag{7-7}$$

The fringes are oriented normal to the x-axis, so the intensity of light reflected from a particle moving through the measuring volume will vary with a frequency proportional to the x-component u_x of the particle velocity:

$$f_D = \frac{u_x}{\delta_f} = \frac{2\sin(\theta/2)}{\lambda} u_x \tag{7-8}$$

–which is identical to the result in (7-5).

Beam alignment

If the two laser beams do not intersect in the beam waists but elsewhere in the beams, the wave fronts will be curved rather than plane, and as a result the fringe spacing will not be constant but depend on the position within the intersection volume. As a consequence the measured Doppler frequency will also depend on the particle position, and as such it will no longer be directly proportional to particle velocity. If the beams are badly misaligned, you will probably not be able to get results at all, but if the beams are just slightly misaligned, the errors will be small, and you may not be aware of them.

7.1.4.4 Measuring volume

Measurements take place in the intersection between the two incident laser beams, and the measuring volume is defined as the volume within which the modulation depth is higher than e^{-2} times the peak core value. Due to the Gaussian intensity distribution in the beams the measuring volume is an ellipsoid as indicated in Figure 7-5.

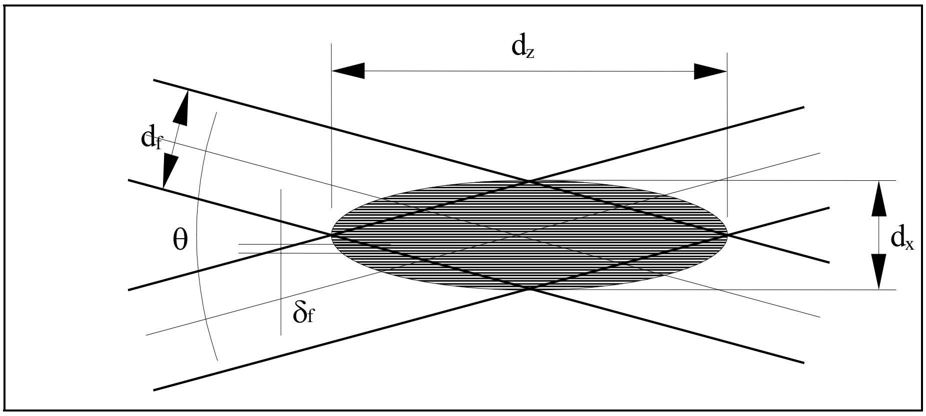


Figure 7-5 Measuring volume.

The size of the measuring volume can be calculated from the beam waist diameter d_f of the focused laser beams and the angle θ between them:

$$d_x = \frac{d_f}{\cos(\theta/2)}, \qquad d_y = d_f, \qquad d_z = \frac{d_f}{\sin(\theta/2)} \tag{7-9}$$

-where d_x is the height, d_y the width and d_z the length of the measuring volume.

Since beam intersection angles are usually small, d_x and d_y are often almost equal, and are sometimes referred to as the diameter of the measuring volume.

You should be aware that the measuring volume dimensions in (7-9) are guidelines only. A very small seeding particle in the outskirts of the measuring volume may not reflect sufficient light to be detected. On the other hand a very large seeding particle may reflect so much light, that it is detected even if technically it is slightly outside the measuring volume as defined above.
Other parameters such as system gain and threshold level influence the measurements similarly.

From the height d_x of the measuring volume and the fringe spacing δ_f, the total number of fringes can be calculated:

$$N_f = \frac{d_x}{\delta_f} = \frac{d_f}{\cos(\theta/2)} \Bigg/ \frac{\lambda}{2\sin(\theta/2)} = \frac{2\,d_f}{\lambda}\tan(\theta/2) \qquad (7\text{-}10)$$

This number of fringes apply for a seeding particle moving straight through the center of the measuring volume along the x-axis. If the particle passes through the outskirts of the measuring volume, it will pass fewer fringes, and consequently there will be fewer periods in the recorded signal from which to estimate the Doppler frequency.
To get good results from your LDA-equipment, you should ensure a sufficiently high number of fringes in the measuring volume. Typical LDA set-ups produce between 10 and 100 fringes, but in some cases you may get reasonable results with less. The key issue here is the number of periods produced in the oscillating intensity of reflected light. Older LDA-processors often require a minimum of 8 periods to validate the burst, while modern processors such as the Dantec BSA can estimate particle velocity from as little as one period. The accuracy will however improve with more periods.

Frequency shift as described in section 7.1.6 will cause the fringe pattern to “roll” through the measuring volume, increasing or decreasing the number of fringes passed by a seeding particle. If the fringes move towards the movement of the seeding particle, the effective number of fringe-passings will increase, and if the fringes move away from the particle, it will decrease, corresponding to an increase or decrease in the number of periods in the recorded signal.

7.1.5 Backscatter versus forward scatter LDA

With the particle sizes used, the majority of light is scattered in a direction away from the transmitting laser, and in the early days of LDA, forward scattering was thus commonly used, meaning that the receiving optics was positioned opposite of the transmitting aperture.
A much smaller amount of light is scattered back towards the transmitter, but advances in technology has made it possible to make reliable measurements even on these faint signals, and today backward scatter is the usual choice in LDA. This so-called backscatter LDA allow for the integration of transmitting and receiving optics in a common housing, saving the user a lot of tedious and time-consuming work aligning separate units.

Forward scattering LDA is not completely obsolete however, since in some cases its improved signal-to-noise ratio make it the only way to obtain measurements at all. Experiments requiring forward scatter might include:

- High speed flows, requiring very small seeding particles, which stay in the measuring volume for a very short time, and thus receive and scatter a very limited number of photons.

- Transient phenomena, such as acoustic shock-waves, which require high data-rates in order to collect a reasonable amount of data over a very short period of time.

- Very low turbulence intensities, where the turbulent fluctuations might drown in noise, if measured with backscatter LDA.

Off-axis scattering

Forward and back-scattering is identified by the position of the receiving aperture relative to the transmitting optics. Another option is off-axis scattering, where the receiver is looking at the measuring volume at an angle. Like forward scattering this approach require a separate receiver, and thus involve careful alignment of the different units, but it helps to mitigate an intrinsic problem present in both forward an backscatter LDA:

As indicated in Figure 7-5 the measuring volume is an ellipsoid, and usually the major axis d_z is much bigger than the two minor axes d_x and d_y, rendering the measuring volume more or less “cigar-shaped”. This makes forward and backscattering LDA sensitive to velocity gradients within the measuring volume, and in many cases also disturb measurements near surfaces due to reflection of the laser beams.

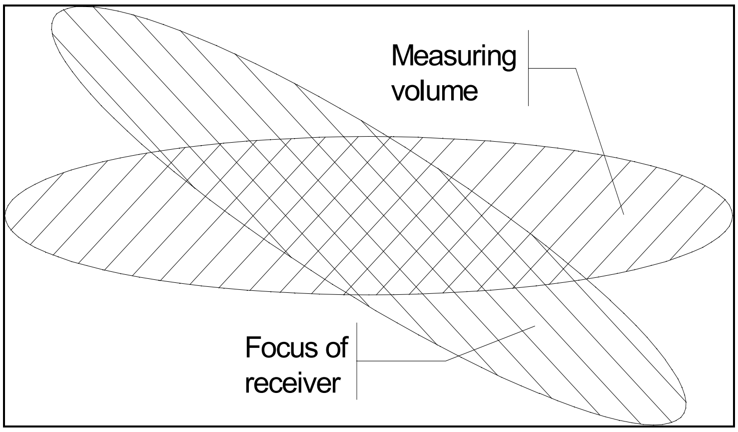


Figure 7-6 Off-axis scattering.

Figure 7-6 illustrate how off-axis scattering reduce the effective size of the measuring volume. Seeding particles passing either end of the measuring volume will be ignored since they are out of focus, and as such contribute to background noise rather than to the actual signal. This reduces the sensitivity to velocity gradients within the measuring volume, and the off-axis position of the receiver automatically reduce problems with reflection. These properties make off-axis scattering LDA very efficient for example in boundary layer measurements.

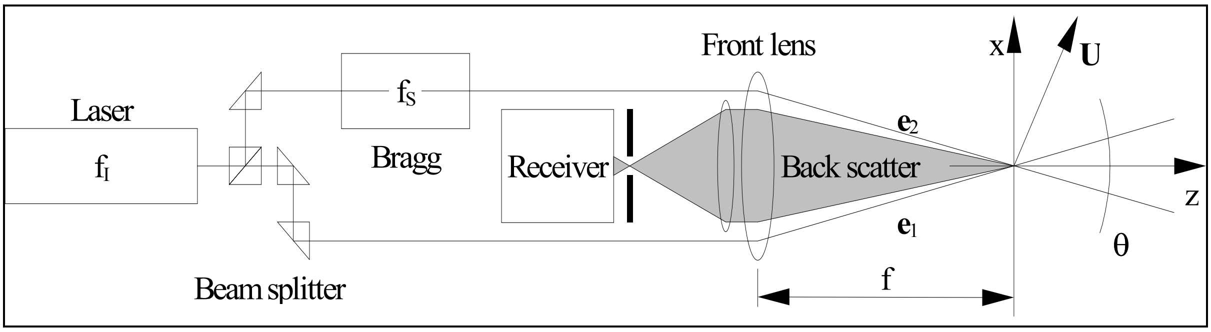


Figure 7-7 Principles of backscatter LDA.

Figure 7-7 shows a schematic of how a backscatter LDA equipment is built. The beam from the laser is split into two identical beams. It is important, that the beamsplitter is adjusted to give approximately the same intensity in the two laser beams produced.

In one of the beams, an acousto-optical component known as a Bragg cell is inserted. This introduces a fixed frequency shift in the particular beam, which as it will be explained later allow us to determine the sign of the measured velocity. The front lens deflects the two beams so they intersect, and in the intersecting volume, seeding particles will scatter the incoming laser light. Part of this light is scattered backwards toward the front lens (back scatter), and registered in the receiver (normally a photomultiplier). Seeding particles passing the laser beams outside of the measuring volume will of course also reflect light, but the receiving optics is focused on the measuring volume, so this will be out of focus, and thus only increase the background noise slightly.

Fibre optics

In modern LDA equipment the light from the beamsplitter and the Bragg cell is sent through optical fibres as is the light scattered back from seeding particles. This reduces size and weight of the probe itself, making the equipment flexible and easier to use in practical measurements. Laser, beamsplitter, Bragg cell and photodetector (receiver) can be installed stationary and out of the way, while the LDA-probe can traverse between different measuring positions.

Beam waist

The beam waist diameter d_f used in formulas (7-9) and (7-10) is calculated from:

$$d_f = \frac{4 f \lambda}{\pi E d_I} \qquad (7\text{-}11)$$

-where f is the focal length of the front lens as shown in Figure 7-7, λ is the laser wavelength, d_I is the beam waist diameter of the laser beam before passing the front lens, and E is the beam expansion factor as explained below.
Please note that d_f and d_I are inversely proportional, meaning that a large d_I is desirable, if you want a small d_f.
It is normally desired to make the measuring volume as small as possible, which according to the formulas in (7-9) mean that d_f should be small. The laser wavelength λ is a fixed parameter, and focal length f is normally limited by the geometry of the model being investigated. Some lasers allow for adjustment of the beam waist position, but the beam waist diameter d_I is normally fixed.

E=1 in (7-11) above correspond to no beam expander, but if the measuring volume is too large, increasing E is the only remaining way to reduce the size of the measuring volume. This corresponds to installing a beam expander.

Beam expander

A beam expander is a combination of lenses in front of or replacing the front lens of a conventional LDA system. It converts the beams exiting the optical system to beams of greater width. At the same time the spacing between the two laser beams is increased, since the beam expander also increase the aperture. Provided the focal length f remain unchanged, the larger beam spacing will thus increase the angle θ between the two beams. According to the formulas in (7-9) this will further reduce the size of the measuring volume.

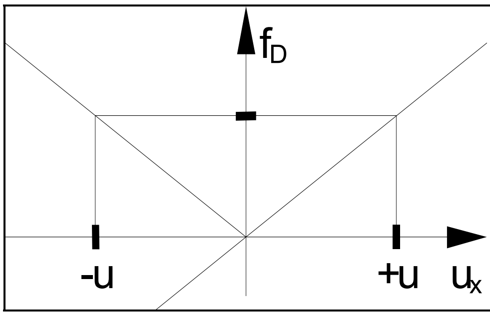
In agreement with the fundamental principles of wave theory, a larger aperture is able to focus a beam to a smaller spot size and hence to create a greater light intensity on the scattering particles. At the same time the greater receiver aperture is able to pick up more of the reflected light.

As a result the benefits of the beam expander is threefold:

- Reduce the size of the measuring volume at a given measuring distance.
- Improve signal-to-noise ratio at a given measuring distance, or ...
- Reach greater measuring distances without sacrificing signal-to-noise ratio.

7.1.6 Frequency shift

A drawback of the LDA-technique described so far is that negative velocities $u_x<0$ according to the formula (7-8) will produce negative frequencies $f_D<0$, but the receiver can not distinguish between positive and negative frequencies, and as such, there will be a directional ambiguity in the measured velocities.



$$f_D = \left| \frac{2\sin(\theta/2)}{\lambda} u_x \right|$$

Figure 7-8 Directional ambiguity without frequency shift.

To handle this problem, a Bragg cell is introduced in the path of one of the laser beams. The Bragg cell shown in Figure 7-9 is a slab of glass. On one side an electro-mechanical transducer driven by an oscillator produces an acoustic wave propagating through the slab generating a periodic moving pattern of high and low density. The opposite side of the slab is shaped to minimize reflection of the acoustic wave and is attached to a material absorbing the acoustic energy.

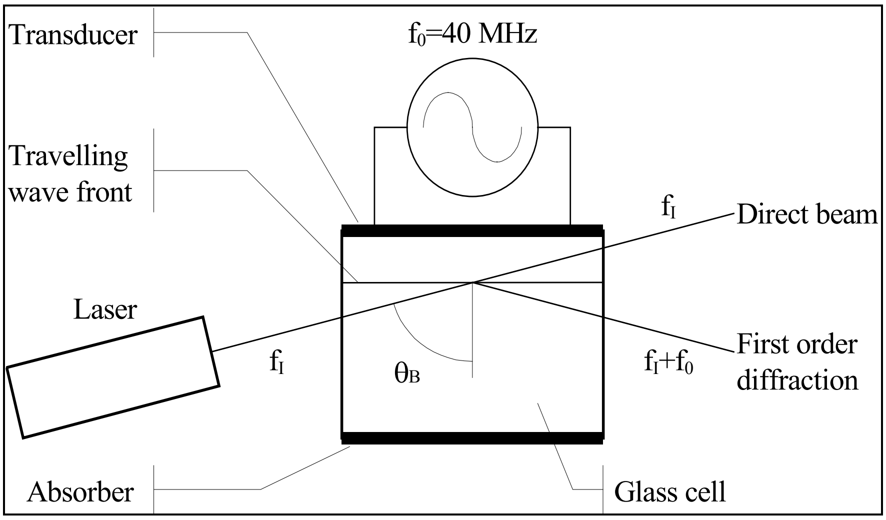


Figure 7-9 Bragg cell.

The incident light beam hits a series of travelling wave fronts which act as a thick diffraction grating. Interference of the light scattered by each acoustic wave front causes intensity maxima to be emitted in a series of directions. By adjusting the acoustic signal intensity and the tilt angle θ_B of the Bragg cell, the intensity balance between the direct beam and the first order of diffraction can be adjusted. In modern LDA-equipment this is exploited, using the Bragg cell itself as beam splitter. Not only does this eliminate the need for a separate beam splitter, but it also improves the overall efficiency of the light transmitting optics, since more than 90% of the lasing energy can be made to reach the measuring volume, effectively increasing signal strength.

The Bragg cell adds a fixed frequency shift f_0 to the diffracted beam, and including this in the equations (7-5) yield:

$$f_{s,2} = (f_I + f_0)\left[1 + \frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_2)\right] = f_I + f_0 + (f_I + f_0)\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_2)$$

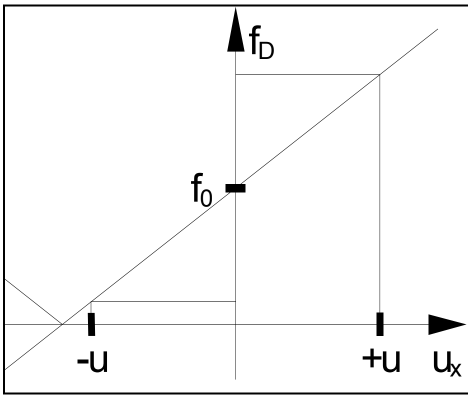
$$f_{s,1} = f_I\left[1 + \frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_1)\right] = f_I + f_I\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_1)$$

$$\begin{aligned} f_D = f_{s,2} - f_{s,1} &= f_0 + (f_I + f_0)\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_2) - f_I\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_1) \\ &= f_0 + f_I\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_2 - \overline{e}_s + \overline{e}_1) + f_0\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_2) \\ &= f_0 + f_I\frac{\overline{U}}{c}\cdot(\overline{e}_1 - \overline{e}_2) + f_0\frac{\overline{U}}{c}\cdot(\overline{e}_s - \overline{e}_2) \\ &= f_0 + \frac{2\sin(\theta/2)}{\lambda}u_x + \underbrace{f_0\underbrace{\left|\frac{\overline{U}}{c}\right|}_{\le 10^{-5}}\underbrace{\left|(\overline{e}_s - \overline{e}_2)\right|}_{\le 2}\underbrace{\cos\varphi}_{\le 1}}_{\text{Negligible}} \end{aligned}$$

$\Downarrow$

$$f_D \cong f_0 + \frac{2\sin(\theta/2)}{\lambda}u_x \qquad \text{(7-12)}$$

As long as the particle velocity does not introduce a negative frequency shift numerically larger than f_0, the Bragg cell will thus ensure a measurable positive Doppler frequency f_D.



$$f_D = \left| f_0 + \frac{2\sin(\theta/2)}{\lambda} u_x \right|$$

Figure 7-10 Resolving directional ambiguity using frequency shift.

In other words the frequency shift f_0 allows measurement of velocities down to

$$u_x > -\frac{\lambda\, f_0}{2\sin(\theta/2)} \tag{7-13}$$

-without directional ambiguity.

Typical values might be λ = 500 nm, f_0 = 40 MHz, θ = 20°, allowing for measurement of negative velocity components down to

$$u_x > -\frac{500\cdot 10^{-9}\,\mathrm{m}\cdot 40\cdot 10^{6}\,\mathrm{s}^{-1}}{2\sin(20°/2)} = -57.6\ \mathrm{m/s}$$

Upwards the maximum measurable velocity is limited only by the response-time of the photo-multiplier and the following signal-conditioning electronics. In modern Dantec equipment this allows measurement well into supersonic velocities.

Fringe model

To get an intuitive understanding of the frequency shift, we use the fringe model once more. Introducing a fixed frequency shift f_0 in one of the beams will cause the fringe pattern itself to roll along the x-axis with constant velocity. This means that even a stationary particle will scatter light with an intensity pulsating at a frequency equal to f_0. A seeding particle moving towards the fringes will produce a Doppler burst of higher frequency, while particles moving in the same direction as the fringes will produce a lower frequency. The lower velocity limit in equation (7-13) correspond to a seeding particle moving with exactly the same speed as the fringes.

The key issue here is the number of fringes crossed by the seeding particle while it is in the measuring volume. If Δt is the particle's residence time within the measuring volume, and f_D is the measurable Doppler frequency according to (7-12), the fringe count N_f is simply calculated as:

$$N_f = f_D \cdot \Delta t \tag{7-14}$$

-This will usually differ from the fringe count calculated from (7-10), which apply only when a seeding particle move straight through the centre of a set of stationary fringes. (i.e. no frequency shift).

If for example the diameter of the focused laser beam is $d_f = 100$ μm,
the laser wavelength is $\lambda = 500$ nm,
and the beam intersection angle is $\theta = 20°$,

equation (7-10) predicts, that a seeding particle passing the measuring volume along the x-axis will cross 70 fringes irrespective of its velocity.

This is sufficient to determine the absolute velocity of the particle, but the direction will be unknown. To resolve the directional ambiguity, a frequency shift of f_0=40MHz can be applied, allowing for detection of velocities $u_x > u_{x,min} = -57.6$ m/s, according to the previous example.

Since the frequency shift cause the fringes to move, the number of fringes crossed by the particle will also change. In the limit $u_x = -57.6$ m/s the particle moves with the same speed as the fringes, and consequently there are no fringe-crossings, and the particle will not be detected at all. It can be shown that for $u_x = ½·u_{x,min} = -28.8$ m/s, the number of fringe crossings will be identical to the case of no frequency shift; $N_f = 70$. For lower velocities the fringe count will be smaller, and for higher velocities it will be bigger. In the special case $u_x = 0$, the fringe count will in principle approach infinity, since the seeding particle remain in the measuring volume. In practice no particle is ever completely immobile, and even if u_x equals 0, u_y or u_z probably don't, and as such ensure that the seeding particle leaves the measuring volume "sideways", thereby limiting the number of fringe-crossings. Nonzero velocity components u_y and/or u_z will generally reduce the fringe count, since they mean that the seeding particle does not pass the measuring volume along the x-axis.

If you are certain that all velocities are bigger than $½·u_{x,min}$, the frequency shift may also help you to increase the effective fringe count in cases, where the number of fringes according to (7-10) might otherwise be too small.

Fringe tilt

In principle the frequency shift will also tilt the fringes slightly, so they are no longer exactly normal to the x-axis, but in practice this can be ignored, since the typical frequency shift of 40 Mhz is several orders of magnitude smaller than the frequency of light. This means that the difference in wavelength between the shifted and the unshifted beam will also be several orders of magnitude smaller than the laser wavelength itself, and consequently the tilt angle of the fringes get negligible.

In the example above ($f_I = c/\lambda = 3·10^8/5·10^{-7} = 6·10^{14}$ Hz, $f_0 = 40$ Mhz and $\theta = 20°$), the tilt angle would be approximately 10^{-5} degrees.

7.1.7 Signals

The primary result of a laser anemometer measurement is a current pulse from the photodetector. This current contains the frequency information relating to the velocity to be measured. The photocurrent also contains noise. The primary source of noise is the photodetection shot noise, which is a fundamental property of the detection process. The interaction between the optical field and the photo-sensitive material is a quantum process, which unavoidably impresses a certain amount of fluctuation on the mean photocurrent. In addition there is mean photocurrent and shot noise from undesired light reaching the photodetector. Much of the design effort for the optical system is aimed at reducing the amount of unwanted reflected laser light or ambient light reaching the detector. Further noise sources are secondary electron noise from the photomultiplier dynode chain and preamplifier thermal noise in the signal processor.

A laser anemometer is most advantageously operated under such circumstances that the shot noise in the signal is the predominant noise source. This shot noise limited performance can be obtained by proper selection of laser power, seeding particle size and optical system parameters. In addition, noise should be minimized by selecting only the minimum bandwidth needed for measuring the desired velocity range by setting low-pass and high-pass filters in the signal processor input.

Very important for the quality of the signal, and the performance of the signal processor, is the number of seeding particles present simultaneously in the measuring volume. If on average much less than one particle is present in the volume, we speak of a bursttype Doppler signal. A typical Doppler burst signal is shown in Figure 7-11 and Figure 7-12 shows the filtered signal which is actually input to the signal processor. The DC-part which was removed by the high-pass filter is known as the Doppler Pedestal, and it is often used as a trigger-signal, which starts sampling of an assumed burst-signal. The envelope of the Doppler modulated current reflects the Gaussian intensity distribution in the measuring volume.

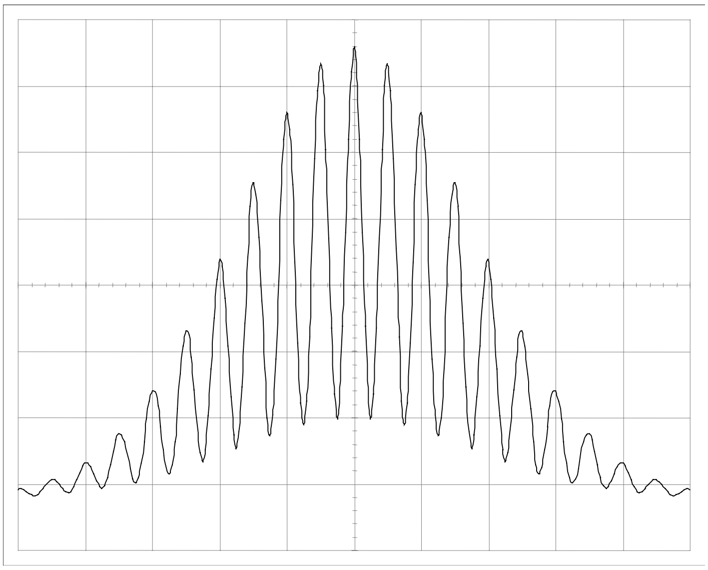


Figure 7-11 Doppler burst.

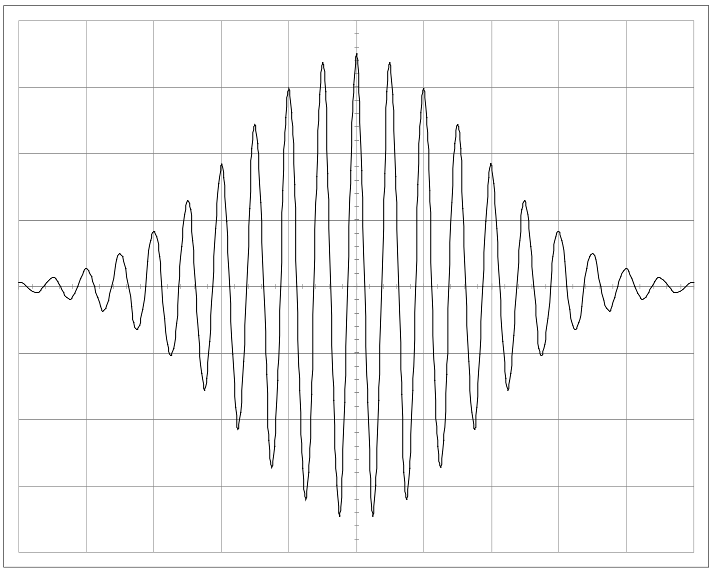


Figure 7-12 Filtered signal with the DC-component removed.

If more particles are present in the measuring volume simultaneously, we speak of a multi-particle signal. The detector current is the sum of the current bursts from each individual particle within the illuminated region. Since the particles are located randomly in space, the individual current contributions are added with random phases, and the resulting Doppler signal envelope and phase will fluctuate.

Most LDA-processors are designed for single-particle bursts, and with a multi-particle signal, they will normally estimate the velocity as a weighted average of the particles within the measuring volume. You should be aware however, that the random phase fluctuations of the multi-particle LDA signal add a phase noise to the detected Doppler frequency, which is very difficult to remove.

7.1.8 Seeding

In LDA it is not actually the velocity of the flow that is measured, but the velocity of particles suspended in the flow. In this respect these seeding particles can be considered to be the actual velocity probes, and seeding considerations are thus important in LDA.

The particles must be small enough to track the flow accurately, yet large enough to scatter sufficient light for the photodetector to be able to detect the Doppler frequency. Ideally, the particles should also be neutrally buoyant in the fluid, that is they should have approximately the same density as the fluid itself, but in many experiments this is a secondary consideration.

Durst, Melling & Whitelaw (1981) state the following desired properties of seeding particles:

Particles whose motion is used to represent that of a fluid should be:

- Able to follow the flow.
- Good light scatterers.
- Conveniently generated.
- Cheap.
- Non-toxic, non-corrosive, non-abrasive.
- Non-volatile, or slow to evaporate.
- Chemically inactive.
- Clean.

7.1.8.1 Seeding as flow field tracers

In general the motion of particles suspended in a fluid is affected by{ XE Particle motion }

- Particle shape.
- Particle size.
- Relative density of particle and fluid.
- Concentration of particles in the fluid.
- Body forces.

{ XE Particle shape }{ XE Particle size }The shape of the seeding particles affect the drag exerted on the particle by the surrounding fluid, and the size of the particles along with their relative density influence their response to velocity changes of the surrounding fluid.

{ XE Particle concentration }The concentration of particles affect particle motion through interaction between different particles. In practice the concentrations used are normally so low, that particle interaction can be neglected.

{ XE Particles, Body forces on- }Also body forces, such as gravity, can normally be ignored, except in very slow flows, where buoyancy of the seeding particles may be an issue. Also in experiments including for example electrostatic fields, body forces may be of importance, but in such cases, they will probably be part of the experiment, and as such they can not really be considered a disturbance.

Particle motion

Since the analysis of particle motion is rather complicated even for spherical particles, and "real" particles can't be modelled properly anyway, only spherical particles in an infinite fluid have been analysed. It is assumed, that the results apply qualitatively also for particles of more irregular shape. This assumption is good for liquid particles and fair for monodisperse solid particles, but poor for other solid particles, such as agglomerates.

Basset derived the equation of motion for a sphere relative to an infinite, stagnant fluid in 1888, and in 1959 Hinze expanded this to a moving fluid, considering the instantaneous velocity $\mathbf{V} \equiv \mathbf{U}_p - \mathbf{U}_f$, of the particle relative to the fluid. (From Durst, Melling & Whitelaw, 1981):

$$\underbrace{\frac{\pi}{6} d_p^3 \rho_p \frac{d\mathbf{U}_p}{dt}}_{\substack{\text{Accelerating}\\ \text{force}}} = \underbrace{-3\pi\mu d_p \mathbf{V}}_{\substack{\text{Stokes}\\ \text{viscous}\\ \text{drag}}} + \underbrace{\frac{\pi}{6} d_p^3 \rho_f \frac{d\mathbf{U}_f}{dt}}_{\substack{\text{Pressure}\\ \text{gradient}\\ \text{force on}\\ \text{fluid}}} - \underbrace{\frac{\pi}{12} d_p^3 \rho_f \frac{d\mathbf{V}}{dt}}_{\substack{\text{Fluid}\\ \text{resistance to}\\ \text{accelerating}\\ \text{sphere}}} - \underbrace{\frac{3}{2} d_p^2 \sqrt{\pi\mu\rho_f} \int_{t_0}^{t} \frac{d\mathbf{V}}{d\xi} \frac{d\xi}{\sqrt{t-\xi}}}_{\substack{\text{Drag force}\\ \text{associated with}\\ \text{unsteady motion}}} \qquad (7\text{-}15)$$

-where subscript *p* refer to the seeding particle, and subscript *f* refer to the fluid.

The first term in this equation represent the force required to accelerate the particle, and the second term describe the viscous drag as given by Stokes law. Acceleration of the fluid produce a pressure gradient in the vicinity of the particle, and hence additional force on the particle as described by the third term. The fourth term is the resistance of an inviscid fluid to acceleration of the sphere, and is predicted by potential flow theory. The last term is the "Basset history integral" representing the drag force arising from derivation of the flow pattern from that occurring in steady flow.

Note that when the first, third and fourth terms are combined, the accelerating force is equivalent to that of a sphere whose mass is increased by an additional "virtual mass" equal to half the mass of the displaced fluid.

The above equation is valid within the following assumptions:

- The turbulence is homogeneous and time-invariant.
- Particles are smaller than the turbulence microscale
- Stokes drag law applies (particles are spherical)
- Particles are always surrounded by the same fluid molecules
- There is no interaction between particles.

Furthermore external forces, such as gravitational, centrifugal and electrostatic forces have been ignored.

7.1.8.2 Lorenz-Mie light scattering theory

{ XE Lorenz-Mie scattering }{ XE Mie scattering }{ XE Light scattering }{ XE Scattering of light }Depending on the nature of the flow, seeding particles used for LDA-measurements usually have particle diameters ranging from 0.1 to 50 μm. This is comparable to the wavelength of the light used, which for a He-Ne laser is 632.8 nm.

With particle sizes comparable to the wavelength of light, the Lorenz-Mie light scattering theory apply. This theory consider spherical particles, and thus describe only the dependency on particle size, but in practice also the shape and orientation of seeding particles play a major role in the scattering of light.

In general large particles scatter more light than smaller ones, but particle size also affect the spatial distribution of the scattered light as shown in Figure 7-13. For large particles the ratio of forward to backward scattered light can be in the order of 10^2 to 10^3, while smaller particles scatter more evenly.

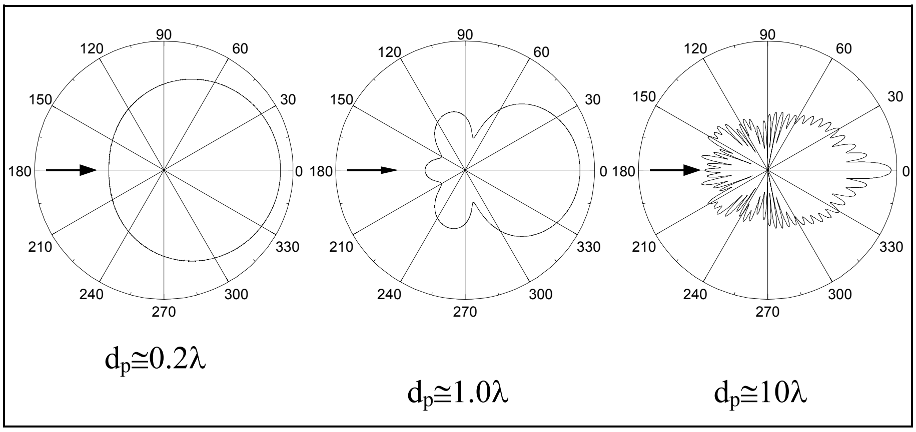


Figure 7-13 Light scattering from spherical particles of different size. The light intensity is shown on a logarithmic scale.

Please note that in Figure 7-13 the radial scale is logarithmic to allow for the large difference between forward and backscattering intensities.
For large seeding particles, direct surface reflection generally dominate the scattered light, and the intensity is thus roughly proportional to the square of the particle diameter. For smaller particles diffraction play a major role in the light scattering, and polarisation of the incident light has significant influence. This is particularly important when using submicron seeding particles, which may be required for measurements in supersonic flows and/or shocks.

7.1.8.3 Type & size of seeding particles

{ XE Seeding:type & size of particles }{ XE Particles, Type & size of- }The choice of seeding depend on a number of parameters. Primarily the seeding material should be chosen considering the flow that is to be measured, and the laser available. In general seeding particles should be chosen as large as possible in order to scatter the most light, but the particle size is limited, since too large particles will not track the flow properly. In general the maximum allowable particle size decrease with increasing flow velocity, turbulence and velocity gradients.

Ideally the seeding material should also be chosen, so the seeding particles are neutrally buoyant in the carrying fluid, but in many flows this is a secondary consideration.

Finally it should be considered how the flow is seeded. Water flows are often implemented using water in a closed circuit, and here commercial seeding particles such as latex beads or pine pollen can easily be added. Air flows on the other hand are often not recirculated, and thus require the seeding to be generated at the inlet and disposed of at the outlet.

The natural concentration of very small particles is often much greater than that of particles in the useful range. In some cases, most often when measuring in liquids, this causes an undesirable shot noise level due to the incoherent signals from the many small particles. In general, it is strongly recommended, whenever possible, to control the size and concentration of the seeding particles by filtering the fluid and subsequently adding seeding particles of known size.

Typical seeding materials for use in air flows are: { XE Seeding: -for air }

Material	Particle Diameter [µm]	Comments
Al_2O_3	< 8	Generated by fluidisation. Useful for seeding flames on account of a high melting point.
Glycerine	0.1 - 5	Usually generated using an atomiser.
Silicone oil	1 - 3	Very satisfactory.
SiO_2 Particles	1 - 5	Spherical particles with a very narrow size distribution. Better light scatterer than TiO_2, but not as good as glycerine.
TiO_2 Powder	From submicron to tens of microns	Good light scatterer and stable in flames up to 2500°C. Very wide size distribution and lumped particle shapes.
Water	1 - 2	Generated by atomisation. Evaporation inhibitor must be added.
MgO		Generated by combustion of magnesium powder giving a dirty unsteady supply of seeding.

Typical seeding materials for use in water flows are: { XE Seeding: -for water }

Material	Particle Diameter [µm]	Comments
Aluminium powder	< 10	Preserves polarisation by scattering.
Bubbles	5 - 500	Can only be used if two-phase flow is acceptable.
Glass balloons	10 - 150	Cheap even in large volumes, but with a large spread in particle size.
Latex beads	0.5 - 90	Can be delivered with relatively narrow size distribution, but quite expensive.
Milk	0.3 - 3	Cheap and efficient.
Pine Pollen	30 - 50	Egg-shaped and swell somewhat after some time in water. Can be supplied in large volumes.

References

F. Durst, A. Melling & J. H. Whitelaw: “Principles and practice of laser-doppler anemometry”, second edition, *Academic Press*, 1981.

H. C. van de Hulst: “Light Scattering by Small Particles”, *Dover publications*, 1981

7.2 Theory of Phase Doppler Anemometry

7.2.1 Basic principles of phase Doppler anemometry

Phase Doppler anemometry (PDA), which is used in Dantec's conventional PDA and *DualPDA* systems, is an extension of Laser Doppler Anemometry (LDA, see chapter 7.1).
This extension to conventional Phase Doppler Anemometry and further to the concept of the DualPDA is discussed in this chapter.

In the LDA system (see chapter 7.1) there was only one photo-detector. If we consider the situation in Figure 7-14, we see two photo-detectors receiving light scattered from the surface of a reflecting spherical particle similar to that we observe in LDA

The point to note here is that the difference in optical path length for the reflections from the two incident beams changes with the position of the photo-detector. This means that, when the particle passes through the measuring volume, both photo-detectors receive a Doppler burst of the same frequency, but the phases of the two bursts vary with the angular position of the detectors.

This phenomenon was first utilized as an indication of the size of a particle by Durst & Zaré, who presented their paper *Laser Doppler Measurements in Two-Phase Flows* in 1975.

Again it is convenient to introduce the fringe model as a first order of approximation.

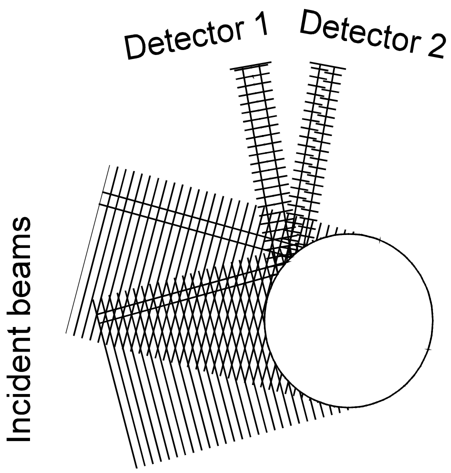


Figure 7-14 The interference patterns differ at the two photo-detector surfaces

Figure 7-15 illustrates the intensity fluctuation in each of the photodetectors and the time lag, Δt, separating the wave fronts reaching the two photo-detectors. The corresponding phase difference would be:

$$\Phi_{12} = 2\pi f \cdot \Delta t$$

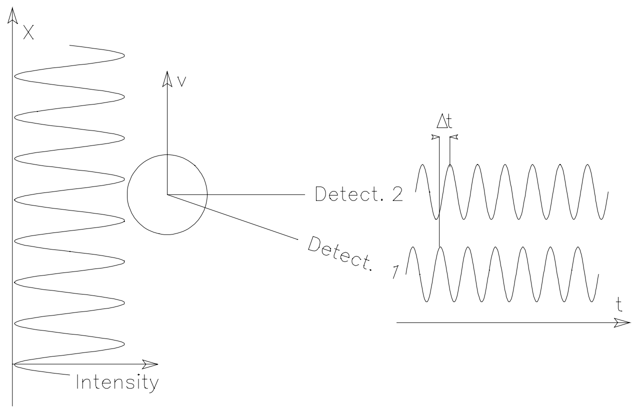


Figure 7-15: The phase difference between two detectors at different angles.

Relationship between phase difference and particle diameter

The property that is of foremost importance is that the phase difference between the two Doppler bursts depends on the size of the particle, provided that all other geometric parameters of the optics remain constant. In Figure 7-38 we see two particles of different size. The phase difference between the Doppler bursts from the large particle exceeds that of the smaller particle.

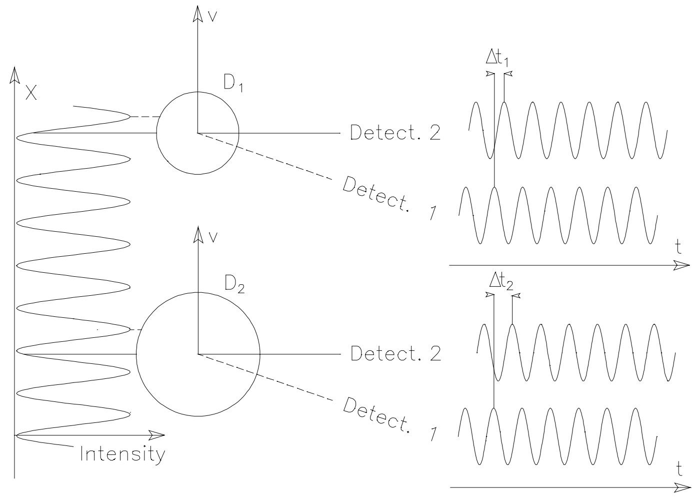


Figure 7-16: Increasing phase difference with increasing particle diameter

Mathematically, we can express the phase of a Doppler burst received at detector *i* as:

$$\Phi_i = \alpha \cdot \beta_i$$

where the size parameter is:

$$\alpha = \pi \frac{n_1}{\lambda} D$$

and where:

n_1 is the refractive index of the scattering medium.

λ is the laser wavelength in vacuum.

D is the particle diameter.

We thus have a linear relationship between particle size and phase (Figure 7-17).

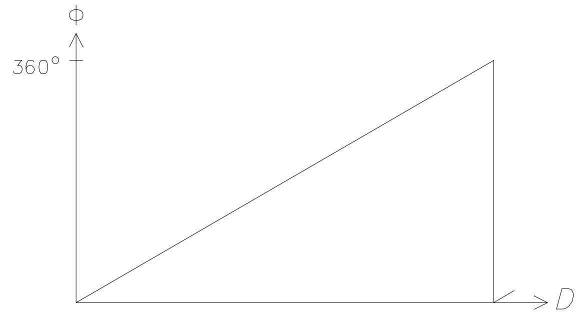


Figure 7-17: The idealized diameter/phase relationship

The geometrical factor, β_i, depends on the scattering mode and the three angles ϑ, φ_i and ψ_i. The full intersection angle between the two incident beams, ϑ, determines the fringe separation, while φ_i and ψ_i define the direction towards the (centroid of the) photo-detector from the measuring volume.

Figure 7-18 illustrates how these angles are defined.

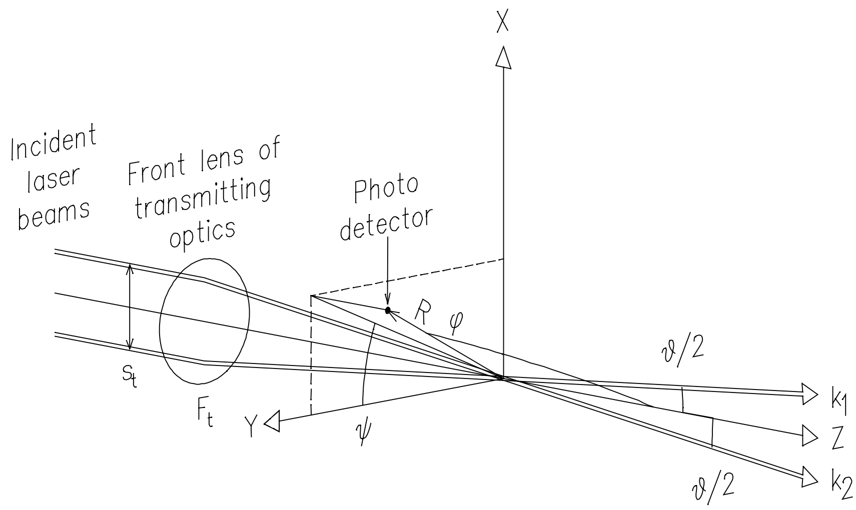


*Figure 7-18**:.** Co-ordinate system used with the PDA.*

The angle of intersection between the two incident beams, ϑ, is determined by the beam separation, S_t, and the focal length of the front lens, F_t.

φ_i is the scattering angle measured from the axis of the transmitting optics (the bisector of the two incident beams; the Z axis).

ψ_i is the azimuth angle giving the rotational position about the Z axis.

The factor β_i between particle diameter and phase shift also depends on the scattering mode. This is illustrated in Figure 7-19, in which ray tracing has been used to depict how incident light will scatter from a spherical particle. Three contributions are included in the representation; reflection from the outer surface of the particle, refraction through the particle (first order refraction) and refraction with one internal reflection (second order refraction).

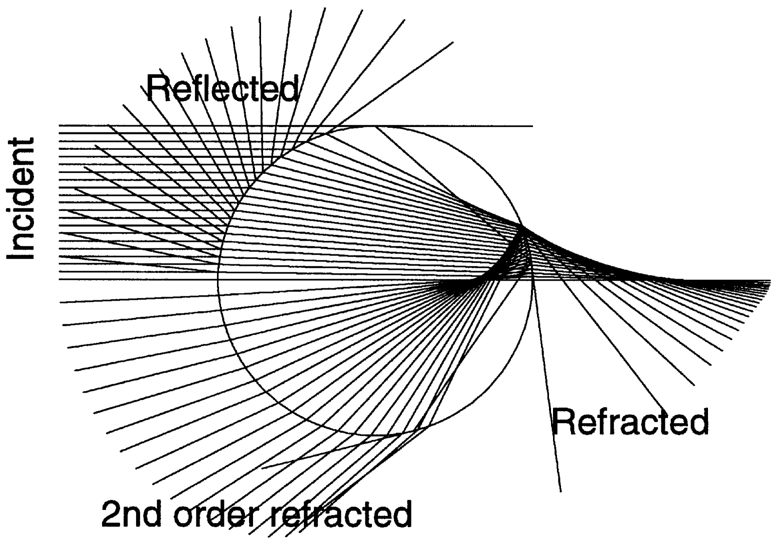


Figure 7-19: The definition of three different light scattering modes.

The formulas expressing the geometrical factor are given below for reflection and (first order) refraction.

For reflection *(*Equation 7-16)

$$\beta_i = \frac{4\pi}{\lambda} \cdot \left\{ \sqrt{1 + \cos\frac{\vartheta}{2} \cdot \cos\varphi_i \cdot \cos\psi_i + \sin\frac{\vartheta}{2} \cdot \sin\psi_i} - \sqrt{1 + \cos\frac{\vartheta}{2} \cdot \cos\varphi_i \cdot \cos\psi_i - \sin\frac{\vartheta}{2} \cdot \sin\psi_i} \right\}$$

The refractive index of the particle, n_2, does not appear in this expression. In practice this means that in situations where the exact value of the refractive index is not known, reflection may be a useful scattering mode.

For first order refraction *(*Equation 7-17)

$$\beta_i = \frac{4\pi}{\lambda} \left[\sqrt{1 + n_{rel}^2 - \sqrt{2} \cdot n_{rel} \cdot \sqrt{f_{i+}}} - \sqrt{1 + n_{rel}^2 - \sqrt{2} \cdot n_{rel} \cdot \sqrt{f_{i-}}} \right]$$

where:

$$n_{rel} = \frac{n_2}{n_1}$$

n_2 = particle refractive index

$$f_{i\pm} = 1 + \cos\frac{\vartheta}{2} \cdot \cos\varphi \cdot \cos\psi_i \pm \sin\frac{\vartheta}{2} \cdot \sin\psi_i$$

For second order refraction, β_i cannot be given as a closed form solution, but must be solved for numerically by an iterative process.

Slope of the diameter-phase relationship

As appears from the expressions for β_i above, the geometrical factor and, hence, the sensitivity and range of the PDA can be altered by changing any of the angles ϑ , φ_i or ψ_i.

This is further discussed in **7.3** *Setting up a PDA system***.**

In practice, the three angles cannot be chosen freely. Typically, the selection of scattering angle, φ, is quite restricted, either to ensure a particular mode of scattering or a sufficient signal-to-noise ratio, or from practical considerations of the measurement situation. The required working distance also affects the possible range of ϑ and ψ_i.

Figure 7-20 illustrates the increase in the slope of the diameter–phase relationship when the angular separation between the photo-detectors is increased, i.e. increasing ψ_{12} (in the middle), and when the fringe separation is reduced by increasing the angle ϑ between the incident beams.

Changing ψ_{12} only affects the slope of the diameter–phase relationship, i.e. the sensitivity and range of the sizing, and has no effect on the velocity-frequency relationship. In practice with the Dantec PDA receiving optics it can be achieved either by changing the focal length of the front lens or selecting another aperture plate as described later in this chapter.

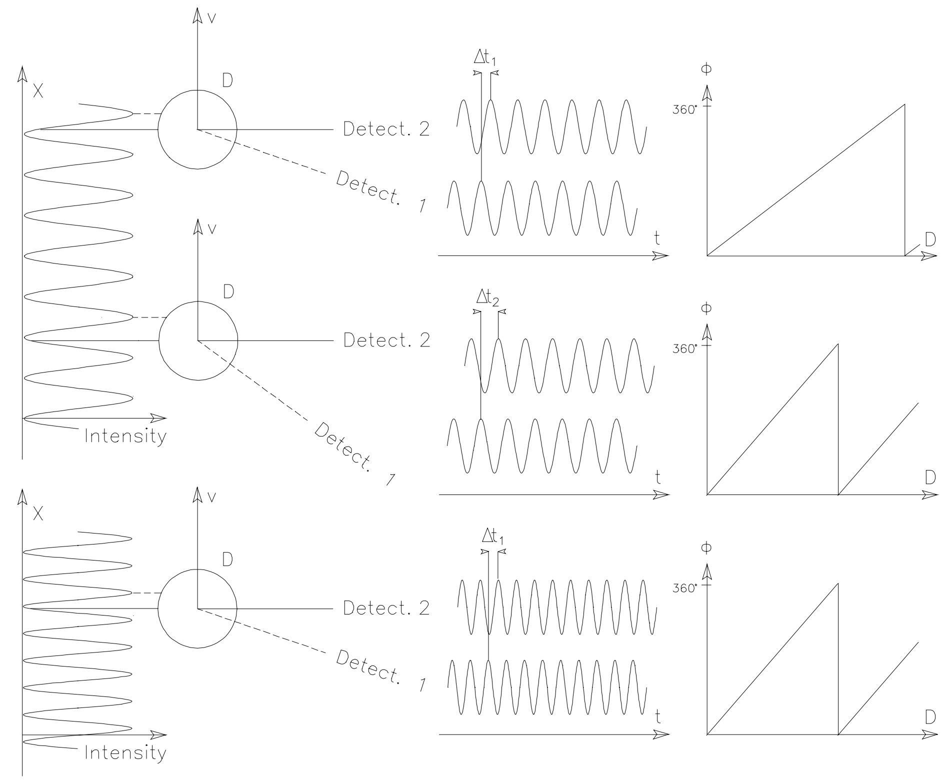


Figure 7-20: The effect of changing the azimuth angle, ψ, and the angle between the incident beams, ϑ, on the slope of the diameter–phase relationship.

Changing ϑ affects both the slope of the diameter phase curve and the velocity-frequency relationship.

ϑ can be changed in two ways:
- Changing the focal length of the front lens of the transmitting optics.
- Changing the beam separation.

The *55X Modular LDA Optics* system, the *60X FiberFlow* series and *65X60 FlowLite* all have exchangeable front lenses of different focal lengths.

Changing the beam separation is a more convenient method of changing ϑ since the working distance remains unaffected. The *55X82 Beam Translator* is meant for this purpose. This unit fits the *55X*-series optical modules and the 85 mm FiberFlow probes (models *60X80*, *60X81*, *60X82* and *60X83*). Also with the 60 mm diameter probe a change in beam separation can be achieved using the special *41X805 Beam Displacer* for *60X60*, *60X62*, *60X64* and *60X66*, and *41X806 Beam Displacer* for *60X61*, *60X63*, *60X65* and *60X67*.

Handling the 2π ambiguity

In Figure 7-21 the phase difference is illustrated for three different particles of increasing size. While the phase difference for the first two particles is within 2π (= 360°), the third particle falls beyond this range.

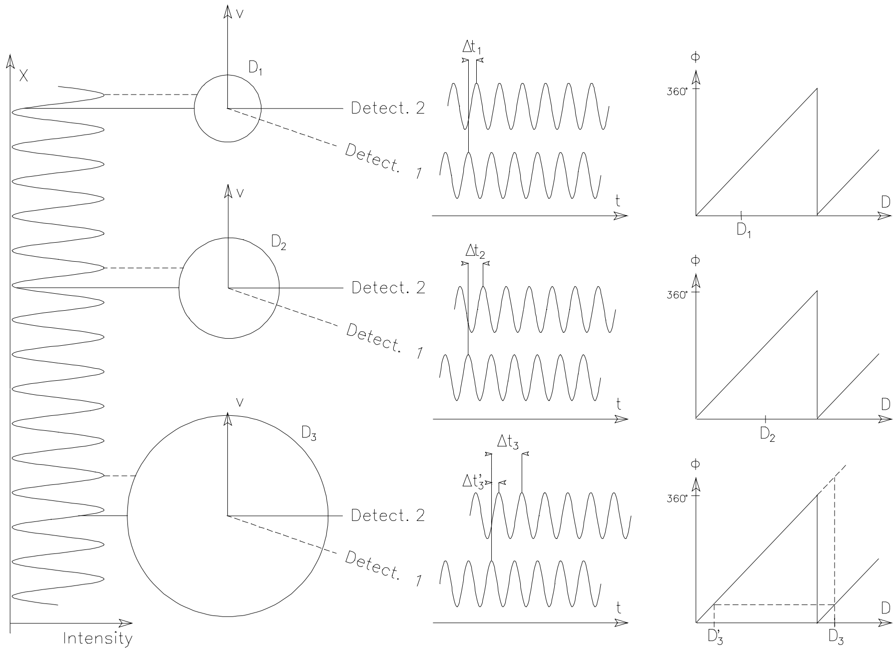


Figure 7-21: The 2π ambiguity.

From measuring the phase difference between the Doppler bursts received by the two detectors alone there is no way to tell whether the diameter is D_3 or D_3' (corresponding to the phase difference –2π). This is referred to as the 2π ambiguity.

Thus, in a system with two photo-detectors, a compromise would be necessary between, on the one hand, high sensitivity and small measurement size range, and on the other hand, a larger measurement size range at the expense of the sensitivity.

The solution to this problem as patented by Dantec is to use additional detectors. In conventional PDA a third detector is introduced so that the three are asymmetrically positioned. Two detectors, *U1* and *U2*, form the more distant pair giving the greater slope of the diameter–phase relationship and hence a higher resolution and smaller working range. The detectors, *U1* and *U3*, form another pair less separated and therefore giving a smaller slope to the diameter–phase relationship (Figure 7-22). This corresponds to a larger measurement size range, but also to a lower resolution. By comparing the phase differences from the two detector pairs one can achieve at the same time the high resolution and the large measurement range. In the DualPDA (7.2.2 *The concept of the DualPDA*) the diameter–phase relationship with the steeper slope is obtained from the detector pair *U1, U2* while the less steep slope is obtained from *V1, V2*.

A series of values for diameter *D* corresponding to a measured phase shift value of Φ_{12} is indicated by arrows in Figure 7-22. The phase shift value of Φ_{13} in the diagram (single arrow) is then used to select which one of the values for *D* is the correct one.

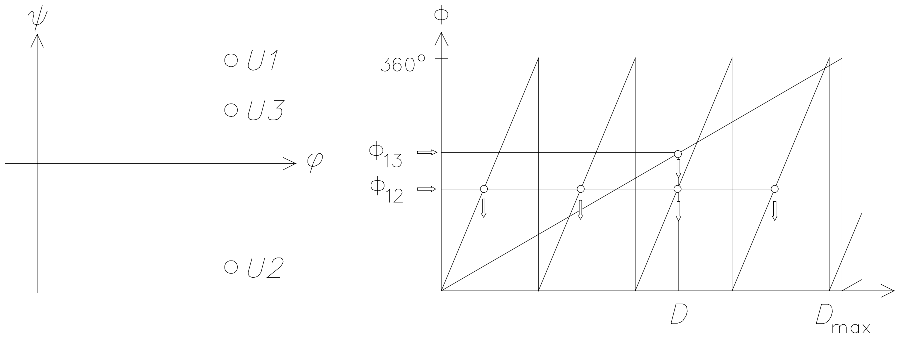


Figure 7-22 The different slopes of the diameter-phase relation obtained in a conventional PDA set-up with two pairs of photo-detectors at different separations.

Particle sphericity

The arrangement with two detector pairs — either formed by three detectors as in the convetional PDA or by four as in the DualPDA — has another useful feature. The phase difference corresponding to each detector pair gives us information about the curvature over a certain arc of the particle surface. With two such pairs we can measure the curvature at two different locations on the surface. If the particle is spherical, two such pairs of photo-detectors should measure identical curvatures.

This is the principle of the spherical check illustrated for the conventional PDA in Figure 7-23: the phase differences Φ_{12} and Φ_{13} should point at the same diameter, *D*. For the DualPDA the corresponding phase differences would be Φ_{U12} and Φ_{V12} (see 7.2.2 *The concept of the DualPDA*)

If the two local curvatures differ, Φ_{12} and Φ_{13} will point at diameter values differing by ΔD (Figure 7-23).

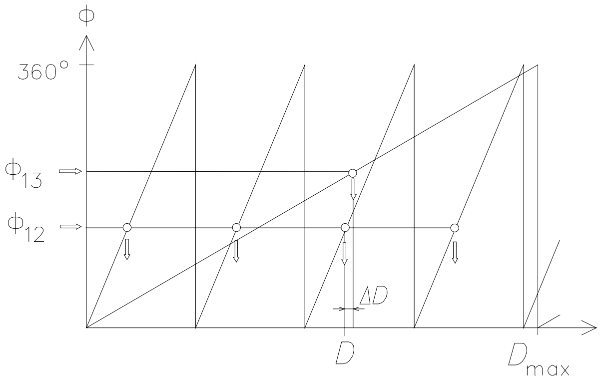


*Figure 7-23**.** Difference, ΔD, in the diameter value corresponding to the two phase differences Φ_{12} and Φ_{13}.*

One validation criterion in *BSA flow software* is the maximum allowable deviation from sphericity. Thus, if ΔD exceeds a certain limit set by the user, the particle is not accepted.

Phase measurements will always have some associated uncertainty (Figure 7-24). The detectors will be specified within certain tolerances, partly there will be noise present influencing the accuracy.

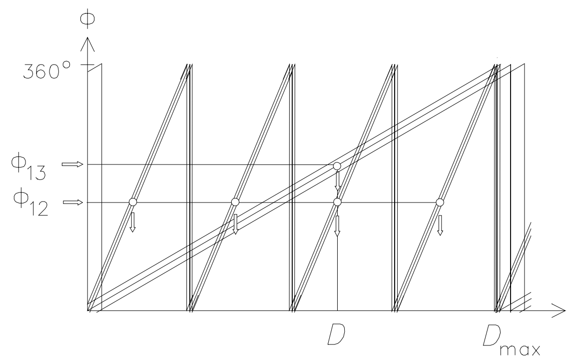


Figure 7-24: Effect of uncertainty in the estimation of the phase difference.

Concentration measurements

Apart from size and velocity, the PDA can also be used for measuring particle concentration. A description of how this is achieved is given in 7.5.2 Moments (one-time statistics)

Note	*An important point is that, in order to maximize the accuracy of the concentration measurement, the main flow direction should be parallel to the X axis.*

7.2.2 The concept of the DualPDA

Although phase Doppler anemometry is a well established technique for measuring size and velocity of spherical particles, there exist some principle difficulties with the measurement of large particles, in particular when the system is set up to detect refractively scattered light, as is usually the case in spray investigations. Large in this connection means that the particle diameter exceeds about one third of the diameter of the measurement volume. In such cases erroneous size measurements may lead to a significant reduction of accuracy in estimating volume weighted flux and concentration, since the volume is proportional to the third power of diameter.

Two effects have been identified as potentially leading to incorrect size measurements in such applications:

- The trajectory effect (or Gaussian beam effect) and
- the slit effect.

Both effects arise when the PDA system is set up to receive refractively scattered light, as is typical for applications to sprays, but instead receives reflectively scattered light. Those signals are then also processed with the phase-diameter relationship based on refraction and thus lead to incorrect size measurements.

Note	*The use of three detectors will not ensure that these effects are suppressed. Furthermore, it is not possible to generalize the magnitude or sense of the error, i.e. it may be positive or negative, depending on the exact operating conditions and droplet diameter.*

Since the droplet diameter enters the mass flux computation to the third power, erroneous size measurements may seriously affect the accuracy of the mass flux computation, even if the size of only very few droplets is measured incorrectly.

In a number of applications the performance and the accuracy of the conventional PDA systems (ClassicPDA and FiberPDA) are therefore not satisfying. This is particularily the case for spray investigations. As already mentioned, the physical reasons for the shift between refractively and reflectively scattered light in such applications are the trajectory effect and the slit effect.

7.2.2.1 The trajectory effect

The trajectory effect can be attributed to the non-uniform (Gaussian) intensity distribution in the measurement volume, as is illustrated in Figure 7-25. In this figure the measurement volume is defined by the receiving optics placed at an angle to receive light scattered by first order refraction. As indicated in this figure, there exist particle positions within the volume (trajectories) where reflection may become the dominant scattering mode due to the much higher intensity of the incident light, in particular on the negative *Y*-axis. In such cases the unwanted, reflectively scattered light contribution will be processed with the refraction-based phase-diameter relation and therefore lead to incorrect size information.

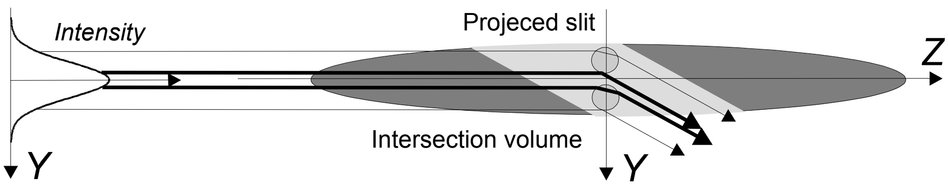


Figure 7-25: The trajectory effect expressed in terms of geometrical optics.

From this representation of the trajectory effect, it is evident that only droplets large relative to the dimensions of the beam waist can be affected. However in dense sprays, it is desirable to drastically decrease the measurement volume dimensions for two reasons; to increase the light intensity and to decrease the probability of multiple particles being in the volume simultaneous. Thus, the trajectory effect becomes of considerable concern, especially since only large droplets are affected, which are most influential in determining the mass flux.

7.2.2.2 The slit effect

The consequences of the slit effect on the calculation of the particle diameter from the measured phase difference are the same as those explained in connection with the trajectory effect, because the presupposed scattering mechanism (refraction) is suppressed. This is graphically depicted in Figure 2-21, again using ray tracing (geometric optics).

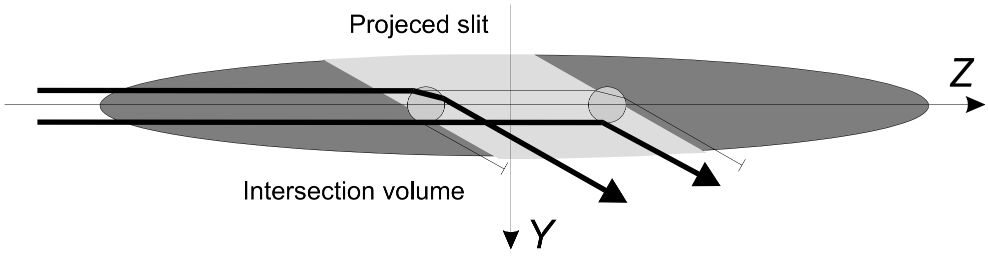


Figure 7-26:Suppression of scattered light due to the slit aperture (slit effect).

For flux measurements a well-defined cross-section through which particles are counted is required. In PDA the length dimension of this cross-section is fixed by placing slit apertures in front of the photo detectors. The projection of these slits onto the beam intersection volume is depicted in Figure 7-26 by a lighter shade of grey.

For certain particle positions (trajectories) within the volume, certain components of the scattered light can be suppressed because they fall outside of the slit aperture. In particular, certain positions suppress refractively scattered light, leaving only reflectively scattered light to be detected. As with the trajectory effect, such signals will result in incorrect size measurements, since refractively scattered light was presupposed in the choice of β.

It is interesting to note that the slit effect occurs also for small particles, i.e. small particles can appear as large particles, thus the potential error in the mass flux is equally high as with the trajectory effect.

7.2.2.3 The DualPDA principle

The DualPDA combines a conventional two-detector PDA and a planar two-detector PDA in one single optical receiving probe, as shown in Figure 2-22, and therefore requires at least a 2D transmitting optics.

Four receiving apertures

The *57X80 DualPDA Probe* thus contains four receiving apertures. The effective size and the shape of the apertures is defined by an interchangeable aperture mask positioned directly in front of the segmented focussing lens. Together with the optical configuration of the transmitting system and the focal length of the DualPDA receiving lens, the mask determines the measurable size range.

DualPDA concept

The basic concept of the DualPDA is to make two independent size measurements, using for one the conventional PDA and for the other the planar PDA. Each system will yield the same result if only refractively scattered light is received at the photodetector and the particle is spherical. If however, reflectively scattered light dominates, due either to the slit effect or the trajectory effect, each system will yield a different size and they will no longer agree. This redundancy can therefore be used as a validation criteria to avoid the slit effect and the trajectory effect.

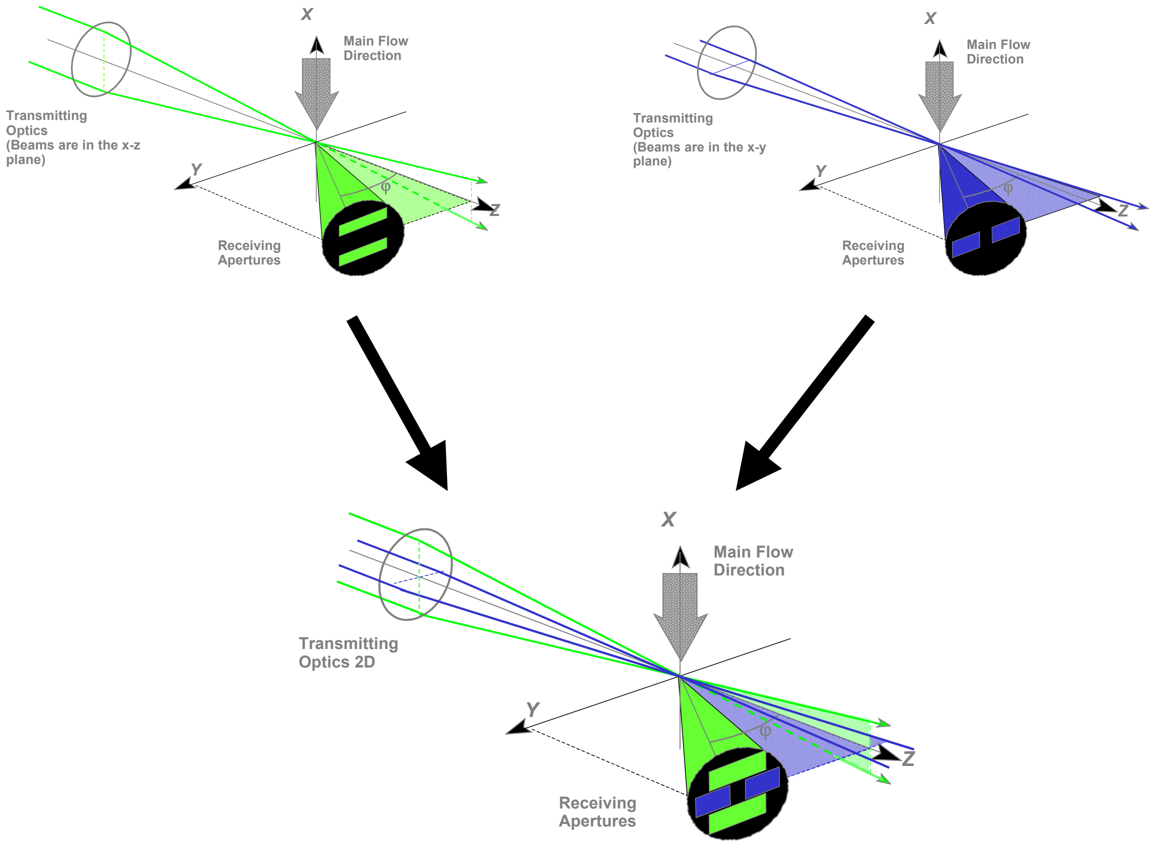


Figure 7-27:The DualPDA as a combination of one two-detector conventional PDA (top left corner) and one planar PDA (top right corner)

The response of the system is illustrated in Figure 7-28, computed for a certain optical configuration. Figure 7-28 shows the typical phase-diameter relationship for each of the conventional and planar systems.

As can be seen from this figure, the conventional PDA (CPDA) has a much larger phase conversion factor, compared to the planar PDA (PPDA). Thus, the 2π ambiguity of the conventional PDA with two detectors is easily resolved by referring to the planar PDA. This is further illustrated in Figure 7-29.

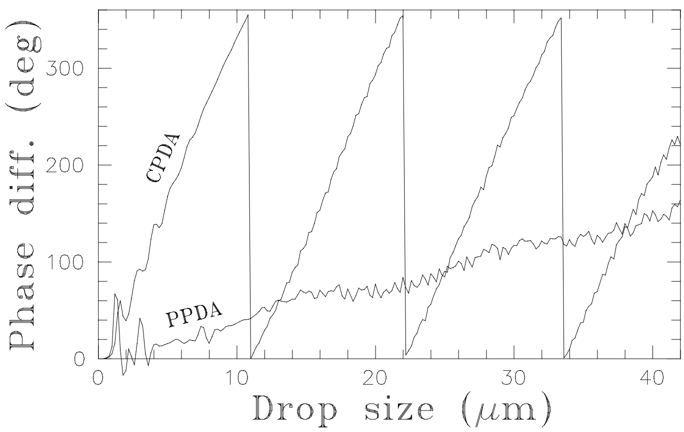


Figure 7-28: Typical DualPDA phase-diameter relationship.

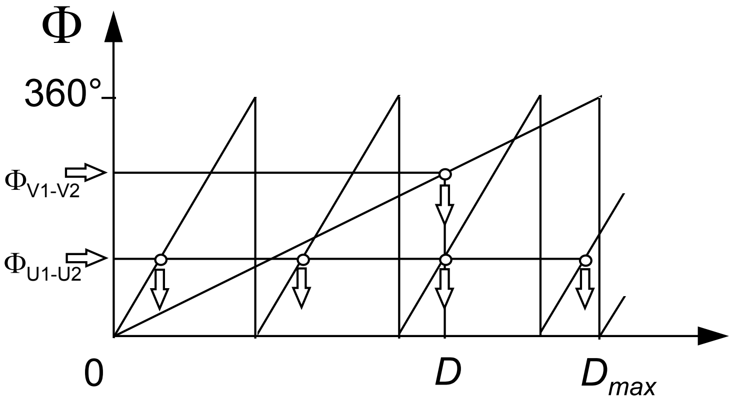


Figure 7-29: The different slopes of the diameter-phase relation in the DualPDA, used to resolve the 2π ambiguity.

Validation routine

The validation routine consists basically of comparing the droplet diameter measured by the planar PDA with the droplet diameter measured by the conventional PDA. A programmable discrepancy is allowed to account for the finite accuracy of the phase measurement in the signal processor and for a certain degree of non-sphericity of the droplets. The size measurement is finally performed using the phase difference measured with the conventional PDA due to the higher resolution. The planar PDA is used to resolve the 2π ambiguity and for validation. As both PDA configurations are affected in a different sense by the trajectory effect and the slit effect, this validation procedure provides an effective means to identify and reject erroneous measurements.

7.2.3 Light scattering from small particles

7.2.3.1 General considerations on scattering

Light scattering theories

Most of the material presented in this appendix is based on geometric optics (ray tracing). The approach using geometric optics (GO) is valid for particles of diameter much larger than the wavelength of light and at a distance much greater than the diameter of the particle. For smaller particles, it is necessary to apply the Lorenz-Mie Theory (LMT) for light scattering and if the Gaussian intensity distribution of the laser beams is also to be taken into account, the Generalized Lorenz-Mie Theory (GLMT) can be used. Such is the case when the trajectory effect, which arises from the Gaussian beam profile, is to be analysed.

7.2.3.2 Basic relations for light hitting an interface

A ray of light hitting an interface between two regions of different refractive index, n_1 and n_2 (Figure 7-30), is examined.

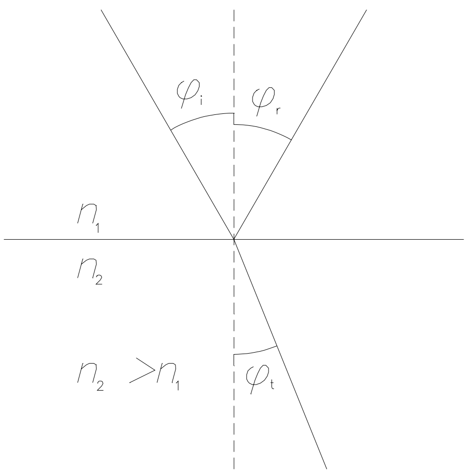


Figure 7-30: Reflection and refraction at an interface (drawn for air-water).

The angles of the reflected and the transmitted light, φ_r and φ_t, are related to the angle of incidence, φ_i, and the refractive indices, n_1 and n_2, by the two equations:

$$\varphi_r = -\varphi_i \qquad \text{(A1-1)}$$

and

$$n_1 \sin \varphi_i = n_2 \sin \varphi_t \qquad \text{(A1-2)}$$

Here, the angles φ_i, φ_r and φ_t all lie in the same plane of incidence, which contains the incident ray and the normal to the interface in the point of incidence.

In the following calculations it is assumed that the materials involved are completely dielectric (non-conductive). Thus, the refractive indices n_1 and n_2 have only real terms. This means that if the incident light is polarized either perpendicular or parallel to the plane of incidence, the transmitted light is polarized in the same orientation.

It should be pointed out that the amplitude of the transmitted light is polarization dependent. Therefore, if the incident light is polarized in another orientation, the polarization of the transmitted light will, as a rule, be rotated.

Critical angle

When the incident light comes from the denser side of the interface ($n_1 > n_2$), there is a critical angle of incidence above which no light is transmitted (total reflection):

$$\varphi_c = \arcsin n_{rel}, \text{ where } n_{rel} = \frac{n_2}{n_1} \tag{A1-3}$$

Amplitude of transmitted and reflected light

The light can be split in two components: one polarized perpendicular (*S*) and one parallel (*P*) to the plane of incidence. Then the amplitude of the transmitted light and of the reflected light relative to the incident light can be estimated for both directions (Fresnel equations):

$$t_S = \frac{2\sin\varphi_t \cos\varphi_i}{\sin(\varphi_t + \varphi_i)} = \frac{2n_1\cos\varphi_i}{n_1\cos\varphi_i + n_2\cos\varphi_t} \tag{A1-4}$$

$$t_P = \frac{2\sin\varphi_t \cos\varphi_i}{\sin(\varphi_t + \varphi_i)\cos(\varphi_t - \varphi_i)} = \frac{2n_1\cos\varphi_i}{n_2\cos\varphi_i + n_1\cos\varphi_i} \tag{A1-5}$$

$$r_S = \frac{\sin(\varphi_i - \varphi_t)}{\sin(\varphi_i + \varphi_t)} = \frac{n_1\cos\varphi_i - n_2\cos\varphi_t}{n_1\cos\varphi_i + n_2\cos\varphi_t} \tag{A1-6}$$

$$r_P = \frac{\tan(\varphi_i - \varphi_t)}{\tan(\varphi_i + \varphi_t)} = \frac{n_2\cos\varphi_i - n_1\cos\varphi_t}{n_2\cos\varphi_i + n_1\cos\varphi_t} \tag{A1-7}$$

We see that for both refraction and reflection the two orientations of polarization depend differently on the angle of incidence, φ_i.

Brewster's angle

A special case is important. If we look at the last expression:

$$r_P = \frac{\tan(\varphi_i - \varphi_t)}{\tan(\varphi_i + \varphi_t)}$$

we see that if $\varphi_i + \varphi_t = \pi/2$ the denominator goes to infinity and, consequently, the fraction becomes zero. The incident angle in this case is called Brewster's angle, φ_B.

By rearranging $\varphi_t = \pi/2 - \varphi_B$, and by applying Snell's law we get:

$$n_1 \sin\varphi_B = n_2 \sin\varphi_t = n_2 \sin\left(\frac{\pi}{2} - \varphi_B\right) = n_2 \cos\varphi_B \tag{A1-8}$$

whence

$$\varphi_B = \arctan\left(\frac{n_2}{n_1}\right) \qquad \text{(A1-9)}$$

At the Brewster angle, all the reflected light is polarized perpendicular to the incident plane (see Figure 7-31)

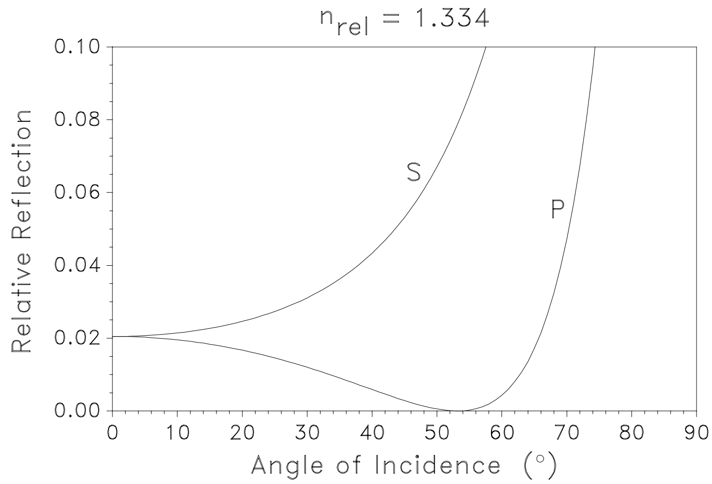


Figure 7-31: The Brewster effect for an air-water interface (φ_B = 53.1°). Polarization: P = parallel and S = perpendicular to the plane of incidence.

7.2.3.3 Characteristic scattering angles

Modes of scattering

Figure 7-32 shows the scattering angles obtained when two parallel rays of light coming from the left hit a spherical particle at angles of incidence (φ_i) and (φ_i + $\Delta\varphi_i$). The angles φ_0, φ_1 and φ_2 are measured from the forward direction and correspond to the reflected, the refracted and second order refracted light. (Higher orders of refraction carry only a small amount of the light intensity and will be neglected in this section.)

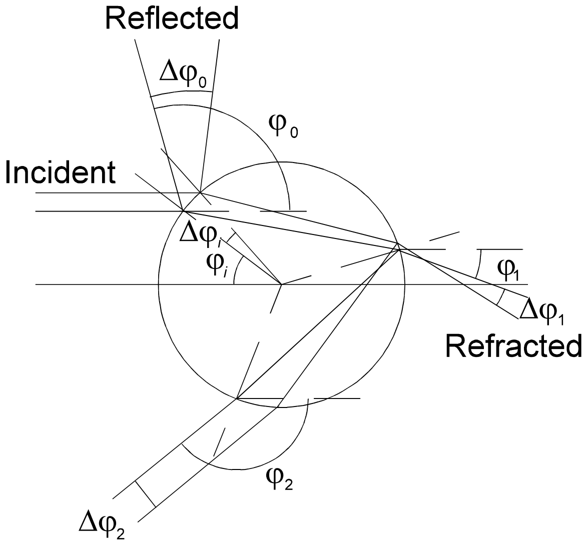


Figure 7-32: The definitions of the modes of scattering.

All three modes of scattering can be used with the PDA. There is, however, one crucial point which is imperative to be kept in mind. The PDA estimates the particle size from the phase differences of the Doppler bursts received by the different photo-detectors in the receiving optics. Since the three modes of scattering give rise to different conversion factors (phase factors), receiving light from more than one scattering mode is likely to give rise to errors.

Therefore, you should always set up a phase Doppler system so that only one mode of scattering dominates the light received by the receiving optics.

Various modes of scattering dominate the scattered light at different scattering angles. This we shall take into account when choosing the scattering angle. In addition, the angular dependence of the intensity of each scattering mode also differs with the polarization orientation of the scattered light, which also can be used to discriminate between the different modes.

Scattering angles

The angles of the reflected, refracted and second order refracted rays (Figure 7-33) can be expressed in terms of the angle of incidence, φ_i, and the relative refractive index n_{rel}.

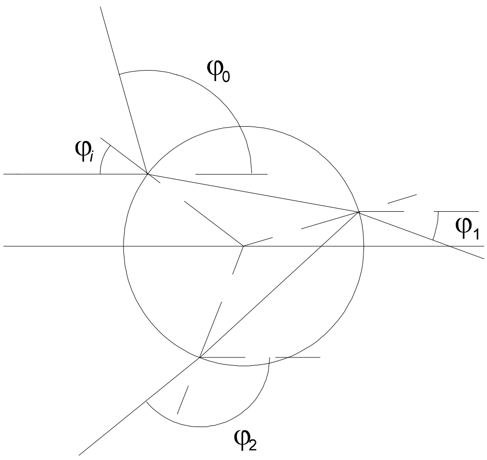


Figure 7-33: Ray tracing illustrating the angles φ_i, φ_0, φ_1 *and* φ_2.

For reflection:

$$\varphi_0 = \pi - 2\varphi_i \tag{A1-10}$$

For refraction:

$$\varphi_1 = 2\left[\arcsin\left(\frac{\sin\varphi_i}{n_{rel}}\right) - \varphi_i\right] \tag{A1-11}$$

For second order refraction:

$$\varphi_2 = 4\arcsin\left(\frac{\sin\varphi_i}{n_{rel}}\right) - 2\varphi_i - \pi \tag{A1-12}$$

Refracted light - importance of critical angle

For a bubble ($n_{rel} < 1$), the critical angle determines whether the incident light at the first interface will be transmitted into the interior. Thus, transmission will take place only when the incident angle is less than the critical angle:

$$\varphi_i < \varphi_c = \arcsin(n_{rel}) \tag{A1-13}$$

In the border case, when $\varphi_i = \varphi_c$ (Figure 7-34), the light will be refracted out again at the same point and in the direction:

$$\varphi_1 = (\pi - \varphi_c) - \varphi_c = 2\left(\frac{\pi}{2} - \arcsin(n_{rel})\right) = \varphi_{c1} \tag{A1-14}$$

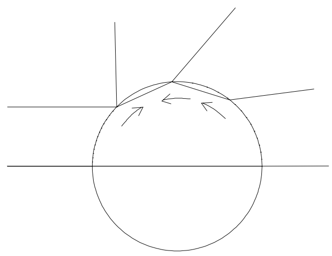


Figure 7-34: Near critical angle condition for a bubble of air in water. Approaching closer to the critical angle condition (arrows) brings closer together the points where reflected, refracted and second order refracted light is emitted.

Hence,

$$\varphi_{c1} = 2\arccos(n_{rel}) \tag{A1-15}$$

For a droplet ($n_{rel} > 1$), the critical angle $\varphi_c = \arcsin(1/n_{rel})$ determines whether light from the interior when hitting the second interface will be transmitted out to the exterior. Thus, transmission will take place only when the incident angle is less than $\pi/2$:

$$\varphi_i < \arcsin(n_{rel}\sin\varphi_c) = \frac{\pi}{2} \tag{A1-16}$$

The direction of the refracted light then becomes:

$$\varphi_1 = 2\left[\arcsin\left(\frac{1}{n_{rel}}\right) - \frac{\pi}{2}\right] = 2\arccos\left(\frac{1}{n_{rel}}\right) = \varphi_{c1} \tag{A1-17}$$

Second order refraction - Rainbow angle

For droplets and other particles with a relative refractive index $n_{rel} > 1$, the maximum intensity is obtained at the rainbow angle, φ_r, i.e. the minimum angle of second order refracted light, viz. the angle where this light folds back. The angle of a ray of second order refraction is φ_2, as expressed in equation (A1-12) above.

This angle has its minimum when:

$$\varphi_i = \arccos\left\{\sqrt{\frac{1}{3}\left(n_{rel}^2 - 1\right)}\right\}$$

$$\varphi_2 = 4\arcsin\left[\cos(\gamma) / n_{rel}\right] - 2\lambda - 2\pi = 4\arccos\left[\cos(\gamma) / n_{rel}\right] - 2\lambda \quad \text{(A1-18)}$$

which is at a minimum when:

$$\gamma = \arccos\left\{\sqrt{\frac{1}{3}\left(n_{rel}^2 - 1\right)}\right\} + \frac{\pi}{2} = \arcsin\left\{\sqrt{\frac{1}{3}\left(n_{rel}^2 - 1\right)}\right\} \quad \text{(A1-19)}$$

A special case occurs when the rainbow angle is:

$$\varphi_{r2} = 4\arcsin\left(\frac{\sin\varphi_i}{n_{rel}}\right) - 2\varphi_i - \pi = \pi \quad \text{(A1-20)}$$

This occurs when :

$$\varphi_i = \arccos\left\{\sqrt{\frac{1}{3}\left(n_{rel}^2 - 1\right)}\right\} = 0 \quad \text{(A1-21)}$$

which is satisfied when:

$$\sqrt{\frac{1}{3}\left(n_{rel}^2 - 1\right)} = 1, \text{ i.e. when } n_{rel} = 2 \quad \text{(A1-22)}$$

Critical angle

For a bubble ($n_{rel} < 1$), there is a range of forward scattering where second order refraction has two components in the same direction. This range is limited by the critical incident angle for the transmission at the first interface. Thus, for the light to be transmitted into the interior $\varphi_i < \varphi_c$.

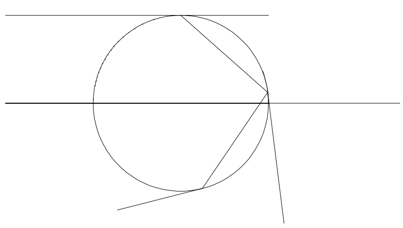


Figure 7-35: The critical angle condition illustrated for a droplet of water.

In the border case when $\varphi_i = \varphi_c$, the light will be refracted out again at the same point and in the direction:

$$\varphi_{c2} = 2\arccos(n_{rel}) = \varphi_{c1} \tag{A1-23}$$

Again, for a droplet ($n_{rel} > 1$), the critical angle expresses that light from the interior will be transmitted to the exterior only when the incident angle $\varphi_i < \pi/2$.

Under critical conditions the scattering angle of second order refracted light is:

$$\varphi_2 = 4\arcsin\left(\frac{1}{n_{rel}}\right) - 2\pi = \varphi_{c2} \tag{A1-24}$$

$$\varphi_{c2} = 4\left[\arcsin\left(\frac{1}{n_{rel}}\right) - \frac{\pi}{2}\right] = 4\arccos\left(\frac{1}{n_{rel}}\right) \tag{A1-25}$$

When the critical angle $\varphi_{c2} < \pi$, the range of the scattering angles between the rainbow angle and the critical angle will have two components of second order refracted light.
For critical angles $\varphi_{c2} > \pi$, the range φ_{r2}–2π to φ_{c2} has two components, while the range 2π to φ_{c2}–π has three components.

The special case $\varphi_{c2} = \pi$ occurs when:

$$\varphi_{c2} = 4\arccos(1/n_{rel}) = \pi \tag{A1-26}$$

$$n_{rel} = 1/\cos(\pi/4) = 1.414 \tag{A1-27}$$

Third order refraction - Rainbow angle

Similar to second order refraction, third order refraction has a rainbow angle:

$$\varphi_{r3} = 2\gamma - 6\cdot\arccos\left(\frac{\cos\gamma}{n_{rel}}\right) \tag{A1-28}$$

where:

$$\gamma = \arcsin\left(\sqrt{\frac{1}{8}\left(n_{rel}^2 - 1\right)}\right) \tag{A1-29}$$

Scattering chart

The relations given above for characteristic scattering angles can be summarized in chart form (A1-7), which is also a useful aid for selecting appropriate scattering angles for a PDA system.

Error! Objects cannot be created from editing field codes.*Figure 7-36**:* *Characteristic angles as functions of the relative refractive index (extended from Naqwi & Durst, 1990). For a tabulation of the numerical values (see 7-50)*

The chart can be subdivided into several regions representing the various characteristic scattering angles.

Reflection

Reflection exists over the entire chart. However, at the curve (dash-dot) representing the Brewster condition (φ_{b1}), parallel polarized reflected light is eliminated.

Using side scatter (reflected light) is therefore uncomplicated when this is the only scattering mode, i.e. in the unshaded area corresponding to the range $1 < n_{rel} < 2$ at scattering angles above the critical angle (φ_{c1}) for refraction (continuous line), and below the rainbow angle for second order refraction (dashed) and the critical angle for second order refraction (dashed). In addition, one should avoid the rainbow angle for second order refraction and the range close below this angle.

For $n_{rel} < 1$, scattering angles just below the critical angle for refraction (continuous line) should be chosen to avoid contributions from refracted light while maintaining light intensity.

Also, when $n_{rel} > 2$ you should choose scattering angles greater than φ_{c1} and, when possible, use parallel polarization in conjunction with φ_{b2} to avoid contributions from second order refraction.

Refraction

Refraction exists at scattering angles below the critical angle (fill patterns comprising horizontal lines and horizontal-vertical cross-hatching, and limited by continuous line). Using *forward scatter* is the best for $n_{rel} > 1.27$, where the optimum scattering angle is φ_{b1}, the Brewster condition (dash-dot) in combination with parallel polarization to avoid contribution from reflected light.

Second order refraction

Second order refraction exists for $n_{rel} > 1$ at scattering angles above the rainbow angle or above the critical angle for second order refraction. In the regions represented by light vertical lines, this mode has only a single contribution. Using *back scatter* is often complicated by the emitted light rays in a given direction emerging at different locations of the particle surface, thus giving two contributions (horizontal-vertical cross-hatching for $n_{rel} < 1$, or medium vertical lines) or three contributions (heavy vertical lines).

Using light from such regions is likely to cause non-linearities in the diameter–phase relationship. To avoid this it is preferable to choose regions of the chart where the rays in a given direction stem from (or at least are dominated by) only one incident ray. This would be the case at scattering angles higher than the critical angle φ_{c2}, and at relative refractive index above about 1.5 below the rainbow angle. Most often the best results are obtained with perpendicular polarization to avoid the Brewster effect around φ_{b2}.

For $n_{rel} < 1$ this mode of scattering exists at all angles.
In the range 0 to $\varphi_{c2} = \varphi_{c0}$ (corresponding to the range of first order of diffraction), there are two contributions.

Third order refraction

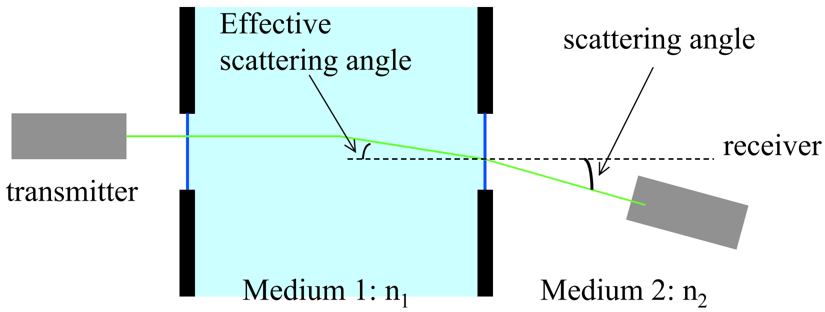
Third order refraction (dotted area) normally carries little enough light that it may be neglected. At its rainbow angle, however, this scattering mode can have sufficient intensity that it will distort the light received from reflection.

The values of the characteristic angles can be obtained from the Receiving optics setup menu of the *SIZEware* by pressing Ctrl-A.

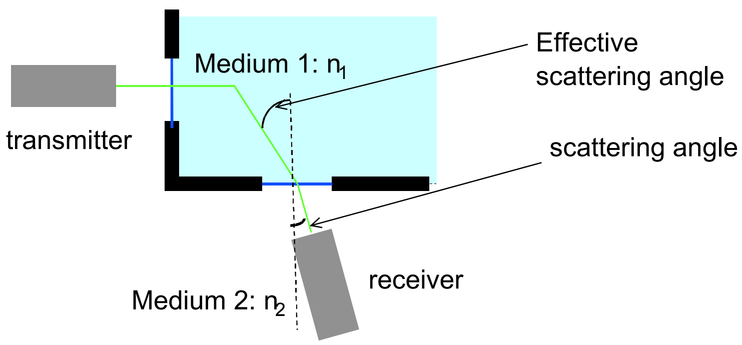
7.2.3.4 Scattering angle and effective scattering angle.

In measuring in a water tank or behind a window, you may have to take into account the deviation of the light due to diference of refractive index. You have to calculate the effective scattering angle. The following pictures give you a formula to calculate the effective scattering angle. These formulas are an approximation of the Snell's law. The effective angle will be used in the BSA software to calculate the good phase factor.

Effective scattering angle = scattering angle / n_{rel} with $n_{rel} = n_1 / n_2$



Effective scattering angle = 90 - scattering angle * n_{rel} with $n_{rel} = n_1 / n_2$



7.2.4 Implementing PDA principles and the DualPDA concept

7.2.4.1 The 57X40 Fiber PDA and the *57X80 DualPDA receiving optics*

Integrated unit

Although the optical arrangement of the Fiber PDA probe and DualPDA Probe, as described in 7.2.2 The concept of the DualPDA is a combination of a two-detectors conventional PDA and a two-detectors planar PDA, it is implemented in the 57X40 Fiber PDA probe and 57X80 DualPDA Probe as an integrated unit. Here, the flexibility of adjustable angular positions of the detectors (by means of exchangeable aperture plates) is combined with the convenience in alignment of having one common front lens. The probe is spray tight and is made of aluminium.

A simplified outline of the *Fiber PDA* and *DualPDA Probes* is shown in Figure 7-37 and Figure 7-38. The main optical components of the probes are indicated schematically.

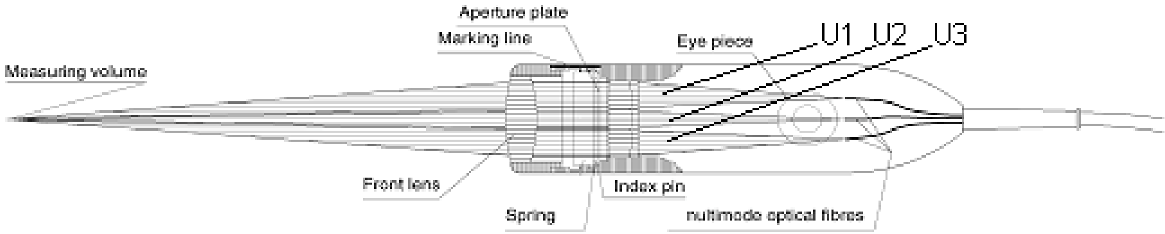


Figure 7-37: The layout of the fiber PDA Probe.The three detectors U1, U2, U3 are in the drwing plane. The eyepiece is looking at fiber U2.

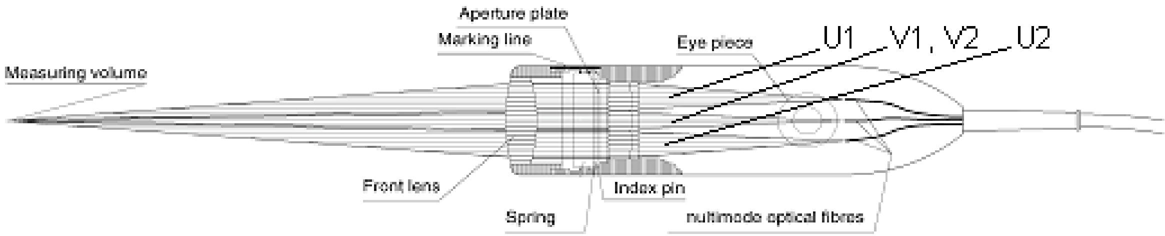


Figure 7-38: The layout of the Dual PDA Probe.The two detectors U1, U2 are in the drawing plane.The two detectors V1, V2 are in the plane perpendicular to the drawing. The eyepiece is looking at fiber V2.

The Fiber PDA and DualPDA Probe collects scattered light from the beam intersection. This light is guided through four multi-mode optical fibres each representing a specific viewing angle. The Fiber PDA probes uses three optical fibres and the Dual PDA probes usues four optical fibres. All of them run in a single cable leading to the Detector nit. At the detector unit end the cable is split into three (Fiber PDA) or four (Dual PDA), each containing one fibre.

Components

The Fiber and DualPDA Probes carrie the main optical components for the collection of light:

- Front lens.
- Aperture plate.
- Composite lens.
- Alignment eyepiece.

The front lens works as a collimator creating a beam of parallel light.

Following the front lens is an aperture plate. This divides the parallel light beam into three segment corresponding to the photomultupliers *U1, U2, U3* for *the Fiber PDA* or into four segments corresponding to the photo-multipliers *U1*, *U2*, *V1* and *V2*. Three exchangeable aperture plates are included for the *Fiber PDA* probe and for the *Dual PDA* probe.

Corresponding to each segment apertures of the aperture plates are focusing lenses cemented together into a composite lens. Each focuses a segment of the parallel light beam forming an image of the intersection volume on one of the slit-shaped spatial filters in front of an optical fibre (Figure 7-39). The part of the image which falls on the slit itself corresponds to the probe volume (see 7.5.2 Moments (one-time statistics). Only the light from the probe volume is passed by the optical fibre to the photo-multipliers.

Alignment

of the eyepiece

The focusing of the image onto the slit-shaped spatial filters can be inspected via an alignment eyepiece. The alignment eyepiece is a lens magnifying the image of the focusing plane on the fibre end of fiber V1 so that the *DualPDA Probe* can be accurately aligned with the beam intersection volume.

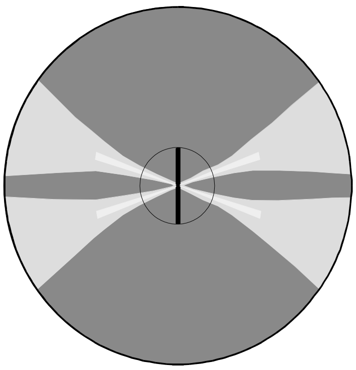


Figure 7-39: The image of the beam crossing on the spatial filter.

Front lenses

A range of front lenses is available. The front lens is a separate unit not included with the probe. All front lenses for the DualPDA receiving optics can be used on the *60X60, 60X61, 60X62, 60X63, 60X64, 60X65, 60X66* and *60X67 FiberFlow Probe*s and vice versa.

Size range

The measurable size range is determined by the following parameters:

- Beam intersection angle of the transmitting optics (defined by the beam separation and the front lens focal length).
- Focal length of the receiving front lens.
- Aperture plate.
- Selected polarization.
- Scattering angle.

The *57X80 DualPDA Probe* is compatible with the *60X60* and *60X61* FiberFlow probes concerning the use of beam expanders, side-looking section, probe supports, etc.

Aperture plates

The aperture plate defines the receiving apertures. The size range can be selected by the choice of aperture plate, without changing the focal length of the front lens or the scattering angle.

Three standard plates are included with the probe (Figure 7-40, Figure 7-41), *A*, *B* and *C*. The effective spatial (azimuthal) position of each segment, and thus the particle size sensitivity and range, depends on which plate is used. The aperture plates are exchangeable.

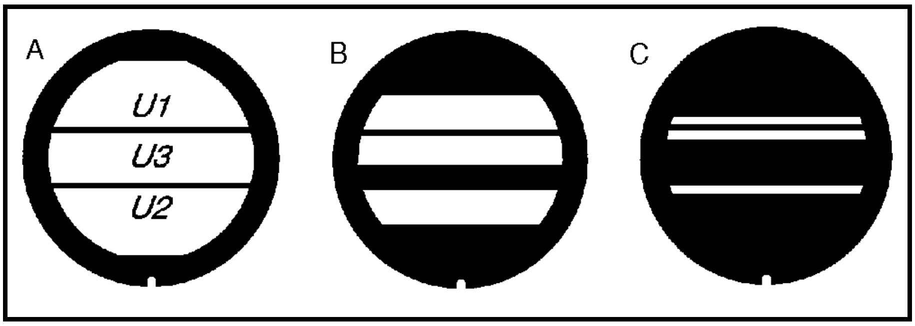


Figure 7-40: The three standard aperture plates for the 57X40 FiberPDA receiving optics .

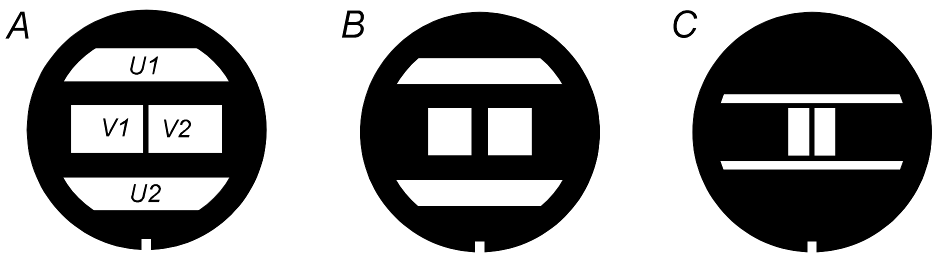


Figure 7-41: The three standard aperture plates for the 57X80 DualPDA Probe.

Segmented lens

The segmented lens consists of three elements for the *FiberPDA* reciving probe nad four elements for the *Dual PDA* receiving probe.Each segment of this lens focuses a portion of the scattered light on the corresponding multi-mode fibre. Each segment of this lens has a focal length of 125 mm.

7.2.4.2 The 58N71 Fiber PDA detector unit and the 58N81 DualPDA Detector Unit

The *58N70 Fiber PDA detector unit* comprises three photo-multipliers and the *58N81 DualPDA Detector Unit* comprises four photo-multipliers. Both of them compise components for calibration and for optical filtering. The multi-mode optical fibres from each probe are connected to this detector unit.

The end of the optical fibre cable away from the *Fiber PDA Probe* is split into three branches with one fibre in each, corresponding to *U1*, *U2*, *U3*. The end of the optical fibre cable away from the *Dual PDA Probe* is split into four branches with one fibre in each, corresponding to *U1*, *U2*, V1 and V2. Each connects to a receptacle on the back panel of the *Detector Unit* and directs its light output onto a photo-multiplier tube.

Interference filters

Interference filters are mounted in front of each photo-multiplier.

- Fiber PDA

This is often not necessary in 1D applications, but for 2D and 3D it is indispensable.

For 1D applications these filters block out background light and are recommended. With He-Ne lasers use filters for wavelength 623.8 nm (red). With argon lasers use filters for wavelengths 514.5 nm (green), or 488 nm (blue) or 476.5 nm (violet).

For 2D applications, the 58N71 2D extension kit is installed in the detector unit. The kit comprises a colour beam splitter, three 514.5 nm interference filters, one 488 nm interference filter and a photo-multiplier.

For 3D applications, the 58N72 2D to 3D extension kit is installed. This kit comprises a colour beam splitter, a 476.5 nm interference filter and a photo-multiplier.

If used for 2D or 3D measurement, i.e. with a 58N71 2D extension kit or (also) a 58N72 3D extension kit installed, the 57X32 filter is required to let in the green light (wavelength 514.5 nm), while blocking out the light carrying the other velocity components.

The light from the middle segment of the probe, U3, passes through one (or two) beam splitters separating out the 488 nm (blue) light, which is directed to the photo-multiplier tube for the V channel (2D and 3D), and the 476.5 nm (violet) light, which is received by the photo-multiplier tube for the W channel (3D).

- Dual PDA

For U1 and U2 these have a narrow pass band at 514.5 nm wavelength corresponding to the green argon line. For V1 and V2 the interference filters pass blue light of wavelength 488 nm.

The *58N82 DualPDA* Velocity Extension Kit comprises a fifth interference filter, with a pass band for the 476.5 nm wavelength.

Calibration system

The electrical response of a photo-multiplier tube lags slightly relative to the light input. This lag depends partly on the individual tube and partly on the high voltage applied to the photo-multiplier anode. Lack of knowledge of the exact value of the difference in delay between channels *U1*, *U2*, *V1* and *V2* could lead to substantial errors in the estimated phase differences and hence to unreliable calculations of the particle diameter.

To remedy this problem, the *58N81 DualPDA Detector Unit* has a calibration system. During calibration, a motor-driven shutter first blocks the light from all four optical fibres from the *57X80 DualPDA Probe*; thus the light input from the probe cannot disturb the measurements.

Then a diode laser built into the signal processor sends an intensity modulated light calibration signal to the four photo-multipliers *U1*, *U2 V1* and *V2* via a multi-mode optical fibre; the differences in the delays of the photo-multiplier tubes are measured and compensated for in the diameter calculations.

7.3 Setting up a PDA system

In setting up any phase Doppler anemometer system for making reliable size measurements some basic understanding of a few scattering phenomena is necessary. These concepts are then applied to the setting up of a conventional PDA system, in particular to the choice of scattering angle. Many of the factors considered apply also to the DualPDA, however there are some special considerations, since in the DualPDA also a planar PDA is being used. Thus the conventional and planar PDA must be simultaneously optimized in the DualPDA. The conditions to achieve this are reviewed in the final section.

This appendix has been purposely been made more comprehensive to provide a more intuitive feeling to the optimization problem. However it certainly does not replace a more thorough treatment of the problem and for this, reference can be made to a number of textbooks and publications.

7.3.1 General

7.3.1.1 Selecting scattering and polarization angles

A phase Doppler system should be set up so that the relationship between particle diameter and phase difference is linear. In general, this is obtained by choosing an angle where one single mode dominates the scattered light received by the receiving optics, and where the signal-to-noise ratio is as high as possible. The scattering modes vary with scattering angle and with orientation of polarization. This can be utilized to obtain the best measuring conditions under the given constrictions imposed by practicality in the specific measurement situation.

The top panel of Figure 7-42 shows ray tracings of reflection and first and second order of refraction. More importantly, the bottom panel shows the intensity of the light scattered by the three different scattering modes against scattering angle for two orientations of polarization, perpendicular (upper half) and parallel (lower half) to the scattering plane, as a function of scattering angle.

In addition the total intensity of the scattered light is shown as calculated from Lorenz-Mie analysis. When the Lorenz-Mie curve is very close to one of the modes, this mode is dominant and we would expect good linearity.

For both orientations of polarization, first order refraction is dominant for small scattering angles, i.e. its intensity is much greater than that for reflected light. Thus, a scattering angle around $\varphi = 30°$ (for a water droplet) can be used with either polarization. Increasing the scattering angle beyond about 30° results in increasingly different behaviour for the two orientations of polarization: whereas refraction gets less dominant for perpendicular polarization, the situation is quite the opposite for parallel polarization.

Due to the Brewster effect on the surface of the droplet, the reflected light is completely subdued at a scattering angle of $\varphi_{b1} = 73.7°$ (for a water droplet). This is therefore a very good angle for measuring the size of water droplets provided the transmitting optics can be set to parallel polarization. The useful range for refraction with parallel polarization is hatched horizontally in Figure 7-42.

Beyond the scattering angle of $\varphi_{c1} = 82.9°$ (for a water droplet) there is no longer any first order refraction. Thus, reflection is the only one of the three modes of scattering present, and can be used with perpendicular polarization in the slant-hatched range of Figure 7-42.

Second order refraction takes over at scattering angles beyond the rainbow angle, $\varphi_r = 138.0°$ (for a water droplet). In general, this mode of scattering should be used only with great caution. In part of the range, two components contribute to this mode yielding non-linearities in the size-phase relationship, and in the remaining range there is not so great a difference in intensity between second order refraction and reflection. If the constrictions are very severe, however, it is possible to make measurements in the range indicated by vertical hatches in Figure 7-42.

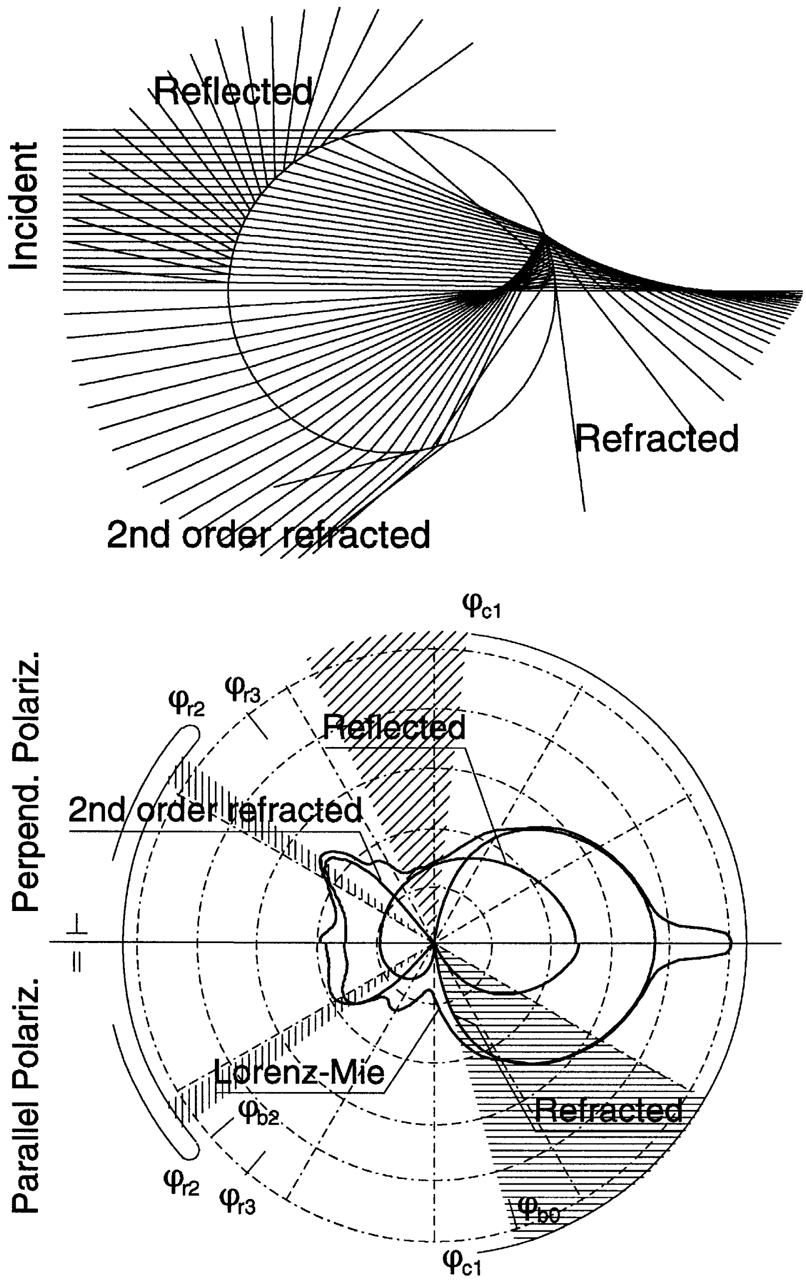


Figure 7-42. The upper panel shows ray traces indicating the three modes of scattering, reflection and first and second order refraction, for a water droplet. In the lower panel, the light intensity (log scale, one decade between each circle) for each of these modes is shown in a polar plot for scattering angles from 0° to 180° and for two polarizations — the upper half at 90° to the scattering plane, and the lower half parallel to the scattering plane.

7.3.1.2 Dependence of geometrical factor on relative refractive index

Refraction by a droplet

As it appears from equation (**For first order refraction** *(*Equation 7-17 in 7.2.1) for first order refraction, the geometrical factor, β, for refraction depends on the relative refractive index of the particle, n_{rel}, in addition to the angles ϑ, ψ and φ. In many situations the exact value of n_{rel} is not known.

As shown in Figure 7-43, the geometrical factor, β, becomes less dependent on n_{rel} as the scattering angle φ increases. Clearly, however, there is a limit to how great a scattering angle can be used, since light scattered by refraction only exists at scattering angles less than φ_{c1}. Moreover, to get a linear size-phase relationship regions where two or more modes of scattering make contributions of the same order of magnitude to the intensity of the scattered light should be avoided.

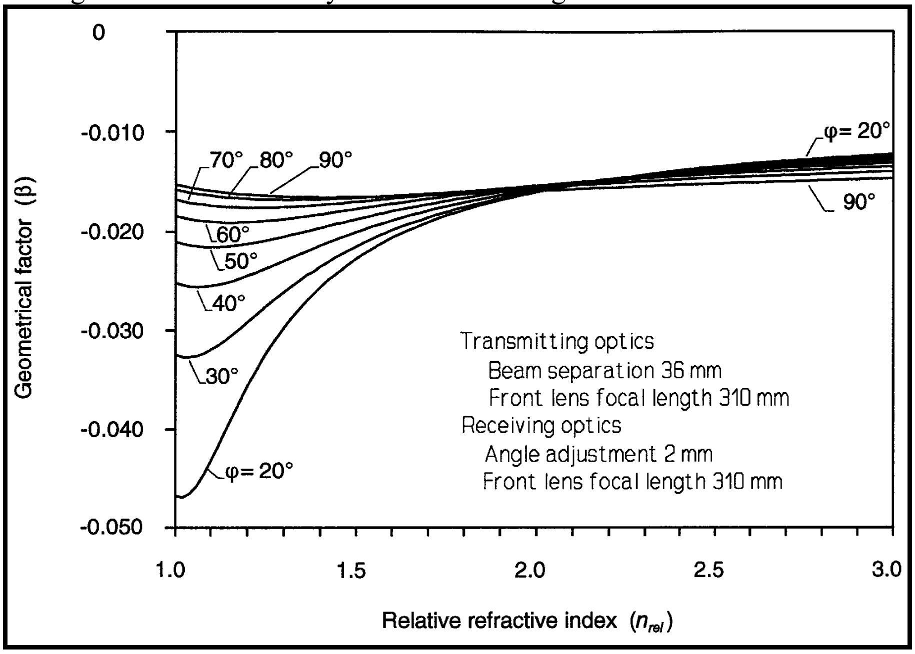


Figure 7-43. The effect of changing the value of the relative refractive index at eight different scattering angles.

Reflection of a droplet

While β for refraction is dependent on n_{rel}, β in the case of reflection shows no such dependence.

As shown below, however, both with reflection and refraction β changes when the scattering angle, φ, is changed. This phenomenon can be used as an additional means of changing the sensitivity and size range of the PDA.

7.3.1.3 Changing the PDA's sensitivity and size range by changing the scattering angle

Refraction

As is evident from Figure 7-43, which shows β as a function of n_{rel} at various values of φ, the relationship between β and φ is heavily dependent on n_{rel}. While at high n_{rel}, such as 2.0, β changes only very little; for φ > 10°, the change becomes considerable for lower values of n_{rel}.

Correspondingly, Figure 7-44 shows that the dependence of β on the relative refractive index is greater at lower scattering angles — such as 30° — than at greater angles.

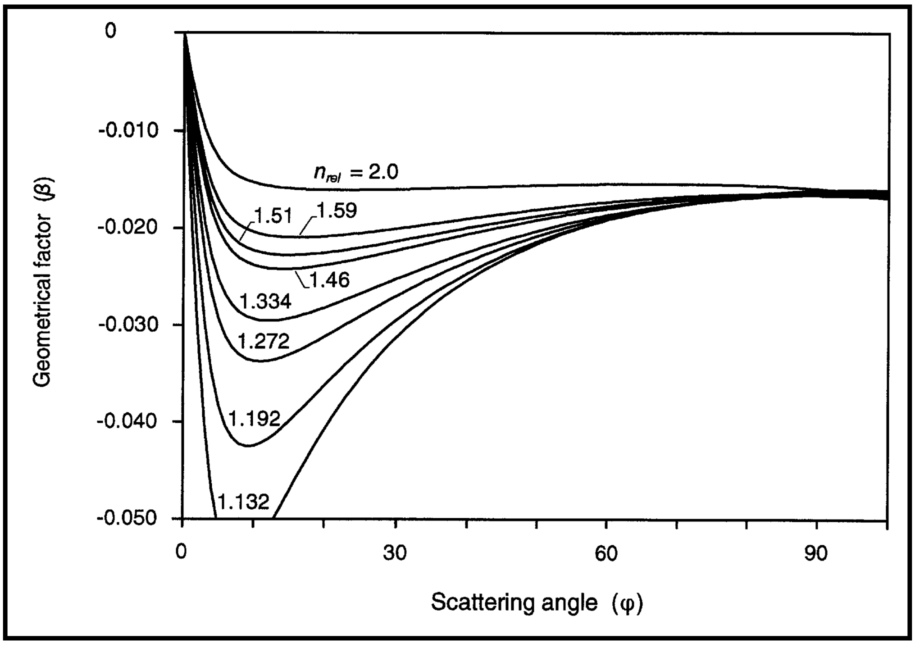


Figure 7-44. The geometrical factor β as a function of the scattering angle φ for different relative refractive indices.

Reflection

Figure 7-45 shows that, while the geometrical factor for reflection is independent of the relative refractive index, it is heavily dependent on the scattering angle. This dependence can be used to supplement or substitute for changes in ϑ or for changing the aperture plate or the micrometer setting of the angle adjustment in the ClassicPDA, respectively.

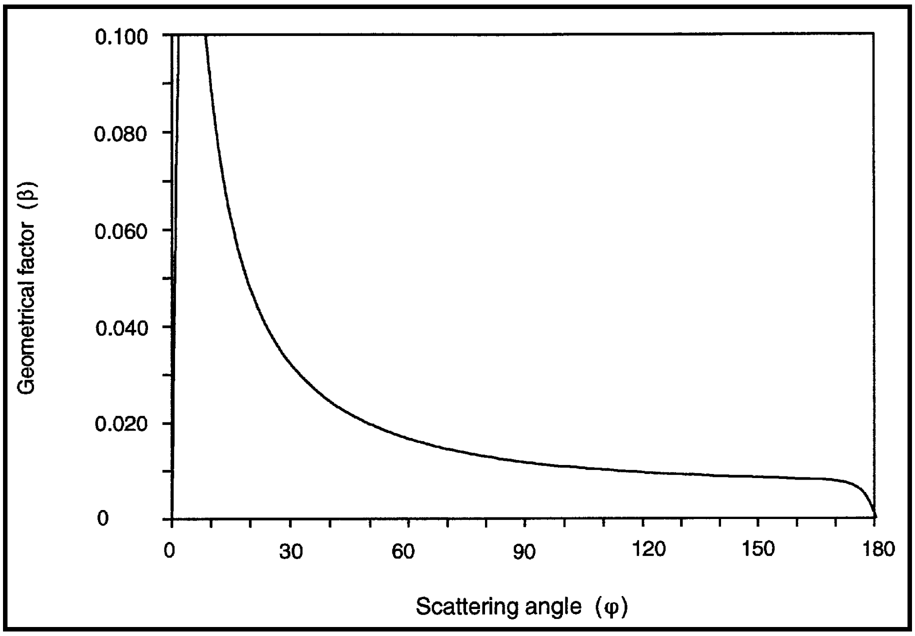


Figure 7-45. The geometrical factor as a function of scattering angle for light scattered by reflection.

When selecting the scattering angle, however, optimum results are obtained only in the range of φ where reflection is the sole mode of scattering. This means that $\varphi > \varphi_{c1}$ and $\varphi < \varphi_r$. If you do not know the exact value of n_{rel}, you must pick the greatest value of φ_{c1} and the smallest value of φ_r.

In addition, it is important to avoid the interference with third order refraction, i.e. either select a scattering angle of minimum 4° to 5° above φ_{r3}, or at least about 15° below this angle. This means that you must consider the range of relative refractive index.

Figure 7-46 illustrates as an example the situation where n_{rel} may vary between 1.334 and 1.46. It is seen here that the rainbow angle of third order refraction sweeps almost the entire sector between the greatest value of φ_{c1} and the smallest value of φ_r, rendering only one useful angle.

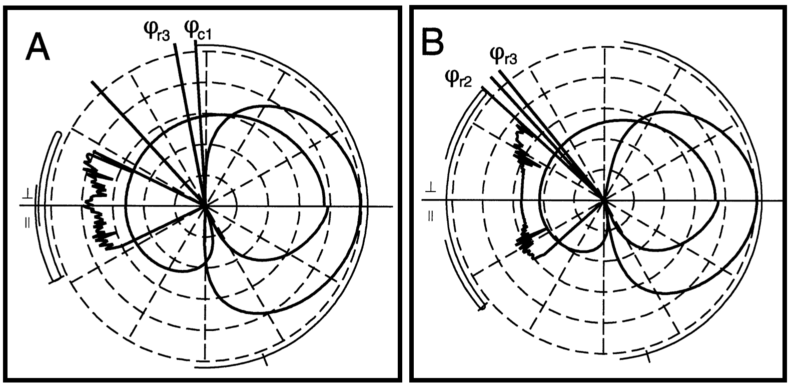


Figure 7-46: Intensity charts representing two relative refractive indices, 1.46 (A) and 1.334 (B), determining the lower and upper bounds to the useful range of scattering angles.

7.3.1.4 Table of characteristic angles

The following table is the basis for Error! Objects **cannot be created from editing field codes.Figure** 7-36*:* It can be used as a tool for selecting the scattering angle. For the definition of the angles please see *7.3.1.5 Definitions*.

n_{rel}	φ_{c1} [°]	φ_{b0} [°]	φ_{c2} [°]	φ_{b2} [°]	φ_{r2} [°]	φ_{r3} [°]
0.00	180.0	180.0	180.0	180.0	–	–
0.01	178.8	178.8	178.8	176.5	–	–
0.02	177.7	177.7	177.7	173.1	–	–
0.03	176.5	176.5	176.5	169.6	–	–
0.04	175.4	175.4	175.4	166.2	–	–
0.05	174.2	174.2	174.2	162.8	–	–
0.06	173.1	173.1	173.1	159.3	–	–
0.07	171.9	171.9	171.9	155.9	–	–
0.08	170.8	170.8	170.8	152.5	–	–

0.09	169.6	169.7	169.6	149.1	–	–
0.10	168.5	168.5	168.5	145.7	–	–
0.11	167.3	167.4	167.3	142.3	–	–
0.12	166.2	166.3	166.2	138.9	–	–
0.13	165.0	165.1	165.0	135.5	–	–
0.14	163.9	164.0	163.9	132.1	–	–
0.15	162.7	162.9	162.7	128.8	–	–
0.16	161.5	161.8	161.5	125.4	–	–
0.17	160.4	160.7	160.4	122.1	–	–
0.18	159.2	159.5	159.2	118.7	–	–
0.19	158.0	158.4	158.0	115.4	–	–
0.20	156.9	157.3	156.9	112.1	–	–
0.21	155.7	156.2	155.7	108.8	–	–
0.22	154.5	155.1	154.5	105.5	–	–
0.23	153.4	154.0	153.4	102.2	–	–
0.24	152.2	153.0	152.2	99.0	–	–
0.25	151.0	151.9	151.0	95.7	–	–
0.26	149.8	150.8	149.8	92.5	–	–
0.27	148.6	149.7	148.6	89.3	–	–
0.28	147.4	148.7	147.4	86.1	–	–
0.29	146.2	147.6	146.2	82.9	–	–
0.30	145.0	146.6	145.0	79.8	–	–
0.31	143.8	145.5	143.8	76.6	–	–
0.32	142.6	144.5	142.6	73.5	–	–
0.33	141.4	143.4	141.4	70.4	–	–
0.34	140.2	142.4	140.2	67.3	–	–
0.35	139.0	141.4	139.0	64.2	–	–
0.36	137.7	140.4	137.7	61.2	–	–
0.37	136.5	139.3	136.5	58.1	–	–
0.38	135.3	138.3	135.3	55.1	–	–
0.39	134.0	137.3	134.0	52.1	–	–
0.40	132.8	136.3	132.8	49.1	–	–
0.41	131.5	135.4	131.5	46.2	–	–
0.42	130.3	134.4	130.3	43.3	–	–
0.43	129.0	133.4	129.0	40.3	–	–
0.44	127.7	132.5	127.7	37.5	–	–
0.45	126.5	131.5	126.5	34.6	–	–

n_{rel}	φ_{c1} [°]	φ_{b0} [°]	φ_{c2} [°]	φ_{b2} [°]	φ_{r2} [°]	φ_{r3} [°]
0.46	125.2	130.5	125.2	31.7	–	–
0.47	123.9	129.6	123.9	28.9	–	–
0.48	122.6	128.7	122.6	26.1	–	–
0.49	121.3	127.7	121.3	23.3	–	–
0.50	120.0	126.8	120.0	20.6	–	–
0.51	118.6	125.9	118.6	17.8	–	–
0.52	117.3	125.0	117.3	15.1	–	–
0.53	115.9	124.1	115.9	12.4	–	–
0.54	114.6	123.2	114.6	9.7	–	–
0.55	113.2	122.3	113.2	7.1	–	–
0.56	111.8	121.5	111.8	4.5	–	–
0.57	110.4	120.6	110.4	1.9	–	–
0.58	109.0	119.7	109.0	0.6	–	–
0.59	107.6	118.9	107.6	3.2	–	–
0.60	106.2	118.0	106.2	5.7	–	–
0.61	104.8	117.2	104.8	8.2	–	–
0.62	103.3	116.4	103.3	10.7	–	–
0.63	101.8	115.5	101.8	13.2	–	–
0.64	100.4	114.7	100.4	15.7	–	–
0.65	98.9	113.9	98.91	18.1	–	–
0.66	97.4	113.1	97.40	20.5	–	–
0.67	95.8	112.3	95.8	22.9	–	–
0.68	94.3	111.5	94.3	25.2	–	–
0.69	92.7	110.7	92.7	27.6	–	–
0.70	91.1	110.0	91.1	29.9	–	–
0.71	89.5	109.2	89.5	32.2	–	–
0.72	87.8	108.4	87.8	34.5	–	–
0.73	86.2	107.7	86.2	36.7	–	–
0.74	84.5	106.9	84.5	39.0	–	–
0.75	82.8	106.2	82.8	41.2	–	–
0.76	81.0	105.5	81.0	43.4	–	–
0.77	79.2	104.8	79.2	45.5	–	–
0.78	77.4	104.0	77.4	47.7	–	–
0.79	75.6	103.3	75.6	49.8	–	–
0.80	73.7	102.6	73.7	51.9	–	–
0.81	71.8	101.9	71.8	54.0	–	–
0.82	69.8	101.2	69.8	56.1	–	–
0.83	67.8	100.6	67.8	58.1	–	–
0.84	65.7	99.9	65.7	60.1	–	–
0.85	63.5	99.2	63.5	62.1	–	–
0.86	61.3	98.6	61.3	64.1	–	–
0.87	59.0	97.9	59.0	66.1	–	–
0.88	56.7	97.3	56.7	68.0	–	–
0.89	54.2	96.6	54.2	70.0	–	–
0.90	51.6	96.0	51.6	71.9	–	–
0.91	48.9	95.3	48.9	73.8	–	–
0.92	46.1	94.7	46.1	75.6	–	–
0.93	43.1	94.1	43.1	77.5	–	–
0.94	39.8	93.5	39.8	79.3	–	–
0.95	36.3	92.9	36.3	81.1	–	–
0.96	32.5	92.3	32.5	82.9	–	–

n_{rel}	φ_{c1} [°]	φ_{b0} [°]	φ_{c2} [°]	φ_{b2} [°]	φ_{r2} [°]	φ_{r3} [°]
0.97	28.1	91.7	28.1	84.7	–	–
0.98	22.9	91.1	22.9	86.5	–	–
0.99	16.2	90.5	16.2	88.2	–	–
1.00	0.0	90.0	0.0	90.0	0.0	0.0
1.01	16.1	89.4	32.2	91.7	27.92	45.6
1.02	22.7	88.8	45.4	93.4	39.28	64.2
1.03	27.7	88.3	55.4	95.0	47.86	78.3
1.04	31.8	87.7	63.7	96.7	54.97	90.0
1.05	35.5	87.2	71.0	98.3	61.15	100.2
1.06	38.7	86.6	77.4	100.0	66.65	109.2
1.07	41.6	86.1	83.3	101.6	71.62	117.5
1.08	44.3	85.5	88.7	103.2	76.18	125.1
1.09	46.8	85.0	93.7	104.7	80.40	132.1
1.10	49.2	84.5	98.4	106.3	84.33	138.6
1.11	51.4	84.0	102.8	107.9	88.00	144.8
1.12	53.5	83.5	107.0	109.4	91.47	150.6
1.13	55.5	83.0	111.0	110.9	94.73	156.1
1.14	57.3	82.5	114.7	112.4	97.83	161.3
1.15	59.1	82.0	118.3	113.9	100.7	166.3
1.16	60.9	81.5	121.8	115.4	103.5	171.1
1.17	62.5	81.0	125.0	116.8	106.2	175.6
1.18	64.1	80.5	128.2	118.3	108.8	179.9
1.19	65.6	80.0	131.2	119.7	111.2	175.7
1.20	67.1	79.6	134.2	121.1	113.6	171.7
1.21	68.5	79.1	137.0	122.5	115.8	167.8
1.22	69.8	78.6	139.7	123.9	118.0	164.1
1.23	71.2	78.2	142.4	125.3	120.1	160.5
1.24	72.4	77.7	144.9	126.6	122.1	156.9
1.25	73.7	77.3	147.4	128.0	124.0	153.6
1.26	74.9	76.8	149.8	129.3	125.9	150.3
1.27	76.1	76.4	152.2	130.6	127.7	147.1
1.28	77.2	75.9	154.4	132.0	129.5	144.0
1.29	78.3	75.5	156.7	133.3	131.2	141.0
1.30	79.4	75.1	158.8	134.5	132.8	138.1
1.31	80.4	74.7	160.9	135.8	134.4	135.3
1.32	81.4	74.2	162.9	137.1	135.9	132.5
1.33	82.4	73.8	164.9	138.3	137.4	129.8
1.34	83.4	73.4	166.9	139.6	138.9	127.2
1.35	84.4	73.0	168.8	140.8	140.3	124.7
1.36	85.3	72.6	170.6	142.0	141.6	122.2
1.37	86.2	72.2	172.4	143.2	143.0	119.8
1.38	87.1	71.8	174.2	144.4	144.2	117.5
1.39	87.9	71.4	175.9	145.6	145.5	115.2
1.40	88.8	71.0	177.6	146.7	146.7	112.9
1.41	89.6	70.6	179.3	147.9	147.9	110.7
1.42	90.4	70.3	179.0	149.0	149.0	108.6
1.43	91.2	69.9	177.4	150.2	150.1	106.5
1.44	92.0	69.5	175.9	151.3	151.2	104.4
1.45	92.7	69.1	174.4	152.4	152.3	102.5
1.46	93.5	68.8	172.9	153.5	153.3	100.5
1.47	94.2	68.4	171.4	154.6	154.3	98.6

n_{rel}	φ_{c1} [°]	φ_{b0} [°]	φ_{c2} [°]	φ_{b2} [°]	φ_{r2} [°]	φ_{r3} [°]
1.48	94.9	68.0	170.0	155.7	155.3	96.7
1.49	95.6	67.7	168.6	156.7	156.2	94.9
1.50	96.3	67.3	167.2	157.8	157.1	93.1
1.51	97.0	67.0	165.8	158.9	158.0	91.3
1.52	97.7	66.6	164.5	159.9	158.9	89.6
1.53	98.3	66.3	163.2	160.9	159.7	87.9
1.54	99.0	65.9	161.9	162.0	160.5	86.3
1.55	99.6	65.6	160.7	163.0	161.3	84.6
1.56	100.2	65.3	159.4	164.0	162.1	83.1
1.57	100.8	64.9	158.2	165.0	162.9	81.5
1.58	101.4	64.6	157.0	166.0	163.6	80.0
1.59	102.0	64.3	155.8	166.9	164.3	78.5
1.60	102.6	64.0	154.7	167.9	165.0	77.0
1.61	103.2	63.6	153.5	168.9	165.7	75.6
1.62	103.7	63.3	152.4	169.8	166.4	74.2
1.63	104.3	63.0	151.3	170.8	167.0	72.8
1.64	104.8	62.7	150.2	171.7	167.6	71.4
1.65	105.3	62.4	149.2	172.6	168.2	70.1
1.66	105.9	62.1	148.1	173.6	168.8	68.8
1.67	106.4	61.8	147.1	174.5	169.4	67.5
1.68	106.9	61.5	146.1	175.4	170.0	66.2
1.69	107.4	61.2	145.1	176.3	170.5	65.0
1.70	107.9	60.9	144.1	177.2	171.0	63.7
1.71	108.4	60.6	143.1	178.0	171.5	62.5
1.72	108.9	60.3	142.1	178.9	172.0	61.3
1.73	109.3	60.0	141.2	179.8	172.5	60.2
1.74	109.8	59.7	140.3	179.3	173.0	59.0
1.75	110.3	59.4	139.3	178.4	173.4	57.9
1.76	110.7	59.2	138.4	177.6	173.8	56.8
1.77	111.1	58.9	137.6	176.7	174.3	55.7
1.78	111.6	58.6	136.7	175.9	174.7	54.7
1.79	112.0	58.3	135.8	175.1	175.1	53.6
1.80	112.5	58.1	134.9	174.3	175.4	52.6
1.81	112.9	57.8	134.1	173.5	175.8	51.6
1.82	113.3	57.5	133.3	172.7	176.2	50.6
1.83	113.7	57.3	132.4	171.9	176.5	49.6
1.84	114.1	57.0	131.6	171.1	176.8	48.6
1.85	114.5	56.7	130.8	170.3	177.1	47.7
1.86	114.9	56.5	130.0	169.5	177.4	46.8
1.87	115.3	56.2	129.3	168.8	177.7	45.9
1.88	115.7	56.0	128.5	168.0	178.0	44.9
1.89	116.1	55.7	127.7	167.3	178.2	44.1
1.90	116.4	55.5	127.0	166.5	178.5	43.2
1.91	116.8	55.2	126.2	165.8	178.7	42.3
1.92	117.2	55.0	125.5	165.0	178.9	41.5
1.93	117.5	54.7	124.8	164.3	179.1	40.6
1.94	117.9	54.5	124.1	163.6	179.3	39.8
1.95	118.2	54.2	123.4	162.8	179.4	39.0
1.96	118.6	54.0	122.7	162.1	179.6	38.2
1.97	118.9	53.8	122.0	161.4	179.7	37.4
1.98	119.3	53.5	121.3	160.7	179.8	36.7

n_{rel}	φ_{c1} [°]	φ_{b0} [°]	φ_{c2} [°]	φ_{b2} [°]	φ_{r2} [°]	φ_{r3} [°]
1.99	119.6	53.3	120.6	160.0	179.9	35.9
2.00	120	53.1	120.0	159.3	180	35.2
2.01	120.3	52.9	119.3	158.7	–	34.4
2.02	120.6	52.6	118.6	158.0	–	33.7
2.03	120.9	52.4	118.0	157.3	–	33.0
2.04	121.2	52.2	117.4	156.6	–	32.3
2.05	121.6	52.0	116.7	156.0	–	31.6
2.06	121.9	51.7	116.1	155.3	–	30.9
2.07	122.2	51.5	115.5	154.7	–	30.3
2.08	122.5	51.3	114.9	154.0	–	29.6
2.09	122.8	51.1	114.3	153.4	–	29.0
2.10	123.1	50.9	113.7	152.7	–	28.3
2.11	123.4	50.7	113.1	152.1	–	27.7
2.12	123.7	50.5	112.5	151.5	–	27.1
2.13	123.9	50.2	112.0	150.8	–	26.5
2.14	124.2	50.0	111.4	150.2	–	25.9
2.15	124.5	49.8	110.8	149.6	–	25.3
2.16	124.8	49.6	110.3	149.0	–	24.7
2.17	125.1	49.4	109.7	148.4	–	24.1
2.18	125.3	49.2	109.2	147.8	–	23.6
2.19	125.6	49.0	108.6	147.2	–	23.0
2.20	125.9	48.8	108.1	146.6	–	22.5
2.21	126.1	48.6	107.6	146.0	–	21.9
2.22	126.4	48.4	107.0	145.4	–	21.4
2.23	126.7	48.3	106.5	144.9	–	20.9
2.24	126.9	48.1	106.0	144.3	–	20.4
2.25	127.2	47.9	105.5	143.7	–	19.9
2.26	127.4	47.7	105.0	143.2	–	19.4
2.27	127.7	47.5	104.5	142.6	–	18.9
2.28	127.9	47.3	104.0	142.0	–	18.4
2.29	128.2	47.1	103.5	141.5	–	17.9
2.30	128.4	46.9	103.0	140.9	–	17.4
2.31	128.6	46.8	102.6	140.4	–	17.0
2.32	128.9	46.6	102.1	139.9	–	16.5
2.33	129.1	46.4	101.6	139.3	–	16.1
2.34	129.4	46.2	101.1	138.8	–	15.6
2.35	129.6	46.1	100.7	138.3	–	15.2
2.36	129.8	45.9	100.2	137.7	–	14.8
2.37	130.0	45.7	99.8	137.2	–	14.4
2.38	130.3	45.5	99.3	136.7	–	14.0
2.39	130.5	45.4	98.9	136.2	–	13.6
2.40	130.7	45.2	98.4	135.7	–	13.2
2.41	130.9	45.0	98.0	135.2	–	12.8
2.42	131.1	44.9	97.6	134.7	–	12.4
2.43	131.3	44.7	97.2	134.2	–	12.0
2.44	131.6	44.5	96.7	133.7	–	11.6
2.45	131.8	44.4	96.3	133.2	–	11.3
2.46	132.0	44.2	95.9	132.7	–	10.9
2.47	132.2	44.0	95.5	132.2	–	10.6
2.48	132.4	43.9	95.1	131.7	–	10.2
2.49	132.6	43.7	94.7	131.2	–	9.9

n_{rel}	φ_{c1} [°]	φ_{b0} [°]	φ_{c2} [°]	φ_{b2} [°]	φ_{r2} [°]	φ_{r3} [°]
2.50	132.8	43.6	94.3	130.8	–	9.5
2.51	133.0	43.4	93.9	130.3	–	9.2
2.52	133.2	43.2	93.5	129.8	–	8.9
2.53	133.4	43.1	93.1	129.4	–	8.6
2.54	133.6	42.9	92.7	128.9	–	8.3
2.55	133.8	42.8	92.3	128.4	–	8.0
2.56	134.0	42.6	91.9	128.0	–	7.7
2.57	134.2	42.5	91.5	127.5	–	7.4
2.58	134.3	42.3	91.2	127.1	–	7.1
2.59	134.5	42.2	90.8	126.6	–	6.8
2.60	134.7	42.0	90.4	126.2	–	6.5
2.61	134.9	41.9	90.1	125.7	–	6.2
2.62	135.1	41.7	89.7	125.3	–	6.0
2.63	135.3	41.6	89.3	124.9	–	5.7
2.64	135.4	41.4	89.0	124.4	–	5.5
2.65	135.6	41.3	88.6	124.0	–	5.2
2.66	135.8	41.2	88.3	123.6	–	5.0
2.67	136.0	41.0	87.9	123.1	–	4.7
2.68	136.1	40.9	87.6	122.7	–	4.5
2.69	136.3	40.7	87.2	122.3	–	4.3
2.70	136.5	40.6	86.9	121.9	–	4.0
2.71	136.6	40.5	86.6	121.5	–	3.8
2.72	136.8	40.3	86.2	121.1	–	3.6
2.73	137.0	40.2	85.9	120.7	–	3.4
2.74	137.1	40.1	85.6	120.3	–	3.2
2.75	137.3	39.9	85.2	119.8	–	3.0
2.76	137.5	39.8	84.9	119.4	–	2.8
2.77	137.6	39.7	84.6	119.1	–	2.6
2.78	137.8	39.5	84.3	118.7	–	2.4
2.79	137.9	39.4	84.0	118.3	–	2.3
2.80	138.1	39.3	83.6	117.9	–	2.1
2.81	138.3	39.1	83.3	117.5	–	1.9
2.82	138.4	39.0	83.0	117.1	–	1.8
2.83	138.6	38.9	82.7	116.7	–	1.6
2.84	138.7	38.7	82.4	116.3	–	1.5
2.85	138.9	38.6	82.1	116.0	–	1.3
2.86	139.0	38.5	81.8	115.6	–	1.2
2.87	139.2	38.4	81.5	115.2	–	1.0
2.88	139.3	38.2	81.2	114.8	–	0.9
2.89	139.5	38.1	80.9	114.5	–	0.8
2.90	139.6	38.0	80.6	114.1	–	0.7
2.91	139.8	37.9	80.3	113.7	–	0.6
2.92	139.9	37.8	80.1	113.4	–	0.5
2.93	140.0	37.6	79.8	113.0	–	0.4
2.94	140.2	37.5	79.5	112.7	–	0.3
2.95	140.3	37.4	79.2	112.3	–	0.2
2.96	140.5	37.3	78.9	112.0	–	0.1
2.97	140.6	37.2	78.7	111.6	–	0.1
2.98	140.7	37.1	78.4	111.3	–	0.0
2.99	140.9	36.9	78.1	110.9	–	0.0
3.00	141.0	36.8	77.8	110.6	–	0.0

7.3.1.5 Definitions

D_{min} The minimum particle diameter to be measured (µm).

n_1 The index of refraction of the particle.

n_2 The index of refraction of the external medium.

n_{rel} The relative index of refraction = n_1/n_2.

φ_{b0} Brewster's angle for external reflection. This is the angle at which reflection is zero for polarization parallel to the scattering plane.

φ_{b2} Brewster's angle for internal reflection. This is the angle at which reflection is zero for polarization parallel to the scattering plane.

φ_{c1} The critical angle for refraction. This is the maximum scattering angle for first order refraction.

φ_{c2} The critical angle for second order refraction.

For $n_{rel} < 1$, $\varphi_{c2} = \varphi_{c1}$.

φ_{r2} The rainbow angle for second order refraction.

φ_{r3} The rainbow angle for third order refraction.

7.3.2 Optimizing measurement conditions for Fiber PDA systems

7.3.2.1 Main flow direction and fringes direction

In 1D PDA configuration, the measured direction of the flow is in the laser beams plan. In 2D and 3D configuration, we will try to measure the main velocity component of the flow with the laser beams used to measure the size.

To improve the measurement, the positive direction of the flow and the positive direction of the moving fringes should be opposite.
A simple 1D FiberPDA configuration for forward scatter is shown in Figure 7-47 and Figure 7-48

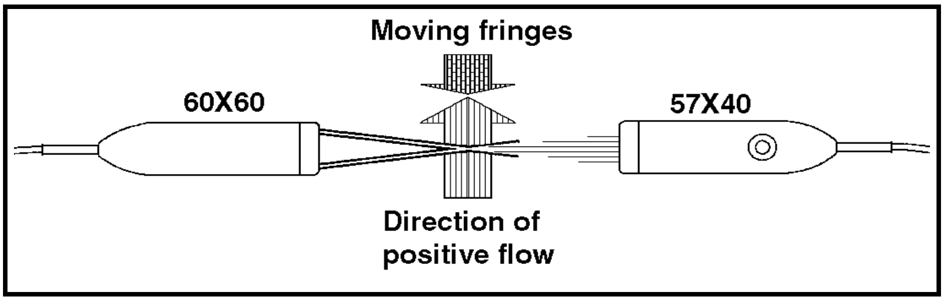


Figure 7-47. A simple 1D FiberPDA configuration for forward scatter.

The direction of the moving fringes is determinedby the position of the laser beam shifted by the Bragg cell. The fringes are moving from the shifted laser beam to the non shifted (see the folowing picture).

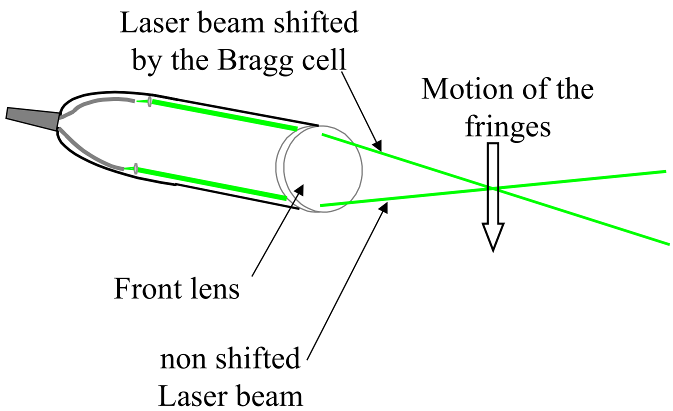


Figure 7-48 Fringe direction

7.3.2.2 Choice of wavelength

Dantec PDA detector are suitable for different wavelength. The filters, at the back of the receiving box, are easy to change.
For a 1D fiber PDA, the main concideration in taking into account is the linearity of the phase/diameter relation.
For a 2 and 3D PDA, we need also that the scattered light power is as equal as possible on all detectors. So we need that all wavelength provide is as equal as possible the same light intensity.

7.3.2.3 Choice of masks and focal lengths

The measurement size range is most directly influenced by the choice of aperture masks and focal lengths, both on the transmitting and receiving side. Further variations are possible if also the beam spacing is altered, for instance using the *55X82 Beam translator* in connection with a *60X81* or *60X83 FiberFlow* probe or the *41X805/806 Beam displacer* for the *60X61* or *60X63 FiberFlow* probes.

However, not only the measurement size range is influenced by these parameters, also the diameter of the measurement volume and/or the frequency/velocity conversion factor may be influenced. Therefore the optimization of the optical system may occur under conflicting constraints.

7.3.3 Optimizing measurement conditions for DualPDA systems

7.3.3.1 General considerations

Increased accuracy

The DualPDA has been developed especially to eliminate sizing errors due to the Gaussian beam effect (trajectory effect) and the slit effect and thereby increase the accuracy of mass flux and concentration measurements, even if the measurement volume is made very small to improve performance, for instance in dense sprays. Both the trajectory effect and the slit effect arise only when operating with the first order refractive mode of scattering, typical for measurement of liquid droplets in a gaseous medium or transparent spheres in a liquid. Therefore the following discussion focusses on the DualPDA application using first order refractive scattering.

As with the conventional PDA, the main goal of the optimization procedure is to insure a linear phase/diameter relation while maximizing the signal intensity. In the case of the DualPDA, this must be performed under the constraint that two PDA systems must be optimized simultaneously, the conventional PDA (CPDA) and the planar PDA (PPDA). The two detecting apertures of the CPDA are in the same receiving unit as the two detecting apertures of the PPDA, thus the scattering angle of the CPDA is at the same time the mean rotation angle of the planar PDA.

One final note of generality applies to the planar PDA. The name "planar" already emphasizes that the two detectors lie in the same plane as the transmitting beams. According to the nomenclature (chaper 7.2.1), the scattering angle of the detectors is zero. The two detectors have then two different rotation angles (see Figure 7-18). However, the equation expressing the geometrical factor for first order refraction, given in chaper 7.2.1 is still valid, at least within the validity of geometric optics.

To simplify notation however, the following discussion will refer to the scattering angle at which the DualPDA probe is placed, meaning scattering angle in the CPDA sense.

7.3.3.2 Main flow direction and fringe direction

With the DualPDA there is no preferred main flow direction. Inherently two components of particle velocity will always be measured. Therefore the mass flux normal to the *YZ*-plane (f_x) and to the *XZ*-plane (f_y) will always be available (see **7.5.3** Diameter statistics: mean diameters and algorithms for concentration and flux measurements).

Nevertheless, the measurement accuracy, especially of mass flux, can still be greatly influenced by the choice of main flow direction. This is apparent when examining the equations given in **7.5.3.** If for instance the main flow direction is along the *X*-axis, the trajectory angle γ will be close to zero and the reference cross-section normal to the *Y*-axis, A_y, will be very sensitive to smallest fluctuations of γ. Thus, while the measurement of the mass flux f_x will be very reliable, the measurement of f_y will exhibit a large statistical variance. Note that this is not a problem inherent in the DualPDA, but rather a very common consideration in measurement science. The best resolution and accuracy when measuring a vector quantity is always obtained when the transducer sensitivity is aligned with the vector.

Also this is usually not a major consideration, since often only one component of the mass flux vector is required, in which case alignment with either the *X*-axis or the *Y*-axis is not harmful. In the end the choice of main flow direction may be decided more on the basis of how the receiving probe can best be mounted.

The choice of the fringe direction is the same as in Fiber PDA (see 7.3.2.1).

7.3.3.3 Choice of wavelength and focal length

The DualPDA is operated with an Ar-Ion laser, providing beams at two wavelengths, green (λ = 514.5 nm) and blue (λ = 488.0 nm). Both wavelengths are used in the size measurement and therefore a decision must be made if the green line is used for the *U*-channels (*U1* and *U2* for the conventional PDA) or for the *V*-channels (*V1* and *V2* for the planar PDA).

Basically there are two considerations in making this decision. One is that the scattered light power should be as equal as possible on all detectors. The second factor involves the linearity of the phase/diameter relation.

Different receiving Areas

The first factor relates to wavelength only because the available power in the respective wavelengths generally varies with overall power. At low power levels the blue line (λ = 488.0 nm) is more intense than the green line (λ = 514.5 nm), whereas the reverse is true for higher laser powers. The incident power levels could conceivably be used to equalize other imbalances in the system, for instance aperture size, gain or different scattering characteristics. The DualPDA is presently layed out with aperture areas as shown below in **Table A1-1**.

	Mask A	Mask B	Mask C
U1, U2	407	176	77
V1, V2	200	100	50

Table A1-1. *Receiving area (in mm²) of the different DualPDA apertures.*

Therefore, to compensate the differences in aperture area, the more intense laser line can be used for the planar PDA, typically the green line. However the system will also function well independent of which wavelength is chosen for the planar PDA, provided a minimum intensity is achieved.

Phase/diameter linearity

The linearity of the phase/diameter curve is a further factor for choosing wavelength. Only for a few selected situations, in particular for very low relative refractive index (m < 1.2), has a discernable difference in linearity been observed. In these situations the planar PDA showed some improvement at low particle sizes using the green line.

However the conventional 2D-PDA (ClassicPDA or FiberPDA) uses the green line for the *U*-channels. To conform with this, and in light of the very restricted range where lower performance is to be expected, the DualPDA is delivered such that the green line is used for the *U*-channels (CPDA) and the blue line for the *V*-channels (PPDA).

Should the opposite arrangement be desirable it is necessary not only to rotate the transmitting probe, however also the following modifications are necessary:

1.) The polarization of the transmitting beams must be rotated by rotating the fiber connectors on the in-coupling side, i.e. at the transmitter box (see below also 7.3.1.1 and 7.3.3.4).

Instead of rotating the transmitting probe and the fiber connectors (in order to maintain the polarization direction) the fiber connectors on the in-coupling side (i.e. at the transmitter box) can be exchanged between the green and the blue channel.

2.) The colour interference filters in the receiving unit, placed just prior to the photodetectors, must be exchanged between the *U*- and the *V*-channels.

Another possibility to achieve a setup having the green beams on the planar PDA system without the necessity of opening the DualPDA detector unit for exchange of the interference filters is the following:

1.) Rotate the transmitting probe or exchange the fiber couplers as described above.

2.) Connect the *U1* and *U2* receiving fibers from the DualPDA probe to the *V1* and *V2* channels of the DualPDA detector unit. Connect the *V1* and *V2* receiving fibers from the DualPDA probe to the *U1* and *U2* channels of the detector unit.

3.) Connect the electrical cables from the MultiPDA signal processor channel *U1* and *U2* to the detector unit channels *V1* and *V2.* Connect the electrical cables from the MultiPDA signal processor channel *V1* and *V2* to the detector unit channels *U1* and *U2.* This is necessary because the burst detector acts on channel *U1* of the MultiPDA signal processor.

7.3.3.4 Choice of polarization

The planar PDA attributes its name not only to the fact that the detectors lie in the same plane as the transmitting beams but also that the polarization lies in this plane (perpendicular polarization). Very early calculations indicated that visibility and the phase/diameter linearity was only acceptable for this polarization. Since the DualPDA receiving unit uses a common polarization filter for all channels, the polarization is chosen to be the same on all transmitted beams, i.e. parallel for the *U*-channels (green) and perpendicular for the *V*-channels (blue).

This also corresponds to the preferred polarization in the case of the CPDA, i.e. the polarization at which a Brewster angle can be expected when working for instance with droplets in air (see 7.3 Setting up a PDA system).

7.3.3.5 Choice of scattering angle

From section 7.3 Setting up a PDA system, we can expect scattering angles in the range $25° < \Phi < 75°$ to be acceptable for the conventional PDA in the DualPDA. However further considerations must be given to the visibility and the phase/diameter linearity of the planar PDA as well as to the overall measurement size range. To investigate these influences, GLMT computations are recommended, some of which will be illustrated below.

Prior to this however, some characteristic features of the DualPDA optical arrangement will be discussed. The following examples are valid for the standard DualPDA arrangement using either 160 mm or 400 mm lenses on the transmitting and receiving probes. To begin, the phase/diameter conversion factor for the CPDA and PPDA is computed using geometric optics, using the aperture centroid as the scattering direction. The results for the case of 160 mm focal length lenses is shown in for various refractive indexes and for scattering angles in the range 20° to 70°.

This figure indicates that scattering angles beyond 40° would severely limit the PPDA at low relative refractive indexes. Values below 20° would lead to disturbances through diffraction. Therefore the operating range of 20° < Φ < 40° is expected to be most useful.

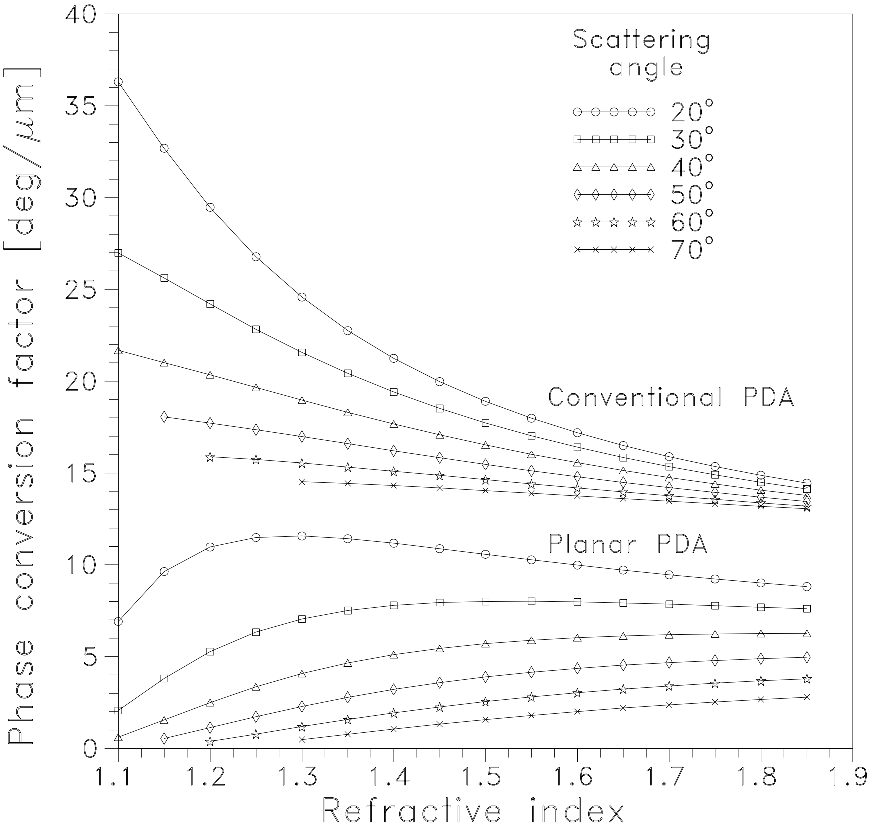


Figure 7-49. Phase/diameter conversion factor versus particle refractive index for various scattering angles. Computations performed according to geometric optics (GO).

7.3.3.6 Choice of masks and focal lengths

The measurement size range is most directly influenced by the choice of aperture masks and focal lengths, both on the transmitting and receiving side. Further variations are possible if also the beam spacing is altered, for instance using the

55X82 Beam translator in connection with a *60X81* or *60X83 FiberFlow* probe or the *41X805/806 Beam displacer* for the *60X61* or *60X63 FiberFlow* probes.

However, not only the measurement size range is influenced by these parameters, also the diameter of the measurement volume and/or the frequency/velocity conversion factor may be influenced. Therefore the optimization of the optical system may occur under conflicting constraints.

To provide an aid in choosing these parameters, **Table A1-2** has been prepared for standard DualPDA arrangements. The calculations have been performed based on a standard beam separation of 38 mm in a *60X61 FiberFlow* probe, a scattering angle of 30° and a slit width of 100 µm in the receiving optics.

Focal length Transmitter (FiberFlow)	Measurement volume diameter	Velocity conversion factor *	Focal length Receiver (DualPDA)	Measurement volume length **	Aperture plate	Upper limit of size range		
[mm]	[µm]	[m/s/MHz]	[mm]	[µm]		[µm]		
						m=1.125	m=1.334	m=1.6
160	78	2,1815	160	256	A	114	44	40
					B	150	57	52
					C	327	124	114
			400	640	A	289	109	100
					B	378	143	131
					C	820	310	284
			1000	1600	A	723	273	250
					B	946	358	327
					C	2050	775	709
400	194	5,4219	160	256	A	303	110	100
					B	398	144	130
					C	869	312	283
			400	640	A	766	275	249
					B	1003	361	326
					C	2174	781	707
			1000	1600	A	1920	690	624
					B	2511	902	816
					C	5434	1953	1768
1000	485	13,541	160	256	A	765	276	250
					B	1005	361	326
					C	2193	782	707
			400	640	A	1933	690	624
					B	2532	903	815
					C	5484	1956	1766
			1000	1600	A	4849	1727	1560
					B	6326	2257	2038
					C	13684	4887	4416

* For wavelength λ = 514.5 nm.
** Length of imaged slit width in the measurement volume.

***Table A1-2.** DualPDA measurement size ranges for different optical configurations.*

7.4 Catalogue of some common particles

7.4.1 How to read the scattering charts

The following charts have been calculated for a small selection of relative refractive indices. Each chart has two panels.

Top panel

The top panel shows the scattering angles for each incident ray. The incident rays are shown for the upper half of the particle alone, although the bottom half is symmetrical, as in Figure 7-50. However, it is difficult to follow the various rays. Therefore, in these illustrations, only the light rays incident on the upper half of each sphere are shown.

Reflection: The angles of light cover a range from 180° to 0°, corresponding to the off-axis distance of the incident beam of 0 to 1.0r (r = radius of the sphere).

Refraction: Similarly, the angles of scattered light span from 0° to φ_{c1}, the critical angle for refracted light.

2nd order refraction: When $n_{rel} > 1$, the light rays show a characteristic property: when the off-axis distance of the incident light increases from 0 to 1r, the angle decreases from 180°, passes through minimum (the rainbow angle) and then increases again till it reaches φ_{c2}, thus folding back and forming a range such that for each output angle there are two incident rays — or even three if 180° is also passed.

When $n_{rel} < 1$, 2nd order refraction covers the entire range of scattering angles and gives double contributions in the range 0 to $\varphi_{c2} = \varphi_{c1}$, i.e. in the range of 1st order refraction.

Bottom panel

The bottom panel shows the angular distribution of the relative intensity of the scattered light (logarithmic scale, 5 decades, 1 decade indicated by each dotted circle) in each of the three modes: reflection, refraction and 2nd order refraction. The calculations were based on geometrical optics, and were made for a particle 50 μm in diameter and a single point receiving aperture.

Upper half: The upper half of the bottom panel shows the situation when polarization is perpendicular (S, ⊥) to the plane common to the optical axes of the transmitting and the receiving optics.

Lower half: The lower half of the bottom panel shows the situation when polarization is parallel (P, ││) to the plane common to the optical axes of the transmitting and the receiving optics.

Concentric arcs to the right and to the left of the diagrams indicate the sectors covered by refracted light and 2nd order refracted light (the regions of multiple contributions due to folding are indicated).

Furthermore, short radial markers indicate the angles where the Brewster condition is met for reflection (φ_{b0}) and 2nd order refraction (φ_{b2}), and the rainbow angle for 3rd order refraction (φ_{r3}) when $n_{rel} > 1$.

To the left of the two panels are the values of the characteristic angles. You will find the mathematical basis and physical significance of these angles in 7.2.3 Light scattering from small particles

Terms used

Often you will run across various symbols and terms, such as:

φ_{b0} The Brewster condition for external reflection: the angle where the P (parallel) polarized reflected light is extinguished.

φ_{b2} The Brewster condition for internal reflection: the angle where (one component of) the P polarized 2nd order refracted light is extinguished.

φ_{c1} The critical angle condition for refraction: the maximum scattering angle for 1st order refraction.

φ_{c2} The critical angle condition for 2nd order refraction. When $n_{rel} < 1$, $\varphi_{c2} = \varphi_{c1}$.

φ_{r2} The rainbow angle for 2nd order refraction.

φ_{r3} The rainbow angle for 3rd order refraction.

n_1 The refractive index of the external medium.

n_2 The refractive index of the particle.

n_{rel} The relative refractive index = n_2/n_1.

Forward scatter generally refers to 1st order refracted light, typical scattering angles 0° to 80°.

Side scatter, on the other hand, refers to reflected light at 80° to 110°.

Backscatter pertains to 2nd order refraction typically at 150° to 170° scattering angle. Although situations occur when backscatter is the only possible choice, this should normally be avoided.

Note

The details are given more explicitly for the first two examples in this catalogue, a water droplet in air and an air bubble in water, than for the rest.

7.4.2 Water droplet in air

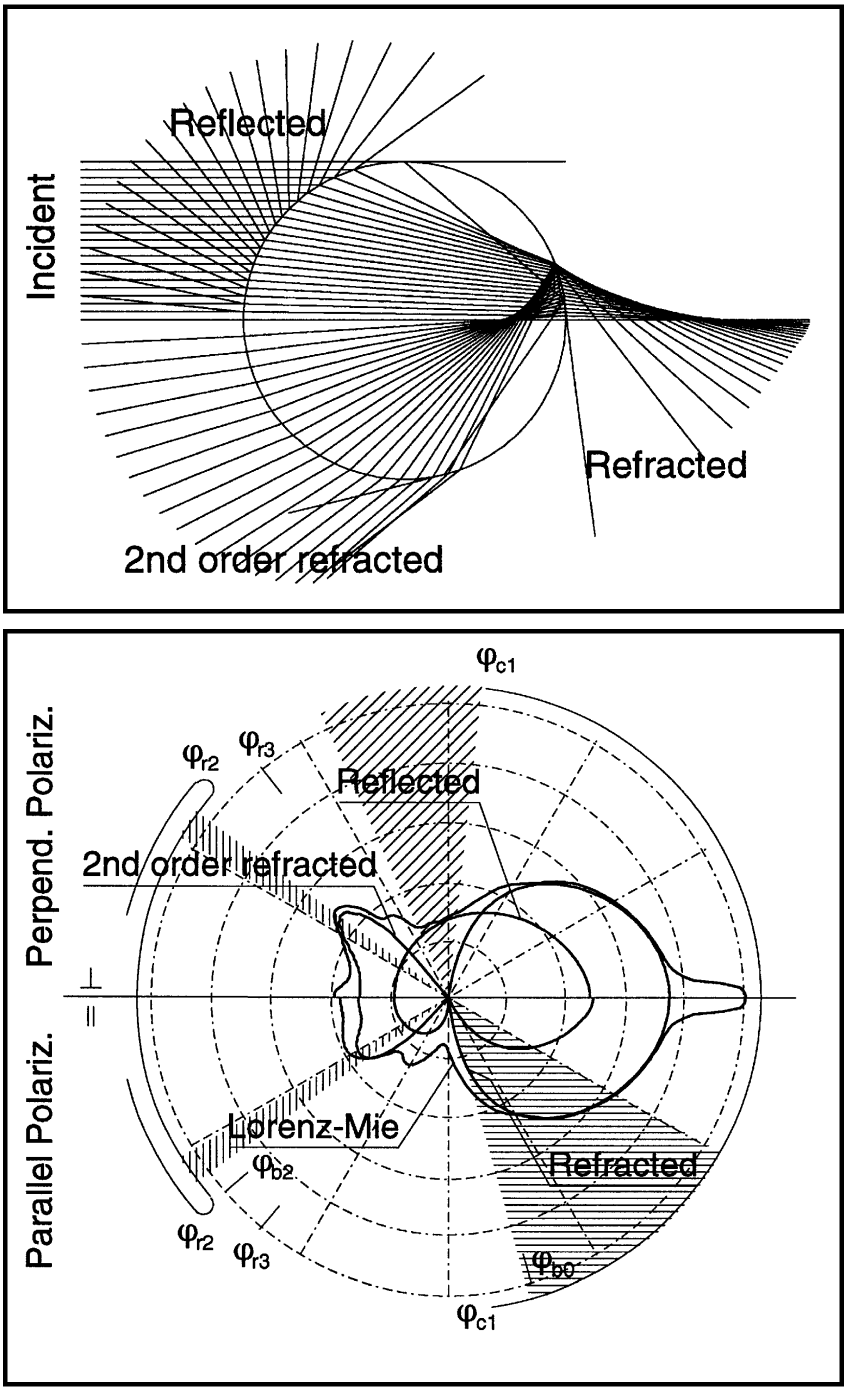


Figure 7-50. Water droplet in air. Top panel: ray tracings; bottom panel: angular dependence on intensity (logarithmic scale; one decade per dotted circle) for perpendicular and parallel polarization.

Characteristics:

- n_{rel} = 1.334.
- Brewster condition for reflected light, φ_{b0}, = 73.7°.
- Brewster condition for 2nd order refraction, φ_{b2}, = 138.8°.
- Critical angle for refracted light, φ_{c1}, = 82.9°.
- Critical angle for 2nd order refraction, φ_{c2}, = 165.7°.

- Rainbow angle for 2nd order refraction, φ_{r2}, = 138.0°
- Rainbow angle for 3rd order refraction, φ_{r3}, = 128.8°.

Recommended acceptance angles of the receiving optics:

1. Refraction: optimum at 73.7°.

   Can be used from 30° to 75°.

   Use parallel polarization (horizontally hatched sector). Preferable with very small droplets due to the higher intensity.

2. Reflection: φ_{c1} to φ_{r3}–15°.

   Can be used from 83° to 115°.

   Use perpendicular polarization and side scatter (obliquely hatched sector).

   Not recommended for the smallest droplets.

3. 2nd order refraction: can be used at φ_r+5° to φ_r+10°, from 144° to 149°, preferably with parallel polarization (vertically hatched sector).

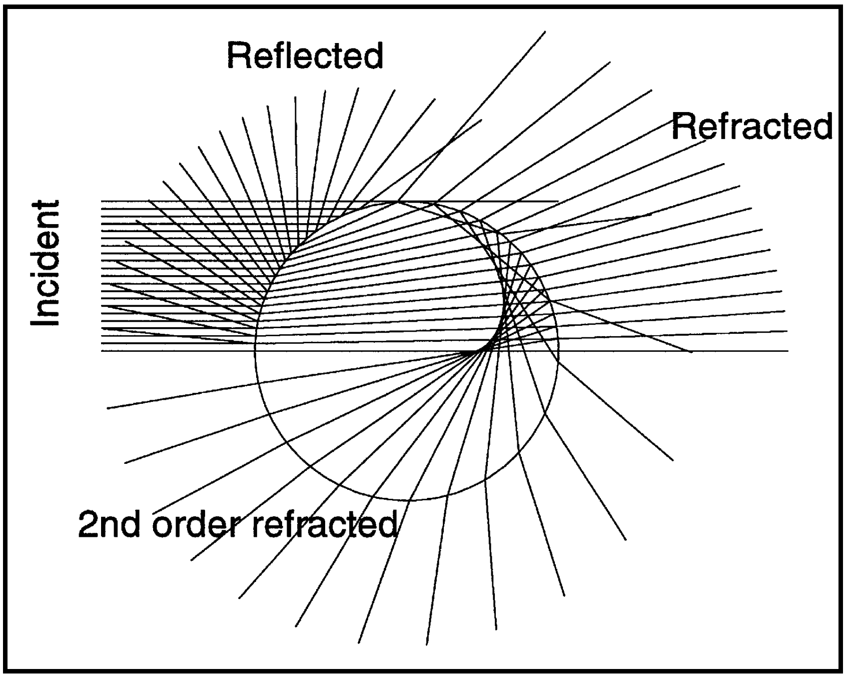
   Can also be used for small droplets.

In the intensity diagram (Figure 7-50), the total intensity of scattered light calculated from Lorenz-Mie analysis is shown together with the first three geometrical scattering modes which it encompasses. The useful sectors are hatched in Figure 7-50.

7.4.3 Air bubble in water

Characteristics:

- $n_{rel} = 0.750$.
- $\varphi_{b0} = 106.2°$.
- $\varphi_{b2} = 41.2°$.
- $\varphi_{c1} = \varphi_{c2} = 82.9°$.



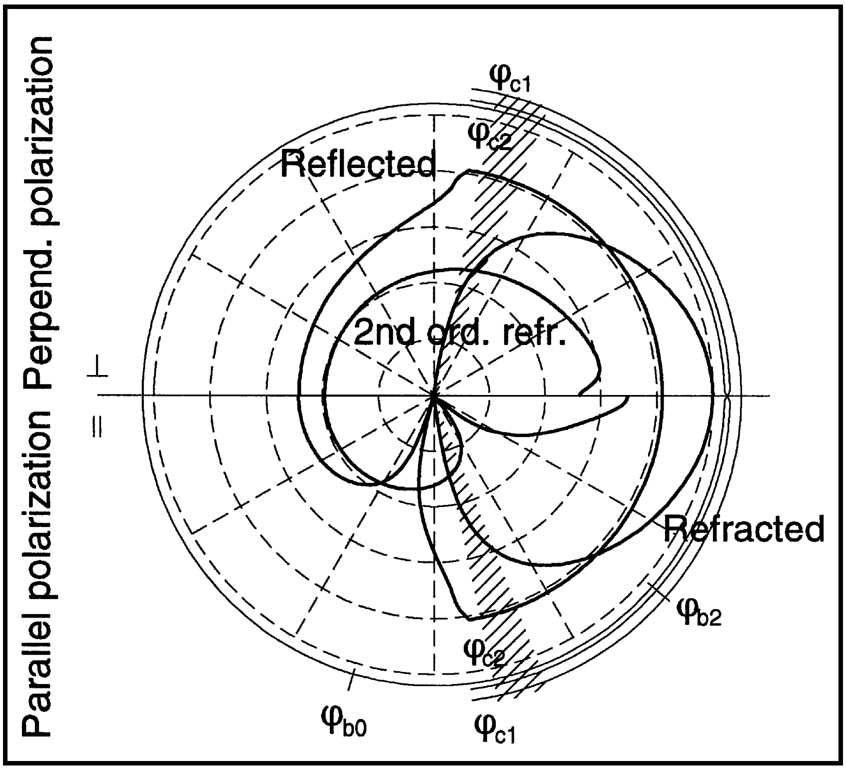


Figure 7-51: Air bubbles in water

Recommended acceptance angles of the receiving optics:

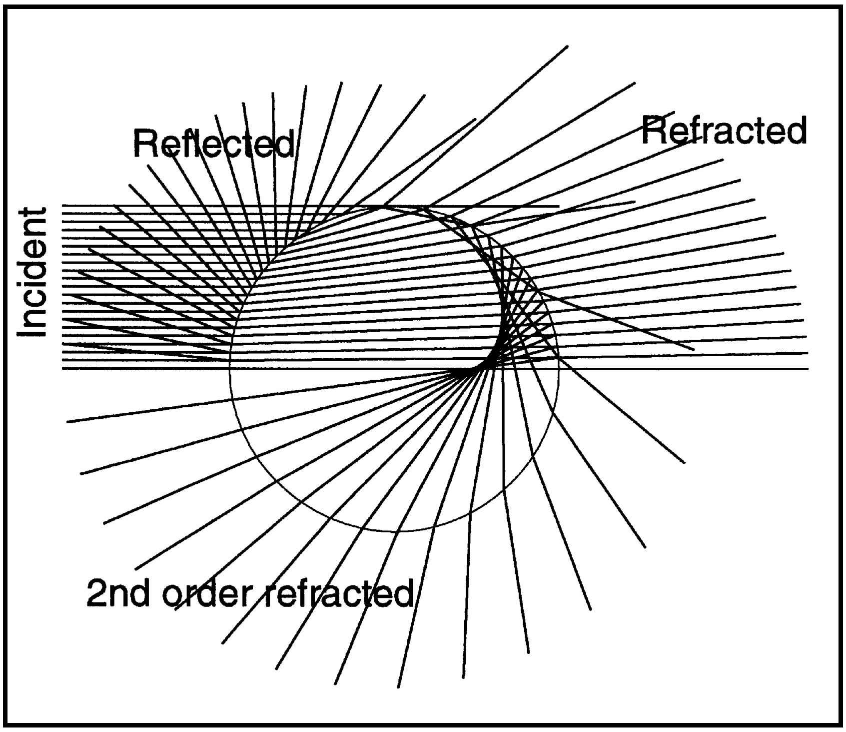
Reflection: optimum near φ_{c1}–0°, near 70°.

Can be used from φ_{c1}–15° to φ_{c1}–5°, 68° to 78°, with either polarization, but parallel best (obliquely hatched sectors).

7.4.4 Air bubble in freon

Characteristics:

- $n_{rel} = 0.833$.
- $\varphi_{b0} = 100.4°$.
- $\varphi_{b2} = 58.8°$.
- $\varphi_{c1} = \varphi_{c2} = 67.1°$.



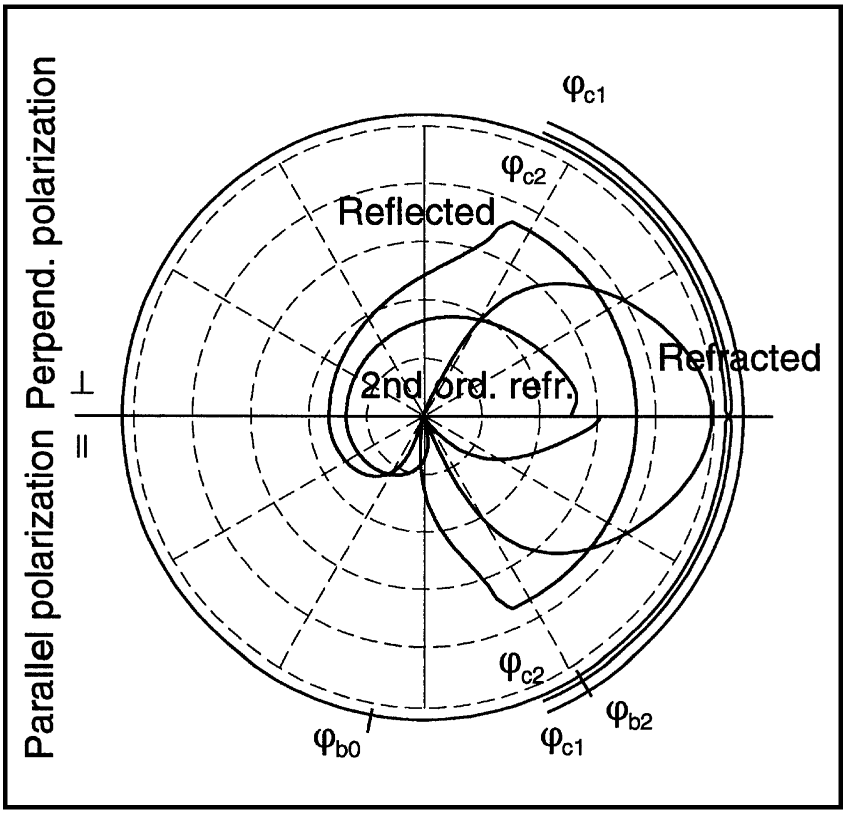


Figure 7-52: Air bubble in freon.

Recommended acceptance angles of the receiving optics:

Reflection: optimum near φ_{c1}–10°, near 57°.

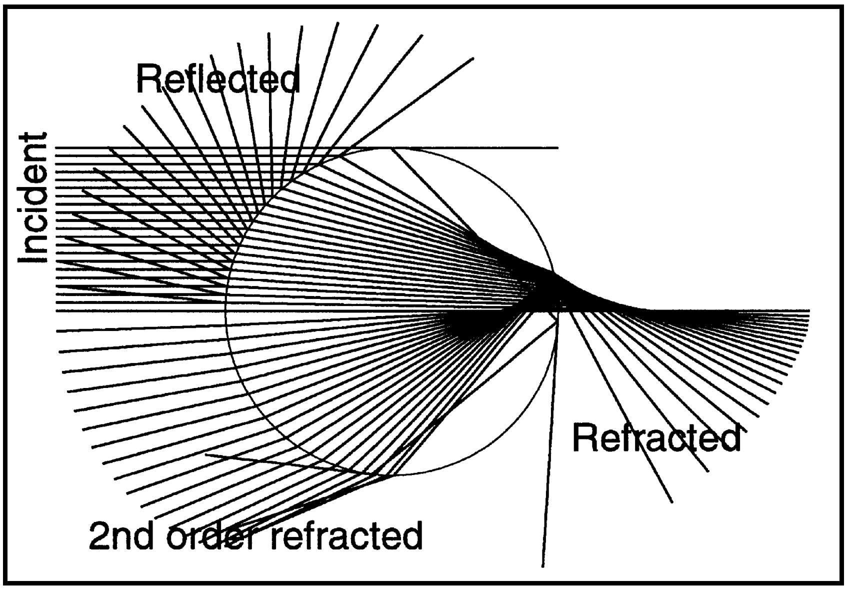
Can be used from φ_{c1}–15° to φ_{c1}–5°: 52° to 62° with either polarization but parallel best.

For a droplet of freon in air the situation is very similar to that of a latex sphere in water (see: 7.4.10 Latex sphere in water).

7.4.5 Droplet of diesel oil or silica spheres in air

Characteristics:

- $n_{rel} = 1.46$.
- $\varphi_{b0} = 68.8°$.
- $\varphi_{b2} = 153.5°$.
- $\varphi_{c1} = 93.5°$.
- $\varphi_{c2} = 172.9°$.
- $\varphi_{r2} = 153.3°$.
- $\varphi_{r3} = 100.5°$.



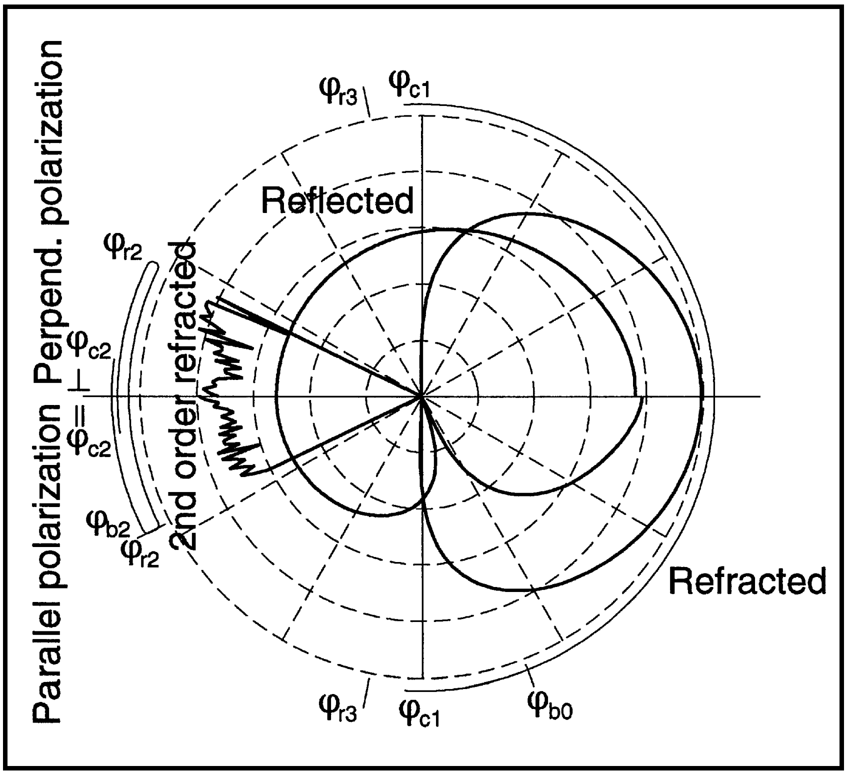


Figure 7-53: Droplet of diesel oil in air.

Recommended acceptance angles of the receiving optics:

1. Refraction: optimum at φ_{b0} = 68.8°.

   Can be used from 30° to 70°.

   Use parallel polarization.

2. Reflection: φ_{c1} to φ_{r2}–5°, 89° to 148°.

   Use side scatter with perpendicular polarization.

3. 2nd order refraction: can be used at φ_{r2}+5° to φ_{r2}+10°, from 158° to 163°, with either polarization.

7.4.6 Bubble of air in diesel oil

Characteristics:

- $n_{rel} = 0.685$.
- $\varphi_{b0} = 111.1°$.
- $\varphi_{b2} = 26.5°$.
- $\varphi_{c1} = \varphi_{c2} = 93.5°$.

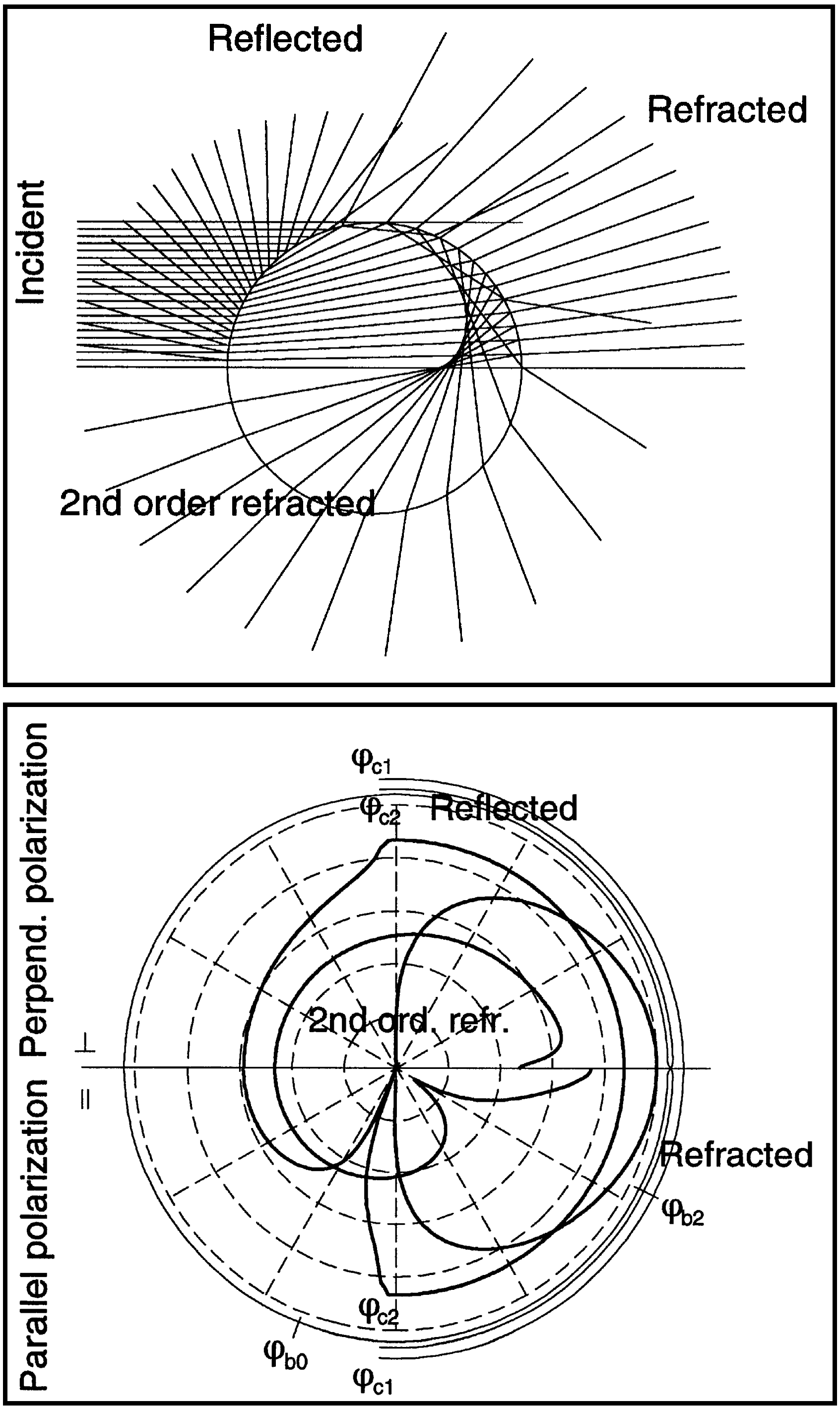


Figure 7-54: Bubble of air in diesel oil.

Recommended acceptance angles of the receiving optics:

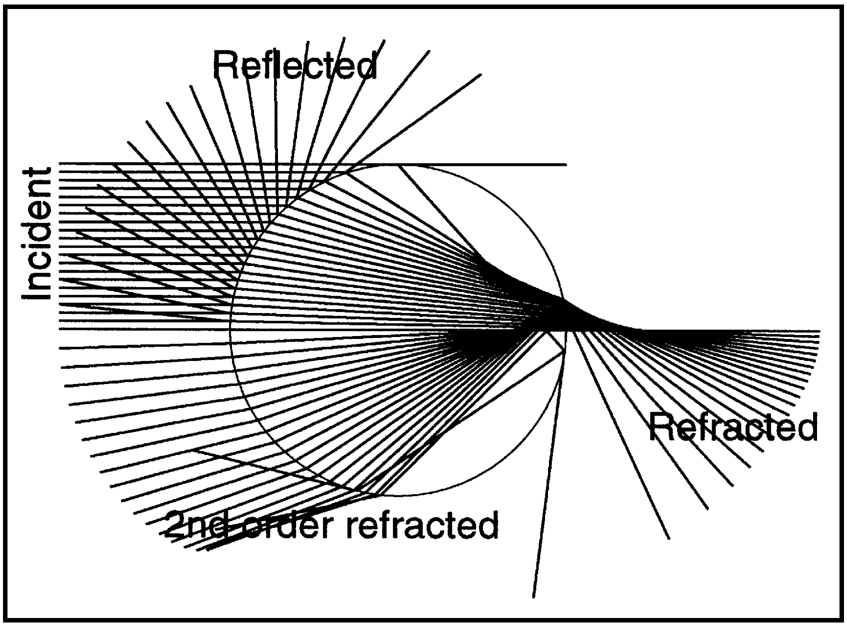
Reflection: optimum near φ_{c1}–10°, near 84°.

Can be used from φ_{c1}–15° to φ_{c1}–5°, from 79° to 89°, with either polarization, but parallel best.

7.4.7 Glass sphere in air

Characteristics:

- $n_{rel} = 1.51$.
- $\varphi_{b0} = 67.02°$.
- $\varphi_{b2} = 158.9°$.
- $\varphi_{c1} = 97.1°$.
- $\varphi_{c2} = 165.8°$.
- $\varphi_{r2} = 158.0°$.
- $\varphi_{r3} = 91.3°$.



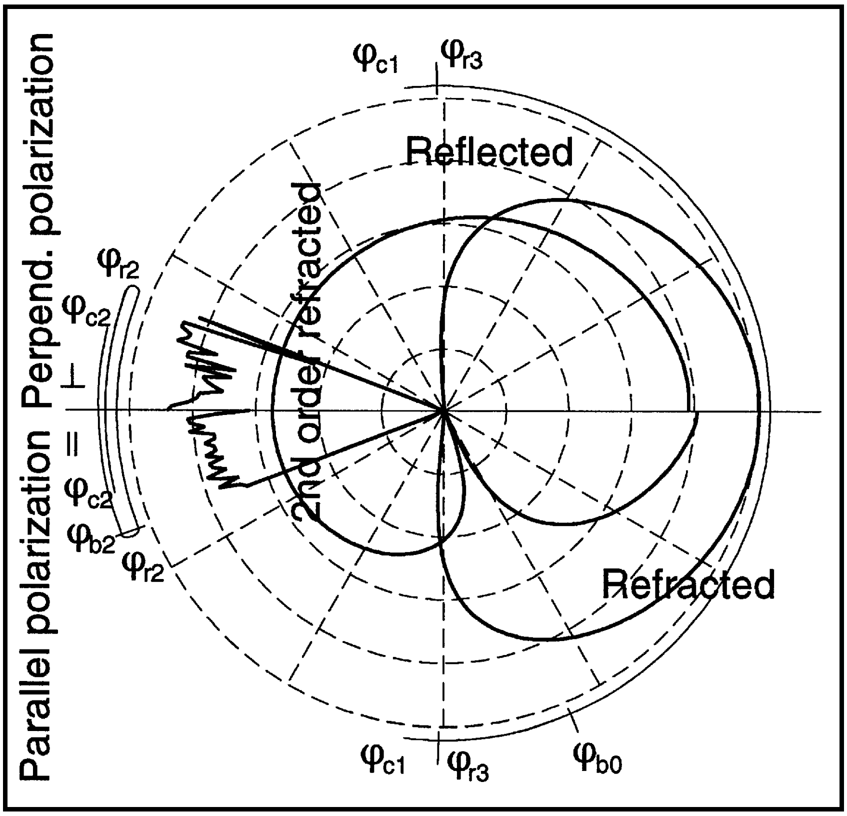


Figure 7-55: Glass sphere in air.

Recommended acceptance angles of the receiving optics:

1. Refraction: optimum at $\varphi_{b0} = 67.0°$.

   Can be used from 30° to 65°.

   Use parallel polarization.

2. Reflection: φ_{c1} to φ_{r2}–5°, from 97° to 153°.

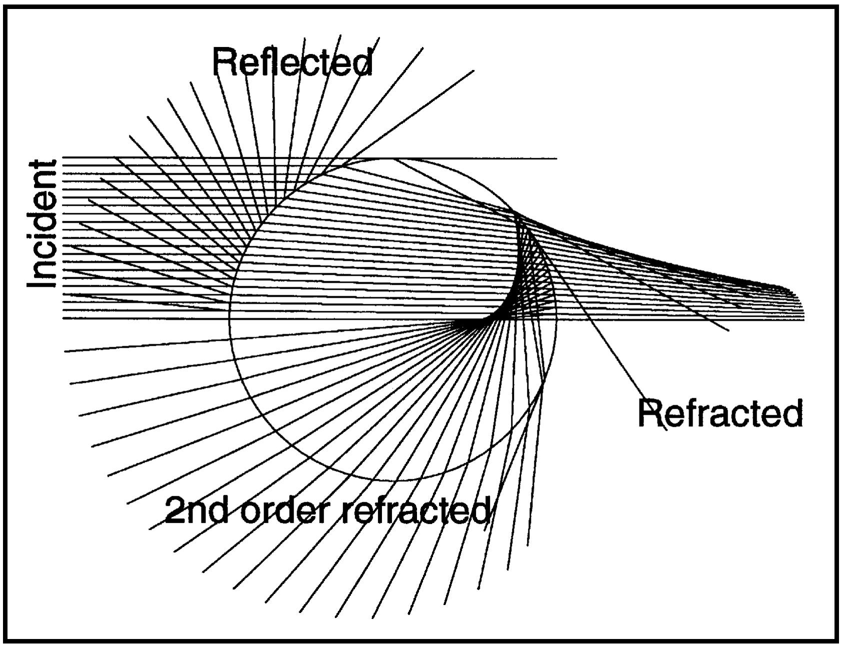
   Use side scatter with perpendicular polarization.

3. 2nd order refraction: can be used at φ_{r2}+5° to φ_{r2}+10°, from 163° to 168°, with either polarization.

7.4.8 Glass sphere in water

Characteristics:

- Glass sphere: n = 1.51.
- Water: n = 1.334.
- n_{rel} = 1.132.
- φ_{b0} = 82.9°.
- φ_{b2} = 111.2°.
- φ_{c1} = 55.9°.
- φ_{c2} = 111.7°.
- φ_{r2} = 93.4°.
- φ_{r3} = 157.2°.



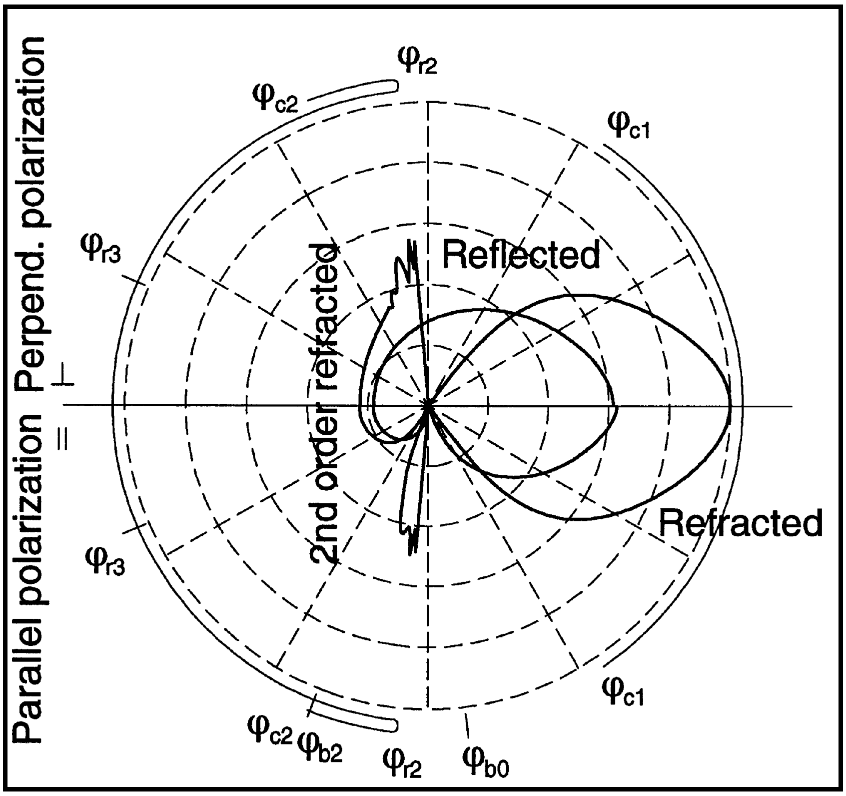


Figure 7-56: Glass sphere in water.

Recommended acceptance angles of the receiving optics:

1. Reflection: φ_{c1} to φ_{r3}–5°, from 56° to 88°.

   Use side scatter with perpendicular polarization.

2. 2nd order refraction: can be used at φ_{r2}+5° to φ_{r2}+10°, from 98° to 103°, with either polarization.

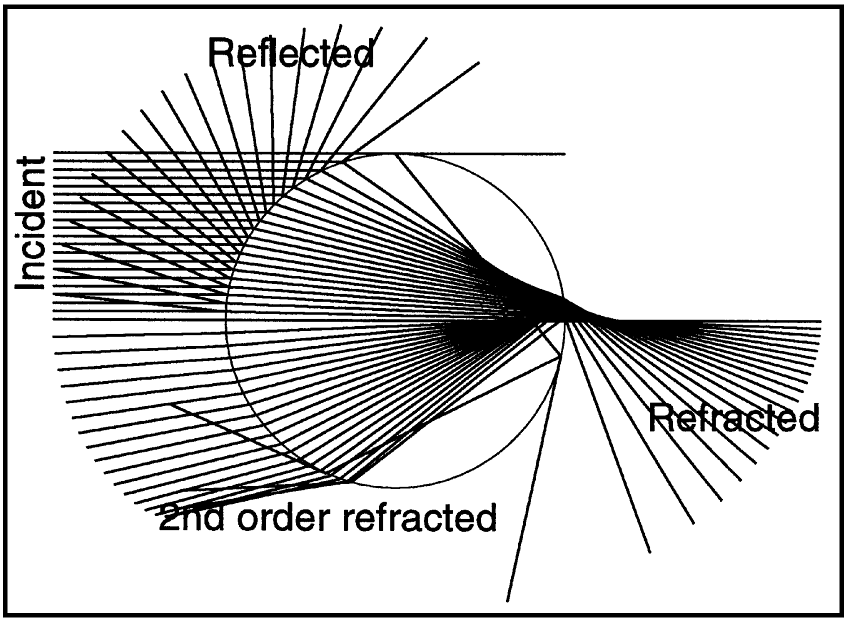
Note

The angle of the Brewster effect in the reflected light, φ_{b0}, is beyond the range of refracted light.

7.4.9 Latex sphere in air

Characteristics:

- $n_{rel} = 1.59$.
- $\varphi_{b0} = 64.3°$.
- $\varphi_{b2} = 166.9°$.
- $\varphi_{c1} = 102.0°$.
- $\varphi_{c2} = 155.8°$.
- $\varphi_{r2} = 164.3°$.
- $\varphi_{r3} = 78.5°$.



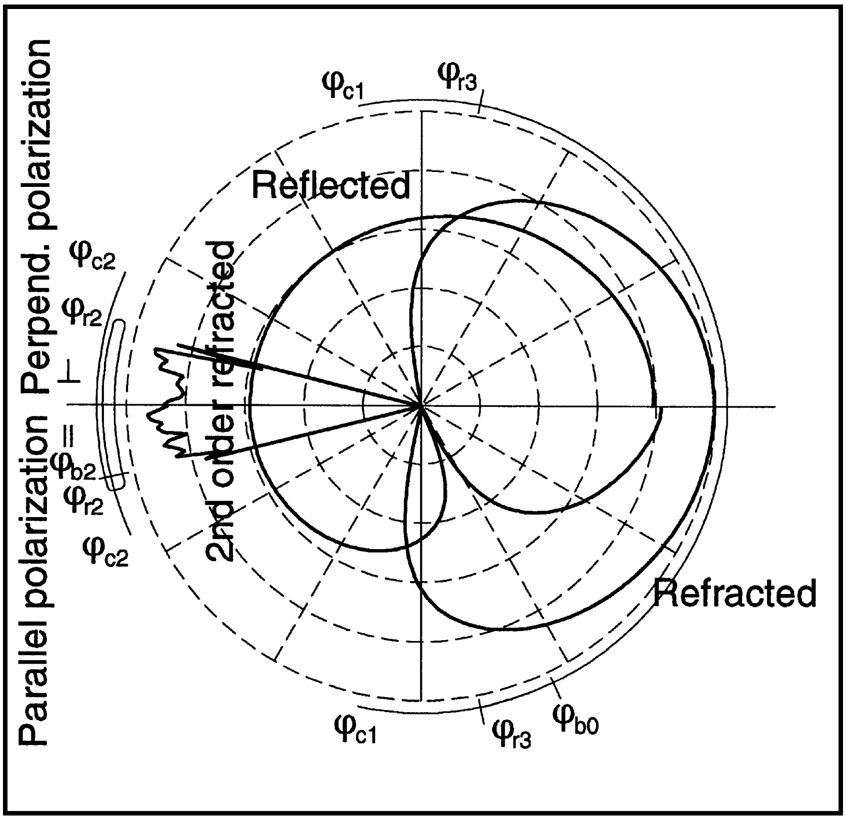


Figure 7-57: Latex sphere in air.

Recommended acceptance angles of the receiving optics:

1. Refraction: optimum at φ_{b0} = 64°.

   Can be used from 30° to 65°.

   Use parallel polarization.

2. Reflection: φ_{c1} to φ_{c2}, from 102° to 155°.

   Use side scatter with perpendicular polarization.

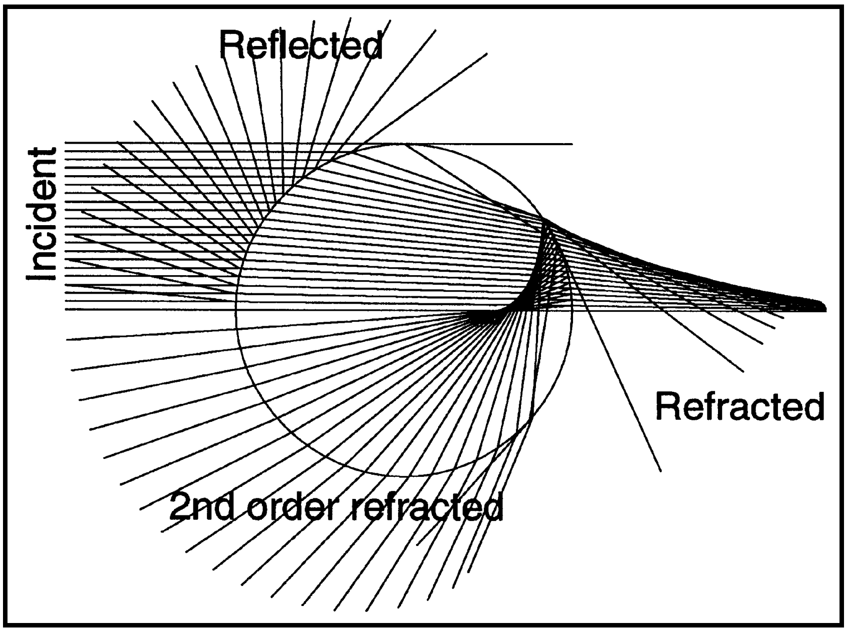
3. 2nd order refraction: can be used at φ_{r2}+5° to φ_{r2}+10°, from 163° to 168° with either polarization.

   The very low intensity third contribution to 2nd order refraction is ignored.

7.4.10 Latex sphere in water

Characteristics:

- Latex sphere: n = 1.59.
- Water: n = 1.334.
- n_{rel} = 1.1919.
- φ_{b0} = 80.0°.
- φ_{b2} = 120.0°.
- φ_{c1} = 65.93°.
- φ_{c2} = 131.8°.
- φ_{r2} = 111.7°.
- φ_{r3} = 175.0°.



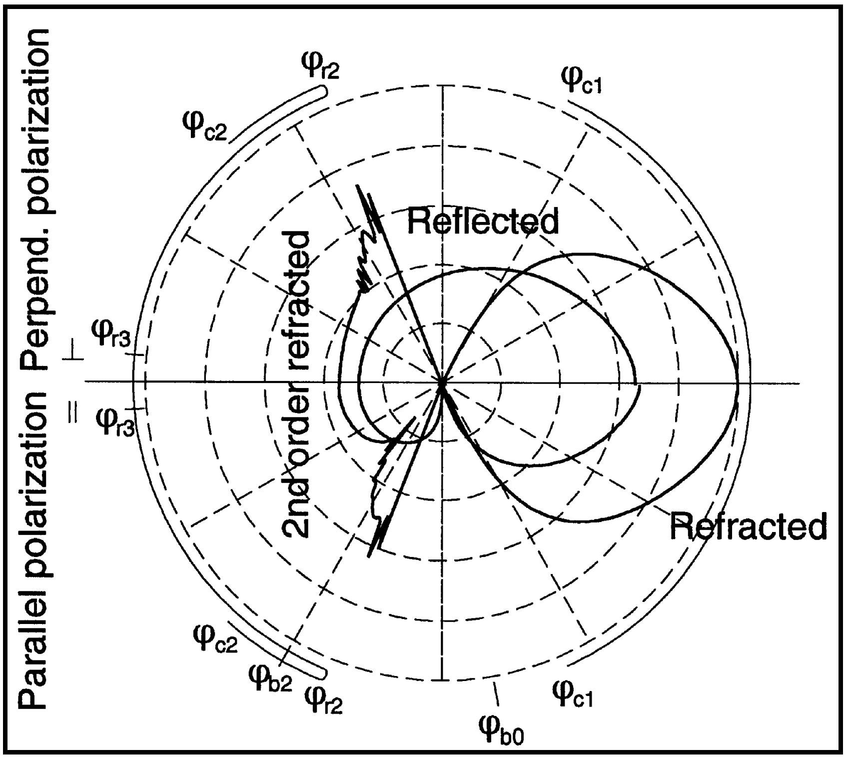


Figure 7-58: Latex sphere in water.

Recommended acceptance angles of the receiving optics:

1. Refraction: 30°, either polarization.

2. Reflection: φ_{c1} to φ_{r2}–5°, from 66° to 107°.
   Use side scatter and perpendicular polarization.

3. 2nd order refraction: can be used at φ_{r2}+5° to φ_{r2}+10°, from 117° to 122°, with either polarization.

Note *The angle of the Brewster effect in the reflected light, φ_{b0}, is beyond the range of refracted light.*

7.5 Data analysis

You should be aware that in this manual there is a distinction between processing and analysis. Processing is done by hardware, and take place in the processor, which may be a BSA, a FVA or something else. In the context of LDA-measurements, the processor receives an analog signal directly from the photodetector(s), and calculates the corresponding particle velocity for each Doppler-burst detected. The calculated velocity is sent to a computer for further analysis along with accompanying information such as particle arrival and transit time. If the processor used support burst-triggered sampling of external signals, the data-package sent to the computer may also include data from external sensors, such as pressure- or temperature- transducers.

The processing thus focuses on individual particles passing the measuring volume, while the data analysis work on the measured velocities of several - usually thousands - of particles. The data analysis performed in the computer yield mean velocity and other statistical properties, such as RMS-values. If several velocity components and/or external signals are measured simultaneously, the analysis may also yield cross moments, allowing for example the calculation of Reynolds stresses. Finally the analysis may include calculation of spectrum and correlation, and to obtain results quickly this can be done using FFT-algorithms.

In LDA there are two major problems faced when making a statistical analysis of the measurement data; velocity bias and the random arrival of seeding particles to the measuring volume. While velocity bias is the predominant problem for simple statistics, such as mean and rms values, the random sampling is the main problem for statistical quantities that depend on the timing of events, such as spectrum and correlation functions.

Figure 7-59 illustrates the calculation of moments, correlation and spectra on the basis of measurements received from the processor.

The velocity data coming from the processor consists of N validated bursts, collected during the time T, in a flow with the integral time scale τ_I. For each burst the arrival time a_i and the transit time t_i of the seeding particle is recorded along with the non-cartesian velocity components (u_i, v_i, w_i).

The different topics involved in the analysis will be described in more detail in the following sections of this manual.

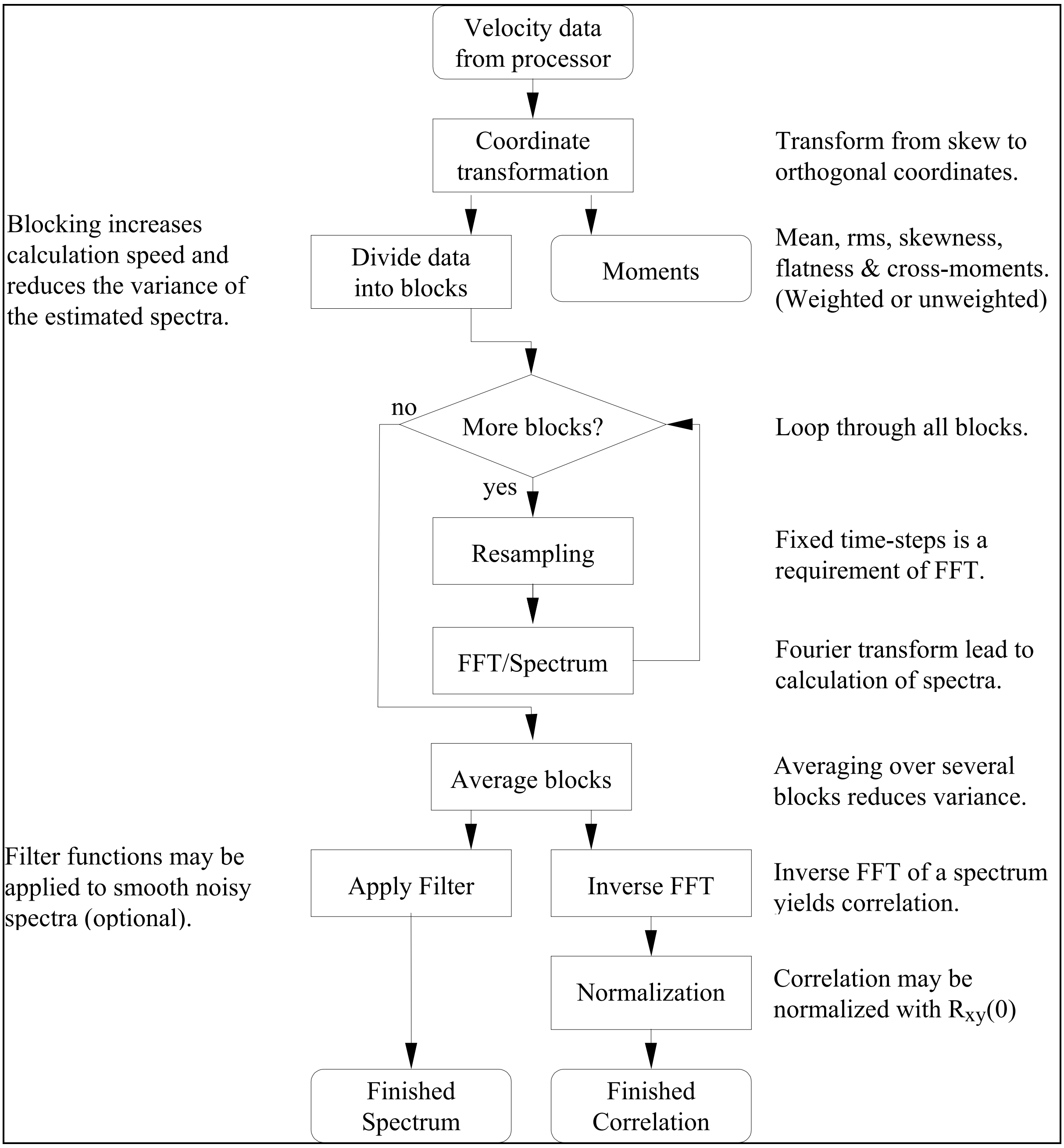


Figure 7-59: Calculating moments, correlations and spectra using FFT-techniques.

7.5.1 Optical transform

The non-cartesian velocity components (u_1, u_2, u_3) are transformed to cartesian coordinates (u, v, w) using the transformation matrix **C**:

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{Bmatrix} C_{11} & C_{12} & C_{13} \\ C_{21} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{Bmatrix} \cdot \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \qquad (7\text{-}18)$$

7.5.1.1 General 3D setup

A typical 3-D LDA setup requiring coordinate transformation is depicted in Figure 7-60, where 3-dimensional velocity measurements are performed with a 2-D probe positioned at off-axis angle α_1 and a 1-D probe positioned at off-axis angle α_2.

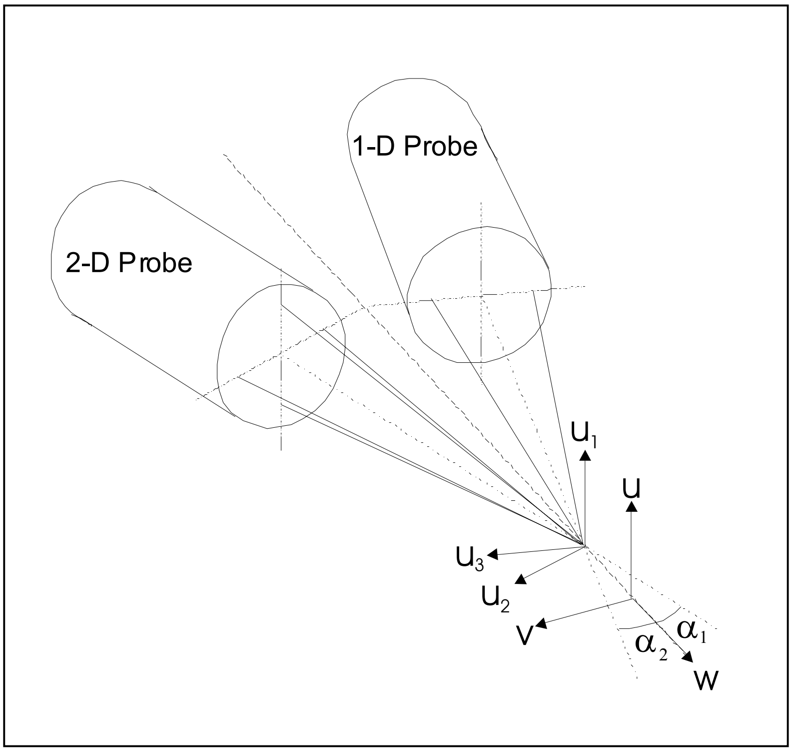


Figure 7-60 Typical configuration of a 3-D LDA system.

The velocities actually measured in Figure 7-60 are u_1, u_2 and u_3, but the velocities desired are in the directions u, v and w. While u_1 corresponds to u directly, v and w must be calculated from u_2 and u_3 knowing the angles α_1 and α_2.

In this particular example we get:

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & -\dfrac{\sin\alpha_2}{\sin(\alpha_1-\alpha_2)} & \dfrac{\sin\alpha_1}{\sin(\alpha_1-\alpha_2)} \\ 0 & \dfrac{\cos\alpha_2}{\sin(\alpha_1-\alpha_2)} & \dfrac{\cos\alpha_1}{\sin(\alpha_1-\alpha_2)} \end{Bmatrix} \cdot \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \tag{7-19}$$

7.5.1.2 Example: Symmetrical 3D setup

In case $\alpha_1 = -\alpha_2 = \alpha/2$ the expression becomes

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & \dfrac{1}{2\cos(\alpha/2)} & \dfrac{1}{2\cos(\alpha/2)} \\ 0 & \dfrac{1}{2\sin(\alpha/2)} & -\dfrac{1}{2\sin(\alpha/2)} \end{Bmatrix} \cdot \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \tag{7-20}$$

7.5.1.3 Example: 3D setup with 2D probe axis aligned with w

In Figure 7-61, the 2-D probe aligned with the w-axis and the 1-D probe is positioned at an off-axis angle α.

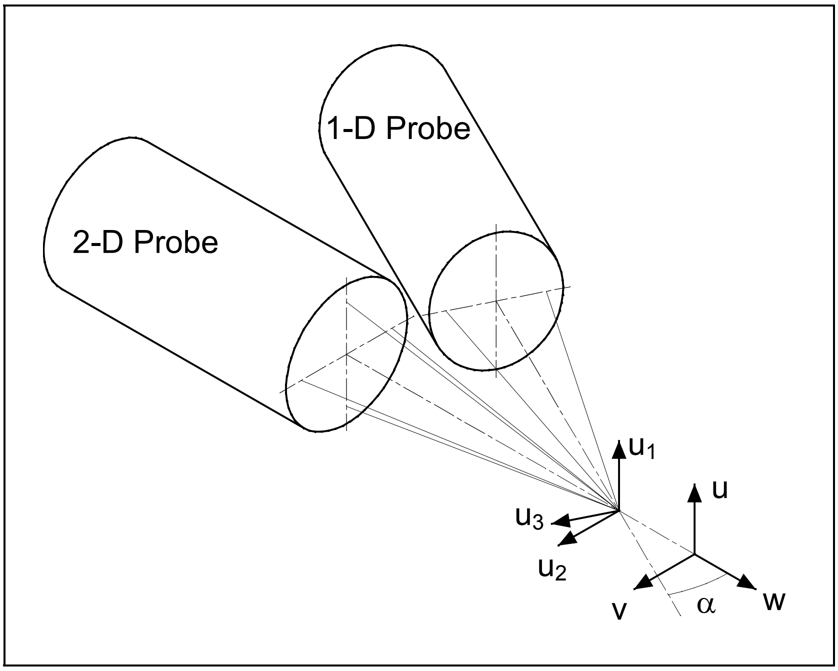


Figure 7-61. 3D optical configuration with 2D probe aligned with w

The velocities actually measured in Figure 7-61 are u_1, u_2 and u_3, but the velocities desired are in the directions u, v and w. While u_1 and u_2 correspond to u and v directly, the third component, w, must be calculated from u_2 and u_3 knowing the angle α.

In this particular example we get:

$$\begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = \begin{Bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & \dfrac{1}{\tan\alpha} & \dfrac{1}{\sin\alpha} \end{Bmatrix} \cdot \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} \tag{7-21}$$

All further calculations are based on the cartesian velocities (u, v, w).

7.5.2 Moments (one-time statistics)

Moments are the simplest form of statistics that can be calculated for a set of data. The calculations are based on individual samples, and the possible relations between samples are ignored as is the timing of events. This leads to moments sometimes being referred to as one-time statistics, since samples are treated one at a time.

In Table 7-1 the formulas for estimating moments are listed. The table operates with velocity-components x_i and y_i, but this is just examples, and could of course be any velocity component, cartesian or not. It could even be samples of an external signal representing pressure, temperature or something else. [BBM1]

Mean	$\bar{u} = \sum_{i=0}^{N-1} \eta_i u_i$	(7-22)
Variance	$\sigma^2 = \sum_{i=0}^{N-1} \eta_i (u_i - \bar{u})^2$	(7-23)
RMS	$\sigma = \sqrt{\sigma^2}$	(7-24)
Turbulence	$Tu = \frac{\sigma}{\bar{u}} \cdot 100\%$	(7-25)
Skewness	$S = \frac{1}{\sigma^3} \sum_{i=0}^{N-1} \eta_i (u_i - \bar{u})^3$	(7-26)
Flatness	$F = \frac{1}{\sigma^4} \sum_{i=0}^{N-1} \eta_i (u_i - \bar{u})^4$	(7-27)
Cross-Moments	$\overline{uv} - \bar{u}\,\bar{v} = \sum_{i=0}^{N-1} \eta_i (u_i - \bar{u})(v_i - \bar{v})$	(7-28)

Table 7-1: Formulas for estimating moments

You may find the so-called weighting factor η_i disturbing, as you would normally expect simply η_i=1/N. Unfortunately this would bias your results, since LDA-measurements especially in highly turbulent flows tend to contain more samples of fast particles than slow ones. To compensate for this fast particles are given less weight than slow ones in the calculations as described in the following section.

7.5.2.1 Weighting factor

Velocity bias Even for incompressible flows where the seeding particles are statistically uniformly distributed, the sampling process is not independent of the process being sampled (that is the velocity field). Measurements have shown that the particle arrival rate and the flowfield are strongly correlated (McLaughlin & Tiedermann (1973)] and [Erdmann & Gellert (1976)]). During periods of higher velocity, a larger volume of fluid is swept through the measuring volume, and consequently a greater number of velocity samples will be recorded. As a direct result, an attempt to evaluate the statistics of the flow field using arithmetic averaging will bias the results in favour of the higher velocities.

Independent samples One way to avoid this so-called velocity bias is to ensure statistically independent samples, meaning that the time between bursts must exceed the integral time-scale τ_I of the flowfield at least by a factor of two: $a_i - a_{i-1} \geq 2 \cdot \tau_I \; \forall \; a_i$.

With statistically independent samples, the weighting factor corresponding to normal arithmetic mean can be used:

$$\eta_i = \frac{1}{N} \tag{7-29}$$

Statistically independent samples can be accomplished using very low concentration of seeding particles in the fluid, but to estimate the integral time-scale τ_I of the flowfield, you need to perform measurements with high data rate, requiring high concentration of seeding particles. This is a contradiction, so this approach is not generally recommended unless seeding concentration is extremely low and you are certain that τ_I is very small.

Dead-time

Some processors may have a dead-time feature as another way to achieve statistically independent samples. The dead-time is a specified period of time after each detected Doppler-burst, during which further bursts will be ignored. Setting the dead-time equal to $2 \cdot \tau_I$, will ensure statistically independent samples, while the integral time-scale itself can be estimated from a previous series of velocity samples, recorded with the dead-time feature switched off.

Bias-correction

If you plan to calculate correlations and spectra on the basis of your measurements, the resolution achievable will be greatly reduced by the low data-rates required to ensure statistically independent samples. To improve the resolution of the spectra, you need a higher data rate, which as explained above will bias the estimated average velocity.

To correct this velocity-bias, a non-uniform weighting factor η_i is introduced. The bias-free method of performing the statistical averages on individual realisations uses the transit time weighting (see [George (1975)]):

$$\eta_i = \frac{t_i}{\sum_{j=0}^{N-1} t_j} \tag{7-30}$$

-where t_i is the transit time of the i'th particle crossing the measuring volume.

Additional information on the transit time weighting method can be found in [George (1978)], [Buchhave, George & Lumley (1979)] and [Buchhave (1979)]. In the literature transit time is sometimes referred to as residence time.

7.5.2.2 Arithmetic Mean diameter.

Arithmetic Mean diameter, Diameter RMS and viariance are only available with the PDA processor.N is the total number of particlesand D_i the diameter of the individual particles.

Mean	$D_{mean} = \frac{1}{N}\sum_{i=0}^{N-1} u_i$	(7-31)
Variance	$\sigma^2 = \sum_{i=0}^{N-1}\left(D_i - D_{mean}\right)^2$	(7-32)
RMS	$\sigma = \sqrt{\sigma^2}$	(7-33)

Table 7-2: Formulas for estimating diameter moments

7.5.3 Diameter statistics: mean diameters and algorithms for concentration and flux measurements

7.5.3.1 Mean diameters

Means diameters are only calculated with the PDA processor. In the Diameter statistics, D_i is the diameter of the size class *i,* N_i the number of size classes (bins) selected by the user, n_i the number of particles in each size class and N the total number of particles

D10

The **mean diameter** is the ensemble or (arithmetic) number mean diameter of the acquired and validated samples:

$$D_{10} = \frac{1}{N}\sum_{i=1}^{N_i} n_i D_i$$

D20

The **area mean diameter** is calculated from the mean squared diameters:

$$D_{20} = \left\{\frac{1}{N}\sum_{i=1}^{N_i} n_i\ D_i^2\right\}^{\frac{1}{2}}$$

D30

The **volume mean diameter** is calculated from the mean of the droplet volumes:

$$D_{30} = \left\{\frac{1}{N}\sum_{i=1}^{N_i} n_i\ D_i^3\right\}^{\frac{1}{3}}$$

D32

The **Sauter mean diameter** (SMD) is calculated as:

$$D_{32} = \frac{\sum_{i=1}^{N_i} n_i D_i^3}{\sum_{i=1}^{N_i} n_i\ D_i^2}$$

D43

The **De Broukere** is calculated as:

$$D_{43} = \frac{\sum_{i=1}^{N_i} n_i D_i^4}{\sum_{i=1}^{N_i} n_i D_i^3}$$

Dv0.1, Dv0.5, Dv0.9 The fractional volume diameters represent the particle diameters below which 10%, 50% or 90% of the total volume is contained, i.e. where the cumulation function of the volume distribution (Q_3) has the value 0.1, 0.5 or 0.9, respectively:

$Q_3(Dv0.1) = 0.1$

$Q_3(Dv0.5) = 0.5$

$Q_3(Dv0.9) = 0.9$

Span The span is an indicator for the width of a size distribution. This parameter actually describes the steepness of the cumulation curve of the volume distribution:

$$Span = \frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}} \cdot 100\%$$

7.5.3.2 Probe volume definition

The basic issue which must be addressed is the cross-sectional area to be used as a reference for counting particles. There are several factors which influence the effective cross-sectional area and which prohibit a single value being used for all measured particles. The situation is depicted in Figure 7-62 for two projections of the measurement volume.

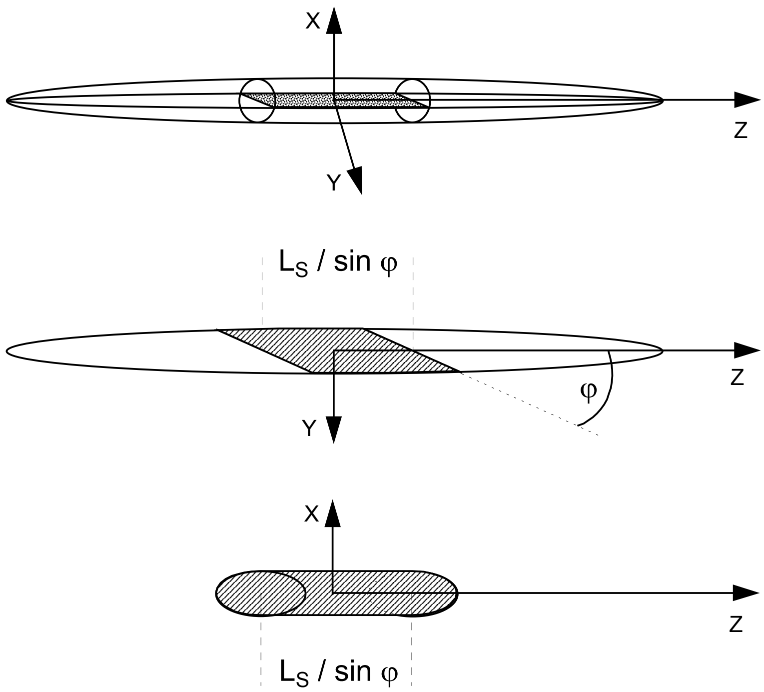


Figure 7-62: Measurement volume with projections onto YZ- and XZ-plane.

According to Figure 7-62 the projected cross-sectional area will depend on the following geometrical/optical parameters:

- beam waist diameter
- scattering angle φ
- width of slit aperture image L_S

Three further factors are however important:

- particle diameter
- particle trajectory
- validation criteria

In particular it is the latter three which are briefly discussed in the following three sub-sections, after which some final expressions for size distribution, fluxes and concentration are given.

7.5.3.3 Size dependent detection area (*X*-*Y*)

This is the effect which has been treated previously by *Saffman (1987),* accounting for the larger effective measurement volume size for larger particles. The algorithm introduced by *Saffman* is adequate for one-dimensional particle trajectories in the *X*- direction. Additional considerations must be made for arbitrary particle trajectories in the *XY*-plane. If flux measurements are performed in both coordinate directions, it is necessary to consider the measurement volume cross section in both the *X*- and *Y*-directions.

The area measurement is based on the concept of an effective measurement volume diameter, d_e, which is particle size dependent. Knowing this size, the cross section in the *X*- and *Y*-direction are given by the following relations respectively, as is shown diagrammatically in Figure 7-62:

$$A_x(D_i) = d_e(D_i)\frac{L_s}{\sin\phi}$$

$$A_y(D_i) = d_e(D_i)\frac{L_s}{\sin\phi} + \frac{\pi}{4}d_e^2\cot\phi$$

Accordingly an on-line measurement of d_e is required. This will be derived below, following an approach analog to *Saffman*, but taking into account both velocity components of the particle in the *XY*-plane.

To begin, it is assumed that the ellipticity of the measurement volume can be disregarded, since the half-intersection angle of the laser beams (ϑ/2) is generally small. The amplitude of the signal envelope can then be expressed as:

$$V(d_p, x', y') = V_{max}(d_p)e^{-\frac{8}{d_o^2}(x'^2 + y'^2)}$$

i.e. as a function of particle size (d_p) and position, where *x'* and *y'* are the particle location in the coordinate system. An example particle trajectory is shown in Figure 7-63. Assuming that only signals exceeding a certain minimum burst length (L_{min}) will be accepted, an effective measurement volume diameter d_e, as illustrated in Figure 7-63 can be defined.

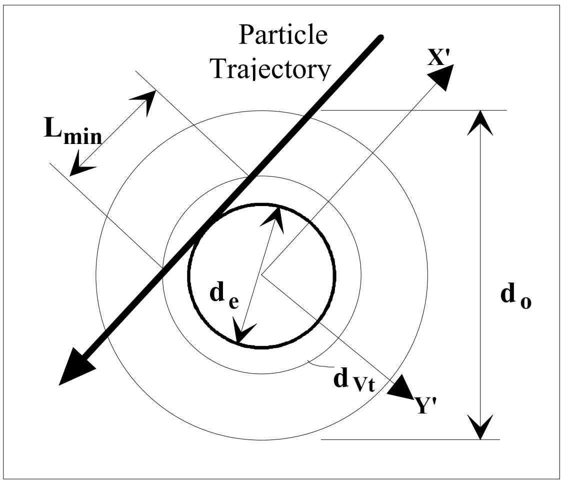


Figure 7-63: *Definition of the effective measurement volume diameter (d_o is the measurement volume diameter at the $1/e^2$-intensity points).*

The burst length validation therefore rejects signals which have not crossed a minimum length of the measurement volume.

The length is determined as:

$$L = \Delta t \cdot u$$ for 1D configurations

$$L = \Delta t \sqrt{u^2 + v^2}$$ for 2D and 3D configurations

where u and v are the measured velocity components of the droplet and Δt is the transit or residence time.

The relationship betwen d_e and L_{min} will depend on the detection trigger level of the processor **L2**, denoted V_t in the following equation:

$$V_t = V_{\max} \, e^{-\frac{8}{d_o^2}\left\{\left(\frac{d_e}{2}\right)^2 + \left(\frac{L_{\min}}{2}\right)^2\right\}}$$

This equation can be solved for d_e :

$$d_e = \sqrt{\frac{d_o^2 * \ln\frac{V_{\max}}{V_t} - 2L_{\min}^2}{2}}$$

An expression for $\ln(V_{max}/V_t)$ must therefore be found. This is possible in terms of the burst length:

$$L(d_p, y') = \sqrt{\frac{\left[\ln\frac{V_{\max}}{V_t}\right] * d_o^2 - 8y^2}{2}}$$

If this expression is squared and integrated over all possible values of *y'* between 0 and $d_e/2$, then normalized by $d_e/2$, which is denoted as $\overline{L^2}$, the following expression can be derived:

$$\ln\frac{V_{\max}}{V_t} = \frac{1}{d_o^2}\left(3\overline{L^2}(d_p) - L_{\min}^2\right)$$

It leads to a final expression for d_e :

$$d_e = \sqrt{\frac{3}{2}\left(\overline{L^2} - L_{\min}^2\right)}$$

Therefore, for each size class, the quantity $\overline{L^2}$ must be measured. There are considerable difficulties with this approach however. For one, there may exist only a few particles in a particle size class, thus the statistical certainty of the estimation is not good. This is particularly the case for larger particle size classes where the measured mean square burst length is therefore completely unreliable.

For this reason, it is necessary to devise a more robust method of estimating the mean square burst length, especially at larger particle sizes, since these will be more influential for the derived mass flux measurements of the instrument. The approach adopted here is to assume that the signal amplitude is proportional to the square of the particle diameter. It can be deduced from the above equations that $\overline{L^2}$ is linearly correlated to the logarithm of particle diameter, i.e.:

$$\overline{L^2} = A * \ln d_p + B$$

The constants A and B must be determined by fitting to the measured data. The measured mean square burst lengths from all size classes that can be set (default value is 100 samples) is used for curve fitting above equation using a least squares approach.

7.5.3.4 Trajectory dependent detection area (*X*-*Y*)

In making size, concentration or mass flux measurements, the number of particles detected and measured is always with respect to a reference cross-sectional area. For particle trajectories in the *X*- or *Y*-direction, these reference areas, A_x and A_y are given in the previous section. If however, the particle has a different trajectory within the *XY*-plane, the effective area over which particle detection takes place will be altered. This is illustrated in Figure 7-64 for the reference area normal to the *X*-coordinate. The effective area becomes:

$$A'_x = \frac{A_x}{\cos\gamma} = \frac{L_s}{\sin\phi} * \frac{d_e}{\cos\gamma}$$

for all particles which just pass through the detection limit defined by d_e.

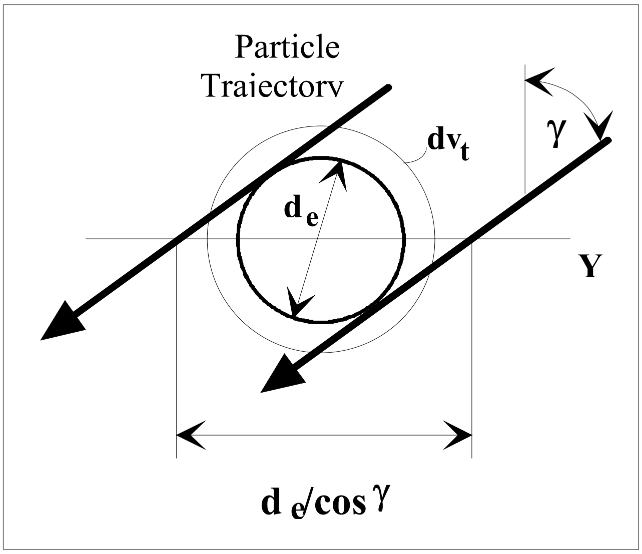


Figure 7-64: Effective detection area normal to the X-axis.

Similarly, the area normal to the *Y*-direction will be altered according to:

$$A'_y = \frac{A_y}{\sin\gamma} = \frac{L_s}{\sin\phi} * \frac{d_e}{\sin\gamma} + \frac{\pi}{4}\frac{d_e^2}{\sin^2\gamma}\cot\phi$$

The angle γ is just given by the measured velocity components of the particle:

$$\gamma = \tan^{-1}\frac{v}{u}$$

7.5.3.5 Flux and concentration

The volume flux can be computed for each vector component. The appropriate expressions for a 2D system are:

$$f_{vx} = \frac{\pi}{6\Delta t}\sum_{i=1}^{n}\frac{D_i^3\cos\gamma_i}{A_x(D_k)}$$

$$f_{vy} = \frac{\pi}{6\Delta t}\sum_{i=1}^{n}\frac{D_i^3\sin\gamma_i}{A_y(D_k)}$$

d_i and γ_I are the diameter and the trajectory of individual particles whereas the reference area A_k is taken for the respective size class d_k as a whole.
Note that the absolute signs are not used in the numerator, thus particles passing through the reference area with a negative velocity will subtract from the total mass flux, i.e. when *cos* or *sin* beomes negative.

The concentration is a scalar quantity. For size class *k* it can be computed as:

$$C(D_k) = \frac{1}{\Delta t} \sum_{i=1}^{N_k} \frac{1}{\sqrt{u_i^2 + v_i^2}} \frac{1}{A(\gamma, D_k)}$$

The area $A(\gamma,D_k)$ refers to the detection and validation cross sectional area projected normal to the particle velocity vector and N_k refers to the number of particles in the size class k. Thus, for a trajectory angle of $\gamma = 0°$, $A(\gamma,D_k)$ should be equal to $A_x(D_k)$ and for a trajectory angle of $\gamma = 90°$, $A(\gamma,D_k)$ should be equal to $A_y(D_k)$. The exact equation describing the area change as a function of trajectory angle is likely quite complicated. A linear change is suggested between the two extremes, i.e.:

$$A(\gamma, D_k) = \left(1 - \frac{\gamma}{90°}\right) A_x(D_k) + \frac{\gamma}{90°} A_y(D_k)$$

The number concentration of m size classes is given by:

$$C_N = \sum_{k=1}^{m} C(D_k)$$

7.5.4 Spectral analysis (two-time statistics)

As opposed to moment-calculation, spectral-analysis investigates the relations between samples and the timing of events. Since all of these calculations are based on pairs of values, this is sometimes referred to as two-time statistics.

Consider an ideal experiment producing continuous measurements represented as time functions u(t) and v(t):

$$u(t), v(t), \dots \quad t \in [0, T] \tag{7-34}$$

In the context of LDA-measurements, u(t) and v(t) will normally be velocities, but may in principle represent temperature, pressure, or something else.

7.5.4.1 Definition of correlation and covariance

Correlation

The exact definition of the correlation function $R_{uv}(t_1,t_2)$ is:

$$R_{uv}(t_1, t_2) \equiv E\left\{ u(t_1) \cdot v^*(t_2) \right\} \tag{7-35}$$

-where E{…} is the notation for the expectation value (mean).

This definition includes the option that u(t) and/or v(t) might be complex. In actual measurements, they are both real, so the complex conjugate $v^*(t)$ equals v(t). Furthermore we assume that both u(t) and v(t) are wide-sense stationary, meaning that the correlation function in (7-35) depends only on the lag time $\tau = t_2 - t_1$ rather than on the exact values of t_1 and t_2.

With these simplifications the correlation function $R_{uv}(\tau)$ can be defined as:

$$R_{uv}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T u(t)\, v(t+\tau) dt \tag{7-36}$$

-where the integration limits 0→T reflects that real measurements always take place over a finite time-span.

Since both u(t) and v(t) are real, the correlation $R_{uv}(\tau)$ is also a real function.

Covariance

For simplicity the literature often assumes that the signals u(t) and v(t) have zero mean, and if they don't calculations are performed on the fluctuating part of the signal, meaning that the mean value is subtracted before correlations are calculated. Strictly speaking this is not correlation, but covariance, $C_{uv}(\tau)$:

$$C_{uv}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T \left[u(t) - \overline{u} \right] \left[v(t+\tau) - \overline{v} \right] dt \tag{7-37}$$

-which again assumes that both u(t) and v(t) are real and stationary.

From (7-36) and (7-37) it is easy to show the following simple relation between correlation and covariance:

$$R_{uv}(\tau) = C_{uv}(\tau) + \overline{u}\,\overline{v} \tag{7-38}$$

Unfortunately much of the literature does not distinguish, and uses the term correlation, even if covariance is actually being calculated.

From (7-38) it is obvious that if either u(t) or v(t) have zero mean, covariance and correlation will indeed be identical, but otherwise they will not, so you should be aware of the difference.

Auto- -correlation & & Cross- -covariance

$R_{uv}(\tau)$ and $C_{uv}(\tau)$ are called cross-correlation and cross-covariance when u(t) and v(t) represent 2 independent measurements, and autocorrelation and autocovariance when u(t) and v(t) represent the same signal.

In the latter case the symbols $R_{uu}(\tau)$ and $C_{uu}(\tau)$ or simply $R(\tau)$ and $C(\tau)$ are often used to designate auto-correlation and auto-covariance respectively.

Note that $R_{uu}(-\tau)=R_{uu}(\tau)$ and $C_{uu}(-\tau)=C_{uu}(\tau)$, meaning that autocorrelation and autocovariance are even functions. This is not the case for crosscorrelation and crosscovariance, since from (7-36) we get $R_{uv}(-\tau)=R_{vu}(\tau)\neq R_{uv}(\tau)$.

Note also that for $\tau=0$; the autocovariance equals the variance of u(t):

$$C(0) = E\left\{\left| u(t) - \bar{u} \right|^2\right\} = \sigma_{uu}^2 = V\{u\} \qquad (7\text{-}39)$$

Similarly the autocorrelation for $\tau=0$ corresponds to the average signal-intensity:

$$R(0) = E\left\{\left| u(t) \right|^2\right\} \qquad (7\text{-}40)$$

The autocorrelation function can be interpreted as a measure of how well future values of the data can be predicted from past observations. As you might expect from this, $R(\tau)$ normally decrease with increasing lag time τ, as does the autocovariance $C(\tau)$. The autocovariance generally approach 0 for $\tau \to \infty$, whereas the autocorrelation approach $(E\{u\})^2$.

The crosscorrelation can be interpreted similarly, but unlike the autocorrelation it is not symmetrical around $\tau=0$. This is easily understood from a simple example: Imagine crosscorrelation between inlet pressure and outlet velocity measured on a length of pipe. Fluctuations in the inlet pressure will cause changes in the outlet velocity, but there is a small delay, which can easily be calculated from the speed of sound (c) and the length of the pipe (L). This will produce a peak in the cross-correlation at lag time $\tau=L/c$, indicating that to some extent future outlet velocities can be predicted from current inlet pressure.

If the crosscorrelation function was symmetrical, this would indicate, that also future inlet pressure could be predicted from present outlet velocity, which of course is impossible.

7.5.4.1.1 Integral time-scale τ_I

In the literature, the integral time-scale τ_I is usually defined on the basis of autocorrelation $R(\tau)$, but this correlation is calculated from the fluctuating part of the measured quantity, meaning that the mean-value has been subtracted. Strictly speaking this is not correlation but covariance as explained on page 7-105, so a more correct definition of the integral time-scale is based on autocovariance $C_{uu}(\tau)$:

$$\tau_I = \int_0^\infty \frac{C_{uu}(\tau)}{C_{uu}(0)} d\tau \qquad (7\text{-}41)$$

The integral time-scale τ_I is a rough measure of the longest connections in the turbulent behaviour. Events more than 2 integral time scales apart, can be considered independent.

7.5.4.2 Definition of the spectrum

The spectral density $S_{uv}(f)$ and the correlation $R_{uv}(\tau)$ form a Fourier transform pair, defining the spectral density function:

$$S_{uv}(f) = \int_{-\infty}^{\infty} R_{uv}(\tau)\, e^{-i2\pi f\tau} d\tau \qquad \text{(Fourier transform)} \qquad (7\text{-}42)$$

$$R_{uv}(\tau) = \int_{-\infty}^{\infty} S_{uv}(f)\, e^{i2\pi f\tau} df \qquad \text{(Inverse Fourier transform)} \qquad (7\text{-}43)$$

Auto- & Cross-spectra $S_{uv}(f)$ is called cross-spectral density or simply cross-spectrum when u(t) and v(t) represent two independent measurements, and auto-spectral density when u(t) and v(t) represent the same physical quantity. In the latter case the symbol S(f) is often used instead of $S_{uu}(f)$, and the auto-spectral density function is frequently referred to as power spectral density (PSD), power spectrum, or simply the spectrum.

As you might expect from (7-42), the cross-spectrum $S_{uv}(f)$ is generally complex, but with real time functions u(t) and v(t), the crosscorrelation $R_{uv}(\tau)$ will be real, and consequently the cross-spectrum will fulfil:

$$S_{uv}(-f) = S^{*}_{uv}(f) \quad \Rightarrow \quad \begin{cases} \mathrm{Mod}\left[S_{uv}(-f)\right] = \mathrm{Mod}\left[S_{uv}(f)\right] & (\text{even}) \\ \mathrm{Arg}\left[S_{uv}(-f)\right] = -\mathrm{Arg}\left[S_{uv}(f)\right] & (\text{odd}) \end{cases} \qquad (7\text{-}44)$$

The autospectral density function $S_{uu}(f)$ can be considered a special case of the cross-spectrum, where the real and even autocorrelation $R_{uu}(\tau)$ lead to $S_{uu}(f)$ also being real and even:

$$S_{uu}(-f) = S_{uu}(f) \qquad (7\text{-}45)$$

Inserting (7-38) in (7-42) it is obvious that the spectral density can also be calculated from the covariance $C_{uv}(\tau)$:

$$\begin{aligned} S_{uv}(f) &= \int_{-\infty}^{\infty} \left(C_{uv}(\tau) + \overline{u}\,\overline{v}\right) e^{-i2\pi f\tau} d\tau \\ &= \int_{-\infty}^{\infty} C_{uv}(\tau)\, e^{-i2\pi f\tau} d\tau + \overline{u}\,\overline{v}\,\delta(f) \end{aligned} \qquad (7\text{-}46)$$

If the delta-function $\delta(f)$ in (7-46) is omitted, the only deviation between the spectrum calculated from $R_{uv}(\tau)$ and the one based on $C_{uv}(\tau)$ will be at f=0, where the calculation based on $C_{uv}(\tau)$ will yield $S_{uv}(0)=0$, since the DC-component of u(t) and v(t) has been removed in the calculation of covariance. This is used to increase the accuracy of the spectrum-calculation, since floating point numbers in computer-calculations are represented with a fixed size mantissa, and large DC-components thus may drown small fluctuations if they are included.

The autospectral density function can be interpreted as the frequency distribution of the turbulent energy in the flow, and periodic phenomena will produce peaks at frequencies corresponding to the dominating frequency/frequencies of the phenomena investigated.

7.5.4.3 Estimating correlations and spectra using finite Fourier transforms

Correlation theorem To reduce calculation time correlations and spectra are estimated using the correlation theorem, which states that the spectral density $S_{uv}(f)$ can be calculated directly from the separate Fourier transforms of u(t) and v(t):

$$S_{uv}(f) = \lim_{T\to\infty} \frac{1}{T} E\left[U(-f,T)\ V(f,T)\right] \qquad (7\text{-}47)$$

–where E[...] represent the expectation (mean) value, and U(f, T) and V(f, T) represent the finite Fourier transforms of u(t) and u(t) respectively:

$$\begin{aligned} U(f,T) &= \int_0^T \left(u(t) - \overline{u}\right) e^{-i2\pi f t} dt \\ V(f,T) &= \int_0^T \left(v(t) - \overline{v}\right) e^{-i2\pi f t} dt \end{aligned} \qquad (7\text{-}48)$$

The mean values of u(t) and v(t) are subtracted to improve calculation accuracy, ensuring that large DC-components do not drown small fluctuations. This will produce U(0,T)=V(0,T)=0, and consequently $S_{uv}(0)=0$ corresponding to (7-46) without the delta function δ(f).

In principle the Fourier transforms should be calculated integrating from -∞ to +∞, but in practice you always sample the signals over a limited period of time, as indicated by the finite limits of the integrations in (7-48). Provided the sampling period is much longer than the largest time scale you wish to investigate, this will be of little significance.

Spectrum estimator

Since both u(t) and v(t) are real, U(-f, T) equals U*(f, T), with U* representing the complex conjugate of U. Exploiting this and omitting the limiting and expectation operations in (7-47), the spectral density function $S_{uv}(f)$ can be estimated from U(f, T) and V(f, T) directly:

$$\hat{S}_{uv}(f) = \frac{1}{T} U^*(f,T)\ V(f,T) \qquad (7\text{-}49)$$

Correlation estimator

Once the spectral density has been estimated, inverse Fourier transformation yield an estimate of the covariance:

$$C_{uv}(\tau) = \int_{-\infty}^{\infty} S_{uv}(f) e^{i2\pi f\tau} df \qquad (7\text{-}50)$$

-from which the correlation can be calculated using (7-38):

$$R_{uv}(\tau) = C_{uv}(\tau) + \overline{u}\,\overline{v}$$

7.5.4.4 Digital calculations based on discrete samples

The definitions of correlations and spectra are based on the assumed knowledge of the true continuous signals u(t) and v(t), but in a real LDA-experiment time history records are not continuous. We get a velocity-sample whenever a seeding particle passes through the measuring volume. This happens with random time intervals, providing a discrete representation of the time history with arrival times in sequence, but with varying interarrival times:

$$\left\{ u(t_i), v(t_i) \,|\, \left(i = 0,\ldots,N-1\right) \wedge \left(0 \le t_i \le t_{i+1} \le T\right) \right\} \qquad (7\text{-}51)$$

Without knowledge of the true continuous signals u(t) and v(t) we can only estimate the spectra $S_{uv}(f)$. The estimates are usually fairly good at low frequencies, but tends to deviate randomly at frequencies significantly above the average sample rate.

In theory the random sampling allow us to determine spectra $S_{uv}(f)$ at very high frequencies, since there is a nonzero probability that samples will occur at time intervals smaller than the mean, thereby providing information on the high frequency components of the signal.

In practice it proves difficult to get satisfactory results at frequencies significantly higher than the mean data rate, because the variance of the estimated spectra becomes very large unless extremely long sampling times are used.

Even with very high data rate the upper frequency of the calculated spectrum is limited, since the measured velocities are averaged over the time it takes for the seeding particle to cross the measuring volume, and the transit time thus limits the upper frequency. For most LDA experiments the latter is no problem, since normally this upper limit is well above the highest frequency of interest.

7.5.4.5 Resampling

To reduce calculation time, the Fourier transformations in (7-48) are implemented using Fast Fourier Transformation (FFT). These algorithms require the discrete samples to be evenly distributed in time, and the process of converting the discrete representation of the time history record into an evenly spaced time history record with constant interarrival times is called resampling.

7.5.4.5.1 Sample-Hold

Several methods for resampling have been suggested, and [Schmidt (1997)] recommends the use of either sample/hold interpolation or exponential interpolation by [Høst Madsen & Caspersen (1995)]. Sample/hold interpolation is the most wide-spread of the two, and also the easiest to implement:

$$\left\{ u_{resamp}(t) = u(t_i) \middle| \left(t_i \le t < t_{i+1} \right) \right\} \qquad (7\text{-}52)$$

As shown in Figure 7-65, the sampled velocity is simply assumed to be constant until a new sample indicates that the velocity has changed.

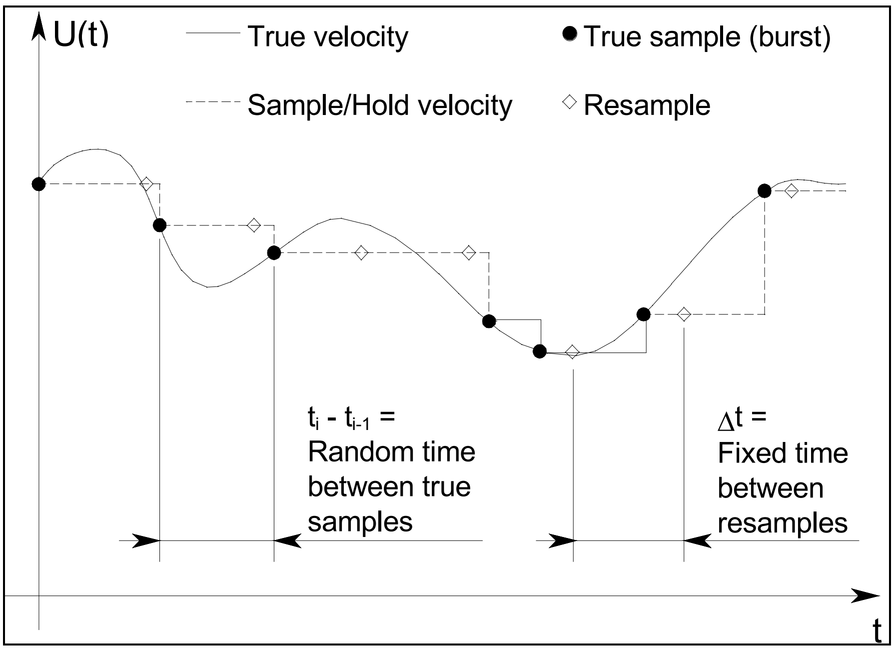


Figure 7-65 Random sampling, sample/hold and resampling.

The sampled and held signal is resampled at regular intervals to provide a series of evenly distributed velocity samples.

This simple approach presents two immediate problems both shown in Figure 7-65. If two neighboring true samples are further apart than the time between resamples, the first one will be resampled several times although no new information about the flow is available. If on the other hand there is more than one true sample in the time between two resamples, the information contained in all but the last one will be lost, since the resampling always take the value of the latest true sample.

Obviously these phenomena depend on both the resampling frequency and the time between true samples. While the former is a matter of choice, the latter must be calculated from the probability distribution of seeding particle arrivals as discussed in section 7.5.4.5.2 below.

Low pass filtering & Step noise

With respect to the calculation of spectra, [Adrian & Yao (1987)] show the presence of two other phenomena associated with the sample and hold approach:

- The sample and hold process acts like a first-order low pass filter attenuating the spectrum at frequencies above $\dot{n}/2\pi$.
- The sample and hold process introduce white noise, so-called step noise, over the entire frequency range of the calculated spectrum.

The low pass filtering is caused by the information loss that occurs during the hold periods, and the step noise is created by the random steps that occur when new samples arrive. Note that according to [Adrian & Yao (1987)] the step noise is itself low pass filtered above $f = \dot{n}/2\pi$.

7.5.4.5.2 Resampling frequency

Poisson process

The homogeneous, but random distribution of seeding particles in the fluid results in particle arrivals following a Poisson process:

$$P(k,\Delta t) = \frac{(\dot{n}\,\Delta t)^k}{k!} e^{-\dot{n}\,\Delta t} \qquad (7\text{-}53)$$

-describing the probability P of k particle arrivals within the period Δt, when the average datarate is $\dot{n}$ particles per second. Actually the datarate $\dot{n}$ is not constant, but depends on the instantaneous velocity (see velocity biasing on page 7-96), but except for highly turbulent flows (7-53) will be a good approximation to the true probability distribution.

With the resampling frequency chosen as c times the average datarate of the original samples, we get: $\Delta t = 1/(c\,\dot{n}) \Leftrightarrow \dot{n}\,\Delta t = 1/c$

Inserting this in (7-53) we can calculate the probability of true samples (particle arrivals) during each of the resampling time slots of duration Δt:

$P(0) = e^{-1/c}$ (No new particle arrivals)

$P(>1) = 1 - P(0) - P(1) = 1 - (1 + 1/c)e^{-1/c}$ (Several new particle arrivals)

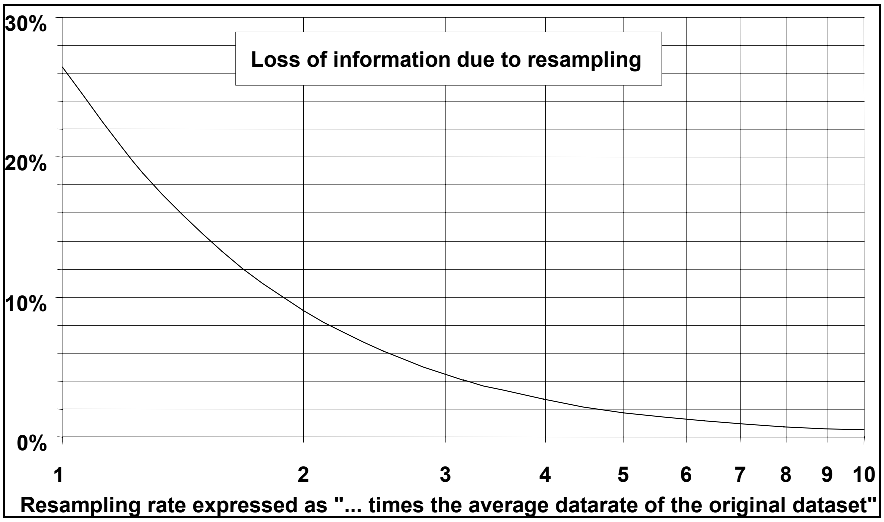


Figure 7-66 : Several particle arrivals between two resamples will cause loss of information, since only the last particle is recorded.

Figure 7-66 shows the likelihood of having more than one true sample in the time between two resamples. Increasing the resampling frequency, will reduce the width of each time-slot, and obviously reduce the risk of having more than one true sample in it. Unfortunately it also increases the probability of no true samples at all (not shown), and furthermore increase the total amount of data, requiring additional storage capacity and increased calculation time. Please note that due to the random nature of particle arrivals, you can never completely avoid loss of data: Even with a resampling rate of 10 times the average data rate, approximately 0.5% of the time-slots will contain two (or more) true samples of which all but the last one will be lost. At the same time the total amount of data will have increased tenfold, but approximately 90,5% of these new samples will be identical to the previous one, since no particles have arrived in the meantime to provide new information on the flow investigated.

7.5.4.5.3 Aliasing

Aliasing is a problem in any periodic sampling procedure: If an oscillating signal is sampled less than twice per cycle, it will produce the same samples as an artificial (aliased) signal with lower frequency.

Knowing only the sample-values, later analysis will be unable to distinguish between the true and the aliased signal, and consequently the high frequency signal will contribute to the calculations as if the frequency was actually lower.

The phenomenon is illustrated in Figure 7-67, where the true signal is sampled 1.6 times per cycle.

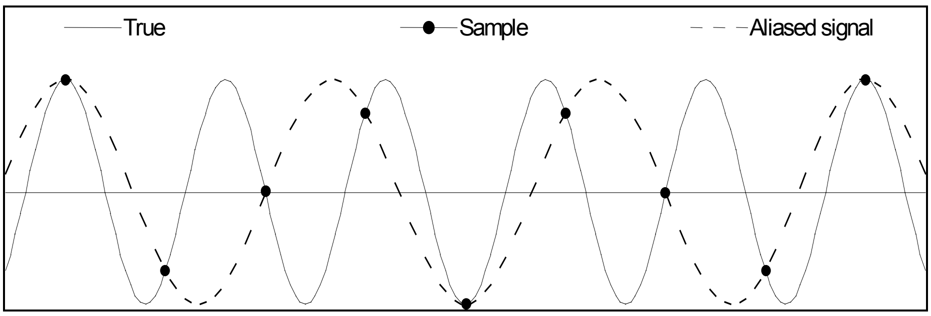


Figure 7-67: Sampling less than twice per cycle cause aliasing.

Nyquist criterion

For any sampling interval Δt there is a special frequency f_c, known as the Nyquist critical frequency, given by:

$$f_c \equiv \frac{1}{2\Delta t} \tag{7-54}$$

If the true signal contain components with frequencies higher than the Nyquist critical frequency, they will be falsely interpreted as lower frequency components with the same signal intensity.

To avoid this so-called aliasing the Nyquist criterion specify that samples should be taken at least twice in each period of the highest frequency contained in the sampled signal.

In the context of spectrum calculation aliasing mean that frequencies higher than half the sampling frequency will falsely contribute to the spectrum at lower frequencies.

Consider for example the signal shown in Figure 7-68: The true signal consists of three components: A 60Hz component, a 150Hz component and some white noise.

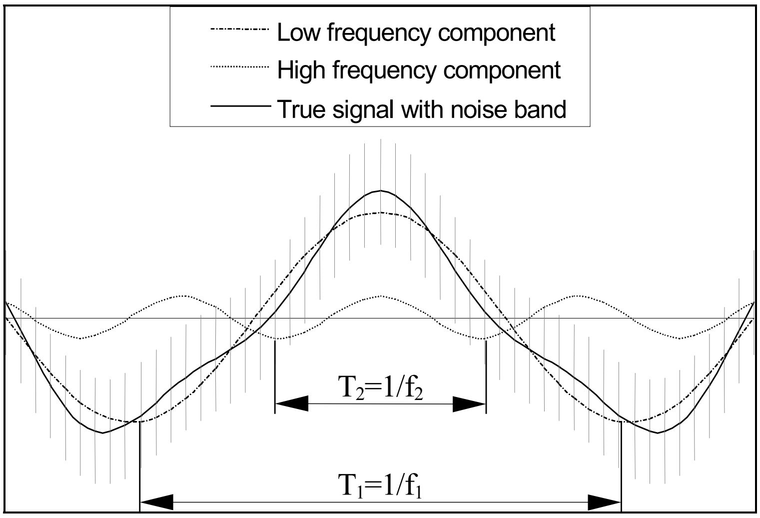


Figure 7-68 : The high frequency component drown in noise, leaving only the low frequency component visible.

On an oscilloscope the 60Hz component will be clearly visible, but the 150Hz component drown in noise and may not be recognized. If the sampling frequency is chosen as 240Hz, the Nyquist criterion state, that frequencies up to 120Hz will be resolved. This is more than enough to resolve the 60Hz component, but the energy contained in the 150Hz component will be aliased, and contribute to the spectrum around 90Hz as shown in Figure 7-69:

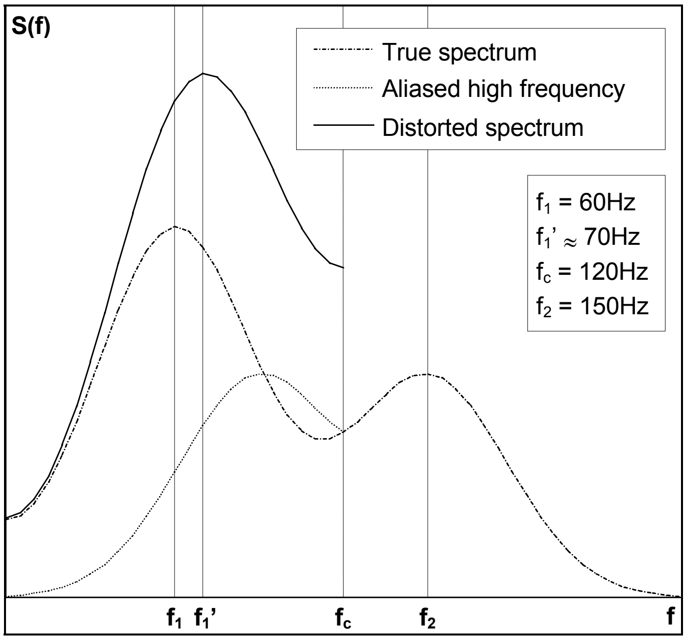


Figure 7-69: Effect of aliasing on the calculated spectrum.

As clearly seen in Figure 7-69, aliasing will distort the true spectrum and move the peak while increasing its height. Since the user was not originally aware of the 150Hz component, and expected a peak at "about" 60Hz, he may be inclined to accept the calculated peak-frequency f_1' although it is false.

In general there are two ways to avoid aliasing:

- Use a sampling rate sufficiently high to satisfy the Nyquist sampling criterion.
- Low-pass filter the signal to remove high frequency components.

As stated earlier, [Adrian & Yao (1987)] have shown that the sample and hold process itself acts like a first-order low pass filter attenuating the spectrum at frequencies above $\dot{n}/2\pi$. A first order lowpass filter will however only attenuate 20 dB/decade above the cut-off frequency, so considerable amounts of high frequency energy will be allowed to pass.

To minimize aliasing you should thus always aim at the highest possible datarate.

7.5.4.6 Spectrum and correlation estimates

With resampled data, the integrals in (7-48) can now be estimated as sums:

$$\begin{aligned} U_k &= \frac{T}{N}\sum_{n=0}^{N-1}\left(u_n - \bar{u}\right)\exp\left(-i2\pi\frac{kn}{N}\right) \cong U(f_k, T) \\ V_k &= \frac{T}{N}\sum_{n=0}^{N-1}\left(v_n - \bar{v}\right)\exp\left(-i2\pi\frac{kn}{N}\right) \cong V(f_k, T) \end{aligned} \qquad (7\text{-}55)$$

-where T/N=Δt is the resampling interval, and each value of k represent a different frequency: f_k=k/T, k=0, 1, 2, … , N/2.

If N, the number of samples, is a power of two, the above expressions can be calculated very fast using FFT-algorithms, and U_k and V_k are multiplied like in (7-49) to produce a spectrum estimate:

$$S_k = \hat{S}_{uv}(f_k) = \frac{1}{T} U_k^* \; V_k \qquad (7\text{-}56)$$

In principle the FFT-analysis also yield spectrum estimates at negative frequencies, but these are not shown, since the spectrum is always symmetrical around f=0.

7.5.4.6.1 Estimator bias

The estimator in (7-56) will produce spectrum estimates at discrete frequencies f_k=k/T (k=0, 1, 2, … ,N/2) and the frequency resolution of the estimated spectrum will thus be Δf=1/T. Each estimate S_k represents an average power spectral density in the range f_k±Δf/2, and will be bias free if the true spectrum is constant or changing at a constant rate within this range. In other words the second order derivative of the true spectrum with respect to frequency should be zero:

$$S''(f) = \frac{d^2S}{df^2} = 0 \quad \text{for } f \in \left[f_k - \frac{\Delta f}{2} \ ; \ f_k + \frac{\Delta f}{2} \right]$$

If this is not fulfilled the estimator will be biased as shown in Figure 7-70.

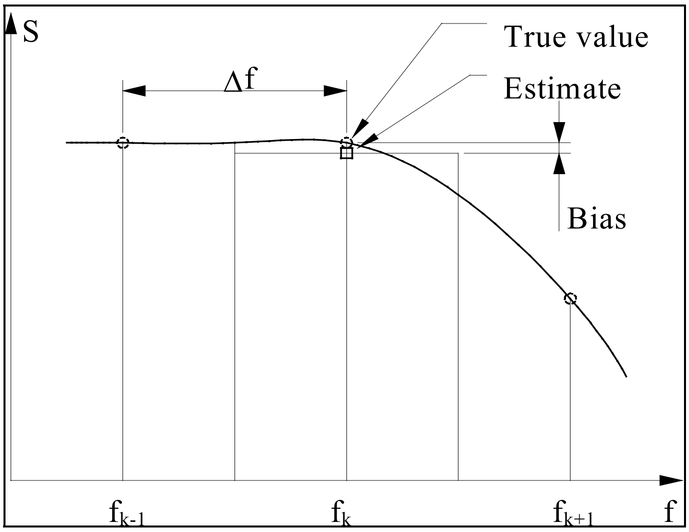


Figure 7-70: Bias of the estimator due to curvature of true spectrum.

Obviously the bias increases with increasing Δf and with increasing S"(f).
Δf decrease with increasing sampling time, so in the limit T→∞ the spectrum estimator (7-56) will be bias free.

7.5.4.6.2 Estimator variance

Intuitively you would expect the estimate to approach the true value as T approaches infinity. This is true with respect to the mean-value of the estimate (bias approaches zero), but unfortunately it doesn't hold for the variance.

On the contrary the normalized standard error ε_r is always a 100%:

$$\varepsilon_r \equiv \frac{\sigma\left[\hat{S}_{uv}(f)\right]}{S_{uv}(f)} = 1$$

-where $\sigma\left[\hat{S}_{uv}(f)\right]$ is the standard deviation of the spectrum estimate $\hat{S}_{uv}(f)$, and $S_{uv}(f)$ is the true value (see [Bendat & Piersol (1971)])

As explained above the frequency resolution Δf of the calculated spectrum depend on the duration T of the sampling period. Consequently the additional information acquired increasing T is used solely to produce spectrum estimates at a higher number of discrete frequencies rather than reducing the variance of any one particular spectrum estimate.

Analysis of LDA-measurements is based on discrete velocity samples, and you might attempt to reduce the estimator variance by increasing the sample rate, producing more samples within the same finite sampling period T. Unfortunately this will not improve things either: According to the Nyquist sampling criterion you will not be able to estimate the spectrum at frequencies above half the sampling rate. The additional information acquired increasing the sample rate will be used to produce additional spectrum estimates at higher frequencies, and again this does not reduce the variance of any one particular spectrum estimate.

7.5.4.6.3 Estimator smoothing

In practice, the random errors of an estimate produced by (7-56) can be reduced by smoothing the estimated spectrum.
–There are two ways of doing this:

- Ensemble smoothing: Averaging over an ensemble of estimates.
- Frequency smoothing: Averaging over neighboring frequencies.

Ensemble smoothing Ensemble smoothing is implemented by splitting the raw data into blocks of equal duration. A separate spectrum estimate is calculated for each block, and the final estimate is determined as the average of the calculated spectra:

$$\hat{S}_{uv}(f) = \frac{1}{q}\sum_{i=1}^{i=q}\hat{S}'_{uv,i}(f) \qquad (7\text{-}57)$$

- where S'(f) is introduced to distinguish the raw and the smoothed estimate.

This will reduce the variance of the estimator by a factor q, where q is the number of blocks used in the calculation. Consequently the standard deviation and thus the normalized standard error is reduced by a factor √q:

$$\varepsilon_r \equiv \frac{\sigma\left[\hat{S}_{uv}(f)\right]}{S_{uv}(f)} = \frac{1}{\sqrt{q}} \qquad (7\text{-}58)$$

Since the duration of each block is only a fraction of the total sampling period, the method has the drawback of reducing the frequency resolution of the calculated spectrum. With a direct estimate based on Fourier transform of the entire sampling period T the frequency resolution becomes $\Delta f=1/T$, while ensemble averaging reduces resolution to $\Delta f=q/T$.

Apart from reducing estimator variance, the ensemble averaging will also reduce calculation time slightly, since a separate Fourier transform of several smaller blocks is faster than calculating the Fourier transform of one large block.

Frequency smoothing Frequency smoothing is done by averaging together the results for ℓ neighboring spectral components in the estimate based on Fourier transform of the entire sampling period:

$$\hat{S}_{uv}(f_i) = \frac{1}{\ell}\sum_{j=(1-\ell)/2}^{j=(\ell-1)/2}\hat{S}'_{uv}(f_{i+j}) \qquad \ell = 1,3,5,\ldots \qquad (7\text{-}59)$$

-again S'(f) is used to distinguish between the raw and the smoothed estimate.

Similar to ensemble averaging, the variance of the estimator is reduced by a factor ℓ, and standard deviation and normalized standard error are thus reduced accordingly:

$$\varepsilon_r \equiv \frac{\sigma\left[\hat{S}_{uv}(f)\right]}{S_{uv}(f)} = \frac{1}{\sqrt{\ell}} \tag{7-60}$$

As opposed to ensemble smoothing this method preserves frequency resolution, but frequency smoothing introduces the problem of peak smearing instead.

The problem arises from the fact that the smoothed spectrum estimate at any one particular frequency is actually the result of calculations performed over a range of neighboring frequencies.

If there is a peak in the true spectrum, the energy contained in this peak will “leak” to neighboring frequencies, while at the same time the true peak is “contaminated” by the lower spectrum estimates from neighboring frequencies. This leads to artificial broadening of peak width and reduction of peak height.
In severe cases a peak in the true spectrum may not be recognized at all.

In practice frequency smoothing is implemented as filter functions, some of which are more advanced than simple mean values. To some extent these advanced filter functions may reduce the above mentioned problem, but it cannot be removed completely. The filter functions are described in more detail later in section 7.5.4.7 of this manual.

Smoothing bias

Both frequency and ensemble smoothing increase bias according to the mechanism illustrated in Figure 7-70. As explained above, ensemble smoothing reduce frequency resolution by increasing Δf, thereby directly increasing bias as explained on page 7-114. Frequency smoothing preserves resolution, but introduce bias by including spectrum estimates from neighboring frequencies. The effect is exactly the same as for ensemble averaging: The resulting smoothed spectrum estimate is an average value estimated over a wider frequency range, and bias is introduced accordingly if the second order derivative of the true spectrum with respect to frequency is nonzero within the range in question.

7.5.4.6.4 End effects

Correlations and spectra are calculated using Fast Fourier Transformation (FFT). This approach gives much higher calculation speed than a direct implementation, but the method is based on the assumption that the input signal is cyclic with period corresponding to the sampling period T. In most cases this assumption does not hold, and consequently errors are introduced. The error is present both in the frequency and the time-domain. In the frequency-domain the error is known as cyclic noise, but the problem is easier explained and understood in the time-domain, where it is known as circular correlation (see Figure 7-71).

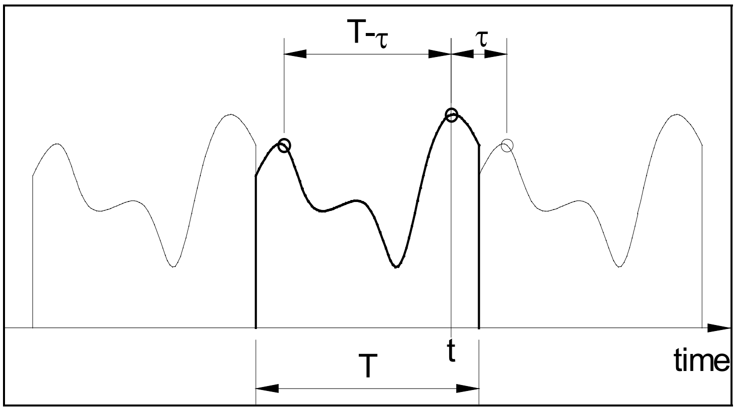


Figure 7-71: Assumed cyclic signal cause circular correlation.

If we consider the definition (7-36) without the limiting function $T \rightarrow \infty$, the correlation function $R_{uv}(\tau)$ may be estimated as:

$$R_{uv}(\tau) \cong \frac{1}{T}\int_0^T u(t)\, v(t+\tau)dt$$

For positive time lags $\tau>0$, $v(t+\tau)$ will obviously require data from times later than t=T, and similarly data prior to t=0 will be required for negative lags $\tau<0$.

These data are not available, and instead the FFT-algorithm fill in the blanks by exploiting the assumed cyclic behaviour of the signal as illustrated in Figure 7-71:

The missing data at time $t+\tau$ is assumed to correspond to the data recorded one "cycle" earlier, i.e. at time $t+\tau-T$. Since the signal is <u>not</u> cyclic, this corresponds to including contributions with lag time $T-\tau$ in the calculations regarding lag time τ.

The consequence of this is illustrated in Figure 7-72, where contributions from both the true $R_{uv}(\tau)$ and the circular $R_{uv}(T-\tau)$ add up to produce a "contaminated" correlation estimate. At $\tau=0$ the estimated correlation is correct, but the contribution from the circular correlation increases with increasing τ, and at $\tau=T$ the true correlation doesn't contribute at all.

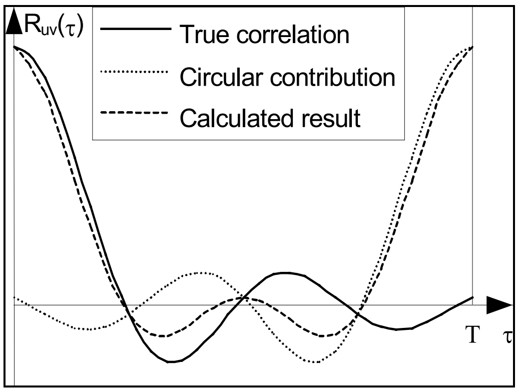


Figure 7-72: Circular correlation.

Note that the circular contribution is actually the mirror image of the true correlation, meaning that the calculated correlation at small time lags is contaminated by true correlation values from large lags.

Often the sampling period T is much larger than the integral timescale τ_I of the flow, meaning that the true correlation will quickly drop off to "almost zero" as τ increases. Consequently the error will be small for small lag times, but it is impossible to obtain reliable correlation estimates for τ>T/2, where the circular contribution will dominate the estimate.

As depicted in Figure 7-72 errors can however be considerable if the sampling period T is of the same order of magnitude as the integral time scale τ_I, and in general the problem of circular correlation cannot be ignored.

7.5.4.6.5 Zero padding

The errors from circular correlation can be avoided completely by the use of a technique called zero padding: Prior to the FFT-analysis, the sampling period is artificially doubled by adding a zero signal of duration T immediately after the sampled signal. The FFT-analysis still assume the signal to be cyclic, but now the assumed period is 2T, and the signal is zero half the time as shown in Figure 7-73.

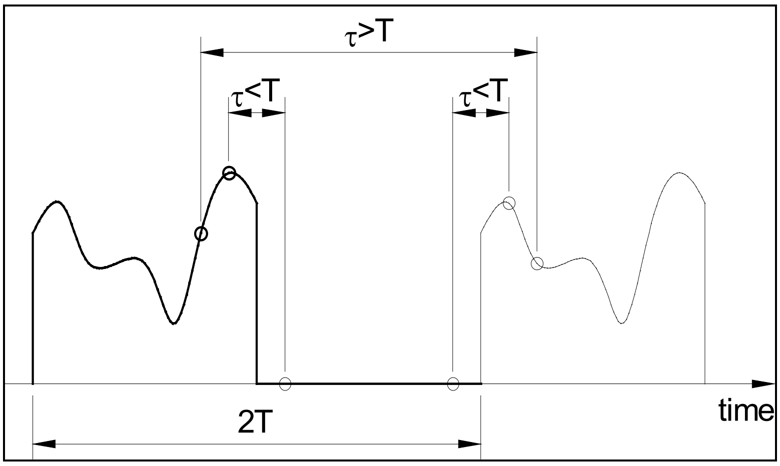


Figure 7-73: Zero padding the sampled signal.

Now the true and the circular correlation is completely separated, since for small lags (τ<T) u(t)·v(t+τ) will equal zero, when t+τ>T, while only large lag times (τ>T) will produce circular correlation due to the assumed cyclic nature of the sampled signal. This is illustrated in Figure 7-74.

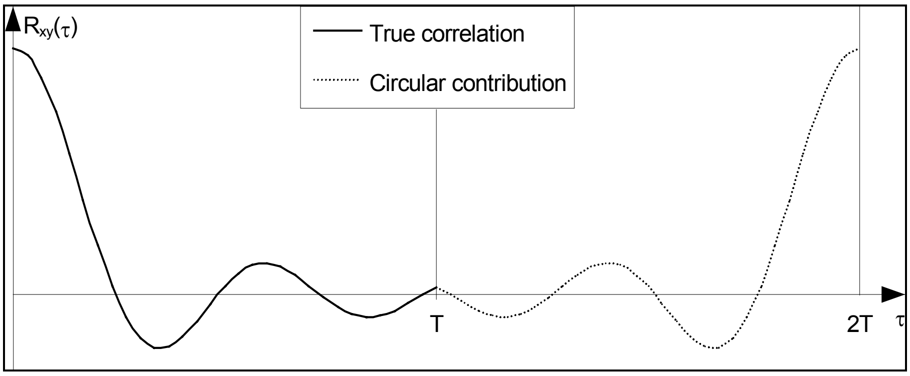


Figure 7-74: Separating true and circular correlation using zero padding.

With zero padding the correlation function can thus be estimated with lag times as big as τ=T. For large lags you should remember however that within the original data set used for the calculation only a very limited number of samples have been available with this long time between them. Consequently the correlations estimated at large lag times may not be very accurate.

Improved resolution Apart from removing cyclic noise, zero padding has the benefit of improving the frequency resolution of the calculated spectra. By adding a number of zeroes after your true samples, the sampling period T is artificially increased. Without zero padding the frequency resolution is $\Delta f=1/T$, but increasing the sampling period to 2T will change the resolution to $\Delta f=1/2T$. In principle more zeroes can be added to improve the resolution further, but since no new information is really added, you should think of this technique as nothing but an intelligent form of interpolation between raw estimates.

Calculation speed

Since the amount of data going into the FFT-analysis increases, zero padding will obviously slow down the calculations. With the number of samples included in a typical LDA-experiment, the FFT-approach will however remain superior to a direct calculation of correlations and spectra.

7.5.4.7 Filters

As explained in section 7.5.4.6.2, the "raw" spectrum estimates may deviate considerably from the true value. Dividing the resampled data into blocks to perform ensemble smoothing will improve this, and further smoothing of the calculated spectrum can be achieved by averaging neighboring spectrum estimates. In practice this so-called frequency smoothing is implemented as filter-functions, sometimes referred to as lag-windows due to the way they are implemented. Frequency-smoothing could be programmed as a sweep over the frequency-range for which estimates have been calculated, but again FFT-algorithms are used to increase speed by swapping back and forth between frequency- and time-domain:

1. Switch to time-domain performing a Fourier-transform of the spectrum.
2. Apply a so-called Lag-window to the resulting correlation estimate.
3. Fourier-transform back to frequency-domain.

The lag-window is implemented by multiplying each correlation estimate with a factor $w_L(\tau)$ depending on the lag-time τ of the estimate itself.

As an example the Hanning window is defined by:

$$w_L(\tau) = \begin{cases} \frac{1}{2}\left(1+\cos\left(\pi\frac{\tau}{T}\right)\right) & \text{for } |\tau| \le T \\ 0 & \text{otherwise} \end{cases} \tag{7-61}$$

-where T is the maximum lag time of the correlation (in the context of filters and lag-windows this is sometimes referred to as window width).

It can be shown (see [Bendat & Piersol (1971)]) that the effect of the Hanning filter is to replace each spectrum estimate with a weighted average of the "old" estimate and its neighbors:

$$\hat{S}_k = \tfrac{1}{4}\tilde{S}_{k-1} + \tfrac{1}{2}\tilde{S}_k + \tfrac{1}{4}\tilde{S}_{k+1} \tag{7-62}$$

–where hats and tildes are used to distinguish the old and the new spectrum estimates.

It is beyond the scope of this text to explain this in detail, but the Hanning filter and many more are described in standard textbooks such as [Bendat & Piersol (1971)]) and [Papoulis (1984)].

8. Trouble shooting

8.1 Installation

Please check the readme.txt in the BSA Flow Software folder for the latest information on corrections and new features in the software. Check also the processor software version in using the Dantec Device configuration from the control panel editor of Windows.

8.1.1 I get error messages trying to run sample projects

If you get the following message, when you try to run a sample project:

the reason may be that you have not installed all required add-ons. Only the sample projects included with the main package can run without further add-ons. Sample projects included with add-ons require the Advanced Graphics Add-on to run.

Check the Help - About BSA Flow Software menu to see which Add-ons and options are enabled by your dongle. If the Advanced Graphics Add-on is not in the list, you can only run sample projects included with the BSA Flow Software main package.

8.2 BSA F/P connection cannot be established

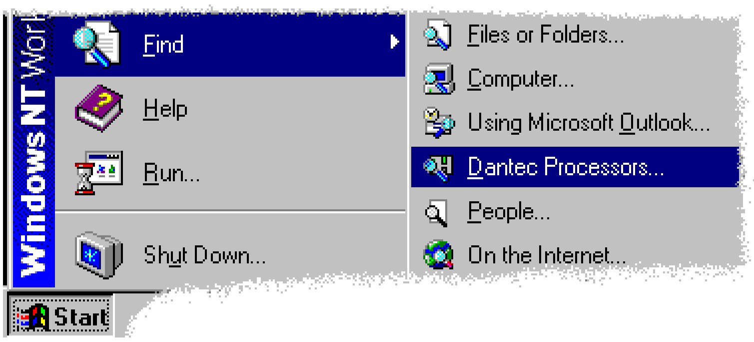
The most probable reason is that the IP address of the BSA is not recognised by the PC.

You can attempt to establish connection in several ways:

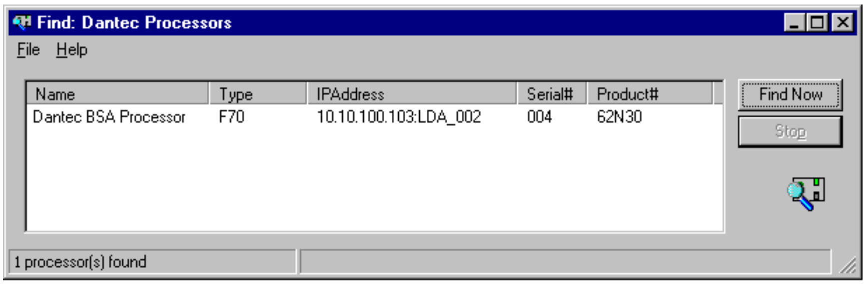
1. Using the Dantec Device Configuration wizard (see chapter 3)
2. Use the Windows Find function, see section 8.2.1
3. Change the BSA IP address by the BSA configuration selector, see section 8.2.2.

8.2.1 Find Dantec processors

In the Windows task bar, click the Start button and select Find - Dantec Processors…

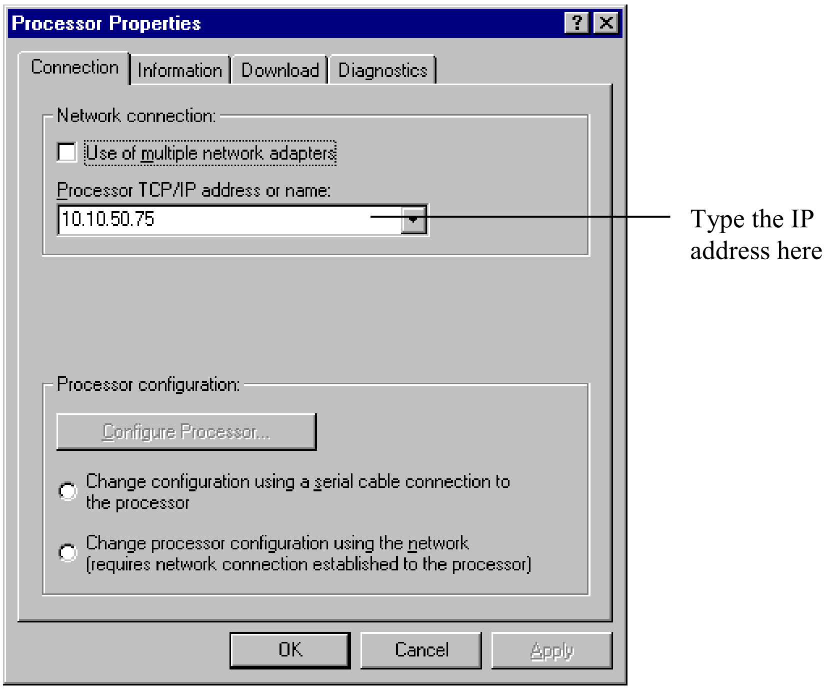


If the software identifies a BSA, you will get a message similar to this:



Write down the IP Address, open the Dantec Device Configuration wizard from the Control Panel:

select Processor - Properties, click on the Connection tab and type the address in the field shown below:


Processor Properties
Connection
Information
Download
Diagnostics
Network connection:
Use of multiple network adapters
Processor TCP/IP address or name:
10.10.50.75
Processor configuration:
Configure Processor...
Change configuration using a serial cable connection to the processor
Change processor configuration using the network (requires network connection established to the processor)
OK
Cancel
Apply
Type the IP address here

8.2.2 BSA Configuration Selector Settings

Figure 8-1 Configuration Selector at BSA rear panel

The BSA Processor is equipped with a Configuration Selector switch on the rear panel. This selector can be used to configure the processor to a number of predefined network settings like IP address and subnet mask, see Table 8-1.
The default position of the selector is 0.
After turning the switch, the processor must be restarted to obtain the selected settings.

Selection	IP Address	Subnet Mask	Comment
0	10.10.100.100	255.0.0.0	System defaults.
1	10.10.100.101	255.0.0.0	
2	10.10.100.102	255.0.0.0	
3	10.10.100.103	255.0.0.0	
4			Not used.
5			Not used.
6			Not used.
7	192.168.255.254	255.0.0.0	FlowMap processor.
8	10.10.100.34	255.0.0.0	
9	10.10.100.30	255.0.0.0	
10	0.0.0.0	255.0.0.0	DHCP Server support.
11			Not used.
12	#.#.#.#	#.#.#.#	User defined in Configuration Service.
13	10.10.100.100	255.0.0.0	Reset to system defaults (set IP address to default).
14			Reset to system defaults (keep IP address).
15			Not used.

Table 8-1 BSA address settings for using the Configuration selector

8.2.3 Peer-to-Peer Configuration

It is recommended that systems running with the BSA Processor runs peer-to-peer with the application PC. This is primarily because of performance and service considerations. When the processor and computer is connected peer-to-peer the two parts have to have nearly the same IP address and subnet masks.

Valid combinations for the *application PC* are:

IP Address	Subnet Mask
10.x.x.x	255.0.0.0

Figure 8-2 Applicable address settings for the PC running BSA Flow Software, using peer-to-peer connection

8.2.3.1 Configuration Service

Another way to change the IP address, subnet mask and processor name is to use the advanced Configuration Service installed in the processor. This service can be reached using an existing network connection or by a serial null-modem cable connection.

When using a network connection, communication can be established using the Telnet utility. In the case of a serial connection the program HyperTerminal can be used. Both programs are found in standard installations of Windows. A quick way to use the Configuration Service is to launch communication from the Connection page in the Device Configuration.

8.3 BSA (57N series) properties do not appear in the property editor

There is no connection. Please check that the BSAs are on and the GPIB cables connected to the GPIB interface in the PC.

The are two links in the connection from the software to the processor:

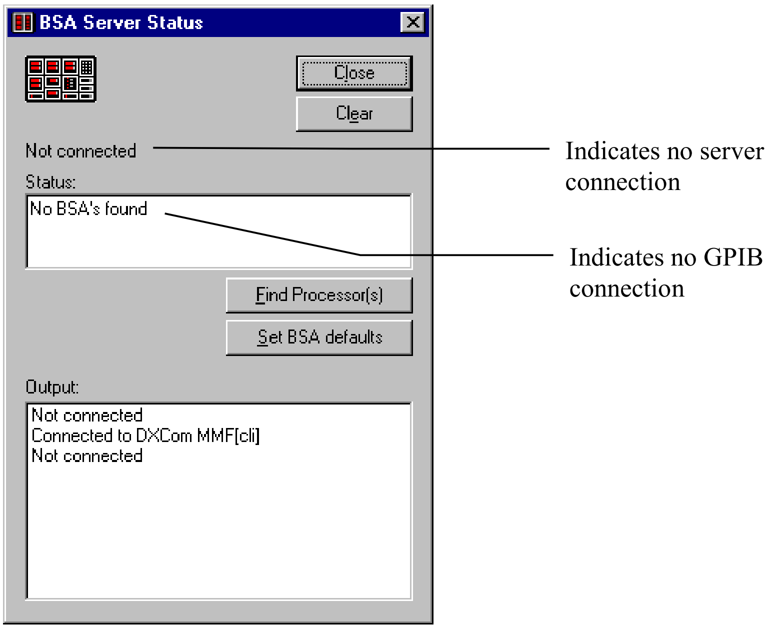
an processor server connection, and

a GPIB connection.

If there is no BSA server icon in the lower right hand corner of the screen, you must first start it by going into the Tools menu, selecting Plug-Ins and BSA server.

To check for connection, right-click on the BSA server icon and select Status.

If you get the following dialog

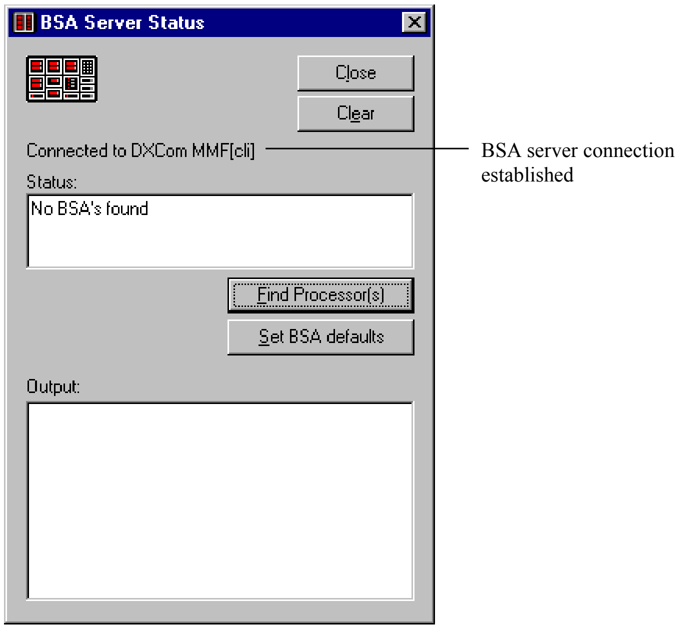


you must do the following:

1. establish BSA server connection:

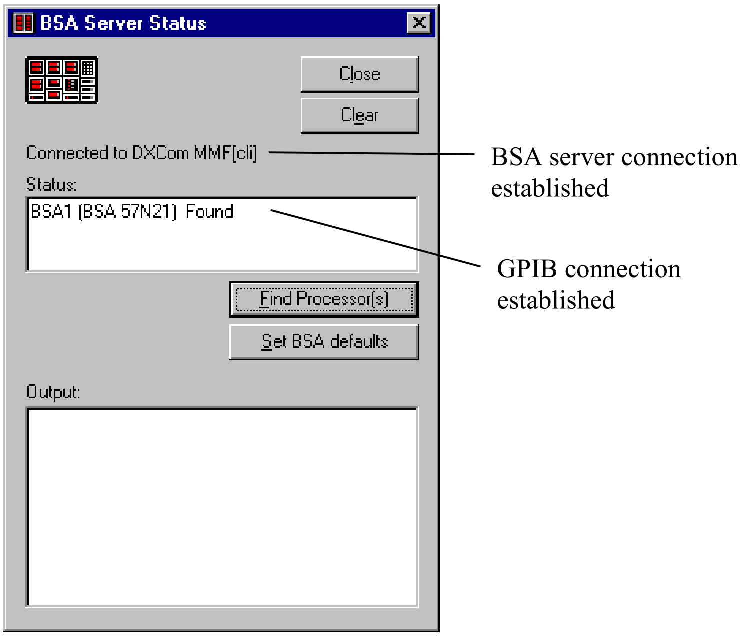
Right-click on the Standard LDA icon in the project explorer - select Connections, selct the Processor server tab and click the Connect button.

The dialog should then change to the following:

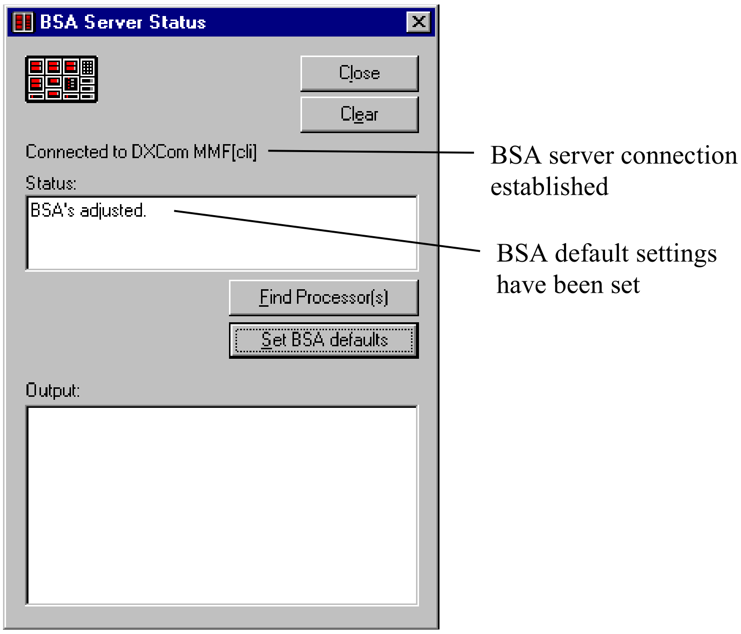


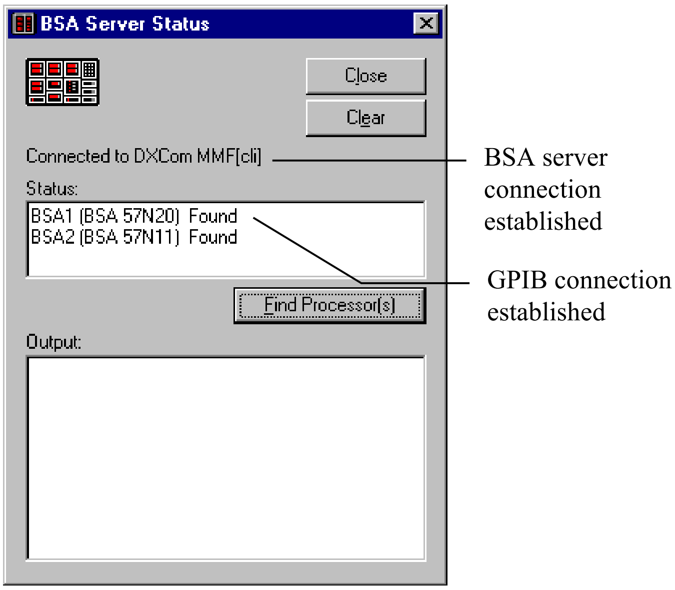
2. Establish GPIB connection.

Click the Find Processor(s) button, and you should get a dialog similar to this, indicating correct functioning:



The BSA settings may be corrupted after this, in which case you should restore default settings by clicking the “Set BSA defaults” button. After this, the BSA Server Status window should appear similar to this:





If you still get the No BSAs found message in the status field, there is the following possibility:

Possible reason	**Remedy**
The GPIB set-up is incorrect	Go through the GPIB set-up as described in chapter 3. Remember to modify the "Device Templates": rename dev. 13, 14 and 15 to BSA1, BSA2 and BSA3.

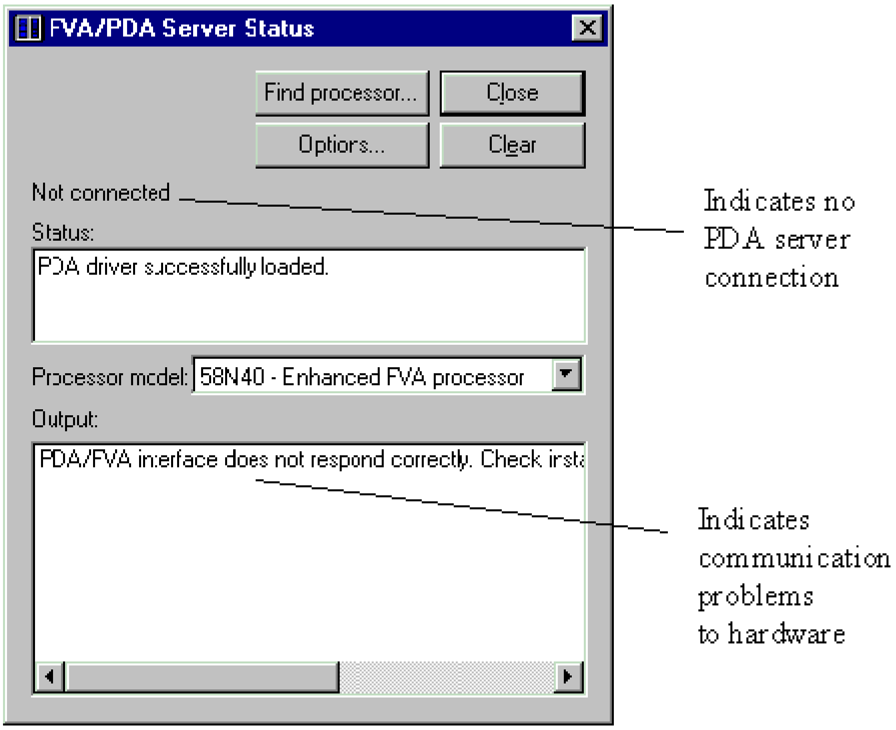
8.4 FVA/PDA processor properties do not appear in the property editor

There is no connection. Please check that the FVA processor is switched on and the interface cable connected to the interface in the PC.

If there is no PDA server icon in the lower right hand corner of the screen, you must first start it by going into the Tools menu, selecting Plug-Ins and PDA server.

To check for connection, right-click on the PDA server icon and select Status.

If you get the following dialog



you must do the following:

1. Establish the PDA server connection:

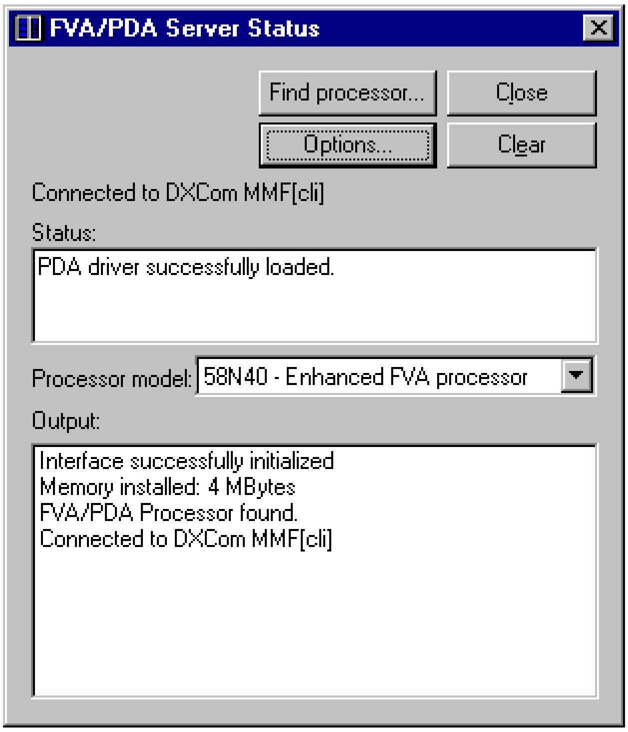
Right-click on the FVA Application icon in the project explorer - select Connections, select the Processor server tab and click the Connect button.

2. Check cable connection between FVA processor and FVA/PDA interface board.

3. Check address setting of the FVA/PDA interface board. To do this click Options... in the FVA/PDA server status dialog. Select proper base address of the board and reboot PC.

4. If the processor had been switched on after the software had been started, you must click the Find processor... button to establish the connection to the FVA processor.

The FVA/PDA server status dialog should then look like this:



8.5 The traverse system does not move when is should

8.5.1 Lightweight traverse

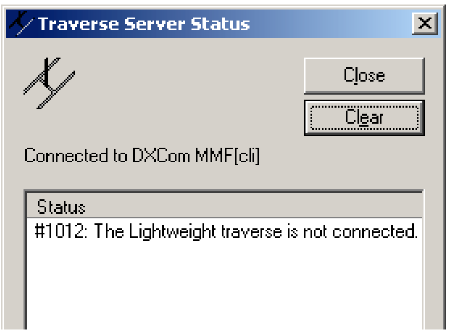
Please check that:

1. the Controller is on
2. the correct cable is connected from the RS232C connector on the controller to a serial port of the PC (NB: beware that the PC label is at the PC side, and the Interface label at the Controller side!)
3. The µP-Reset button on the Controller is off (the light is off). If it is on, press it once to switch it off.

If there is no Traverse server icon in the lower right hand corner of the screen, you must first start it by going to the Tools menu, selecting Plug-Ins and Traverse server.

To check for connection, right-click on the Traverse server icon and select Status.

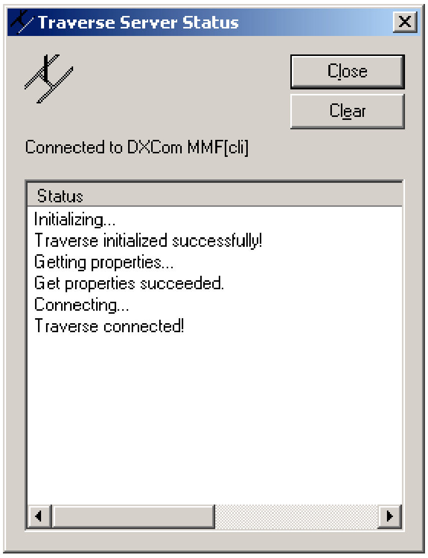
If you get the following dialog



there are the following possibilities:

Possible reason	Remedy
Incorrect type of traverse specified	Close BSA Flow, open the Dantec Device Configuration and specify the correct type of traverse system. Open BSA Flow again.
The traverse controller is connected to another COM port of the PC than specified in the traverse properties	Right-click on the traverse server icon and select status. If the correct COM port has been selected, a message similar to the one shown below should appear
The Traverse server connection is not established	Right mouse click the BSA Application icon in the project explorer. Select Connections from the drop down list, select the Traverse Server tab and click the Connect button.

When the traverse set-up is correct, the status dialog should look like this:



8.5.2 57G15 Traverse

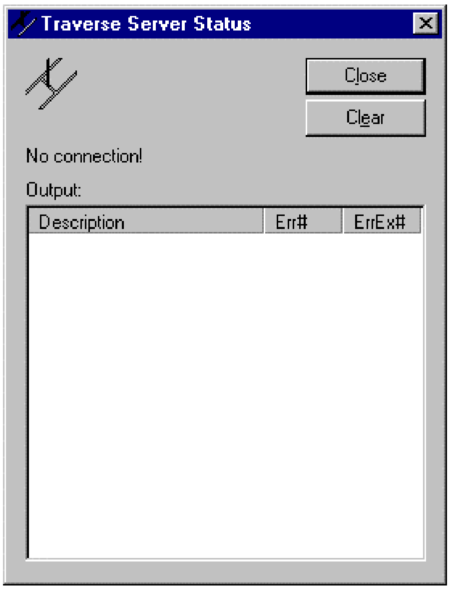
Please check that:

1. the Controller is on
2. the GPIB cable is connected from the 57G15 Traverse interface to the GPIB interface in the PC

If there is no Traverse server icon in the lower right hand corner of the screen, you must first start it by going to the Tools menu, selecting Plug-Ins and Traverse server.

To check for connection, right-click on the Traverse server icon and select Status.

If you get the following dialog



there are the following possibilities:

Possible reason	Remedy
Incorrect type of traverse specified	Close BSA Flow, open the Dantec Device Configuration and specify the correct type of traverse system. Open BSA Flow again.
The GPIB parameters are not correct	Go through the GPIB set-up as described in chapter 3. Remember to modify the "Device Templates": rename dev. 10 to 57G15

When the traverse set-up is correct, the status dialog should look like this: